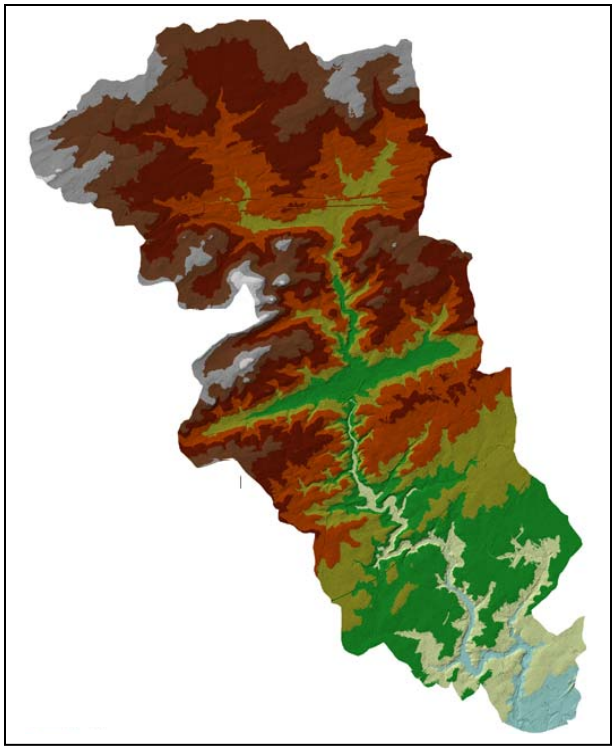
Applying the EPA's Regional Vulnerability Assessment (ReVA) Approach to the Pennypack Creek Watershed



Final Report

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Executive Summary

The Center for Sustainable Communities (CSC) at Temple University was engaged by the Pennsylvania Department of Environmental Protection to determine whether the ecological modeling approach known as ReVA (Regional Vulnerability Assessment) developed by the Environmental Protection Agency for large ecosystems or river basins could be applied at a much smaller scale for watersheds in Pennsylvania. The CSC chose the 57 square-mile Pennypack Creek Watershed (PCW) in southeastern Pennsylvania for this application. The CSC engaged a study team of scientists and researchers from universities, nonprofit organizations, and consulting firms to conduct this analysis.

This report presents the results of this work. It includes a detailed assessment of the ReVA methodology and its applicability to the PCW, the preparation of a comprehensive Geographic Information System (GIS) database, the delineation of ecological indicators, the preparation of land-use scenarios, and the evaluation of the differential impacts of those scenarios on various watershed attributes.

The study team has concluded that the ReVA modeling approach can be scaled down so as to be informative and appropriate for smaller watershed assessments in the Commonwealth of Pennsylvania. While many larger-scale ReVA assessment tools and data variables are too coarse for assessment at the local level, it is feasible to use such processes with more refined local data to accurately outline the impacts of alternative land-use and resource-allocation decisions on ecological and other watershed attributes.

The approach developed for the PCW also can be used as a template for other watersheds. While the PCW is a seriously impaired watershed in a dense urban setting in the Greater Philadelphia region, the assessment protocol outlined in this study can be accurately applied for less developed and more pristine watersheds as well. The report outlines data needs and analytical tools for this information transfer.

Finally, the ReVA modeling process also can be used to develop watershed sustainability indicators. The study team outlines four broad indicator categories that can be applied elsewhere and aggregated to larger regions in Pennsylvania. While the lack of good time series information makes ecological evaluations difficult, better models and more accurate digital information on topography and hydrology allow researchers to more accurately assess many watershed attributes.

1. **Introduction: Objectives of the Study**

Ecological assessment is a subject of paramount importance as the nation moves to prevent further degradation of the environment. While many environmental problems are global or regional in nature, the local level affects them, and is affected by them. The US Environmental Protection Agency (EPA) has undertaken regional and national assessments over the past few decades. The Environmental Monitoring and Assessment Program (EMAP) is a long-term research effort to enable status and trend assessments of aquatic ecosystems across the U.S. The Mid-Atlantic Integrated Assessment (MAIA) project incorporates data from state, regional and national environmental monitoring programs into regional assessments for the Mid-Atlantic region. An outgrowth of MAIA is the Regional Vulnerability Assessment (ReVA) Program. The evolution of this monitoring and assessment is what the current research has as its focus.

This project was a collaboration among individuals from the federal, state and local levels of government, local universities, and non-government organizations (NGOs). The expertise of the research participants spanned the natural and social sciences. The list of participants is:

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The objectives of the project were clearly stated at the outset: (1) Determine whether the ReVA modeling approach can be scaled down so as to be informative and appropriate for watershed assessment in the Commonwealth of Pennsylvania; (2) Determine whether the assessment model developed for the Pennypack can be used as a "template" for assessments in other watersheds in Pennsylvania and elsewhere; and (3) Determine whether the ReVA modeling process can be used to develop watershed sustainability goals and indicators. The Pennypack Creek Watershed (PCW) was used to assess the applicability of ReVA methods.

Section 2. describes the PCW and applies ReVA methods to some aspects of the watershed’s ecology. The reader interested in a more detailed account of ReVA methodology is invited to visit Appendix A.1. and the references cited there. The methods include data acquisition and generation, metadata creation, indicator development, scenario generation and impact assessment. These ultimately lead to vulnerability assessment. Section 3. discusses what aspects of the methodology of Section 3. can and cannot be directly applied to other small watersheds. Section 4. contains a brief discussion of the potential for informing and organizing officials from neighboring municipalities with the purpose of inducing watershed-wide cooperation in avoiding ecological vulnerabilities. Some Conclusions follow section 4., and References direct the reader to sources of further information. The Appendices contain more detail on some of the topics in the text.

2. **Applications of ReVA Methodology to the Pennypack Creek Watershed**

As noted above, the ReVA program evolved from two EPA programs that began earlier: EMAP & one of its sub-programs, MAIA. A concise overview of ReVA is given in the words of the EPA:

> The ReVA Program focuses on regional scale integrated assessment with the aim of assisting decision makers in identifying and locating both environmental resources and the conditions that are stressing those resources. ReVA strengthens the decision-making process by identifying the current status and relationships between stressors and sensitive environmental resources and estimating the environmental changes that follow from specific actions. (p.1, US EPA 2006b)

The PCW research team has examined these data and methods with the charge of determining what aspects of EMAP/MAIA/ReVA methodology are relevant to watersheds smaller than the USGS hydrologic accounting units in the Hydrologic Unit Code (HUC) used by the MAIA research team. (Jones et al. 1997) The application of ReVA methodology in this section will essentially follow the ReVA assessment questions: (1) What is the overall condition of the region? (2) What is the relative environmental condition given all variables or a subset (e.g. those related to water quality)? (3) What and where are the current most pressing environmental risks for a region? (4) What and where is the greatest risk in the future likely to be? (5) Where are the strategic planning or restoration priorities for a region? (US EPA 2006b)

Questions (1) and (2) are answered in the description in Section 2.2. and the relatively exhaustive data accumulation recounted in Section 2.1. and Appendix A.2. The answer to Question (3) took the form of assessing the relative values of indicators measured in Pennypack Creek as described in Section 2.3. The diagnosis is that certain stressors have put considerable pressure on the Creek's resources with the result that the Creek is designated "moderately impaired." The future risks referred to in Question (4) took the form of hydrological impacts resulting from the residential growth scenarios in Section 2.4, and other environmental impacts discussed in Section 2.5 based on alternative placement scenarios. Question (5) is dealt with in Section 2.5 and in the Conclusion.

2.1. **Developing a GIS-Based Watershed Data Inventory**

Watershed management and vulnerability assessment require an interdisciplinary approach to a complex problem. Comprehensive Geographic Information Systems (GIS) inventories of the natural and built environment provide watershed managers with the data, tools, and techniques to manage the complexities. The tools of GIS and spatial analysis allow decision-makers and citizens to understand and visualize the many features of a watershed, from land-use patterns to species diversity to flood-hazard areas. The powerful spatial analytic features of the ArcGIS[1] system, combined with increasingly available high-quality digital data should prove of great benefit to all concerned with managing the complex ecological, economic, and political systems involved in a watershed.

The Center for Sustainable Communities (CSC) has developed a comprehensive inventory of the PCW's natural and built environment. ArcGIS served as the primary platform for data collection and analysis from a multidisciplinary team of researchers, including urban planners, landscape architects, geologists, civil engineers, economists and biologists. Data layers covering the physical (geology, soil, slope), biological (fish, insect populations), chemical (pollutant loads, dissolved oxygen), hydrologic (rainfall, runoff, stream flow), demographic, and land-cover/land-use features were collected for the entire watershed. Table 2.1.1. shows a list of data layers generated for this project.

In order to undertake a more refined assessment of the 56-square-mile PCW, the study team subdivided the PCW into 49 smaller sub-watersheds or sub-basins, which would correspond to the size and location of the first-order streams within its boundaries. Sub-basins were delineated from stream line files based on stream order and topographic elevation data using the Watershed Modeling System (WMS) 7.1 and HEC-GeoRAS software.[2]

In defining sub-basins, the study team sought to create them to allow aggregation and dis-aggregation from current and past studies. Originally, the watershed was divided into 10 sub-basins to correspond with the CSC's hydrologic and hydraulic modeling studies. Those 10 sub-basins provided the basis for preparation of detailed maps of the watershed's floodways, and 100-year and 500-year floodplains. Those 10 were further sub-divided into 20 watersheds to correspond with the Philadelphia Water Department's (PWD) 20 water-quality sampling sites. In order to improve the potential richness of the

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[1] ArcGIS is a GIS software package developed by the Environmental Systems Research Institute (ESRI) Inc.
[2] HEC-GeoRas is an ArcView 3.2 (ESRI software) extension developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC). It prepares GIS data for import into the HEC River Analysis System (HEC-RAS) and generates GIS data from RAS output.

ecological assessment, the basins were ultimately sub-divided into the 49 smaller, first-order sub-watersheds.

2.1.1. **Natural Resources Inventory**

Biological data for the watershed were collected from monitoring stations of the PWD. Data on fish species, insect habitat and macroinvertbrates provided indicators of water quality and the suitability of the streams and riparian areas to support a wide variety of species. Sampling data were available at 20 locations within the watershed. ArcGIS was used to assign those sampling points to the sub-basin(s) draining to the sampling point. The spatial tools within ArcGIS thus allow statistical analysis of the relationships between various land-use patterns and water quality or biological integrity.

Table 2.1.1. A List of GIS data layers

Data	Source	Year
Biological Data		
Fish	Philadelphia Water Department (PWD)	2002
Habitat	PWD	2002
Macroinvertebrate	PWD	2002
Water Related Data		
Wetland	Delaware Valley Regional Planning Commission (DVRPC)	1981
Bridge & Culvert	Center for Sustainable Communities, Temple University(CSC)	2005
Dam	PWD	1999
Riparian Buffer	Heritage Conservancy	2002
Effluent Concentration	PWD	2003
Discharges & Withdrawals	Delaware River Basin Commission (DRBC)	1996
Stream	Center for Sustainable Communities, Temple University(CSC)	2004
Floodplain	Federal Emergency Management Agency (FEMA)	1996
Geological Data		
Bed Rock Geology	DRBC	1998
Soil	DRBC	Unknown
Base Flow	PWD	1998
Demographic Data		
Household Density	US Census Bureau	1990/2000
Median Household Income	US Census Bureau	1990/2000
Population Density	US Census Bureau	1990/2000
Land Features Data		
Land use	DVRPC	1990/1995/2000
Land Cover	United States Geological Survey (USGS)	2001
Tree Canopy Density	USGS	2001
Impervious Surface	Pennsylvania State University, Dr. Toby Carlson	1985/2000

Slope	CSC	2004
Road Density	CSC	2005
Forest Fragmentation	CSC	2005

An essential feature of the field of "landscape ecology" and the EPA's ReVA analysis is that landscape patterns – particularly human-influenced landscape change – affect ecological processes. The ArcGIS tools, combined with freely available specialized extensions, allows for a detailed understanding of the effect of landscape change on ecological integrity.

Hawthorne's Analysis Tools for ArcGIS (www.spatialecology.com) is one of a number of free extensions for the ArcGIS 8 and 9 systems with specialized tools for landscape measurement. The "Count Points in Polygon" tool, for example, was used to calculate the number of bridges, culverts, dams, and discharge points within each sub-basin. The tool, "Sum Line Lengths in Polygons," was used to calculate the length of roads within buffer-distances from streams (30 and 100 feet), and to calculate the extent of impaired riparian buffers along each segment of the waterway. Those data can assist in prioritizing stream segments for mitigation or restoration efforts, as well as indicating the impact of stream impairments on water quality. The Model Builder feature in ArcGIS was used to perform many of the repetitive geo-processing steps. Figure 2.1.1. shows an example of a Model, clipping with buffer distance.

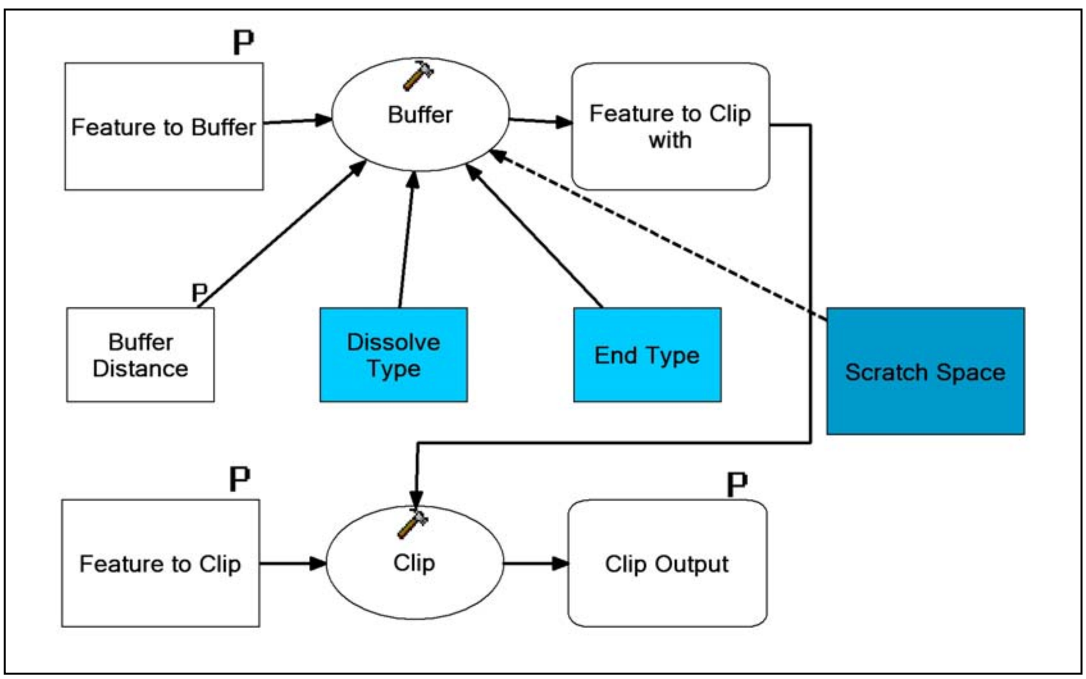


Figure 2.1.1. Clipping with Specified Buffer Distance

As part of the hydrologic modeling of the watershed, Curve Numbers (CNs) were calculated for each sub-basin of the watershed. The CN, developed by US Department of Agriculture Natural Resource Conservation Service (formerly the Soil Conservation Service), is a measure of the stormwater runoff potential for a drainage area. Calculation of the CNs involved using land-use class data, as well as data in hydrologic soil groups in the ArcCN-Runoff extension. CNs were calculated for each distinct land-user/soil group type, and aggregated to produce a composite CN for each sub-basin.

One of the purposes of a comprehensive watershed inventory is flood hazard mitigation. ArcGIS tools combined with high-resolution digital ortho-photography provide an important tool in hazard mitigation planning. The Q3 Flood Data from the Flood Insurance Rate Maps (FIRMS) were collected from FEMA in digital form. Building footprints for all buildings in the watershed were digitized from high-resolution (1.5 sq.ft. resolution) digital ortho-photography provided by the DVRPC. When flood-plain and building-footprint layers were overlain in ArcGIS, software tools were used to count the number of buildings in the floodplains.

2.1.2. **Built Environment Inventory**

In order to understand the human influences on watershed, demographic and land-use data were collected. Demographic data were collected at the Census Block Group level for 1990 and 2000 from the US Census Bureau website. Census TIGER/Line boundary files for 1990 and 2000 were also downloaded from the Census to identify block groups located in the PCW. Data on the population, number of housing units, median income, population density, and housing-unit density were summarized for each of the 49 sub-basins. Data show wide variation in new housing construction across the sub-basins. Demographic data were combined with land-use change data to produce scenarios of future land use.

A number of data sources were combined to produce a detailed picture of the land uses and landscapes within the watershed. The 2001 National Land Cover Database is a consistent land-cover database for the entire continental US at a 30m resolution, and was downloaded from seamless.usgs.gov. In addition, the National Land Cover Database provides tree-canopy and impervious-surface data at the same resolution. For Pennsylvania, higher-resolution impervious-surface data was estimated by Dr. Toby Carlson of Penn State University and is available for 1985 and 2000 to show changes in impervious surfaces within a watershed. The DVRPC made available digital land-use data interpreted from high-resolution digital ortho-photography. Data from 1990, 1995 and 2000 allow for an assessment of land-use patterns and land-use change. Although few areas of the country currently have available consistently-interpreted, high-resolution land-use data from more than one time period, these data are becoming increasingly available.

ArcGIS tools combined with high-quality land-use and land-cover data from multiple sources allow for a detailed assessment of landscape patterns. Forests, for example, play an important role in both species habitat and water quality. Detailed measures of forest fragmentation can be used to assess ecosystem threats and prioritize land conservation strategies. Using an ArcGIS extension written by Kurt Paulsen (author of Section 3.4) and a collaborator, measures of forest fragmentation are calculated for each sub-basin. Hawthorne's Tool was used to calculate distances between forest patches, and the proximity of forested patches to streams.

The next section puts these data and the ArcGIS tools to work in discussing the hydrology and ecological indicators for the PCW.

2.2. **The State of the Watershed**

The PCW is a 56 square mile area located in southeastern Pennsylvania that contains a population of about 300,000. It contains parts of Bucks, Montgomery and Philadelphia Counties. Besides a section of Northeast Philadelphia, the watershed resides in all or part of 11 municipalities: Abington, Bryn Athyn, Hatboro, Horsham, Jenkintown, Lower Moreland, Rockledge, Upper Southampton, Upper Dublin, Upper Moreland and Warminster. The topography of the watershed is characterized by gently rolling hills in the headwaters, moderately sloping valley in the central part of the watershed, and tidal flats draining to the Delaware River. The elevation over the watershed ranges from 436 feet to less than 10 feet above sea level. The flow regimen in the Creek and the interrelationships between surface and groundwater within its watershed are complicated not only by development and other human activities within the basin, but also by its complex environmental character. In particular, the bedrock geology is highly diverse and the geologic history spans more than 600 million years. There are great differences in the physical characteristics of the many different rock types within the watershed. The Pennypack Creek system contains roughly 79 miles of surface waters and is classified for the following uses: warm water fishery, trout stocking fishery, aquatic life, water supply and recreation. The climate of the region is characterized by warm summers and cold winters with moderate intermediate seasons. The mean annual temperature is 54^{o}F and the average annual precipitation is 41.41 inches. (Meenar 2006)

Much of the PCW area was developed as a part of the “inner ring suburbs” of Philadelphia from the 1950s to the 1980s. As can be seen in Figure 2.2.1., the area is quite built up and hosts a myriad of land uses that impact energy use and the air, water and biological integrity.

The water quality in the PCW is significantly influenced by the large Upper Moreland-Hatboro Sewage Treatment Plant (UM-H STP). Its location is shown in Figure 2.3.3. The UM-H STP is authorized by the PA DEP through an NPDES permit and DRBC to discharge treated sewage at an average annual rate of

7.173 mgd and a maximum monthly flow of 9.08 mgd. According to the permits, the STP is required to provide advanced secondary treatment and ultraviolet disinfection prior to discharge to the Pennypack Creek. Discharge monitoring reports (DMRs) provided by the plant operator to the DEP indicate that the STP operates at or near its maximum design capacity. The service area of the STP includes the Borough of Hatboro and portions of Horsham, Upper Dublin and Upper Moreland Townships, Montgomery County, PA and a portion of Warminster Township, Bucks County, PA. The UM-H STP is one of four point sources of discharge in the watershed. The remaining three are small “package” plants that do not have significant adverse impacts on water quality.

Air quality is dependent on the mix of land uses in the PCW. Except for Vacant, Water, & Wooded, the land uses listed in the figure legend entail the use of human-processed energy & materials for everyday functioning. Where electricity in not the end-use energy source, fuels are generally burned in stationary or mobile sources to provide goods and services while generating entropy and waste materials. Ambient air quality over the PCW is generally good, and affected mostly by mobile-source emissions.

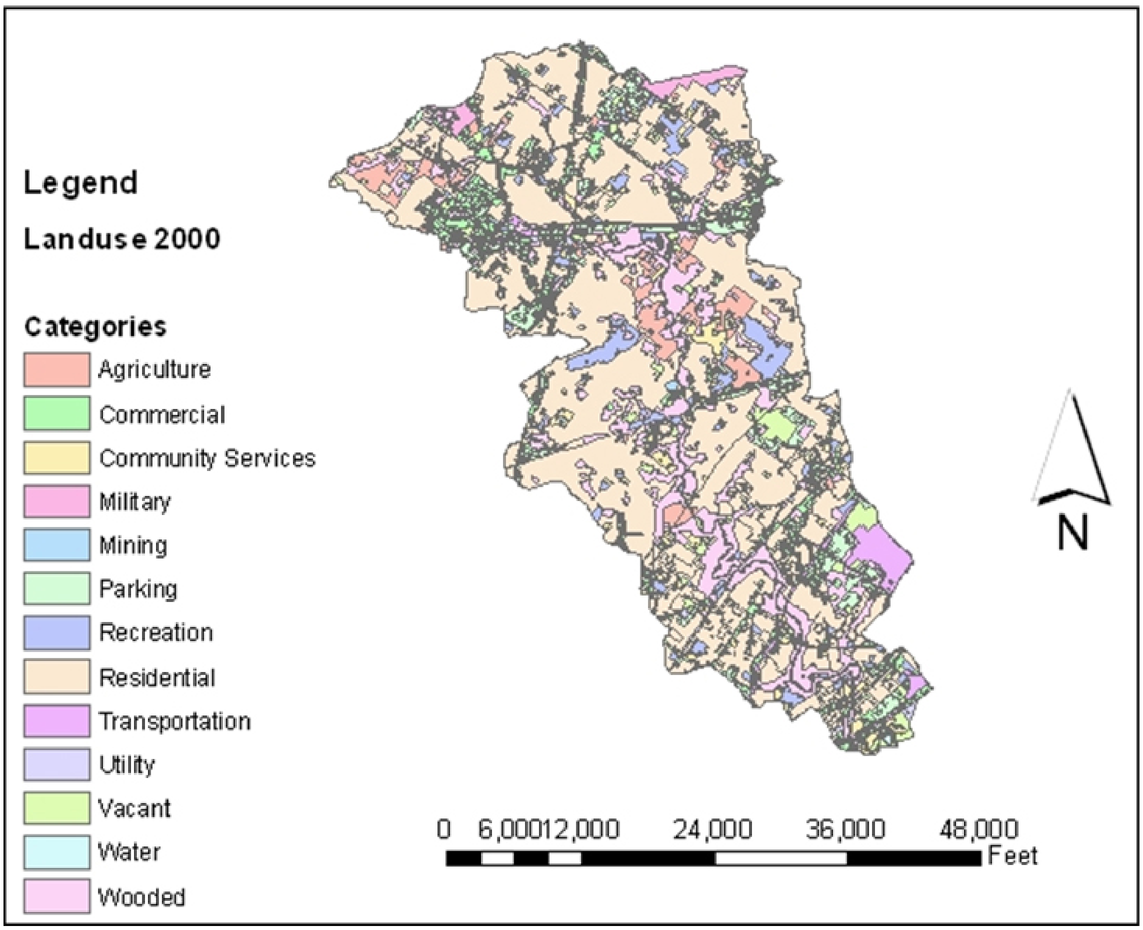


Figure 2.2.1. PCW Land-Use, 2000

2.2.1. **Hydrology**

The interactions and relationships among the components of the hydrologic cycle (precipitation, evapo-transpiration, runoff, etc) must be understood in order to predict a stream's responses to changes in any of those components, whether natural or manmade. Rigorous hydrologic modeling was performed in the PCW to gain such an understanding of the watershed's hydrologic regimen.

It has been long and widely known that the changes in land cover that accompany urbanization generally result in decreases in evapo-transpiration and infiltration (and consequently in baseflow), and increases in surface runoff, (US EPA 1993). What has also been long, but perhaps less widely realized, is that the most effective or dominant channel-forming flow of a stream, i.e., that which transport the largest total amount of sediment over a period of years, is the bankfull stage (Walman and Miller 1960). This most effective of flows has a recurrence interval of 1.5 years in the annual maximum flood series 9 and 0.9 years in the partial duration series in a large variety of streams (Dunne and Leopold 1978).

The CNs used in the hydrologic modeling discussed below are measures of the influence of the land cover characteristics on infiltration and runoff. CNs are empirically derived, and depend on a combination of factors: vegetation types and conditions; impervious cover; land use practices; and hydrologic soil groups (HSGs). As forest gives way to pasture or cropland, and then the lawns in subdivisions, as pavements and roofs are introduced, and as soils are compacted, CNs increase in value, and so too does surface runoff.

Thus, the causal relations are clear – increased CN leads to increased runoff, which in turn produces increases in the amount of flow in the above-mentioned bankfull discharge (or conversely, the larger flows have reduced recurrence intervals). This increased dominant channel-forming flow must then enlarge the channel to accommodate the increased runoff. In other words, the stream flows with recurrence intervals of 0.9 to 1.5 years (depending on the series used) are larger and the channel must adjust itself accordingly. It will do this by eroding its banks, and, where the gradients permit, by downcutting its bed as well.

During our field reconnaissance, examples of such channel enlargement, recent and ongoing, were found throughout the watershed – in virtually all tributaries, as well as the main stem. The most dramatic examples noted were those where the stream beds of tributaries were founded in bedrock, leading to marked widening of the channels. Such widespread channel erosion will produce corresponding increases in sediment transport and thereby in the Total Suspended Solids (TSS), load of the streams, one of the principal factors cited in the impairment of stream quality in this and similar watersheds.

While the causal and qualitative relationships outlined above are clear, additional research is needed to quantify the linkages. That is, we can model directly the runoff increases that will result from specific increases in the CNs, but the channel responses to those increased bankfull discharges, the consequent erosion, and the resultant increases in TSS will require more study.

The Hydrologic Modeling

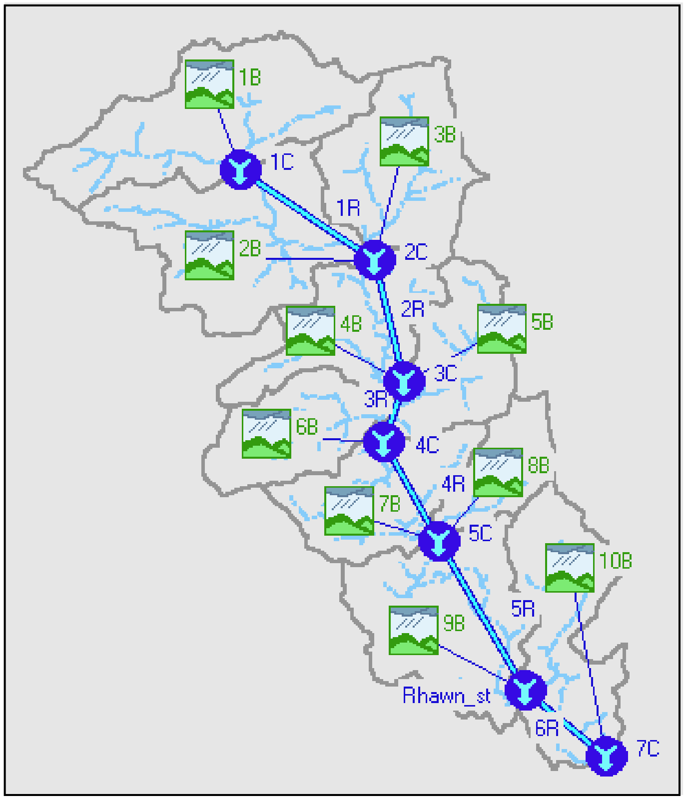


Figure 2.2.2. The PCW Hydrology

For hydrologic modeling, the U.S. Army Corps of Engineers' (ACOE) software HEC-HMS was used. The watershed was treated as consisting of 10 subbasins, whose areas range from 2.6 to 8.3 mile^2 with an average of 5.5 mile^2. A CN was computed for each subbasin based on Land Use Land Cover (LULC) data and soil type data.

The outflows from the subbasins were assumed to pass through six Junctions as available from HEC-HMS. The junctions are designated by the symbols C in Figure 2.2.2. (e.g., junction 2C). They were connected to each other and to the outlet of the watershed by six reaches (designated by the symbol R in Figure 2.2.2., (e.g., 3R). The routing of water flow through the reaches was conducted using the Modified Puls method, which required evaluation of the number of subreaches. In this work, the following approach was followed for each reach:

1. A Hec-RAS model was developed using multiple cross sections at a spacing of 30 – 200 feet.
2. Different flow rates, varying from 100cfs to 30,000 cfs were routed.
3. The cumulative volume of water for each reach was recorded and a storage-outflow table was developed for each reach (see details under the section “reach properties”).
4. An average travel time was determined for each reach based on the computational interval of 15 minutes. The number of sub-reaches was then computed.
5. The number of sub-reaches from 4) was allowed to change by ± 20% in matching simulated hydrographs to observed hydrographs at the USGS station (Rhawn Street).

The values of the hydrologic parameters are reported in Table 2.2.1. and 2.2.2. These values were obtained in a two step process, where the values computed based on watershed characteristics (such as LULC, soil type, slope) were altered by calibration of the model to the outflow at the Rhawn Street USGS station in Philadelphia. In general, the differences between the final and initial values were less than 5% for CN (Table 2.2.1.) and 20% for the time lags (Table 2.2.1.) and the travel times in reaches (Table 2.2.2.).

Table 2.2.1. Sub-basin Properties

Basin	**Area ($mile^2$)**	**CN**	**Percent Impervious**	**Time lag (minute)**
1B	8.314	80.53	13.34	126
3B	5.9627	77.93	11.64	116
2B	7.9365	80.03	21.32	122
4B	4.9918	74.3	2.37	95
5B	4.1826	77.45	7.41	102
6B	3.9409	77.7	6.8	85
7B	4.7719	74.92	5.14	98
8B	2.6074	74.97	22.39	128
9B	7.1235	73.13	25.49	145
10B	6.0329	76.71	34.97	182

Table 2.2.2. Reach Properties

Reach ID	Length (feet)	Width (feet)	Slope (ft/ft)	Manning's n
1R	17691	15	0.003	0.035
2R	15963	20	0.0017	0.035
3R	1782	25	0.0047	0.035
4R	16502	25	0.0008	0.035
5R	28211	30	0.0018	0.035
6R	18306	30	0.0008	0.035

Hydrologic Data

Topography plays a vital role in the distribution and flux of water and energy in a watershed. The USGS has prepared 7½° quadrangle topographic maps at a scale of 1:24,000 for most of the country, and a common contour interval is 10 ft. This scale is generally considered the minimum scale in hydrologic modeling and a tighter interval is preferred for accurate and detailed studies. With the help of a research grant obtained for the *Pennypack Creek Watershed Study* (Meenar 2006), the CSC consultant, Aero2 Inc., created the digital ortho-photography and 2 ft-resolution elevation data. The aerial mapping was done in the non-growing season, when foliage was off the trees. Aero 2 has undertaken the following steps:

- Aerial Photography at 1"=660' negative scale using Airborne GPS technology flight;
- Ground Control Survey, performed by licensed land surveyor;
- Analytical Aero-triangulation, which performs image measurements to achieve interior and exterior image parameters; and
- Stereo compilation and creation of new data.

Integration of GIS and hydrologic modeling connects geospatial data with hydrologic process models describing how water moves through the environment. GIS is commonly used for watershed delineation, runoff estimation, hydrologic modeling, and floodplain mapping. In addition to the GIS-based data inventory described in the previous section, the newly created GIS datasets include 2003 digital ortho-photographs (1 ft pixel resolution), 2 ft resolution elevation data such as DEM, Triangulated Irregular Network (TIN), and contour intervals, updated stream networks, flow-paths, bridges and culverts, dams, and building foot prints.

Research has indicated that the precipitation values (Herschfield 1961) widely used in previous studies are no longer valid. These values were used in the creation of existing Pennypack Flood Insurance Rate Maps (FIRMs) as well. It has been well established that TP-40 systematically underestimated the extreme precipitation events. This was due to a number of factors: the short average duration of the precipitation records analyzed; the relatively small number of weather stations; and the statistical distribution used to analyze the data. The Temple researchers requested and received permission from FEMA to use more recent data from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14, which can be accessed at: http://hdsc.nws.noaa.gov/hdsc/pfds/orb/pa_pfds.html.

This makes a very significant difference in the inputs to the hydrologic and hydraulic models employed in the re-delineation of the floodplains in the watershed. For instance, according to TP-40, the precipitation from the 100-year, 24-hour storm in our study area was expected to be 7.2 inches, and this number has been codified in virtually all local stormwater management ordinances. The more recent data indicates that the 100-year, 24-hour event is 8.75 inches, a difference of more than 20%.

Streamflow data used for calibration were obtained from the USGS Station 01467048 located approximately at Rhawn Street. As mentioned previously, in predicting the runoff resulting from the 100-year storm, the depth of rainfall estimated by the NOAA Atlas 14 (8.75 inches) was used instead of the older TP-40 study. This greater rainfall depth along with the new land use data resulted in runoff peak values and volumes that are larger than those predicted in prior studies in the PCW. At the location (Lat=40.1; Long=-75.3), the upper 95% confidence gave 6.28, 7.19, 8.18, 10.81, for the 25, 50, 100, and 500 year storms. The temporal distribution of rainfall pulses for the design storms for the area are of the SCS Type II.

Calibration

The hydrologic modeling process entails developing an actual or hypothetical design storm and then calculating the runoff and peak discharge for the selected event. Eight storms were used for the calibration. They are listed in Table 2.2.3. along with the total amount of rainfall and the runoff duration. The automatic calibration option in HEC-HMS was not used because it provided a different set of parameters for each storm. We elected to adjust the parameters based on heuristic arguments and to put a special effort on matching the peak value and the time-to-peak. This resulted in a unique set of parameters, reported in Tables 2.2.1. and 2.2.2.

Table 2.2.3. Rainfall Events Used for Calibration

#	Date	Total Rainfall (inch)
1	October 08, 1996	2.00
2	October 16, 1996	3.46
3	September, 1999 [1]	7.03
4	November, 99	1.12
5	December, 99	1.65
6	March, 2002	1.15
7	May, 2002	1.50
8	June, 2002	1.62

(1) Hurricane Floyd

The graphs in Section A.3.1. of Appendix A.3. show the comparison between predicted (or simulated) runoff and those observed.

2.3. **Ecological Indicators in the PCW**

Indicators are used to describe and quantify the status of a system. Changes in indicators can gauge the outcomes of actions or policies. Indicators are often used to avoid having to process large amounts of detailed information. Meadows (1998) presented a list of characteristics that sustainability indicators should display. They should be, among other things: (1) clear in value; (2) clear in content, with units that make sense; (3) measurable at reasonable cost; (4) timely; (5) appropriate in scale; (6) hierarchical; (7) based on physical units rather than money and prices; and (8) leading, so as to provide information in time to act on them. These criteria will be discussed below. In the sequel, the terms *variables*, *environmental metrics* and *indicators* will be used synonymously.

2.3.1. **Water Volume**

Based on the hydrology discussion above, this indicator seeks to measure the current amount of water that is consistently available as compared to the amount of water that would be available if the watershed were in a natural state. As the area within a watershed is developed, less water is generally available because impervious surfaces such as buildings, streets, parking lots and driveways cause water to run immediately into streams rather than infiltrating into the groundwater system. Groundwater moves slowly through cracks and spaces in the bedrock, providing water for streams in dry weather as well as drinking water from wells. New development reduces groundwater supply at the same time that it increases water demand. This means that as development increases, planning for adequate, long-term supplies of high-quality water becomes increasingly important.

Data and Methods

Baseflow (often called the dry-weather flow) of a stream, a flow which is supplied by groundwater. Because of this, baseflow is a good measure of water availability. Figure 2.3.1. (Map BASEFLOW1) shows the bedrock geology areas of the Pennypack watershed. The Pennypack baseflow was calculated using data from the USGS Rhawn St. Stream Gauge in Philadelphia. Figure 2.3.2. (Map BASEFLOW2) shows the area that drains to the Rhawn St Gauge. The lack of additional operative stream gauges in the PCW currently makes it impossible to calculate the baseflow at more than one point along the Creek. This limitation is considerable, particularly when considering that the discharge from the UM-H STP falsely inflates the baseflow, and the only functioning stream gauge is downstream of this plant. The average daily discharge for the UM-H STP was obtained from the Pennsylvania Department of Environmental Protection (PA DEP). Figure 2.3.3. (Map BASEFLOW3) shows the area that drains to the UM-H STP.

The natural baseflow rates used for this discussion came from the Water-Use Analysis Program for the Neshaminy Creek Basin in Bucks and Montgomery Counties, prepared by the USGS and the DRBC. This report contains the baseflow discharge rates for the various geologic formations in PCW.
The 25-year baseflow at the Rhawn St gauge was arrived at by separating the hydrographs of the stream gauge data using a computer program based on the local-minimum method. (Sloto and Crouse 1996) Low-flow conditions was selected for these calculations because it is during dry periods that water supply presents a problem, and the aim of the indicator is to assess the water supply that would be consistently available. The 25-year low flow was selected because it is the most extreme condition that could be accurately modeled with the available data. The 25-year low-flow condition is the low flow, or drought condition that is predicted to occur one year out of every 25 years, or has a 4% chance of occurring in any given year. The amount of the discharge from the UM-H STP plant that was drawn from outside the PCW was then calculated, and that amount was subtracted from the baseflow calculated by the separation of hydrographs. This is the current 25-year baseflow. The natural 25-year baseflow was calculated by finding the areas of each geologic formation in the PCW. These areas were then multiplied by the flow rate for each geologic formation. The sum of these values represents the natural baseflow at the Rhawn St. Gauge. For more details on these calculations see Appendix A.3.

Three parameters affect the *peak* flows in watersheds. These are the CN, the time of concentration, t_c, and the percent impervious.

The potential infiltration, S, of a watershed is given by (in inch):

$$S = \frac{1000}{CN} - 10 \qquad (2.3.1.)$$

Where CN is the Curve Number, a number between 0 and 100, but commonly ranging from 60 to 90. Higher values of CN imply lower potential infiltration, and thus higher runoff and, most likely, higher peak flows.

The time of concentration represents the time it takes for the water parcel to propagate from the most hydraulically remote location of the watershed to the outlet. There is a relation between the time of concentration and the CN. This relation is:

$$t_c = \frac{5}{3} \frac{L^{0.8}(S+1)}{1900\, y^{0.5}} \qquad (2.3.2.)$$

Where L is the length of main channel and y is the average slope of the watershed (in percent).

Equations (2.3.1.) and (2.3.2.) indicate that the time of concentration is inversely proportional to the CN, which is intuitive in many aspects; an increase in CN is commonly a result in an increase in the impervious areas (concrete replacing open soil) causing water to propagate faster in the watershed. However, Equation (2.3.1.) should be used with great care, because the quantity length L and average slope are not pure geomorphic quantities, but they depend rather on water pathways. Different drainage patterns are expected to affect water flow differently; dendritic drainage patterns (spatially random) tend to drain watersheds slower than rectangular patterns. The evaluation of drainage capability becomes more difficult in urban watersheds, where the geomorphic significance of the length L and the slope vanishes in favor of hydraulic significance, mostly due to constructed channels.

The percent impervious that we are referring to herein differs from that would be incorporated in the CN evaluation. This one relates to impervious areas directly connected to the channels, and thus their increase causes direct effects (increase) on peak flows. The US Army Corps of Engineers' model, HEC-HMS accounts for these areas explicitly.

Results and Interpretation

The calculated current one-year-in-25 annual baseflow at the Rhawn St. gauge was found to be 6.7292 million gallons per day, while the natural baseflow at that gauge was found to be 12.8178 millions of gallons per day. Restated as a percentage, current baseflow is only 52.5% of natural baseflow. This means that during low-flow conditions, approximately half of the water that would naturally be available for drinking water, waste assimilation, fish and wildlife habitat, etc. will not be available. Although this area is water-rich, drought is a regularly recurring problem, and a decreasingly reliable water supply will only serve to exacerbate the effects of what might otherwise be minor problems. Additionally, during low-flow conditions water demand by human beings decreases only slightly. This means that the proportion of the water supply that is used by human beings increases greatly, leaving less for the natural communities, particularly aquatic communities.

Downstream of the sewage treatment plant, the effects of lower baseflow would appear to be lessened. The stream does have over 90% of its natural baseflow due to the discharge from the UM-H STP. However, from a regional perspective the appearance of improvement disappears. The service area for the sewage treatment plant extends beyond the watershed boundaries, resulting in an inter-basin transfer of water. Water that is imported to the Pennypack has been removed from other watersheds, further depleting their water supply. Also, the water discharged into the stream is not of the same quality as the water already in the stream.

The results for this indicator show that the Pennypack baseflow has decreased from what it would be in an estimated natural state. However, the lack of stream

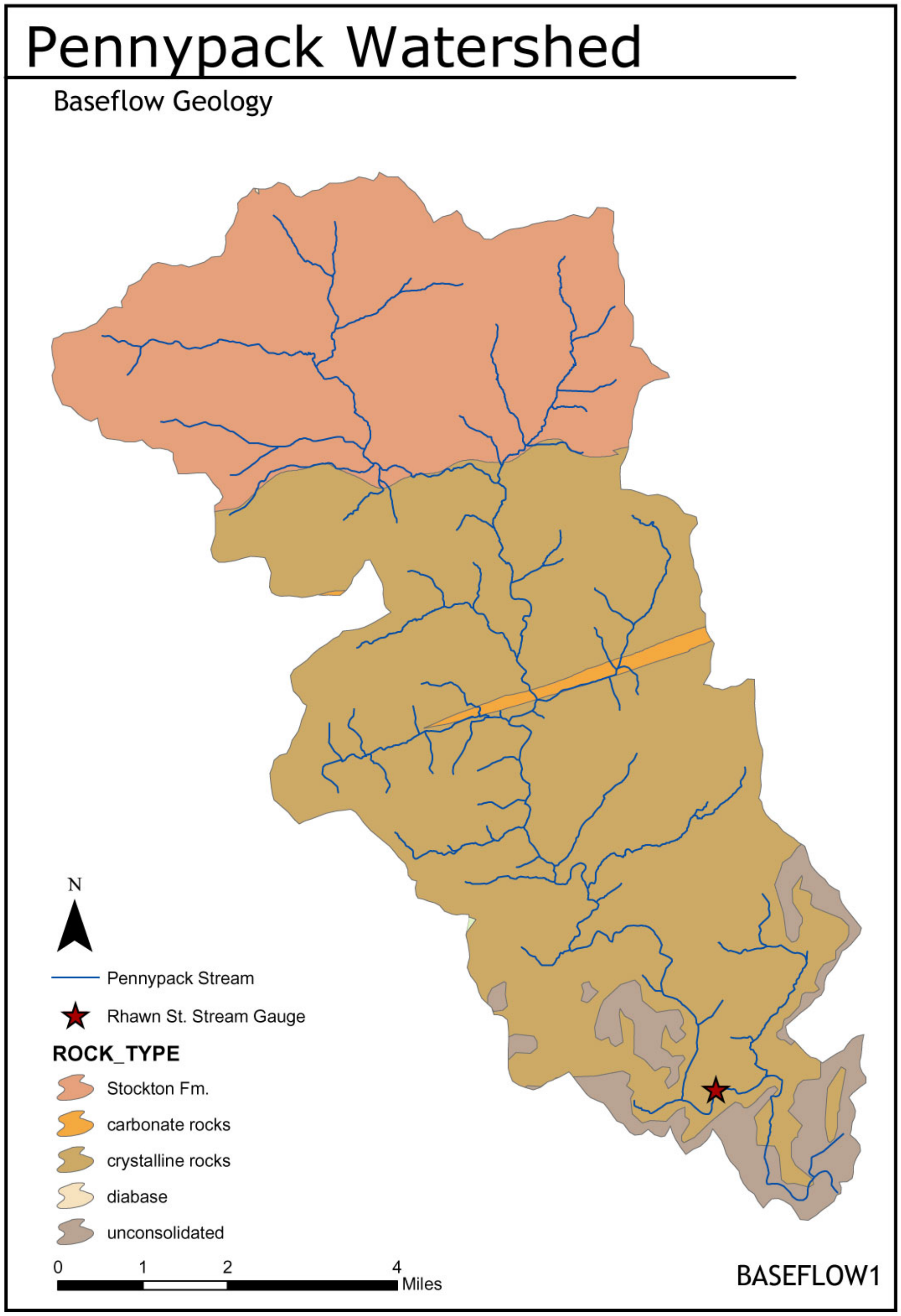


Figure 2.3.1. PCW Baseflow Geology

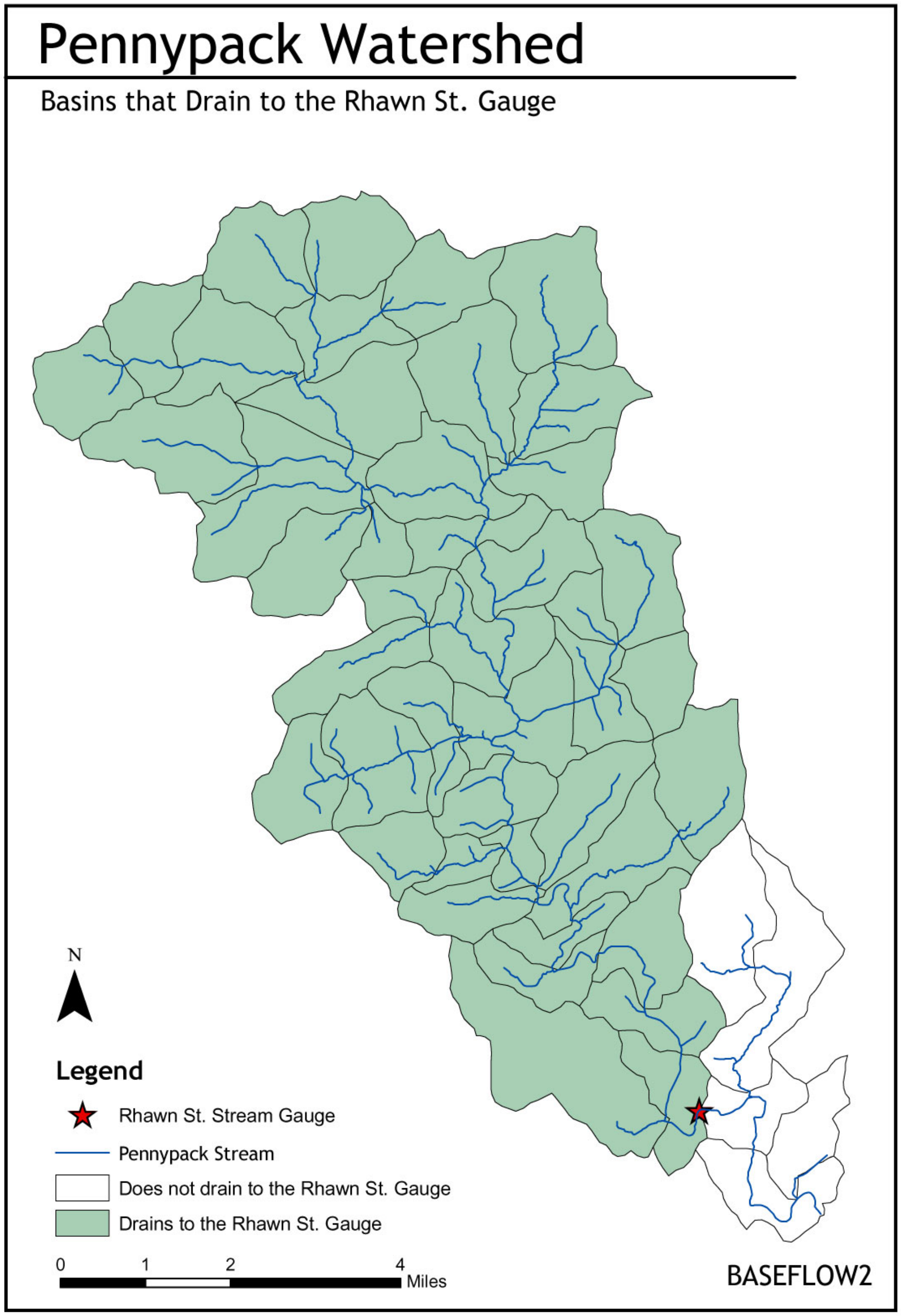


Figure 2.3.2. PCW Drainage to the Rhawn St. Gauge

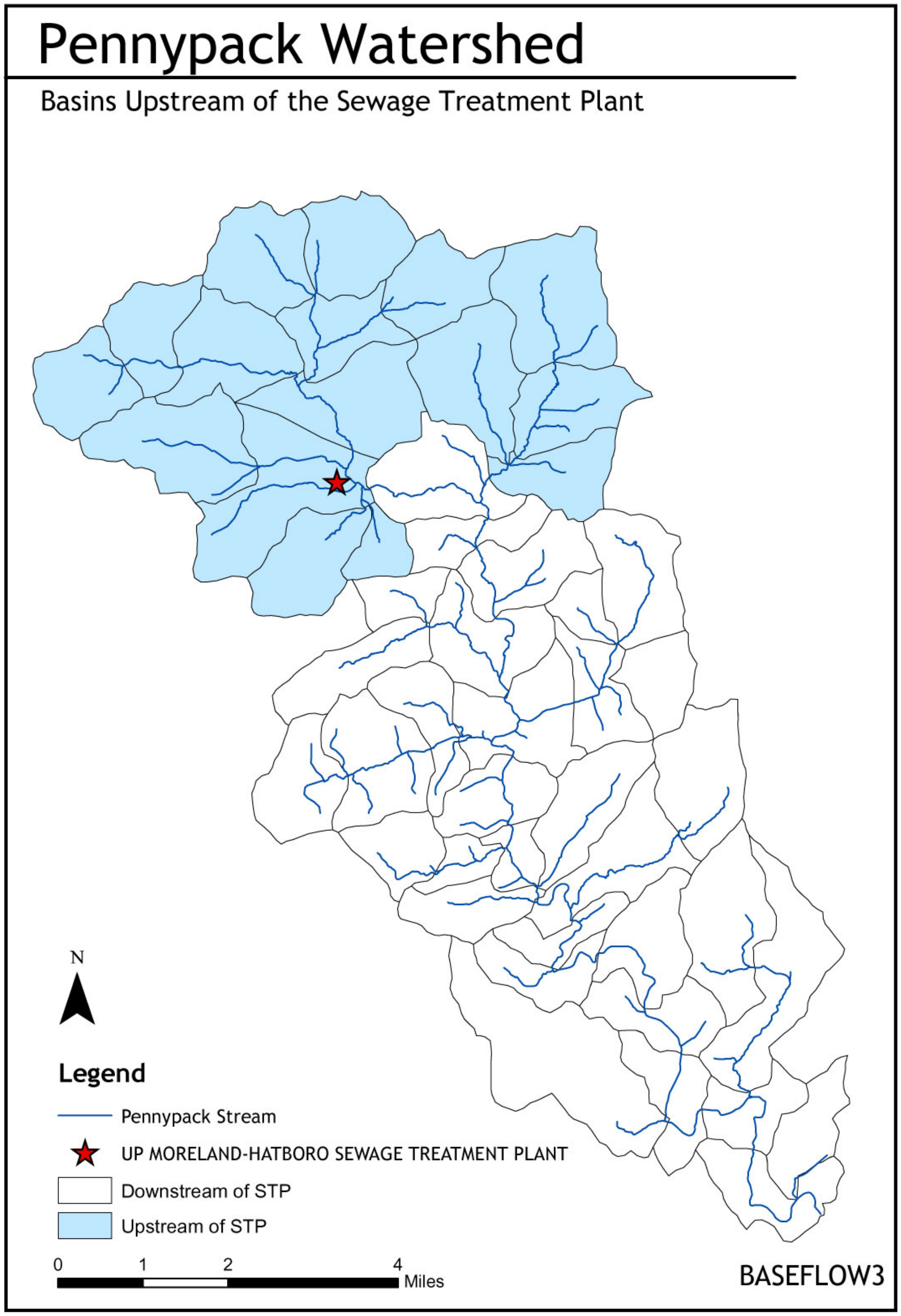


Figure 2.3.3. PCW Upstream of the UM-H STP

gauges in the watershed imposes serious limitations on the analysis. The effect of development on the baseflow of the Pennypack Creek is generally clear. However, continuous and more detailed monitoring is necessary to track carefully the effects of future development, as well as efforts to remediate the problem.

