PIEDMONT BASIN

Preliminary Assessment Report

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Acknowledgments

This comprehensive report on Delaware's Piedmont Basin was compiled by the Delaware Department of Natural Resources and Environmental Control's *Whole Basin Management – Piedmont Team*. The Piedmont Team, under the leadership of environmental scientist Jenny McDermott, undertook a unique approach to assessing Delaware's northernmost drainage basin. This approach, known as *Whole Basin Management*, challenged scientists, engineers, planners, and managers throughout the Department to merge their data, information, and talents to assess the Piedmont Basin from a multidisciplinary perspective.

The Piedmont Team members included John Barndt, Lynn Broaddus, Pearl Burbage, William Cohen, Bruce Cole, Peggy Emslie, Betsy Frey, Frank Gavas, Rick Greene, Randy Greer, Kyle Gulbronson, Peder Hansen, Rob Hossler, Sergio Huerta, Lyle Jones, John Kennel, Steve Langseder, Rob Line, Stewart Lovell, Miriam Lynam, John Maxted, Jenny McDermott, Hassan Mirsajadi, Bill Moyer, Dennis Murphy, Dave Scheppens, John Schneider, Brad Smith, Blair Venables, Andrew Whitman, Xia Xie, and Patti Zietlow.

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INTRODUCTION

The *Whole Basin Management* approach developed by the Delaware Department of Natural Resources and Environmental Control (DNREC) focuses on protecting Delaware's environment by managing it in a comprehensive and coordinated fashion — by drainage basin. Using major drainage basins as our chief management units, we can bring together the expertise from all our divisions — Air and Waste Management, Fish and Wildlife, Parks and Recreation, Soil and Water Conservation, and Water Resources — to assess, monitor, and protect the health of Delaware's environment.

The basis for developing this report comes from our realization that virtually every activity that takes place in the environment impacts multiple resources or land-use activities. For example, improper disposal of hazardous substances on land can contaminate more than simply surface soils. Contaminants can leach into groundwater or be transported to streams and other surface waters during storms, thus potentially affecting public drinking water supplies, aquatic life, and recreational fishing. Additionally, abandoned contaminated sites challenge state and local governmental agencies to find ways to make these areas safe and attractive for industrial uses and other needs. Thus, managing the complex natural world we call "the environment" requires us to examine the many resources that compose it from multiple perspectives in an integrated fashion.

Delaware's Drainage Basins

DNREC's *Whole Basin Management* approach aims at managing all the biological, chemical, and physical environments of geographic areas in Delaware defined on the basis of drainage patterns. As shown in Map 1, five major drainage basins encompass the state: the Piedmont, Chesapeake Bay, Delaware Bay, Delaware Estuary, and Inland Bays/Atlantic Ocean basins. Each basin consists of smaller management units, or sub-basins, known as watersheds. A watershed represents the area drained by a river, stream, or creek — in simplest terms, the area "shedding the water" to a given water body. There are 41 watersheds in Delaware.

Whole Basin Management involves eight phases to effectively assess the health of a targeted basin and develop an implementation plan to address its environmental problems (see Table 1). The paramount objectives of the process are to protect the environment, improve relations within and outside DNREC, maximize wise resource use, and promote environmental education and stewardship. For more information, see the *Whole Basin Management Framework Document* in the DNREC Office of the Secretary.

The Piedmont Basin Preliminary Assessment

The first basin DNREC is assessing under *Whole Basin Management* is the Piedmont Basin in northern New Castle

Table 1

WHOLE BASIN MANAGEMENT PLAN PROCESS

PHASE I: Planning (Months 0 – 4)

- Assemble Whole Basin Coordination Team
- Resolve/Clarify Issues
- Revise/Improve Standard Operating Procedures/Framework Document
- Define/Assemble Basin Team and Select Leader
- Educate Basin Team — Consensus Building *(Training and Workshop)*
- Educate Department (Fact Sheet/Meeting)
- Define Geographic Locations/Boundaries

PHASE II: Preliminary Assessment (Months 5 – 16)

- Inventory Existing Projects/Information/Data
- Assess Status and Identify Trends
- Identify Specific Issues of Interest/Concern
- Recommend Areas for Focus and Integration
- Identify Data Gaps
- Develop Intensive Monitoring Plan

PHASE III: Intensive Basin Monitoring (Months 0 – 36)

- Implement Monitoring Plan:
  - Canvass for Information
  - Analyze Information
  - Prioritize Problems and Critical Issues
  - Implement Updates to Monitoring Plan

PHASE IV: Public Participation (Months 0 – 60)

- Perform Agency and Public Review
- Address Public Concerns/Incorporate Recommendations into Monitoring and Basin Plans

PHASE V: Comprehensive Analysis (Months 25 – 48)

- Quantify Problems and Issues

PHASE VI: Management Options Evaluation (Months 42 – 58)

- Develop Management Strategies

PHASE VII: Resource Protection Strategy (Months 42 – 60)

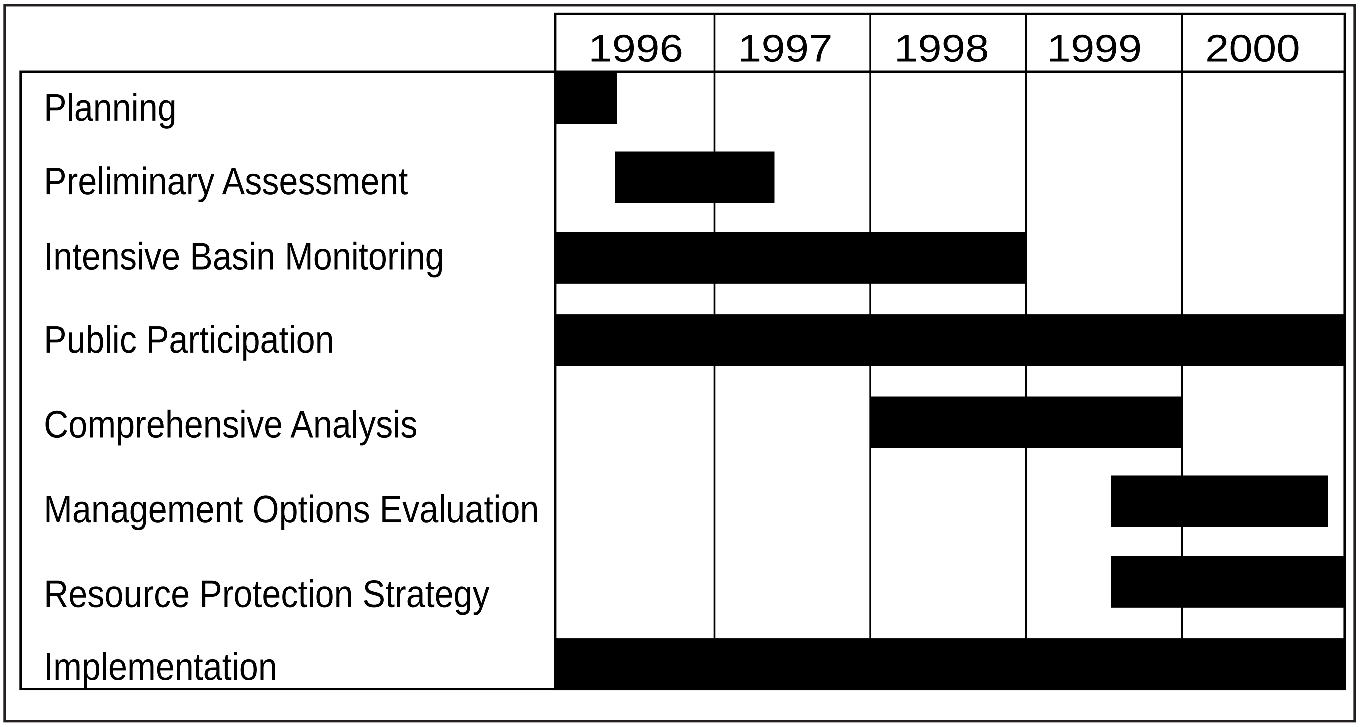
- Prepare Draft Basin Plan
- Hold Public Workshops/Review and Address Comments
- Finalize Basin Plan

PHASE VIII: Implementation (Months 0 – 60)

- Formulate Implementation Plan and Schedule
- Identify Roles and Responsibilities of Agencies

Figure 1

PIEDMONT BASIN MANAGEMENT PROGRAM TIMELINE



County. Named after the geological province in which it resides, this basin encompasses the White Clay Creek, Red Clay Creek, Brandywine Creek, Shellpot Creek, Naamans Creek, and Christina River watersheds (see Map 2).

This *Piedmont Basin Preliminary Assessment Report* — written by the 28-member Piedmont Team representing every division in DNREC — depicts the current state of the basin, issues of concern, and assessment needs. As shown in Figure 1, the preliminary assessment is a critical phase in the development of the five-year management plan for the basin.

The preliminary assessment phase required gathering and assessing existing information on the Piedmont Basin from each division within DNREC and from agencies outside it. Specific goals included the following:

1. Compile readily available chemical, physical, and biological data on the Piedmont Basin.
2. Evaluate status and trends; identify stressed resources, provide their locations, and describe concerns.
3. Identify areas of outstanding resource value as candidates for preservation, and consider buffers to protect these areas.
4. Describe the environmental state of the Piedmont Basin and its individual watersheds.
5. List actions that can be implemented based on our current level of knowledge.
6. Identify data gaps and limitations.
7. Prioritize recommendations for future data collection.

This preliminary assessment report should provide the "state of the environment" for the Piedmont Basin. At a minimum, it should answer these basic, but essential, questions:

- ◆ *What do we know about the Piedmont Basin?*
- ◆ *What don't we know?*
- ◆ *What do we need to know?*

The report also identifies immediate actions that may be taken to improve the Piedmont Basin's health, and it makes recommendations for additional or enhanced monitoring of specific environmental indicators. Additionally, the report identifies data trends and gaps, areas of programmatic overlap, initiatives that may be integrated, areas requiring additional focus, environmental stressors, and other findings germane to promoting healthy management of the ecosystem. This preliminary assessment will now fuel development of the Intensive Basin Monitoring Plan — the next phase in DNREC's *Whole Basin Management* approach for the Piedmont Basin.

PIEDMONT BASIN: CURRENT STATUS

GEOLOGY

The Piedmont Basin is found within two physiographic provinces: the Piedmont Province and Atlantic Coastal Plain Province. Delaware's Piedmont Province occupies the northernmost, 6% of the state and is commonly referred to as "Delaware's hard rock country." The basin takes its name from this geologic province in which it primarily resides — "the Piedmont" — which literally means lying at the base or the foot of the mountains. While Delaware's highest elevations, greater than 400 feet above sea level, are found in the Piedmont Province, the basin's elevation generally averages about 250 feet above sea level. Much of the basin is characterized by deeply incised streams, steep slopes, and gently rolling hills. Note that even though they are completely surrounded by the low-lying Atlantic Coastal Plain, Chestnut Hill and Iron Hill (referred to as Piedmont "outliers"), located south of Newark, are included in the Piedmont Province.

The geology of the Piedmont Province consists predominantly of a thick mass of highly deformed metamorphic and igneous rocks estimated to be more than 500 million years old, likely ranging from Proterozoic to early Paleozoic in age (Woodruff and Plank, 1995). These rocks are highly faulted, folded, jointed, and foliated in some areas. Gneisses and schists form the major rock types. Igneous intrusive rocks, including coarse varieties of granite called pegmatites, are also present in some areas. This crystalline mass is overlain with saprolite (weathered rock material) and in some isolated areas is capped with much younger fluvial sedimentary deposits. Recent work by Woodruff and Plank (1995) categorizes the Piedmont crystalline rock complex into five units. Table 2 provides their names, ages, and lithologies.

The Baltimore Gneiss forms the base upon which all the younger Piedmont Basin sediments were deposited. In Proterozoic time, the basin was under water, and the Baltimore Gneiss formed the ocean floor. The Setters, Cockeysville, and Wissahickon formations were originally deposited as sedimentary cover over the Baltimore Gneiss (Woodruff and Plank, 1995).

The Cockeysville Formation resulted from shallow-water deposition of carbonates on a continental margin, while the Wissahickon Formation formed as a result of deep-water sedimentation and turbidity-current deposits. During Paleozoic time, a mountain-building event — the Taconic Orogeny (480 to 435 million years ago) — caused extreme deformation and metamorphism of the sedimentary deposits. This is when the majority of the Wilmington Complex rocks are believed to have formed (Woodruff and Plank, 1995).

Beginning in the Devonian Period (345 to 405 million years ago), much of the Piedmont Province emerged from the ocean

Table 2

ROCKS OF THE PIEDMONT BASIN

(ADAPTED FROM WOODRUFF AND PLANK, 1995)

ROCK UNIT NAME	AGE (millions of years)	GENERAL LITHOLOGICAL DESCRIPTION
Wilmington Complex	340 Early Paleozoic Period	◆ Mafic and felsic gneisses and intrusive igneous rock including gabbroic and dioritic plutons and amphibolites
Glenarm Series		
Wissahickon Formation		◆ Gneisses and schists derived from sandstones and mudstones, amphibolites, and serpentinite
Cockeysville Formation Setters Formation	> 570 Proterozoic Period	◆ Calcareous schists and dolomitic marble ◆ Impure quartzite
Baltimore Gneiss	> 570 Proterozoic Period	◆ Gneisses of varying lithologies and amphibolites

and remained emerged until Cretaceous time. During this period, thousands of feet of crystalline rock were removed from the area by extensive erosion (Woodruff and Thompson, 1975). Delaware's Piedmont Province continues to undergo this weathering and erosion.

Due to the extensive saprolite mantle — in excess of 80 feet thick in some areas — fresh, unaltered exposures of the aforementioned rock units are not common. The saprolite's thickness in Delaware's Piedmont Province averages approximately 20 to 50 feet (Christopher and Woodruff, 1982).

Of the formations described, the Wilmington Complex and the Wissahickon Formation are by far the most widespread surficial units of the Piedmont Province. In contrast, the Baltimore Gneiss, Setters Formation, and Cockeysville Formation have been mapped only in the northwestern portion of the basin in small, isolated locations. The remainder of this section will focus on the basin's two geological provinces: the Piedmont (Wilmington Complex, Wissahickon and Cockeysville formations, and Piedmont fluvial deposits), and the Atlantic Coastal Plain. See Map 3.

Predominant Geologic Areas of the Piedmont Province

The Wilmington Complex

The Wilmington Complex represents the dominant rock type in the eastern Piedmont Province. This formation is more resistant to chemical and physical weathering than the Wissahickon Formation; for this reason, the eastern Piedmont Province is characterized by relatively gentle slopes and less deeply incised valleys than found in its western portions (Christopher and Woodruff, 1982).

Wilmington Complex rocks are generally massive and do not exhibit significant secondary porosity (faults and joints). These rocks do not readily transmit or store groundwater and do not make good aquifers. An average domestic well in the Wilmington Complex typically yields one gallon per minute or less (Woodruff, 1981). Small quantities of groundwater of questionable quality do exist where the saprolite is of sufficient thickness.

The Wissahickon Formation

The Wissahickon Formation forms the dominant rock type in the northwestern Piedmont Province and may be greater than 8,000 feet thick (Woodruff and Plank, 1995). This formation is less resistant to chemical and physical weathering than the Wilmington Complex. Thus, deeply incised stream valleys and steep slopes characterize this portion of the basin. Amphibolites and gneisses of the Wissahickon support ridges while mica schists erode to form deep-sided valleys (Christopher and Woodruff, 1982). The formation has considerably more secondary porosity than the Wilmington Complex and therefore has more capacity to store and transmit groundwater. Although high densities of joints and faults exist in some locations and may be able to support initial groundwater yields of 300 to 400 gallons per minute, groundwater typically yields 10 gallons per minute (Woodruff, 1981).

The Cockeysville Formation

This formation occupies relatively small geographical areas in the Hockessin/Yorklyn and Pleasant Hill valleys in the northwestern portion of the Piedmont Province. The Cockeysville marble is estimated to range from 400 to 800 feet thick. The overlying saprolite of the Cockeysville varies in thickness, ranging from several feet to 50 feet thick. The unweathered portion of the formation is massive. Where weathered, the Cockeysville Formation serves as an excellent aquifer and is the most highly productive crystalline rock aquifer in the state (Woodruff and Plank, 1995). Aquifer tests in the Pleasant Hill area indicate that the Cockeysville Formation is capable of yielding groundwater at a rate of several hundred gallons per minute (Woodruff and Plank, 1995).

The Cockeysville Formation receives significant quantities of recharge water due to sinkholes that have developed in the streambeds (Woodruff and Plank, 1995). These and other sinkholes characteristic of the formation put the aquifer at considerable risk of being quickly contaminated by human activities that introduce contaminants to streams and land areas within the valleys underlain by the Cockeysville.

Due to the Cockeysville Formation's significance as a water supply source, the Water Resources Agency for New Castle County has mapped it as a Water Resource Protection Area (WRPA), which is protected by New Castle County ordinance. The WRPA ordinance is designed to protect the quality and quantity of ground- and surface water for water-supply purposes through controls that restrict the percent impervious and density of new developments.

Piedmont Fluvial Deposits

As mentioned previously, unconsolidated, fluvial deposits (silts, sands, and gravels) cap the Piedmont Province rocks in some areas. These sediments are generally less than 50 feet thick, with the Columbia Formation comprising the bulk of the sediment volume. The majority of the deposits occur in the southern portion of the Piedmont Province just north of the Fall Line (the boundary between Piedmont rocks and Atlantic Coastal Plain sediments). A relatively thin cover of Columbia sediments also occurs in the eastern portion of the Piedmont Province, along the Delaware River. The gravels of the Bryn Mawr Formation (whose age currently is unknown) occur in three isolated areas north of Wilmington (Woodruff and Thompson, 1972 and 1975). Neither the Columbia nor the Bryn Mawr formation is considered a significant aquifer due to their limited areal extent and relative thinness. The Columbia Formation will be discussed in more detail in the next section.

The Atlantic Coastal Plain Province

The Christina River watershed lies primarily within the Atlantic Coastal Plain, which consists of an unconsolidated mass of caustic sediments that increases in thickness south of the Fall Line. Within the Christina River watershed, Delaware Geological Survey maps indicate that this sediment mass ranges from approximately 20 to 50 feet deep just south of the Fall Line to more than 500 feet deep near the southern portion of the basin. Two geologic formations — the Potomac Formation and the Columbia Formation—comprise the bulk of the Atlantic Coastal Plain sediments in the study area. Relatively small volumes of recent (less than 10,000 years old) and primarily fine-grained Holocene deposits are also found in some stream stretches, ponds, and marshes in the area. See Map 3.

The Potomac Formation

Deposition of the Potomac Formation occurred during the early to late Cretaceous period (Woodruff and Thompson, 1975). The sands, silts, and clays of this formation were derived from the emergent Appalachian chain and were laid down in a fluvial to deltaic depositional environment (Woodruff, 1977). The Potomac Formation is generally much thicker than the Columbia Formation and reaches a maximum thickness within the Christina River basin of approximately 450 feet around Bear, Delaware.

The Potomac Formation is primarily a fine-grained, vari-colored unit composed of pink, white, and gray clays (Woodruff, 1981). Sandy units do occur but are generally thin and not horizontally extensive in the northern portion of the Christina River basin where the formation is thin. To the south, where the formation thickens, lower sand units become thicker and more extensive. The thick sandy units are good aquifers; wells installed in these zones are capable of yielding 400 to 500 gallons per minute. In other areas, thin sandy zones are capable of yielding only several gallons per minute to wells (Woodruff, 1977). The largest percentage of groundwater used in upper New Castle County is derived from the Potomac Formation.

The Columbia Formation

The Columbia Formation lies on top of the Potomac Formation. While the thickness of the Columbia Formation is highly variable, it generally averages 20 to 30 feet thick in the Piedmont Basin. The poorly sorted sands, gravels, and silts of the Columbia Formation are much younger (Pleistocene) than the Potomac Formation and were deposited by glacial streams. These streams cut deeply into the underlying Potomac Formation in some areas and formed relatively deep valleys (paleochannels) that contain thick sections of the Columbia Formation (Woodruff, 1981). Areas with relatively thick deposits of Columbia sediments, and which may be indicative of paleochannels, include an area just east of Chestnut Hill and Iron Hill, from Brookside to just north of Cooch's Bridge; an area just northeast of Bear; and an area in the vicinity of Cherry Island, Delaware.

Where thick, the Columbia Formation makes a highly productive aquifer capable of producing well yields of several hundred gallons per minute. Due to its permeability, the Columbia Formation serves as a recharge area for the underlying Potomac aquifers. In some locations, the Columbia sands are in contact with underlying sands of the Potomac Formation. In these areas, the two formations serve as a single hydrogeologic unit or aquifer (Woodruff, 1981).

Table 3 provides a summary of the age relationships and lithology of the Atlantic Coastal Plain sediments within the Piedmont Basin.

Table 3

ROCKS OF THE ATLANTIC COASTAL PLAIN — PIEDMONT BASIN

ROCK UNIT NAME	AGE (millions of years)	GENERAL LITHOLOGICAL DESCRIPTION
Columbia Formation	Pleistocene Age 1.8 – 0.01	◆ Brown and tan, poorly sorted sands, gravels, and clays.
Potomac Formation	Cretaceous Age 140 – 65	◆ Predominantly vari-colored reddish white and gray clay and silt. ◆ Sandy zones are present.

The Influence of Geology on Stream Flow and Stream Quality

Most major streams in Delaware are considered to be *gaining streams*. In addition to receiving water directly through rainfall, gaining streams receive groundwater from the geologic formation in which they are in contact. The amount of groundwater discharged to streams is governed largely by the aquifer characteristics of the underlying and surrounding geologic formations. As noted earlier, formations such as the Wilmington Complex have limited aquifer potential and do not contribute as much water to a crossing stream as does the highly transmissive Columbia Formation.

Due to its acidic and slow-moving nature, groundwater is able to dissolve certain minerals from the formations that surround it and discharge these ions to streams. If groundwater constitutes a significant volume of the total water in a stream, then the chemistry of the area's geology may significantly affect stream chemistry. Thus, we can determine which streams would most likely be significantly influenced geochemically and make comparisons between existing and predicted stream water quality based on an area's leachable minerals. Information gathered from such comparisons may prove useful in studying and identifying surface-water contaminants.

Table 4 describes the major geologic formations that comprise each of the watersheds in the Piedmont Basin.

Table 4

MAJOR GEOLOGIC FORMATIONS COMPRISING THE PIEDMONT BASIN'S SIX WATERSHEDS

PIEDMONT WATERSHED	MAJOR GEOLOGIC FORMATION	GENERAL DESCRIPTION
Naamans Creek	Wilmington Complex	Limited Columbia Formation deposits occur near the Delaware River.
Shellpot Creek	Wilmington Complex	Most of the Bryn Mawr Formation deposits occur within this watershed. A small southern portion of the watershed contains Atlantic Coastal Plain sediments.*
Brandywine Creek	Wissahickon Formation Wilmington Complex	The Wissahickon Formation is highly faulted and occupies the northwest portion of the watershed. The Wilmington Complex predominates in other areas.
Christina River	Columbia Formation Potomac Formation	The majority of the watershed lies within the Atlantic Coastal Plain. Wilmington Complex rocks exist in a substantial area in the northeast portion of the watershed.
Red Clay Creek	Wissahickon Formation	Wilmington Complex rocks exist in the southern portion of the watershed. A small portion of the Cockeysville Formation occurs in the northern portion of the watershed in the Yorklyn area.
White Clay Creek	Wissahickon Formation	Wilmington Complex rocks exist in the southern portion of the watershed. Most of the Cockeysville Formation occurs in this watershed. The Cockeysville Formation is found in the Hockessin and Pleasant Hill areas.

** Based on field survey data obtained by DNREC's Division of Water Resources, Environmental Services Section, Piedmont streams do not deeply incise the Atlantic Coastal Plain. Comparisons of stream depths and Columbia Formation thickness indicate that most of the stream bottoms occur within the Columbia Formation. Groundwater contributions to the streams in the Atlantic Coastal Plain are therefore primarily through the Columbia, not the Potomac Formation. As stated previously, all six watersheds — with the exception of Naamans Creek — contain Atlantic Coastal Plain sediments in relatively small areas in their extreme southern portions.*

GROUNDWATER

Groundwater is defined as the water that occurs beneath the water table in soils and geologic formations that are fully saturated. Groundwater studies, however, must also consider subsurface water found above the water table — termed the "unsaturated (or vadose) zone" — as well as water bodies on the land surface. All three are tightly interrelated as part of the hydrologic cycle.

Groundwater is both an important environmental and economic resource in the Piedmont Basin because it provides base flow to streams and wetlands (particularly important during times of low rainfall and drought), and it supplies water for domestic, public, and industrial users. Compared to the remainder of the state of Delaware, where groundwater is essentially the sole source of fresh water, the Piedmont Basin has significant fresh surface-water resources, which support the majority of human needs in the area.

Groundwater Quality Characteristics

Groundwater is found throughout the Piedmont Basin at relatively shallow depths beneath the land surface. However, the quantities of groundwater differ significantly between the two geologic provinces in the basin — the Piedmont and the Atlantic Coastal Plain. With the exception of the Cockeysville Formation, the crystalline rocks of the Piedmont have much less usable quantities of groundwater than the unconsolidated sands and gravels of the Atlantic Coastal Plain. Because of these marked differences between the two provinces and their hydrogeologic character, groundwater quality will be addressed within the watershed assessments with these two provinces in mind.

General groundwater-quality information is provided for each of the six watersheds in the Piedmont Basin. Sources of information include reports from the Delaware Geological Survey; U.S. Geological Survey; public water-supply purveyors; industry reports; Office of Drinking Water records; DNREC; and the Water Resources Agency for New Castle County. This information comes from a patchwork of sources since an overall groundwater-quality monitoring network does not exist for the Piedmont Basin.

Information on existing or potential sources of groundwater contamination has also been assembled; their locations are demarcated on Map 4. These include National Priority List sites, Hazardous Substance Control Act sites, active solid waste sites, hazardous waste treatment/storage/disposal sites, leaking underground storage tank sites, and non-hazardous waste sites. Information on nonpoint sources was obtained from the *1996 Delaware Watershed Assessment Report (305[b])* and includes land used for agriculture and unsewered areas with septic system use.

The special water resource areas referenced in this section are defined as follows:

Class A Wellhead Protection Areas — Areas within a 300-foot radius around community public water-supply wells.

Class B Wellhead Protection Areas — Glendale and Eastern States Wellfield, delineated using EPA code.

Class C Wellhead Protection Areas — Wellhead areas delineated by use of geologic and hydrologic maps and reports.

Recharge Protection Areas — Areas having the best potential for groundwater recharge.

Cockeysville Formation — Areas that are directly underlain by the Cockeysville Formation.

Hoopes Reservoir Watershed — The sub-watershed that drains into Hoopes Reservoir.

Public Water-Supply Intakes — Surface-water intakes used for supplying drinking water to community water systems. Note that only community public water-supply wells are presently included under the Water Resource Protection Area (WRPA) ordinance and the associated WRPA maps. DNREC and New Castle County have, however, identified the locations of all non-transient, non-community wells.

The following material will be presented by watershed; however, some of the studies referenced did not consider watershed boundaries. While many surface-water and shallow groundwater-flow patterns allow for a watershed-by-watershed approach, deeper unconfined or confined aquifer systems do not follow watershed boundaries. Rather, regional flow patterns, large pumping well centers, and other geologic and hydrogeologic factors control flow rather than the topographic boundaries between watersheds and basins. With this in mind, this assessment includes information available for the Potomac Aquifer, including deeper portions where wells draw water from these regional flow regimes. This approach was taken because major groundwater sources occur within these confined or semi-confined aquifers.

Naamans Creek Watershed Characterization

The Naamans Creek watershed extends from northeastern Delaware into extreme southeastern Pennsylvania. The area is underlain exclusively by rocks of the Wilmington Complex. Water-yielding potential is low, and only one shallow public water-supply well (Crestfield Water Company) is found in the upper part of the basin. No other Water Resource Protection Areas are found in the watershed. The watershed is primarily urban/residential (76%).

Water-quality results for the Crestfield Water Company well revealed nitrates at 5.1 and 4.3 mg/l for 1990 and 1995, respectively. These levels are below the drinking water standard of 10 mg/l, but are above an assumed ambient level of 1–2 mg/l. Thus, groundwater in this area is being impacted by human activities such as septic system use, lawn fertilizer, or present/past agricultural activities. Information on organic chemical analyses for this well was not available from the Office of Drinking Water data base.

Shellpot Creek Watershed Characterization

Almost all of the Shellpot Creek basin is found within the Piedmont geologic province, composed of igneous rocks of the Wilmington Complex that generally have low water-bearing capacity. However, the northwestern portion of the basin parallel to Concord Pike (Route 202) contains sediments of the Piedmont province in excess of 10 feet but less than 50 feet. Considered the Bryn Mawr Formation, these unconsolidated sediments do not yield significant quantities of groundwater due to their thinness and limited areal extent. The extreme southern part of the basin is located in the Atlantic Coastal Plain, composed of the Cretaceous-aged Potomac Formation and Quaternary-aged sediments.

No public water-supply wells or Water Resource Protection Areas are found within this watershed.

Brandywine Creek Watershed Characterization

Almost all of the Brandywine Creek watershed is found within the Piedmont geologic province — with the northern half underlain by rocks of the Wissahickon Formation and the southern and eastern area underlain by the Wilmington Complex. A small area in the northeastern corner, adjacent to Concord Pike (Route 202), contains unconsolidated sediments of the Bryn Mawr Formation.

Water-well production is variable but averages 10 gpm in the gneisses and schists of the Wissahickon while the Wilmington Complex rocks have somewhat lower yields. Water is obtained from weathered rock atop the bedrock and from fractures within the bedrock.

Four public water-supply wells are found in the northern part of the Brandywine Creek watershed within the Wissahickon Formation and are owned by Winterthur. All four are in very close proximity to one another and are found to the northeast of Hoopes Reservoir. Although no other community public water wells are found within this watershed, the City of Wilmington's two water-supply intakes (and its only direct source of water) are found on Brandywine Creek located near the Interstate 95 overpass.

Analytical data available for the Winterthur community public water-supply wells are very limited from the Office of Drinking Water data base. Additional information may be available within hard-copy files.

Red Clay Creek Watershed Characterization

Almost all of the Red Clay Creek watershed is found within the Piedmont geologic province, composed of rocks of the Wissahickon Formation in the northern half and the Wilmington Complex in the south. The extreme southern portion, near Stanton, lies within the Atlantic Coastal Plain. The eastern arm of the Cockeysville Formation is located in the northwestern part of the basin; however, most of the Cockeysville Aquifer extends southwest of this arm into the White Clay Creek basin. The Cockeysville Formation is an important aquifer, with major public water-supply wells owned by the Artesian Water Company. These will be described in the White Clay Creek watershed assessment, since 90% of this formation is found there and all the public water-supply wells are located there.

According to the U.S. Geological Survey, groundwater discharges into Brandywine Creek along most reaches. However, there appears to be some conflict between the U.S. Geological Survey study (1993) and the Delaware Geological Survey – U.S Geological Survey Cockeysville Aquifer study (1995). The former indicated that the Red Clay Creek may be "losing" water into the Cockeysville Aquifer as it crosses the area underlain by the aquifer just west of Yorklyn. This may be the result of either nearby pumping wells or pumping centers in the main body of the aquifer located in the White Clay Creek watershed. Regardless, the aquifer appears very sensitive and vulnerable to surficial contamination.

There are two community public water-supply systems. The Lower Snuff Mill well is located near the Cockeysville Formation in the northwestern corner of the basin. A second system, composed of three wells owned by the Methodist Country Home, is located within the Hoopes Reservoir subwatershed located along the northeastern boundary of the Red Clay Creek watershed. In addition to these public water-supply wells, Hoopes Reservoir and its drainage area are located in the northern half of the basin. This reservoir is used by the City of Wilmington to store water which is pumped from Brandywine Creek to Hoopes Reservoir for storage. In addition, the United Water Company maintains two water-supply intakes at the confluence of Red Clay Creek and White Clay Creek at the southern extreme of these watersheds. While Artesian Water Company relies on groundwater from wells, United Water relies on these surface-water intakes to supply its customers.

Inorganic analytical data for October 1995 from the Methodist Country Home had background nitrate levels (less than 1 mg/l) and iron levels that exceeded the secondary maximum contaminant level of 0.3 mg/l. Organic analytical data were not available from the data base. No information is available for the Lower Snuff Mill well, and the Office of Drinking Water no longer classifies it as a community public water supply.

The U.S. Geological Survey completed the first of two reports (Vogel et al., 1993) on groundwater quality in the Red Clay Creek watershed. Groundwater base flow discharging to the stream ranged from 62% –71% of stream flow over the study periods. Along most of the stream reach, water flows from groundwater into the stream except where the stream flows over the Cockeysville Formation and possibly along a reach near Hoopes Reservoir. Groundwater-quality sampling was not done as part of the most recent report, but groundwater data from the Pennsylvania portion of the watershed were summarized. A second U.S. Geological Survey report on water quality in the watershed is expected and, when available, should be included in the Piedmont Basin assessment.

White Clay Creek Watershed Characterization

The northern and western portions of the White Clay Creek watershed are found within the Piedmont geologic province, consisting of rocks of the Wissahickon Formation, the Wilmington Complex, and two surface exposures of the Cockeysville Formation. Some thin sections of unconsolidated Quaternary-aged sediments are found atop the Wilmington Complex bedrock from Newark east-northeast toward Stanton. The remainder of the southern and eastern portion of the basin is in the Atlantic Coastal Plain, which contains the Potomac Formation overlain by Quarternary-aged sediments that range from 50 feet thick in the Newark area to 0 feet near the Fall Line.

According to Martin et al. (1984), the lower Potomac Aquifer subcrops within all the Coastal Plain portions of the White Clay Creek watershed and the northern portion of the Christina River watershed located south of the White Clay Creek watershed. Many of the City of Newark's southern wells are screened within this aquifer.

A number of important groundwater supplies are found within the watershed, including supply wells in the Hockessin Valley within the Cockeysville Aquifer, the Laird Track wells within the Wissahickon Formation, and the northern half of Newark's southern wellfield. Eleven Class-A Wellhead Protection Areas (the 300-foot radius surrounding community public water-supply wells) are found within these three well fields. Approximately 90% of the Cockeysville Aquifer is found in the northeastern corner of the watershed, and a second small exposure of Cockeysville marble is located north of Newark along Pike Creek. Two Class-B Wellhead Protection Areas consisting of the Laird Tract wells and the northern part of the Newark southern wellfield are found in the Newark area. Important public water-supply intakes are also found within the watershed including the City of Newark's intake located north of Newark on White Clay Creek and the United Water intakes at the confluence of Red and White Clay creeks. Portions of two small recharge protection areas are also found in the eastern portion of the watershed — one within Newport and the second just to the east of Churchmans Marsh.

The Delaware Geological Survey (1977) investigated groundwater availability within the Piedmont province of White Clay Creek. This study identified the Pike Creek (Cockeysville) Marble Southern Exposure and the Laird Tract as having water-supply potential due to the presence of fractures. Water-quality information from this study indicated that iron and manganese were significant and would require treatment. The City of Newark is not currently using the Laird Tract wells due to the iron problem. However, according to Mr. Stewart Lovell (pers. comm.), Artesian Water Company may begin using existing wells in the southern exposure of the Cockeysville Formation along Pike Creek.

Information on water quality from the Office of Drinking Water is not structured to allow individual wells to be identified with analytical data. However, DNREC is exploring the possibility of obtaining well-specific analytical data directly from Artesian Water Company. The information was not available at the time of this assessment.

Upper Christina River Watershed Characterization

The upper Christina River watershed extends from a line at Ogletown south, with the upper Christina watershed to the west and the lower Christina watershed to the east. Most of the watershed is composed of Potomac Formation sediments overlain by Pleistocene-aged sediments of the Columbia Formation that range from 0 – 80 feet thick. The Iron Hill and Chestnut Hill intrusive rocks rise as an island to the southwest of the University of Delaware stadium and are mapped as gabbro and chert. The Christina River runs along the northeastern face of these rocks. The extreme northwestern corner of the basin south of McClellandville consists of rocks of the Piedmont province, with the Wissahickon in the north and Wilmington Complex rocks south of these. The Fall Line runs essentially along the Baltimore and Ohio Railroad to the west of the City of Newark.

Most of Newark's southern wellfield is located in the northern corner of the upper Christina River watershed. Iron problems, however, have prevented Newark from using these wells to their potential. Another wellfield is located on the south side of Iron Hill, and a portion of the Eastern Estates wellfield is found along the Maryland state line in the southwestern corner of the basin.

Thirteen Class-A Wellhead Protection Areas are found in the watershed, most within the Class-B Wellhead Protection Areas of Newark and of Eastern Estates. Very small recharge protection areas are also found in the southern half of the watershed.

The City of Newark has conducted an investigation of the iron problems within its southern wellfield. Analytical data from the Division of Public Health do not identify specific wells but do give an overall assessment of the types of contaminants found throughout the wellfields. Data from 1993 to 1995 reveal nitrate levels ranging from non-detectable to 8.4 mg/l. No levels above 10 mg/l were found. Iron levels were well above the 0.3 mg/l secondary maximum contaminant level in some of the wells with high values of 8.2 mg/l found in a few samples. Approximately half the samples exceeded 0.3 mg/l of iron.

Organic contaminants also continue to be detected within Newark's public water-supply wells although certain wells appear to be responsible for many of the organic chemicals that were found. However, a much more thorough analysis of the Division of Public Health records is needed to pinpoint those wells that have specific problems. The organic chemicals found include dichlorodifluoromethane, 1,1-dichloroethane, trichlorofluoromethane, chloroform, benzene, tetrachloroethene, trichloroethene, 1,2-dichloropropane, dichloromethane, chloroethane, chloromethane, 1,2-dichloroethane, bromodichloromethane, and trihalo-methanes (disinfection by-products). Some wells, such as Well Number 8, have been taken out of service due to organic chemical contamination.

Lower Christina River Watershed Characterization

The entire southern and western part of the lower Christina River watershed is found within that portion of the Atlantic Coastal Plain composed of the Potomac Formation overlain by Quaternary-aged sediments. The northeastern portion of the basin is composed mostly of rocks of the Wilmington Complex located north of the Fall Line. This area is largely urban with Elsmere and southwestern Wilmington located here.

Quarternary-aged sediments greater than 40 feet have been identified in the eastern end of the basin — in the vicinity of Cherry Island and along the southern shore of the Christina River at its mouth into the Delaware River. Another similar unit is found near Wilmington Airport. Both a recharge protection area and Class-A Wellhead Protection Area exist here also. Thick Quaternary-aged sediments just north of Bear contain an important Wellhead Protection Area and a Recharge Protection Area associated with public water-supply wells (the Glendale wellfield) of Artesian Water Company.

Two surface-water supply intakes used for drinking water are found in the lower Christina watershed on Smalley's Pond, which is located southwest of Christiana, on the Christina River.

Numerous studies associated with the Potomac Aquifer have been conducted within the Christina River watershed. Various references describe two or three recognized aquifer units within the Potomac Formation — the lower, middle, and upper. However, the fluvial processes that deposited these sediments are such that sand bodies are discontinuous both areally and vertically. The lower aquifer unit subcrops within much of the Christina watershed — mainly on the north side of the river, north of Interstate 95. The middle aquifer unit subcrops within the Christina watershed near the Christina River — south of the river in the western area, along it in the central area, and south of it in the eastern part of the watershed. The upper Potomac Aquifer subcrops farther south and outside of the Piedmont Basin within the Delaware River, Red Lion Creek, Dragon Run Creek, and Chesapeake and Delaware Canal watersheds.

Two important wellfields, the Glendale wellfield and the Airport public water-supply wells, are sampled by Artesian Water Company. As with the Cockeysville Aquifer wells, DNREC is exploring the possibility of obtaining well-specific analytical data directly from Artesian Water Company. That information was not available at the time of this assessment.

Trends

Information on groundwater quality is limited to what is available from existing regulatory programs. This discussion will focus on (1) overall quality based on Delaware Geological Survey information, and (2) public water-supply monitoring data from the Division of Public Health's Office of Drinking Water.

Groundwater-quality information is also available on specific sites with potential groundwater-quality impacts such as leaking underground storage tanks, hazardous waste, Superfund, and non-hazardous waste sites. This type of information generally contains groundwater-quality information specific to the facility being regulated. For instance, although there are many monitoring wells associated with leaking underground storage tank sites, analytical data is very specific to gasoline-indicative compounds (benzene, toluene, ethylbenzene, and xylenes). While these data are important for regulatory purposes, they will be of limited value in evaluating overall trends in groundwater quality. See "Sources of Impacts" in this section for a description of the types of groundwater monitoring requirements at these regulated facilities.

Public Water-Supply Well Data

This evaluation focuses on specific public water-supply well systems found within the Piedmont Basin. Data are derived from the Office of Drinking Water for all systems other than those of the Artesian Water Company. The latter data come from the Artesian laboratory.

Cockeysville Formation. The U.S. Geological Survey and the Delaware Geological Survey (Woodruff and Plank; Werkheiser, 1995) collected water-quality samples from wells and streams in the Cockeysville Aquifer area from 1990 to 1991. Twenty-nine well-water samples were analyzed for major ions, nutrients, trace metals, and radon. Six wells were resampled and analyzed for organonitrogen and organophosphorous pesticides and were scanned for volatile organic compounds. The following were some key findings:

- The chemistry between the streams draining into the Hockessin Valley and the Cockeysville Aquifer supported hydrologic studies that indicate that streams lose water into the aquifer in the Hockessin Valley and thus, are a source of recharge into the Cockeysville Aquifer. None of the chemical constituent concentrations exceeded EPA maximum contaminant levels although three exceeded secondary maximum contaminant levels.
- None of the samples exceeded the nitrate maximum contaminant level of 10 mg/l; however, most were above 2 mg/l, which indicates the influence of human activity.
- No measurable concentrations of pesticides or volatile organic compounds were detected although only six wells were sampled.
- Chloride concentrations were indicative of human activity such as road salting and waste disposal.

Newark South Wellfield. Considerable study has been devoted to evaluating iron and manganese problems from wells in Newark's south wellfield (Duffield and Hill, 1994). This study was an outgrowth of a recommendation by the *Newark Water Supply Advisory Committee Report* (1991), which addressed numerous issues concerning the city's water system.

The Delaware Division of Public Health noted historic problems with organic contaminants: tetrachloroethylene (Well Number 8, 1984), benzene (Well Number 13, 1986), tetrachloroethylene (Well Number 15, 1989), and iron (Well Numbers 15 and 16, 1990). (Well Number 8 was taken out of service due to tetrachloroethylene contamination.)

Treatment of these water supplies reduced concentrations of organic contaminants to below levels of concern. Consequently, the sources of these contaminants have not been thoroughly investigated. There are, however, various potential sources in the area.

The south wellfield was investigated as to the cause of iron and manganese contaminations, which began to rise dramatically in 1989. All these wells are found in the Atlantic Coastal Plain and draw water from both the Potomac and Columbia sands. The key finding of this study was that the source of dissolved iron was from the dissolution of iron-containing minerals — siderite and pyrite. The report argues that marked increases in dissolved iron were due to recharge declines or water withdrawal increases, causing water to be produced from less permeable sections of the aquifer. Since siderite and pyrite minerals were prevalent in these less permeable sections of the aquifer, iron concentrations dramatically increased.

However, there is technical disagreement about these findings. The behavior of production Well Number 15 seemingly favors the consultant's interpretation, with fluctuating iron concentrations declining in 1993 – 1994. An anthropogenic source would be less likely to follow this pattern.

Wellfields Requiring Further Evaluation. The following wellfields may be evaluated further once DNREC has completed work with both the Delaware Office of Drinking Water and the Artesian Water Company aimed at allowing access to analytical data for specific wells: Glendale Wellfield (AWC), Wilmington Airport wells (AWC), Crestfield Water Company, Winterthur, Methodist Country Home, and Newark Laird Tract Wellfield.

Sources of Impact

Groundwater quality may be impaired by both natural and anthropogenic sources. The most common natural quality problems are dissolved iron, chloride, dissolved solids, sulfur compounds, and pH. In many instances, these naturally occurring problems may be the secondary result of groundwater pumpage such as with saltwater intrusion and suspected iron problems at the Newark south wellfield.

Anthropogenic sources are from both point-source discharges and nonpoint source practices. Common contaminants associated with these sources include nitrates, iron, chlorides, pesticides, volatile organic compounds, semivolatile organic compounds, and dissolved metals. The locations of known regulated point sources have been plotted on Map 4. Estimates for typical nonpoint sources were taken from the *1996 Delaware Watershed Assessment Report (305[b])*. Table 5 summarizes the number and type of contaminant sources by watershed.

Table 6 summarizes the number and type of potential sources of contamination that are within, or less than 150 meters from, Water Resource Protection Areas; and Maps 5 and 6 show their locations. (This type of analysis was not possible prior to the Piedmont Basin Assessment and is the result of improvements in DNREC's GIS capabilities and support from other agencies.)

Groundwater-Quality Data at Regulated Facilities

Hydrogeologic and groundwater-quality information is routinely collected at many facilities that have the potential to affect groundwater quality. The Delaware Comprehensive State Groundwater Protection Profile summarized state programs that collect groundwater-quality and quantity information. Table 7 summarizes these programs and the type of groundwater-quality information collected. Most programs are found within DNREC, although important programs are also found in the Delaware Department of Agriculture and the Delaware Division of Public Health.

The Delaware Geological Survey also collects basic information but does not regulate facilities causing groundwater-quality problems. Groundwater-quality information from both the Delaware Geological Survey and the U.S. Geological Survey has been described under each watershed assessment.

Naamans Creek Watershed Contaminant Sources

Most potential point sources of contamination in the Naamans Creek watershed are found in the lower portion of the watershed to the east of Interstate 95 and adjacent to the Delaware River. These include 2 Treatment, Storage, and Disposal (TSD) sites (Sun Company and General Chemical) and 19 Leaking Underground Storage Sites (LUSTs). Four of the LUST sites have likely affected groundwater quality. Other sites include 6 federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or state Hazardous Substance Control Act (HSCA) sites, and 33 hazardous waste generators.

The Sun Company refinery straddles the Pennsylvania-Delaware state line, with a small portion extending into the northeastern tip of Delaware. The Pennsylvania Department of Environmental Protection has assumed environmental oversight, with coordination by the Delaware Hazardous Waste Management Branch. The Sun Company has identified 10 contaminated areas at their site, one of which occurs in Delaware and is identified as Area 5. Groundwater monitoring wells have been installed, and sampling has been done since 1990, which identified and delineated both light and dense non-aqueous phase liquid plumes in the unconfined aquifer. Seeps of these contaminants have reportedly occurred along both the northern and southern banks of Middle Creek, which flows into the nearby Delaware River.

The General Chemical Corporation has two major areas being evaluated as part of a Resource Conservation and Recovery Act (RCRA) closure: the Spent Acid Lagoon area and East and West Lagoons area. For the Spent Acid Lagoon, quarterly sampling for pH, specific conductance, Appendix IX metals, and RCRA detection monitoring parameters are required. Monitoring of full Appendix IX parameters are required for the East and West Lagoons area. For the Spent Acid Lagoon, monitoring is required for very low pH and numerous metals with high concentrations, including tin, antimony, arsenic, cadmium,

Table 5

SUMMARY OF POTENTIAL CONTAMINANT SOURCES AND SPECIAL WATER RESOURCE PROTECTION AREAS BY WATERSHEDS FOUND IN THE PIEDMONT BASIN

Sources of Contamination	CERCLA & HSCA Sites	Hazardous Waste Generators	#TSD Sites	# Solid Waste Sites	Resource Province	#LUST w/GW ImpactS	#LUST w/o GW Impacts	Total LUST	#W/W Disposal Sites	Domestic Septics Percent of Basin	Agricultural Percent of Basin	Water Resources	Class-A Wells Community PWS	Wellhead Area Class B & C	Recharge Areas	Cockeysville Aquifer	Surface-Water Intakes
Christina River	62	354	3	14	2	59	96	155	0	10.2%	22%	–	20	4	11	0	1
White Clay Creek	20	104	0	2	0	19	31	50	0	8.70%	26%	–	11	11		90%	2
Red Clay Creek	6	40	1	1	0	6	21	27	1	8%	27%	–	2	2	0	10%	2
Brandywine Creek	10	77	1	0	0	11	43	54	1	15.8%	26%	–	4	4	0	0	1
Shellpot Creek	8	57	2	13	1	11	22	33	0	10.4%	2%	–	0	0	0	0	0
Naamans Creek	6	33	2	0	0	4	15	19	0	<1%	4%	–	1	1	0	0	0
Total in Basin	**112**	**665**	**9**	**30**	**3**	**110**	**228**	**338**	**2**				**38**	**4**	**n/a**	**n/a**	**6**

Table 6

SUMMARY OF POTENTIAL CONTAMINANT SOURCES THAT ARE WITHIN OR LESS THAN 150 METERS FROM WATER RESOURCE PROTECTION AREAS

	Sources of Contamination	CERCLA & HSCA Sites	Hazardous Waste Generators	#TSD Sites	# Solid Waste Sites	Resource Recovery Facility	#LUST w/GW IMPACTS	#LUST w/o GW Impacts	TOTAL LUST	#W/W DISPOSAL SITES
Water Resource Protection Areas	**Class-A Wells Community PWS***	0	6	0	0	0	1	5	6	0
	Class-B & C Wells Community PWS*	9	48	0	1	0	4	6	10	0
	Recharge Protection Areas*	5	34	0	0	0	11	13	24	0
	Cockeysville Aquifer*	5	4	0	0	0	3	8	11	0
	Hoopes Reservoir	0	1	0	0	0	0	0	0	0
	Numbered Sites Within All WRPAs	17	71	0	1	0	16	11	27	0

chromium, cobalt, nickel, zinc, cyanide, and mercury. The East and West Lagoon samples are monitored for numerous volatile (especially chlorobenzene and benzene) and semi-volatile compounds (especially the dichloro-benzene family), as well as pesticides.

Nonpoint sources from agriculture and on-site domestic septic systems are negligible although urban runoff and related sources may affect groundwater quality. However, nitrates in a public water-supply well indicate nonpoint source impacts, likely from septic systems or fertilizer application.

Shellpot Creek Watershed Contaminant Sources

The Shellpot basin contains 2 HSCA sites, 2 TSD sites (Harper Thiel site and the DuPont Edgemoor site), 3 solid waste sites (the DP & L Edgemoor Ash Landfill, DuPont Edgemoor Landfill, and much of the Cherry Island Landfill), and 33 LUST sites. All solid-waste facilities, HSCA sites, and 1 TSD site are located in the lower portion of the basin adjacent to the Delaware River. LUST sites are scattered throughout the basin and, of these, 11 have significantly affected groundwater quality. A number of these LUST sites are found within the Bryn Mawr Formation and thus were included within this basin although they are located on the boundary between the Shellpot and Brandywine Creek basins. A clear boundary resolution is needed as well as individual site groundwater-flow direction evaluations. Other sites include 33 hazardous waste generators.

The DuPont Cherry Island Landfill collects water elevations and chemical analyses with semiannual data from wells in the 20-foot zone (dredge spoils), 50-foot zone (recent Delaware River floodplain sediments), and 90-foot zone (Columbia Formation). Analytical data include total dissolved solids, total organic carbon, pH, specific conductance, chlorides, ammonia, iron, lead, zinc, manganese, and nickel.

The DP & L Edgemoor Ash Landfill collects water levels and chemical analyses with quarterly data from three shallow wells completed in the Columbia Formation. Analyses include pH, sulfate, total dissolved solids, specific conductance, chloride, and 13 metals.

The Delaware Solid Waste Authority's Cherry Island Landfill collects water levels and chemical analyses with quarterly, semiannual, and/or annual data from wells developed in the dredge spoil, recent floodplain sediments, the Columbia Formation, and the Potomac Formation. A large number of parameters are measured. The Wilmington Sewage Treatment Plant lagoons are also affecting groundwater quality and are located near the Cherry Island Landfill.

The basin contains 646 acres that are not serviced by central sewer. Thus, there is a potential impact from domestic septic systems. Only 2% of the watershed contains agricultural lands. As in most watersheds in the Piedmont, stormwater and related urban sources of contamination may also contribute to groundwater-quality degradation.

Brandywine Creek Watershed Contaminant Sources

The Brandywine Creek watershed contains 10 CERCLA HSCA sites, 1 TSD site (DuPont Experimental Station), 1

Table 7

STATE PROGRAMS COLLECTING GROUNDWATER QUALITY AND QUANTITY INFORMATION

PROGRAM	FREQUENCY OF GROUNDWATER MONITORING	Typical Analyses	Data Repository	Status of Mapping and Geo-referencing	Responsible Agency
Wastewater Spray Irrigation	Quarterly (could be more or less frequent for specific sites)	Metals, nutrients, water levels	Hard copy; more recent data currently being placed into electronic data base	Sites in DNREC - GIS. Many have corrected GPS locations	DNREC Groundwater Discharges Section
Large On-Site Septics	Quarterly (could be more or less frequent for specific sites)	Nutrients, chloride, bacteria, water levels	Hard copy; more recent data currently being placed into electronic data base	Sites in DNREC - GIS. Many have corrected GPS locations	DNREC Groundwater Discharges Section
Sludge Application	Quarterly (if required)	Metals, nutrients, water levels	Hard copy	Individual site files	DNREC Surface Water Discharges Section
Underground Injection Control	Required at sites with a UIC permit as part of corrective action	Specific to type of cleanup	Hard copy	Individual site files	DNREC Groundwater Discharges Section
Solid-Waste Facilities	Semiannual or quarterly; summarized in yearly reports	Priority pollutants or TCL; (may use indicator parameters); water levels	Hard copy in site files	DNREC - GIS on all active facilities	DNREC Solid Waste Branch
Federal CERCLA/State HSCA (Hazardous Waste Sites)	Various sampling events - site investigation, remedial investigation, corrective action, long-term monitoring - site specific frequency	Priority pollutants; TCL; water levels	Hard copy in site files and summary in remedial investigation reports	Site maps on file; GIS - ??	DNREC Site Investigation and Remediation Branch
Hazardous Waste Facilities	Quarterly with annual summaries; annual Appendix IX sampling	Site specific compounds; RCRA Appendix VIII and IX; indicator parameters; water levels	Hard copy in special groundwater section of files	GPS available on most sites	DNREC Hazardous Waste Management Branch
Underground Storage Tank	One-time during investigation; periodic monitoring during corrective action	Benzene, toluene, ethylbenzene, xylenes, total petroleum, hydrocarbons; haz substances (rarely); water levels	Hard copy in facility file	GPS for leaking USTs in New Castle County, on-going in Kent and Sussex counties	DNREC Underground Storage Tank Branch
Groundwater-Quality Studies	Variable for specific studies; long-term monitoring on established frequency	Nutrients, chlorides, pesticides; water levels	Hard copy for specific studies; long-term monitoring on data base	Sites not mapped; long-term monitoring in site file; GPS on wells	DNREC Water Supply Section
Emergency Response	One-time specific to incident	Specific to incident	Hard copy in site file	Sites not mapped	DNREC Emergency Response Branch
Nonpoint Source	Variable for limited-term special studies	Nutrients; water levels	Site files	Sites not mapped	DNREC Nonpoint Source Program
Water Allocation	Daily water withdrawal rates; weekly water levels reported monthly in annual reports	Water-use reports; well water levels	Hard copy in water-use files; Delaware Water Use Data System data base	Latitude/longitude available in DWUDS (mostly LORAN, some GPS corrected)	DNREC Water Supply Section
Public Water-Supply Program	Varying frequency for different systems and for different chemicals	All chemicals with maximum contaminant levels	Hard copy files; recent data in electronic data base	Almost all community PWS wells have GPS-corrected locational data	Delaware Division of Public Health
Pesticide	System began in 1996 - 111 wells statewide	Six pesticides with SMP requirements	N/A	Confidential data base	Delaware Department of Agriculture

wastewater spray irrigation site, and 54 LUST sites. Of these LUST sites, 11 have significant groundwater impacts. Most of these sites are located in the extreme southern portion of the basin within the City of Wilmington proper. Other sites include 77 hazardous waste generators.

The DuPont Experimental Station has groundwater samples analyzed initially on a quarterly and presently on a semi-annual basis for volatile organic compounds and field parameters. Eleven sampling events are scheduled to be performed over a five-year period. Various chlorinated solvents have been detected at significant levels, and benzene, toluene, ethyl benzene, and total xylene compounds at less significant levels.

The basin contains 2,313 acres that are not serviced by central sewer. The 1995 Delaware Comprehensive Statewide Wastewater Facilities Study identified the community as needing central sewer. This area is located in the extreme northwestern portion of the basin and extends into the Red Clay Creek basin along the Pennsylvania border. Approximately 26% of the watershed, located largely in the north, is used for agriculture, predominantly pastureland. The nonpoint source impacts from domestic septic systems and agriculture are ranked high and low, respectively, by the 1996 Delaware 305(b) report.

Red Clay Creek Watershed Contaminant Sources

The Red Clay Creek watershed contains 6 CERCLA/HSCA sites (Hercules Research Center), 1 TSD site, 27 LUST sites, and 1 wastewater spray irrigation site. Three LUST sites, 1 HSCA site, and 1 wastewater spray irrigation are located within or very near to the Cockeysville Aquifer. Almost all other sites are located in the southern extreme of the watershed near the Fall Line. Of the 27 LUST sites, 6 have documented groundwater impacts. Other sites include 40 hazardous waste generators.

The Hercules Research Center has two Solid Waste Management Units (SWMUs) which analyze for Target Compound List VOCs, semi-volatiles, metals, PCBs, pesticides, and cyanides. Despite significant impacts to soils at the two SWMUs, only low levels of VOCs (chlorinated solvents), pesticides, and a few metals have been detected in groundwater. In addition to groundwater samples collected thus far as part of RCRA Corrective Action, chlorinated solvents have been detected in on-site drinking water wells sampled by the Division of Public Health's Office of Drinking Water.

As with the Brandywine Creek watershed, the Red Clay Creek basin is 27% agriculture, but most is low-density pastureland. Central sewering does not exist for 1,577 acres, and one area in the northeastern corner of the basin has been identified as needing central sewer. The lower portions of the basin are urbanized, and stormwater and related urban sources of contamination may contribute to groundwater contamination.

White Clay Creek Watershed Contaminant Sources

The White Clay Creek watershed contains 20 CERCLA / HSCA sites and 50 LUST sites (of which 19 LUST sites have significant groundwater impacts). Although most of these sites are located in the southern portion of the basin within the City of Newark or the Newport area, five of the LUST sites are located within the Cockeysville Aquifer area in the Hockessin Valley. One of these has documented groundwater contamination. One CERCLA site is located in the Newport area north of Churchmans Marsh. Other sites include 104 hazardous waste generators.

Natural iron problems have been identified within the Laird Track and within wells in the Potomac Aquifer. One northern well of the south Newark wellfield was contaminated by tetrachloroethylene (PCE) and is no longer used, as described more extensively elsewhere.

At the DuPont Glasgow facility, two volatile organic carbon (VOC) plumes, at different locales, have been identified: one in the confined aquifer segment of the Columbia Formation; the other in the water-table aquifer portion. Groundwater is sampled for VOCs and field parameters at both areas. Compounds consistently detected include TCE, 1,1,1-TCA, 1,1-DCE, chloroform, PCE, di- and tri-chlorofluoromethane, total xylenes, ethylbenzene, and toluene.

Approximately 26% of the area within the White Clay Creek watershed is used for agriculture, but as with the Red Clay Creek watershed, these areas are not intensive and are regarded as a lower concern. Approximately 30% of the watershed does not have central sewer and is concentrated in the central part of the watershed in the Pike Creek Valley area. However, no areas have been identified as needing central sewer.

Upper and Lower Christina River Watershed Contaminant Sources

The upper and lower Christina watersheds collectively contain 62 CERCLA/HSCA sites, 3 TSD sites, and 155 LUST sites, of which 59 have groundwater impacts. There are 62 CERCLA/HSCA sites, 354 hazardous waste generators, 14 solid waste landfills, and 2 resource recovery facilities.

In the upper watershed, the LUST sites are scattered, with concentrations in the Newark area and at the intersection of Route 896 and Route 40. In the lower watershed, LUST sites are scattered throughout the basin, both on the northern and southern side of the Christina River watershed, although most are located to the east of Churchmans Marsh. Three

LUST sites and one HSCA site are found within the recharge protection area and close to public water-supply wells near Wilmington Airport. No LUST sites are located near the Glendale wellfield and recharge protection area. The DRPI industrial landfill is found along the south bank of the Christina River near Interstate 295. Two TSD facilities (DuPont – Chestnut Run, and General Motors) are found in the northeastern portion of the basin. DNREC's Superfund Branch and the Water Resources Agency for New Castle County began a study of site locations, historical land use, and environmental impacts from Superfund sites. Detailed maps are available, but no formal report was written.

Currently, quarterly water level and annual analytical data are being collected from the Columbia/Shallow Potomac Aquifer and the deeper Potomac Aquifer, and water level and chemical analyses are being performed at the DRPI Chesapeake and Delaware Landfill. Standard indicator parameters are also being collected.

As mentioned previously, iron problems have risen dramatically in recent years in wells located in the south Newark wellfield. One possible cause may be the oxidation of iron-containing compounds, (e.g., pyrite) which were exposed to oxygen during drought periods. Another possibility could be an as yet unidentified anthropogenic source. Regardless of the cause, iron treatment is needed for these wells. However, the City of Newark is now obtaining much of its water from a surface-water intake on White Clay Creek.

Salt-storage piles on the north side of Interstate 495 along the Christina River have caused local contamination by sodium and chlorides. A groundwater monitoring network existed in the early 1980s for the site. Other salt piles are also found on the southeastern side of Interstate 495. Other potential sources of groundwater contamination in this area include dredge spoils.

Natural saltwater intrusion problems may occur in the eastern portion of the basin. However, most large pumping centers are located to the southeast of the watershed. Sundstrom et al. (1967) argued that thick intervening clays prevent recharge to the Potomac aquifers from surface-water sources, and saltwater intrusion is unlikely. However, Phillips (1987) suggested that saltwater intrusion may occur due to erosion of continuing units and deposition of more permeable sands and gravels during the Pleistocene and Holocene periods in the vicinity of the Delaware River. Chloride concentrations above ambient levels (10 – 21 mg/l) have been found (40 – 8,600 mg/l). However, most of these areas are occurring in wellfields located to the southeast of the Christina River watershed. Modeling using various scenarios indicated that saltwater intrusion could occur due to recharge of river water caused by large pumping centers. DNREC currently monitors wells in the Potomac Aquifer adjacent to the Delaware River although most of these wells are located south of and outside of the Piedmont Basin.

Water in the Potomac Aquifer contains relatively low total dissolved solids (80 ppm), but total iron is higher than for other aquifers (Woodruff, 1970), ranging from 0 – 11 mg/l.

While much of the watershed is served by central sewer, relatively large pockets that are not sewered exist throughout much of the watershed, particularly along the western extent adjacent to the Maryland state line. The Christina River basin is 16% agricultural and 4,598 acres unsewered. The agricultural activities are of low concentration and are of minimal concern.

Positive Initiatives

Efforts to protect groundwater from becoming contaminated and, where contaminated, to clean up or minimize environmental or human health risks, are numerous and occur within local (county and municipal), state, and federal programs. Examples of all of these occur in the Piedmont Basin, where a large part of Delaware's population lives.

Water Resource Protection Area Ordinances

Both New Castle County and the City of Newark adopted ordinances that (1) delineate the most sensitive and valuable Water Resource Protection Areas (see Maps 5 and 6), and (2) establish standards for zoning requirements within these critical areas. Included as important Water Resource Protection Areas are groundwater recharge protection areas, wellhead protection areas (i.e., areas surrounding public water-supply wells), and the Cockeysville Formation (aquifer) protection areas. Both the city and county ordinances rely on the Water Resource Protection Area maps dated 1993. These maps are updated periodically and will likely be modified in 1997.

These ordinances address both groundwater-quantity and quality issues. First, they attempt to control practices that may reduce recharge from the surface into the groundwater system by minimizing the amount of impervious surface allowed on land within these areas, thus protecting the quantity of groundwater. Second, the storage of hazardous substances and petroleum products is controlled. This includes hazardous substances (listed in 40 CFR 116) in quantities above a "reportable quantity" (defined in 40 CFR 117), which are prohibited or tightly controlled by requirements for aboveground storage tanks and underground storage tanks. However, ultimate regulatory control of most hazardous substances resides within state or federal programs.

The county seeks the advice of a technical advisory committee composed of representatives from the following: the chemical industry, a local water company, Consulting Engineer's Council, Delaware Geological

Survey, DNREC, New Castle County Chamber of Commerce, New Castle County Department of Planning, New Castle County Department of Public Works, and the Water Resources Agency for New Castle County.

Water Resources Agency for New Castle County

Created under the auspices of New Castle County, the state of Delaware, the City of Newark, and the City of Wilmington, this agency advises the county, cities, and state on many water-quantity and quality issues, including the Water Resource Protection Area ordinance. The Water Resources Agency also maintains an extensive Geographical Information System (GIS) that covers the entire Piedmont Basin as well as the remainder of New Castle County.

Hazardous Substance and Waste Management Programs

The "Contaminant Sources" section of the *Piedmont Basin Preliminary Assessment Report* describes the numerous programs at the state level that address sources of contamination, including many that impact groundwater directly such as leaking underground storage tank sites, underground storage tank facilities, solid-waste landfills, hazardous waste treatment storage disposal facilities, federal and state Superfund sites, and non-hazardous waste sites. The cleanup and control of groundwater contaminants have always been an important priority in these programs. Most monitor for groundwater contamination using monitoring wells or vadose monitoring techniques.

Safe Drinking Water Act

The Safe Drinking Water Act provides for the regulation of public drinking water supply systems. The Delaware Division of Public Health, Office of Drinking Water, oversees the regulation of these — both surface-water and groundwater dependent systems. These regulations require periodic sampling of systems by the Division of Public Health's Office of Drinking Water. The Artesian Water Company samples its own supplies and provides the information to the Office of Drinking Water. This information is an important component in developing a groundwater monitoring system statewide.

DNREC's Water Supply Section is continuing efforts in coordination with the Office of Drinking Water to automate and link the drinking-water data base with the water-well data base. This type of information exchange allows for evaluations using existing sources of information for groundwater-quality data.

Comprehensive State Groundwater Protection Program (CSGWPP)

The coordination and integration of all programs (federal, state, and local) with groundwater protection responsibilities has been fostered under the Comprehensive State Groundwater Protection Program (CSGWPP) approach. DNREC has developed a profile of the status of all groundwater-related programs, which is included in the *Performance Partnership Agreement* between EPA and DNREC. Delaware's CSGWPP has been provided to EPA for their endorsement. Once the program has been endorsed, Delaware will be seeking greater flexibility in EPA-delegated groundwater protection programs.

SURFACE WATER

Surface water is all the visible water on the Earth's surface. In all its forms, including oceans, lakes, rivers, streams, and wetlands, surface water covers more than 70% of the Earth. Surface water is critical to all life cycles; it houses resources, nutrients, minerals, and energy, and provides a three-dimensional medium for flora and fauna.

Delaware has diverse surface-water resources, from faster-moving Piedmont streams to slow-moving Coastal Plain streams, the Delaware Bay and Inland Bays estuaries, and many tidal rivers containing fresh or brackish waters. Delaware surface waters support uniquely diverse fish and wildlife populations, provide multiple recreational opportunities, and provide approximately 70% of the drinking water supply for New Castle County.

The progress of humankind has taken its toll on surface water quality. Recent improvements have helped, but pollution is still a major concern. As recently as 1975, Delaware routinely experienced serious water pollution and public health problems as a result of the discharge of untreated sewage and wastes. Since then, as a result of voluntary efforts, regulatory actions, and significant private and public investments in wastewater treatment facilities, localized improvements in water quality have been achieved.

The need for additional cleanup and pollution prevention continues. The focus of water-quality management has shifted from point source discharges (end-of-pipe) to decreased stream flows and nonpoint source problems, such as urban and agricultural runoff, erosion, and sedimentation. Unaddressed, these problems lead to poor habitat conditions for fish and other aquatic life, decreased enjoyment of our surface waters for recreation, and unhealthy conditions for those surface waters upon which we rely for drinking water and other domestic uses.

As a result of water-quality protection programs that are in place in Delaware, surface-water quality generally has remained fairly stable in spite of increasing development and population growth. Impacts to waters are generally the result of past practices or contamination events, activities that are not regulated nor otherwise managed, or changes that are occurring on a larger regional scale. For example, air pollutants from sources outside of Delaware contaminate Delaware's surface waters via rainfall.

Improvements in water quality have been documented in localized areas where a discharge was eliminated or better treatment was installed. Basin-wide water-quality improvements in waters being impacted by historical contamination and yet unquantified pollution sources are very difficult to detect over a short period of time. Targeted monitoring over long periods (years) is necessary in order to detect changes.

Although Delaware's surface-water quality may not have changed significantly over the last several years, there have been many improvements in watershed assessment approaches and methodologies. Additionally, many water-quality criteria are stricter as a result of amendments to the state's Water Quality Standards. Therefore, we have become more proficient at identifying water-quality problems and, at the same time, are calling for higher-quality waters.

The stability of Delaware's surface-water quality is likely the result of increased efforts to control both point and nonpoint sources of pollution. In addition to the significant investments in wastewater treatment technologies previously mentioned, many private business interests are investing in practical and cost-effective nonpoint source pollution control practices (Best Management Practices) on farms, residential developments, and commercial and industrial sites. Likewise, public agencies such as the Delaware Department of Transportation are investing revenues in improved stormwater management practices and wetlands creation to mitigate the impacts of maintenance and new highway construction activities.

Stream Characteristics

The White Clay Creek, Red Clay Creek, Brandywine Creek, and Christina River are part of a common hydrologic unit in southeastern Pennsylvania, northern Delaware, and northeastern Maryland known as the Christina Sub-basin. The sub-basin contains waters of high recreational use and ecological significance and also is used as a public drinking water supply in both Pennsylvania and Delaware. In addition, lands within the sub-basin have high historical and cultural value.

The White Clay Creek, Red Clay Creek, and Brandywine Creek are tributaries of the Christina River and flow southward out of the Piedmont geologic province in Pennsylvania and into Delaware near Newark, Yorklyn, and Wilmington, respectively. The headwaters of the Christina River lie within the state of Maryland and enter Delaware west of Newark. Collectively, the White Clay, Red Clay, Brandywine and upper Christina are used to supply drinking water to more than 50% of New Castle County's population. Except for their very lower reaches, which are tidal, the White Clay, Red Clay, and Brandywine creeks are free-flowing streams. The Christina River is tidal from just south of the town of Christiana to its confluence with the Delaware River at Wilmington. The Red and White Clay creeks converge in the vicinity of Stanton, Delaware, and the combined flow empties into the tidal Christina near Churchmans Marsh. Extensive tidal freshwater wetlands, including Churchmans Marsh, exist along the lower Christina. The Brandywine Creek flows through Wilmington and enters the Christina River just before the Christina flows into the Delaware River.

A host of water resource issues have arisen within the Christina Sub-basin over the past several years. These include interstate and intrastate coordination of monitoring, modeling, and pollution controls; balancing increased demands for potable water with minimum pass-by requirements for aquatic life; protection of high-quality, yet vulnerable areas; timely evaluation and cleanup of hazardous waste sites; and restoration of wetlands and other critical habitats. This survey plan is primarily intended to address the first issue: inter- and intrastate coordination of monitoring, modeling, and pollution controls. Interstate coordination is needed to ensure adequate spatial coverage of the basin and to ensure consistency between Pennsylvania and Delaware on basic issues such as monitoring objectives, sample frequency and sample timing, parameter coverage, and analytical methods. Consistency on these basic issues will make subsequent modeling work easier and more defensible.

Hydrodynamics of the Christina River

Lower portions of the Christina River, and the White Clay, Red Clay, and Brandywine creeks are under tidal influence. Accurate information about physical characteristics of the Christina River and its main tributaries are needed in order to develop and calibrate a hydrodynamic and water-quality model of the river. The following is a brief review of the available information.

Tidal Elevations

Currently, the U.S. Geological Survey (USGS), through a cooperative agreement with DNREC, is maintaining two tide gauges in the Christina River. They are located at the Marine Terminal, Wilmington, and at the Rte. 141 Bridge, Newport, and have been in operation since 1993. In addition, the Water Resources Agency for New Castle County is operating and maintaining a tide gauge at White Clay Creek just above the Amtrak railroad bridge (see Map 7). Tidal elevations at these sites are monitored every 15 minutes (see Figure 2). Information collected at these gauging stations will be used to develop and calibrate the hydrodynamic model of the Christina River.

Tidal Currents

The tidal currents of the Christina River were surveyed during the summer of 1994 by USGS through a cooperative agreement with DNREC. During these surveys, mid-channel tidal velocity was measured at the Wilmington and Newport gauge sites every 15 minutes for a full tidal cycle. Figure 3 summarize the results of these surveys.

Information collected during these surveys will be used to develop and calibrate the hydrodynamic and water-quality model of the Christina River.

Bathymetry

The latest bathymetric surveys of the Christina River and its main tributaries were conducted during summer 1994.

Figure 2
TIDAL ELEVATIONS AT MARINE TERMINAL, WILMINGTON, AND AT RTE. 141 BRIDGE, NEWPORT (AUGUST 3 – 6, 1995)

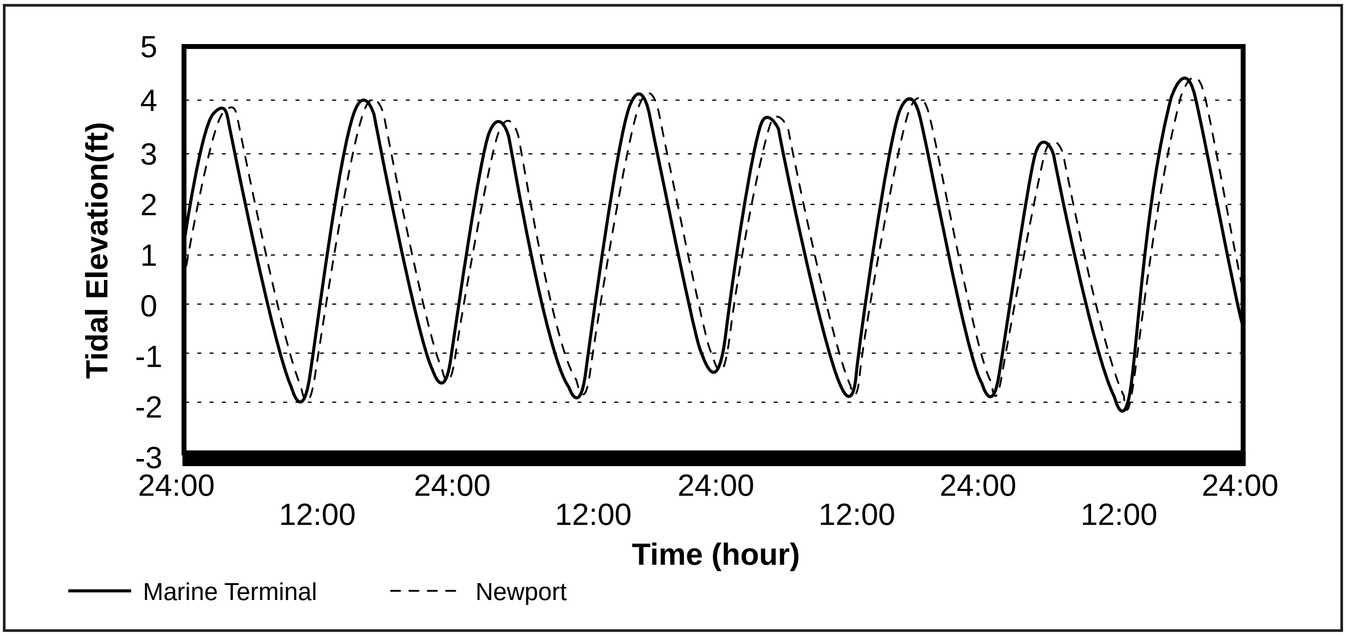


Figure 3
TIDAL VELOCITY AT MARINE TERMINAL, WILMINGTON, AND RTE. 141 BRIDGE, NEWPORT (MAY 17 AND 19, 1994)

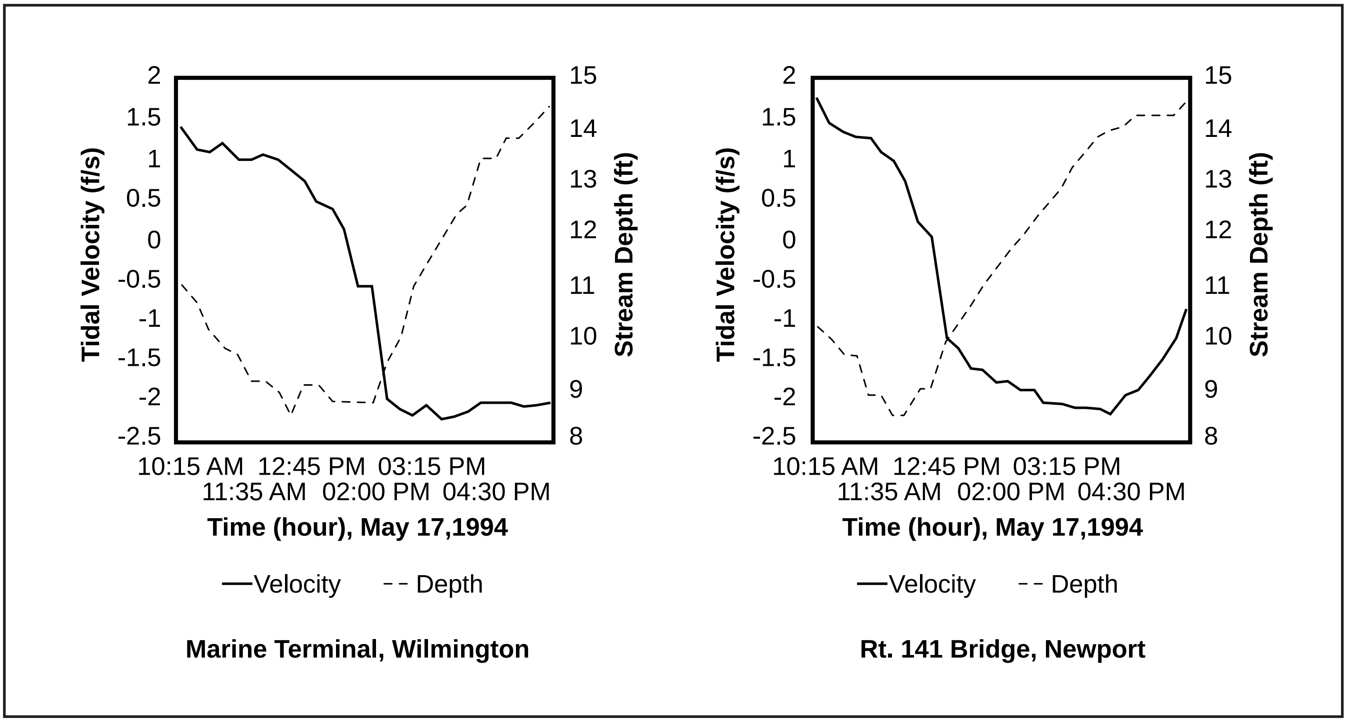
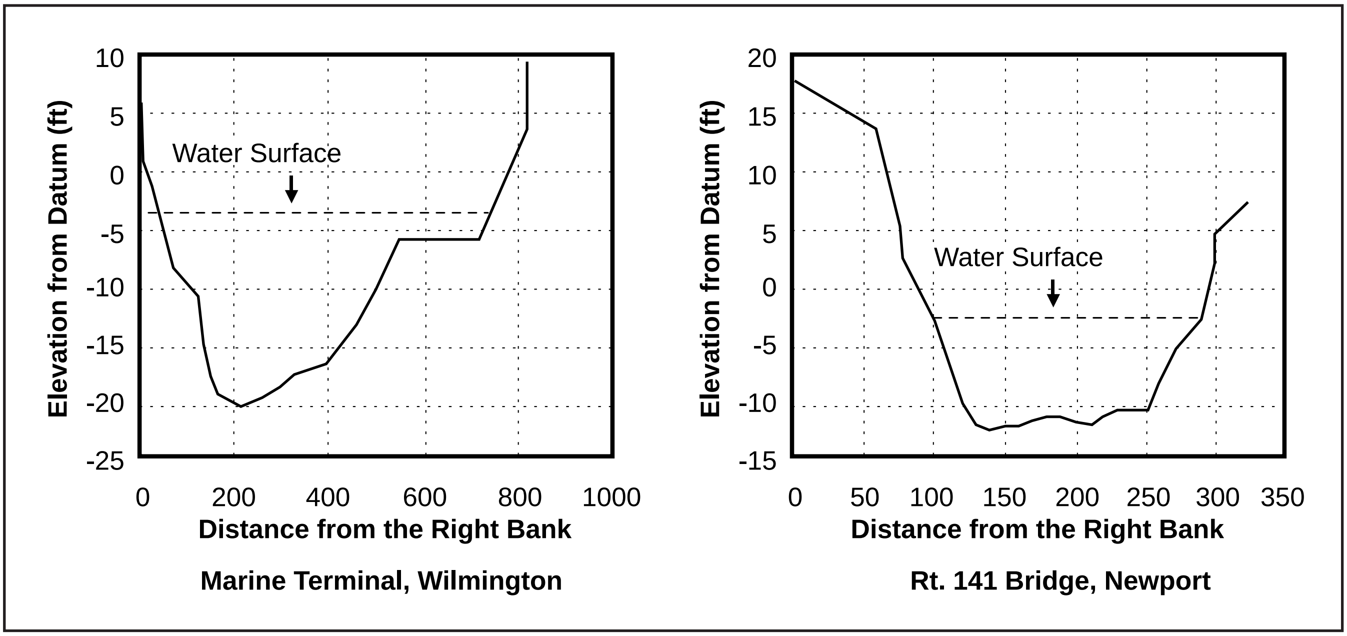


Figure 4
CHRISTINA RIVER BATHYMETRY AT MARINE TERMINAL, WILMINGTON, AND AT RTE. 141 BRIDGE, NEWPORT (SUMMER 1994)



During these surveys, cross-sectional profiles at 10 locations along the Christina River, White Clay Creek, Red Clay Creek, and Brandywine Creek were surveyed. The location of these sites is shown on Map 7; bathymetric profiles of two sites are shown in Figure 4.

Information obtained during these surveys, along with previous bathymetric studies performed by other agencies including the Federal Emergency Management Agency, will be used to develop and calibrate a hydrodynamic and water-quality model of the Christina River.

Stream Flows And Gauging Stations

Currently, there are seven USGS stream-flow gauging stations in the Delaware portion of the Christina River Sub-basin (Map 8). General information about these stations, such as locations, the size of the catchment areas, and annual and seven-day ten-year low flows (7Q10) are shown in Table 8.

Meteorological Data

Three long-term meteorological stations are currently in operation in the Delaware portion of the Christina River Sub-basin. Information about these stations is provided in Table 8, and their locations are shown on Map 8. At these stations, daily meteorological data such as temperature, precipitation, and wind speed are recorded and maintained by the Northeast Regional Office of the National Weather Service.

Detailed meteorological data collected at these stations will be used to develop and calibrate the watershed model for the Christina River Sub-basin.

Table 8

WEATHER STATIONS IN THE CHRISTINA RIVER SUB-BASIN

STATION	STATION NO.	LATITUDE	LONGITUDE	DATA SINCE	OPERATED BY
Newark University Farm	076410	39° 40′	75° 44′	8/1/48	University of Delaware, Agriculture Farm
Wilmington WSO Airport	079595	39° 40′	75° 36′	8/1/48	National Weather Service
Wilmington Porter Reservoir	079605	39° 46′	75° 32′	8/1/48	City of Wilmington

Trends

Surface Water Quality Assessment

This section reports the findings of the preliminary assessment of water-quality data for the Piedmont Basin. For this assessment, data from over 34 sampling locations were analyzed. Sampling locations were distributed along the Christina River, Brandywine Creek, Red Clay Creek, White Clay Creek, Naamans Creek, and Shellpot Creek in Delaware. For each sampling location, up to 22 water-quality parameters were analyzed, including chemical and physical parameters, bacteria, nutrients, and metals.

Water-quality data assessed in the study were retrieved from the EPA's Water Quality Information System and were manipulated or treated before applying statistical methods because of missing values, censored values, outliers, multiple observations within a month, and small sample sizes.

This preliminary study characterized the water and identifies existing and potential water-quality problems in streams through trend and status analysis. It applied all three types of statistical analysis methods — graphical method, estimation method, and test of hypotheses —on each parameter for each sampling location. The study also identified and discussed data gaps that affected the statistical analysis.

The assessment revealed many existing and potential water-quality problems. In some cases, water-quality criteria were frequently violated or trends indicated potential future problems, or both.

- Enterococcus bacteria concentrations frequently exceeded criteria throughout the Piedmont Basin.
- Zinc exceedances of criteria occurred frequently along Red Clay Creek.
- Iron violations of criteria occurred along the lower reach of the Christina River.
- Total phosphorus excessive concentrations (average above 0.1 mg/l) support the concern for nutrient over-enrichment in the Christina River, Brandywine Creek, Red Clay Creek, and White Clay Creek watersheds; however, concentrations are on the decline.
- Dissolved-oxygen concentrations decreased steadily within the last 26 years in the entire Piedmont Basin, although criteria were not violated frequently. Therefore, trends indicate that future violations will occur frequently.
- Nitrate-nitrogen increasing trends in the Christina River, Brandywine Creek, Red Clay Creek, and White Clay Creek during 1970 to 1990 suggest that water quality had declined and will continue to decline in these regions.

Data Selection and Description

Water-quality data for this analysis were retrieved from the EPA's Water Quality Information System called STORET (STOrage and RETrieval). Stream-flow data were collected from USGS flow records. The Piedmont Basin has been monitored for over 26 years. During this time, DNREC's stream water-quality monitoring protocol changed due mainly to resource constraints. This caused difficulty for the statistical analysis of the data. In briefly examining available data stored in the STORET system, we noticed problems such as (1) short records for some stations and parameters; (2) changes in frequency, location, and method of measurement; (3) significant variations in monitoring period among stations; (4) many missing data points; and (5) lack of monitoring protocols to support important correlative data analyses, such as stream flow and conductivity along with other water-quality data. These shortcomings restricted this assessment to statistical analysis in carefully selected stations and water-quality parameters.

Thirty-four stream water-quality monitoring stations were determined suitable and thus were selected for this study. Such selection considered the following factors: (1) each station's strategic location in the watershed, (2) each station's representativeness of an area and of a pollutant of concern, and (3) each station's data availability in terms of data record length and value to support statistical analysis. These 34 stations are listed in Table 9 and marked on Map 9.

Initially, data for 50 water-quality parameters were retrieved for each of the chosen stations. However, for the analysis, many parameters were questionable. After careful review, the data were narrowed down to 22 parameters (see Table 10) with data quality suitable for the study.

As with any water-quality data, these data are also characterized by censored values, missing values, outliers, and field replicates (multiple observations within a time interval), as well as seasonal patterns and serial correlations. These kinds of data have to be treated before using them for statistical analysis. Treatments for censored values, missing values, seasonal patterns, and serial correlation are associated with specific analytical methods.

The treatments for outliers and multiple observations used for all analyses are as follows. Multiple observations within a month interval were averaged to obtain a single value for the month. Outliers were identified by examining data graphically and analytically. Suspected values were verified by the laboratory before removal from the records.

Preliminary Assessment Approaches

To reach the objectives, the assessment team employed statistical methods to analyze the water-quality data. The two general categories of the analysis were status analysis and trend analysis. Status analysis evaluated average condition and extreme condition (excursion) of water quality. Trend analysis detected both sudden and gradual changes of water quality over time. Based on the analysis results, the existing and potential water-quality problems were easily identified. Data gaps were also becoming clear during the process of preparing data for each statistical analysis with each parameter. This section provides an explanation about how these analyses were performed and what data sets were used.

Average-Condition Analysis

Average-condition analysis provides a general overview of how good or poor the water is by describing the general situation of a given water body. It consists of calculating mean, median, standard deviation, skew coefficient, and quartiles for each individual water-quality parameter at each station and displaying the data graphically.

To differentiate most-current condition from historical background condition, this analysis examined most current data separately from historical data. A *current data set* includes the data collected between September 1991 and May 1996, whereas a *historical data set* contains all data collected before May 1996.

For current data, only the mean, median, and standard deviation were calculated. For historical data, a time series plot, a seasonal box plot, an annual box plot, and interquartile ranges were generated besides the calculation of the mean, median, standard deviation, and skewness. For the parameters of concern, multiple Box-and-Whisker plots were also generated.

Extreme-Condition Analysis

Extreme-condition (excursion) analysis provides information on how observed water quality compares with Delaware's water-quality standards. Analyzed were those parameters that have applicable water-quality criteria. Table 11 lists these criteria and their origins. Under those parameters, the current data sets (September 1991 to May 1996), as defined in the *Average-Condition Analysis*, were used. In the extreme-condition analysis, each value of a data set was compared against the criteria. Exceedances of a specific criterion were accounted and reported in a percentage over the total reviewed data points.

Gradual Trend Analysis

Trend analysis, in this case, refers to the detection of a gradual increase or decrease of a pollutant concentration over time. It is used in determining if water quality has changed (become *better* or *worse)* at particular locations over specific periods.

Table 9

SELECTED MONITORING STATIONS

STATION NUMBER	LOCATION	RIVER MILE
Christina River		
106011	US Rte. 13 at 3rd St. Bridge	70.8/2.1
106021	DE Rte. 141 at drawbridge, Newport	70.8/6.9
106031	Smalleys Dam spillway	70.8/13.6
106111	Road 346 Bridge	70.8/15.4
106121	Becks Pond at Salem Church Road	70.8/17.0/0.1/0.5
106131	Sunset Lake at Sunset Lake Road	70.8/17.0/1.7
106141	Road 26 at Old Baltimore Pike	70.8/20.4
106161	West Branch at DE Rte 2	70.8/20.9/1.0
106171	Sandy Brae Road at Persimmon Run	70.8/20.9/0.6/0.3
106181	DE Rte. 2 at Elkton Road	70.8/23.5
106191	DE Rte. 273 above Newark	70.8/25.5
Brandywine Creek		
104011	Foot Bridge in Brandywine Pike	70.8/1.5/3.0
104021	Road 279 Bridge, DuPont Experimental Station	70.8/1.5/4.6
104051	Smith Bridge	70.8/1.5/9.6
Red Clay Creek		
103011	DE Rte. 4 at Stanton Bridge	70.8/10.0/1.5/0.8
103021	Road 332 in Marshallton	70.8/10.0/1.5/1.72
103031	DE Rte. 48 at Woodale, USGS 01480000	70.8/10.0/1.5/4.35
103041	Road 258A in Ashland	70.8/10.0/1.5/8.73
103051	Road 252 in Yorklyn	70.8/10.0/1.5/10.3
103061	Confluence of Burroughs Run with Red Clay Creek, Rte. 241 at bridge	70.8/10.0/1.5/8.4
White Clay Creek		
105011	DE Rte. 7 Bridge, Stanton	70.8/10.0/2.9
105021	DE Rte. 2 Bridge near Newark	70.8/10.0/8.0
105031	Road 329 near Thompson's Bridge	70.8/10.0/13.1
105041	East side of DE Rte. 72 at bridge	70.8/10.0/9.8
105071	Just above the confluence with Mill Creek	
105101	Pike Creek at Road 322	
105151	35-ft. downstream from a road owned by DE Racing Association	
Naamans Creek		
101011	Behind Phoenix Steel	
101021	Naamans Rd	
101031	South Branch behind housing	
Shellpot Creek		
102011	US Rte. 13 Bridge (Gov. Printz Blvd.)	
102021	Rd. 214 at Shipley Road	
102031	Matson Run, off US Rte. 13	
102041	Cherry Island, Road 501 Bridge	

Table 10

SELECTED WATER-QUALITY PARAMETERS

PARAMETER CODE	DESCRIPTION	UNIT
General Chemical and Physical		
00300	Dissolved oxygen	mg/l
00530	Total suspended solids	mg/l
00900	Total hardness as $CaCO_3$	mg/l
00400	pH	std unit
00010	Water temperature	°C
*****	Flow rate	cfs
04101	Alkalinity	mg/l
00940	Chloride	mg/l
00076	Turbidity	FTU
Bacteria		
31639	Enterococcus bacteria	#/100 ml
Nutrient		
00665	Total phosphorus	mg/l
00671	Dissolved phosphorus	mg/l
*****	Total nitrogen (TKN + NO_3 + NO_2 as N)	mg/l
00625	Total Kjeldahl nitrogen (TKN)	mg/l
00620	Nitrate nitrogen (NO_3 - N)	mg/l
00615	Nitrite nitrogen (NO_2 - N)	mg/l
00630	Combination of NO_3 - N & NO_2 - N	mg/l
00610	Ammonia nitrogen (NH_3 + NH_4^+ -N)	mg/l
Metal		
01045	Total iron	µg/l
01051	Total lead	µg/l
01055	Total manganese	µg/l
01092	Total zinc	µg/l

Methods. Trend analysis is performed by testing for the statistical significance of an apparent change (increase or decrease) in concentration over time. The Mann-Kendall Test and Seasonal Kendall Test were used since they are nonparametric and robust methods that can accommodate missing values and non-detects without gross effect on the results (Helsel and Hirsch, 1992; Gilbert, 1987). Generally, a Seasonal Kendall Test was used for data records of more than five years, and the Mann-Kendall test for data records of shorter length — less than five years (*WQStat User's Manual*, 1988). A trend was reported for a parameter over a specified period if the change was statistically significant (90% confidence level). If no trend was reported, it may be a result of one or more of the following: (1) no data, (2) short data record, (3) too many missing values in a defined period, and (4) no trends indeed. A step-by-step trend testing procedure is shown in Figures 5 and 6.

Besides knowing whether a trend exists, we need to estimate its magnitude. This magnitude is expressed as a slope (value per year). Closely related to the Seasonal Kendall and Mann-Kendall tests, the Seasonal Kendall Slope Estimator and Sen Slope Estimator were calculated to show the changes in magnitude.

Data Selections. Data used in this trend analysis include two subsets from available data for each parameter at each location. One subset is a *long-term data set*, which includes all data collected between 1970 and 1996. Usually, it has the same length as the *historical data set*. Another subset is a *short-term data set*, which consists of data collected between January 1984 and May 1996. A dilemma arose in deciding how long a record should be used for this trend analysis. A trend that is now in existence may have existed for only a few years or for a very long time, or may even be

Figure 5

TREND ANALYSIS WITH DATA RECORD LENGTH >5 YEARS

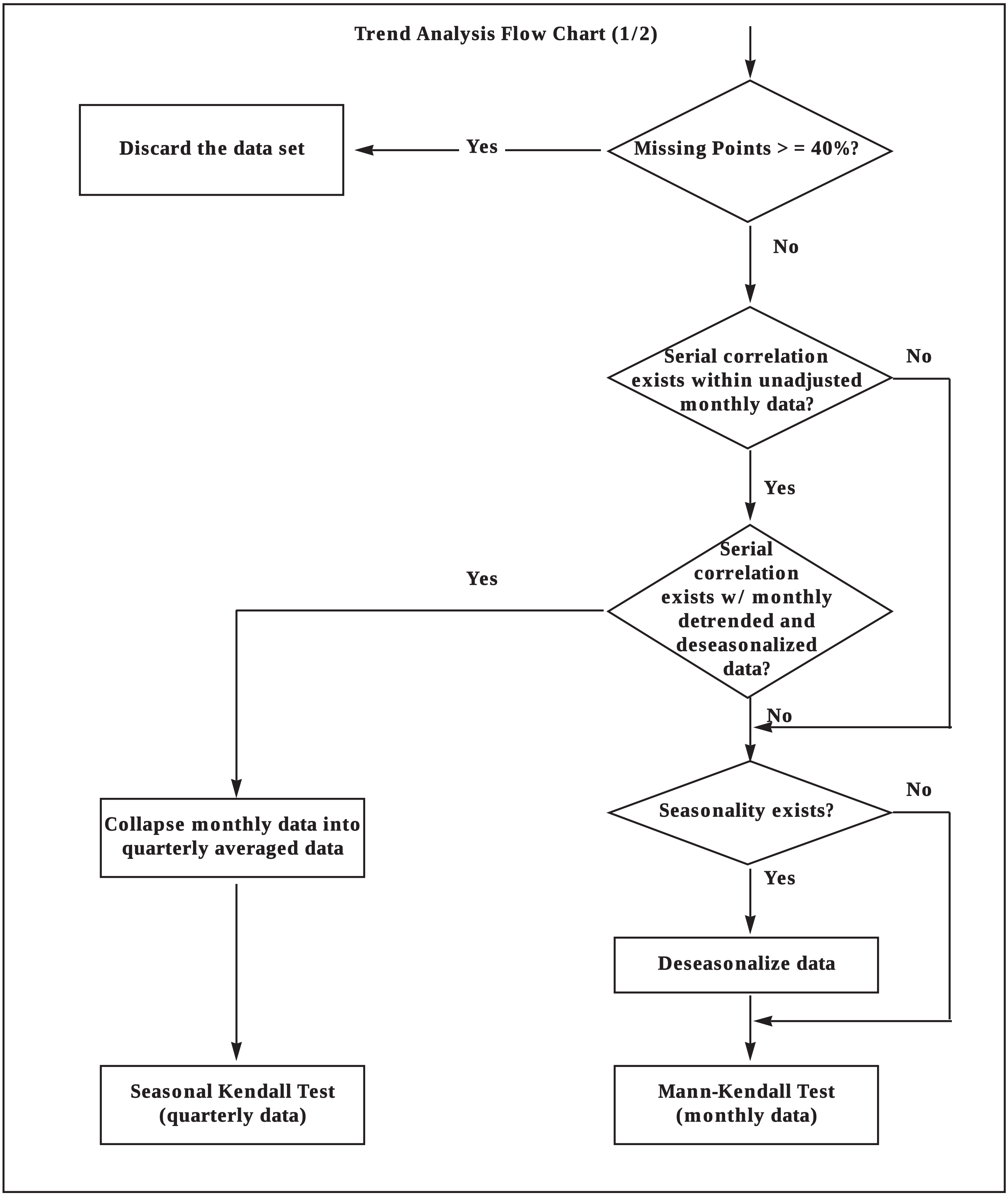


Figure 6

TREND ANALYSIS WITH DATA RECORD LENGTH ⩽ 5 YEARS

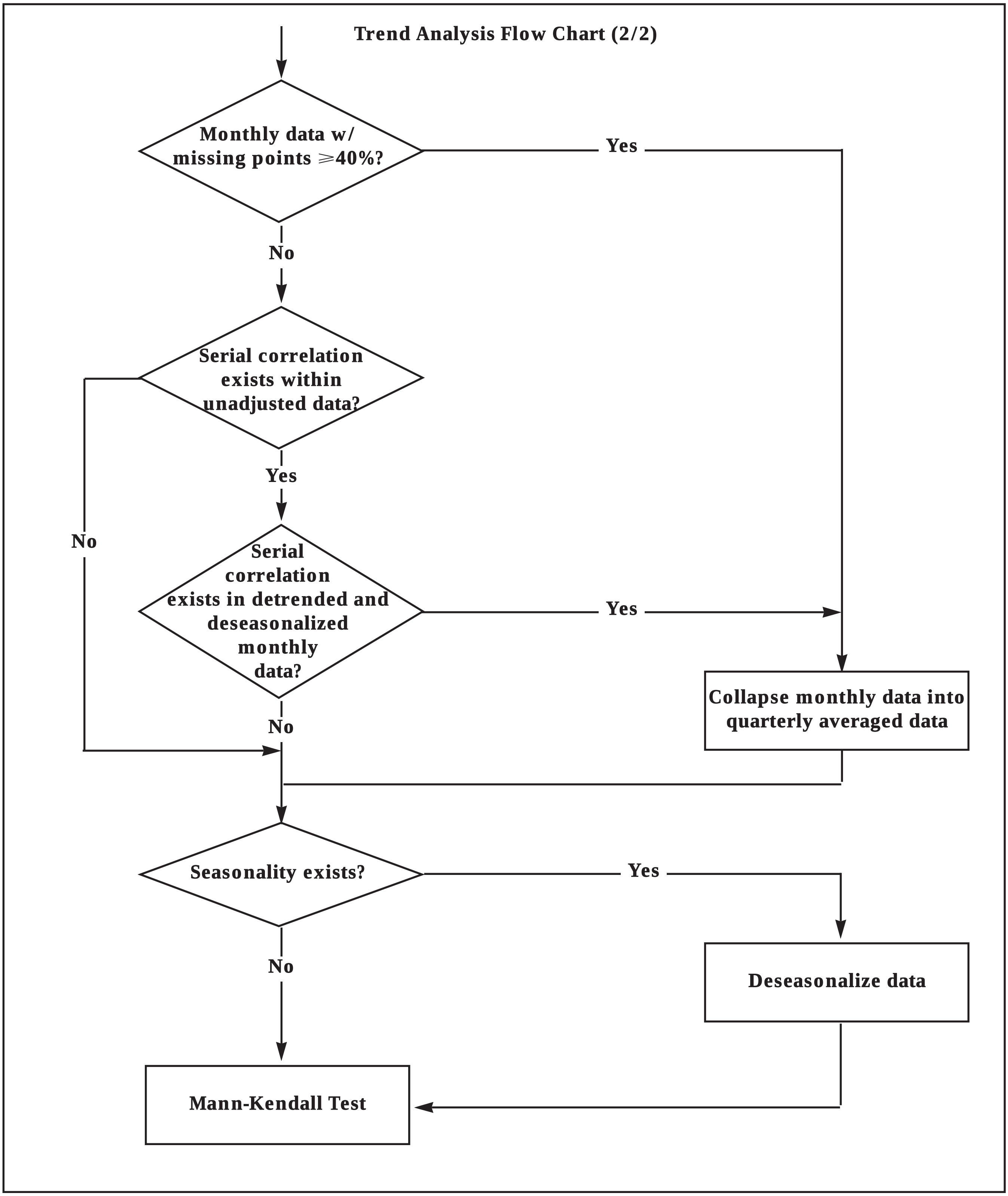


Table 11

WATER-QUALITY CRITERIA

PARAMETER	CRITERIA	ORIGIN*
Bacteria	Concentration ⩽ 100#/100 ml	A
DO	Daily average ⩾ 5.5 mg/l for the June – Sept. period The minimum = 4.0 mg/l	A
pH	Within 6.5 – 8.5 su	A
Alkalinity	Conc. ⩾ 20 mg/l as $CaCO_3$	A
Phosphorus	Conc. < 0.025 mg/l within a lake < 0.05 mg/l right before a stream entering a lake < 0.1 mg/l in streams not flowing directly into lakes	B
Iron	Conc. < 1000 µg/l chronically	A
Zinc	Conc. < $e^{(1.273[\ln(hardness)]-1.460)}$ acutely < $e^{(1.273[\ln(hardness)]-4.705)}$ chronically	A

*A — *State of Delaware Surface Water-Quality Standards* [2]. B — *EPA Quality Criteria for Water* [3].

a reversal of a previous trend. If a very short record is used, it may not contain enough data to identify a trend or to distinguish it from the natural variability in the data. On the other hand, a long record may include opposite trends, or later data points in the record may offset the trend which appeared among the earlier data points. In spite of the dilemma, the two subsets as defined above were considered a reasonable, although arbitrary, choice of record length for this stage of study.

Data Treatment. As mentioned earlier, water-quality data have the characteristics of multiple observations, missing values, censored values, seasonal patterns, and serial correlation. These characteristics affect trend testing in various degrees. To reduce this effect, before trend testing, the data were treated for different situations as noted below:

- Any multiple observations within a month, such as from laboratory repeats or field replicates, were averaged to obtain a single value.
- In a record, if less than 40% of the data points were recorded as either non-detected or greater than values, the data set was considered valid for trend testing. Then, one-half of the detection limit was used to replace those non-detected points, and the detection limit was used to replace those greater than points (Helsel and Hirsch, 1992).
- If more than 40% of the data points were recorded as the censored values in a record, the record was considered not suitable for trend testing and thus was not used in the trend analysis (Helsel and Hirsch, 1992).
- For data showing seasonal patterns, the seasonal Kendall Test was used. Otherwise, the Mann-Kendall Test was used for trend testing (*WQStat User's Manual,* 1988).
- Quarterly averages, calculated by collapsing monthly averages, were used for data having serial correlations (Helsel and Hirsch, 1992; Gilbert, 1987).
- Possible influence of stream-flow variations on trend testing for an individual parameter was evaluated by testing the correlation between the parameter and stream flow. If the correlation was strong, flow-adjusted concentrations for this parameter were used in the trend test. Otherwise, non-adjusted data were used.

It is recognized that there are many confounding factors in stream water-quality analysis and that it is difficult, if impossible, to identify and account for all of them. However, by using the nonparametric methods and by collapsing data into quarterly values, the trend test gives us more confidence with its results (Helsel and Hirsch, 1992).

Computer Software. WQStat II, a water-quality statistics computer software developed by Colorado State University, was employed for trend analysis and trend-plot generation.

Notes about Trend Analysis. Although trend analysis can be very informative, there are a number of difficulties or precautions that must be considered before drawing conclusions. To make trend analysis meaningful, at least five years' data are needed to be able to detect a trend reliably (*WQStat User's Manual*, 1988). For a record less than five years, it was reported as insufficient data. Furthermore, data must be collected using a consistent methodology over the length of a record, i.e., all sampling procedures and analytical methods should be the same over the period of a record. Any change made to sampling or analytical procedures may produce observed changes that are not related to environmental conditions. At this stage of analysis, identification of changes in data collection (including sampling and analytical procedures) was not conducted. Besides, even if statistically significant trends are detected, the absolute magnitude of the change may be very small and not be necessarily significant in terms of the overall water-quality perspective. So it is not always easy to explain the results of a trend analysis.

Step-Change Analysis

A step change is an abrupt change in water-quality concentration that may be caused by addition or elimination of a pollution source or by a change in data collection procedures. As with gradual trend analysis, step-change analysis does not examine the causes, but the change itself.

The change was evaluated by comparing the median values of the two data sets before and after the change was observed in a record. The first step was to visually examine the time-series plot to spot abrupt changes. When a change was identified, both median values before and after the abrupt changes were calculated. Then, the Mann-Whitney method was employed to test if the two median values were significantly different (at 95% confidence level). If it was, a step change was reported. Otherwise, no change was detected. The WQStat statistical software was used for this analysis, too.

Findings and Discussions

With the methods described above, each water-quality parameter at each station was analyzed for trend and status. In the results of the study, the characteristics of the water became clear, and major concerns surfaced, through parameters reflecting the existing and potential water-quality problems. This section briefly discusses these characteristics and concerns through the related parameters for each watershed.

Christina River

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that most stations had 25% of the data exceeding the criteria of 100 colonies/100 ml, suggesting that the river's use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 26 years (1970 to 1996, or 1977 to 1996) in large parts of the watershed. Although the dissolved oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids had a decrease in large parts of the watershed. This indicates that water quality has improved during this long period in regard to solids.

Phosphorus. The total phosphorus concentration (average above 0.1 mg/l) supports the concern about nutrient enrichment in large parts of the watershed, as indicated in Map 11. Excursion analysis showed that the lower part of the river (Stations 106011 to 106031) exceeded the EPA-recommended criterion of 0.1 mg/l more than 68% of the time.

Nitrogen-to-phosphorous ratios were calculated at each station for possible limiting nutrient in the eutrophication process (Davis, 1993). The ratios of total nitrogen to total phosphorus at all stations were well above 10, which suggests that phosphorus may be the limiting nutrient in the watershed.

Decreasing trends of total phosphorus were detected in large parts of the watershed during 1980 to 1996, although the magnitudes of the decrease were very small. Map 12 shows the areal distribution of the detected trend in the watershed.

Nitrate-Nitrogen. An increasing trend of nitrate-nitrogen in large parts of the watershed during 1970 to 1990 suggests that water quality had declined in these regions. The areal distribution of trends is shown in Map 13.

Iron. Iron concentrations violated the state water-quality standard along the lower reaches of the Christina River (from Station 106011 to Station 106031). Historical and current data showed that average concentrations of total iron were above the criterion of 1000 µg/l, and more than 55% of current data exceeded the criterion.

Brandywine Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that more than 48% of the data exceeded the criteria of 100 colonies/100 ml throughout the watershed, suggesting that the use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations have decreased steadily over the last 26 years, from 1970 to 1996, throughout the watershed. Although dissolved oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of the trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids decreased throughout the watershed. This indicates that water quality has improved during this period in regard to solids.

Phosphorus. Total phosphorus concentrations (average above 0.1 mg/l) support the concern about nutrient enrichment throughout the watershed, as indicated in Map 11. Excursion analysis showed that total phosphorus at all stations exceeded the EPA-recommended criterion of 0.1 mg/l more than 55% of the time.

Nitrogen-to-phosphorus ratios were calculated at each station for possible limiting nutrient in the eutrophication process (Thomann, 1987). The ratios of total nitrogen to total phosphorus at all stations were above 10, which suggests that phosphorus may be the limiting nutrient in the watershed.

Decreasing trends of total phosphorus were detected throughout the watershed during 1980 to 1996, although the magnitudes of the decreases were very small. Map 12 shows the areal distribution of the detected trend in the watershed.

Nitrate-Nitrogen. A widespread increasing trend of nitrate-nitrogen during 1970 to 1990 suggests that water quality has declined in the watershed. The trend distribution is shown in Map 13.

Red Clay Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that more than 50% of the data exceeded the criteria of 100 colonies/100 ml throughout the watershed, suggesting that the use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 26 years in large parts of the watershed. Although the dissolved-oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of the trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids had a decrease in large parts of the watershed. This indicates that water quality has improved during this long period in regard to solids.

Phosphorus. Total phosphorus concentrations (average above 0.1 mg/l) support the concern about nutrient enrichment throughout the watershed, as indicated in Map 11. Excursion analysis showed that the main stem of the Red Clay Creek (Stations 103011 to 103051) exceeded the EPA-recommended criteria 0.1 mg/l more than 90% of the time.

Nitrogen-to-phosphorus ratios were calculated at each station for possible limiting nutrient in the eutrophication process (Thomann, 1987). The ratios of total nitrogen to total phosphorus at all stations were above 10, which suggests that phosphorus may be the limiting nutrient in the watershed.

Decreasing trends of total phosphorus were detected in large parts of the watershed during 1980 to 1996, although the magnitudes of the decrease were very small. Map 12 shows the areal distribution of the detected trend in the watershed.

Nitrate-Nitrogen. A widespread increasing trend of nitrate-nitrogen in the main stream during 1970 to 1990 suggests that water quality had declined in the watershed. The trend distribution is shown in Map 13.

Zinc. Zinc criteria exceedances occurred frequently along the main stream of the Red Clay Creek (from Station 103011 to Station 103041). Although the decreasing trend of total zinc concentration was observed along this reach, current data still frequently exceed the acute and chronic criteria of the state water-quality standard (for more than 85% of observed data points).

White Clay Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that more than 50% of the data exceeded the criterion of 100 colonies/100 ml throughout the watershed, suggesting that the use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 26 years in large parts of the watershed. Although dissolved-oxygen concentrations showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of the trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids had a decrease in large parts of the watershed. This indicates that water quality has improved during this period in regard to solids.

Phosphorus. Total phosphorus concentrations (average above 0.1 mg/l) support the concern about nutrient enrichment in the main stem of the stream, as indicated in Map 11. Excursion analysis showed that total phosphorus along the main stream exceeded the EPA-recommended criterion of 0.1 mg/l more than 40% of the time.

Nitrogen-to-phosphorus ratios were calculated at each station for possible limiting nutrient in the eutrophication process (Thomann, 1987). The ratios of total nitrogen to total phosphorus at all stations were above 10, which suggests that phosphorus may be the limiting nutrient in the watershed.

Nitrate-Nitrogen. An increasing trend of nitrate-nitrogen in large parts of the watershed during 1970 to 1990 suggests that water quality had declined. Trend distribution is shown in Map 13.

Naamans Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that more than 50% percent of the data exceeded the criterion of 100 colonies/ 100 ml throughout the watershed, suggesting that the use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 25 years in large parts of the watershed. Although the dissolved-oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids showed a decrease in large parts of the watershed. Thus, water quality has improved during this period in regard to solids.

Shellpot Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that the data exceeded the criterion of 100 colonies/100 ml in large parts of the watershed, suggesting that the use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 25 years in parts of the watershed. Although the dissolved-oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen The areal distribution of trends is shown in Map 10.

Table 12

PARAMETERS FREQUENTLY EXCEEDING CRITERIA

WATERSHED	BACTERIA	ZINC	IRON	PHOSPHORUS
Christina River	Yes		Yes	Yes
Brandywine Creek	Yes			Yes
Red Clay Creek	Yes	Yes		Yes
White Clay Creek	Yes			Yes
Naamans Creek	Yes			
Shellpot Creek	Yes			

Conclusion 1: Poor water quality. Based on the analysis results, initial concerns arose with bacterial contamination, metal pollution, and nutrient overenrichment. Table 12 summarizes the pollutants that frequently exceeded water-quality criteria in the listed watersheds.

Table 13

PARAMETERS IN COMPLIANCE WITH CRITERIA

WATERSHED	DO	pH	IRON	PHOSPHORUS
Christina River	Yes	Yes		
Brandywine Creek	Yes	Yes	Yes	
Red Clay Creek	Yes	Yes	Yes	
White Clay Creek	Yes		Yes	
Naamans Creek	Yes	Yes	Yes	Yes
Shellpot Creek	Yes	Yes		

Conclusion 2: Good water quality. Table 13 shows the parameters in compliance with the water-quality standards.

Conclusions

From the previous analysis and discussion, the conclusions shown in Tables 12, 13, 14, and 15 are made based on parameters showing *poor* water quality, *good* water quality, and the direction of water quality change.

Problems. Due to missing data points and censored values, statistical analyses could not be performed for certain parameters. Missing data were particularly a problem during the period from 1991 to 1994. Non-detected values were very common in metal records, which seriously hampered analyses of metals data. Another problem encountered during this study was lack of pertinent data such as stream flow and conductivity. Typically, many water-quality data correlate with these two physical parameters.

Table 14

PARAMETERS SHOWING
WATER-QUALITY DETERIORATION

WATERSHED	DO	NO_3-N	NO_3+NO_2-N
Christina River	Yes	Yes	
Brandywine Creek	Yes	Yes	
Red Clay Creek	Yes	Yes	Yes
White Clay Creek	Yes	Yes	
Naamans Creek	Yes		
Shellpot Creek	Yes		

Conclusion 3: The water is becoming worse. Table 14 lists the parameters that have shown significant trends in stream water-quality deterioration in the watersheds.

Table 15

PARAMETERS SHOWING WATER-QUALITY IMPROVEMENT

WATERSHED	TSS	TKN	PHOSPHORUS	ZINC
Christina River	Yes		Yes	
Brandywine Creek	Yes			
Red Clay Creek	Yes	Yes	Yes	Yes
White Clay Creek	Yes	Yes		
Naamans Creek	Yes			
Shellpot Creek				

Conclusion 4: The water is becoming better. Table 15 lists the parameters that have shown significant trends in stream water-quality improvement in the watersheds.

Sources of Impact

Point Source Discharges

Point source discharges in the state of Delaware are regulated through issuance of National Pollutant Discharge Elimination System (NPDES) permits. Section 402 of the Clean Water Act, as amended by the Water Quality Act of 1987, gives the EPA and states with approved NPDES programs the authority to issue discharge permits. Seventeen facilities in the Piedmont Basin have active NPDES permits to discharge into surface waters. The permit is generally issued for a five-year period and regulates the type, concentration, and load of pollutants that can be discharged from a facility. Furthermore, NPDES permits establish monitoring and reporting requirements to be conducted by the facility.

All facilities with active NPDES discharge permits in the state are required to monitor their discharges regularly and to report the results of the monitoring to DNREC quarterly using Discharge Monitoring Reports. This information is maintained by DNREC and can be accessed through the EPA's centralized Pollution Compliance System data base.

The impact of point source discharges on the water quality of the Christina River and its main tributaries will be evaluated during the water-quality modeling phase of the five-year Christina Basin Watershed Management Plan.

Nonpoint Sources

Generally defined, nonpoint source pollution of surface waters results from runoff, percolation, and groundwater discharge to surface waters and atmospheric deposition of pollutants to water. It can also be defined as any human-induced pollution that does not come from a precise location such as a waste pipe discharging to a river. Examples of nonpoint source pollution include runoff from agriculture, silviculture, construction, and land-disposal sites.

Delaware's Nonpoint Source Pollution Program seeks to address nonpoint source pollution through coordination with other agencies and by funding control and mitigation projects. Many private businesses are investing in practical and cost-effective nonpoint source pollution control practices (Best Management Practices) on farms, residential developments, and commercial and industrial sites. Likewise, public agencies such as the Delaware Department of Transportation are investing revenues in improved stormwater management practices and wetlands creation to mitigate the impacts of maintenance and new highway construction activities.

Waste Sites

Runoff and leachate from waste sites can adversely impact aquatic ecosystems and human health. The "Contaminant Sources" section of this *Preliminary Assessment Report* discusses various waste sites in the Piedmont Basin and their known or potential impact. Significant progress has been made in controlling these sites. However, uncertainties such as the link between waste sites and fish contamination, for example, need to be addressed.

Atmospheric Deposition

Pollutants emitted into the air from various sources can be deposited into aquatic ecosystems far removed from their original source. Studies have proven that atmospheric deposition can be a major contributor to the degradation of water quality, producing significant human health and ecological impacts. Much work is needed to quantify the impact of atmospheric deposition in the Piedmont Basin.

Positive Initiatives

Christina River Initiative

DNREC, in cooperation with the Pennsylvania Department of Environmental Protection, EPA, Delaware River Basin Commission, and other federal, state, and local agencies, has initiated the development of a comprehensive water-quality management plan for the Christina River watershed. The plan will cover the entire 564 square miles of the watershed in Delaware and Pennsylvania and includes Brandywine Creek, White Clay Creek, and Red Clay Creek. Specific tasks included as part of this five-year study include intensive water-quality and quantity monitoring; comprehensive assessment of water-quality conditions; development of water-quality models for the watershed and for receiving streams; establishment of total maximum daily loads for point and nonpoint sources of pollution; and public education and participation. Total maximum daily loads establish the maximum amount of a pollutant (or pollutants) that a water body can assimilate and still meet water-quality standards and support designated uses.

Currently, DNREC is actively involved in the second year of the above five-year plan. Efforts are under way to finalize the comprehensive water-quality assessment of the Christina River watershed; conduct intensive water-quality and quantity monitoring; build an inventory of Geographic Information System (GIS) data layers regarding land use/land cover, geology, soil, topography, etc., for the watershed; and develop hydrodynamic and water-quality models for the watershed and for receiving streams.

The Northern Delaware Wetlands Rehabilitation Program was established by DNREC to bring together civic and business leaders, scientists, resource managers, and property owners to develop strategies to restore nearly 10,000 acres of wetlands (31 distinct sites) along the Christina and Delaware rivers. Start-up funding was provided by NOAA to the Delaware Coastal Management Program, and this project has become a cooperative effort between that program and DNREC's Division of Fish and Wildlife. The goals of the Northern Delaware Wetlands Rehabilitation Program are to improve water quality, increase wildlife populations, control nuisance plants, control mosquitoes, control flooding, and improve recreational and educational opportunities near the two rivers.

Citizens Monitoring Programs in Delaware

In recent years, many citizens groups have been formed nationwide in response to growing concerns about degraded water quality. Delaware was one of the first states to initiate a citizens water-quality monitoring program of streams to augment fixed monitoring by state agencies. The involvement of citizens in collecting data and making observations on their streams results in an educated public with an appreciation for their watersheds and an awareness of pollution threats to vital resources. Data and observations collected by citizens with a strong sense of environmental stewardship will contribute to the long-term success of environmental strategies. Delaware has four programs that use citizens to monitor water quality. Stream Watch was established in 1985 by the Delaware Nature Society in cooperation with DNREC. The Inland Bays Citizen Monitoring program was established by the University of Delaware Sea Grant College Program in 1990 as part of the Inland Bays Estuary Program. The Nanticoke Citizen Monitoring Program was founded in 1991 by concerned citizens of the city of Seaford in cooperation with DNREC. The most recent addition is the Adopt-a-Wetland Program initiated in May 1993 by the Division of Water Resources.

Delaware Stream Watch

Delaware Stream Watch, a grass-roots volunteer water resource protection program, is a cooperative effort of the Delaware Nature Society, DNREC, and more recently, industry. Since its inception in 1985, Stream Watch has focused on pollution detection and water-quality education. Four monitoring programs are presently being conducted: Stream Adoption, Technical Monitoring, White Clay Creek Macroinvertebrate Survey, and the Red Clay Creek Microbiological Monitoring Project. As part of the Stream Adoption program, some 159 sites in 28 of Delaware's 41 watersheds have been formally adopted. Technical Monitoring now includes more than 30 adults and college students and 16 high-school students monitoring over 25 sites monthly in the greater Christina basin. Over 400 hours of volunteer time were donated by 30 volunteers to conduct a quantified macroinvertebrate survey on three sites in the Delaware portion of the White Clay Creek. Finally, a small enterococcus monitoring project is being conducted in the Red Clay Creek basin. In addition, various educational events are conducted each year to train nearly 900 persons in monitoring techniques and to increase awareness of water issues for an additional 4,000 persons.

Stream Adoption

To reach the largest audience, the Stream Adoption Program is designed with flexibility for the volunteers. Volunteer Stream Watchers are trained in a three-hour workshop to recognize and report four major water pollution problems: toxic, organic, nutrient, and sediment problems. They are also trained to conduct three types of water-quality surveys (visual, chemical/physical, and macroinvertebrate) using simple methods and equipment.

The visual survey includes an inventory of pollution signs such as excess algae and unusual water color or odor; potential pollution sources such as water discharge pipes or materials stockpiled next to the water; and obvious ecological factors that may affect stream health such as bank erosion due to loss of vegetation.

The chemical/physical survey includes air and surface temperature and the use of field test kits to determine the pH, levels of dissolved oxygen, and occasionally in coastal waters, salinity.

The macroinvertebrate survey consists of collecting aquatic insects from rocks, leaf packets, vegetation, sticks, logs, and/or bottom sediments, using washing and sieving techniques or constructed nets. Volunteers are then taught to recognize four types of aquatic insect larvae or nymphs that are useful indicators of pollution.

Each volunteer receives an illustrated, step-by-step *Delaware Stream Watch Guide* to reinforce and supplement the information provided during the workshop. They are encouraged to adopt a stream (or other body of water) and choose from among the survey methods according to the type of waterway and their individual interests and capabilities. They are requested to fill in data sheets and mail them to DNREC upon completion of the survey. Monitoring seasonally at least four times per year is encouraged.

Stream Watchers can adopt waterway sections as individuals or as a group. Of the 159 sites currently adopted, approximately one-quarter are monitored. Some volunteers collect and mail in detailed visual, chemical, and/or macroinvertebrate data at a minimum of three to four times per year. A few volunteers collect and mail in data on a monthly or bimonthly basis. The remaining volunteers visually monitor for evidence of pollution. These volunteers report any pollution problems to the appropriate agency, but are not required to record and mail in data sheets.

Technical Monitoring

In 1995, Stream Watch expanded the Technical Monitoring program from the original six sites in the Red Clay Creek basin to more than 25 sites in the greater Christina basin (which includes the Red Clay, White Clay, and Brandywine Creek sub-basins). The technical monitoring program's monthly sampling frequency, strategic site selection, and rigorous quality-control and assurance measures provide accurate baseline data and allow for subtle trend analysis. Volunteers range from persons with advanced engineering and science degrees to two high-school groups. Field test kits are used to monitor air and surface-water temperature, dissolved-oxygen levels, pH, nitrate-nitrogen, and alkalinity. Some visual observations are also recorded.

White Clay Creek Macroinvertebrate Survey

In partnership with the Stroud Water Research Center, the White Clay Watershed Association, and the University of Delaware, Stream Watch began an annual quantified macro-invertebrate survey on three sites in the Delaware portion of the White Clay Creek. Four survey samples are collected at each site, and specimens are preserved in the field. Later, in the laboratory, specimens are identified to family or order level and the taxa are tallied. Data are analyzed at the Stroud Center.

Red Clay Creek Microbiological Project

Seven sites are sampled monthly in the Red Clay Creek basin and tested at the University of Delaware for enterococcus bacteria. The purpose of the project is to establish baseline data.

The program's educational focus is extended through various avenues. The semiannual editions of *Stream Talk* reach a mailing list of over 1,400 concerned citizens. Water-quality monitoring and stream ecology workshops involve 100 citizens, 100 teachers, and 700 kindergarten through college students per year. Other educational activities conducted statewide include slide presentations, public exhibits, and seminars and conferences on water-quality concerns.

Contact with Stream Watch Adopters is maintained in several ways. All Stream Watchers receive the newsletter *Stream Talk*, edited by Delaware Nature Society and published twice a year. Volunteers are also encouraged to attend a refresher/enrichment training session once a year. At this session, volunteers also may be retrained in chemical test-kit procedures and macroinvertebrate identification, are able to check the validity of their individual test kits, and receive one-on-one answers to their monitoring questions. Volunteers with questions or concerns call the Stream Watch office, the DNREC liaison, or their watershed cluster leader (an experienced volunteer in their local area) for assistance. In addition, the DNREC liaison maintains personal written contact with volunteers, responding to every data report submitted and answering individual questions on monitoring techniques, malfunctioning equipment, or biological observations. The DNREC liaison also phones the volunteers when necessary to recommend an appropriate agency to solve a pollution problem.

Stream Watch pollution reports have been well received by state and county officials. Telephone calls from Stream Watchers to DNREC's toll-free 24-hour Environmental Complaint Hotline or through the DNREC liaison are welcomed by enforcement officers because they know that the individuals have been trained to recognize signs of pollution. The detailed observations and site locations provided by Stream Watchers make responses faster and more effective. Since the program's inception, Stream Watch volunteers have been the first to report fish kills, illegal trash dumping, high coliform counts, failing septic systems, sewer overflows, and erosion/sedimentation problems.

Delaware Nature Society employs one full-time coordinator and two part-time assistants to conduct the Stream Watch program. The staff at Delaware Nature Society recruit, train, support, and cultivate the volunteers; plan and administer the program; serve as information resources; and provide various educational programs. DNREC also employs a Stream Watch coordinator, who serves as a liaison to receive, acknowledge, and direct responses to the data received from the volunteers and report regulatory problems to enforcement personnel, who respond as appropriate. The DNREC coordinator also develops and conducts workshops and participates in some of the educational activities organized by the Delaware Nature Society.

Funding for Stream Watch is from DNREC, the Delaware Nature Society, and industry. Originally, DNREC funds were obtained via a grant from the EPA and later from penalty fees resulting from enforcement actions. Currently, Stream Watch receives the major portion of its funding ($65,000) through a line-item in the DNREC budget. The Delaware Nature Society provides office space, equipment, and in-kind services in addition to contributing funds directly. The society also receives grants for specific items in the Stream Watch budget. In particular, the technical monitoring program is almost entirely supported by funds and in-kind support from several local industries.

For More Information

The 1996 Delaware Watershed Assessment Report provides a statewide assessment of all surface-water and groundwater resources and highlights Delaware's initiatives in water resources management and pollution control during 1994 and 1995. This report summarizes the statewide water-quality assessment and provides an overview of major initiatives and concerns for each watershed in the state.

For further information, please contact:

Watershed Assessment Branch
Department of Natural Resources
and Environmental Control
89 Kings Highway
Dover, Delaware 19903
Phone: (302) 739-4590

WATER QUANTITY

Water quantity is the flow or volume of surface- and groundwater — the sources of which include but are not necessarily limited to rivers, streams, lakes, ponds, and aquifers; and the availability of such supplies for public, private, industrial, irrigation, and recreational purposes, and to sustain other organisms that depend on such supplies.

Characterization

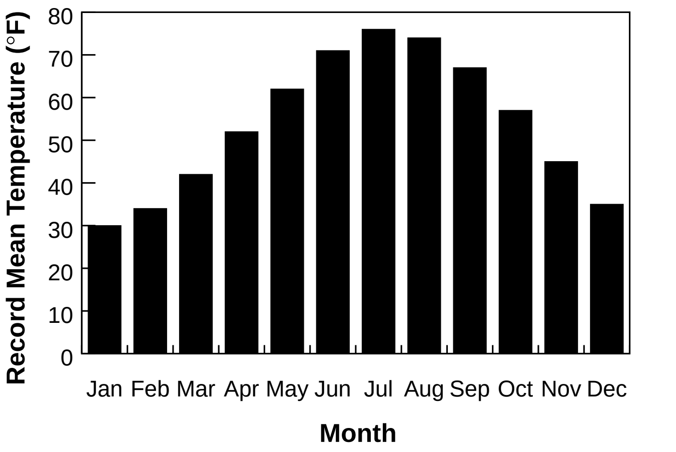
The following characterization of water supply or quantity addresses available sources of water and the complementary water-supply systems and facilities serving public, industrial, and irrigation needs.

Climate, Geology, and the Hydrologic Cycle

Everywhere on Earth, climate is the single-most influential factor determining the amount of water received in a given area. New Castle County's climate is classified as mid-latitude, continental marine, which is characteristically humid with moderate temperatures and with, on the long-term average, a fairly even distribution of precipitation throughout the year. Precipitation does, however, vary considerably from normal, leading to extended dry or wet periods that may cause droughts and floods. The nearby Atlantic Ocean is the dominant climatic influence. Figures 7 and 8 illustrate the monthly variations in temperature and precipitation for the area. These data were collected from the National Weather Service Observatory at Greater Wilmington Airport. The mean-value precipitation is based on the 30-year, long-term normal period from 1950 to 1981. Mean-value temperature is based on a 103-year period of record.

Figure 7

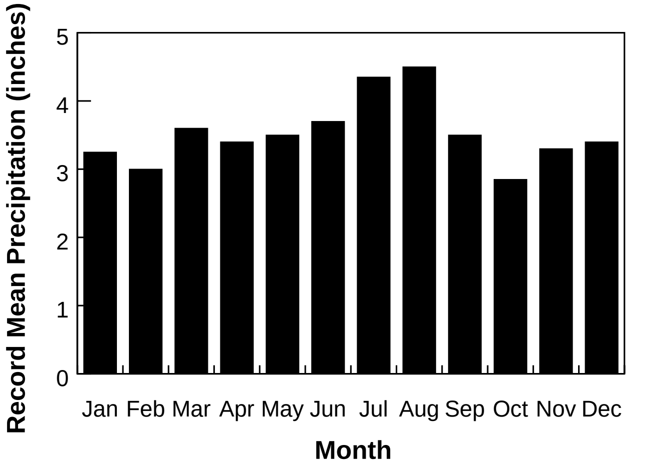
MONTHLY MEAN TEMPERATURE
WILMINGTON, DELAWARE



Source: National Oceanic and Atmospheric Administration, *Local Climatological Data, Annual Summary with Comparative Data,* Asheville, NC, 1988.

Figure 8

MONTHLY MEAN PRECIPITATION
WILMINGTON, DELAWARE



Source: National Oceanic and Atmospheric Administration, *Local Climatological Data, Annual Summary with Comparative Data,* Asheville, NC, 1988.

These climatic forces shape a characteristic hydrologic system and, accordingly, the types and occurrences of animal and plant inhabitants in conjunction with the geology of the area. The dynamics of this water-based system can be expressed in terms of the "hydrologic cycle."

Climate determines the net amount of water inflow into the local hydrologic system. Both climate and *weather* (or the temporal and spatial variability of climate in a given area), are also important factors influencing the discharge of water from the system in the form of evapotranspiration.

Evapotranspiration is the combination of evaporation and transpiration, or plant uptake of water. Evaporation varies annually according to the weather from near zero to a large amount of water that is intercepted. During periods of high rates of evapotranspiration, stream base flows recede and groundwater levels decline; the opposite occurs the remainder of the time. These cycles correspond to recharge and discharge periods. The remainder of the water at any given time is discharged either naturally or artificially. All water evapotranspired or otherwise discharged from the system eventually returns to the ocean, thus completing the cycle.

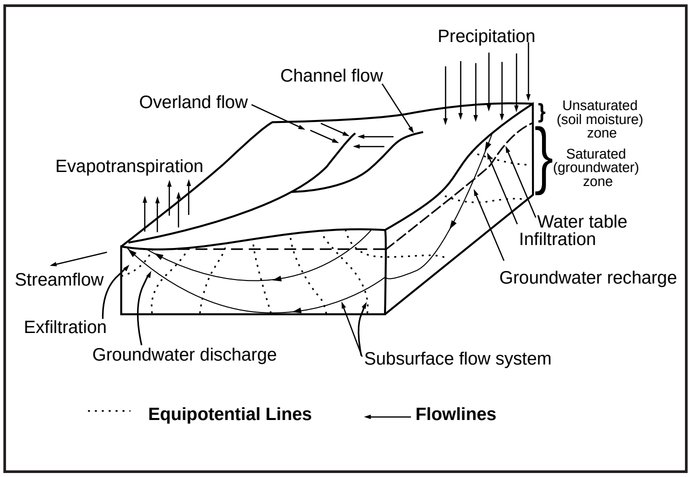
Short-term variations in inflow due to changing weather patterns lead to drought or flood events, which are more intensely expressed by changes in surface discharge. Groundwater systems, being more reflective of long-term water availability, respond very slowly to these comparatively brief weather events. Thus, the surface waters are much more sensitive to swings in precipitation. As noted, precipitation in the Piedmont Basin has considerable variation, with period-of-record minimum and maximum annual totals of 29 inches and 62 inches, respectively. The standard deviation on the long-term normal annual precipitation of 42 inches is approximately 5 inches. This is significant in that drought conditions and water-supply shortages as determined by hydrologic indices and other indicators occur when precipitation totals fall 3 inches below normal over a six-month period. In other words, drought conditions exist statistically within one standard deviation of long-term normal precipitation, and thus drought events must be considered completely ordinary rather than uncommon events. In fact, drought recurs in this area to some degree of seriousness approximately three times each decade.

On an average or long-term basis, water-supply availability in the Piedmont Basin is a function of groundwater storage determined by the geologic controls that capture, store, and discharge water to the surface streams and through the ground systems. The *geology* of the area is, in fact, a more significant determinant than the weather in controlling the specific occurrence of water and the amount that is actually available for human uses (as well as the amount available to support all other living populations). These elements of the hydrologic cycle are shown schematically in Figure 9.

The other important factor in the occurrence and distribution of available water is human impact on natural systems. As discussed later in this section under "Sources of Impact," water usage by humans in the study area exerts significant stress on the environment at certain critical times.

Figure 9

SCHEMATIC REPRESENTATION OF THE HYDROLOGIC CYCLE



Qualitative Hydrology of Water Supplies

The Piedmont Basin has two major direct sources of water — which make up the hydrogeology of the area — surface supplies and ground supplies.

Surface-water supplies consist of rivers, streams, and several minor, man-made ponds and impoundments. The Christina River basin's drainage area, which actually extends beyond the Delaware portion referred to herein as the Piedmont Basin, is characterized as a low-order stream system with a dendritic drainage pattern established on basement-complex rocks. (Stream order indicates number of tributaries in a basin. While the Christina River is a third-order stream, a large, continental basin such as the Mississippi River would be a ninth-order stream.) This drainage pattern reflects the underlying geologic structure of faulted and folded rocks and the relationship of geology to the prevailing climate.

The stream network or drainage system can also be characterized by a parameter termed *drainage density*. As a rule, humid regions with consistent slopes and infiltration-resistant soils and rocks develop high drainage densities, or lengths of streams per unit area. The Christina River basin has a high drainage density value of roughly 1,000, reflected by close spacing of drainage ways. (In comparison, southern California has a drainage density value of 30).

Although the summit or highest relief at the perimeter of the Christina River basin stands 1,200 feet above sea level, the overall stream gradient is rather low. In the Christina River basin, a major geologic transition occurs from the Piedmont to the Coastal Plain and is demarcated along a line termed the "Fall Line." The minor tributaries in the Delaware River basin — Naamans and Shellpot creeks — differ from streams in the Christina River basin in that they flow directly from the Piedmont region to the Delaware River, traversing only narrow strands of riverbank deposits of recent origin.

Stream gradients above the Fall Line are somewhat steeper than those below, and flow decelerates downstream of this transition. Together, these parameters are indicative of an "old-age" drainage system. In the lower part of the basin, below the Fall Line, the drainage undergoes a transition to a meandering pattern with a slightly lower drainage density and gradient although discharge increases within these main-tributary segments, which have significantly larger cross-sectional area and depth compared to the Piedmont segments.

In these lower reaches, the streams are part of the Delaware River estuary and are thus under tidal influence. Due to the very low stream elevations relative to sea level, tidal influence extends considerably inland. The tide influences stream stages diurnally and extends 12 stream miles on the Christina River, where the tide is impeded at Smalley's

Dam; 8 stream miles on White Clay Creek, to near Delaware Park; and 3 stream miles on Brandywine Creek, to City Dam in Wilmington.

The basin is fairly complex geomorphically, and it should also be noted that all of these stream reaches have been considerably altered from their natural state. Significant alterations include sedimentation from erosion caused by urbanization of the area; channel engineering; changes in discharge, particularly during high-flow periods caused by increased runoff from impermeable surfaces; and inflow from stormwater sewers. For example, sections of the original stream channels in the Mill Creek drainage have been filled with over 10 feet of sediment this century.

Groundwater supplies are derived from aquifers and aquifer systems in the Piedmont and Coastal Plain. The American Geologic Institute defines an aquifer as a "a body of rock that is sufficiently permeable to conduct water and to yield economically significant quantities of water to wells and springs." This definition itself, however, requires further explanation due to the term "rock" being commonly misinterpreted to mean hardened geologic material. As defined by the American Geological Institute, rock is "an aggregate of one or more minerals" regardless of the degree of hardening of the material. With these definitions aside, the aquifers of each geologic province are distinctly different, reflecting the two major rock classifications in those two provinces, and this has a significant bearing on the amount of usable water that can be obtained.

Groundwater yield is determined by calculating a set of aquifer parameters by a variety of analytical techniques used to work on data collected primarily from aquifer tests. (These tests are colloquially called "pump tests," which is a misnomer since it is the aquifer, not the pump, that is being tested.) Of the several aquifer parameters, some represent the intrinsic, physical properties of the aquifer, while other parameters are derived. Intrinsic physical parameters include porosity and permeability. *Porosity* is defined as the ratio of void space to a unit volume of rock, while permeability is the rate of fluid flow in the rock. From these and other intrinsic parameters, several derived parameters have been established to determine hydraulic response of wells and aquifer yield. The two most important of these are *storativity,* which is the volume of water that can be released from a unit surface area of aquifer per unit decline in normal hydraulic gradient, and *transmissivity,* which is the volumetric rate of water release from an aquifer over time.

Piedmont aquifers are composed of ancient fractured rocks of igneous, meta-igneous, and meta-sedimentary genesis while rocks in the Coastal Plain, being far younger, are predominantly unconsolidated or soft and substantially underformed. Aquifers in the Coastal Plain typically yield an order of magnitude or more of water over a given unit size of aquifer material than do those in the Piedmont.

Piedmont formations contain porosity that has resulted from brittle deformation causing fractures, crevices, faults, and other discontinuities and defects (generically termed *strain*) occurring over the 600 million years of their existence. This type of porosity, also known as secondary porosity, comprises a very minor amount of void space for water to occupy. The void space that does exist is usually not well interconnected, and thus permeability is low and results in low bulk transmissivity values. Thus, Piedmont wells typically have very limited yield.

Groundwater flow is also complicated and often highly directional as a result of the orientation of the stresses and resulting strain in the rocks. Special exploratory and well-construction techniques can be used to both initially site and develop wells in the Piedmont that will yield more water than would otherwise be obtained. Several such wells in the Piedmont are important sources of public and industrial supply. In any location in the Piedmont, however, a well can be installed that will provide for at least the water needs of a single home.

A important function of groundwater in the Piedmont, arguably more so than as a source of water for wells, is as the source of base flow to streams during fair weather. A major portion of the net flow in the streams of the Piedmont comes directly from groundwater discharge in the form of continual leakage or seepage into the streambed overlying the various geologic formations. Local exceptions to the above exist, with the most notable in the Hockessin Valley. The Hockessin Valley merits special mention due to its unusual geology and hydrogeology for Delaware.

In that area, the underlying formation, called the Cockeysville Formation, is composed of the carbonate rocks including marble, dolomite, and dolomitic limestone. Rock that is highly resistant to weathering — predominantly the gneisses and schists that comprise most of the Piedmont — rim the Cockeysville Aquifer. The easier-to-erode Cockeysville has been removed at a faster rate.

This differential weathering of adjacent formations is primarily responsible for creation of the Hockessin Valley and the geomorphic features within it, all of which are a type of terrane termed *karst*. Karst develops in carbonate formations exposed to humid climates and creates aquifers whose porosity is caused primarily from chemical dissolution of the rocks. Because the Cockeysville is part of the Piedmont, fracture-induced porosity is present in the Cockeysville as well. This results in exceedingly complex flow regimes and other notable geologic features such as sinkholes.

While sinkholes have been documented in Hockessin, caves that open to the atmosphere, which are common in other karst areas, do not exist here. Karst aquifers have the capability to yield considerable quantities of water to wells. Another karstic feature of the area is that streams crossing it lose flow rather than gain flow. Mill Creek in the Hockessin Valley does just that; it leaks water *into* the ground, rather than the reverse, as is typical of the Piedmont. This leakage of water from Mill Creek contributes, on an annual average, 22% of the groundwater supply extracted from the aquifer. The creek flows at a perpetual 100-year drought condition.

Another occurrence of the Cockeysville Formation also exists in the White Clay Creek watershed near the intersection of Pike Creek and Paper Mill roads. This area has not been developed as a major water supply source but remains as a source of supply for homes and a school.

The Cockeysville Formation in Hockessin is a major source of water supply and requires considerable care in management of point and nonpoint discharges in Mill Creek and the surrounding tributaries since contaminants can directly enter the groundwater system and be transmitted to wells in unpredictable ways. Due to this sensitivity of the hydrologic system in Hockessin, New Castle County has adopted a special resource protection ordinance to further control land use in the valley and protect water supplies. (For more information, see "Groundwater.")

In contrast to Piedmont aquifers, Coastal Plain aquifers are composed of granular material whose pore space is a much larger percentage of the volume of rock and more continuously interconnected. The result is aquifers with high transmissivity values (greater than 50,000 gallons per day per foot of saturated aquifer thickness). In qualitative terms, the aquifers have "moderate" to "high" yield capability. Yields from individual wells of several hundred thousand gallons per day are obtainable in certain locations.

In the Coastal Plain, the rocks have not yet been transformed into hardened material and undergone major deformation. Thus, the portions of the formations that remain (after some erosion) are nearly intact as originally deposited. This results in so-called *layer-cake geology*, where formations are stacked, in beds, one upon the other in relatively even, sheet-like fashion.

As always, real geology is never quite as simple as a layer cake. Of the two formations in the Coastal Plain, the uppermost Columbia is expressed as a fairly regular sheet deposit at the surface, but at depth is irregularly deposited on the older, eroded surface of the Potomac Formation. This causes great local variation in thickness of the Columbia where in a lateral distance of several feet, the formation can vary in thickness by up to 100 feet. The Columbia Formation contains the namesake water-table aquifer.

The underlying Potomac Formation is substantially more consistent in thickness in a given area than is the Columbia; however, its internal composition is extremely variable and the entire formation is not level with the land surface but is warped downward slightly in a southeasterly direction. This warp or tilt is called *bedding dip*.

Overburden weight in the Potomac Formation has helped cause it to subside, creating the dip. In general, the greater the dip, the more material is deposited. Compaction does thin the sediments somewhat after burial, but downwarping also accelerates the rate of deposition so an increasing amount of accumulation occurs down-dip and the formation grows progressively thicker.

An important implication of the concept of dip is its relation to aquifer recharge. Dip along with erosion has caused the Potomac Formation and the aquifers within it to be exposed or nearly exposed at the surface at their northwestern end, forming *outcrop areas*. Where buried by the Columbia in the up-dip portion, the Potomac forms *subcrop* areas. The outcropping and subcropping areas of the aquifers are also the recharge areas where the aquifers receive the most water inflow from precipitation. The Columbia, of course, receives its recharge directly since it is the surficial aquifer, although variable permeability at the surface of the Columbia has areas where the potential for recharge is greater than in others, and these areas are designated recharge areas as well.

Any substances that may be in that water such as contaminants clearly put the aquifer at risk of damage. The bulk of the water in the Potomac is extracted outside the Christina basin; however; as explained above, the source is from within the basin. Accordingly, the need for protection of aquifer recharge areas should be apparent for all recharge areas. Historical contamination events have rendered many parts of these aquifers unusable, resulting in a loss of water supply.

In the down-dip portions of the Potomac Formation, the aquifers become bounded above and below by relatively impermeable, fine-grained sediments forming confined aquifers. These aquifers are more protected from contamination than water-table aquifers, but some level of protection is still required, particularly for proper well-construction techniques.

Rates of recharge and discharge are also functions of the composition of the deposits along with their spatial orientation. At the contacts of these various formations, flow boundaries exist. At the Fall Line, some minor inter-flow does occur between the two provinces although it is insignificant in terms of net flow in the basin system. This is a no-flow boundary.

As stated above, Coastal Plain rocks steadily thicken in a southeasterly direction from a "feather edge" at the Fall Line to several hundred feet. As a result, most of the Coastal Plain groundwater system is simply not in contact with the streams. The limited portions of the Coastal Plain rocks that are in contact with the streams are mostly isolated from them by fine-grained sediments, which inhibit flow between the systems. Thus, the surface- and groundwater systems in the Coastal Plain are primarily a no-flow boundary, but local variation exists.

Groundwater in the Coastal Plain aquifers flows predominantly in a southeasterly direction (the direction of dip) with natural discharge ultimately going to the Delaware River and Atlantic Ocean at slow flow velocities on the order of inches per day. This flow is part of a large, regional flow system that extends along much of the middle Atlantic seaboard. No-flow and low-flow boundaries occur within Coastal Plain formations in the form of silt and clay layers, which act to separate internal aquifers from each other. Although complex, these systems are intensively used for water supply and have been afforded a large amount of study including digital models and therefore are fairly well understood.

In the Piedmont, the aquifers are in extensive contact with the surface systems and a significant amount of natural groundwater discharge is to streams rather than into a deep, regional flow system. The meager amount of groundwater discharge in the Piedmont expressed by low well yields would appear to contradict the fact that the streams are important water-supply sources. The reason the opposite is true is that the stream flow is derived from accumulated groundwater discharge from the much larger upper basin in Pennsylvania.

The above descriptions are necessarily abbreviated and simplified since the actual systems are much more complicated than can be described with any ease. Plan-view and cross-sectional maps are useful for general depictions of the systems, but it must be understood that the systems are dynamic, three-dimensional, and highly heterogeneous and can only be understood at the site-level with careful study.

There are very few consistently similar characteristics of the various hydrologic systems in the basin, and about the only commonality they share is the same climate. As explained by the geology, this is why, despite receiving an equal amount of precipitation, the characteristics of the systems are remarkably different.

Based on quantitative analysis of the various drainage and yield parameters for the Christina basin, overall it has a limited water-supply capacity in comparison to the intensity of its use as a source of fresh water. The consequence of this is that while the Christina basin is still the major source of supply for the area, other sources have been developed to augment this supply. Namely, reservoirs have been constructed to store runoff for periods of low flow and water is imported from outside the Christina River basin and in fact from outside the Delaware River basin.

The vast majority of these augmented supplies exist in and are for use by Pennsylvania, but Delaware does receive a small increment of that water. Our supplies are primarily based on those that are naturally available. Thus, nearly 70% of the public water in the area is derived directly from the surface sources, which also support aquatic habitat and a variety of other primary and secondary uses. Use of the surface water is becoming increasingly competitive.

Even with the limitations of the surface sources, they are more accessible than groundwater sources and were developed early in the settlement of the area. Later, as additional supplies were needed, groundwater was exploited. Overall, the groundwater systems in the study area are the most complicated and variable in Delaware. Still, aquifers supply about 25% of the total water for the area, and in the relatively small watershed of 100 square miles, 50% of the groundwater pumped in the entire state for drinking water is produced from the Christina River basin. Put another way, the concentration of the population and the demand it imposes on supplies has resulted in both ground- and surface-water supplies being at nearly 100% development.

Quantitative Hydrology of Water Supplies

Surface-Water Resources

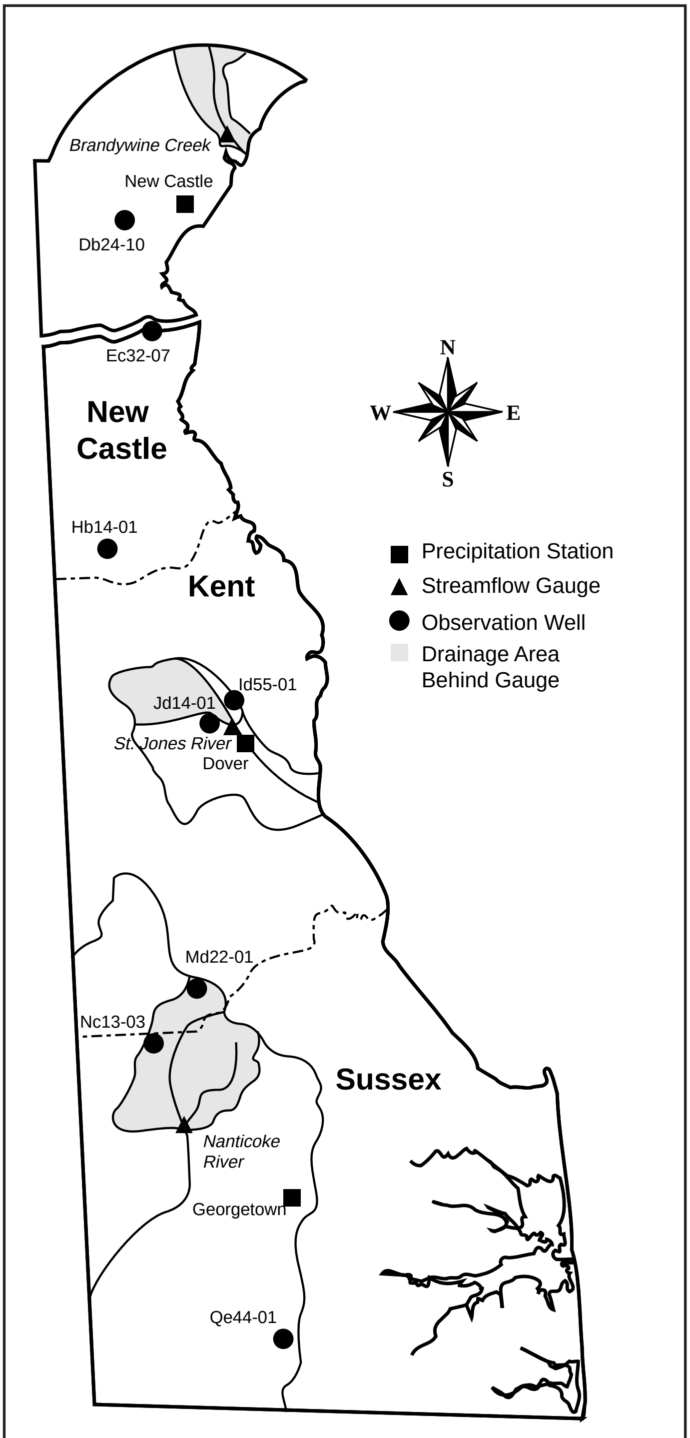
Data for stream flow is collected routinely via a system of stream-gauging stations operated and maintained by the U.S. Geological Survey and reported annually in their Water Resources Data publications for each "water year." The water year starts October 1 and ends September 30, and the Water Resources Data contain records for the previous year. For example, the 1995 Water Resources Data covers the period October 1, 1994, through September 30, 1995. These publications are usually distributed in July of the calendar year following the reported water year, in this case July 1996. The locations of these stations are shown on Figure 10.

Data from only those gauging stations in operation during that year are reported. Data from discontinued stations can be obtained on-line from the U.S. Geological Survey's central computer database, WATSTORE, in Reston, Virginia.

The report for each gauge consists of descriptions of its location, basin drainage area, period of record, gauge type, qualifying remarks, and any factors that can influence flow such as diversions upstream, extreme flows, and tabulations of mean daily flows and monthly totals. Beginning in 1993, in addition to the tabulated data, rudimentary statistics were added for each month of the reported water year as well as for the period of record. A hydrograph of the water year was also added. See Figure 11. Some of the important statistical data that are available are recurrence interval flows. Note that these recurrence intervals are not

Figure 10

MAP OF LOCATIONS OF HYDROLOGIC MONITORING STATIONS



Acknowledgments: U.S. Geological Survey, National Weather Service, Delaware Division of Highways,University of Delaware, City of Dover, City of Lewes, City of Wilmington, Daniel and Connie Swartzentruber.

Source: Delaware Geological Survey Summary of Water Conditions in Delaware for July, August, and September 1996.

actual flows but statistical derivations, and they should not be misconstrued as predictors of when a given flow event will occur. For instance, the recurrence of a certain flow every 50 years does not mean such a flow will occur regularly every 50 years. Instead, such a flow may occur two years back to back and not again for 100 years.

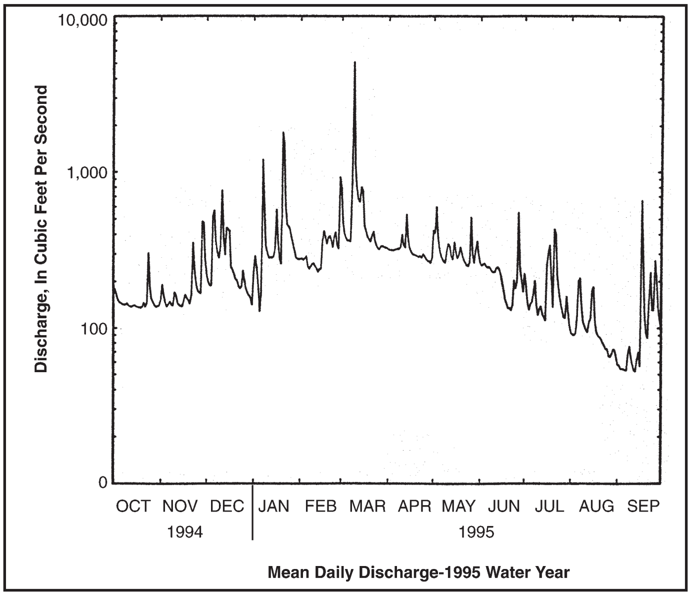
Conversely, the possibility of flows above or below extremes of record must be acknowledged in light of the limited period of record for most stations (several decades) compared to the age of the streams (thousands of years). Therefore, new extremes will occur that will alter the record. For instance, a 50-year-flood flow may occur three times in 50 years. Still, recurrence flow data are useful for assessing stream behavior and the various application of such data for water resources management. One type of recurrence flow of wide importance is one termed "the Q7-10 statistical low-flow." It is used as a standard for maintaining stream water quality. The standard requires that a minimum flow equal to the Q7-10 low-flow must be maintained in the stream otherwise water-quality standards will be violated. This subject is covered in more detail in "Positive Initiatives."

Other information not reported in the Water Resources Data can also be obtained from the U.S. Geological Survey for both operating and discontinued stations. These data include detailed statistics derived from gauging-station flow records.

Published data are not organized by the U.S. Geological Survey for entire basins but rather for those stations within a

Figure 11

U.S. GEOLOGICAL SURVEY WATER RESOURCES DATA, MARYLAND AND DELAWARE, 1995



given district. If the district includes all stations for a particular drainage basin, such data would be found within one Water Resources Data publication. Otherwise, data covering an entire watershed would need to be obtained from Water Resources Data published by two (or more) different districts. This is the situation with the Christina River basin. Reports from the Maryland and Delaware district would be needed along with that of the southeast Pennsylvania district in order to obtain data for the entire watershed.

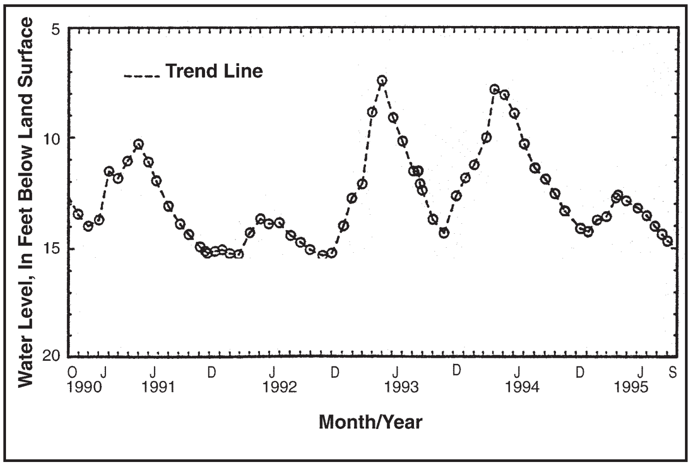
Real-time, or instantaneous, discharge data can be obtained automatically at continuous recording stations at which a sufficiently long history of flow data has been collected. Such data is analyzed by hydrologists using various computational techniques which also are used to determine the various statistical flows mentioned above. These data are used to establish rating curves for the gauges. The rating curves allow translation of stream level, or stage, to discharge measurements. Note that all flow data are reported in cubic feet per second.

Instrumentation in the gauging station is calibrated to read stream levels every 15 minutes (or more often if necessary) and record the stage measurement. Some stations are accessible remotely and can transmit in simulated voice or by electronic signal a stage reading, which can be translated manually to a discharge measurement by reference to the rating curve for the gauge. Only authorized personnel are permitted to access gauges remotely to both minimize maintenance cost associated with activating the instrumentation and to avoid busy telephone lines for use by authorized personnel. This is not an inconvenience to persons interested in these data as instantaneous reading could be obtained upon request by asking Delaware Geological Survey staff. Water-quality data are collected at some gauging stations. Only discharge data are collected at gauging stations in Delaware.

Stream gauges require regular maintenance since channel shifts from storms and sedimentation will alter the stage readings and thus give erroneous discharge measurements. Readings are not absolute but are subject to fluctuations due to tides, up-stream diversions, and other influences. These variations are routinely factored out to produce corrected discharge measurements.

In some instances, however, uncorrected discharge readings become more than a problem with the data simply being in error. One such problem occurred in 1995 when Marsh Creek Reservoir in Chester County, Pennsylvania, failed to make required water releases to the Brandywine Creek because its control gauge at Kennett Square was reading a higher flow than actual. Once this problem was detected, it was remedied minimizing the amount of deprived releases. Routine maintenance of this particular gauge was being neglected, and it is suspected that this

Figure 12
FIVE-YEAR HYDROGRAPH
OCTOBER 1, 1990,THROUGH SEPTEMBER 30, 1995



was at least partially due to government services cutbacks. Gauges in Delaware are supported in a cooperative program by both public and private contributors. While the program in Delaware is relatively strong, some stations have had to be discontinued for lack of available funds to keep them operational. Similar problems with gauge operation and maintenance should be expected as service and funding cutbacks continue.

Groundwater Resources

Companion to the surface discharge records, the U.S. Geological Survey also publishes data on groundwater levels in key observation wells throughout the state. Five of the twelve wells in the observation network are present in the Christina River basin, and all are within the lower Christina watershed, as shown on the Water Resources Data well location map in Figure 10. As with the surface gauging network, data are presented for the water year (see above for explanation), and each well has descriptions of location, hydrologic unit, station characteristics, remarks, and extremes of record. In addition, each well has a hydrograph plot of the previous five years of records. Figure 12 shows records for a representative water-table observation well. The U.S. Geological Survey does not routinely collect groundwater-quality data in the study area.

The Delaware Geological Survey also maintains a groundwater network similar to that of the U.S. Geological Survey using a different set of observation wells in the basin. These data are reported in the Summary of Water Conditions report on an as-needed basis. The last available report is shown in Figures 13 through 15. Only one well, Db24-10, a key water-table observation well, is located within the Christina basin, in the lower Christina watershed. The report also contains stream-flow data for Brandywine Creek (collected by the

U.S Geological Survey) and precipitation data (collected at the National Weather Service Observatory at the Greater Wilmington Airport). The Delaware Geological Survey also compiles more detailed data during droughts.

As noted, various hydrologic data originate from single sources but are frequently reported by various agencies using different formats depending on the purpose of the report. The single source of basic hydrologic data are weather data from the National Weather Service at the Greater Wilmington Airport. This is the source of official long-term normal temperature and precipitation records.

Other unofficial weather observatories exist within the basin at the City of Wilmington's Porter Reservoir off Concord Pike and at the University of Delaware's College of Agricultural Sciences in Newark, and at some casual observation sites maintained by private citizens.

The U.S. Geological Survey is the source of all streamflow data. Both the U.S. and the Delaware Geological Survey maintain separate but overlapping networks for groundwater data. See the references for special project reports on groundwater quality conducted by both agencies in the Christina basin.

All routinely collected surface- and groundwater-quality data in the basin are collected and reported by DNREC. The Department of Health and Social Services, Division of Public Health, also collects water-quality data from public water suppliers.

Water Systems

Northern New Castle County is reputed to be the most highly interconnected system of public water suppliers in the country. The degree of connection of the five major water suppliers resulted in great part from recommendations from the Water 2000 reports issued by the Water Resources Agency for New Castle County as the major outcome of the county's water-supply planning effort in the mid-1980s. It was recognized that until a major new water-supply facility could be constructed, the mutual reliability of the systems could be increased substantially by making provisions for both ongoing and emergency transfers of water among the utilities.

Two key principles enable these transfer projects to be successful. One is that even in a relatively small geographic area, none of the systems experiences peak demand situations simultaneously due to the unique characteristics of each system's customer and plant base. Therefore, excess pumping and treatment capacity is almost always available to permit sharing of supplies. Also, the advantage of conjunctive use of sources is made by exploiting a variety of different supplies. For instance, if one particular source, say groundwater, becomes unusable due to contamination or stream flows are low due to drought, alternate supplies available to the unaffected utilities can be used to back up the systems. Alternate supplies also include imported water from Pennsylvania via two interconnections with the Chester Water Authority, which draws its supply from the Susquehanna River. Backup supply from other river basins is a wise management approach given the low probability that water shortages would simultaneously affect two entire river basins. These transfer arrangements are patterned after the long-used practice of the electric utilities in their "grid" systems for peaking and emergency backup.

The increase in reliability of supplies provided by these transfer arrangements comes with several costs. First, customers pay a premium to have water imported or transferred between utilities within the state. This is not that such projects are inherently more expensive to construct than normal service-extension projects; they are not. Rather, the supplier providing the water usually imposes considerable surcharges for the privilege and requires minimum purchases. These costs are passed on to consumers. Second, transfers may be interrupted at the discretion of the supplier. Still, transfers are an effective way to increase supplies and are invaluable in emergency situations.

To date, 23 interconnections exist, with several new, smaller connections and expansions and a final major transmission line project between the City of Wilmington and United Water Delaware to be completed by 2000. Artesian Water Company is also pursuing and is expected to secure an extension and increase its transfer contract with Chester, now set to expire in 2002. At that point, virtually every practical transfer arrangement within the county would have been exploited, and the systems would be fully optimized. The remaining potential transfer project would then consist of large-scale importation from Pennsylvania. Such a project is under consideration as a county-wide option under the New Castle County Water Supply Plan, as described in "Positive Initiatives."

Because of the interconnections, however, it is neither a practicable nor a very straightforward task to determine water distribution or usage patterns on the basis of watersheds as defined in the study area. Interestingly enough, though, the service areas of the four utilities in the Christina River watershed do correspond to watershed drainages, which reflects the system engineering considerations for lifting water over major drainage divides. Map 15, of Public Water Service System Areas of New Castle County, shows the present arrangement of the utilities.

Wilmington occupies the Brandywine Creek and lower Christina River watersheds. Newark, Artesian, and United Water all occupy to some extent the upper Christina, while Artesian also has rights to the remainder of the White Clay Creek not controlled by Newark, and all of the Red Clay

Figure 13

DELAWARE GEOLOGICAL SURVEY SUMMARY OF WATER CONDITIONS IN DELAWARE FOR JULY, AUGUST, AND SEPTEMBER 1996

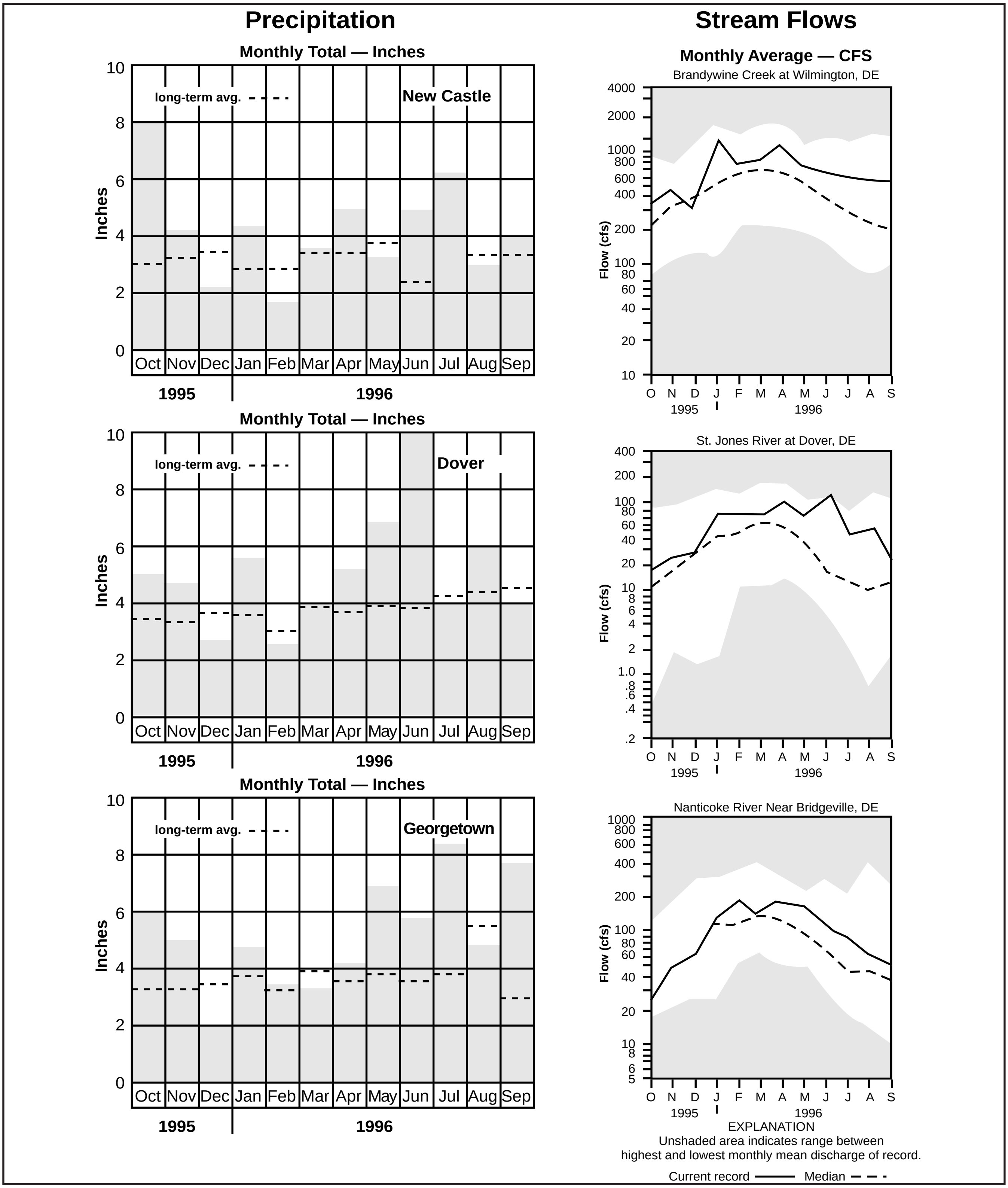


Figure 14

DELAWARE GEOLOGICAL SURVEY SUMMARY OF WATER CONDITIONS IN DELAWARE
FOR JULY, AUGUST, AND SEPTEMBER 1996 — CONT'D.

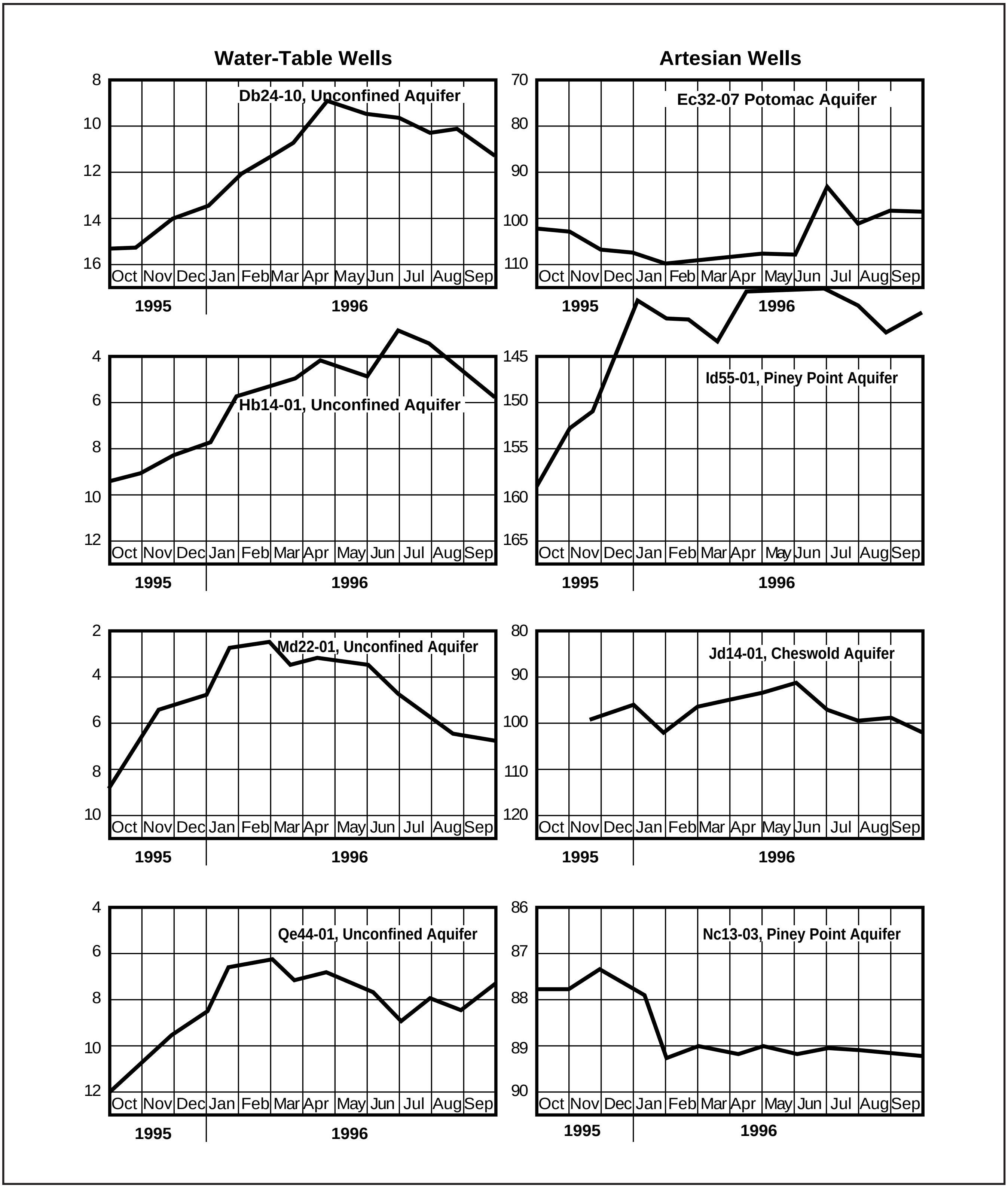
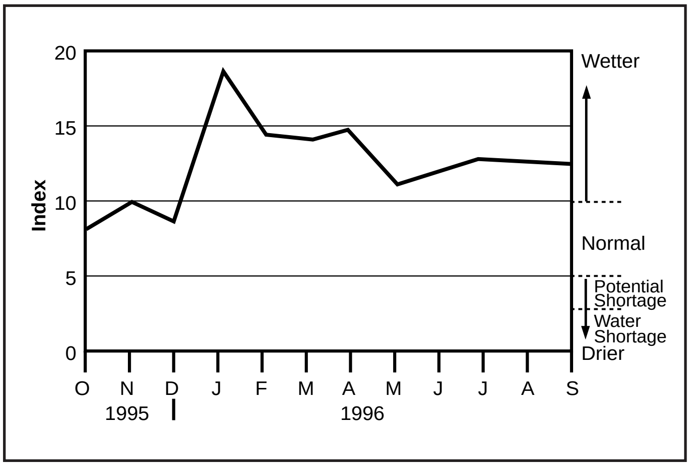


Figure 15

WATER CONDITIONS INDEX FOR
NEW CASTLE COUNTY



Water Conditions for July, August, and September 1996

Precipitation during July was generally above normal throughout Delaware with totals ranging from 8.32" (225% of normal) at Georgetown to 3.84" (93% of normal at Dover. August was somewhat drier than July with rainfall above normal at Dover, normal at New Castle, and slightly below normal at Georgetown. Precipitation was generally above normal during September with over 7" of rain at Georgetown. An exception was New Castle, where precipitation was slightly below normal.

Precipitation for the three-month period ranged from 20.77" (8.2" above normal) at Georgetown to 13.35" (2.29" above normal) at New Castle.

Precipitation for the 1995 – 1996 Water Year was significantly above average and much greater than during the 1994 – 1995 Water Year, with totals ranging from 65.13" (141% of normal) at Wilmington to 50.99" (125% of normal) at New Castle. For the 1994 – 1995 Water Year, precipitation was 36.05" at Wilmington and 31.25" at New Castle.

OCT 1, 1995 SEPT. 30, 1996	NEW CASTLE (NWS)	WILMINGTON (PORTER RES)	DOVER	BRIDGEVILLE-GREENWOOD	GEORGETOWN	LEWES
Total Precipitation	50.99"	65.13"	59.00"	54.68"	61.89"	56.44"
Normal Precipitation	40.84"	46.06"	44.14"	44.36"	43.79"	44.31"
Departure	+10.15	+19.07	+14.86"	+10.32"	+18.10"	+12.13"
Percent of Normal	125%	141%	134%	123%	141%	127%

Monthly mean stream flows were generally above normal during the reporting period and were significantly higher than those recorded during the corresponding period one year ago when drought conditions prevailed. Surface-water flows were more than adequate to meet public water-supply demands.

Although groundwater levels in three shallow water-table wells declined seasonally during the period, they remained in the normal to above normal range for this time of the year. Water levels exhibited a rise in well Qe44-10 near Trap Pond and a record high water level was established in September.

Water levels in the deeper artesian observation wells exhibited little change during July, August, and September. Water levels during September 1996 were approximately 23 ft. higher than during the corresponding period a year earlier.

The Water Conditions Index for New Castle County changed very little and remained in the lower end of the "wetter" range during the reporting period. Overall, water-supply conditions are very good to excellent for this time of the year.

Source: Delaware Geological Survey. *Summary of Water Conditions in Delaware for July, August, and September 1996.*

Creek. United Water Delaware controls the Naamans and Shellpot Creek basins. Curiously, United Water Delaware serves no customers within miles of its main Stanton Treatment Plant; instead Artesian has the service rights.

This illustrates a point regarding service territories and rights of service. A utility franchise denotes only the authority to serve, not the right to withdraw water. Other users can withdraw within other service areas. Another point is that *service area* does not automatically equate with *service provision*. Large tracts of land in some of the utilities' service areas do not have water service extended there, and water is provided by private wells. Utilities often exercise "first right of refusal" so that customers cannot force extension of service that would be an operating loss for the utilities. This is the case with the City of Wilmington's area in the Greenville vicinity and Artesian's area in the southwestern portion of the county. When sufficient demand exists in those areas to make service extension economical, it will be provided. By the same token, when service is extended, existing private wells are not normally required to hook up to the public system, and owners can retain full or partial usage of their system through negotiation with the utility and via permit from DNREC.

The City of Wilmington system is fully self-sufficient and feeds within its corporate limits and some adjacent areas. The City of Newark draws on supplies primarily within its corporate boundary but relies on steady transfers from United Water Delaware, a private utility, to meet demand. The cities' systems are not expected to undergo any significant growth in the foreseeable future, and may, in fact, decline.

Wilmington is expected to become a larger water exporter, however, when the transfer project with United Water Delaware is completed. Although not in the basin, the City of New Castle Board of Water and Light Commissioners transfers a small amount of water into the basin.

The private, investor-owned utilities of Artesian Water and United Water Delaware will absorb the majority of demand increases due primarily to residential housing for the next several decades in addition to some incremental commercial demand with an unknown measure of increasingly aggressive marketing to expand their water service.

Acquisition of whole or parts of public utilities by the investor-owned companies is not out of the question within the next 10 or so years as municipal systems continue to struggle to maintain operations under restrictive budgets, aging customer bases, and business flight. This has already occurred in southern New Castle County and in nearby Chester County, Pennsylvania.

Water Usage

Quantities and proportions of these various sources of supply for public water are shown in Table 16.

Tables 17 through 23 give breakdowns by utility on current and projected water usage. Again, all categories of usage are expected to remain flat or decrease slightly for the planning period with the exception of residential supply. Numerous tables are available from the New Castle County Water Supply Plan study reports giving extensive detail on usage projections, facility capacities, and other water-supply data.

In addition, Tables 24 through 28 provide a breakdown of major freshwater uses within the public suppliers' service areas and include basic information consisting of owner, location, water source (aquifer or stream), facility capacity, and withdrawal allocation limits. Excluded are the cooling water intakes of the large industries along the Delaware River. Some facilities outside of the basin are included also, owing to the categorizing of the information by utility.

While accurate at the time of compilation, the lists may not be complete or accurate at any given time due to continuous changes in the systems. Also, actual usage varies and will typically be less than the listed permit limits. Wells, in particular, are taken in and out of service regularly, or are abandoned and sometimes replaced by new facilities. A committee called the Resource Protection Area Technical Advisory Committee — consisting of DNREC and New Castle County agencies and other advisors — was created, in part, to track new wells designated by the EPA as "Community Water Systems." The DNREC Water Supply Section (phone: 302-739-4793), the Water Resources Agency for New Castle County (phone: 302-831-4925), and system owners must be consulted for current information on water-supply system facilities and water-use data. Information on drinking water quality for the public supplies is available from the Division of Public Health, Office of Drinking Water (phone: 302-739-5410).

As noted earlier, under certain critical conditions, naturally available water supply in the Delaware portion of the Christina River basin cannot meet demand. New sources of supply will be required at some time in the future in order to meet normal demands. During droughts, naturally available supply is much less than demand. Various projects are under development or evaluation in order to increase conservation and water-use efficiency and to provide for additional supply.

Water-Supply Regulation

Regulation of all water facilities and water withdrawals is administered by DNREC, and by the Delaware River Basin Commission (for withdrawals in excess of 1 million gallons per day, averaged over 30 days). Regulation is provided through the Well Construction and Water Allocation programs in DNREC and through DNREC's administrative agreement with the Delaware River Basin Commission.

Table 16

SOURCES OF PUBLIC WATER SUPPLY

	SURFACE WATER	GROUNDWATER	IMPORTS	TOTAL
STATE	50 MGD (54%)	40 MGD (43%)	3 MGD (3%)	93 MGD
NCC	50 MGD (68%)	20 MGD (27%)	3 MGD (4%)	73 MGD
N. NCC	50 MGD (69%)	19 MGD (26%)	3 MGD (4%)	72 MGD

The systems are regulated in terms of maximum daily, monthly, and yearly withdrawal. For groundwater withdrawals from confined aquifers, a maximum allowable draw-down limit is stipulated for each well to prevent groundwater mining. As described earlier, regulations are being developed to provide for additional, needed protection of in-stream flow, and this will apply to all stream withdrawals in the area. Permittees are required to submit water usage reports annually — or more often, at DNREC's request — and must prove compliance with the operational limits.

An important component of these regulations concerns water conservation and drought emergency plans, which the suppliers must implement and update regularly. As a result of these planning efforts, the utilities and other systems operate at a generally much higher efficiency than comparable systems in the area and are well prepared for drought response. A good indication of system efficiency is conveyance loss or leakage, usually expressed as a ratio of production to sales. The difference from 100% is termed *unaccounted for usage*. The majority of unaccounted for usage is leakage. This is a major problem for older systems, in particular, where leakage can approach 40% of production or more. The overall leakage rate for the county's public water systems varies between 10% and 12%, which is considered "tight" and as efficient as practical under current water utility economics.

As seen in Table 29, there are 140 individual supply facilities in the study area with a combined capacity from ground- and surface-water sources of 130 million gallons per day. Surface-water sources are known to be over-allocated since naturally available supply is inadequate to meet prevailing demand at all times. Groundwater sources are at virtually full development, but evaluation of monitoring data and actual production records indicate that withdrawals are within a "safe," sustainable level and have not been overdrafted.

Table 17
ARTESIAN WATER COMPANY
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY[1] (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	20.55	16.60	0.00	0.00	16.60	- 3.95
1995	21.38	16.60	0.00	6.00	22.60	1.22
2000	22.14	16.60	0.00	6.00	22.60	0.46
2005	22.84	16.60	0.00	0.00	16.60	- 6.24
2010	23.69	16.60	0.00	0.00	16.60	-7.09
2020	24.90	16.60	0.00	0.00	16.60	- 8.30
2030	26.33	16.60	0.00	0.00	16.60	-9.73
2040	27.67	16.60	0.00	0.00	16.60	-11.07

[1]*Includes DNREC allocations and pending allocations.*
Source: Metcalf & Eddy, 1991.

Table 18
WILMINGTON SUBURBAN WATER CORPORATION
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	DNREC ALLOCATION MAXIMUM DAILY GROUNDWATER PRODUCTION CAPACITY (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY[1] (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	26.93	0.00	36.00	2.00	38.00	11.07
1995	26.80	0.00	36.00	2.00	38.00	11.20
2000	27.07	0.00	36.00	2.00	38.00	10.93
2005	27.30	0.00	36.00	2.00	38.00	10.70
2010	27.42	0.00	36.00	2.00	38.00	10.58
2020	28.81	0.00	36.00	2.00	38.00	9.19
2030	30.00	0.00	36.00	2.00	38.00	8.00
2040	31.15	0.00	36.00	0.00	36.00	4.85

[1]*Total combined surface- and groundwater treatment capacity. Assumes the existence of adequate raw water supply.*
Source: Metcalf & Eddy, 1991.

Table 19
CITY OF WILMINGTON
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY[1] (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	35.76	0.00	50.00	0.00	50.00	14.24
1995	33.41	0.00	50.00	0.00	50.00	16.59
2000	34.24	0.00	50.00	0.00	50.00	15.76
2005	31.65	0.00	50.00	0.00	50.00	18.35
2010	31.18	0.00	50.00	0.00	50.00	18.82
2020	31.95	0.00	50.00	0.00	50.00	18.05
2030	32.35	0.00	50.00	0.00	50.00	17.65
2040	32.76	0.00	50.00	0.00	50.00	17.24

[1]*Total combined surface and groundwater treatment capacity. Assumes the existence of adequate raw water supply.*
Source: Metcalf & Eddy, 1991.

Table 20
CITY OF NEWARK
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY[1] (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY[2] (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	5.79	4.80	0.00	0.00	4.80	-0.99
1995	5.32	4.80	3.00	0.00	6.00	0.68
2000	5.12	4.80	4.00	0.00	7.00	1. 88
2005	4.94	4.80	5.00	0.00	8.00	3.06
2010	4.80	4.80	5.00	0.00	8.00	3.20
2020	4.96	4.80	5.00	0.00	8.00	3.04
2030	5.06	4.80	5.00	0.00	8.00	2.94
2040	5.16	4.80	5.00	0.00	8.00	2.84

[1]*DNREC allocation for maximum daily withdrawal.*
[2]*Total combined surface and groundwater treatment capacity. Assumes the existence of adequate raw water supply. Some groundwater must be treated at a treatment plant.*
Source: Metcalf & Eddy, 1991.

Table 21
NEW CASTLE BOARD OF WATER AND LIGHT
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	**PROJECTED MAXIMUM DAILY DEMAND** (MGD)	**MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY**[1] (MGD)	**SURFACE-WATER PRODUCTION CAPACITY** (MGD)	**IMPORTED WATER FROM OUT OF COUNTY** (MGD)	**TOTAL MAXIMUM DAILY PRODUCTION CAPACITY** (MGD)	**WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–)** (MGD)
1990	0.83	1.67	0.00	0.00	1.67	0.84
1995	0.85	1.67	0.00	0.00	1.67	0.82
2000	0.85	1.67	0.00	0.00	1.67	0.82
2005	0.85	1.67	0.00	0.00	1.67	0.82
2010	0.86	1.67	0.00	0.00	1.67	0.81
2020	0.90	1.67	0.00	0.00	1.67	0.77
2030	0.95	1.67	0.00	0.00	1.67	0 72
2040	0.99	1.67	0.00	0.00	1.67	0.68

[1]*DNREC allocation for maximum daily withdrawal.*
Source: Metcalf & Eddy, 1991.

Table 22
SELF-SUPPLIED SYSTEMS NORTH OF THE C&D CANAL
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	**PROJECTED MAXIMUM DAILY DEMAND** (MGD)	**ESTIMATED 1988 MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY** (MGD)	**SURFACE-WATER PRODUCTION CAPACITY** (MGD)	**IMPORTED WATER FROM OUT OF COUNTY** (MGD)	**TOTAL MAXIMUM DAILY PRODUCTION CAPACITY** (MGD)	**WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–)** (MGD)
1990	18.86	18.74	0.00	0.00	18.74	-0.12
1995	18.95	18.74	0.00	0.00	18.74	-0.21
2000	19.11	18.74	0.00	0.00	18.74	-0.37
2005	19.31	18.74	0.00	0.00	18.74	-0.57
2010	19.64	18.74	0.00	0.00	18.74	-0.90
2020	20.21	18.74	0.00	0.00	18.74	-1.47
2030	20.78	18.74	0.00	0.00	18.74	-2.04
2040	21.35	18.74	0.00	0.00	18.74	-2.61

Source: Metcalf & Eddy, 1991.

Table 23
NEW CASTLE COUNTY NORTH OF C&D CANAL
WATER-SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	**PROJECTED MAXIMUM DAILY DEMAND** (MGD)	**MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY**[1] (MGD)	**SURFACE-WATER PRODUCTION CAPACITY** (MGD)	**IMPORTED WATER FROM OUT OF COUNTY** (MGD)	**TOTAL MAXIMUM DAILY PRODUCTION CAPACITY**[2] (MGD)	**WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–)** (MGD)
1990	109.08	42.16	86.00	2.00	130.16	21.08
1995	107.09	42.16	89.00	6.00	135.36	28.27
2000	107.13	42.16	91.00	6.00	137.36	30.23
2005	107.25	42.16	91.00	2.00	133.36	26.11
2010	107.95	42.16	91.00	2.00	133.36	25.41
2020	112.09	42.16	91.00	2.00	133.36	21.27
2030	115.83	42.16	91.00	2.00	133.36	17.53
2040	119.47	42.16	91.00	0.00	131.36	11.89

[1] *Includes DNREC allocations and pending allocations for public purveyors and estimated 1988 withdrawals for self-supplied water users.*
[2] *Total combined surface and groundwater treatment capacity. Assumes the existence of adequate raw water supply. Some groundwater must be treated at a treatment plant.*
Source: Metcalf & Eddy, 1991.

Table 24
1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

PURVEYOR	**LOCATION**	**BASE SOURCE**	**FACILITY SOURCE**	**Facility Source Pumping Capacity**		**DNREC Allocation Mil. Gal. Per**	
				GPM	**MGD**	**DAY**	**MONTH**
(AWC cont.)							
INDUSTRIAL							
Crown Advanced Films•	New Castle	Potomac	2 Wells	720	0.20	0.20	6.00
E. I. du Pont	Glasgow Site	Columbia**	3 Wells	330	0.42	0.42	12.70
NVF	Yorklyn	Red Clay Creek	2 Intakes	4490	3.50	3.50	96.00*
Hercules Inc.	Wooddale	Wissahickon	14 Wells	453	0.55	0.55	14.00
Hercules Research Cent.	Wooddale	Red Clay Creek	1 Intake	625	0.90	0.90	22.00*
Army Creek Landfill• *(Recovery Wells)*	New Castle	Upper Potomac	15 Wells	2,500	3.60	0.00	0.00
RECREATIONAL							
Hercules Country Club	Wooddale	Red Clay Creek	1 Intake	350	0.50	0.50	5.00*
Delcastle Golf Club	McKennans Church Road	Pond #2	1 Intake	750	0.26	0.26	5.20
		Wissahickon	1 Well	50	0.07	0.07	1.50
Three Little Bakers CC	Wilmington	Pond #1	1 Intake	1,000	0.24	0.24	7.20
Cavalier's Country Club	Newark	Pond #1	1 Intake	1,000	0.59	0.59	8.15*
		Christina River	1 Intake	400	—	(combined total)	
Samuel Beard	Wilmington	Red Clay Creek	1 Intake	100	0.03	0.03	0.93
			Subtotal	**23,293**	**22.93**	**19.02**	**573.30**

•*Out of Basin*
***Water Table Aquifer*

Table 25

1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

				Facility Source Pumping Capacity		DNREC Allocation Mil. Gal. Per	
PURVEYOR	**LOCATION**	**BASE SOURCE**	**FACILITY SOURCE**	**GPM**	**MGD**	**DAY**	**MONTH**
Artesian Water Co.							
PUBLIC							
	Airport Industrial Park•	Potomac	2 Wells	400	0.49	0.72	21.60
	Artisan Village•	Upper Potomac	3 Wells	2,110	3.02	3.02	90.72
	Caravel Farms	Potomac	1 Well	200	0.25	0.29	8.64
	Castle Hills•	Upper Potomac	3 Wells	800	0.98	1.37	42.41
	Collins Pk.	Potomac	1 Well	300	0.46	0.46	12.96
	Fairwinds•	Upper Potomac	4 Wells	1,100	1.35	2.00	60.00
	Glendale	Columbia**	2 Wells	450	0.62	0.50	15.00
		Upper Potomac	3 Wells	900	0.94	1.30	39.03
	Hockessin	Cockeysville	6 Wells	1,800	2.20	1.90	100.00
	Jefferson Farms•	Upper Potomac	2 Wells	700	0.79	1.30	38.88
	Llangollen Ests.•	Upper Potomac	5 Wells	1,400	1.55	2.00	60.00
	Midvale•	Potomac	2 Wells	300	0.30	0.58	17.28
	Old County Road	Potomac	2 Wells	1,700	2.45	2.45	69.00
	Wilmington Airport	Lower Potomac	3 Wells	525	0.43	0.86	25.92
	Wilm. Manor Gardens•	Columbia**	2 Wells	450	0.55	0.49	15.25
			Subtotal	**13,135**	**16.38**	**19.24**	**616.69**

***Water Table Aquifer.* *Source:* DNREC, 1997.

•*Out of Basin.*

Table 26

1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

				Facility Source Pumping Capacity		DNREC Allocation Mil. Gal. Per	
PURVEYOR	**LOCATION**	**BASE SOURCE**	**FACILITY SOURCE**	**GPM**	**MGD**	**DAY**	**MONTH**
United Water Delaware							
PUBLIC							
North Service Area	Red & White Clay Creeks	Red & White Clay Creeks	Stanton WTP	20,835	30.00	pending	
River Road System	Smalley's Pond (Christina River)	Christina River	Christina WTP	4,165	6.00	pending	
INDUSTRIAL							
Standard Chlorine•	Red Lion	Columbia**	5 Wells (1)	240	0.35	0.36	10.80
Star Enterprise•	Delaware City	Columbia**	4 Wells (1)	200	0.22	0.22	6.48
		Holocene**	Inter. Trench	400	0.10	0.10	3.00
		Lower Potomac	8 Wells	5,000	6.00	6.00	180.00
		Potomac	1 Well			(combined total)	
		Red Lion Creek	1 Intake	900	1.30	1.30	38.90
		Dragon Run	1 Intake	1,300	1.87	1.87	56.20
ICI Americas•	New Castle	Lower Potomac	1 Well	500	0.61	3.92	60.00
		Colum./M. Potomac	4 Wells	2,225	2.71	Note: Total DNREC allocation	
IRRIGATION							
Marvin Hershberger	Smalley's Pond Headwaters	Christina River	1 Intake	60	0.02	0.02	0.35
			Subtotal	**35,825**	**49.17**	**13.79**	**355.73**

**Listed under Middle Potomac in Summary Table.*

***Water Table Aquifer.* *(1) Extraction Well.*

•*Out of Basin.*

Table 27
1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

PURVEYOR	LOCATION	BASE SOURCE	FACILITY SOURCE	Facility Source Pumping Capacity GPM	MGD	DNREC Allocation Mil. Gal. Per DAY	MONTH
City of Wilmington							
PUBLIC	Brandywine WTP	Brandywine Creek	Brandywine P.S.	13,890	20.00	pending	
	Porter WTP	Brandywine Creek	Wills P.S.	16,670	24.00		
INDUSTRIAL							
Wilmington Finishing	Wilmington	Brandywine Creek	Intake #1 & #2	3,600	1.00	1.00	25.00
RECREATIONAL							
Dupont Country Club	Wilmington	Brandywine Trib.	1 Intake	550	0.36	0.36	11.00*
		Brandywine Creek	1 Intake	250	0.36	0.36	11.00*
Ed Oliver Country Club	Wilmington	Pond #1	1 Intake	1,250	0.45	0.45	8.00*
Wilmington Country Club	Kennett Pike	Brandywine Trib.	1 Intake	1,800	1.30	1.30	24.40
		Brandywine Trib.	1 Intake	300	0.43	(combined total)	
		Wissahickon	3 Wells	200	0.14	0.14	4.32
		Brandywine Trib.	1 Intake	50		(combined total)	
		Wissahickon	2 Wells	100	0.14	0.14	1.20
Brandywine Country Club	Shipley Road	Pond #1	1 Intake	500	0.51	0.51	7.00*
		Wilmington Comp.	1 Well	200	0.15	0.15	2.00*
(1) Inactive			**Subtotal**	**39,360**	**48.84**	**4.41**	**93.92**

Table 28
1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

PURVEYOR	LOCATION	BASE SOURCE	FACILITY SOURCE	Facility Source Pumping Capacity GPM	MGD	DNREC Allocation Mil. Gal. Per DAY	MONTH
City of Newark							
PUBLIC							
North	Academy St.		2 Wells	0	0.00	pending	
South	S. Chapel St.	Columbia**	6 Wells	1,000	1.30	1.60	47.70
		Potomac	4 Wells	950	0.90	1.40	41.00
Laird Tract	Creek Rd.	Wissahickon	2 Wells***	0	0.00	1.80	54.00
INDUSTRIAL							
Curtis Paper (1)	Newark	White Clay Creek	1 Intake		1.00	pending	
NVF	Newark	White Clay Creek	1 Intake	4,500	1.50	1.50	35.00*
E. I. du Pont	Louviers	White Clay Creek	1 Intake		0.29	pending	
RECREATIONAL							
Dupont Country Club	Louviers Golf Course	White Clay Creek	1 Intake	700	0.23	0.23	6.75*
			Subtotal	**7,150**	**5.22**	**6.53**	**184.45**

***Water Table Aquifer.*
****Out of Service.*
(1) Capacity based on reported maximum month.

The combined facility pumping-capacity is sufficient for future water supply needs. Overall water availability, however, is inadequate during times of high demand and low flow. Accordingly, DNREC will not issue new major allocations of either groundwater or surface water in the area without the addition of supplemental supply.

Trends

Water-supply protection is being given increasing attention as evidenced by the establishment of recharge and wellhead protection areas instituted by county ordinance. The protection area ordinance for recharge is an “overlay” zoning that specifies minimum lot sizes and maximum amounts of impervious surface in high-potential aquifer recharge areas. This helps allow for essential replenishment of groundwater supplies that are impacted by dense residential zoning and construction of paved surfaces. The wellhead protection areas are, likewise, overlay zoning measures; however, it must be noted that the wellhead protection areas do not regulate pre-existing conditions.

The ordinance provides no means to require remediation of known contamination in those areas. For instance, the City of Newark has contaminated wells within delineated wellhead protection areas. The Newark South Wellfield, in fact, is a classic example of the potential efficacy of wellhead protection. In the years following the development of the wellfield, the predominant zoning in the area (manufacturing and commercial) allowed development incompatible with the resource and eventually the wellfield became contaminated. With the installation of new wells, however, the potential source of contamination would be regulated to protect supplies. The protection areas are designated on the Water Resource Protection Area Map. (See Map 5.)

Other trends are toward the installation of high-efficiency plumbing fixtures and implementation of other water conservation measures. The statewide uniform plumbing code was, in fact, amended in 1991 and now specifies the installation of fixtures having specific flow rates that are considered conserving, as opposed to previous code standards that allowed considerably higher flows. Initial concerns from plumbing interests — such as inadequate drain-line carry and retrofitting to old waste systems — were unfounded. Some water managers expressed concern that disruption of the waste treatment process would occur due to insufficient flow; this problem did not materialize either.

One meritorious concern that has been expressed is the increased “tightening” or “hardening” of demand that results from making water use more efficient. To some degree, this concern is legitimate since less water will be available to save during a water shortage as the percentage of dwelling units and businesses with new standard plumbing will steadily increase over time. If the expectation is that large-demand savings can always be relied upon during drought times based on past experience — for instance the 25% demand reductions achieved during the 1995 drought — that water may not be available to “save,” possibly leading to drought management problems. On the other hand, that argument must be rebutted by saying that water should not be wasted so that it can be saved during droughts. The eventual solution is to provide additional backup water supplies and to institute appropriate drought management measures as needed, with more emphasis on innovative approaches.

There are a variety of ongoing projects that are being implemented in the interest of enhancing water supply. To name a few, the aging diversion structures on the Brandywine and White Clay creeks could benefit from renovation to provide for better control of the diversion and reduce leakage losses. The Curtis Treatment Plant in

Table 29
FACILITY INFORMATION PER WATER SUPPLY SOURCE
AND ACCOMPANYING ALLOCATED WITHDRAWALS

BASE SOURCE	FACILITY SOURCE	CAPACITY		ALLOCATION	
		GPM	**MGD**	**MGD**	**MG/30**
GROUNDWATER					
Piedmont					
Wissahickon Fm. + *Wilm. Complex.*	27 Wells	1,183	1.05	3.11	84.00
Cockeysville Fm.	6 Wells	1,800	2.20	1.90	100.00
Subtotal	29 Wells	2,983	3.25	5.01	184.00
Atlantic Coastal Plain					
Columbia Fm.	22 Wells	2,670	3.46	3.10	92.96
Potomac Fm.	52 Wells	21,140	22.71	24.81	678.93
Subtotal	83 Wells	25,967	27.28	29.02	804.73
GROUND TOTAL	**116 Wells**	**28,950**	**30.53**	**34.03**	**988.73**
SURFACE WATER					
Brandywine Creek	10 Intakes	37,860	53.90	53.90*	1,617.00*
Red Clay Creek	5 Intakes	5,565	4.93	4.93	147.90
White Clay Creek	6 Intakes	26,035	35.02	35.02	1,050.60
Christina River	4 Intakes	5,625	6.61	6.61	8.50
Impoundments	4 Intakes	3,500	1.46	1.46	27.40
SURFACE TOTAL	**24 Intakes**	**78,585**	**99.92**	**101.92**	**2,827.43**

City of Wilmington unpermitted withdrawals included — capacity 44 MGD.

Newark was completed in 1992; however, it incorporated the existing diversion works, raceway, and settling lagoons used by the Curtis Paper Company, installed in the late 19th century. The Wilmington Raceway is a registered historic structure, which may preclude renovation efforts that would alter its appearance.

One intriguing area of research in the water-supply industry is in the application of Artificial Storage and Recovery (or ASR, as it is commonly known). Simple in concept but complex in application, a suitable source of excess water is treated and injected into suitable aquifer systems, usually for withdrawal at a later time during high-demand periods. The technique can, however, be applied to meet a variety of resource management objectives, including to repel salt-water intrusion or other contamination of aquifers, or to provide an emergency water supply. A proposal to use this technology in a unique way has been offered by DNREC to implement a very large-scale application as a single source of future water supply for the entire county. Small-scale variations of this concept have been suggested as well.

Before any aquifer recharge project can be established as a reliable supply, extensive geological and hydrochemical test programs have to be performed. Installation of the infrastructure is relatively conventional. Opinions expressed by various experts in the field about the potential for a successful large-scale application of aquifer recharge range from doubtful to very optimistic. Only research and pilot studies will prove who is right. These studies will be undertaken in both the private sector and by DNREC over the next few years.

Innovative research by the University of Delaware has been conducted in the area of demand-side management. Three years of study on the effectiveness of pricing controls on the customers of Artesian Water Company revealed that customers, contrary to conventional thought, were highly sensitive to price increases and reduced demand in response to price increases by approximately twice as much as was presumed based on the results of other rate-impact studies.

In 1992, the Water Resources Commission of New Castle County was required by the General Assembly to investigate the feasibility and encourage the adoption of conservation-oriented water-rate structures for the utilities it regulates. This resulted in approval of a true conservation rate structure that was adopted by Artesian Water Company. However, the effort falls short since municipal suppliers — who provide most public water — remain unaffected, and only Artesian has a true conservation rate structure among the private utilities. There is no incentive for the utilities to continue to advance its usage.

Sources of Impact

Drought

New Castle County is a metropolitan-suburban area experiencing continued population growth and faced with contamination problems and periodic shortages of water supply during droughts. The area's water systems are not reliable in terms of adequate supply. This was brought into sharp focus in the Drought of 1995. For all of its inconveniences to the public and industry, the drought forced a firsthand look at the associated impacts and sharpened focus on the need to deal with water supply issues.

At the height of the drought, water quality had deteriorated to the point that it was estimated that 40% of the water in Brandywine Creek was composed of treated sewage effluent. The Water Quality Standards were waived. The effluent in the Brandywine originated in Pennsylvania and while it did help provide for augmented flow in the stream, it also made treatment for drinking water difficult. The City of Wilmington's water intakes were not built to operate at the low stream levels that occurred, and the intakes became partially inoperable. Fortunately, no primary drinking water violations were reported in the city's system; however, this was in great part due to the substantial use of Hoopes Reservoir water.

The situation at United Water Delaware's Stanton and Christina Treatment plants was also very problematic. High levels of chlorides and sodium were entering the distribution system due to excursion of brackish water from the Delaware River during low tide. The company issued a public health advisory for persons with diagnosed hypertension to consume bottled water. Certain industries also curtailed or ceased purchase of United's water due to the high dissolved solids content, which was incompatible with their processes.

The affected industries were able to continue operations only by activating idle sources of self-supplied water such as unused wells and by making dramatic improvements in water-use efficiency. (United continues to experience depressed industrial sales, which is believed to be the effect of residual conservation efforts by its large industrial customers.)

The groundwater-supplied utilities fared better in terms of both quality and quantity problems, with no unusual cases reported. While some additional groundwater supply was available during the drought, it was produced by the temporary waiving of draw-down limits. Since recovery from the drought, no impact to the groundwater system has been experienced by the temporary overdrafts.

The impact to the stream habitat was able to be investigated in some detail coincidental to the height of the drought. Biological studies consisting of fish species surveys and habitat evaluations that were already planned before the drought by the Joint Task Force on In-Stream Flow Needs were conducted in late summer. These studies revealed that certain sections of the supply streams in the vicinity of the withdrawals were impacted in terms of insufficient depth, velocity, and dissolved oxygen. Withdrawals were essentially 100% of naturally available flow at the time. Comparison of the measured depths and velocities to habitat criteria for certain key fish species indicated that the habitat was definitely impacted, but the extent is still not known in the absence of any direct evidence such as fish kills. The best assessment of the amount of permanent damage to the ecosystem from the drought is that remarkably little occurred. This likely was the result of the drought having a relatively short serious period followed immediately by a strong recovery.