The peak flows in the PCW for the two-year storm under the current conditions are shown at the PWD monitoring stations in Figure 2.3.4 and numerically in Table 2.5.1.

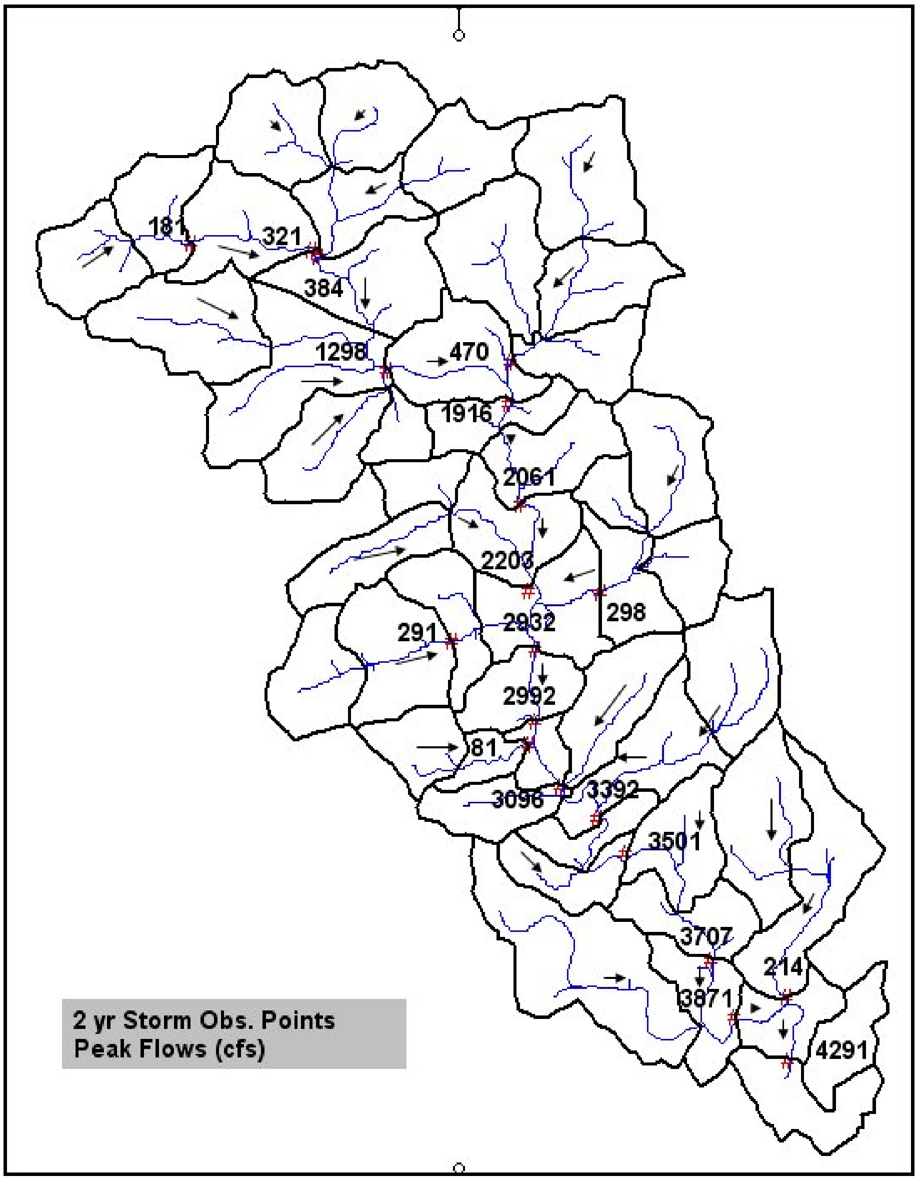


Figure 2.3.4. <u>Peak Flows under Current Conditions</u>

These flows will be compared in Section 2.5.1. with the conditions that result from the first two residential development scenarios.

2.3.2. **Water Quality**

This indicator seeks to measure the chemical contamination of the water. Chemicals enter the aquatic system from both point and non-point sources. Point sources are factories and other facilities that discharge directly into a stream. These sources are highly regulated. Non-point sources are farms, lawns, parking lots, etc. Chemicals from these sources are carried by rainwater into streams. These non-point sources are very difficult to regulate, and so are relatively uncontrolled.

Regardless of their source, chemicals that contaminate surface and groundwater impair the water's ability to act as habitat for wildlife, and make it dangerous for humans or animals to drink it unless treated. Concentrations of nutrients and pesticides in streams and shallow groundwater generally increase with increasing amounts of agricultural and urban land in a watershed. This situation develops because chemical use increases and less water is available from undeveloped lands to dilute the chemicals. (USGS 1999)

<u>Data and Methods</u>

The data for this analysis came from the PWD's Baseline Assessment of PCW (2002-2003) (Lance et al. 2003). This study assessed the levels of a variety of contaminants at 20 sampling points along the Pennypack Creek. Figure 2.3.4. (Map CHEM1) shows these sampling points and the sub-basins to which the data was attributed. Seven factors that comprise a majority of the impairment in most streams were chosen to make up this indicator. These factors are described below.

Alkalinity

Alkalinity is a measure of a stream's ability to resist changes in pH. It is often referred to as the buffering capacity of a stream, and is important because it allows a stream to neutralize acidic pollution or contamination. The target range for this factor is 100-200 mg $CaCO_3$/L (Lehigh Earth Observatory). The results of this analysis are on Figure 2.3.5. (Map CHEM2).

Dissolved Oxygen

Dissolved oxygen is absorbed from the atmosphere and from the result of photosynthesis. If more oxygen is consumed than produced or imported, some organisms will die. The target for this factor is 6 mg/L (US EPA 2005).

Fecal Coliform

These bacteria are present in the feces and intestinal tracts of humans and other warm-blooded animals, and can enter water bodies from human and animal waste. If a large number of fecal coliform bacteria (over 200 colonies/100 ml of water sample) are found in water, it is possible that pathogenic organisms are also present in the water. High concentrations of the bacteria in water may be caused by septic tank failure, poor pasture and animal keeping practices, pet waste, and urban runoff (BASIN 2002). The target for this factor is 200 colonies/100mL (US EPA 2005). The results of this analysis are on Figure 2.3.6. (Map CHEM3).

Nitrate

Nitrate is the most completely oxidized state of nitrogen commonly found in water and is the most readily available state utilized for plant growth. High nitrate levels combined with phosphates cause excessive plant and algae growth, which is a deteriorating process called eutrophication. Higher concentrations in water are unsafe to drink due to the possible presence of altered forms of nitrite, which may cause serious illness to both humans and wildlife. The target for this factor is 1 mg/L (Lehigh Earth Observatory 2005). The results of this analysis are on Figure 2.3.7. (Map CHEM4).

Ortho-phosphate

Ortho-phosphate is the form of phosphate used in fertilizer and applied to agricultural fields and residential lawns. Like nitrates, phosphates negatively impact water by causing accelerated rates of eutrophication. The target for this factor is .03 mg/L (Lehigh Earth Observatory). The results of this analysis are on Figure 2.3.8. (Map CHEM5).

Suspended Solids

Suspended solids include all particles in water with a diameter of less than 0.45 microns. Typically, suspended solids include items such as soil, algal cells, and plant particles. High levels of suspended solids smother some aquatic organisms. The target for this factor is 10 mg/L (Lehigh Earth Observatory). The results of this analysis are on Figure 2.3.9. (Map CHEM6).

pH

pH is a measure of acidity. Variations in pH affect chemical and biological processes in water. Low pH increases availability of metals and other toxics for intake of aquatic life. It is critical to survival, growth, and reproduction of fish and macro invertebrates to maintain a constant pH. Exposure to very low or high pH may cause death or reproductive problems for fish and other aquatic life. The target range for this factor is 6.5-8.5 (US EPA 2005).

The actual values were transformed into percentages of the target. For chemicals where the actual values were below the target the percentage was calculated by dividing the actual value by the target. For chemicals where exceeding the target does not have a negative impact, any value exceeding the target was treated as 100%. For chemicals where exceeding the target is negative, the percentage of the target was calculated by dividing the target by the actual value (an inverse percentage). Targets for water quality for these contaminants were determined using information from the State of Massachusetts Division of Water Pollution Control and Lehigh University (Sherry 2005). For more details on these calculations see Appendix A.3.

Results and Interpretation

The indicator value for the Pennypack Creek was 47.47%. This means that the water is less than half of pristine condition. This value would have been much lower, but both pH and dissolved oxygen were at optimal levels. The values for Suspended Solids, Ortho-phosphate, and Fecal Coliform were all very far from the target, in many cases more than ten times the target value. Nitrate values were also very high. These results implicate the UM-H STP and non-point sources. No standard for nitrates and phosphates has been set for aquatic life, but EPA and the New Jersey Dept of Environmental Protection (NJ DEP) have suggested a level of around 3 mg/L NO_3-N . With respect to phosphates, concentrations exceeding 0.3 mg/L are considered problematic.

The Temple research team evaluated the performance of the STP in removing nutrients. (Meenar 2006) In September of 2004, automatic samplers were placed up and downstream of the STP. The upstream sampler was about 2200 ft from the treatment plant property and the downstream sampler was about 1300 ft from the STP. The samplers collected water from Pennypack Creek at 10 am every day for three weeks.

The sampling results highlight the importance of large point sources in influencing water quality in urban streams. Upstream of the plant, the nitrate concentrations were steady at 1-2 mg/L, which are typical values for urban streams as noted by the USGS. Downstream of the plant, however, concentrations were much higher, typically over 10 mg/L and up to 22 mg/L.

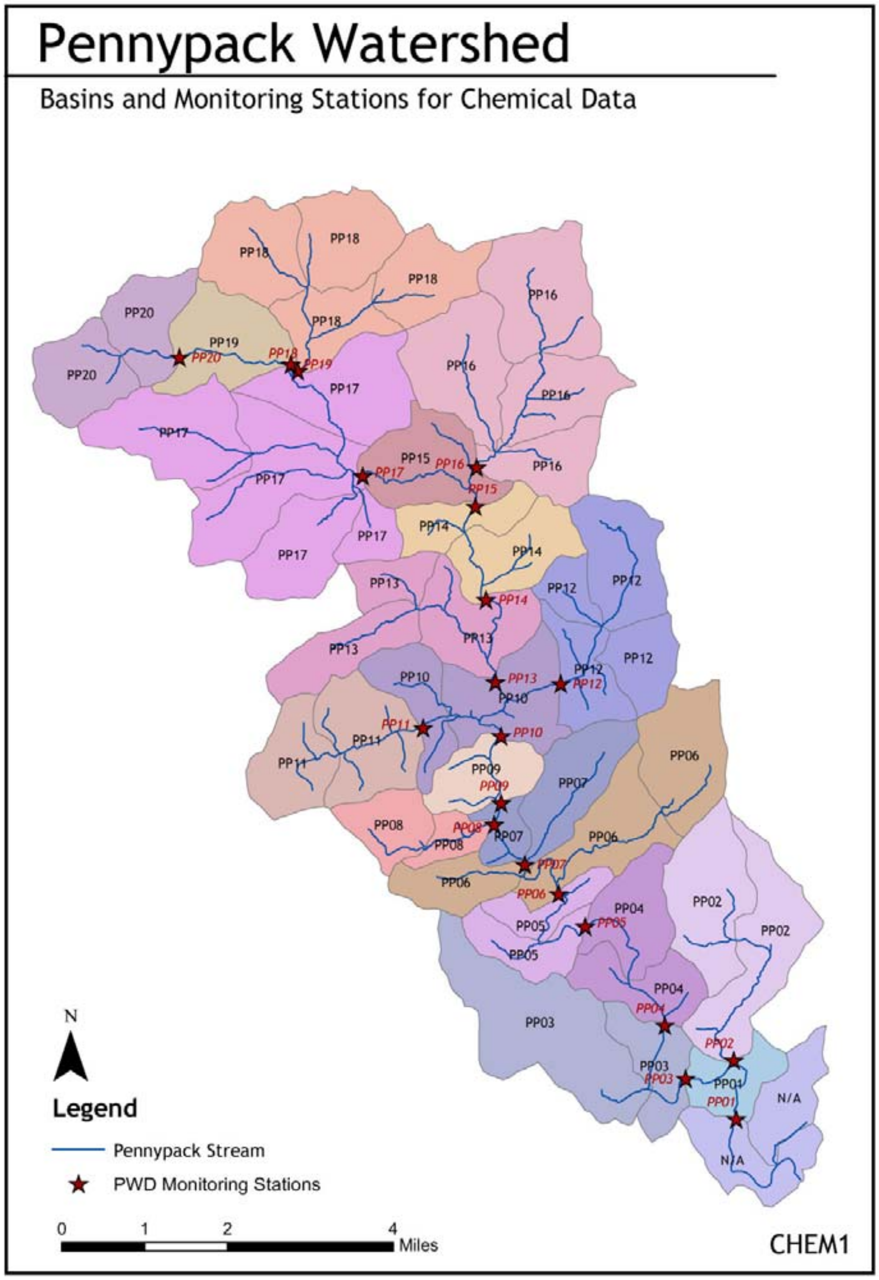


Figure 2.3.5. PWD Stations & Associated Sub-Basins: Chemical Data

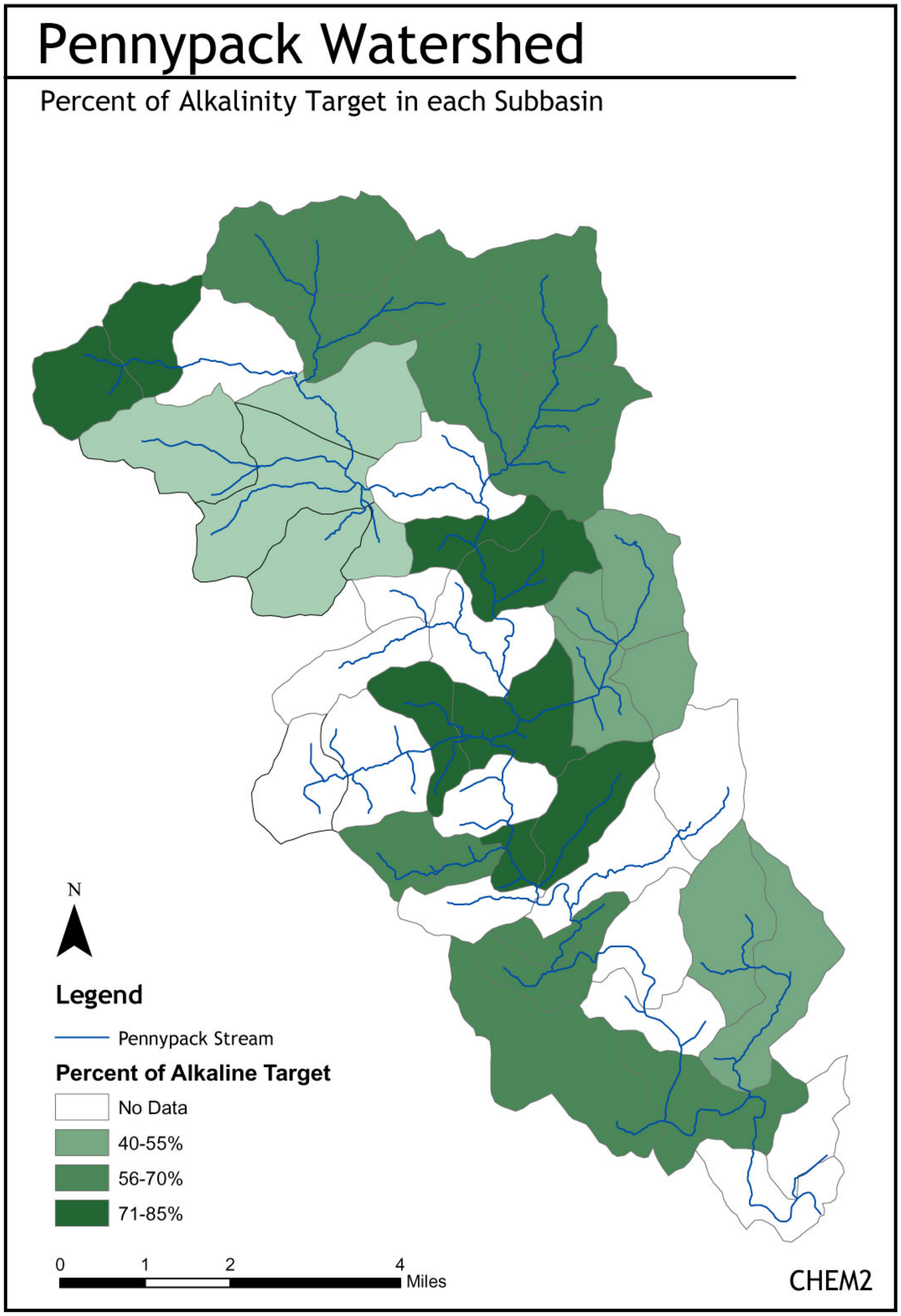


Figure 2.3.6. <u>%-Alkalinity: Sub-Basin Classification</u>

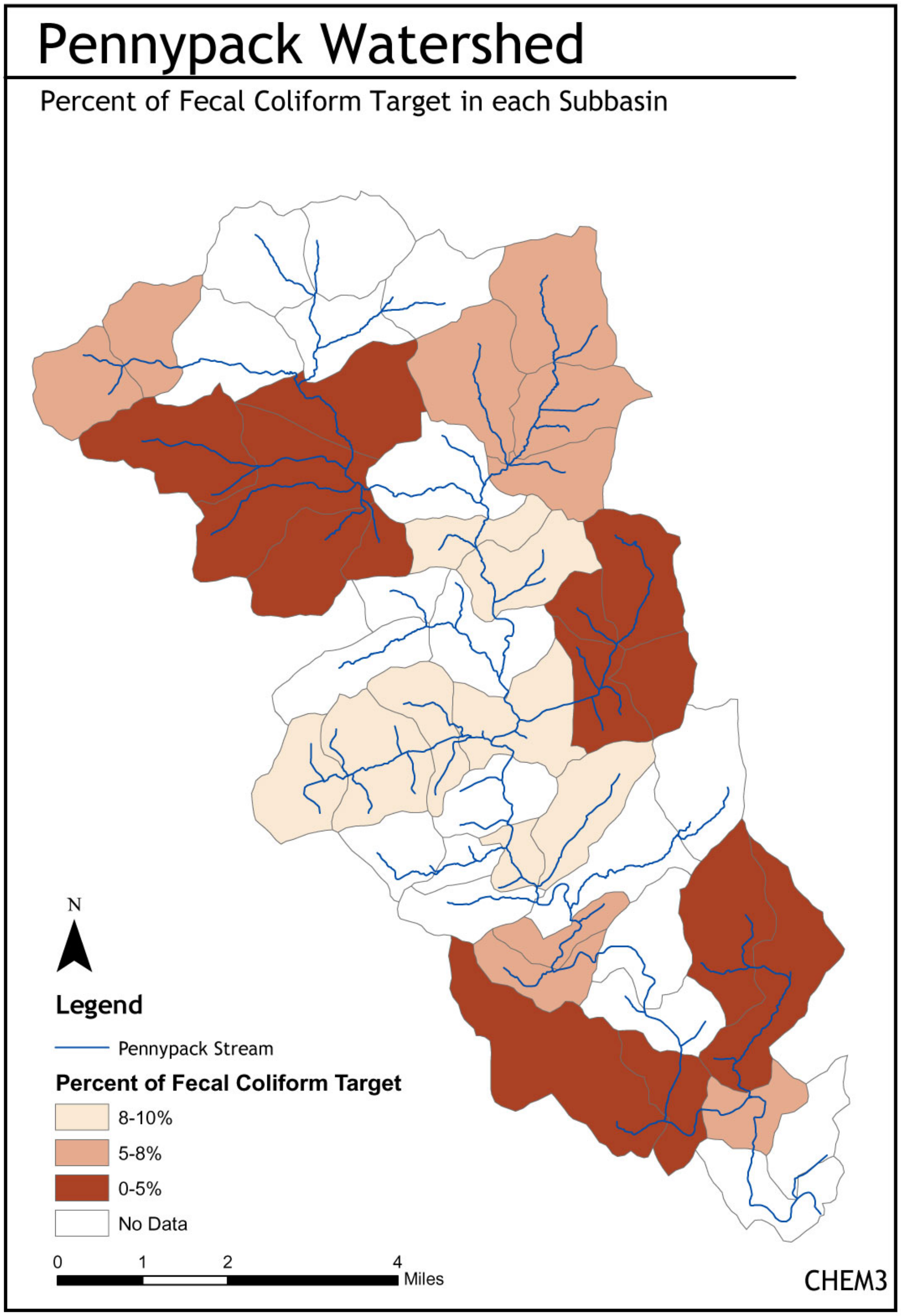


Figure 2.3.7. %-Fecal Coliform: Sub-Basin Classification

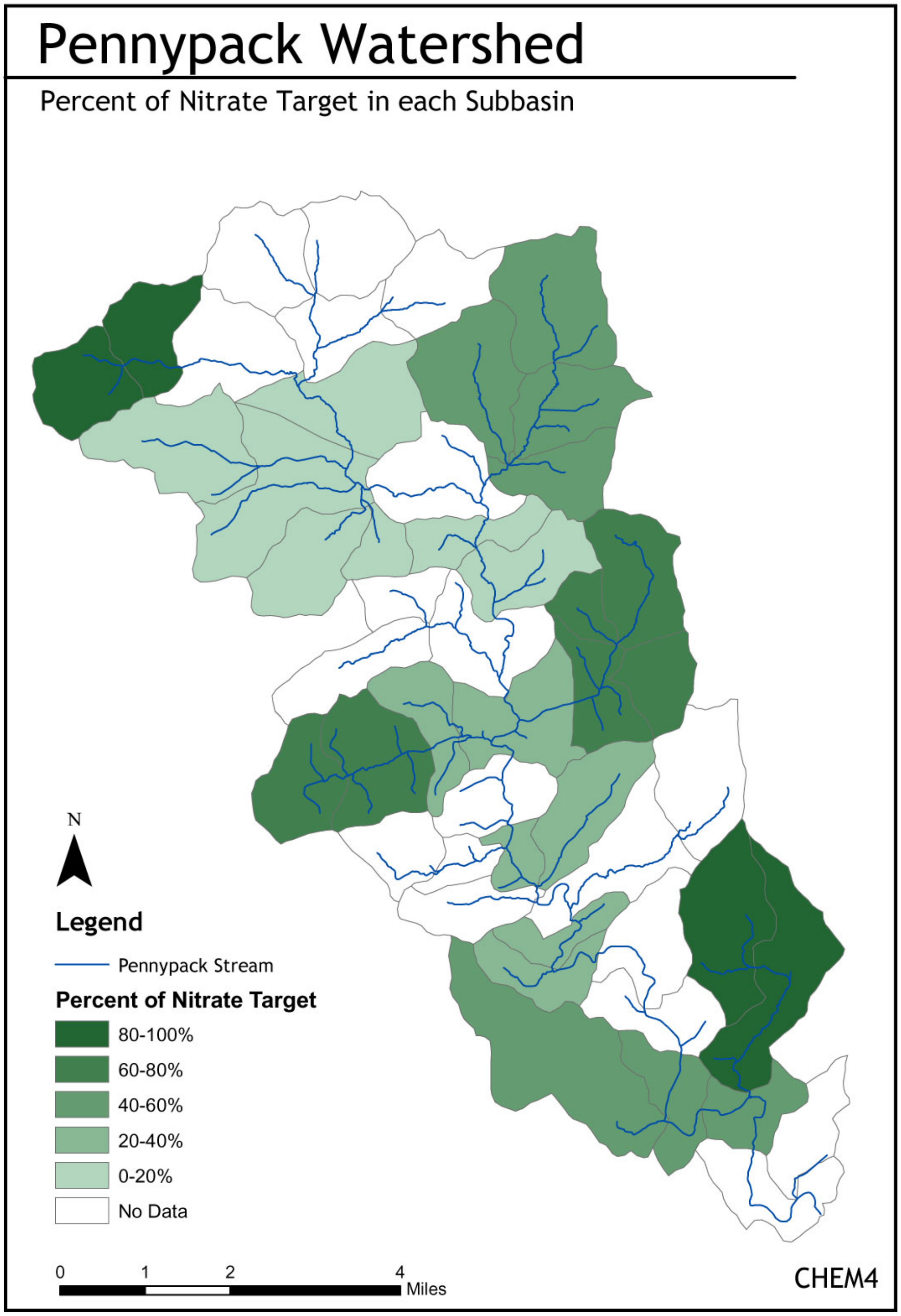


Figure 2.3.8. %-Nitrate: Sub-Basin Classification

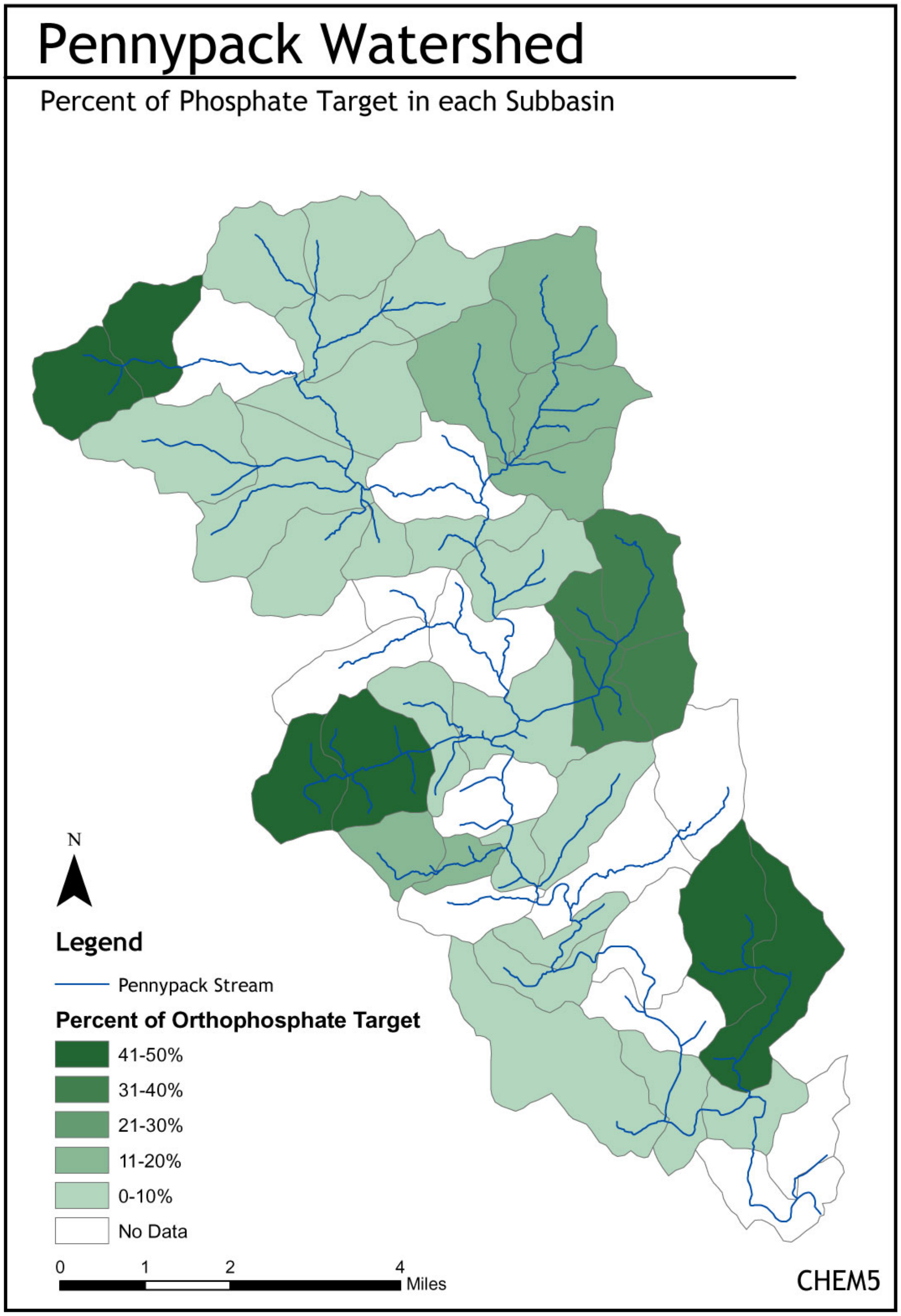


Figure 2.3.9. %-Phosphate: Sub-Basin Classification

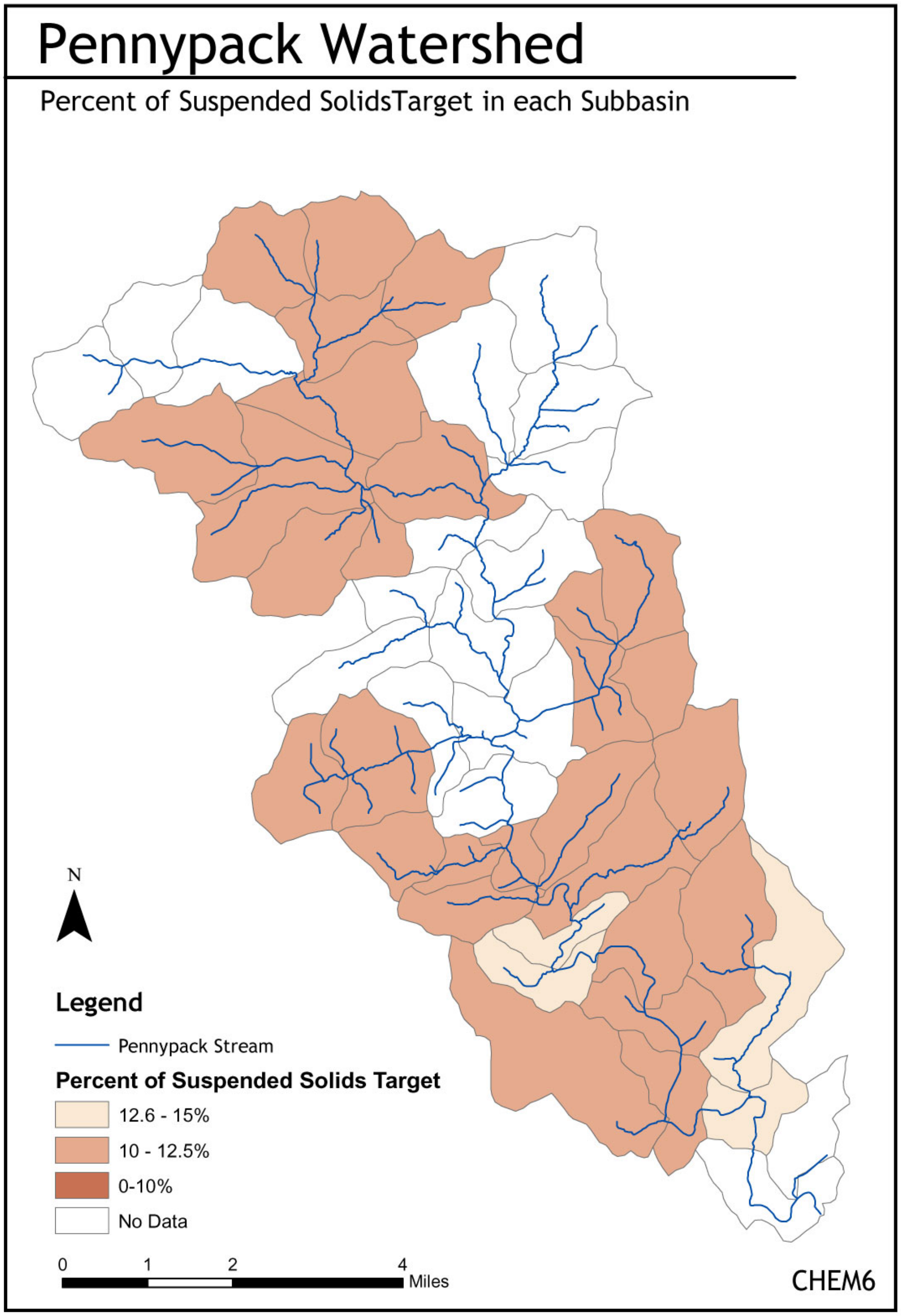


Figure 2.3.10. %-Suspended Solids: Sub-Basin Classification

Concentrations dipped below 10 mg/L during storm events on 9/8/04 and 9/18/04, and were lower in the hand sample collected after Tropical Storm Jeanne. With respect to phosphate, high concentrations of this nutrient were also confirmed by the CSC research team. These concentrations were quite small above the plant. Downstream, high concentrations, typically 1.5 mg/L, were found during non-storm events. These sampling results were generally consistent with previous sampling efforts conducted by the PWD in 2002 at a location near the CSC's sampler downstream of the plant.

Non-point sources, however, are responsible for a majority of the impairment in the Pennypack in terms of geographic context. Non-point-source contamination comes from many diffuse sources, including fertilizers and pesticides from agricultural and residential lands, and nutrients from livestock, pet wastes, and septic systems. Non-point-source contamination is the leading and most widespread cause of water-quality degradation, and it can have harmful effects on drinking-water supplies, recreation, fisheries, and wildlife.

2.3.3. **Biological Integrity**

Data and Methods

This indicator seeks to measure the health of the aquatic ecosystem in the PCW. Ecosystems rely on the delicate interplay of many different factors including the availability of food and habitat, the diversity of species, and the chemical composition, temperature and clarity of the water. This reliance on many factors makes biological integrity a strong composite indicator of the health of the watershed. Also, biological criteria are essential to tracking impaired conditions such as invasive species or loss of biodiversity, that are not directly caused by chemical factors (Davis, 1995). Upstream land use changes and alterations of the stream corridors affect the quality of the water delivered to the stream channel as well as the structure and dynamics of the adjacent riparian environments (Davis, 1995). The status of the biological community can provide information about these factors that would not appear in a chemical analysis.

The data for this analysis came exclusively from the PWD Baseline Assessment (Lance et al. 2003). This study assessed the biological integrity of both the macroinvertebrate populations and the fish populations in the PCW. The macroinvertebrates were collected from a period of 4/2/02 to 4/9/02 using Rapid Bioassessment Protocols (RBPs; Barbour 1999) at 20 locations along Pennypack Creek. Figure 2.3.10. (Map BIO1) shows these locations and the sub-basins to which the data were attributed. EPA's RBPs were designed to provide cost-effective biological methods for states, and local agencies. The protocols exist for periphyton, benthic macroinvertebrate, fish, and habitat assessment, and all of these protocols have been tested in streams in various parts of the country. The biological integrity at each site was determined by PWD following RBPs and was compared to a reference site. Table 2.3.1. taken from the PWD study gives a framework for understanding the biological integrity scores. (Lance et.al. 2003)

Table 2.3.1. Interpreting Biological Integrity Scores

Biological Integrity Score	Condition	Attributes
> 83%	Non-impaired	Comparable to the best situation in an ecoregion. Balanced trophic structure. Optimum community structure for stream size and habitat
54-82%	Slightly Impaired	Community structure less than expected. Species composition and dominance lower than expected due to the loss of some pollution intolerant forms. Percent contribution of pollution tolerant forms increases.
21-53%	Moderately Impaired	Fewer species due to loss of most of the pollution intolerant forms.
< 20%	Severely Impaired	Few species present. If there are high densities of organisms then the system is dominated by one or two *taxa*.

The fish surveyed in this study were collected in July and August of 2002 at eleven of their monitoring stations along the Pennypack Creek. Figure 2.3.11. (Map BIO3) shows these locations and the sub-basins to which the data was attributed. The fish were collected by electrofishing as described in Barbour (1999). The biologic integrity of the fish community was then assessed using the Index of Biological Integrity (IBI) developed by Karr (1981). Table 2.3.2. explains the meaning of ranges of the IBI score.

A scale of 0 to 100% was established as the common framework for the all of the indicators in this study. The macroinvertebrate data were already in this framework. To transform the fish data to match the IBI score, the latter were multiplied by 2. An average percentage for both fish and macroinvertebrates was then determined. A weighted average for the two was also calculated in the interest of having a single score for the indicator. For more details on these calculations see Appendix A.3.

Table 2.3.2. Ranges of the IBI Score

IBI Score	Condition	Attributes
45-50	Excellent	Comparable to pristine conditions, exceptional assemblage of species
37-44	Good	Decreased species richness, particularly pollution intolerant species
29-36	Fair	Pollution intolerant and sensitive species are absent. The trophic structure is skewed.
10-28	Poor	Top carnivores are absent or rare. Omnivores and pollution tolerant species dominate.
<10	Very Poor	Few species and individuals are present. Pollution tolerant species are dominant. Diseased fish are prevalent.

Results and Interpretation

The average biological integrity score of the macroinvertebrate communities studied in the PCW was 21.67%, which according to the system devised by PWD is at the lower end of the moderately impaired category. The highest score for any station was 66.67% - slightly impaired, and this was a station at the extreme upstream portion of the watershed. Figure 2.3.12. (Map BIO2) presents these results. In general the stations that monitored tributaries had higher scores than those stations on the main stem. However, none of the stations monitored had a non-impaired macroinvertebrate community, and a majority of the communities were either severely or moderately impaired. These insects are an important link in the aquatic food web, converting plant and microbial matter into animal tissue that is then available to fish, and their loss makes it difficult for fish and other predators to survive. The average biological integrity score for the fish communities studied in the PCW was 61.20%.This is considerably higher than the score yielded by the macroinvertebrates.This is at least partially due to the fact that the fish had greater biodiversity in the tidal areas. The macroinvertebrates fared poorly there due to the unstable water levels (Lance et. al. 2003) Figure 2.3.13. (Map BIO4) presents these results.

Combining these scores yielded an overall biological integrity score for the watershed of 45.39%. This low score strongly suggests that the effects of human habitation are strongly and negatively impacting the biological communities in the Pennypack Creek.