Arguably, the most severe impact from the drought was on human populations. Even with the successful management of the drought through conservation efforts from citizens and businesses, the economic impacts were substantial. Hard numbers on the economic losses due to the drought are not available. One golf course did, however, report turf damage repairs on the order of $50,000. Many landscaping companies laid off all laborers and went out of business for the season due to restrictions on watering. It is not unreasonable to assume that millions of dollars in lost business revenue in the "green industry," as well as private landscaping investments, were incurred due to the drought.

Contamination of Drinking Water Supplies

Aside from drought impacts, which are transient, other more frequent impacts on water supplies exist and are due to natural and man-made contaminants. Ultimately, this becomes a cost pass-down to the consumer.

Occasionally, contamination of water supplies represents a total, permanent *loss* of water supply. Other contaminants can be treated so the supply is not lost. One type of contamination not usually recognized as such but representing a major operating expense for the utility is highly turbid water that results from sediment-loading from erosional runoff. Highly turbid water carries organic matter in both the water column and adsorbed to sediment. In the disinfection process, organics or fine sediment containing organics that are not filtered react with the chlorine-based disinfectants commonly used in the water industry. These reactions produce toxic by-products in a class of compounds called trihalomethanes. More stringent regulatory requirements have reduced the allowable concentrations of these disinfection by-products and thus have necessitated changes in treatment processes. Treatment plant upgrades to comply with the more stringent rules for disinfection by-products have been in the multi-millions of dollars for the region's water utilities.

Spills represent a particular danger for utilities drawing on surface water. To prevent interception of contaminants in the streams after a spill, an emergency response network has been established throughout the basin. Numerous minor spills have occurred, affecting public water-supply systems. Some contaminants have been inadvertently drawn into the distribution systems, but with no known health effects due to rapid dilution in the distribution system. So far, the streams have purged themselves quickly of these spills, and service disruption has not been experienced. A major persistent spill of any particularly dangerous compound has not yet occurred, but is recognized as an event that would seriously cripple major portions of the area's water service.

Sodium chloride from road salting is a chronic and occasionally acute contaminant problem in the area. Alternatives to sodium chloride exist, but efforts to change to these alternatives have not been successful because of the cost issue even though the problem has caused the shutdown of the United Water Delaware water treatment plant at Smalley's Pond on the Christina River on several occasions.

Other contaminants particularly in the groundwater have also required advanced treatment, which again represents a cost for utilities and, ultimately, consumers. Some of these occurrences are from synthetic organic contaminants while others are elevated concentrations of dissolved solids in the raw water, usually iron and manganese. As marginal sources are brought into production and treatment processes have to be upgraded, the costs for public water will continue to rise. For more information, please see Maps 4, 5, 6, 14, and 15.

Positive Initiatives

Water Supply Plan for New Castle County, "Churchmans Marsh EIS"

Integrated Resources Planning has not yet been utilized for planning future water supplies. In fairness, Integrated Resources Planning methods were not in wide use when previous studies of future water supply were undertaken. Still, no matter the type of planning method used, the first and most fundamental element of any supply planning effort is the definition of future needs. Several studies going back as early as the 1950s resulted in recommendations for a new, large reservoir for the county. These proposals never materialized for a variety of institutional and regulatory reasons, with one of the main objections being that the reservoir was sized to meet a need that would not arise until far into the future and thus would be very costly to build.

Nonetheless, the need for additional supply has long been recognized by water resources officials and the problem remained largely unaddressed. With support from the state and the county water utilities, the Water Resources

Agency for New Castle County produced its ten-volume series of reports entitled *Water 2000* as a road map for securing future water supply. The study's major recommendation was the construction of a two-billion-gallon reservoir at Churchmans Marsh. DNREC subsequently adopted the *Water 2000* study as part of the state's water plan in 1985 followed by adoption into the comprehensive plan of the Delaware River Basin Commission later that year.

Thompson's Station Reservoir was selected as a secondary alternative since indications were given by DNREC that the wetlands issues associated with Churchmans Marsh were considerable and the project would have to overcome significant hurdles to receive approval. Reservoir projects in the Piedmont that had been proposed in the past also met with objection. The leading contender prior to the *Water 2000* report was a reservoir known as the "Newark Project." It was conceived as a four-billion-gallon reservoir on the main stem of White Clay Creek just north of Newark. The impoundment would have inundated several thousand acres of land, forming a pool extending into Pennsylvania. By the time *Water 2000* was issued, land that would have been inundated had begun being denoted to the state for dedicated open space as part of what is now White Clay Creek State Park and the Bi-State Preserve. Also, a review of previous demand projections for the "Newark Project" found they were over-estimated and such a large facility was unnecessary. Accordingly, the "Newark Project" was permanently dropped from the state's water plan in 1984 concurrent with the adoption of the Churchmans Marsh and Thompsons Station projects.

Since the proposed primary project was a reservoir and would be located in wetlands, the regulatory requirements of the National Environmental Policy Act of 1974 had to be addressed — involving the preparation of an Environmental Impact Statement. The U.S Army Corps of Engineers is the federal agency responsible for conducting an Environmental Impact Statement (EIS), and the Corps of Engineers coordinates the study along with the project applicant and the involved federal review agencies: the U.S. Environmental Protection Agency; the U.S. Fish and Wildlife Service; and the National Marine Fisheries Service of the National Oceanographic and Atmospheric Administration.

With the need established to conduct a formal Environmental Impact Statement, a voting Project Management Committee was formed, consisting of Artesian Water Company; Wilmington Suburban Water Corporation (now United Water Delaware); and New Castle County; and the Delaware Department of Finance, Delaware Economic Development Office, and DNREC (all represented by one vote). In 1995, the City of Newark joined, as the fifth voting member, and became the project sponsor. A Public Advisory Group and Technical Coordinating Committee were created as well, to provide for early public input into the process.

To engage the federal review process, an application was submitted in 1988 by New Castle County to the Corps of Engineers for a Clean Water Act, Section 401 permit for construction of a reservoir in Churchmans Marsh — concurrent with application to DNREC for an accompanying ("tidal") wetlands permit and subaqueous lands permit. These applications prompted the Corps of Engineers to require that an Environmental Impact Study be conducted to fulfill federal requirements. Such a study, when completed, becomes a U.S. Army Corps of Engineers document. The Project Management Committee contracted with a consultant to perform the supply-and-demand analysis, with the intent of leading into the preparation of an Environmental Impact Statement. Formal study began in 1989.

The consultant then started winnowing through the list of alternatives also evaluated in *Water 2000,* including 68 separate projects and 38 combination projects. In the intervening seven years, the study has slowly progressed with elimination of most proposed projects to enable detailed analysis of a core group of feasible alternatives.

A side note is that because the permit application to the Corps of Engineers names Churchmans Marsh as the application project, the subsequent study has been erroneously dubbed the "Churchmans Marsh EIS (Environmental Impact Statement)." This leads many to conclude that only Churchmans Marsh is being studied, and that a reservoir is to be constructed there upon completion of the study. The study requires comparative evaluation of feasible and practicable alternatives, and it must be understood that issuance of the required permits is not a given.

An important component of the federal laws for water-supply planning is the identification and evaluation of alternative projects for comparison of impact on the human community and ecological systems. The study is highly process-driven, and critical to the process is that all significant impacts from a proposed project must be identified in sufficient detail to enable comparison among alternative projects. The key decision-making guidelines on whether a project may be permitted are that it must be one that first *avoids* environmental impacts, or if unavoidable, *minimizes* such impacts, and as necessary provides *compensatory mitigation* for environmental impacts.

The specific review criteria that are being used in this study to evaluate and compare projects are technical, environmental, legal, institutional, neighborhood, and economic. (The resulting acronym is "TELINE.") Due to the variety of locales and the different media within each project, direct comparisons of the above criteria are not possible. For instance, each reservoir site would impact habitats of different qualities, values, and functions. Therefore, a consensus is developed on the way environmental impacts are to be ranked. Some evaluation criteria are straightforward, such as cost to construct, provided projects are compared on the same design basis.

The study has proven to be an exceedingly difficult, expensive, and controversial undertaking. In fact, the study process is intentionally designed to pit diverse and usually opposing interests and subjects all projects and interest groups to intense scrutiny in order to emerge with a legally defensible justification for the decision the Corps must make on the permit application. Corps personnel in this Environmental Impact Statement have stated that it must be assumed that the decision the agency will make will result in a lawsuit being filed; therefore, the process needs to be able to stand severe legal tests.

Through the course of the study, most effort was expended on detailed field work for the reservoir projects since they represent the highest cost, and any determined not to be feasible would be eliminated to concentrate on a final select few sites. Up until this year, Churchmans Marsh was still considered a viable project. Other potential reservoir sites were eliminated due to various fatal flaws — any of a variety of site problems so severe they could not be compensated for. In April 1996, the Corps held its first public "scoping" meeting, and unexpected public concern was expressed over the just-released fish consumption advisory for Christina River in the vicinity of Churchmans Marsh. Throughout the study, cost estimates consistently placed Churchmans Marsh at the top of the list due to excavation requirements and for wetlands replacement. With the discovery of contaminated sediments in the marsh, the cost estimates increased further since expensive landfilling may be required for the excavated sediment rather than as use for cover material as originally proposed. These findings and other accumulating evidence showed that the environmental and economic impacts of a reservoir in Churchmans Marsh were so unfavorable the project was exceedingly unlikely to receive state or federal approval. Other less impacting projects were available.

A definitive decision has just been made to eliminate Churchmans Marsh from further study. As a result, the project will never be constructed unless it can be shown at some time in the future that no other alternative is available. The Project Management Committee will resubmit to the Corps of Engineers an application for Thompsons Station Reservoir as the new preferred alternative. To reiterate, the study is not to determine which project will be constructed but whether or not the Corps will issue a permit to construct the preferred reservoir project, which is now Thompsons Station.

If a reservoir is chosen for development, however, a variety of institutional issues will require resolution first, involving multiple-party project ownership and operation, certain regulatory decisions, and other technical and legal complexities that while they have been routinely handled in many other parts of the country, have no precedent in Delaware. Consultant services are being secured to recommend the best ownership and financing arrangement to carry the selected project forward once the Environmental Impact Statement is completed. This and the normal engineering design and construction schedules will likely place the development of any selected project past the year 2005.

As of this writing, five projects remain under review, consisting of the following:

- Thompsons Station Reservoir
- Artesian Marsh Reservoir
- Desalination
- Philadelphia Pipeline
- Chester County Pipeline

Detailed study is now being performed on the non-reservoir projects. Since the Artesian Marsh project shares many similar negative impacts as does Churchmans Marsh, as well as not being able to provide 100% of the supply need, this project will remain on the list of alternatives until definitive decisions are made on the other projects. If no others are found to be viable, Artesian Marsh will then be subjected to additional study as the third alternative reservoir site.

In-Stream Flow Needs Evaluation

Delaware has never set regulations for minimum in-stream flows relative to allocation of surface waters. Regulations exist that specify certain design flows for adequate assimilative capacity of wastewater discharges in order to protect aquatic habitat but make no provision for assuring such flows will exist.

When flow falls below critical levels, the Water Quality Standards are not expected to be met and are, in effect, suspended for the duration. The frequency of such suspensions is expected to occur no more often than the design flow. Among the several design flows, one, the Q7-10 low-flow value, is the most conservative and is the minimum flow value that is usually required.

Withdrawals for water supply obviously deplete available flow, and at certain critical times, if withdrawals are high enough and stream flow is low enough, the Water Quality Standards will not be able to be maintained. The frequency of this can occur more often than would occur naturally if withdrawal was being made. In this instance, the standards will be violated and protection of the aquatic habitat cannot be provided. This is the situation with the streams in the study area and is a direct result of over-allocation of the resource or, alternately, inadequate management. Existing regulation on this matter only states a requirement for in-stream flow in qualitative terms, rather than in specific quantities. Numerous water-supply systems went into operation or continued to operate without required allocation permits, and in the absence of any standard for minimum in-stream flow, resulted in the available supplies not being reliable or inadequate to meet demand under some conditions. This topic is further detailed below.

In 1989, the water-supply needs analysis that prefaced the Churchmans Marsh study assumed two design criteria (of a different type and purpose) in determining the amount of available water supply from the four major water supply streams in northern New Castle County. The first assumption made was that the amount of surface water that would be available would be that which would occur during a 90-day drought of record. The drought of record for this area was at that time the drought of the mid-1960s, but has since been slightly surpassed by the Drought of 1995. This quantity of water is called the design flow. Current design flows for the supply streams are shown in Table 30. (Re-calculation of the design flows is likely to be required prior to the completion of the Water Supply Plan). Superimposed on this design flow was a certain amount of surface water that would be required to be left in-stream rather than be available for withdrawal. The amount of this flow was assumed to be Q7-10 low-flow as computed at the locations of the four surface-water intakes on White Clay Creek at Curtis Mill, White Clay Creek at Stanton, Christina River at Smalley's Pond, and Brandywine Creek at the Wills Pumping Station.

Q7-10 flow is that flow which is computed to occur over a continuous seven-day period once every ten years. (Q7-10 high-flow is also calculated for each stream.) This flow is calculated from gauging records collected by the U.S. Geological Survey. Gauging station locations where these data are collected are displayed on Map 16.

The rationale for selecting the Q7-10 flow is, as explained above, that it is the accepted design flow for the protection of aquatic habitat from discharges to streams from wastewater treatment plants, and it is set in regulation by DNREC's Water Quality Standards as well as the Delaware River Basin Water Code.

The assumption of this minimum in-stream flow proved controversial since it totaled 81 million gallons per day. This amount of water is actually *more* than currently used on an average demand day for the entire county. The consequence of assuming this large amount of water would not be allowed to be withdrawn and would remain in the stream to "pass by" the intakes is obviously significant in that it would have a deciding influence on the type and size of any future water-supply project that would be required. In other words, provision would have to be made to meet future water demands as well as to provide for in-stream flow. This was the first time Delaware was faced with dealing with this issue and several regulatory and policy considerations further complicated the matter, which will be discussed shortly.

For the purposes of water management and planning, there are three methods that could be used individually or in combination to provide for additional supply as well as to maintain a certain amount of in-stream flow. One is to construct a reservoir that would augment stream flow and provide supply. Another is to develop some other alternative supply project that would provide enough water to enable stream withdrawals to be curtailed to an equivalent amount such that Q7-10 flow could be maintained. These approaches are termed *supply-side management*.

Demand-side management could also be employed to curb demand for the same effect as adding water to the system. Usually, modern economics and regulatory requirements dictate that demand-side techniques be applied to supply-side project construction, although no standard approaches exist to do so and much controversy has arisen over how to integrate the two. Nonetheless, under the state's water management plan for drought, which is when critical low flows would occur, demand controls are a matter of law. Different supply-side approaches, reservoir versus non-reservoir, each have advantages and disadvantages. Obviously, an evaluation of in-stream flow needs and the potential outcomes this would have on determining the type of project selected for development is integral to the Water Supply Plan.

Adding to the impetus to conduct a formal study of in-stream flow needs were regulatory actions taken by the Delaware River Basin Commission on the City of Newark in 1991 and on Wilmington Suburban Water Corporation (now United Water Delaware) in 1993.

The history involved in this initiative is complex, but it is important to show the cross-cutting nature of water supply issues. The City of Newark approached DNREC in 1989 to construct a surface-water treatment plant at Curtis Paper Mill, which would have been the first new surface facility in Delaware since the 1940s. DNREC approved the allocation for a diversion of 5 million gallons per day from White Clay Creek. However, in the absence of a flow standard, none was imposed in the allocation issued by DNREC. However, recognizing the pre-existing diversion downstream of Newark on White Clay Creek at Stanton by Wilmington Suburban Water Corporation, DNREC required the city to cease withdrawal on White Clay Creek whenever flow was insufficient to meet prevailing demand at the Stanton intake.

Following the issuance of the allocation to Newark, the city also applied for approval of the diversion to the Delaware River Basin Commission. The resulting docket decision also required that Newark curtail its withdrawal under certain conditions. That condition required a passing flow of Q7-10 be maintained as long as naturally available, and if not available, all natural stream flow be allowed to pass the intake. As did the state's allocation permit, the docket specified that a certain amount be allowed to pass by to meet demand at the Stanton intake.

However, the amount the Delaware River Basin Commission decided would be needed for protection of downstream flow to Wilmington Suburban Water Company was based on a value of 16 million gallons per day, which is equal to the entitlement the commission issued to Wilmington Suburban Water Company in 1974. The commission under authority of its compact began charging water users under its jurisdiction in 1974. Water users who pre-dated the commission's formation were issued an "entitlement," which authorized those users to legally use a certain amount of water without paying water-use charges to the commission. The amount of water entitled this way was equal to the maximum pumping capacity existing at that time. In the case of the Wilmington Suburban Water Company that capacity was 16 million gallons per day. It must be emphasized that entitlements do not constitute a "right" or allocation to withdraw, only an exemption from water-use charges. The Delaware River Basin Commission's unwritten policy is that entitled users would not be required to obtain permits for their withdrawal unless the user has exceeded its entitlement, a policy generally termed "grandfathering." This was the situation with the Wilmington Suburban Water Company. In contrast, the City of Wilmington's Entitlement of 60 million gallons per day will likely never be exceeded, and thus the city would never be required to obtain the commission's approval for its withdrawal. State regulations do not authorize grandfathering although pre-existing uses are "recognized." As of this date, the City of Wilmington has no legal authority to withdraw water from the Brandywine Creek. Resolution of this matter may require adjudication.

Since 1974, Wilmington Suburban Water Company had almost doubled its plant capacity at Stanton to 30 million gallons per day, but without regulatory approval. The City of Newark obtained approval to "infringe" on the pre-existing diversion by Wilmington Suburban, which the Delaware River Basin Commission did not formally recognize at present capacity. By coincidence, the amount required to pass by Newark's intake as specified in both permits was almost the identical value, or specifically 14 million gallons per day.

To make matters worse, Wilmington Suburban eventually received an allocation permit from both DNREC and the commission in 1993, after Newark. This constitutes a final irony in that Wilmington Suburban had been established on White Clay Creek since the mid-1940s but because its permit to withdraw came after Newark's, Newark's withdrawal legally precedes Wilmington Suburban's and the subsequent permitting of Wilmington Suburban at present-day capacity resulted in White Clay Creek technically and legally being over-allocated. The commission's solution to this dilemma was to authorize Wilmington Suburban to use Hoopes Reservoir to provide flow augmentation for the pass-by requirement. However, this authorization was only permitted for three years, after which the company would have had to develop an alternative source of supply. This alternative will be discussed in the following section.

In light of the above permitting complexities and related issues raised in the Churchmans Marsh Environmental Impact Statement, DNREC initiated a formal study of in-stream flow needs. The goal of this study was to determine the adequacy of Q7-10 as a flow standard and to make recommendations on flows that would be established for the water-supply streams of northern New Castle County. In total, these activities, as difficult and controversial as they remain even today, are having the positive effect of forcing establishment of long-neglected in-stream flow standards.

The study concluded in early 1997 with the production of the second of two reports. The first one issued in 1995 concentrated on the basic hydraulics of the study reaches and determined tentative target fish species along with recommendations for a second phase of study to focus on habitat surveys, literature search, and refinement of target fish species. Map 16 shows the study area and stream reaches. The essence of the study approach has been to identify critical stream sections under various flow scenarios (analyzed by calibrated computer models) and compare stream depths and velocities to available habitat criteria for the target fish species. Some fish species had no criteria available but were adopted from similar species for evaluation purposes. It should be noted that target fish species were selected based on indigenous populations indicative of the health of the aquatic system, rather than commercial species such as stocked trout.

Preliminary results of the study are that generally the Q7-10 flow provides for at least the minimum of the various fish species criteria and in some instances exceeds that required for aquatic habitat. Thus, the Q7-10 standard appears to be appropriate for the supply streams and would prevail for water-quality purposes where fish habitat criteria were lower than Q7-10.

The opposite situation exists on one section of White Clay Creek above Newark which appears to be impacted by withdrawal during low flow, and certain habitat criteria are not supported by Q7-10 flow. A separate study of this situation will be conducted in conjunction with the renewal of the city's Delaware River Basin Commission docket which expired this year. In that section of the stream, a higher than Q7-10 passing flow may be required. Promulgation of flow standards is on hold, pending additional study. For more in-formation contact the DNREC Division of Water Resources at (302) 739-4793.

Tidal Control Structure

As explained in the preceding section, the passing-flow requirement imposed on the United Water Delaware Stanton Treatment Plant in 1993 mandated that the company allow a Q7-10 flow to "pass by" its intake. In that section of White Clay Creek where the withdrawals are made, the Q7-10 flow equals 17.3 million gallons per day. Under "normal" conditions, the company would not be able to withdraw at full capacity 16% of the time, with operational difficulties anticipated for several weeks every year on average, usually in the dry months of September and October.

The first summer the passing-flow requirement was imposed, United Water had to obtain releases from Hoopes Reservoir in order to meet both the flow standard and demand. The company had an emergency release arrangement with the City of Wilmington since 1972, but invoked it for the first time in 1993 under authorization of the Delaware River Basin Commission. Again in 1994, Hoopes Reservoir releases were required as a result of the pass-by requirement. The next year during the worst part of the 1995 drought, at the time the Governor declared the drought emergency, flow in White Clay Creek at Stanton was as low as 12 million gallons per day while demand was running at 15 million gallons per day. White Clay Creek was actually being pumped at over 100% of available flow with some flow from reversal of ebb tide which entrained brackish water into the treatment plant. The rest of the supply shortfall was being made up again by releases from Hoopes Reservoir in addition to the considerable demand reduction of at least 25% of normal. Under such emergency conditions, waiving of the passing-flow requirement for the entire month of September was permitted to allow all available flow to be withdrawn for public water supply to protect public health and welfare.

While this action is appropriate during a water shortage emergency, it also raises the issue of frequency of allowing such waivers and the resultant effect on the stream ecology since flow in the stream should not be allowed to be depleted below the prevailing standard of Q7-10 more often than the design flow. Or, in other words, a flow of no less than 17.3 million gallons per day should occur for more than seven days every ten years as dictated under the state Water Quality Standards.

Accordingly, the flow standard was not upheld for weeks on end during the drought. Still, the issue lingered

Table 30
30-DAY DESIGN LOW-FLOWS

	MINIMUM STREAM FLOW[1]	30-DAY LOW FLOW					
		1966 DROUGHT		20-YEAR RECURRENCE INTERVAL		50-YEAR RECURRENCE INTERVAL	
	(CFS)	(CFS)	LESS 7Q10 (CFS)	(CFS)	LESS 7Q10 (CFS)	(CFS)	LESS 7Q10 (CFS)
Christina River @ Smalley's Pond	3.23	2.88	_	4.30	1.07	3.23	–
Red Clay Creek @ Stanton	11.18	11.10	_	11.77	0.59	9.76	–
White Clay Creek @ Stanton	17.46	15.80	_	18.03	0.57	13.79	–
Brandywine Creek @ Wilmington	76.28	86.2	9.92	80.03	3.75	69.66	–
Total (CFS)		**115.98**	**9.92**	**114.13**	**5.98**	**96.44**	**0**
Total (MGD)		**74.96**	**6.41**	**73.76**	**3.86**	**62.33**	**0**

[1]*Minimum Stream Flow* = 7Q10.
Source: Metcalf & Eddy, 1991.

of providing for adequate flow to support the stream habitat and avoid violating the Water Quality Standards. One approach would be to revise the Water Quality Standards to allow for lower passing flows and thus extend available supply. On several counts, this approach is not prudent. The standards were developed based on scientific criteria for protection of in-stream biota, and from a water management and policy perspective it would be difficult to recommend lower flow standards which would likely result in further, gradual degradation of surface water quality — the opposite of DNREC's objectives. From a practical standpoint, the difference between Q7-10 flow and a lesser standard of, say Q7-50, is only several million gallons per day. While this difference is proven to be critical for providing adequate flow for aquatic habitat, it is not significant for existing and future water supply.

To compound matters, Hoopes Reservoir was only allowed to be utilized under United Delaware's Delaware River Basin Commission allocation permit for a period of three years after the permit's issuance. The company was faced with complying with minimum stream-flow requirements, with the expectation that the Q7-10 standard would be used, and at the same time meet demand, all without having a county-wide storage project or other regional supply.

The innovative engineering solution to this dilemma was in fact conceived prior to the 1995 drought. This positive initiative is named the Tidal Control Structure. Now under development, the Tidal Control Structure will consist of an inflatable and deflatable heavy-gauge rubber dam constructed across White Clay Creek in the vicinity of the Metroform area. The concept of the project is simple: take advantage of the diurnal tidal inflow and capture it at maximum water-level elevation. This will be done by inflating the rubber dam at the correct time to coincide with flood tide and withdrawal from the pool behind the dam. Shortly before ebb tide, the dam will be deflated and the cycle repeated as necessary. As part of the design, enough water will also be captured to enable passing of the Q7-10 flow. The net result of the project is that the passing-flow requirement can be maintained at the same time the reliability of the treatment plant is improved.

Fish passage is the greatest concern for potential impact of the project, but is considered of minimal concern in the view of the Division of Fish and Wildlife. The structure will be operated only at times of low flow — typically five to six weeks out of the year.

Fish passage is of highest concern during the spring spawning season when the dam will not be in operation, so no impact is expected at that time and limited impact is expected during the times of operation when indigenous species "run" with the tide. Another concern is "back water" effects and potential aggravation of historical flooding problems in the nearby Glenville development. Since it is a "low-head" dam rising approximately 5 feet above the streambed, any excess runoff that may occur during storm events will easily flow over the dam if it is inflated at the time of highest stage. Thus, no flooding potential is expected. Hydraulic model runs have been performed which confirm these aspects.

As can now be further seen, there is extensive intermingling of issues common to the In-stream Flow Needs Study and the Churchmans Marsh Study. After numerous meetings with the regulatory agencies over these issues, United Water Delaware made a business decision to undertake development of a project that would allow them to meet the passing-flow requirement under almost all conditions while enabling them to meet prevailing demand as opposed to arguing for exemption or lessening of the flow standard. United's action will result in improvement of protection to the stream and needed security of the public water supplies, which extend to its customers and others throughout the county.

Christina River Basin Drought Management Committee

In the late 1980s after Delaware's Piedmont Basin and nearby Chester County, Pennsylvania, were exposed to two fairly serious droughts — one in 1981, another in 1985 — water management officials were prompted to propose creation of a new entity to address drought and other water-supply related issues separate from the Delaware River Basin Commission. The major situation that prompted this was the discontinuance of the drought declaration in 1985 that had been announced for the entire Delaware River basin based on improvement of storage conditions in the upper basin. Conditions in the lower basin, however, were substantially different, and the Pennsylvania portion of the Christina River basin remained in serious drought. Loss of cooperation with the drought management efforts resulted although finally conditions improved and supplies returned to normal.

The lesson was learned, however, and a new mechanism was desired for dealing with local drought events based on local conditions. Unfortunately, the commission refused to allow the Christina River basin to exempt itself from commission drought rules even if the Christina River basin's conditions did not indicate drought. (The commission refers to this policy as "equal hardship.")

The Christina River Basin Drought Management Committee was approved by the Delaware River Basin Commission in 1988 and incorporated into Pennsylvania's and Delaware's drought management plans. Its inaugural meeting was held December 18, 1991. The committee is composed of an equal number of public and private water utilities from both states along with the respective environmental agencies and representatives from the Delaware

Geological Survey, the Delaware River Basin Commission, and the two counties' water resources agencies. Chairmanship of the committee rotates annually between the two state agencies. (Ironically, all drought response action recommended by the committee so far has occurred only under Delaware's chairmanship.)

Key activities and responsibilities of the committee include continuous monitoring of hydrologic and water-supply conditions and coordinating drought response action in an advisory capacity to the state's governors. Two indices are used to measure and monitor water-supply conditions in Delaware: one is DNREC's Hydrologic Index, and the other is Delaware Geological Survey's Water Conditions Index. These indices are calculated using measures of precipitation, stream flow, groundwater levels, and population. Although the two indices use significantly different methods of calculating conditions, years of experience particularly during periods of drought or near-drought conditions show that they produce compatible results and are closely synchronous.

The two indices differ when conditions are approaching or are wetter than normal. In this case, DNREC's index lacks a clear indication of wet conditions; however, this reflects the primary function of the index as a drought management tool. In contrast, the Delaware Geological Survey's index was designed to register the full range of water conditions, dry through normal through wet. Figure 15 shows the most recently issued conditions graph.

A major initiative of the committee is to revise the operating plan of the largest reservoir in the basin at Marsh Creek. This action was prompted by the 1995 drought to allow for emergency stream-flow augmentation in Brandywine Creek under certain conditions. The proposal is for a three-year agreement based on presumption of a new water-supply project being developed in New Castle County by the year 2000. This agreement was signed by the Pennsylvania Department of Environmental Protection Secretary in 1997. More information regarding drought coordination and monitoring of water conditions can be obtained by calling the DNREC Water Supply Section at (302) 739-4793 or the Delaware Geological Survey at (302) 831-2833.

SOILS

The following description of soils is provided by the U.S. Department of Agriculture's Soil Conservation Service (subsequently renamed Natural Resources Conservation Service):

> Soils are the collection of natural bodies in the Earth's surface, in places modified or even made by man of earthy materials, containing living matter or capable of supporting plants out-of-doors. Its upper limit is air or shallow water. At its margin, it grades to deep water or to barren areas of rock or ice. Its lower limit to the "not-soil" beneath is perhaps the most difficult to define. Soil includes the horizons near the soil surface that differ from the underlying rock material as the result of interactions, through time, of climate, living organisms, parent materials, and relief. In the few places where it contains thin cemented horizons that are impermeable to roots, soil is as deep as in the deepest horizon. More commonly, soil grades at its lower margin to hard rock or to earthy materials virtually devoid of roots, or marks of other biological activity, which generally coincides with common rooting depth of native perennial plants. . . . The lower limit of soil, therefore, is normally the lower limit of biological activity, which generally coincides with common rooting depth of native perennial plants (USDA, 1975, 1993).

In Delaware's Piedmont Basin, soil depth approaches the limits of this definition in the form of weathered, micaceous crystalline rock (saprolite). The rock margin of saprolites grade from tidal marsh to deep water near the terminus of the Christina River. Certain areas in and around Wilmington have soils consisting entirely of man's earthy materials; in other areas, the parent material of the soils consist primarily of sands, silts, and clays.

Topography, or "relief," controls or modifies soil formation. Relief affects the landscape distribution of soils and moisture, affects erosion and alleviation patterns, affects temperatures that are influenced by aspect (the compass direction the slope faces), and affects the combined temperature and rainfall effects that result from elevation differences (Fanning and Fanning, 1989). Soil temperatures are 2° F to 5°F warmer on the south-facing slopes compared to the north-facing slopes (Fanning and Fanning, 1989). The physical and chemical characteristics of Piedmont Basin soils are significantly affected by the slope, aspect, and rock content. Soil depth is usually shallow on the steeper slopes and increases as the slopes become flatter. Soil rock content is dependent on aspect; warmer, south-facing slopes face the sun and are usually rockier than the north-facing, cooler slopes.

Relief reduces the portion of water available to infiltrate into the soil. Although those soils in the Piedmont Basin that have formed from crystalline rock are more permeable than some soils from the Potomac Formation — the formation characteristic of the Atlantic Coastal Plain portion of the basin — most of the rainfall on the steeper Piedmont Basin slopes drains directly from the soil surface into nearby watercourses. Movement of that water which does infiltrate is affected by the elevation at which, and the material (formation) through which, it flows. Surface-water runoff either collects in depressions or flows in watercourses, whereas infiltrated water discharges into depressions or into sloping seep areas. These depression and seep areas contain many of the nontidal wetlands in the Piedmont Basin.

Tidal wetlands are found in the floodplains of the Christina River and along the lower portions of Red and White Clay, Brandywine, Naamans, and Shellpot creeks. All these creek and river areas are urbanized and have lost many of their associated wetlands. Some of the wetlands within the basin have been flooded by reservoirs or ponds; this storage of surface waters commonly has negative effects on the downstream riparian wetlands. Road construction also has significant effects on wetlands. Because roadbeds serve as a dam to water movement, wetlands that have no surface-water inlets or outlets and which thereby interact only with groundwater can be significantly affected by road construction. Landscape changes caused by paving portions of the watershed, channelization of the stream, or cutting-and-filling slopes within a watershed to accommodate urban growth can significantly alter flow volumes. Stream channeling can do likewise. Both practices can affect wetland hydrology — either by reducing the water supply available to the wetland or by increasing the speed in which the water flows through the wetland. In addition, these practices tend both to increase sediment loads to streams due to bank scouring and increase water velocities, allowing streams to transport those sediments longer and farther.

Perhaps the most important factor affecting the hydrology of the Piedmont Basin is the draw-down of groundwater by wells. Groundwater is not plentiful in this basin; thus removal of groundwater through wells reduces the water available to the wetlands by redirecting groundwater flow away from the wetland and toward the pumping well.

Interpreting soils for the purposes of determining suitable land use tends to be difficult in the portion of the basin that rests in the Piedmont geologic province. Saprolite color is often inherited from the rocks from which it was formed, and this saprolitic parent material often lacks indicators (redoximorphic features) of seasonally high water tables. In certain areas of the White Clay Creek watershed, for example, inherited colors mask evidence of seasonal wetness. "Dips" in the tightly folded rocks range from nearly vertical to steeply dipping and serve as a conduit through which water flows to produce springs at the base of topographic lows. Usually, such conduits are not evident until the soils have been cut or graded; as a result, many basements become wet after these conduits are intercepted during home construction. Many land parcels also have numerous springs and seeps that affect septic system performance, the placement of encumbrances, or landscaping.

Characteristics

Four major soil associations make up the Piedmont Basin (see Map 17). These associations reflect the geologic formations from which they have been born. The Glenelg-Manor-Chester association — located in the northern and northwestern parts of the region — comprises about 30% of the region. These are nearly level to steep, well-drained, medium-textured soils formed over micaceous crystalline rocks on uplands. The Glenelg soils make up approximately 43% of the association; the Manor, 23%; and the Chester, 14%. The Glenelg and Chester soils are moderately erodible, while the Manor soils are highly erodible. Limitations for suitability of human land use are generally due to the severity of the slopes.

The Sassafras-Fallsington-Matapeake association (18% of the basin) consists of level to gently rolling, well-drained and poorly-drained soils on uplands (see Map 18). These soils have formed from Coastal Plain sediments, and their textures are generally moderately coarse to medium. The eastern portion of the river basin is comprised mainly of the Neshaminy-Talleyville-Urban Land association (12% of the basin), which consists of level to moderately sloping, well-drained, medium-textured soils that are relatively undisturbed to severely disturbed. These soils are formed over dark-colored gabbroic rocks. Also included is the Neshaminy-Aldino-Watchung association (6.5% of the basin), which consists of level to steep, well-drained to poorly-drained, medium-textured soils formed over dark-colored gabbroic rocks. Urban Land-Soil Complexes and other minor soils make up the remaining 24%.

A significant portion of the soils found in the basin are poorly to very poorly drained. Some of these soils would be considered hydric. *Hydric soil* is defined by the U.S. Department of Agriculture's Soil Conservation Service (1982) as a soil that is either (1) saturated at or near the soil surface with water that is lacking free oxygen for significant periods during the growing season, or (2) flooded frequently for long periods during the growing season.

The following soils have the potential to be considered hydric: Bayboro, Calvert, Elkton, Fallsington, Hatboro, Johnston, Kinkora, Mixed Alluvial Land, Othello, Pocomoke, Tidal Marsh, and Watchung. Areas are considered to be wetlands when composed of hydrophytic plants, hydric soils, and hydrology indicative of periods of continuous soil saturation during the growing season. Many such soils are associated with the floodplains of the creeks and rivers, and floodplain soils comprise 9.5% of the Piedmont Basin.

White Clay Creek Watershed

The Glenelg-Manor-Chester association (see Map 17) makes up the majority (approximately 55%) of the soils in the White Clay Creek watershed and is generally found in the northern and northwestern portions of the watershed. These are nearly level to steep, well-drained, medium-textured soils formed over micaceous crystalline rocks on uplands. The Chester soils make up approximately 65% of the association; the Manor, 20%, and the Glenelg, 8%. Floodplain soils constitute 10% of the Delaware portion of the White Clay Creek watershed.

Most of the soils within White Clay Creek watershed are highly erodible (see Map 19). The inherent erodibility of a soil — its "K factor" — is influenced by its infiltration capacity, soil, and structural stability. The K factor is a relative value that ranges from near 0 to nearly 0.6. Soils with low erodibility tend to be sandy and have K factors below 0.2. Soils with intermediate infiltration capacities and moderate soil stability have K factors of 0.2 to 0.3. And soils that are easily eroded have K factors greater than 0.3; such soils tend to have low infiltration capacities.

The Glenelg and Chester soils are moderately erodible while the Manor soils are highly erodible. With the high inherent erodibility of the soils in this watershed, coupled with steep slopes associated with Glenelg-Manor-Chester soils, erosion can be a significant factor affecting surface water quality. As stated previously, the cutting and grading associated with the initiation of new residential and commercial development projects make these soils highly erodible. Despite existing state erosion-control regulations that require areas not to be worked for at least two weeks to be stabilized, Delaware's rainfall pattern can allow considerable erosion even where control measures are employed. During the development of those erosion-control regulations, DNREC had estimated that exposed Piedmont soils could erode at a rate of 100 tons/acre/year.

The soils of the southern portion of the watershed, near its juncture with the Christina River, are predominantly from the Elsinboro-Delanco-Urban association (14% of the watershed) and the Sassafras-Fallsington-Matapeake association (6% of the watershed in Delaware). The Elsinboro-Delanco-Urban soils are formed from old alluvium on stream terraces associated with White Clay Creek. These associations tend to be more erodible than, and tend to have wetter soils than, the Glenelg-Manor-Chester association. Consequently, construction work is generally hindered by the presence of residual boulders in the saprolite of the Elsinboro-Delanco-Urban soil. Throughout the Piedmont, slope failures along bedding planes and joints can be a hazard during excavation. Minor soils constitute the remaining 15% of the watershed.

Red Clay Creek Watershed

The majority of the Red Clay Creek watershed (77% of Delaware's portion of the watershed, primarily the northern portion) is comprised of the Glenelg-Manor-Chester association (see Map 17). These soils vary from nearly level to steep and are well-drained (see Map 18), medium-textured soils formed over micaceous crystalline rocks on uplands. The Glenelg soils make up approximately 43% of the association; the Manor, 23%; and the Chester, 14%. The Glenelg and Chester soils are moderately erodible, while the Manor soils are highly erodible (see Map 19). Usage limitations for parcels with such soils are generally attributable to slope severity or to soil wetness where the soils are associated with floodplains. Suitability for septic systems on land parcels with such soils ranges from gravity-fed systems to engineered, pressurized systems on the steeper slopes and the wetter soils.

The southern portion of the watershed is composed mainly of the Elsinboro-Delanco-Urban association (8% of Delaware's portion of the watershed), consisting of level to moderately sloping, well-drained, medium-textured soils ranging from relatively undisturbed to severely disturbed. This association tends to be more erodible than the Glenelg-Manor-Chester association because of its location adjacent to the creek. The floodplain soils comprise 8.6% of Delaware's portion of the Red Clay Creek watershed, and minor soils constitute the remaining 6.4% of the watershed.

Brandywine Creek Watershed

The Glenelg-Manor-Chester soil association (40% of Delaware's portion of the watershed) occupies the upper reaches of the watershed; the Neshaminy-Aldino-Watchung association (20%) is located centrally; and the Neshaminy-Talleyville-Urban Land association (26.5%) is located in the southern portion of the Brandywine Creek watershed (see Map 17). Wilmington and the surrounding areas (4% of the watershed) are extensively "Made Land" (i.e., urban). These "Made Land" soils are composed of severely cut and graded or artificially filled soils. Often, this Made Land is very poorly drained. As stated previously, most of these soils are highly erodible (see Map 19). A considerable portion of the lower section of the watershed is covered by impervious surface materials that promote rapid runoff. Flood-plain soils comprise 7.5% of the Delaware portion of the Brandywine Creek watershed, and minor soils constitute the remaining 2.0%.

Shellpot Creek Watershed

Neshaminy-Talleyville-Urban Land soil (62%) and the Neshaminy-Aldino-Watchung association (13%) predominate the Shellpot Creek watershed (see Map 17). Toward the mouth of Shellpot Creek, soils grade into the Aldino-Keyport-Mattapex-Urban association 6% of the watershed). These soils are much less well-drained than the Neshaminy-Talleyville-Urban Land soil association, very little agriculture occurs in this watershed, and a considerable portion of the watershed is covered by impervious surface materials that promote rapid runoff. Floodplain soils comprise 16% of Delaware's portion of the Shellpot Creek watershed, and minor soils make up the remaining 3%.

Naamans Creek Watershed

The Neshaminy-Aldino-Watchung association (23% of the watershed) and the Neshaminy-Talleyville-Urban Land soil associations (59% of the watershed) predominate in this watershed (see Map 17). Most of these soils are highly erodible (see Map 19) and tend to have slow permeabilities due to moderately fine and fine-textured subsoils. The Aldino-Keyport-Mattapex-Urban association comprises 9% of the watershed. Neshaminy-Aldino-Watchung and Neshaminy-Talleyville-Urban Land associations tend to be less suited for septic systems due to slow permeability and soil wetness. Floodplain soils comprise 7% of the Naamans Creek watershed, and minor soils constitute only 2.0%.

Christina River Watershed

The Christina River watershed has some of the most diversified soils in the Piedmont Basin because part of the watershed is located in the Atlantic Coastal Plain. Most of the northern portion of the Christina River watershed (9% of the watershed) is comprised of the Glenelg-Manor-Chester association (See Map 17). These soils are nearly level to steep, well-drained, medium-textured soils formed over micaceous crystalline rocks on uplands. Two Piedmont province outliers occur in the southern portion of the watershed; these outliers (i.e., Chestnut Hill and Iron Hill) are just south of Newark and — although completely surrounded by Coastal Plain sediments which isolate them from the Piedmont proper — are included in Delaware's Piedmont Basin (see Map 3). The Glenelg soils make up approximately 43% of the association; the Manor, 23%; and the Chester, 14%.

The southern portion of the Christina River watershed (northern Coastal Plain) is composed of five major soil associations (see Map 17). The Sassafras-Fallsington-Matapeake association (44% of the watershed) consists of level to gently rolling, well-drained, and poorly drained soils on uplands. These soils have formed from Coastal Plain sediments, and their textures are generally moderately coarse to medium. The Matapeake-Sassafras association is comprised of nearly level to steep, well-drained, medium-textured and moderately coarse-textured soils on uplands. A small area (9% of the watershed) is comprised of the Matapeake-Sassafras-Urban Land association. The Aldino-

Keyport-Mattapex-Urban Land association (3% of the watershed) makes up the area around New Castle, Newport, and northeastern Wilmington. The Tidal Marsh association (3% of the watershed) traverses the Delaware River and short tidal streams. Extensive areas in and around Wilmington (11% of the watershed) are Made Land. Floodplain soils comprise 9% of the Christina River watershed, and minor soils make up only 10%.

The southern portion (see Map 19) of the watershed has some of the most erodible soils in the Piedmont Basin. Soil infiltration capacities tend to be slower due to the amount of silt and clay in the Matapeake, Elkton, and Keyport soils. Elkton soils occupy 5% of the watershed. Many of the other soils in the southern portion of the basin have very silty surface horizons, which make them more susceptible to erosion.

Trends

Development will only continue within the Piedmont Basin. It is expected that the number of septic systems will initially increase, but with time, more of the basin will become sewered and the number of septic systems will decrease. It may not be possible to provide central sewer to all unsewered communities and locations. The Wetlands/Soil Assessment Branch developed an evaluation criteria at the request of the Wastewater Facilities Advisory Councils to determine relative need and feasibility for central sewer. The evaluation criteria considered water-quality issues, other environmental issues, soils suitability for septic systems, septic system siting limitations, distance to existing sewers, cost-effectiveness of providing central sewer, and community well-being. These criteria were used to identify the unsewered communities with the highest, medium, or lowest needs for central sewer. The Centerville area was the only community evaluated within the basin. Based on the evaluation criteria, Centerville had very low need for central sewer when compared to the 59 other communities statewide included in the feasibility assessment.

Sources of Impact

Soils tend to become a wastebasket for anthropogenic activities. They are used to renovate wastewater from residences, to serve as landfills for our garbage, depositories for unwanted and often hazardous wastes, sources of earthy fills, and storage areas for automobiles and other items. Buried wastes produce methane and other natural gases, which can explode and contaminate groundwater. Storage tanks often leak due to corrosion effects from groundwater and soil acidity. The Piedmont Basin has its share of wastebaskets and depositories. A tremendous amount of development has taken place within the basin. Major soils areas within the basin have been modified to accommodate human progress.

Unfortunately, when new development projects (residential or commercial) are initiated, most of the soils are cut and graded, which makes them highly susceptible to erosion. Delaware's erosion-control regulations require that areas that will not be worked for at least two weeks are to be stabilized. With Delaware's rainfall pattern, considerable amount of erosion can occur even with control measures. During development of erosion-control regulations, DNREC estimated that exposed Piedmont soils could erode at a rate of 100 tons/acre/year. The acceptable soil erosion loss that will maintain soils for crop production is only *two tons/acre/year*. The erosion-control regulations allow 50 times this rate.

Septic systems are the main method for treatment of domestic wastewater in the unsewered areas of the basin. In some areas of the unsewered sections, cesspools are still being used; most are undocumented. However, as sewer systems are developed in areas where septic systems and cesspools are used, they are slowly being decommissioned.

Positive Initiatives

Before construction or replacement of septic systems in Delaware, a site evaluation must be conducted. Performed by a private site evaluator, site evaluations consist of investigating, evaluating, and reporting the basic soil and site conditions, which are used to define on-site system design. Each report describes specific site conditions or limitations including, but not limited to, isolation and separation distances, slopes, existing wells, cuts and fills, and unstable landforms. Each report also contains information about zoning verification, the type of on-site disposal system that must be constructed in the acceptable on-site disposal area, the appropriate hydraulic conductivity test conducted in configuration encumbrances, easements, and underground and overhead utilities in the evaluated area. The site plans show reference points such as a utility pole number, telephone or electrical box, building(s), and/or a fixed survey marker.

This procedure ensures that septic systems are sited based on soil properties [permeability, texture, structure, consistence, redoximorphic features (seasonal high water-table indicators), slope and depth to rock] which limit or hinder septic system performance. A siting system based on these parameters, as well as those listed above, ensures that the system type is designed to minimize the soil's limiting factors, which in turn improves system performance and reduces loading rates to water sources. New Castle County has restricted any development on slopes that are greater than 15% and prohibits development on slopes greater than 25%. This slope restriction ordinance effectively reduced the proposal of developments on sloping lands. Also, the New Castle County Zoning and Subdivision Code limits septic systems to a minimum density of two acres per dwelling in Water Resource Protection Areas and one acre per dwelling elsewhere.

SEDIMENT

Sediment can be defined as the particles of soil, surficial material, and rock that become detached as a result of the hydrologic *(fluvial)* processes of sheet, rilling, and gully erosion; and through the mass wasting action of the wind *(eolian)*. Fluvial processes are predominant in the Piedmont Basin. Thus, the remaining discussion will concentrate on this form of erosion.

Characteristics

Soil erosion from upland areas is an ongoing natural process, and a certain amount of sediment bed-load transport is necessary to maintain stream stability. However, through human influence on the landscape, this process can be accelerated by orders of magnitude. As a result, the natural balance is upset, often leading to serious environmental degradation. According to the EPA's *1992 National Water Quality Inventory Report*, siltation is the most prevalent cause of impairment in assessed rivers and streams and is one of the five leading causes of lake impairment.

The characterization of sediment is, of course, closely linked to the geology, climate, and soils of a particular watershed. The ratio of silt, sand, and clay in an individual soil series determines its cohesiveness and thus its capability to withstand erosive forces. Soils composed mostly of silt and sand will erode more easily, with heavier sands tending to settle out in the stream system, and lighter sands and silts being deposited in ponds, lakes, and tidal outfalls. Eroded clays often stay in suspension, causing turbidity problems. However, if detained long enough for flocculation to occur, they can also be deposited in receiving waters. In general, the soils found in the Piedmont geological province contain all three textural classes and contain a higher percentage of fine soils than those found in the Atlantic Coastal Plain. (For a more detailed discussion, please see the Soils section in this document.)

In addition to soil texture, vegetative cover and land slope are other major factors used in assessing potential soil erosiveness. In the watersheds of the Piedmont Basin, as in most watersheds, the more erosion-prone, steeper slopes tend to be adjacent to streams and tributaries. This can be seen on Map 20, which shows the soil slope classifications for the individual mapped soils within the basin. (Under this classification system, slope tends to increase as the factor progresses from "A" to "E." The slope factor does not indicate the same slope range between soil series, but rather is a relative measure of slope within the soil series. However, it is a good indication of whether a particular mapped soil is at the flatter or steeper range at which it can be found.) In general, Map 20 indicates that as the distance to a stream channel decreases, the soil slope factors tends to be steeper.

Where appropriate, soils were also mapped as being "moderately eroded" or as "severely eroded" in their natural state during the course of the soil survey. As expected, and as shown on Map 21, the "severely eroded" soils were generally located on the steeper slopes adjacent to the tributaries. Map 21 also indicates that, except for the tidal reaches lower in the basin, many of the remaining soils were mapped as being "moderately eroded." The implication is, of course, that the eroded material became sediment in the receiving waters.

As a physical pollutant, excessive accumulation of sedimentary material can fill streams and lakes to the point where they are no longer navigable. The acceleration of the erosion process started with the colonization of North America, as the native forest cover was converted to agricultural land uses. Such is evident in the Piedmont Basin, where many colonial ship landings such as the town of Christiana are no longer accessible by larger watercraft. A more contemporary impact is the loss of water carrying capacity in the streams of the Piedmont Basin and their associated bridges, culverts, etc. This can lead to flooding problems and disrupt the transportation infrastructure. Keeping these streams and structures sediment-free requires constant maintenance in many instances, and this, of course, translates into public expenditures. Sediments that are not deposited in the streams themselves tend to settle out in the ponds and lakes fed by those streams. For water-supply reservoirs, this results in a loss of capacity as well as increased treatment costs due to turbidity problems. For recreational ponds and lakes, surface area is often lost as the upper reaches silt in.

In some cases, it may be necessary to dredge accumulated sediments to restore recreational capabilities. The records of the Division of Soil and Water Conservation's Dredging Program indicate that the following dredging projects have been completed in the Piedmont Basin:

Follies Pond (Christina River)	28,000 yd^3 removed in 1979
Carousel Pond (White Clay Creek)	30,000 yd^3 removed in 1986
Smalley's Pond (Christina River)	50,000 yd^3 removed in 1989
Bellevue State Park (Shellpot Creek)	20,000 yd^3 removed in 1990
Lewis Pond (Christina River)	3,600 yd^3 removed in 1992
Four Seasons Pond (Christina River)	8,500 yd^3 removed in 1993

Besides human impacts, sediment has serious physical impacts on aquatic ecosystems. It can cover the stream bottom, smothering fish eggs and bottom-dwelling organisms that rely on the "nooks and crannies" provided by the natural bottom substrate. Sediment particles can abrade and accumulate on the gills of fish and other aquatic creatures, causing stress and even death in some cases. Similar impacts can be observed in lake systems as well. It is generally accepted that deposition of sedimentary material and associated nutrients is the major mechanism leading to accelerated eutrophication of ponds and lakes. Submerged aquatic vegetation is particularly susceptible to problems associated with excessive sedimentation. The act of removing accumulated sediments can itself have negative impacts, as wetlands and other aquatic ecosystems are disturbed in the process.

During the fall of 1993, DNREC's Watershed Assessment Section conducted an assessment of the habitat quality of 38 Piedmont streams. Several of the parameters, or "metrics," associated with that study were directly related to stream channel stability and sediment deposition. These included bank stability, velocity/depth ratio, sediment deposition, and embeddedness. This study suggested that an estimated 90% of the nontidal streams in the region had degraded (i.e., "Fair" or "Poor") physical habitat. The study also indicated a strong relationship between the amount of impervious area in a watershed and the degree of habitat degradation.

Ambient water-quality data historically have been collected by DNREC for the EPA's Storage and Retrieval of U.S. Waterways Parametric Data Base. The sampling sites located in the Piedmont Basin are depicted in Map 9. The sampling protocol is based on random sampling and does not distinguish between "dry flow" and "wet flow" conditions. A measure of total suspended solids is often used to characterize soil particles in the water column itself. Although this protocol does not include total suspended solids, it does include a measure of the total non-filterable residue, which can be used as an indicator for total suspended solids. Based on an analysis of the data from selected stations in the Piedmont Basin from 1991 through 1993, the mean total non-filterable residue concentrations for the various watersheds were as follows:

Christina River	12.69 mg/l (14 stations, N = 54)
White Clay Creek	6.00 mg/l (7 stations, N = 48)
Red Clay Creek	17.79 mg/l (5 stations, N = 48)
Brandywine Creek	4.29 mg/l (5 stations, N = 42)
Shellpot Creek	10.50 mg/l (3 stations, N = 10)
Naamans Creek	6.00 mg/l (3 stations, N = 9)

Based on data generated for the EPA's Water Body System, Becks Pond (Christina River watershed), was classified as only *partially supporting* primary contact recreation and recreational fishing. Siltation and suspended solids were indicated as having high likelihood as a cause of this non-attainment of the designated use. (Non-attainment of the designated use was indicated to have a high likelihood of being caused by siltation and suspended solids.) It was also indicated that this was linked with land development, highway construction and maintenance, drainage and filling operations, and removal of riparian vegetation. In this same data base, a 1.8-mile segment of Little Mill Creek (Christina River watershed) was classified as *threatened* for recreational fishing. Siltation was also shown to be a moderate cause for this non-attainment, with a positive link to land development.

Some of the more serious environmental impacts associated with sediment are of a chemical nature. Individual sediment particles have a large surface area, and many molecules easily adsorb or attach to them. As a result, sediments can act as chemical sinks by adsorbing metals, nutrients, hydrocarbons, pesticides, and other potentially toxic materials. Indicator bacteria are also associated with runoff-borne soil and organic matter. Thus, areas of high sediment deposition sometimes have high concentrations of nutrients and persistent (i.e., long-lived) chemicals and contaminants, which can be later released. Sediments that contain concentrations of constituents greater than those found in nature are classified as "enriched," while those with concentrations of constituents that are not normally found in natural sediments are classified as "contaminated."

According to the *1994 Delaware Watershed Assessment Report* (also known as the *305[b] Report*), bacteria are the most widespread contaminants in Delaware's surface waters, but nutrients and toxics pose the most serious threats to aquatic life and human health. Many bottom-dwelling organisms are filter feeders. As contaminated sediments pass through their bodies, some of the contaminants can be absorbed into body tissues. Since these organisms are often on the bottom tier of the "food web," the contaminants can move through the entire web, eventually reaching vertebrates such as fish. If higher vertebrates, such as birds and mammals (including humans), consume these fish in large enough quantities, there can be serious health consequences. This scenario has been well documented in the case of polychlorinated biphenyls (PCBs). Based on studies done within and outside DNREC, elevated concentrations of the following constituents have been identified either directly in the sediments or in fish tissue in these respective watersheds:

Christina River	PCBs, polynuclear aromatic hydrocarbons, zinc, other miscellaneous metals
White Clay Creek	PCBs, zinc, other miscellaneous metals
Red Clay Creek	PCBs, zinc, dioxin, chlorinated pesticides, other miscellaneous metals
Brandywine Creek	PCBs

Trends

The only historic sediment trend analysis that was found while researching this topic was completed by the U.S. Geological Survey for one of its gauge stations on the Brandywine Creek at Wilmington (Station 01481500). An analysis of the cumulative daily suspended sediment data indicated there was no significant change in annual loadings for the period of record from 1948 to 1979.

Ambient water-quality data, which have been collected in support of the EPA's Storage and Retrieval Program, were analyzed in 1996 by DNREC's Watershed Assessment Section. A trend analysis indicated that total suspended solids concentrations have generally declined for all the Piedmont stations analyzed. The period of record varied by station and no distinction was made for wet-flow and dry-flow conditions. However, this appears to complement findings of the U.S. Geological Survey.

No data were found on long-term sediment deposition. This prevents any kind of trend analysis for this important parameter. However, there is a very clear trend in land use in the Piedmont Basin, with a steady conversion of agricultural and forested lands to urban/suburban land uses. As discussed in the next section, this will likely continue to make sediment a significant environmental stressor throughout the basin.

No data were available to assess trends in contaminated sediments. Historic discharges from past unregulated industry may be responsible for much of the sediment contamination in the basin. However, it is likely that many of the nutrients, metals, toxics, and other contaminants currently identified in sediments are still being actively deposited. What is not well established at this point is the magnitude of current loadings.

Sources of Impact

Sediment has been identified by the EPA as one of the major nonpoint source pollutants due to its diffuse nature. Nationwide, agricultural activity has been identified as the leading source of sediment to receiving waters. This is probably also true for the state of Delaware as a whole. However, the Piedmont Basin encompasses the most urbanized area of the state. Based on 1992 land-use data, none of the sub-watersheds of the Piedmont Basin exceeded 27% in agricultural lands. Additionally, these areas are shrinking as they continue to be converted to urban and suburban land uses. Although construction activity is considered to be a temporary land use, up to 10 times more erosion than agricultural land uses and up to 2,000 times more erosion than forested land uses can occur over the same period of time. This conversion process is therefore expected to be the major contributor of sediment loading in surface runoff as build-out continues in the basin.

Recent studies performed in other parts of the country also indicate that a significant portion of the sediment load in receiving waters of urbanized watersheds is coming from the stream channel system itself. The natural stream channel gradients associated with the Piedmont Basin are the steepest in the state, which results in the highest flow velocities. As impervious surfaces are added, runoff volumes increase and bank-full storm flows occur at a greater frequency. Higher stream velocities, longer duration of flow, and more frequent high-flow conditions can cause the system to interfere and go out of equilibrium, resulting in accelerated stream channel erosion.

Potential contamination sources for sediments are typically associated with point sources. The location of known Superfund and Hazardous Waste Facilities in the Piedmont Basin is illustrated in Map 4. These should not be interpreted as known contamination sites, but as areas that could potentially act as sources for sediment contamination.

Map 4 also shows the location of all sites in the basin regulated under the federal National Pollutant Discharge Elimination System (NPDES). These sites are typically associated with industrial activities and wastewater treatment facilities with defined discharge points. They have the potential for discharging "clean sediments" as well as materials that could lead to contaminated sediments.

Positive Initiatives

The entire Christina River watershed is currently under study as part of DNREC's comprehensive five-year plan being initiated under the Nonpoint Source Pollutant Management Strategy for the Christina River basin using funds provided by Section 319 of the Clean Water Act.

DNREC's Nonpoint Source Program and Delaware Coastal Management Program provide grant funding for initiatives that strive to reduce the impacts of both agricultural and urban nonpoint source pollution.

The New Castle Conservation District prepares individual Conservation Plans for agricultural landowners in the watershed. These plans are intended to reduce nonpoint source pollution associated with agricultural activities.

Since the passage of the Delaware Sediment and Stormwater Law in 1991, all new construction activities that disturb over 5,000 square feet are required to have an approved sediment and stormwater plan unless specifically exempted. The program is delegated to various local agencies with oversight by DNREC's Sediment and Stormwater Program and uses a "best available technology" approach to control nonpoint source pollution associated with construction activities.

DNREC's National Pollutant Discharge Elimination System Program regulates stormwater discharges for specific industries, as identified in the law. At the time this report was being prepared, it was not clear if Phase II of the program was to be implemented. If so, all major storm drainage outfalls in New Castle County would also fall under these regulations.

DNREC's Hazardous Waste Management Branch oversees existing facilities and performs routine investigations, which sometimes involve contaminated sediments. If contaminated sediments are found, rigorous control and /or cleanup procedures are implemented in conformance with appropriate regulations.

The federal Superfund Program was established to address the country's worst hazardous waste sites. These sites have been determined to pose a significant risk to public health or the environment and have the potential to be sources for some of the most toxic contaminants. DNREC's Site Investigation and Restoration Branch oversees the cleanup of those sites that will not be addressed by the federal government.

WETLANDS

Wetlands are composed of physical, chemical, and biological components. They may be transitional areas between uplands and aquatic habitats, may occur as isolated depressions within uplands, may occur on slopes, or may be fringing wetlands associated with tidal or nontidal waters. In wetlands, the water table is at or near the surface of the soil during all or part of the year, creating conditions favorable for life adapted to inundated or saturated soil conditions (Cowardin et al., 1979). A regulatory, as well as an *ecological,* definition developed in response to Section 404 of the Clean Water Act of 1977 defines wetlands as:

> Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Wetlands generally have three ecological characteristics: wetland vegetation (hydrophytes), wetland soils (hydric soils), and wetland hydrology. Hydrophytic vegetation consists of those plant species adapted to grow under anaerobic conditions through morphological, physiological, or reproductive mechanisms. Hydric soils are those soils that develop under reducing conditions, are associated with low oxygen, and are unmodified. Wetland hydrology implies that soils are flooded or saturated with water either periodically or permanently. These three ecological characteristics are present in most wetlands and are important in wetland *identification* and *delineation*. The federal regulatory definition of wetlands incorporates the three characteristics as technical criteria in a method for determining federal wetlands jurisdiction. The identification and delineation of wetlands also rely on the use of field indicators, or conditions occurring in wetlands that help in establishing technical criteria. Both the regulatory and the scientific community recognize the interdependence of hydrophytic vegetation, hydric soils, and wetland hydrology (National Research Council, 1995).

Ecological Classification

Wetlands are classified according to their ecological characteristics for such purposes as communication among scientists, planning, and assessment. The U.S. Fish and Wildlife Service developed a classification system to provide national consistency for wetland concepts, terminology, and classification — the *1979 Classification of Wetlands and Deepwater Habitats of the United States* (commonly referred to as the "Cowardin et al. Classification System," after the authors of that publication). This system employs a hierarchical approach to classifying various wetland types. It first describes wetlands broadly by five *systems:* Marine, Estuarine, Riverine, Lacustrine, and Palustrine. Each system (with the exception of the Palustrine System) is further divided into *subsystems* based on major hydrologic characteristics. Subsystems are subdivided into *classes*, describing the general vegetative types or substrate types. The classes are then divided into *subclasses,* which describe either dominant substrate type in unvegetated areas (e.g., bedrock, rubble, cobble-gravel, sand, mud, or organic), or dominant vegetation type (e.g., persistent or non-persistent emergents, moss, lichen, or broad-leaved deciduous, needle-leaved deciduous, broad-leaved evergreen, needle-leaved evergreen, and dead woody plants). Additional modifiers describing hydrologic and soil properties, water chemistry, or physical modifications of the wetland are commonly used following the class or sub-class designation.

Four varieties of specific modifiers (Water Regime, Water Chemistry, Soil, and Special) describe particular wetland or deep-water habitats with respect to hydrologic, chemical, and edaphic (soil-influenced) characteristics and human impacts. These modifiers may be applied to class and lower levels of the classification hierarchy. Water regime modifiers describe soil inundation or saturation conditions and are distinguished as tidal and nontidal. Special modifiers describe activities affecting and effecting wetlands and deep-water habitats. Special modifiers include excavated, impounded (i.e., obstructed hydrology outflow), diked (i.e., obstructed hydrology inflow), partly drained, farmed, and artificial (i.e., materials deposited to create or modify a wetland or deep-water habitat) (DNREC, *Delaware Freshwater Wetlands Restoration*, 1992).

Of the five wetland *systems* described above, the two most prevalent in the Piedmont Basin are Estuarine (tidally influenced wetlands of salinities varying from seawater to fresh water), and Palustrine (nontidal freshwater wetlands and tidal freshwater wetlands with salinities of less than 5 parts per thousand). For example, palustrine (P), forested (FO), broad-leaved deciduous (1), temporarily flooded (A) wetlands (PFO1As) are a common nontidal wetland type. Palustrine refers to the *system,* forested indicates the *class,* temporarily flooded identifies the *water regime*, and broad-leaved deciduous is a *sub-class* that further characterizes the specific type of vegetation.

Palustrine forested wetlands are the most prevalent type of wetland in Delaware and probably in the Piedmont Basin. These wetlands are dominated by trees such as *Acer rubrum* (red maple), *Fraxinus americanus* (green ash), *Liquidambar styraciflua* (sweet gum), *Nyssa sylvatica* (black gum), *Salix nigra* (black willow), and *Quercus* (oaks).

Palustrine scrub-shrub wetlands — a less common type of nontidal wetland — is dominated by a number of water regimes and woody vegetation less than 20 feet tall. Scrub-shrub wetlands may be characterized by shrub species such as C*ephalanthus occidentalis* (buttonbush), *Salix* (willow), *Viburnum* (arrowwood), and *Cornus* (dogwood), or may be thickets dominated by native vines, such as *Smilax* (catbrier) or *Vitis* (grape), or by invasive/alien vines such as *Rosa multiflora* (multiflora rose) and *Lonicera japonica* (Japanese honeysuckle) vines. Scrub-shrub wetlands may be early successional stages of forests characterized by scattered hydrophytic tree saplings associated with a wet meadow, or they may characterize Coastal Plain ponds (Table 32). Palustrine emergent marshes are a relatively uncommon type of nontidal wetland in the Piedmont Basin and occur along ponds, seeps, streams, and rivers, or in depressions. Palustrine marshes may be characterized by *persistent* vegetation, which is biologically active year-round, such as *Typha* (cattails), or by *non-persistent* vegetation — which is perennial but dormant during the winter, such as *Peltandra* (arrow arum) and *Pontederia* (pickerelweed).

Plant Communities

DNREC's Delaware Natural Heritage Program has characterized natural plant community associations based primarily on vegetation collected by its biologists over the past decade. Tables 31 – 35 show specific examples of wetland plant communities occurring in the Piedmont Basin. They are a reflection of the Delaware Natural Heritage data base as well as preliminary natural community classifications developed respectively by Clancy (1993) and Rawinski (1989).

Hydrologic Classification

Wetland hydrologic types are important in wetland identification and delineation, restoration, and compensation efforts because hydrology is the driving force in the creation and maintenance of wetlands. The source, direction, and hydrodynamics of water are also important in understanding wetland groundwater recharge and/or discharge properties and water-quality mechanisms. In a discussion of the hydrologic characteristics and hydrologic processes that occur in wetlands, Novitiski (1989) identified four simple wetland classes that have been widely accepted as applicable to most situations (Figure 16).

Surface-water depression wetlands occur where precipitation and overland runoff collect and where water leaves primarily by infiltration and evapotranspiration. The bottoms of the depressions are above the water table most of the time. Water levels are typically high in spring (immediately after snowmelt) and decline through the rest of the year, although periodic rises may result from intense storms.

Surface-water slope wetlands occur along the margins of lakes or streams and extend to shallow but permanently flooded parts of lakes or river up-slopes to points flooded only occasionally. These wetlands receive lake or river floodwaters in addition to runoff and direct precipitation; water leaves primarily by drainage as the stage of the lake or river declines, as well as by infiltration and evapotranspiration. Water levels are controlled by the lake or river stages and are typically high in spring and decline through the rest of the year. Lake-edge wetlands differ from river-edge wetlands in that lake levels fluctuate more slowly than river stages.

Groundwater depression wetlands occur in depressions that intercept the water table and receive groundwater inflow as well as precipitation and overland flow. The amount of groundwater inflow to the wetland may be only a small percentage of its total water budget; however, since the inflow is continuous rather than seasonal, it is a determining factor in the type of plant community that develops and in the rate of soil development, in addition to other processes. Water usually leaves this wetland by evapotranspiration although it may occasionally recharge the water table. If the water table slopes toward the wetland from all sides, the wetland functions most of the time as a groundwater discharge point. In spring, when the wetland water level may rise briefly above the local water table, the local water table may decline briefly below the wetland bottom, resulting in the wetland recharging the local groundwater.

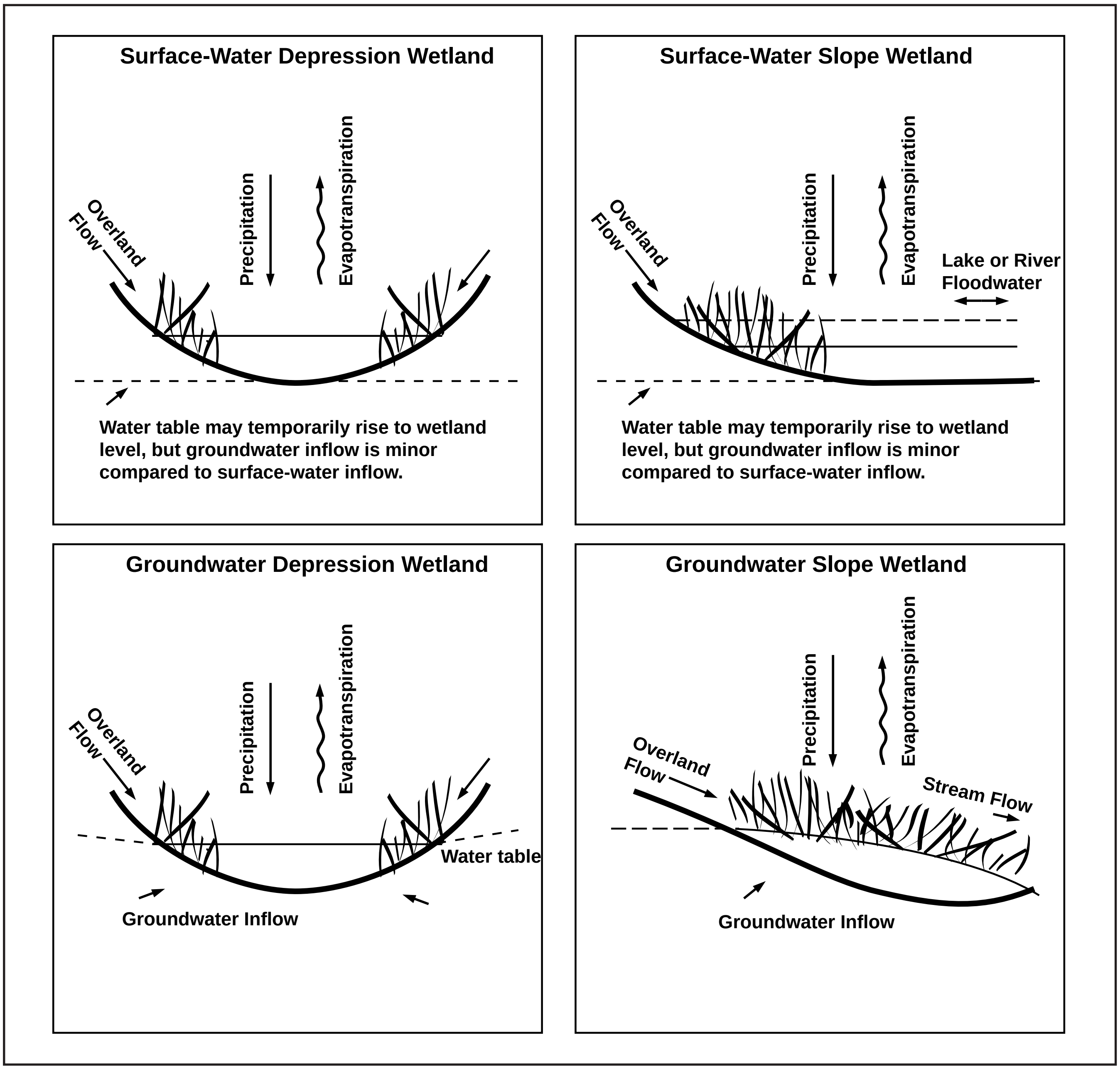
Groundwater slope wetlands occur where groundwater discharges continuously as a spring or seep at the land surface. The amount of groundwater inflow to the wetland may range from a relatively small percentage to a major portion of the total water budget, which results in wide differences among wetland plant communities and soil development rates. This type of wetland is rarely flooded because water can drain away down-slope. The water table surrounding the wetland typically is at or above (artesian) the wetland surface (Novitski, DNREC, *Delaware Freshwater Wetlands Restoration*, 1992).

Landscape Classification and Wetland Functions

In the Piedmont Basin, wetlands are associated with headwaters (upper reaches) of streams and rivers, occur as isolated depressions, occur on slopes, or are associated with tidal estuaries. Often, riparian wetlands occur within floodplains, which serve some of the same functions as jurisdictional wetlands.

Wetland functions include such physical mechanisms as flood flow alteration, water storage, and nutrient and sediment trapping. Biochemical processes include nutrient attenuation through denitrification and plant assimilation. Biological processes include food web support, habitat, and biodiversity. All wetlands provide functions, but wet-

Figure 16
HYDROLOGY OF SURFACE-WATER AND GROUNDWATER WETLANDS
(Redrawn from Noviski 1982; in Tiner, 1985)



lands in different landscape positions and with differing types and degrees of disturbance vary in their ability to perform their functions. Accordingly, one approach to classifying wetlands and describing wetland functions is based on the position of the wetland in the landscape.

Headwater riparian wetlands, for example, are important for their contribution to the maintenance of stream water quality through the removal of nonpoint source nutrients and contaminants. Sediment trapping and the seasonal or temporary uptake of nitrogen and phosphorus by wetlands associated with first-order streams may be as important as in riverine systems since headwater wetlands cumulatively represent an area comparable to second- or third-order stream floodplains (Brinson, 1988, 1991). Headwater wetlands provide important habitat for plants, fish, and wildlife through the maintenance of water quality for headwater

Table 31
WETLAND PLANT COMMUNITIES OF THE PIEDMONT BASIN

COMMUNITY TYPE	COMMUNITY CHARACTERISTICS	DISTRIBUTION
DECIDUOUS FORESTED PALUSTRINE ASSOCIATIONS		
Scientific Designation: *Platanus occidentalis/Acer negundo/Lindera benzoin* Floodplain Forest Common designation: Sycamore–Box Elder/Spice Bush Floodplain Forest	◆ This association is found along streams of the Piedmont as far south as the Fall Line and is characterized by the canopy consisting of *Platanus, Acer negundo,* occasionally *Acer rubrum,* and *Liriodendron tulipifera. Lindera benzoin* is usually the dominant shrub. ◆ Due to the periodic disturbance from flooding and past impacts from logging/clearing — and the lack of adequate buffers, combined with very fertile soils — these wetlands provide a haven for weedy species, particularly the following: R*obinia pseudoacacia, Celastrus orbiculatus, Berberis thunbergii, Lonicera japonica, Lonicera morrowii, Pachysandra procumbens, Euonymus alatus, Hedera helix, Alliaria petiolata, Ligustrum vulgare,* and *Microstegium vimineum.* ◆ Additional woody native species often encountered include *Ulmus rubra, Acer rubrum, Fraxinus pennsylvanica, Carpinus caroliniana, Prunus serotina, Cornus florida, Viburnum dentatum var. lucidum, Toxicodendron radicans, Smilax rotundifolia, Juglans nigra,* and *Carya spp.* ◆ Herbs include *Onoclea sensibilis, Woodwardia areolata, Arisaema triphyllum, Pilea pumila, Polygonum virginianum, Polystichum acrostichoides,* and *Impatiens capensis.*	Piedmont streams and associated tributaries (e.g., Red Clay Creek, White Clay Creek) in New Castle County; frequently found at the base of narrow seepage wetlands.
Scientific Designation: *Acer rubrum* Series Common designation: Red Maple Series	◆ A palustrine forest dominated by *Acer rubrum* (which may approach 100% cover), with only scattered occurrences of associated tree taxa (e.g., *Fraxinus pennsylvanica, Nyssa sylvatica, Liquidambar styraciflua, Pinus taeda*). ◆ Floristically, the understory can be diverse or depauperate, and may consist of the following tree and shrub species: *Magnolia virginiana, Lindera benzoin, Cornus amomum (only occasional), Ilex opaca, Ilex verticillata, Clethra alnifolia, Vaccinium corymbosum, Itea virginica, Euonymus americanus, Viburnum nudum,* and *Leucothoe racemosa,* to name a few. ◆ Likewise, the herbaceous stratum can be diverse or depauperate and may consist of a combination of the following species: *Arisaema triphyllum, Osmunda regalis, Osmunda cinnamomea, Woodwardia areolata, Boehmeria cylindrica, Peltandra virginica* (though usually found in tidal occurrences), *Sambucus canadensis, Cicuta maculata, Saururus cernuus, Symplocarpus foetidus, Impatiens capensis, Mitchella repens, Viola cucullata, Lycopus spp.*, and *Carex spp.*	This series consists of the following forest community associations that are ubiquitous throughout the Coastal Plain of Delaware (including the Coastal Plain portion of the Piedmont Basin). Red maple is typically the conspicuous component of these communities, but occasionally it may be sparse.

Table 32

WETLAND PLANT COMMUNITIES OF THE PIEDMONT BASIN — CONT'D.

COMMUNITY TYPE	COMMUNITY CHARACTERISTICS	DISTRIBUTION
DECIDUOUS FORESTED PALUSTRINE ASSOCIATIONS		
Scientific Designation: *Acer rubrum* Wetland Forest Association Common Designation: Red Maple Swamp	◆ These forests may have either a low or moderately high structural complexity: low if there appears to be a uniform, singular tree stratum (suggesting that the canopy consists of an even-aged forest stand), or high where the forest stand consists of multi-layered strata. ◆ The former may have been previously clear-cut. The latter may represent a more mature and usually a higher-quality forest stand. Such communities are less common, but are represented in Piedmont Basin forested wetlands (pers. comm. between P. Emslie and K. Clancy, 1996).	Along streams or in isolated wetlands in New Castle County (as well as Kent and Sussex Counties).
Scientific Designation: *Acer rubrum – Liquidambar styraciflua – Nyssa sylvatica* Wetland Forest Common Designation: Red Maple – Sweet Gum – Black Gum Swamp	◆ This natural community type is quite abundant on the Delmarva coastal plain and is very similar to the previously described community, except that the canopy consists of two or more co-dominant species (e.g., red maple, sweet gum, black gum). ◆ *Nyssa* is usually less common than red maple or sweet gum. Overall species composition of this community may be nearly identical to the *Acer rubrum* wetland community above. ◆ Typical woody species include *Diospyros virginiana, Magnolia virginiana, Ilex opaca, Ilex verticillata, Leucothoe racemosa, Lindera benzoin, Clethra alnifolia, Vaccinium corymbosum, Viburnum dentatum var. lucidum, Cornus amomum,* and *Viburnum nudum*. ◆ The herbaceous layer may be sparse or well developed, and includes many of the same species found in the red maple community association (see above).	Along palustrine streams in New Castle County (as well as in Kent and Sussex counties).
DECIDUOUS SCRUB PALUSTRINE		
Scientific Designation: *Cephalanthus occidentalis Scrub* Wetland Series Common Designation: Buttonbush Scrub Wetlands	◆ This wetland type — characterized by an abundance of *Cephalanthus occidentalis* — is mainly found in isolated depressional wetlands (i.e., Coastal Plain ponds or Delmarva bays), but occasionally may be present in elevated scrubby marsh areas. ◆ In Coastal Plain ponds, the occurrence of *Cephalanthus* may be quite variable. *Cephalanthus* may be densely or sparsely distributed throughout the pond or along the pond perimeter, or may be restricted to the pond center.	These ponds are most common in central Delaware (southwestern New Castle County and northwestern Kent County) in the region known for its abundance of Delmarva bays.

Table 33

WETLAND PLANT COMMUNITIES OF THE PIEDMONT BASIN — CONT'D.

COMMUNITY TYPE	COMMUNITY CHARACTERISTICS	DISTRIBUTION
	DECIDUOUS SCRUB PALUSTRINE ASSOCIATIONS	
	◆ The *Cephalanthus occidentalis* wetland basin community is significant because it may harbor rare species. (DNREC's Division of Water Resources proposed, via the Freshwater Wetlands Act, to afford greater regulatory protection to such wetlands.) Perhaps more importantly, such wetlands occur in unique geological entities known as Coastal Plain ponds or Delmarva bays. These wetlands are intermittently flooded (the degree and duration of seasonal flooding varies year to year), typically drawing down late in the growing season. ◆ Rare species known to occur in these wetlands include *Hottonia inflata, Eragrostis hypnoides, Fimbristylis perpusilla, Ambystoma maculatum, Ambystoma tigrinum, Hyla chrysoscelis,* and *Hyla gratiosa*. *Fimbristylis perpusilla* is a Federal Candidate species for listing and is only known to occur in four Delaware ponds (see also, Coastal Plain Ponds).	
Scientific Designation: *Acer rubrum* Scrub Wetland Series Common Designation: Red Maple Scrub Wetlands	◆ Very similar to the *Acer rubrum* Wetland Forest Association (see above) but with lower-statured trees (i.e., scrub size). This association may consist of many of the same species as its taller, forested counterpart. This series may either represent an early successional stage to the *Acer rubrum* Wetland Forest or may, in fact, represent a more stable climax community (e.g., for those red maple scrub habitats located along freshwater tidal streams). ◆ Typical species include scattered occurrences of small individuals of such tree taxa as *Fraxinus pennsylvanica, Nyssa sylvatica, Liquidambar styraciflua,* and *Pinus taeda*. Other species present include *Magnolia virginiana, Lindera benzoin, Cornus amomum, Rosa palustris, Ilex opaca, Ilex verticillata, Clethra alnifolia, Vaccinium corymbosum, Itea virginica, Viburnum nudum,* and *Leucothoe racemosa*, among woody species. ◆ The herbaceous layer may also be quite diverse consisting of a combination of species such as *Osmunda regalis, Osmunda. cinnamomea, Decodon verticillatus, Woodwardia areolata, Boehmeria cylindrica, Peltandra virginica, Sambucus canadensis, Sium suave, Cicuta maculata, Iris versicolor, Saururus cernuus, Impatiens capensis, Viola cucullata,* and *Carex spp.* ◆ These scrub communities may either have a low or moderately high structural complexity. Low structural complexity is anticipated if there appears to be a uniform, singular tree stratum — suggesting that the community may have developed after a recent clear-cut; high structural complexity (multiple strata) might suggest a more natural, stable, and mature community.	Frequently found along freshwater tidal streams in New Castle County (as well as in Kent and Sussex counties).

Table 34

WETLAND PLANT COMMUNITIES OF THE PIEDMONT BASIN — CONT'D.

COMMUNITY TYPE	COMMUNITY CHARACTERISTICS	DISTRIBUTION
	EMERGENT TIDAL/NONTIDAL MARSHES *General Community Description*	
	Emergent herbaceous palustrine wetlands in Delaware are varied and, accordingly, the array of natural communities found in these wetlands is quite diverse. The following are examples of some of the more frequently encountered herbaceous wetlands.	
Scientific Designation: *Nuphar lutea* Emergent Wetlands Common Designation: Spadderdock Marshes	◆ Located in freshwater tidal and nontidal streams, this wetland community may be composed of pure stands of *Nuphar*. Conversely, it may be more diverse with scattered stands of *Acorus calamus, Zizania aquatica,* or *Pontederia cordata*. ◆ Other species present, but in much lower numbers, include *Peltandra virginica, Polygonum spp. (punctatum, arifolium, sagittatum), Impatiens capensis, Sagittaria latifolia,* and *Amaranthus cannabinus.*	Along edges of freshwater portions of tidal streams, in millponds or along nontidal streams above millponds, in the Nanticoke River, Delaware Bay, Atlantic Ocean, and Piedmont basins. Churchman's Marsh is an example of an extensive *Nuphar lutea* emergent marsh in the tidal freshwater portion of the Christina River.
Scientific Designation: *Acorus calamus* Emergent Wetlands Common Designation: Sweet Flag Marshes	◆ A wetland that may be composed of large, extensive, nearly mono-specific stands of *Acorus.* Or, sweet flag may form small- to medium-sized discrete colonies within other community types. ◆ Additional species that may be found (generally in low numbers) in sweet flag marshes include *Impatiens capensis, Bidens laevis, Zizania aquatica, Typha spp.,* and *Sagittaria latifolia*. (Some of these species may form other distinct communities.)	Along edges of tidal streams, in upper freshwater portions of the Nanticoke River, Delaware Bay, and Atlantic Ocean drainages (above the *Nuphar lutea* zone). An *Acorus calamus* emergent wetland in the Piedmont Basin is a privately owned site associated with a nontidal floodplain in Pike Creek Valley.

Table 35
UNIQUE WETLAND ECOSYSTEMS OF THE PIEDMONT BASIN

UNIQUE PIEDMONT STREAM VALLEY WETLAND ECOSYSTEMS

General Ecosystem Description

Preliminary surveys of Piedmont stream valley wetlands were conducted in 1993 by the Delaware Heritage Program to determine the potential for Category I (rare or unique) wetland ecosystem designation. These investigations include natural community and rare plant and animal community associations as well as observations on other ecological factors such as hydrology and soils. Two of the six unique wetland communities found statewide are represented in the Piedmont Basin.

Piedmont Stream Valley Wetlands	◆ Two types of candidate plant communities are identified. The more frequent type is an emergent wetland characterized by herbaceous species — many are rare — with scattered shrubs and stunted trees. This graminoid-forb type of wetland is usually found at the base of a steep slope at groundwater discharge (seep) areas and is sometimes also influenced by seasonal overbank flooding. Several of these wetlands appear to be located in former stream channels or river oxbows. All but one site contains rare plants, and several of these rare species may be restricted to this wetland type (Clancy and McAvoy, 1994). ◆ Additionally, the Piedmont stream valley wetland is believed to be prime habitat for the bog turtle, a candidate species for [imminent] listing as either "threatened" or "endangered" by the U.S. Fish and Wildlife Service. Surveys by the Division of Fish and Wildlife Non-game and Endangered Species Program in 1992 have found this reptile in Piedmont stream valley wetlands of a similar description to the plant association described by the Delaware Natural Heritage Program. Piedmont stream valley wetlands are also believed to be breeding sites for Neotropical migratory songbirds (pers. comm. between P. Emslie and L. Gelvin-Innvaer, 1996).
Red Maple-Dominated Forested Floodplain Wetlands	◆ Only one example of this wetland has been identified in Delaware and is found in the Red Clay Creek watershed. This wetland is typified by its high species richness, its low number of nuisance species, and its many rare species, including the smooth white violet *(Viola macloskeyi spp. pallens)*, the only known location in the state for this species (Clancy and McAvoy, 1994).
Coastal Plain Ponds	◆ Although primarily found in concentrated areas in the Atlantic and Chesapeake basins farther to the south, some Coastal Plain ponds are represented in the more southerly portion of the Piedmont Basin. ◆ Coastal Plain ponds are unique wetlands due to a combination of interacting ecological factors including hydrogeology, soils, and plant communities. ◆ These ponds are relatively small, oval to elliptical, isolated wetlands fed primarily by seasonally fluctuating groundwater and characterized by unique plant communities. ◆ They provide habitat for state rare and endangered plant and animal species and are especially good habitat for amphibians (see Buttonbush Scrub Community). Due to their small, isolated nature, Coastal Plain ponds are vulnerable to filling from development pressures, and to indirect and cumulative impacts.

Table 36

IMPACT DESCRIPTIONS

IMPACT	DESCRIPTION
Plant Community Alteration	◆ Evapotranspiration from a wetland may be altered by altering the wetland vegetation; for example, deforestation of a forested wetland may yield an emergent wetland. Alteration of plant communities in the drainage basins of wetlands may have various effects on wetlands because of changed water regime and sedimentation. ◆ Complete removal of the transpiration process could result in considerable more water being made available for surface runoff and/or groundwater recharge. Wetlands associated with altered surface water and groundwater flow regimes may be enhanced, changed, or destroyed, depending on how the flow regime is altered.
Surface-Water Storage	◆ Surface water can be stored in reservoirs along the main stem of rivers (on-channel storage) in lowlands, or in reservoirs off the main stem (off-channel storage). [In Delaware, surface water storage is most likely to be effectuated by the creation of lakes or ponds (e.g., on-channel).] ◆ Because wetlands commonly occur in floodplains of major rivers, on-channel storage obliterates the wetlands drowned by the reservoir. ◆ Also, storage of water commonly has a negative impact on riparian wetlands downstream from the dam because the natural flow regime upon many wetlands were formed and maintained is altered.
Road Construction	◆ Can significantly effect wetlands, because road bed serves as a dam to water movement, even if culverts are used to connect the separated areas of wetland. It is not unusual to find dead vegetation on one side of a road and a living viable wetland on the other side. However, even the side with living plants undergoes change to adjust to the new condition of water flow. ◆ In the case of wetlands interacting with surface water, it is relatively easy to visualize obstruction of natural water flow by roadbeds. However, wetlands without surface water inlets and outlets and with interactions with ground water also can be significantly affected by road construction.
Surface Water and Groundwater Drainage	◆ Drainage is a common practice in regions of flat and/or hummocky topography. Because ponded water or slowly moving water enhances wetlands formation, removal of water from a wetland is detrimental. Drainage can completely destroy wetlands with little or no groundwater inflow. ◆ Drainage of any area can affect wetlands downstream. Drainage of uplands results in increased delivery of water to lowlands, streams, and lakes. This increased volume of water could drown or alter existing riparian wetlands. However, the increased delivery of water to the lowlands could enhance the formation and persistence of wetlands in the lowlands by providing additional water. ◆ Historically, road construction divides a floodplain into an area that floods more frequently and an area that almost never floods. Surface water quality parameter changes are almost exclusively restricted to those areas that flood. Sediment deposition, phosphorus retention, and turnover rates are greater in flooded areas. Extractable soil nitrates and nitrogen concentration of leaf litter can be higher in areas not flooded. There may be no differences, however, between the two areas in annual litter production rates, but rates of decomposition were higher in the non-flooded area.

Table 37
IMPACT DESCRIPTIONS — CONT'D.

IMPACT	DESCRIPTION
Recharge Alteration due to Water Removal	◆ Increasing the efficiency of water removal from areas of flat slope by ditching reduces recharge to groundwater. Not only is less water available because of the drainage, but the resulting lowered water table reduces the hydrologic head that provides the driving force for recharge. ◆ Drainage of small seasonal wetlands will eventually lower the water table enough to change the hydrologic function of lower wetlands, changing them from groundwater flow-through or groundwater discharge wetlands to recharge wetlands. The end result will be a lower water table throughout the entire area. ◆ Drainage is not the only practice that will decrease the quantity of water available for recharge. Other modifications to the landscape that will have the same effect include paving or building over extensive areas with the attendant storm runoff pulses. ◆ Other modifications to the landscape that could affect groundwater recharge, and, ultimately, the wetlands that receive that groundwater as discharge, include forest clearing, tillage, and other modifications to vegetative cover.
Groundwater Pumping	◆ Groundwater development can have an impact on surface water and wetlands. Groundwater pumping causes a lowering of hydrologic head within an aquifer that results in a cone-shaped depression of hydraulic head centered on the well. In the case of unconfined aquifers, the water table itself takes the shape of a cone centered on the well. If the cone depression extends areally to intersect a wetland, the lowered hydraulic head can cause seepage from the wetlands. ◆ From the perspective of groundwater development, the practice of pumping groundwater near wetlands is beneficial, because water that would be used to sustain plants is available to the well instead. This practice is commonly referred to by hydrologists as "salvaging evapotranspiration." ◆ From the perspective of wetland ecology, of course, groundwater pumping specifically at the expense of the wetland is extremely detrimental. But even if not specifically designed to impact the wetland, groundwater pumping anywhere within the flow field may impact surface water. Decreasing the hydraulic head by pumping, even some distance away from a wetland, will cause the flow-field configuration, in some cases enough to decrease groundwater discharge to the wetland or even to induce seepage from it.

streams and downstream habitats. Large tracts of headwater wetlands provide habitat for Neotropical migratory birds and overwintering and reproductive habitat for other birds, reptiles, and mammals.

Floodplain wetlands store floodwaters and buffer surface- and groundwater from the effects of agricultural, residential, and industrial development. Riverine floodplains are believed to interact extensively with surface- and groundwater, thereby contributing to water-quality maintenance (Brinson, 1988). The water-quality and water-storage functions of wetlands become increasingly important in the rapidly developing landscape of New Castle County. Floodplain wetlands provide food, shelter, and migratory corridors for furbearing mammals including fox, otter, mink, and beaver; for Neotropical migratory songbirds; and for many other forest species (Mitsch and Gosselink, 1986).

Isolated, depressional, or basin wetlands may be geographically located in any landscape position and are discontiguous to nontidal streams. These wetlands may serve as groundwater recharge basins for precipitation, as well as provide the functions of water storage and nutrient and contaminant trapping (Brinson, 1988). Where surrounded by urban or rural development, these isolated wetlands may be oases of habitat for wildlife in an otherwise developed landscape.

Estuarine or tidally influenced vegetated wetlands in the Piedmont Basin are primarily comprised of emergent wetlands and are found in the lower reaches of the basin watersheds. Estuarine wetlands are highly productive wetlands, specializing in functions such as nutrient cycling and organic matter production. They may be nutrient sinks and /or export organic matter in the form of detritus to surrounding tidal waters, providing primary production to the base of complex food webs. The role of the tidal marsh/ estuarine ecosystem as a nursery for both nearshore and offshore fisheries has been well documented. Tidal wetlands provide feeding, resting, and nesting habitat for resident waterfowl and waterbirds, and resting and feeding grounds for migratory waterfowl and shorebirds.

Trends

The most recent status of remaining wetland acreage in Delaware is based on the U. S. Fish and Wildlife Service's National Wetlands Inventory conducted during the late 1970s and early 1980s. This information is available by county and by wetland type in both map and digitized form in a Geographical Information System (GIS). In 1982, Delaware had approximately 215,000 acres of wetlands, representing about 17% of the state's surface area. Most of this acreage (68%) was nontidal wetlands, with forested wetlands being the predominant class (DNREC, 1996).

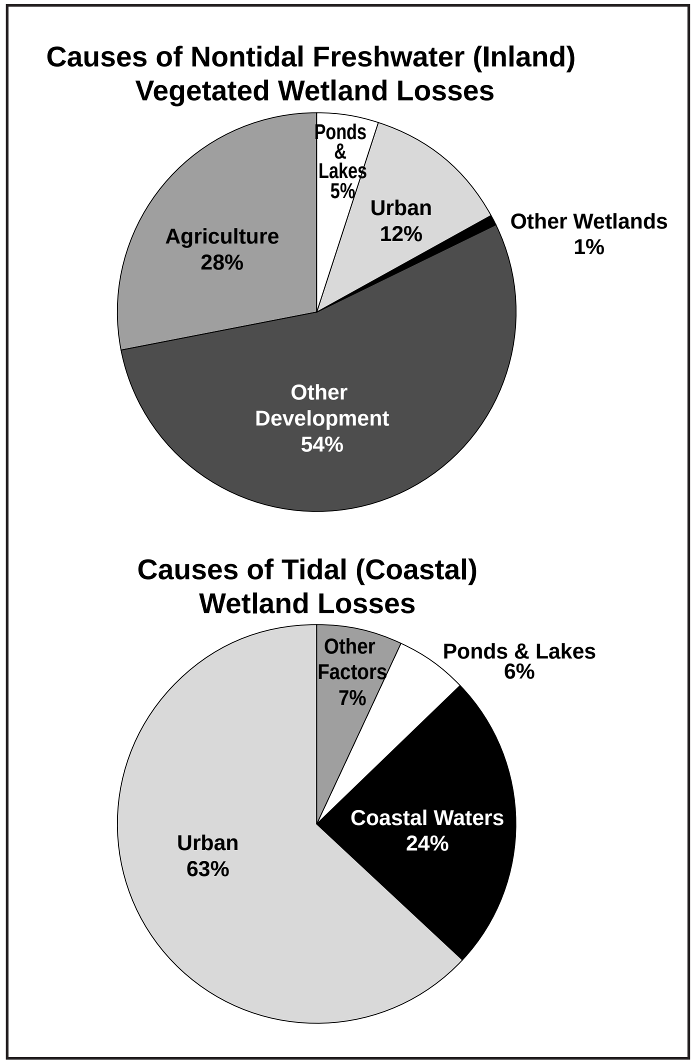
The National Wetlands Inventory uses color infrared imagery from the mid-1970s to the early 1980s to map wetlands using a modified version of the Cowardin Classification System described earlier. Based on the National Wetlands Inventory, wetlands comprise about 13% of New Castle County's land mass. Of this percentage, estuarine wetlands make up about 8% of the total New Castle County wetland acreage, and palustrine (primarily nontidal) wetlands make up 5% of the total wetland acreage (Tiner, 1985). The ongoing Statewide Wetlands Mapping Project will provide updated information on the location, acreage, and type of wetlands in the Piedmont Basin.

Delaware is one of 22 states that have lost approximately half their wetlands since pre-Colonial times (Dahl et al., 1991). A recent, five-state wetlands trends study conducted by the National Wetlands Inventory for the period between the mid-1950s and the early 1980s estimates wetland loss rate by wetland type for the Mid-Atlantic region and within each of the five states. Delaware experienced a 21% loss of the state's palustrine wetlands and a 6% loss of estuarine wetlands during the study period. A significant net loss of 42,000 acres of vegetated wetlands was experienced for the entire state during the period for a resultant average annual (statewide) loss of about 1,600 acres. No figures are available by basin or by county (Tiner, 1985).

Causes of inland (nontidal) wetlands losses were attributed to other development, mainly channelization and ditching projects (54%), agricultural development (28%), urban development (12%), pond and lake creations (5%), and change to other wetlands (1%). For coastal (estuarine and tidal vegetated) wetlands, losses during the period were attributed to urban development (63%), loss to coastal waters through sea-level rise and dredging (24%), coastal pond and impoundments (6%), and other factors (7%). See Figure 17 (Tiner and Finn, 1987).

Figure 17

DELAWARE WETLAND TRENDS
FOR THE PERIOD 1955 TO 1981
(Adapted from R. W. Tiner, Jr., 1987.
Mid-Atlantic Wetlands: A Disappearing Treasure)



Sources of Impact

Natural Impacts

As shown in Tables 36 and 37, both natural and human-induced threats impact wetlands. Natural threats are dynamic processes, including sea-level rise, natural succession, fluctuation of hydrologic cycles over time, sedimentation, erosion, and fire. Sea-level rise may significantly alter tidal wetland and/or estuarine ecosystems. Changes in weather and rainfall patterns may affect the hydrologic budgets of nontidal wetlands, making them particularly sensitive to anthropogenic impacts. Erosional forces may remove wetlands, while sedimentation may result in the creation of new ones. Fire, a natural occurrence in historical times, is largely suppressed in modern-day Delaware, indirectly affecting succession and climax communities.

Other natural impacts to wetlands include flooding and wind damage from hurricanes and other severe storms. In the undeveloped landscape, beaver-dam floods in forested wetlands and uplands set the stage for an increased diversity of wetland habitats over time. In a developed landscape such as the Piedmont Basin, however, the potential impacts of beavers may be the flooding of human developments as well as natural communities. Other natural impacts (which may be exacerbated by human disturbances) include such biotic effects as invasion of non-native plant species and grazing by herbivorous waterfowl (e.g., snow geese) and mammals (e.g., muskrat) (Tiner, 1985).

Human Impacts

Human-induced threats include direct effects such as filling for residential, commercial, and industrial development; discharge of point and nonpoint source pollutants; drainage for agriculture; flooding for the creation of lakes, ponds, and waterfowl impoundments; stream channelization for flood control and navigation; and groundwater removal for drinking water, irrigation, or other purposes. These impacts have both direct and indirect as well as cumulative effects. Direct impacts completely remove or alter wetland functions. Human impacts are directly related to increasing population growth, bringing about increased alterations in the natural landscape.

The Delaware Department of Transportation undertakes highway projects of potential major impact to wetlands in the Piedmont Basin and elsewhere in the state. Permit review is led by the U.S. Army Corps of Engineers, in coordination with other federal agencies and DNREC's Division of Water Resources, Wetlands and Subaqueous Lands Section. Highway construction further fragments the landscape, resulting in the loss of wildlife habitat for species such as nesting Neotropical migratory birds.

Other impacts to Piedmont Basin wetlands include those from large public projects and smaller county and municipal projects. Of major potential impact is the ongoing Northern Delaware Water-Supply Project, where proposed alternative sites include Piedmont riparian and floodplain wetlands and tidal and nontidal freshwater marshes farther downstream in the watershed. Other, smaller potential impacts include the construction and upgrade of public facilities such as libraries, parks, and emergency facilities. The reconstruction and upgrading of utilities maintained by New Castle County are considered to be temporary impacts, but may have cumulative effects on the hydrologic functioning of floodplain wetlands. Increased paving from all forms of development increases quantities of surface-water runoff but decreases flood storage time, thereby contributing to the increase in flash-flooding in the Piedmont Basin (pers. comm. between P. Emslie and L. Jones, 1996).

Cumulative Impacts

It has become apparent that cumulative impact may threaten the integrity of wetland ecosystems within the landscape. Cumulative impact is defined by the Council on Environmental Quality as:

> The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

Disturbances to wetlands with cumulative impacts are highlighted in Tables 36 and 37. (DNREC, *Delaware Freshwater Wetlands Restoration*, 1992).

Positive Initiatives

Regulatory Oversight

The Wetlands Act — Tidal Wetlands Regulatory Program. Since 1973, the "Wetlands Act" (Title 7, *Delaware Code*, Chapter 66) has been effective in conserving Delaware's remaining tidal wetlands. Under a concurrent review process with the Corps of Engineers and the regulatory oversight provided by the Clean Water Act, the state requires a permit for any non-exempt activity including dredging, filling, or construction in state-mapped wetlands. Proposed activities are evaluated in consideration of environmental, aesthetic, economic, and cumulative impacts. Any proposed permit action must be consistent with county zoning ordinances. Tidal wetlands jurisdiction is determined based on aerial photo-interpretive identification of specified vegetation and topography as depicted on regulatory maps. Since passage of the Wetlands Act, the loss rate of tidal wetlands has been greatly reduced. The Division of Water Resources, Wetlands and Subaqueous Lands Section implements the state wetlands regulatory program.