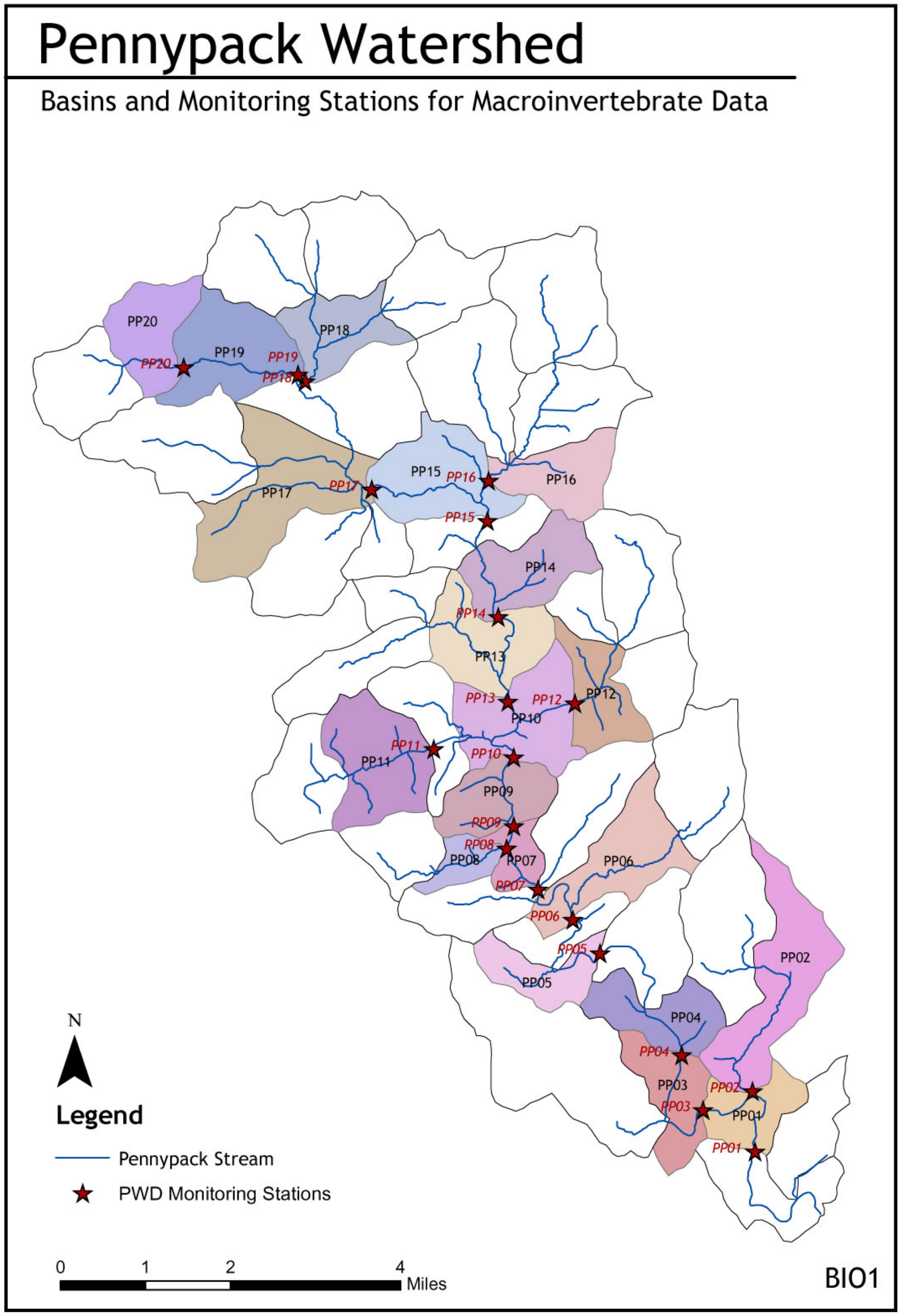


Figure 2.3.11. PWD Stations & Associated Sub-Basins: Macroinvertebrate Data

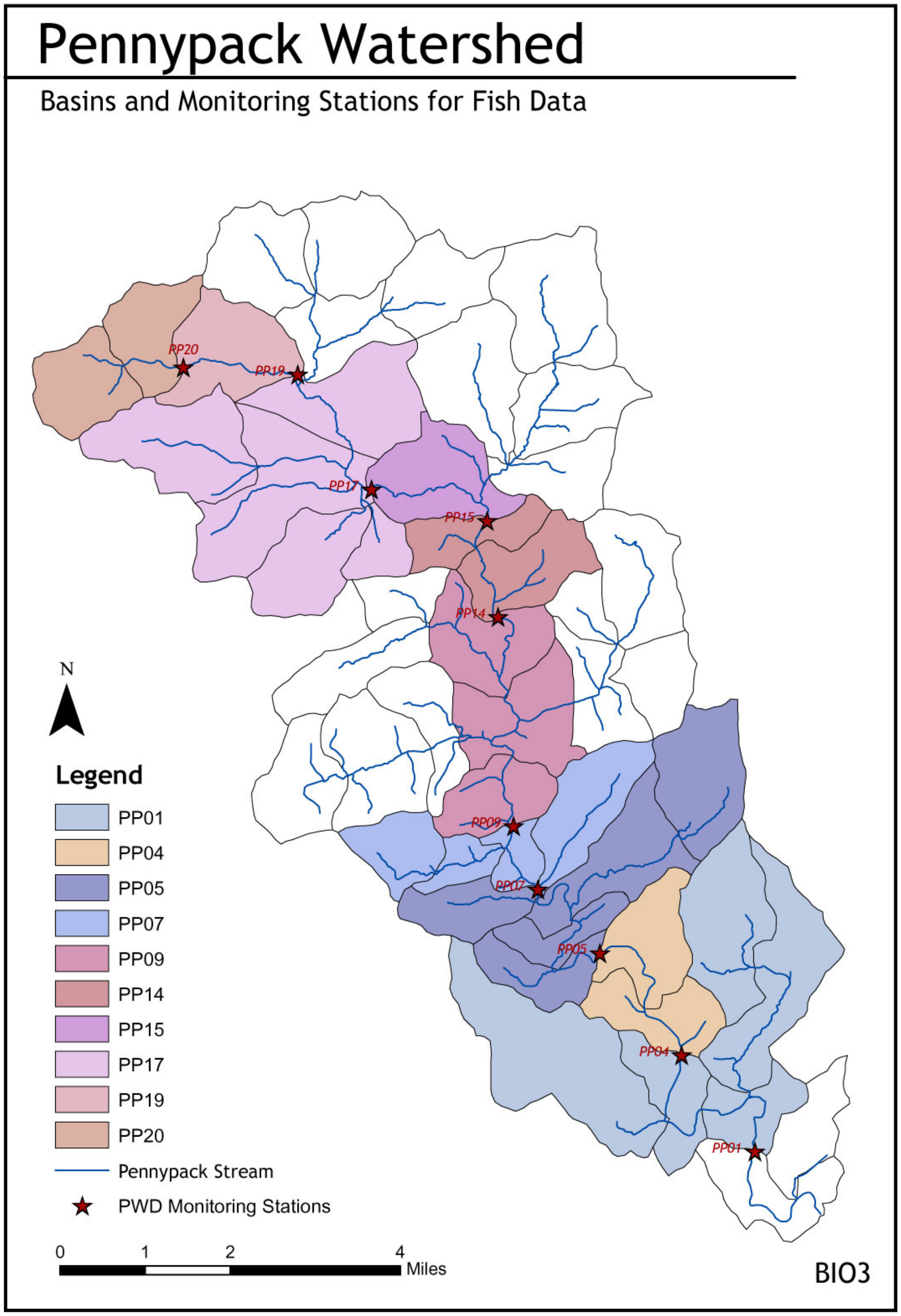


Figure 2.3.12. PWD Stations & Associated Sub-Basins: Fish Data

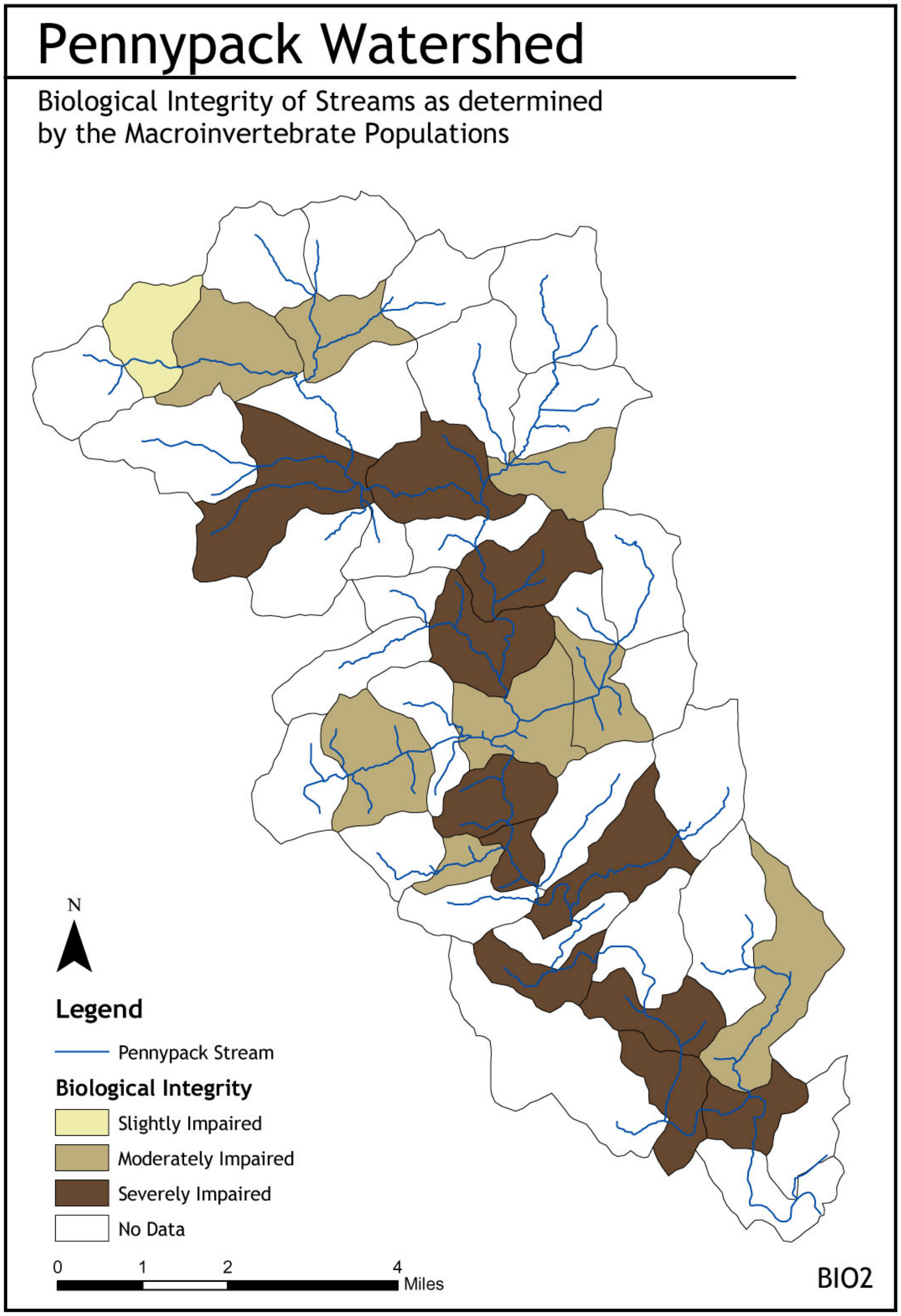


Figure 2.3.13. Biological Integrity for Macroinvertebrates: Sub-Basin Classification

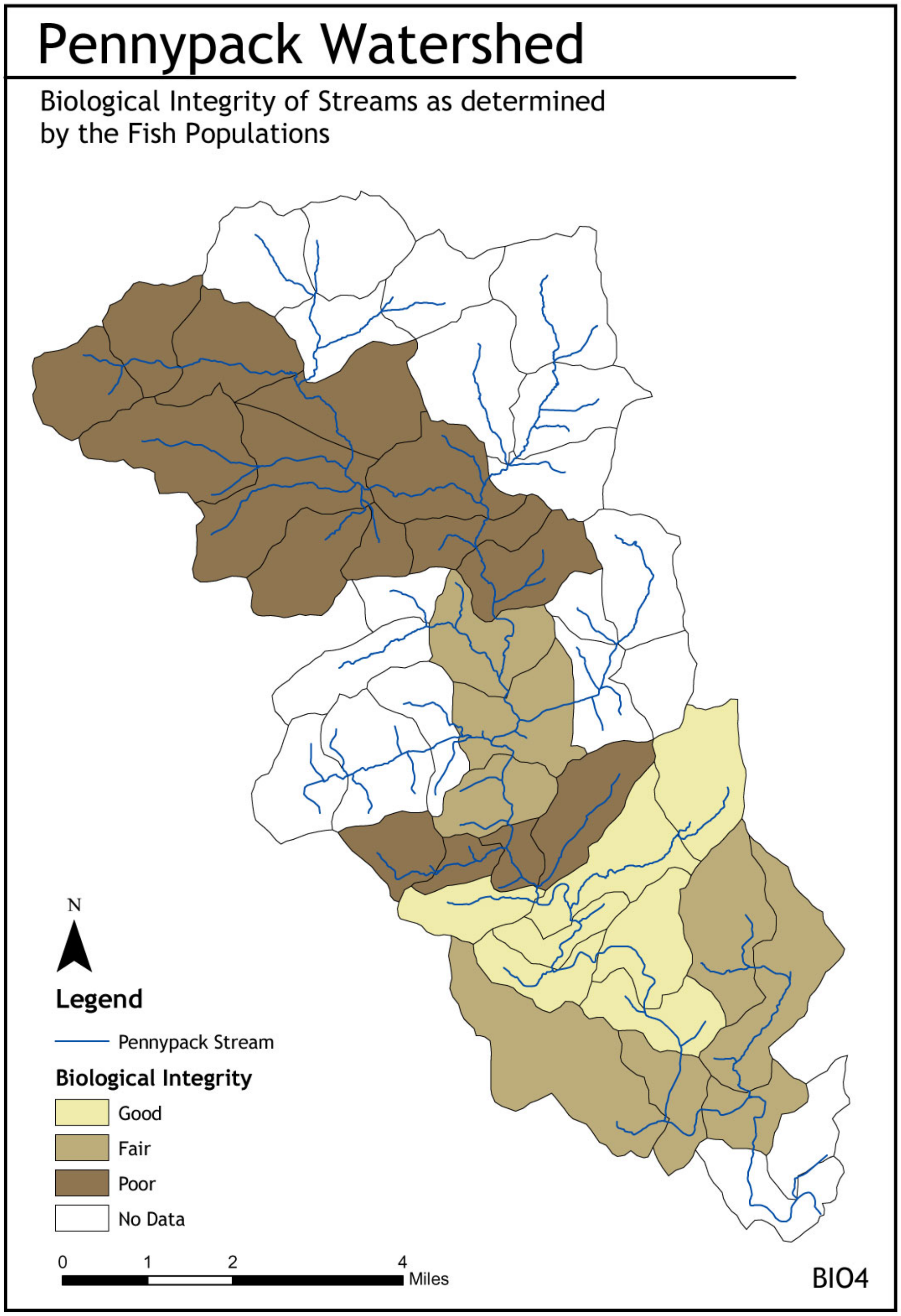


Figure 2.3.14. Biological Integrity for Fish: Sub-Basin Classification

2.3.4. **Impervious Surface**

This indicator seeks to measure the percentage of the land within the watershed that is impervious. In natural settings, very little annual rainfall is converted to runoff, and about half of the water that seeps into the underlying soils becomes groundwater. In urbanized areas, impervious surfaces prevent the rainfall from seeping into the ground, and as a result the rainfall is converted into runoff. This water runs directly to the streams and increases stream volume during rainfall events. Depending on the degree of impervious cover, the annual volume of stormwater runoff can increase by 2 to 16 times its pre-development rate, with proportional reductions in groundwater recharge. (Schueler 1994) Impervious surfaces raise the velocity as well as the volume of stormwater runoff. This increases erosion and sedimentation, and washes oil and other chemicals from roadways and parking lots into surface waters. Impervious surfaces also absorb heat, and often increase stream temperatures during runoff events. These physical changes are generally accompanied by decreasing water quality and decreasing biodiversity (Capiella, 2002).

Data and Methods

The Impervious Surface Data originated from The National Land Cover Database, 2001. The data in this database were generated from satellite photography. The satellite data provided a percentage of impervious coverage for each 25 m x 25 m pixel. The raster containing impervious surface data was clipped to the PCW boundary and then converted to a shapefile. The shapefile containing the 49 sub-basins was converted to a raster and then back to a shapefile, to match the transformed raster's boundary. Using Hawth's Tool: Polygon in Polygon Analysis, the average percentage of surface covered by impervious was calculated for each sub-basin. Then, based on this average of the impervious surface and the area of each sub-basin, the area covered with impervious surface (in square miles) was calculated. This can be seen on Table 2.3.14. (Map IMPERVIOUS1). The mean of these percentages provided the average impervious surface for the PCW. For more details on these calculations see Appendix A.3.

Results and Interpretation

On average 29.67% of the PCW is covered by impervious surface. Many different studies from various geographic areas, employing different methods and concentrating on different variables, have all come to the conclusion that stream degradation occurs at relatively low levels of imperviousness 10-20% (Schueler, 1994). This suggests that the PCW is experiencing significant impacts to its water quality, biological integrity, and groundwater/baseflow from the high percentage of impervious surface in the watershed. The results from the other three indicators all support this conclusion. The current baseflow levels are at just over half what they would be if the watershed were not developed. The biological integrity of the aquatic communities is fair at best, and the levels of many of the pollutants in the stream greatly exceed the acceptable levels, if not the EPA guidelines. If the trend of development in the watershed continues, then all of these indicators will continue to worsen unless efforts are put into place to mitigate the effect of development.

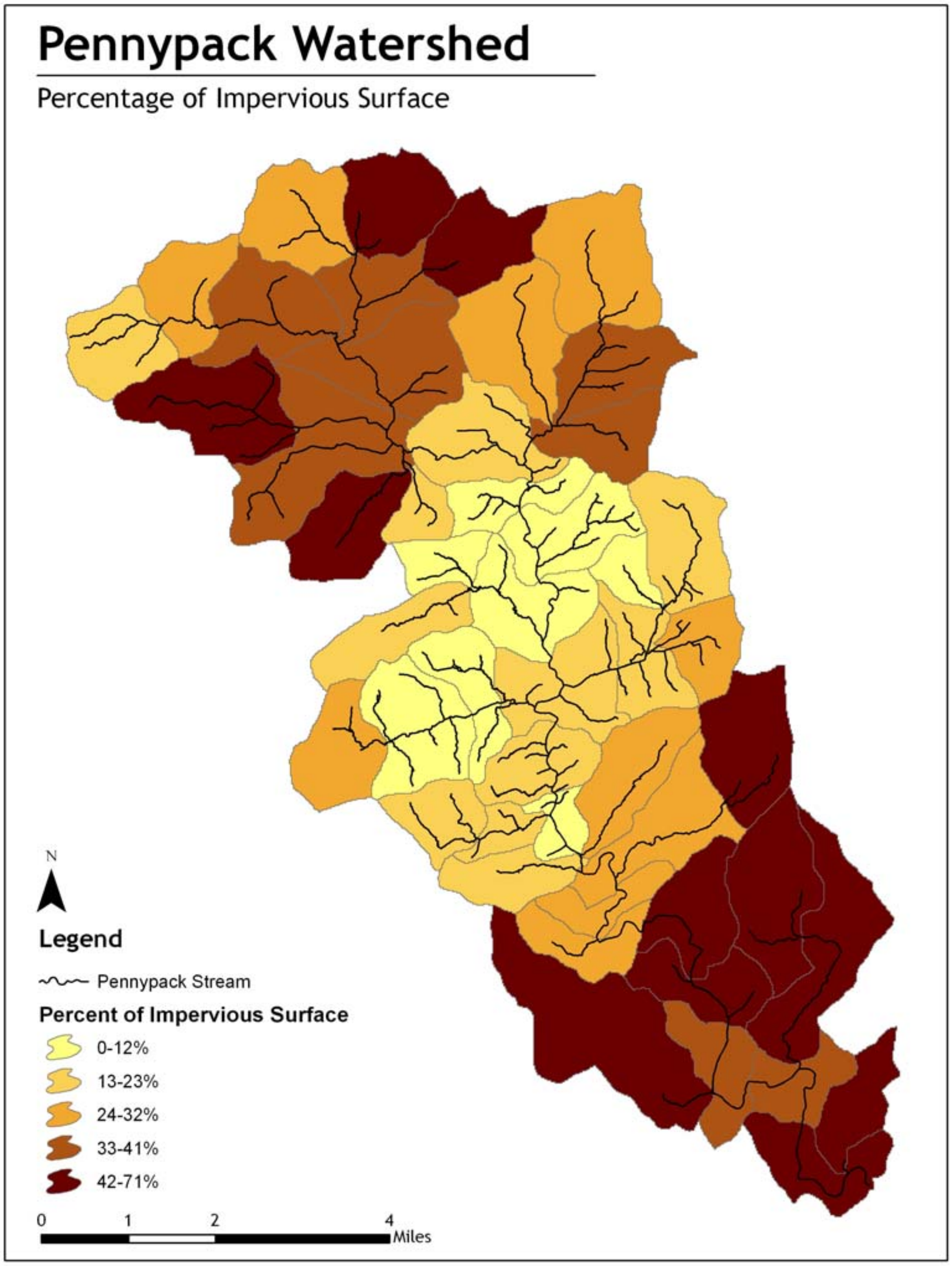


Figure 2.3.15. %-Impervious Surface: Sub-Basin Classification

2.4. **Two Land-Use Scenarios**

In the analysis of the regional environmental future for the Pennypack Creek Watershed, it is important to project possible future land use scenarios and futures. In this section, we describe three alternative future land use scenarios. These scenarios are primarily focused on macro trends in land use change, and do not reflect site-specific innovations which might occur, such as floodplain acquisitions or increased use of site-level stormwater management best practices.

The analysis started with an examination of the demand for land from projected population growth. The most recent official population forecasts were acquired from the DVRPC, the designated regional and Metropolitan Planning Organization (MPO) covering the PCW. We compared the official DVRPC population forecasts to those utilized by the Montgomery County Planning Commission and found no significant differences. The official population forecasts are used by DVRPC for transportation planning and modeling, and serve as an objective source of population and employment forecasts. The forecasts have been updated in 2005 to account for changes in municipal population from 2000-2005. In this analysis, only the projected population growth rates in the 11 municipalities outside of the city of Philadelphia are examined for two reasons. First, nearly all the land within the watershed in Philadelphia is already considered developed. Second, the neighborhoods within Philadelphia in the PCW are not forecasted to experience any significant population changes, absent large-scale redevelopment efforts.

The official population forecasts for each of the 11 non-Philadelphia municipalities which have some or all of their land area in the PCW are then scaled down to represent the housing and population growth needs of the areas of the municipalities which lie within the boundaries of the watershed. Using the land use and demographic databases described in Appendix A.2., it can be determined how much of a municipality's population and land area lie within the PCW using the weighted-average technique. These percentages were used to apportion future population growth targets to the appropriate watershed. For example, if a weighted average of 30 percent of a municipality's housing units and land area were within the PCW, then 30 percent of the forecasted population growth rates were apportioned to future growth within the watershed. This seemed the most reasonable approach. However, it is certainly possible that as a result of this planning effort, municipalities may choose to allocate a larger portion of their future housing and employment growth to other watersheds within their boundaries.

One of the difficulties in watershed planning and land use forecasting within smaller watersheds in Pennsylvania is that fundamental land use decisions are made by municipalities and the boundaries of municipalities do not conform to watershed boundaries. Municipalities are generally required to make adequate provision in their zoning for their projected population growth, but determining into which watershed the growth will be directed is difficult.

Table 2.4.1. presents the future population needs for PCW municipalities, representing only those future populations assigned to growth within the watershed. The first two columns represent the adjusted official population forecasts for the years 2020 and 2030 for each municipality. Columns 3 and 4 convert population forecasts into an indication of aggregate housing unit needs. Based on standard practice, these are calculated as future population divided by average number of persons per occupied housing unit for each municipality in the most recent Census (2000). Thus, the assumption is made that the average number of persons per occupied housing unit will remain the same over the 30 year planning horizon. This assumption is the best assumption of household sizes, even though average household size in the US has been consistently declining. It would be possible to re-estimate the following scenarios assuming smaller household sizes, which would only have marginal impacts on residential land needed. As well, household size will also be a variable somewhat within the control of municipalities in the zoning policies which control the types and sizes of housing units constructed. Within the PCW, the average household size is 2.66 persons per household, ranging from a low of 2.2 persons per household in Jenkintown Borough to a high of 3.5 persons per household in Bryn Athyn Borough. Housing unit needs were also adjusted upwards by 2 percent to reflect an estimated average vacancy rate of 2 percent. In the year 2000 within the watershed, the vacancy rate was 2.4 percent.

Columns 5 and 6 of Table 2.4.1. convert the gross housing unit needs of the years 2020 and 2030 into the number of new units which need to be constructed during the planning horizon. These figures are arrived at by subtracting from housing needs the number of existing units in the year 2020. Overall, the results of the demographic analysis do not show much growth in the non-Philadelphia municipalities of the PCW. Population is only expected to grow from a 2000 level of approximately 100,000 to a 2030 population of 106,000. Only 1855 new housing units in a 30 year time period would be needed to accommodate this population growth. As demonstrated below in the land use scenarios, however, if these housing units are produced at lower densities, the amount of undeveloped land remaining in the PCW would be significantly reduced.

Table 2.4.1. Forecasted Population Growth and Housing Unit Construction Needed

	Population 2020	Population 2030	2020 Housing Unit Need	2030 Housing Unit Need	2020 New Unit Construction	2030 New Unit Construction
Bucks County						
Upper Southampton Twsp.	4659	4768	1818	1860	157	199
Warminster Twsp.	16056	16803	5923	6198	696	971
Montgomery County						
Abingdon Twsp.	28063	28134	11067	11094	-205	-177
Bryn Athyn Borough	1410	1420	401	404	20	23
Hatboro Borough	7470	7500	3134	3147	13	26
Horsham Twsp.	9022	9707	3449	3711	399	661
Jenkintown Borough	523	513	242	238	-10	-14
Lower Moreland Twsp.	9937	10324	3695	3839	73	217
Rockledge Borough	1383	1366	580	573	-28	-35
Upper Dublin Twsp.	892	904	322	327	16	20
Upper Moreland Twsp.	24655	24625	10183	10170	-24	-36
TOTAL PENNYPACK WATERSHED	**104069**	**106064**	**40814**	**41562**	**1108**	**1855**

2.4.1. **Scenario 1: Trend Development**

Table 2.4.2. represents the land use analysis associated with Scenario 1: Trend Development. In this scenario, we assume that each new housing unit will use the same amount of land as the existing year 2000 average housing unit land use for each municipality. That is, in this scenario we assume that current densities (reflecting current zoning and current development practices) predict future densities. This assumption is still somewhat conservative in terms of land use, because newer housing units generally are produced at densities lower than existing average densities.

Table 2.4.2. Land Development Rates: Trend Development Scenario

	2020 Residential Need	2030 Residential Need	2020 Non-Residential Need	2030 Non_ Residential Need	2020 Total Need	2030 Total Need	Land Suitable for Development
Bucks County	Acres	Acres	Acres	Acres	Acres	Acres	Acres
Upper Southampton Twsp.	67	85	18	23	84	108	164
Warminster Twsp.	209	292	90	125	299	416	404
Montgomery County							
Abingdon Twsp.	-59	-51			-59	-51	432
Bryn Athyn Borough	13	15	3	3	16	18	58
Hatboro Borough	3	5	4	5	6	10	55
Horsham Twsp.	172	284	48	80	220	364	736
Jenkintown Borough	-1	-2			-1	-2	0
Lower Moreland Twsp.	46	135	11	28	56	163	236
Rockledge Borough	-4	-5			-4	-5	0
Upper Dublin Twsp.	8	11	2	2	10	13	15
Upper Moreland Twsp.	-6	-10	6	5	0	-5	439
TOTAL PENNYPACK WATERSHED	446	758	181	270	627	1029	2539

Using the high-resolution digital land data, gross residential housing unit densities are determined for each municipality as the number of housing units divided by land classified as in residential use. (Residential classifications by DVRPC include streets internal to a development, utility rights-of-way and stormwater drainage facilities, but do not include commercial facilities or non-local roads.) Thus, the estimate of gross residential housing unit densities is a good estimate of the amount of land used per housing unit. Using the figures from 2000, we project aggregate residential land use in Table 2.4.2., shown in columns 1 and 2. Development densities across the region range from a low of 1.6 housing units per acre in Bryn Athyn to a high of 7.8 housing units per acre in Jenkintown.

Estimates of the amount of land needed in non-residential development (including commercial, industrial, office, utility, and transportation needs) can be estimated with detailed employment growth forecasts to convert employment needs into space requirements. Unfortunately, at the small scale of a municipality or portion of a municipality, employment forecasts are difficult to obtain and of questionable quality. The alternative approach, common in many planning applications, is to assume a fixed amount of non-residential land per capita, and therefore, to assume that non-residential land use needs are driven by local population growth. In this case, we project that per-capita demand for non-residential land will be approximately 2000 square feet. That is, each person added will produce a demand for an additional 2000 square feet of non-residential urban development. These assumptions were parameterized based on an analysis of aggregate land development uses within the entire Philadelphia metropolitan area. Based on DVRPC data, we estimate that non-residential urbanized land uses amount to approximately 2212 square feet per resident in the region not including Philadelphia and 1833 square feet per resident when Philadelphia is included. Thus, the assumption of an additional 2000 square feet of non-residential urban land use per new additional resident seems a reasonable assumption based on existing development trends. However, in municipalities which are projected to experience population decline, we assume that the same amount of urbanized non-residential land is maintained.

The analysis in Table 2.4.2. indicates that, at current trend densities, the PCW will see an aggregate additional 1029 acres converted to urban development in the 30 year period between 2000 and 2030. However, the estimate of 1029 acres is aggregated across some municipalities where population growth is forecasted to be negative. If, as in this scenario, it is assumed that each municipality must accommodate its own projected growth needs, and that declining population municipalities retain the same amount of developed land, then 1092 total additional acres will be needed to service new urban development by 2030.

For this scenario, in order to apportion future land use growth in the various scenarios, the suitability and capability of currently undeveloped land to accommodate land development and growth were analyzed. The first step was to create a layer of land use which is "potentially developable." Potentially developable land was defined as all land currently in use in the agricultural, wooded, recreation or vacant categories. We then overlaid layers of known permanently-preserved open space land (state, county and municipal parks, PERT land, etc.) to remove lands which would not be developed due to preservation easements or public ownership. All the remaining land is considered "potentially developable."

Within the land classified as potentially developable, two criteria were applied to identify those lands which are most suitable for development. The first criterion was the absence of environmental constraints and the second criterion was the availability of sewer infrastructure. For the environmental constraint criteria, we used data on slopes, streams, floodplains and wetlands. Land was identified as being environmentally constrained if it were over 15 percent sloped, within a floodplain, within 100 feet of a stream or within 25 feet of the edge of a wetland. A data set was used on "sewer service areas" (from DVRPC) to identify those lands which are within a sewer service area. Thus, those lands which are most suitable for development are those lands which are within a sewer service area and which lack environmental constraints. Within the entire PCW (including Philadelphia), there are nearly 3900 acres considered suitable for development under this methodology, of which over 2500 acres are outside of the city of Philadelphia.

Of these 3900 acres potentially more suitable for development, over 40 percent are currently wooded and nearly 13 percent are in agriculture. Thus, one of the planning challenges facing the watershed is balancing the growth needs with preserving forested and agricultural landscapes. In this analysis, an area being classified as potentially suitable for development does not mean that development of these landscapes is the most appropriate policy choice.
In the future land use development envisioned under this scenario, each municipality develops land to meet its own projected residential and non-residential needs. In this scenario, growth needs were compared with lands designated in the analysis above as suitable for development. As can be seen in a comparison of the growth needs in columns 5 and 6 of Table 2.4.2. with column 7 (lands suitable for development), nearly every municipality has adequate suitable land to meet its forecasted growth needs at present densities. The only exception is Warminster Township, which in this scenario would use 416 acres in the 30 year planning period, while having only 404 acres available for development. In the scenarios constructed, it is assumed that all development for municipalities occurs on lands classified as suitable for development. For Warminster, the additional 12 acres of development needs are assumed to come from land designated as un-sewered but not environmentally constrained (of which 20 acres are available.)

Each municipality accommodating its *own* projected land development needs in many ways represents the trend in Pennsylvania land use planning by municipalities, as each municipality is under an affirmative obligation to "accommodate reasonable overall community growth, including population and employment growth" (PDCED; 2005) absent a shared land-use agreement within a multi-municipal plan.

Thus in the Trend Development scenario, the following rules are used to accommodate each municipality's future population growth in the 20 and 30 year planning horizons. First, if the municipality shows a negative projected population growth rate, it is assumed that land use patterns in 2020 and 2030 will remain the same as in 2000. That is, even though population will decline, it is assumed that the number of housing units and the amount of land in non-residential urban use will not change. Given the durable nature of infrastructure, housing and urban development, this is a reasonable assumption. Second, if the municipal growth can be accommodated on land which has public sewers available and is not environmentally constrained, all of its development needs were simulated on that land. As much development as possible was first allocated on land currently classified as "vacant." Third, for the one municipality (Warminster) which required additional land for development, its remaining development needs were allocated to land which was not environmentally constrained, without public sewers.

Figures 2.4.1. shows the projected land use in 2030 under Scenario 1.

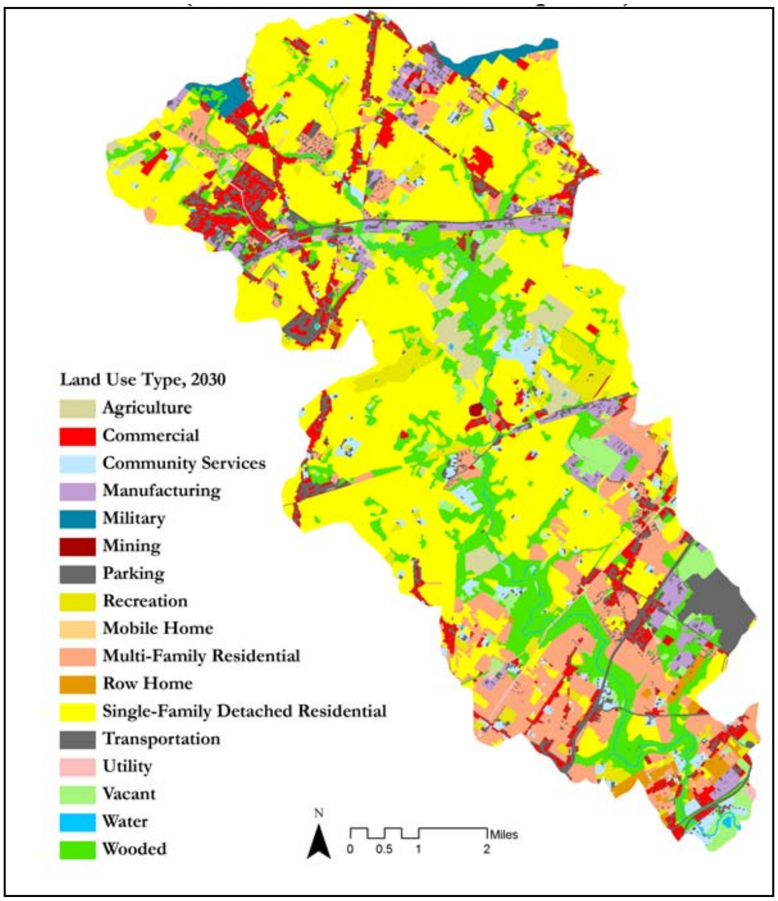


Figure 2.4.1. Trend Development Land Use, 2030

Much of the undeveloped land near the various streams of the watershed is protected in this scenario from development because of the environmental constraints. Most of the land conversion under this scenario occurs in the currently less developed townships in the northern portion of the watershed.

2.4.3. **Scenario 2: Smart Growth**

Municipal Smart Growth

In this scenario, each municipality accommodates its forecasted population growth needs, but accommodates the residential portion of that growth at significantly higher gross housing densities and the non-residential portion at slightly increased intensities. In order to illustrate this scenario, densities of 6 units per gross residential acre were chosen to simulate all new residential development in the less dense municipalities. Abington Township and Upper

Moreland Township were excluded because the analysis in Table 2.4.1. showed a negative household land-use need.

Depending on the planning decisions of these municipalities accommodating growth at higher densities in terms of housing mix and design standards (e.g. cluster subdivisions), some of these housing units could be townhouses and others would be cluster houses on smaller lots (e.g., 8000 ft^2). Further, in this smart growth scenario, only 1500 square feet of residential land per new resident was assumed, in that commercial and other uses were developed at higher intensities. The results are shown in Table 2.4.3.

Table 2.4.3. Land Development, Municipal Smart Growth Scenario

	2020 Residential Need	**2030 Residential Need**	**2020 Non-Residential Need**	**2030 Non-Residential Need**	**2020 Total Need**	**2030 Total Need**	**2020 Land Saved**	**2030 Land Saved**
Bucks County	Acres	Acres	Acres	Acres	Acres	Acres	Acres	Acres
Upper Southampton Twsp.	26	33	13	17	39	50	45	58
Warminster Twsp.	116	68	68	93	184	255	115	161
Montgomery County								
Horsham Twsp.	67	36	36	60	103	170	117	194
Lower Moreland Twsp.	12	8	8	21	20	57	36	106
Upper Dublin Twsp.	3	1	1	2	4	5	6	8
TOTALS	**224**	**126**	**126**	**193**	**350**	**537**	**320**	**527**

The last column of Table 2.4.3. indicates that, in comparison with the trend development scenario illustrated in Table 2.4.2., 527 additional acres of forested and agricultural landscapes would be preserved with accommodation by each municipality of its future residential needs at reasonably higher densities, consistent with smart growth. Comparing these figures with the amount of land which is suitable for development in Table 2.4.2., each municipality has more than enough land available for this smarter development. Figure 2.4.2. shows the projected land use futures for 2030 under Scenario 2.

Regional Smart Growth

In this third scenario, the region still accommodates its forecasted population, but accommodates the development by sharing uses among municipalities. Future growth needs are targeted to existing vacant (but developed) land as infill development or redevelopment. It is assumed as well that the existing housing stock of areas forecasted to lose population, are occupied, and therefore, absorb

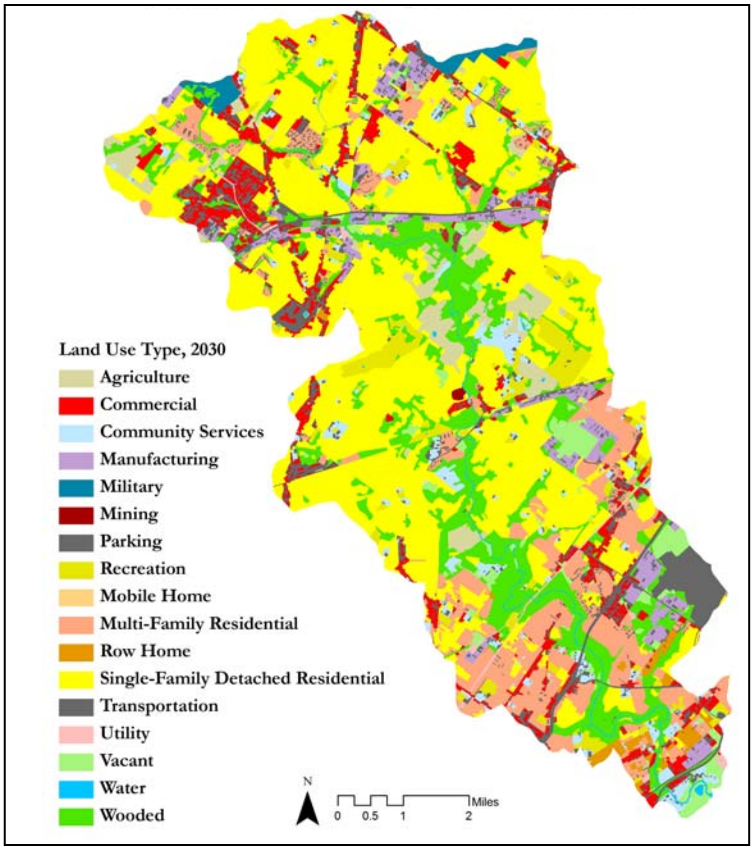


Figure 2.4.2. Municipal Smart Growth Land Use, 2030

a significant proportion of overall population growth in the region. For example, the estimates in Table 2.4.1. for Abington Township show an actual population loss equivalent to 205 households. In this scenario, 205 forecasted new households from other municipalities would instead move into the existing housing stock in Abington, reducing the need for new construction. In this scenario, the number of new households which could be accommodated in existing housing units was calculated first. For the region as a whole, only 1108 new net housing units need to be constructed to 2020 and 1855 net new housing units to 2030.

Table 2.4.4. presents an analysis of land available within the region which is considered “vacant” (not wooded, not agricultural) and also “suitable for development” (no environmental constraints, public sewer available.)
It should be apparent in examining Table 2.4.4., that all of the PCW’s net new housing unit development, if accommodated at urban densities, could be easily accommodated in the currently vacant land in the city of Philadelphia within the watershed. If the watershed were to undertake something like a regional “transfer

of development rights" program, all of the projected growth needs for 30 years could be accommodated without any additional conversion of currently undeveloped land to urban development.

Table 2.4.4. Regional Smart Growth Scenario

	Vacant Land, Suitable for Development (acres)
Bucks County	
Upper Southampton Twsp.	44
Warminster Twsp.	77
Montgomery County	
Abingdon Twsp.	50
Bryn Athyn Borough	0
Hatboro Borough	14
Horsham Twsp.	62
Jenkintown Borough	0
Lower Moreland Twsp.	23
Rockledge Borough	0
Uper Dublin Twsp.	1
Upper Moreland Twsp.	70
Philadelphia County	
Philadelphia	564
TOTAL PENNYPACK WATERSHED	**905**

2.5. **Differential Impacts of Residential Development Scenarios**

Two separate analyses were undertaken to estimate some impacts of traditional vs. smart residential development. Section 2.5.1. estimates hydrological changes that result from the trend and municipal smart growth scenarios in Section 2.4 above. Section 2.5.2. assesses impacts based on *two slightly different development scenarios*: Smart Growth and Sprawl. In future research, it is hoped that the analyses in Sections 2.5.1. and 2.5.2. can be unified.

2.5.1. **Hydrology**

Given the land-use changes forecasted in the development scenarios described in Section 2.4., Trend Development and Smart Growth, the peak flows were estimated with the USGS HEC-RAS model. They are shown in Table 2.5.1. Figures 2.5.1. and 2.5.2.

Table 2.5.1. Peak Flows (cfs) for Varying Conditions

PWD Station	Current Flows	Trend Flows	Smart Growth Flows	Trend Flows with t_c reduced 10%	Smart Growth Flows with t_c reduced 10%
1	160	235	178	254	193
2	271	403	317	436	343
3	374	518	376	561	408
4	1303	1606	1360	1740	1476
5	403	574	438	622	476
6	1795	2277	1895	2468	2051
7	1900	2394	2010	2594	2180
8	2035	2543	2159	2756	2342
9	253	259	259	280	280
10	2640	3193	2800	3461	3036
11	248	250	250	271	271
12	2691	3250	2856	3524	3098
13	91	115	115	124	124
14	2809	3378	2982	3661	3235
15	3050	3585	3191	3886	3462
16	3141	3671	3277	3980	3556
17	3331	3816	3424	4138	3713
18	3470	3905	3511	4232	3809
19	202	202	202	214	214
20	3690	4087	3697	4436	4016

The Trend Development and Smart Growth flows are shown in Figures 2.5.1. and 2.5.2.

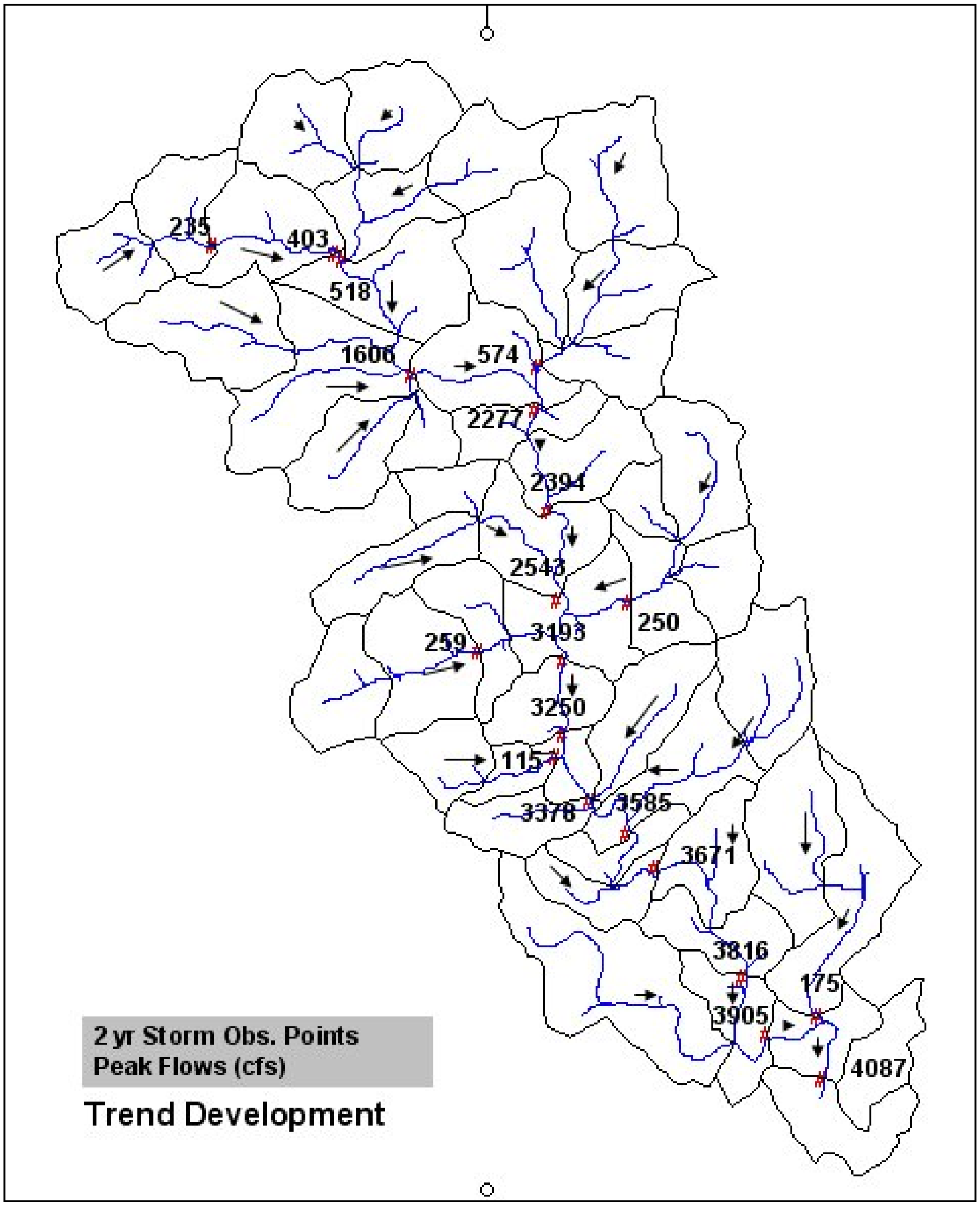


Figure 2.5.1. Flows from Trend Development

2.5.2. Energy Use, Air and Greenhouse Gas Emissions, Water Quality and Biological Integrity

In this section, the analysis of residential development involved four steps: (1) desirable attributes of development behavior were transformed into suitability criteria using GIS software to find areas into which housing can be sustainably placed; (2) development scenarios were created; (3) the energy and environmental impacts of the placements were estimated; and (4) the effects on the value of ecosystem functions were estimated. Housing placed randomly in the most suitable sites represents the *Smart Growth* scenario. Housing placed randomly among non-restricted locations in the PCW represents the *Sprawl* scenario.

Suitability Analysis for Smart Growth

The criteria used to determine the suitable areas for the Smart Growth scenario were that development should: (A) be on a suitable site (vacant and low-density residential land uses, though possible in other areas); (B) not be within the restricted areas (floodplain boundary; wetland, and other water resources, parks, open spaces, woodlands, and other protected spaces); (C) minimize the necessity of new infrastructure and services (minimize distance to existing road infrastructure, schools, and shopping centers); (D) minimize the impact on air quality in the airshed (minimize contribution to traffic congestion and minimize distance to public transit stations); & (E) minimize the impact on water quality in the PCW (protect the riparian buffer areas, floodplains and open spaces).

More specifically, the criteria were set within the following two broad categories: (i) *Land Features*: on lands free from floodplains, wetlands, ponds, and other water resources; on impervious surface (the goal is to protect pervious surfaces); on relatively flat land; on suitable land cover; on impermeable soil type (Impermeable soil should be better for development, as it has minimum impact on water transmission to soil. Soil types A (high rank) to D (low rank) were considered.); and (ii) *Infrastructure and Facilities*: near public transit stops (only rail station data was used), roads and bike trails, schools, hospitals, and parks and open spaces. It was assumed for this analysis that the current residential housing stock stays intact. Though *zoning* is recognized as an important determinant of housing placement, it was assumed that it can be changed to accommodate new development. In addition, the zoning ordinances of the municipalities in the PCW have different coding systems. This makes it difficult to create a comprehensive zoning map for this multi-municipal watershed.
The GIS software used for this study was ArcGIS 9.1 (ESRI 2005). The input data and their sources were:

- Land Cover – US Geological Survey (USGS)
- Landuse – Delaware Valley Regional Planning Commission (DVRPC)
- Floodplains – Center for Sustainable Communities (CSC), Temple University Ambler
- Stream Bank and Buffer – CSC
- Slope – CSC
- Wetlands, Ponds, and Other Water Resources – CSC
- Roads – ESRI
- Soil – PA Spatial Data Access (PASDA)
- Impervious Surface – PASDA
- Southeastern Pennsylvania Transit Authority (SEPTA) Rail Stations – DVRPC

- Bike Trails – DVRPC
- Municipal Boundaries – DVRPC
- Job Centers – DVRPC
- Schools – ESRI
- Hospitals – ESRI

All of these datasets were available in vector format (points, lines and polygons), except impervious surface data. Vector data were converted to raster (pixels) and then those layers were reclassified according to the suitability criteria.
After reclassification, the layer Scale Values were determined. The Scale Values ranged from 10 to 1 – most suitable to least suitable.
Layer: Floodplains, Wetlands, Ponds, Floodway, Wetland, Pond: Restricted
    100-Year Floodplain: 1
    500-Year Floodplain: 2
    Other Areas: 10
Layer: Impervious Surfaces
    Lowest 2 categories (in other words, highest impervious) are restricted
Layer: Slope
    Lowest 4 categories (in other words, highest slope) are restricted
Layer: Land Cover
    Value 0 is restricted land cover
Layer: Hydrologic Soil Group
    Group B: 5
    Group C: 9
    Group D: 10
Layer: Streets
    Value 0 is a restricted area

Finally, Layer Influence (user-chosen %s) was determined before the final raster calculation. These are shown on Table 2.5.2.. The map of suitable sites for the Smart Growth scenario is shown in Figure 2.5.2.

<u>Suitability Analysis for Sprawl</u>

In this scenario, only the restricted areas were excluded from the total watershed in order to keep the other areas open for new development or re-development as much as possible. Restricted areas are those that are restricted by state or local municipal law, such as state or county parks and open spaces, floodways, and other protected lands. The output of this analysis is shown in Figure 2.5.3.