Freshwater Wetlands Act. In the early 1990s, DNREC developed the "Freshwater Wetlands Act" (subsequently referred to as Substitute Senate Bill 248), to enable state regulation of nontidal wetlands. This legislation sought to achieve no-net loss of nontidal wetlands by acreage and function; to provide greater protection of the state's higher-value wetlands; and to reduce the regulatory burden to the public through improved predictability, flexibility, and responsiveness. This participatory legislative process gained the support of the vast majority of the state's constituent groups but did not pass the legislature. However, information generated as part of the development of the freshwater wetlands program has provided the state with the information to approach wetlands protection through alternative regulatory and non-regulatory means. Furthermore, the counties may incorporate freshwater wetlands program development information into their land-use planning processes and ordinances. For example, the draft New Castle County Comprehensive Development Plan (July 1996) recommends that freshwater wetlands (including higher-value wetlands such as in Coastal Plain ponds and Piedmont stream valleys) be given additional protection by the county.

Clean Water Act — Federal Programs. Current regulatory oversight of nontidal wetlands is provided by the federal government through Sections 404 and 401 of the Clean Water Act. The federal regulatory program is administered by the U. S. Army Corps of Engineers, Philadelphia District ("the Corps"). Authorization is required for the placement of "dredge and fill" material in wetlands and other "waters of the state." For projects involving significant potential wetlands impacts, an individual permit is required and involves a review by federal and state agencies. The Council on Environmental Quality specifies that mitigation be defined for the purposes of the 1972 Clean Water Act as:

- Avoiding the impact altogether by not taking a certain action or parts of an action.
- Minimizing impacts by limiting the degree or magnitude of the action and its implications.
- Rectifying the impact by repairing, rehabilitating, or restoring the affected environment.
- Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action.
- Compensating for the impact by replacing or providing substitute resources or environment (40 Certified Federal Registry 1508.20).

Section 401 of the Clean Water Act allows for broadened oversight by the states of the Corps' "dredge and fill" program, as well as a scientific basis for permit review. This law requires that states certify that issuance of a Corps individual permit will not degrade "waters of the state" including wetlands. Individual states have the prerogative to deny, certify, or issue with condition, individual and nationwide Corps permits based on potential impacts of the project to water quality. Water quality and coastal zone management consistency certificates are issued on a case-by-case basis for individual Corps permits.

These and other provisions of the Clean Water Act of 1972 are believed to have slowed the loss rate of freshwater, nontidal wetlands. However, cumulative losses of wetlands and wetland functions continue due to increasing development pressures, inadequate regulatory programs, gaps in the understanding of the science, and lack of resource management actions.

Subaqueous Lands Act. DNREC's Division of Water Resources, Wetlands and Subaqueous Lands Section regulates subaqueous lands, which include streams, ponds, and other waterways (Title 7, *Delaware Code*, Chapter 72). A permit is required for the placement of a structure, or for a non-exempt regulated activity in public, or over private, subaqueous lands. This legislation provides state regulatory oversight for activities in jurisdictional state waters. In addition, the Division of Fish and Wildlife manages certain millponds for freshwater fisheries. A "Pond Policy" guides the decision-making process in providing comments on subaqueous lands permit applications for structures and activities in millponds which may be deemed incompatible with fisheries management practices.

Wetland Development Projects

The following wetland program development projects have been undertaken by DNREC with funding from EPA Region III. The information generated through these efforts is important to the overall development of a Comprehensive Conservation and Management Plan for nontidal wetlands and to a whole basin management approach.

Identification and Preliminary Characterization of Unique Wetland Ecosystems

As part of a DNREC freshwater wetlands legislative and program development initiative between 1990 and 1994, the Division of Water Resources contracted with the Delaware Natural Heritage Program to characterize six wetland ecosystems considered to be of highest functions and values: Coastal Plain ponds (Delmarva bays); interdunal wetlands; Atlantic white cedar wetlands; bald cypress wetlands, Piedmont stream valley wetlands, and sea-level fens. These characterizations provide detailed information based on field surveys and literature review on wetland plant community profiles, associated ecological factors, and locations. Of these five rare and unique wetland ecosystems, two are found in the Piedmont Basin: the Piedmont stream valley wetland, and the Coastal Plain pond. The Coastal Plain pond, however, although present in the more southerly portions of the Piedmont Basin (in the Inner Coastal Plain physiographic region), is represented to a greater degree in the Chesapeake Basin.

Evaluation of Remote Sensing/GIS Methodologies for Nontidal Wetlands Restoration

Wetlands compensatory mitigation may include the enhancement of existing wetlands, the restoration of former wetlands that have been converted to non-wetlands, the creation of wetlands from previously non-wetland areas, or, occasionally, the preservation of existing wetlands. Of those mitigation procedures described, wetlands restoration and wetlands creation are most consistent with stated federal and state goals of both areal no-net loss of wetlands functions and values (The Conservation Foundation, 1988). The primary difficulty in achieving these two types of wetlands establishment is associated with the pre-identification of sites that exhibit characteristics indicative of potential success. This study includes efforts by the DNREC Division of Water Resources to identify a wetlands restoration siting methodology that would advance Delaware's goal to meet federal and state wetlands compensatory mitigation mandates.

Wetlands restoration siting may also have a crucial role in the development of watershed planning initiatives, with the recent policy shift in the EPA, the Corps of Engineers, and DNREC regarding consideration of multiple environmental impacts and natural resource conservation from a landscape perspective. Appropriately sited and successful wetlands restoration projects can protect or rehabilitate watersheds where wetlands resources are lacking due to historical degradation or conversion. Toward this end, wetlands restoration siting is a potentially valuable component of the evolving Delaware Whole Basin Planning Initiative (DNREC, *An Evaluation of Three Remote Sensing/Geographic Information System Methodologies*, 1995).

Restoration/Creation/Enhancement and Compensation Banking Criteria

This report reflects the collection, review, and evaluation of literature on the wetlands restoration science with respect to natural resources and regulatory management. Delaware (and the nation's) wetlands resource base continues to decline, increasing the need to initiate actions that re-establish or expand wetlands area or functions. Three general approaches to (re)establishing wetlands are recognized:

- Wetlands Creation — involves the establishment of wetlands at a site where wetlands did not historically exist.
- Wetlands Enhancement — involves the net increase of wetlands function within an existing wetland.
- Wetlands Restoration — involves the re-establishment of wetlands at a site where wetlands historically existed but were subsequently lost.

Wetlands restoration seeks to rehabilitate damaged wetlands systems as a means to reverse historical or anticipated future losses. In principle, effective and efficient restoration ecology may (1) return functioning wetlands to sites where wetlands previously existed; (2) help maintain existing genetic integrity by protecting endangered or threatened species from extinction due to habitat loss; (3) reduce recreational and commercial pressure on more pristine ecosystems by providing alternative areas that may be more suitable but less sensitive; (4) slow or reverse destruction processes to allow time over which societal adjustments can occur; and (5) educate the public as to the costs of restoration and the true costs of environmental destruction. Thus, effective wetlands restoration may slow the rate at which, and decrease the net impact of, wetlands loss such that sustainable-use practices can be sufficiently developed. Social and political recognition must be given to ecosystem services that may not be restored more quickly than those services can be expended.

Compensatory mitigation involves the creation, restoration, enhancement — and more rarely, preservation — of wetlands to compensate for unavoidable adverse wetlands impacts. More specifically, compensatory mitigation banking involves these practices to mitigate adverse wetlands impacts associated with *anticipated* regulated activities. Compensatory mitigation banking, or "compensation banking," differs from most wetlands compensation projects in that it is established by agencies, nonprofit organizations, or private entities. Compensation banks usually provide a relatively large site to be used to collectively compensate, in advance, for one or more projects affecting wetlands. In contrast, individual wetlands compensation projects commonly involve restoration, creation, or enhancement activities concurrent with, or after, the permitted wetlands impacts (DNREC *Delaware Delaware Freshwater Wetlands Restoration*, 1992).

Comparison of Wetland Assessment Methodologies

The objective of this study is to identify, evaluate, and compare the advantages and disadvantages of three "rapid" wetland functional assessment models and a fourth method — Best Professional Judgment — to determine their applicability within the developing freshwater wetlands program. A secondary objective is to evaluate palustrine forested, Coastal Plain wetland functions and their indicators using the expertise of an interdisciplinary team of wetland scientists. The results of this study provide recommendations for the use of functional assessment methods and information on indicators of specific functions, as well as gaps in the knowledge of wetlands science. The establishment of a core set of reference wetlands provides baseline monitoring information useful for future wetlands studies (DNREC, *A Comparison of Four Wetland Assessments*, 1995).

LIVING RESOURCES

By the beginning of the 16th century, the land that would become the political entity known as the state of Delaware encompassed a region of outstanding natural diversity. Clear freshwater rivulets tumbled down rocky streams and rivers from the Appalachian Mountains into the drowned Delaware River Valley, recently flooded by a rising ocean. This river valley broadened into Delaware Bay, the center of a vast estuary, bordered with productive coastal marshes, abundant with shellfish and waterfowl.

Today, following nearly 400 years of natural resource consumption and the conversion of habitats for agricultural purposes, Delaware's remnant natural areas — woodlands, rivers, swamps, and marshes — still provide a biological history of Delaware. Yet, these natural remnants are under continually increasing pressures from humans. This portion of the document will assess the current status of these living resources, measure their spatial change and trends, outline protection and restoration efforts, and suggest possible solutions to retaining a dynamic natural resource base for Delaware's future.

Characterization

In many ways, our living resources reveal more about the state of our environment than any other factor. Our native species, which have evolved to depend upon, as well as play their role in, the intricate web of life are generally the first indicators of change or disruption. They experience firsthand the direct impact of habitat loss, degraded air and water quality, and competition from exotic species. In particular, studies of rare and declining species can play special roles as environmental indicators. These are generally the species most sensitive to environmental change and habitat degradation, and hence can bring the first hints of environmental impact. The trick is in knowing how to observe and understand nature's messages.

For instance, a stream's invertebrate fauna tells volumes about the water quality in a tributary. Although not usually included as a standard water-quality indicator, the diversity of freshwater mussels is an excellent tool for understanding the health of a waterway. Mussels are filter feeders and thus are notoriously sensitive to the effects of sedimentation and pollutants. Furthermore, many mussel species require the presence of particular fish species, to which their larvae must attach to complete their life cycle. When native fish species decline due to loss of habitat, damming of streams, or introduction of non-native fish, the mussels are often the first to feel the impact.

Changes in an area's avifauna can also illustrate the accumulated environmental changes that often proceed unnoticed. Steep declines in insectivorous forest birds may indicate the loss and fragmentation of mature forests in our area. Increased numbers of American robins are in some ways comforting after the scare of Rachel Carson's *Silent Spring* in the early 1960s, but are also reminders that mowed lawns have replaced most of what used to be pastureland and forest. Similarly, the presence of daunting numbers of non-migratory Canada geese is largely a result of land managers' recent habit of maintaining turf adjacent to human-made ponds. Ironically, these large numbers of urban geese can lull the uninformed into complacency about their environment when, in fact, *migratory* Canada geese are experiencing region-wide declines.

There have been a number of studies, both ongoing and short-term, of the Piedmont Basin's flora and fauna. Fish and waterfowl are probably the two best-studied groups of species, largely because of federal funds available to support the work. Annual waterfowl counts date back to 1955, with more than 20 years of species-specific counts (Whittendale 1996). Fish species were inventoried for all of Delaware's major Piedmont tributaries in 1988 and summarized in two reports funded by the Federal Aid in Fisheries Restoration Act (Shirey, 1988, 1991).

Ongoing studies of some of the basin's rare and declining species have been conducted by the Delaware Division of Fish and Wildlife. The Delmarva fox squirrel, once found in the forests of Delaware, was extirpated from the entire state. Re-introductions have been moderately successful in Sussex County, but have not been attempted in the Piedmont Basin in part because of a federal moratorium on new releases. The division receives annual federal funding for mark, release, and recapture studies of bog turtles. This species is notoriously difficult to study because of its elusive habits; its rarity only compounds the challenge. Annual reports indicate that very few individuals of this species have been captured in Delaware and that, despite concerted effort, findings are declining (Gelvin-Innvaer and Stetzar, 1992; Gelvin-Innvaer and Greenwood, 1995).

The Delaware Natural Heritage Program, (formerly the Delaware Natural Heritage Inventory), also part of the Division of Fish and Wildlife, conducts ongoing inventories of natural communities as well as rare and declining species (e.g., state and globally rare plants, birds, insects, mussels, reptiles, and amphibians). It maintains a data base, both electronic and manual, of its findings throughout the state. The program has never conducted a comprehensive review of the status of biodiversity in the Piedmont physiographic province or any of its drainages, but from data that have been collected, it is known that an alarming number of species that were once common in the Piedmont are now known from only one or two locations, or have been extirpated entirely.

For instance, the regal fritillary is a butterfly that was abundant in many old fields just 30 years ago. Now, for unknown reasons, it is thought to be entirely gone from the region even in the isolated areas where one finds appropriate habitat and food plants. It is also known that of all 50 states, Delaware has lost the highest proportion of its native flora (Kutner and Morse, 1996). Although not confirmed, it is thought that a large portion of this decline is due to habitat loss and degradation in the Piedmont Basin.

Historic Biotic Communities

The land surface of North America has been divided into more than 20 physiographic provinces, each with its own unique history of formation and erosion (Lobeck, 1948). The physiographic provinces in Delaware are the Atlantic Coastal Plain and the Piedmont. These provinces intersect in Delaware within the Piedmont Basin along the "Fall Line," a zone from 2 to 4 miles wide stretching east to west across the state, roughly paralleling the Christina River. The entire Piedmont Basin, 80% of which lies within the Commonwealth of Pennsylvania, ultimately empties into the Delaware River and is considered to be part of the Delaware Estuary (Dove et al., 1995).

The Piedmont flora in Delaware is almost identical to that of the adjoining parts of Pennsylvania. The rich bottomland soil in the valleys and rocky terrain on the steep hillsides "support a flora of great variety and richness, including many species rare or non-existent on the Coastal Plain" (Tatnall, 1946). Most of the soil, rocks, and boulders on the surface of the Piedmont province originate from ancient metamorphic rock that produces predominantly acid soils. However, a surficial exposure of alkaline serpentine rock occurs in Delaware in a single outcrop east and northeast of Mount Cuba. In addition, the Cockeysville Marble Formation, an important aquifer recharge area, is a limestone formation that emerges as an outcrop on the surface along Pike Creek east of Pleasant Hill at a site known as the Eastburn Complex.

The following descriptions summarize the natural communities found within Delaware's Piedmont Basin, including adjacent areas along the Fall Line and within the Christina River watershed. This list should not be construed as representing the entire array of natural communities found in this part of Delaware; additional data are needed. Many of these communities support a plethora of animal and plant species of special concern.

Forest Communities

Delaware's Piedmont Basin is home to a variety of important forest communities, most of which occur as repeating units on the landscape. These forests would fall within the broadly classified *Mixed Mesophytic Forest Region* of Braun (1950). In general, the forests are composed of a mixture of hardwoods, dominated by oaks, beech, tulip poplar, hickories, and sweet birch on the steep slopes and dry ridge tops, and by box elder, sycamore, sweet gum, slippery elm, red maple, tulip poplar, and sometimes river birch and black willow along narrow stream-side forests. American chestnut and, to a lesser degree, American elm were formerly important components of the mixed mesophytic forest.

There is tremendous variability in the ages and quality of these forests. It is safe to say that all the woodlands in the Piedmont Basin are second- or third-growth forest, most with trees less than 50 to 100 years old. Yet, some of the oldest trees in the state are found in the Piedmont Basin, where several forests contain specimens nearing 200 years of age. Even though the age of these magnificent trees is unusual in the Delaware Piedmont, and indeed in the entire watershed, many of these huge plants are just past middle age. Although the term "old growth" is frequently used to describe patches of forest containing these large specimens; a true, virgin old-growth forest is not likely to remain in the Piedmont Basin. However, several of these mature forest patches are developing some of the typical characteristics of an old-growth forest.

Areas adjacent to these older forests may support young successional woods, or maturing forests that are composed of a high proportion of exotic species. However, nearly 75% of the Piedmont Basin's terrestrial forests are no longer in existence, having been cleared long ago for pastureland and early settlements, or more recently for urban sprawl. Additionally, forests that are present on the drier ridge tops are typically of very poor quality, often consisting of young second- and third-growth thickets with a smothering blanket of exotic vines, shrubs, and herbs.

Tables 38 – 41 provide brief descriptions of the forest types that one is likely to encounter in the Piedmont region and adjacent Fall Line area of Delaware.

Trends

An undeniable fact within the Piedmont Basin is that the species composition of the remaining natural areas is changing at an unnaturally rapid pace. Direct habitat conversion has altered a functioning natural landscape into a sprinkling of isolated islands and ribbons of natural areas. Add to this the further insults of alien species, pollution, excessive sedimentation, altering of natural waterways, etc., and each natural area is further eroded. In addition to species loss from these direct impacts, the theories of island biogeography have shown that, in general, as landscape patches become smaller and more isolated, they can each sustain a diminished number of species (Harris, 1984). In

Table 38
PIEDMONT REGION FOREST TYPES

COMMUNITY TYPE	COMMUNITY CHARACTERISTICS
FOREST COMMUNITIES	
Scientific Designation: *Quercus spp. – Liriodendron tulipifera – Fagus grandifolia* Forest Community Common Designation: oak – tulip poplar – beech forest	◆ This community usually occupies the relatively steep, rocky slopes associated with stream valleys. ◆ The oak – tulip poplar – beech forest may be extremely diverse and of good to excellent quality. ◆ Oaks usually present include red oak *(Q. rubra)*, black oak *(Q. velutina)*, scarlet oak *(Q. coccinea)*, white oak *(Q. alba)*, and chestnut oak *(Q. prinus)*. Common associates include *Fraxinus americana, Carya ovata, C. glabra, C. tomentosa, Lindera benzoin, Kalmia latifolia, Hamamelis virginiana, Carpinus caroliniana, Rhododendron periclymenoides, Viburnum prunifolium*, and *Cornus florida* among other woody taxa. ◆ Herbs are typified by such species as *Arisaema triphyllum, Thelypteris hexagonoptera, Podophyllum peltatum, Asarum canadense, Claytonia virginica, Dentaria laciniata, Aster divaricatus, Prenanthes altissima, Cimicifuga racemosa, Erythronium americanum, Aralia nudicaulis,* among a host of other species.
Scientific Designation: *Liriodendron tulipifera* Forest Community Common Designation: tulip poplar forest	◆ A forest community where the majority of the canopy is comprised of tulip poplar. ◆ This is similar to the preceding community but without the oaks and beech (though certainly these may be present but in low numbers). ◆ This community is found on the lower slopes more often, but may also be on the mid- to upper portions of steep slopes. ◆ The understory may be comprised of many of the same species as in the previous community.
Scientific Designation: *Quercus prinus – Betula lenta/Kalmia latifolia* Forest Community Common Designation: Chestnut oak – sweet birch/mountain laurel forest	◆ Occurs as small isolated stands on steep, dry rock outcrops on upper slopes. ◆ It is characterized by having a canopy co-dominated by chestnut oak and sweet birch, and a dense shrub layer of mountain laurel. ◆ The herbaceous layer is generally less diverse than other Piedmont forest communities. A rare natural community in Delaware.
Scientific Designation: *Platanus occidentalis – Acer negundo/Lindera benzoin* Wetland Forest Community Common Designation: sycamore – box elder/spice bush wetland forest	◆ Found as narrow occurrences along Piedmont streams. ◆ Associates include *Acer rubrum, Juglans nigra, J. cinerea, Quercus palustris, Ulmus rubra, Fraxinus pennsylvanica, Carpinus caroliniana, Staphylea trifolia, Prunus serotina, Cornus florida*. Included among the woody species and herbs are *Onoclea sensibilis, Rudbeckia laciniata, Laportea canadensis, Geum canadense, Woodwardia areolata,* and *Impatiens capensis*. ◆ These communities, especially when adjacent to roads, often have an infestation of exotic species.

Table 39
PIEDMONT REGION FOREST TYPES — CONT'D.

COMMUNITY TYPE	COMMUNITY CHARACTERISTICS
FOREST COMMUNITIES	
Scientific Designation: *Acer rubrum* Wetland Forest Common Designation: red maple wetland forest	◆ Found in seepage wetlands along lower slopes that empty into Piedmont streams, as well as on narrow or broad floodplains. ◆ While *Acer rubrum* may be the dominant canopy tree, several additional canopy associates may include *Fraxinus pennsylvanica, Quercus palustris, Acer negundo*, and *Platanus occidentalis.* ◆ The subcanopy woody layer is comprised of *Cornus amomum, Cephalanthus occidentalis, Prunus spp., Lindera benzoin*, and *Viburnum dentatum*, among others. ◆ Herbs may include various sedges *(Carex spp.), Symplocarpus foetidus, Juncus effusus, Impatiens capensis, Scirpus cyperinus, Phalaris arundinacea, Solidago rugosa, Cinna arundinacea, Polygonum hydropiperoides, Aster puniceus, Lycopus spp., Arisaema triphyllum, Onoclea sensibilis, Acorus calamus, Chelone glabra, Thelypteris palustris, Woodwardia areolata*, and *Boehmeria cylindrica.*
Scientific Designation *Acer rubrum – Liquidambar styraciflua* Forest Community Common Designation red maple – sweet gum forest	◆ This community may be found on dry as well as wet sites. ◆ It is often indicative of second or third growth forest stands, and often may be characterized as disturbed or degraded. ◆ On dry sites, associates include *Lindera benzoin, Viburnum dentatum, V. prunifolium, Toxicodendron radicans, Smilax rotundifolia, Lonicera japonica, Rosa multiflora, Prunus serotina, Podophyllum peltatum, Smilacina racemosa, Bartonia virginica, Cypripedium acaule*, and *Maianthemum canadense.* ◆ Wet sites may consist of *Lindera benzoin, Sambucus canadensis, Vitis labrusca, Smilax rotundifolia, Symplocarpus foetidus, Apios americana, Boehmeria cylindrica, Carex prasina, Cryptotaenia canadensis, Dioscorea villosa, Glyceria striata*, and *Impatiens capensis.*
Scientific Designation *Quercus spp. – Carya spp.* Forest Community Common Designation oak – hickory forest	◆ Found in drier habitats where there has been little disturbance, usually at the highest elevations on the more level uplands. ◆ Characterized by an abundance of oaks *(Q. alba, Q. prinus, Q. rubra, Q. coccinea, Q. velutina)* and hickories *(C. cordiformis, C. ovata, C. glabra, C. tomentosa).* ◆ Associates may include *Liriodendron tulipifera, Acer rubrum, Betula lenta, Fraxinus americana, Carpinus caroliniana, Hamamelis virginiana, Kalmia latifolia, Staphylea trifolia, Viburnum acerifolium, V. dentatum, V. prunifolium, Cornus florida, Lindera benzoin, Euonymus americanus, Lonicera japonica, Prunus serotina, Ariseama triphyllum, Aster divaricatus, Aralia nudicaulis, Chimaphila maculata, Cimicifuga racemosa, Dentaria laciniata, Galium spp., Circaea lutetiana, Sanguinaria canadensis, Epifagus grandifolia, Podophyllum peltatum, Smilacina racemosa, Thelypteris noveboracensis*, and *Aster divaricatus.*

Table 40

PIEDMONT REGION FOREST TYPES — CONT'D.

COMMUNITY TYPE	COMMUNITY CHARACTERISTICS
SCRUB-SCRUB COMMUNITIES	
Scrub-shrub communities can be quite variable and are generally small in areal extent, and some may only represent an early seral stage of a forested community. Many of the scrub-shrub communities are more accurately described as impenetrable thickets, with a dense understory of brambles and greenbrier. The more persistent scrub-shrub communities are usually found in seepage wetlands and along stream sides, and are often situated between marsh and forest habitats. Only a brief mention of this community type will be made; more data for scrub-shrub habitats are needed.	
HERBACEOUS COMMUNITIES	
Herbaceous communities described in this section include small seepage wetlands surrounded by forested habitats and flood-plain marshes. These communities can be extremely diverse, or conversely, be relatively depauperate in species composition.	
Scientific Designation: *Impatiens capensis – Sagittaria latifolia – Peltandra virginica* 'Herbaceous Wetland Common Designation: Jewelweed – arrowhead – arrow arum herbaceous wetland	◆ Fresh/tidal marsh with the above species as co-dominants, but also with an assemblage of other species. ◆ Associates may include *Amaranthus cannabinus, Acorus calamus, Polygonum arifolium, P. punctatum, P. sagittatum, Cuscuta spp., Nuphar lutea, Bidens laevis, Leersia oryzoides, Phalaris arundinacea,* and *Zizania aquatica,* in addition to others.
Emergent Herbaceous Wetlands	◆ Extremely diverse herbaceous wetlands of freshwater marshes (tidal and nontidal). ◆ Some of the species found in these wetlands include *Acorus calamus, Bidens spp., Carex spp., Asters spp., Cinna arundinacea, Cyperus spp., Eupatorium spp., Hibiscus moscheutos, Impatiens capensis, Iris spp., Juncus spp., Leersia oryzoides, Lilium superbum, Nuphar lutea, Onoclea sensibilis, Peltandra virginica, Phragmites australis, Polygonum spp., Rumex spp., Sagittaria latifolia, Sium suave, Solidago spp., Thalictrum pubescens, Typha,* and *Zizania aquatica.* ◆ This community is found along the Christina River.
Piedmont Stream Valley Seepage Wetlands	◆ Primarily open herbaceous graminoid and forb dominated wetlands with scattered shrubs and small trees, usually located at the base of a steep slope. ◆ Plant diversity is usually high and includes such species as *Symplocarpus foetidus, Arisaema triphyllum, Osmunda cinnamomea, O. regalis, Carex spp., Juncus effusus, Glyceria striata, Athyrium thelypteroides, Cardamine spp., A. filix-femini, Impatiens capensis, Chelone glabra, Sambucus canadensis,* and *Onoclea sensibilis.* ◆ Scattered shrubs and trees include *Acer rubrum, A. negundo, Liriodendron tulipifera, Platanus occidentalis, Juglans nigra, Fagus grandifolia, Lindera benzoin,* and *Sassafras albidum.* ◆ These wetlands are hydrologically influenced by groundwater seepage flowing from the base of the slope. ◆ A significant natural community assemblage in Delaware. ◆ More data are needed to adequately distinguish seepage wetland community types.

Table 41
PIEDMONT REGION FOREST TYPES — CONT'D.

COMMUNITY TYPE	COMMUNITY CHARACTERISTICS
HERBACEOUS COMMUNITIES	
Scientific Designation: *Spartina alterniflora* Salt Marsh Common Designation: smooth cordgrass marsh	◆ In northern New Castle County, this community may be found as small colonies in the intertidal zone along the Delaware River. ◆ Intermingled with the cordgrass may be *Sagittaria calycina, Scirpus pungens,* and *Lythrum salicaria,* as well as others.
MODERN ANTHROPOGENIC OR EARLY SUCCESSIONAL COMMUNITIES	
Cultivated Fields, Pastures, Wastelands	◆ These are common habitats throughout the state, as well as in the Piedmont Basin. ◆ Disturbed, anthropogenic habitats that contain a diversity of plant species; many of these species are exotics.
Old Fields	◆ Fields that have remained fallow for several years and are dominated by tall grasses and other forbs (many of the same species occurring in the previous habitat types occur in old fields; however, fewer aliens are present). ◆ Common old-field herbaceous species include bluestem, panic and other grasses, asters, milkweeds, thistles, clovers, goldenrods, as well as many others. ◆ Scattered young trees and other woody plants are also present, including red cedar, privet, red maple, sweet gum, grapes, honeysuckle, multiflora rose, sumacs, sweet gum, poison ivy, Virginia creeper, and several blackberries.
Xeric Old Fields	◆ Old fields where soils are drier and succession rates are extremely slow (has also been referred to as *Dry Upland Glades* (Newbold et al., 1988). ◆ Typical species here include sweet vernal grass *(Anthoxanthum odoratum),* little bluestem *(Andropogon virginicus),* short husk-grass *(Brachyelytrum erectum),* tumblegrass *(Eragrostis spectabilis),* Indian grass *(Sorghastrum nutans),* and purpletop *(Tridens flava),* among numerous other species.

sum, direct loss and degradation of habitat, as well as the loss of connectivity between habitats, have resulted in a significant loss of species diversity from our natural areas.

A number of bird species are experiencing local, regional, and, for some, global declines. The taxa most affected are those that depend on pristine, forest-interior habitats, as well as insectivorous and ground-nesting species (Davis, 1996). There are a number of local and regional factors in addition to direct habitat loss that are thought to contribute to their decline. One likely factor is the loss of structural diversity within forests. This, in turn, is thought to be due in part to over-grazing by white-tailed deer, as well as a desire for "clean" forests in areas directly managed by people. An additional factor is the explosion in domestic cat populations, both feral cats and pets. In many areas, these "super hunters" are present at densities far beyond natural-predator densities, and are taking a disproportionate toll on songbird populations (Frink, 1996).

With the exception of fish and freshwater macroinvertebrate species (Shirey, 1991; Maxted, 1994) little is known of the current status of animal populations and their distribution in the Piedmont Basin. Several other animal groups including birds, reptiles, amphibians, and some insects (butterflies) have been sporadically sampled throughout the region. Of the animals that are listed by the Delaware Natural Heritage Program (1995) as species of concern, many are found exclusively in Piedmont habitats. Generally, the more secretive the animal, the less is known about it. The bottom line is if more habitat can be protected, both in diversity, connectivity, and size, then the greatest number of species of plants and animals will be able to survive in Delaware into and beyond the next century.

While many native species have been lost, or severely diminished, others are increasing. To our knowledge, while no one has taken on the task of systematically summarizing these trends, if they did, they would no doubt have raccoons, opossums, American robins, Canada geese, rock doves, and brown-headed cowbirds on their list. These are adaptable, "broad-niche" species that can tolerate or even thrive living in a human-dominated, suburbanized landscape. While they may be as close to "wildlife" as many people ever come, their ubiquity is in many ways an indication of just how unbalanced our natural systems are becoming.

Additional sources of impact include the following:

- Fragmentation due to increased road capacity.
- No nontidal wetlands legislation in the state.
- No upland forest protection provisions.
- Many natural areas not included in the state Natural Areas Inventory.
- Sedimentation.
- Inadequate or inappropriate management practices within natural areas (due to funding constraints, conflicting resource needs, lack of knowledge).
- Stormwater management design.
- Gravity sewer lines.

Sources of Impact

Loss of Available Habitat

The alteration of habitat by humans has been occurring in Delaware's Piedmont Basin since the arrival of the first Paleo-Indians. Along with the climatic and vegetational changes that accompanied the retreat of the continental ice sheets to the north, humans have played a significant role in the extinction of large herbivores (Martin, 1986). With the adoption of agricultural techniques in the Mid-Atlantic region approximately 3,000 years ago, the woodland culture became more dependent on crops and on the use of fire to clear the forest. Their slash and burn type of agriculture opened park-like gaps in the woodlands. The introduction of European agricultural practices meant a conversion of a significant percentage of forest to agriculture and pasture, extermination of predators, and the over-harvesting of game and furbearing animals. Numerous species were exterminated from Delaware, including elk (1855), eastern gray wolves, eastern cougar (1899), and black bear (1900). Wild turkey fell to logging practices and market hunting by 1880, later to be re-established from Pennsylvania populations in the 1970s. White-tailed deer were essentially gone from Delaware by 1900 for the same reasons. In fact, it was illegal to hunt white-tailed deer in Delaware for over 150 years, until the 1950s. The majority of forest clearing for agriculture and wood products occurred prior to the 20th century in the Piedmont Basin.

Dependence upon the horse and other livestock directly influenced the intentional creation of meadows or "old field habitat," dominated by Eurasian plant species. These areas have become part of the American landscape and are valued recreationally and aesthetically. They were neither natural, nor native, but with the transition from the horse to engines, much of this man-made habitat has been converted to other land uses or reverted to forest.

Baseline data of the original historic habitat in the Piedmont Basin are not available. However, a series of aerial photographs taken approximately every decade from 1926 until the present provide a glimpse of the changes in available habitat in the basin over the last 70 years. The Piedmont Basin forest acreage reached a low point in the late 19th century as the demands for pasture for horses, wood for construction and energy, and farmland reached its zenith. Abandonment of unproductive farms, invention of the automobile and tractor, and the increased use of coal and oil for heat led to an overall increase in total forest acreage in the early 20th century. Suburban development and economic prosperity, beginning in the middle of this century began replacing these second-growth forests with homes, roads, retail shopping centers, and commercial areas. This permanent loss of upland habitat is continuing today.

Assessments of the change in forest cover have been conducted by the U.S. Department of Agriculture three times over the last 40 years, most recently in 1986. The document, *Forest Statistics for Delaware — 1972 and 1986* (Frieswyk et al.,1988), compares the last two forest inventories for Delaware with a breakdown for each county. Broad indications of the reduction in forest cover over this period in the Piedmont Basin can be found in this document.

Most losses of wetland habitats in Delaware have also occurred following European settlement. Over the last 300 years, the landscape gradually has became drier due to the construction of canals, drainage ditches, and stream channelization projects to promote agriculture, shipping, and mosquito control. Dams, to build mill ponds for water power, and dikes, to create freshwater impoundments along the coast, altered natural freshwater and tidal fluctuations, creating new anthropogenic habitats that replaced the existing natural ones. Thousands of acres of wetlands were drained throughout the state, but largely south of the

Piedmont Basin. Most of the affected areas in the Piedmont Basin were along the lower elevations of the Christina and Delaware rivers. More detailed information regarding the loss of wetland habitats in the Piedmont Basin can be found in the Land Use section of this report.

Fragmentation of Habitat

In addition to the loss of available habitat, the remaining habitat in the Piedmont Basin has become increasingly splintered and isolated. Fragmentation of the Piedmont forest has been increasing at a steady rate over the last half of the 20th century, largely for the development of new suburban housing, supporting infrastructure (roads and utilities), and commercial businesses. Privately owned forest tracts over 50 acres in size are becoming increasingly rare and isolated. Most of the remaining forest in the Piedmont Basin is found along steep slopes that are too difficult to farm or develop, along narrow stream bottoms and floodplains, and within the boundaries of large 19th-century family landholdings. The latter example is property that essentially established private preserves for these families, which later in the 20th century have become the best remaining examples of Delaware's natural heritage in the Piedmont Basin. Some of these properties have been donated to, or purchased by public entities, for state and local parks and open space protection.

The clearing of the Piedmont forest over the last 50 years has had several effects. Some non-game animal species which require extensive, mature forests to persist have become significantly reduced in numbers or extirpated. The remaining fragmented habitats contain a high ratio of "edge" as opposed to interior forests. Edge effects on the forest include increased sunlight, wind exposure, drying of soils, higher temperatures, loss of interior species, and vulnerability to exotic species invasion. Fragmentation favors species that prefer an open patchwork of woodlots, edges, and meadows such as the red fox, brown-headed cowbird, raccoon, white-tailed deer, and the newly invading coyote. These animals have become more numerous than ever in close proximity to humans. This may have long-range management implications as human/pet/wild animal conflicts increase. Already, the increased threat from zoonotic diseases — lyme disease, hanta virus, rabies — has caused some public health concerns where animal and human populations interact.

Sedimentation

Sediment accumulation in streams has had terrible consequences for the aquatic systems in the Piedmont Basin. Centuries of forest clearing, livestock grazing, agriculture, and now, the steady stream of development construction projects, has contributed enormous amounts of soil and rock to Piedmont Basin rivers, creeks, and streams, both in nontidal and tidal waters. The addition of impervious surfaces, such as roads, roofs, and parking lots in the 20th century, has contributed to the decline of stream habitat by increasing runoff volume, thereby increasing the erosion potential of stream banks. Modern stormwater management practices have reduced the sediment load, but there is desperate need for improvement. The historic practice of using stream corridors for gravity sewer systems, which is still in use today, has contributed to major disruptions of many of the basin's streams.

As a result of this sediment load, fish spawning areas, which require clean sand, have been destroyed. Sediment has contributed greatly to the demise of numerous species of mollusks and other filter feeders. Some historic species no longer survive in Delaware. Others have been driven to extinction in all but the highest quality streams. Many species exist only in the protected portions of the watershed, mainly small tributaries. The small Thompson Station tributary of White Clay Creek, currently under consideration as a possible location for a drinking water reservoir for New Castle County, has the greatest macroinvertebrate diversity left in Delaware's entire Piedmont Basin.

From an optimistic view, once sediment loads are sufficiently reduced, it would be possible to achieve a higher level of stream quality in the basin. Stream habitat would gradually improve over succeeding decades. At some point in time, aquatic habitat would become available to be repopulated by the refuge populations of stressed aquatic species. But first, we must save all the aquatic components possible. Aquatic fauna and flora must be allowed to survive in the remnants of quality habitat that are left, or there will not be much diversity to spread throughout the watershed when better days arrive.

Exotic Species

A major threat to the fragmented natural areas in public (which are assumed by many to be protected) and private holdings has been the introduction of numerous exotic or alien species of plants and animals that have successfully invaded all types of natural areas. Unlike most introduced plant species which are benign additions to the landscape, invasive exotic species are overrunning forests, wetlands, open habitat, and aquatic communities at all levels: submersed, emergent, herbaceous, shrub, mid-canopy, and canopy layers. Native plant communities are in direct competition with introduced exotics. The threat of exotic species, combined with habitat destruction and fragmentation along with an overpopulation of white-tailed deer, has placed the remaining natural habitat in the Piedmont Basin under severe pressure. Over one-third of the species in Delaware's flora are exotic. Of this number, several dozen species have the capability of permanently altering habitat. To date, only the largest, oldest, most intact forest tracts have been able to resist the exotic invasion, but even these forests are ultimately vulnerable to shade-tolerant exotic species such as Norway maple. Many sites are in grave need of exotic species control and habitat restoration.

Although the presence of exotic species is well known, very little data has been collected that documents the extent of the exotic infestation in the Piedmont Basin. Clearly, the problem is large and growing. The only data that exist are presence/absence data. Invasive exotic species issues have not been a priority with land managers, planners, or heritage data bases. Meanwhile, new species of plants are being introduced into natural areas, sometimes intentionally. As the exotic plant species compete with native species for the already reduced available habitat, they do so without the threat of disease or insect herbivores that affect natives. Even deer, which eat almost anything, seem to favor the native plants that they have been eating for eons, over the new, unfamiliar, and/or unpalatable imported exotics.

A common event, such as the blowing down of a large tree during a thunderstorm, creates available habitat for exotic invasion, especially from vines (i.e., Asiatic bittersweet, *Celastrus orbiculatus*). Once established in sunny gaps created by the death of a mature tree, the vines smother the normal successional replacements of the fallen tree: native saplings. Clambering over the young trees, covering them with their leaves, denying them sunlight, the vines maintain an exotic tangle that native species can not penetrate. These vine thickets are permanent. In the normal successional process, this canopy gap would eventually become forest once more. Today, once the exotic vines become established, the forest will not recover without intervention. Instead the vines slowly kill surrounding trees, gradually expanding the gap in an ever-widening circle.

Under these circumstances, a catastrophic storm would create the same scenario simultaneously over a large area. For decades in most Piedmont Basin forests, an incredible number of exotic seeds have been raining on the forest floor every year. Seedling vines have sprouted to become a significant understory component. Once an ice storm, northeaster, tornado, or hurricane strips or kills the forest canopy, these seedling vines will be able to utilize the increased nutrient load released from the dead leaves and branches left by the storm. The combination of the nutrient boost and the increased sunlight from the reduced canopy will allow the vines to permanently alter and dominate entire forests. At this point, the cost of restoration management of these forests would be enormous. An effort to protect the best forests must begin in the immediate future, before a catastrophic event. It is only a matter of time until this scenario becomes a reality.

Major climatic storm events occur on a regular, if not predictable basis. These events are part of the abiotic processes to which all plants and animals in the region are subjected. Human alteration of habitat over the past 200 years has made some parts of the ecosystem more vulnerable and less likely to recover from future storms. Any event that can open up the canopy will promote the spread of exotic plant species, thereby further degrading the remaining forests.

Insufficiently Protected Habitat

Protection of land in Delaware has been accomplished through three different approaches: private ownership, public ownership, and regulatory protection. Of these approaches, protection via regulatory processes has been the most difficult and least successful. New Castle County protects lands by ordinance if they are on steep slopes, floodplains, water recharge areas, or identified as Critical Natural Areas. The level of protection that is accomplished by these laws is significant, especially when compared to Kent and Sussex counties. However, variances granted to developers; lack of buffer protection along tributaries, streams, and rivers; and the lack of protection for sites not included in the state's Natural Areas Inventory have all contributed to a continuing pattern of fragmentation and degradation of remaining habitat. Upland areas that do not fit under one of the ordinances are particularly vulnerable.

Other

Historic industrial and nonpoint pollution, including heavy metal and pesticide residues, have contributed to the degradation of Piedmont Basin habitats; especially aquatic ecosystems. The current 1996 fish consumption warnings on most of the major streams in the basin are indicative of the bioaccumulation of chemicals and heavy metals in the food chain. In-depth discussions of these issues are contained in the *Possible Contaminant Sources* and *Surface Water* sections in this document.

Positive Initiatives

Protection of Habitat

Large family estates in the Piedmont Basin that were gradually acquired over the previous 150 years ultimately have led to the preservation of large tracts of natural areas in the basin. Protection efforts in the basin began as early as 1906, when William Bancroft began orchestrating the acquisition of lands along the Brandywine. His efforts were mirrored by various members of the duPont family, mainly in the valleys of the Brandywine, Red Clay, and White Clay creeks. These private holdings were the first efforts to conserve open space. Clearly, without the foresight and financial investment of these people early in the 20th century, the quality of the remaining natural areas in the Piedmont Basin would have been greatly reduced.

However, the large family holdings have been breaking apart during the later part of the 20th century. Some parcels have been developed. Private nonprofit organizations, such as the Woodlawn Trustees, Brandywine Conservancy, and the Delaware Nature Society have long worked with the area's major landowners to continue to preserve the natural resource values of the basin. The Brandywine Conservancy has purchased many acres in this watershed in Pennsylvania and also holds conservation easements granted by the landowners to protect thousands of more acres in the Piedmont Basin — primarily in Pennsylvania, but also in Delaware. The Woodlawn Trustees are the owners and land stewards of a significant portion of Brandywine Creek Valley.

In 1973, Delaware Nature Education Center, Incorporated (now Delaware Nature Society) brought together 25 experts in their respective fields to identify the most important natural areas in Delaware. Led by project director Norman G. Wilder and principal author Lorraine M. Fleming, this effort culminated in the publication of *Delaware's Outstanding Natural Areas and Their Preservation* in 1978.

The State of Delaware enacted Title 7, *Delaware Code,* Chapter 73 — Natural Areas Preservation System on February 10, 1978. This legislation and the subsequent regulations that were passed provided the State of Delaware, through the DNREC Office of Nature Preserves in the Division of Parks and Recreation — the ability to dedicate public and private nature preserves; identify and maintain a statewide Natural Areas Inventory; and establish a Natural Areas Advisory Council to review and make recommendations to the DNREC Secretary regarding the identification, protection and acquisition of natural areas throughout the state. Delaware's first nature preserves, Freshwater Marsh and Tulip Tree Woods, were established in the Piedmont Basin in Brandywine Creek State Park in 1982.

The definition of a natural area in the State of Delaware enabling legislation (Natural Areas Preservation System, Title 7, *Delaware Code,* Chapter 73) is an area "of land or water, or both land and water, whether in public or private ownership, which either retains or has re-established its natural character (although it need not be undisturbed), or has unusual flora or fauna, or has biotic, geological, scenic or archaeological features of scientific or educational value." Natural character refers to the native plant and animal species and associations that occupied Delaware under the influence of Native Americans at the time of European occupation.

In selecting a state-recognized natural area, the Office of Nature Preserves, in conjunction with the Natural Areas Advisory Council, evaluates a site based on the following non-prioritized criteria: representativeness; biological rarity; uniqueness; diversity; size; viability; defensibility; research, education, or scenic value; and outstanding geological, archaeological, or aquatic features. Sites can be added or deleted from the inventory.

The Natural Areas Inventory was not intended to include every natural area remaining in Delaware. The intent was to include only the areas that were of statewide significance. As a result, many areas that meet the criteria were not included in the inventory. During the 18 intervening years since the inventory was established, a tremendous amount of suburban expansion has taken place in the Piedmont Basin. Lands formerly considered marginal for housing purposes are, today, being developed. Areas not currently included on the inventory are being reconsidered for inclusion. Among the concerns and priorities of this review is providing adequate upland buffer to wetlands and stream and river corridors, and protecting the larger isolated upland forest patches and rare habitats scattered throughout the region.

New Castle County's Ordinance No. 91-028 provides protection for lands within New Castle County that have been listed on the state's Natural Areas Inventory. The county ordinance refers to lands on the inventory as Critical Natural Areas. County planners work closely with the Office of Nature Preserves and private landowners to coordinate protection of these identified natural areas. This ordinance, along with other county codes protecting steep slopes and floodplains, provides the only non-voluntary state or local protection of privately held natural areas within the Piedmont Basin.

Land purchased by local and state governments with monies derived from the 21st Century Fund is the latest and perhaps the most important step in accomplishing protection for areas that contain significant habitat. Thousands of acres scattered across the watershed are now owned by public agencies. Significant habitat remains on these properties. Much of this land was also purchased from large landholding estates throughout the Piedmont Basin. The New Castle County Parks and Recreation Department has concentrated upon acquisitions in the floodplain of the Christina River and in the Middle Run Natural Area. State acquisitions have centered primarily around White Clay Creek, Brandywine Creek, and Bellevue State parks.

The State of Delaware has acquired land through various programs for the recreational benefit and natural resource protection on behalf of its citizenry for many years. This has been especially true in the Piedmont Basin. The State of Delaware enacted Title 7, *Delaware Code,* Chapter 75 — The Delaware Land Protection Act, on July 13, 1990. Perhaps better known as the *Open Space Program,* the initial funding for this program was provided by the sale of bonds. Lands identified throughout the state as State

Resource Areas are the priority lands for acquisition. State Resource Areas in the Piedmont Basin include lands along Brandywine Creek, Red Clay Creek, White Clay Creek, the Christina River, and the upper Delaware River. (See Map 22.) At present, the program is funded as part of the 21st Century Fund. From 1990 through 1996, the acquisition of 1,752 acres of land within the Piedmont Basin for a total net cost of $30,360,450 reflects the increasing cost of land acquisition for this voluntary program. It does not reflect the cost of maintaining these properties. An additional $14 million dollars of funding has been released by the legislature to continue the purchase of additional open space statewide through July 1997, with a similar amount projected for the following year.

The Delaware Division of Fish and Wildlife, in conjunction with the U.S. Fish and Wildlife Service, provides wildlife habitat restoration planning and funding to private landowners through a program called Partners for Wildlife. The division also has spearheaded the Northern Delaware Wetlands Rehabilitation and Restoration Program, which ultimately will restore the degraded marshes along the lower Christina River. For more detailed information about this and other wetland-related projects, refer to the Wetlands section in this document.

Restoration Actions

Several restoration initiatives have begun in the Piedmont Basin. The Delaware Nature Society has several staff members and many volunteers working on the Middle Run Restoration Project, a reforestation effort. Approximately 35 acres of former pasture and agricultural fields have been planted with thousands of native seeds and seedlings. Delaware Nature Society is also mounting a reforestation effort at their Burrows Run Nature Preserve. Both projects include exotic plant species control efforts. In addition, Delaware Nature Society sponsors stream cleanup days throughout the region on several of the watersheds.

The Division of Parks and Recreation, Office of Nature Preserves, is conducting two natural area management projects. The first project, at Tulip Tree Woods Nature Preserve in Brandywine Creek State Park, is establishing a baseline of the native and exotic vegetation cover at all levels in the forest. Some of the study areas will be maintained as control plots. Ultimately, this information will provide a measure of the success or failure of the long-term management goals for the preserve. The second project, in Flint Woods Nature Preserve, is testing the efficacy of various exotic-plant control techniques on different exotic plant species. This project will also develop a per-unit-cost analysis to provide managers with a realistic budget estimate for exotic plant control at similar sites throughout the Piedmont Basin.

Local involvement is critical to the successful management of natural areas. The Village of Arden is committed to managing its forests. Arden has been actively involved in the preservation of the municipal forestlands of the community. The village's Conservation Committee has been learning all they can about the value of their natural resources and how to protect them. They have begun an exotic species control program, are establishing a baseline data set about their forest, and are working on a forest management plan. A forest fire management plan has been completed by the village in consultation with a DNREC forester. Arden has recruited the neighboring villages of Ardencroft and Ardentown and the neighboring developments of Indian Field and Buckingham Greene into a partnership concerned about the issues along Perkins Run and the South Branch of Naamans Creek. Arden has applied for a Partners for Wildlife grant to purchase adjacent forestland, and has contacted the National Park Service for assistance in developing a management plan for the village's public areas.

A private nonprofit organization, Friends of Brandywine Creek, has sponsored stream restoration activities on Brandywine Creek near the zoo. These efforts involved the installation of coconut fiber logs into the eroded banks of the creek and replanting them to restore the bank.

Target Needs

In pulling together this information, we have been overwhelmed with how little we know and how little effort has been made to pull together diverse sources of information. We have identified the following major needs:

- Freshwater mussel surveys (Red Clay Creek has had an initial survey, but other creeks are unsurveyed).
- A more thorough synthesis of available information.
- Collection of additional information from academic, nonprofit, and governmental institutions.
- Incorporation of Delaware Natural Heritage Program data base with other planning data bases.
- A survey of habitat types remaining in the Piedmont Basin, overlaid with rare species data bases.
- Identification of restoration possibilities to increase connectivity between available habitats.

AIR

For the purposes of this preliminary assessment report, air is defined as the part of the lower atmosphere (troposphere) located over the geographic area that constitutes the Piedmont Basin. *Ambient air* refers to the outdoor atmosphere and does not include indoor air. Ambient air constantly changes as it moves into and out of, as well as mixes vertically within, the Piedmont Basin.

The ambient air of the Piedmont Basin is best thought of as one small volume of an “ocean of air”; it is not separate from the air in nearby communities or states. With the lack of strong elevation features such as mountain ranges or deep valleys, the air moves relatively freely through and is generally well mixed across the Piedmont Basin. This means that ambient concentrations of most gaseous pollutants are fairly consistent throughout the area.

Characterization

Ambient Air

On a synoptic or regional scale, air flow is generally from west to east — which means that pollution sources to the west have a major influence on air quality in our region. In numerous instances, however, air moves into the Piedmont Basin from areas to the north or south of Delaware. In the summer, for example, the Piedmont Basin (and most of New Castle County) is often affected by air moving up from the Baltimore -Washington area. Generally speaking, the “airshed” affecting the Piedmont Basin is hundreds of square miles in size, is irregular in shape, and has a significant westerly component.

In considering the local influences on air quality in the Piedmont Basin, it is important to note that both a significant proportion of the state’s population and many sources of air pollution are concentrated in this area. Some of the state’s most heavily traveled traffic corridors (such as Interstate 95) are in this area, as well as a significant number of industrial facilities. Many small sources of pollution — such as dry cleaners and auto body shops — are found in areas with the greatest population density.

General Status

In general, air quality in the Piedmont Basin meets all federal regulatory pollutant standards, except ozone. Although there is no regulatory standard for acid precipitation, monitors outside the Piedmont Basin show an acidic precipitation, with an average annual pH of 4.2. There are also no ambient air standards for visibility or for the various chemicals generally referred to as “air toxics.” In the follow-

Figure 18
1995 DAILY AIR-QUALITY INDEX FOR NEW CASTLE COUNTY

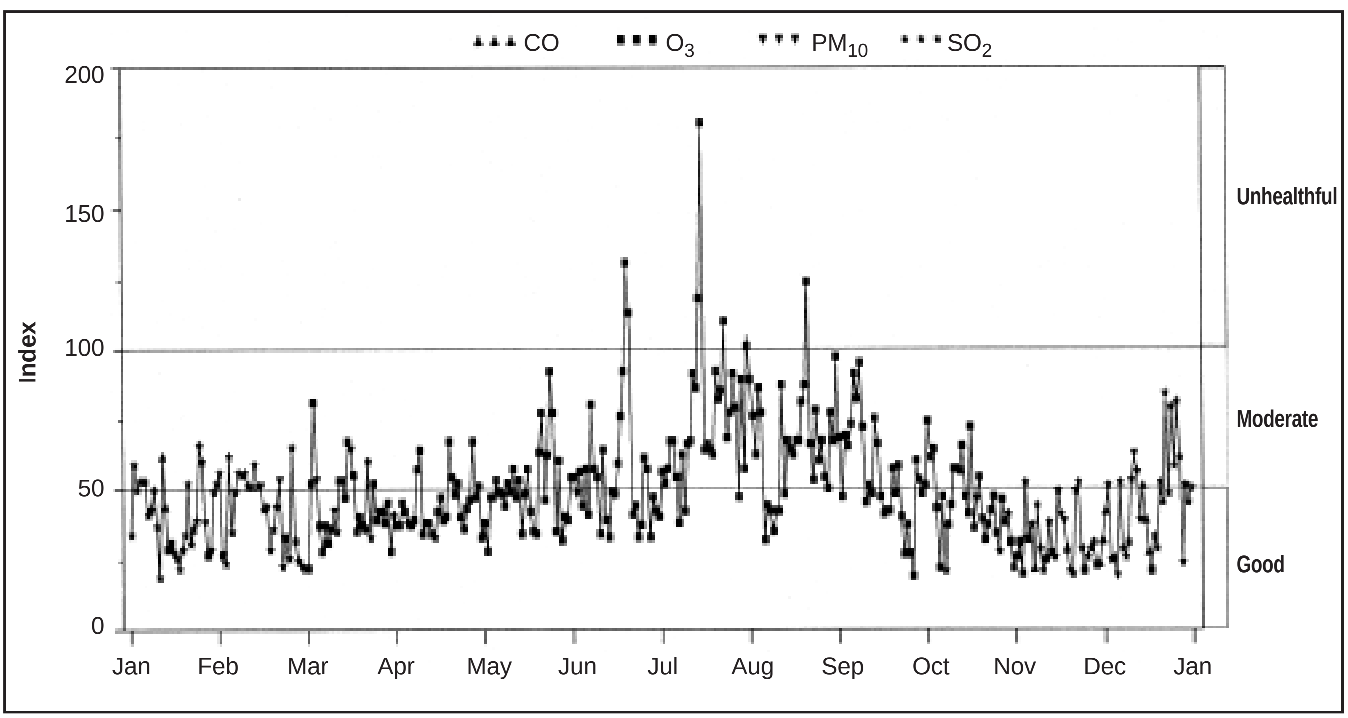


Table 42

PIEDMONT BASIN AIR-MONITORING SITES AND PARAMETERS

SITE	O_3	CO	SO_2	NO_2/NO_x	PM_{10}	ACID RAIN
Brandywine	X					
Bellefonte	X		X	X	X	
Wilmington		X	X		X	
*Lums Pond	X			X		X

Note: Sites active in 1995.
** Located outside the boundaries of the Piedmont Basin.*

Figure 19

PIEDMONT BASIN — 1995 AMBIENT AIR POLLUTANT CONCENTRATIONS

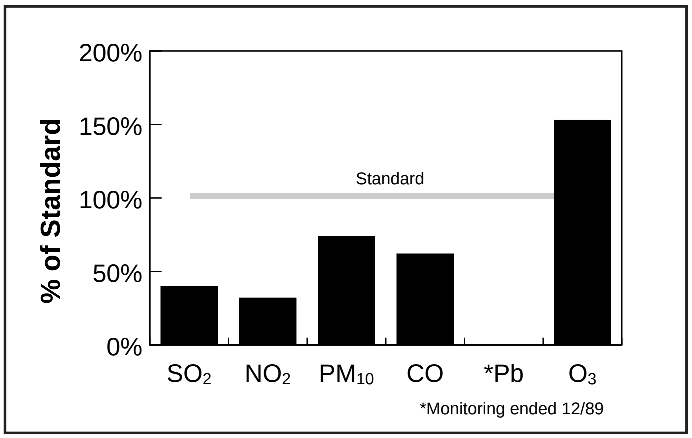


Table 43

OZONE — 1995 MAXIMUM CONCENTRATIONS AND NUMBER OF EXCEEDANCES OF NAAQS

1-HOUR AVERAGES (PPM)

SITE	#EXC.	1ST MAX.	2ND MAX.	3RD MAX.	4TH MAX.
Brandywine	3	0.144	0.130	0.126	0.116
Bellefonte	5	0.145	0.141	0.134	0.132
Lums Pond*	5	0.184	0.139	0.137	0.134

National Ambient Air Quality Standard (NAAQS):
Maximum 1-hour average = 0.12 ppm

**Although the monitoring site at Lums Pond is not located within the boundaries of the Piedmont Basin, the ambient air concentrations monitored here are considered representative of the southern portion of the basin and thus are included.*

ing discussion, "below the standard" means that the pollutant concentration in the air is lower than the National Ambient Air Quality Standard (NAAQS) set by the U.S. Environmental Protection Agency (EPA) to protect human health.

The EPA has established a system for measuring overall air quality. The concentrations of five ambient pollutants — ozone, sulfur dioxide, carbon monoxide, nitrogen dioxide, and particulate matter — are converted into a health-related numeric value called the "Pollutant Standards Index." Data for New Castle County — which are representative of the Piedmont Basin — indicate that during 1995 there were 210 days with good air quality, 149 days with moderate air quality, and 6 days with unhealthful air quality. All days with unhealthful air were determined to be so due to excessive ozone concentrations. Figure 18 shows the worst pollutant on each day during 1995.

Pollutants

Delaware has three air-monitoring stations in the Piedmont Basin. As shown on Map 23, they are located in Bellefonte (River Road Park), Brandywine Creek State Park, and Wilmington (12th and King Streets). The Bellefonte and Wilmington monitoring stations operate year-round, while the station at Brandywine Creek State Park operates only during the ozone season (April through October). Just outside the Piedmont Basin, a monitoring station at Lums Pond State Park records concentrations that are likely representative of the southern part of the Piedmont Basin and therefore are included in this discussion.

Table 42 describes those pollutants that are monitored at sites in or adjacent to the Piedmont Basin. Figure 19 is a graph of the current status of monitored pollutants relative to their associated ambient air-quality standard.

Pollutants with Air-Quality Standards

Ozone

Ozone is a highly reactive gas and is the main component of smog. While ozone in the upper atmosphere (the stratosphere) is beneficial because it absorbs ultraviolet light, in the lower atmosphere it is considered a pollutant. It is a strong respiratory irritant that affects healthy individuals as well as people with impaired respiratory systems. It can cause respiratory inflammation and reduced lung function. It also adversely affects trees, crops (soybeans are a particularly sensitive species), and other vegetation. Ozone is also implicated in white pine damage and reduced growth rates for red spruce at high elevations.

Note, however, that currently there is no quantitative data on damage to crops/vegetation in the Piedmont Basin caused by any form of air pollution. Vegetation or crop damage estimates are seldom measured directly because of the number of confounding factors (drought, insects, etc.)

Table 44

SULFUR DIOXIDE (SO_2) — 1995 ANNUAL AVERAGES AND MAXIMUMS (PPM)

SITE	ANNUAL ARITHMETIC MEAN	24-HOUR AVERAGES		3-HOUR AVERAGES	
		1ST MAX.	2ND MAX.	1ST MAX.	2ND MAX.
Bellefonte	0.008	0.031	0.029	0.065	0.059
Wilmington	0.012	0.044	0.044	0.097	0.091

National Ambient Air Quality Standard (NAAQS): Annual arithmetic mean = 0.03 ppm, 24-hour average = 0.14 ppm, 3-hour average = 0.5 ppm

that also cause damage. The EPA's estimates were generated by computer models that use data from smog chamber studies on individual plant species along with estimates of total crop acreage and average ozone levels.

In the Piedmont Basin, ozone is measured at Brandywine Creek State Park, at Bellefonte, and at Lums Pond, which is just outside the basin. Concentrations at these sites routinely exceed the acceptable standard several times each year, including six days during 1995 (see Table 43). The current standard for ozone (0.12 parts per million, or ppm) is based on a one-hour peak level that has been shown to adversely impact human health. The highest level measured during 1995 was 0.184 ppm at Lums Pond on July 15.

It has been recognized for some time that some of the vegetation damage from ozone is more clearly related to longer-term average levels of ozone than to one-hour peak concentrations. Recent human health studies have also implicated longer-term (eight-hour average) ozone concentrations. The EPA is reviewing the ozone standard and is expected to propose a change to a longer-term averaging interval as an ambient standard.

Sulfur Dioxide

Sulfur dioxide is a pungent, poisonous, yellow gas. It is an irritant that can interfere with normal breathing functions even at low levels. It aggravates respiratory diseases such as asthma, emphysema, and bronchitis. These effects can be magnified by high particulate levels. Sulfur dioxide can also cause plant chlorosis and stunted growth.

In the Piedmont Basin, sulfur dioxide is monitored at Bellefonte and Wilmington. Current ambient levels are well below the standard (see Table 44). Somewhat elevated levels (but still below the standard) occasionally occur at both monitoring sites when they are downwind of Delmarva Power's Edgemoor power plant. Sulfur dioxide levels also follow a seasonal pattern, with the highest levels recorded in the cold-weather months.

Nitrogen Dioxide

Nitrogen dioxide is a reddish-brown, toxic gas. It irritates the lungs and upper respiratory system and lowers resistance to respiratory infections. It is also known to damage vegetation by stunting growth and reducing seed production.

In the Piedmont Basin, nitrogen dioxide and other oxides of nitrogen are monitored at Bellefonte and at Lums Pond. Nitrogen dioxide levels in the Piedmont Basin are well below the acceptable standard (Table 45).

Carbon Monoxide

Carbon monoxide is a colorless, odorless, poisonous gas produced by the incomplete combustion of fossil fuels. It reduces the blood's ability to carry oxygen. Exposure to moderate concentrations can cause fatigue, headache, and impaired judgment and reflexes; at high levels, unconsciousness and death can result. People with heart disease, angina, emphysema, and other lung or cardiovascular diseases are most susceptible.

Carbon monoxide concentrations are highest along heavily traveled highways and decrease quickly with increasing distance from traffic. For this reason, carbon monoxide monitors are usually located close to roadways or in urban areas.

Table 45

NITROGEN DIOXIDE (NO_2) —
1995 ANNUAL AVERAGES (PPM)

SITE	ANNUAL AVERAGE
Bellefonte	0.017
*Lums Pond	0.016

National Ambient Air Quality Standard (NAAQS):
Annual arithmetic mean = 0.053 ppm

**Although the monitoring site at Lums Pond is not located within the boundaries of the Piedmont Basin, the ambient air concentrations monitored here are considered representative of the southern portion of the basin and thus are included.*

Table 46
CARBON MONOXIDE — 1995 MAXIMUM CONCENTRATIONS (PPM)

SITE	1-HOUR AVERAGE 1ST MAX.	1-HOUR AVERAGE 2ND MAX.	8-HOUR AVERAGE 1ST MAX.	8-HOUR AVERAGE 2ND MAX.
Wilmington	11.4	10.0	5.6	4.6

National Ambient Air Quality Standard (NAAQS):
1-hour average = 35 ppm, not to be exceeded more than once per year.
8-hour average = 9 ppm, not to be exceeded more than once per year.

In the Piedmont Basin, carbon monoxide is monitored at the Wilmington site. Carbon monoxide concentrations are below the standard (Table 46). Levels at the Wilmington site, which would be expected to be the highest, show concentrations to be well below the standard.

Particulate Matter

Particulate matter (PM_{10}) is the portion of total suspended particulates that is less than 10 microns in diameter and thus small enough to be inhaled into the lungs. Particulate matter can include solid or liquid droplets that remain suspended in the air for various lengths of time. Particles small enough to be inhaled can carry other pollutants and toxic chemicals into the lungs. Major effects of particulate matter can include aggravation of existing respiratory and cardiovascular disease, alterations in immune responses in the lung, damage to lung tissue, and premature mortality. The most sensitive populations are those with chronic obstructive pulmonary or cardiovascular disease, asthmatics, the elderly, and children. Particulates are also a major cause of reduced visibility and can be involved in corrosion of metals (acidic dry deposition).

In the Piedmont Basin, particulate matter is measured at Bellefonte and at Wilmington. Levels are well below the standard, with the highest concentrations occurring at the urban Wilmington site (Table 47).

Recent studies have linked the smallest particulate matter particles (those with diameters of 2.5 microns or less) to human health effects. The EPA therefore currently is reviewing the air-quality standard and is expected to propose adding a new standard for these smaller particles in 1997.

Lead

Lead is a highly toxic metal that affects several physiological processes, including the renal (kidney), nervous, and blood-forming systems. It accumulates in both bone and soft tissues. Lead was monitored at Wilmington and Claymont from 1979 until sampling ended in 1989 because the majority of samples had concentrations below the analytical detection limit.

Pollutants without Air-Quality Standards

Air Toxics

This term is often used to refer to many chemicals that are toxic, or suspected of being toxic, in some way to humans. The complex chemical composition and the multitude of these compounds make comprehensive monitoring difficult. In the Piedmont Basin, Delaware has conducted limited monitoring for specific compounds in urban Wilmington and in some areas around large point sources. There are currently no accepted ambient air standards for these chemicals. Ambient monitoring in the Piedmont area has shown average concentrations of all chemicals monitored to be less than 1 part per billion (ppb) (see Table 48).

Heavy Metals

Heavy metals that harm human health — such as chromium, nickel, and cadmium — are not currently monitored in Delaware. From 1983 to 1987, ambient levels of 14 metals in total suspended particulates were monitored at two urban sites in Wilmington. Concentrations were similar to those reported for other urban areas (Table 49). There are no current ambient air standards for metals, except lead.

Table 47
PARTICULATE MATTER (PM_{10}) — 1995 MAXIMUM 24-HOUR AVERAGES AND ANNUAL AVERAGES ($\mu G/M^3$)

SITE	ANNUAL AVG.	1ST MAX. 24-HR AVG.	2ND MAX. 24-HR AVG.	3RD MAX. 24-HR AVG.	4TH MAX. 24-HR AVG.
Bellefonte	29.2	70	68	54	51
Wilmington	37.0	77	73	73	67

National Ambient Air Quality Standard (NAAQS): Annual arithmetic mean = 50 $\mu g/m^3$, 24-hour average = 150 $\mu g/m^3$

Pollutant Deposition: Wet and Dry Deposition

Chemicals are removed from the atmosphere and deposited on surfaces through a variety of mechanisms. Deposition can occur through both wet (rain, snowfall, fog) and dry processes. Both gases and particles can interact with water droplets as well as other chemical compounds to form contaminants that deposit on the Piedmont Basin. Again, atmospheric transport from varying distances plays an important role. Although the importance of atmospheric deposition in ecosystem health is becoming increasingly recognized, there is still a significant lack of knowledge concerning the physical and chemical processes.

Table 48

AIR TOXICS — 1995 SORBENT TUBE MONITORING ANNUAL AVERAGES (PPB)

COMPOUND	WILMINGTON-LIMITED NUMBER OF SAMPLES	*LUMS POND
Benzene	0.3	0.3
Toluene	0.7	0.4
m,p-Xylenes	0.3	0.2
o-Xylene	0.2	0.1
Ethyl benzene	0.1	0.1
1,1,1-Trichloroethane	0.1	0.1

** Located outside the boundaries of the Piedmont Basin.*

Table 49

HEAVY METALS — 1983 TO 1987
AVERAGE CONCENTRATIONS OF TOTAL SUSPENDED PARTICULATES MEASURED (µG/M^3)

METAL	ANNUAL CONC. µG/M^3
Arsenic	0.0020
Beryllium	0.0024
Barium	0.0000
Cadmium	0.0008
Chromium	0.0125
Cobalt	0.0009
Copper	0.1042
Iron	0.5460
Lead	0.0920
Manganese	0.0236
Molybdenum	0.0017
Nickel	0.0118
Vanadium	0.0158
Zinc	0.0547

Note: All monitoring occurred in Wilmington.

Acid Rain

Acid rain (more appropriately called *acid precipitation*) is rain, snow, or fog that contains sulfuric and/or nitric acids. The acids result from the reaction of water in the atmosphere with sulfur and nitrogen oxides released from various combustion processes. These chemical compounds can travel for many miles in the air before falling in acid rain.

Delaware collects weekly composite precipitation (wet only) samples at the Lums Pond site. Currently, the only measurements are for pH and conductivity. From 1983 to 1994, additional analyses were performed that identified various ion concentrations; these data have not yet been analyzed in detail. The annual average pH of the precipitation is 4.2 and is considered acidic ("clean" rain has a pH of around 5.6). This acidity is likely representative of precipitation throughout the Piedmont Basin.

Dry Deposition

Dry deposition consists of any type of particle that is deposited on a surface. This can include organic as well as inorganic compounds and trace metals. No monitoring of dry deposition has taken place in the Piedmont Basin.

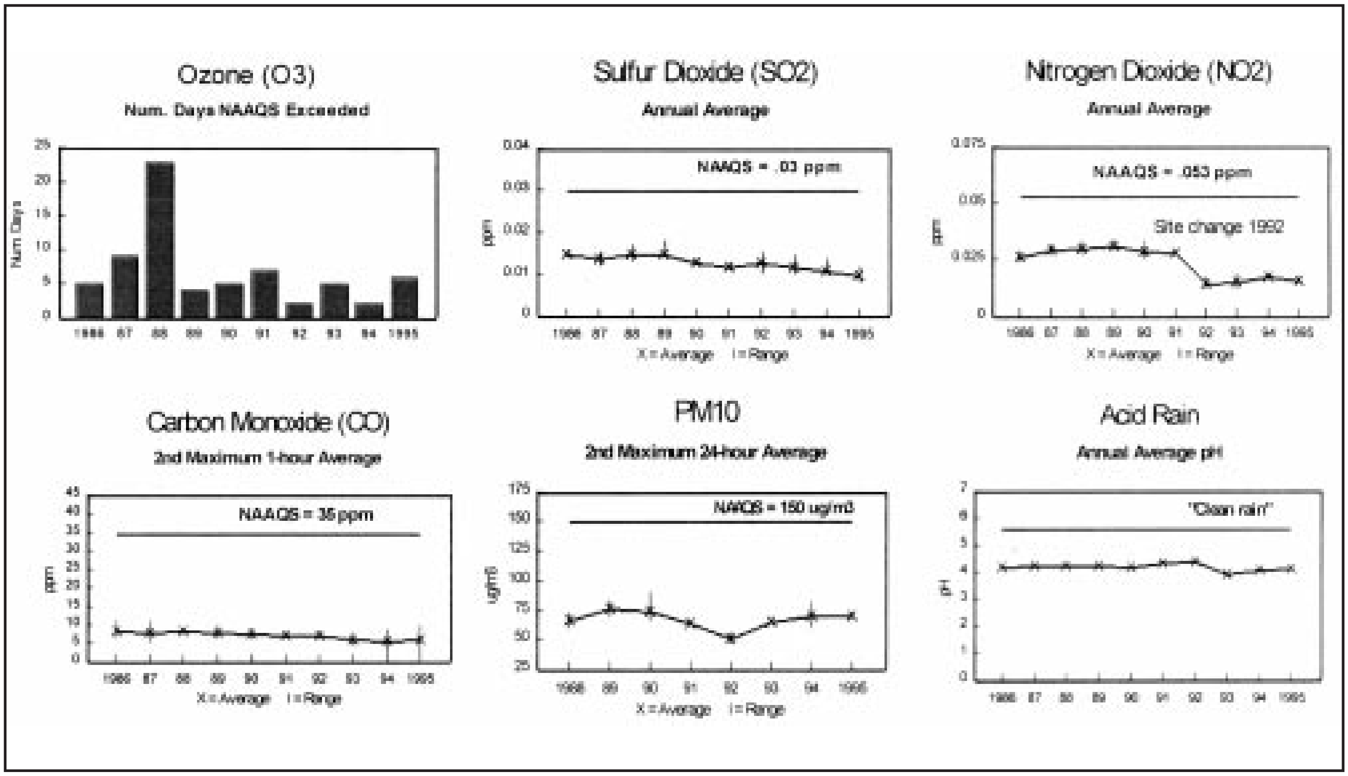
Sulfur Compounds

Sulfur dioxide can bind to dust particles and aerosols in the atmosphere, traveling long distances on the prevailing winds. It can also be oxidized to sulfur trioxide and combine with water vapor to form sulfuric acid and fall as acid rain. Sulfur compounds contribute to visibility degradation. The only current monitoring of sulfur compounds in the Piedmont Basin is for sulfur dioxide, as previously described.

Nitrogen Compounds

Reactions between nitrogen oxides and other compounds in the atmosphere can form nitric acid, which contributes to the acid rain problem. Other reactions can produce nitrate compounds that affect visibility. Atmospheric deposition of oxides of nitrogen can be a significant source of nitrogen to estuarine systems. The only current monitoring of nitrogen compounds in the Piedmont Basin is for nitrogen dioxide (along with nitrogen oxide and oxides of nitrogen), as previously described.

Figure 20
AMBIENT AIR POLLUTANT TRENDS IN THE PIEDMONT BASIN



Trends

Pollutants Measured in Ambient Air

See Figure 20 for trends graphs for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and particulate matter.

Ozone

Ozone trends are difficult to measure because of the influence of meteorology. In general, ozone concentrations during the 1990s are significantly lower and there are fewer exceedances of the standard than in meteorologically similar years during the 1980s. Improvements are attributed to pollution-reduction measures such as improved pollution controls on large industrial sources, vapor recovery on gasoline pumps, and lower volatility of gasoline and various solvents.

Sulfur Dioxide

Sulfur dioxide levels declined rapidly in the 1970s and appear to have remained relatively constant over the past 10 years. This improvement is largely due to the change to low or lower sulfur fuels in power plants as well as to improved control technologies.

Nitrogen Dioxide

Nitrogen dioxide levels have changed little since monitoring began and suggest no apparent upward or downward trend; this is also true of other oxides of nitrogen.

Carbon Monoxide

Its levels have decreased significantly since monitoring began in the 1970s, and recent data indicate that concentrations are remaining at low levels. Improvements are largely attributable to cleaner engines in cars and tighter automobile emissions standards.

Particulate Matter

Particulate matter (PM_{10}) concentrations have only been monitored since 1988, so there is limited data for estimating trends. However, it appears that particulate matter levels are relatively constant, currently suggesting no significant trend.

Deposition/Acid Rain

Measurements collected at Lums Pond since 1984 indicate no significant trend in precipitation pH, and precipitation continues to average around pH 4.2 annually. As stated previously, no detailed analysis of ion concentrations has been performed.

Air Toxics

The Wilmington monitoring site is being used to establish trends for some toxic compounds; however, the monitoring methodology is still in development, and reliable data only exist since 1994. This is insufficient to establish trends at this time.

Heavy Metals

Monitoring was only done in the urban Wilmington area; samples were collected twice a month for four years. No trends were apparent.

Lead

Concentrations of lead in ambient air decreased 94% between 1978 and 1988. This dramatic improvement is attributed to the change from leaded to unleaded gasoline for automobiles. In 1989, the majority of samples collected were below the analytical detection limit, at which time the state ended its ambient air monitoring for lead.

Emissions

Pollutant emissions come from a wide variety of sources and are difficult to measure accurately. Sources are usually divided into several categories: *point* (large facilities with large amounts of emissions); *area* (small facilities such as dry cleaners and auto repair shops that are considered as a group); *mobile* (such as automobiles, trucks, farm equipment, airplanes); and *natural sources* (wind-blown dust, ash from forest fires) including those termed “biogenic,” such as vegetation (e.g., pine trees are a significant source of isoprene, a flammable liquid hydrocarbon).

Methods of quantifying emissions from all categories of sources in order to track trends and evaluate efforts to improve air quality have improved significantly in recent years. While this means that emissions inventories developed since 1990 are more accurate, it also means they are not easily comparable to earlier inventories, and therefore there is very little data available to estimate trends.

Ozone Emissions

Emissions inventories of ozone precursors for the Piedmont Basin are complete for 1990 but only in draft form for 1993, so no trends are clear at this time. Pollutants included in these comprehensive inventories are volatile organic compounds, nitrogen oxides, and carbon monoxide. In addition, there are point source inventories that have been compiled for particulate matter (particulate matter$_{10}$ and/or total suspended particulates), sulfur oxides, and lead. (Please see the Appendix — Emission Estimation Methods for specific information on how the ozone precursor inventories are generated.)

Air Toxics Emissions

Specific information on emissions of air toxics is limited. The Toxics Release Inventory is one data base that can be used to examine emissions. More than 650 toxic chemicals are subject to release reporting by the manufacturing industry on an annual basis under this program. This information is presented in Tables 50 and 51. Air releases from reporting facilities covered by the inventory within the Piedmont Basin have declined by 55% since 1989 (see Figure 21).

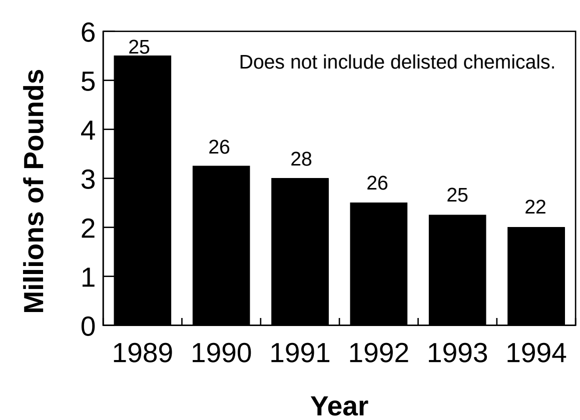
Sources of Impact

The determination of source-receptor relationships in air pollution is complex, and distinguishing between local and remote sources of pollution is extremely difficult. Observational data alone are usually insufficient to determine source-receptor relationships. Computer modeling is required, yet existing models have many limitations, and there are large degrees of uncertainty associated with the results. While it is possible to inventory the large air pollution emission sources located within the Piedmont Basin, the sources actually impacting the basin are not so easily determined. The following discussion is therefore limited in some areas to general statements and conclusions.

Maps 23 and 24 show the location of two types of emission sources — large point sources (facilities with large amounts of emissions of at least one of the following pollutants:

Figure 21

TOTAL TOXICS RELEASE INVENTORY AIR RELEASES IN PIEDMONT BASIN — 1989 TO 1994



The figure above each bar indicates the number of facilities within the basin reporting air releases.

Table 50

1994 TOXICS RELEASE INVENTORY EMISSIONS IN PIEDMONT BASIN

MAP NO.	FACILITY/ CHEMICAL	CAS NO.	AIR RELEASES
1	Allied Signal		
	Ammonia	7664-41-7	8,720
	1,3-Dichloropropylene	542-75-6	40
	Hydrochloric Acid	7647-01-0	10
	Toluene	108-88-3	1,020
	Facility Total		**9,790**
7	Alloy Surfaces		
	Nickel	7440-02-0	50
	1,1,1-Trichloroethane	71-55-6	300
	Facility Total		**350**
9	Ametek Haveg Division		
	Formaldehyde	50-00-0	11
	Hydrochloric Acid	7647-01-0	152
	Phenol	108-95-2	93
	Facility Total		**256**
18	Cabot Safety Corp.		
	Dichloromethane	75-09-2	42,975
	Methylenebis (Phenylisocyanate)	101-68-8	10
	Toluenediisocyanate (Mixed Isomers)	26471-62-5	10
	Facility Total		**42,995**
17	Chrysler		
	Benzene	71-43-2	562
	N-Butyl Alcohol	71-36-3	17,300
	Copper	7440-50-8	18
	Ethylbenzene	100-41-4	38,900
	Ethylene Glycol	107-21-1	43
	Glycol Ethers	N230	51,200
	Hydrochloric Acid	7647-01-0	93
	Methanol	67-56-1	18,700
	Methyl Ethyl Ketone	78-93-3	18,800
	Methyl Isobutyl Ketone	108-10-1	147,000
	Phosphoric Acid	7664-38-2	430
	Toluene	108-88-3	32,000
	1,2,4-Trimethylbenzene	95-63-6	21,100
	Xylene (Mixed Isomers)	1330-20-7	306,000
	Facility Total		**652,146**
14	CIBA-Geigy		
	Aniline	62-53-3	604
	Biphenyl	92-52-4	4,063
	Methanol	67-56-1	116,503
	Xylene (Mixed Isomers)	1330-20-7	525
	Facility Total		**121,695**
	CITISTEEL U.S.A.		
	Chromium Compounds	N090	274
	Copper Compounds	N100	447
	Lead Compounds	N420	3,230
	Manganese Compounds	N450	2,409
	Nickel Compounds	N495	85
	Zinc Compounds	N982	29,622
	Facility Total		**36,067**
6	DuPont Edge Moor		
	Carbonyl Sulfide	463-58-1	198,500
	Chlorine	7782-50-5	10,407
	Chlorodifluoromethane (HCFC-22)	75-45-6	520
	Hydrochloric Acid	7647-01-0	10,934
	Titanium Tetrachloride	7550-45-0	489
	Toluene	108-88-3	994
	Facility Total		**221,844**
22	DuPont Exp. Station		
	Acetonitrile	75-05-8	75
	Methanol	67-56-1	2,986
	Pyridine	110-86-1	3
	Xylene (Mixed Isomers)	1330-20-7	7
	Facility Total		**3,071**
15	DuPont Holly Run		
	Chromium Compounds	N090	823
	Sulfuric Acid (Aerosol)	7664-93-9	2
	Facility Total		**825**
16	FMC Newark		
	Hydrochloric Acid	7647-01-0	341
	Facility Total		**341**
2	General Chemical		
	Ammonia	7664-41-7	7,303
	Hydrogen Fluoride	7664-39-3	2,430
	Lead Compounds	N420	50
	Sulfuric Acid (Aerosol)	7664-93-9	19,020
	Facility Total		**28,803**
10	General Motors		
	Benzene	71-43-2	59
	N-Butyl Alcohol	71-36-3	92,778
	Ethylbenzene	100-41-1	69,414
	Ethylene Glycol	107-21-1	4,370
	Methanol	67-56-1	61,537
	Methyl Ethyl Ketone	78-93-3	66,344
	Methyl Isobutyl Ketone	108-10-1	195,908
	Toluene	108-88-3	42,853
	Xylene (Mixed Isomers)	1330-20-7	752,307
	Facility Total		**1,285,570**

Air releases are given in pounds.
Source: *DNREC Toxics Release Inventory Data Base, July 1996.*
CAS = Chemical Abstracts Service

Table 51

TOXICS RELEASE INVENTORY EMISSIONS — CONT'D.

MAP NO.	FACILITY/ CHEMICAL	CAS NO.	AIR RELEASES
21	Hercules Research		
	Toluene	108-88-3	1,584
	Facility Total		**1,584**
11	Insteel Wire Products		
	Hydrochloric Acid	7647-01-0	2,500
	Facility Total		**2,500**
13	Medal		
	Freon 113	76-13-1	8,400
	Methanol	67-56-1	14,000
	Facility Total		**22,400**
8	Noramco		
	1,3-Dichlorobenzene	541-73-1	423
	Dichloromethane	75-09-2	17,200
	Hydrochloric Acid	7647-01-0	343
	Methanol	67-56-1	6,000
	Methyl Isobutyl Ketone	108-10-1	2,980
	Toluene	108-88-3	2,320
	Facility Total		**29,266**
5	NVF Yorklyn		
	Hydrochloric Acid	7647-01-0	250
	Facility Total		**250**
19	Perma-Flex Rollers		
	Dichloromethane	75-09-02	37,800
	Facility Total		**37,800**
12	Rockland Technologies		
	Methanol	67-56-1	6,100
	Facility Total		**6,100**
20	Rodel		
	Methyl Ethyl Ketone	78-93-3	14,877
	Facility Total		**14,877**
3	Sun Refining & Mrkting.		
	Ethylene	74-85-1	111,000
	Ethylene Oxide	75-21-8	9,280
	Facility Total		**120,280**
	PIEDMONT BASIN TOTAL		**2,638,810**

Air releases are given in pounds.

Source: *DNREC Toxics Release Inventory Data Base, July 1996.*

CAS = Chemical Abstracts Service

carbon monoxide, sulfur oxides, nitrogen oxides, volatile organic compounds, particulate matter, or lead); and toxics release inventory sources. These maps were generated using data from the 1993 Point Source Emissions Inventory and the 1994 Toxics Release Inventory data base. The Point Source Emissions Inventory is limited to sources with significant emissions of pollutants involved in the formation of ozone.

Other kinds of pollution sources are mobile sources and small sources ("area sources"). Motor vehicles are significant sources of many pollutants; there is a high concentration of heavy traffic corridors in the Piedmont Basin, including the City of Wilmington. Map 25 shows the traffic network in the Piedmont Basin. The densities of housing and area sources in the Piedmont Basin are also significant factors in total emissions; Map 26 shows the population density in the Piedmont Basin.

Pollutant Sources Affecting the Piedmont Basin

Ozone

Ozone is not emitted directly by sources; it is formed in the atmosphere from precursors (mainly nitrogen oxides and volatile organic compounds) that react in the presence of sunlight and warm temperatures. Significant sources of nitrogen oxides include motor vehicles and power plants. Sources of volatile organic compounds include motor vehicles and a variety of commercial and industrial sources as well as natural biogenic emissions. Figure 22 shows the relative contribution of the various source categories in New Castle County. Since ozone formation is directly linked to warm temperatures and sunlight, elevated levels occur almost exclusively in the summer months.

In northern Delaware, including the Piedmont Basin, both local and distant upwind sources of nitrogen oxides and volatile organic compounds contribute to ozone formation. Since there is some time required to form ozone and there is usually some level of air flow across the Piedmont Basin, many local sources such as the Interstate 95 corridor and the City of Wilmington may contribute more to ozone in downwind areas than in the basin itself. The Baltimore-Washington area contributes significantly to Piedmont Basin ozone levels under many meteorological conditions. In other cases, Philadelphia or the Richmond area may be contributing. Recent studies indicate that even more remote sources in the Midwest or Southeast may be significant as well. On days with stagnant wind conditions, high temperatures, and little cloud cover, local sources become more important.

Due to the complex nature of ozone formation, computer modeling of different specific high-ozone episodes is necessary to evaluate the relative contribution of (and thus control strategies for) the various sources of volatile organic compounds and nitrogen oxides in a given area. This work is presently under way for the areas in Delaware that are not in attainment of the ozone standard.

Sulfur Dioxide

Its main source is fossil fuel combustion, mostly by power plants and industrial boilers. In the Piedmont Basin, both local sources and those in neighboring states contribute to ambient concentrations.

Nitrogen Dioxide

The majority of nitrogen dioxide comes from a combination of mobile sources and point sources that burn fossil fuels. Both types of sources are present in the Piedmont Basin. Both local and remote sources contribute to the basin's ambient concentrations.

Carbon Monoxide

The major source of carbon monoxide in the Piedmont Basin is motor vehicles. As stated earlier, this means that the highest concentrations of carbon monoxide are in urban areas and along highways. Because carbon monoxide dissipates so quickly with distance from emission sources, ambient concentrations in the Piedmont Basin are mainly from nearby (within a few hundred yards) sources. Relative contributions of different source types are shown in Figure 22.

Particulate Matter

Both local and regional sources of particulate matter impact the Piedmont Basin. Sources include power plants, automobiles, various industrial facilities, unpaved roads, and agricultural activities. The smaller components of particulate matter such as particles smaller than 3 microns in diameter can travel very long distances and are considered to be a regional problem. The sources of these small particles are mainly anthropogenic activities, particularly fuel combustion.

Lead

In the past, lead concentrations in ambient air were due mainly to the use of leaded gasoline in automobiles. Currently, ambient concentrations are of concern only in areas affected by point sources, such as smelters and battery production facilities. The emissions inventories for the Piedmont Basin currently include no such sources.

Acid Rain

The relationship between the emission of sulfur oxide and nitrogen oxide gases and the formation of acid rain is complex. Emissions of acid-neutralizing compounds also play a role and can make contributions from various sources even harder to determine. In general, the sources of the sulfur and nitrogen compounds that contribute to acid rain are similar to those described above for sulfur

Figure 22

1993 PRELIMINARY PERIODIC OZONE INVENTORY EMISSIONS IN NEW CASTLE COUNTY

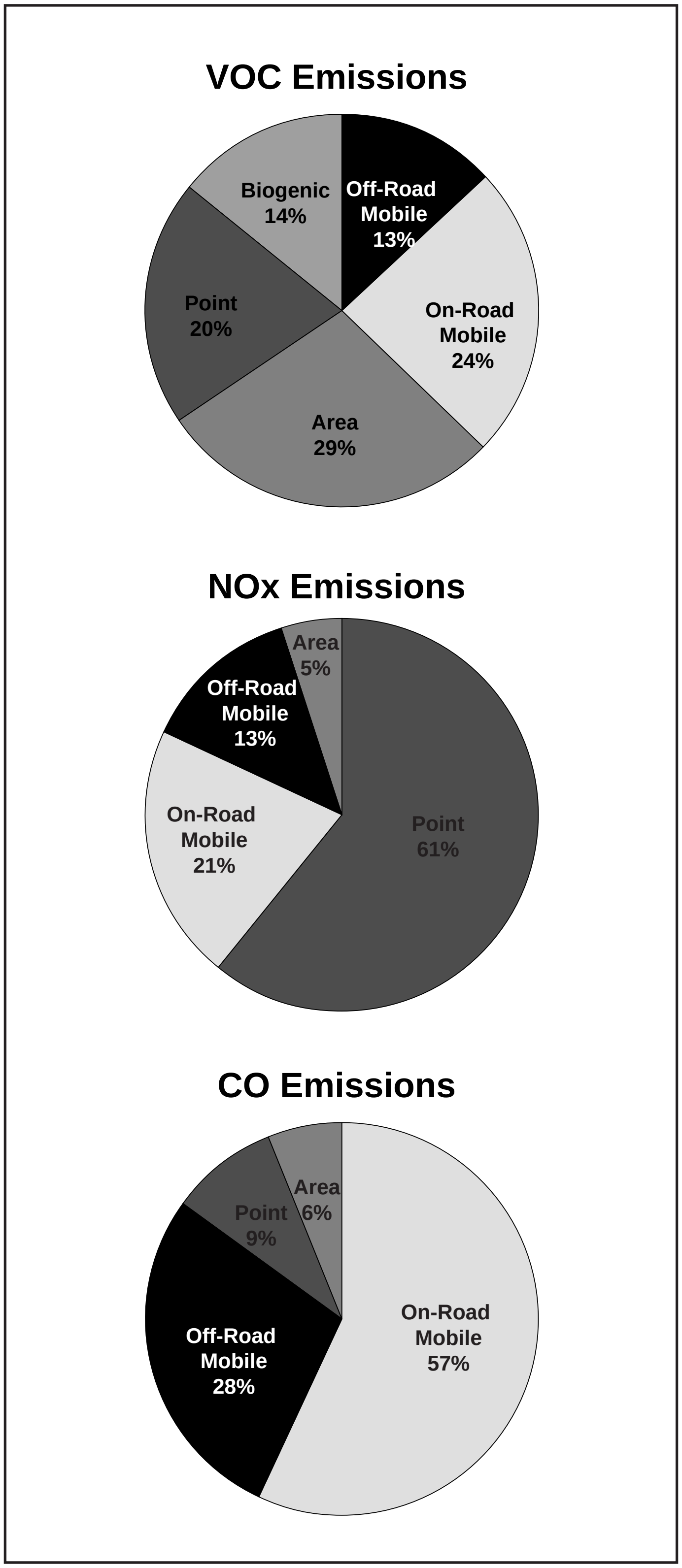


Table 52

LARGE POINT SOURCES INCLUDED IN OZONE PRECURSOR

		TONS PER YEAR				
MAP ID.	**FACILITY NAME**	**VOC**	**NO_X**	**CO**	**SO_X**	**PM_{10}**
1	Allied Signal, Inc.	19.44	0.00	0.00	0.00	0.00
34	Atlantic Aviation	19.17	5.64	0.51	16.25	0.80
17	Blacktop Products - Commerce Street	0.00	0.00	0.00	0.00	0.00
36	Chrysler Motors	1167.65	91.77	15.04	83.62	7.27
28	Ciba - Geigy Corporation	460.66	46.74	10.00	19.11	7.03
5	Citisteel USA	64.25	76.04	2950.92	116.76	53.94
24	Clean Earth of New Castle	12.04	14.09	10.21	0.05	0.00
29	Crowell Corporation	12.25	5.60	15.22	3.75	7.08
19	DE Solid Waste Authority - Cherry Island	79.40	0.00	0.00	0.00	0.00
32	Delaware Air National Guard	9.96	0.88	0.20	1.03	0.03
15	Delmarva Power - Edgemoor	65.82	8095.36	474.93	17523.07	543.46
13	Delmarva Power - Hay Road	10.90	398.70	58.80	3.75	0.00
21	Diamond Materials, Inc.	2.40	2.60	1.26	1.90	0.04
11	DuPont - Chestnut Run	7.72	56.57	5.14	137.52	9.36
9	DuPont - Edgemoor	142.79	33.52	3913.96	129.29	107.26
6	DuPont Experimental Station	21.58	190.46	17.81	443.88	36.72
38	DuPont Stine - Haskell Laboratory	12.76	53.66	7.22	127.14	9.26
39	E-A-R Specialty Composites Corporation	10.39	0.00	0.00	0.00	0.15
25	Edgemoor Materials, Inc.	4.90	2.90	5.40	0.30	3.19
37	Free - Flow Packaging Corporation	109.11	0.55	0.11	0.00	0.01
2	General Chemical Corporation	0.56	64.18	8.08	709.42	39.89
20	General Motors	894.12	117.34	15.58	245.02	17.41
22	Georgia - Pacific	16.94	48.86	0.23	1.51	46.87
8	Hercules Incorporated Research	2.32	40.88	3.74	117.61	8.00
26	Medal L. P. - Willow Bank	22.18	2.03	0.51	0.00	0.04
10	Medical Center of Delaware	3.39	37.20	3.39	94.36	4.64
30	New Castle Hot Mix, Inc.	2.30	2.09	2.61	0.00	0.64
41	New London Textile, Inc.	12.40	0.05	0.01	0.00	0.00
16	NORAMCO of Delaware, Inc.	19.14	3.15	18.14	0.01	0.07
4	NVF Company Yorklyn	0.52	102.63	9.33	272.27	18.54
18	Rockland Technologies, Inc.	6.77	0.00	0.00	0.00	0.00
40	Rodel Inc.	15.28	1.33	0.00	0.00	0.00
3	Sun Refining & Marketing	180.44	1141.90	95.11	210.98	16.13
23	Tilcon - Terminal Avenue	6.38	3.75	7.00	0.00	0.83
35	University of Delaware	6.69	77.24	10.19	212.74	9.83
33	Westvaco Corporation	29.54	0.80	0.16	0.00	0.02
12	Wiley Cork Company	10.13	0.14	0.04	0.00	0.00
27	Wilmington Chemical Company	0.00	0.00	0.00	0.00	0.00
7	Wilmington Finishing Co.	20.92	13.58	3.25	2.67	0.45
14	Wilmington Waste Water Treatment Facility	272.55	10.33	0.12	1.47	0.02
31	Zeneca Specialties	1.20	0.00	0.00	0.00	0.00
	TOTALS	**3756.96**	**10742.6**	**7664.22**	**20475.5**	**948.98**

dioxide and nitrogen dioxide. Because many of the sulfur and nitrogen compounds can travel long distances, remote sources such as coal-burning power plants in the Ohio River valley impact the Piedmont area. Some computer modeling work, combined with extensive monitoring in the state of Maryland, indicates that 70% or more of the sources contributing to the acid precipitation in Maryland are located outside the state (Maryland Critical Loads Study, 1995); this is probably representative of the situation in the Piedmont Basin as well.

Air Toxics

The emissions data base most directly involved with air toxics is the Toxics Release Inventory. As recorded by this data base, sources of air toxics include many types of large and small industrial facilities. In 1994, the most recent year available, the number of reporting facilities located within the Piedmont Basin was 28, which represents 39% of all the inventoried facilities in Delaware. Twenty-two of the 28 facilities indicated having air releases of one or more Toxics Release Inventory chemicals and are shown on Map 24.

There are several caveats that must be considered in evaluating Toxics Release Inventory data. Most data are derived from engineering estimates as opposed to actual measurements. In addition, only certain types of facilities and only certain chemicals are covered. Sources of air toxics that are not covered include on- and off-road mobile sources and non-manufacturing facilities. Finally, exposure estimates cannot be made from the annual amounts re-ported and it is therefore difficult to assess the effects of the releases on humans or the environment. Please see the *Annual Toxics Release Inventory Report*, available from the Air Quality Management Section, for more information.

Positive Initiatives

Many of the programs initiated to control pollutants in ambient air have the added benefit of reducing deposition to land and water surfaces as well. Since the sources impacting the Piedmont Basin are not limited to Delaware, this discussion covers regional and national as well as state initiatives. The following is a brief listing of actions currently under way that will affect the air quality in the Piedmont Basin.

The Clean Air Act Amendments of 1990 represent a comprehensive nationwide attempt to address ambient air pollution, and many sections impact the Piedmont Basin's ambient air. Included are requirements to:

- Reduce nitrogen oxide emissions to improve ozone. The Ozone Transport Commission agreement calls for nitrogen oxide emission reductions from large boilers (> 250 mm btu/hour rating) from 1990 levels of 65% by 1999 and 75% by 2003; Delaware will therefore reduce nitrogen oxide emissions by 24 tons per day by 1999. This will also result in significant improvements in nitrogen deposition as well.
- Reduce sulfur dioxide emissions nationally to reduce acid deposition; the goal is a reduction of 10 million tons per year from 1980 levels. This represents a reduction of approximately 40%. There is also a national cap on major point-source emissions.
- Expand Maximum Available Control Technology standards to sources of toxic emissions not previously covered. Standards nearing completion will result in reduced emissions of benzene from wastewater treatment plants by 95%, emissions of chrome from cooling towers by nearly 100%, and significantly reduced emissions of tetrachloroethylene (perchloroethylene) from dry cleaning and chrome electroplating.
- Reduce volatile organic compounds emissions to attain the ozone standard. The Clean Air Act Amendments require Delaware to reduce peak ozone-season daily emissions in New Castle and Kent counties by 15% from 1990 to 1996 with further reductions of at least an additional 3% per year to reach attainment of the ozone standard by 2005. (Please see Appendix for more detailed information.)
- Reduce Toxics Release Inventory emissions from current (1994 inventory) levels by a further 30% by 2000.
- Implement Title V of the Clean Air Act Amendments by establishing a new operating permit program for all major stationary sources of air pollutant emissions. This program will ensure that both industry and the public are knowledgeable as to the rules and regulations that all major stationary sources are required to meet.

Many of these actions will have added benefits as control technologies implemented for one type of pollutant can also reduce emissions of other types of pollutants. For example, since many volatile organic compounds are also considered air toxics, overall reductions aimed at improving ozone will result in lower ambient concentrations of air toxics as well.

CONTAMINANT SOURCES

A contaminant source is a site that has released or has the potential to release toxics to the air, soil, groundwater, surface water, or sediment. Contaminant sources may include, but are not limited to, small businesses (such as dry cleaners and gas stations), large businesses (such as factories and refineries), landfills, farms, abandoned industrial sites, military facilities, mines, and septic systems.

Underground Storage Tanks, Landfills, Hazardous Wastes

Known and Potential Contaminants: General Classes

Known and potential contaminant sources are regulated and/or monitored by eight different groups within DNREC. The sections that follow describe the mission, regulated community, positive initiatives, information collected, and contact information for each group. The sources section that immediately follows includes a table listing the known and potential contaminant sources regulated by the group under discussion. Although the format of each table varies, each table includes the facility or site name, the map identification number, the general classes of known and/or potential contaminants present at the facility, and the media affected. The general classes of contaminants used for each table may include the following:

- *Solvents:* Include organic chemicals such as degreasers, paint thinners, alcohols, and certain chemical feedstocks. Many of these chemicals are carcinogenic or poisonous to humans and/or other organisms.
- *Metals:* Include lead, zinc, arsenic, and iron. Some metals are carcinogenic or poisonous to humans and/or other organisms. In high quantities, metals such as iron and manganese can make water unsuitable for drinking due to taste and staining, even though they might not cause specific health problems.
- *Petroleum:* Includes gasoline, fuel oil, jet fuel, kerosene, diesel fuel, and waste oil. Certain compounds contained within each product, such as benzene, are carcinogenic or poisonous to humans and/or other organisms. Petroleum vapors pose a serious explosive threat to buildings and utilities.
- *Pesticides/Herbicides:* Include compounds that are carcinogenic and/or poisonous to humans or other organisms. Many also have the potential to be biologically concentrated in the higher part of the food chain.
- *Polychlorinated Biphenols (PCBs):* This class of organic compounds formerly was used in electrical transformers and switches. These compounds are generally insoluble and break down slowly, if at all, under normal environmental conditions. They tend to accumulate in stream sediments where they can be directly or indirectly ingested by fish. Many polychlorinated biphenols are carcinogens.
- *Other:* Includes sulfate, chloride, nitrate, and ammonia. In high quantities, any of these contaminants can make water unsuitable for drinking for either health or aesthetic reasons. They can also have significant effects on freshwater and marine life. Some or all of these contaminants typically occur in landfill leachate.

Each source listed on the tables is also plotted on Map 4 and designated by its map identification number.

Any substance can be considered a contaminant in the proper context. Other contaminants discussed in this section include bacteria, nutrients (such as phosphorus and nitrogen), and sediment. These contaminants are typically related to land-use activities such as construction, agriculture, or forestry. Note that air contaminants are not discussed in this section. They are discussed in detail in the Air section.

Contaminant Sources

Underground Storage Tanks/Systems. An underground storage tank can be defined as any tank or a combination of tanks with associated piping used to contain regulated substances, the volume of which is 10% or more beneath the ground surface. An underground storage tank system includes all tanks, piping, and ancillary equipment (i.e., dispensers) and their containment system, if any.

Underground storage tanks and systems typically contain petroleum compounds including gasoline, diesel, kerosene, jet fuel, waste oil, and fuel oils. Tanks may also contain a wide range of hazardous substances.

Statewide, there are 3,013 registered underground storage tank facilities with a total of 9,662 registered tanks. Of this number, there are 1,265 active facilities, with 3,375 tanks in use. Of the tanks in use, 1,752 are located at 707 facilities in New Castle County, many of which located in the Piedmont Basin. Map 4 shows only the location of tank sites with a known release to groundwater. The map does not show the location of all tank facilities in use or tank facilities that have had a minimal release or have completed a cleanup. Any facility with underground storage tanks has release potential. The largest concentration of leaking underground storage tank sites is in the Christina watershed.

Tables 53 – 55 detail the sites regulated by the Underground Storage Tank Branch that have released petroleum compounds to groundwater in the Piedmont Basin. These tank facilities are also represented on Map 4. The sites are further broken down on the basis of impact severity with a numerical designation from 3 to 5, with 3 designating an on-site dissolved-phase impact, 4 an on-site free-phase impact, and 5 an off-site impact. It is important to note that the table represents the condition of the sites at the time the table was compiled. The site status will change as remediation takes place.

From the compliance side's perspective, release prevention from operating tank facilities is the major emphasis. By December 1998, all bare-steel tank systems, a current total of 912 tanks, must be either closed, upgraded, or replaced.

Currently, 73% of the federally regulated tank population is in compliance with state leak-detection requirements. Ad-ditionally, the mandated financial responsibility regulations require that operating tank facilities carry insurance to clean up releases if they occur. In this time of rapid property transfers, the banking and real estate industries are driving the tank program. In response to this trend, the branch is educating these communities to assure regulatory compliance.

Landfills. Large quantities of solid waste are generated each year in the Piedmont Basin by households and offices; construction, demolition, and land-clearing activities; and by industry. Most of this waste has been or will be disposed of in excavations or diked areas called landfills. Because landfills concentrate large quantities of waste in a small area, they represent a significant threat to the surrounding environment if not properly managed. As rainwater percolates into a landfill, it leaches soluble material and decayed organic products from the waste. The resulting leachate typically contains large quantities of dissolved metals, salts, and organics. It may also contain hazardous chemicals if they were disposed of in the landfill. If the leachate seeps into groundwater it can make the water unsuitable for human use because of health risks and objectionable odors and taste. If the leachate is allowed to seep into streams, it can have serious consequences, poisoning stream life directly and depleting the oxygen dissolved in the stream water, limiting the kinds of animals that can live there. Besides leachate, landfills also generate methane and other organic gases as the organic matter in the waste decays. These gases are an environmental concern on the local scale because of odor problems and on the global scale because of their contribution to global warming.

Over time, the number of operating landfills in the Piedmont Basin has decreased, while the size of the average landfill has increased. Today, there are only two operating landfills in the basin: one municipal waste landfill and one construction- and demolition-debris industrial landfill. Together, these two facilities cover more than 400 acres, and they landfill over 700,000 tons of solid waste each year. Besides these operating landfills, there are closed or inactive landfills in the Piedmont Basin. These inactive sites are concentrated near the mouth of the Christina River in the Coastal Plain portion of the basin.

Landfills are regulated by DNREC's Solid Waste Management and Site Investigation and Restoration branches. Table 56 shows the Piedmont Basin landfills regulated by the Solid Waste Branch. All of these sites are shown on Map 4.

Hazardous Materials Management Facilities. Hazardous materials are chemical compounds that can cause serious health and environmental damage. Hazardous characteristics include toxicity, flammability, corrosivity, reactivity, radioactivity, etc. Hazardous materials can be both new (usable) and waste chemical compounds.

Hazardous Materials Management Facilities are businesses (small and large) that produce, store, use, and/or dispose of hazardous materials. These businesses can include food and fuel manufacturers, dry cleaners, and auto repair shops.

A waste can be any solid, liquid, or containerized gas that is no longer used and is either disposed of, recycled, or stored. A waste is hazardous if it exhibits the characteristics of ignitability, corrosivity, reactivity, or toxicity or is specifically listed within the *Delaware Regulations Governing Hazard-ous Waste, November 19, 1980, Revised, July 23, 1996.*

The contaminant sources map (Map 4) is intended to show the *general* distribution of hazardous waste generators and treatment, storage and disposal facilities. The map represents *approximate* locations only. One dot on the map may represent more than one facility (especially in industrial parks). As illustrated on the map, hazardous waste generators in the Piedmont Basin are concentrated in industrial parks, along Kirkwood Highway, and in the incorporated limits of the City of Wilmington. The Christina watershed and the tidal portion of the Brandywine Creek contain the greatest number of hazardous waste generators.

Table 57 presents a breakdown of generators by size and zip code in the Piedmont Basin. Conditionally exempt small-quantity generators are facilities that generate no more than 220 pounds of hazardous waste in any calendar month. Small-quantity generators produce more than 220 pounds, but less than 2,200 pounds of hazardous waste in any calendar month. Large-quantity generators generate more than 2,200 pounds of hazardous waste in any calendar month. As presented in the table, most of the hazardous waste generators in the Piedmont Basin are conditionally exempt and small-quantity generators.

The amount of hazardous waste produced is decreasing with time, due in part to DNREC's pollution prevention efforts. Many facilities continue to implement waste reduction opportunities that result not only in environmental benefits, but in economic savings as well.

Table 53

LEAKING UNDERGROUND STORAGE TANK SITES IN THE PIEDMONT BASIN

MAP ID #	SITE NAME	SITE LOCATION	GW ID #
L0009	AIR NATIONAL GUARD	NEW CASTLE	4
L0022	896 DELI (ANTHONY AUGUST)	2505 PULASKI HWY., NEWARK	4
L0026	ARCO CUMBERLAND FARMS	RTE. 4 & KIAMENSI RD., STANTON	3
L0028	ARCO FOULK & SILVERSIDE	WILMINGTON (SHELL)	4
L0029	ARCO GLASGOW 896 & 40 (SHELL)	GLASGOW	5
L0032	ARCO LANCASTER & FORD	2711 LANCASTER AVE, WILMINGTON	4
L0038	AVON NEWARK	2100 OGLETOWN RD., NEWARK	4
L0056	CHEVRON GULF GLASGOW 896	2394 PULASKI HWY., GLASGOW	3
L0060	CHRYSLER MOPAR DIVISION		3
L0061	CHRYSLER ASSEMBLY PLANT		3
L0072	DOT - OGLETOWN	NEWARK	3
L0088	DIAMOND FUEL OIL – AST SPILL	HEALD & LOBDELL ST., WILMINGTON	4
L0103	DUPONT COUNTRY CLUB	ROCKLAND ROAD, WILMINGTON	4
L0106	DUPONT STINE/HASKELL	NEWARK	4
L0109	DUPONT TATNALL BUILDING	WILMINGTON	5
L0111	DUPONT GLASGOW	GLASGOW	4
L0119	EXXON RTE. 273 & CHAPMAN RD.	NEWARK	4
L0122	EXXON SERVICE CENTER 1-95		4
L0125	EXXON CASTLE MALL	NEWARK	5
L0127	EXXON FOULK & SILVERSIDE	WILMINGTON	5
L0132	EXXON OGLETOWN & HARMONY	NEWARK	4
L0134	EXXON ROSE HILL GARAGE	SEE AS N8711074	3
L0138	EXXON SECOND & UNION		3
L0153	SHELL GODWIN'S	804 S. COLLEGE AVE., NEWARK	5
L0155	GULF I- 95 SERVICE CENTER		4
L0163	KAYO OIL CO., CONOCO, ELSMERE	1500 KIRKWOOD HWY., ELSMERE	4
L0169	KERSHAW CONSTRUCTION	473 OLD AIRPORT RD., NEW CASTLE	4
L0182	LAWN DOCTOR ABBOTT	CASTLE MALL, 995 S. CHAPEL	5
L0186	LYNAM'S MOBIL	1716 DELAWARE AVE., WILMINGTON	3
L0202	GULF HESSEY	235 E. DELAWARE AVE., NEWARK	3
L0205	NVF CORPORATION	NEWARK	3
L0217	PENCADER PRESBYTERIAN	GLASGOW	3
L0242	SHELL OGLETOWN & MARROWS RD.	NEWARK	5
L0244	SHELL OIL COMPANY CLAYMONT	PHILA. PIKE & SEMINOLE AVE., CLAYMONT	4
L0245	SHELL OIL COMPANY KIRKWOOD & 7	WILMINGTON	4
L0247	SHELLHORN & HILL GULF		3
L0258	SUNOCO CONCORD PIKE, TALLEYVILLE	TALLEYVILLE, 3930 CONCORD PIKE	4

Table 54

LEAKING UNDERGROUND STORAGE TANK SITES IN THE PIEDMONT BASIN — CONT'D.

MAP ID #	SITE NAME	SITE LOCATION	GW ID #
L0259	SUNOCO CONCORD PIKE FAIRFAX	2401 CONCORD PIKE, FAIRFAX	4
L0266	TEXACO CLAYMONT	NAAMANS CREEK. & DEL. R., CLAYMONT	4
L0271	TEXACO PIKE CREEK (AULT COURT)	AULT CT., LINDEN HEATH, WILMINGTON	4
L0272	THREE J'S TIRE INC., EAST		3
L0298	SUNOCO ELKTON ROAD	287 ELKTON RD., NEWARK	4
L0300	SUNOLIN CHEMICAL COMPANY	P.O. BOX F, CLAYMONT	3
L0307	RON'S DISCOUNT ENERGY MART	PHILADELPHIA PIKE, CLAYMONT	5
L0321	MOTOR LODGE GULF (896)	1107 S. COLLEGE AVE., NEWARK	3
L0350	DELCASTLE VOTECH	W1LMINGTON	4
L0357	CHRYSLER CORP.-ASSEMBLY PLANT	NEWARK ASSEMBLY PLANT, NEWARK	3
L0377	MOBIL (OGLETOWN)	4029 OGLETOWN RD, NEWARK, DE	4
L0379	CHRYSLER ASSEMBLY PLANT	P.O. BOX 6040, NEWARK	3
L0396	PENNYHILL GULF (NOW BP)	WILMINGTON	5
L0407	MOBIL SERVICE CENTER	1106 S. COLLEGE AVENUE, NEWARK	4
L0411	LOUVIERS COUNTRY CLUB	NEWARK	4
L0433	CHRYSLER ASSEMBLY PLANT	550 S. COLLEGE, NEWARK	3
L0471	D AND J AUTO SERVICE	WILMINGTON	3
L0475	MERIT OIL STATION	506 DUPONT HWY., NEW CASTLE	4
L0495	DIAMOND STATE TELEPHONE	LEA BLVD.,WILMINGTON	3
L0505	CIBA-GEIGY CORP. NEWPORT	REFER TO SUPERFUND	3
L0523	SOUTHWOOD FARMS	HOCKESSIN	3
L0578	AIRCO INDUSTRIAL GASES, INC.	CLAYMONT	4
L0595	GULF-LAWRENCES HOCKESSIN	41 & YORKLYN RD., HOCKESSIN	4
L0B30	CONOCO-1701 PENNSYLVANIA AVE.	WlLMINGTON	3
L0656	EXXON LOVERING AVENUE	1705 LOVERING AVE., WILMINGTON	4
L0676	LOUVIERS MAINT. YARD	SEE N9109200	4
L0678	7-11 STORE 1126-23128, MEM. DR.	RTE. 13 & MEM. DR., NEW CASTLE	4
L0690	GULF 1700 MARSH RD.	1700 MARSH ROAD, WILMINGTON	4
L0695	AIR NATIONAL GUARD, 2701 GWAP	NEW CASTLE CO. AIRPORT	3
L0718	KIRKWOOD MOTORS, INC.	4800 KIRKWOOD HWY., WILMINGTON	4
L0784	GULF CHRISTIANA GATEWAY	LOBDELL & HEALD ST., WILMINGTON	4
L0841	JAMES JULIAN, HEALD STREET	1100 S. HEALD ST.,WILMINGTON	3
L0876	B AND M AUTO	525 S. MARKET ST., WlLMINGTON	3
L0885	BARONE'S MOB1L (GETTY #08643)	2801 CONCORD PIKE, WILMINGTON	3
L0930	7–11 1126-22003, CHRISTIANA RD.	284 CHRISTIANA RD., NEW CASTLE	5
L0934	DEL CAMPO BAKERY SERT INCIDENT	2006 RODMAN STREET, WILMINGTON	3
L1016	HODGSON VO-TECH	GLASGOW	3

Table 55

LEAKING UNDERGROUND STORAGE TANK SITES IN THE PIEDMONT BASIN — CONT'D.

MAP ID #	SITE NAME	SITE LOCATION	GW ID #
L1019	KIRKWOOD TEXACO – RICE'S TEX.	13625 KIRKWOOD HWY., WILMINGTON	13
L1125	TIPTON TRUCKING TANK REMOVALS	TOWNSEND & LOBDELL , WILMINGTON	4
L1127	DELAWARE AUTO SERVICE	1603 PENN. AVENUE, WILMINGTON	3
L1143	UNIV. OF DEL., WORRILOW HALL	UNIV. OF DEL., NEWARK	13
L1144	UPS, A STREET	700 A STREET, WILMINGTON	13
L1147	LINCOLN CAMERA SHOP	2001 DELAWARE AVE., WILMINGTON	13
L1163	W. CARL CULLEN, INC.	2034 SUNSET LAKE RD., NEWARK	l3
L1177	EXXON 820 S. COLLEGE, NEWARK	820 S. COLLEGE AVE.,NEWARK	3
L1225	AL'S AUTO SERVICE CENTER, INC.	4001 WASHINGTON ST., WILMINGTON	3
L1272	PANELTROL, INC.	9 N. COLONIAL AVE., ELSMERE	3
L1288	LOUIS DREYFUS ENERGY #3	TOWNSEND & LOBDELL, WILMINGTON	4
L1302	DE STATE POLICE, TROOP #1	603 PHILADELPHIA PIKE, WILMINGTON	5
L1311	UNIV. OF DEL., 55 W. MAIN STREET	55 W. MAIN ST., NEWARK	4
L1324	MARIO MEDORI	402 MECO DRIVE, WILMINGTON	3
L1358	HOLLINGSWORTH PROPERTY - COTTMA	3410 OLD CAPITAL TRAIL, WILMINGTON	4
L1452	TEXACO 505 N. DUPONT HWY., N.C.	505 N. DUPONT HWY., NEW CASTLE	4
L1455	GETTY PHIL. PIKE	PHIL. PIKE & DUPONT AVE.,WILMINGTON	4
L1587	SANDALWOOD APTS., #3	SANDALWOOD DRIVE, NEWARK	4
L1588	NORMAN E. WRIGHT TRUST	6515 GOV. PRINTZ BLVD., WILMINGTON	13
L1590	OAKTREE APARTMENTS	NEWARK DRIVE, NEWARK	3
L1597	PENSKE TRUCK LEASING	1600 MATASSINO DRIVE, NEW CASTLE	3
L1645	NVF COMPANY	YORKLYN	3
L1670	M/M ROBERT SMITH RESIDENCE	1411 OLD BALTIMORE PIKE, NEWARK	3
L1674	RYDER TRUCK RENTAL	6605 GOV. PRINTZ BLVD.,WILMINGTON	4
L1726	USA TRAINING ACADEMY	955 S. CHAPEL ST., NEWARK	4
L1727	MERIT GAS STATION	5801 KIRKWOOD HWY., WILMINGTON	3
L1774	LOUIS DREYFUS ENERGY #4	S. HEALD & LOBDELL ST., WILMINGTON	4
L1811	DELDOT	RTE. 7 & CHURCHMAN'S RD.	3
L1828	ROLLINS LEASING CORP.	51 BOULDEN BLVD., NEW CASTLE	4
L1891	LITTLE SISTERS OF THE POOR	185 SALEM CHURCH ROAD, NEWARK	3
L1903	BRANDYWINE MANAGEMENT	4TH & SPRUCE, WILMINGTON	5
L1978	INGLESIDE RETIREMENT APTS.	1005 N. FRANKLIN ST., WILMINGTON	4
L1983	WM. TAYLOR RESIDENCE	54 QUARTZ MILL RD., NEWARK	4
L2002	GENE'S GULF SERVICE	1001 WEST 4TH ST., WILMINGTON	4
L2018	AVIR CORP., SARDO WAREHOUSE	6TH ST., NEW CASTLE	3
L2020	COCA-COLA BOTTLING CO.	GRAY & 2ND, GREENHILL & 2ND, WILM.	3

All listed releases are petroleum related. Only sites with a groundwater impact are listed.
Site status may change as corrective action is completed.

Table 58 lists facilities regulated by the Hazardous Waste Management Branch that are known to have contaminated the environment. All facilities regulated by this branch have the potential to release contaminants to the environment; however, most facilities manage their hazardous materials and potential pollutants in a responsible manner. "Potential to contaminate" *does not* mean that the facility has released or will release pollutants to the environment. "Potential" means that the facility uses or generates materials that could negatively impact human health and the environment.

The Toxics Release Inventory requires companies to report on listed chemicals manufactured, processed, or otherwise used above certain annual thresholds under the Emergency Planning and Community Right-to-Know Act. The following facilities in the Piedmont Basin submitted reports for 1994:

Allied Signal	General Chemical
Ametek Haveg Division	General Motors
Alloy Surfaces	Hercules Research Center
BOC Gases	Insteel Wire Products
Brandywine Compounding	Medal L.P.
Cabot Safety Corp.	Noramco of Delaware
Chrome Deposit	NVF Yorklyn
Chrysler	Pepsi-Cola Bottling
Ciba Geigy	Perma Flex Rollers
Citisteel	Rockland Technologies
Dupont Edgemoor	Rodel
Dupont Experimental Station	Roller Service
Dupont Holly Run	Speakman
FMC	Sun Refining and Marketing

Few of these facilities reported actual releases to land or water. The following facilities reported releases of over 100 pounds for the given chemical:

NVF Yorklyn	31,901 pounds of zinc to water
General Chemical	3,600 pounds of ammonia to water
DuPont Edgemoor	600 pounds of hydrochloric acid to water

The Hazardous Chemical Inventory requires all facilities that maintain material safety data sheets and have listed chemicals on-site above a certain quantity to report to DNREC. Information reported includes the maximum amount of the chemical on-site in the reporting year and its location on the site. A data base is maintained from approximately 1,200 reporting facilities each year and is used by local emergency planning committees.

Other. Besides the sources described above, there are a number of other potential and /or known contaminant sources in the Piedmont Basin that may be locally significant. These include the following:

- *Dredge Spoil Disposal Areas.* These areas contain sediment dredged from rivers and lakes. The dredged sediment, especially from industrial areas like the Port of Wilmington, are often contaminated with heavy metals, polychlorinated biphenyls, and/or semivolatile organic compounds. During dredging operations sediment is slurried into diked areas. Here, the sediment settles out and the clear water is allowed to drain back into the main water body. Contaminants from the dredge spoils can potentially

Table 56

SOLID WASTE MANAGEMENT BRANCH — PIEDMONT BASIN LANDFILLS
KNOWN/POTENTIAL CONTAMINANT SOURCES

MAP NO.	FACILITY	SOLVENTS	METALS	PETROLEUM	PEST./HERB.	PCBS	OTHER	DESCRIPTION
LF01	DuPont Cherry Island		P				P	Industrial Waste LF
LF02	DSWA NSWMC#2	P	P	P			P	MSWLF
LF03	DP&L Edgemoor		P				P	Coal Ash LF
LF04	DRPI		K				K	C&D/Industrial Waste LF
LF05	Booker, Booker & Ryan		P				P	Dry Waste LF–Closed
LF06	Taylor		P				P	Dry Waste LF–Closed
LF07	Timko		P				P	Dry Waste LF–Closed
LF08	Petrillo Bros		P				P	Dry Waste LF–Closed
RR01	Clean Earth			P				Pet. Contam. Soil Roaster
RR02	VFL		P				P	Sewage Sludge Recycler
RR03	Rolite		P				P	Ash Recycler

Abbreviations: K-Known contaminant source, P-Potential contaminant source (present on site), LF-Landfill, MSW-Municipal Solid Waste, C&D-Construction and Demolition Debris, Pest.-Pesticide, Herb.-Herbicide, PCBs-Polychlorinated Biphenols.

percolate into the groundwater below the disposal area, or they may travel back into the water body with the return water. The largest dredge spoil area in the Piedmont Basin is operated by the U.S. Army Corps of Engineers on Cherry Island at the mouth of the Christina River.

- *Salt Piles*. There is at least one large, uncovered road salt pile in the Piedmont Basin located on the west side of Interstate 495, just south of the Christina River. Rain has the potential to leach salt from the pile into groundwater. More investigation needs to be performed to determine if there are other uncovered salt piles in the basin.
- *Tire Piles*. There are 18 known piles of discarded tires in the Piedmont Basin ranging in size from fewer than 100 to over 75,000 tires. These piles are a concern because they are excellent breeding sites for mosquitoes and because they are a fire hazard. Tire pile fires are extremely hard to extinguish and they generate large quantities of noxious smoke. They also generate organic liquids as they burn that can contaminate groundwater. Most tire piles in the Piedmont Basin are located in the lower Christina River Valley and are listed in Table 59.
- *Auto Salvage Yards*. Salvage yards are a potential source of contamination from leaking fluids such

Table 57

NOTIFIED HAZARDOUS WASTE REGULATED FACILITIES IN THE PIEDMONT BASIN

ZIP CODE	AREA	NO. OF CONDITIONALLY EXEMPT SMALL QTY. GENERATORS OF HAZ. WASTE	NO. OF SMALL QTY. GENERATORS OF HAZ. WASTE	NO. OF LARGE QTY. GENERATORS OF HAZ. WASTE	NO. OF TREATMENT, STORAGE AND DISPOSAL FACILITIES OF HAZ. WASTE
19701	Bear	3	9	4	
19702	Newark	15	16	3	
19703	Claymont	7	12	2	
19707	Hockessin	3	2		
19711	Newark	16	48	8	
19713	Newark	21	23	4	
19714	Newark	3	4	1	
19715	Newark	1	1		
19716	Newark		1		
19720	New Castle	44	79	12	
19736	Yorklyn	1		2	
19801	Wilmington	14	23	4	
19802	Wilmington	9	22	3	
19803	Wilmington	9	14		1
19804	Newport	23	44	8	
19805	Wilmington	13	16	3	1
19806	Wilmington	3	10	2	
19807	Wilmington	1	2		
19808	Wilmington	15	32	3	
19809	Wilmington	4	7	2	1
19810	Wilmington	5	9		
19898	Wilmington	1	4	3	1
19899	Wilmington	3	7	2	
	Totals	**214**	**385**	**66**	**4**

as oil, grease, gasoline, antifreeze, and heavy metals such as lead from batteries. There are a number of large salvage yards in the lower Christina River Valley.

- *Resource Recovery Facilities*. There are three facilities in the Piedmont Basin that process contaminated waste (sewage sludge, coal ash, or petroleum-contaminated soil) into a usable product. Each of these facilities is a potential source of contaminants if the unprocessed waste material is not handled properly. These facilities are listed in Table 60.

Program Descriptions

Solid Waste Management Branch. DNREC's Solid Waste Management Branch is charged with assuring that landfills are built and operated in an environmentally responsible manner. This branch issues permits that require landfills to collect and treat the leachate and gas they may generate. Landfill facilities are also required to monitor groundwater and surface water for the presence of potential contaminants. Additionally, the Solid Waste Branch regulates recycling facilities, waste haulers, and infectious waste, and tracks tire piles.

In December 1994, Delaware adopted revised regulations governing solid waste. These new regulations, mandated by changes in federal solid waste regulations, increased the construction standards and monitoring requirements for landfills.

The Solid Waste Branch maintains a list of waste haulers and has compiled a recyclers' directory. Files are also maintained on the design, operation, and monitoring of all regulated facilities. Contact the branch at (302) 739-3820 for more information.

Underground Storage Tank Branch. The Underground Storage Tank Branch regulates petroleum and hazardous substance tanks through their entire life cycle. The branch derives its authority from Section 7, *Delaware Code*, Chapter 74, the Underground Storage Tank Act and Delaware's Regulations Governing Underground Storage Tank Systems. Two groups within this branch interface to assure complete regulatory compliance. The *underground* storage tank group monitors the compliance of in-use and out-of-service tanks and the installation of new tanks to prevent potential releases.

Table 58

HAZARDOUS WASTE MANAGEMENT BRANCH
KNOWN CONTAMINANT SOURCES — PIEDMONT BASIN FACILITIES

		CONTAMINANT CLASS						DATA AVAILABLE					
MAP NO.	**FACILITY**	**SOLVENTS**	**METALS**	**PETROLEUM**	**PEST./HERB.**	**PCB**	**OTHER**	**AIR**	**SOIL**	**SEDIMENT**	**SURFACE WATER**	**GROUNDWATER**	**DESCRIPTION**
	DuPont Chestnut Run	P	P	K			P		D,I				Research facility. Hazardous waste storage pad.
	DuPont Edgemoor	P	P				P						Titanium dioxide manufacturer.
	DuPont Experimental Station	K	K		K		K		D,I	D,I	D	D,I	Research facility. Hazardous waste incinerator.
	DuPont Glasgow	K		K			K		D,I	D	D	D,I	Research and manufacturing facility.
	General Chemical	K	K		K		K		D			D,I	Sulfuric acid manufacturer.
	Harper Thiel		K				P		D,I	D			Electroplater.
	Hercules Research Center	K	K		K	K	K		D,I	D	D	D,I	Research facility.
	Sun Company Marcus Hook Refinery	K		K								D,I	Petroleum refinery that straddles the PA/DE state line. PA DER has the lead for state oversight.

Abbreviations: K-Known Contaminant Source, P-Potential Contaminant Source (present on site), I-Media Impacted, D-Data Available

Table 59
USED TIRE PILES IN THE PIEDMONT BASIN

MAP NO.	FACILITY	CONTAMINANT CLASS: SOLVENTS	METALS	PETROLEUM	PEST./HERB.	PCB	OTHER	DATA AVAILABLE: AIR	SOIL	SEDIMENT	SURFACE WATER	GROUNDWATER	NUMBER OF TIRES
N01	Breitenbach's Auto Salvage			P			P						3,000
N02	Little Jimmy's Auto Salvage			P			P						3,00
N03	Joe Morgan's Auto Salvage			P			P						6,000
N04	Delaware Auto Salvage			P			P						50
N05	B and F Towing			P			P						3,000
N06	Skyline Auto Salvage			P			P						50
N07	Necastro Auto Parts			P			P						8,000
N08	Two Guys Auto Parts			P			P						30,000
N09	1-A-Used Auto Parts			P			P						5,000
N10	Don Wilson Auto Parts			P			P						10,000
N11	A.M. Domino Auto Salvage			P			P						15,000
N12	Caspers Auto Parts			P			P						75,000
N13	City of Wilmington			P			P						500
N14	Ed & Son Auto Salvage			P			P						35,000
N15	Earl Van Den Heuvel			P			P						1,500
N16	Eastern Auto Salvage			P			P						1,000
N17	Keith Harris			P			P						8,000
N25	Continental Auto Salvage			P			P						3,000

Abbreviations: K-Known Contaminant Source, P-Potential Contaminant Source (present on site), I-Media Impacted, D-Data Available

Table 60
RESOURCE RECOVERY FACILITIES IN THE PIEDMONT BASIN

MAP NO.	FACILITY	CONTAMINANT CLASS: SOLVENTS	METALS	PETROLEUM	PEST./HERB.	PCB	OTHER	DATA AVAILABLE: AIR	SOIL	SEDIMENT	SURFACE WATER	GROUNDWATER	DESCRIPTION
RR01	Clean Earth	P										D	Pet. Contam. Soil Roaster
RR02	VFL		P										Sewage Sludge Recycler
RR03	Rolite		P										Ash Recycler

Abbreviations: K-Known Contaminant Source, P-Potential Contaminant Source (present on site), I-Media Impacted, D-Data Available

The *leaking* underground storage tank group oversees the cleanup of known tank releases to minimize the threat to human health and the environment.

Many tank programs have been initiated to accommodate the regulated community. The Small Retail Gasoline Station Assistance Program offers low-interest loans for system upgrades to achieve regulatory compliance. The Contractor Certification Program was instituted to assure the proper installation, closure, and upgrade of tank systems. Technical publications are constantly reviewed to assure that the regulations and guidance documents keep pace with the changing environment. Educational opportunities are provided for consultants, contractors, site owners, and operators, along with the general public.

The Underground Storage Tank Branch maintains multiple data bases to track all aspects of the tank program. The branch's publication, *Think Tank*, reports on issues pertinent to the regulated community. Most records are available through the Freedom of Information Act. Branch representatives may be contacted at (302) 323-4588.

Hazardous Waste Management Branch. The Hazardous Waste Management Branch regulates a specific type of contaminant source — facilities that generate, treat, transport, store, or dispose of hazardous waste as defined by Section 7, *Delaware Code*, Chapter 63, and Delaware's Regulations Governing Hazardous Waste.

Within the Hazardous Waste Branch, two groups operate. The Compliance Monitoring and Development Group inspects facilities, tracks annual reports and manifests, develops the program and regulations, maintains the branch data base, and grants site closures. The Treatment, Storage, and Disposal Group issues permits and oversees corrective action at release sites.

The broad goal of the hazardous waste program is to protect human health and the environment by ensuring regulatory compliance, and thus, proper hazardous waste management. Historically, regulatory compliance was achieved through an inspection program of detecting violations and pursuing enforcement, including monetary penalties, as a means to correct violations and deter future ones. However, over the last several years the Hazardous Waste Management Branch has supplemented these seemingly negative activities with positive approaches to achieving regulatory compliance by providing educational opportunities for all hazardous waste generators.

Although it initially centered around hazardous waste regulatory compliance, the hazardous waste program continues to expand its educational focus. Through the cooperation of DNREC's Pollution Prevention Program, hazardous waste and pollution prevention staff conduct site visits to supply both regulatory and pollution prevention education. With the advent of multi-media, technical assistance is offered across many DNREC programs, thus advancing a more holistic approach to pollution prevention and regulatory compliance. The branch continues to view the educational approach as one that provides not only regulatory knowledge to achieve and maintain compliance, but one that also affords businesses the opportunity to reduce both solid and hazardous waste generation, which is not only a sound environmental practice, but a cost-effective one.

This branch has also devised a program targeting small business sectors, auto body shops, and dry cleaners for educationally based Hazardous Waste Compliance Assessments. In an effort to educate these businesses not only on hazardous waste issues, but the impacts of the Clean Air Act, the Hazardous Waste Management Branch works jointly with DNREC's Air Quality Management Section, to conduct educational workshops. The branch also conducts on-site assessments with the goal of educating these small businesses to the benefits of properly managing and disposing of their hazardous waste. The on-site assessments not only emphasize hazardous waste regulatory compliance, but multi-media compliance, liability issues, and pollution prevention techniques specific to the business sector.

In 1995, the branch expanded its educational goals to work with students entering the work force as automotive maintenance and repair professionals. As a result, hazardous waste regulatory classes are conducted throughout Delaware for students studying these professions in the state's vocational high schools. The students are given an excellent foundation in hazardous waste generation and management issues. This knowledge is invaluable whether the students start their own business or work for an established one.

Due to the success of educating high school students, the Hazardous Waste Branch has made the one-day hazardous waste regulatory class an annual event for seniors. The branch looks forward to conducting these classes each year and is expanding the program to include not only regulatory education, but pollution prevention education.

Another facet of the branch's educationally based program is Hazardous Waste Audits for new businesses that generate hazardous waste. The audits are courteous inspections that stress regulatory and liability concerns, pollution prevention techniques and technical assistance.

To assist hazardous waste generators in remaining up to date with frequent regulation revisions, the branch conducts annual workshops discussing proposed amendments to the *Delaware Regulations Governing Hazardous Waste*. The workshops provide all businesses with an avenue to learn the new and revised regulations, along with the opportunity to express their opinions and concerns.

For additional technical assistance, the branch has implemented the *Hazardous Waste Help Line* (302) 739-3689. The *Help Line* is staffed with a hazardous waste information expert that will work one-on-one to answer any questions businesses may have.

The results of the branch's non-threatening educational programs have been positive — an effect reflected in not only higher compliance rates, but also in the development of ongoing cooperation and trust between the branch and the business community. For the approximately 650 small and large businesses in the Piedmont Basin that manage hazardous waste, the ongoing educational programs, technical assistance, and compliance assessments performed by the Hazardous Waste Management Branch significantly lower the likelihood of hazardous waste being released to the environment. And that results in a cleaner and safer environment for Delaware.

The branch is also actively involved in investigating, evaluating risk, and cleaning up contamination at sites that have known releases of contaminants to the environment. The branch maintains a list of hazardous waste generators, transporters, and treatment, storage, and disposal facilities within the State of Delaware. Environmental sampling data are also available for sites where releases are known or suspected. The Hazardous Waste Management Branch contact is Nancy C. Marker at (302) 739-3689.

Site Investigation and Restoration Branch. The Site Investigation and Restoration Branch, formerly the Superfund Branch, identifies, investigates, and remediates sites that release or threaten to release hazardous substances into the environment. "Superfund" refers to the process established in 1980 by the Comprehensive Environmental Response, Compensation, and Liability Act to address the country's most serious hazardous substance release sites.

The federal Superfund Program established a National Priority List of the country's worst sites. Twenty-one were located in Delaware. See Tables 61 – 63. Realizing that nearly 300 Delaware sites would not be addressed by the federal program, the state legislature enacted the Hazardous Substance Cleanup Act or Section 7, *Delaware Code*, Chapter 91, in 1990.

In 1993, DNREC created the Voluntary Cleanup Program (VCP) to allow potentially responsible parties to come forward, identify releases, and voluntarily clean them up. The Site Investigation and Restoration Branch instituted the VCP to expedite site cleanups and promote the development and reuse of abandoned, idled, or underutilized industrial and commercial facilities known as brownfields. The VCP has been heavily promoted through public workshops, publications, and the branch's Web page.

Incentives such as tax credits, low-interest loans, and grants were created to promote participation in the VCP and encourage the development of brownfields. The Site Investigation and Restoration Branch continues to work with other state agencies and members of the private sector to refine and develop incentives and raise public awareness.

In an effort to streamline the remedial process, the branch has developed brief, standardized VCP agreements. The agreements are written in layman terms and allow the signatory to terminate the agreement, provided that certain conditions are met. This has reduced legal costs and expedited the initiation of investigations and cleanups. To further streamline the process, the branch has developed cleanup standards, which may be used in place of risk assessments. This enables a larger group of property owners, developers, and consultants to evaluate sites and make decisions regarding property acquisition and disposition.

Since 1995, 22 sites have been remediated under the VCP/Brownfield Program, putting approximately 236 acres back to use.

In addition to streamlining the remedial process, the branch has developed a computerized site-status data base, implemented an automated cost recovery system, expanded its field screening capabilities, and purchased mobile laboratory equipment. The branch continues to seek and acquire improved technology to increase efficiency and reduce the cost of environmental investigations and cleanups.

The Site Investigation and Restoration Branch also produces an annual report. Additional information contained within the administrative record is available for each site through the Freedom of Information Act. Branch representatives may be reached at (302) 323-4540.

Toxics Release Inventory. The Toxics Release Inventory is one of several reporting programs under the Emergency Planning and Community Right-to-Know Act. Manufacturing facilities are required to report releases, transfers, on-site waste management, and other information for any chemical listed that the facility makes, processes, or otherwise uses above an annual threshold. Facilities report by July 1 on activities for the previous calendar year to DNREC and the EPA.

As referenced earlier, DNREC's Air Quality Management Section receives and compiles these data for all reporting years (1987 through 1994). The Toxics Release Inventory data base is routinely updated and is available on e-mail, disk, or hard copy for selected information. The program also prepares an annual report. This report and other program information is available by contacting the section's Emergency Planning and Right-to-Know Program at (302) 739-4791.

Table 61

SUPERFUND SITES IN THE PIEDMONT BASIN, DELAWARE

ID. NO.	SITE NAME	CATEGORY	DESCRIPTION	WATERSHED
DE-025	Capitol Recovery	HSCA	Criminal case – no site	Brandywine Creek
DE-094	Container Corporation of America	HSCA	Inactive landfill	Brandywine Creek
DE-097	Sixteenth Street Quarry	HSCA	Quarry	Brandywine Creek
DE-111	Kruse Playground	HSCA	Former coal gas facility, leather tannery, currently used as a playground	Brandywine Creek
DE-174	Electric Hose & Rubber Recon.	HSCA	Former wire and hose manufacturer	Brandywine Creek
DE-280	Atlas Sanitation	HSCA	Filled area	Brandywine Creek
DE-281	Diamond State Salvage	EPA Removal	Salvage operation	Brandywine Creek
DE-020	E. l. DuPont, Newport Landfill (OU1, OU3-OU8)	NPL	Pigment manufacturing facility	Christina
DE-034	Chapmans Road	HSCA	Former rendering plant	Christina
DE-047	Harvey and Harvey Landfill	VCP	Former landfill currently used for container storage	Christina
DE 067	Halby Chemical	NPL	Former chemical manufacturing facility	Christina
DE-095	Clayville Dump	HSCA	Former dump site	Christina
DE-099	City of Wilmington Marine Terminal	HSCA	Marine terminal	Christina
DE-1003	Del. Air National Guard	HSCA	Air Force National Guard Base	Christina
DE-1005	Toni Dry Cleaners	HSCA	Dry cleaner	Christina
DE-1006	Fox Run Development	HSCA	Residential development – vegetative debris pits	Christina
DE-1026	Terminal Avenue	HSCA	Road widening project	Christina
DE-1033	Victoria Woods	HSCA	Residential development – vegetative debris pits	Christina
DE-1034	Anchor Motor Freight	VCP	Tractor sales and service facility	Christina
DE-1039	Eagle Run	VCP	Former manufacturing/warehouse	Christina
DE-1040	400 South Madison Street	HSCA	Former shipbuilding site w/waste pile	Christina
DE-1041	Dravo Marsh	HSCA	Freshwater tidal marsh	Christina
DE-1043	Wilmington Coal Gas Western Section	HSCA	Former coal gasification plant	Christina
DE-1044	CSX Property	VCP	Vacant lot	Christina
DE-1046	Wilmington Coal Gas Northern Property	VCP	Former coal gasification plant	Christina
DE-105	Chrysler Assembly Plant		Automobile assembly	Christina
DE-1051	Pusey and Jones Shipyard	PA/SI	Former shipyard, current use industrial (metal fabrication & rail car refurbishing)	Christina

Table 62

SUPERFUND SITES IN THE PIEDMONT BASIN OF DELAWARE — CONT'D.

ID. NO.	SITE NAME	CATEGORY	DESCRIPTION	WATERSHED
DE-1055	250 South Madison		Freshwater tidal marsh	Christina
DE-114	Wllmington Coal Gas Southern Section		Coal gas site	Christina
DE-125	DuPont – Haskell Labs	HSCA	Laboratories and research facility	Christina
DE-140	High Voltage Maintenance Site	HSCA	Warehouse and maintenance facility	Christina
DE-141	Rte. 40 Steel Drum Site	HSCA	Drum collection and resale company	Christina
DE-155	Glasgow Drive Dump Site	HSCA	Dump site	Christina
DE-158	Atlantic Avenue	HSCA	Buried drums discovered during utility construction	Christina
DE-159	Wilmington Train Yard	HSCA	Train maintenance yard	Christina
DE-161	Robscott Manor	HSCA	Residential development/possible dump site	Christina
DE-165	Estate of Lester Nolan	VCP	Dump site	Christina
DE-169	Potts Property	HSCA	Former ore processing plant/currently bulk storage area	Christina
DE-173	Syntech	HSCA	Specialty chemical manufacturer	Christina
DE-185	Meco Drive Site (Boxwood)	HSCA	Industrial site	Christina
DE-187	Applied Technology	HSCA	Unknown	Christina
DE-191	Petinaro Transformer Site	HSCA	Electric power transformer substation	Christina
DE-193	Salem Church – Muddy Run Dump	HSCA	Surface dump – commercial, industrial, and household debris	Christina
DE-I-95	Wilmington Suburban Water Co.	HSCA	Water pumping facility with sludge lagoons	Christina
DE-210	Wilmington Suburban Water Co. – Christiana	HSCA	Water pumping facility with sludge lagoons	Christina
DE-230	North American Smelting Co.	VCP	Abandoned smelter operation	Christina
DE-248	DuPont Reston Products	HSCA	Former manufacturer/current research and development of circuit boards site	Christina
DE-256	Homalib	HSCA	Optical plastics manufacturer	Christina
DE-259	Newark Munition Site	HSCA	Former WW II munitions storage area	Christina
DE-270	Budd Metal	VCP	Former metal fabrication business	Christina
DE-271	Ciba-Geigy Seep	EPA Removal		Christina
DE-282	Cress Collision Services Inc.	HSCA		Christina
DE-283	Necastro Auto Salvage	HSCA	Auto salvage business	Christina
DE-285	Browntown		400 acres within city of Wilmington	Christina
DE-286	Bell Alley			Christina
DE-046	Citi Steel Corporation	HSCA	Steel manufacturer	Naamans Creek
DE-050	Texaco Inc., Claymont Terminal	HSCA	Petroleum product terminal	Naamans Creek
DE-059	Olin Corp. – Sunolin Chemical	HSCA	Chemical manufacturer	Naamans Creek

Table 63
SUPERFUND SITES IN THE PIEDMONT BASIN OF DELAWARE — CONT'D.

ID. NO.	SITE NAME	CATEGORY	DESCRIPTION	WATERSHED
DE-249	Allied Chemical Drum site	HSCA	Spill site	Naamans Creek
DE-054	O & T Realty	HSCA	Landfill	Red Clay Creek
DE-071	NVF (Yorklyn)	HSCA	Fiber product manufacturer	Red Clay Creek
DE 081	NVF Stab Line Landfill	HSCA	Landfill	Red Clay Creek
DE-166	Spatz Fiberglass	HSCA	Molded fiberglass products manufacturer	Red Clay Creek
DE-176	Ametek Inc.	HSCA	Plastic products manufacturer	Red Clay Creek
DE-1001	Fox Point Park Phase I	HSCA	Former landfill	Shellpot
DE-024	Wilmington Municipal Sewage System	HSCA	Municipal sewage treatment plant	Shellpot Creek
DE-1011	Fox Point Park Phase II	HSCA	Former landfill	Shellpot Creek
DE-1054	Pure Green Industries	VCP	Former landfill	Shellpot Creek
DE-126	Juliano Site	HSCA	Residence	Shellpot Creek
DE-266	Amtrak Railyard	VCP	Railyard/maintenance facility	Shellpot Creek
DE-039	Newark Landfill	HSCA	Inactive landfill	White Clay Creek
DE-184	Brookside Dump	HSCA	Dump site	White Clay Creek
DE-018	FMC Corporation	HSCA	Former Landfill	White Clay Creek
DE-019	Koppers Co. Facilities Site	NPL	Wood preserving facility	White Clay Creek
DE-035	Newark Concrete	HSCA	Dump site	White Clay Creek
DE 044	Newport City Landfill	HSCA	Former landfill	White Clay Creek
DE-052	Newark Housing Authority Landfill	HSCA	Inactive landfill	White Clay Creek
DE-062	SES Incorporated	HSCA	Research facility	White Clay Creek
DE-072	Reevis & Reevis Clay Pit	HSCA	Former dump site	White Clay Creek
DE-079	Mt. Pleasant Railroad Dump	HSCA	Former dump site	White Clay Creek
DE-162	Windy Hills	HSCA	Former dump site	White Clay Creek
DE-163	Del Chapel Place	BPA ll	Buried rail cars	White Clay Creek
DE-175	Motor Wheel Corporation	HSCA	Wheel manufacturer	White Clay Creek
DE-199	NVF Newark	HSCA	Fiber products manufacturer	White Clay Creek
DE-214	W.L. Gore & Assoc. – Newark	HSCA	Manufacturing facility	White Clay Creek
DE-229	Newport Drum Site	HSCA	Drum site	White Clay Creek

Notes:
• *Hazardous Substance Cleanup Act (HSCA)* • *National Priority List (NPL)* • *Environmental Protection Agency (EPA)*
• *Brownfield Preliminary Assessment (BPA)* • *Voluntary Cleanup Program under HSCA (VCP)*
This is the current listing of the sites located in the Piedmont Basin of Delaware and is subject to change without notification.

On-Site Waste Disposal Systems, Agriculture, Silviculture, Resource Extraction, Hydromodification

Nonpoint source pollution is the deposition of pollutants to water by runoff, percolation, and atmosphere. The term can also be defined by negation as any human-induced pollution that does not come from a precisely defined location such as a drainage pipe discharging waste into a river.

While any contaminant may fall under Nonpoint Source Program jurisdiction, some contaminants are more clearly nonpoint source related. These include bacteria, nutrients, sediment, and polychlorinated biphenyls (PCBs).

Contaminant Descriptions

Bacteria. According to the 305(b) report, most of the Piedmont Basin's surface waters do not support primary contact use as a result of high indicator bacteria levels. This information by itself has strong implications. However, measuring indicator bacteria levels to determine human health risk is not a precise technology. As the name suggests, indicator bacteria are associated with the pathogens that cause human illness but are not themselves the concern. Several conditions can cause indicator bacteria counts to be misleading. A few are noted here:

- Normally, the correlation between indicator bacteria and illness-causing pathogen levels is good if the appropriate indicator bacteria are chosen for monitoring. Pathogens are not exactly correlated to indicator bacteria, however. Sometimes the indicator bacteria can die off before or after illness-causing pathogens. Also, pathogens may grow back after an initial die-off while the indicator bacteria do not. Indicator bacteria monitoring alone may not be accurate.
- Bacteria, including indicator bacteria, are present everywhere and are especially associated with organic matter. They exist throughout soils and plant matter even if pathogenic organisms do not. Research on pulp and paper mill effluent showed that total and fecal coliform levels were high, while no pathogenic organisms were present (Pipes 1992). Degraded waters may have high bacteria levels but not be a threat to human health.
- Higher risk is associated with human waste than animal waste pathogens. Yet indicator bacteria monitoring cannot differentiate between the two. One study suggests that a fecal coliform to fecal streptococci ratio of 4:1 is an indication that contamination is from a human source. However, the authors of that study warn that this ratio is only valid within a narrow set of conditions. The ratio is not meaningful in urban settings and should only be considered for samples coming from outfalls that are within a 24-hour travel time of the source (Geldreich, 1969). Water-quality standards are sometimes based on the assumption that indicator bacteria levels are associated with pathogens from human sources. Because high levels of fecal indicator bacteria can be present without human fecal sources existing, indicator bacteria monitoring may be too conservative.

Literature suggests that, in spite of the inexactness of indicator bacteria monitoring, it is still the most effective method we have to determine human health risk from pathogens. However, indicator bacteria monitoring is most effective if accompanied by a sanitary survey so that data can be evaluated in relationship to sources (Pipes, 1992).

Bacteria proliferation is correlated with the nutrient levels and temperature of a water body (Pipes, 1992). While the health risk indicated in the 305(b) information may be conservative, we can surmise from the data that water-quality degradation is occurring. Indicator bacteria counts also cause swimming closures. While those standards may be conservative, they are our best tool. The only way to reduce the number of closures is to reduce bacteria concentrations in surface waters.

Nutrients. Nitrogen and phosphorus are the major nutrients that cause eutrophication of surface waters. In the environmental protection field, eutrophication carries a negative connotation for causing nuisance levels of aquatic plant and algae growth. Excessive plant growth may cause odor problems; entangle swimmers, fishermen, and boaters; and may cause a reduction in the population, size, and diversity of fish as a result of oxygen depletion and excessive pH fluctuation from plant die-off.

Phosphorus is normally the nutrient that limits growth in fresh waters while nitrogen is typically the limiting nutrient in estuaries and bays. Adding more of a limiting nutrient to a water body will result in increased aquatic plant and algae growth.

Nitrogen. Nitrogen may reach surface waters by runoff of fertilizer and animal waste from agricultural and residential lands. Ritter (1984) noted, however, that base flow to streams was a greater nitrogen contributor than stormwater. Base flow is assumed to be entirely from groundwater (Johnson, 1976). A more pervasive concern, then, is leaching of nitrate to groundwater. Manure and chemical fertilizers from agricultural activities and residential lawn care, as well as localized concentrations of septic systems, may contribute to groundwater nitrate levels.

Phosphorus. Because phosphorus, by its chemical nature, is held tenaciously to soil particles, erosion and runoff have always been considered to be the major cause of phosphorus loading. Groundwater is not considered a phosphorus-loading pathway. A study of 30 lake watersheds throughout the state noted that greater than 50% of phosphorus transport was in base flow (Ritter, 1992).

If phosphorus is not found in the groundwater that supplies base flow, the most likely source of base-flow phosphorus is stream and lake-bed sediments. Under low oxygen conditions, iron-bound phosphorus may be released from sediments. Also, organically bound phosphorus may be released when biota consume organic matter in the sediments. Historic erosion is the likely source of stream and lake-bed sediments, which may be releasing phosphorus currently.

Sediments. Eroded sediments both carry pollutants and are a pollutant. Pathogens, nutrients, and toxic substances are transported in sediments. Prevention is the less expensive solution.

Most of the problems caused by sediments acting as a transport mechanism are discussed elsewhere in this report:

- Indicator bacteria are present at degrading levels in nearly all of Delaware's surface waters. Much of the problem is associated with runoff-borne soil and organic matter.
- Nutrients are high in most of our waters. The sediments underlying streams and ponds are a major source of those nutrients. Some of the sediments are from detritus within the water body. The rest comes from erosion and runoff. Because phosphorus strongly adheres to soil particles, eroded sediments are thought to be the dominant mechanism for phosphorus loading.
- PCBs, the major toxic contaminant for which fish consumption advisories are issued, are typically soil-borne and transported by erosion and runoff. Waterways that currently have advisories can't be remediated, and more streams will have advisories placed on them if sediments are not controlled.
- Some ponds have a turbidity problem. The swimming area at Becks Pond, for example, has been permanently closed as a result of chronically high bacteria and turbidity levels.
- Many Piedmont Basin streams that have good habitat along their banks have poor habitat in the water. Stones, gravel, and branches, which supply spawning and feeding areas, have been buried by sediments. Even though the water quality is adequate, the stream is dead.
- The New Castle County Conservation District's dredging and excavation operations are not at a loss for work. Creeks and ponds that have filled in with sediments may be dredged to maintain water-body depth and reduce flooding. Although sedimentation is a natural process, human activities accelerate the rate. All of Delaware's citizens pay to maintain water bodies suffering from accelerated sedimentation.

Sediment erosion is both an urban and an agricultural problem. Where land is disturbed, erosion occurs. Sediment and stormwater control is at least one of, if not the major tool, for prevention of surface-water contamination from all other pollutants. Sediment and stormwater volume is a cause of stream habitat destruction.

Advanced methods for sediment and stormwater control are needed for both agricultural and urban communities. Regional land-use planning and zoning are imperative to successful urban control. The agricultural industry has long understood the importance of erosion control to sustaining profitable crop production. Tying existing efforts to water-quality improvements is the next step.

Polychlorinated Biphenyls (PCBs). Polychlorinated biphenyls (PCBs) are the major cause of fish consumption advisories in Delaware. PCBs were widely used before being banned, and they don't break down readily. Consequently, contamination is extensive. Erosion of contaminated soils into surface waters is the typical transport mechanism. The EPA allows contaminated sites to have a maximum of 50 ppm PCBs in the soil. While this level is safe in situ, erosion from several sites in a watershed may lead to hazardous levels in the bottom sediments of receiving waters (Rick Greene, personal communication).

Remediation of PCBs typically involves either leaving sediments in place so that they may be buried with further sedimentation over time or by dredging the sediments out. When dredged, large volumes of removed sediments must either be disposed of properly or treated before being used. A model is being developed that will help scientists and engineers evaluate the time required for sediments to be buried naturally. Knowing this will help them weigh remediation options more effectively. Neither treatment will work unless the source of contamination is stopped. Thus, erosion and stormwater runoff control is the first step to successful remediation.

Historic use of PCBs has left a legacy that we will be addressing for many years to come. The pervasive nature of PCB contamination makes remediation complex and challenging. Remediation is further complicated by the continual loading from erosion and runoff. If the source is not stopped, remediation is pointless.

Nonpoint Sources

Nonpoint sources are normally evaluated by dividing them into eight categories:

Table 64

LAND USE IN THE CHRISTINA BASIN
OCTOBER 22, 1996
(Compiled by Water Resources Agency for New Castle County)

LAND USE	AREA, SQUARE MILES (Percent of Total Land Use in State)	
	DELAWARE	**PENNSYLVANIA**
Urban/Surburban	87 (52%)	108 (27%)
Agricultural	18 (11%)	160 (40%)
Public/Private Open Space	21 (13%)	5 (1%)
Wooded	37 (22%)	123 (31%)
Water	3 (2%)	3 (1%)
Total	**166**	**399**

Table 65

PERCENT AGRICULTURAL LAND BY WATERSHED
(Delaware Portion Only)

WATERSHED	PERCENT
Shellpot Creek	2%
Naamans Creek	4%
Christina River	16%
White Clay Creek	26%
Brandywine Creek	26%
Red Clay Creek	27%

1. Agriculture
2. Silviculture
3. Construction
4. Urban Runoff
5. Resource Extraction/Exploration/Development
6. Land Disposal (runoff/leachate from permitted areas)
7. Hydrologic/Habitat Modification
8. Other (atmospheric deposition, waste storage leaks, etc.)

Since categories 3, 4, 6, and 8 are covered comprehensively in other sections of this document, they will not be evaluated here.

The Piedmont Basin is one of the most complex drainage basins in Delaware. Basin waters run extensively through Pennsylvania, and to a minor extent through Maryland, before reaching Delaware. Thus, we inherit the results of practices and land-use patterns in those states, and then add on our own. Successive land-use patterns layer their effects on top of those preceding, rendering an amalgamation that is challenging to unravel. See Table 64. This is especially so for the White Clay, Red Clay, and Brandywine creeks; most of these watersheds comprise rural lands in Pennsylvania, then become residential and urban in Delaware. Each landscape contributes its own type of nonpoint sources. Ultimately we cannot solve our water-quality problems in this basin without the help of adjoining states.

Agriculture in Delaware. New Castle County is experiencing a shift from agriculture to urbanization. From 1964 to 1984, the percentage of urban land use steadily increased, but the percentage of agricultural land stayed the same (J. MacKenzie, personal communication). See Table 65. As agricultural land became developments, forestland was cleared to make new agricultural land. Now, however, farmland acreage is not being replaced, and total acreage is diminishing.

Delaware is predominantly urban above the Christina River. A small acreage of the existing agricultural land is used for corn-soybean-small grain rotation for profit. Most of the farmland is kept in pasture or cropped for wildlife management on county and state preserves. The University of Delaware has a research farm in Newark.

Much of the agricultural land below the Christina River and above the Chesapeake and Delaware Canal is slated for development. Agriculture will not be a major land use in the near future.

Addressing agricultural practices in Delaware's Piedmont Basin is a low priority since very little agricultural land exists in northern New Castle County. Most existing agricultural land is in pasture and hay fields, which result in little pollution. Basin lands in Pennsylvania, however, are extensively agricultural.

Agriculture in Pennsylvania. The Piedmont Basin is comprised of 40% agricultural lands in the Pennsylvania portion. In Chester County, the primary types of agriculture are corn-soybean-wheat/hay rotation, dairy, and mushroom farming, with the dominant crop being mushrooms. See Table 66.

Erosion of sediments is the primary concern with grain-rotation crops in Pennsylvania as a result of steep slopes. Even if farmers are using minimum tillage practices, terraces and waterways are still necessary. According to the Watershed Plan and Environmental Assessment (1996) put together by the Conservation Districts in Delaware and Pennsylvania, 68,000 tons of sediment from cropland reach surface waters

Table 66

NUTRIENT RUNOFF ASSOCIATED WITH PROBLEM SOURCES OF AGRICULTURAL NONPOINT POLLUTION

(From Red-White Clay Creeks Watershed Plan and Environmental Assessment, 1996)

AGRICULTURAL NONPOINT	NITROGEN (LBS/YEAR)	PHOSPHORUS (LBS/YEAR)
Mushroom Operations:		
Field-spread spent substrate	79,000	5,000
Runoff from loading/unloading	33,000	3,000
Wash-down operations	150,000	15,000
Runoff from spent substrate	120,000	12,000
Livestock Operations:		
Livestock concentration areas	24,500	9,000
Field-spread manure	9,000	3,000
Milk-house waste effluent	500	1,000
Livestock stream access	27,000	5,000
Stream Banks	17,000	7,000
Cropland Runoff	221,000	90,000
Total	**681,000**	**150,000**

Table 67

SOIL EROSION AND NUTRIENT LOSSES FROM CROPLAND — RED – WHITE CLAY WATERSHED

(From Red–White Clay Creeks Watershed Plan and Environmental Assessment, 1996)

	PENNSYLVANIA	DELAWARE	TOTAL
Cropland (acres)	18,000	3,500	21,500
Sheet/Rill Erosion (Tons/Year)	162,000	25,000	187,000
Concentrated Flow Erosion (Tons/Year)	14,500	2,500	17,000
Total Erosion (Tons/Year)	176,500	27,500	204,000
Total Nitrogen (lbs/Year)	476,500	74,500	551,000
Total Phosphorus (lbs/Year)	194,000	30,000	224,000

each year from the Red and White Clay creeks alone. See Table 67. Fifty-five thousand tons of that sediment reach the mouth of the Christina River. The report notes that repairing ditches, culverts, and bridges as a result of that sediment costs about $60,000 per year.

Dairy operations will contribute nutrients, bacteria, and oxygen-demanding organic materials to surface waters if not properly managed. Proper use of manure and milk-house wastes, as well as removal of direct access of animals to streams, must be achieved to avoid pollutant loading.

Mushroom production facilities can cause sediment, pesticide, and bacteria loading to nearby surface waters. There are approximately 96 mushroom production facilities in the Piedmont Basin. Twenty-six of those facilities have signed up with the Conservation District to develop cooperative conservation plans. While large operations are currently working with the Conservation District, considerable effort is still required to provide numerous small operations with conservation management strategies.

General Agriculture. The Consolidated Farm Service Agency (formerly ASCS), the Natural Resource Conservation Service (formerly SCS), the Conservation Districts, University Extension Systems, and other agencies have been working with farmers to advance sustainable high-production farming. Erosion control has always been targeted with government incentives and engineering, and by advocating agronomic practices such as conservation tillage and cover cropping. When the chemical fertilizer industry came about, practices that maximized their effectiveness were promoted. When petroleum prices soared and chemicals became expensive, efficient use was promoted. Growth curves that show the fertilizer application rate at which yields level off, and historical yield information helped farmers improve net income by avoiding the expense of unnecessary inputs. Scouting methods have been developed so that pesticide inputs can be reduced to application only when necessary rather than automatic preventative application.

Development and implementation of these practices have reduced water-quality impacts coincidentally. Reducing total chemical input and carefully timing applications to meet crop needs automatically reduces leaching and runoff of excesses to ground- and surface waters. Reducing erosion in the field reduces sediment delivery to surface waters. As the knowledge of water-quality impacts from agriculture has increased, though, maintaining water quality has become a goal of farmers and agricultural agencies rather than a side benefit.

Raising the priority level of water-quality management has two particular benefits: (1) documentation of improved agricultural practices can be kept in a way that allows for correlation between those practices and water quality;

(2) management practices can be geared more effectively toward high agricultural productivity as well as reducing water-quality impacts.

In the Piedmont Basin, the Natural Resources Conservation Districts in Chester County, Pennsylvania, and New Castle County, Delaware, work with farmers to develop conservation plans. Farmers agree through conservation plans to manage farming operations in a way that minimizes nutrients, pesticides, and sediment loading to ground- and surface waters.

The two districts and the Brandywine Conservancy have signed an agreement to target the Red and White Clay creeks with concentrated conservation efforts to achieve water-quality improvements. The Watershed Plan and Environmental Assessment developed by those agencies addresses the treatment of nonpoint source pollution to restore water quality and aquatic habitat. Listed in the document are recommendations to establish agricultural waste management systems, cropland resource management systems, and riparian area treatment systems. Benefits anticipated from this effort include a 28% reduction in sediment loading, 27% reduction in nutrient loading, reduced water treatment costs, 85% of the cropland protected from erosion, 3,000 acres using improved nutrient management, and 5,000 acres using improved pesticide management.

Pennsylvania has passed legislation requiring animal production operations to have nutrient management plans. The regulations required to carry out that legislation are under review. Ratification is anticipated in 1997.

The Natural Resources Conservation Districts in New Castle County, Delaware, and Chester County, Pennsylvania, are in the process of mapping agricultural lands and the locations of existing installed management practices. This information will be used to model pollution loading from agriculture and to prioritize sub-watersheds for implementation.

Silviculture. Forestland, outside of parks and preserves, has been generally reduced to areas along stream and river banks. These areas, though localized, may pose greater environmental risk if harvested because of their immediate proximity to surface water. Very little clear-cutting occurs in New Castle County other than clearing acreage for development. Select cutting is the dominant practice (Julie Klapperoth, personal communication). Since select cutting disturbs the land less, it is preferred over clear cutting. See Table 68.

Table 68

PERCENT WOODED LAND BY WATERSHED

(Delaware Portion Only)

WATERSHED	PERCENT
Shellpot Creek	10%
Naamans Creek	12%
Christina River	24%
White Clay Creek	26%
Brandywine Creek	27%
Red Clay Creek	29%

Resource Extraction. Sand and gravel are the only materials mined in Delaware. The sites, known as borrow pits, are located throughout the state. Borrow pits vary in size. A relatively small pit may be opened to supply sand for poultry-house floors. Large sites may supply sand and gravel for road construction. Active pits are a concern because (1) the groundwater table may be lowered, potentially affecting local wells; (2) sloughing of the perimeter may cause unintended expansion into adjacent properties; and (3) ground- and surface waters could be con-taminated by fuel and other industry-related materials.

Although statewide extractive-use regulations have been proposed, they have not been promulgated. The three counties have individual strategies for dealing with borrow pits. New Castle County has rigorous regulations. A proposed site must go through rezoning specifically for borrow pit activity. Applications for a permit must include an erosion and sediment control plan and a restoration and stabilization plan. Groundwater monitoring and semi-annual reporting are required. The work-face area is limited to 25 acres. New Castle County has four active borrow pits, one suspended site, and one application in-house for a new operation. Their regulations are comprehensive and effectively inhibit small operations.

Hydromodification. Hydromodification involves waterway modification (ditching, dredging, stream-bank stabilization) to manage flooding, improve navigation, improve drainage, and minimize stream-bank erosion. This category also includes flow alteration by installation of dams and water-control structures. Although not a direct waterway modification, a substantial change in flow has occurred in the Piedmont Basin as a result of development in general. Increased impervious surface, drainage swales, French drains, and detention ponds all change drainage patterns in a watershed.

Flood control and stream-bank stabilization resulting from historic development as well as construction and future maintenance of sediment and stormwater detention ponds in new developments are the major concerns of municipal public works departments and the New Castle County Natural Resources Conservation District. The larger part of their work is fixing erosion and stormwater problems in neighborhoods that were built before stormwater regulations and floodplain ordinances existed. Also, older downstream developments are affected by more recent upstream developments.

In-stream flood control typically involves excavation of deposited sediments, clearance of obstructions such as brush, and widening of engineered structures such as culverts. Stream-bank stabilization typically involves use of hard surfaces, rip rap, and soil bioengineering as required by stream-flow energy. Within neighborhoods and developments, stormwater flow may be modified using swales, storm drains, and detention ponds. While these activities do not occur in-stream, redistribution of hydraulic energy will ultimately affect streams.

In-stream modification may result in temporary or permanent degradation of riparian and subaqueous habitat. Fixing a problem upstream can transfer problems downstream, in some cases requiring additional in-stream engineering. Improving or returning flow may increase sediment and pollutant transport and deposition downstream and alter hydraulic energy so that erosion, scouring, and flooding may occur farther downstream.

Efforts are made to minimize environmental impacts and anticipate downstream effects when planning flood-, stormwater-, and erosion-control projects. However, not all impacts can be avoided.

As noted earlier in the Sediment section, the extent of impervious surface (pavement, roofs) in a watershed increases stormwater runoff and increases hydraulic energy delivery to surface waterways. Somehow the streams and rivers must adjust to increased energy. The streambed will widen as stormwater scours out banks. The scoured-out sediments will be deposited downstream, which will eventually result in flooding. When properties exist along those adjustment areas, the properties are adversely affected and protection measures must be installed. If the hydraulic energy is not reduced, the stream will respond to those protection measures elsewhere.

At some point, a stream's natural characteristics are irreparably degraded. While the chemical water quality may be adequate, the stream will be devoid of life. Public works departments are then destined to maintain and repair streams in their altered condition so long as property is maintained along the stream. The public pays for these services through taxes.

Dredging and Excavation. For the purposes of this report, dredging is delineated from excavation by intent and equipment used. Dredging typically refers to removal of bottom sediments to enhance navigation. Typically, though not exclusively, hydraulic equipment is used. Excavation is removal of sediments for flood control or drainage, using mechanical equipment. The terms are often used interchangeably, however. Concerns with both activities are disturbance of habitat, temporary increases in turbidity, the potential for removed and resuspended sediments to be contaminated, clearance of riparian habitat for access, and disturbance of fish spawning areas.

Dredging is not common in the Piedmont Basin. Wilmington Harbor is dredged regularly to maintain commercial traffic. The project is sponsored by the U.S. Army Corps of Engineers. Approximately 550,000 cubic yards are removed along 6,300 linear feet between Lobdell Canal and the Delaware River about every nine months. Dredging has occurred as far as 9 miles from the Delaware River to approximately where Route 41 crosses the Christina River. The source of sediments is generally felt to be from erosion in the Christina River tributaries. Further information on dredging projects in Piedmont Basin ponds can be found in the Sediment section of this document.

Dredging projects require permits from the U.S. Army Corps of Engineers and from DNREC. Before permits are issued, applicants must verify consistency with the policies and requirements of the Delaware Coastal Management Program, the U.S. Department of Fish and Wildlife, and the National Marine Fisheries Service within the National Oceanic and Atmospheric Administration (NOAA).

Excavation is sometimes necessary to remove sediments that fill in streams and ponds in the Piedmont Basin. Little Mill Creek (off the Christina River) and Red Clay Creek near its confluence with White Clay Creek are currently being evaluated as possible excavation projects to reduce flooding.

Dams and Water-Control Structures. There are about 20 dams in the Piedmont Basin, ranging in height from 6 feet to 127 feet at Hoopes Reservoir. Rockland Dam and the Brandywine Creek Dam in Wilmington were built as far back as 1800. Many others were built in the early 1900s. The primary concern with dams is to maintain adequate pass-by flow during low-flow conditions. Failure to do so could result in fish kills from low-oxygen conditions downstream of dams. No incidences have been documented.

Water-control structures, which include weirs, sluice gates, and flap or tide gates, are not common in the Piedmont Basin. A tide gate controls tidal flow on the Shellpot River. One-way tide gates are considered detrimental to wetlands.

Tide gates, used to control flow in tidal tributaries draining to the Delaware River and Bay, were originally installed by colonists and have not changed much in design until only recently. The traditional "one-way" structure would allow water to drain from tributaries, but prevent water from flowing back in from the river during high tide. This type of management causes degradation of wetland habitat quality because it inhibits the necessary flushing and oxygenation of surface waters. New structures that allow flow both ways currently are being studied for environmental impact. If managed properly, mosquitoes and *Phragmites* can be controlled, fish populations can be diversified, and hard pans from salt deposition can be avoided.

Stream-Bank Stabilization and Restoration. As noted, stream banks may be stabilized to reduce sediment loading from scouring and to reduce property loss from stream encroachment. Typically riprap (loose stone) is placed on stream banks and is effective, where placed, at stopping scouring. However, the hydraulic energy is not diminished by this practice, and further damage may occur downstream. Also, stream-bank habitat, though already degraded by scouring, is further degraded. The Conservation District promotes maintenance of vegetative cover along the higher portions of the stream bank to reduce shade and habitat loss.

The City of Newark, in conjunction with the Conservation District, initiated a stream-bank restoration demonstration project on a section of the upper Christina River. Soil bioengineering measures were installed to stabilize degraded stream banks in a heavily used city-owned park. A similar project was implemented in the Brandywine Creek near the Wilmington Zoo. Results are currently being monitored. Such innovative techniques have not been as fully explored in Delaware as they have been in surrounding states, particularly in areas funded by the Chesapeake Bay Program. However, bioengineering efforts may be constrained by the level of shade along Piedmont Basin stream banks.

County Hydromodification Management. The Delaware Department of Transportation constructs and maintains drainage systems associated with roads. The New Castle County Public Works Department "is responsible for providing open and free-flowing conditions in public non-tidal waterways and maintaining all county-constructed drainage infrastructure" according to the Drainage Maintenance Section Program narrative. This service is "provided on a complaints or 'as called' basis."

The Public Works Department also maintains 33 stormwater management basins owned by the county and inspects all stormwater basins in public trust (managed by neighborhood maintenance associations, for instance) that were built after July 1991. The county is concerned with who will be required to maintain "public trust" basins should neighborhoods fail to maintain them. Cost of maintaining stormwater ponds is estimated at $1000/acre/year.

The Public Works Department is interested in combining, where possible, detention requirements for several developments into one basin instead of having individual basins for each development. Though compelling, actually accomplishing "co-brokering" is difficult.

In 1991, New Castle County adopted an ordinance that protects public water-supply resources. Included are the Cockeysville Formation areas, wellhead areas, surface-water areas, and recharge areas. The surface-water areas include floodplains, erosion-prone slopes, and public surface-water-supply intakes. Several county departments in conjunction with the Water Resources Agency for New Castle County are currently formulating an ordinance regarding riparian zones with habitat and water-quality protection in mind.

Both the Department of Transportation and the county Department of Public Works have been delegated authority to carry out state-level stormwater management requirements. Additionally, the county and the Department of Transportation have applied jointly to DNREC for a "Phase II" stormwater permit under the National Pollution Discharge Elimination System Program. The application process actually stipulates conditions that will be included in the permit. Included in the application are discussions regarding new development concerns, inclusion of water-quality analysis in flood studies, and participation by the county and the Department of Transportation in basin projects.

A key frustration voiced by the chief of Drainage Operations, and mirrored by other agencies and the public, is the difficulty in determining how surface waters are delineated from one environmental program or agency to the next. Workshops have been held with the county to clarify those delineations. However, delineations may still be elusive when trying to comply with regulations on a day-to-day basis. Not only are legal delineations difficult, but understanding how a project affects different environmental goals may be confusing, and perhaps contradictory, as well. For many, understanding why a project may be acceptable according to state subaqueous regulations but not to federal Army Corps of Engineers regulations, or why the project will not cause concern to the Division of Fish and Wildlife but will be harmful according to the Wetlands and Subaqueous Lands Section, is a challenge. That frustration and confusion may inhibit our ability to establish cooperative relationships with other agencies.

As noted in the program description, waterway clearance efforts are made upon request. The county has a backlog of requested projects. This system of response to requests does not allow resources for holistic watershed planning. While some watersheds in the Christina basin are developed so extensively that proactive measures are not possible, some watersheds may benefit from comprehensive hydraulic modeling and subsequent planning. Resources do not currently exist for such efforts.

On-Site Waste Disposal Systems. Septic systems are the main method for treating domestic wastewater in the unsewered areas of the Piedmont Basin. In portions of unsewered sections, cesspools are still being used; however, most are undocumented. As sewer systems are developed in areas where septic systems and cesspools are used, the latter are slowly being decommissioned.

A cesspool is usually a large, open-bottomed tank that drains both liquid and solid wastes directly to the subsurface. A septic system is a more engineered waste disposal system, usually composed of a holding tank for solids and a distribution box and drainage field for liquids. The drainage field may be either gravity-fed or pressure-dosed.

The New Castle County Department of Public Works has the governing authority over central sewer and its location. Information regarding central sewer locations has not yet been provided by New Castle County; however, both the 1980 and 1990 census provide percentages of central sewer systems versus on-site disposal systems. Although breakdown of central sewer versus on-site systems per county was obtained from the 1980 census (percentage profile provided by DNREC, 1987; and Delaware Economic Development Office), a per-county breakdown was not available for the 1990 census.

During 1980 in New Castle County, 137,359 households (92.5 %) were centrally sewered, while 10,529 households (7.1 %) had on-site disposal systems. Per the 1990 census, 212,793 households statewide had central sewer while 74,541 households had on-site systems.

In 1986, New Castle County allowed DNREC to conduct site evaluations in the county. Since then, 1,763 site evaluations have been conducted in the Piedmont Basin. This count includes lots evaluated prior to subdivision, possibly suggesting a lower number of sites than that actually permitted. Based upon septic records, 1,559 septic permits have been issued since DNREC took over the permitting program in April 1991; until then, New Castle County approved septic system installations. Within the Piedmont Basin, five failing septic systems have been reported to Environmental Enforcement since January 1996. Complaints were directed to the Groundwater Discharge Branch for compliance follow-ups. Seven holding tank permits have been issued within the Piedmont Basin.

White Clay Creek Watershed. As shown on Map 27, 26% of the developed residential area of this watershed is served by on-site disposal systems. A significant portion of the dwellings are served by cesspools. In recent years, however, the number of cesspools has diminished. Most of the land that is developed with septic systems has a slope greater than 10%. New Castle County has restricted any development on slopes that are greater than 15% and prohibits development on slopes greater than 25%. This slope-restriction ordinance has effectively reduced slope development in this watershed. Generally, the White Clay Creek watershed has moderate to severe limitations for on-site waste disposal due to the presence of slopes in excess of 15%, poorly drained soils, and isolation-distance requirements to watercourses. A significant portion of this watershed is sewered by New Castle County. Septic systems presently range from gravity-fed systems to engineered, pressurized systems on the steeper slopes and in wetter soils. Only a few holding tanks have been allowed in the Piedmont Basin.

To evaluate impacts from on-site waste management practices, Nizeyimana et al. (1996) studied nitrogen loading to groundwater from septic systems in Pennsylvania. They developed a methodology to compute nitrogen loading using a Geographical Information System, 1990 census data, and the state soil geographic data base. The White Clay Creek watershed was one of 14 watersheds in Pennsylvania that had very high nitrogen-loading rates from septic systems. The investigators estimated the loading rate to be about one pound per acre per year of nitrogen and concluded that nitrogen loads correlate with population density. This study demonstrated that a significant amount of nitrogen loading to ground- and surface waters may originate from septic systems. Much of the nutrient loading to the White Clay Creek watershed could originate from outside Delaware's border from developments with on-site septic systems.

Red Clay Creek Watershed. The Red Clay Creek watershed (see Map 27) has a slightly greater number of *residences* (34%) served by septic systems, but actually has fewer *individuals* on septic systems. A significant portion of the dwellings are still served by cesspools. Most of the developable land has a slope greater than 10%. Slopes tend to be steeper than those found in the White Clay Creek watershed. Most of the septic systems in this watershed are gravity systems. Where slopes are greater than 10%, the systems are engineered and often pressurized to compensate for slope.

Nizeyimana et al. (1996) calculated a loading rate to groundwater of approximately one pound per acre per year of nitrogen for the Red Clay Creek watershed, similar to that estimated for the White Clay Creek watershed. This watershed was also one of 14 watersheds in Pennsylvania with high nitrogen-loading rates from septic systems. Similar to the White Clay Creek, much of the nutrient loading may originate from outside Delaware. A significant portion of this watershed is served by the New Castle County sewer system.

Brandywine Creek Watershed. Brandywine Creek watershed has one of the highest percentages (60%) of land area served by septic systems although this watershed has the fewest septic systems per acre in the Piedmont Basin. Many of the developed parcels tend to be larger than 5 acres. Many older dwellings in the Chateau area of the watershed are still served by cesspools. Brandywine Creek watershed has some of the steepest and rockiest slopes in the Piedmont Basin. The Neshaminy-Aldino-Watchung and the Neshaminy-Talleyville-Urban Land Associations tend to be less suited for septic systems due to their low permeability and poor drainage. These areas are served by the New Castle County sewer system.

Nizeyimana et al. (1996) estimated the nitrogen-loading rate to groundwater to be approximately 0.7 pound per acre per year. This loading rate is lower than that in the Red Clay Creek or White Clay Creek watersheds, but is still considered a high rate. Brandywine Creek watershed has the only commercial spray irrigation facility within the Piedmont Basin. This spray facility was recently permitted for a dairy operation near the Pennsylvania state line.

Shellpot Creek Watershed. Most of this watershed is urban and is served by the New Castle County sewer system. Only 646 acres of the total residential area (7,367 acres) are not sewered.

Naamans Creek Watershed. Most of this watershed is urbanized and sewered by New Castle County. Only 6 acres of the residential area (2,995 acres) are not sewered.

Christina River Watershed . The Christina River watershed has the largest area of residential development in the Piedmont Basin. Approximately 60% of the area is served by septic systems. Most of these developments are relatively recent. Some of the earliest subdivisions within the watershed were developed with cesspools on soil that was unsuitable for residential development. The Christina River watershed has some of the least sloping ground in the Piedmont Basin. Overall, this watershed has moderate to severe limitations for on-site waste disposal due to slopes greater than 15%, poorly drained soils, and isolation distance requirements to watercourses. Systems that are suitable for this area range from gravity-fed systems to engineered pressurized systems.

Extrapolating from the Nizeyimana et al. (1996) study, the nitrogen-loading rate of the Christina River watershed ranges from 0.7 to 1.0 pound per acre per year. The Chris-tina River basin has a high percentage of septic systems and, unlike the Red Clay Creek or White Clay Creek and Brandywine watersheds, most of the nitrogen nutrient load is likely attributed to septic systems located within Delaware. New Castle County has already eliminated the use of many septic systems in areas of high failures, unsuitable soils, and sewer-system availability. Many older subdivisions are now proposed for septic elimination.

Another source of contamination appeared during the winter of 1995. A single mushroom farm in Pennsylvania stockpiled its composted horse manure. Seepage from the piles eventually discharged into Mill Creek, affecting turbidity and ammonia levels. Elevated ammonia, nitrogen, and total coliform concentrations were detected at levels toxic to aquatic life. This scenario could occur throughout the basin if compost-handling best management practices are not employed.

Program Descriptions

Nonpoint Source Pollution Program. Delaware's Nonpoint Source Pollution Program (319 Program) seeks to address nonpoint source pollution through coordination with other agencies and by funding projects through a competitive grant process. To utilize resources efficiently, the 319 Program is required by law and by guidance to assess the extent and causes of nonpoint source pollution and to direct control and mitigation.

The two guiding documents of the Nonpoint Source Program are the Assessment Report and the Management Plan. The Assessment Report identifies waters that require work to attain or maintain water-quality standards, identifies nonpoint sources that contribute significant pollution to those waters, and describes measures that will reduce nonpoint sources. Watersheds and issues are prioritized for efficient use of grant funds. The White Clay Creek and the Christina River are priority watersheds for the Nonpoint Source Program. The Management Plan identifies management practices that will reduce pollutant loadings and programs that can implement those management practices, and establishes a schedule containing annual milestones for implementation.

As a prioritized watershed, the Christina River and its tributaries have been targeted for resource allocation by the Nonpoint Source Program. Over the next several years, the Christina basin project will be the most comprehensive project that the Delaware Nonpoint Source Program has participated in to date. Many agencies are involved:

- Chester County Conservation District
- Chester County Water Resources Authority
- City of Newark, Delaware
- Delaware Department of Natural Resources and Environmental Control, Nonpoint Source Program and Watershed Assessment Branch
- Delaware Geological Survey
- New Castle Conservation District
- Pennsylvania Department of Environmental Resources, Nonpoint Source Program
- U.S. Geological Survey
- Water Resources Agency for New Castle County

Begun as a "Total Maximum Daily Load" (TMDL) process for the Christina River, a core work group, composed mainly of point-source experts and hosted by the Delaware River Basin Commission, met in 1994 in West Chester, Pennsylvania, to determine a plan of action. Because the basin has strong point and nonpoint components, a sub-work group was formed to develop a nonpoint source strategy that would be compatible with the ongoing process.

A model was chosen as a vehicle to quantify nonpoint-source pollutant loads and integrate those quantifications with point-source pollutant load quantifications. Over the next several years, existing information will be gathered, additional necessary data will be collected, the basin will be modeled, sub-watersheds will be prioritized for targeting action, and a comprehensive watershed management plan will be created. Throughout the process, educational and demonstration projects will be implemented.

Underground Discharge Branch. Building a septic system in Delaware is a three-step process. The Groundwater Discharges Branch is responsible for ensuring that the process meets Title 7, *Delaware Code*, Chapter 60. The first step requires a site evaluation, which consists of investigating, evaluating, and reporting the basic soil and site conditions that are used to design on-site systems. Each report describes specific site conditions or limitations including, but not limited to, isolation and separation distances, slopes, existing wells, cuts and fills, and unstable landforms. Each report also contains information about zoning verification; the type of on-site disposal system that must be constructed in the acceptable on-site disposal area; the hydraulic conductivity test conducted; easements, and underground and overhead utilities in the evaluated area.

This siting procedure ensures that septic systems are located based on soil properties: permeability, texture, structure, consistence, redoximorphic features, slope, and depth to rock. New Castle County has restricted any development on slopes that are greater than 15% and prohibits development on slopes greater than 25%.

The second step requires hiring a licensed system designer to design the septic system required by the approved site evaluation and obtaining design approval by the Underground Discharge Branch. After the permit is approved, a licensed system contractor is hired to construct the system under the branch's supervision.

Direct Surface-Water Discharge Program. Pursuant to both state and federal law and regulations, any discharge of a "pollutant" from a "point source" to state waters is unlawful unless such discharge is sanctioned by a permit. Such permits are issued and administered in accordance with the National Pollutant Discharge Elimination System (NPDES). Every NPDES permit issued must include conditions that reflect the application of either the "best available technology economically achievable" or the "best conventional pollutant control technology", as defined by the administrator of the EPA. More stringent limitations or conditions may be imposed when deemed necessary to meet any applicable surface-water-quality standards and to protect the designated uses of the receiving waters.

While it is obvious that industrial, municipal, and agricultural wastes discharged into water are considered "pollutants," the term is broadly defined as any material or substance that adversely changes the chemical, physical, biological or radiological properties or characteristics of water. Whether or not a substance is actually a pollutant, then, depends upon the amount or concentration discharged and the effect it has on the receiving waters.

A "point source" is generally a pipe, ditch, channel, or other discrete conveyance from which pollutants are discharged. Point-source discharges can be linked to a specific source and location. They typically include discharges from municipal wastewater treatment plants and industrial facilities. Discharges of urban runoff, stormwater "associated with industrial activities," cooling water, and combined sewer overflows may also be regulated as "point source discharges of pollutants."

Although an NPDES permit legally sanctions the discharge of substances that may be considered pollutants, it is designed to effectively limit the discharge of those substances such that the discharge would not, or would not be expected to, adversely affect the quality of the receiving waters or interfere with the designated uses of those waters.

The Surface Water Discharges Section within the Division of Water Resources is responsible for administering the NPDES program in Delaware. The public is notified whenever the division makes a tentative determination on a given NPDES permit application (e.g., a decision to issue, re-issue, or deny the application; or if a permit is to be issued, the conditions to be included in the permit and the basis for those conditions). The public is given an opportunity to comment on the draft permit and have a voice in reaching a final decision. See Table 69.

While the NPDES Program relies on the discharger to generate and report the information needed to demonstrate that the discharge meets the objectives of the permit (i.e., each NPDES permit issued includes provisions that require the discharger to collect representative samples of the discharge, analyze specified parameters, and report the results), Surface Water Discharges Section staff review the data submitted, conduct their own surveillance and monitoring program, and provide whatever assistance is deemed necessary to assure permitted facilities regain or maintain compliance.

Table 69

DELAWARE INDIVIDUAL NPDES PERMITS

PERMIT NO.	COMPANY	MINO AJO	IND/ MUNIC	BIO-MONIT.	RECEIVING WATERS	BASIN	RIVER	TRIBUTARY	DISCHARGE DESCRIPTION
DE 00004	Ciba-Geigy Corp.	Minor	Ind.	A	Delaware Riv	Christina River			Contam. Stormwater
DE 00217	Winterthur	Minor	Mun.		Delaware Riv	Christina River	Brandywine Riv	Clenney Run	Small STP
DE 00509	AMTRAK	Minor	Ind.		Delaware Riv	Christina River	Brandywine Riv	B'wine (001), Shellpot Creek	Contam. Stormwater
DE 00000	DuPont Exp. Sta.	Minor	Ind.		Delaware Riv	Christina River	Brandywine Riv		Stormwater&Cooling
DE 00005	DuPont Chestnut Run	Minor	Ind.	C	Delaware Riv	Christina River	Little Mill Creek	Chestnut Run & Willow R	Cooling Water
DE 00005	Gen. Motors Assembly	Minor	Ind.	A	Delaware Riv	Christina River	Little Mill Creek		Storm & Groundwater
DE 00510	Boeing	Minor	Ind.	A	Delaware Riv	Christina River	Nonesuch Creek		Contam. Stormwater
DE 00217	Greenville Country Club	Minor	Mun.		Delaware Riv	Christina River	Red Clay Creek	Tributary	Small STP
DE 00500	Center for Creative Arts	Minor	Mun.		Delaware Riv	Christina River	Red Clay Creek	Tributary	Small STP
DE 00002	Hercules, Inc.	Minor	Ind.		Delaware Riv	Christina River	Red Clay Creek		Cooling Water
DE 00004	NVF, Yorklyn	Minor	Ind.	C	Delaware Riv	Christina River	Red Clay Creek		Cooling & Processing
DE 00001	FMC Corp.	Minor	Ind.	A	Delaware Riv	Christina River	White Clay Creek	Cool Run	Cooling Water
DE 00201	Dragon Run Terrace MH	Minor	Mun.		Delaware Riv	Dragon Run			Small STP
ELIMINATED NPDES DISCHARGES									
DE 00003	Airco Industrial Gases	Minor	Ind.		Delaware Riv	Naamans Creek			Cooling Water
DE 00002	Ametek-Haveg Div.	Minor	Ind.	A	Delaware Riv	Christina River	Red Clay Creek		Cooling Water
DE 00507	Artesian Water Co.	Minor	Ind.		Delaware Riv	All N.C.C. Streams			Water Tank Rinse
DE 00216	Brandywine Raceway	Minor	Mun.		Delaware Riv	Christina River	Brandywine Riv	Br. of Beaver Creek.	Small STP
DE 00003	DuPont Stine-Haskell	Minor	Ind.		Delaware Riv	Christina River	West Branch		Cooling Water
DE 00218	Eleutherian Mills Lib	Minor	Mun.		Delaware Riv	Christina River	Brandywine Riv		Small STP
DE 00218	Hagley Museum	Minor	Mun.		Delaware Riv	Christina River	Brandywine Riv		Small STP
DE 00005	MEDAL, Willow Bank	Minor	Ind.		Delaware Riv	Christina River			Cooling Water
DE 00004	NVF Newark	Minor	Ind.		Delaware Riv	Christina River	White Clay Creek		Cooling Water
DE 00505	Q-C, Inc.	Minor	Mun.		Delaware Riv	Christina River	Red Clay Creek (Tributary of)		
DE 00508	Shellhorn & Hill	Minor	Ind.		Delaware Riv	Christina River			
DE 00002	Wilming. Finishing Co.	Minor	Ind.		Delaware Riv	Christina River	Brandywine Riv		Cooling Water

LAND USE

Land use, in its most fundamental sense, is the classification of how land is used. Categories including residential, commercial, industrial, and community facilities; recreation; and open space all attempt to define settlement patterns — how land is developed or not developed (please see Maps 28, 29, 30).

Land-use analysis attempts to show the physiographic relationships between the natural environment and the developed environment, including resource limitations indicated by hydrologic and topographic features, and developable land factors indicated by soils, areas with aquifer recharge potential, and landscape vistas. Other variables are also included in the analysis of land use, such as ownership patterns and economic land values.

Land-Use Characteristics, Trends, and Sources of Impact

As illustrated in Maps 28 and 29 showing Piedmont Basin land use in 1982 and in 1992, respectively, the Anderson Land-Use Classification System, used by DNREC's Geographical Information System (GIS), separates land uses into these categories: Urban Built-Up, Agriculture, Brushland, Rangeland, Forestland, Wetlands, Water, and Barren Land. For the purposes of this report, Urban Built-Up includes residential, commercial, and industrial areas, as well as transportation, utilities, mixed urban, and other undifferentiated urban, institutional, and recreational areas. Agricultural land is a separate category. Forestland, Brushland, Rangeland, and Barren Land is combined under the Forest/Open Land category. Wetlands and Water also have been combined since relative to other categories of land use, this category changed little over the study period. These categories were compared to one another in the tables found in this section.

The trends section was generated by a rough comparison of time-series changes in land-use and land-cover data taken from 1982 and 1992 photography. These projects used similar variations of the Anderson Land-Use Classification System. The 1982 photography was interpreted and mapped in 1982 according to 7.5-minute U.S. Geological Survey quadrangles at a 10-acre minimum mapping unit, which means that the predominating use in each 10-acre or larger tract was used to label the individual polygons. The 1992 photography was interpreted and mapped at the quarter-quadrangle level using a 4-acre minimum mapping unit.

Therefore, the 1992 information is much more useful for showing smaller individual features such as settlement patterns and is not directly comparable to the 1982 data. For example, the total acreages for the watersheds are not exactly the same for the two data sets. However, since the differences are small numbers with respect to the whole watersheds, the acreages and percentages are shown for comparisons. In addition, the acres changed between 1982 and 1992 are relative numbers, but the errors are a small fraction of the total watersheds. Finally, the data for both years could be further refined to determine and correct the cause of discrepancies and classification errors in the original photo interpretation.

White Clay Creek Watershed

Urban Built-Up

As shown in Table 70, this category of land use shows a marked increase, from 38% in 1982 to 54% in 1992. In this watershed, the Pike Creek and Hockessin areas are experiencing heavy growth pressures. These areas in conjunction with the Pencader Hundred region will probably continue to lead the Piedmont Basin in growth in the near future.

There are active industrial sites located adjacent to the White Clay Creek and inactive industrial sites in Newark that present opportunities for providing high-quality employment opportunities without disrupting any critical habitats. Several abandoned industrial sites downstream of the Curtis Paper Mill could be redeveloped using the Brownfields and Blue Collar Jobs programs.

A major highway improvement that could stimulate growth is being built at the Route 273 and Ogletown Interchange. The interchange could connect to the new U.S. 301 if the 1995 to 2001 Delaware Transportation Capital Improvement Plans are fully implemented. Improvements to Route 7, Polly Drummond Hill Road, the Route 7 Christiana Crossing intersection, Route 58 extension, Pike Creek Road, Stoney Batter Road, and Valley Road are planned and could further stimulate growth.

There has been some study by Newark and the Delaware Department of Transportation of a future highway bypass around Newark that could cut through developed and undeveloped areas to the south and to the west of the city. This project would be located in the Christina River watershed, but development pressures would also be felt in the White Clay Creek watershed. Recently, funds were designated to improve signalization in the City of Newark to manage congestion.

Rail transportation for industry, passenger service, and bulk shipment is provided by the Consolidated Rail Corporation and the Amtrak Northeast Corridor. Several abandoned industrial sites including the NVF facility by Curtis Mill and the Continental/Budd/NVF plant enjoy rail access. Passenger service along the Amtrak line is possible in Newark, and a regional commuter station has been proposed in the Bread and Cheese Island area. Rail transportation produces fewer air impacts, has fewer hazardous material accidents per ton mile, and is more energy efficient. However, a regional commuter station at Bread and Cheese Island would have to be carefully planned to avoid impacts to wetlands and wildlife habitat.

Agriculture

This land use declined from 27% as measured in the 1982 mapping to 12% in 1992. Due to land prices, the economic attractiveness of development, tax laws that favor selling assets of estates, the breakdown of local agribusiness, and other pressures, the loss of agriculture in this area will likely continue, but at a slower rate because University of Delaware agricultural lands are located here. It is unlikely that the university will develop its agricultural land in this watershed. However, the potential loss of the remaining privately owned farmland is high. Such development could impact habitat quality and increase the potential for nonpoint source pollution and flooding.

Forest/Open Land

This category registered 33% in 1982 and 31% in 1992. The decreased acreage in this category is probably due to development activity. Some forested areas are too sloped for farm machinery or development, and some large forested tracts have been preserved through acquisition efforts. Since there are so few active farming operations, it is unlikely that significant forestland was cleared to provide additional cropland. There is a large connected tract of forest north of Newark and along the northern sections of Middle Run. Other connected forests and open land along Pike Creek and Mill Creek are important to the quality of those waterways.

Wetlands/Water

The small 424-acre gain in wetlands, which was 2% of the total watershed in 1982 and 3% in 1992, is probably due to changes in the minimum mapping unit from 10 acres in the 1982 project to 4 acres in 1992. There was also a gain in Churchman's Marsh, where lands were classified as brushland in the 1982 project and as wetlands in 1992. The gain in water in 1992 is probably due to differences in the Churchman's Marsh area. The 1992 map, which recognized the White Clay and Red Clay junction and greater surface water in the Churchman's Marsh area, is probably indicative of the conditions that existed in 1982.

Red Clay Creek Watershed

Urban Built-Up

As expected from increases in population and development activity, this category rose from 40% in 1982 to 58% in 1992. See Table 71. This classification includes land in commercial, services, institutional, industrial, transportation, utilities, communication, and recreational categories. Most of the new growth occurred in the upper areas of the watershed around Hockessin and Yorklyn.

There are active industrial sites adjacent to Red Clay Creek that have upgraded their operations, but historic contamination and some pollutants from Pennsylvania have curtailed recreational uses of the stream. Major improvements are under construction on Route 48 (Lancaster Pike) and planned for Hercules Road (SHR 282). These improvements could stimulate new development and may lead to greater air pollution and other impacts.

Recreational rail transportation is provided by the volunteer-operated Wilmington and Western Railroad. This line uses restored historic steam engines and passenger cars to operate a railroad along Red Clay Creek. The recreational use of the stream helps educate visitors about the waterway's values and beauty.

Agriculture

Agricultural land use declined from 27% in 1982 to 12% in 1992. Due to the economic attractiveness of development, tax laws that favor selling off the assets of estates, the breakdown of local agribusiness, and other pressures, the loss of agriculture in the area is likely to continue. Most of

Table 70
WHITE CLAY CREEK WATERSHED LAND USE/LAND COVER COMPARISON

CLASSIFICATION	1982 ACRES	PERCENT OF WATERSHED	1992 ACRES	PERCENT OF WATERSHED	ACRES CHANGED
Urban Built-Up	11,286	38%	15,898	54%	4,612
Agriculture	7,842	27%	3,490	12%	-4,352
Forest/Open Land	9,852	33%	9,245	31%	-607
Wetlands/Water	492	2%	916	3%	424
Total	**29,472**	**100%**	**29,549**	**100%**	

the remaining land in agriculture is in large estates. Some of these are protected through conservation agreements with Delaware Nature Society.

Forest/Open Land

Forest and open land declined slightly during the period, from 32% in 1982, to 28% in 1992. As indicated by the maps, some forested and open land south of Hoopes Reservoir was converted to residential development. Connected forested and open land is around the reservoir and on the riparian steep slopes north and west of the reservoir.

Wetlands/Water

The total acreage of wetlands and water stayed nearly constant during this period, composing just 1% of the watershed in 1982, and 2% of the watershed in 1992. More wetlands appeared to have been recognized by the 1992 maps in the lower section of Red Clay Creek before it leaves the watershed due to the greater resolution of the 1992 data. In the 1992 map, Hoopes Reservoir appears larger, perhaps due to the greater resolution of the 1992 data.

Brandywine Creek Watershed

Urban Built-Up

This category of land use rose from 43% of the total basin in 1982 to 60% in 1992. See Table 72. As indicated by the maps, most of this new growth occurred in the northern Delaware sections of the watershed.

There are inactive industrial sites in Wilmington located along Brandywine Creek, including the Bancroft Mills, and underutilized industrial sites along the lower Brandywine that have redevelopment potential. Through cleanup and adaptive reuse, these sites can provide economic growth with smaller environmental costs, compared to developing in pristine areas where little or no infrastructure exists. In addition, according to the Governor's Task Force on the Future of the Brandywine and Christina Rivers, there are riparian tracts between Josephine Gardens and the industrial park adjacent to 12th Street that are junkyards which could be acquired for parkland or housing. They present opportunities for providing high-quality recreational amenities and employment without disrupting any critical habitats.

Urban growth is stimulated by easy access to Interstate 95, which connects Delaware to the bustling mega-

Table 71
RED CLAY CREEK WATERSHED LAND USE/LAND COVER COMPARISON

CLASSIFICATION	1982 ACRES	PERCENT OF WATERSHED	1992 ACRES	PERCENT OF WATERSHED	ACRES CHANGED
Urban Built-up	5,413	40%	7,882	58%	2,469
Agriculture	3,623	27%	1,610	12%	-2,013
Forest /Open Land	4,257	32%	3,721	28%	-536
Wetlands /Water	165	1%	293	2%	128
Total	**13,458**	**100%**	**13,506**	**100%**	

Table 72
BRANDYWINE CREEK WATERSHED LAND USE/LAND COVER COMPARISON

CLASSIFICATION	1982 ACRES	PERCENT OF WATERSHED	1992 ACRES	PERCENT OF WATERSHED	ACRES CHANGED
Urban Built-up	6,249	43%	8,759	60%	2,510
Agriculture	3,684	25%	1,953	13%	-1,731
Forest/Open Land	4,625	32%	3,680	25%	-945
Wetlands/Water	115	< 1%	314	2%	-199
Total	**14,673**	**> 100%**	**14,706**	**98%**	

lopolis that includes New York, Philadelphia, Baltimore, and Washington, DC. Major arteries include Concord Pike, Route 13, Kirkwood Highway, Route 141, and Kennett Pike, which connect the watershed with Philadelphia, Dover and other points south, Newark, and Kennett Square. Highway access to major population centers stimulates growth and causes air-quality and other concerns.

Other planned highway changes are designed to accommodate existing growth such as improvements to Route 141 at the Rockland Road intersection. The upgrading of Route 141 to four lanes is continuing to improve traffic flow to Route 202 (Concord Pike) from Newport and Route 13. The planned building of an additional twin-lane span across the Brandywine adjacent to the Tyler McConnell Bridge will further improve capacity and stimulate growth.

Rail transportation is provided in the area between steel mills in Pennsylvania and the Port of Wilmington by the Octoraro Railroad. Amtrak operates the Wilmington Shops facility in the lower Brandywine. Rail transportation stimulates economic growth and produces fewer environmental impacts compared to highway transportation. Historic contamination exists along many rail facilities.

Agriculture

In 1982, agricultural uses constituted 25% of this watershed. In 1992, only 13% of the land was used primarily for agriculture. As indicated by the maps, this loss probably was due to increased development into residential uses. Much of the remaining agricultural land in this watershed remains in large private estates.

Forest/Open Land

Acreage in this category decreased from 32% in 1982, to 25% in 1992. As indicated by the maps, this decline could be attributed to a transition to urban uses. Most of the remaining forest and open land in the watershed is connected and occurs along Brandywine Creek and some of its tributaries.

Wetlands/Water

As shown by the maps, this category was less than 1% of the total watershed in 1982, and 2% in 1992. The difference in wetlands from 115 acres in 1982 to 46 acres in 1992 was probably due to differences in land classifications between the two projects. As indicated on the maps in 1982, an area around the Wilmington Shops – Amtrak Maintenance Facility was classified as wetlands. In 1992, this same area is unclassified, and more riparian wetlands along the Brandywine Creek are recognized. With respect to water, the most apparent difference in the maps is the inclusion of the main stem of Brandywine Creek in the 1992 map.

Shellpot Creek Watershed

Urban Built-Up

Residential uses increased from 77% in 1982, to 84% in the 1992 data. See Table 73. As indicated by the maps, the gain was due to the development of agricultural land and lands classified as wetlands and water. Major highways that serve this area and are important stimulators of growth include Interstate 95, Interstate 495, Business Route 13, and Route 13. Important arteries include Marsh Road, Foulk Road, and portions of Harvey Road. Rail transportation crosses the area for the Conrail and Amtrak lines.

Agriculture

Agriculture declined from 3% in 1982, to 1% in 1992. The maps indicate that the loss was due to development.

Forest/Open Land

Forested and open land remained relatively constant at 12% in 1982 and in 1992. The remaining forest and open

Table 73
SHELLPOT WATERSHED LAND USE/LAND COVER COMPARISON

CLASSIFICATION	1982 ACRES	PERCENT OF WATERSHED	1992 ACRES	PERCENT OF WATERSHED	ACRES CHANGED
Urban Built-up	6,955	77%	7,742	84%	787
Agriculture	252	3%	97	1%	-155
Forest/Open Land	1,089	12%	1,100	12%	11
Wetlands/Water	774	9%	254	3%	-520
Total	**9,070**	**101%**	**9,193**	**100%**	

land appears to occur along riparian areas that may be unsuitable for development due to the presence of slopes, floodplains, and wetlands.

Wetlands/Water

Wetlands declined from 9% in 1982, to 3% in 1992. This loss appears to be due to changes in classification of the 1982 wetlands around the Wilmington Shops – Amtrak Maintenance facility to an unclassified use in 1992, the changes in classification of the wetlands along the Fox Point State Park due to higher tides in 1992, and the change in the classification of the Cherry Island Landfill from wetlands in 1982 to barren land in 1992. The Amtrak facility appears to be in the Brandywine and Shellpot watersheds.

Water was not classified in the 1982 map. In 1992, water accounted for 2% of the watershed. The gains occurred at the Wilmington Waste Water Treatment Plant and a body of water at Bellevue State Park.

Naamans Creek Watershed

Urban Built-Up

The data indicate a rise of 297 acres of developed areas, from 83% of the watershed in 1982 to 87% in 1992. See Table 74. As the maps show, small changes in the watershed of new land conversions to urban uses have occurred.

Agricultural

Agricultural land declined from 3% in 1982 to 1% in 1992. A relatively large area south of the Marcus Hook oil refinery was classified as agricultural in 1982. However, in 1992, this was shown as residential.

Forest/Open Land

As indicated by the maps and the data, forested lands remained nearly constant at 13% to 12% from 1982 to 1992. During this period, only 39 more acres were classified as forest. Nearly all the remaining forestland occurs in a connected parcel on the border of Arden along Naamans Creek.

Wetlands/Water

This category was less than 1% for the period. In 1982, there were 8 acres in this classification; in 1992, there were 35 acres. The differences probably reflect the use of a smaller minimum mapping unit in 1992.