Table 2.5.2. Relative Importance of Suitability Criteria

Layer	Influence
Floodplains, Wetlands, Ponds	.30
Impervious Surfaces	.15
Slope	.05
Land Cover	.10
Soil	.10
Transit Stops (rail station)	.10
Roads	.10
Schools	.02
Hospitals	.02
Parks and Open Space	.02
Trails	.04

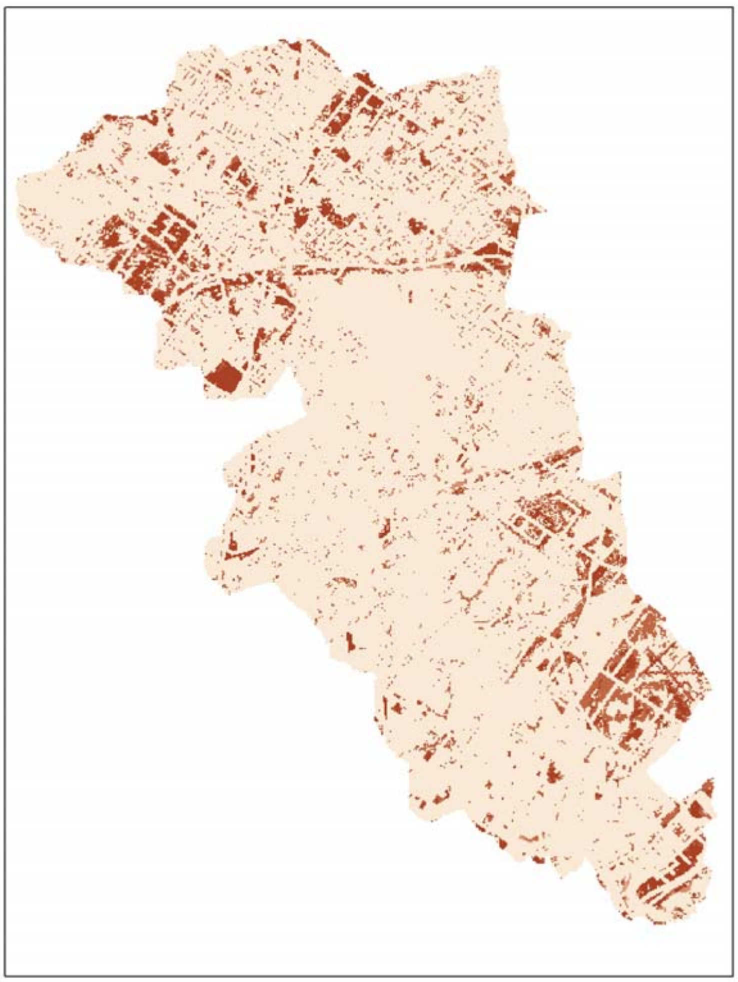


Figure 2.5.2. Sites for Smart Growth: Darker Is More Suitable

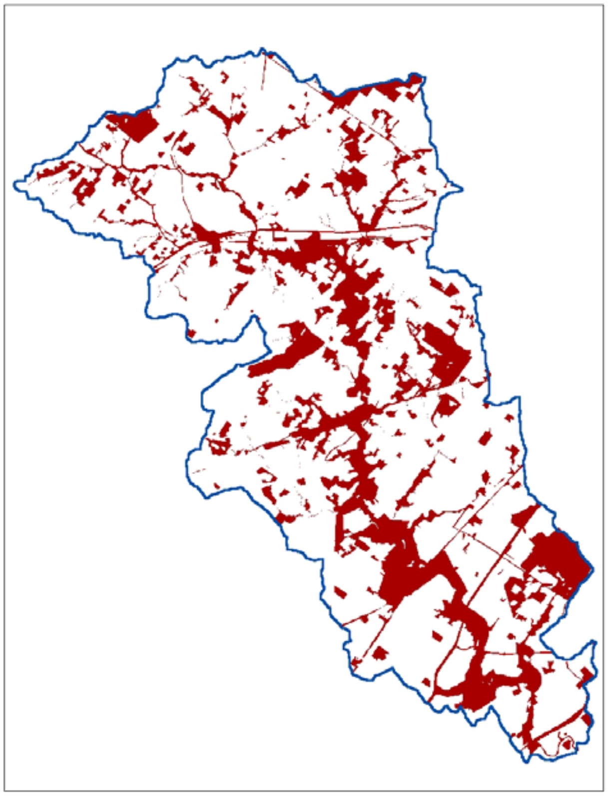


Figure 2.5.3. Sites for Sprawl: All but Dark Sites Acceptable

Residential Development

The 1855 units in Table 2.4.1. projected to be needed by 2030 were assumed to be placed in 2006, and to be distributed over the suburban municipalities and the part of Philadelphia in the watershed. The building units were placed at various sites for the two scenarios. Hawth's Tool, an extension of ArcGIS, was used for generating random points representing the building units. For the Smart Growth Scenario, 1855 points were randomly generated in the highest suitable areas (with ranks 10 and 9). The following steps accomplished this task: create a polygon file from the suitability output raster file; dissolve according to suitability categories; choose only areas with 10 and 9 and create a new layer; generate random points for the whole area (using Hawth's Tool); select only those points that are inside areas with 10 and 9 ranking, and randomly choose 1855 points from the selection. Once the building units were placed, distances were calculated from these points to the nearest commuter rail stations (points) using Hawth's Tool. The method was same for the sprawl scenario. The only difference from the Smart Growth selection process is that random points were generated in areas suitable for the sprawl scenario, i.e., all unrestricted areas.

Energy and Environmental Impacts

As this work deals with residential housing *placement*, it was assumed that the same type of housing would be placed in any location chosen. As the goal was to compare placement in the Sprawl scenario to that in the Smart Growth scenario, the assumption of the same type of housing obviates the need to specify the structural, energy-use and emissions characteristics of the houses themselves. It was also assumed that residents in any location will drive the same class of automobile. The energy-use and emissions characteristics of the representative vehicle are given below.

Auto Energy Use, Greenhouse Gases and Air Quality

To calculate energy use and greenhouse gas and criteria air pollutant emissions of miles driven by residents in the two scenarios, a beta version of the GREET 1.7 program created by the Argonne National Lab's Center for Transportation Research (Wang; 2005) was used. Based on fuel type, technology type, market share and many other parameters chosen by the user, the program can generate "well-to-pump," "well-to-tank" and "well-to-wheels" estimates for energy use and greenhouse gas and criteria air emissions.

The estimates used here are for a car with a conventional spark-ignition (SI) engine using conventional gasoline (CG) or reformulated gasoline (RFG). Table 2.5.3. shows some parameters used.

Table 2.5.3. Fuel Economy & Emissions Rates of Baseline Vehicles

Items	**SI Vehicle: CG & RFG**
MPG	24.8
Exhaust VOC (all g/mi)	.122
Evaporative VOC	.058
CO	3.745
NO_x	.141
Exhaust PM_{10}	.0081
Brake & Tire Wear PM_{10}	.0205
CH_4	.0146
N_2O	.012

The results of the GREET run in terms of energy use and emissions are given in Table 2.5.4.

Table 2.5.4. Energy Use & Emissions from a Typical Automobile

Gasoline Vehicle: CG and RFG				
	Btu/mile or grams/mile			
Item	**Feedstock**	**Fuel**	**Vehicle Operation**	**Total**
Total Energy	188	981	4,912	6,081.497
Fossil Fuels	181	968	4,835	5,983.208
Petroleum	60	470	4,835	5,364.766
CO_2	19	73	368	459.778
CH_4	0.448	0.085	0.021	0.553
N_2O	0.000	0.005	0.012	0.018
GHGs	29	77	372	477.733
VOC: Total	0.017	0.116	0.218	0.351
CO: Total	0.041	0.040	4.917	4.998
NO_x: Total	0.117	0.134	0.268	0.518
PM_{10}: Total	0.010	0.038	0.029	0.077
SO_x: Total	0.047	0.109	0.006	0.162
VOC: Urban	0.003	0.074	0.135	0.212
CO: Urban	0.001	0.018	3.058	3.078
NO_x: Urban	0.006	0.057	0.167	0.229
PM_{10}: Urban	0.000	0.004	0.018	0.022
SO_x: Urban	0.004	0.048	0.004	0.057

In both scenarios, automobile energy use and greenhouse gas and criteria air pollution emissions are computed by multiplying the GREET numbers in Table 2.5.4. by the number of miles residents would drive when they are placed in chosen locations. Though this could have been done for any or all of the other types of infrastructure (e.g., roads, schools), distances from the chosen housing sites to the nearest commuter rail stations were calculated. Assuming two trips/day, five days/week and forty-nine weeks/year yielded 1,894,340 miles for Sprawl and 933,940 miles for Smart Growth. The results are shown in Table 2.5.5. Columns 3 and 4 show the products of the items in column 2 and the miles computed for the two scenarios. The Smart growth miles were 50.7% of the Sprawl miles.

Suitability Analysis for Sprawl

In this scenario, only the restricted areas were excluded from the total watershed in order to keep the other areas open for new development or re-development as much as possible. Restricted areas are those that are restricted by state or local municipal law, such as state or county parks and open spaces, floodways, and other protected lands. The output of this analysis is shown in Figure 2.5.3.

Table 2.5.5. Energy Use & Emissions in Sprawl & Smart Growth

Gasoline Vehicle: CG and RFG				
Item	Btu/mile or grams/mile	Miles in Sprawl 1894340	Miles in Smart Growth 933940	
Quantities	Per Mile	Energy Use/Emissions		Difference
Total Energy	6,081.50	11,520,423,027	5,679,753,308	5,840,669,719
Fossil Fuels	5,983.21	11,334,230,243	5,587,957,280	5,746,272,963
Petroleum	5,364.77	10,162,690,824	5,010,369,558	5,152,321,266
CO2	459.778	870,975,857	429,405,065	441,570,791
CH4	0.553	1,047,570	516,469	531,101
N2O	0.018	34,098	16,811	17,287
Total GHGs	477.733	904,988,731	446,173,958	458,814,773
VOC: Total	0.351	664,913	327,813	337,100
CO: Total	4.998	9,467,911	4,667,832	4,800,079
NOx: Total	0.518	981,268	483,781	497,487
PM10: Total	0.077	145,864	71,913	73,951
SOx: Total	0.162	306,883	151,298	155,585
VOC: Urban	0.212	401,600	197,995	203,605
CO: Urban	3.078	5,830,779	2,874,667	2,956,111
NOx: Urban	0.229	433,804	213,872	219,932
PM10: Urban	0.022	41,675	20,547	21,129
SOx: Urban	0.057	107,977	53,235	54,743

Water Quality and Biological Integrity

As noted in Sections 2.3.2. and 2.3.3. the PWD (2003) provided a chemical analysis and a biological integrity assessment of the water for each of their 20 monitoring stations located along the Pennypack Creek. For each station, the water quality index was computed using the components and their target levels. Each measurement was divided by the target level for that component. Since some components are negative to water quality (by their nature, or if they exceed the target), a minus sign was added. The resulting “signed” ratios were added over the components. Due to the relative magnitudes of the ratios, the sums are invariably negative. Hence, water quality is highest at those stations with smaller negative values. Ratios of the observed components of water quality to target levels are shown in Table A.3.6. The Water Quality Index in Table 2.5.5.. is simply the sum of the row sum for each station.

The biological integrity values from Tables A.3.7. and A.3.8. are combined and presented in Table2.5.7. It should be pointed out that the presence of .0000 in the table implies different things for macroinvertibrates and fish. For macroinvertibrates, it means that no significant numbers were found at a site. For fish, it is due to the fact that only 10 stations were sampled. The Total Biological

Integrity was gotten by choosing the only non-zero number in the row, or by averaging the numbers in the row.

Table 2.5.6. Water Quality Index

Station	**Water Quality Index**
1	-38.03
2	-36.10
3	-50.82
4	-50.82
5	-40.47
6	-40.47
7	-43.29
8	-36.36
9	-36.36
10	-47.39
11	-23.04
12	-32.31
13	-32.30
14	-63.55
15	-63.55
16	-31.34
17	-79.12
18	-174.51
19	-174.51
20	-22.55

Table 2.5.7. Biological Integrity

Station	Macro-Invertebrates Biological Integrity (%)	Fish Biological Integrity (%)	Total Biological Integrity (%)
1	0.0000	0.6800	0.6800
2	0.4000	0.0000	0.4
3	0.0667	0.0000	0.067
4	0.0000	0.7600	0.76
5	0.0000	0.7600	0.76
6	0.0000	0.0000	0
7	0.0000	0.5600	0.56
8	0.4000	0.0000	0.4
9	0.1333	0.6400	0.38665
10	0.2667	0.0000	0.2667
11	0.4667	0.0000	0.4667
12	0.4000	0.0000	0.4
13	0.0000	0.0000	0
14	0.1333	0.5600	0.34665
15	0.2000	0.5200	0.36
16	0.4000	0.0000	0.4
17	0.0000	0.4800	0.48
18	0.4000	0.0000	0.4
19	0.4000	0.4800	0.44
20	0.6667	0.4800	0.57335

Analytical relationships between various land uses and water quality and biological integrity were not established. To gauge the water-related impacts of the Smart Growth and Sprawl scenarios, the Water Quality Index and the Biological Integrity were “weighted” by the placement of the housing units. The water quality and biological integrity assigned to the stations were then attributed to the sub-basins. The number of housing units in each sub-basin served as a weight by which to multiply the sub-basin water quality and biological integrity. The result was a Weighted Water Quality and Weighted Biological Integrity. The results of the calculations are summarized in Table 2.5.9.

Reduction in the Value of Ecosystem Services

Absent an explicit inventory created by the PCW research team, the general list of these services given by deGroot, Wilson and Boumans (2002) was used. These authors collected a range of values for these services as estimated in other studies. Table 2.5.8. shows the ecosystem services and the midpoint $/acre values of the ranges provided by the authors.

Table 2.5.8. Value of Ecosystem Functions/Services

Service Category	Service	Midpoint ($/acre)
Regulation	Gas regulation	55
	Climate regulation	63
	Disturbance regulation	1465
	Water regulation	1102
	Water supply	1538
	Soil retention	55
	Soil formation	2
	Nutrient cycling	4287
	Waste treatment	1367
	Pollination	8
	Biological control	16
Habitat	Refugium function	309
	Nursery function	68
Production	Food	560
	Raw materials	206
	Genetic resources	24
	Medicinal resources	n.a.
	Ornamental resources	30
Information	Aesthetic	358
	Recreational & tourist	1214
	Cultural & artistic	n.a.
	Spiritual & historic	5
	Scientific & Educational	n.a.
Total Ecosystem Service Value		**$12732**

Source: Adapted from deGroot, Wilson and Boumans (2002)

Without a model to link water-related attributes to ecosystem services, the latter were treated in the aggregate. The percentage *relative* reduction in total ecosystem service value (TESV) will be taken as an average of the percentages by which the Sprawl scenario impacts exceed those of the Smart Growth. This average, giving Sprawl credit for having a better WWQ, is (.507 + .533 -.212)/3 = .277. If the sum of the midpoints of the value ranges provided by deGroot, Wilson & Boumans (2002) are updated from the 1st half of 1994 to the 1st half of 2006 by the all-item, urban CPI, then the average relative reduction in the TESV is ($12732/acre)*(1.36)*(.277)*(1029 acre) = $4,935,495**.** Table 2.5.9. contains a finer breakdown.

Table 2.5.9. Impacts Summary

Scenario		**Sprawl**	**Smart Growth**
Total Energy Use (bbl of oil)		2300	1140
Greenhouse Emissions (short tons/yr)	CO_2	960.09	473.34
	CH_4	1.15	0.57
	N_2O	0.038	0.019
	GHG: Total	997.58	491.82
Air Emissions (short tons/yr)	VOC: Total	0.73	0.36
	CO: Total	10.44	5.15
	NO_x: Total	1.08	0.53
	PM_{10} : Total	0.16	0.08
	SO_x: Total	0.34	0.17
Grnhse & Air % Net Reduction in TESV		50.70%	
Grnhse & Air $$ Net Reduction in TEFSV		$9,033,559	
Weighted Water Quality "Index"		-104075	-124395
Water % Net Reduction in TESV			19.50%
Water $$ Net Reduction in TESV			$3,474,446
Biological Integrity		450	684
Bio % Net Reduction in TESV		52.00%	
Bio $$ Net Reduction in TESV		$9,265,188	
Total $$ Net Reduction in TESV		$18,298,747	$3,474,445

The results clearly show that the Sprawl Scenario generates more than *five times* the ecosystem value reduction than that caused by Smart Growth.

2.6. **Pennypack Ecological Vulnerability Assessment (PEVA)**

The PEVA team found three particular sources of vulnerability: the main Philadelphia intake, the PCW-resident sewage treatment plant and PCW stormwater management.

Philadelphia Water Supply

In 2002, the PWD (2002; p. 14) stated that, “The Baxter Water Treatment Plant provides treated water that comes from the Delaware River. … Particular tributaries that require special attention to address polluted runoff from urban/residential areas and agricultural lands include the Pennypack Creek …” The 600-mgd Baxter Plant is located just up-stream from the confluence of the Pennypack Creek and the *tidal* Delaware River, and is the primary source of Philadelphia water supply. The water supply is vulnerable to PCW impairment because at flood tides, the Pennypack water moves up river.

The Sewage Treatment Plant

It is apparent that the UM-H STP is severely impacting aquatic life as concentrations in its discharges far exceed recommended limits. Considering the land use scenarios conducted as part of this analysis, increasing wastewater flows and sewage to this plant, which is operating near capacity, will only complicate nutrient removal and further impair aquatic life and recreation in and along the Pennypack Creek downstream of the STP. Publicly Owned Treatment Works (POTWs) are least efficient when operated at capacity because the hydraulic retention time in primary and secondary clarifiers is reduced, limiting the ability of plants to settle out solids, including nutrients. Unless the plant is expanded and outfitted with nutrient-removal technology, water quality would continue to degrade. As part of its PCW Study (Meenar 2006), the CSC research team recommended that the Upper Moreland-Hatboro Joint Sewer Authority conduct a feasibility study to evaluate possible upgrades to significantly improve the plant’s performance in reducing nutrient levels in its effluent.

Both the Trend and Smart Growth scenarios assume that 1855 new structures will be built in the watershed. If they are all built within the service area of the WTP, this would increase flows to the plant by about 0.3 mgd for both scenarios. (1855 units x 2.66 people per unit x 60 gallons per capita per day of sanitary water usage = 296,058 gpd). Additional commercial development would also increase flows and the need for additional treatment capacity." This combined with a reduction in baseflow stemming from additional ground water withdrawals in the watershed would further exacerbate the nutrient problems downstream of the WTP. The receiving stream would have less flow and the larger volume of effluent would increase loadings of nitrate and phosphate absent a nutrient removal program. This would further degrade aquatic habitat in the Pennypack Creek.

Unless the STP improves its nutrient removal, other efforts to improve stream water quality will only provide nominal improvements. treatment options include biological removal or chemical additives.

Stormwater Management

It was not until the 1970s that requirements for controlling the quantity or quality of runoff coming from a developed site were a consideration. Water was routed from a site to the nearest stream in the most expedient manner. This increased volume of water accelerates erosion and sedimentation and destroys stream habitat. From the 1970s until recently, stormwater management relied primarily on the use of detention basins to manage stormwater. While these basins controlled the peak flows of water, they did not reduce the overall volumes of runoff and did nothing to address or improve the water quality of runoff.

Stormwater BMPs and regulatory requirements are improving stormwater management in new developments. However, these actions do little to address the sins of the past. Water quality and quantity issues in older developments will require the retrofitting of existing stormwater facilities or the installation of stormwater controls where none exist in order to reduce the runoff volumes.

Many existing stormwater management facilities in the PCW have become completely or partially dysfunctional because of poor or no maintenance, ineffective design, or a combination of such factors. Some of these were obviously constructed many years ago, as evidenced by their filling by sediments and debris and the abundant tree growth within them. However, many have been constructed in recent years, and some have been observed that are quite new, but which are already evidencing poor performance.

In the summer of 2004 through spring of 2005, a visual assessment of the entire PCW was performed by Temple researchers in order to get a full picture of what was actually happening on the ground within the creek's watershed and its surrounding riparian corridors. The reconnaissance was conducted mostly on foot, but often had to resort to "windshield survey" methods, especially in areas such as residential subdivisions or industrial properties where access was severely limited or completely prohibited.

This assessment evaluated the condition and functionality of existing stormwater facilities, assessed the potential for retrofitting such facilities so as to improve both their environmental and flood control performance, and sought locations for recommended new stormwater Best Management Practices (BMPs).

Field observations were made at a total of 421 locations within the seven suburban sub-basins into which the entire watershed study area was divided for hydrologic and hydraulic modeling purposes. Whatever their age, many dysfunctional or poorly functioning facilities, whether with respect to management of discharge rates, volumes, or water quality, have been identified on the abovementioned maps as having the recommended "Highest Priority" or "High Priority" for renovation, redesign, and/or retrofitting.

Among the 421 observation locations, the CSC has identified that only 73 locations have some form of stormwater management facilities. However, 48 of these existing facilities are, in the judgment of the study team, either completely dysfunctional or performing poorly.

One strategy being employed in urbanized watersheds is to retrofit existing stormwater structures to better control stormwater volume and to improve water quality. However, public perception and acceptance of stormwater retrofits cannot be taken for granted. The recent spread of West Nile virus has raised public concern regarding perceived mosquito breeding sites; basin naturalization and changes in basin/site hydrology tend to tap into this anxiety despite abundant evidence that facilities such as wet ponds or constructed wetlands can provide habitat for insect predators and are actually less likely to harbor such disease vectors. New stormwater management approaches need to be carefully explained and resident concerns must be addressed.

The need for education and demonstration of successful stormwater retrofits is essential to illustrating the effectiveness of such BMPs and alleviating these public misconceptions, all while improving the conditions within these urbanized watersheds. Opportunities that municipalities can take advantage of immediately are those which they can implement on publicly owned lands. Each municipality owns and/or manages sites that could be potentially “retrofitted” with some form of BMPs. These sites would not only reduce stormwater impacts, but also serve as model sites within the region.

The Urban Storm Water Workgroup of the Chesapeake Bay Program compiled data on the pollutant removal efficiencies of urban storm water management BMPs. While the actual performance of specific BMP installations varies, the Workgroup found that practices that could be used in parking areas such as porous pavement, bioretention areas and infiltration trenches had pollutant removal efficiencies for Total Suspended Solids (TSS) of 85 to 90% and for Total Nitrogen (TN) and Total Phosphorous (TP) of 40 to 70%. Conventional detention basins have pollutant removal efficiencies for TSS of only 10% and for TN and TP of 5 to 10%. In contrast, practices that might be used to replace or retrofit dry detention basins had significantly higher pollutant removal efficiencies. For example, a dry extended detention basin had a pollutant removal efficiency of 60% for TSS, 20% for TN and 30% for TP. A wet pond had an efficiency of 80% for TSS, 30% for TN and 50% for TP.

The overall watershed stormwater runoff can be controlled through the effective control of individual sub-basin stormwater runoff. Retrofitting existing stormwater facilities as well as areas developed prior to the implementation of any stormwater management controls with BMPs is the key to reducing water quality and quantity problems within the Pennypack Watershed. The CSC researchers recommend that each municipality create a stormwater management utility to provide sufficient revenues to fund such retrofits, to efficiently operate and maintain all stormwater facilities, and to ensure preservation of critical areas that perform vital stormwater management functions. Furthermore, each municipality should concentrate its initial efforts on implementing retrofits at the priority sites within each sub-basin where BMPs can have a significant and cost-effective impact on controlling stormwater runoff.

2.7. **Relation of PEVA to Pennsylvania's Sustainability Indicators**

The Pennsylvania Consortium for Interdisciplinary Environmental Policy (PCIEP; 2004) created the list of environmental indicators shown in Table 2.7.1. Indicator #1 clearly includes Pennypack Creek. It was found to be moderately impaired, and a return to a more natural "designated use" will require some adjustments. Indicator #3. can be related to the Pennypack in at least two ways: the UM-H STP and landowners may be considered to be using the Creek's capacity to receive waste discharges and/or runoff beyond the "sustainable yield" of the Creek remaining healthy. Indicator #5 applies directly to the PCW – Trend or Sprawl development will have greater impacts on air, climate and water than the Smart development. Indicators #6 and #7 are directly affected by increased peak flows and impairment of the water in the Pennypack. Indicator #9 directly addresses the impairment of surface water. Besides the STP, the PCW experiences considerable non-point source pollution. The fuel-use impacts estimated in Section 2.5.2. directly address Indicator #13. The CSC has shown that Indicator #14 related to the PCW with respect to property damage and flooding. It was determined that there are 738 buildings in the 100-year floodplain. (Meenar 2006) Finally, Indicators #15 and #16 are relevant to the PCW because the local municipalities are cooperating on sustainable stormwater management, and the Pennypack Trust under the Directorship of Dr. David Robertson is spearheading forest, wetlands and Creek restoration.

The research work presented in the previous sections can help a watershed management group to define PCW sustainability goals and indicators more refined than the general ones listed in Table 2.7.1. This work remains, and can be accomplished with future funding.

Table 2.7.1. PA Sustainability Indicators

GOAL 1: Sustain, conserve, protect, enhance, & restore PA's environment, natural resources, & ecological diversity	1: # of lakes & surface stream miles supporting their designated use for aquatic life
	2: # of designated groundwater sampling points for each ground water basin located in a watershed that meets primary drinking water standards
	3: # of water resources being used beyond their sustainable yield
	4: Acres of land by use
	5: # of days & # of Pennsylvanians affected when air quality does not meet health standards
	6: Index of ecological diversity
	7: Ecosystems or species threatened by environmental conditions
	8: Quantity of waste (by type) generated, recycled, reused & eliminated
GOAL 2: Reduce harmful effects from environmental contaminants & conditions.	9: Quantity of pollutants released into air, land & water
	10: Annual mean pH of PA precipitation
	11: # of public water supply systems meeting all drinking water standards & maximum contaminant levels
	12. Quantity of waste disposed (by type)
	13: Energy use by fuel type
	14: Lives lost & property damage from flooding & mining
GOAL3: Engage all Pennsylvanians as active & informed stewards of the environment.	15: # of businesses/commercial activities, government agencies, communities & individuals implementing sustainable practices
	16: # of community-based groups performing activities towards improving their environments
	17: Level of environmental literacy of Pennsylvanians

3. **Potential Applications to Other Watersheds**

The methodology of the Pennypack Ecological Vulnerability Assessment (PEVA) study can be easily applied to other watersheds of similar size. The major steps followed in the PEVA study are: (a) development of a GIS data inventory; (b) assessment of the state of the watershed; (c) projection of alternate future landuse scenarios; and (d) assessment of differential impacts of the scenarios. The summary of the PEVA study work flow has been graphically represented in Figure 3.1.

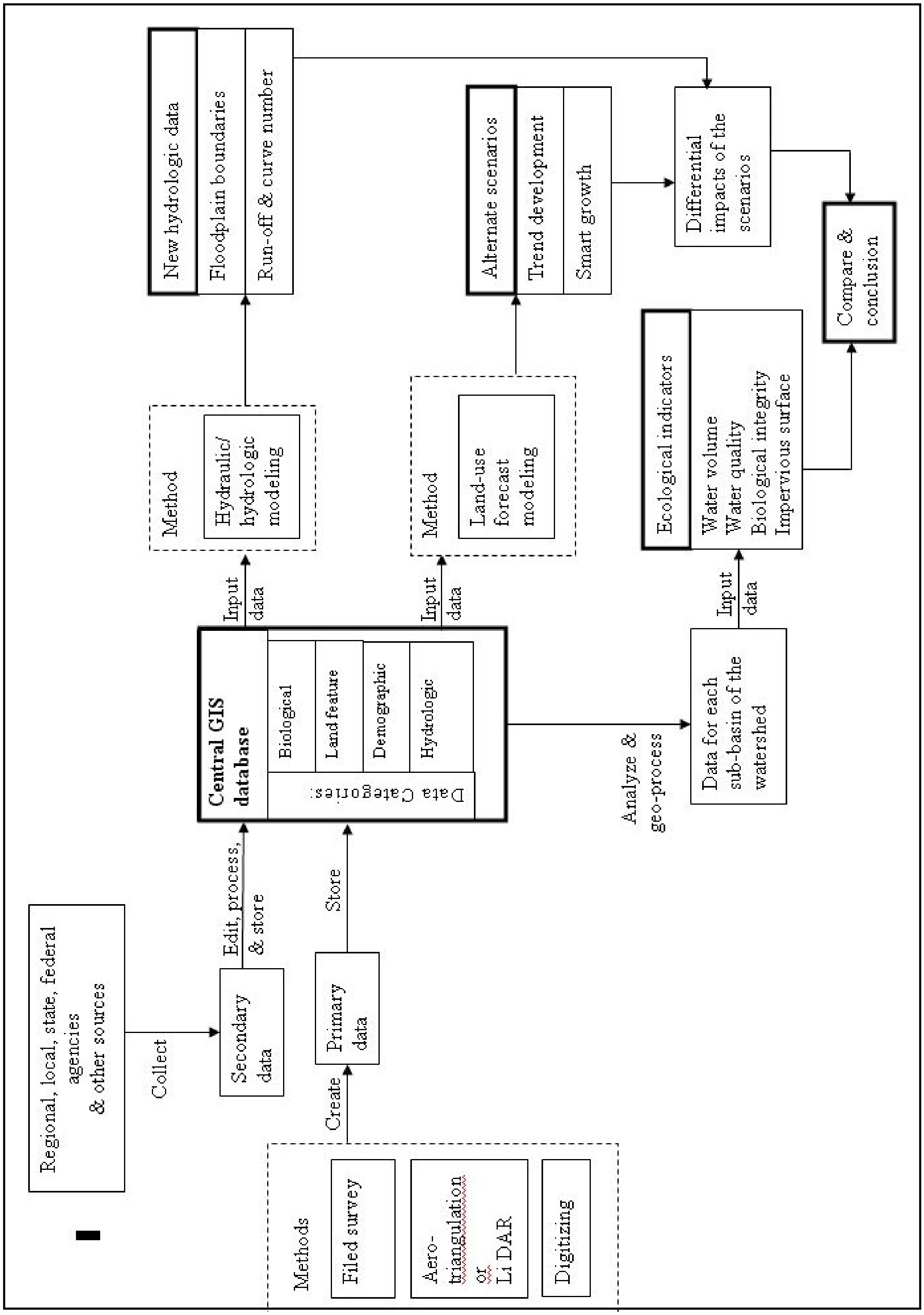


Figure 3.1 Generic Ecological Vulnerability Assessment Workflow

3.1. **Data and Metadata**

A watershed study team should include researchers from various disciplines, including environmental and landuse planning, civil and environmental engineering, ecology, economics, geology, geography, and landscape architecture. The research team should consider developing a central GIS database that will include spatial and non-spatial data and metadata. The database should be available to every researcher.

The database may include basically two types of data: primary and secondary. Primary datasets can be created using field surveys, digitizing, aero-triangulation, or LiDAR technologies. Examples of primary datasets can be high resolution elevation data, including DEM and contour and high resolution ortho-photos. The PEVA team hired a consultant for creating the high-resolution (2 ft interval) elevation data and other features, such as stream, bridges and culverts, dams, and lakes. The building footprint data can be created by digitizing the footprints from ortho-photos. Primary data can be also collected from a watershed-wide BMP survey, a water quality survey, and a biological data survey.

The secondary data may be collected from a number of local, regional, state, or federal agencies, as well as other organizations and online sources. Such types of data may include demographic data from the U.S. Census Bureau, soil and geology data from local/regional river basin commissions, landuse and transportation data from regional planning agencies, parcel and zoning data from local municipalities, and land cover and tree canopy density data from the US Geological Survey (USGS). A number of free GIS datasets are also available from ESRI or other online data provides, statewide GIS data warehouses (e.g., the Pennsylvania Spatial Data Access (PASDA), the New York State GIS Clearinghouse, and the Virginia Geographic Information Network), university sponsored GIS data warehouses (e.g., the Cornell University Geospatial Information Repository), and local non-profit agencies and conservancy groups.

Both primary and secondary datasets should be stored in the central GIS database with required editing and processing. Metadata should be developed for each type of dataset. Finally, the datasets can be rearranged according to some broader categories: biological, land feature, and hydrological.

In order to undertake a more refined assessment of the watershed, the study team may emulate the use by EPA’s ReVA Program of the USGS HUCs . The watershed can be subdivided into a number of smaller sub-watersheds or sub-basins, which would correspond to the size and location of the first-order streams within its boundaries. Sub-basins can be delineated from stream line files based on stream order and topographic elevation data using the Watershed Modeling System (WMS) 7.1 and HEC-GeoRas software.

Once the sub-basins are delineated, all of the datasets can be analyzed and geo-processed to re-assign watershed wide data in each of the smaller sub-basins. The sub-basins should be given unique IDs before this analysis is performed. Metadata should be updated for each type of data.

The PEVA assessment was done for the following ecological indicators: water volume, water quality, biological integrity, and impervious surface. Depending on data availability, more indicators can be assessed in other watersheds. Thorough analyses should be done for each of the indicators along with results and interpretations. The GIS maps and tables showing the results in each sub-basin will help in assessing the overall current state of any watershed.

3.2. **Models**

In conducting the analyses for the project, the PEVA research team used several hydrologic models. Two were developed by the Army Corps of Engineers, in particular its Hydrologic Engineering Center (HEC), and are regularly used for hydrologic analyses around the United States. They are HEC-HMS and HEC-RAS. (USACE 2007)

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of complex watershed systems. It can be applied to a wide range of geographic areas for solving a broad range of problems. This includes larger river basin flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation. (USACE 2007)

The WMS software can be used in conjunction with the Corps software as it has the ability to interface with GIS data. WMS is a graphical modeling package to be used for watershed hydrology and hydraulics. WMS has embedded HEC-HMS and HEC-RAS.

The HEC-RAS system contains four one-dimensional river analysis components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis. All four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, HEC RAS contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

While these models are readily available, they require considerable expertise to operate. Users who are unfamiliar with such models should take at least one introductory course before attempting to use them. The HEC offers several courses on a regular basis. In Pennsylvania, Villanova University sponsors short courses taught to introduce these models to prospective users.

Streamflow and Baseflow Information

The lack of stream gauges can pose a problem for conducting ReVA-type analyses for watersheds without them. In such cases, researchers must use hydrologic values from adjacent and similar watersheds to predict runoff, both for low flows and extreme events.

Stream gauge data with extensive periods of record enable users to calibrate models to actual recorded events. Once this is done, watersheds can be disaggregated into many smaller ones and calibrated again. This allows for an accurate representation of hydrologic values at a small scale.

Accurate baseflow information can be secured by conducting hydrograph separations of recorded streamflow data. There are numerous methods for do so, including the local minimum method, which was described earlier. In the absence of stream gauge data, information can be obtained from the USGS or PA DEP. As part of the Act 220 State Water Planning process, the PA DEP has extended the work done by the USGS for the DRBC to the rest of the Commonwealth. Through use of a software tool called WAVE, baseflow and water withdrawal information can be obtained for all watershed areas. Users then can estimate natural baseflows and current flows, the latter by subtracting water withdrawals and inter-basin transfers. While this is far from precise, it can give decision makers a better understanding of the impacts of land and water development on low flow conditions.

In predicting the runoff for extreme events like the 100-year storm, precipitation data can be obtained from NOAA and its Atlas 14, which is widely available throughout the Commonwealth. These data are preferred to the data available in the older Technical Paper (TP) 40 study published by the U.S. Weather Bureau. (Herschfield 1961) As part of its *Pennypack Creek Watershed Study*, the CSC learned that the TP 40 values, which are widely used throughout the U.S., are no longer valid as they systematically underestimated the extreme precipitation events. This was due to a number of factors: the short average duration of the precipitation records analyzed; the relatively small number of weather stations; and the statistical distribution used to analyze the data. The NOAA precipitation data vary from place to place within watersheds, but are generally 10-20% higher than the values contained in TP 40.

3.3. Scenario Generation

Based on existing data and projected population data, a number of alternate future landuse scenarios can be generated. At a minimum level, two scenarios should be generated: trend development and smart growth.

In preparation of these land use futures, the PEVA research team had a conversation with Ms. Megan Mehaffey of US EPA ReVA office (June 5, 2006) in regards to the various approaches to land use change modeling undertaken in other ReVA studies. Ms. Mehaffey indicated that there is no one standard approach, and that the techniques and approaches vary with the size of the region, the environmental focus of the study, and the type of data available.

Many of the modeling approaches in ReVA -type studies have been utilized at, and are more appropriate to, larger-scale watersheds. One of the purposes of the present project is to evaluate the suitability of ReVA methodologies in smaller watersheds. Based on the PEVA project team's review of previous studies and the academic literature, it was concluded that standard, off-the-shelf land use forecasting programs and models were unsuited to smaller watersheds. As well, many of these standard programs and methodologies would not make good use of the higher quality land use data collected for this project. In smaller scale projects, ReVA-type analyses have utilized standard planning support systems software such as "What If?", "INDEX", or "CommunityViz". The methodology described below utilized similar techniques, but without requiring any of these programs.

Land use change models can be simplistically broken down into two approaches: "demand driven" and "rule driven." Many of the larger land use change models, including some used by NASA, USGS, and EPA (such as SLEUTH, Gigapolis, Clarke Growth Models, and Cellular Automota models) forecast land use change based mostly on the physical attributes of land (slope, wetlands, etc), and distance to growth inducers/growth repelers (usually roads). Though often quite complex and sophisticated, these models simulate urban growth as a series of algorithms or rules without statistical calibration on previous land use change in a region. One advantage of these models is that they require relatively few inputs, usually the easily available USGS Digital Elevation Models (DEM) and the National Land Cover Data. The output of the models is usually a variable indicating whether a particular pixel is developed or not, with some models allowing the intensity of development to vary between high, medium and low.

Demand driven models, more common in the urban planning field, start with population and economic growth forecasts. Residential uses and jobs are the prime drivers of urbanized land uses, and therefore, are the "demand" factors in these models. In these approaches, the population and employment forecasts are converted into demand for urbanized land of different types and at different densities/intensities. Users and decision makers can, interactively, vary the assumptions about the density/intensity of land use to accommodate projected land use demand. The models then allocate future urban land uses based on any number of criteria specific to the model or approach, including availability of infrastructure and underlying soil and physical suitability. Most simulation models allow the users to specify lands excluded from development (such as near streams, wetlands, steep slopes, etc.) and to direct/prioritize the growth allocation (such as contiguous with existing development, in areas with existing infrastructure, such as public water supply, sewers, and roads). The allocation of land use demand is iterative, and allows decision makers to test the viability and impacts of various scenarios. However, one of the difficulties of most demand-based simulation software is that the assumptions and allocation techniques of many software packages are “black box” approaches where the user is not certain of allocation criteria.

The approach taken in PEVA study was to utilize the approach and techniques of the “demand driven” modeling strategy, and to do so with transparent models and techniques. In part, this decision was driven by the large amount of high-quality, high-resolution data collected for the Pennypack region. The data collected would not usually be utilized in some off-the-shelf software packages. A goal in this work is to demonstrate that ReVA-type analyses could be performed using standard land use planning analysis techniques and basic GIS software.

3.4. **Impacts Assessment**

In an ideal world, there would be a wealth of natural science, demographic and economic data to feed a detailed, comprehensive and integrated ecologic-economic model of the region under study. It is fortunate that the PCW has been the subject of considerable data accumulation, but there is no detailed ecologic-economic model that can generate impacts of actions taken to perturbate the fundamental variables. In the absence of such a model, impacts must be assessed in a piecemeal fashion. The hydrologic models can estimate changes in base and peak flows, and a qualitative description of potential impacts beyond the physical and chemical changes may serve to paint a rough picture for decision support. In the analysis above, the hydrological impacts were estimated using one set of residential development scenarios, and the air- and water-related impacts from two related, but different scenarios. If the resources are available, then these should be combined.

The GREET model (Wang 2005) was very useful for energy use and air and greenhouse gas emissions, though there is some sacrifice in specificity with respect to the geographic locale. For water quality and biological integrity, the literature provides significant guidance. The weighted water quality index above was the ReVA method of simple sum, with the adjustment made for negative impacts. The biological integrity was fairly standard. Both were constrained by the paucity of PCW data.

4. **The Involvement of Local Officials**

As noted in Section 1. above, the PCW research team included some individuals from government and local NGOs. While not explicitly including local municipal officials in the ReVA-related work, the CSC has been cooperating with a group of local officials on floodplain realignment and best stormwater management practices. Table 4.1. gives the list of suburban municipalities and the designated official who participated in the effort. It is expected that these same officials will be receptive to decision support regarding ecological vulnerabilities in the PCW that may affect their constituents. Once feedback is gotten on the research presented above, the next step for the CSC is to make local officials aware of what was done.

Table 4.1. Municipalities Involved in PCW Stormwater Management

Township/Borough	Name	Title
Abington Township	Burton T. Conway	Manager
Bryn Athyn Borough	Vikki Trost	Manager
Hatboro Borough	James Gardner	Manager
Horsham Township	Michael J. McGee	Manager
Jenkintown Borough	Edwin Geissler	Manager
Lower Moreland Township	Alison D. Rudolf	Manager
Rockledge Borough	Michael J. Hartey	Manager
Upper Dublin Township	Paul A. Leonard	Manager
Upper Moreland Township	David Dodies	Manager
Upper Southampton Township	Joseph W. Golden	Manager
Warminster Township	Barbara Sultzbach	Assistant Manager

5. **Conclusions**

The PEVA team has concluded that the ReVA modeling approach can be scaled down so as to be informative and appropriate for smaller watershed assessments in the Commonwealth of Pennsylvania. The basic steps are: (a) development of a GIS data inventory; (b) assessment of the state of the watershed; (c) projection of alternative future land-use scenarios; and (d) assessment of differential impacts of the scenarios. While many larger-scale ReVA assessment tools and data variables are too coarse for assessment at the local level, it is feasible to use such processes with more refined local data to accurately outline the impacts of alternative land use and resource allocation decisions on ecological and other watershed attributes.

The approach developed for the Pennypack Creek Watershed (PCW) also can be used as a template for other watersheds. While the PCW is a seriously impaired watershed in a dense urban setting in the Greater Philadelphia region, the assessment protocol outlined in this study can be accurately applied for less developed and more pristine watersheds as well. The report outlines data needs and analytical tools for this information transfer. The PEVA team urges others conducting such studies to create a multi-disciplinary study team and consider developing a central and accessible GIS database that includes both spatial and non-spatial data.

Finally, the ReVA modeling process also can be used to develop watershed sustainability indicators. The PEVA team outlined four broad indicator categories that can be applied elsewhere and aggregated to larger regions in Pennsylvania. It should be noted, however, that for many water quality and biological variables, good time series information is not available and linking land-use change to changes in water quality and biological diversity is difficult. Fortunately, for other variables, such as water volume and impervious surface, new models and better topographic and hydrologic information allow researchers to more accurately assess them under different future conditions.

References

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. (1999). Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. US EPA; Office of Water; Washington, DC.

BASIN. (2002). *BASIN Water Quality Terminology*. Retrieved from http://bcn.boulder.co.us/basin/natural/wqterms.html on August 10, 2005. Boulder Area Sustainability Information Network.

Capiella, Karen and Brown, Kenneth (2002*). Impervious Cover and Land Use in the Chesapeake Bay Watershed*. Prepared for the U.S. EPA Chesapeake Bay Program, Unpublished.

Daniels, Tom and Katherine Daniels. (2003). *The Environmental Planning Handbook for Sustainable Communities and Regions*. Planners Press, Chicago, IL.

Davis, W. S. and T. P. Simon (eds) (1995). *Biological assessment and criteria: tools for water resource planning and decision making*. Lewis Publishers, Boca Raton, FL.

de Groot, Rudolf S., Matthew A. Wilson and Roelof M.J. Boumans. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, Vol. 41 (3): 393 – 408.

Dunne, T. and Leopold, L.B. (1978). Water in Environmental Planning, W.H. Freeman and Co., NY.

Featherstone, Jeffrey P. (1996). Source Water Protection Programs in the Delaware River Basin, *Source Water Protection: An Ounce of Prevention*. American Water Works Association. Blue Bell, PA.

Gunther, O. (1998) *Environmental Information Systems*, Springer-Verlag, NY.

Hershfield, D.M., 1961: "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods From 1 to 100 Years," Technical Paper No. 40, Weather Bureau, US Dept of Commerce, Washington, DC.

Hitchings, Benjamin. (1998). A typology of regional growth management system. *The Regionalist* 3, 1/2: 1-14.

Jones, K. Bruce et al. (1997). An Ecological Assessment of the United States Mid-Atlantic Region: A Landscape Atlas. EPA/600/R-97/130. Office of Research & Development, US EPA.

Kneese, Allen V. & Blair T. Bower. (1979). The Lower Delaware Valley Case Study, in *Environmental Quality & Residuals Management*. Resources for the Future. Johns Hopkins University Press, Baltimore, MD.

Kepner, William (2003) "Scenario Analysis for the San Pedro River, Analyzing Hydrological Consequences for a Future Environment." ReVA-EPA-MAIA Conference: Using Science to Assess Environmental Vulnerabilities, Valley Forge, PA, May 13-15, 2003.

Lance H. Butler, et al. (2003). Baseline Assessment of Pennypack Creek Watershed (2002-2003). Philadelphia Water Dept. , Philadelphia, PA.

Lehigh Earth Observatory. (2005) Lehigh River Water Quality Project. Retrieved on July 21, 2005, from Lehigh University Earth Observatory Website: http://www.leo.lehigh.edu/projects/hydroprobe/wqdef.html .

Meadows, D. (1998). Indicators and Information Systems for Sustainable Development. Sustainability Institute. Last accessed on 5/30/06 at http://www.sustainabilityinstitute.org/pubs/Indicators&Information.pdf.

Meenar, Md Mahbubur R., ed. (2006). Pennypack Creek Watershed Study. Center for Sustainable Communities, Temple University Ambler, for the US Federal Emergency Management Agency.

Myers, M., "Retrofitting Rocky Branch: Applying Natural Features in Urban Stream Design" *Landscape Architecture*, Volume 90, Number 3, March, 2000.

National Land Cover Database. (2007). At http://www.epa.gov/mrlc/nlcd.html

Pennsylvania Consortium for Interdisciplinary Environmental Policy (PCIEP; 2004). The State of the Commonwealth: Is Pennsylvania Moving Toward a Sustainable Future? at http://www.paconsortium.state.pa.us/StateoftheCommonwealth.pdf . Last accessed on 5/30/06.

Pennsylvania Department of Community and Economic Development. (PDCED; 2005). Pennsylvania Municipalities Planning Code, Article VI. Zoning, cf. 53 P.S. § 10604 [5]. at mpc.landuselawinpa.com/MPCode.pdf, last accessed on January 15, 2007

Philadelphia Water Department (PWD; 2002). Drinking Water Quality Report at www.phillywater.org/wqr/wqr2002/wqr2002.pdf . Last accessed 1/28/07.

Philadelphia Water Department (PWD; 2005). *Pennypack Creek Watershed River Conservation Plan* at http://www.phillywater.org/pennypack/River Conservation Plan/RCP Final Report.htm . Last accessed 1/28/07.

Schueler, T. (1994). The Importance of Imperviousness. *Watershed Protection Techniques* 1(3): 100-111.

Sherry, Jesse (2005*) Sustainability Indicators for the Pennypack Creek Watershed*, Master's Thesis, Department of Community & Regional Planning, Temple University Ambler.

Sloto, R.A., and Crouse, M.Y. (1996). HYSEP: A computer program for streamflow hydrograph separation and analysis: U.S. Geological Survey Water-Resources Investigations Report 96-4040.

Steinitz, Carl (1993). Geographical Information Systems: A Personal Historical Perspective, The Framework For A Recent Project, (And Some Questions For The Future); European Conference on Geographic Information Systems, Genoa, Italy, March 30. (Process available at http://www.gsd.harvard.edu/studios/brc/maps/fig_5.html).

US Army Corps of Engineers (USACE 2007). HEC-HMS and HEC-RAS Programs at http://www.hec.usace.army.mil/software/hec-hms and http://www.hec.usace.army.mil/software/hec-ras . Last accessed 1/30/07/

US EPA. (1993). Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA-840-B-93-001c. Washington, DC: Office of Water.

US EPA 2000a. Guidelines for Preparing Economic Analyses. National Center for Environmental Economics, EPA 240-R-00-003.

US EPA 2000b. Environmental Planning for Communities: A Guide to the Environmental Visioning Process Utilizing a Geographical Information System, Office of R&D, EPA/625/R-98/003. At http://www.epa.gov/ORD/WebPubs/gis/625r98003.pdf.

US EPA. (2005a) Regional Vulnerability Assessment for the Mid-Atlantic Region: Evaluation of Integration Methods and Assessments Results. Office of Research and Development. EPA 09LCB04.RPT.

US EPA. (2005b) *Massachusetts Class B and SA Surface Water Quality Standards*. Retrieved from http://www.ipswatch.sr.unh.edu/314cmrclasses.html on July 21, 2005. Ipswich-Parker Suburban Watershed Channel.

US EPA. (2006a) Regional Vulnerability Assessment Program: A Research Strategy for 2001-2006 (http://www.epa.gov/reva/reva-strategy.pdf) .

US EPA. (2006b) Regional Vulnerability Assessment Program: Toolkit (http://amethyst.epa.gov/revatoolkit/Welcome.jsp) .

US EPA (2007) Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. At http://www.epa.gov/owow/monitoring/rbp/ . Last accessed on 1/18/07.

US EPA. (2007). Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. At http://www.epa.gov/owow/monitoring/rbp/ . Last accessed on 1/18/07.

US Geological Survey. (USGS 1996). Water-Use Analysis Program for the Neshaminy Creek Basin, Bucks and Montgomery Counties, Pennsylvania.

US Geological Survey. (1999). USGS Circular 1225: The Quality of Our Nation's Waters, Nutrients and Pesticides. U.S. Department of the Interior and U.S. Geological Survey, Washington, D.C.

Wang, Michael. (2005). Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation. Systems Assessment Section, Center for Transportation Research, Argonne National Laboratory, DuPage County, IL.

Wolman, M. G. and Miller, J. P. (1960). Magnitude and frequency of forces in geomorphic processes, Journal of Geology, vol. 68. no. 1. pp. 54-74.

Appendices

Appendix A.1. **ReVA Web Page Summaries**

The ReVA Toolkit helps decision-makers evaluate the vulnerability of ecological goods and services that are valued by society, using several types of information such as current resource conditions and distributions, estimated sensitivity of resources to the various stresses, and estimated spatial distributions of stressors. Of primary importance is the definition of vulnerability. *Vulnerability* is the degree to which a system is likely to experience harm due to exposure to perturbations or stress. Vulnerability considers both the quality of the valued resources & the intensity of the stressors. It should be noted that heavily urbanized urban areas are not considered to be vulnerable because they have already lost most of their valued natural resources.