Christina River Watershed

Urban Built-Up

As expected from changes in population and development activity, this category of land use has grown. The data indicate residential uses rose from 48% to 59% during the 1982 – 1992 period. See Table 75. While the difference between the two data sets is not as high a percentage change as in the other Piedmont Basin watersheds, this watershed has the highest number of acres of new urban uses. Much of the growth has occurred in the Pencader/Glasgow region. A good deal of what we see under construction today has occurred since the 1992 photography was prepared and shows that this watershed, along with the Hockessin and Pike Creek areas, will lead the Piedmont Basin in growth.

The Christina River has been an industrial river since colonial times. While cleanup has produced benefits, facilities in Newport and along the urban waterfront including the Port of Wilmington still impact the lower Christina River watershed. Industrial discharges and site runoff produce water-quality impacts from point and nonpoint sources. Redevelopment and revitalization of this area can produce economic and environmental benefits. Incentives applied here can benefit conservation efforts elsewhere since accommodating growth here will make use of existing infrastructure, be conducted in parallel with cleanup, and relieve development pressure on more viable habitat in less developed areas.

Water transportation is provided at public access points along the river for small recreational boats at Route 7, Newport, and the Seventh Street Peninsula in Wilmington. At various times, commercial traffic used the river. The town of Christiana was a seaport in colonial times.

Table 74
NAAMANS CREEK WATERSHED LAND USE/LAND COVER COMPARISON

CLASSIFICATION	1982 ACRES	PERCENT OF WATERSHED	1992 ACRES	PERCENT OF WATERSHED	ACRES CHANGED
Urban Built-up	5,345	83%	5,642	87%	297
Agriculture	215	3%	63	1%	-152
Forest/Open Land	859	13%	761	12%	-98
Wetlands/Water	8	< 1%	35	< 1%	27
Total	**6,427**	**> 99%**	**6,501**	**> 100%**	

However, the Christina River is much shallower now due to silt from erosion and runoff. Major improvements are planned and are in various stages of development along the Wilmington urban waterfront, which was a major industrial area and shipbuilding facility in World War I and II. The improvements are being coordinated by the Wilmington Waterfront Development Corporation.

The Port of Wilmington, owned and operated by the state of Delaware, provides ocean access for the region. Development is encouraged at the port to serve the state's economic needs. The port may need to be expanded in the future in order for it to remain competitive with other ports in the region.

This watershed also contains the New Castle County Airport, which is the only commercial air facility in the state capable of handling cargo and passengers on supersonic transports and jumbo jets. There is also a Delaware National Guard base at the airport.

Agriculture

This use declined from 16% in 1982 to 8% in 1992. Due to the economic attractiveness of development, tax laws that favor selling off the assets of estates, the breakdown of agribusiness, and other pressures, the loss of agriculture in the area is likely to continue.

Forest/Open Land

The data indicate that forest and open land uses were 32% in 1982 and 25% in 1992, with a loss over the period of 2,866 acres less in 1992. As of this writing, greater losses than that could be expected due to ongoing development pressures and agricultural conversion of forestland into cropland to replace lost agricultural lands. Major connected forested areas appear to be along the riparian corridor in floodplain areas, in wetlands west of Glasgow, and on and around Iron Hill and Chestnut Hill.

The maps indicate barren land associated with development activity in Glasgow Industrial Park, Fox Run, and other shopping centers along Route 40. There are also several large tracts of land being developed around the routes 40 and 273 intersection and the Cherry Island Landfill. As other lands, including agricultural areas, are displaced for development, they may become barren because they are not cropped but left in a holding pattern between productive uses.

Wetlands/Water

The 911-acre gain in wetlands and water, from 5% in 1982 to 7% in 1992, is probably due to poor wetland and water-layer coverage in the 1982 map, which used a 10-acre minimum mapping unit, as compared to the 1992 map, which used a 4-acre minimum mapping unit. Many wetlands are rather small areas of land and will not show up well at the 10-acre mapping unit. Known losses of wetlands have occurred since 1982, including a classification change in 1992 from wetland to barren land for the Cherry Island Landfill, progression of wetland areas into forest, and losses due to development. In 1982, the 10-acre minimum mapping unit appeared to interfere with recognition of the Christina River and its smaller tributaries as water. Also in 1982, the main stem of the river is not classified at all. Finally, it appears that the tide was higher in the 1992 map. These factors could explain the differences in the maps.

Positive Initiatives

There are many positive land-use initiatives under way in the Piedmont Basin. For example, the county has several land-use regulations such as wetland protection policies, floodplain protection programs, steep slopes protection, open space requirements, water resource protection overlay districts, designation of critical natural areas, and requirements for transportation analysis in rezoning and development that are applied throughout the county. In addition, cluster development regulations can be applied to develop sites and conserve significant areas of sensitive lands. Finally, the comprehensive land-use plan for the county is undergoing an update. The update will incorporate

Table 75
CHRISTINA WATERSHED LAND USE/LAND COVER COMPARISON

CLASSIFICATION	1982 ACRES	PERCENT OF WATERSHED	1992 ACRES	PERCENT OF WATERSHED	ACRES CHANGED
Urban Built-up	20,530	48%	25,468	59%	4,938
Agriculture	6,727	16%	3,322	8%	-3,405
Forest/Open Land	13,497	32%	10,631	25%	-2,866
Wetlands/Water	1,968	5%	2,879	7%	911
Total	**42,722**	**101%**	**43,004**	**99%**	

the 10 goals of “Shaping Delaware’s Future.” The completed and approved plan will be used as the basis for future county environmental protection programs.

White Clay Creek Watershed

The City of Newark recently annexed a tract to its north that resulted in the conservation of sensitive lands by designating them as parkland in the orderly provision of infrastructure and services. The annexation plan was used to identify lands with no development potential, lands with development limitations, and lands with desirable development potential. Comprehensive annexation plans and joint governance districts around municipalities in cooperation with the county and state can provide for the protection of sensitive resources and cost-effective provision of infrastructure and government services.

Upstream of Newark, a large portion of the Delaware land bordering White Clay Creek is protected. These forested areas provide water-quality and quantity benefits. Major water supplies for Newark and United Water are provided by this watershed. Other direct-surface water supplies for industrial use include the Curtis Paper Mill and closed industrial sites downstream from it, owned by the NVF Company.

The White Clay Creek watershed has been designated as a “Study River” for possible inclusion in the “Wild and Scenic Rivers System.” If the creek meets the criteria for inclusion, a possible outcome of the upcoming National Park Service’s draft management plan could be White Clay Creek’s nomination as a “Wild and Scenic River.”

Red Clay Creek Watershed

The Delaware Nature Society is very active in this watershed in acquiring voluntary conservation easements.

Brandywine Creek Watershed

The Brandywine Conservancy and WoodIawn Trustees are two land conservation organizations that are active and have significant holdings in the Brandywine Valley. The Wilmington Waterfront Development Corporation is actively working to redevelop Wilmington’s sections of the Brandywine to correct past environmental oversights and bring economic development to the city.

Upstream of Wilmington, a large portion of the Delaware land bordering Brandywine Creek is protected. These forested and open areas provide water-quality and quantity benefits for a large fraction of northern New Castle County’s population. Brandywine Creek will require future land-conservation efforts to reduce threats to its quality and the area’s welfare.

Christina River Watershed

The Wilmington Waterfront Development Corporation is interested in designating a Wilmington Wildlife Refuge and redevelopment and remediation of brownfields associated with the underutilized industrial and urban waterfront. This can result in a cleaner waterfront that accepts development pressures in a concentrated area as compared to scattered development in more sensitive areas at greater economic and environmental costs.

RECREATION

Recreation can be defined as any type of conscious enjoyment that occurs during leisure time. Recreation resources such as an athletic facility, an open meadow, or a fishing area can be classified as natural resources and/or man-made resources that are used for the conscious enjoyment of leisure time. For the purposes of this study, only outdoor recreational facilities such as parks and greenways and activities associated with natural resources such as hiking, and fishing will be discussed. The identification of these facilities and activities is important in watershed management because they provide a linkage between environmental quality and use of natural resources.

Characterization

Parks and Greenways

Recreation is only one type of land use competing for land in the allocation of scarce resources. As development pressures have intensified, Delawareans have become increasingly concerned about losses of forest and open space to development. Compared to our neighboring states, Delaware has less public parkland per citizen. As the state and the Piedmont Basin region continue to experience increased development and population growth, the acquisition of additional land for public outdoor recreation will be a top priority in the State Comprehensive Outdoor Recreation Plan (SCORP). As population density increases in the Piedmont Basin, linear areas of open space or greenways connecting parks with population centers will help support greater use and maximization of our limited recreational resources.

Parks, recreational facilities, and open space are an important part of the social, cultural, and physical fabric of the community. Collectively, they embody a significant environmental resource that enhances both the health of the environment and the citizens of the basin. Although land dedicated to public recreational use in state, county, and municipal parks in the Piedmont Basin totals 9,000 acres (see Map 31), demand for outdoor recreation and recreational facilities exceeds the capacity of a significant portion of the Piedmont Basin's recreation base/resources. The demographics of the population — its nature, density, and distribution — greatly influence the need and demand for recreation and open space. Demographics by sub-watershed vary substantially and determine the scope and intensity of recreational needs in those communities.

A statewide recreational needs survey was conducted by DNREC's Division of Parks and Recreation with the cooperation of the University of Delaware College of Urban Affairs in spring 1995. The Piedmont Basin results again supported the fact that differences in demographics by sub-basin resulted in different perceived recreational needs. In older, more stable areas, such as the Brandywine and Red Clay sub-basins, there were no perceived additional recreational needs, with the exception of more paved walking, hiking, and biking trails. In newer, rapidly developing areas such as the White Clay and Christina sub-basins, the need for additional open space and recreational facilities of all categories ranked high.

Fish and Wildlife Recreation

Recreational opportunities such as hunting, fishing, and boating have traditionally been and continue to be limited in the Piedmont Basin due to suburban sprawl and high human population. Boating has also been restricted due to a limited number of public boat ramps. Although limited, those sporting activities available in the basin provide some of the most unique opportunities in the state. Arguably, the most unique of these opportunities, and one that receives tremendous participation, is the freshwater trout fishing available at six designated trout streams within the basin (see Map 32). The Division of Fish and Wildlife annually stocks more than 30,000 legal-sized trout along 19 miles of these streams, the only streams in Delaware that receive trout. The number of anglers purchasing Delaware's required state trout stamp annually exceeds 5,500, with the majority (48.9% or 2,718) of these anglers residing in the Piedmont Basin. One of these trout streams, White Clay Creek, has a fly-fishing-only section, providing anglers an unparalleled experience within the state.

Another unique fishing opportunity in the Piedmont Basin is Brandywine Creek, which provides the only sustainable smallmouth bass fishery within the state. This water body also occasionally yields unusual catches, such as muskellunge, and other species that are transients from nearby Pennsylvania. Other popular fishing areas within the basin include Christina River and Becks Pond, each of which have public boat-launching facilities — two on the Christina River and one at Becks Pond.

Unfortunately, the Piedmont Basin also has several water bodies that have fish consumption advisories due to the presence of contaminants found within edible portions of some fish. These water bodies of concern include Red Clay Creek (PCBs, dioxin, and chlorinated pesticides); the Christina River (PCBs); and portions of the Brandywine, White Clay, Little Mill, and Christina creeks (PCBs). However, none of the areas stocked for recreational fishing shows significantly elevated levels of contaminants, and no advisory is being issued for these areas.

Hunting opportunities within the basin occur primarily on private property, as no State Wildlife Areas exist in the region; however, both the White Clay Creek and Brandywine Creek State Parks use recreational hunting as a mechanism to control excessive deer populations. Although there are limited hunting opportunities within the region, hunting is an important recreational activity among Piedmont Basin residents, as approximately 30% (5,992) of all state resident hunting licenses are sold within the region. The establishment of a special non-migratory Canada goose season has expanded waterfowl hunting opportunities in the area, but these activities have thus far been limited to several local golf courses and country clubs that experience problems with nuisance geese populations.

Outdoor recreational activities during the summer are very susceptible to problems associated with high mosquito populations. The Division of Fish and Wildlife's Mosquito Control Section conducts extensive surveillance and control of nuisance and disease-carrying mosquitoes. One form of routine surveillance in the Piedmont Basin consists of six light traps operated seasonally in four of the watersheds. These traps are used to monitor nightly increases of mosquito populations and to assess annual population levels. Annual populations are assessed based on the number of "nuisance-free nights" between June 1 and September 15 (107 days). A "nuisance-free night" is a dusk-to-dawn period when fewer than 25 female mosquitoes of a known nuisance or potentially disease-vectoring species are captured per light trap. The average annual number of "nuisance-free nights" within the basin — as determined by these six light-trap locations — is 90, or 83% of the surveyed period.

Mosquito-control practices within the Piedmont Basin are generally confined to the extensive marshes and forested wetlands of the Christina River watershed because the hilly topography of the other watersheds does not lend itself to large expanses of standing water usually required for extensive mosquito breeding. Large-scale larviciding via fixed winged aircraft is used to control extensive mosquito breeding over 1,755 acres of marsh at five wetland sites within two watersheds. On average, these marshes are treated 3.25 times per summer, with approximately 8,778 pounds of insecticide applied annually. Additional aerial applications of insecticide occur via helicopter during the early spring in scattered forested wetlands in the southwest corner of the Christina River Basin.

Trends

Parks and Greenways

As northern New Castle County moves from a generally suburban environment to an urban environment, and opportunities for new recreational lands and facilities become minimized, the demand for such lands and facilities increases. Smaller parcels of vacant land within communities are being recognized as possible recreational areas. Linking existing recreational areas to population centers by a network of greenways will allow greater access to a larger number of residents, increasing their recreational opportunities. Greenways can be defined as linear open space established along either a natural corridor such as a stream valley or ridge line, or a landscaped course for pedestrian or bicycle passage that links parks, nature preserves, cultural features, or historic sites with each other. Greenways provide recreational opportunities "close to home" — a need demonstrated in the State Comprehensive Outdoor Recreation Plan.

As mentioned earlier, there are approximately 8,000 acres of land dedicated to public recreation in the Piedmont Basin. The National Recreation and Park Association suggests that a park system, at a minimum, be composed of a core system of parklands with 6.25 to 10.25 acres per 1,000 population with *adjunct* parkland of regional open space of 15 to 20 acres per 1,000 people, or a total of 21.25 to 30.25 acres per 1,000 people for a well-rounded system of parks and recreation areas. Using those criteria, the population-to-parkland ratio for the basin is approximately 21.4, falling into the "acceptable" range within National Recreation and Park Association guidelines. Although within the acceptable range, the population-to-parkland ratio for the Piedmont Basin is on the lower end of the scale. With rapid growth projected to continue in portions of the basin, active open space acquisition will be necessary to maintain and improve our population-to-parkland ratio.

As with all other resources, recreational resources have a specific *carrying capacity*. In broad terms, carrying capacity is the amount of use a given resource can sustain before irreversible deterioration in the quality of the resource begins to occur. *Recreational carrying capacity* is defined as the number of recreational opportunities that a specific unit of a recreation resource can provide without the significant biological or physical deterioration of the resource or substantial impairment of the recreational experience. Currently, the carrying capacity of many of the Piedmont Basin's recreational resources is maximized or exceeded. This is due not only to population increase, but also to demographic trends in different communities within the region. For example, as the population in the upper portions of the Brandywine watershed ages, demand for playgrounds declines as the need for paved walking trails and senior-oriented forms of recreation increases.

Demonstrated impacts of overuse of recreational resources can be seen throughout the Piedmont Basin. Overused or unmaintained recreational facilities continue to be a constant problem. Vandalism of existing facilities also continues to be a serious concern which, unfortunately, prohibits many recreation providers from expanding or improving recreation programs and facilities. Overuse and inappropriate use of unpaved hiking and walking trails lead to degradation of resources and result in erosion and destruction of habitat on adjacent lands.

Fish and Wildlife Recreation

Recreational Fishing. Development, industry, and poor agricultural practices in the Piedmont Basin and surrounding areas have had a negative effect on recreational fishing by causing a general degradation of aquatic habitats within the region. An increase in suburban development and "clean" farming practices within the watersheds have increased stormwater runoff and nonpoint source pollution. Increased stormwater runoff and its associated increase in sediment loading have caused a loss of fish habitat by extensive erosion of stream banks and the sedimentation of potential spawning areas. The increase in nonpoint source pollution entering these systems can decrease water quality within both streams and ponds. Individually, poor water quality or loss of suitable fish habitat can suppress game fish populations; however, when combined, their impacts can be dramatic.

Historic industrial and agricultural practices have contributed to the presence of contaminants within numerous water bodies. Many of these contaminants are long-lived and bioaccumulate within fish tissue, which in turn can pose a health risk to humans if consumed. This health risk has prompted the Division of Fish and Wildlife and the Division of Public Health to impose fish consumption advisories for several Piedmont Basin water bodies. Potential sources of these contaminants include the numerous Superfund and hazardous waste sites within the Christina River, Brandywine Creek, and Red Clay Creek valleys, as well as historic agricultural and mosquito-control practices within the watershed.

In an effort to reduce upland flooding and accommodate agricultural practices within wetland areas, early settlers installed an extensive series of dikes and water-control structures (tide gates) along the Delaware and Christina rivers. Many of these tide gates, located on tributaries to these rivers, have been maintained for centuries allowing only one-way exchange out of these formally tidal systems. Maintaining these structures continues to exclude many estuarine and anadromous fish species from tributaries where fishing opportunities exist. These tide gates further impact fishing opportunities by restricting access by game fish and important forage fish species to historic spawning and nursery areas.

Sales of trout stamps have shown that trout fishing in the Piedmont Basin has annually become increasingly more popular. In response, the Division of Fish and Wildlife has increased the number of trout stocked within the region. However, studies have shown that stocking higher numbers of trout does not necessarily result in higher catch rates and that a limiting factor in angler success is public access to stocked areas. Public access is limited by the posting of private property along these designated streams and the lack of adequate angler parking. Future stocking levels will probably not increase until additional public access is available on those streams currently stocked, or until other streams within the region are determined suitable for stocking.

Public access is also a problem for boaters within the basin as the three public boat-launching facilities are currently inadequate to handle the ever-increasing boat traffic. Currently, there are approximately 8,400 registered boats within the Piedmont Basin. This increased boat pressure has been attributed to a number of factors including improvement in water quality and recreational fisheries in the upper Delaware River and its tributaries and rejuvenation of the Christina River waterfront in Wilmington. However, one of the most substantial increases in boat traffic on the Christina River has been caused by the advent of personal watercraft ("jet skis"). Additional safe and adequate public launching facilities to accommodate these highly popular watercraft, as well as small trailered boats, are needed to provide access to the Delaware and Christina rivers. A potential source of impact to recreational fishing and boating involves the proposed development of an additional water-supply reservoir within the Piedmont Basin. How and where this reservoir is created could have significant impacts on recreational fishing and boating.

Recreational Hunting. The primary impact to recreational hunting in the Piedmont Basin has been associated with increased urbanization and development in the region. Increased suburban sprawl in the basin has limited hunting opportunities because of moral and safety concerns, in many cases resulting in an increase in wildlife populations beyond a social carrying capacity. Excessive deer populations in portions of the Piedmont Basin have caused unacceptable browsing damage to crops and ornamental shrubs and increased deer / vehicular collisions, and have been associated within an increased risk of Lyme disease. Recreational hunting, where it can safely occur, is the recommended management tool to reduce deer populations to acceptable levels on both public and private properties in the basin.

Another species in which hunting is providing the primary tool for population management is resident Canada geese. It is estimated that there are 3,500 non-migrating geese residing within the Piedmont Basin. This population exceeds the species' social carrying capacity by creating annoyances such as excessive noise, defecation on lawns, eutrophication of small ponds, and herbivory of lawns and ornamental plantings. These problems are especially evident at golf courses and corporate centers where hunting opportunities have been traditionally limited. The Division of Fish and Wildlife has a trap and transfer program that annually removes approximately 350 geese from these nuisance areas and releases them on State Wildlife Areas; however, this solution frequently just relocates the problem, as many of these geese move off the State Areas and become a nuisance elsewhere. Recreational hunting combined with other damage prevention and control methods — for example, habitat modifications, fencing, and elimination of public feeding — are currently the best solutions. However, in order for this strategy to be successful, more public and private areas where hunting programs can safely occur need to be implemented within the basin.

Philosophical, medical, moral, and ethical objections to the use of pesticides have been increasing in the basin. These objections have to some extent slowed prompt response to mosquito-breeding problems or restricted some mosquito-control practices. These problems have been compounded by the migration of urban dwellers into new developments surrounded by mosquito-breeding habitat. Additionally, several areas within the basin that annually produce the most extensive breeding of pestiferous mosquitoes are formerly tidal wetlands that have been impounded and separated from the mosquito-control benefits associated with tidal exchange. These same marshes require the majority of the pesticides applied.

Positive Initiatives

Parks and Greenways

Although demands on our recreational resources will continue to grow and change in the Piedmont Basin, there are a number of positive initiatives under way. Through the Delaware Open Space Program, the Division of Parks and Recreation has actively been acquiring additional lands for resource protection and recreation. Over 1,300 acres of land have been added to Bellevue, Brandywine Creek, and White Clay Creek state parks since 1991, with an additional 371 acres protected through conservation easements. Additional lands are currently under negotiation by the division for future acquisitions.

The Delaware Greenway Program has made great strides in connecting existing open space with residential and commercial areas and historic and cultural sites. Currently there are several major greenway projects under way. The Northern Delaware Greenway will provide a multi-purpose trail and recreational facility that will link residential areas, parks, and cultural and historic resources. When completed, this greenway will extend from the Delaware River at Fox Point State Park to White Clay Creek State Park near the Maryland state line. The greenway will provide linkages with the City of Wilmington, Brandywine Creek State Park, Delcastle Recreation Area, and the Middle Run Natural Area. The Christina River Greenway is in the planning stages and will provide a river walk along the Christina in the City of Wilmington and a multi-purpose trail along the middle and upper Christina, linking parks and open space northwest to Newark. The Pencader Greenway will link the rapidly growing Pencader area to the Christina River Greenway by providing pedestrian and bicycle access to community open space and county parks along tributaries and area roadways.

In Newark, a greenway trail is planned, which will link the downtown commercial area north to White Clay Creek State Park and west to the Mason-Dixon Trail System along Christina Creek. The Division of Parks and Recreation is also working with the East Coast Greenway Alliance, which is fostering the creation of an urban greenway network connecting all the major cities along the Atlantic coast, from Boston to Miami. A portion of this greenway network will cross the basin.

Although most greenway projects serve a recreation and transportation component, they also can act to protect and conserve the environment. All the above-mentioned greenway projects also include a land preservation component, especially along stream corridors. A major stream corridor greenway protection program has been undertaken in the Piedmont Basin by the Delaware Nature Society. Through the society's Stream Corridor Greenway Program, landowners in defined stream corridor greenways have been contacted regarding environmentally sensitive land management and means of permanent land protection. To date, more than 763 stream-side landowners have been contacted and have received information regarding proper streamside management.

Funding for land acquisition and park and greenway development by local governments is supplemented by the Delaware Land and Water Conservation Trust Fund. Established in 1986 as a means for providing a permanent source of funding for local parks and greenways , the trust offers matching grants to communities for this purpose. Since 1986, more than $5 million have been granted to communities in the basin for park and Greenway acquisition and development.

The Division of Parks and Recreation also assists communities by offering technical assistance. Information can be exchanged regarding recreation and park master planning, open-space acquisition and preservation techniques, greenway development, playground safety, fund-raising, facility management, and recreational programming.

In addition to state programs, New Castle County, the cities of Newark and Wilmington, and the town of Elsmere all support active parks and recreation programs. Both New Castle County and the City of Newark are actively acquiring additional recreational lands. The majority of the new lands purchased by local municipalities has been along streams, primarily the Christina and White Clay creeks. The City of

Wilmington has been proactive in improving trail opportunities through the Wilmington Walkways Program. Every incorporated community in the basin has some land dedicated to open space and parks.

Fish and Wildlife Recreation

In an effort to improve fishing opportunities in the Piedmont Basin, the Division of Fish and Wildlife has developed and is implementing aquatic habitat improvement plans for several public ponds and streams in the region. These include developing long-range fishery management plans, stocking water-quality-tolerant fish species, and creating stream and pond habitat improvement devices (stone deflectors, bank cover devices, and brush shelters). The division also has a program to improve aquatic habitat on private property by providing technical assistance to private pond owners. In 1995, seven pond consultations were conducted within the basin, providing assistance ranging from fish and water-quality sampling to recommending herbicide, mechanical weed control, or beneficial plantings.

The divisions of Fish and Wildlife and Soil and Water Conservation are implementing a wetland rehabilitation program on the tidal tributaries of the Christina and Delaware rivers. Regional objectives of this program, the Northern Delaware Wetlands Rehabilitation Program, include (1) restoring limited tidal exchange between the Delaware Estuary and formerly tidal tributaries and wetlands; (2) restoring spawning, nursery, and feeding sites to several species of anadromous, estuarine, and riverine fish species; and (3) improving a wide variety of recreational opportunities in wetland, estuary, and adjacent upland habitats. One method being used to accomplish these goals is replacement of traditional one-way tide gates with automated or mechanical water-control structures that allow two-way tidal flow.

Initiatives to improve recreational hunting opportunities within the Piedmont Basin are directly tied to reducing excessive wildlife populations to socially accepted carrying capacities. Controlled public hunts in two state parks have been a successful and economical mechanism to control excessive deer populations while also providing recreational opportunities. It is hoped that the success of these controlled hunts will promote additional hunting opportunities on other public and private properties within the basin where deer populations are exceeding social carrying capacities and can be safely harvested.

The control of nuisance resident-geese populations has also increased recreational hunting opportunities through the establishment of a special non-migratory Canada goose season. This recently established season was designed specifically to reduce nuisance geese populations within the region by utilizing recreational hunting as the management tool. To date, the season has had limited success because hunting access has been restricted to several local golf courses and country clubs. It is hoped that, with time, this management tool will be employed in all areas where recreational hunting can be safely used to reduce nuisance geese populations.

Although the high human population levels in the Piedmont Basin limit fish and wildlife recreational opportunities, this population density does lend itself to environmental education opportunities. During the 1996 state fiscal year, 347 students received boating safety instruction and 200 scientists and teachers were exposed to aquatic resource education activities in the basin, such as Adopt-a-Wetland and Fish Banks programs. In addition, several special youth fishing and hunting events were conducted to expose urban and single-parent youths to these recreational activities. It is anticipated that in the future these educational opportunities will increase as additional emphasis is being placed on environmental education and several outdoor education facilities are being proposed within the region.

Mosquito control within the Piedmont Basin will probably always be necessary at some level to allow the public to enjoy safe outdoor recreational activities since avoidance and tolerance of existing mosquito populations do not appear to be acceptable alternatives. Mosquito control within the basin now involves an Integrated Pest Management approach that uses a variety of control measures to achieve its goals. These measures include water management, biological controls (fish, birds, bats, bacteria), insecticides, and insect growth regulators. This integrated approach provides better control by not relying solely on any one particular control measure, such as pesticides. The Mosquito Control Section is also constantly updating and researching the products they use, in many cases, switching to more expensive but more environmentally sound products.

As the public becomes more educated about pesticides and their uses, the Mosquito Control Section is spending increasingly more time on education and advance notification of spray events. This education is in the form of detailed brochures about the methods and products used, meeting with community civic associations, and presenting information at state fairs and universities. An extension of this education involves eventually updating all mosquito-breeding areas within the basin on an existing computerized data base in order to better monitor pesticide usage and improve mosquito surveillance.

Another objective of the Northern Delaware Wetland Rehabilitation Program is to control pestiferous mosquito populations through improved water management practices, thereby reducing the use of chemical insecticides. These improvements in water management, such as the reintroduction of tidal exchange, are currently being proposed for several large wetland areas that contain extensive mosquito-breeding habitat.

PUBLIC EDUCATION

DNREC offers citizens in the Piedmont Basin a wealth of opportunities to obtain information regarding environmental conditions in their watershed, from public meetings and workshops to Earth Day activities, river cleanups, seminars, and forums. Local citizens can also take advantage of programs in state parks that provide recreation and environmental education. Brochures and pamphlets are available from all divisions. Public participation is encouraged in DNREC programs and is the essential ingredient in citizen monitoring programs to protect the health of streams and wetlands. Initiatives addressing environmental issues, such as the Whole Basin Management Plan, need input and advocacy from citizens in order to succeed.

The "Departmental Overview" in the *Mission of the Department of Natural Resources and Environmental Control* states that DNREC "increasingly must respond quickly and effectively to . . . an increasingly more aware and environmentally concerned public." Further, if people are the primary cause of a deteriorating environment, then people must be informed about the consequences of their actions and their need to become involved.

DNREC's mission to preserve and protect the natural resources is facilitated by offering a wide variety of educational programs for citizens of all ages. These programs that explore and interpret our natural resources are designed to be fun, educational and multidisciplinary while encouraging environmental stewardship.

Three divisions in DNREC have full-time coordinators who conduct educational programs. All divisions have educational components which conduct public outreach at the Delaware State Fair, Earth Day and other events. Workshops are also conducted for clients who need specific information to meet regulations.

Educational Programs

DNREC offers teachers, youth leaders, and students in the Piedmont Basin, and throughout Delaware, a variety of environmental education resources. These resources, in the form of teacher training, special programs, curricula, volunteer programs, and printed and audio/visual materials, address a broad range of environmental issues including pollution prevention, habitat and wildlife, water quality, specific ecosystems, and aquatic resources.

Project Wet

National Project Wet is an interdisciplinary water education program intended to supplement an educator's existing curriculum. Its goal is to facilitate and promote the awareness, appreciation, knowledge, and stewardship of water resources through the dissemination of classroom-ready teaching aids. Teachers K–12 can obtain the guides by attending in-service workshops (2.5 credit).

Project Wild

This internationally recognized curriculum supplement addresses the issues of habitat and wildlife and man's relationship to the natural world. The hands-on activities develop not only science skills, but other disciplines such as social studies, language arts and math. Teachers K–12 can obtain the workbooks by attending in-service training (2.5 credit).

Aquatic Wild

This curriculum is the "wet" version of Project Wild, focusing on aquatic habitats and wildlife. Participants must have completed Project Wild as a prerequisite. Teachers receive 2.5 in-service credit.

Three R's for the 90s: Reduce, Reuse, Recycle

This Delaware-specific curriculum supplement is geared to a K–8 audience and addresses the concept of pollution prevention through recycling, reusing and reducing our waste streams. Hands-on activities develop multi-disciplinary skills. Teachers and youth leaders receive materials after completion of in-service training (2.5 credit).

Water Quality

The Water Quality Education Program addresses wastewater treatment, surface water, groundwater and water conservation and is geared toward a K–12 level. Corporate sponsors adopt a school and provide funds for participating teachers to receive a resource guide, video, student guides and related handouts at a three-hour workshop on each unit topic.

State Park Environmental Education and Interpretive Field Studies

The statewide environmental education and interpretive programs are flexible activities suited to the grade level of the student. These programs are offered on-site at most state parks, in the classroom, or at other requested locations. These studies encourage an environmental ethic in our natural, cultural and historic world, and stress small group interaction. Programs are designed for public and school groups and teachers. The program content and topics can be readily adapted to integrate with previous classroom studies. Groups may attend for an hour, a day, or at some parks, overnight. Teacher training with in-service credit is also available.

Aquatic Resource Education

This new program is housed at the Aquatic Resource Education Center on Route 9 near Smyrna. Programs have been developed to address such topics and issues as fisheries management, wetlands education, fishing skills, and aquatic resources management. These programs are available for teachers, youth and school groups. A boardwalk over the marsh was completed in 1996 as well as a pavilion for instruction and lunch.

Boating Safety

A new Delaware law requires all persons born after January 1, 1978, to successfully complete a boating safety course prior to operating a vessel in Delaware waters. Courses are offered statewide and cover topics such as ebb and flow of tides, rules of the road, and potential hazards from weather.

Hunting Safety

Persons born after January 1, 1967 must successfully complete a hunter safety course in order to purchase a Delaware hunting license. Topics of the course include, in addition to firearm safety, landowner relations, ethical behavior, wildlife identification and conservation laws.

Speaker's Bureau/Resource Experts

DNREC can provide personnel to address youth groups or classrooms on a host of topics. For more information, contact the Office of Information and Education at (302) 739-4506.

Good NaturEd News

This newsletter, published three times each year, is a guide to environmental education resources available in Delaware and nationally. The publication is distributed to all public school teachers in the state.

Technical Water Quality Monitoring

Be a scientist—join a Water Quality Monitoring Program that provides reliable baseline physical/chemical data. Technical programs are being conducted on several Delaware waterways. Volunteers range from high school students to retired chemists. Initial training and follow-up sessions insure quality control in sampling procedures.

Electronic Bulletin Board

The Department operates a portion of the Department of Public Instruction electronic bulletin board system. Teachers and students can access information about Delaware's natural resources, teaching materials and programs and activities through a personal computer and a modem.

Volunteer Programs

These programs are a great way to involve students and youth group members in outdoor, hands on activities that are educational and beneficial to our environment.

Stream Watch

This program, operated in conjunction with the Delaware Nature Society, trains volunteers to assess water quality in ponds, rivers and streams around the state using basic water testing kits, visual and biological surveys.

Adopt-a-Wetland

Groups can learn more about wetland habitat and work to enhance these valuable areas by adopting a wetland area.

Coastal Cleanup

This one-day event, held each fall, teaches participants the problems caused by litter in aquatic environments.

River Cleanups

Each spring, the Department sponsors a river cleanup in conjunction with Earth Day.

Envirothon: A High School Environmental Challenge

The Envirothon is a competitive, problem-solving, natural resource event for students to educate them about the environment. High school students are meeting this challenge every year. They are now more concerned and informed about the world around them.

Education Facilities

The message of DNREC park brochures invites visitors to come "relax and enjoy nature at its best; escape to tranquil beauty of forest hills, cool green leaves, and rushing streams." As visitors hike trails and observe wild flowers, songbirds, deer, and other wildlife, a sense of responsibility to preserve Delaware's natural wonders develops. White Clay Creek State Park, in the Piedmont Basin, is an example of a partnership forged among private citizens, government agencies, conservation organizations and corporations to protect the natural resources of the White Clay Creek valley.

Several DNREC-owned properties, including both land and buildings, have been identified as areas that can be used for environmental education purposes. These areas are open to the public and are available primarily free of charge. Designated usage, availability, location, and/or educational features are listed below. Volunteers are welcome to assist with projects and programs.

- *Bellevue State Park.* (Parks and Recreation). Interpretive programs for general public, youth groups, and special populations; summer day camps; seasonal programs for special populations.
- *Brandywine Creek State Park and Nature Center.* (Parks and Recreation). Open year-round to the public. Exhibits; enclosed wildlife observation area; interpretive programs for school groups (K–12), general public, youth groups, summer day camps for youths; two self-guided interpretive trails; two designated nature preserves with trails; 12 miles of nature trails; within the park containing various habitats (Piedmont) available for nature study.

- *White Clay Creek State Park, White Clay Creek Visitor Center and Possum Hill Preserve Center.* Year-round interpretive programs for year-round visitors; 560 acres within park containing various habitats (Piedmont) available for nature study; 1700 untouched acres (White Clay Creek Preserve); year-round programs for the public and school groups.

Public Participation and Advocacy

If the natural resources of Delaware are to be preserved, then the public must be made aware of the problems and participate in the plans and tactics for environmentally sound solutions. DNREC encourages citizens to become stewards of their watersheds by taking part in workshops, public meetings and hearings, Earth Day activities, the University of Delaware's Coast Day, Delaware State Fair, and other environmental education events. DNREC uses various media to reach the public and encourage their participation and input on various issues.

Citizen Monitoring

Stream Watch Technical Monitoring. Citizens work with DNREC scientists, monitoring selected sites using chemical methods. Data will be used to build models for determining total minimum daily loads of the watershed.

Newsletters from Conservation Organizations

Newsletters keep citizens informed of current issues and ways they can interact with agencies and legislative bodies to express their opinions.

Brochures

Brochures such as the Clean Water Series, Water Quality Nonpoint Source Pollution Fact Sheets, Managed Forests, and Clean Water instruct citizens in environmentally sound methods of protecting the environment and preventing pollution.

Workshops and Conferences

The Landowners' Watershed Protection Conference sponsored by Delaware Nature Society and the Statewide Water Resources Conference organized by the Delaware League of Women Voters are examples of events focused on critical issues and how consensus can be reached and action taken to protect and improve water quality and supply in the state.

Special Events

Each year thousands of Delawareans make saving the environment part of their routine lives as they participate in efforts to enhance the beauty of roads, highways, beaches, rivers, and streams. The departments of Natural Resources, Agriculture, and Transportation, and the Federation of Garden Clubs sponsor programs such as "Get The Drift and Bag It," "Help Keep Delaware Clean," "Operation Wildflower," "The Planting of the Green," and river cleanups.

Cooperative Agreements

DNREC has cooperative agreements with many organizations. This often results in advocacy for Best Management Practices and recommendations to improve the quality of natural resources. An example is the recent agreement with Winterthur to establish a comprehensive plan for managing and conserving its physical and natural resources, developing expanded non-museum program opportunities, and integrating Winterthur plans with the larger area. This will result in a master land-use plan that will establish overall conservation land management practices and guidelines, site-specific natural area recommendations, facilities expansion and replacement guidelines, and an implementation strategy for selected environmental programs. This planning process will take place in four phases in the next three years. Cooperation between DNREC and Winterthur staff will result in consolidation of efforts to preserve sensitive areas and achieve goals of both organizations.

KEY ISSUES

GROUNDWATER

The more sensitive and valuable groundwater protection areas have been delineated for New Castle County. Critical areas are found in both the Piedmont and Coastal Plain province portions of the Piedmont Basin. The following are key groundwater-quality issues for the Piedmont Basin:

- The important Cockeysville aquifer is currently producing at quantities that have lowered the water table to below stream levels. Consequently, water flows from surface streams into the underlying aquifer. Thus, in addition to the Cockeysville Formation itself, the Mill Creek sub-watershed should be identified as an important drainage area because of the potential vulnerability of the Cockeysville Aquifer to water from Mill Creek, which recharges the aquifer. This watershed is primarily in Delaware although the northwestern extreme extends into Pennsylvania.
- Natural and anthropogenic problems continue to plague the Newark southern wellfields. The City of Newark could rely more heavily on this source of groundwater once recommendations concerning wellfield management and treatment are implemented. Currently, high iron and manganese levels limit production from some of the wells.
- Specific groundwater-quality impacts into surface water bodies currently are neither well understood nor evaluated. This is important within those watersheds that have major drinking-water withdrawals.
- An adequate ambient groundwater monitoring network sufficient to assess groundwater resources does not exist. However, improved coordination between state agencies on data integration will be a first step in developing such a network. However, some amount of resources is needed.
- Not all waste programs have adequately addressed sites described for this report that are causing groundwater contamination.
- The Office of Drinking Water data base currently is being placed in an electronic format. However, certain field procedures, such as including well-permit identification numbers with well samples, will greatly improve use of that data in groundwater-quality assessments.
- The Potomac aquifers found in the Coastal Plain extend well beyond the boundaries of the Piedmont Basin watersheds. Monitoring designs will, thus, be designed with these larger flow systems in mind.
- The GIS advances developed for this project, which give locational data for groundwater resources and for contaminant sources, should allow specific programs to set priorities with respect to the more critical groundwater resource areas.
- A characterization of areas with concentrations of domestic septic systems and domestic water wells is needed.
- An analysis to combine resource protection measures, such as greenways and parkland, is needed to maximize state and local resource protection measures.
- Locations of non-transient non-community, transient non-community, and miscellaneous public water-supply wells should be verified similar to what has been done for community wells.

SURFACE WATER

Exceeded Criteria

The preliminary assessment of water quality for the Piedmont Basin analyzed data over 34 sampling locations distributed along the Christina River, Brandywine Creek, Red Clay Creek, White Clay Creek, Naamans Creek, and Shellpot Creek in Delaware. For each sampling location, up to 22 water-quality parameters were analyzed, including general chemical and physical parameters, bacteria, nutrients, and metals. Data assessed in the study were retrieved from the U.S. Environmental Protection Agency's Water Quality Information System and were manipulated prior to statistical evaluation due to missing values, censored values, outliers, multiple observations within a month, and small sample sizes.

The preliminary study characterized the water and identified existing and potential water-quality problems in streams through trend and status analysis. It applied all three types of statistical analysis — the graphical method, the estimation method, and a test of hypotheses — on each parameter for each sampling location. The study also identified data gaps that affected the statistical analysis.

As a result of the study, major concerns surfaced with regard to the following parameters in which concentrations frequently violated water-quality criteria:

- Enterococcus bacteria concentrations frequently exceeded criteria throughout the Piedmont Basin.
- Zinc exceedances of criteria occurred frequently along Red Clay Creek.
- Iron violations of criteria occurred along the lower reach of the Christina River.

- Total phosphorus excessive concentrations (average above 0.1 mg/l) support the concern for nutrient over-enrichment in the Christina River, Brandywine Creek, Red Clay Creek, and White Clay Creek watersheds; however, concentrations are on the decline.

Trends

Trends in surface-water quality also have been documented in the preliminary assessment of water-quality data for the Piedmont Basin. As a result of the study, major concerns surfaced regarding the following parameters, which show an undesirable trend in direction:

- Dissolved oxygen concentrations decreased steadily within the last 26 years throughout the entire Piedmont Basin, although criteria were not violated frequently. Therefore, trends indicate that future violations will occur frequently.
- Nitrate-nitrogen increasing trends in the Christina River, Brandywine Creek, Red Clay Creek, and White Clay Creek from 1970 to 1990 suggest that water quality has declined and will continue to decline in these regions.

Fish Consumption Advisories

DNREC and the Delaware Department of Health and Social Services issued a public health advisory on the consumption of fish taken from the Christina River basin in April 1996. The advisory is the result of intensive study of contaminants in fish tissues and is being issued due to the detection of elevated levels of polychlorinated biphenyls (PCBs) in the fish. The immediate goal of the advisory is to reduce the population's exposure to PCBs.

The advisory does not apply to drinking water in the Christina basin. Drinking water samples collected from the City of Wilmington, the City of Newark, and United Water Delaware did not reveal elevated levels of PCBs. All sample results were hundreds of times below the federal standard for drinking water and therefore are considered safe.

Specifically, the advisory recommends *no consumption* of any finfish caught in the tidal portion of the Christina River (from the mouth of the river up to Smalley's Dam), the tidal portion of the Brandywine (from the mouth of the river up to Baynard Boulevard), the tidal portion of White Clay Creek (from the mouth up to Route 4), and Little Mill Creek (from its mouth up to Kirkwood Highway). The advisory recommends *limited consumption* of fish caught in the nontidal areas of the Christina River (from Smalley's Dam to Interstate 95), White Clay Creek (from Route 4 to Paper Mill Road) and the nontidal portion of the Brandywine (from Baynard Boulevard to the Pennsylvania state line). Fishermen and their friends and families eating fish caught in the areas where a limited consumption advisory has been issued are advised to limit their meals of fish from these waters to no more than one 8-ounce meal per month. The advisory also reaffirms the existing advisory on Red Clay Creek, which recommends *no consumption* of fish caught in that waterway. (Please see Map 33.)

Fish taken from the White Clay Creek between the Pennsylvania state line and Paper Mill Road, as well as Becks Pond, did not show elevated levels of PCBs, and no advisory is being issued for these areas.

The findings of the study are consistent with a study completed in 1994 which discovered elevated levels of PCBs in several species of fish taken from the Delaware River and Bay. A consumption advisory remains in effect for the Delaware River and Bay for several fish species.

The advisory is a precautionary measure and is based on a projected health risk to fishermen, their friends, and family who may consume fish from these waterways over a long period of time. For instance, scientists project the lifetime cancer risk to people who consume fish from the tidal Christina River from Newport to Christina Park — the area where the highest levels of PCBs were found — ranges from 1 in 100,000 for those consuming as little as one meal per year, to greater than 1 in 1,000 for those consuming one meal per week. Environmental and public health agencies often seek to reduce exposures when risks exceed a 1-in-100,000 level.

In addition to cancer risks, PCBs also pose special non-cancer health risks to pregnant women and their unborn offspring as well as to nursing mothers and young children. These groups should pay particular attention to the advice given in such announcements. Ultimately, each individual must weigh the risks and benefits of consuming fish from the Christina River in deciding whether to eat or not eat the fish. Those who decide to consume their catch should follow proper trimming and cooking methods.

Along with the study of contaminants in fish and drinking water, DNREC has also conducted sediment sampling throughout the lower Christina basin to determine the magnitude and extent of contamination. Initial results indicate higher levels of PCBs in the sediments in the areas of the river where fish with the highest levels of PCBs were found.

DNREC has been working actively to investigate land-based activities in these areas to determine potential sources and to clean up sites that may be contributing to the contamination. In addition to the Whole Basin Management Program described in this preliminary assessment report, another tool DNREC is using to clean up contaminated sites is the Brownfields initiative, which is designed to promote voluntary cleanup and reuse of abandoned industrial sites. The longer-term goal of DNREC is to be able to lift the advisory once contaminant levels in the fish are reduced to a safe level.

PCBs are a heat retardant formerly used in many applications, especially electrical transformers, capacitors, and other heavy-duty electrical equipment. The manufacture of PCBs was banned in the United States in 1977, although they are still used in closed systems. Prior to 1977, the manufacture, use, and disposal of PCBs were not closely controlled. Consequently, significant quantities of PCBs entered our nation's air, water, and soil. Today, PCBs are released into the environment from unidentified or poorly maintained hazardous waste sites, illegal or improper dumping of PCB wastes, and leaks or releases from equipment containing PCBs.

The International Agency for Research on Cancer and the EPA consider PCBs to be probable cancer-causing agents. When administered in moderate to high doses to experimental animals, PCBs have been shown to increase the incidence of liver cancer and cause other adverse health effects including neuro-development problems in offspring as well as disorders of the immune system. Similar effects in humans though suggested, are not proven.

PCBs tend to adsorb to soil particles and are typically transported to waterways as part of stormwater runoff. Once in the water, these particles settle to the bottom where they accumulate in sediments and become available for transfer to the food chain. PCBs are long-lived in the environment and may take decades to break down into forms that are harmless to living organisms.

Biological Quality of Nontidal Streams

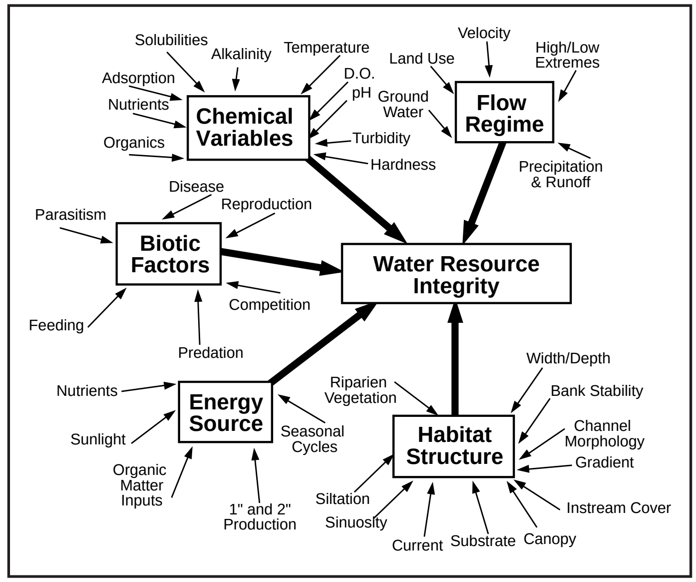
Nontidal streams are by far the most widespread and extensive aquatic resources in the northern Piedmont region: they amount to 272 miles of ephemeral and perennial streams. Approximately 60% of the resource has flow year-round (perennial), while 40% is made up of small headwater channels that go dry for part of the year (ephemeral). The nontidal stream resource extends from the headwaters of the major watersheds in Pennsylvania and Maryland down to the head of tide at (1) Smalley's Pond near Christiana, (2) just below the confluence of the White Clay, Red Clay, and Mill creeks near Stanton, (3) the Brandywine Creek at the Route 13 bridge in downtown Wilmington, and (4) Naamans and Shellpot creeks at the Delaware River.

The ecological quality of surface waters, including nontidal streams, is made up of a complex web of attributes that interact together to support the system as a whole (see Figure 23). Each attribute can be assessed using a variety of discrete measurements. Assessments have traditionally focused on chemical and flow measurements because these best describe point sources of pollution that fall under regulatory control. Measures of biological quality using resident organisms reflect a wide range of attributes of the system and thus can detect impacts from both point and nonpoint sources.

Figure 23

AQUATIC RESOURCE INTEGRITY

(From Yoder, 1991)



Resident organisms provide a direct measure of aquatic life use attainment as required by the Clean Water Act.

A wide variety of aquatic organisms are found in nontidal streams including algae and aquatic mosses, aquatic and semi-aquatic vascular plants (e.g., wild celery *Vallisneria spp.* and duckweed *Lemna spp.*), invertebrate animals (e.g., insect larvae and snails) and vertebrate animals (e.g., fish and amphibians). Various studies have been completed over the years to assess the condition of resident aquatic organisms found in nontidal streams in the region encompassing the Piedmont Basin.

Nontidal streams in the region support a variety of human uses including fishing, swimming, boating, and public water supply. Aquatic organisms are an effective measure of the quality of water supporting these uses. Fishing is a popular activity in all the major creeks and streams in the region. Canoeing and tubing are popular activities in White Clay Creek and Brandywine Creek. Approximately 69% of the potable water in New Castle County comes from surface waters taken directly from nontidal streams or from reservoirs fed by nontidal streams (DNREC, 1996). (The adverse effects of eating contaminated fish in the region were presented earlier.) Therefore, the quality of aquatic organisms in the region affects both recreation and human health interests.

In fall 1993, DNREC collected macroinvertebrate samples and conducted habitat assessments in 39 nontidal streams within the northern Piedmont Basin (DNREC, 1994). Sites were randomly selected to provide un-biased estimates of the proportion (percent) of stream miles in the region with three classes of quality: “good” (comparable to a reference), “fair” (moderately degraded), and “poor” (severely degraded). This framework provided the basis for an overall assessment of the biological condition of nontidal streams to complement the more detailed assessments that have been completed on specific streams or stream reaches. See Map 34.

The biological monitoring program within DNREC’s Division of Water Resources uses aquatic macroinvertebrates as the indicator of biological quality in nontidal streams. Aquatic macroinvertebrates, principally the larval stages of insects, are good indicators of stream quality because they (1) have a short range and thus represent local conditions; (2) are long-lived (many have life spans of one to five years), and thus reflect long-term conditions; (3) are known to be sensitive to pollution; and (4) are the primary food source for recreationally and economically important fish. These aquatic organisms, in turn, support terrestrial organisms such as birds and humans. As part of the biological assessment, physical habitat measures are also taken to further broaden the ecological assessment and to assist in the interpretation of the biological data.

Percent area estimates were reported using two biological indices and one habitat index. “Percent of reference” estimates were first determined for each site by comparing quantitative measures (i.e., metrics) from each site to those from least impacted reference sites (i.e., forested watersheds). Each site was then classified into one of the three quality classes using the following criteria:

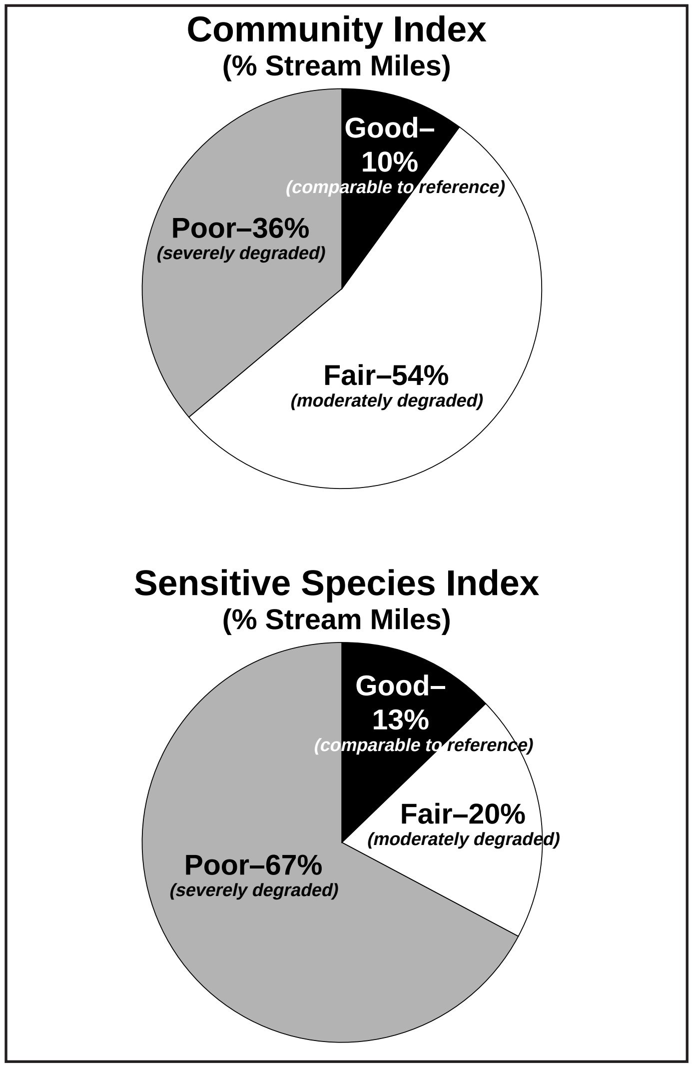
Class	Biological Quality	Habitat Quality
good	> 67%	> 89%
fair	34 to 67%	< 34%
poor	60 to 89%	< 60%

The percent area (percent stream miles) was determined as the percent of the 39 sites in each class. Technical procedures follow those developed by the EPA (Plafkin et al., 1989). Confidence intervals were determined using procedures contained in Walpole and Myers (1976).

Biological data were summarized using a Community Index and a Sensitive Species Index. See Figure 24. The Community Index was used to characterize overall condition and was derived from several measures of the macroinvertebrate community. A “poor” Community Index classification indicated severe degradation, including reduction of taxonomic diversity, loss of sensitive species, and loss of community structure and balance. A “fair” Community Index classification indicated an intermediate degree of impairment. The Sensitive Species Index was derived using only

Figure 24

BIOLOGICAL QUALITY OF NONTIDAL STREAMS IN THE PIEDMONT BASIN



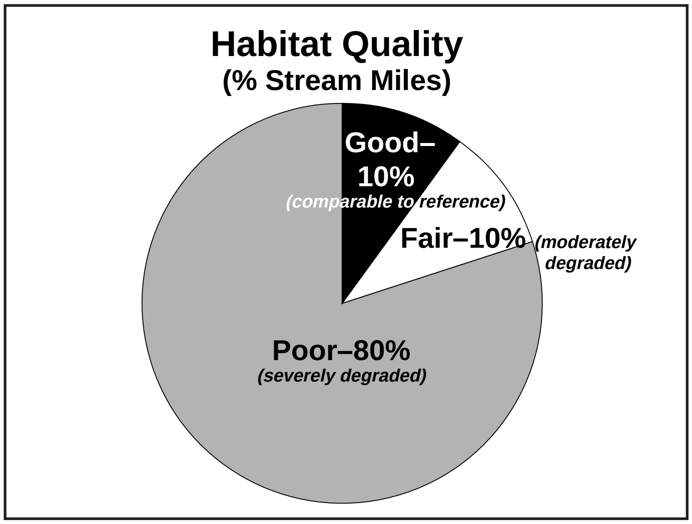
Proportion (%) of nontidal streams in the Piedmont Basin with three classes of biological quality using two indices (90% confidence interval of +/- 9% to 13%).

those organisms that are known to be sensitive to pollution. A “poor” classification using the Sensitive Species Index indicated almost complete loss of sensitive species while a “fair” classification indicated partial loss of sensitive species.

Three-fourths (74%) of nontidal stream resources in the region were found to have degraded biological conditions; an equal number of sites were moderately and severely degraded (see Figure 24). Degraded (“poor”) sites were dominated by fly larvae, snails, and worms, while “good” sites were dominated by mayfly, stone fly, and caddis fly larvae. Degraded sites were dominated by pollution-tolerant species

Figure 25

BIOLOGICAL QUALITY OF NONTIDAL STREAMS IN THE PIEDMONT BASIN



Proportion (%) of nontidal streams in the Piedmont Basin with three classes of habitat quality (90% confidence interval of +/- 8% to 3%).

while “good” sites were dominated by pollution-sensitive species. Almost all (87%) of the sites in the region showed some loss of sensitive species, with two-thirds (67%) having almost complete loss of sensitive species and consequently being listed as “poor” sites biologically.

Almost all (90%) of the nontidal streams had undergone some degree of habitat degradation (Figure 25) as exhibited by eroded banks, newly deposited sediment in the channel, lack of a shade canopy, and human activity in the riparian zone. Two factors contributed to the degraded habitat conditions of streams in the region. First, stream channels appeared to be unstable, with active erosion along bends and runs, and had newly deposited sediment in the channel. This condition is indicative of urban streams, where the impervious surfaces in the watershed (roads, parking lots, rooftops, etc.) have increased the frequency and magnitude of peak flows. Second, native vegetation (for example, trees) was often replaced by grass (lawns) in the riparian zone. Natural wooded riparian zones promote channel stability, moderate stream temperatures, and provide a buffer between streams and contaminant sources.

Identification of Problems and Sources

Nonpoint Sources — Urbanization

The 39 sites sampled by DNREC in 1993 were used to provide an initial analysis of the relationships between biological quality, physical habitat quality, and land use. Physical habitat appeared to be an important stressor affecting nontidal streams in the region. The association between biological quality and physical habitat quality ($r^2 = 0.35$, $n = 38$) provided objective evidence that the impacts to physical habitat may be contributing to the biological condition of these streams (Figure 25). This association was further supported by the classification information. The majority of sites classified as “good” or “poor” for one measure received the same classification using the other measure. None of the sites with “good” biology had “poor” habitat.

Urbanization is a major land use in the region. The habitat conditions at impacted sites were consistent with those associated with urbanization. These included human alteration of the riparian zone, erosion of banks, and deposition of new sediment in channels. Soil is eroded from stream banks when it rains and is deposited as sediment in the channel, where it smothers productive habitats such as pools and riffles. Productive riffles are partially buried in fine sediment in urban streams. Woody material, also important habitat for aquatic organisms, is picked up by storm flows and transported downstream, often accumulating in large piles at bridges.

The scatter in the association between biological and physical habitat quality (Figure 26) may be due to the variability in the two measurements or due to stressors other than physical habitat. Other stressors likely in the region include temperature (due to lack of shade), chloride (due to road salts), dissolved oxygen (due to nutrient enrichment and lack of shade), and a variety of metal and organic contaminants (due to stormwater runoff). There are insufficient data to determine the relative contributions of these possible stressors.

To further evaluate the relationship between biological condition and urbanization, we compiled land-use data for the watersheds upstream of each of the 39 sampling stations. Percent impervious cover estimates for each site were calculated to provide the basis for evaluating relationships between biological condition and urban land use. The relationships between percent impervious cover and the Community Index (Figure 27) indicated that the degree of urbanization was associated with the macroinvertebrate community. The association between impervious cover and the Community Index was particularly strong ($r^2 = 0.71$, $n = 19$) for low-density urbanization (< 30% impervious cover).

An even stronger relationship was found between impervious cover and the Sensitive Species Index (Figure 28). There was an almost complete loss of sensitive species once the watershed reached 15% impervious cover. Low-density residential development with acre lots has a 25% impervious cover using these procedures. The association between impervious cover and the Sensitive Species Index was particularly strong ($r^2 = 0.78$, $n = 19$) for low-density urbanization (< 30% impervious cover).

Figure 26

EFFECT OF PHYSICAL HABITAT ON BIOLOGICAL QUALITY OF NONTIDAL STREAMS — PIEDMONT BASIN

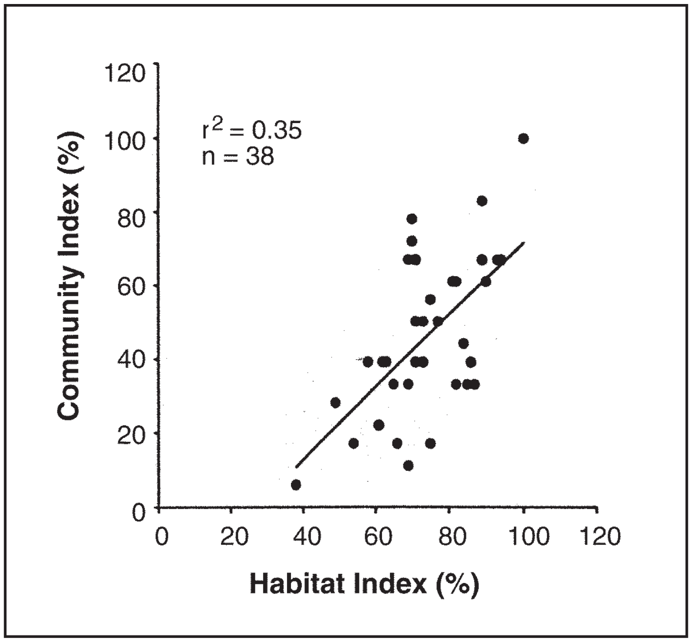


Figure 27

RELATIONSHIP BETWEEN IMPERVIOUS COVER AND COMMUNITY INDEX — PIEDMONT BASIN

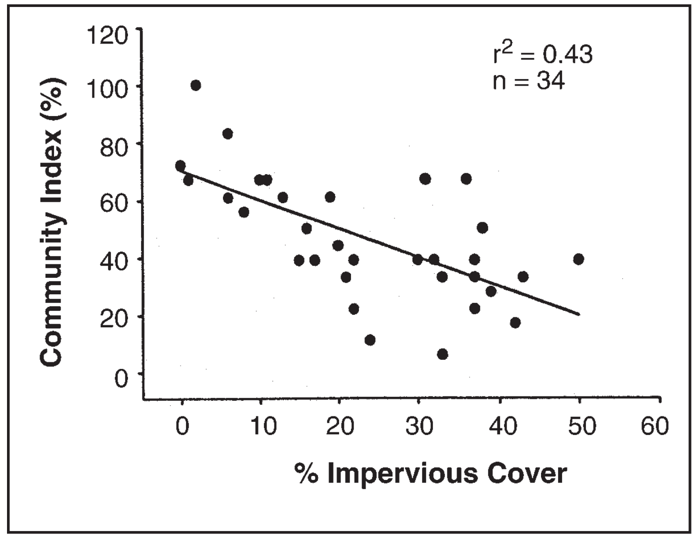
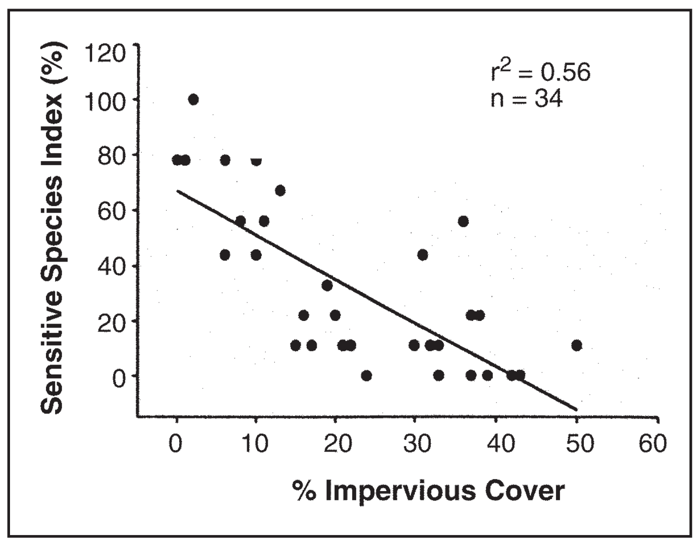


Figure 28

RELATIONSHIP BETWEEN IMPERVIOUS COVER AND SENSITIVE SPECIES INDEX — PIEDMONT BASIN



Conclusions

Aquatic organisms are severely impacted throughout the region. Urbanization appears to be a major nonpoint source of pollution affecting almost all (90%) of the stream miles in the region. Likely stressors include changes in hydrology, water quality, sediment quality, and physical habitat related to urbanization. Further study is needed to define the relative contributions of the various stressors impacting the biota. Point sources and hazardous waste sites also impact a small proportion of the nontidal streams in the region. Most major point sources in the region discharge to tidal waters — with the exception of Red Clay Creek, which receives several discharges in both Pennsylvania and Delaware. Agriculture is no longer a dominant land use in the region, but may also have adverse effects in selected areas.

A small proportion of stream miles (10%) in the region were found to be comparable to reference conditions for either biological or physical habitat quality. Therefore, approximately 30 miles of nontidal streams in the region still remain in "good" condition after 200 years of European settlement and development. The vast majority of stream miles are impacted by a variety of human activities, with urbanization the most widespread. The protection of rare high-quality stream segments and the restoration of numerous impacted segments are management priorities in the region.

Recommendations

- Continue to implement stormwater controls for new developments; aggressively implement controls, including land-use controls, in the few remaining undeveloped, forested watersheds in the region.
- Coordinate the monitoring of reference areas in Pennsylvania and Maryland to augment the reference site data base for Delaware.

- Conduct additional studies to identify specific stressors.
- Evaluate the effectiveness of National Pollutant Discharge Elimination System and stormwater controls.
- Quantify the economic value of recreational fishing in the region.

WATER QUANTITY

This Key Issues section should be read in consideration of the climate of the Piedmont Basin — humid-temperate and with generally plentiful rainfall, averaging about 42 inches of fairly evenly distributed annual rainfall. This rainfall replenishes aquifers and maintains perennial stream flow. Rainfall amounts can be erratic, however, being relatively high in some years and low in others. Geology, and its resultant topography, cause both surface and groundwater availability to be unevenly distributed, and the locations of water availability and demand are not coincident.

The largest freshwater supply in the Piedmont Basin is Brandywine Creek, with most of the Brandywine drainage area in Chester County, Pennsylvania. Although the largest water supply for the Piedmont Basin is actually the Delaware River, use is limited to industrial cooling due to the brackish-to-saline nature of the water. Other sources of surface-water supply include the smaller Red and White Clay creeks and the Christina River. These streams have a combined drainage area smaller than that of the Brandywine.

Brandywine Creek has been developed as a source of water supply for several centuries, paralleling the industrialization of the area. The creek was both the source of water supply and water power for a series of early mills that played a crucial role in the development and preservation of the United States as a young nation. By the mid-20th century, the City of Wilmington had bought up the old mill rights and had established a claim to the entire flow of Brandywine Creek as its source of water supply. Wilmington also built Hoopes Reservoir during the 1930s which, along with Brandywine Creek, created excess water-supply capacity for the city.

The flight of population to the suburbs began in the 1950s, where the only surface-water supplies were smaller streams (Red Clay, White Clay, and Christina) that had lower dependable flow; this created a growing imbalance of water-supply capacity relative to demand. Water was one of the City of Wilmington's few bargaining assets which the growing suburbs coveted. The early 1960s drought demonstrated that the combined flows of the smaller streams were insufficient to meet water demands; accordingly, the city was considered the principal source of future water supply for the entire county. However, influential developers had different ideas, and instead of negotiating with the City of Wilmington for water, the utilities serving the suburbs accelerated the development of groundwater.

At the same time, anticipation of ever-increasing county-wide growth led to the proposal of a large dam on the White Clay Creek above Newark. Flaws with the proposed project — including housing developments in the proposed flood pool, the fact that about half of the flood pool would cover land in Pennsylvania, and the huge cost — proved this project infeasible. Subsequent review of those previous demand projections indicate that population growth was indeed grossly overestimated, as were the water demands that the reservoir would have been designed to meet. Forecasts for heavy growth in water demands, particularly in Wilmington during the last half of the 20th century, have not materialized since the Wilmington population decreased by 125,000 inhabitants in 1950 to a decrease of 75,000 in 1990, and water-using heavy industries either closed or became more efficient. The DuPont Company had acquired and set aside large tracts of land for the project, but most of this land was sold or donated for public parks by the early 1980s. The so-called "Newark Project" was formally stricken from the state's Water Supply Plan in 1984.

At about this time, agencies concerned with water issues became established and /or grew. Planning agencies — including WILMAPCO, the Chester County Water Resources Authority, and the Water Resources Agency for New Castle County — and regulatory agencies — including the Delaware River Basin Commission, Pennsylvania Department of Environmental Regulation (now the Department of Environmental Protection), and DNREC — gradually contributed to the widespread accumulation of reliable data on water usage, improved forecasts of water demands, estimates of sustainable yields of water sources, and criteria for additional water resource development.

Studies of groundwater supply availability conducted during the mid-1950s to the early 1970s estimated progressively higher yield estimates. Such optimism was the result of extensive water exploration and experience with increasing water development projects — particularly in the productive Coastal Plain aquifers relative to the less productive Piedmont aquifers. Any increased water demands in northern New Castle County were met during the 1970s and 1980s by improved management of the existing surface and groundwater supplies through construction of a series of water system interconnections and agreements brokered by the Water Resources Agency for New Castle County. During the 1980s, Artesian Water Company entered an agreement with the City of Chester, Pennsylvania, to tap excess capacity that Chester had developed in the Susquehanna River basin. This arrangement, with progressive annual increases in permitted withdrawals, significantly augmented the dependable public water supply available for New Castle County.

Thus, the fortunate and near-optimal development of water supply in northern New Castle County can be attributed to the geology and history of the area, as well as to technological development: surface-water sources were developed first, incremental groundwater capacity was added, management of capacity was improved through interconnections, and the acquisition of out-of-state surplus waters was eventually accomplished.

One key water quantity issue is that today all of the "easy" water is gone, and increased competition for limited supplies will continue. Groundwater withdrawals can be sustained, but not appreciably increased without the use of artificial recharge technology. All groundwater developed from this point forward will contain naturally objectionable quality due to high iron levels and high corrosivity, which causes problems with metals leaching in plumbing systems. Under the new "Lead and Copper" rule of the Safe Drinking Water Act, the increased levels of water treatment required to minimize such problems will translate into considerable costs.

Local water sources and developed supplies are susceptible to human contamination. Sediment runoff, which causes high turbidity, has dramatically increased with urbanization; this indirectly represents an actual health threat rather than the normally identified villains of organics and metals. Highly turbid water requires higher levels of disinfectants and oxidizers which, along with their by-products (trihalomethanes, aldehydes, ozone, and chlorine), are more of a health threat (cancer risk) than organics and metals. Moreover, the organics and metals are effectively removed by the treatment processes, even though the processes are primarily designed to clarify turbid water. This removal is, however, incidental. Under new treatment rules for surface water and stricter standards for disinfectants and disinfectant by-products, risk from these substances should be reduced. Treating for turbidity also represents a large cost for the consumer.

As described earlier in this report, the Piedmont Basin's quest for future water supplies continues today with the ongoing Water Supply Plan for New Castle County. Additional, substantial supplies *will be required* early in the next century. Addition of any significant new water source — especially a reservoir project — would be expensive and could involve a necessary degree of environmental loss; this environmental loss would need to be better determined before an informed decision could be made.

As with the abandoned "Newark Project," the added capacity of Thompsons Station — or any other large project for that matter — would have to be paid for in total, although actual demand for the water will only rise incrementally. To minimize the large up-front costs, the new source of supply should be compatible with existing water treatment and distribution capacity to the extent possible. Storage would also help offset some of these added costs, such as Hoopes Reservoir does for the City of Wilmington, which uses that stored water supply as a source when Brandywine Creek is turbid.

Improving stream flow would be beneficial — by releases from storage, by reduction of diversions by use of an alternate source(s), or both. Consideration also has to be given to the impact occurring both in-state and particularly in Pennsylvania — which diverts considerable water and has caused quality problems. Thompson's Station reservoir would help offset these problems.

Another key issue is that, despite a wealth of information available to the planning processes, optimal solutions *do not appear to be forthcoming.* Complicating this, future water supply for the county is envisioned as a joint venture among both public and private interests; therefore, numerous regulatory and institutional issues unprecedented in Delaware remain to be resolved involving project financing, ownership, and operation. The current idea is that an "authority" or similar entity would be created to run the project although this concept is in its infancy and has not yet received scrutiny. Until these issues are resolved, an actual construction date for the project is indeterminable. Fortunately, other interim projects are being developed, providing an additional measure of security for the county's overall water supply.

To date, water supply, water quantity, environmental restoration, and public health protection programs have not been well-coordinated due to bureaucracy and compartmentalization resulting from separate complex statutes and regulations and separate funding mechanisms. One year, for example, more money was spent monitoring soil and shallow groundwater beneath a field in the Delaware City industrial complex — which posed no threat to water supplies or the aquatic environment — than on the statewide public water monitoring program. Current regulations are extremely weak in these critical areas of economics. Little resources are devoted to innovative areas of study and planning.

The cost of water should be expected to rise dramatically in the next decade in response to necessary and unnecessary cost increases. Combined cost for water and water for average residential customers (at today's consumption rates) will likely double to more than $10 per thousand gallons in the very near future.

SOILS

The state required all counties to develop or revise their comprehensive plans. The New Castle County Comprehensive Plan has sections entitled Natural Resources, Community Facilities and Services, and Growth Management Program. Most of the discussion presented in this plan was very similar to the discussion that took place in the Piedmont Whole Basin Workshop held August 27–29, 1996, at Grassdale, New Castle County, Delaware. The plan relays the good understanding expressed at that workshop regarding New Castle County's existing conditions and problems; the plan even discusses *sustainability* in the Update section and promotes "new alternative forms of development that reduce the rate of land absorption, maximize open space, preserve resources, and are conducive to increasing use of public transit."

The plan recognizes the need to promote compact development patterns to minimize infrastructure costs, reduce fragmentation of open space, and protect critical areas. Further, the plan states that:

> Septic systems should be discouraged since their failure rates and maintenance costs are high, and they can potentially degrade groundwater. Sewer infrastructure operation and maintenance costs will be higher in southern New Castle County due to lack of slope, which will necessitate the use of high energy pumping stations to convey wastewater. In addition, community wastewater treatment systems will be significantly more expensive to operate and maintain as compared to larger regional systems serving more customers.

Substantive proof that septic systems are failing at an alarming rate or that septic systems are leading to significant groundwater pollution is lacking, especially on the larger parcels in New Castle County. A recent professional paper in the *Journal of Environmental Quality* by Nizeyimana et al. (1996) documents that septic systems located in land areas in Pennsylvania adjacent to New Castle County load groundwater at a rate of 0.7 to 1 pound of nitrogen per acre per year. Is that an alarming rate when compared to nitrogen loading rates from lawn fertilization or agricultural production? Dr. William Ritter of the University of Delaware stated in *Report Nutrient Budgets for Appoquinimink Watershed* that cropland contributes 75% of the nitrogen and phosphorus loads from nonpoint sources. By comparison, nitrogen discharged by the Middletown-Odessa-Townsend wastewater treatment plant is less than that contributed from nonpoint sources; and nitrogen from septic systems — though greater than the Middletown-Odessa-Townsend treatment plant discharges — is still less than that contributed from cropland. Any time development takes place, pollution will result, regardless of the type of wastewater treatment employed. Anthropogenic activities damage the environment. Septic systems are not solely responsible and can be as environmentally safe as other wastewater treatment options.

As landscape changes occur, our water resources are directly affected. These changes include alterations to drainage patterns and to land perviousness, hence affecting the amount and quality of runoff to surface waters; alterations to the amount and quality of water available for groundwater recharge; and alterations in the amount of pollution generated on a particular parcel of land through human activities. It is technically difficult to predict changes in the amount of pollution that will occur as a result of changes on the land surface; it is important, however, to recognize that such changes will occur. For example, if forestland is converted to agricultural, residential, commercial, or industrial use, a significant increase in the amount of pollution will result. In addition to habitat loss and impacts on living resources caused by the conversions, increased pollution will negatively effect both groundwater and surface water quality. Over time, the cumulative impact of these conversions may threaten the sustainability of our water resources.

New Castle County has consolidated amenities into riparian areas with dire results. The loss of riparian buffers increases downstream flooding, and the placement of those amenities within these buffers contributes to the loss of valuable wetlands. Unfortunately, the New Castle County Comprehensive Plan made no recommendations regarding riparian buffers, although research has shown that 100 feet could provide adequate protection for most situations and a 300-foot buffer could be applied for especially critical areas. In any case, a buffer should be larger than the floodplain it is to protect, and its size should be based on available research. DNREC would certainly offer to work with New Castle County toward determining appropriate buffer widths.

SEDIMENT

Deposition

Sediment deposition due to accelerated erosion has significant adverse environmental impacts and exacerbates flooding problems. Because of their topography, the watersheds of the Piedmont Basin are particularly susceptible to sediment deposition problems. The costs of removing sediment from blocked drainage structures, ponds, and tidal areas can be calculated. However, the environmental costs associated with lost habitat and other associated impacts are more difficult to assess. In considering the sources of sediment and the cumulative impacts of adding impervious surfaces in a watershed, it is important to recognize the link with land use.

Suspended Solids

Suspended sediment particles cause turbidity problems in the water treatment process and act as an environmental stressor on aquatic life. The soils in the Piedmont geologic province have a relatively higher percentage of clays than those of the Coastal Plain. Public water supplies are also more dependent on surface waters in the Piedmont than in the Coastal Plain. Therefore, suspended solids are of particular concern in the watersheds of the Piedmont Basin. The exposure of soils as a result of construction activities and, to a lesser degree, agricultural activities, is considered the major nonpoint source of suspended sediments in the Piedmont Basin.

Contaminated and Enriched Sediments

As soil particles wash off the land through the erosion process, their chemically active nature makes them particularly conducive to transporting adsorbed nutrients, metals, toxics, and other contaminants into the receiving waters. Since most of the heavy industry in Delaware historically has been located in the watersheds of the Piedmont Basin, the potential for contaminated and/or enriched sediments is of special concern in this area.

WETLANDS

Identification and Delineation

The interrelatedness of wetland ecological characteristics is significant for wetland identification in areas where one or more hydrologic indicators is missing due to seasonal variations in surface- or groundwater, or due to problematic soils or vegetation. For example, some Piedmont riparian areas are distinguished by hydrophytic plant communities and wet but non-hydric or marginally hydric soils. Other floodplain soils may be hydric but lack hydric soil indicators, making wetland identification and delineation problematic.

A difficulty in nontidal wetland assessments in the Piedmont Basin is determining whether wetland hydrology is present. Areas with sufficient groundwater discharge (seeps) may lack surface-water indicators. For surface-water driven wetlands, historical stream gauge data collected by the U. S. Geological Survey for calculating flood frequency and duration may be irrelevant in light of the rate of recent upstream watershed development (pers. comm. between P. Emslie and R. Simmons). The difficulty of identifying and delineating problematic wetlands is significant given the lack of state nontidal wetlands legislation, existing deficiencies in the federal regulatory program, and gaps in the protection of all riparian areas through county floodplain ordinances (DNREC, Delaware Field Evaluation, 1992).

Recommendations

- Refine understanding and interrelatedness of wetland ecological characteristics through monitoring in reference wetlands.
- Identify and use non-regulatory mechanisms to protect riparian areas and drier-end “difficult to delineate” wetlands.

Legislative and Regulatory Initiatives

Despite public outreach and a participatory effort with stakeholders and special interest groups, DNREC, to date, has been unsuccessful in passing the Freshwater Wetlands Act. There is presently no state regulatory oversight for freshwater, nontidal wetlands.

At the federal level, the U. S. Army Corps of Engineers’ general permits or nationwide permits are issued for similar classes of activities that result in impacts considered to be either individually or cumulatively minimal on wetland functions, water quality, or the aquatic environment. Nationwide Permit 26, for example, allows discharges of up to 10 acres of fill to *headwater* and *isolated* wetlands. (A predischarge notification is required for fills of between 1 and 10 acres.)

Site-specific wetland functional assessment studies have been conducted to apply and compare scientific wetlands assessment techniques, including Best Professional Judgment, to wetlands within various landscape positions. These studies indicate that *above-headwater* wetlands may demonstrate high functionality across the suite of wetland functions. Additionally, although considered to be of minimal impact, case studies on the effects of Nationwide Permit 26 in other states have found off-site impacts to fish and wildlife habitat in most cases (Gladwin and Roelle, 1992). In Delaware, lack of state legislation and deficiencies in the federal regulatory program pose a particular threat to unique wetland ecosystems of less than one acre and to headwater wetlands of high functionality.

Section 401 of the Clean Water Act allows for states to strengthen the U.S. Army Corps of Engineers’ “dredge and fill” program through certification that permit actions will not adversely impact wetlands, surface-water quality, or aquatic ecosystems. Delaware issues water-quality certification for individual U. S. Army Corps of Engineers permits on a case-by-case basis. However, to date, the state has chosen to waive water-quality certification for nationwide permits.

Delaware’s Subaqueous Lands Act does not adequately protect all nontidal rivers, streams, and ponds/lakes. State jurisdiction is defined based on a legal interpretation of “navigability,” which is determined by the depiction of the waterway as a blue line on a U.S. Geological Survey topographic map. This excludes many headwater Piedmont streams and associated riparian and slope wetlands that are intermittent but which provide important water-quality and habitat functions. Additionally, the recent passage of Senate Bill 320 exempts any public agency in New Castle County from the subaqueous permit review process for activities in waterways where the purpose is the “repair, retrofit, or maintenance” of waterways or structures within state jurisdictional waters. The lack of scientific and regulatory oversight for the dredging and/or channelization of Piedmont streams for flood control may directly or indirectly adversely impact associated riparian wetlands. The Subaqueous Lands Act lacks a buffer provision, allowing indirect and cumulative impacts to aquatic systems, including wetlands from construction projects.

Recommendations

- Use information generated through EPA state wetland program development grants as one basis for setting conditions for state water-quality certification for individual U. S. Army Corps of Engineers permits.
- Consider any future or potential certification of nationwide permits for nontidal wetlands as part of the overall Comprehensive Conservation and Management Plan for nontidal wetlands.
- Strengthen the Subaqueous Lands Act through revised means of determining jurisdictional waters so that headwater and intermittent streams are regulated.
- Consider amending the Subaqueous Lands Act to include a buffer provision.

LIVING RESOURCES

White Clay Creek Watershed

White Clay Creek has been the focus of numerous fish and macroinvertebrate studies, some of which are still under way. Stangl (1994) studied the northern portion of the Delaware stretch of this creek looking at the feasibility of establishing a permanent trout fishery. Although not native to White Clay Creek, stocked trout have supported a popular sport fishery in the creek for many years. Stangl found a deficiency of suitable trout habitat. This was apparently due to a number of factors including excessive bank erosion and siltation, inadequate pool habitat and vegetative overhang, extreme high summer water temperatures, and high nutrient runoff. As part of the study, inventories of macroinvertebrates and fish species were conducted. Stangl is now preparing a report that will recommend the minimum allowable flow rates required to maintain fish populations in the creek.

In addition to the above study, Stream Watch volunteers have been collecting macroinvertebrate data in White Clay Creek for the past five years. In general, they have found a pattern of declining water quality in the lower (Delaware) portion of the creek relative to the upper (Pennsylvania) portion (Bernard Sweeney, pers. comm.). At the conclusion of this year, the fifth year of study, the Stroud Water Research Center will summarize and report on the findings.

The creek and the area immediately surrounding it provide habitat for a number of rare species — most notably the bog turtle and a long list of Delaware's rare plants, including four which are found nowhere else in the state. This type of habitat has been surveyed and is summarized (Delaware Natural Heritage Program, 1994). White Clay Creek State Park contains appropriate habitat for the Delmarva Fox Squirrel, which could be considered for future releases if the federal moratorium is lifted (Ken Reynolds, pers. comm.). A federally listed mussel species has been recorded in the Pennsylvania portion of the tributary; the Delaware portion has never been surveyed for mussels, but potential habitat exists. A variety of botanical and zoological inventories have been conducted in selected sites in the watershed and can be referenced for species lists (e.g., National Park Service, 1994; White Clay Creek Study Task Force and Advisory Committee, 1994; and White, 1990b and 1991).

Many parts of the watershed are protected from development, but one of two high-quality tributaries within the watershed may potentially be dammed to form a backup reservoir for New Castle County. This move would result in direct and dramatic habitat loss in these areas.

Red Clay Creek Watershed

In the earlier part of this century, Red Clay Creek suffered extremely severe impacts from toxic pollutants. In the 1950s and 1960s, there were no fish living in the creek (Shirey, 1991). By the late 1980s, things had recovered to the point where fish were once again inhabiting the creek, but 1995 surveys found no mussel species in the creek (Delaware Natural Heritage Program, 1996b). Odonates (dragonflies and damselflies), another group which is sensitive to water quality, are apparently in a degraded but improving state (Delaware Natural Heritage Program, 1996b). A 1995 study of the macroinvertebrates and algae in the portion of the creek near Ashland found that the creek was "severely impaired" (Mercatante, 1995).

The Delaware Nature Society has played an active role in land protection in the watershed and has supported studies of living resources in some of these areas. These reports include Delaware Nature Society, 1995; Durell, 1992; Gallagher, 1994; and Mercatante, 1995.

Studies of terrestrial fauna indicate that there is some bog turtle habitat in the watershed although good estimates of population size or stability do not exist. The Delaware Natural Heritage Program inventoried declining bird species that were nesting in selected areas of the watershed. A number of parcels provided habitat for forest-interior species that are declining in the Piedmont Basin and throughout their range. Surprisingly, no forest-dependent birds of prey were observed during the study, although the researcher had expected to find barred owls, Cooper's hawks, broad-winged hawks, and/or red-shouldered hawks (Delaware Natural Heritage Program, 1996b). This is cause for concern.

In addition to the species mentioned above, the Delaware Natural Heritage Program data base indicates that there are numerous occurrences of state-rare vertebrates and state-rare plants in the watershed, including six plant species that occur nowhere else in the state.

The watershed is also the site of Delaware's portion of the "state line serpentine barrens." Serpentine barrens are unique grassland habitats that occur on soils formed atop outcrops of serpentinite rock. The rock and soils are high in chromium, magnesium, and other minerals, and hence are toxic to all but the few plant species that have evolved tolerances. This community type, one of the rarest in the United States, has a clustering of occurrences in the vicinity of the Maryland-Delaware-Pennsylvania confluence. This community is of conservation concern not only because of the rarity of the community type, but also because it provides habitat for state and globally rare plant species.

In 1932, Delaware had approximately 500 acres of this unique habitat. By 1975, this habitat had been reduced to 27 acres; and by 1992, it had degraded even further. A portion of the habitat loss is due to the creation of Hoopes Reservoir, which flooded some serpentine barrens; the remaining loss is due to conversion of former barrens to planted lawns. Much of the remaining barrens are threatened with overgrowth by red cedar *(Juniperus virginiana)* trees and exotics. These areas, including those managed as lawns, are restorable (McAvoy, 1992; Nature Conservancy, 1992).

Brandywine Creek Watershed

The Delaware Natural Heritage Program data base indicates that numerous state-rare animal and plant species are found in and around the creek, including seven plant species found nowhere else in Delaware. Bog turtles have been found in this watershed; and the regal fritillary, a federally listed butterfly that is now extirpated from Delaware, was last found here. Brandywine Creek State Park has appropriate habitat for Delmarva fox squirrels, but a reintroduction has never been attempted in the park. Some years ago, a reintroduction in an adjacent area in Pennsylvania was attempted but was not successful (Ken Reynolds, pers. comm.).

Brandywine Creek State Park is a favorite spot for amateur naturalists, especially bird-watchers. The park maintains lists of birds observed as well as other natural history data collected within the park. See also White (1985, 1990a) for inventories of terrestrial vertebrate species in the watershed.

The presence of stone flies *(Plecoptera)* in the northernmost Delaware sections of the creek and the creek's northern Delaware tributaries indicate good water quality (Shirey, 1991). At one time, shad spawned in the creek, but excessive damming resulted in the loss of this fish species. They temporarily returned when the upper Delaware River was overly polluted, and fish ladders were installed on Brandywine Creek. As the Delaware River pollution was cleaned up, the fish abandoned the Brandywine. The fish ladders fell into disrepair and have since been removed.

Shellpot Creek Watershed

No studies of the living resources in this watershed were uncovered, other than Shirey (1991), which lists fish species found in the creek. The Delaware Natural Heritage Program data base shows virtually no occurrences of rare species within this highly degraded watershed.

Naamans Creek Watershed

As with Shellpot Creek, the South Branch of Naamans Creek has not, to our knowledge, been the subject of any specific studies of its living resources other than Shirey (1991). In the summer of 1996, it was the subject of media attention because of a fish kill, apparently caused by careless draining of chlorinated water from a community pool directly into the creek.

Recently, the forested habitat adjacent to the creek was severely damaged by the replacement and expansion of a gravity-fed sewer line parallel to the creek. The vegetation and topsoil from a forested swath approximately 50 feet wide, adjacent to the creek, were completely removed. As a result of repetitive construction activity, virtually no native plants remained in the corridor, and the soil was sufficiently altered and compacted so as to prevent rapid recolonization by native species. The long-term effect of this activity, if not remedied, will be to fragment and degrade the forest community and to introduce non-native species into the forest.

Upper Christina River Watershed

A botanical inventory of the riparian zone of the Christina River was conducted in 1995 (Delaware Natural Heritage Program, 1996b). Floodplains of the watershed have suffered great degradation. Environmental stress has led to the establishment of alien plant species and garden escapes, which are displacing native vegetation. Activities such as the installation of sewer lines within the floodplain and clearing of native vegetation by neighboring homeowners contributed to establishment of exotics and the overall floodplain degradation. There were a handful of state rare-plant species, with one glaring exception. In the 1930s, the Christina River floodplain harbored populations of swamp pink *(Helonias bullata)*, a federally listed species. These populations gradually declined in the 1970s and are now apparently extirpated from the basin. The primary cause of the decline is thought to be increased rates of sedimentation and direct habitat manipulation.

Upland forests adjacent to the riparian areas were also inventoried and described within the report. As with the entire Piedmont Basin, the general lack of large, mature, undisturbed forests was noted. Complete species lists for each of these areas is given within the report.

Mid- and Lower Christina River Watershed

A botanical inventory of the riparian zone of the Christina River was conducted in 1995 (Delaware Natural Heritage Program, 1996b). The freshwater tidal marshes west of Churchmans Marsh were found to be in very good shape. Although there was low floristic diversity and no rare plant species, this is normal for this type of habitat. These marshes provide important wetlands functions and wildlife habitat.

Bald eagles use the marshes and waters of the lower Christina River and can often be seen soaring above Interstate 95. Their protection is a critical concern in this watershed.

Habitat in this watershed continues to be lost to development. In addition, large portions of marsh (Churchmans Marsh or Artesian Marsh) will be lost if the new reservoir for New Castle County is placed here. The Delaware Division of Fish and Wildlife has incorporated the tidal marshes and impoundments along the lower Christina as part of the Northern Delaware Wetlands Rehabilitation Project.

AIR

Ozone

Ozone is the only air pollutant currently monitored by the state that is known to be present in concentrations high enough to cause harm to human health and welfare (including effects on vegetation and damage to some materials). Episodes of high ozone occur during the summer months and impact the entire Piedmont Basin.

Deposition

Deposition of pollutants from the atmosphere to land and water surfaces can affect the Piedmont Basin.

Nitrogen

Atmospheric deposition of nitrogen (both wet and dry) is known to be an important contributor to excess nutrient problems in ecosystems like the Piedmont Basin; estimates of nitrogen entering a system from the atmosphere range from 10% – 40% of the total nitrogen.

Acid Rain

Precipitation in the Piedmont Basin is known to be acidic, with an annual average pH of 4.2.

Air Toxics

Chemicals commonly known as air toxics can be a concern due to ambient air concentrations and/or deposition. Limited ambient air monitoring has been done; some is continuing. Monitoring for toxics in deposition has not been done. There have been no direct studies in the Piedmont Basin on ecosystem impacts of air toxics.

CONTAMINANT SOURCES

Solid Waste

Piedmont residents and businesses together throw away more than 800 million pounds of trash each year. Nearly all of this waste is disposed of in landfills. Improperly designed or operated landfills can cause pollution of groundwater, surface water, and air and serve as a potential breeding ground for disease-carrying insects and rodents. Since the mid-1960s, landfills have been regulated by the state to reduce these risks. Modern landfills regularly cover the waste to control insects and rodents and are designed to include both a bottom liner to prevent leachate ("garbage juice") from contaminating ground- or surface water and a gas collection system to control odors and collect methane. Where once nearly every community had its own town dump, today there are only two landfills operating in the Piedmont Basin (see Map 4).

The most pressing solid waste environmental concern today is what to do with our trash when the existing landfills run out of space. Locating a new landfill in a densely populated area like the Piedmont Basin would be difficult if not impossible because no one wants to live next door to even a "modern" landfill. To make our existing landfills last as long as possible, we must reduce the amount of waste to be landfilled. This can be achieved through the following:

- *Reducing Waste Generated* — The state through its Pollution Prevention Program is working with businesses to reduce waste by using raw materials more efficiently and to eliminate unnecessary packing materials from consumer goods.
- *Recycling Waste* — Currently there are 47 drop-off recycling centers in the Piedmont Basin that annually collect some 14 million pounds of recyclables.
- *Burning Waste* — Several communities in Pennsylvania burn their waste to both reduce the volume of material that must be landfilled and to generate electricity.

Septics

Septic systems may contribute significantly to groundwater nitrate levels. New Castle County has already eliminated the use of many septic systems in areas of high failures, unsuitable soils, and sewer-system availability.

Many older subdivisions are now proposed for septic elimination. To minimize nutrient-loading problems from septic systems, we need to encourage development that works with the existing landscape rather than a cut-and-fill philosophy and promote the establishing of buffers along streams to improve water quality and habitat.

Hazardous Materials

In 1995, Delaware businesses generated approximately 27,158 tons of hazardous waste. Of that amount, 19,212 tons were generated by Resource Conservation and Recovery Act (RCRA) large-quantity generators. Eighty-eight percent of the hazardous waste generated by RCRA large-quantity generators came from facilities in New Castle County. One of the greatest challenges facing DNREC today is helping industry find ways to reduce or eliminate the amount of hazardous materials managed. The impacts from even a small reduction in the amount of hazardous materials managed improves environmental quality in a number of ways. Important reduction measures include the following:

- Decreasing the levels of hazardous constituents managed through air stacks, National Pollutant Discharge Elimination System (NPDES) outfalls, and Publically Owned Treatment Works (POTWs).
- Reducing the chances of releasing hazardous chemicals during their storage, handling, transportation, treatment, and disposal. The less waste managed, the fewer opportunities for spills.
- Decreasing the hazardous constituents in consumer products.
- Eliminating or decreasing the need for hazardous waste disposal capacity, thereby reducing the potential for releases from disposal units.

Other challenges facing DNREC include the following:

- Working with zoning and land-use planning agencies to encourage the siting of businesses managing hazardous materials away from residential areas, schools, day care centers and environmentally sensitive areas such as riparian zones, floodplains, wetlands, and Water Resource Protection Areas (see Map 5).
- Working with businesses and industries to locate in and/or re-use brownfields via the Voluntary Cleanup Program.
- Accelerating the rate of cleanup of RCRA Corrective Action sites.
- Accelerating the rate of cleanup of Hazardous Substance Cleanup Act (HSCA) sites.
- Helping hazardous waste generators achieve 100% compliance with the Delaware Regulations Governing Hazardous Waste.
- Identifying non-reporting hazardous waste generators.
- Identifying sites that release or may release hazardous substances.

LAND USE

There are many land-use issues in the Piedmont Basin. These are the selected issues for the preliminary assessment where DNREC has a role.

The growth in all Piedmont Basin watersheds is a result of easy access to the Washington, Baltimore, Philadelphia, and New York megalopolis and to population growth. Most of the growth that has occurred since 1982 has been related to suburban housing, office, and commercial development. The development of large tracts of land into large-lot suburban tracts consumes land quickly as compared to village centers, community integrated development, extension of existing communities, and infill. On a per-capita basis, urban development produces fewer environmental, infrastructure, and services costs as compared to sprawled development.

The Shellpot Creek and Naamans Creek watersheds are subject to flash floods due to the high percentage of impervious areas. Much of the development in these watersheds was built or approved before there were controls on floodplain development, filling of wetlands, and stormwater management.

Small communities such as Arden, Ardencroft, Ardentown, Bear, Bellefonte, Centerville, Christiana, Claymont, Elsmere, Hockessin, Newport, Stanton, and others may not have the ability to raise their quality of life through redevelopment, infill, joint governance districts, and annexations. They may lack information to make informed choices and not be organized. To facilitate desirable growth, many communities will require the assistance and cooperation of federal, state, and county governments.

Land-Use Related Opportunities for DNREC

The greatest development pressure in the Piedmont Basin exists in the Hockessin, upper White Clay, Glasgow, and Pencader Hundred areas. These are areas where DNREC may have a limited window of opportunity to acquire and preserve important open space and guide development to attain environmental goals.

The Shellpot and Naamans watersheds appear to be almost completely built out, which means that providing waterway restorations to address flash-flooding may be prohibitively expensive throughout these watersheds.

Research may reveal cost-effective methods to ameliorate flash floods in these watersheds.

Nearly all undeveloped areas in the Piedmont Basin are zoned for some type of development or are in public open space. To achieve better land-use decisions, DNREC may find it in its best interest to focus its efforts where it may actually have some influence over important causes and effects. For instance, zoning has been associated with stream sedimentation, changes in flooding patterns, wetlands losses, habitat losses, toxicity in the food chain especially where fish consumption advisories are concerned, increases in the costs of services delivered to sprawled development, increases in infrastructure costs, increases in the extent of impervious area, reduced air quality, reduced habitat diversity, and decreases in the quality of life.

Improvements in land-use decision making could be made, and it appears that DNREC could focus on improving zoning because it is something for which we have some resources to work on and it can positively affect other areas of concern. Efforts are already under way in the state to improve the quality of information that is provided to local governments on planning issues. For the first time since 1967 as part of the Delaware Tomorrow Commission, the state of Delaware has developed planning goals and guiding principles as part of the 1995 Shaping Delaware's Future Act. DNREC has supported strengthening the link between growth management and capital improvements programming, sunsetting, infill, clustering, mixed-use zoning, municipal redevelopment, and historical structure adaptive re-use to promote sustainable uses of the Piedmont Basin's resources. This could be implemented by DNREC representatives attending planning and zoning meetings and providing information to support environmentally sensitive land-use decisions.

Comment:

Zoning began in New Castle County in 1954. About two years later, the county established a planning department. At that time, most environmental issues were not as great a concern as they are today, either nationally or locally. However, much of our present settlement pattern was established as an outgrowth of the cumulative effect of all the development decisions made since the Swedes landed at the Rocks on the Christina River in 1638. Zoning is used to preserve property values and control nuisances by providing for separation of individual uses and wide separation of incompatible uses. After World War II, federal programs provided economic subsidies for sprawled suburban development, which had a substantial impact on current land-use patterns in New Castle County.

There is a need to assess and thoughtfully weigh, along with other criteria, the environmental impacts of infrastructure plans before they are approved. The state Wastewater Facilities Advisory Council is developing a methodology that can serve as an example for other infrastructure-enhancing programs. Modeling of the environmental impacts of projected probable build-out scenarios should lead to useful information for improved environmental decision making and management.

Land-Use Related Opportunities for Other State Agencies

The present Delaware GIS (DEGIS) map is not accurate for guiding land-use policies and decisions at the individual parcel level. But if it is refined, the DEGIS project can become a much more effective tool. More effort is needed from all state agencies to create a fortified, more comprehensive, and more refined state GIS map to make it a more useful decision-making tool for individual programs.

New infrastructure-building patterns could lead to inappropriate settlement/development (build-out) patterns. State agencies that provide or approve infrastructure should coordinate with DNREC and the Office of State Planning Coordination to ensure that the resulting development pattern is environmentally reasonable.

Land-Use Related Opportunities Available in Water-Supply Planning Initiatives

Land-use impacts in the White Clay Creek watershed would likely result from the building of a reservoir at Thompson Station or Corner Ketch. Creating waterfront property would attract people who may want to build on the water if sections of the shore are privately owned. If a possible reservoir is publicly owned, there would be an incentive to use it for recreation. These sites would require buffer areas and low-density development to control impacts to water quality in the reservoir.

Hoopes Reservoir in the Red Clay Creek watershed provides emergency supply to the City of Wilmington and the Piedmont Basin. Wilmington's infrastructure once served 120,000 people and now serves 72,000 residents. Its reserve capacity and the lands that protect it will continue to be important to the Piedmont Basin.

The only public surface-water supply intake in the Christina watershed is at Smalley's Pond. Upstream of the pond, there are opportunities to protect this section of the Christina. Development pressure in the area, soils that stay suspended in water, and other nonpoint source problems including septic system failures all impact Smalley's Pond and the Becks and Sunset ponds that empty into it. Due to the public expense of building a major reservoir, additional protection of existing surface supplies such as Smalley's Pond should be evaluated. These sites require natural buffer areas and development controls to limit impacts on water quality and quantity.

Complying with the Shaping Delaware's Future Act: Watershed Issue Identification

In each of the Piedmont Basin watersheds, the three most applicable state planning goals and priority watershed issues were identified to show which direction the monitoring phase, management plan, and other phases could take.

White Clay Creek Watershed

Goal: Protect critical natural resource areas from ill-advised development. The White Clay is important for water supply and for recreation. It is also an area where strong pressure for development may infringe on DNREC's ability to provide for these needs unless land acquisition and other conservation efforts are strengthened.

Goal: Encourage redevelopment and improve livability of existing communities and urban areas, and guide new employment into underused commercial and industrial sites. Several vacant industrial sites in the City of Newark have high potential under initiatives such as the brownfields program to provide high-quality employment and other opportunities.

Goal: Streamline regulatory processes and provide flexible incentives and disincentives to encourage growth in desired areas. If strengthened, existing brownfields and other redevelopment programs could recycle more sites.

Red Clay Creek Watershed

Goal: Protect critical natural resource areas from ill-advised development. Development pressure around the Hockessin area may limit the opportunity for land acquisition and conservation programs to protect ground- and surface-water supplies.