The variables used to estimate vulnerability fall into three basic categories. *Resource distribution variables* record the current geographic distribution of important environmental and human resources. *Sensitivity variables* are conditions, or changes in conditions, that modify a resource's response to stress. *Stressor variables* indicate the distribution of activities or conditions that combine to cause environmental degradation.
Although the impacts of each individual stressor are important to consider, the geographic areas most at risk are those that are subject to multiple stresses. Although the cumulative impacts of multiple stresses across a region cannot yet be quantified, areas where the possibility of cumulative impacts is high can be identified.
Species diversity is a good proxy for overall environmental health, since degraded environmental condition often results in declines in biological populations. Information about the geographic distribution of cumulative impacts and resources can be used to identify areas that are most vulnerable to environmental degradation. For example, areas with high levels of stress and with high aquatic species diversity might be considered to have the most vulnerable aquatic populations. Areas with high levels of stress but low numbers of species are already degraded.
In selecting between alternative scenarios that simulate the future, it is useful to be able to compare the likely outcomes of each scenario. All land use change models have some degree of uncertainty. One way to estimate the probability of a certain type of change is to use a "weight of evidence" approach, as we have done here. Responsible decision-making requires balancing among multiple criteria, and various stakeholders value criteria differently. For example, decisions about land development may involve changes in air quality, water quality, economic conditions, and native biodiversity. Stakeholders concerned about environmental conservation will likely prioritize criteria differently from those concerned about economic development. The EDT allows one to view how various stakeholders' preferences (values) would affect decision priorities.

Stakeholder values can be viewed using only variables important to the individual or group (e.g. selecting variables relevant to conserving native aquatic species or for evaluating human health risks) or in multiple weighting combinations to illustrate trade-offs.

A.1.1. **Data Preparation**

One basic operation preceding assessment was putting data on a consistent scale. Integrating the data to get a watershed summary across all variables involves a few pre-processing steps. To use the variables in a consistent manner, the data need to be transformed to the same scale. All variables are scaled so that they were on a 0 (best) to 1 (worst) scale for each variable. To do this, the following was applied to all variables:

1. (Rescale) Subtract the minimum value for each variable from the data, setting the minimum value to zero.
2. (Normalize) Divide the data by the maximum value. This sets the maximum value to one, and sets all values in between to be on the [0, 1] scale.
3. (Directionalize) If the variable's direction dictates that "higher is better", then take the variable and reverse its normalized direction.

For example, suppose a variable has values of {3, 5, 7, 10, 11}, where the "direction" for this variable is "-1" (higher is better). Following our steps, the data becomes:

1. Rescale: {3, 5, 7, 10, 11} -> {0, 2, 4, 7, 8}
2. Normalize: {0, 2, 4, 7, 8} -> {0.00, 0.25, 0.50, 0.875, 1.00}
3. Directionalize: {0.00, 0.25, 0.50, 0.875, 1.00} -> {1.00, 0.75, 0.50, 0.125, 0.00}

Rescaling makes all data range from a set minimum to a set maximum, normalizing allows comparisons between variables on a consistent scale, and directionalizing creates a consistent direction for good and bad values of a variable. Among groups of variables that were correlated to each other, one variable was chosen to represent the group.

A few of the variables are fairly skewed (most values are near either zero or one on the normalized scale). This may slightly affect a couple of the integration methods, such as PCA. Methods that involve ranking, such as the quintile methods, remain unaffected. The criticality method and clustering should also be relatively unaffected since they are based on a distance measure.

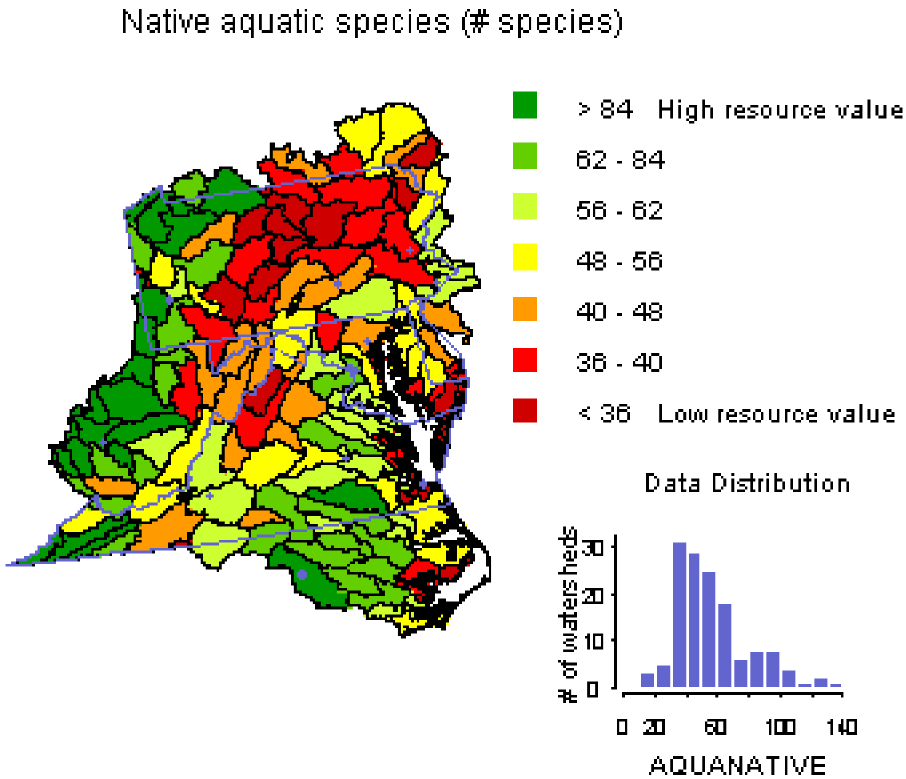
In terms of types of data, the ReVA methods focus on a few important categories. The first category is Sensitive Environmental Resources. This includes ecosystems already stressed, migratory bird stopovers, regions critical to native species, intact interior forest patches, and ecosystems with low acid-neutralizing capacity. The second category is Current Conditions, which contains forest productivity, air quality, groundwater quality, water quality, aquatic & terrestrial biodiversity, human health, and fiscal health. The third group is made up of Drivers of Change. The drivers are resource extraction, land use, non-indigenous species, pollution, and climate change. Key generic Stressors are given as agricultural runoff, atmospheric deposition, loss of habitat, and non-point source pollution. With respect to EPA Region III, the Mid-Atlantic Region, the Stressors are acid deposition, coal mining, human population, landscape pattern, agricultural nitrogen, ground-level ozone, and soil erosion / sedimentation.

The methods used to integrate the data into regional overviews and environmental assessments covered a relatively wide range of analysis. The *best quintile method, the worst quintile method, and the radar summary* give a high-level glance at overall environmental quality. The *summation method*, in combination with the *Principle Components Analysis / Distance method*, can highlight sensitivity areas. These two methods have different and complementary sensitivities. Areas that show well or poor in both have the strongest indications of environmental quality. The *state space method*, because of its distance measure, tends to differentiate between the middle (not worst or best) watersheds. The *weighted sum method* allows user defined weights for individual variables or groups. This method allows for the decision-maker to differentiate based on specific preferences or interests. The *stressor/resource matrix method* indicates the most critical stressors and most stressed resources across the region. The *overlap method* compares a hypothetical future scenario to a present environmental condition. The *criticality method* attempts to highlight areas at risk for major change. This method uses a distance measure to a pre-defined "natural state." *Cluster analysis and self-organizing maps* can be used as planning tools, as these methods can be tailored for specific planning objectives.

A.1.2. **Examples of Variables Used to Estimate Vulnerability**

Resource Distribution

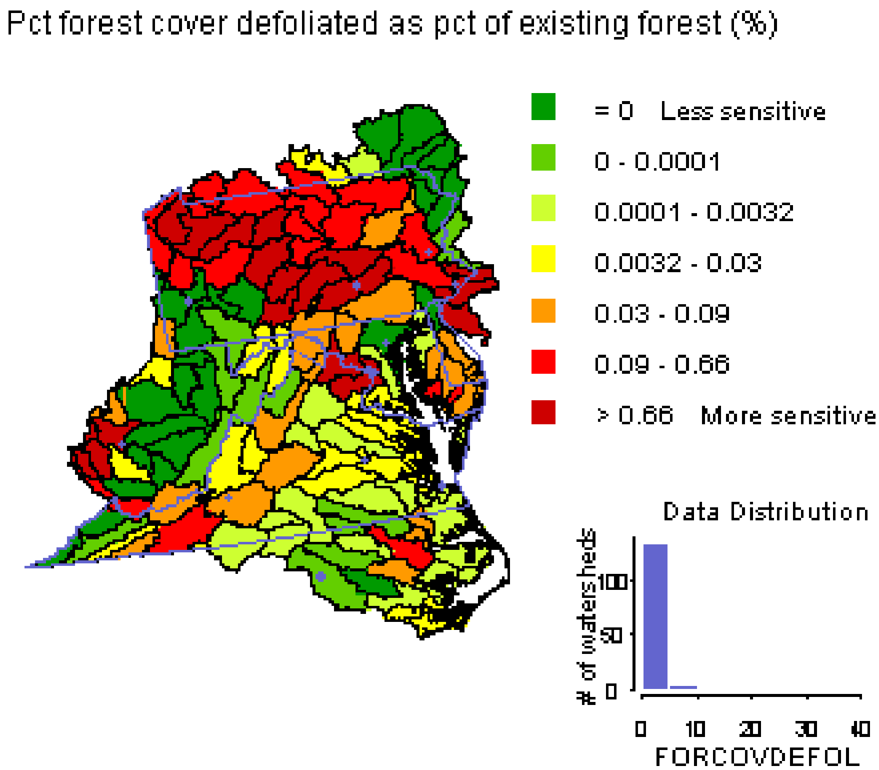
Numbers of native aquatic species are a resource of value to society. High numbers of these species indicate areas that could be a higher priority for protection over areas with low numbers of species. Numbers of native species can also tell us where stresses have been acting for some time (low numbers of native species) or where stress has historically been low (high numbers). ReVA uses red to indicate lower resource value and green to indicate higher resource value.



Sensitivities

For example, the percent of forest cover that has been defoliated is an indication of how susceptible to damage a given area of forest may be to additional stress, and thus is considered to be a sensitivity variable for forest condition in general. Forests that have been heavily defoliated are more likely to experience high levels of mortality when an additional stress, such as air pollution, is also high. High levels of forest mortality can in turn result in increased sediment loadings (through reduced uptake of water by trees with higher runoff) and increased nutrients (through decay of trees) in streams.

In a final integration for vulnerability, a user may chose to weight this factor more highly. Thinking of it in terms of an if-then scenario may be helpful; for example, research and experience may indicate that the stress on a forest jumps significantly as percent defoliation rises above some threshold level. In this case, the cumulative stress displayed for areas above the threshold level can be amplified by some appropriate factor. In time and with experience, the best guesses for appropriate threshold and amplification factors may be better understood.

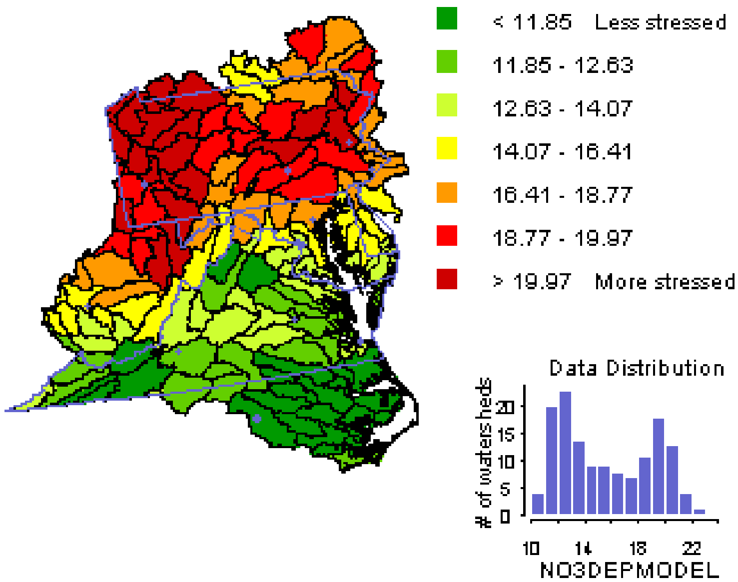


Stressor Distribution

For example, acid rain stresses plants, contributing to poor forest health. Nitrate (NO3) and Sulfate (SO4) are the major pollutants contributing to acid rain, and thus estimates of Nitrate wet deposition are commonly used as an indication of acid rain. The degree to which Nitrate wet deposition becomes a pollutant depends on the location and the physiochemistry of the forest soils or waterbody upon which it falls. Some important variables cannot be measured directly, but their distribution can be estimated using well-established models. In this example, the spatial distribution of wet nitrate deposition is estimated from rainfall data (amount) and proximity to sources of NOx air pollution (from fossil fuel burning). Nitrate from air pollution contributes to nutrient levels in streams, which affects aquatic habitat (in particular aquatic plants) and native species' condition.

Here ReVA uses red to indicate higher presence of stressors and green to indicate lower presence of stressors.

Nitrate wet deposition - modeled (kg/ha)



A.1.3. **Assessment Questions**

Resource managers and other decision-makers are frequently required to make decisions about priorities. A common question is "Given limited resources, what environmental problems and what geographic areas are most in need of attention?" Answering this difficult question requires exploration of a series of focused assessment questions before actions are taken to protect valued resources, human health, or quality of life. These questions might focus on information such as:

- an evaluation of current overall conditions
- risk of future environmental degradation
- sustainability of the system
- current and future value to society
- feasibility of taking some action

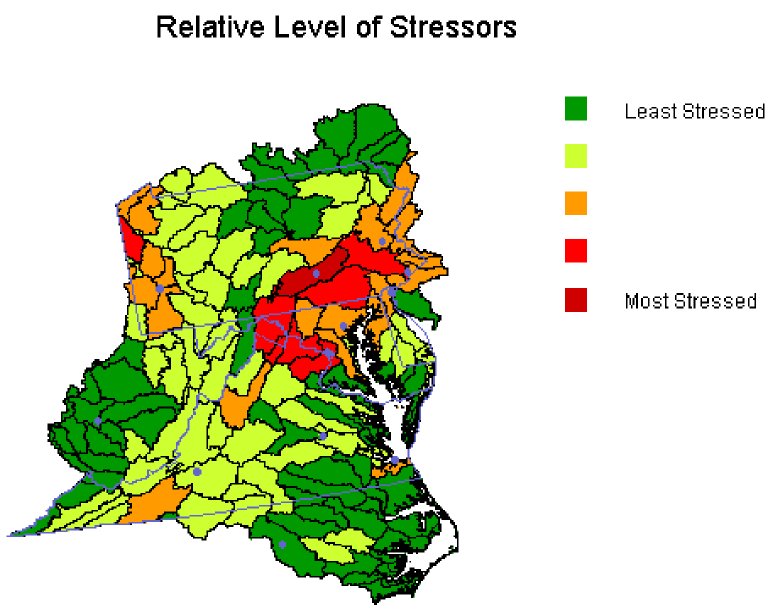
All of these assessment questions can be addressed to some degree using available data and information. Each requires a different integration method (see the tutorial for more information on this), and each receives a different answer, or in the case of a visual representation, a different map.

Different assessment questions require different types of variable data and metrics, and possibly different analysis or integration methods. The selection of variables and methods is driven by the particular issues of concern and the questions a user brings to the vulnerability assessment. Further information on selecting data and analysis methods is provided in the tutorial and in the analytical sections of the tool.

To help you understand how the ReVA EDT can assist in answering these questions, the next few pages show examples of the types of information that the web tool can provide.

Cumulative Impacts

This map shows all four stressors: nitrogen, sediment, aquatic exotic species and nitrate deposition). The individual stressor information has been combined using an integration method that counts the number of times that a watershed is among the worst 20% (the Worst Quintiles integration method). All stressors are equally weighted.

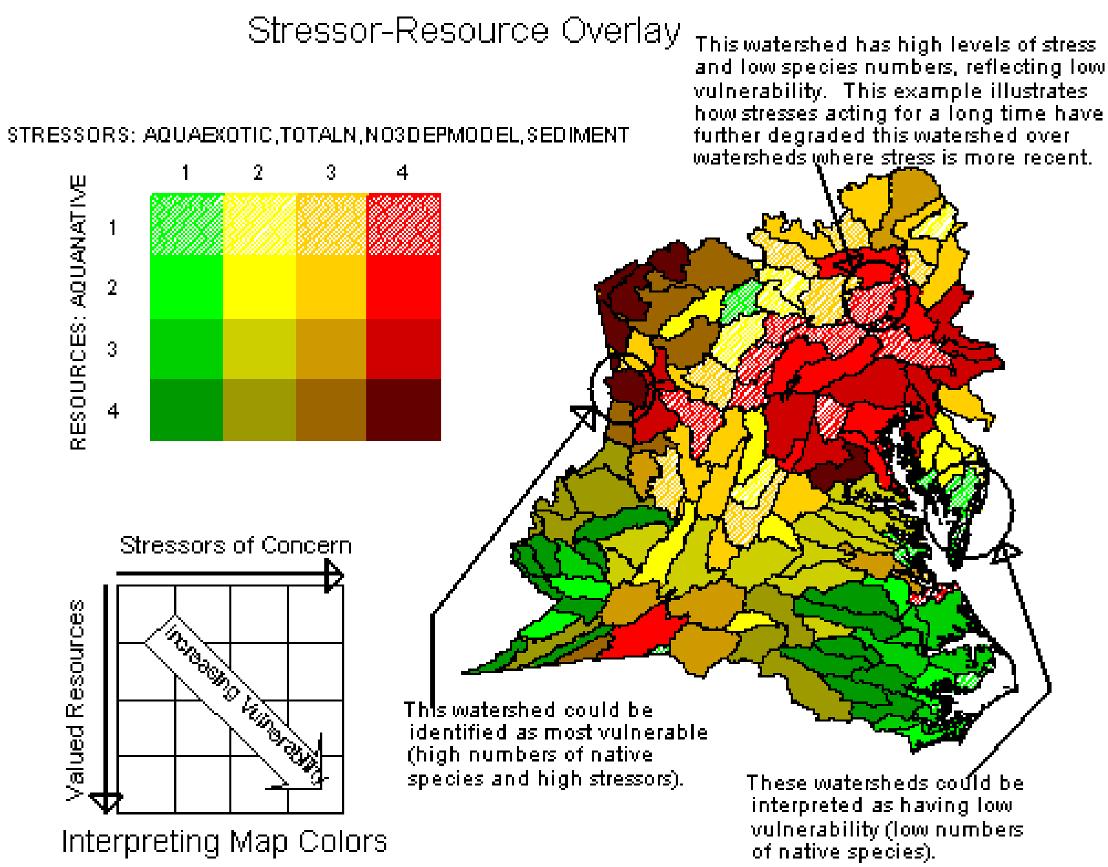


<u>Distribution of Resources</u>

One of the first questions asked in any assessment is "Where are the most important environmental resources?" It is important to identify areas where management actions can prevent further damage and improve conditions. While restoration of degraded areas is valuable, preservation of areas that are still in good shape is a critical and cost-effective way to maintain a region's environmental health. Areas with high species diversity have often been less impacted by stressors while highly impacted areas show little native species diversity. The duration of stress will also influence condition; unfortunately historical data on stressor distributions are rarely available.

Assess Vulnerability

This map shows the distribution of aquatic native species in relative terms; i.e. the 25% of watersheds with lowest species counts up to the 25% with highest counts. This map adds the normalized values of the stressors and breaks them into four equal bins with the ones with the most stressors in the right most column (column 4). The single resource uses the normalized value and breaks it into 4 equal bins.

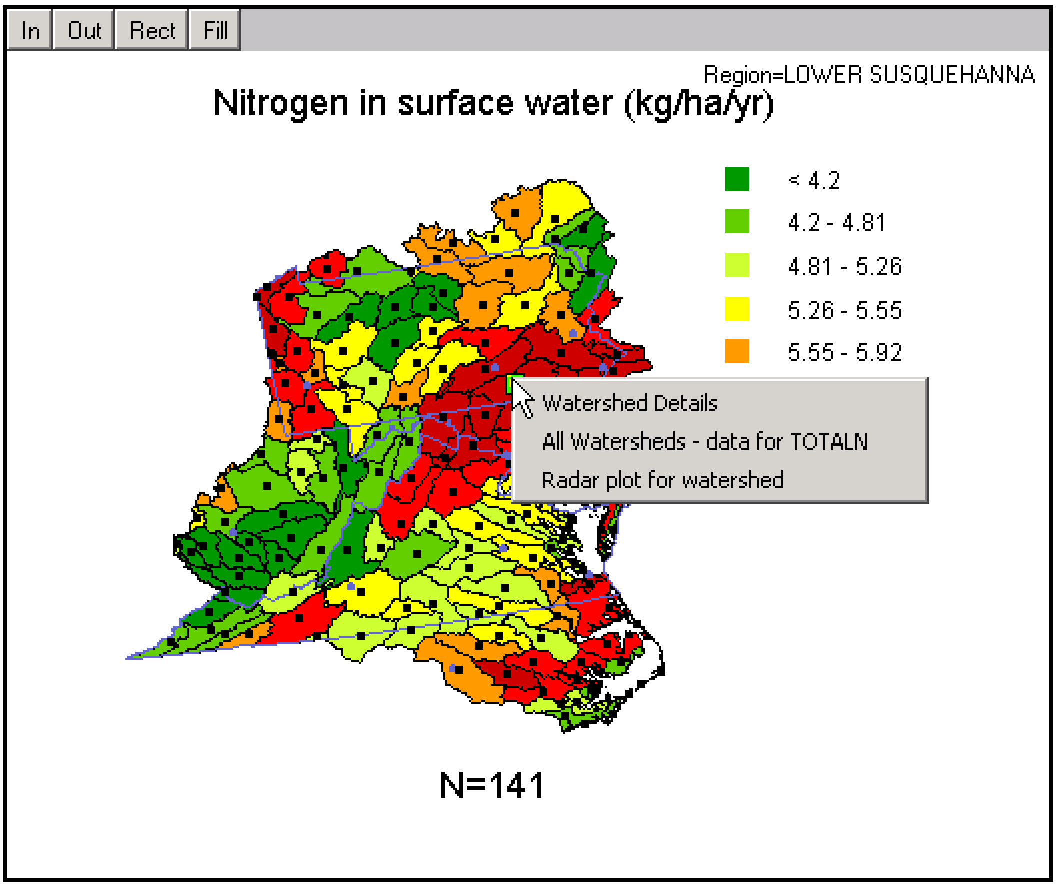


Interactive Maps

In the analysis tools, some maps like this map are interactive which allows you to get detailed information about the watersheds and the variables displayed. You can drill-down into the information and get other maps and visualizations similar to the radar plots displayed on the next page.

As the cursor moves over each watershed, the name is displayed in the upper right hand corner. A right-click on a watershed brings up a menu with drill-down options. This screen shot shows the Lower Susquehanna selected and the menu with available drilldown options. The available options include:

* Watershed Details - For the selected watershed, this displays all the watershed's raw data for all the indicators.
* All Watersheds - data for TOTALN - This selection displays a table with the variable (Nitrogen in surface water) values for all watersheds.
* Radar plot for watershed - This displays the radar plot for the selected watershed (an example is on the next page).

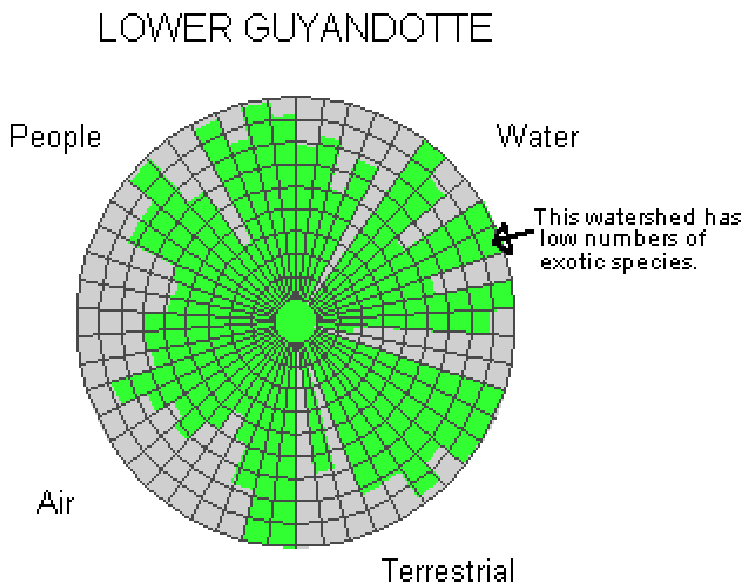


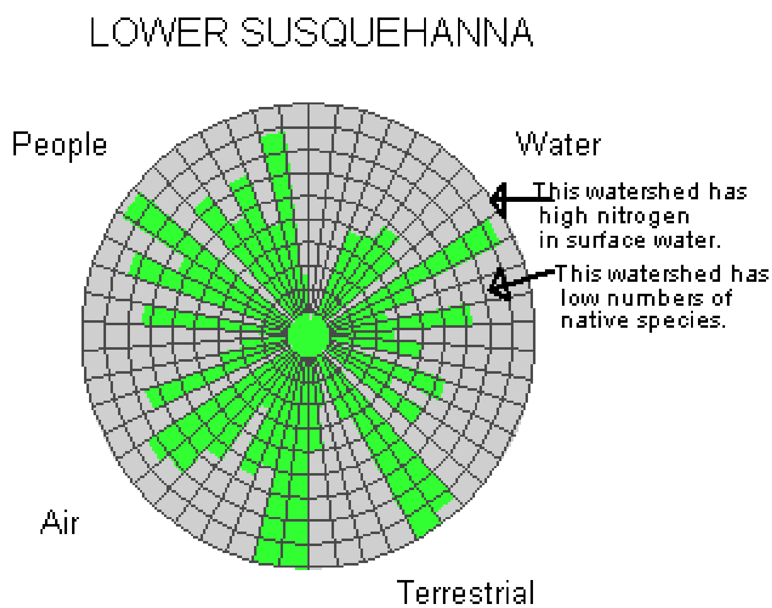
In the upper right hand corner, the name of the watershed is displayed.

<u>Data Visualization</u>

The EDT includes many different types of variables for each watershed and several methods for viewing and assessing these variables. For example, the radar plots below provide a quick overview of a specific watershed's condition. A radar plot can be thought of as a histogram that has been bent into a circle with each individual spoke representing a variable. Plots with more green indicate watersheds with less degraded resources or fewer stressors. Each individual spoke displays more green if the value of the variable is good. If the value of a variable is bad for a watershed, it will show less or no green. In the toolkit, the variable descriptions show up in the interactive graph so that the user can tell which variable is represented by each spoke.

The Lower Guyandotte watershed (first plot) exhibits better ecological condition than the Lower Susquehanna watershed (second plot).

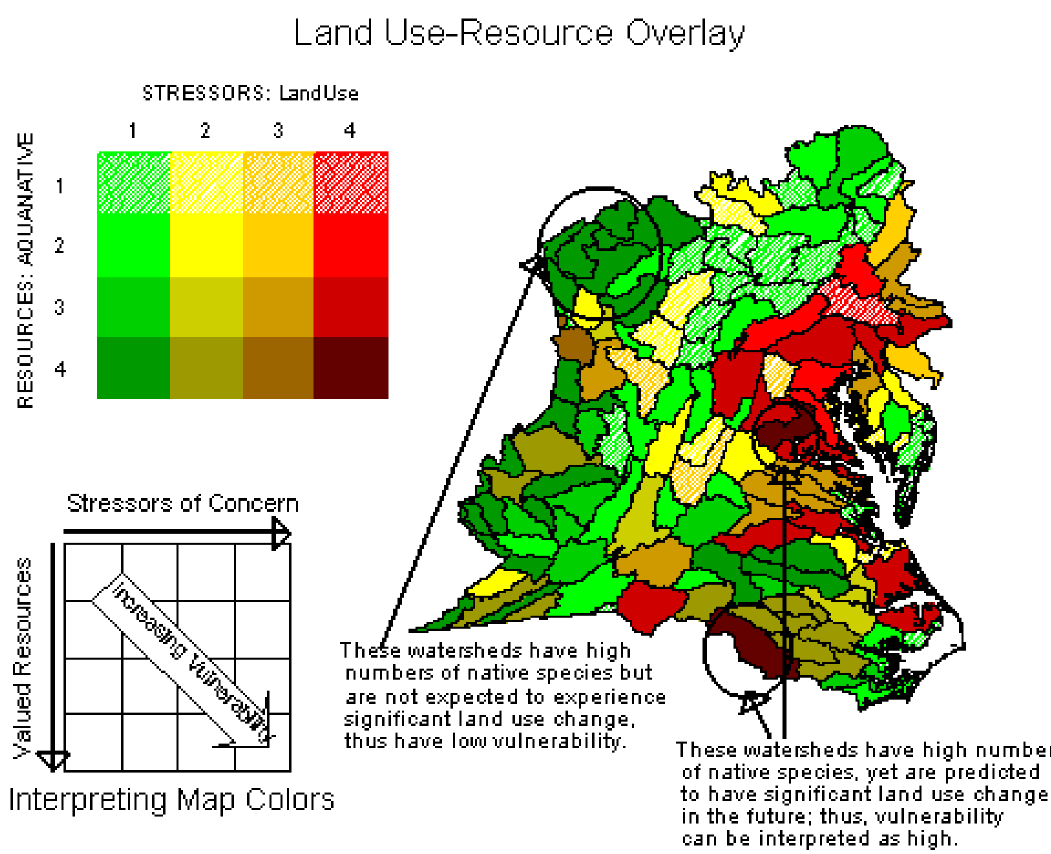




A.1.4. **Future Vulnerability**

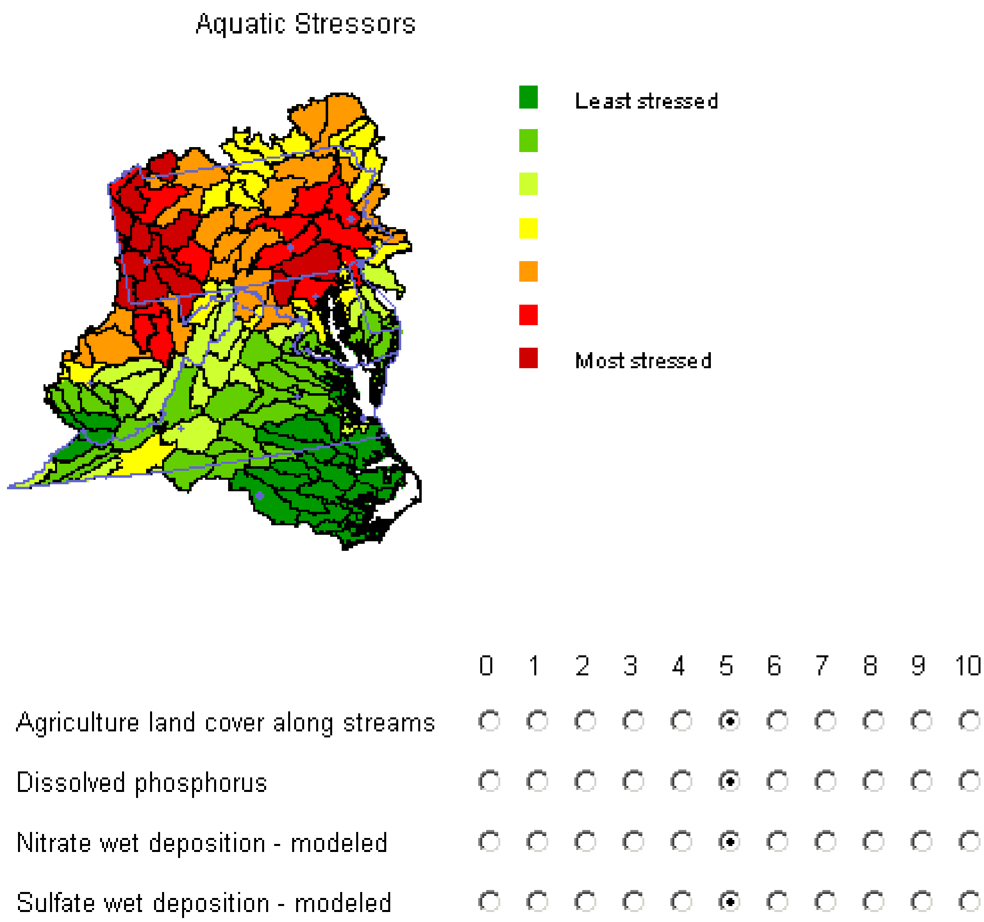
We cannot predict the future, but available models do allow us to estimate the likely distribution of environmental vulnerability in the future based on decisions made today. For example, the future distribution of stresses on aquatic biodiversity can be estimated based on land use change models and current species distribution information. This map shows the distribution of areas that both have high species diversity today and are likely to experience increased human development.

This graphic shows where different models of land use change agree: watersheds where 4-5 models all predict significant change are considered most likely to experience change.



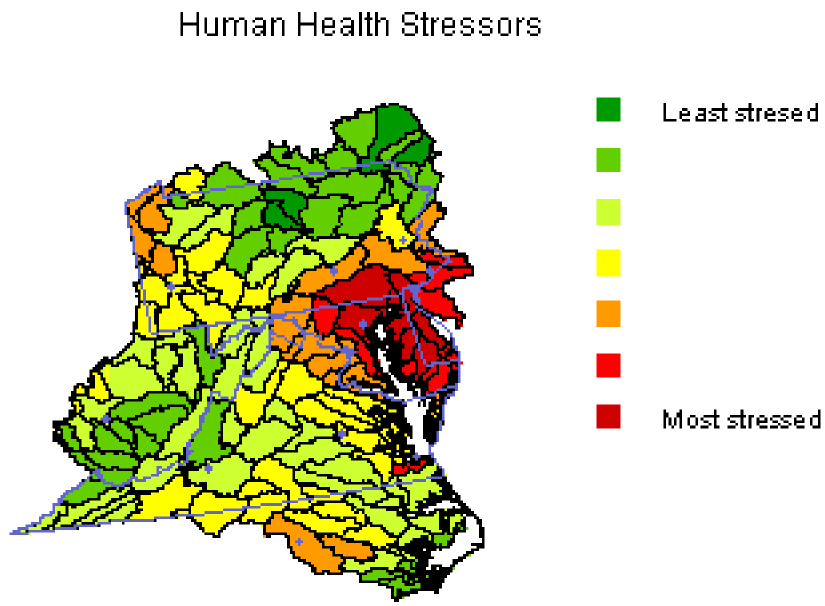
A.1.5. **Multiple Criteria Decision-making**

Below are two examples of vulnerability maps that highlight multiple criteria. In one case aquatic species are highlighted. The other case highlights human health stressors. Decisions about resource allocations will depend on how these various perspectives are reconciled.



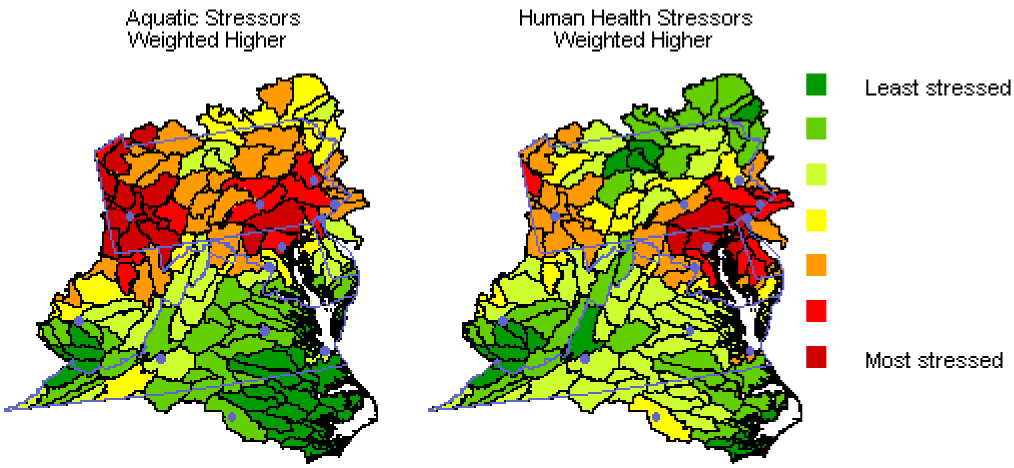
A decision criterion of aquatic stress is made up of a combination of individual variables. These variables can be weighted differently to reflect knowledge about the relative importance of individual stressors (e.g. nitrogen in surface water may be more important than risk of forest mortality in defoliated areas), or by feasibility of reducing the stress (e.g. it may be easier to reduce nonpoint runoff of nutrients than to reduce regional air pollution). The EDT allows weights to be interactively set between 0 and 10. The map above was created by setting these weights as shown below (above).

Another potential decision criterion is human health stressors. Again, this decision criterion is made up of a combination of variables, with weights selected for the individual variables.



Trade-offs

Trade-offs between decision options can be evaluated by additionally weighting the decision criteria based on alternative priorities. The maps below show where actions would be targeted if reducing stress to aquatic species is a priority (left), and where reducing stress to human populations is priority (right).



Next Steps

This concludes the guided tour. Now that you have some feel for how the EDT can be used, we invite you to try it out for yourself. Environmental decision-making is a complex process and no single view of regional conditions or vulnerabilities can sufficiently represent the many factors that could be considered. Our goal in creating the EDT has been to help people gain a broader understanding of the complex interactions that influence environmental health.

To learn more or to use the tool, check out these pages:

* Tutorial - this part of the EDT provides more detailed information about the statistics used to integrate data and model results as well as which integration method should be used for different assessment questions. It also provides information about data preparation. http://www.waratah.com/revanew/Tutorial.asp
- Online User's Guide - the user's guide provides specific guidance for how to access the full capabilities of the EDT.
- Glossary - direct links are provided to define highlighted words throughout the EDT.
- Bottom-line data analysis - this part of the tool is designed for those who want to see the bottom-line without delving deeply into the data. It has a number of default variables preselected for different assessment questions.
- Full data analysis - use of this capability requires a good understanding of the available data and statistical relationships. The analytical part of the tool can be used to explore possible relationships between and among different variables, display individual variables, drill-down to individual watersheds, etc. http://www.waratah.com/revanew/demonstrations.asp

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A.1.6. **Demonstrations**

The following demonstrations give various graphical views of the MAIA region data. The data consist of many resources/stressors. The visualizations allow the user to view data for the subareas of the region. There are 141 watersheds and 733 EMAP hexes in the MAIA region. From this page you can get to the various visualizations of the data.

<u>Preferences</u>

User can choose region to work with and possibly other items. Current Preferences: Region - All of MAIA

<u>Variable Summaries</u>

The variable summaries provide graphical summaries of the variable data and regional maps with single variables displayed. The user can interact with some of the maps via drill-down into watershed and EMAP hex details and moving between graphical views.

<u>Integration Methods</u>

The area summaries provide maps of the area of interest either watersheds or EMAP hexes, displaying results of integration methods and allowing one to compare two integration methods together. The user gets to make various choices such as integration methods to compare and whether to display watersheds or EMAP hexes.

<u>Restoration Opportunities</u>

This demonstration allows one to weight various coverages to see how they affect restoration in various watersheds.

<u>Overview of region</u>

This visualization allows you to display various land features to get an idea of where cities, roads, rivers, and other features are in the region. This allows one to view where roads maybe causing a watershed to have more stressors and fewer resources.

<u>Data Download</u>

From this page, you can select to download the various data used in these demonstrations. You can download the raw data, the normalized data, or information about the variables. This page will also include detailed metadata about the variables in the future.

Appendix A.2. **Data & Metadata: Technical Details & Tables**

A.2.1. **List of GIS Files**

49BASIN (Pennypack 49 Sub Basins)

Two shape files:

- BASIN_BOUND: Pennypack Creek Watershed Boundary
- 49BASIN: 49 Sub Basin boundaries with specific ID numbers

BASE_DATA

Three shape files:

- MUNI_BOUND: Municipal Boundaries in the watershed
- STREAM: Habitat data of 20 monitoring stations set by PWD

BIO (Biological Data)

Three shape files:

- FISH: Fish data of 20 monitoring stations set by PWD
- HABITAT: Habitat data of 20 monitoring stations set by PWD
- MACRO: Macroinvertebrates data of 20 monitoring stations set by PWD

DEMOG (Census Block Group Level Demographic Data)

Two shape files:

- DEMOG1990
- DEMOG2000

GEOL (Geology and Soil)

Two shape files:

- GEOL_BF: Location of different types of rocks and their base flow amount
- SOIL: Hydrologic Soil types

LANDF (Land Features)

Three shape files:

- LU1990: Landuse by Category in 1990
- LU1995: Landuse by Category in 1995
- LU2000: Landuse by Category in 2000

Six raster files:

- FVC1985: Fractional Vegetative Coverage in 1985
- FVC2000: Fractional Vegetative Coverage in 2000
- LC2001: Land Cover by Category
- IMPV2000: Impervious Surface in 2000
- IMPV1985: Impervious Surface in 1985
- CAN2001: Canopy Coverage

WTR_REL (Water Related)

Nine shape files:

- A_EC: Amount of Effluent Concentration for 20 monitoring stations set by PWD
- A_TGWW: Total Groundwater Withdrawals
- BRIDGE_CULVERT: Location of culverts and bridges
- DAM: Location of Dams
- MPD: Maximum Permitted Discharge
- RIP_BUF: Location of banks where riparian buffer is absent either on one side or both sides.
- WETLAND: Wetland areas
- SSA: Sewer Service area
- WSA: Water service area

A.2.2. **Shape File Metadata**

Shape File Name: 49BASIN (49 Sub Basins of Pennypack Watershed)

Author Information:
Name: Md Mahbubur Meenar, ASM Bari
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: meenar@temple.edu, asmbari@temple.edu
Date: July 15, 2005

Description:
Sub basin is a drainage area or small basin within a large watershed.

Type of feature:
Polygon

Purpose:
The existing models for the Regional Vulnerability Assessment (ReVA) Program — which may be used by researchers to create future development scenarios — focus predominantly on large river basins. The CSC study is taking the methodology of ReVA and downscaling it for smaller watersheds, such as the Pennypack Creek. In order to assess the vulnerability of the watershed, the whole area needs to be divided into smaller sub basins. The purpose of this shape file is to display the sub basin boundaries generated by the researchers for this study.

Original Data Source:
Data originated at the CSC.
Stream centerline file source: CSC

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
Using the stream centerline shape file as a reference, the whole Pennypack Watershed is divided into 49 Sub Basins based on the stream order, stream flow, and DEM data. This Sub Basin boundary creation process was administered by Dr. Michel Boufadel of

the Department of Civil and Environmental Engineering at Temple University. The software WMS 7.1 was used to generate the boundaries.

Description of Attribute Table Fields:
No of Fields (not including FID and Shape): 3
No of Records: 49

Field Name	Description
BASIN_ID	Randomly chosen Basin IDs for every Sub Basin
AREA_SWM	Area of Sub Basin in square mile
AREA_SQF	Area of Sub Basin in square feet

Shape File Name: FISH

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: CSC, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu

Description:
Data describes the Fish species present at various sites and the water quality derived by analyzing these species.

Type of feature:
Point

Original Data Source:
Philadelphia Water Department (PWD)
Data creation year: 2002
Data acquired by CSC in 2004.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
Following the twenty monitoring stations set by PWD, the original data was cleaned up and all categories were arranged by Dr. Peter Petraitis (ppetrait@sas.upenn.edu) of the University of Pennsylvania.
Description of Fields of Attribute Table:
No. of Fields (except FID and shape): 21

Field Name	Description
F_NO_SP	Total Number of Fish Species
F_NO_BEN	Number of benthic insectivorous species
F_NO_WAT	Number of Water Column Species
F_NO_INT	Number Of Intolerant/Sensitive Species

F_P_WHSK	Percent White Sucker
F_P_GEN	Percent Generalist
F_P_INSE	Percent Insectivores
F_P_CARN	Percent Top Carnivores
F_P_DIS	Percent of individuals with disease and anomalies
F_P_DOM	Percentage of dominant species
F_DEN	Density
F_NO_IND	Number Of Individuals
F_BIOM	Biomass per square meter
F_MODIND	Modified Index Of Well-Being
F_SWDI	Shannon-Weiner Diversity Index (H')
F_NO_CYP	Number of Cyprinid Species
F_P_RES	Percent of Resident Species
F_P_EXOT	Percent of Introduced/Exotic Species
F_IBI	The Index of Biological Integrity Score (IBI) from the PWD Reporti
F_BIO_IN	The IBI Score expressed as a percentage
BIO_ID	PWD Monitoring Stations From which data for this basin was taken

No. of Records: 20

Shape File Name: HABITAT

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005
Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: CSC, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu

Description:
Habitat is the physical location or type of environment in which an organism or biological population lives or occurs. (http://www.biology- online.org/dictionary/habitat). This data describes the habitat present at various sites along the Pennypack Stream.

Type of feature:
Point

Original Data Source:
Philadelphia Water Department (PWD)
Data creation year: 2002
Data acquired by CSC in 2004.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South

Following the twenty monitoring stations set by PWD, the original data was cleaned up and all of the categories were arranged by Dr. Peter Petraitis (ppetrait@sas.upenn.edu) of the University of Pennsylvania.

Description of Fields of Attribute Table:
No. of Fields (except FID and shape): 17

Field Name	Description
L_BANK	Bank Stability (Left Bank)
R_BANK	Bank Stability (Right Bank)
CH_ALT	Channel Alteration
CH_FLOW	Channel Flow Status
CH_SIN	Channel Sinuosity
EMBED	Embeddedness
EPIF_SUB	Epifaunal substrate cover
RIF_FREQ	Frequency of Riffles (or Bends)
POOL_SUB	Pool Substrate Characterization
POOL_VAR	Pool Variability
RIP_V_L	Riparian Vegetative Zone Width (Left Bank)
RIP_V_R	Riparian Vegetative Zone Width (Right Bank)
SED_DEP	Sediment Deposition
VEG_P_L	Vegetative Protection (Left Bank)
VEG_P_R	Vegetative Protection (Right Bank)
VEL_DEPT	Velocity/Depth Regime
BIO_ID	PWD Monitoring Stations From which data was taken

No. of Records: 20

Shape File Name: MACRO (Macroinvertebrates)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: CSC, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu

Description:
Data describes the Macroinvertebrates present at various sites and the water quality derived by analyzing these invertebrates. A Macroinvertebrate is an animal without a backbone in at least one stage of its life cycle, usually the nymph or larval stage[ii].

Benthic macroinvertebrates such as insects, worms, and molluscs are the preferred group of aquatic organisms monitored in water quality assessment programs (Hellawell 1986) because: (1) they provide an extended temporal perspective (relative to traditional water samples that are collected periodically) because they have limited mobility and relatively long life spans (e.g., a few months for some chironomid midges to a year or more for some insects and molluscs); (2) the group has measurable responses to a wide variety of environmental changes and stresses; (3) they are an important link in the aquatic food web, converting plant and microbial matter into animal tissue that is then available to fish; (4) they are abundant; and (5) their responses can be analyzed statistically (Weber 1973). Thus, the presence or conspicuous absence of certain macroinvertebrate species at a site is a meaningful record of environmental conditions during the recent past, including ephemeral events that might be missed by assessment programs, which only rely on periodic sampling of water chemistry. Most stream ecosystems have relatively diverse macroinvertebrate assemblages with species from a number of different orders [e.g., mayflies (Ephemeroptera), and caddisflies (Trichoptera), stoneflies (Plecoptera), beetles (Coleoptera), true flies (Diptera)]. Likewise, the common trophic groups (i.e., herbivores, detritivores, and predators) are represented by a number of different species. Various abiotic factors (e.g., hydrology, substrate, temperature, oxygen, and pH) and biotic factors (e.g., food quality and quantity, interactions with competitors or predators) have molded, through natural selection, a unique set of optimum environmental requirements for each species. These environmental requirements contribute significantly to the distribution and abundance of these organisms within and among natural stream ecosystems and influence their response to environmental perturbation.[iii]

Type of feature:
Point

Original Data Source:
Philadelphia Water Department (PWD)
Data creation year: 2002
Data acquired by CSC in 2004.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
Following the twenty monitoring stations set by PWD, the original data was cleaned up and all of the categories were arranged by Dr. Peter Petraitis (ppetrait@sas.upenn.edu) of the University of Pennsylvania.