Goal: Encourage redevelopment and improve livability of existing communities and urban areas, and guide new employment into underused commercial and industrial sites. The Red Clay Creek has contamination from zinc in its sediments from the NVF operation and PCBs from a waste dump in Kennett Square. The fishery is not used, and little contact recreation occurs. Efforts to remediate Red Clay Creek could result in enhanced recreation and improve the quality of the water supply to United Water at Stanton.

Goal: Promote mobility for people and goods through a balanced, multi-modal transportation system. The historic investment in transportation infrastructure, if maintained and managed, could stimulate greater use of mass transit and reduce dispersion of development into more sensitive areas.

Brandywine Creek Watershed

Goal: Protect critical natural resource areas from ill-advised development. The protection of the water supply for the City of Wilmington through land conservation is important to the county and to the state.

Goal: Encourage redevelopment and improve livability of existing communities and urban areas, and guide new employment into underused commercial and industrial sites. Brownfields along Brandywine Creek and in Wilmington present opportunities for economic growth and environmental improvements.

Goal: Promote mobility for people and goods through a balanced, multi-modal transportation system. Wilmington has the population density and the transportation infrastructure for an effective mass transit system.

Shellpot Creek Watershed

Goal: Encourage redevelopment and improve livability of existing communities and urban areas, and guide new employment into underused commercial and industrial sites. Brownfields along the waterfront and in urban areas have redevelopment potential.

Goal: Direct state investment and future development to existing communities, urban concentrations, and designated growth areas. This watershed is almost completely built out. Improving the quality of life in existing communities reduces environmental stress on open land and increases benefits from existing infrastructure.

Goal: Promote mobility for people and goods through a balanced, multi-modal transportation system. This watershed has the population concentration and transportation infrastructure to facilitate mass transit.

Naamans Creek Watershed

Goal: Encourage redevelopment and improve livability of existing communities and urban areas, and guide new employment into underused commercial and industrial sites. Brownfields along the waterfront and in urban areas have redevelopment potential.

Goal: Promote mobility for people and goods through a balanced, multi-modal transportation system. This watershed has the population concentration and transportation infrastructure to facilitate mass transit.

Goal: Protect critical natural resource areas from ill-advised development. High-quality wetlands along Naamans Creek in the Lancashire, Arden, and Radnor Green areas are an important community asset in public and private open space. According to the Arden Office of Community Planning, the watershed's riparian habitat requires additional conservation efforts including preserving remaining forestlands, correcting mapping errors that deleted blueline streams, and transferring administration of stormwater management back to DNREC.

Christina River Watershed

Goal: Direct state investment and future development to existing communities, urban concentrations, and designated growth areas. Wilmington's infrastructure once served more than 110,000 residents; now 72,000 people reside there. The Port of Wilmington is an important state economic asset.

Goal: Encourage redevelopment and improve livability of existing communities and urban areas, and guide new employment into underused commercial and industrial sites. Large brownfields in and around the urban waterfront and other areas are attractive for redevelopment.

Goal: Promote mobility for people and goods through a balanced, multi-modal transportation system. Wilmington, with its population concentration, and as a hub for rail, highway, air, and water transportation, is the state's best prospect for developing an effective mass transit system that can consume less energy and produce less pollution per person and ton mile.

RECREATION

White Clay Creek Watershed

Parks and Recreation

The White Clay Creek watershed possesses the greatest acreage of protected open space of any of the six watersheds in the Piedmont Basin. These protected lands represent nearly 4,350 acres, with 7.3 miles of undeveloped riparian habitat along the main stem of the White Clay Creek. Nearly all the protected land is dedicated to public recreation. The majority of the land is located in White Clay Creek State Park, the White Clay Creek Bi-State Preserve north of Newark, and the Middle Run Natural Area administered by New Castle County. These recreational resources are regional in scope, attracting visitors from throughout the tri-state region. The remaining open space areas are maintained by New Castle County and the City of Newark park systems. The watershed has a wide array of land-based recreation along with above-average access to water-based recreation.

The development of a possible reservoir in the White Clay Creek watershed at any of the proposed locations including Corner Ketch, Thompsons Station, or Churchmans Marsh, would have lasting impacts on recreation in this watershed. Should Corner Ketch or Thompsons Station be selected for the proposed reservoir, large areas of recreational land, much of which lies within White Clay Creek State Park, would be lost for public use. Generally, lands along Churchman's Marsh are privately held, restricting public recreation at present.

Demographically, residents of the watershed are younger than the county average; therefore, the recreation needs here differ from the other northernmost watersheds. The population is beginning to stabilize after a decade of rapid growth. As indicted by the 1995 Recreational Needs Survey, the majority of the residents believe that more lands should be protected for conservation and recreational pursuits. Residents also indicated the need for additional paved hiking and bicycle trails, more freshwater fishing opportunities, and additional programs for teens and residents with disabilities.

Fish and Wildlife Recreation

The White Clay Creek watershed contains three of the state's six designated freshwater trout streams: White Clay Creek, Pike Creek, and Mill Creek. These streams receive approximately 72% (22,220) of the annual stocking of legal-sized trout, with White Clay Creek receiving by far the most (69%, or 21,300 trout) and Mill Creek receiving the least (1%, or 360 trout). Due to the number of fish stocked and the public access provided along the entire length of the stream, White Clay Creek receives the greatest fishing pressure of all stocked streams and has the highest angler success rate. Mill Creek receives one of the lowest amounts of fishing pressure and has the lowest angler success rate. Pike Creek receives moderate fishing pressure and has the second-highest angler success rate. Although Pike Creek has a high angler success rate, private property signs and fencing erected along portions of the stream have greatly decreased the fishing area available to anglers. If additional access along this stream is not secured, stocking of this popular and successful stream might be discontinued. Public access to the other streams is not as immediate a concern; however, both streams have been hampered by the lack of adequate angler parking. This problem is especially evident at White Clay Creek during the opening weekend of the season.

The upper stretch of White Clay Creek is designated as a special Fly-Fishing Only Area and provides a fishing opportunity unlike any other in Delaware. In an effort to improve this unique fishing opportunity, the Division of Fish and Wildlife has proposed to protect, enhance, and restore a 1,000-foot section of stream habitat by modifying existing conditions in or along the stream using habitat improvement devices. These devices would consist of natural materials such as rocks and logs, and although primarily designed to improve fish habitat, they would also benefit other aquatic species and improve the stream's water quality. This proposal was presented to the White Clay Creek Preserve Bi-State Advisory Council — consisting of members of special interest groups and organizations that make recommendations to state agencies on activities within the preserve — and rejected in February 1995. Although the council's decisions are not binding, the Division of Parks and Recreation's internal policy has been to endorse their decisions as much as possible. Therefore, the habitat improvement project has been shelved indefinitely.

The only other area that receives substantial recreational fishing within the White Clay Creek watershed is at the confluence of Churchman's Marsh, Christina River, and White Clay Creek. This area is a popular boating and fishing area with target species including striped bass, catfish, and white perch. However, a fish consumption advisory has been issued for the area due to the presence of contaminants in edible portions of these species. Several small private ponds provide additional, but limited fishing opportunities within the watershed, and several of these have received pond management consultation from the Division of Fish and Wildlife for weed control and other water-quality problems. No public boat ramp facilities are available within the watershed and none is currently proposed.

Public hunting areas in White Clay Creek watershed are limited to White Clay Creek State Park. This park implements a very successful controlled deer hunting program, which annually provides over 650 hunters with archery and firearm sporting opportunities. Success rates of hunters vary between years and among the different seasons, but on average, over 70 deer are harvested per year, yielding approximately an 11% success rate. Although no other public areas allow hunting within the watershed, a fair amount of recreational hunting does occur on numerous private properties throughout the region.

Increasing deer populations within other portions of the White Clay Creek watershed have caused browsing damage to crops and ornamental shrubs, have increased deer/vehicular collisions, and have been associated with an increased risk of Lyme disease. Another species whose population has increased beyond acceptable levels within the watershed is resident, non-migrating Canada geese. This species exceeds its social carrying-capacity by creating annoyances such as excessive noise, defecation on lawns, eutrophication of small ponds, and herbivory of lawns and ornamental plantings. Recreational hunting, where it can safely occur, is the recommended management tool to reduce deer and resident geese populations to socially acceptable levels on both public and private lands; however, in order to increase the success of this management tool, more public and private areas within the watershed need to implement hunting programs.

Three of the four final reservoir alternatives proposed to alleviate water supply problems in northern New Castle County are within the White Clay watershed. The impact of these proposed reservoirs on fish and wildlife recreational opportunities would be both positive and negative. A Churchmans Marsh reservoir would benefit recreational fishing, if permitted within the reservoir, while its construction would impact current recreational uses of the marsh, such as fishing, boating, and waterfowl hunting. Construction of the reservoir would also eliminate access of recreationally important anadromous and estuarine fish species from entering the marsh to spawn and feed.

Construction of either the Thompsons Station or Corner Ketch reservoirs would similarly benefit recreational fishing within the proposed reservoir, but also benefit the White Clay Creek by creating a cold-water trout fishery. If water was periodically released from the bottom of either of these reservoirs, water temperatures within the White Clay Creek would remain colder, possibly supporting a year-round trout fishery. Currently, the White Clay Creek is limited to a spring "put-and-take" trout fishery because trout are unable to survive in the stream's warm water for extended periods. The negative impacts to fish and wildlife recreation associated with the construction of either of these reservoirs would be the loss of private hunting areas.

Red Clay Creek Watershed

Parks and Recreation

Although there are large tracts of protected open space in the Red Clay Creek watershed, many of these tracts are not open to the general public. At present, there are only 422 acres of public parkland in this watershed. The New Castle County Department of Parks and Recreation provides a good variety of recreational opportunities in the southern half of the watershed, which is the most densely populated area. Major recreational facilities include the Delcastle Recreation Area, which is located on the divide between the Red and White Clay Creek watersheds, Brandywine Springs Park, Greenbank Park, and Ford Powell Park.

Population demographics show an aging, stable population, which is reflected in the recreational needs voiced by the watershed's residents. Residents generally are happy with the level of recreational opportunities existing in the watershed but would like to see additional programs for the elderly, teens, and people with disabilities. Residents also indicated a desire for greater access to water-based recreation. Unfortunately, the water quality of Red Clay Creek does not support any type of contact recreation or fishing.

Fish and Wildlife Recreation

Recreational fishing and boating opportunities in the Red Clay Creek watershed are currently limited to several small private ponds. However, two areas — Red Clay Creek and Hoopes Reservoir — have the potential to provide outstanding recreational fishing. Red Clay Creek was a popular trout fishing stream until studies in 1986 revealed that the tissue of recently stocked trout was becoming contaminated with PCBs and chlorinated pesticides. In response, the divisions of Fish and Wildlife and Public Health have issued and continue to issue a fish consumption advisory for this stream. The stream has since been deleted from the trout-stocking program. In order for this stream to be reconsidered as a public fishery, sources of these contaminants would have to be determined and addressed, and then a monitoring program implemented to update contaminant levels within selected fish species.

Hoopes Reservoir, a reservoir for the City of Wilmington in which fishing is prohibited, has been periodically identified as a potential public fishing area. Although there is little argument about the reservoir's recreation potential, land-owners in the surrounding area have vehemently opposed making it a public use area. Their primary concerns have been increases in traffic, litter, noise, and other negative attributes sometimes associated with the creation of a public recreation area.

Although there are no public hunting areas within the watershed, a fair amount of recreational hunting does occur on numerous private properties throughout the region. Increasing deer populations in portions of the Red Clay Creek watershed have caused unacceptable browsing damage to crops and ornamental shrubs, have increased deer/vehicular collisions, and have been associated with an increased risk of Lyme disease. Recreational hunting, where it can safely occur, is the recommended management tool to reduce deer populations to socially acceptable levels on both public and private lands. However, in order to increase the success of this management tool, more public and private areas within the watershed need to implement hunting programs.

The majority of the mosquito surveillance and control in the Red Clay Creek watershed has been targeted to the marshes and surrounding uplands at the confluence of the Red and White Clay creeks. These marshes and vestigial creek beds are frequently flooded by severe rain events, and require and average of 3.3 aerial applications of insecticide per year to control larval mosquito populations. Control measures, as determined by light trap counts in the Glenville area, annually afford residents an average nuisance-free night rate of 87%, or 93 nights. The hilly topography of the more northern sections of this watershed do not lend themselves to extensive mosquito breeding and require less surveillance and control and have a higher average nuisance-free night rate.

Brandywine Creek Watershed

Parks and Recreation

Large portions of the Brandywine Creek watershed north of the City of Wilmington have been protected through a number of means. Additional lands have been added to Brandywine Creek State Park, and large tracts of land are protected through conservation easements or are privately held by institutions such as Winterthur Museum and non-profit organizations such as Woodlawn Trustees. There are also several large parks owned by the City of Wilmington and managed by Delaware State Parks. These include Alapocas Woods, Rockford Park, and Brandywine Park. The New Castle County Department of Parks and Recreation also operates several community parks within the older suburban developments west of Concord Pike. The protection of lands along Brandywine Creek is critical to Wilmington's water supply.

Demographics in this watershed indicate an aging population. The upper portion of the watershed shows the oldest average age in New Castle County while a much younger population resides in the southern half of the watershed in Wilmington. This mix of ages validates residents' requests for additional programs for children, teens, and the elderly. The need for additional opportunities for walking, hiking, and biking, as well as greater access to water-based recreation, was indicated in all areas of the watershed.

Fish and Wildlife Recreation

The Brandywine Creek watershed contains two of the state's six designated freshwater trout streams: Wilsons Run and Beaver Run. These streams receive approximately 14% (4,210) of the legal-sized trout stocked annually, with Wilsons Run receiving 10% (3,095 trout) and Beaver Run receiving 4% (1,115 trout). Beaver Run receives the lowest amounts of fishing pressure and the second lowest angler success rate. Wilsons Run receives moderate fishing pressure and has moderate angler success. The higher fishing pressure at Wilsons Run can be partially attributed to its better public access, as the majority of the stream flows through Brandywine Creek State Park. Public access to Beaver Run is not an immediate concern; however, both streams have been hampered by the lack of adequate angler parking.

The only other area that receives substantial recreational fishing within the Brandywine Creek watershed occurs within Brandywine Creek itself. The nontidal portion of this stream provides the only sustainable smallmouth bass fishery in the state. This water body also occasionally yields unusual catches — such as muskellunge, walleye, and other species — which are transients from nearby Pennsylvania. The tidal portion of this stream is a popular boating and fishing area with target species including striped bass, catfish, and white perch.

Unfortunately, the divisions of Fish and Wildlife and Public Health have issued a fish consumption advisory for this creek because of the contaminants found in edible portions of various fish species. A no-consumption-of-finfish advisory is in place for the tidal portions of this stream, while a limited-consumption-of-finfish advisory is in place in the stream's nontidal portion. A limited consumption advisory recommends limiting meals of fish from these waters to no more than one 8-ounce meal per month. Several small private ponds provide additional, but limited fishing opportunities within the watershed, and several of these have received pond management consultation from the Division of Fish and Wildlife for weed control and other water-quality problems. No public boat ramp facilities are available in the watershed, and none is currently proposed.

Public hunting areas in the Brandywine Creek watershed are limited to Brandywine Creek State Park. This park implements a special antlerless deer hunting program in which approximately 85 hunters participate each year, while also helping to maintain the deer herd within the park's carrying capacity. On average, 43 deer are harvested per year, yielding a success rate of approximately 57%. Although no other public areas allow hunting in the watershed, a fair amount of recreational hunting does occur on numerous private properties throughout the region.

Increasing deer populations in other portions of the Brandywine Creek watershed have caused unacceptable browsing damage to crops and ornamental shrubs, have increased deer-vehicular collisions, and have been associated within an increased risk of Lyme disease. Another species whose population has increased beyond acceptable levels within the watershed is resident, non-migrating Canada geese. This species exceeds its social carrying capacity by creating annoyances such as excessive noise, defecation on lawns, eutrophication of small ponds, and herbivory of lawns and ornamental plantings. Recreational hunting, where it can safely occur, is the recommended management tool to reduce deer and resident geese populations to socially acceptable levels on both public and private lands. However, in order to increase the success of this management tool, more public and private areas within the watershed need to implement hunting programs.

In an effort to introduce recreational hunting to youths, especially adolescents (ages 12 –15 years) with single parents, the Division of Fish and Wildlife has initiated a special Youth Hunt in the Flint Woods Section of the Brandywine Creek watershed. This new hunter education program provides young people the opportunity to experience recreational deer hunting under the guidance of a hunter education instructor.

Shellpot Creek Watershed

Parks and Recreation

The Shellpot Creek watershed represents the most suburbanized drainage area in the Piedmont Basin. Demographically, the population is aging and very stable. The region is home to several large recreational facilities: Bellevue State Park, Fox Point State Park, Rockwood Museum, Bringhurst Woods Park, Rock Manor Golf Course, and over 30 community parks. In total, there are approximately 1,030 acres of land dedicated to public recreation in the watershed. New Castle County operates most of the community parks as well as Talley-Day Park, which functions as a regional park. Many of these facilities are or soon will be connected by a system of pedestrian/bicycle trails, which will maximize the recreational opportunities not only for the residents of the Shellpot watershed, but northern New Castle County as well.

Needs expressed by the residents of this sub-watershed were additional hiking and biking trails, increased access to the Delaware River shoreline, and more programs for the elderly and for teens.

Fish and Wildlife Recreation

Fish and wildlife recreational opportunities are limited within the Shellpot Creek watershed because it represents one of the most suburbanized watersheds in Delaware. Recreational hunting in this watershed is extremely limited because of human population densities and safety concerns. Recreational fishing and boating opportunities here are primarily limited to a few tributaries of the Delaware River and several private ponds scattered throughout the area. Bellevue and Fox Point state parks provide the only public fishing areas in the watershed, and no public boating or hunting areas exist. The pond at Bellevue State Park, a popular fishing area, is annually the site of several youth fishing days and skills clinics. These programs, hosted by the Division of Fish and Wildlife's Aquatic Resources Education Center, Delaware Bassmasters, and Stren, are geared to providing urban minority youths and adults with a supervised fishing experience.

Fox Point State Park provides some shoreline fishing of the Delaware River and has been considered a potential site for an additional public boat launching facility. The preliminary plans are to design a ramp to accommodate small trailered boats and personal watercraft ("jet skis"). To date, these plans have been stymied because of potential contaminant problems within sections of the park and will not progress until these issues are resolved.

Naamans Creek Watershed

Parks and Recreation

Naamans Creek watershed is another highly suburbanized drainage area. As with most of Brandywine Hundred, the residents of the watershed are aging, and the population is stable. Although small in size, the area is served by a good system of community parks operated by New Castle County, and the northern section of Fox Point State Park lies along a substantial portion of the Delaware River shoreline. This section of Fox Point State Park is not yet developed. Plans for the development of this section are under way. The towns of Arden, Ardentown, and Ardencroft also have parks and open space within their corporate boundaries. Many of these areas are connected by a system of pedestrian trails. Residents in this area have expressed a desire to create an extended greenway along Naamans Creek, protecting the Naamans Creek Natural Area and providing opportunities for passive recreation.

Needs expressed by the residents of this watershed were very similar to those of the residents of Shellpot Creek watershed, such as additional hiking and biking trails, increased access to the Delaware River shoreline, and additional programs for seniors.

Fish and Wildlife Recreation

Fish and wildlife recreational opportunities are limited within Naamans Creek watershed because of its small size and high human population density. Recreational hunting is extremely limited here because of safety concerns. Recreational fishing and boating opportunities are primarily limited to a few tributaries of the Delaware River and several private ponds scattered throughout this highly suburbanized area. Fox Point State Park provides the only public fishing area in the watershed, and no public boating or hunting areas exist. This state park provides some shoreline fishing of the Delaware River and has been considered a potential site for an additional public boat launching facility. Preliminary plans are to design a ramp to accommodate small trailered boats and personal watercraft ("jet skis"). To date, these plans have been stymied because of potential contaminant problems in sections of the park and will not progress until these issues are resolved.

Christina River Watershed

Parks and Recreation

The Christina River watershed is the most rapidly growing watershed in the Piedmont Basin. The area is served by a number of parks and recreational facilities operated by the cities of Newark and Wilmington and by New Castle County. The New Castle County Department of Parks and Recreation is actively acquiring recreational land along the Christina River through the subdivision development process. Major recreational land holdings include Iron Hill Park, Becks Pond Park, Lewden Green, and Coventry Ridge parks in the upper and middle sections of the watershed and Banning and Canby parks in the lower watershed. Many of these facilities will be linked by the Christina Greenway. These facilities offer a wide array of recreational opportunities. The City of Wilmington also operates many smaller neighborhood parks in the watershed.

Overall, the demographics of the Christina watershed are substantially different from those of the other watersheds in the basin. The population of this area is growing rapidly and is substantially younger than that of the county as a whole, although there are demographic differences in different portions of the watershed. The lower portion of the Christina watershed demographically is characterized as urban and densely populated, with extremes in terms of population age. Generally, the older suburban areas west of Wilmington including the towns of Newport and Elsmere support an aging population while the population within the City of Wilmington tends to be younger. The upper and middle reaches of the watershed west of the Christina River and southwest of Newark have been experiencing a development boom, attracting a young, family-oriented population. This growth has placed a strain on existing recreational facilities.

Recreational needs expressed by residents are in line with the demographics of the watershed. Residents indicated a need for more land acquisition for recreation and preservation, additional playground and sports facilities, opportunities for historic and nature education programs, and increased programs for teens. A need for additional spending by state and county governments for parks and land acquisitions was also indicated.

Fish and Wildlife Recreation

The Christina River watershed contains the only state-managed warm-water pond in the Piedmont Basin: Becks Pond. This 25-acre pond is consistently ranked among Delaware's top five ponds (ranked second in 1994) in terms of popularity among anglers (33,000 angler days) and for the last 20 years has been consistently the most heavily fished pond (1,284 angler days per acre). This fishing pressure is triple that of any other managed pond in Delaware, with the most significant increase in pressure occurring between 1990 and 1994. As a consequence of this tremendous fishing pressure, Becks Pond has a low angler success rate, ranked 28th of the 36 ponds surveyed in 1994. Part of this low angling success can also be attributed to the decline in water quality of the pond caused by increasing development of the watershed.

In an effort to improve angler success on this heavily fished pond, the Division of Fish and Wildlife has implemented several management and research programs. These include developing a long-range management plan, monitoring game fish populations, promoting the implementation of better stormwater management practices in the watershed, improving habitat by constructing brush shelters, increasing the minimum legal length of largemouth bass taken from the pond from 12 to 15 inches, and supplementing game fish populations by stocking lower water-quality tolerant species, such as channel catfish.

The Christina River watershed also contains one of the state's six designated freshwater trout streams, Christina Creek. This stream receives approximately 14% (4,470) of the annual stocking of legal-sized trout, second only to White Clay Creek. This stream is also the second most popular in terms of fishing pressure and has a moderate angler success rate. Public access to Christina Creek is not an immediate concern; however, access is hampered by the lack of adequate angler parking.

Other areas that support substantial recreational fishing within the Christina River watershed are the Christina River, Smalley's Dam, Sunset Lake, and the ponds in Banning Park. The Christina River is the most popular of these areas, with target species including striped bass, catfish, white perch, and largemouth bass. Unfortunately, the divisions of Fish and Wildlife and Public Health have issued a fish consumption advisory for this river due to contaminants found in edible portions of various fish species. A no-consumption-of-finfish advisory is in place for the tidal portions of this river (from the mouth of the river up to Smalley's Dam), while a limited-consumption-of-finfish advisory is in place for Smalley's Dam and the nontidal portion of the river (from Smalley's Dam to Interstate 95). A limited-consumption advisory recommends limiting meals of fish from these waters to no more than one 8-ounce meal per month. Several small private ponds and tributaries to the Christina River provide additional, but limited fishing opportunities within the watershed. Several of these small ponds have received pond management consultation from the Division of Fish and Wildlife for weed control.

All three of the public boat ramp facilities in the Piedmont Basin are located in this watershed — two on the Christina River and one at Becks Pond. These ramps receive tremendous boating pressure, with the Christina River ramps being considered inadequate to handle the ever-increasing boat traffic utilizing them. This increased boating pressure has been attributed to a number of factors including improvement in water quality and recreational fisheries in the Christina and Delaware Rivers, rejuvenation of the Christina River waterfront in Wilmington, and the advent of personal watercraft ("jet skis"). An additional public launching facility is currently being sought within this basin to accommodate small, trailered boats and personal watercraft access to the Delaware and Christina rivers.

The Christina River watershed also contains one of the four final reservoir alternatives proposed to alleviate water-supply problems in northern New Castle County. Artesian Marsh, located along Interstate 95 and the Christina River, has been proposed not only as a reservoir alternative, but also as a wetland mitigation site if another alternative is chosen. Currently, Artesian Marsh provides little if any fish and wildlife recreational opportunities; however, the construction of a reservoir or the restoration of this former wetland to a tidal marsh or tidal impoundment would benefit recreational fishing. Therefore, the impact of the proposed reservoir or wetland mitigation at Artesian Marsh would have a positive impact on fish and wildlife recreational opportunities.

Approximately 2,100 acres of degraded tidal wetlands scattered among 12 sites within the Christina River watershed are currently proposed for restoration and enhancement under DNREC's Northern Delaware Wetlands Rehabilitation Program. These restoration sites include popular or formally popular fish and wildlife recreation areas such as Churchmans Marsh, Old Wilmington Marsh, and the Nonesuch Creek Wetland Complex (a popular muskrat trapping area). A regional objective of this program is to improve a wide variety of recreational opportunities in the wetland, riverine, and adjacent upland habitats of each project site. One method being used to accomplish this goal is to restore tidal exchange and fish passage by replacing the traditional one-way tide gates with automated or mechanical water-control structures that allow two-way tidal flow. Currently, several of these rehabilitation projects are in the planning and development stages. These projects include Old Wilmington Marsh, which is a joint project between DNREC and the City of Wilmington; NeCastro Marsh, which is a wetlands remediation site associated with the Newport Superfund Site; and Newport Marsh and the Nonesuch Creek Wetland Complex, which are both joint projects between the Delaware Department of Transportation and DNREC.

Although there are no public hunting areas within the watershed, a fair amount of recreational hunting does occur on numerous private properties throughout the region. Increasing deer populations in portions of the Christina River watershed have caused unacceptable browsing damage to crops and ornamental shrubs, have increased deer-vehicular collisions, and have been associated within an increased risk of Lyme disease. Another species whose population has increased beyond acceptable levels within the watershed is resident, non-migrating Canada geese. This species exceeds its social carrying capacity by creating annoyances such as excessive noise, defecation on lawns, eutrophication of small ponds, and herbivory of lawns and ornamental plantings. Recreational hunting, where it can safely occur, is the recommended management tool to reduce deer and resident geese populations to socially acceptable levels on both public and private lands. However, in order to increase the success of this management tool, more public and private areas within the watershed need to implement hunting programs.

Mosquito surveillance and control efforts in the Christina River watershed are concentrated in two distinct areas: the forested wetlands in the southwestern section of the watershed, and along the Christina River. The forested wetlands along the Maryland border produce a group of mosquito species that breed in seasonally flooded areas, usually influenced by snow melt or spring rains. These areas are annually treated with insecticides via helicopter in early spring. Control measures in this area, as determined by light trap counts in Hickory Woods, annually afford residents an average nuisance-free night rate of 73%, or 78 nights.

Several formally tidal marshes of the Christina River are extensive mosquito-breeding areas following significant rain events. The Artesian, Southbridge, Airport, and Cherry Island marsh complexes each annually require an average of three aerial applications of insecticide over a combined total of approximately 4,500 acres. These marshes are usually treated during the summer via fixed-wing aircraft. Control measures in this area, as determined by light trap counts in Banning Park, annually afford residents an average nuisance-free night rate of 92%, or 98 nights.

ASSESSMENT NEEDS

GROUNDWATER

A comprehensive assessment of Piedmont Basin groundwater quality is not currently available. However, numerous wells exist and could be networked similar to those in southern New Castle County by the Delaware Geological Survey. Such a network need not equally cover all areas of the Piedmont Basin, and areas such as the northeastern Naamans and Shellpot watersheds where groundwater resources are less available may be deferred until adequate resources warrant inclusion in the network. Financial and programmatic resources and priorities could dictate the identification of areas requiring groundwater monitoring, followed by the compilation of existing data sources for those areas.

Identification of Areas Requiring Groundwater Quality Monitoring

The single most important role of groundwater in the Piedmont Basin is for drinking water. Priority areas based on drinking water use would include the following:

Piedmont Province Areas:

- Cockeysville Aquifer (Hockessin Valley)
- Cockeysville Aquifer (Pike Creek)
- Laird Tract Wellfield

Potomac/Columbia Aquifers (Coastal Plain):

- Newark South Wellfields
- Eastern Estates
- Glendale Wellfield
- Artesian Airport Wellfields

Piedmont Basin groundwater also serves as the source of base flow to streams that are used as drinking water sources. Since these watersheds encompass large land areas extending into Pennsylvania, interstate coordination is necessary. These watersheds include the following:

- Brandywine Creek
- Red Clay Creek
- Hoopes Reservoir
- White Clay Creek
- Mill Creek
- Christina River
- Smalley's Dam

The groundwater-quality monitoring regimes would differ between the two purposes — direct drinking-water supply versus stream base flow — yet both would initially include existing sources and existing well points, supplemented by new monitoring wells as needed. As discussed previously, a very similar approach was taken for southern New Castle County. The agencies involved in developing a network would be DNREC; Delaware Geological Survey; the Water Resources Agency for New Castle County; and the Department of Public Health's Office of Drinking Water.

Identification of Existing Sources of Groundwater Quality Information

There are numerous possible sources of information and available well sampling points. However, each program collects different types of information at various frequencies and stores the information largely on hard-copy files. Integration and electronic data storage are needed to allow an ambient network to be fashioned from these diverse sources. Possible sources include the following:

- Office of Drinking Water — public water supply sampling
- DNREC — regulated point sources
- Water Resources Agency for New Castle County — WRPA-monitored facilities
- Delaware Geological Survey and U.S. Geological Survey — special studies

Once existing sources have been evaluated as to their quality and adequacy in representing overall groundwater quality, gaps would be identified where sampling should be augmented, quality improved, and new sampling points added.

SURFACE WATER

DNREC, in cooperation with the Pennsylvania Department of Environmental Protection (PADEP), the EPA, the Delaware River Basin Commission (DRBC), and other federal, state, and local agencies, has initiated the development of a comprehensive water-quality management plan for the Christina River watershed. The plan will cover the entire 564 square miles of the watershed in Delaware and Pennsylvania and includes Brandywine Creek, White Clay Creek, and Red Clay Creek. Specific tasks that are part of this five-year study include intensive water-quality and water-quantity monitoring; comprehensive assessment of water-quality conditions; development of water-quality models for the watershed and for the receiving streams; establishment of total maximum daily loads (TMDL) for the point and nonpoint sources of pollution; and public education and participation. TMDLs establish the maximum amount of a pollutant (or pollutants) that a water body can assimilate and still meet water-quality standards and support designated uses.

Currently, DNREC is actively involved in the second year of the five-year project. Efforts are under way to finalize the water-quality assessment of the watershed; conduct intensive water-quality and quantity monitoring; build an inventory of Geographical Information System (GIS) data layers regarding land use for the watershed — such as land coverage, geology, soil, and topography; and develop hydrodynamic and water-quality models for the watershed and for the receiving streams.

Intensive data collection within the Delaware portion of the Christina River watershed (Christina Sub-basin) is expected to continue with some modifications and additions. Monitoring activities planned by the Division of Water Resources for the state fiscal year (July 1997 – June 1998) are summarized below.

Intensive (Bi-Monthly) Monitoring

The objective of this element of the Christina Sub-basin Monitoring Plan is to collect appropriate water-quality data that will be used for development and calibration of a hydrodynamic and water-quality model of the Christina River and its major tributaries. The collected data will provide the basis for calibration of the model to ensure that it accurately predicts water-quality and quantity conditions. Monitoring stations were selected based on one or more of the following factors: proximity to state line; proximity (or collocation) with U.S. Geological Survey stream gauging stations; proximity to surface-water intakes; confluence of major tributaries; above / below urban areas; above / below point-source discharges; availability of historic data; and ability to serve as a clean reference site.

Stormwater Monitoring

The objective of stormwater monitoring in the Christina River Sub-basin is to collect stormwater related water-quality and quantity data. This information will be used to characterize stormwater runoff based on various land-use activities in the watershed and will be used to calibrate the watershed model. This monitoring activity is part of the Interstate Christina Sub-basin Nonpoint Source Management Strategy and is based on a comprehensive plan developed by the U.S. Geological Survey.

Special Surveys

The purpose of this element of the Christina Sub-basin monitoring activity is to collect additional data that are not covered under other monitoring activities in the sub-basin. Data collected during this activity will be used to satisfy modeling needs. The special surveys may include continuous monitor deployments and / or hydrologic and hydrodynamic surveys of the streams. Hydrodynamic surveys of the tidal portion of the Christina River will be conducted using an acoustic doppler current profiler. During these surveys, tidal currents at several locations will be monitored for a full tidal cycle. The information collected will be used to calibrate the hydrodynamic model of the Christina River.

Fish Consumption Advisories

DNREC and the Department of Health and Social Services issued a public health advisory on the consumption of fish taken from the Christina River Sub-basin in April 1996. The advisory was the result of an intensive study of contaminants in fish tissue and is being issued due to the detection of elevated levels of polychlorinated biphenyls (PCBs) in the fish. The immediate goal of the advisory is to reduce the level of human exposure to PCBs.

Along with the study of contaminants in fish and drinking water, DNREC has also conducted sediment sampling throughout the lower Christina Sub-basin to determine the magnitude and extent of contamination. Initial results of the study indicate higher levels of PCBs in the sediments in the areas of the Christina where fish with the highest levels of PCBs were found.

DNREC has been working actively to investigate land-based activities in these areas to determine potential sources and to clean up sites that may be contributing to the contamination. Another tool DNREC is using to clean up contaminated sites is the Brownfields initiative, which is designed to promote voluntary cleanup and reuse of abandoned industrial sites. The longer-term goal of DNREC is to be able to lift the advisory once contaminant levels in the fish are reduced to a safe level. As cleanups continue, improvements to water quality will be assessed.

Biological Assessment

In fall 1993, DNREC collected macroinvertebrate samples and conducted habitat assessment in 39 nontidal streams within the Piedmont Basin. Sites were randomly selected to provide unbiased estimates of the proportion (percent) of stream miles in the region with three classes of quality: “good,” “fair” (moderately degraded), and “poor” (severely degraded). This framework provided the basis for an overall assessment of the biological condition of nontidal streams to complement the more detailed assessments that have been completed on specific streams or stream reaches.

Aquatic organisms were found to be severely impacted throughout the region. Urbanization appears to be a major nonpoint source of pollution and habitat degradation, affecting almost all (90%) of the stream miles in the region. Likely stressors include changes in hydrology, water quality, sediment quality, and physical habitat. Further study is needed to define the relative contributions of the various stressors impacting the biota.

A small proportion of stream miles (10%) in the region were found to be comparable to reference conditions for either biological or physical habitat quality. Therefore, approximately 30 miles of nontidal streams in the region still remain in "good" condition after 200 years of European settlement and development. The vast majority of stream miles are impacted by a variety of human activities, with urbanization the most widespread. The protection of rare high-quality stream segments and the restoration of numerous impacted segments are management priorities in the region.

Recommendations

- Continue to implement stormwater controls for new developments; aggressively implement controls, including land-use controls, in the few remaining undeveloped forested watersheds in the region.
- Coordinate monitoring and assessment activities with Pennsylvania and Maryland.
- Conduct additional monitoring to identify specific stressors at "fair" and "poor" sites.
- Evaluate the effectiveness of National Pollutant Discharge Elimination System (NPDES) and stormwater controls.
- Repeat the biological assessment using the same approach and methodologies as appropriate.

WATER QUANTITY

Assessment needs consist solely of additional program staff to help administer the water allocation and hydrologic conditions monitoring programs.

- Integrated water resources planning, with particular emphasis on pricing techniques and demand-side management, should be adopted as a matter of regulatory policy and water utility management by municipally owned suppliers.
- The water quantity management (allocation) program should be used to help encourage more efficient use, restore potentially useful aquifers, assure against further overdrafting of supplies, reallocate surface supplies, and impose appropriate minimum stream-flow standards to protect designated uses.
- Investigate ASR technology.
- Encourage reuse — after treatment — of groundwater contaminated by volatile organic chemicals through the allocation and environmental restoration programs. This would serve to "clean up" and create a benefit (continued incentive) for the remediation.
- Investigate reuse of wastewater.
- Enhance water conservation practices entailing increased public education in cooperation with the utilities.
- Support local government recharge maintenance efforts and water-supply protection efforts.
- Support investments to maintain basic hydrologic monitoring programs in the state and federal governments.
- Develop cost-effective, environmentally beneficial water-supply projects in conjunction with demand-side measures.
- Use the model of the Christina River Basin Drought Management Committee as successful implementation of *Whole Basin Management*.

SOILS

The *Soil Survey of New Castle County* was conducted in the 1960s by the U.S. Department of Agriculture's Soil Conservation Service and was published in October 1970. The concepts and protocols currently applied in the mapping and classification of soils has changed significantly since that soil survey was published. Little, if any, laboratory work was conducted on the soils during that survey, and most soils information was extrapolated from adjacent areas in Maryland and Pennsylvania. The soil survey was primarily prepared for agricultural purposes, and many of the wooded and urban areas were mapped using a very large scale, which resulted in the loss of now-necessary detail and accuracy. Recently, New Castle County commissioned the Natural Resources Conservation Service (formerly the Soil Conservation Service) to re-map southern New Castle County. The Piedmont Basin similarly should be re-mapped to today's standards of accuracy.

Such a new soil survey — in conjunction with DNREC's new statewide wetland mapping project and associated new land-use and land-cover data — should facilitate the identification of areas within the Piedmont Basin where growth could be encouraged and areas where development should be discouraged due to unique and/or rare plant communities or wetlands.

Each site evaluation to replace an existing septic system or construct a new one is identified by a tax-parcel number. This information could be further specified as to the *actual on-site septic approvals granted and the type of system approved*. If the site evaluation data base could be linked with other DNREC Geographical Information System data, such as soils and land use/cover layers, it would enable, for instance, the estimation of nutrient-loading rates to ground- and surface waters from septic systems. A survey of all dwellings in unsewered areas also needs to be conducted to determine areas of high septic system failure or high cesspool numbers, followed by DNREC's encouraging the government of New Castle County to sewer these areas first.

SEDIMENT

Monitoring

The following efforts are needed in order to accurately assess sediment impacts in the Piedmont Basin:

- Data on stream channel erosion, sediment transport, and deposition.
- A monitoring program to assess the degree to which contaminated sediments are a "historic" or ongoing problem.
- Sampling for total suspended solids in surface runoff (i.e., before reaching receiving waters).
- Sediment sampling in the Shellpot Creek and Naamans Creek watersheds.
- Expansion of surface-water quality monitoring programs utilizing the "triad" approach in characterizing sediment contamination at selected sites.
- Additional stream habitat assessments to verify links with watershed imperviousness.

Information Gathering

GIS coverage of tax-map parcel data for New Castle County, active construction sites, and existing stormwater management facilities should be developed in order to accurately assess sediment impacts in the Piedmont Basin.

Evaluation

The following analyses/evaluations should be conducted in order to accurately assess sediment impacts in the Piedmont Basin:

1. Evaluation of existing U.S. Waterways Parametric data to determine if it is possible to separate wet weather data from dry weather data.
2. If #1 is feasible, conduct a trend analysis for total suspended solids under "wet" and "dry" weather data.
3. Analysis of existing sediment sampling data to assess the possibility of determining the historic rate of deposition and measurement of bed-load flux.
4. Analysis of data collected under the EPA's Environmental Monitoring and Assessment Program.

WETLANDS

Comprehensive Conservation and Management Plan for Nontidal Wetlands

A parallel and requisite component of the Freshwater Wetlands Act was to be the development and implementation of a Comprehensive Conservation and Management Plan for Nontidal Wetlands. Intended to be one component of that comprehensive legislative initiative, the absence of its enabling statute and associated regulations necessitated that this plan become instead a major umbrella under which various *non-regulatory* approaches could be developed and implemented.

The principal objective of the plan is to identify all potential tools, mechanisms, and participants available to achieve freshwater, nontidal wetlands conservation. Main plan components address wetland acquisition strategies, voluntary wetland rehabilitation measures, compensatory mitigation instruments, and means by which to build community support through public outreach and technical assistance. This approach necessarily involves coordination with other state, county, and federal agencies, as well as private non-profit entities. Currently under development by the Division of Water Resources' Watershed Assessment Section, the Comprehensive Conservation and Management Plan is organized into the following focus areas:

- Inventory of the Resource/Status and Trends
- Laws and Regulations
- Land Protection
- Land-Use Planning
- Research Initiatives/Status of the Science
- Restoration/Creation/Enhancement and Compensation Banking
- Building Support/Education
- Technical Assistance

The developing Comprehensive Conservation and Management Plan includes parallel projects integral to the overall planning effort, from refinement in the characterization of the wetland plant communities to evaluating methodologies for wetlands restoration siting and for wetlands functional assessment.

Recommendation

- Complete *Comprehensive Conservation and Management Plan for Nontidal Wetlands — Technical report and Strategy*. Implement the plan and strategy, where feasible, in conjunction with the Whole Basin Management approach.

Statewide Wetlands Mapping Project

The Statewide Wetlands Mapping Project will provide recent statewide estimates of wetland acreage by wetland type. Based on the previous mapping project conducted by the National Wetlands Inventory discussed above, the Statewide Wetlands Mapping Project employs a state-modified classification scheme (Cowardin et al., 1979) to further characterize wetland resources. Larger-scale, rectified aerial photography, smaller minimum mapping units, and the depiction of identifiable Category I wetlands will more accurately detail the location, extent, and character of Delaware's wetland resources in both hard copy (mylar) and computerized formats. Geographical Information System analysis of the digital wetlands data will allow for wetland type and acreage analysis for the Piedmont Basin and for each watershed contained therein. Further, completion of the Statewide Wetlands Mapping Project will advance both the recent trends study and the wetlands aerial mapping/tracking methodology, described below.

Recent Wetlands Trends Study

A wetlands trends study is being undertaken through a Memorandum of Understanding with the U.S. Fish and Wildlife Service. Using maps generated through the Statewide Wetlands Mapping Project (see above), the recent trends study will determine the type, location, and cause of lost wetland acreage *by basin* from 1982 to 1992.

Recommendation

- Use results from Trends Study as input in formulating a Comprehensive Conservation Management Strategy for Nontidal Wetlands.

Wetlands Aerial Mapping / Tracking Methodology

A future Watershed Assessment Section project will develop a wetlands aerial mapping/tracking method for determining future wetlands trends over regular time intervals. This method will be designed on a whole-basin basis, using the 1992 Statewide Wetlands Mapping Project as a recent baseline from which to monitor future changes. This information will be important for (1) determining basin and watershed wetland loss rates; (2) justifying to the public the need to enhance and expand public and private protection programs; and (3) identifying wetland restoration sites and mitigation banking needs by basin and watershed.

Reference Wetlands and Hydrogeomorphic Classification

A national research initiative is seeking to classify wetlands based on principles of hydrogeology (Brinson, 1993). A classification system based on the position of wetlands in the landscape will provide information on the source, direction, and hydrodynamics of water movement within a hydrogeomorphic class. The Hydrogeomorphic Approach to Functional Assessment identifies five wetland classes: riverine, depressional, slope, fringe, and flats. Functional assessment models have been developed for each wetland class and for specific wetland functions. Theoretically, each hydrogeomorphic class and set of functional models must be modified to meet regional conditions. This is achieved through case studies to identify hydrogeomorphic subclasses and differences in regional functional variables. The models are then scaled to regional hydrogeomorphic conditions through the use of reference wetlands. A case study has been developed by an interagency federal/state work group for the riverine wetland class in the Coastal Plain province of the Mid-Atlantic region. Delaware is participating in this study to identify riverine hydrogeomorphic subclasses and to select appropriate reference wetland sites within the state.

The DNREC Division of Water Resources, Watershed Assessment Section, is undertaking a study to provide baseline data on the ecological integrity of nontidal wetland functions. To coordinate with other restoration initiatives, the St. Jones watershed has been selected as the particular watershed in which reference wetlands would be chosen using a hydrogeomorphic approach. Knowledge gleaned from this pilot Coastal Plain study should be useful in the design of wetlands monitoring studies for the Piedmont Basin.

Recommendation

- Improve the understanding of wetland hydrogeomorphic classification and wetland functions through monitoring in reference wetlands.

Wetlands Compensatory Mitigation and Mitigation Banking

Compensatory mitigation banking remains a relatively new regulatory concept that has gained increased attention by federal, state, and local governments as a wetland management strategy due, in part, to evidence that individual wetland restoration, creation, and enhancement projects may not adequately compensate for permitted wetlands impacts. Caution is still warranted in the use of mitigation banking as a conservation measure due to the lack of quantitatively and qualitatively identifiable successes among the relatively few existing mitigation banks. However, the current difficulty in predictably establishing, monitoring, and evaluating mitigation banks should be weighed in consideration of the same difficulties associated with individual (non-banking) compensatory mitigation projects.

To date, mitigation banking program design and implementation have generally necessitated the investment of substantial expertise, financial resources, time, and property. An objective of a recent Division of Water Resources effort has been to identify the situations where mitigation banking — employing wetlands restoration, creation, enhancement, and preservation — can be used to effectuate nontidal wetlands conservation in Delaware. DNREC recognizes that efficiency and expediency in the development and implementation of effective resource and compensatory mitigation programs will benefit both the regulated community and the natural resource. To the greatest extent possible, compensation banking should be undertaken to meet multiple environmental objectives and should consider local, statewide, and regional goals.

Recommendation

- Establish and encourage the use of public and private sector mitigation banks through the developing Delaware Compensation Banking Program.

Establishment of Interagency Mitigation Banking Agreement

A draft interagency mitigation banking agreement — "The Wetlands Compensatory Mitigation Banking Agreement for the State of Delaware" — has been developed by the Division of Water Resources for the purposes of enabling wetlands banking in Delaware. The agreement endeavors to effectively and efficiently expedite and encourage wetlands banking as a compensatory mitigation instrument for unavoidable impacts to waters of the United States, including wetlands, resulting from projects occurring within Delaware. The wetland banking agreement is a means of insuring that the wetland banking program in Delaware will be consistent with existing federal and state regulatory programs. The agreement will also facilitate comprehensive natural resource management by integrating wetlands compensation into other watershed protection and management programs, such as *Whole Basin Management* (DNREC Draft Agreement, 1996).

Wetlands Restoration in the Silver Lake Watershed

A pilot project to use wetlands as a component of overall watershed management is under way in the Silver Lake subwatershed of the St. Jones watershed. This watershed was selected based on restoration site suitability (such as the existence of former wetlands which have been drained for farming), the recent deterioration of water quality due to urbanization, and the opportunity to coordinate with other environmental, technical, and educational initiatives within the watershed. The development of a detailed wetlands/watershed restoration plan will provide information that may serve as a prototype for use in the Piedmont Basin.

Wetlands Restoration in Critical Watersheds

Another facet of wetlands restoration is the identification of watersheds or basins in which wetlands restoration is needed. The Watershed Assessment Section will undertake a study (1997–1998) to identify critical basins and watersheds based on past and current federal permit activity in nontidal wetlands. The goal of this study is to locate critical watersheds in which wetlands restoration is needed and for which compensatory mitigation is (or will likely be) required. Thus, compensatory wetlands banks may be sited to improve the ecological health of a watershed while facilitating the compensation process. Additional information on the identification of critical watersheds for wetlands restoration also may be gained through the 1996 – 1997 trends study.

LIVING RESOURCES

Recommendations

- Upland forests have experienced severe declines. They continue to decline because of encroaching development and the ensuing invasion of exotic species. A survey of the Piedmont Basin should be conducted as soon as possible to identify remaining upland forests and to evaluate the quality of these areas by such factors as biodiversity, size, age, and exotic infestation. Appropriate actions should then follow, such as natural area designation for qualifying tracts, legal protection, and/or restoration.
- Some rare habitat types may be in danger of disappearing completely from the Delaware portion of the Piedmont Basin. A survey of such habitats should be conducted and summarized. Appropriate actions should be taken to protect these areas, including natural area designation for qualifying tracts, legal protection, and/or restoration.
- Guidelines for natural resource protection exist in the New Castle County Comprehensive Plan. The New Castle County Comprehensive Plan has already incorporated some of the ideas put forward in this document. A dedicated effort to enforce the plan must be made in the future to prevent further degradation of the natural resources of the county.
- County ordinances restricting development in the floodplain have been helpful, but do not sufficiently protect this critical habitat. Sewer lines or sewer line improvements should be prohibited within the floodplain.
- The majority of our most critical living resources depend on good-quality aquatic habitats and a natural

flooding regime. Activities that eliminate unnaturally high sedimentation and erosion rates and unnaturally high nutrient inputs should be promoted. Water conservation to minimize water withdrawals, especially from White Clay Creek, should be encouraged.

- One of the most significant impacts on our environment comes from the direct and indirect effects of new construction in areas more and more peripheral to existing urban areas, schools, and employment centers. When and where construction is needed, we should encourage infill to existing developed areas rather than development of "green" spaces.
- With their population increasing annually, resident geese are becoming a nuisance species in the Piedmont Basin. These birds are most problematic in grassy, mowed areas especially those adjacent to ponds, lakes, and streams, where their feces and feather residues contribute to eutrophication. Even without the geese, these areas often suffer negative effects from the lack of or insufficient buffer along pond and stream edges. Efforts to relocate or hunt the geese are ineffective and impractical. Stream and pond management that incorporates wide buffers of natural vegetation, including stands of woody species, should be encouraged when possible.
- Loss of forests and shade trees is an issue throughout the Piedmont Basin. In addition to their role in providing habitat, trees provide diverse ecological functions including stabilizing soil, filtering air-borne particulate matter, providing visual and sound barriers, and cooling the environment. As population increases place additional demands on the environment, these free environmental services provided by trees will become more critical. Reforestation in appropriate natural areas and tree planting in urban and suburban areas, especially along roads and stream corridors, should be encouraged.
- DNREC maintains multiple data bases regarding the state of the environment, many of which are geographically based. All divisions and many sections or programs within those divisions maintain GIS data bases and employ GIS specialists, yet there is no formal coordination of those efforts. A DNREC-wide GIS working group needs to be formalized and supported. The purpose of this group will be to ensure data and equipment compatibility and to facilitate data exchange where appropriate. Make data available to local governments and planning agencies to help these entities make more informed decisions.
- We need to recognize the threat of invasive exotic plant and animal species in the Piedmont Basin. The situation is far worse in this basin than elsewhere in the state. We need to discourage the planting of invasive exotic plants, and encourage the use of native and non-aggressive exotic plant species. Management personnel need to be trained to recognize exotic invasives and to develop management strategies. This information needs to be made available to local citizens.

AIR

Monitoring Pollutants with Air-Quality Standards

Sulfur Dioxide, Nitrogen Dioxide, Carbon Monoxide, Lead, and Ozone

The existing monitoring network is sufficient to provide adequate information on ambient concentrations. At this time, no expansion of the monitoring network is needed.

Particulate Matter (PM_{10})

The existing monitoring network is sufficient to provide adequate information on ambient concentrations. However, when the EPA promulgates new standards for particulate matter, the network will be re-evaluated. No expansion of the monitoring network is presently needed; re-evaluation will occur after promulgation of new particulate matter standards.

Monitoring Pollutants without Air-Quality Standards

Deposition

Nitrogen deposition to the Piedmont Basin has not been quantified. However, monitoring is resource intensive, and resources are limited. Acid precipitation monitoring at Lums Pond is probably representative of precipitation across the Piedmont Basin. Required resources should be assessed to do actual monitoring of wet and/or dry nitrogen deposition in the basin. Acid precipitation monitoring should continue; no expansion is recommended at this time.

Air Toxics

Monitoring for air toxics can include either ambient air or deposition monitoring. Ambient monitoring data in the Piedmont Basin are limited; deposition has not been monitored. Monitoring methodology for both ambient concentrations and deposition varies and is largely still under development; existing methods are resource intensive. Recommendations include continuing current ambient monitoring and continuing to work with the Division of Public Health on a monitoring plan as part of a larger effort to assess environmental pollutant impacts on human health.

Information Gathering — Pollutants with Air-Quality Standards

Sulfur Dioxide, Nitrogen Dioxide, Carbon Monoxide, and Lead

Adequate information currently exists to evaluate the status and trends of these pollutants. No further action is presently required; continue current data collection and evaluation process.

Ozone

The regional nature of the ozone problem makes it essential that we continue to participate with other states and regional agencies in data-sharing efforts. Delaware currently works with other states, regional agencies, and the EPA to communicate ozone data among various states and agencies. This data-sharing effort should continue.

Particulate Matter (PM_{10})

Adequate information exists to evaluate the status and trends of particulate matter. When new particulate standards are promulgated, information needs will be assessed. No further action is presently required; continue current data collection and evaluation.

Information Gathering — Pollutants without Air-Quality Standards

Deposition

There has been a significant increase in research relating to atmospheric deposition in recent years, some of it resulting from requirements in the 1990 Clean Air Act Amendments. Since actual monitoring is resource intensive, it is important to avoid "reinventing the wheel" by duplicating work already done that is relevant to the Piedmont Basin. Recommendations for nitrogen and acid precipitation include the following: review published research on this subject (particularly work associated with Chesapeake Bay); coordinate with nonpoint pollution and watershed assessment programs; and review recently received data on ion concentrations in the historical data base.

Air Toxics

Deposition of toxic compounds to watersheds has not been the subject of as much research as nitrogen and acid rain. There is a larger body of work relating to measurement of ambient concentrations although there is less data on health or ecosystem impacts. Reviewing published research (particularly work associated with the Chesapeake Bay and the Clean Air Act Amendment's Great Waters Section) in these areas is recommended.

Emissions Inventories

The periodic ozone precursor emission inventories for volatile organic compounds, nitrogen oxides, and carbon monoxide are compiled every three years; they are comprehensive and cover all emission source categories. Emission inventories for sulfur dioxide, particulate matter, total suspended particulates, lead, and toxics are performed annually, but only for point sources. Comprehensive inventories of these pollutants are recommended in order to gain additional information on impacts to the Piedmont and other basins. Compiling more comprehensive inventories, however, is resource intensive and cannot be accomplished with current resources. Impacts of emissions on the Piedmont and other basins could also be improved by developing methods to enable area, mobile, and biogenic emissions to be illustrated in graphical form, such as on a GIS map.

Recommendations

- Explore options for acquiring the needed support to produce comprehensive, periodic inventories of sulfur dioxide, particulate matter, total suspended particulates, lead, and toxics.
- Develop a method to allocate and graphically portray area, mobile, and biogenic emissions to river basins.

Evaluation of Pollutants with Air-Quality Standards

Sulfur Dioxide, Nitrogen Dioxide, Carbon Monoxide, and Lead

Analysis of current data and trends indicates that ambient air-quality standards are being met; average ambient concentrations are stable or declining. No further action is required; continue current data collection and evaluation.

Ozone

Delaware is participating with the EPA and other regional agencies in data analysis, control strategy development and evaluation, and modeling efforts. While ozone remains a problem, significant progress is being made.

Particulate Matter (PM_{10})

Analysis of current data and trends indicates that ambient air-quality standards are being met; average ambient concentrations do not show an increase at this time. When new particulate matter standards are promulgated, the data will be reviewed.

Evaluation of Pollutants without Air-Quality Standards

Deposition

The literature and data reviews described previously must be completed before the evaluation phase.

Recommendations

- *Nitrogen* — Evaluate published research for its applicability to the Piedmont Basin; determine costs/benefits of monitoring in the Piedmont Basin versus using data generated in other regions.

- *Acid Rain* — Evaluate as above; determine if there should be any changes to existing monitoring program.

Air Toxics

As stated earlier, the literature and data reviews must be completed before an evaluation can be made. In doing so, one should continue the following:

- Literature and data reviews for applicability to the Piedmont Basin.
- Coordination with the Division of Public Health, as stated earlier.
- Existing monitoring with emphasis on detection of trends.
- Enhanced review of Toxics Release Inventory data for accuracy.
- Review of emissions and Toxics Release Inventory data to determine need for expansion/changes in monitoring.

CONTAMINANT SOURCES

Solid Waste

Groundwater and surface water in Shellpot Creek in the Cherry Island area (the Delaware River floodplain between the mouth of the Christina River and Fox Point State Park) are both contaminated. A number of groundwater samples collected from this area have detected anomalous levels of arsenic, iron, zinc, ammonia, and COD (chemical oxygen demand). Surface-water samples from near the mouth of Shellpot Creek have detected anomalous iron, lead, manganese, nickel, zinc, and pH levels. This area needs further assessment to determine the source of this contamination. Possible sources in the area include one municipal, one industrial, and three coal-ash landfills; one resource recovery facility; the City of Wilmington sewage treatment plant; past and ongoing dredge spoil operations; several chemical plants; several Superfund sites; and several National Pollutant Discharge Elimination System (NPDES) outfalls.

Septic Recommendations

- From the new soil survey, freshwater wetland maps, and 1992 land-use maps and data, determine areas where growth could be encouraged and areas were development should be discouraged due to unique and/or rare plant communities or wetlands.
- Conduct a survey of all dwellings in unsewered areas to determine areas of high septic system failure or high cesspool numbers. Encourage New Castle County to sewer these areas first.

Hazardous Materials

DNREC needs to determine if all contributing contaminant sources in regions with polluted air, soil, groundwater, surface water, and/or sediment have been identified. If DNREC has not yet identified all contributing sources, the Hazardous Waste Management Branch can conduct Resource Conservation and Recovery Act (RCRA) compliance assessments at hazardous waste generators located in these regions to assess whether the generators may be a contributing source. The Site Investigation and Restoration Branch will continue to perform investigations to determine sources of contamination.

DNREC also needs to identify hazardous materials management facilities and other sites that may release hazardous substances located in environmentally sensitive areas such as locales with species of concern, riparian zones, Water Resource Protection Areas, floodplains, and near wetlands. DNREC can work with facilities located in these areas to help them reduce the amount of hazardous materials on-site and to educate them about proper management of these materials to prevent releases to the environment. The Pollution Prevention Program can also target these facilities for pollution prevention assistance.

Improving coordination and information sharing with publicly owned treatment works is another assessment need. Such coordination can help DNREC identify non-reporting hazardous waste generators and areas where releases of contaminants to the environment may be occurring. The publicly owned treatment works can also assist in encouraging facilities to adopt pollution prevention practices.

LAND USE

Planning

Identifying Technical Problems, Issues, and Opportunities

The Comprehensive Development Plan Update approaches an array of technical matters in a straightforward and easy-to-comprehend manner. The following stand out as areas that are well presented or identified as to their importance in the comprehensive planning process. In some cases, new concepts or ideas have become woven into the essence of the plan. This clearly demonstrates that the New Castle County Department of Planning is responsive to and supportive of a variety of concepts and techniques to improve the county's planning capability. Special note should be made of the following:

- Reiteration of an "environmental planning ethic" from the 1988 plan to "build an environmental consciousness" that emphasizes preservation and mitigation.

- Recognition of the *Whole Basin Management* approach as a valuable multidisciplinary effort to evaluate and address environmental issues on a basin-wide level. This is one area where the technical capability of both the state and county can work hand-in-hand to understand environmental problems and develop technical solutions and public policy directions that can improve overall quality of life.
- Acknowledgment of the *DNREC/EPA Performance Partnership Agreement* and the county's desire to join in this effort.
- Preparation of a "Conservation Plan" to serve as an inventory as well as to "send a clear message" that natural resources must be protected.
- Discussion of strategies to link transportation and land use that begin to realistically look at the symbiotic relationship between these two components of growth.
- Creation of "scenic transportation corridors" that would promote leaving certain country roads as they are by not increasing capacity and only making improvements for safety reasons.
- Presentation of the "village pattern" as a viable land-use alternative to suburban sprawl and as a reinforcement to maintain the social, cultural, and economic vitality of existing villages in the county. This approach is unique and has great potential.

Growth Management and the Plan

The area that requires a serious evaluation is how the county proposes to manage change, which underscores the transition from policy recommendations to implementation measures. The plan devotes an entire chapter to a "growth management program" and adequately addresses a host of elements that need to be incorporated into the ongoing planning process. There are several "implementation initiatives," as summarized below, that have special merit in effectuating the county plan:

- *Village Zoning Districts*. Using the justification that the village land-use pattern "should not be subject to the same regulations that are applied to the county's suburban areas," it is recommended that special zoning regulations be adopted to account for the unique qualities that existing (and perhaps even future) villages possess. The Department of Planning proposes a further study to inventory existing villages and evaluate what other communities have done. This seems to be unnecessary considering the information base that already exists and the amount of involvement that DNREC has committed to analyzing its village resources. What needs to be done at this point is to fashion the village zoning concept into a zoning code amendment for enaction.
- *Transit Overlay District*. This concept is proposed to allow for a "transit friendly neighborhood within walking distance of public transportation in order to increase the efficiency of the transit system." The concept, while not radical, fits comfortably with the initiatives of WILMAPCO and the state to provide for alternative uses within the transportation system. It should receive top priority for detailed analysis by DNREC working with WILMAPCO and DelDOT.
- *Neighborhood Mixed-Use Zoning*. This is a Department of Planning proposal that would pave the way for implementation of the village zoning district and the transit overlay zone. This somewhat intimate zoning concept would be the base to make the other two zoning districts feasible. It seems obvious because of the focused intent of this zoning approach that areas throughout the county could be selected immediately as candidates for implementing the neighborhood mixed-use zoning.

The Breakdown Between Planning and Implementation

To argue that there has been a failure in the comprehensive planning approach would not be completely fair. The prescription to create and sustain a community based on the interrelationship of protecting environmental integrity, advancing social needs, and allowing for monitored development is at the core of all our plans. At the very least, the concepts, ideas, and proposals have been well established.

Unfortunately, much of our planning has not lived up to expectations to insure orderly growth, which is the basis to achieve a quality of life. Succinctly stated, the problem has not been because of a lack of planning. Rather, what we have witnessed for too long is that there has been a breakdown between the plan-development function and the implementation of approved plans through the regulatory mechanism of zoning.

Where we have gone astray is that the political decision-making process at the local level has not fully embraced planning as a viable approach to guiding future growth. This has resulted in a haphazard pattern of rezonings, which at the time of approval might have had merit on an individual basis, but have demonstrated with time, to be incongruous with long-range goals and policies.

"Shaping Delaware's Future" hopefully will rectify this disparity and re-establish a legitimate context for comprehensive planning at the local level. A positive state role will be to create a new acceptance of insuring that there is a conscientious process to make plans that will be implemented in accordance with agreed-upon goals and visions for the future.

The main critique of the county's *Comprehensive Development Plan Update* (1996) is the ability of the county to make the commitment to implement the various recommendations and proposals it contains. The commitment must start with the Department of Planning itself, which should not become sidetracked in performing more detailed studies. Rather, the department should proceed to develop new regulations or amendments to existing regulations in order to best manage growth. We keep hearing about the "window of opportunity" that we have to address the planning and zoning process and make it fully responsive to the overwhelming consequences of seemingly uncontrolled growth, or sprawl. The county needs to act before the window closes.

Whole Basin Management: Connecting Planning with Environmental Quality

The *Whole Basin Management* approach to assess and manage the state's resources offers an important methodology to evaluate environmental conditions and improvements in a geographical unit. With the designation of the Piedmont Basin and its six watersheds, DNREC will, for the first time, concentrate on a broad analysis of biological, chemical, and physical factors as these determine environmental quality.

There is a cause-and-effect relationship between land use and environmental quality. If the *Whole Basin Management* approach will measure environmental conditions, could we also determine a method to evaluate land-use impact on the environment? More specifically, could we, through the *Whole Basin Management* program, develop a land-use monitoring technique to measure the effectiveness of comprehensive planning in guiding land-use change?

This challenge, if addressed through the Piedmont Basin study, would offer a new basis to understand the connection between land-use development and its impact on the environment, as well as its relationship to comprehensive planning.

Land-Use Monitoring

As noted by James R. Bernard in a workshop at DNREC on April 9, 1996, environmental indicators "describe, analyze, and present scientifically based information on environmental conditions, trends, and their significance. Environmental indicators look at the effects of human activities on the environment as well as the implications of those actions for human health, quality of life, and the integrity of ecosystems."

Through the Piedmont Basin study, the opportunity exists to prepare an information base of "land-use monitoring indicators," modeled after these "environmental indicators." This approach could serve as a "monitoring" of the effectiveness and viability of the comprehensive planning process. With baseline data in hand, we could monitor the changes in land use as they are consistent or inconsistent with the local plan, and how these land-use changes impact the environment. With time, it should be possible to subscribe some short- and long-range projections for sustaining or improving the quality of life in the watershed predicated on land-use changes and their relationship to the environment.

If this approach can be proven to be both methodologically sound and practical in its application, it might even be suggested that land-use monitoring indicators could become part of the comprehensive planning process. The success of this proposal will be how effective the monitoring indicators are in judging the ability of comprehensive planning to guide future land use. Time will tell.

Land-Use Information Needs

The following discussion suggests that certain additional information will be needed to develop the next two phases of the Piedmont Basin Study: the monitoring phase and the management phase. In addition, this information will be useful in developing the land-use monitoring indicators.

- A more thorough and complete analysis of the 1982 – 1992 Changes in Land Use/Land Cover should be undertaken, which goes back to the original photography and corrects the classifications of the various polygons and overcomes the problems associated with comparisons of the 10-acre minimum mapping units used in the 1982 project and the 4-acre minimum mapping units used in the 1992 project. Such a project will produce a product with a higher confidence level with respect to accuracy. The product produced in this report is still useful, however, for indicating that sprawled residential and other urban uses are rapidly filling in the Piedmont Basin and that natural areas are rapidly being lost.
- The Water Resources Agency for New Castle County (WRA) and the Chester County Water Resources Agency (CCWRA) are conducting a "Christina River Basin Nonpoint Source Management Strategy" study, which will provide useful land-use data. The study has field verified the 1992 Land Use/Land Cover mapping of the Christina Basin in order to bring it up to date and placed it in GIS format. The goal is to provide data in acres per watershed for uses of land. These data should provide us with a higher-quality assessment of the Christina River Basin than the DNREC data because it has been field verified and can be used for an up-to-date, build-out analysis on the watershed level. The build-out will compare approved but unbuilt subdivisions and zoning maps with the updated 1992 land-use maps to project what development can be expected using population projections. The build-out can be used to project future infrastructure investment needs and future environmental impacts with respect to different development

policy scenarios, which could yield objective arguments for legislative and policy actions.

- The WRA is maintaining data layers for maps for this project and others. An updated and detailed list of the data is provided in the July 1996 quarterly report to the Division of Soil and Water. The available information section contains a summary table of the data.
- Estimates for the sewer capacity expansions, including areas affected, could be very useful indicators of future growth. Wherever central wastewater service is provided, there is an almost irresistible incentive for additional growth. Designation of future growth areas should precede sewer capacity expansion in order to avoid inappropriate growth however that is defined.
- New aerial photography is needed every five years to map features and changes to the landscape for creating models for pollution management, highway planning, permit writing, zoning analysis, drainage planning, infrastructure planning, and other needs. Land-use and land-cover data used in this analysis were obtained from a multi-agency project involving the Delaware Department of Transportation and DNREC. These data benefited the U.S. Geological Survey, the three county public works agencies, county planning agencies, Delaware Department of Transportation, DNREC, and other agencies. By employing this approach in the future, we can develop maps that meet the needs of many agencies and programs from a single set of aerial photographs at a much lower cost than the customary practice where each agency contracted on its own for photography and maps.
- On a sub-watershed level, there may still be some streams in New Castle County where impervious land cover has not exceeded the threshold to cause stream habitat decline. These areas for conservation land use should be mapped and tabulated on a sub-watershed level to identify those areas likely to be less than 10% – 15% impervious land cover.
- Any critical natural areas that are undeveloped and not included in State Resource Areas should be identified as part of the monitoring plan. If these are lands zoned for development, they could be used in a conservation plan that identifies protection mechanisms.

Summary of Land-Use Assessment Needs

Recommendations

- Use the “Shaping Delaware’s Future Goals” to formulate and implement the monitoring and management plans.
- Focus efforts on improving information provided to the county to improve zoning.
- Develop a definition and a “vision” of sustainable development for the Piedmont Basin.
- Assess state subsidies for their effects on land use in the Piedmont Basin.
- Use the build-out study from the WRA /CCWRA Christina River Basin Study to project development trends and model impacts.
- Program infrastructure building to facilitate environmentally sensitive settlement and development patterns.
- Fortify and improve the accuracy of the Delaware GIS (DEGIS) to overcome limitations of the present map.
- Use the bi-state Christina River Basin Study to implement monitoring and cleanup/management through existing and planned environmental programs that are already endorsed by Pennsylvania local governments.
- Address surface-water issues in the Smalley’s Pond watershed caused by rapid land-use changes that may threaten public water supply.
- Address stormwater management and other high priority issues in the Shellpot and Naamans watersheds.
- Perform a more detailed analysis of land use/land cover changes similar to what was done in the Nanticoke River to monitor environmental impacts and to program land acquisition.
- Focus efforts to preserve any unique or important natural areas in the areas of greatest development pressure and remaining open lands.

Land-Use Monitoring Indicators. The following recommendations concern land use and comprehensive planning:

1. Develop a set of “land-use monitoring indicators” that would identify baseline information concerning the land-use settlement pattern.
2. Determine a method to utilize the monitoring indicators to evaluate land-use impact on the environment.
3. Evaluate the possibility of having land-use monitoring indicators incorporated in the comprehensive planning process at the local level.

RECREATION

Parks and Greenways

The assessment of recreational opportunities indicates that the recreational needs of the citizens of the Piedmont Basin are adequately served when evaluated by national standards. Although the basin ranks as *average*, this is not to say that improvements need not be made. As mentioned earlier, as population density increases in the basin, so will the demand for recreation. Also, as demographics change in the basin, so will desired recreational activities and facilities. Due to these demographic trends, it is obvious that in order to maintain the current level of recreation in the Piedmont Basin, strategies to maximize recreational opportunities in an urban environment must be identified.

In order to improve the current range of recreational opportunities and expand needed open space and provide additional recreational facilities, the following initiatives and programs must be instituted and expanded.

- Continue a concerted cooperative effort among all recreation providers to provide quality recreational opportunities and facilities in line with recommendations established in the State Comprehensive Outdoor Recreation Plan.
- Continue the active acquisition of additional and strategically located open space by local governments and the state. Additional lands should be actively acquired/protected in the rapidly developing Christina River and White Clay Creek watersheds. Available lands suitable for recreation/resource protection adjacent to existing facilities should also be a high priority for acquisition.
- Increase funding to local governments for open space acquisition and greenway and park development through the Delaware Land and Water Conservation Trust Fund. Encourage participation by the private sector in providing funding and assistance for recreational improvements.
- Maximize the benefit of existing recreational facilities by connecting them to population centers through a statewide system of greenways.

Fish and Wildlife Recreation

The assessment of fish and wildlife recreation opportunities within the Piedmont Basin indicate that, although limited by continued high human population levels, the opportunities that are available receive tremendous participation and provide some of the most unique sporting opportunities within the state. Unfortunately, ever-increasing suburban sprawl within the region has raised moral and safety concerns about hunting and fishing and further restricted public access, while development, industry, and poor agricultural practices continue to degrade the fish and wildlife habitats on which these activities depend. Therefore, in order to continue to meet the region's recreational needs, programs and initiatives that address these detriments to fish and wildlife recreation must be implemented, supported, and expanded.

These efforts should include the following:

- Continued support and expansion of aquatic habitat protection and improvement initiatives, specifically those addressing stormwater management, fish habitat improvement, and nonpoint source pollution and sediment control.
- Continuing research to determine sources of, remediation of, and extent of contaminants within finfish of the Christina, Brandywine, and Red Clay watersheds.
- Continuing support of the assessment of impacts and alternatives to proposed water supply solutions within northern New Castle County.
- Continued support and expansion of recreational hunting programs specifically designed to reduce nuisance wildlife populations to within social carrying capacities.
- Continued support and expansion of the Northern Delaware Wetlands Rehabilitation Program's efforts to restore tidal exchange to tributaries of the Christina River, thereby improving wetland functions and values to these highly degraded wetland complexes.

APPENDIX

AIR

Emission Estimation Approach

Point Sources

A point source is defined as a stationary source facility that emits 10 tons per year or more of volatile organic compounds or 100 tons or more of oxides of nitrogen or carbon monoxide, sulfur dioxide, particulate matter smaller than 10 microns in diameter, total suspended particulates, or lead. The point source inventory represents estimated actual emissions from these facilities.

In general, one of three estimation methods is used. In order of preference, the estimation methods are (1) stack testing or continuous emissions monitoring, (2) material balance calculations, and (3) emission factor calculations based on units of throughput or activity. All data necessary to make the emissions estimations are collected by means of annual reporting by the facility. All point source data are entered into a computer data base called *i-STEPS®*.

Stationary Area Sources

Area source emissions are compiled once every three years for the Ozone State Implemen-tation Plan Inventory. The pollutants covered are volatile organic compounds, nitrogen oxides, and carbon monoxide. Area source emissions are estimated by multiplying an emission factor by a known indicator of collective activity for each source category within the inventory area. An indicator is any parameter associated with the activity level of a source, such as production, employment, or population that can be correlated with the air pollutant emission from that source.

In general, one of four emission estimation approaches was used to calculate area source emissions:

- per capita emission factors,
- employment-related emission factors,
- commodity consumption-related emission factors, or
- level-of-activity-based emission factors.

A major portion of the work involved in creating an area source inventory is in collecting the information defining the collective activity for the source category. Several methods are available for estimating area source activity levels and emissions. Estimates can be derived by:

- treating area sources as point sources,
- surveying local activity levels,
- apportioning national or statewide activity totals to local inventory areas,
- using per capita emission factors, or
- using emission-per-employee factors.

Sources activity may fluctuate significantly on a seasonal basis. Because area emissions are generally a direct function of source activity, seasonal changes in activity levels were examined closely. Emissions were calculated on a tons-per-year basis and were seasonally adjusted for peak ozone season daily emissions.

On-Road Mobile Source Emissions

On-road mobile emissions are compiled once every three years beginning with 1990 for the Ozone State Implementation Plan Emissions Inventory. The pollutants covered are volatile organic compounds, nitrogen oxides, and carbon monoxide emitted by vehicles traveling on the Delaware highway system.

The mobile source emissions inventory provides estimates of statewide emissions through the application of a network-based travel demand model. Two models of Delaware's highway system are available: one that represents New Castle County and one that represents Kent and Sussex counties. These travel-demand models have been updated to 1993. They are adaptable to estimating vehicle-miles traveled for various temporal and seasonal conditions, and they have an extensive capability for forecasting future vehicle-miles traveled based on changes in land use and in the transportation system. The model networks include federal highway functional classes and local collector roads.

The New Castle County travel-demand models estimated for 1993 were derived from the traditional four-step trip generation, trip distribution, model split, and trip assignment process. The Kent and Sussex counties' model is similar to New Castle County's, except for the model split component.

Both models generate 24-hour volumes representative of average annual daily traffic. The models were modified to also produce morning and evening peak-period traffic data with travel speeds representative of these periods. The off-peak hour data (20 hours) were generated by subtracting the total peak-period data from the 24-hour data. Further adjustments were made to represent the typical ozone day. The traffic data were adjusted to August for New Castle and Kent counties and to July for Sussex County.

The emission factors were developed by the Delaware Department of Natural Resources and Environmental Control (the Department) using MOBILE5a. MOBILE5a is the EPA's computer model used to calculate volatile organic compounds, nitrogen oxides, and carbon monoxide vehicle emission factors. These emission factors take into account numerous parameters that affect vehicle emissions, such as county-specific vehicle registration age distribution, an inspection and maintenance program, ambient temperatures appropriate for the ozone season, gasoline Reid Vapor Pressure, operating mode, and vehicle speeds.

Off-Road Mobile Sources

Off-road mobile sources inventories are compiled once every three years beginning with the 1990 Ozone State Implementation Plan Emissions Inventory. The pollutants covered are volatile organic compounds, nitrogen oxides, and carbon monoxide. Off-road mobile sources are not calculated with the same methods as on-road mobile source emissions. The off-road mobile source categories are aircraft, marine vessels, railroad locomotives, auto racing, and other off-road sources. The other off-road sources category includes miscellaneous equipment such as construction equipment, farm equipment, industrial equipment, lawn and garden equipment, motorcycles, and recreational vehicles. All emissions were estimated on an annual basis and on a peak ozone season daily basis.

Progress Toward Attainment of the NAAQS for Ozone for Delaware

The 1990 Clean Air Act Amendments contain provisions for the attainment and maintenance of the National Ambient Air Quality Standards (NAAQS). Control plans must be developed in designated non-attainment areas. Plan requirements vary depending on the severity of the individual area's air pollution problem. The Piedmont Basin is located in New Castle County, Delaware, which is considered to be a severe non-attainment area for ozone.

One key requirement of the Clean Air Act Amendments for moderate and above ozone non-attainment areas, of which the Piedmont Basin is one, involves the achievement of Reasonable Further Progress toward the attainment of the NAAQS. States must demonstrate Reasonable Further Progress by achieving at least a 15% reduction of peak ozone-season daily volatile organic compounds (VOC) emissions from 1990 levels by 1996. In addition, states must offset any net growth projected from 1990 to 1996. A 9% reduction of VOC or NO_x is required for every three years between 1997 and 2005. 2005 is the year for which severe non-attainment areas must demonstrate attainment through computer modeling. Modeling results may indicate that reductions greater than the Reasonable Further Progress reductions are required to achieve attainment of the ozone NAAQS.

Progress toward attainment of the NAAQS in the year 2005 is measured by periodic emission inventories conducted every three years, beginning in 1993. Actual air emission data are inventoried for reactive VOCs, oxides of nitrogen (NO_x), and carbon monoxide (CO) from point, area, and mobile sources.

Point sources, as defined for the 1990 base year and successive inventories, are those facilities/plants/activities that have actual emissions greater than or equal to at least one of the following 10 tons per year VOC, 100 tons per year NO_x, or 100 tons per year CO. Detailed plant, point, and process data is maintained by each point source. Area sources represent collections of many small air-pollutant emitters existing within a specified geographical area. Because area sources are too small and/or too numerous to be surveyed and characterized individually, area source emissions must be estimated collectively. Mobile sources are represented by all forms of transportation (commercial, recreational, and private), as well as portable implements and tools powered by internal combustion engines. Emissions for mobile sources are estimated through primary data, computer modeling, and collective estimates.

In 1994, DNREC submitted a 15% VOC reduction plan for 1996 to the EPA; it targeted reductions through multiple control strategies including gasoline vapor collection, low-volatility coatings and solvents, and the controlling of leaks in manufacturing processes. There is a summertime ban on open burning. Further reductions in VOCs will be achieved through the use of reformulated gasoline.

Delaware must produce three more rate-of-progress plans for target years 1999, 2002, and 2005, producing an additional 9% reduction in VOCs. In addition, a year 2005 model attainment demonstration must be completed. Many new emission control strategies must be developed and implemented to attain the ozone standard by 2005.

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Map Information

Data used to prepare the soils maps referenced in this section were produced by Roy F. Weston, Inc., through their *Wastewater Needs Evaluation and Plan for Southern*

New Castle County, Delaware. This data layer is housed in DNREC's Geographical Information System (directory: arc/piedbas/ncsoils). The data cover soil classifications, soil series, erodibility (K) factors, septic suitability factors, slope information, erosional characteristics, and acceptable soil-loss factors.

This preliminary assessment called for an in-house literature review of geological reports and maps. Most of those found consisted of Delaware Geological Survey publications, as well as reports by the U.S. Geological Survey in Dover, the Delaware Geological Survey, and the Water Resources Agency for New Castle County. The following is a summary of the more important Piedmont geological/ soil resources.

Delaware Geological Survey Maps

A regolith thickness (overburden) map and geologic maps are available for the entire Piedmont geologic province. The Delaware Geological Survey developed these maps through field exercises designed to characterize earth resources in the area.

Geology Maps

Geology of the Newark Area, Delaware, 1972.
Geology of the Wilmington Area, Delaware, 1975.

These maps provide the following pertinent information regarding locations and boundaries of geologic formations that comprise the Piedmont province: lithological descriptions of geologic formations, including the mineral assemblages comprising them; and major geological structures (faults, folds, and joints, etc.).

Digital information is not available. Hard copies (paper documents) are available. These maps provide a starting point for estimating the natural soil chemistry for various areas within the Piedmont. Piedmont field mapping is currently in progress, and a new digital geology map will be developed within approximately two years that is substantially different from current maps due to the use of newer criteria for making geological interpretations (pers. comm., Kevin Ramsey, Delaware Geological Survey).

Regolith Map

Thickness of Regolith in the Delaware Piedmont (Province), 1982.

This map provides general information regarding the erodibility of the Piedmont geologic formations and the various sediment textures derived from their weathering. They also provide regolith thickness zones for the entire Piedmont. (The slopes for these areas are also provided.) These maps enable users to identify areas where large volumes of sediments exist. Hard copies (paper documents) are available. Digital information is not available.

Water Resource Protection Area Maps

The Water Resources Agency for New Castle County, with the assistance of other state and county agencies, developed Water Resource Protection Area maps for the purpose of protecting public ground- and surface-water supplies in New Castle County. Three maps cover the entire county. Map 1 of that set covers Delaware's Piedmont Basin. (Also, see Map 30 in this report.)

Water Resource Protection Areas for City of Newark, City of Wilmington, New Castle County, Delaware, 1993. (Map 1 of 3.)

These maps provide floodplain locations upgradient of an approved public surface-water supply intake. Flood areas consist of the 100-year floodplain (as derived from the 1986 Federal Emergency Management Agency Flood Insurance Rate maps), and flood-hazard soils and tidal marsh soils (as defined in 1970 U.S. Department of Agriculture soil survey maps of New Castle County). These maps also provide erosion-prone slope locations upgradient of an approved public water-supply intake by identifying areas that have the potential to contribute significant amounts of sediments into streams. (Erosion-prone slopes consist of those areas containing soils with service capability classifications as defined in the aforementioned soil survey.) The maps also show the Cockeysville Formation outcrop area. (The outcrop area for the Cockeysville Formation was taken from a map produced by the Delaware Geological Survey.)

Digital information for the floodplain locations and for the erosion-prone slope locations is available from the Water Resources Agency for New Castle County's Geographical Information System.

Delaware Geological Survey Reports

Many of the Delaware Geological Survey reports describe the geology of Delaware's Piedmont Basin. However, the best descriptions are provided through the aforementioned geologic maps. For this reason, an exhaustive listing of these reports is not warranted.

The Delaware Geological Survey's Bulletin #19, *Geology and Hydrology of the Cockeysville Formation, Northern New Castle County, Delaware*, provides an in-depth and updated description of the geology of the Pleasant Hill - Hockessin area. A recent geologic map is provided with this report. Information from this report will prove useful in environmental assessments of the White Clay Creek and Red Clay Creek watersheds.

Table 76

NUMBER OF SITE EVALUATIONS BY TAX PARCEL

TAX PARCEL #	# OF SITE EVALUATIONS
06009.00001 to 06131.00151	22
07001.00011 to 07026.00002	472
08001.00003 to 08232.00082	510
09002.00002 to 09037.00036	156
10006.10029 to 10053.00029	96
11002.00006 to 11102.03190	507
Total	**1,763**

Table 77

NUMBER OF PERMITS ISSUED BY TAX PARCEL

TAX PARCEL #	# OF PERMITS ISSUED
06009.00001 to 06131.00151	22
06009.00001 to 06131.00151	8
07001.00011 to 07026.00002	214
08001.00003 to 08232.00082	545
09002.00002 to 09037.00036	163
10006.10029 to 10053.00029	105
11002.00006 to 11102.03190	524
Total	**1,559**

Data from Water Supply Branch

Modified grid numbers are used to locate on-site wells and the corresponding septic approval numbers for DNREC's Division of Water Resources, Water Supply Branch. Information can be obtained about depth and type of wells in a given area, septic system permit numbers, and in some cases, the location of the septic system.

Data from Small Systems Branch

The Small System Branch of the Division of Water Resources has maintained a d-Base III file of New Castle County site evaluations and permits from 1987; however, permit data for the Piedmont Basin does not begin until 1991. Tables 76 and 77 account for the total number of site evaluations approved by DNREC.

The Hazardous Waste Management Branch had soil samples analyzed for various volatile organic compounds, semi-volatile organics, polychlorinated biphenyls, pesticides, herbicides, cyanide, metals, dioxins/furans, sulfides, and base neutral extractables from their permitted hazardous waste treatment, storage, and disposal facilities. The Superfund Branch collected various chemical information on soils associated with their Superfund sites.

SEDIMENT

GIS Coverages

- Land Use.
- New Castle County Soils.
- Storage and Retrieval of United States Waterways Parametric Data Stations.
- Habitat Assessment Sampling Stations.
- Superfund Sites.
- Hazardous Waste Facilities.
- National Pollutant Discharge Elimination System Outfalls.
- New Castle County Regulated Erosion Prone Slopes.

Data/Data Bases

- Sampling data from Harper Thiel Inc., Hercules Research Center, DuPont Glasgow Site, and DuPont Experimental Station (Hazardous Waste Management Branch).
- Sediment data from Superfund sites (Site Investigation and Restoration Branch).
- Storage and Retrieval of U.S. Waterways Parametric Data Stations Data Base (Division of Water Resources).
- Habitat Assessment Data (Division of Water Resources).
- Active Construction Site Data Bases (Division of Soil and Water Conservation).
- Existing Stormwater Management Facilities Data Bases (Division of Soil and Water Conservation).
- Sediment toxicity and sediment chemistry data from the Environmental Monitoring and Assessment Program for Station #357; Estuaries, Virginia Province, VA91-357 (U.S. EPA, Region III).

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Ambient Air Quality Monitoring Data

Current and historical monitoring data for the Piedmont Basin are available for ozone, sulfur dioxide, nitrogen dioxide/nitrogen oxides, carbon monoxide, and particulate matter. There are also historical data for lead and some heavy metals. The number of data and the averaging interval vary by pollutant. A summary of the current data and a discussion of trends are included in the *Delaware Annual Air Quality Report* (published for 1991 through 1994; 1995 is in preparation) available from the DNREC Air Quality Management Section. Detailed air-monitoring data (hourly or daily averages) are maintained in a data base in the New Castle Office of the Air Quality Management Section. The data are also submitted to the National Airometric Information Retrieval System data base maintained by the EPA, where they are available for retrieval. This data base includes monitoring data from the early 1970s (varies by pollutant) to the present.

Acid deposition data are available for the years 1983 through 1995. Data are for wet deposition only; ion concentrations are available for 1983 through 1994. This data base is maintained in the Air Surveillance Branch; there are currently no standard printed reports from this data base.

Air toxics data for 14 specific toxic volatile organic compounds (sorbent tube monitoring, 24-hour averages every sixth day) are available for 1993 through 1995; however, there are significant gaps and various levels of confidence and accuracy. The data base is maintained in the Air Surveillance Branch; there are currently no standard printed reports from this data base, although summary information is included in the *Delaware Annual Air Quality Report*.

Peak ozone season (June through August) data on more than 50 volatile organic compounds from the Lums Pond site are available from 1994 to the present, although some years have significant gaps. The data base is maintained in the Air Surveillance Branch as well as in EPA's national data base. There are currently no standard printed reports from this data base.

Emissions Information

Toxics Release Inventory

This inventory, generated annually, covers more than 650 toxic chemicals. The major limitation of the inventory is the restricted universe of facilities required to report releases. The EPA recently proposed adding seven more industry sectors to the program: metal mining, coal mining, electric utilities, commercial hazardous waste treatment, chemical wholesalers, bulk petroleum wholesalers, and solvent recovery services. These inventories have been compiled and reported since 1987; the current annual toxics release inventory report (1994) is available from the Air Quality Management Section.

Ozone Precursor Emissions Inventories (State Implementation Plan Inventories)

These inventories are compiled every three years. The first inventory was done in 1990 and is referred to as the 1990 Base Year Inventory. Inventories compiled after that are referred to as Periodic Emissions Inventories. These cover emissions of ozone precursors (volatile organic compounds, nitrogen oxides, and carbon monoxide) from all types of sources in Delaware. Point source emissions are compiled for each facility. Area, mobile, and biogenic emissions are compiled by county. At this time, the 1990 Base Year Inventory has been completed, and the 1993 Periodic Inventory is in draft form. Copies of summary reports are available from the Air Quality Management Section. The actual inventory documents, which are several hundred pages in length, can be reviewed at the section's New Castle or Dover offices.

Annual Point Source Inventory

This inventory is compiled annually. It covers emissions of volatile organic compounds, nitrogen oxides, carbon dioxide, sulfur dioxide, particulate matter, total suspended particulates, and lead from facilities that are major source emitters or potential major source emitters of at least one of these pollutants. This inventory has been generated since 1990. Currently, 1990, 1992, and 1993 are completed; 1994 is in draft form. Currently, there are no written reports of these inventories, but emissions summary printouts can be generated from the computer data base called *i-STEPS®*.

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LAND USE

Applicable GIS data layers that the DNREC Division of Water Resources is responsible for include the following: Drainage Basins, Ground Water Recharge Areas, Land Use, NPDES Discharges, Sewer Districts, Shellfish Closure Areas, Sludge Disposal Areas, Storet Stations, Subaqueous Structures, and Water Supply Franchise Areas. The DNREC GIS Office is responsible for the following data layers: Census, Floodplain Maps (data not available at this time), National Wetlands Inventory, Population Projections (by county), Quad Index, Railroads, Roads All, Roads Major, Towns, and Water.

As a product of their Christina River Basin Nonpoint Source Strategy Plan, the Water Resources Agency for New Castle County has provided maps of the Christina River Basin that also include the Pennsylvania portion of the Christina River. These maps cover the Piedmont Preliminary Assessment study area except for the Shellpot and Naamans watersheds.

October 1995 Base Map. Data layers on this map show the Christina Basin, Watersheds, Sub-basin Boundaries, Major Roadways, Major and Minor Hydrology, and Municipal Boundaries

May 1996 Land Use Map. This map shows areas that are classified according to uses of lands including Single Family, Multi-Family, Office, Industrial, Transportation/Utility, Commercial, Institutional, Public Private Open Space, Wooded, Agriculture, Mining, Water, and Vacant Land.

April 1996 Water Resource Areas Map. Shown are data layers for Water Resource Protection Areas including the Cockeysville Formation, Wissahickon Formation, Cockeysville Drainage Area, Class-C Wellhead, Hoopes Reservoir Watershed, Floodplains (100-Year FEMA), Erosion-Prone Slopes, Recharge Areas, and National Wetlands Inventory.

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This 16-page report measures land-use changes in acres and percent by county through digitizing and photo-interpreting 1974 and 1984 photography. During this period, residential land – single family/duplex was the fastest growing category, showing an increase of 4,492.2 acres, displacing agriculture, which showed a loss of 5,489.3 acres, and wetlands, which showed a loss of 1,502.1 acres. Also during this period, 7,400 new persons were added to New Castle County's population, which resulted in the conversion of 5,074 acres into residential uses, for a ratio of 1.46 new persons per acre converted. A greater number of acres also were converted to residential uses in Kent and Sussex counties.

The Delaware Coastal Management Program's Coastal Ocean Management, Planning, and Assessment System (COMPAS) can be used to model the relationship between selected nonpoint pollution sources, land-use activities, habitat trends, and associated species. To date, COMPAS has not been involved with studies in the Piedmont Basin. However, it has applications for modeling using multiple attributes for resource management and is likely a useful tool for Whole Basin Management.

Other sources include census data from the State Data Center and special reports from the University of Delaware Bureau of Demographic Research. Reports and land-use planning/consulting also are available from the University of Delaware College of Urban Affairs and Public Policy, including the Delaware Public Administration Institute and the Center for Energy and Environmental Policy.

The Delaware Population Consortium provides population projections for use by all agencies in Delaware who need population growth forecasts. These projections are provided and can be used at the census-tract level, which very roughly coincides with the Piedmont Basin boundary. Data can be shown for population, income, age, race, and targeted census subdivision that coincide with blue-collar jobs credit programs.

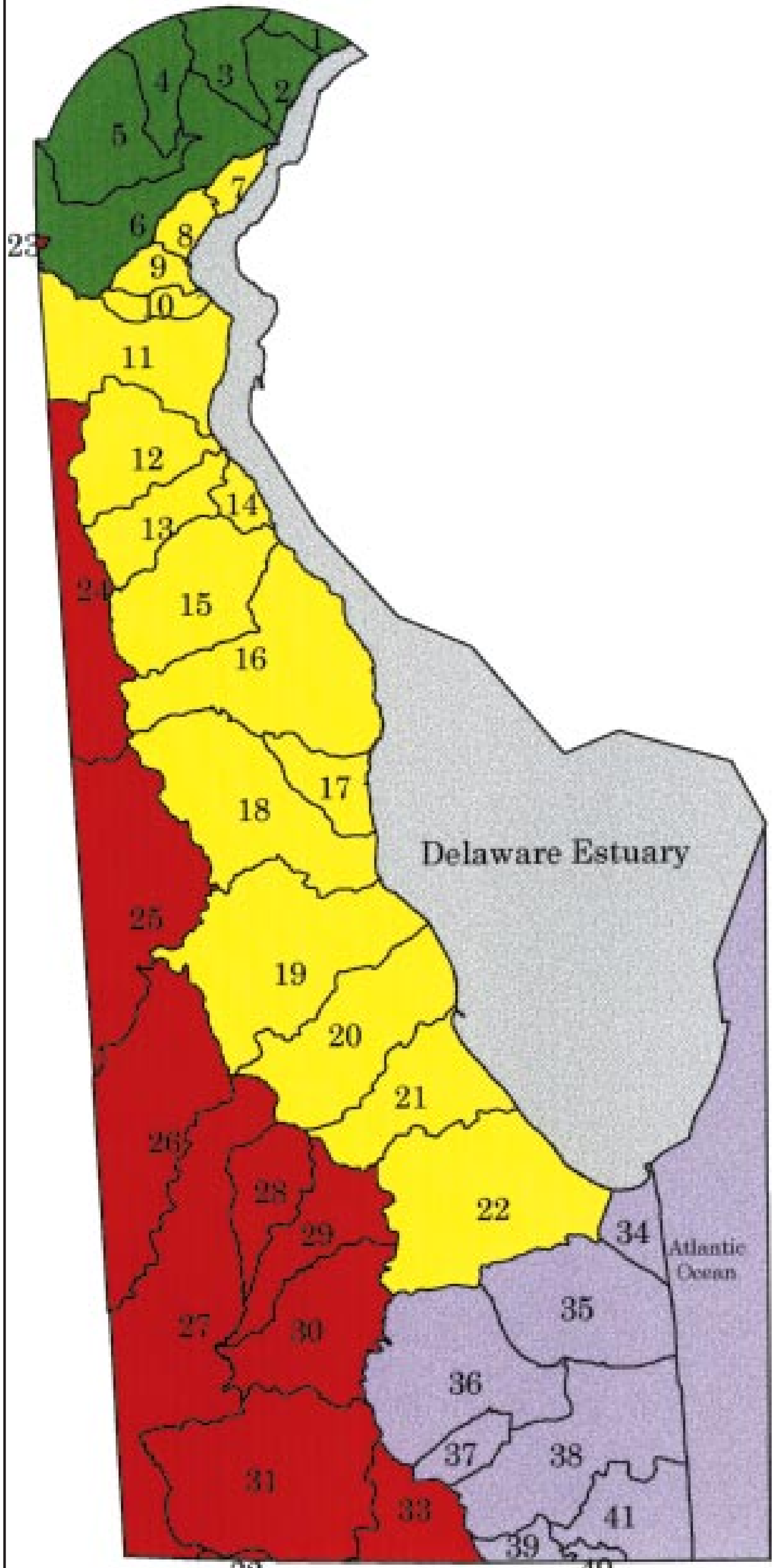
RECREATION

Parks and Greenways

The DNREC Division of Parks and Recreation maintains detailed information and records regarding recreation resources. The division has created a comprehensive Outdoor Recreation Inventory, which includes information on all recreational facilities and parks in Delaware. The Delaware State Parks' Geographic Information Systems Lab maintains the geographic component to the Outdoor Recreation Inventory data base, incorporating all open space and recreational facilities, including greenways and trails. The division also updates the State Comprehensive Outdoor Management Plan approximately every five years. This document depicts the state of recreation in Delaware and general trends, and outlines a course of action to meet the state's recreational needs.

WHOLE BASIN

State of Delaware Basins



PIEDMONT
1. Naamans Creek
2. Shellpot Creek
3. Brandywine Creek
4. Red Clay Creek
5. White Clay Creek
6. Christina River

DELAWARE BAY DRAINAGE
7. Delaware Bay Drainage
8. Army Creek
9. Red Lion Creek
10. Dragon Run Creek
11. Chesapeake & Delaware Canal
12. Appoquinimink River
13. Blackbird Creek
14. Delaware Bay
15. Smyrna River
16. Leipsic River
17. Little Creek
18. St. Jones River
19. Murderkill River
20. Mispillion River
21. Cedar Creek
22. Broadkill River

CHESAPEAKE BAY DRAINAGE
23. Elk Creek
24. Chesapeake Drainage System
25. Choptank River
26. Marshyhope Creek
27. Nanticoke River
28. Gum Branch
29. Gravely Branch
30. Deep Creek
31. Broad Creek
32. Wicomico
33. Pocomoke River

INLAND BAYS/ATLANTIC OCEAN
34. Lewes Rehoboth Canal
35. Rehoboth Bay
36. Indian River
37. Iron Branch
38. Indian River Bay
39. Buntings Branch
40. Assawoman
41. Little Assawoman

DELAWARE ESTUARY

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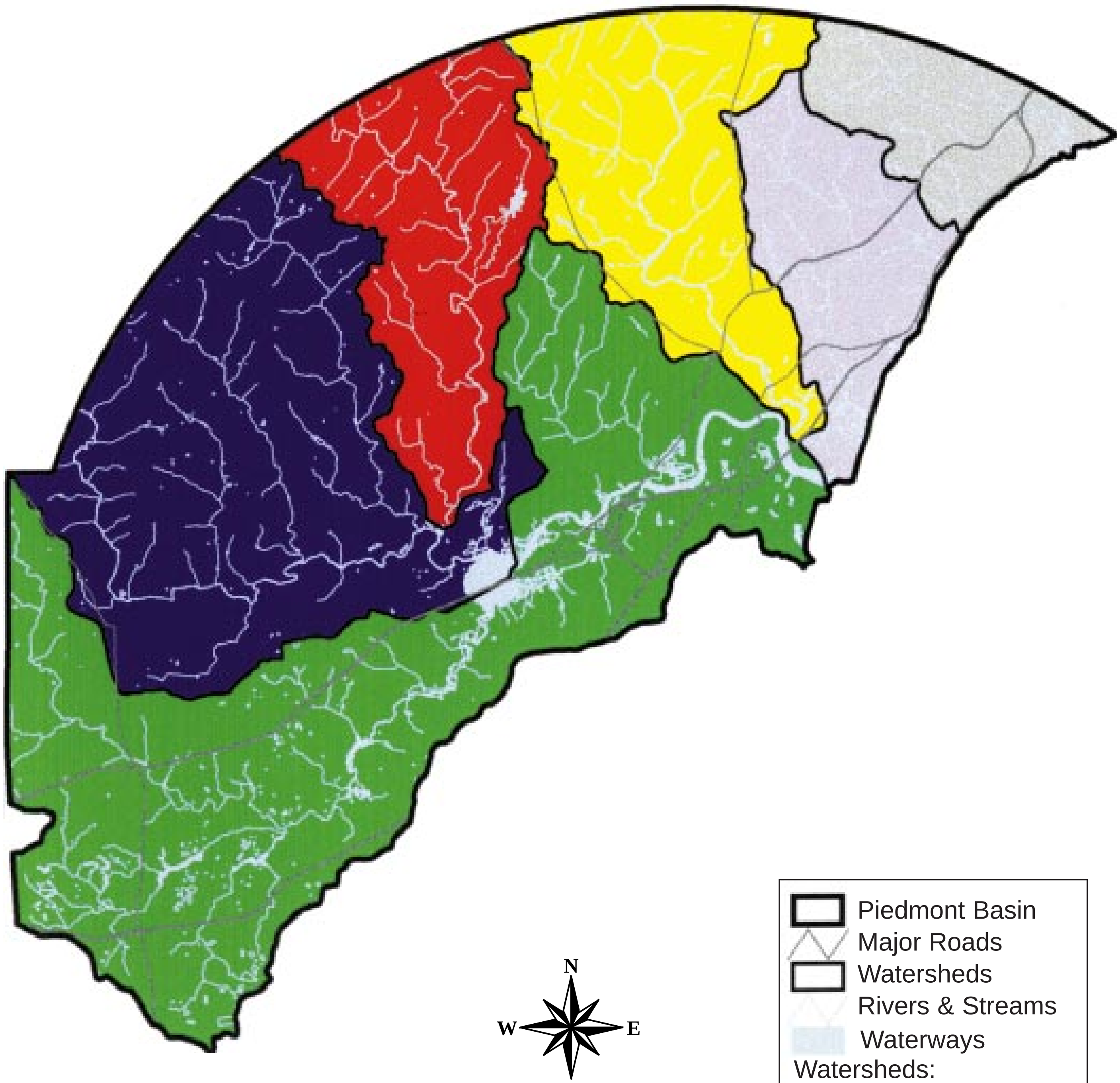
PIEDMONT BASIN

Piedmont Basin Watersheds



1 0 1 2 Miles

June 1997

- Piedmont Basin
- Major Roads
- Watersheds
- Rivers & Streams
- Waterways

Watersheds:

- Brandywine Creek
- Christina River
- Naamans Creek
- Red Clay Creek
- Shellpot Creek
- White Clay Creek

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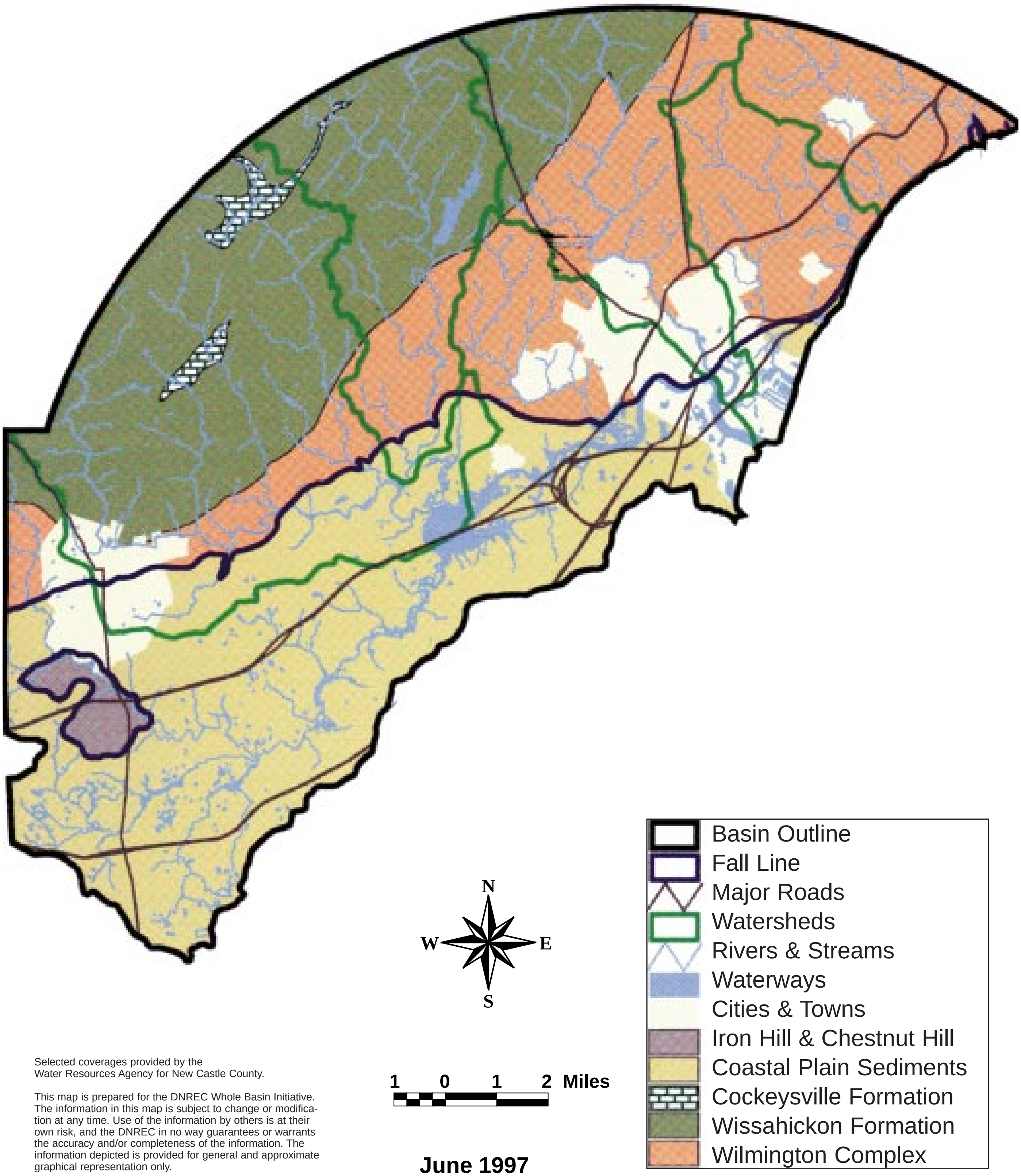
PIEDMONT BASIN

Generalized Geology



Selected coverages provided by the Water Resources Agency for New Castle County.