Description of Fields of Attribute Table:
No. of Fields (except FID and shape): 14

Field Name	Description
M_NO_SP	Number of Species
M_HBI	Hilsenhoff Biotic Index
M_P_DOM	Percent of the Taxa that is the Dominant Taxa
M_D_TAX	Dominant Taxa
M_P_FIL	Percent of Filter/Collector Species
M_P_GATH	Percent of Gatherer/Collector Species
M_P_SCR	Percent of Scraper Species
M_P_SHR	Percent of Shredder Species
M_P_MODT	Percent of Moderately Tolerant Species
M_P_TOL	Percent of Tolerant Species
M_P_INTO	Percent of Intolerant Species
M_BIO_AS	Biological Assessment of Stream based on the Macroinvertebrate Population from the PWD Reportiv
M_BIO_IN	Percentage representing the Biological Integrity of the Pennypack from the PWD Report[iii]
BIO_ID	PWD Monitoring Stations from which the data was taken

No. of Records: 20

Shape File Name: DEMOG1990 (Census Block Groups)

Contact Information:
Name: Kurt Paulsen, Ph.D.
Organization: Center for Sustainable Communities, Temple University, PA
Email: kurt.paulsen@temple.edu
Date: 08-18-2005

Description:
1990 Census Block Groups with basic demographic data.

Original Data Source:
Data are from the United States Census Bureau. Shape files are from Census TIGER/Line Cartographic Boundary files, Census Block Groups for 1990. Census Data for 1990 (STF3) were accessed from CD-Roms.

Actions Taken for Data Processing:
Shape files: Data for 1990 are originally in unprojected Geographic (lat/lon) format. Shape files were reprojected into Pennsylvania State Plane Feet South (NAD83). Census Block Groups for Bucks, Montgomery and Philadelphia Counties were initially produced.

Block groups which had any portion of their area within the Pennypack Creek watershed were selected. For population and housing unit estimates, the percent of a Census Block Group within the Pennypack watershed and/or within subbasins were used to adjust figures. For example, if a Census Block Group has 10 percent of its area within the watershed, then 10 percent of its housing units and population are assumed to be located within the watershed. Similarly, if 10 percent of a block group is located in one sub-basin, then 10 percent of its population and housing figures were assigned to that sub-basin.

Data files: Data for 1990 were from the Census SF3 (Summary File 3). The following tables/variables were collected:

P001001: Total Persons
P080A001: Median household income in 1989
H0010001: Total Housing Units

Description of Fields of Attribute Table:
No. of Fields (except FID and shape): 8

Field Name	Description
STATEFP	State FIPS Code (Pennsylvania =42)
CNTY	County FIPS Code
TRACT	Census Tract FIPS Code
BLCKGR	Census Block Group Number
BLCKFIPS	Census Block FIPS code
P0010001	Total Population
P080A001	Household Median Income, 1999

H0010001	Total Housing Units

No. of Records: 221

Additional Information:
Census Bureau estimates of median-household income use 1-year prior to each decennial census because the question asks respondents to report household income for the previous year. Note: data for income are in nominal (non-inflation adjusted) dollars.

Shape File Name: DEMOG (Census Block Groups)

Contact Information:
Name: Kurt Paulsen, Ph.D.
Organization: Center for Sustainable Communities, Temple University, PA
Email: kurt.paulsen@temple.edu
Date: 08-18-2005

Description:
2000 Census Block Groups with basic demographic data.

Original Data Source:
Data are from the United States Census Bureau. Shape files are from Census TIGER/Line Cartographic Boundary files, Census Block Groups for 2000. Census Data (SF3) for 2000 were downloaded from http://factfinder.census.gov.

Actions Taken for Data Processing:
Shape files: Data for 2000 are originally in unprojected Geographic (lat/lon) format. Shape files were reprojected into Pennsylvania State Plane Feet South (NAD83). Census Block Groups for Bucks, Montgomery and Philadelphia Counties were initially produced. Block groups which had any portion of their area within the Pennypack Creek watershed were selected. For population and housing unit estimates, the percent of a Census Block Group within the Pennypack watershed and/or within subbasins were used to adjust figures. For example, if a Census Block Group has 10 percent of its area within the watershed, then 10 percent of its housing units and population are assumed to be located within the watershed. Similarly, if 10 percent of a block group is located in one sub-basin, then 10 percent of its population and housing figures were assigned to that sub-basin.

Data files: Data for 2000 were from the Census SF3 (Summary File 3). The following tables/variables were collected:

- P001001: Total Persons
- P053001: Median household income in 1999
- H001001: Total Housing Units

Description of Fields of Attribute Table:
No. of Fields (except FID and shape): 8

Field Name	Description
STATE	State FIPS Code (Pennsylvania =42)

COUNTY	County FIPS Code
TRACT	Census Tract FIPS Code
GROUP	Census Block Group Number
STFID	Standard Tape File Identification (=Census Block Group FIPS)
P001001	Total Persons
P053001	Household Median Income in 1989
H001001	Total Housing Units

No. of Records: 302

Additional Information:
Census Bureau estimates of median-household income use 1-year prior to each decennial census because the question asks respondents to report household income for the previous year. Note: data for income are in nominal (non-inflation adjusted) dollars.

Shape File Name: GEOLOGY & BASE FLOW

Contact Information:
Name: Md Mahbubur R Meenar, GIS Coordinator
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: meenar@temple.edu
Date: 07/15/05

Description:
Bed rock refers to the rock underlying other unconsolidated material, i.e. soil. This file displays the percentages of different types of generalized geology in each of the 49 sub basins of Pennypack Watershed Area. Each type reflects a designation of certain hydrologic properties.

Type of feature:
Polygon

Purpose:
Increased development in major parts of the Pennypack Creek Watershed has increased public, industrial, and commercial demand for water. Further withdrawals may reduce groundwater availability and stormflow. This database will help conduct any groundwater assessment for the Pennypack Watershed Area.

Original Data Source:
Sources: Philadelphia Water Department (PWD) and Delaware River Basin Commission (DRBC)
Year of Publication: 10/01/98 for DRBC data
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South

The original files were collected and/or processed into GIS shape file format. The PWD shape file covers the geology of the watershed area inside Montgomery and Bucks

Counties and DRBC shape file covers the watershed area inside Philadelphia County. These shape files are coded differently for different rock type. Following Dr. Jeffrey Featherstone's (Director, CSC) suggestion the DRBC rock type coding was taken as standard and these codes were incorporated in the PWD shape file. Once these files were merged together, the final shape file was clipped by Pennypack Watershed Area. Rock codes have been assigned to different types of rocks. This coding is consistent with the Geology shape file that the CSC has developed.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 7

Field Name	Description
ROCK_TYPE	This is an attribute used to assign a general geologic class. It reflects a designation of certain hydrologic properties. Five types of rocks are listed.
ROCK_CODE	A numeric code for each type of rock, randomly assigned by CSC 1 = Crystalline Rock other than Diabase 2 = Unconsolidated Sediment 3 = Carbonate Rock 4 = Sedimentary other than Carbonates 5 = Diabase
AREA	Square mile area of the polygons for each rock type
MEDIAN	This attribute assigns the median baseflow rate in mgal/day/sqm for each of the five geologies listed above
TEN_YR	This attribute assigns the ten year recurrence baseflow rate in mgal/day/sqm for each of the five geologies listed above
TWENTYFIVE	This attribute assigns the twenty five year recurrence baseflow rate in mgal/day/sqm for each of the five geologies listed above
FIFTY_YR	This attribute assigns the fifty year recurrence baseflow rate in mgal/day/sqm for each of the five geologies listed above

No of Records: 12

Additional Information:
In order to get the contact information for the original metadata or any other relevant information from DRBC, please visit their web site at www.state.nj.us/drbc.

Shape File Name: SOIL (Hydrologic Group)

Contact Information:
Name: Md Mahbubur R Meenar, GIS Coordinator
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: meenar@temple.edu
Date: 08/02/05
Description:
A hydrologic group is a group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that influence the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozenv. The soils are placed into four groups, A, B, C and D, and three dual classes, A/D, B/D, and C/D. According to the National Soil Survey Handbook of the Natural Resources Conservation Services, the definitions of the hydrologic soil classes are as follows:

A. (Low runoff potential). The soils have a high infiltration ratevi even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmissionvii.
B. The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.
C. The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.
D. (High runoff potential). The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

Dual hydrologic groups, A/D, B/D, and C/D, are given for certain wet soils that can be adequately drained. The first letter applies to the drained condition, the second to the undrained. Only soils that are rated D in their natural condition are assigned to dual classes.

Type of feature:
Polygon

Purpose:
This file might be used in planning watershed-protection and flood-prevention projects. Hydrologic groups are used in equations that estimate runoff from rainfall needed for solving hydrologic problems (NRCS web site, see end note I). The purpose of this data is to display the percentages of different types of hydrologic soil types present in each sub basin of the Pennypack Watershed area.

Original Data Source:
Sources: Natural Resources Conservation Services (NRCS) and Delaware River Basin Commission (DRBC)
Year of Publication: Unknown
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
Soil data at the scale of 1:24,000 for Montgomery, Bucks, and Philadelphia Counties were collected from Soil Survey Geographic (SSURGO) Database of NRCS. Their other lower resolution dataset is called STATSGO, which is available at 1:250,000 scale and was not used. Other soil data from the Philadelphia Water Department (PWD) was available at a much smaller resolution and was not used.

The following steps were taken by the Department of Civil and Environmental Engineering at Temple University, PA.
Soil data (in GIS shape file format) for each county was clipped to the region belonging to the watershed. Information for soil groups A, B, C, and D was added to the clipped files. This information was originally available as database files and was imported in GIS

as dbf files. Some soil types lacked a HYDGRP (hydrologic group) value or had multiple HYDGRP values were edited. The attribute MUSYM (Map Unit Symbol) was used to join the soil type shape files. MUSYM is a soil code that changes from county to county. Hence a single dbf file could not be used for all three counties. All three clipped shape files were then appended or merged to create the final soil shape file.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 3

Field Name	Description
MUSYM	Stands for Map Unit Symbol, which is an alphanumeric code. MUSYM is a soil code that changes from county to county.
COMPNAME	A single Map Unit may contain up to three different soil components or soil types which are too small or intermixed to represent graphically on a map. COMPNAME contains the name of the soil component for each Map Unit.
HYDGRP	Hydrologic soil types (A= Sandy, free draining soil, D = clayey, poorly drained soil, B and C are intermediate soil groups).

No of Records: 1544

Additional Information:
In order to get the contact information for the original metadata or any other relevant information from NRCS, please visit their web site at http://www.nrcs.usda.gov/ or NRCS Soils web site at http://soils.usda.gov/.

Shape File Name: CAN2001 (Canopy Coverage)

Contact Information:
Name: Kurt Paulsen
Organization: Center for Sustainable Communities, Temple University, PA
Email: kurt.paulsen@temple.edu
Date: August 18, 2005

Description:
Estimates of tree canopy density for each 30-meter pixel, based on satellite imagery.

Purpose:
Land cover and land use maps designate areas as “forested” but do not estimate canopy density. Additionally, tree canopy coverage may occur in pixels not classified as “forested” in land cover or land use classifications. Tree canopy cover data is useful in a number of ecological and hydrological models.

Original Data Source:
National Land Cover Database Zone 60 Tree Canopy Layer. A product of the United States Geological Survey (USGS). Data were extracted from http://seamless.usgs.gov web server. Data server allows user to identify geographic coordinates for downloading files. Data were extracted based on Pennypack Creek watershed boundaries.

Original Citation Details:

References: Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing (in press).

Huang, C., L. Yang, B. Wylie, and C. Homer, 2001. A strategy for estimating tree canopy density using Landsat 7 ETM+ and high resolution images over large areas. In: Third International Conference on Geospatial Information in Agriculture and Forestry; November 5-7, 2001; Denver, Colorado. CD-ROM, 1 disk.

The National Land Cover Database 2001 land cover layer for mapping zone 60 was produced through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium. The MRLC Consortium is a partnership of federal agencies (www.mrlc.gov) that consist of the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), the Forest Service (USFS), the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), the Bureau of Land Management (BLM) and the USDA Natural Resources Conservation Service (NRCS). One of the primary goals of the project is to generate a current, consistent, seamless and accurate National Land Cover Database (NLCD) circa 2001 for the United States at medium spatial resolution. For a detailed definition and discussion on MRLC and the NLCD 2001 products, refer to Homer et al. (2003) and <http://www.mrlc.gov/mrlc2k.asp>.

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD83) and subsequently reprojected into Pennsylvania State Plane Feet South (NAD83). Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields of Attribute Table:
No. of Fields (not including FID and Shape): 2

Field Name	Description
Value	Percent of pixel canopy density, 2001
Count	Field created by Hawth's tools in clipping process. Count is number of pixels within clip area with same value.

No. of Records: 95

Additional Information:
Detailed accuracy assessment of the tree-canopy density estimation algorithm is contained in: Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing (in press).

Database Name: FVC2000 (Fractional Vegetative Coverage, 2000)

Contact Information:
Name: Kurt Paulsen
Organization: Temple University, Center for Sustainable Communities

Email: kurt.paulsen@temple.edu
Date: 08-16-2005

Description:
Estimate of the percentage of a pixel covered by vegetation. Vegetative coverage was estimated based on satellite imagery.

Purpose:
Vegetation serves many important ecological functions related to species habitat and water quality. Fractional vegetation data is a biophysical variable that describes the percent of vegetation covering the area of a raster cell. Fractional vegetation is used as input to hydrologic, meteorologic and plant growth models. Hydrologically, plant cover reduces the amount and velocity of rainfall hitting the surface, thus reducing erosional forces. Plant cover also intercepts sun light reducing thermal emission from the soil surface.

Original Data Source:
Downloaded from Pennsylvania Spatial Data Archive (www.pasda.psu.edu). Data created by Dr. Toby Carlson, Pennsylvania State University Department of Meteorology. Title: Fractional Vegetation Cover for Southeast Pennsylvania, 2000

Full Metadata online at:
http://www.pasda.psu.edu/documents.cgi/isa_pa/pa2000fvca_se.xml

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD27) and reprojected into Pennsylvania State Plane Feet South (NAD83). Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields of Attribute Table:
No. of Fields (not including FID and Shape): 2

Field Name	Description
Value	Percent of pixel covered by vegetative growth, 2000
Count	Field created by Hawth's tools in clipping process. Count is number of pixels within clip area with same value.

No. of Records: 57

Additional Information:
Original estimates of pixel vegetative coverage by Dr. Toby Carlson were based on the NDVI (Normalized Difference Vegetation Index) method. Fractional vegetative coverage, the percent of a pixel covered by vegetation (where zero is bare soil and one is dense vegetation) is the NDVI squared.

Database Name: IMPERV2000 (Impervious Cover, 2000)

Contact Information:
Name: Kurt Paulsen

Organization: Temple University, Center for Sustainable Communities
Email: kurt.paulsen@temple.edu
Date: 08-18-2005

Description:
Estimate of the percent of a pixel covered by impervious surfaces. Impervious surfaces were estimated based on satellite imagery.

Purpose:
"Impervious cover is an important indicator of watershed health… [and] is a critically important variable in most hydrologic and water quality models used to analyze urban watersheds." (Center for Watershed Protection: Impervious Cover and Land Use in the Chesapeake Bay Watershed. January 2001, p. iii)

Original Data Source:
Downloaded from Pennsylvania Spatial Data Archive (www.pasda.psu.edu). Data created by Dr. Toby Carlson, Pennsylvania State University Department of Meteorology.
Title: Impervious surface area for Southeast Pennsylvania, 2000
Full metadata online at:
http://www.pasda.psu.edu/documents.cgi/isa_pa/pa2000isaa_se.xml

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD27) and reprojected into Pennsylvania State Plane Feet South (NAD83). Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields of Attribute Table:
No. of Fields (not including FID and Shape): 2

Field Name	Description
Value	Percent of pixel covered by impervious surface, 2000
Count	Field created by Hawth's tools in clipping process. Count is number of pixels within clip area with same value.

No of Records: 58

Additional Information:
Accuracy of original satellite imagery classification was verified visually using high-resolution digital orthophotography available from Delaware Valley Regional Planning Commission. A comparison of the Impervious Surface layer available from the USGS National Land Cover Database and the Impervious Surface coverage from Dr. Toby Carlson at Penn State with the digital orthophotography revealed that the Penn State data was of superior quality and higher resolution, and hence was used in this analysis.

Shape File Name: LU1990.SHP (Land Use, 1990)

Contact Information:
Name: Kurt Paulsen
Organization: Temple University, Center for Sustainable Communities
Email: kurt.paulsen@temple.edu

Date: 08-18-2005

Description:
Digital land use layer for Pennypack Creek watershed in 1990. Interpretation of land use from aerial photography by Delaware Valley Regional Planning Commission.

Purpose:
To document and describe land use patterns and land use change in the Pennypack Creek Watershed.

Original Data Source:
DVRPC Land Use Digital Data for 1990

Actions Taken for Data Processing:
Data were originally projected in UTM Zone 18N (NAD83) and subsequently reprojected into Pennsylvania State Plane Feet South (NAD83). Data were clipped to Pennypack Creek watershed boundary.

Description of Fields of Attribute Table:
No. of Fields (not including FID and Shape): 2

Field Name	Description
LU_CODE	Numeric code representing land use.
DESCRIPTIO	Land use description

No. of Records: 1968

Additional Information:
Data was collected from aerials flown in Spring, 1990. Data digitized from non-orthocorrected photography at a scale of 1 inch = 400 feet.

Shape File Name: LU1995.SHP (Land Use, 1995)

Contact Information:
Name: Kurt Paulsen
Organization: Temple University, Center for Sustainable Communities
Email: kurt.paulsen@temple.edu
Date: 08-18-2005

Description:
Digital land use layer for Pennypack Creek watershed in 1995. Interpretation of land use from aerial photography by Delaware Valley Regional Planning Commission.

Purpose:
Document and describe land use patterns and land use change in the Pennypack Creek Watershed.

Original Data Source:
DVRPC Land Use Digital Data for 1995

Actions Taken for Data Processing:

Data were originally projected in UTM Zone 18N (NAD83) and subsequently reprojected into Pennsylvania State Plane Feet South (NAD83). Data were clipped to Pennypack Creek watershed boundary.

Description of Fields of Attribute Table:
No. of Fields (not including FID and Shape): 2

Field Name	Description
LU_CODE	Numeric code representing land use.
CATEGORY	Land use description.

No. of Records: 2361

Additional Information:
Data was collected from aerials flown in Spring, 1995. Data digitized from non-orthocorrected photography at a scale of 1 inch = 400 feet.

Shape File Name: LU2000.SHP (Land Use, 2000)

Contact Information:
Name: Kurt Paulsen
Organization: Temple University, Center for Sustainable Communities
Email: kurt.paulsen@temple.edu
Date: 08-18-2005

Description:
Digital land use layer for Pennypack Creek watershed in 2000. Interpretation of land use from high-resolution digital orthophotography by Delaware Valley Regional Planning Commission.

Purpose:
Document and describe land use patterns and land use change in the Pennypack Creek Watershed.

Original Data Source:
DVRPC Land Use Digital Data for 1990

Actions Taken for Data Processing:
Data were originally projected in UTM Zone 18 (NAD83) and subsequently reprojected into Pennsylvania State Plane Feet South (NAD83). Data were clipped to Pennypack Creek watershed boundary.

Description of Fields of Attribute Table:
No. of Fields (not including FID and Shape): 4

Field Name	Description
LU_CODE	Numeric code representing land use
DESCRIPTIO	Land use description

No. of Records: 2915

Additional Information:
Data was collected from aerials flown in Spring, 2000. Data digitized from digital orthophotography. The imagery has a pixel resolution of 1.5 square feet, a positional accuracy of +/- 5 feet and is designed for use at a scale of 1 inch = 200 feet.

Shape File Name: FVC1985 (Fractional Vegetative Coverage, 1985)

Contact Information:
Name: Kurt Paulsen
Organization: Center for Sustainable Communities, Temple University, PA
Email: kurt.paulsen@temple.edu
Date: August 18, 2005

Description:
Estimate of the percentage of a pixel covered by vegetation. Vegetative coverage was estimated based on satellite imagery.

Purpose:
Vegetation serves many important ecological functions related to species habitat and water quality. Fractional vegetation data is a biophysical variable that describes the percent of vegetation covering the area of a raster cell. Fractional vegetation is used as input to hydrologic, meteorologic and plant growth models. Hydrologically, plant cover reduces the amount and velocity of rainfall hitting the surface, thus reducing erosional forces. Plant cover also intercepts sun light reducing thermal emission from the soil surface.

Original Data Source:
Downloaded from Pennsylvania Spatial Data Archive (www.pasda.psu.edu). Data created by Dr. Toby Carlson, Pennsylvania State University Department of Meteorology. Title: Fractional Vegetation Cover for Southeast Pennsylvania, 1985

Full Metadata online at:
http://www.pasda.psu.edu/documents.cgi/isa_pa/pa1985fvca_se.xml

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD27) and reprojected into Pennsylvania State Plane Feet South (NAD83). Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields of Attribute Table:
No. of Fields (not including FID and Shape): 2

Field Name	Description
Value	Percent of pixel covered by vegetative growth, 1985
Count	Field created by Hawth's tools in clipping process. Count is number of pixels within clip area with same value.

No. of Records: 99

Additional Information:

Original estimates of pixel vegetative coverage by Dr. Toby Carlson were based on the NDVI (Normalized Difference Vegetation Index) method. Fractional vegetative coverage, the percent of a pixel covered by vegetation (where zero is bare soil and one is dense vegetation) is the NDVI squared.

Database Name: IMPERV1985 (Impervious Cover, 1985)

Contact Information:
Name: Kurt Paulsen
Organization: Temple University, Center for Sustainable Communities
Email: kurt.paulsen@temple.edu
Date: 08-18-2005

Description:
Estimate of the percent of a pixel covered by impervious surfaces. Impervious surfaces were estimated based on satellite imagery.

Purpose:
"Impervious cover is an important indicator of watershed health… [and] is a critically important variable in most hydrologic and water quality models used to analyze urban watersheds." (Center for Watershed Protection: Impervious Cover and Land Use in the Chesapeake Bay Watershed. January 2001, p. iii)

Original Data Source:
Downloaded from Pennsylvania Spatial Data Archive (www.pasda.psu.edu). Data created by Dr. Toby Carlson, Pennsylvania State University Department of Meteorology. Title: Impervious surface area for Southeast Pennsylvania, 1985

Full metadata online at:
http://www.pasda.psu.edu/documents.cgi/isa_pa/pa1985isaa_se.xml

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD27) and reprojected into Pennsylvania State Plane Feet South (NAD83). Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields of Attribute Table:
No. of Fields (not including FID and Shape): 2

Field Name	Description
Value	Percent of pixel covered by impervious surface, 1985
Count	Field created by Hawth's tools in clipping process. Count is number of pixels within clip area with same value.

No of Records: 97
Additional Information:
Accuracy of original satellite imagery classification was verified visually using high-resolution digital orthophotography available from Delaware Valley Regional Planning Commission. A comparison of the Impervious Surface layer available from the USGS

National Land Cover Database and the Impervious Surface coverage from Dr. Toby Carlson at Penn State with the digital orthophotography revealed that the Penn State data was of superior quality and higher resolution, and hence was used in this analysis.

Shape File Name: LC2001 (Land Cover, 2001)

Contact Information:
Name: Kurt Paulsen
Organization: Temple University, Center for Sustainable Communities
Email: kurt.paulsen@temple.edu
Date: 08-18-2005

Description:
Classification of land cover for each 30-meter pixel, based on satellite imagery.

Purpose:
Description of land cover characteristics.

Original Data Source:
National Land Cover Database Zone 60 Land Cover Layer. A product of the United States Geological Survey (USGS). Data were extracted from http://seamless.usgs.gov web server. Data server allows user to identify geographic coordinates for downloading files. Data were extracted based on Pennypack Creek watershed boundaries.

Original Citation Details:
References: Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing (in press).

The National Land Cover Database 2001 land cover layer for mapping zone 60 was produced through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium. The MRLC Consortium is a partnership of federal agencies (www.mrlc.gov), consisting of the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA) Forest Service (USFS), the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), the Bureau of Land Management (BLM) and the USDA Natural Resources Conservation Service (NRCS). One of the primary goals of the project is to generate a current, consistent, seamless, and accurate National Land cover Database (NLCD) circa 2001 for the United States at medium spatial resolution. For a detailed definition and discussion on MRLC and the NLCD 2001 products, refer to Homer et al. (2003) and <http://www.mrlc.gov/mrlc2k.asp>.

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD83) and subsequently reprojected into Pennsylvania State Plane Feet South (NAD83). Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields of Attribute Table:
No. of Fields (not including FID and Shape): 2

Field Name	Description
Value	Classification of pixel land cover (see Additional Information)
Count	Field created by Hawth's tools in clipping process. Count is number of pixels within clip area with same value.

No. of Records: 13

ADDITIONAL INFORMATION:
Land Cover Codes and Explanations, from National Land Cover Database:

11. Open Water – All areas of open water, generally with less than 25% cover of vegetation or soil.
21. Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.
23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
24. Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.
31. Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
41. Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
42. Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
43. Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
82. Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
90. Woody Wetlands - Areas where forest or scrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

95. Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Shape File Name: A_EC (Amount of Effluent Concentrations)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 08/09/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: CSC, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu

Description:
This data contains concentrations of common and important dissolved chemicals. This data was collected at 20 different stations by the Philadelphia Water Department during the summer of 2002. No data is represented by -999.
Type of feature:
Point

Original Data Source:
Source: Philadelphia Water Department (PWD)
Year of Publication: 2003, Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
Following the twenty monitoring stations set by PWD, the original data was cleaned up and all of the categories were arranged by Dr. Peter Petraitis (ppetrait@sas.upenn.edu) of the University of Pennsylvania.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 10

Field Name	Description
ALKAL	Alkalinity (mg CaCO3/L)
AMMON	Ammonia (mg/L)
DIS_02	Dissolved O2 (mg/L)
E_COLI	E. coli (colony forming units per 100mL)
FEC_COL	Fecal Coliform (colony forming units per 100mL)
NITRATE	Nitrate (mg/L)
NITRITE	Nitrite (mg/L)
ORTHOPHO	Orthophosphate (mg/L)
TOT_PHOS	Total Phosphorus (mg/L)
CHLOR_A	Chlorophyll A (mg/L)

No of Records: 20

Shape File Name: A_TGWW (Groundwater Withdrawals)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: CSC, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu

Description:
Groundwater Withdrawals are a major source of drinking water for the Pennypack watershed. This data provides the amount of groundwater withdrawn at each major well in the watershed.

Type of feature:
Point

Purpose:
The purpose of this data is to gain a better picture of the water balance in each of the sub basins.

Original Data Source:
Source: Delaware River Basin Commission (DRBC)
Year of Publication: 1996
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
The original shape file was clipped according to Pennypack Watershed boundary.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 6

Field Name	Description
NAME	The owner and designation of the well
ZIP	The zipcode the well is located in
DAYS_OPER	The number of days per year the well is operational
HRS_OPER	The number of hours per day the well is operational
MGYRTOTAL	The total (in millions of gallons) that the well withdraws in a year
AVERAGEMGD	The average withdrawal in millions of gallons per day

No of Records: 99

Shape File Name: BRIDGES & CULVERTS

Data Analyst:
Name: ASM ABDUL BARI

Organization: Center for Sustainable Communities, Temple University, PA
Email: asmbari@temple.edu
Date: July 15, 2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu
Date: 7/22/2005

Description:
A bridge is a structure built to span a gorge, valley, road, railroad track, river or any other physical obstacle. A culvert is a closed conduit built to convey surface drainage water under a roadway or other impediment.

Purpose:
The purpose of this shape file is to determine the number of culverts and bridges in each sub basin. Points were generated at the intersections of road and stream centerlines.

Original Data Source:
Data originated at the Center for Sustainable Communities.
Aerial images (2000) street centerline file source: DVRPC
Stream centerline file source: CSC

Actions Taken for Data Processing:
Input GIS shape files were street centerline and stream centerline of Pennypack Watershed boundary. Hawths Toolbar was used to generate the intersection points of stream centerlines and street centerlines. The tool's name is Intersect Lines (Make Points). Once the points were generated, random quality checking was done with reference to DVRPC 2000 aerial images. No field verification could be made because of time constraint. The other tool used from Hawths Toolbar was Count Points in Polygons in order to get the number of bridges and culverts in each sub basin.

Description of Attribute Table Fields:
No of Fields (not including FID and Shape): 3

Field Name	Description
POINT_X	Location of X coordinate of Bridge/ culvert
POINT_Y	Location of Y coordinate of Bridge/ culvert
BASIN_ID	Sub basin ID number where the bridge/ culvert is located

No of Records: 339

Shape File Name: DAM

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu
Date: 7/22/2005

Description:

This shape file displays the dams located in Pennypack Watershed Area. A dam is a structure for impounding and storing available water as a reservoir for further use. The dams indicated here are line features, with two points on either side of the waterway each dam impedes.

Type of feature:
Line

Purpose:
The purpose of this shape file is to show the number of dams within each sub basin.

Original Data Source:
Philadelphia Water Department (PWD).
Data creation year: 1999
Data acquired by Center for Sustainable Communities in 2002.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
Shape file was clipped by Pennypack Watershed Area.
Some of the original fields were deleted because of unavailability of metadata.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 5

Field Name	Description
LENGTH	Length of the dam
GPSDATE	Date of data collection using GPS device
GPSTIME	Time when field data were collected using GPS device
MATERIAL	Construction material of the dam
CONDITION	Condition of dam according to field survey

No of Records: 9
Note: Some field information for one record was not available

Shape File Name: MPD (Maximum Permitted Discharge)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: CSC, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu

Description:
Discharges into streams are a major source of water pollution, but are also the most regulated type of discharge. Non-point sources are largely unregulated and so often

have a powerful impact on water quality. This data provides water discharge amounts for each point source in the watershed.

Type of feature:
Point

Original Data Source:
Source: Delaware River Basin Commission (DRBC)
Year of Publication: 1996
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
The original shape file was clipped according to Pennypack Watershed boundary.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 3

Field Name	Description
FAC_NAME	The owner of the discharge point
MGAL_YR	The amount of water discharged at this point in millions of gallons per year
MGAL_DAY	The amount of water discharged at this point in millions of gallons per day

No of Records: 18

Shape File Name: RIP_BUF (Riparian Buffer)

Contact Information:
Name: Md Mahbubur R Meenar, GIS Coordinator
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: meenar@temple.edu
Date: 07/22/05

Description:
A Riparian Buffer is a zone of protection made up of trees and other vegetation that grow along the banks of a waterway. Riparian Buffers help keep a stream healthy by reducing stream bank erosion and acting as a natural soil filter[viii].

The Philadelphia Water Department (PWD) classified the forest buffer according to a fifty foot standard, and digitized sections of the stream bank lacking a forest buffer using aerial photography taken in 2000 and provided by the Delaware Valley Regional Planning Commission. The term “Lacking Forest Buffer” is defined as a stream bank with less than fifty foot wide layer of forest cover and less than 50% canopy closure.

Where the stream bank appeared to be lacking a forest buffer on both sides, the section was classified as such. Otherwise, each side of the creek was treated separately. Larger pond or lake areas that result from the damming of the main stem creek or major tributary were assessed; small water bodies, such as man-made farm ponds, were not.

Type of feature:
Line

Purpose:
The purpose of this data is to identify stream banks within Pennypack Watershed Area lacking riparian forest buffers.

Original Data Source:
Source: Heritage Conservancy
Year of Publication: 2002 (Data created from 2000 aerial photography. Field checks performed in 2002)
Data acquired by CSC in 2003.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
The original shape file was clipped according to Pennypack Watershed boundary.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 2

Field Name	Description
TYPE	This field informs whether the stream bank is lacking Riparian Buffer on one side or both sides. Each line feature is represented by either "one" or "both"
LENG_FT	Length of the line feature

No of Records: 302

Additional Information:
Heritage Conservancy has published the original Riparian Buffer Status shape file for Southeastern Pennsylvania region. Contact information for Heritage Conservancy:
Heritage Conservancy
85 Old Dublin Pike, Doylestown, Pa 18901
Ph: 215-345-7020, Fax: 215-345-4328
www.heritageconservancy.org

Shape File Name: WETLAND

Author Information:
Name: ASM ABDUL BARI
Organization: Center for Sustainable Communities, Temple University, PA
Email: asmbari@temple.edu
Date: July 15, 2005

Description:
Wetlands are land areas seasonally or permanently waterlogged by either fresh or salt water. These include lakes, rivers, estuaries and freshwater marshes. Wetlands are areas where water saturation is the dominant factor that determines the nature of soil development and the types of plant and animal communities living in the soil and on its surface. Most wetlands contain soil or substrate that is at least periodically saturated with or covered by water. The water creates severe physiological problems for plants and animals that are not adapted for life in water or in saturated soil.

Type of feature:
Polygon

Purpose:
The purpose of this file is to calculate the percentage of wetland area in each sub basin.

Original Data Source:
Delaware Valley Regional Planning Commission (DVRPC)
Data creation year: 1981
Scale: 1:80000 roughly as indicated in the original metadata.
DVRPC converted this data from National Wetlands Inventory (NWI) data by U.S. Fish & Wildlife Service.
Data acquired by Center for Sustainable Communities in 2002.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
Shape file was clipped by Pennypack Watershed Area.
Some of the original fields (AREA and PERIMETER) were deleted because those were in MKS (Meter, kilogram, Second) unit. Instead a new field called AREA_SQM has been created to store AREA information in FPS (Foot, Pound, Second) unit.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 2

Field Name	Description
ATTRIBUTE	Wetland codes (34 unique codes in this database)
AREA_SQM	Area in square miles

No of Records: 180

Additional Information:
The code explanation was not given with the original data National Wetlands Inventory Mapping Code Description http://www.nwi.fws.gov/atx/atx.html does not have all the code listed.

Shape File Name: SSA (Sewer Service Area)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar, GIS Coordinator
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu
Date: 07/25/05

Description:

These polygons show the sewer service areas for the Pennypack Watershed. Original file only covers the suburban portion of the watershed. The southern portions, which is the Philadelphia portion is covered by the Philadelphia Water Dept was later added by the CSC.

Type of feature:
Polygon

Original Data Source:
Source: Delaware River Basin Commission (DRBC)
Year of Publication: 1996
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
The original shape file was clipped according to Pennypack Watershed boundary.
Philadelphia portion of the service area was added using union function of overlay analysis tools of ArcToolbox.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 1

Field Name	Description
SSA	The provider of Sewer Service for this area. NO DATA means there is no public sewer in this area.

No of Records: 14

Shape File Name: WSA (Water Service Area)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: Md Mahbubur R Meenar, GIS Coordinator
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: meenar@temple.edu
Date: 07/25/05

Description:
These polygons show the water service areas for the Pennypack Watershed. This file only covers the suburban portion of the watershed. The southern portions, which is the Philadelphia portion is covered by the Philadelphia Water Dept.

Type of feature:
Polygon

Original Data Source:
Source: Delaware River Basin Commission (DRBC)
Year of Publication: 1996
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
The original shape file was clipped according to Pennypack Watershed boundary.

Description of Fields of Attribute Table:
No of Fields (not including FID and Shape): 1

Field Name	Description
WSA	The provider of Water Service for this area. NO DATA means there is no public water service in this area.

No of Records: 11

Section 3: List of Database

49BASIN (49 Sub Basins of Pennypack Watershed)

Field Name	Field Type	Description
BASIN_ID	Short Integer	Sub Basin ID Created by Temple University

BIO (Biological Data)

FISH

Field Name	Field Type	Description
F_NO_SP	Double	Total Number of Fish Species
F_NO_BEN	Double	Number of benthic insectivorous species
F_NO_WAT	Double	Number of Water Column Species
F_NO_INT	Double	Number Of Intolerant/Sensitive Species
F_P_WHSK	Double	Percent White Sucker
F_P_GEN	Double	Percent Generalist
F_P_INSE	Double	Percent Insectivores
F_P_CARN	Double	Percent Top Carnivores
F_P_DIS	Double	Percent of individuals with disease and anomalies
F_P_DOM	Double	Percentage of dominant species
F_DEN	Double	Density
F_NO_IND	Double	Number Of Individuals
F_BIOM	Double	Biomass per square meter
F_MODIND	Double	Modified Index Of Well-Being
F_SWDI	Double	Shannon-Weiner Diversity Index (H')
F_NO_CYP	Double	No. Of Cyprinid Species
F_P_RES	Double	Percent Resident Species
F_P_EXOT	Double	Percent Introduced/Exotic Species
F_IBI	Double	Index of Biological Integrity1
F_BIO_IN	Double	Percentage representing the Biological Integrity of the Pennypack based on the Fish populations arrived at by dividing the IBI score by the max IBI score (50).
F_M_STAT	Text	PWD Monitoring Stations From which data for this basin was taken

HABITAT

Field Name	Field Type	Description
L_BANK	Double	Bank Stability (Left Bank)
R_BANK	Double	Bank Stability (Right Bank)
CH_ALT	Double	Channel Alteration
CH_FLOW	Double	Channel Flow Status
CH_SIN	Double	Channel Sinuosity
EMBED	Double	Embeddedness
EPIF_SUB	Double	Epifaunal substrate cover
RIF_FREQ	Double	Frequency of Riffles (or Bends)
POOL_SUB	Double	Pool Substrate Characterization
POOL_VAR	Double	Pool Variability
RIP_V_L	Double	Riparian Vegetative Zone Width (Left Bank)

RIP_V_R	Double	Riparian Vegetative Zone Width (Right Bank)
SED_DEP	Double	Sediment Deposition
VEG_P_L	Double	Vegetative Protection (Left Bank)
VEG_P_R	Double	Vegetative Protection (Right Bank)
VEL_DEPT	Double	Velocity/Depth Regime
H_M_STAT	Text	PWD Monitoring Stations from which data for this basin was taken

MICROINVERTEBRATE

Field Name	Field Type	Description
M_NO_SP	Integer	Number of Macroinvertebrate Species
M_HBI	Double	Hilsenhoff Biotic Index
M_P_DOM	Double	Percent of the Taxa that is the Dominant Taxa
M_D_TAX	Text	Dominant Taxa
M_P_FIL	Double	Percent of Filter/Collector Species
M_P_GATH	Double	Percent of Gatherer/Collector Species
M_P_SCR	Double	Percent of Scraper Species
M_P_SHR	Double	Percent of Shredder Species
M_P_MODT	Double	Percent of Moderately Tolerant Species
M_P_TOL	Double	Percent of Tolerant Species
M_P_INTO	Double	Percent of Intolerant Species
M_BIO_AS	Text	Biological Assessment of Stream based on the Macroinvertebrate Population from the PWD Reportix
M_BIO_IN	Double	Percentage representing the Biological Integrity of the Pennypack based on the Macroinvertebrate populations from the PWD Report1
M_M_STAT	Text	PWD Monitoring Stations From which data for this basin was taken

DEMOG (Census Block Group Level Demographic Data)

Field Name	Field Type	Description
POP_1990	Double	Sub-basin estimated population, 1990
HU_1990	Double	Sub-basin estimated number of housing units, 1990
AHHMI_89	Double	Sub-basin average household median income, 1989
POP_2000	Double	Sub-basin estimated population, 2000
HU_2000	Double	Sub-basin estimated number of housing units, 2000
AHHMI_99	Double	Sub-basin average household median income, 1999
PDENS90	Double	Sub-basin population density, 1990. Calculated as persons per square mile of residentially-classified land.
PDENS00	Double	Sub-basin population density, 2000. Calculated as persons per square mile of residentially-classified land.
HUDENS90	Double	Sub-basin housing unit density, 1990. Calculated as housing units per square mile of residentially-classified land.
HUDENS00	Double	Sub-basin housing unit density, 2000. Calculated as housing units per square mile of residentially-classified land.

FP_REL (Flood Plain Related)

Field Name	Field Type	Description
P_FP_100	Double	Percentage of Land Area within 100-year Floodplain
P_FP_500	Double	Percentage of Land Area within 500-year Floodplain
NBLFP100	Short Integer	Number of Buildings in 100 Year Floodplain
NBLFP500	Short Integer	Number of Buildings in 500 Year Floodplain

GEOL (Geology, Baseflow, and Soil)

Field Name	Field Type	Description
P_GEO_R1	Double	Percentage of Rock Type 1 Note: This code is created by CSC. There are 5 types of Rock formations. Roc Codes are generated as 1 to 5 and the information will be provided in separate lookup table.
P_GEO_R2	Double	Percentage of Rock Type 2
P_GEO_R3	Double	Percentage of Rock Type 3
P_GEO_R4	Double	Percentage of Rock Type 4
P_GEO_R5	Double	Percentage of Rock Type 5
P_SOIL_A	Double	Percentage of Soil Type 1 Note: This code is created by CSC. There are 98 Soil Types. Therefore, soil code will be inserted as 1 to 98. Soil information will be provided in separate lookup table
P_SOIL_B	Double	Percentage of Soil Type 2
P_SOIL_C	Double	Percentage of Soil Type 3
P_SOIL_D	Double	Percentage of Soil Type 4
A_MBF	Double	Amount of Median Base Flow in GPD/SQM Note: GPD= Gallon per day and SQM= Square Mile

LANDF (Land Features)

Field Name	Field Type	Description
P_IMP85	Double	Percent of sub-basin covered by impervious surface, 1985
P_IMP00	Double	Percent of sub-basin covered by impervious surface, 2000
FVC_85	Double	Sub-basin fractional vegetative coverage, 1985
FVC_00	Double	Sub-basin fractional vegetative coverage, 2000
P_CNP01	Double	Sub-basin percent canopy density, 2001
P_LC_11	Double	Percent of sub-basin land cover in Open Water, 2001
P_LC_21	Double	Percent of sub-basin land cover in Developed, Open Space, 2001
P_LC_22	Double	Percent of sub-basin land cover in Developed, Low Intensity, 2001
P_LC_23	Double	Percent of sub-basin land cover in Developed, Medium Intensity, 2001

P_LC_24	Double	Percent of sub-basin land cover in Developed, High Intensity, 2001
P_LC_31	Double	Percent of sub-basin land cover in Barren Land, 2001
P_LC_41	Double	Percent of sub-basin land cover in Deciduous Forest, 2001
P_LC_42	Double	Percent of sub-basin land cover in Evergreen Forest, 2001
P_LC_43	Double	Percent of sub-basin land cover in Mixed Forest, 2001
P_LC_81	Double	Percent of sub-basin land cover in Pasture/Hay, 2001
P_LC_82	Double	Percent of sub-basin land cover in Cultivated Crops, 2001
P_LC_90	Double	Percent of sub-basin land cover in Woody Wetlands, 2001
P_LC_95	Double	Percent of sub-basin land cover in Emergent Herbaceous Wetlands, 2001
P_LC_DEV	Double	Percent of sub-basin land cover “Developed” (sum of land cover codes 21, 22, 23, and 24)
P_LC_FOR	Double	Percent of sub-basin land cover “Forested” (sum of land cover codes 41, 42, 43)
P_LC_AG	Double	Percent of sub-basin land cover “Agriculture” (sum of land cover codes 81 and 82)
P_LC_WWL	Double	Percent of sub-basin land cover “Water or Wetlands” (Sum of land cover codes 11, 90 and 95)
P_LU00_01	Double	Percent of sub-basin land use in residential: single family detached, 2000
P_LU00_02	Double	Percent of sub-basin land use in residential: multi-family and row-homes, 2000
P_LU00_03	Double	Percent of sub-basin land use in manufacturing/light industrial, 2000
P_LU00_04	Double	Percent of sub-basin land use in transportation, 2000
P_LU00_05	Double	Percent of sub-basin land use in utility, 2000
P_LU00_06	Double	Percent of sub-basin land use in commercial, 2000
P_LU00_07	Double	Percent of sub-basin land use in community services, 2000
P_LU00_08	Double	Percent of sub-basin land use in military, 2000
P_LU00_09	Double	Percent of sub-basin land use in recreation, 2000
P_LU00_10	Double	Percent of sub-basin land use in agriculture, 2000
P_LU00_12	Double	Percent of sub-basin land use in wooded, 2000
P_LU00_13	Double	Percent of sub-basin land use in water, 2000
P_LU00_14	Double	Percent of sub-basin land use in vacant, 2000
P_LU00_15	Double	Percent of sub-basin land use in non-residential parking, 2000
P_LU95_01	Double	Percent of sub-basin land use in residential: single family detached, 1995
P_LU95_02	Double	Percent of sub-basin land use in residential: multi-family and row-homes, 1995
P_LU95_03	Double	Percent of sub-basin land use in manufacturing/light industrial, 1995
P_LU95_04	Double	Percent of sub-basin land use in transportation, 1995
P_LU95_05	Double	Percent of sub-basin land use in utility, 1995
P_LU95_06	Double	Percent of sub-basin land use in commercial, 1995

P_LU95_07	Double	Percent of sub-basin land use in community services, 1995
P_LU95_08	Double	Percent of sub-basin land use in military, 1995
P_LU95_09	Double	Percent of sub-basin land use in recreation, 1995
P_LU95_10	Double	Percent of sub-basin land use in agriculture, 1995
P_LU95_12	Double	Percent of sub-basin land use in wooded, 1995
P_LU95_13	Double	Percent of sub-basin land use in water, 1995
P_LU95_14	Double	Percent of sub-basin land use in vacant, 1995
P_LU95_15	Double	Percent of sub-basin land use in non-residential parking, 1995
P_LU90_01	Double	Percent of sub-basin land use in residential: single family detached, 1990
P_LU90_02	Double	Percent of sub-basin land use in residential: multi-family and row-homes, 1990
P_LU90_03	Double	Percent of sub-basin land use in manufacturing/light industrial, 1990
P_LU90_04	Double	Percent of sub-basin land use in transportation, 1990
P_LU90_05	Double	Percent of sub-basin land use in utility, 1990
P_LU90_06	Double	Percent of sub-basin land use in commercial, 1990
P_LU90_07	Double	Percent of sub-basin land use in community services, 1990
P_LU90_08	Double	Percent of sub-basin land use in military, 1990
P_LU90_09	Double	Percent of sub-basin land use in recreation, 1990
P_LU90_10	Double	Percent of sub-basin land use in agriculture, 1990
P_LU90_12	Double	Percent of sub-basin land use in wooded, 1990
P_LU90_13	Double	Percent of sub-basin land use in water, 1990
P_LU90_14	Double	Percent of sub-basin land use in vacant, 1990
P_LU90_15	Double	Percent of sub-basin land use in non-residential parking, 1990
SIFF_90	Double	Sub-basin Simpson Index of Forest Fragmentation, 1990
SIFF_00	Double	Sub-basin Simpson Index of Forest Fragmentation, 2000
MSIF_90	Double	Sub-basin mean shape index of forested patched, 1990
MSIF_00	Double	Sub-basin mean shape index of forested patched, 2000
ANNDF_90	Double	Sub-basin average nearest neighbor distance of forested patches, in feet, 1990
ANNDF_00	Double	Sub-basin average nearest neighbor distance of forested patches, in feet, 2000
PSL0_2	Double	Percentage of Slope 0-2
PSL2_5	Double	Percentage of Slope 2-5
PSL5_15	Double	Percentage of Slope 5-15
PSL15_25	Double	Percentage of Slope 15-25
PSLG25	Double	Percentage of Slope greater than 25
R_DEN_M	Double	Road Density in Mile per Square Mile

WTR_REL (Water Related)

Field Name	Field Type	Description
P_WL	Double	Percentage of Wet Land
N_BC	Short Integer	Number of Bridges and Culverts
N_DAM	Short Integer	Number of Dams
P_RB_1SL	Double	Percentage of Riparian Buffer Lacking on one side
P_RB_2SL	Double	Percentage of Riparian Buffer Lacking on both sides
P_RB_2SE	Double	Percentage of Riparian Buffer Existing on both sides
MPD	Double	Maximum Permitted Discharge in MGD Note: MGD= Million Gallon per Day
ALKAL	Double	Alkalinity (mg $CaCO_3$/L)
AMMON	Double	Ammonia (mg/L)
DIS_02	Double	Dissolved O_2 (mg/L)
E_COLI	Double	E. coli (colony forming units per 100mL)
FEC_COL	Double	Fecal Coliform (colony forming units per 100mL)
NITRATE	Double	Nitrate (mg/L)
NITRITE	Double	Nitrite (mg/L)
ORTHOPHO	Double	Orthophosphate (mg/L)
TOT_PHOS	Double	Total Phosphorus (mg/L)
CHLOR_A	Double	Chlorophyll A (mg/L)
A_TGWW	Double	Amount of Total Groundwater Withdrawal in MGD Note: MGD= Million Gallon per Day
CN_AWM	Double	Area Weighted Mean Curve Number for each Sub Basin for storm water runoff potential
L_STRM_M	Double	Length of Stream in Mile
PS_30FR	Double	Proportion of total Stream Length that has Road within 30 Feet
PS_100FR	Double	Proportion of total Stream Length that has Road within 100 Feet

SSA (Sewer Service Area)

Field Name	Field Type	Description
S_ABING	Double	The percentage of the basin served by the Abington Township STP.
S_BUCKS	Double	The percentage of the basin served by the Bucks County Water and Sewer Authority
S_DELC	Double	The percentage of the basin served by the Delcora
S_HORSH	Double	The percentage of the basin served by the Horsham Township Sewer Authority
S_UP_MOR	Double	The percentage of the basin served by the Upper Moreland - Hatboro Joint Authority
S_WARM	Double	The percentage of the basin served by the Warminster Township Municipal Authority
S_PWD	Double	The percentage of the basin served by the Philadelphia Water Dept.
S_NO_SERV	Double	The percentage of the basin not served by any sewer service

T_SSA	Double	The Percentage of the basin served by the Total Sewer Service Area

WSA (Water Service Area)

Field Name	Field Type	Description
W_HATBOR	Double	The percentage of the basin served by the Hatboro Water Authority
W_HORSHA	Double	The percentage of the basin served by the Horsham Township Water Authority
W_NWALES	Double	The percentage of the basin served by the North Wales Water Authority
W_PHLSUB	Double	The percentage of the basin served by the Philadelphia Suburban Water Company
W_UPPSTH	Double	The percentage of the basin served by the Upper Southampton Township Municipal Authority
W_WARMIN	Double	The percentage of the basin served by the Warminster Township Municipal Authority
W_WILGRO	Double	The percentage of the basin served by the Willow Grove USNAS
W_PWD	Double	The percentage of the basin served by the Philadelphia Water Dept.
T_WSA	Double	The Percentage of the basin served by the Total Water Service Area

Note: Any missing data, if text then it will be typed as NO DATA and if number then will be typed as -999.

Section 4: DBF File Metadata

Database Name: FISH (Fish Data for Pennypack Watershed)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: CSC, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu

Description:
Data describes the Fish species present at various sites and the water quality derived by analyzing these species.

Original Data Source:

Philadelphia Water Department (PWD)
Data creation year: 2002
This data was originally in point form and the attributes were ascribed to the basins that drain to these points. Following the twenty monitoring stations set by PWD, the original data was cleaned up and all of the categories were arranged by Dr. Peter Petraitis (ppetrait@sas.upenn.edu) of University of Pennsylvania.
Data acquired by CSC in 2004.

Actions Taken for Data Processing:
The data for twenty monitoring stations were transferred to the 49 sub basins by the following method. The data for each monitoring point was attributed to the basins upstream from the monitoring station and downstream from any other monitoring point. Major branches without a monitoring station were not attributed data.

Description of Fields:
No. of Fields: 21
No. of Records: 49

Field Name	Description
F_NO_SP	Total Number of Fish Species
F_NO_BEN	Number of benthic insectivorous species
F_NO_WAT	Number of Water Column Species
F_NO_INT	Number Of Intolerant/Sensitive Species
F_P_WHSK	Percent White Sucker
F_P_GEN	Percent Generalist
F_P_INSE	Percent Insectivores
F_P_CARN	Percent Top Carnivores
F_P_DIS	Percent of individuals with disease and anomalies
F_P_DOM	Percentage of dominant species

F_DEN	Density
F_NO_IND	Number Of Individuals
F_BIOM	Biomass per square meter
F_MODIND	Modified Index Of Well-Being
F_SWDI	Shannon-Weiner Diversity Index (H')
F_NO_CYP	Number of Cyprinid Species
F_P_RES	Percent of Resident Species
F_P_EXOT	Percent of Introduced/Exotic Species
F_IBI	The Index of Biological Integrity Score (IBI) from the PWD Reportx
F_BIO_IN	The IBI Score expressed as a percentage
F_M_STAT	PWD Monitoring Stations From which data for this basin was taken

Database Name: HABITAT (Habitat Data for Pennypack Watershed)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: CSC, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu
Description:
Habitat is the physical location or type of environment in which an organism or biological population lives or occurs. (http://www.biology- online.org/dictionary/habitat). This data describes the habitat present at various sites along the Pennypack Stream.

Original Data Source:
Philadelphia Water Department (PWD)
Data creation year: 2002
This data was originally in point form and the attributes were ascribe to the basins that drain to these points. Following the twenty monitoring stations set by PWD, the original data was cleaned up and all of the categories were arranged by Dr. Peter Petraitis (ppetrait@sas.upenn.edu) of the University of Pennsylvania.
Data acquired by CSC in 2004.

Actions Taken for Data Processing:
The data for twenty monitoring stations were collected from the 49 sub basins by attributing data for each monitoring point to the basin immediately upstream from the monitoring point.

Description of Fields:
No. of Fields: 17
No. of Records: 49

Field Name	Description
L_BANK	Bank Stability (Left Bank)

R_BANK	Bank Stability (Right Bank)
CH_ALT	Channel Alteration
CH_FLOW	Channel Flow Status
CH_SIN	Channel Sinuosity
EMBED	Embeddedness
EPIF_SUB	Epifaunal substrate cover
RIF_FREQ	Frequency of Riffles (or Bends)
POOL_SUB	Pool Substrate Characterization
POOL_VAR	Pool Variability
RIP_V_L	Riparian Vegetative Zone Width (Left Bank)
RIP_V_R	Riparian Vegetative Zone Width (Right Bank)
SED_DEP	Sediment Deposition
VEG_P_L	Vegetative Protection (Left Bank)
VEG_P_R	Vegetative Protection (Right Bank)
VEL_DEPT	Velocity/Depth Regime
H_M_STAT	PWD Monitoring Stations from which data for this basin was taken

Database Name: MACROINVERTEBRATES (Macroinvertebrates Data for Pennypack Watershed)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: CSC, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu

Description:
Data describes the Macroinvertebrates present at various sites and the water quality derived by analyzing these invertebrates. A Macroinvertebrate is an animal without a backbone in at least one stage of its life cycle, usually the nymph or larval stage. xi

Benthic macroinvertebrates such as insects, worms, and molluscs are the preferred group of aquatic organisms monitored in water quality assessment programs (Hellawell 1986) because: (1) they provide an extended temporal perspective (relative to traditional water samples that are collected periodically) because they have limited mobility and relatively long life spans (e.g., a few months for some chironomid midges to a year or more for some insects and molluscs); (2) the group has measurable responses to a wide variety of environmental changes and stresses; (3) they are an important link in the aquatic food web, converting plant and microbial matter into animal tissue that is then available to fish; (4) they are abundant; and (5) their responses can be analyzed statistically (Weber 1973). Thus, the presence or conspicuous absence of certain macroinvertebrate species at a site is a meaningful record of environmental conditions during the recent past, including ephemeral events that might be missed by assessment programs, which only rely on periodic sampling of water chemistry. Most stream ecosystems have relatively diverse macroinvertebrate assemblages with species from a

number of different orders [e.g., mayflies (Ephemeroptera), and caddisflies (Trichoptera), stoneflies (Plecoptera), beetles (Coleoptera), true flies (Diptera)]. Likewise, the common trophic groups (i.e., herbivores, detritivores, and predators) are represented by a number of different species. Various abiotic factors (e.g., hydrology, substrate, temperature, oxygen, and pH) and biotic factors (e.g., food quality and quantity, interactions with competitors or predators) have molded, through natural selection, a unique set of optimum environmental requirements for each species. These environmental requirements contribute significantly to the distribution and abundance of these organisms within and among natural stream ecosystems and influence their response to environmental perturbation. xii
Original Data Source:
Philadelphia Water Department (PWD)
Data creation year: 2002
This data was originally in point form and the attributes were attributed to the basins that drain to these points. Following to the twenty monitoring stations, as set by PWD, the original data was cleaned up and all of the categories were arranged by Dr. Peter Petraitis (ppetrait@sas.upenn.edu) of Philadelphia University, PA.
Data acquired by CSC in 2004.

Actions Taken for Data Processing:
The data for twenty monitoring stations were collected from the 49 sub basins by attributing data for each monitoring point to the basin immediately upstream from the monitoring point.

Description of Fields of Attribute Table:
No. of Fields: 14
No. of Records: 49

Field Name	Description
M_NO_SP	Number of Species
M_HBI	Hilsenhoff Biotic Index
M_P_DOM	Percent of the Taxa that is the Dominant Taxa
M_D_TAX	Dominant Taxa
M_P_FIL	Percent of Filter/Collector Species
M_P_GATH	Percent of Gatherer/Collector Species
M_P_SCR	Percent of Scraper Species
M_P_SHR	Percent of Shredder Species
M_P_MODT	Percent of Moderately Tolerant Species
M_P_TOL	Percent of Tolerant Species
M_P_INTO	Percent of Intolerant Species
M_BIO_AS	Biological Assessment of Stream based on the Macroinvertebrate Population from the PWD Report1
M_BIO_IN	Percentage representing the Biological Integrity of the Pennypack from the PWD Report1
M_M_STAT	PWD Monitoring Stations From which data for this basin was taken

Database Name: DEMOGRAPHY

Contact Information:
Name: Kurt Paulsen, Ph.D.
Organization: Center for Sustainable Communities, Temple University, PA

Email: kurt.paulsen@temple.edu
Date: 08-18-2005

Description:
Estimates of sub-basin population counts, housing units, median household income, population density and housing unit density

Purpose:
Describe human and population influences on watershed.

Original Data Source:
Data are from the United States Census Bureau. Shape files are from Census TIGER/Line Cartographic Boundary files, Census Block Groups for both 1990 and 2000. Census Data (SF3) for 2000 were downloaded from http://factfinder.census.gov. Census Data for 1990 (STF3) were accessed from CD-Roms.

Actions Taken for Data Processing:
Shape files: Data for both 1990 and 2000 are originally in unprojected Geographic (lat/lon) format. Shape files were reprojected into Pennsylvania State Plane Feet South (NAD83). Census Block Groups for Bucks, Montgomery and Philadelphia Counties were initially produced.

Block groups which had any portion of their area within the Pennypack Creek watershed were selected. For population and housing unit estimates, the percent of a Census Block Group within the Pennypack watershed and/or within subbasins were used to adjust figures. For example, if a Census Block Group has 10 percent of its area within the watershed, then 10 percent of its housing units and population are assumed to be located within the watershed. Similarly, if 10 percent of a block group is located in one sub-basin, then 10 percent of its population and housing figures were assigned to that sub-basin.

Data files: Data for both 1990 and 2000 were from the Census SF3 (Summary File 3). The following tables/variables were collected:

1990: P001001: Total Persons
P080A001: Median household income in 1989
H0010001: Total Housing Units

2000: P001001: Total Persons
P053001: Median household income in 1999
H001001: Total Housing Units

Description of Fields:
No. of Fields (not including FID and Shape): 10

Field Name	Description
POP_1990	Sub-basin estimated population, 1990
HU_1990	Sub-basin estimated number of housing units, 1990
AHHMI_89	Sub-basin average household median income, 1989
POP_2000	Sub-basin estimated population, 2000
HU_2000	Sub-basin estimated number of housing units, 2000

AHHMI_99	Sub-basin average household median income, 1999
PDENS90	Sub-basin population density, 1990. Calculated as persons per square mile of residentially-classified land.
PDENS00	Sub-basin population density, 2000. Calculated as persons per square mile of residentially-classified land.
HUDENS90	Sub-basin housing unit density, 1990. Calculated as housing units per square mile of residentially-classified land.
HUDENS00	Sub-basin housing unit density, 2000. Calculated as housing units per square mile of residentially-classified land.

No. of Records: 49

Additional Information:
Census Bureau estimates of median-household income use 1-year prior to each decennial census because the question asks respondents to report household income for the previous year. Note: data for income are in nominal (non-inflation adjusted) dollars.

Database Name: FP_REL (Floodplain Related)

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: Center for Sustainable Communities, Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu
Date: 08/02/2005

GENERAL INFORMATION:
No of fields: 4 (Excluding BASIN_ID3)
No of Records: 49

CATEGORY: FLOODPLAIN

Description:
The floodplain is an area of land that is normally dry but that will be under water during a flood. A 100-year flood is a flood with a 1% chance of happening within any given year. A 500-year flood is a flood with a 0.2% chance of happening within any given year. The Q3 Flood Data are derived from the Flood Insurance Rate Maps (FIRMS) published by the Federal Emergency Management Agency (FEMA). The file is in geographic projection and decimal degree coordinate system with a scale of 1:24000.

Purpose:
The purpose of this dataset is to calculate the percentages of areas inside 100 year and 500 year floodplains in each sub basin of Pennypack Creek Watershed Area.

Original Data Source:
Sources: FEMA
Year of Publication: 1996
Data acquired by CSC in 2003.

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[3] BASIN_ID is the key field that ties each record with 49 sub basin boundaries generated by CSC.

Actions Taken for Data Processing:
FEMA 100 year and 500 year floodplain data were converted in GIS shape file format. Data were clipped by Pennypack Watershed boundary. Percentages of areas inside 100 year and 500 year floodplains in each sub basin was calculated using Polygon in Polygon Analysis tool of Hawth's Analysis Tool for ArcGIS.

Description of Fields:

Field Name	Description
P_FP_100	Percentage of area of 100 year floodplain in each sub basin
P_FP_500	Percentage of area of 500 year floodplain in each sub basin

CATEGORY: BUILDINGS IN FLOODPLAIN

Description:
Buildings those would be inundated by flood at any given year over the every 100 or 500 years time period. Generally flood means a general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or of two or more properties[4].

Purpose:
The purpose of this dataset is to calculate the number of buildings/structures within the 100 year and 500 year floodplains in each sub basin of Pennypack Creek Watershed Area.

Original Data Source:
Sources: CSC / DVRPC.
Year of Publication: 2000
Data acquired by CSC in 2002.
Data digitized by CSC in 2005.

Actions Taken for Data Processing:
Building footprints were digitized using the DVRPC 2000 aerial/ortho photograph. Selection by location command of ArcGIS was used to select the buildings that are intersected by the 100 and 500 year floodplain. Centroids of the selection were calculated by each sub basin using Count Points in Polygons tool of Hawth's Analysis Tool for ArcGIS.

Description of Fields:

Field Name	Description
NBLFP100	Number of Buildings in 100 Year Floodplain
NBLFP500	Number of Buildings in 500 Year Floodplain

Database Name: GEOL (Geology, Base Flow, and Soil)

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: Center for Sustainable Communities, Temple University, PA

[4] Source: FEMA

Email: asmbari@temple.edu, meenar@temple.edu
Date: 08/02/2005
GENERAL INFORMATION:

No of fields: 9 (Excluding BASIN_ID5)
No of Records: 49

CATEGORY: GEOLOGY & BASE FLOW

Description:
Bed rock refers to the rock underlying other unconsolidated material, i.e. soil. This file displays the percentages of different types of generalized geology in each of the 49 sub basins of Pennypack Watershed Area. Each type reflects a designation of certain hydrologic properties.

Purpose:
Increased development in major parts of the Pennypack Creek Watershed has increased public, industrial, and commercial demand for water. Further withdrawals may reduce groundwater availability and stormflow. This database will help conduct any groundwater assessment for the Pennypack Watershed Area.

Original Data Source:
Sources: Philadelphia Water Department (PWD) and Delaware River Basin Commission (DRBC)
Year of Publication: 10/01/98 for DRBC data
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
The original files were collected and/or processed into GIS shape file format. The PWD shape file covers the geology of the watershed area inside Montgomery and Bucks Counties and DRBC shape file covers the watershed area inside Philadelphia County. These shape files are coded differently for different rock type. Following Dr. Jeffrey Featherstone's (Director, CSC) suggestion the DRBC rock type coding was taken as standard and these codes were incorporated in the PWD shape file. Once these files were merged together, the final shape file was clipped by Pennypack Watershed Area.

Using the Union tool of ArcToolBox, the sub basin shape file and the geology shape file were overlaid to combine attribute information of geology and 49 sub basins. From the output shape file, polygons with the same rock type in each sub basin were merged together using the Editor Toolbar. After merging, rock type areas in each sub basin were calculated. Finally, a Pivot Table was created and areas of all rock types were arranged as separate fields and Basin IDs were placed as rows.

The Pivot Table was joined with the original sub basin shape file attribute table (based on the common field – Basin ID) to get the area information for each sub basin. Percentages of areas of different types of rocks present in each sub basin were calculated. Finally, amount of Base Flow was calculated. This is the weighted average of Median Base Flow according to percentages of different type of rocks present in each sub basin.

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[5] BASIN_ID is the key field that ties each record with 49 sub basin boundaries generated by CSC.

Description of Fields:

Field Name	Description
P_GEO_R1	Percentage of area covered by Rock Type 1 (Crystalline Rock other than Diabase) in each sub basin
P_GEO_R2	Percentage of area covered by Rock Type 2 (Unconsolidated Sediments) in each sub basin
P_GEO_R3	Percentage of area covered by Rock Type 3 (Carbonate Rock) in each sub basin
P_GEO_R4	Percentage of area covered by Rock Type 4 (Sedimentary other than Carbonates) in each sub basin
P_GEO_R5	Percentage of area covered by Rock Type 5 (Diabase) in each sub basin
A_MBF	Amount of Base Flow. Weighted average of Median Base Flow according to percentages of different rock types present in each sub basin. Unit is GPD/SQM (Gallon per day per square mile).

Additional Information:
In order to get the contact information for the original metadata or any other relevant information from DRBC, please visit their web site at www.state.nj.us/drbc.

CATEGORY: SOIL

Description:
A hydrologic group is a group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that influence the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozenxiii. The soils are placed into four groups, A, B, C and D, and three dual classes, A/D, B/D, and C/D. According to the National Soil Survey Handbook of the Natural Resources Conservation Services, the definitions of the hydrologic soil classes are as follows:

A. (Low runoff potential). The soils have a high infiltration ratexiv even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmissionxv.

B. The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

C. The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.

D. (High runoff potential). The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

Dual hydrologic groups, A/D, B/D, and C/D, are given for certain wet soils that can be adequately drained. The first letter applies to the drained condition, the second to the undrained. Only soils that are rated D in their natural condition are assigned to dual classes.

Purpose:
This file might be used in planning watershed-protection and flood-prevention projects. Hydrologic groups are used in equations that estimate runoff from rainfall needed for solving hydrologic problems (NRCS web site, see end note I). The purpose of this data is to display the percentages of different types of hydrologic soil types present in each sub basin of the Pennypack Watershed area.

Original Data Source:
Sources: Natural Resources Conservation Services (NRCS) and Delaware River Basin Commission (DRBC)
Year of Publication: Unknown
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Soil data at the scale of 1:24,000 for Montgomery, Bucks, and Philadelphia Counties were collected from Soil Survey Geographic (SSURGO) Database of NRCS. Their other lower resolution dataset is called STATSGO, which is available at 1:250,000 scale and was not used. Other soil data from the Philadelphia Water Department (PWD) was available at a much smaller resolution and was not used.

1. The following steps were taken by the Department of Civil and Environmental Engineering at Temple University, PA.
Soil data (in GIS shape file format) for each county was clipped to the region belonging to the watershed.
Information for soil groups A, B, C, and D was added to the clipped files. This information was originally available as database files and was imported in GIS as dbf files. Some soil types lacked a HYDGRP (hydrologic group) value or had multiple HYDGRP values were edited. The attribute MUSYM (Map Unit Symbol) was used to join the soil type shape files. MUSYM is a soil code that changes from county to county. Hence a single dbf file could not be used for all three counties.

All three clipped shape files were then appended or merged to create the final soil shape file.

2. Using the Intersect tool of ArcToolBox, the soil shape file and the Pennypack Watershed sub basin shape file were intersected to combine the attribute information of 49 sub basins and soil. From the intersected shape file, polygons with the same Basin ID and hydrologic soil code (HYDGRP) were combined using the Dissolve tool of ArcToolBox. After dissolving, the areas for each soil type in each sub basin were calculated. Finally, a Pivot Table was created and areas of all the soil types were arranged as separate fields and Basin IDs were placed as rows.

3. The Pivot Table was joined with the original sub basin shape file attribute table (based on the common field – Basin ID) to get the area information for each sub basin.

4. Percentages of areas of different types of soil present in each sub basin were calculated.

Description of Fields:

Field Name	Description
P_SOIL_B	Percentage of areas of hydrologic soil type B in each sub basin
P_SOIL_C	Percentage of areas of hydrologic soil type C in each sub basin
P_SOIL_D	Percentage of areas of hydrologic soil type D in each sub basin

Additional Information:
In order to get the contact information for the original metadata or any other relevant information from NRCS, please visit their web site at http://www.nrcs.usda.gov/ or NRCS Soils web site at http://soils.usda.gov/.

Database Name: LANDF (Pennypack Land Features)

Contact Information:
Name: Kurt Paulsen, Ph.D.
Organization: Temple University, Center for Sustainable Communities
Email: kurt.paulsen@temple.edu
Date: 08-16-2005

GENERAL INFORMATION:
No of fields: 76 (Excluding BASIN_ID6)
No of Records: 49

CATEGORY: IMPERVIOUS SURFACE

Description:
Estimate of the percentage that a sub-basin is covered by impervious surfaces. Impervious surfaces were estimated based on satellite imagery.

Purpose:
"Impervious cover is an important indicator of watershed health… [and] is a critically important variable in most hydrologic and water quality models used to analyze urban watersheds." (Center for Watershed Protection: Impervious Cover and Land Use in the Chesapeake Bay Watershed. January 2001, p. iii)

Original Data Source:
Downloaded from Pennsylvania Spatial Data Archive (www.pasda.psu.edu). Data created by Dr. Toby Carlson, Pennsylvania State University Department of Meteorology.
Title: Impervious surface area for Southeast Pennsylvania, 2000
Title: Impervious surface area for Southeast Pennsylvania, 1985

Full metadata online at:
http://www.pasda.psu.edu/documents.cgi/isa_pa/pa2000isaa_se.xml
http://www.pasda.psu.edu/documents.cgi/isa_pa/pa1985isaa_se.xml

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[6] BASIN_ID is the key field that ties each record with 49 sub basin boundaries generated by CSC.

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD27) and reprojected into Pennsylvania State Plane Feet South (NAD83).
Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields:

Field Name	Description
P_IMP85	Percent of sub-basin covered by impervious surface, 1985
P_IMP00	Percent of sub-basin covered by impervious surface, 2000

Additional Information:
Accuracy of original satellite imagery classification was verified visually using high-resolution digital orthophotography available from Delaware Valley Regional Planning Commission. A comparison of the Impervious Surface layer available from the USGS National Land Cover Database and the Impervious Surface coverage from Dr. Toby Carlson at Penn State with the digital orthophotography revealed that the Penn State data was of superior quality and higher resolution, and hence was used in this analysis.

CATEGORY: VEGETATIVE COVERAGE

Description:
Estimate of the percentage that a sub-basin is covered by vegetation. Vegetative coverage was estimated based on satellite imagery.

Purpose:
Vegetation serves many important ecological functions related to species habitat and water quality. Fractional vegetation data is a biophysical variable that describes the percent of vegetation covering the area of a raster cell. Fractional vegetation is used as input to hydrologic, meteorologic and plant growth models. Hydrologically, plant cover reduces the amount and velocity of rainfall hitting the surface, thus reducing erosional forces. Plant cover also intercepts sun light reducing thermal emission from the soil surface.

Original Data Source:
Downloaded from Pennsylvania Spatial Data Archive (www.pasda.psu.edu). Data created by Dr. Toby Carlson, Pennsylvania State University Department of Meteorology.
Title: Fractional Vegetation Cover for Southeast Pennsylvania, 2000
Title: Fractional Vegetation Cover for Southeast Pennsylvania, 1985

Full Metadata online at:
http://www.pasda.psu.edu/documents.cgi/isa_pa/pa2000fvca_se.xml
http://www.pasda.psu.edu/documents.cgi/isa_pa/pa1985fvca_se.xml

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD27) and reprojected into Pennsylvania State Plane Feet South (NAD83).
Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields:

Field Name	Description
FVC_85	Sub-basin fractional vegetative coverage, 1985
FVC_00	Sub-basin fractional vegetative coverage, 2000

Additional Information:
Original estimates of pixel vegetative coverage by Dr. Toby Carlson were based on the NDVI (Normalized Difference Vegetation Index) method. Fractional vegetative coverage, the percent of a pixel covered by vegetation (where zero is bare soil and one is dense vegetation) is the NDVI squared.

CATEGORY: TREE CANOPY DENSITY

Description:
Estimates of tree canopy density for each sub-basin. Estimates were based on satellite imagery.

Purpose:
Land cover and land use maps designate areas as “forested” but do not estimate canopy density. Additionally, tree canopy coverage may occur in pixels not classified as “forested” in land cover or land use classifications. Tree canopy cover data is useful in a number of ecological and hydrological models.

Original Data Source:
National Land Cover Database Zone 60 Tree Canopy Layer. A product of the United States Geological Survey (USGS). Data were extracted from http://seamless.usgs.gov web server. Data server allows user to identify geographic coordinates for downloading files. Data were extracted based on Pennypack Creek watershed boundaries.

Original Citation Details:
References: Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing (in press).

Huang, C., L. Yang, B. Wylie, and C. Homer, 2001. A strategy for estimating tree canopy density using Landsat 7 ETM+ and high resolution images over large areas. In: Third International Conference on Geospatial Information in Agriculture and Forestry; November 5-7, 2001; Denver, Colorado. CD-ROM, 1 disk.

The National Land Cover Database 2001 land cover layer for mapping zone 60 was produced through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium. The MRLC Consortium is a partnership of federal agencies (www.mrlc.gov) that consist of the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), the Forest Service (USFS), the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), the Bureau of Land Management (BLM) and the USDA Natural Resources Conservation Service (NRCS). One of the primary goals of the project is to generate a current, consistent, seamless and accurate National Land Cover Database (NLCD) circa 2001 for the United States at medium spatial resolution. For a detailed definition and discussion on MRLC and the NLCD 2001 products, refer to Homer et al. (2003) and <http://www.mrlc.gov/mrlc2k.asp>.

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD83) and subsequently reprojected into Pennsylvania State Plane Feet South (NAD83).
Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields:

Field Name	Description
P_CNP01	Sub-basin percent canopy density, 2001

Additional Information:
Detailed accuracy assessment of the tree-canopy density estimation algorithm is contained in: Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing (in press).

CATEGORY: LAND COVER

Description:
Estimates of percent of sub-basin in various land cover classes. Estimates are based on satellite imagery.

Purpose:
Detailed description of the land cover characteristics of each sub-basin.

Original Data Source:
National Land Cover Database Zone 60 Land Cover Layer. A product of the United States Geological Survey (USGS). Data were extracted from http://seamless.usgs.gov web server. Data server allows user to identify geographic coordinates for downloading files. Data were extracted based on Pennypack Creek watershed boundaries.

Original Citation Details:
References: Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing (in press).

The National Land Cover Database 2001 land cover layer for mapping zone 60 was produced through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium. The MRLC Consortium is a partnership of federal agencies (www.mrlc.gov), consisting of the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA) Forest Service (USFS), the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), the Bureau of Land Management (BLM) and the USDA Natural Resources Conservation Service (NRCS). One of the primary goals of the project is to generate a current, consistent, seamless, and accurate National Land cover Database (NLCD) circa 2001 for the United States at medium spatial resolution. For a detailed definition and discussion on MRLC and the NLCD 2001 products, refer to Homer et al. (2003) and <http://www.mrlc.gov/mrlc2k.asp>.

Actions Taken for Data Processing:
Data were originally projected in Albers Conical Equal Area (NAD83) and subsequently reprojected into Pennsylvania State Plane Feet South (NAD83). Data were then clipped to the boundary of the Pennypack Creek watershed using Hawth's Tool: Clip Raster by Polygon.

Description of Fields:

Field Name	Description
P_LC_11	Percent of sub-basin land cover in Open Water, 2001
P_LC_21	Percent of sub-basin land cover in Developed, Open Space, 2001
P_LC_22	Percent of sub-basin land cover in Developed, Low Intensity, 2001
P_LC_23	Percent of sub-basin land cover in Developed, Medium Intensity, 2001
P_LC_24	Percent of sub-basin land cover in Developed, High Intensity, 2001
P_LC_31	Percent of sub-basin land cover in Barren Land, 2001
P_LC_41	Percent of sub-basin land cover in Deciduous Forest, 2001
P_LC_42	Percent of sub-basin land cover in Evergreen Forest, 2001
P_LC_43	Percent of sub-basin land cover in Mixed Forest, 2001
P_LC_81	Percent of sub-basin land cover in Pasture/Hay, 2001
P_LC_82	Percent of sub-basin land cover in Cultivated Crops, 2001
P_LC_90	Percent of sub-basin land cover in Woody Wetlands, 2001
P_LC_95	Percent of sub-basin land cover in Emergent Herbaceous Wetlands, 2001
P_LC_DEV	Percent of sub-basin land cover "Developed" (sum of land cover codes 21, 22, 23, and 24)
P_LC_FOR	Percent of sub-basin land cover "Forested" (sum of land cover codes 41, 42, 43)
P_LC_AG	Percent of sub-basin land cover "Agriculture" (sum of land cover codes 81 and 82)
P_LC_WWL	Percent of sub-basin land cover "Water or Wetlands" (Sum of land cover codes 11, 90 and 95)

Additional information:
Land Cover Codes and Explanations, from National Land Cover Database:

11. Open Water – All areas of open water, generally with less than 25% cover of vegetation or soil.
21. Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.

23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
24. Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.
31. Barren Land (Rock/Sand/Clay) - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
41. Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
42. Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
43. Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
82. Cultivated Crops - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
90. Woody Wetlands - Areas where forest or scrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95. Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

CATEGORY: LAND USE

Description:
These are estimates of the percent of sub-basin land use distribution for 1990, 1995 and 2000.

Purpose:
Document and describe land use patterns and land use change in the Pennypack Creek watershed.

Original Data Source:
DVRPC Land Use Digital Data for 1990, 1995 and 2000

Actions Taken for Data Processing:
Data were originally projected in UTM Zone 18N (NAD83) and subsequently reprojected into Pennsylvania State Plane Feet South (NAD83).
Data were clipped to Pennypack Creek watershed boundary.

Description of Fields:

Field Name	Description
P_LU00_01	Percent of sub-basin land use in residential: single family detached, 2000
P_LU00_02	Percent of sub-basin land use in residential: multi-family and row-homes, 2000
P_LU00_03	Percent of sub-basin land use in manufacturing/light industrial, 2000
P_LU00_04	Percent of sub-basin land use in transportation, 2000
P_LU00_05	Percent of sub-basin land use in utility, 2000
P_LU00_06	Percent of sub-basin land use in commercial, 2000
P_LU00_07	Percent of sub-basin land use in community services, 2000
P_LU00_08	Percent of sub-basin land use in military, 2000
P_LU00_09	Percent of sub-basin land use in recreation, 2000
P_LU00_10	Percent of sub-basin land use in agriculture, 2000
P_LU00_12	Percent of sub-basin land use in wooded, 2000
P_LU00_13	Percent of sub-basin land use in water, 2000
P_LU00_14	Percent of sub-basin land use in vacant, 2000
P_LU00_15	Percent of sub-basin land use in non-residential parking, 2000
P_LU95_01	Percent of sub-basin land use in residential: single family detached, 1995
P_LU95_02	Percent of sub-basin land use in residential: multi-family and row-homes, 1995
P_LU95_03	Percent of sub-basin land use in manufacturing/light industrial, 1995
P_LU95_04	Percent of sub-basin land use in transportation, 1995
P_LU95_05	Percent of sub-basin land use in utility, 1995
P_LU95_06	Percent of sub-basin land use in commercial, 1995
P_LU95_07	Percent of sub-basin land use in community services, 1995
P_LU95_08	Percent of sub-basin land use in military, 1995
P_LU95_09	Percent of sub-basin land use in recreation, 1995
P_LU95_10	Percent of sub-basin land use in agriculture, 1995
P_LU95_12	Percent of sub-basin land use in wooded, 1995
P_LU95_13	Percent of sub-basin land use in water, 1995
P_LU95_14	Percent of sub-basin land use in vacant, 1995
P_LU95_15	Percent of sub-basin land use in non-residential parking, 1995
P_LU90_01	Percent of sub-basin land use in residential: single family detached, 1990
P_LU90_02	Percent of sub-basin land use in residential: multi-family and row-homes, 1990
P_LU90_03	Percent of sub-basin land use in manufacturing/light industrial, 1990
P_LU90_04	Percent of sub-basin land use in transportation, 1990
P_LU90_05	Percent of sub-basin land use in utility, 1990
P_LU90_06	Percent of sub-basin land use in commercial, 1990
P_LU90_07	Percent of sub-basin land use in community services, 1990
P_LU90_08	Percent of sub-basin land use in military, 1990
P_LU90_09	Percent of sub-basin land use in recreation, 1990
P_LU90_10	Percent of sub-basin land use in agriculture, 1990
P_LU90_12	Percent of sub-basin land use in wooded, 1990
P_LU90_13	Percent of sub-basin land use in water, 1990
P_LU90_14	Percent of sub-basin land use in vacant, 1990

P_LU90_15	Percent of sub-basin land use in non-residential parking, 1990

Additional Information:
Land use code 01: Single family includes mobile homes
Land use code 02: Multi-family and row-homes includes associated parking.
Land use code 08: Military includes associated parking
Land use code 15: Non-residential parking includes parking associated with: Manufacturing, utility, commercial, community services and recreation

CATEGORY: FOREST FRAGMENTATION

Description:
Calculations of various metrics to describe forest fragmentation within the watershed

Purpose:
Document and describe forest fragmentation patterns in the Pennypack Creek watershed. Forest fragmentation is an important indicator of ecosystem health, landscape integrity and has played an important role in ReVA analyses.

Original Data Source:
DVRPC Land Use Digital Data for 1990, 1995 and 2000. For this analysis, the processed Pennypack land use files for 1990 and 2000 were used. Detailed calculations below.

Actions Taken for Data Processing:
Calculations of the Simpson Index of Forest Fragmentation and of the Shape Index were performed using the LandUseAnalysis Wizard, a landscape analysis extenstion for ArcGIS 8.3, written by Dr. Kurt Paulsen.
Calculations of Nearest Neighbor distance were performed utilizing Hawth's tools: Distance Between Points (within layer)

Description of Fields:

Field Name	Description
SIFF_90	Sub-basin Simpson Index of Forest Fragmentation, 1990
SIFF_00	Sub-basin Simpson Index of Forest Fragmentation, 2000
MSIF_90	Sub-basin mean shape index of forested patched, 1990
MSIF_00	Sub-basin mean shape index of forested patched, 2000
ANNDF_90	Sub-basin average nearest neighbor distance of forested patches, in feet, 1990
ANNDF_00	Sub-basin average nearest neighbor distance of forested patches, in feet, 2000

Additional Information:
Simpson Index of Forest Fragmentation:

The Simpson Fragmentation index is patch-size and scale independent measure of fragmentation, based on entropy theory. The "intuitive" interpretation of this index is: what percent "fragmented" is a land use class. The index is:

$$SimpsonFragmentationIndex = 1 - \frac{\sum_{i=1}^{n} Area^2}{\left(\sum_{i=1}^{n} Area\right)^2}$$

Where i=1…..n indexes the number of patches of a certain land use class within a defined area (here, forested patches within a sub-basin), and area indicates the calculated area of each forest patch. Similar to other entropy measures, the Simpson Fragmentation index is 1 minus the sum of squares over the square of sums. The index is defined to range from 0 to 1 with 0 indicating perfect consolidation (only one patch of forest in a sub-basin) and 1 indicating perfect fragmentation. Higher numbers indicate a higher percentage of fragmentation. The calculation results in one fragmentation for each sub-basin for each year. Note that the calculation is based on area and not on the distance between forested patches.

Shape Index:
The shape index is also a measure of fragmentation with a particular emphasis on patch-shape morphology. Patch shape is a critical measure of ecological integrity and species habitat, with some applications to watershed analysis. Generally speaking, the more "square" is a patch of forest, the less "edge" effect and the greater "core" area. Greater core area is associated with greater species diversity and with improved ecological function.

The ReVA Mid-Atlantic assessment presented measures of watershed forest habitat shape in terms of edge and interior metrics. The Shape Index incorporates both edge and interior concepts, and makes use of the higher-resolution vector land use data available for this watershed. The shape index measures the deviation of a patch of land from a perfectly square patch and is given by:

$$PatchShapeIndex_i = \frac{.25 * Perimeter_i}{\sqrt{Area_i}}$$

That is, for each patch "i" the Shape Index measures its deviation from a perfect square. The Shape Index equals 1 when the patch is a square, and increases with increasing shape complexity. For each subbasin, the measure reported is the mean (average) shape index for all forested patches within the sub-basin.

Nearest-Neighbor Distance:
The distance between patches of forest is an additional indicator of fragmentation. When distinct patches of forest are further apart, there is less ecological integrity. For each unique patch of forested land within the Pennypack watershed, the distance to the nearest forest patch is calculated (in feet.) These values are then averaged over each sub-basin.

CATEGORY: SLOPE

Description:
This shape file has five classifications of slope values. The classifications are 0-2%, 2-5%, 5-15%, 15-25% and more than 25%.

Purpose:
This slope information will help to determine the areas suitable for development within the watershed.

Original Data Source:
The slope data was derived from a Digital Elevation Model created for the Center for Sustainable Communities in 2004.

Actions Taken for Data Processing:
Slope file was generated using 50 feet pixel resolution because of the ArcGIS 9 inability to convert 2 feet pixel resolution DEM (Digital Elevation Model) to slope. Spatial Analyst extension was used to derive the slope. After that this file was reclassified with percentage classification determined by Professor Kurt Paulsen and Mary Myers from Temple University. This reclassified grid file was converted into a shape file and later intersected with the sub basin file and dissolved according to the classification code. Simultaneously area for the classified slope area was calculated. All of these are done using a model developed by ASM Bari, GIS coordinator or CSC, Temple University. After that pivot table functionality of ArcGIS was used to determine the percentage slope for each category for each sub basin.

Description of Fields:

Field Name	Description
PSL0_2	Percentage of Slope 0-2
PSL2_5	Percentage of Slope 2-5
PSL5_15	Percentage of Slope 5-15
PSL15_25	Percentage of Slope 15-25
PSLG25	Percentage of Slope greater than 25

CATEGORY: ROAD DENSITY

Description:
Road density is the average total road length per unit of landscape. Many ecological phenomena, from wildlife to flooding to biodiversity are related to road density.[7]

Purpose:
To determine the impacts of the road network on the Watershed.

Original Data Source:
Road file from the DVRPC was used to calculate the road density (2000/2005).

Actions Taken for Data Processing:
Sum Line Lengths in Polygon functionality of Hawth's tools was used to determine the road length by sub basin.
After that, it was divided by total area by each sub basin to determine the density.

Description of Field:

[7] Forman, Richard, et al. Road Ecology: Science and Solutions. Island Press: 2003

Field Name	Description
R_DEN_M	Road Density in Mile per Square Mile

Database Name: WTR_REL (Water Related Data for Pennypack Watershed)

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu
Date: 7/22/2005

GENERAL INFORMATION:

No of fields: 23 (Excluding BASIN_ID[8])
No of Records: 49

CATEGORY: WETLAND

Description:
Wetlands are land areas seasonally or permanently waterlogged by either fresh or salt water. These include lakes, rivers, estuaries and freshwater marshes. Wetlands are areas where water saturation is the dominant factor that determines the nature of soil development and the types of plant and animal communities living in the soil and on its surface. Most wetlands contain soil or substrate that is at least periodically saturated with or covered by water. The water creates severe physiological problems for plants and animals that are not adapted for life in water or in saturated soil.

Purpose:
The purpose of this data is to calculate the percentage of wetland area in each sub basin.

Original Data Source:
Delaware Valley Regional Planning Commission (DVRPC)
The data was created in 1981.
Scale: 1:80,000 roughly, as indicated in the original metadata.
DVRPC converted this data from National Wetlands Inventory (NWI) data by U.S. Fish & Wildlife Service.
Data acquired by CSC in 2002.

Actions Taken for Data Processing:
Original data was available in GIS shape file format. The shape file was clipped by Pennypack Watershed Area.
From the attribute table, some of the original fields (AREA and PERIMETER) were deleted, because those were in MKS (Meter, kilogram, Second) unit. Instead, a new field called AREA_SQM has been created to store AREA information in FPS (Foot, Pound, Second) unit.

[8] BASIN_ID is the key field that ties each record with 49 sub basin boundaries generated by CSC.

Using Polygon in Polygon tool of Hawth's Analysis Tool for ArcGIS, areas of wetland in each sub basin (49 in total) were calculated in a new shape file. A new dbf (database) file was exported from the shape file. The dbf file was joined with sub basin file in order to get the areas of each sub basin. Percentages of areas of wetland in each sub basin were calculated.

Description of Fields:

Field Name	Description
P_WL	Percentages of areas of wetland in each sub basin

Additional Information:
The code explanation was not given with the original data. The National Wetlands Inventory Mapping Code Description at http://www.nwi.fws.gov/atx/atx.html does not have all the code listed.

CATEGORY: BRIDGES & CULVERTS

Description:
A bridge is a structure built to span a gorge, valley, road, railroad track, river or any other physical obstacle. A culvert is a closed conduit built to convey surface drainage water under a roadway or other impediment.

Purpose:
The purpose of this data is to determine the number of culverts and bridges in each sub basin. Points were generated at the intersections of road and stream centerlines.

Original Data Source:
Data originated at the CSC.
Aerial images (2000) street centerline file source: DVRPC
Stream centerline file source: CSC

Actions Taken for Data Processing:
Input GIS shape files were street centerline and stream centerline of Pennypack Watershed boundary. Hawth's Analysis Tool for ArcGIS was used to generate the intersection points of stream centerlines and street centerlines. The tool's name is Intersect Lines (Make Points). Once the points were generated, random quality checking was done with reference to DVRPC 2000 aerial images. No field verification could be made because of time constraint. The other tool used from Hawth's Analysis Tool was Count Points in Polygons in order to get the number of bridges and culverts in each sub basin.

Description of Fields:

Field Name	Description
N_BC	The number of bridges and culverts in the sub basin

CATEGORY: DAMS

Description:

A dam is a structure that impounds and stores water in a reservoir, making it available for future use. The dams indicated here are line files, with two points on either side of the waterway each dam impedes.

Purpose:
The purpose of this data is to show the number of dams within each subdivision.

Original Data Source:
Philadelphia Water Department.
Data creation year: 1999
Data acquired by CSC in 2002.

Actions Taken for Data Processing:
The original shape file was clipped by Pennypack Watershed Area. The sub basin boundary shape file was overlaid on top of Dam shape file. No of dams present in each sub basin was counted and recorded in the database file.

Description of Fields:

Field Name	Description
N_DAM	No of dams in each sub basin

CATEGORY: RIPARIAN BUFFER

Description:
A Riparian Buffer is a zone of protection made up of trees and other vegetation that grow along the banks of a waterway. Riparian Buffers help keep a stream healthy by reducing stream bank erosion and acting as a natural soil filterxvi.

The Philadelphia Water Department (PWD) classified the forest buffer according to a fifty foot standard, and digitized sections of the stream bank lacking a forest buffer using aerial photography taken in 2000 and provided by the Delaware Valley Regional Planning Commission. The term "Lacking Forest Buffer" is defined as a stream bank with less than fifty foot wide layer of forest cover and less than 50% canopy closure. Where the stream bank appeared to be lacking a forest buffer on both sides, the section was classified as such. Otherwise, each side of the creek was treated separately. Larger pond or lake areas that result from the damming of the main stem creek or major tributary were assessed; small water bodies, such as man-made farm ponds, were not.

Purpose:
The purpose of this data is to identify stream banks within Pennypack Watershed Area lacking riparian forest buffers.

Original Data Source:
Source: Heritage Conservancy
Year of Publication: 2002 (Data created from 2000 aerial photography. Field checks performed in 2002)
Data acquired by CSC in 2003.

Actions Taken for Data Processing:

In order to calculate the percentage of streams with Riparian Buffers in each sub basin, knowing the total length of each stream and the length of stream segments lacking Riparian Buffers on one side or both sides was essential. The original Riparian Buffer assessment data was created for the banks, but not for the stream, and creating Riparian Buffer assessment data for the stream itself was beyond the scope of this project. The solution was to calculate the percentages by comparing the length of the banks to the length of the stream. Below are the major data processing steps:

The original file was available in GIS shape file format and the feature type was line. In the attribute table, two fields were created from the original field providing information about a lack of buffer on one or both sides. Data was rearranged according to the 49 sub basins. To accomplish this, Sum Length of Lines in Polygons tool from Hawth's Analysis Tool for ArcGIS was used. Using this tool, an extension of ArcMap designed for spatial analysis, the line feature was clipped for each of the 49 sub basins and the total sum of length for the clipped lines was added as a value in a new field in the attribute table. Total length of streams in each sub basin was added in a new field. Percentages were calculated.

Description of Fields:

Field Name	Description
P_RB_1SL	Percentage of stream lacking Riparian Buffer on one side (in mile)
P_RB_2SL	Percentage of stream lacking Riparian Buffer on both sides (in mile)
P_RB_2SE	Percentage of stream having Riparian Buffer on both sides (in mile)

Additional Information:
Heritage Conservancy has published the original Riparian Buffer Status shape file for Southeastern Pennsylvania region. Contact information for Heritage Conservancy:
Heritage Conservancy
85 Old Dublin Pike
Doylestown, Pa 18901
Ph: 215-345-7020
Fax: 215-345-4328
www.heritageconservancy.org

CATEGORY: DISCHARGES AND WITHDRAWALS

Description:
This data indicates the amount of groundwater withdrawn in each sub basin on an average daily basis in millions of gallons per day, as well as the amount of water released back into streams in each sub basin on an average daily basis in millions of gallons per day.

Purpose:
The purpose of this data is to gain a better picture of the water balance in each of the sub basins.

Original Data Source:
Delaware River Basin Commission (DRBC)
Data creation year: 1996
This data was originally in point form and the attributes were attributed to sub basins.

Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Originally, the data was connected to points indicating the locations of withdrawals and discharges. This data was then transferred to the 49 sub basins by means of attributing each point to the basin the point lies within. If there was more than one point in a basin, the values for those points were summed and that sum was attributed to the basin.

Description of Fields:

Field Name	Description
A_TGWW	Ground Water Withdrawals (Million Gallons Per Day)
MPD	Discharges into Stream (Million Gallons Per Day)

CATEGORY: CURVE NUMBER

Description:
The Curve Number or 'CN' is a hydrologic constant factor used to measure the storm water runoff potential for drainage area or sub basin. The CN is a function of the soil and landuse of a drainage basin. Therefore, estimation of a CN requires processing of the soil and landuse data based on unique soil types and unique land use categories within the drainage basin boundaries. This CN index was developed by the Soil Conservation Service (SCS), which is now called the Natural Resource Conservation Service (NRCS). 9

Purpose:
The purpose of this data is to map the storm water runoff potential for the sub basin.

Original Data Source:
Sources: Natural Resources Conservation Services (NRCS), Delaware River Basin Commission (DRBC), and Delaware Valley Regional Planning Commission (DVRPC).
Year of Publication: 2000 for Landuse, unknown for Soil
Data acquired by CSC in 2003/2005.

Actions Taken for Data Processing:
Soil data and Landuse data (in GIS shape file format) for each county was clipped to the region belonging to the watershed.
An index of Runoff Curve Numbers for Urban areas for each hydrologic soil group and Landuse type was developed by modifying the parameters developed by NRCS (NRCS SCS TR-55). The Anderson Landuse Classification type was associated with similar Landuse type.
Intersect function of ArcToolbox was used to combine the Soil and Landuse GIS data so that the attribute table of this new data will have a Soil group code for each Landuse category. Similar Landuse category and Soil group was dissolved to minimize the geoprocessing type of the ArcGIS software. ArcCN-Runoff extension developed by Min-Lang Huang and Xiaoyong Zhan (Kansas Geological Survey, The University of Kansas) was downloaded from the ESRI web site to calculate the Curve Number. Area weighted mean value of CN was then calculated for each sub basin by using Polygon in Polygon

[9] Source: United States Department of Agriculture (USDA), Natural Resource Conservation Service Website (http://www.nrcs.usda.gov/), last accessed on August 5, 2005.

Analysis of Hawth's Tools. This tool is a freeware and can be downloaded from http://www.spatialecology.com/htools/digxy.php .

Description of Fields:

Field Name	Description
CN_AWM	Area Weighted Mean Curve Number for each Sub Basin for storm water runoff potential

CATEGORY: STREAM LENGTH

Purpose:
The purpose of this data is to calculate the length, in miles, of stream centerlines in each sub basin. There are two additional fields: Proportion of total stream length that has road within thirty feet and proportion of total stream length that has road within one hundred feet.

Original Data Source:
Data originated at the CSC.

Actions Taken for Data Processing:
In order to find out the stream length, Sum Length of Lines in Polygons tool from Hawth's Analysis Tool for ArcGIS was used. In order to get the proportion of total stream length that has roads within 30 feet and 100 feet, a buffer of 30 feet and a buffer of 100ft around the streets were drawn. Then the stream was clipped and the length of stream was calculated by each sub basin using Sum Length of Lines in Polygons tool. After that the proportion of stream length was calculated by dividing the clipped stream length with the total stream length for each sub basin.

Description of Fields:

Field Name	Description
L_STRM_M	Length of stream in miles
PS_30FR	Proportion of total stream length that has road within 30 feet
PS_100FR	Proportion of total stream length that has road within 100 feet

CATEGORY: EFFLUENT CONCENTRATION

Description:
This data contains concentrations of common and important dissolved chemicals. This data was collected at 20 different stations by the Philadelphia Water Department during the summer of 2002. No data is represented by -999.

Type of feature:
Point

Original Data Source:
Source: Philadelphia Water Department (PWD)
Year of Publication: 2003
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
Projection information: State Plane NAD 1983 (Feet) Pennsylvania South
Following the twenty monitoring stations set by PWD, the original data was cleaned up and all of the categories were arranged by Dr. Peter Petraitis (ppetrait@sas.upenn.edu) of the University of Pennsylvania.

Description of Fields:

Field Name	Description
ALKAL	Alkalinity (mg CaCO3/L)
AMMON	Ammonia (mg/L)
DIS_02	Dissolved O2 (mg/L)
E_COLI	E. coli (colony forming units per 100mL)
FEC_COL	Fecal Coliform (colony forming units per 100mL)
NITRATE	Nitrate (mg/L)
NITRITE	Nitrite (mg/L)
ORTHOPHO	Orthophosphate (mg/L)
TOT_PHOS	Total Phosphorus (mg/L)
CHLOR_A	Chlorophyll A (mg/L)

Database Name: SSA (Sewer Service Area Data for Pennypack Watershed)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu
Date: 7/22/2005

GENERAL INFORMATION:
No of fields: 9 (Excluding BASIN_ID[10])
No of Records: 49

CATEGORY: SEWER SERVICE AREA

Description:
For each basin, the percentage of its area served by the various local Sewer Authorities is presented.

Purpose:
The purpose of this data is to calculate how much of the sub basins have sewer service.

Original Data Source:
Delaware River Basin Commission (DRBC)

[10] BASIN_ID is the key field that ties each record with 49 sub basin boundaries generated by CSC.

Data creation year: 1996
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
The sewer service areas were overlaid by the basins and the percentage of each basin that is served by each service was calculated.

Description of Fields:

Field Name	Description
S_ABING	The percentage of the basin served by the Abington Township STP.
S_BUCKS	The percentage of the basin served by the Bucks County Water and Sewer Authority
S_DELC	The percentage of the basin served by the Delcora
S_HORSH	The percentage of the basin served by the Horsham Township Sewer Authority
S_UP_MOR	The percentage of the basin served by the Upper Moreland - Hatboro Joint Authority
S_WARM	The percentage of the basin served by the Warminster Township Municipal Authority
S_PWD	The percentage of the basin served by the Philadelphia Water Dept.
S_NO_SERV	The percentage of the basin not served by any sewer service
T_SSA	The Percentage of the basin served by the Total Sewer Service Area

Database Name: WSA (Water Service Area Data for Pennypack Watershed)

Data Analyst:
Name: Jesse Sherry
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: jsherry@temple.edu
Date: 7/21/2005

Contact Information:
Name: ASM Abdul Bari / MD Mahbubur R Meenar
Organization: Center for Sustainable Communities (CSC), Temple University, PA
Email: asmbari@temple.edu, meenar@temple.edu
Date: 7/22/2005

GENERAL INFORMATION:

No of fields: 9 (Excluding BASIN_ID[11])
No of Records: 49

CATEGORY: WATER SERVICE AREA

Description:
For each basin, the percentage of its area provided with water service from the various local water authorities is presented.

[11] BASIN_ID is the key field that ties each record with 49 sub basin boundaries generated by CSC.

Purpose:
The purpose of this data is to calculate how much of each sub basin is provided with water service.

Original Data Source:
Delaware River Basin Commission (DRBC)
Data creation year: 1996
Data acquired by CSC in 2005.

Actions Taken for Data Processing:
The sewer service areas were overlaid by the basins and the percentage of each basin that is served with water was calculated.
Description of Fields:

Field Name	Description
W_HATBOR	The percentage of the basin served by the Hatboro Water Authority
W_HORSHA	The percentage of the basin served by the Horsham Township Water Authority
W_NWALES	The percentage of the basin served by the North Wales Water Authority
W_PHLSUB	The percentage of the basin served by the Philadelphia Suburban Water Company
W_UPPSTH	The percentage of the basin served by the Upper Southampton Township Municipal Authority
W_WARMIN	The percentage of the basin served by the Warminster Township Municipal Authority
W_WILGRO	The percentage of the basin served by the Willow Grove USNAS
W_PWD	The percentage of the basin served by the Philadelphia Water Dept.
T_WSA	The Percentage of the basin served by the Total Water Service Area

A.3. **Ecological Indicators: Technical Details & Tables**

A.3.1. **Graphs and Tables for the Hydrological Modeling**

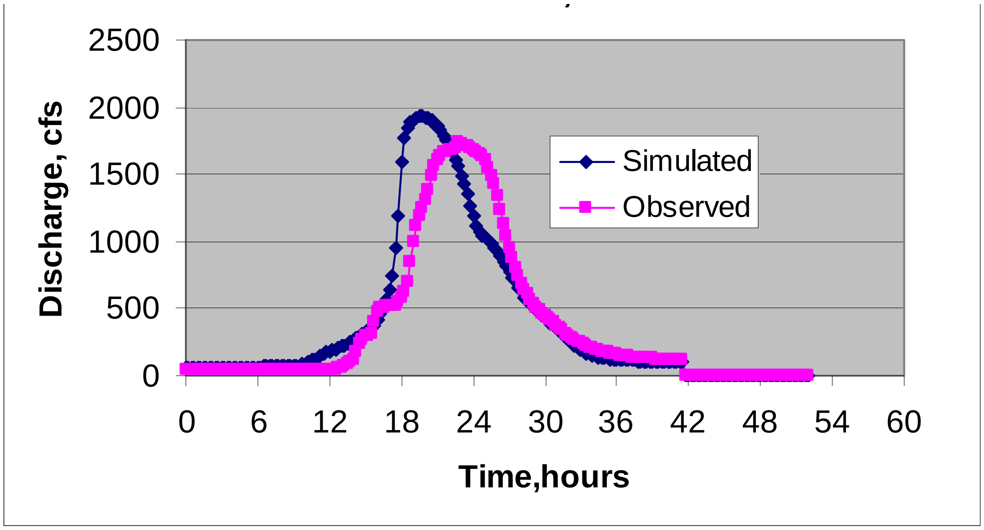

Figure A.3.1. Storm 1 - October 08, 1996

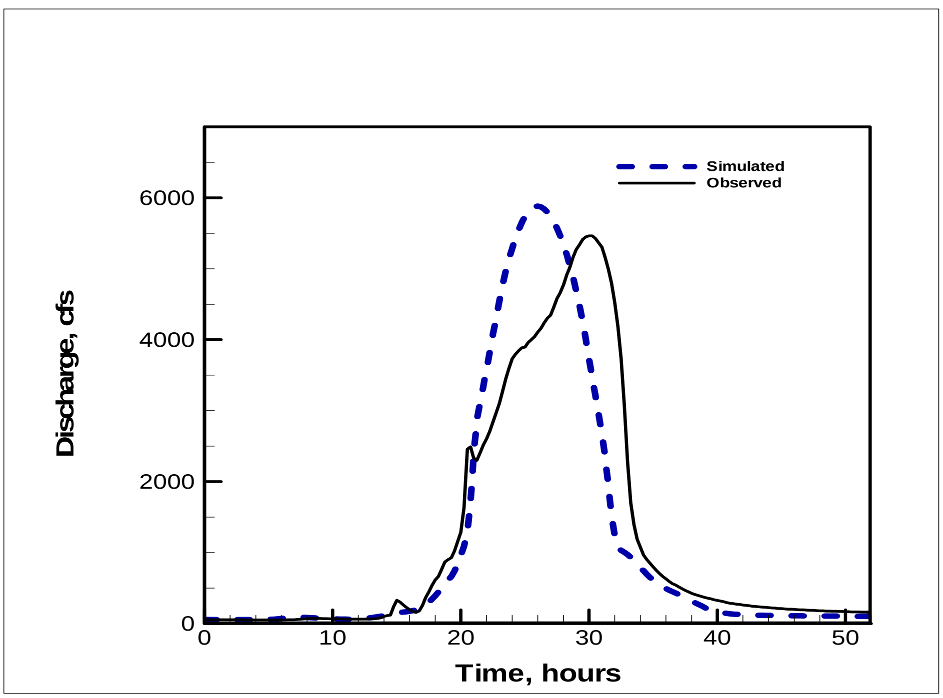

Figure A.3.2. Storm 2 - October 18, 1996

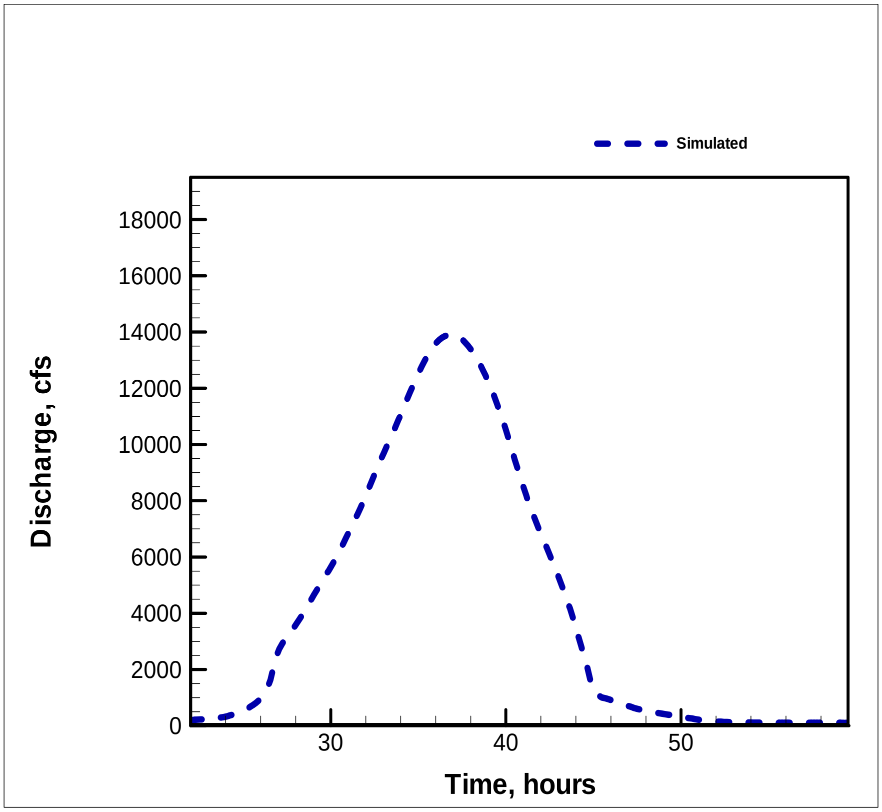

Figure A.3.3. Storm 3 - September 3, 1999 (Floyd)

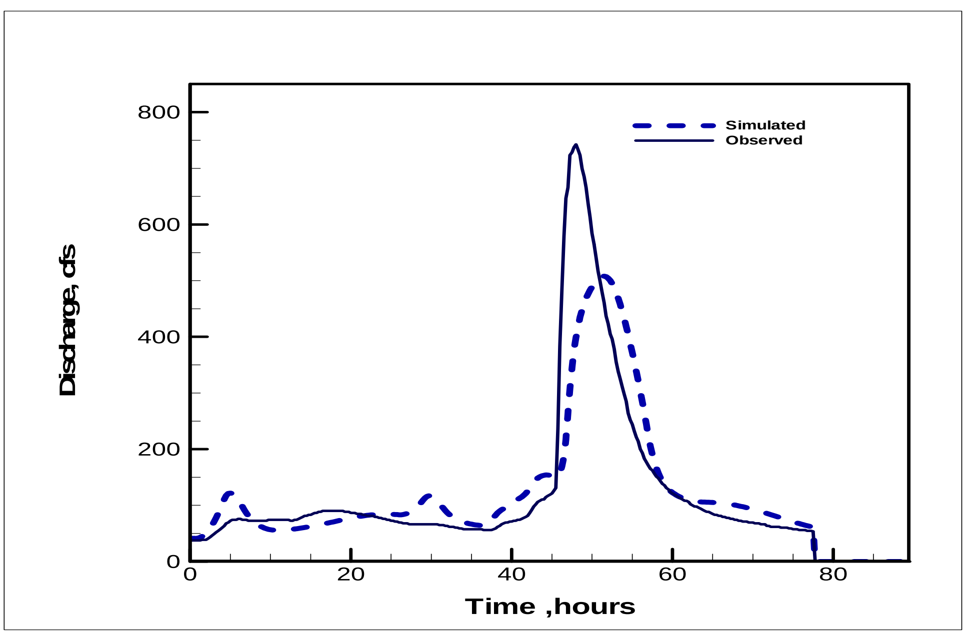

Figure A.3.4. Storm 4 - November 1999

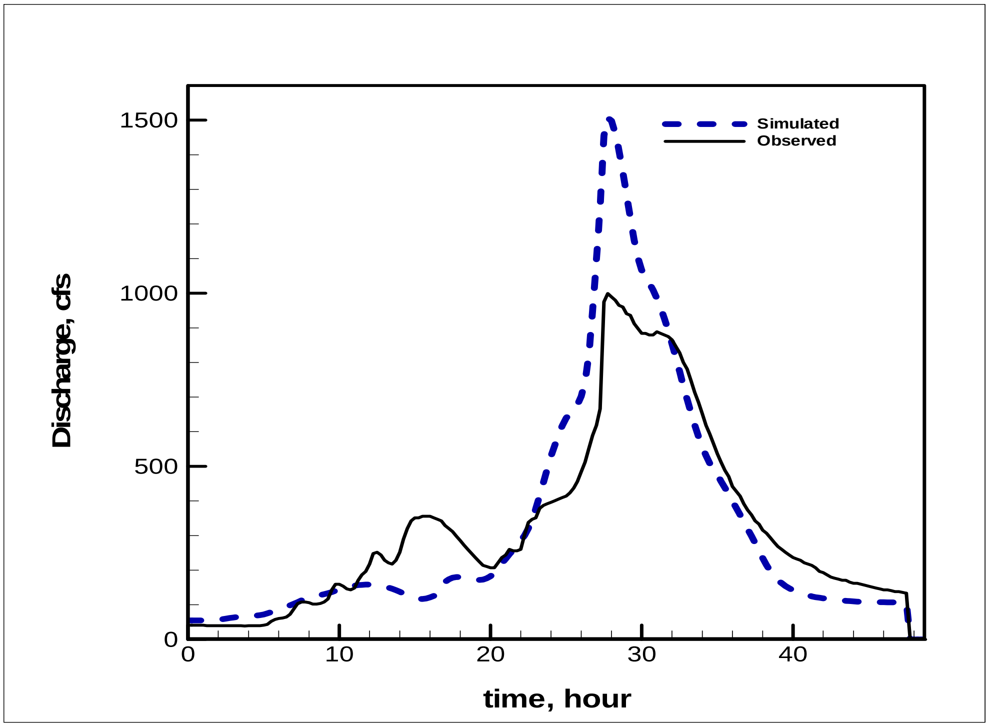

Figure A.3.5. Storm 5 - December, 1999

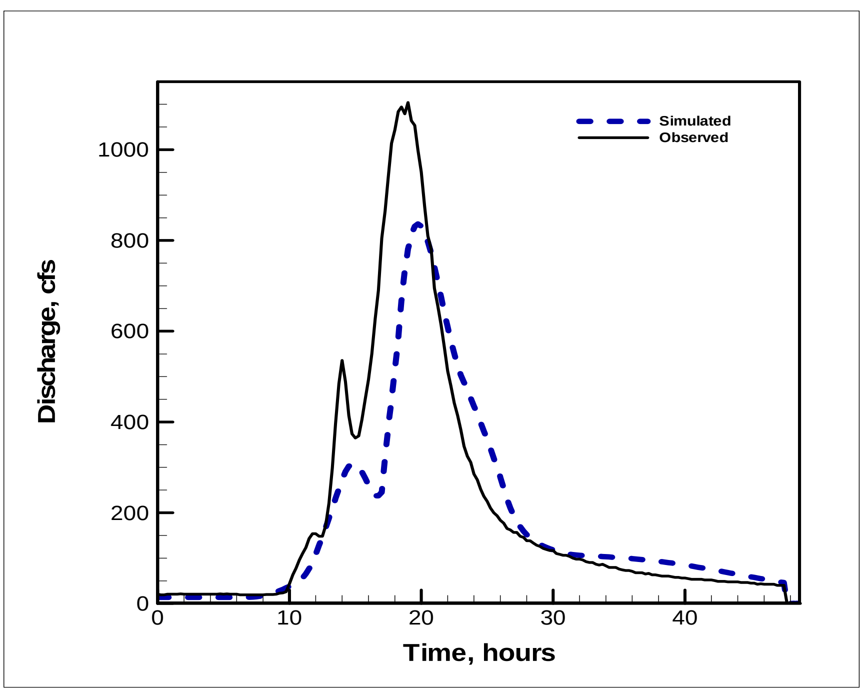

Figure A.3.6. Storm 6 - March 2002

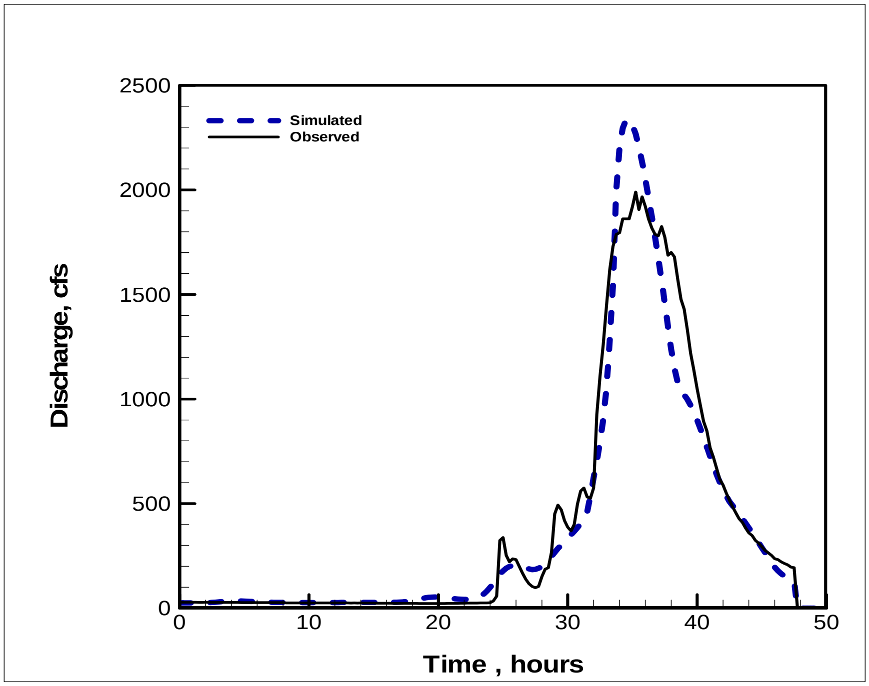

Figure A.3.7. Storm 7 - May 2002

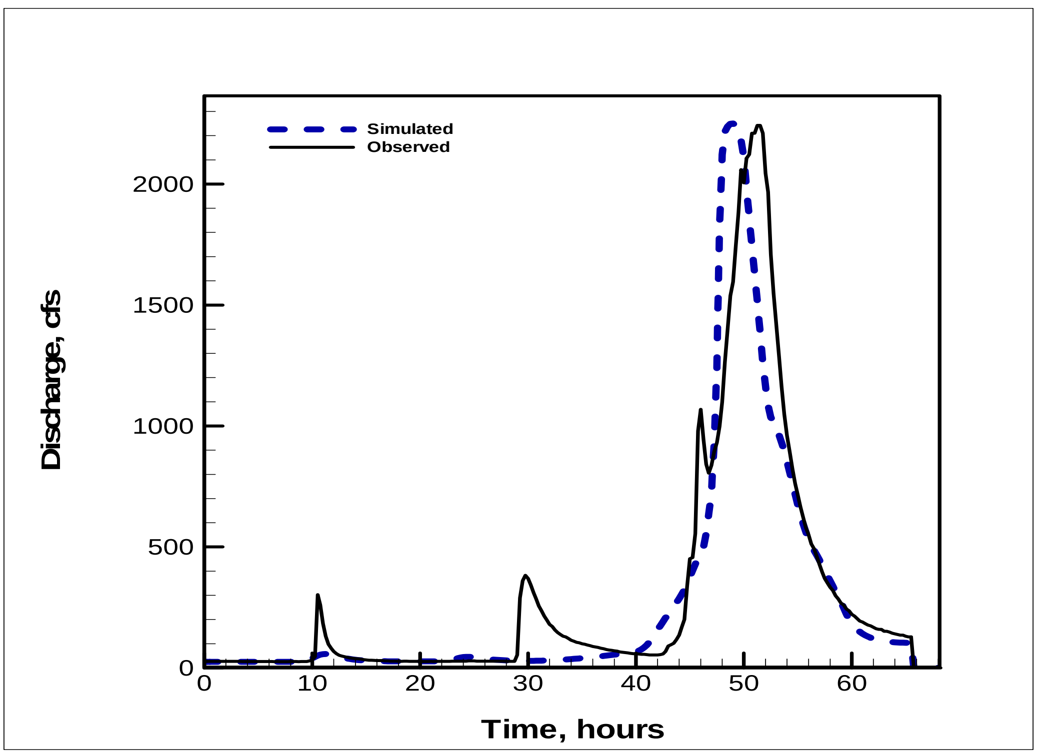

Figure A.3.8. Storm 8 - June 2002

Reach Properties

Table A.3.1. Reach One

Discharge (cfs)	Volume (Acre-foot)	Travel Time (hour)
100	27.42	2.52
250	51.42	2.05
500	94.69	1.81
1000	191.09	1.75
2000	422.08	2.23
4000	914.35	2.57
7000	1398.22	2.27
10000	1835.37	2.09
15000	2593.17	1.96
20000	3369.15	1.9
25000	4102.78	1.85
30000	4786.73	1.81

Table A.3.2. Reach Two

Discharge (cfs)	Volume (Acre-foot)	Travel Time (hour)
100	26.71	2.99
250	37.93	1.72
500	53.86	1.23
1000	80.72	0.93
2000	166.91	0.95
4000	347.12	0.93
7000	655.66	1.01
10000	996.55	1.09
15000	1481.48	1.08
20000	1823.04	1.02
25000	2158.92	0.97
30000	2511.59	0.96

Table A.3.3. Reach Three

Discharge (cfs)	**Volume (Acre-foot)**	**Travel Time (Hour)**
100	11.49	1.32
250	15.15	0.71
500	20.5	0.48
1000	31.44	0.37
2000	87.98	0.49
4000	259.84	0.56
7000	572.1	0.68
10000	827.52	0.73
15000	1257.24	0.83
20000	1492.83	0.76
25000	1809.15	0.76
30000	1926.97	0.68

Table A.3.1. Reach Four

Discharge (cfs)	**Volume (Acre-foot)**	**Travel Time (Hour)**
100	39.28	4.03
250	58.65	2.57
500	82.91	1.88
1000	121.26	1.4
2000	186.73	1.08
4000	341.1	1
7000	588.5	0.99
10000	813.91	0.96
15000	1205.42	0.92
20000	1463.39	0.83
25000	1739.85	0.78
30000	2001.36	0.75

Table A.3.5. Reach Five

Discharge (cfs)	Volume (Acre-foot)	Travel Time (Hour)
100	88.95	9.94
250	130.46	5.95
500	228.48	5.28
1000	360.36	4.21
2000	457.72	2.52
4000	769.35	2.19
7000	1306.06	2.13
10000	1794.46	2.08
15000	2677.56	2.07
20000	3209.88	1.86
25000	3534.6	1.64
30000	4592.11	1.78

Table A.3.6. Reach Six

Discharge (cfs)	Volume (Acre-foot)	Travel Time (Hour)
100	186.45	21.45
250	195.57	9.02
500	210	4.92
1000	238.66	2.82
2000	301.58	1.77
4000	474.16	1.4
7000	786.51	1.32
10000	1210.83	1.42
15000	1904.16	1.48
20000	2368.76	1.39
25000	2602.68	1.22
30000	2989.46	1.17

Table A.3.7. Channel routing – Number of sub-reaches calculation

Reach ID	Length (ft)	Ave. Travel-Time (hr) [(1)]	Selected Travel-Time (hr) [(2)]	Corresponding-Flow(cfs) [(3)]	No. of Sub-Reaches[(4)]
1	18180	2.0675	2.25	250-25000	6
2	15320	1.24	1	500-30000	3
3	4165	0.6975	0.75	2000-30000	2
4	16689	1.4325	1	2000-30000	3
5	28227	3.4708	2	4000-30000	5
6	19329	4.115	1.5	2000-30000	4

[(1)] HEC-RAS 'travel time ave.' averaged over the 12 flow rates (100 cfs to 30,000 cfs).
[(2)] Travel time based on the most likely flow rates involved during a 100- year flood.
[(3)] The flow rate for which the selected travel time values are reasonable.
[(4)] Number of Sub-Reaches= (Selected Travel Time /1.5)/ (Time interval) where:
1.5 = Ratio of wave velocity/ average flow velocity; time interval =0.25 hrs. (15 min.)

A.3.2. **Calculations for the Water Volume Indicator**

The **Rhawn St Stream Gauge** is the only presently functioning stream gauge in the PCW and is also the stream gauge with the longest period of record. Due to the **need for long periods** of record to find the low-flow conditions this was the only point at which the baseflow calculations were conducted.

Calculating the Natural Flow at the Rhawn St. Stream Gauge**:**

A previous study commissioned by the DRBC conducted by R.E. Wright Associates determined the natural baseflow rates for the basic geological formations in Southeastern Pennsylvania. The PCW is contained in the area studied and so it is possible to use the results from this study to estimate the natural baseflow at the Rhawn St. Gauge. Using Arcview 9.0, the areas of these geologic formations were determined and these areas were multiplied by the flow rate for each geologic formation from the R.E. Wright Study. The sum of these values represents the natural baseflow at the Rhawn St. Gauge. The table below shows these calculations.

Table A.3.8. Natural Baseflow

25 yr low flow	Area	Rock Type	Calculated Baseflow
(mgd/sq. mile)	(sq. mile)		mgd
0.299	29.541	crystalline rocks	8.8328
0.299	0.446	unconsolidated	0.1334
0.299	0.028	unconsolidated	0.0084
0.299	0.591	unconsolidated	0.1767
0.289	0.507	carbonate rocks	0.1465

0.289	0.011	carbonate rocks	0.0032
0.189	18.404	Stockton Fm.	3.4784
0.154	0.002	diabase	0.0003
0.299	0.058	unconsolidated	0.0173
0.299	0.070	unconsolidated	0.0209
	Total Calculated	Natural Baseflow	12.8178 mgd

Calculating the Baseflow at the Rhawn St. Stream Gauge**:**

Daily Streamflow data was available from the USGS Rhawn Street Stream Gauge for the period of from June 1, 1965 to the present. The stream gauge data is freely available from the USGS-NWIS website (http://waterdata.usgs.gov/nwis/)

A *baseflow separation* was then conducted using the daily streamflow data from June 1, 1965 through September 30, 2003. This was done using a hydrograph separation computer program based on the local-minimum method.
The mean daily baseflow for each year is presented below in millions of gallons per day.

Table A.3.9. Mean Daily Baseflow

Year	Baseflow (mgd)		Year	Baseflow (mgd)
1966	12.87433739		1984	31.30797216
1967	26.87509365		1985	11.49848451
1968	17.75934976		1986	17.02884794
1969	16.80829931		1987	20.36145059
1970	22.44521688		1988	15.61943228
1971	24.02986678		1989	26.67228037
1972	38.22665225		1990	27.09586725
1973	41.93693342		1991	19.75784884
1974	30.1283519		1992	17.62926179
1975	35.48657303		1993	24.46359038
1976	21.51855848		1994	28.23392992
1977	19.77640883		1995	15.7021773
1978	31.43029373		1996	31.58958812
1979	38.03735947		1997	23.182198
1980	22.95256525		1998	19.89273682
1981	16.39900948		1999	17.82220466
1982	24.34030943		2000	25.12756324
1983	32.2240425		2001	23.77671553

These values were then graphed to show the *recurrence intervals* of the baseflows. Figure A.3.1. shows the recurrence interval of the various baseflows at this point on the Pennypack. Where the red lines cross is the point that represents the 25-year low flow event, or the low flow event that has a one in 25 chance of occurring in any given year. This is the lowest flow event that can be determined given the limited period of record for the data. According to the chart the estimated 25-year low flow is approximately 12 mgd.

At this point the difference between the measured baseflow and the natural baseflow appears to be slight, only ~0.8 mgd. However, the Upper Moreland – Hatboro Sewage Treatment Plant discharges directly into Pennypack Stream and much of the water that this plant discharges is drawn from outside the watershed, falsely inflating the current baseflow. To determine the amount of outside water entering the Pennypack at the plant, the amount of water that is drawn from within the Pennypack Watershed was found and subtracted from the discharge. What remained was water that had been taken from outside the Pennypack Watershed and is being discharged into the Pennypack. The table below shows the calculations.

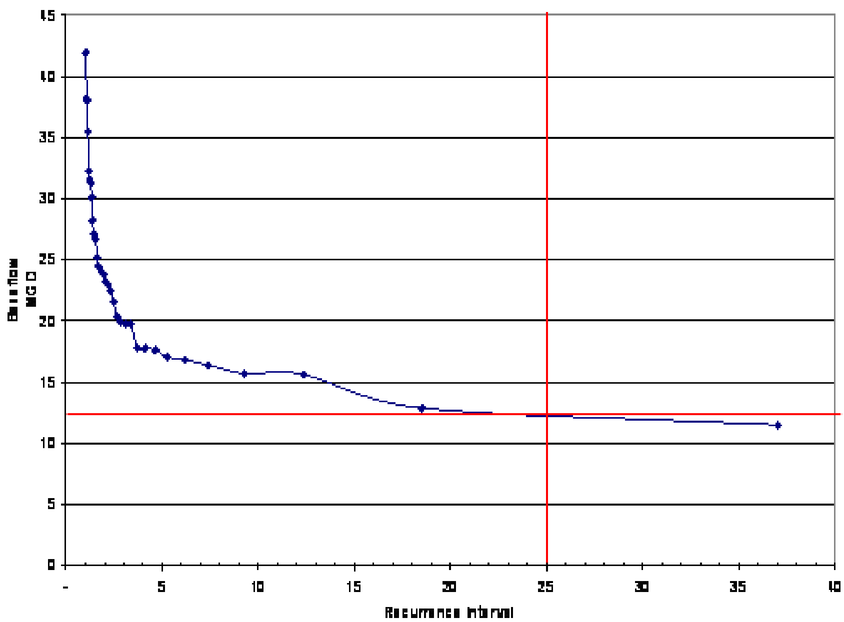

Figure A.3.9. Pennypack Baseflow at the Rhawn St, Gauge

The mean daily discharge from the plant is 7.173 mgd.

7.173 mgd – 1.9022 mgd = 5.2708 mgd

Thus the baseflow of the Pennypack Stream at the Rhawn St. Gauge is being overstated by 5.2708 mgd. The more realistic figure is

12 mgd – 5.2708 = 6.7292 mgd.

Thus the measured 25-year low flow baseflow as a percentage of natural 25-year low flow baseflow is 6.7292 / 12.8178 = 52.50%

Table A.3.10. Imported PCW Water

Withdrawal Site	MGD
HATBORO BORO AUTH WELL #1	0.0000
HATBORO BORO AUTH WELL #2	0.0000
HATBORO BORO AUTH WELL#12	0.0492
HATBORO BORO AUTH WELL#13	0.0000
HATBORO BORO AUTH WELL#14	0.1051
HATBORO BORO AUTH WELL#15	0.0357
HATBORO BORO AUTH WELL#16	0.0000
HATBORO BORO AUTH WELL#17	0.2040
HATBORO BORO AUTH WELL#18	0.0000
HATBORO BORO AUTH WELL#20	0.2516
HATBORO BORO AUTH WELL#21	0.0378
HATBORO BORO AUTH WELL#3	0.0000
HATBORO BORO AUTH WELL#6	0.0761
HATBORO BORO AUTH WELL#7	0.0000
HATBORO BORO AUTH WELL#8	0.1448
HATBORO BORO AUTH WELL#9	0.1206
HORSHAM TWP WATER AUTHORITY WELL#1	0.0433
HORSHAM TWP WATER AUTHORITY WELL#10	0.0573
HORSHAM TWP WATER AUTHORITY WELL#2	0.1285
HORSHAM TWP WATER AUTHORITY WELL#20	0.2166
HORSHAM TWP WATER AUTHORITY WELL#22	0.3231
HORSHAM TWP WATER AUTHORITY WELL#26	0.0000
HORSHAM TWP WATER AUTHORITY WELL#5	0.0000
HORSHAM TWP WATER AUTHORITY WELL#6	0.0582
HORSHAM TWP WATER AUTHORITY WELL#9	0.0503
Total	**1.9022**

A.3.2. **Calculations for the Water Quality Indicator**

The PWD Report provided chemical levels for many common pollutants for each of their 20 sampling sites located along the Pennypack Creek. The average values for each site are shown below. The units are either in milligrams (mg) per liter (L) or colony forming units (cfu) per 100 milliliters (mL).
Targets for water quality for these contaminants were determined using information from the State of Massachusetts Division of Water Pollution Control and Lehigh University. These targets were for bodies of water designated as an excellent habitat for fish, other aquatic life and wildlife. These values are an approximation of an unpolluted, natural state.

Table A.3.11. PCW Chemical Measurements

Station	Alkalinity	Dissolved O2	Fecal Coliform	Nitrate	Ortho-phosphate	Suspended Solids	pH
	(mg $CaCO_3$/L)	(mg/L)	(cfu/100mL)	(mg/L)	(mg/L)		(mg/L)
PP01	61.00	10.96	3124.17	3.10	0.38	88.72	7.48
PP02	46.42	10.68	4760.00	2.08	0.10	89.79	7.60
PP03	64.00	10.39	5160.83	3.17	0.41	103.39	7.33
PP04	No Data	No Data	No Data	No Data	No Data	95.17	7.57
PP05	66.92	10.25	2696.67	3.96	0.49	88.48	7.41
PP06	No Data	No Data	No Data	No Data	No Data	95.03	7.50
PP07	74.00	9.59	2322.50	4.71	0.59	93.92	7.51
PP08	58.00	No Data	No Data	No Data	0.28	92.34	7.39
PP09	No Data	No Data	No Data	No Data	No Data	No Data	7.80
PP10	76.00	10.28	2160.83	5.24	0.77	No Data	7.80
PP11	85.17	10.41	2068.33	2.53	0.10	91.40	7.52
PP12	46.67	10.83	3693.33	2.47	0.11	98.20	7.58
PP13	No Data	No Data	No Data	No Data	No Data	No Data	7.80
PP14	77.58	10.02	2055.83	6.53	1.15	No Data	7.70
PP15	No Data	No Data	No Data	No Data	No Data	103.28	7.58
PP16	68.58	10.31	3425.83	3.50	0.23	No Data	7.80
PP17	85.17	8.61	3645.83	7.21	1.37	100.16	7.37
PP18	64.00	No Data	No Data	No Data	2.34	96.84	7.31
PP19	No Data	No Data	No Data	No Data	No Data	No Data	7.70
PP20	75.50	10.10	3242.50	1.43	0.10	No Data	7.62

Table A.3.12. “Target” Stream Measurements

	Alkalinity	Dissolved O2	Fecal Coliform	Nitrate	Ortho-phosphate	Suspended Solids	pH
	(mg $CaCO_3$/L)	(mg/L)	(cfu/100mL)	(mg/L)	(mg/L)	(mg/L)	
Target	100-200	6	200	1	.03	10	6.5-85

The actual values were then transformed into percentages of the target. For Alkalinity where the actual values were below the target the percentage was calculated by dividing the actual value by 100mg (the lower end of the target range). For Dissolved Oxygen where exceeding the target does not have a negative impact, any value exceeding the target was treated as 100%. For pH where all of the values fell within the target range each value was treated as

100%. For the other categories, where exceeding the target is the negative condition the percentage of the target was calculated by dividing the target by the actual value (an inverse percentage). The results are displayed in the table below.

Table A.3.13. Chemical Measurements: % of Target Levels

Station	Alkalinity	Dissolved O2	Fecal Coliform	Nitrate	Ortho-phosphate	S. Solids	pH
PP01	61.00%	100.00%	6.40%	32.31%	7.83%	11.27%	100.00%
PP02	46.42%	100.00%	4.20%	48.00%	30.00%	11.14%	100.00%
PP03	64.00%	100.00%	3.88%	31.55%	7.41%	9.67%	100.00%
PP04	No Data	No Data	No Data	No Data	No Data	10.51%	100.00%
PP05	66.92%	100.00%	7.42%	25.27%	6.18%	11.30%	100.00%
PP06	No Data	No Data	No Data	No Data	No Data	10.52%	100.00%
PP07	74.00%	100.00%	8.61%	21.22%	5.12%	10.65%	100.00%
PP08	58.00%	No Data	No Data	No Data	10.56%	10.83%	100.00%
PP09	No Data	No Data	No Data	No Data	No Data	No Data	100.00%
PP10	76.00%	100.00%	9.26%	19.09%	3.92%	No Data	100.00%
PP11	85.17%	100.00%	9.67%	39.52%	30.00%	10.94%	100.00%
PP12	46.67%	100.00%	5.42%	40.48%	26.35%	10.18%	100.00%
PP13	No Data	No Data	No Data	No Data	No Data	No Data	100.00%
PP14	77.58%	100.00%	9.73%	15.33%	2.60%	No Data	100.00%
PP15	No Data	No Data	No Data	No Data	No Data	9.68%	100.00%
PP16	68.58%	100.00%	5.84%	28.61%	13.03%	No Data	100.00%
PP17	85.17%	100.00%	5.49%	13.87%	2.18%	9.98%	100.00%
PP18	64.00%	No Data	No Data	No Data	1.28%	10.33%	100.00%
PP19	No Data	No Data	No Data	No Data	No Data	No Data	100.00%
PP20	75.50%	100.00%	6.17%	100.00%	29.56%	No Data	100.00%
Mean	67.79%	100.00%	6.84%	34.60%	12.57%	10.54%	100.00%

Each of these chemical factors was given an equal weighting, so that the final water quality value is the mean of the category means. This value is 47.47%.

A.3.3. **Calculations for the Biological Integrity Indicator**

Calculating the Macroinvertebrate Biological Integrity

The Philadelphia Water Department (PWD) Report provided a Biological Quality value for each of their 20 sampling sites located along the Pennypack Stream. These biological quality values took the form of percentages and were based on comparison to a stream with similar drainage area and geomorphologic attributes, but with an unimpaired ecology. One hundred percent would indicate unimpaired macroinvertebrate ecology and zero percent is severely impaired macroinvertebrate ecology. These Biological Quality scores are presented below.

Table A.3.14. Macroinvertebrate Biological Quality Scores

Station	Biological Quality		Station	Biological Quality
PP01	0%		PP11	46.67%
PP02	40%		PP12	40%
PP03	6.67%		PP13	0%
PP04	0%		PP14	13.33%
PP05	0%		PP15	20%
PP06	0%		PP16	40%
PP07	0%		PP17	0%
PP08	40%		PP18	40%
PP09	13.33%		PP19	40%
PP10	26.67%		PP20	66.67%

Due to the relatively stationary nature of macroinvertebrate communities the results for each point were only attributed to the subbasin immediately upstream of the point. This basins attributed to each station are shown in map BIO1 and the biological integrity score for each basin is shown in map BIO2. The scores for these twenty subbasins were then averaged to yield an overall score for the Pennypack. This score is 21.67% which according to the system devised by PWD is at the bottom end of the Moderately Impaired Range.

Calculating the Fish Biological Integrity

The PWD Report also provided an Index of Biotic Integrity score for each monitoring station at which they sampled the fish population. These scores are on a range from 0 to 50, they were transformed into percentages by multiplying them by 2. These values are all presented in the table below.

Table A.3.15. Fish Biological Quality %s

Station	Biotic Integrity	Percentage	Station	Biotic Integrity	Percentage
PP01	34	68%	PP14	28	56%
PP04	38	76%	PP15	26	52%
PP05	38	76%	PP17	24	48%
PP07	28	56%	PP19	24	48%
PP09	32	64%	PP20	24	48%

Fish are more mobile than macroinvertebrates and so it was determined that the scores for the fish could be attributed to more than just the upstream basin. The scores for each station were attributed to all the basins that were upstream of the monitoring station and downstream of another monitoring station. Major branches of the creek that were not directly monitored were not attributed any data. Map BIO3 shows exactly which stations were attributed to which basins, and map BIO4 shows the biological integrity attributed to those basins. Thirty basins were assigned data from the monitoring stations, so the data from these thirty basins were averaged to yield an overall Index of Biotic Integrity for the

Pennypack. This score is 61.20%. This is considerably higher than the score ~~of~~ yielded by the macroinvertebrates. In reviewing the PWD report it was clear that the fish had greater biodiversity in the tidal areas whereas the macroinvertebrates fared poorly there due to the unstable water levels. The tidal nature of the lower portions of the Pennypack means that neither of these populations is completely indicative of the biological integrity of the stream. In the interests of providing a single score and due to this fact that neither population is completely indicative it was decided to provide a weighted average. Each overall score was multiplied by the number of basins it represented; the two products were then added and divided by the total number of basins (50) to yield a score of 45.39%.

Macroinvertebrates
21.67% x 20 = 4.33

Fish
61.20% x 30 = 18.36

18.36 + 4.33 = 22.69

22.69/50 = 45.39%

A.3.4. **Calculations for the Impervious Surface Indicator**

The Impervious Surface Data originated from Satellite photography. The satellite data provided a percentage of impervious coverage for each 30m x 30m pixel. For each pixel the percentage impervious was multiplied by the pixel size. This yielded the amount of impervious land in each pixel. These values were summed for each subbasin to obtain the amount of impervious land in each subbasin. This amount of impervious land was then divided by the total area of in each subbasin to yield the percentage of imperviousness for each subbasin. The table below shows these calculations.

Table A.3.16. Sub-Basin Impervious Surface

Basin ID	Total Area (sq. mi)	Impervious Area (sq. mi)	Percent Impervious		Basin ID	Total Area (sq. mi)	Impervious Area (sq. mi)	Percent Impervious
1	1.0671	0.1292	12.11%		25	1.0748	0.3073	28.59%
2	0.9925	0.2945	29.67%		26	1.4887	0.1146	7.70%
3	1.2543	0.3625	28.90%		27	0.9112	0.0918	10.07%
4	1.2179	0.5054	41.50%		28	1.4510	0.3101	21.37%
5	1.0823	0.5483	50.66%		29	0.9040	0.1716	18.99%
6	1.8176	0.5628	30.97%		30	0.7693	0.2250	29.24%
7	1.7223	0.8720	50.63%		31	0.7592	0.1307	17.21%
8	1.4274	0.5389	37.75%		32	0.9373	0.1134	12.10%
9	0.9286	0.3473	37.40%		33	1.2292	0.3932	31.99%
10	2.1699	0.8699	40.09%		34	1.4573	0.8006	54.94%
11	1.6467	0.6422	39.00%		35	0.7949	0.1817	22.86%
12	1.6117	0.4987	30.94%		36	0.3806	0.0562	14.76%
13	1.2037	0.6183	51.36%		37	0.4054	0.0190	4.70%
14	1.1684	0.3751	32.10%		38	2.7683	1.6770	60.58%
15	1.4356	0.2083	14.51%		39	0.7449	0.1913	25.68%
16	0.4486	0.0603	13.45%		40	0.5531	0.1411	25.51%
17	0.7539	0.0323	4.29%		41	1.4028	0.4342	30.95%
18	0.9433	0.3228	34.22%		42	0.9160	0.3477	37.96%
19	0.5261	0.0433	8.23%		43	0.9590	0.4747	49.50%
20	1.1634	0.0670	5.76%		44	1.1197	0.4651	41.54%
21	1.3354	0.2316	17.34%		45	1.6508	0.9157	55.47%
22	1.0150	0.1915	18.86%		46	1.8207	0.9611	52.79%
23	1.2703	0.0736	5.80%		47	0.7659	0.2754	35.96%
24	0.4394	0.0457	10.39%		48	1.0292	0.4859	47.21%
					49	0.7920	0.5572	70.35%

The mean of these impervious surface values is the average impervious surface value for the PCW, 29.67%.

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[i] BASELINE ASSESSMENT OF PENNYPACK CREEK WATERSHED (2002-2003), Produced by the Philadelphia Dept. of Water, Office of Watersheds. http://www.phila.gov/water/index.html

[ii] http://www.hylebos.org/Stream_Team/Macro_Definition.htm

[iii] from chapter 5 of the Stroud Water Research Center Report on New York's Watersheds accessed at http://www.stroudcenter.org/research/NYReport/

[iv] BASELINE ASSESSMENT OF PENNYPACK CREEK WATERSHED (2002-2003), Produced by the Philadelphia Dept. of Water, Office of Watersheds. http://www.phila.gov/water/index.html

[v] National Soil Survey Handbook (NSSH), Part 618 - Soil Properties and Qualities, Natural Resources Conservation Services (NRCS), http://soils.usda.gov/technical/handbook/contents/part618p2.html#35, accessed on August 2, 2005.

[vi] **Infiltration Rate** is the rate at which water enters the soil at the surface and is controlled by the surface conditions, as defined in National Soil Survey Handbook (NSSH), Part 618 - Soil Properties and Qualities, Natural Resources Conservation Services (NRCS).

[vii] **Transmission Rate** is the rate at which water moves in the soil and is controlled by soil properties, as defined in National Soil Survey Handbook (NSSH), Part 618 - Soil Properties and Qualities, Natural Resources Conservation Services (NRCS).
[1] Source: Philadelphia Water Department Web Site (http://www.phillywater.org)

[ix] BASELINE ASSESSMENT OF PENNYPACK CREEK WATERSHED (2002-2003), Produced by the Philadelphia Dept. of Water, Office of Watersheds. http://www.phila.gov/water/index.html

[x] BASELINE ASSESSMENT OF PENNYPACK CREEK WATERSHED (2002-2003), Produced by the Philadelphia Dept. of Water, Office of Watersheds. http://www.phila.gov/water/index.html

[xi] http://www.hylebos.org/Stream_Team/Macro_Definition.htm

[xii] from chapter 5 of the Stroud Water Research Center Report on New York's Watersheds accessed at http://www.stroudcenter.org/research/NYReport/

[xiii] National Soil Survey Handbook (NSSH), Part 618 - Soil Properties and Qualities, Natural Resources Conservation Services (NRCS), http://soils.usda.gov/technical/handbook/contents/part618p2.html#35, accessed on August 2, 2005.

[xiv] **Infiltration Rate** is the rate at which water enters the soil at the surface and is controlled by the surface conditions, as defined in National Soil Survey Handbook (NSSH), Part 618 - Soil Properties and Qualities, Natural Resources Conservation Services (NRCS).

[xv] **Transmission Rate** is the rate at which water moves in the soil and is controlled by soil properties, as defined in National Soil Survey Handbook (NSSH), Part 618 - Soil Properties and Qualities, Natural Resources Conservation Services (NRCS).
[1] Source: Philadelphia Water Department Web Site (http://www.phillywater.org)