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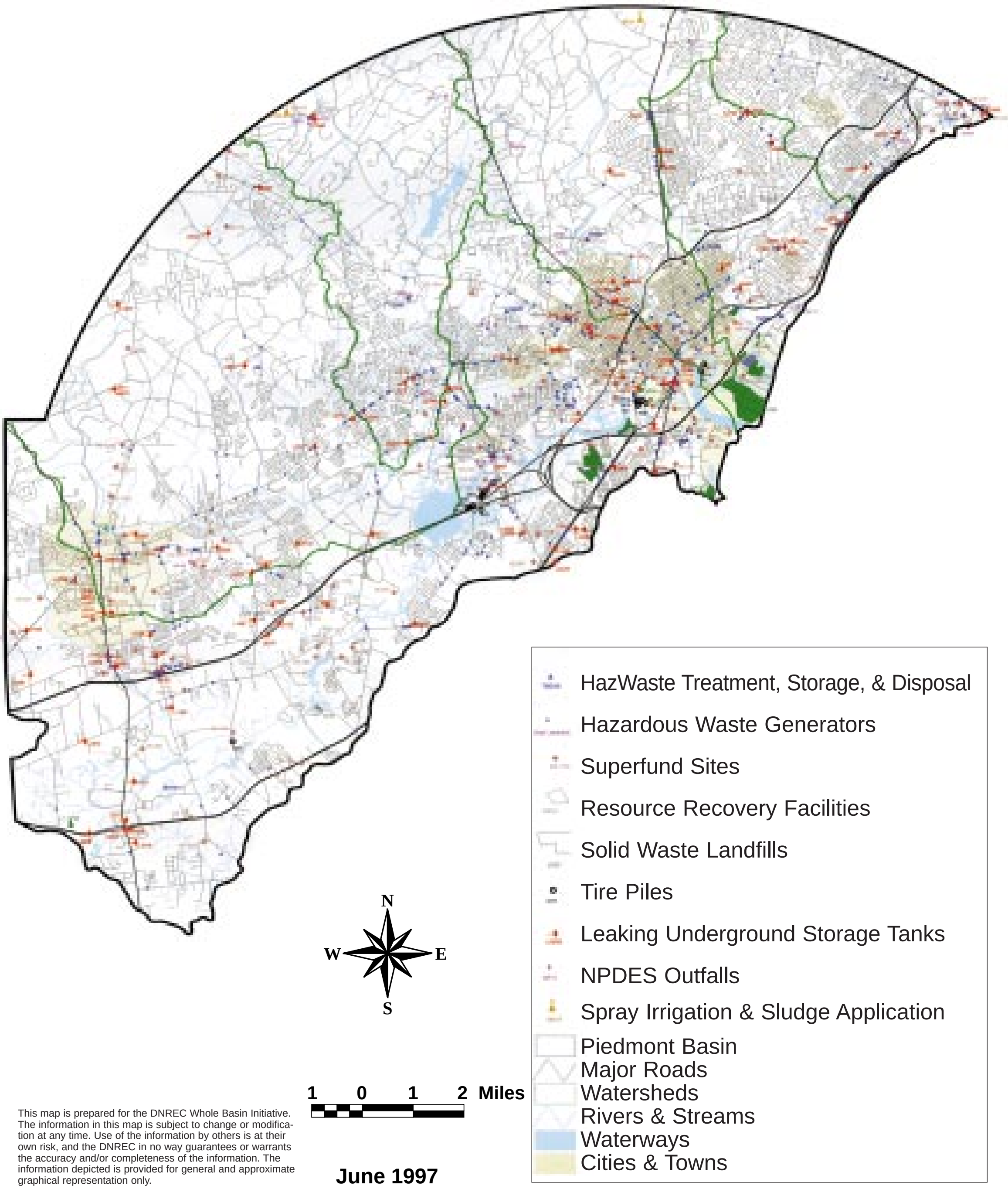
Possible Contaminant Sources



1 0 1 2 Miles

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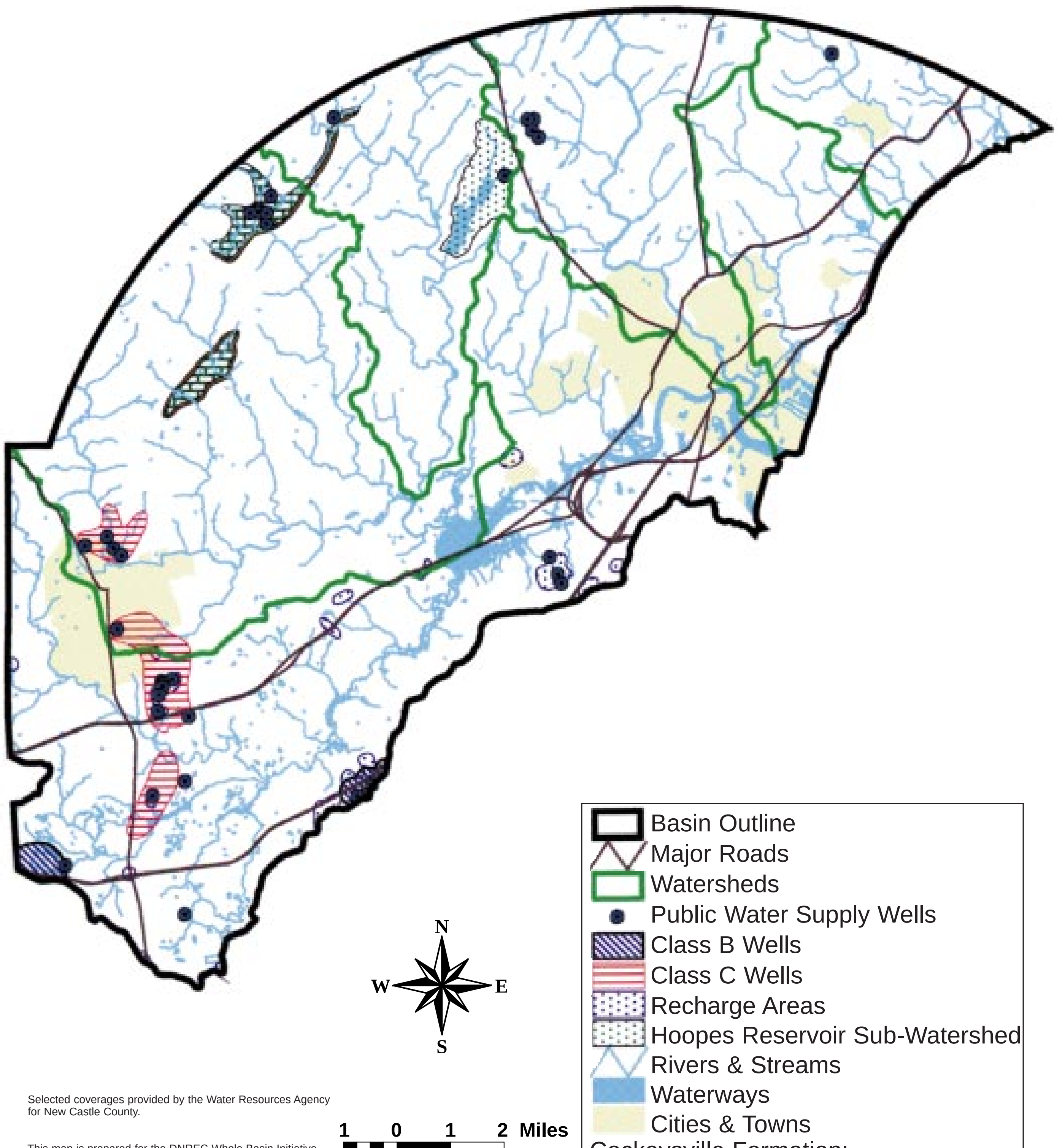
Water Resource Protection Areas



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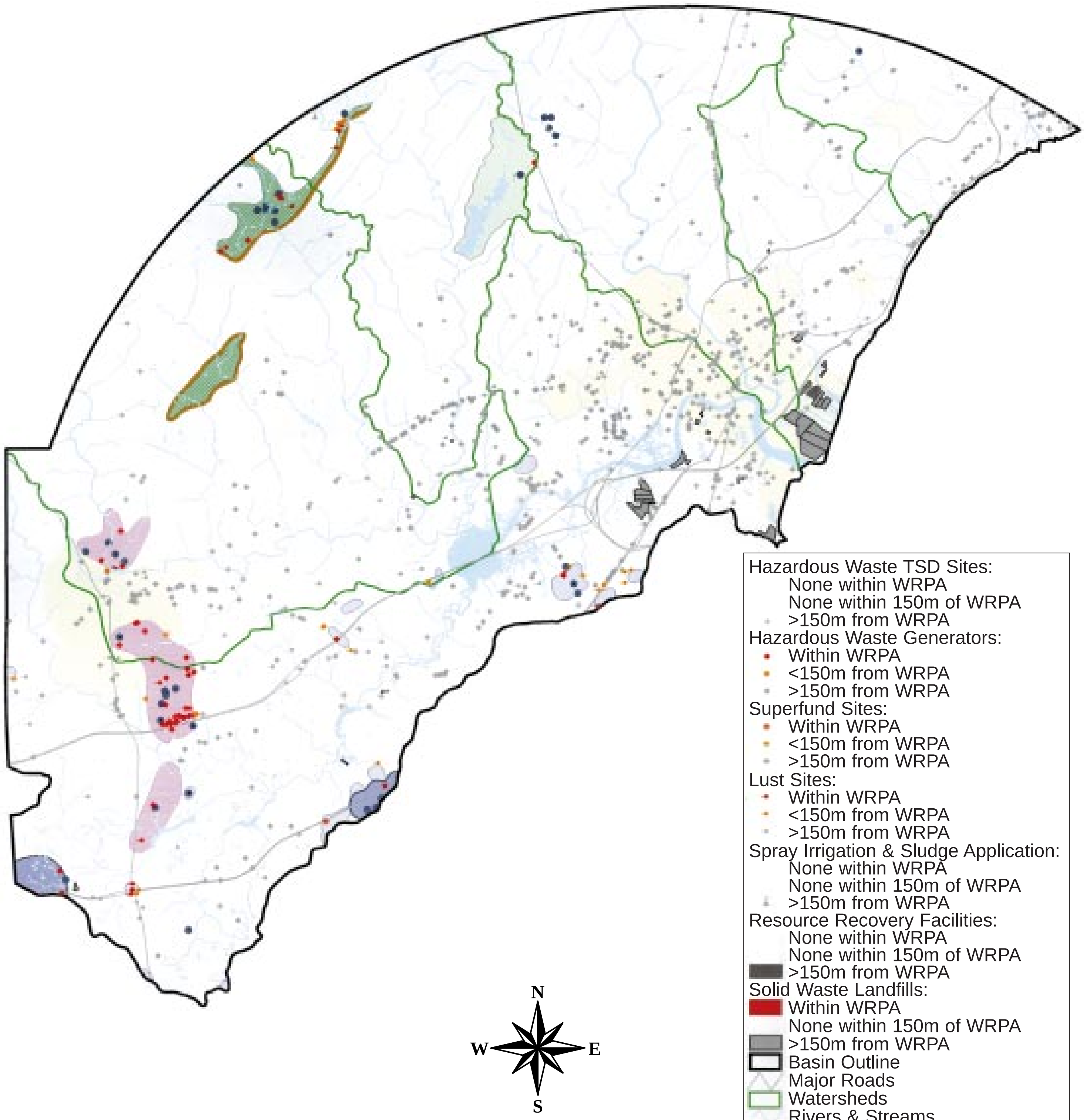
Possible Contaminant Source Proximity to Water Resource Protection Areas



1 0 1 2 Miles

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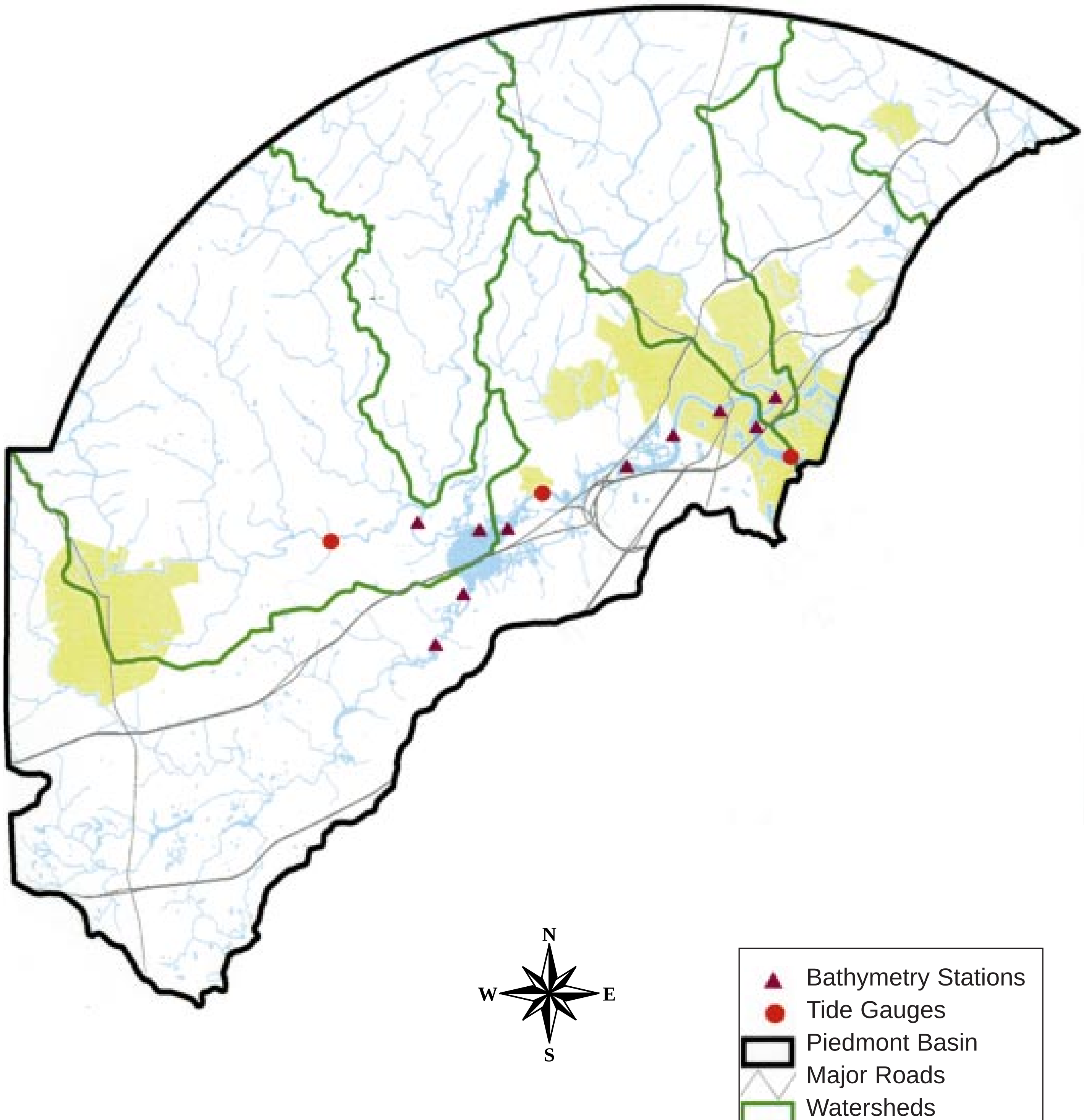
Tide Gauges and Bathymetry Stations



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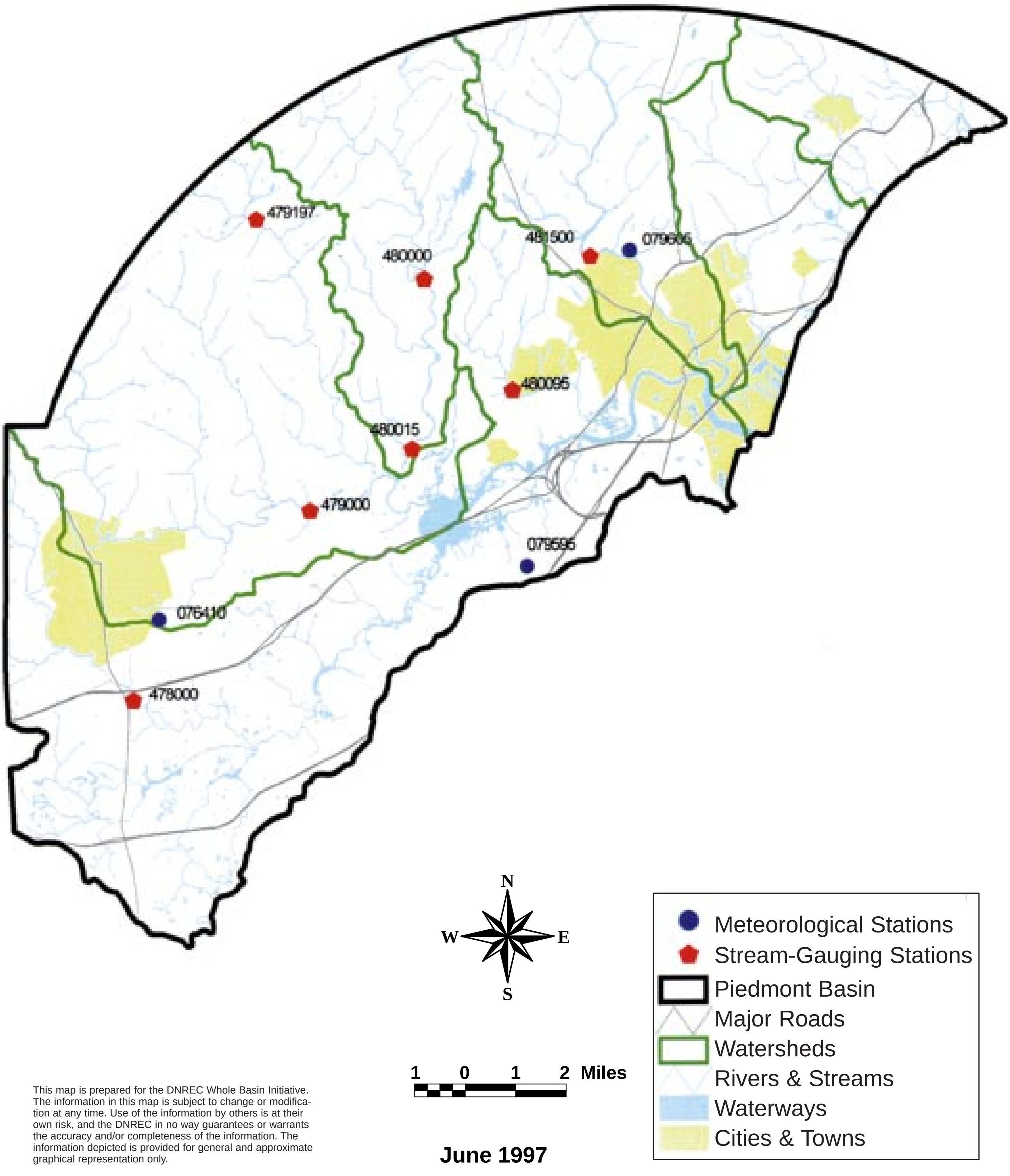
Location of Flow and Rain Gauge Stations



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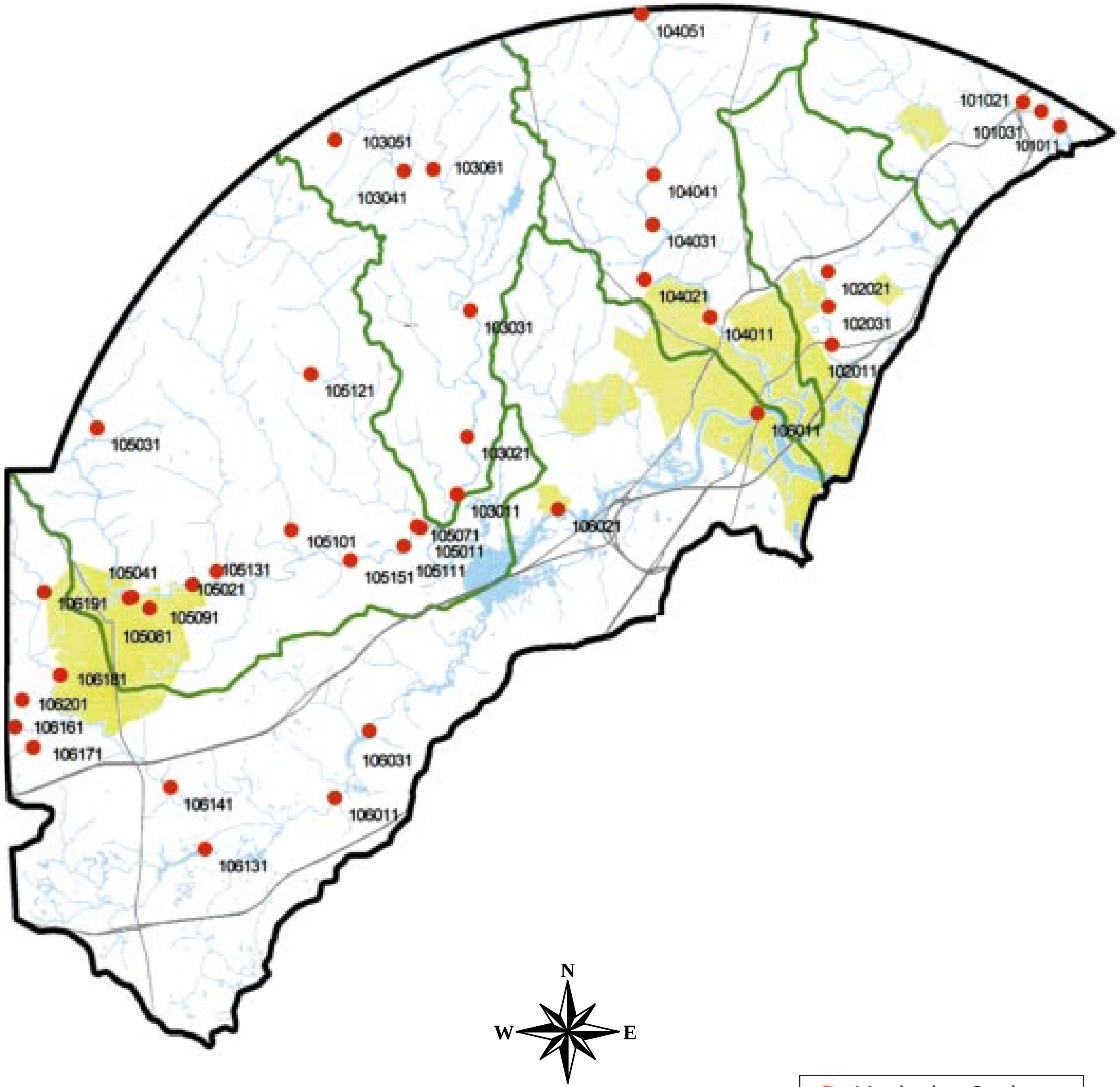
Water-Quality Monitoring (STORET) Stations



1 0 1 2 Miles

- Monitoring Stations
- Piedmont Basin
- Major Roads
- Watersheds
- Rivers & Streams
- Waterways
- Cities & Towns

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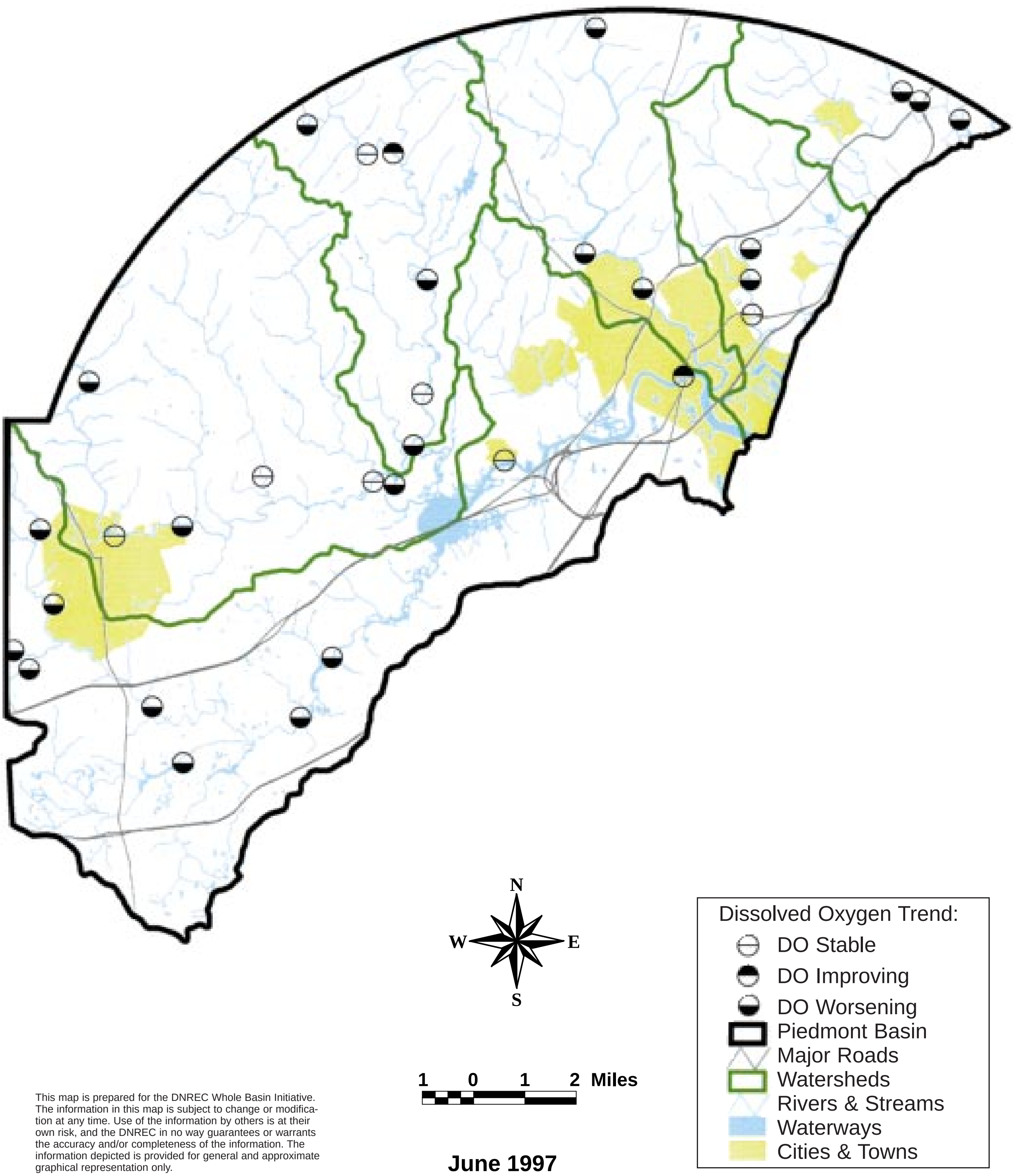
Dissolved Oxygen Trend Analysis



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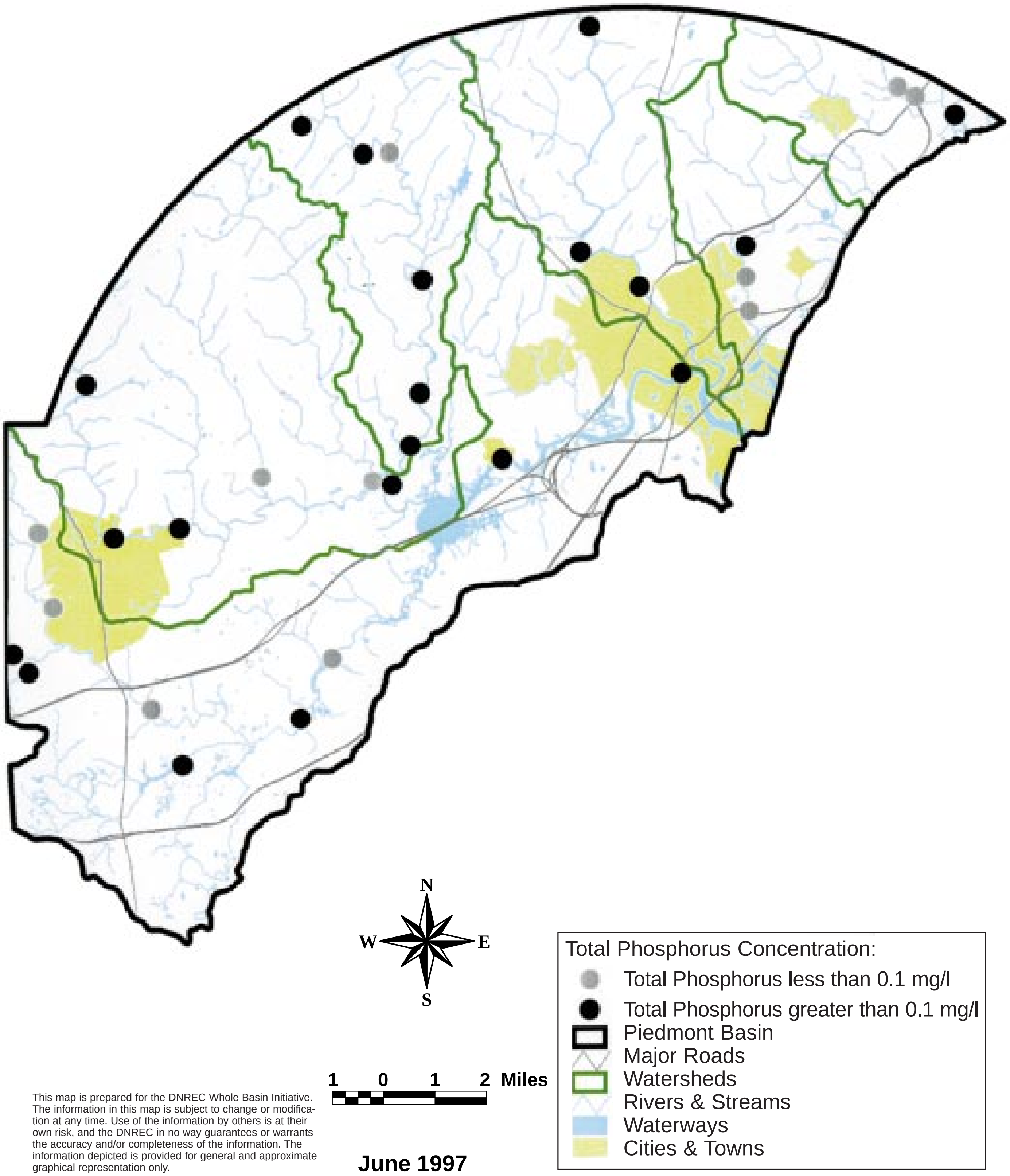
Total Phosphorus Concentration



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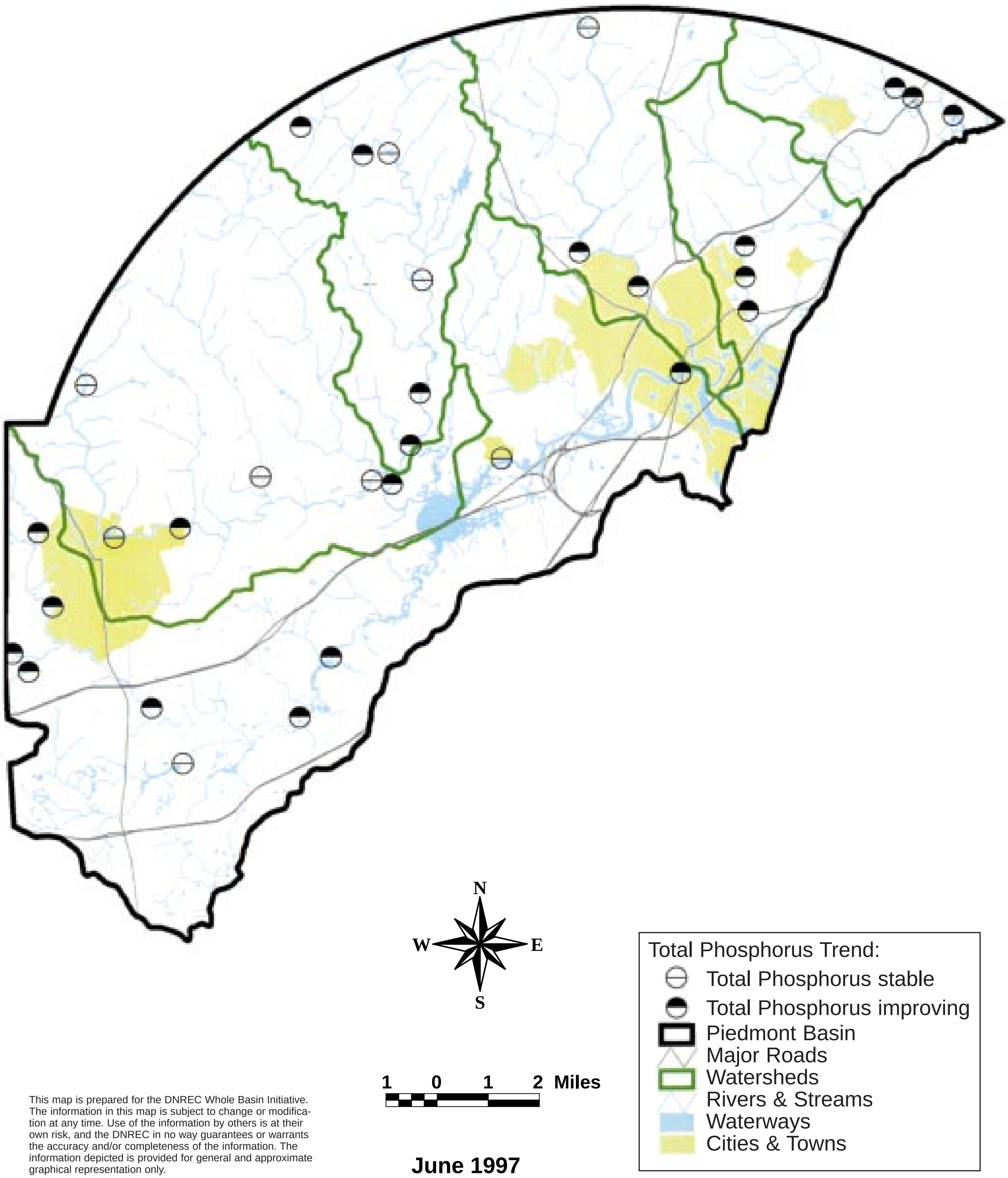
Total Phosphorus Trend Analysis



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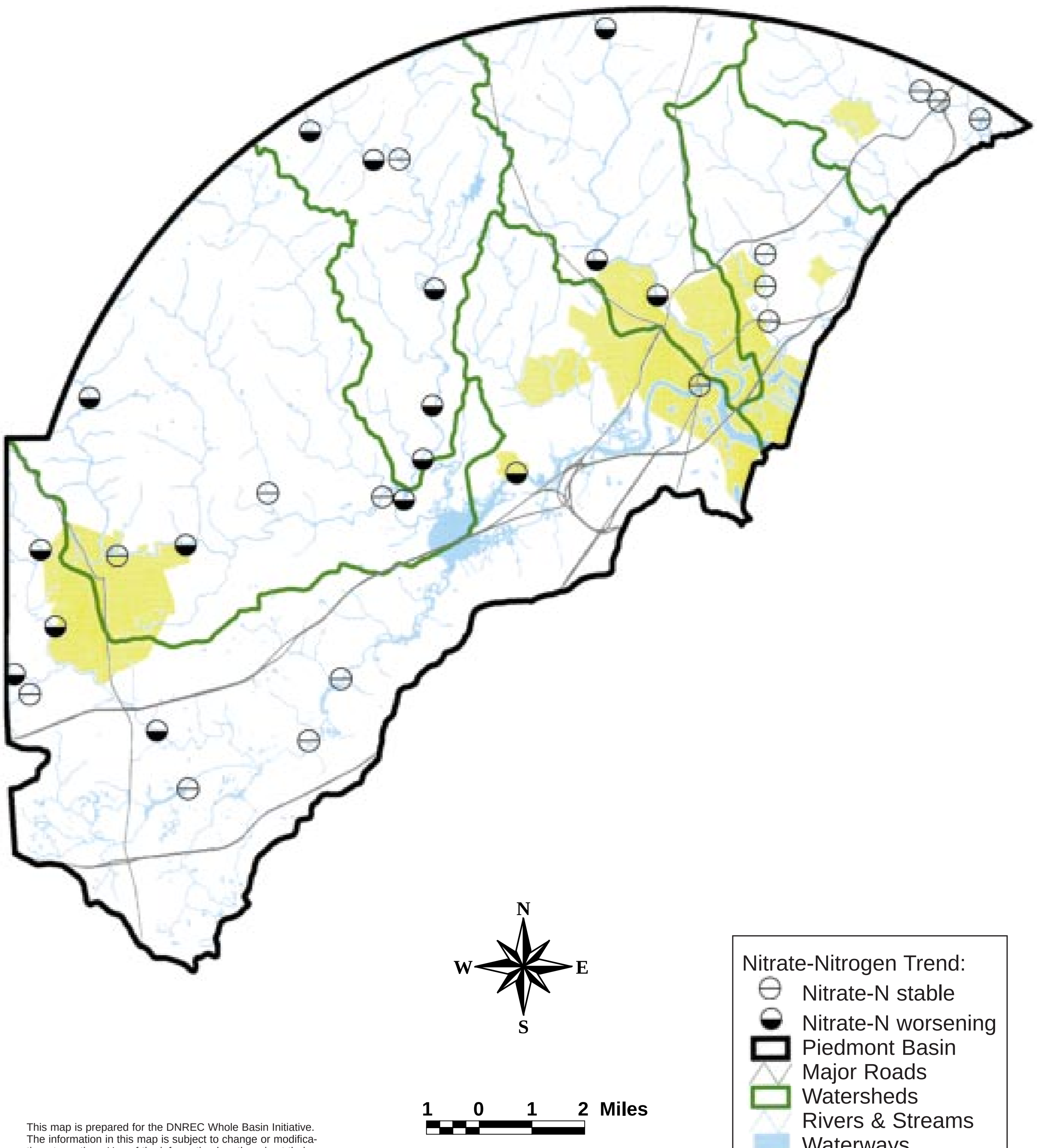
Nitrate-Nitrogen Trend Analysis



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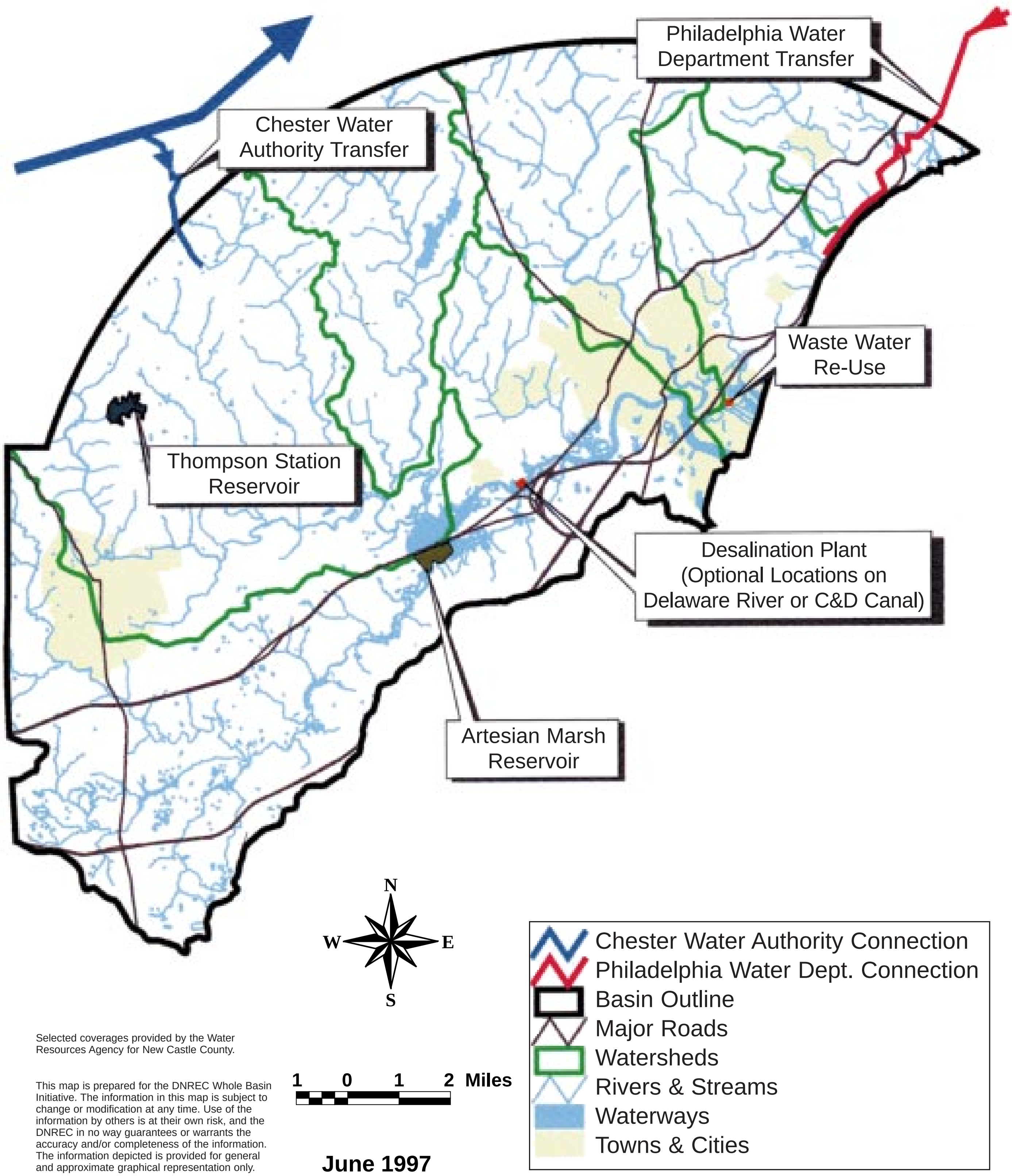
Water Supply Alternatives



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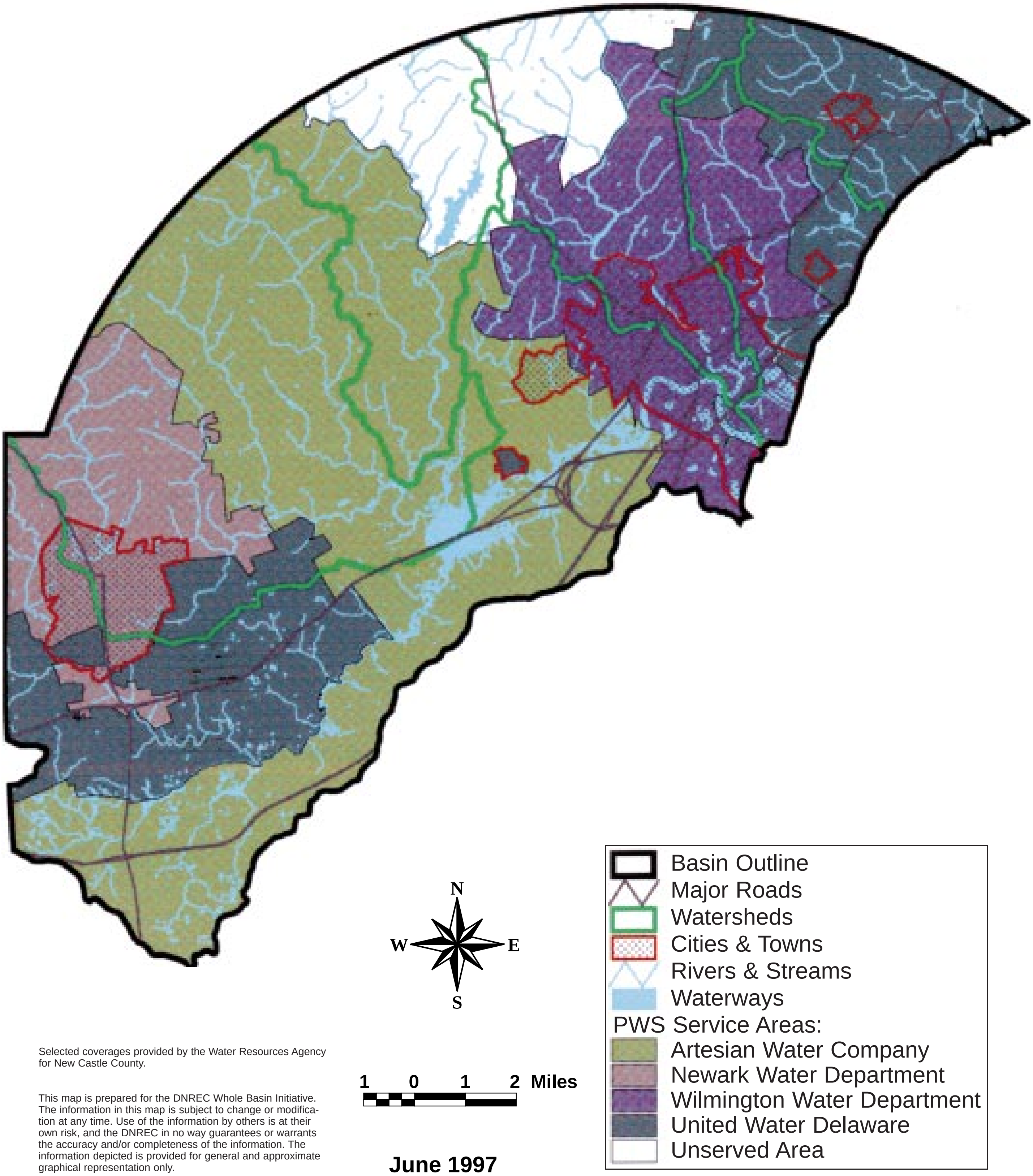
Public Water-Supply Systems Service Areas



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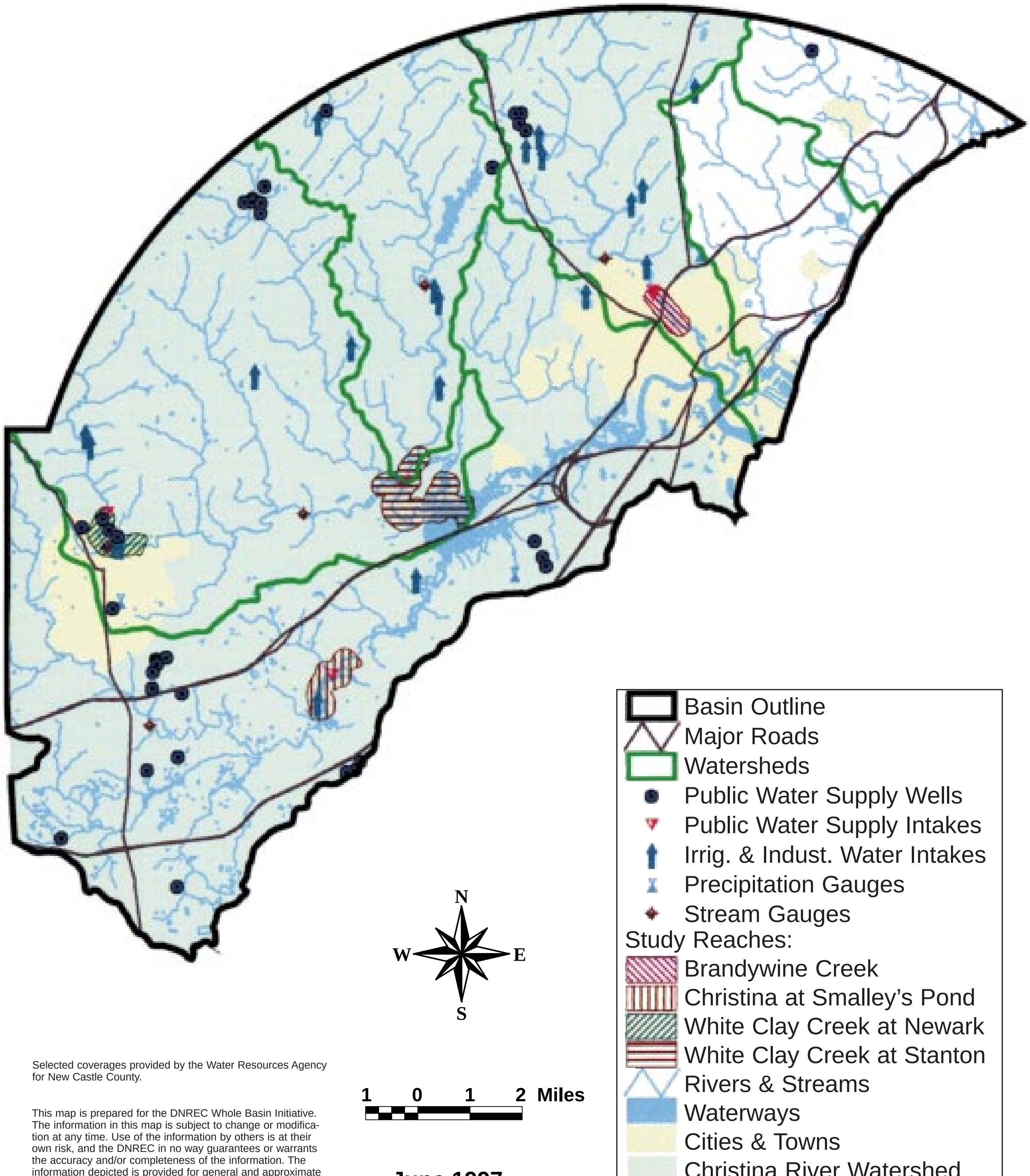
In-stream Flow Needs Analysis



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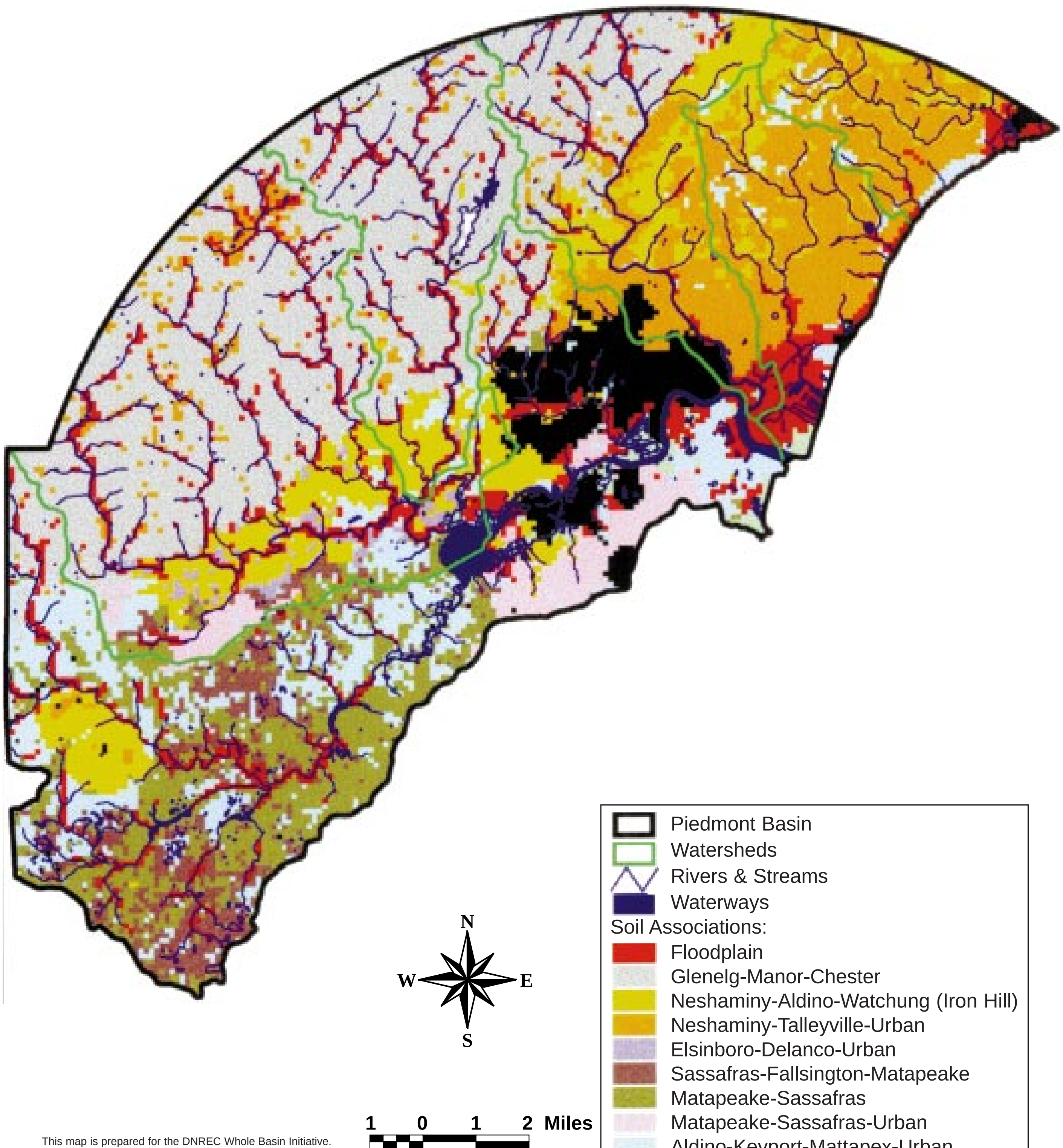
Soil Associations



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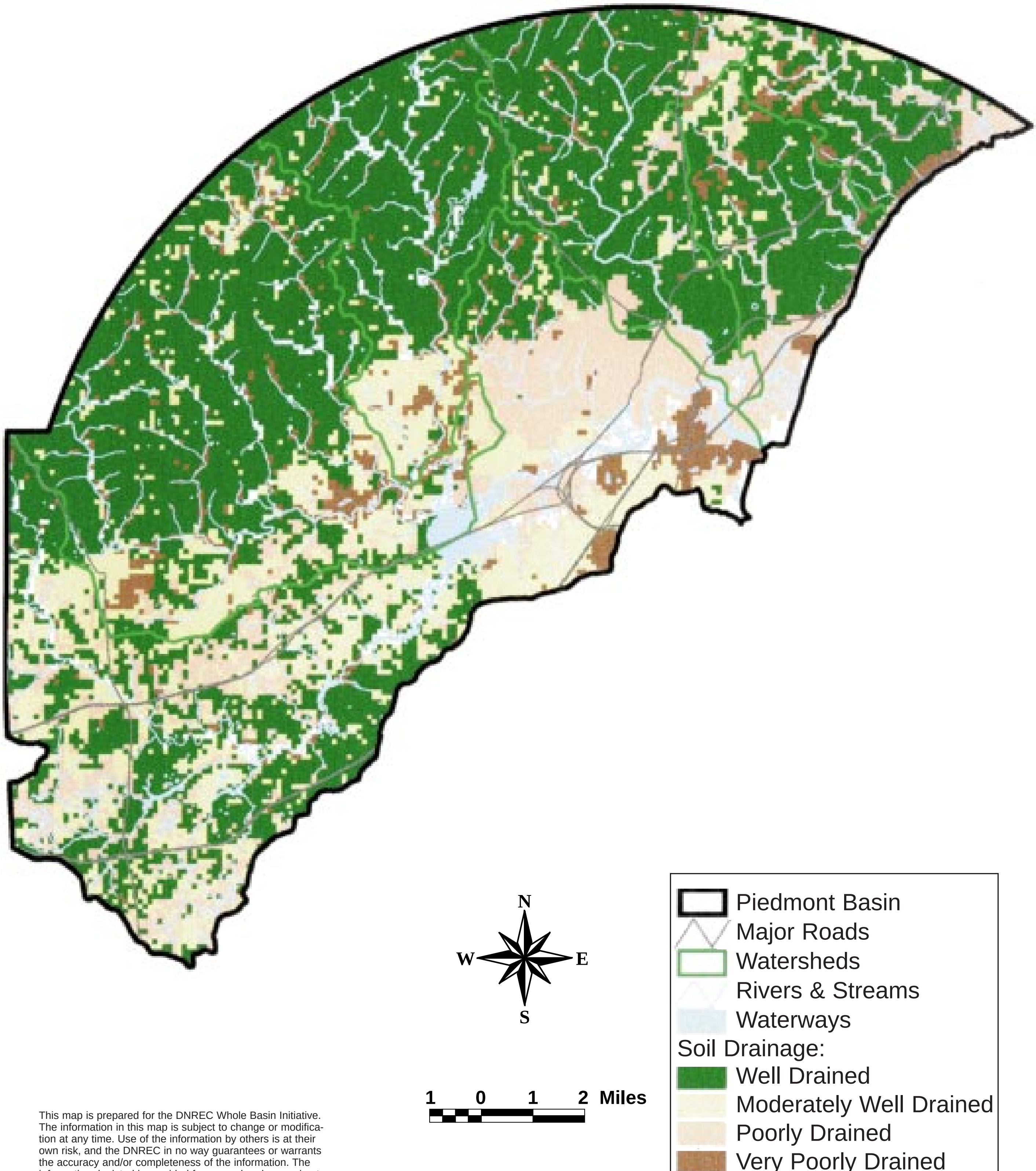
Soil Drainage Characteristics



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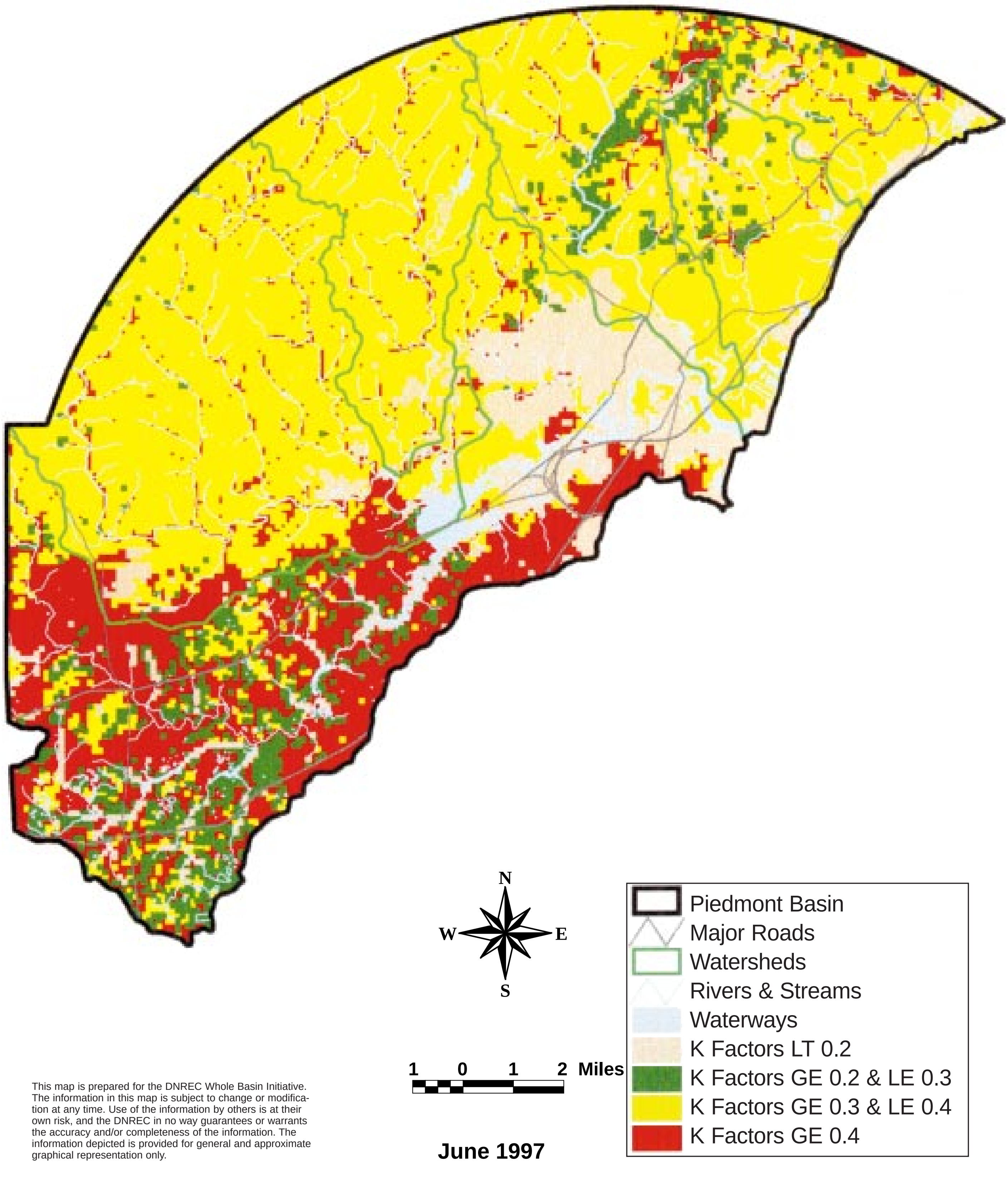
Erodibility (K) Factors



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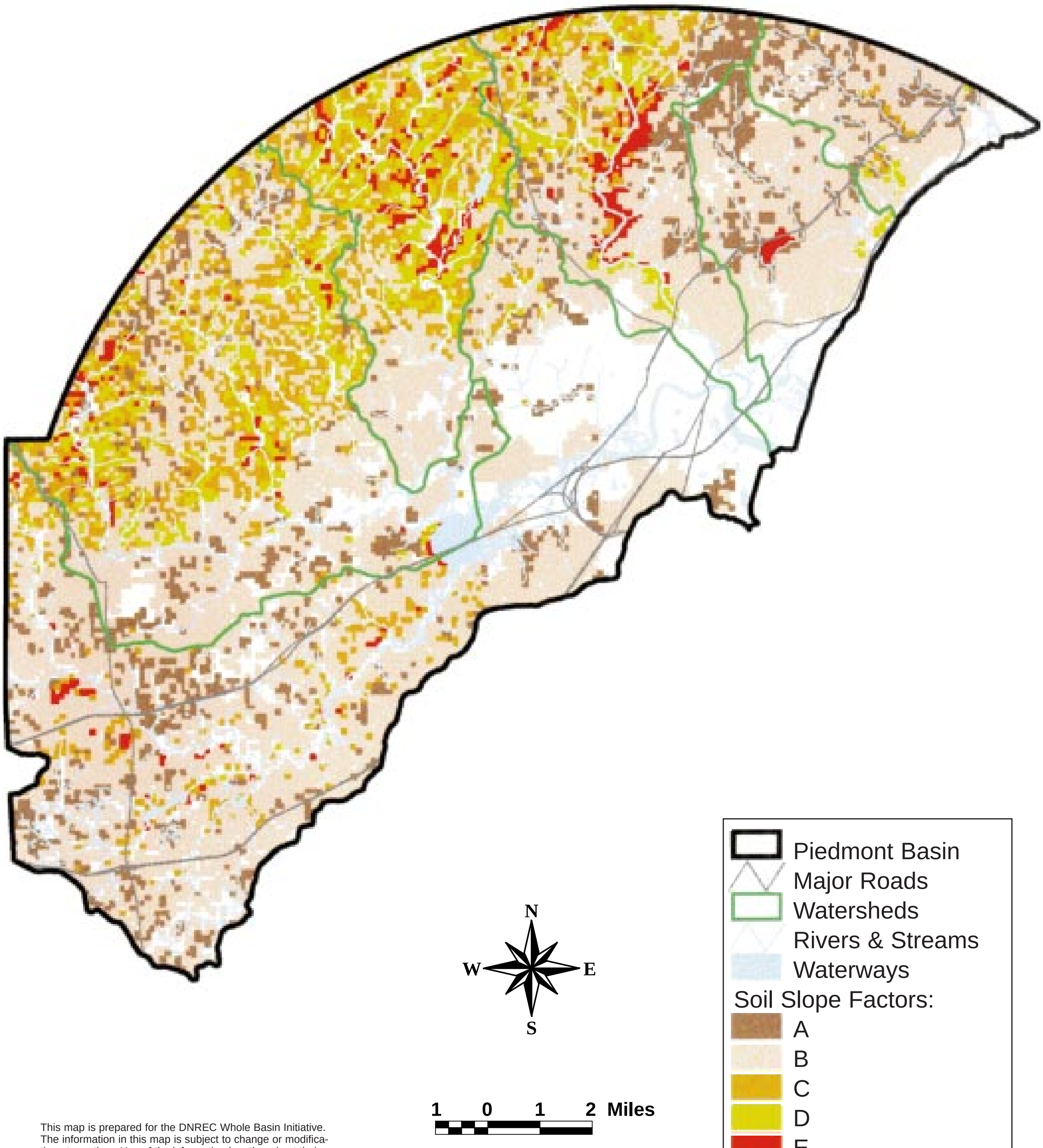
Soil Slope Factors



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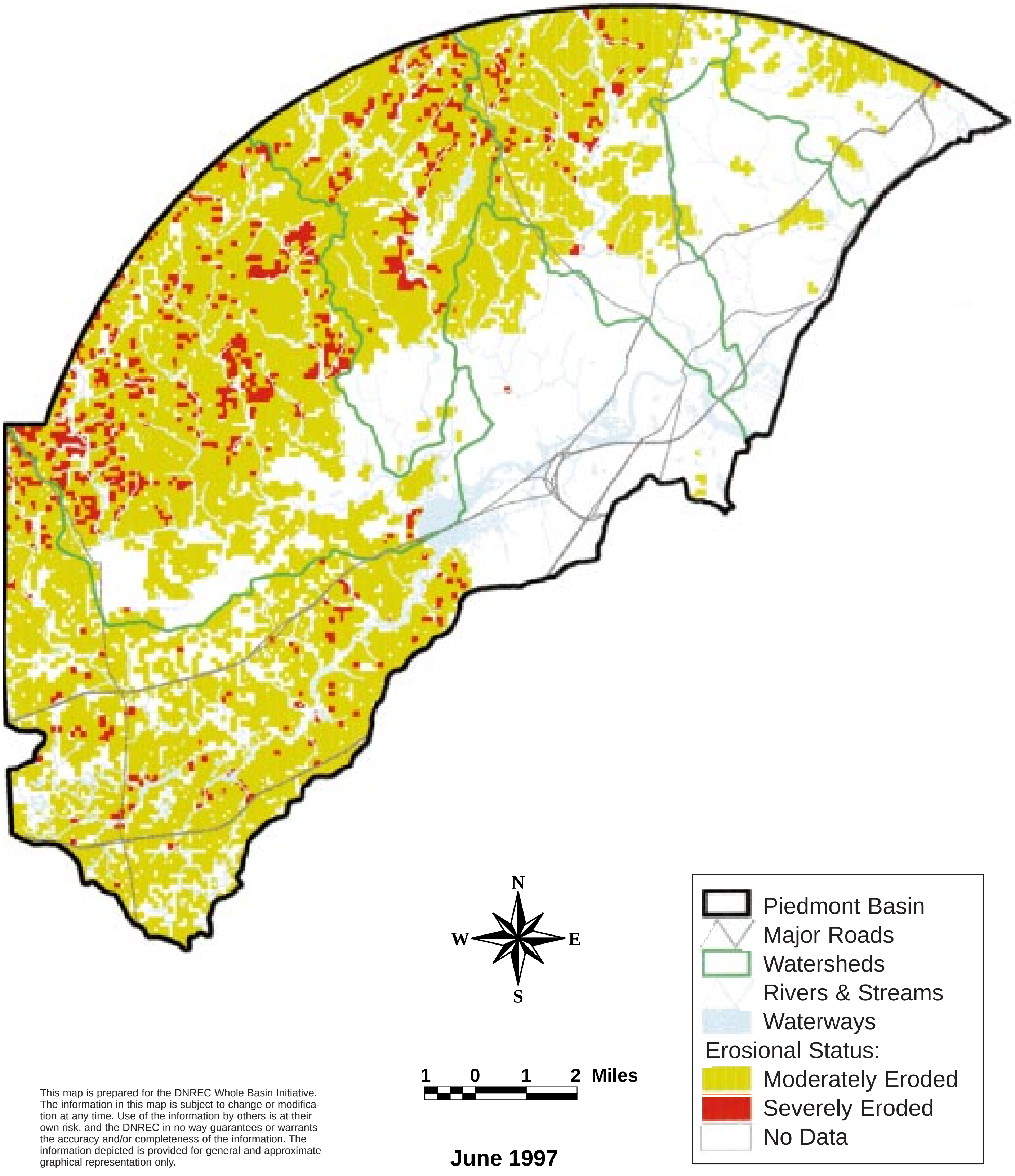
Erosional Status As Mapped in 1970



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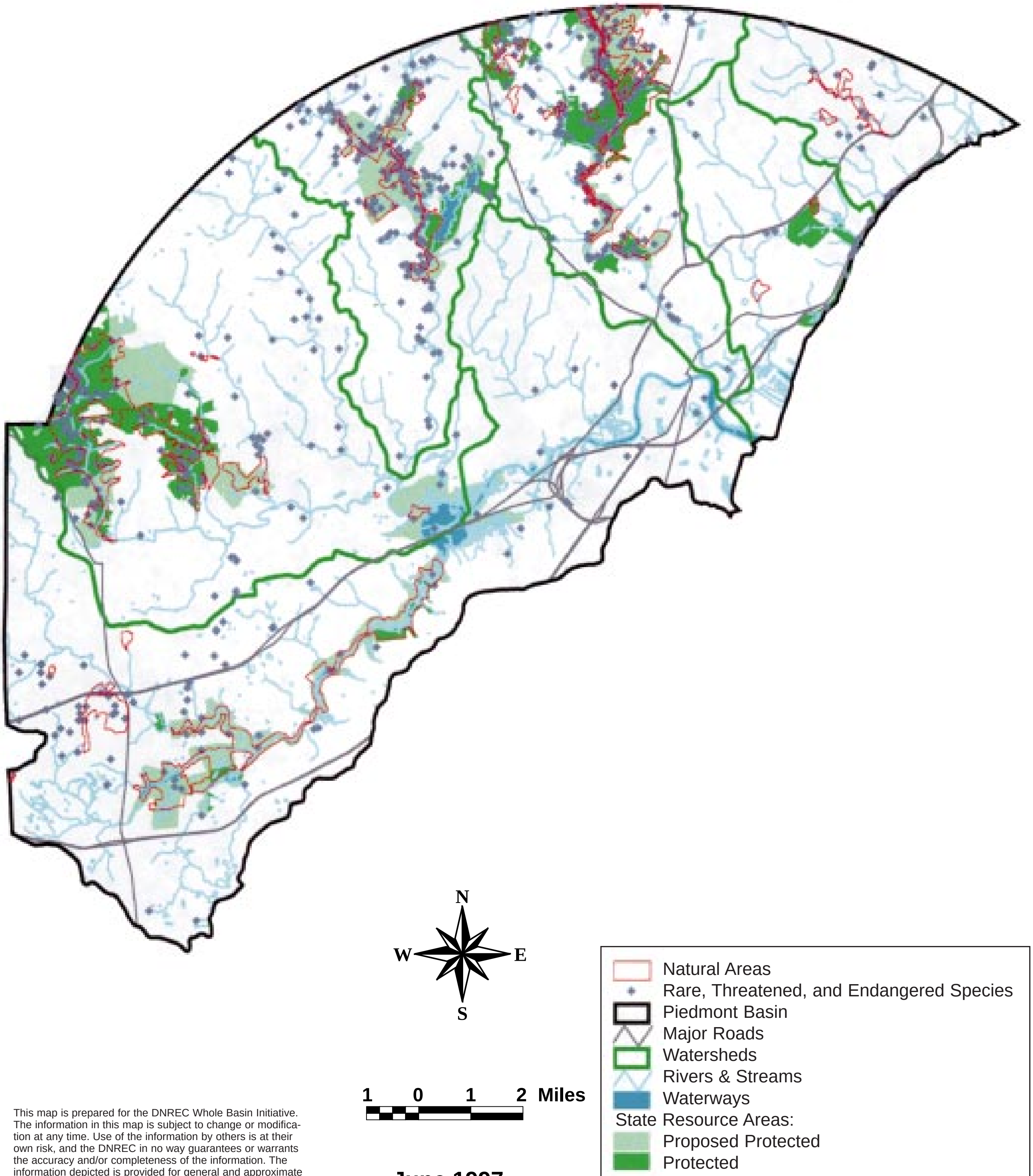
Land Preservation and Living Resources



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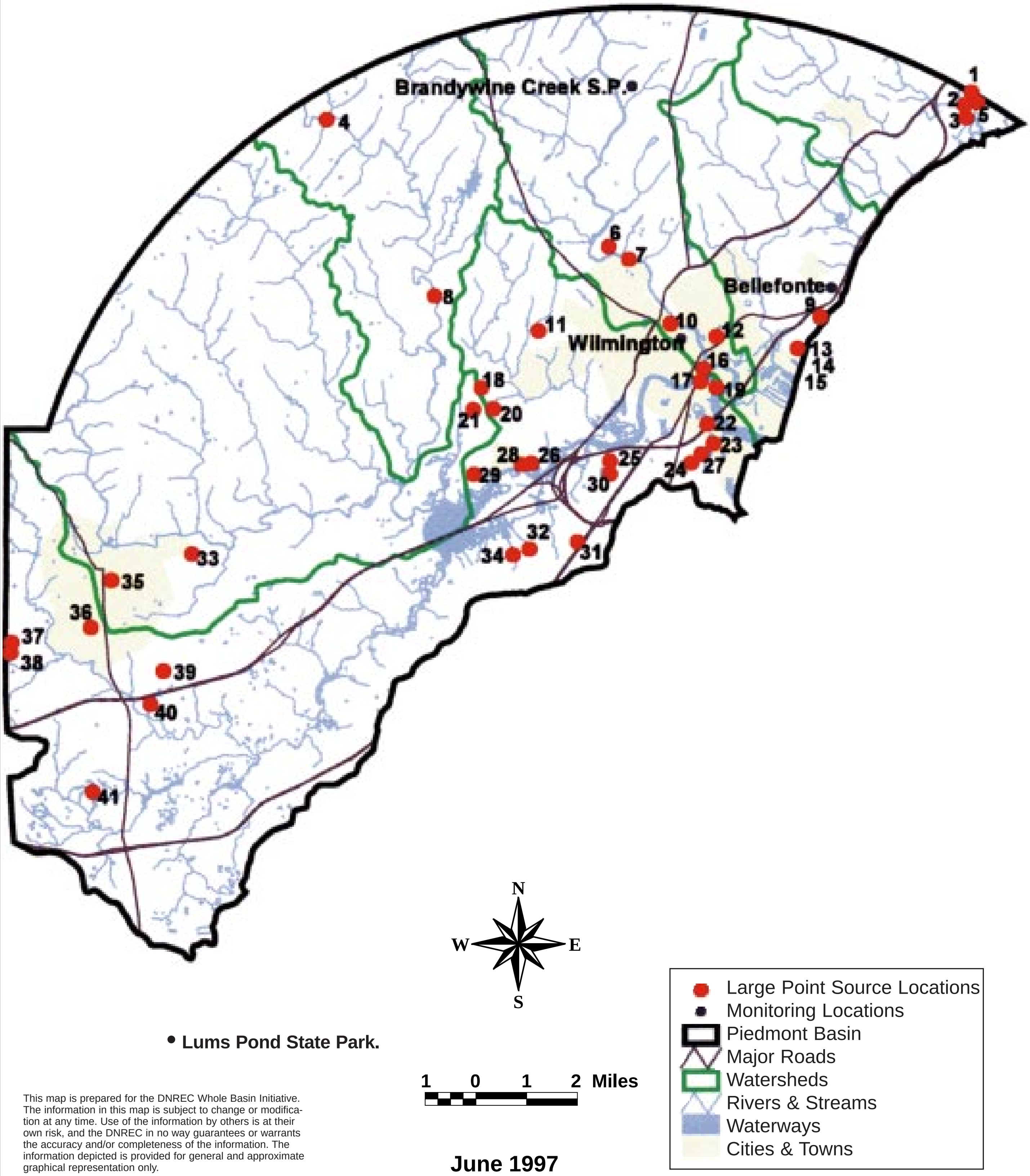
Large Point Sources Included in Ozone Precursor Emissions Inventories



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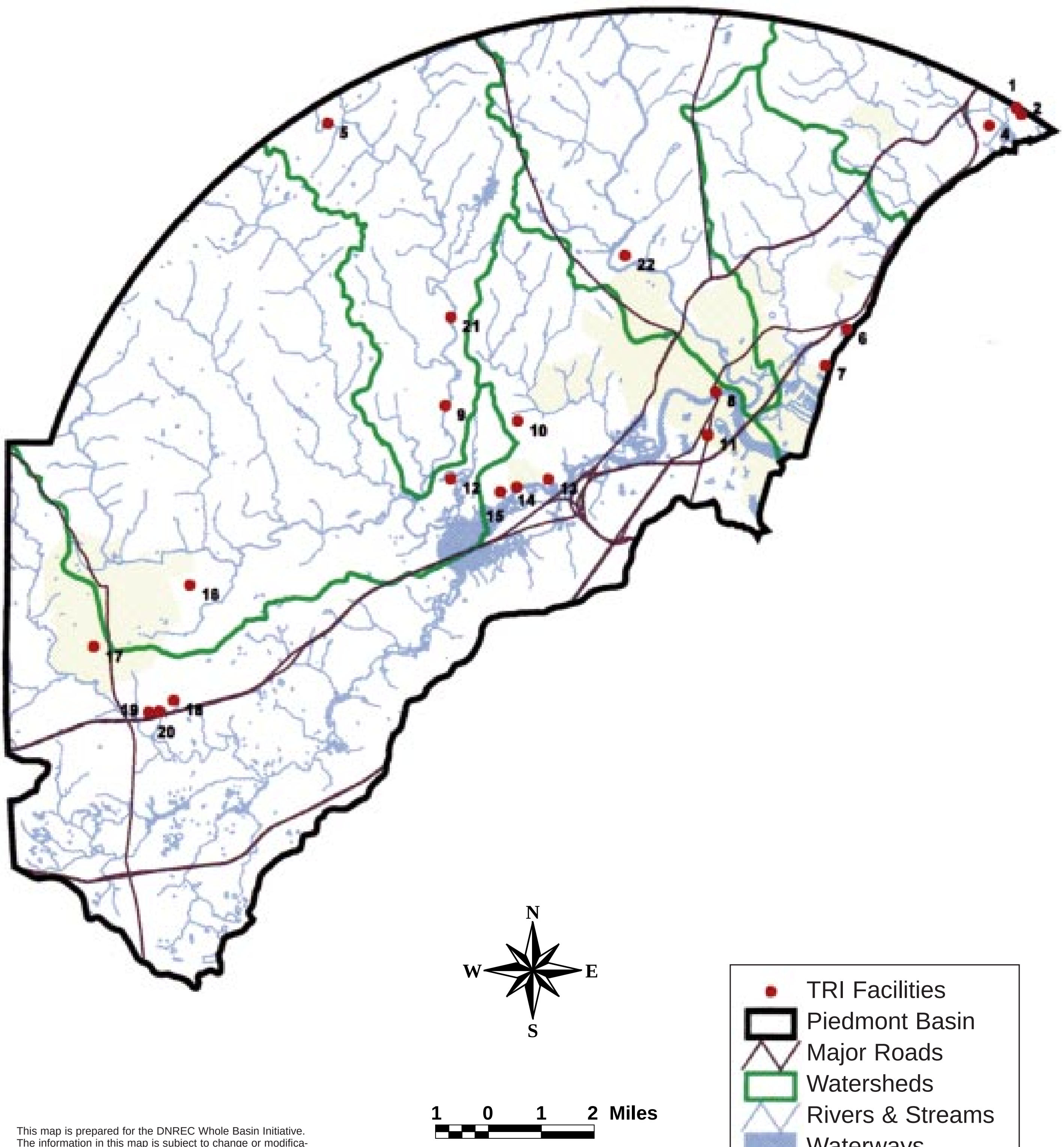
1994 Toxic Release Inventory Facilities with Air Releases



TRI Facilities
Piedmont Basin
Major Roads
Watersheds
Rivers & Streams
Waterways
Cities & Towns

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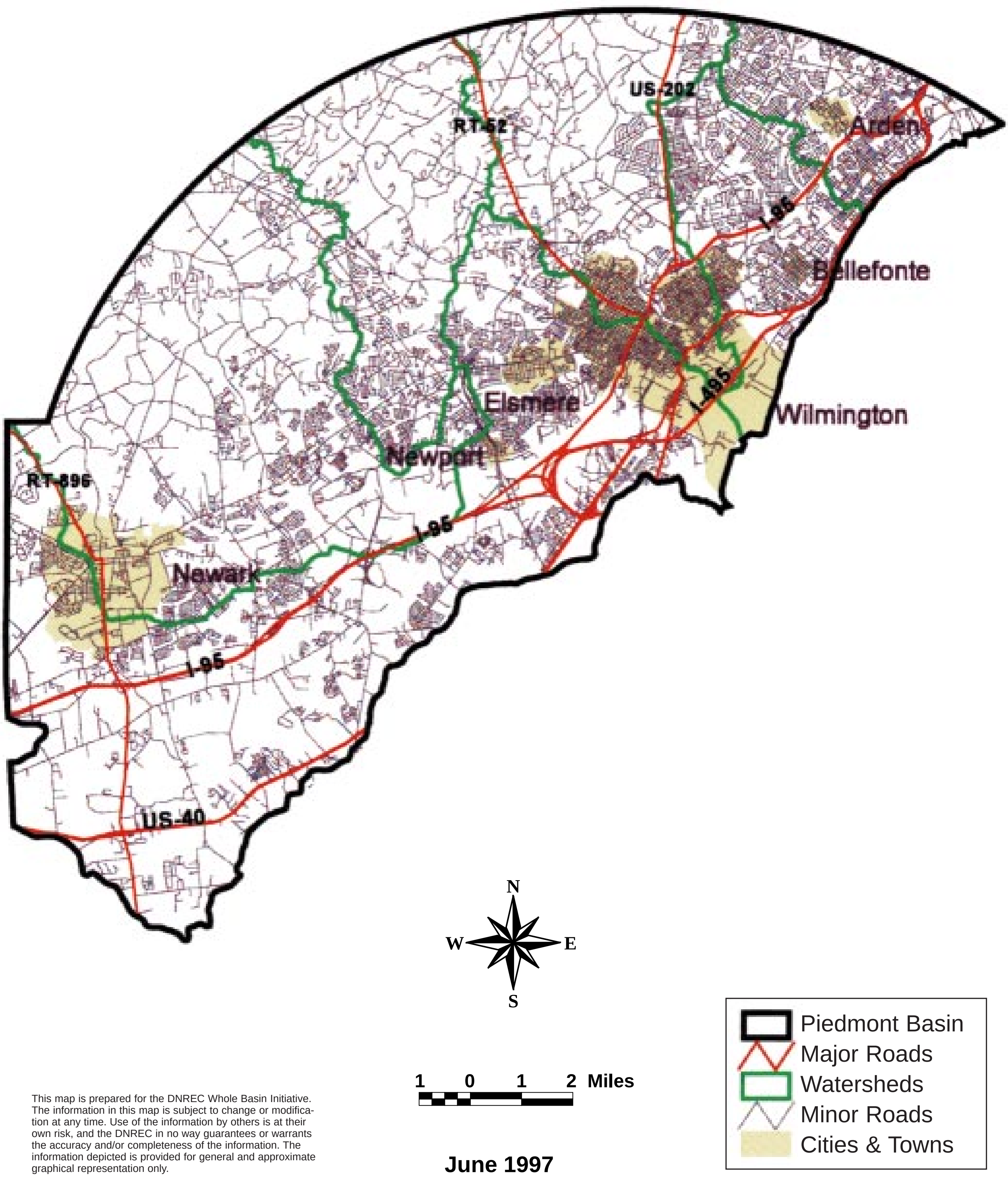
Traffic Network for Mobile Source Emissions



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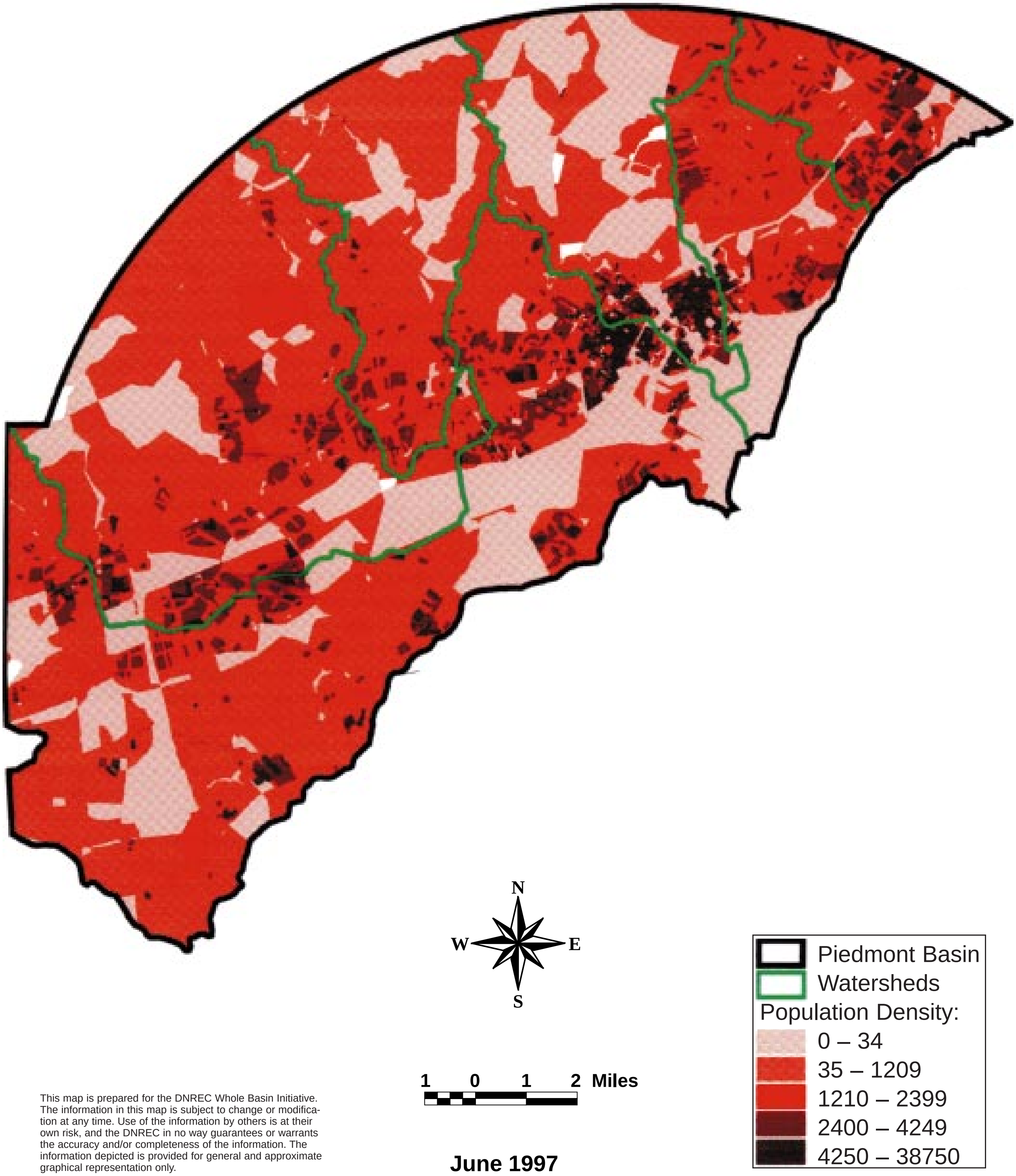
Population Density for Area Source Emissions



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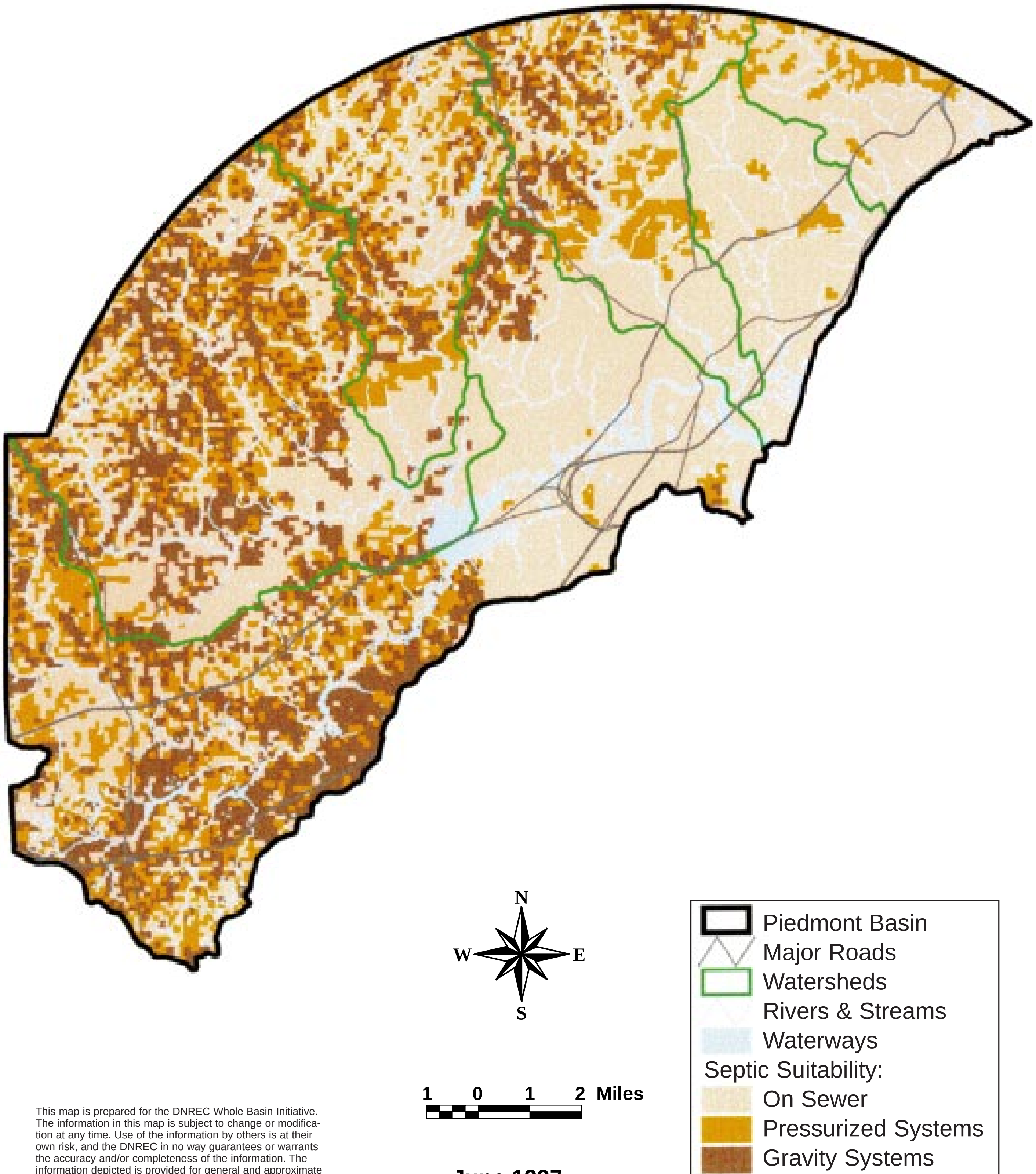
Septic Suitability



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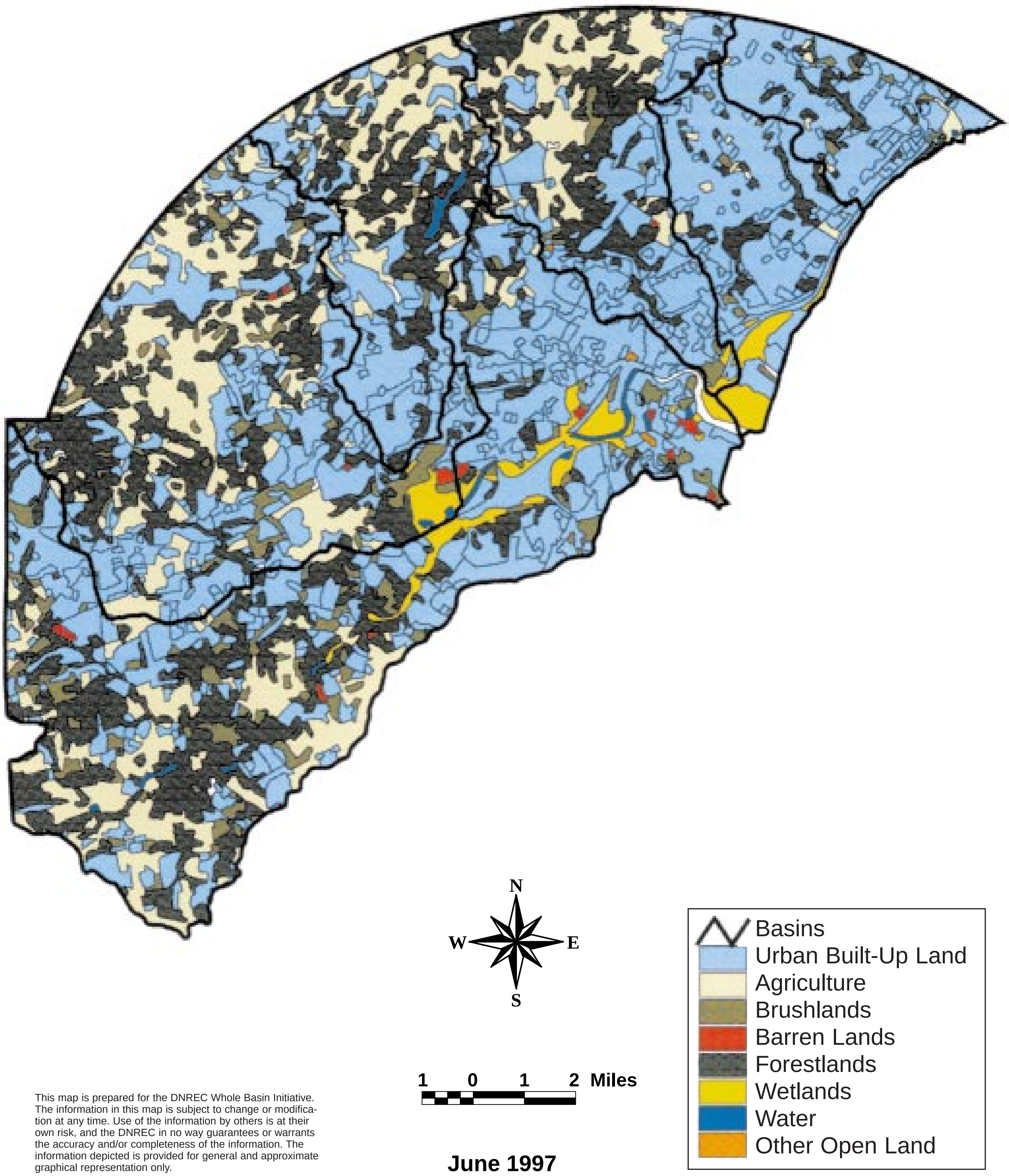
1982 Land Use



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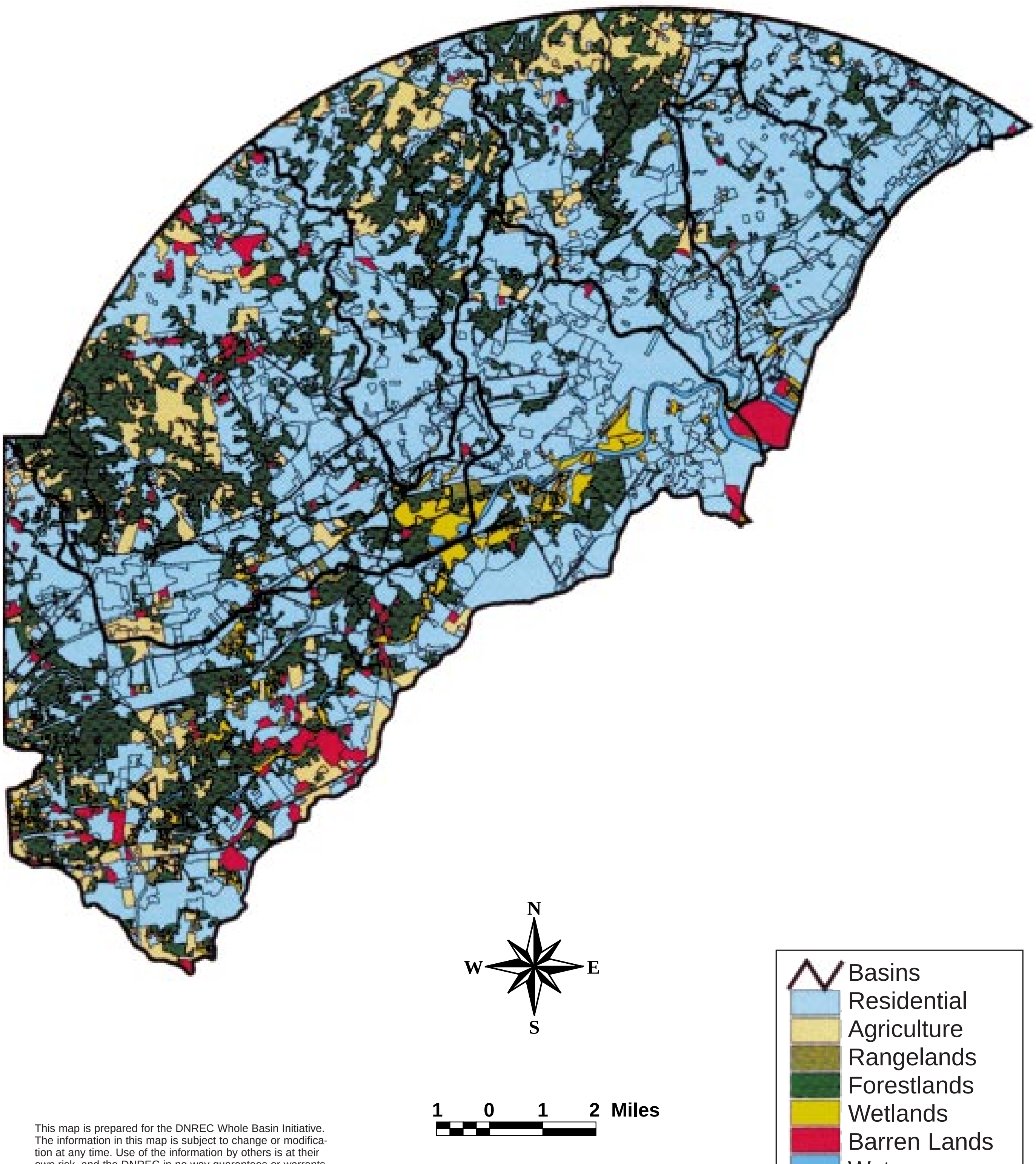
1992 Land Use



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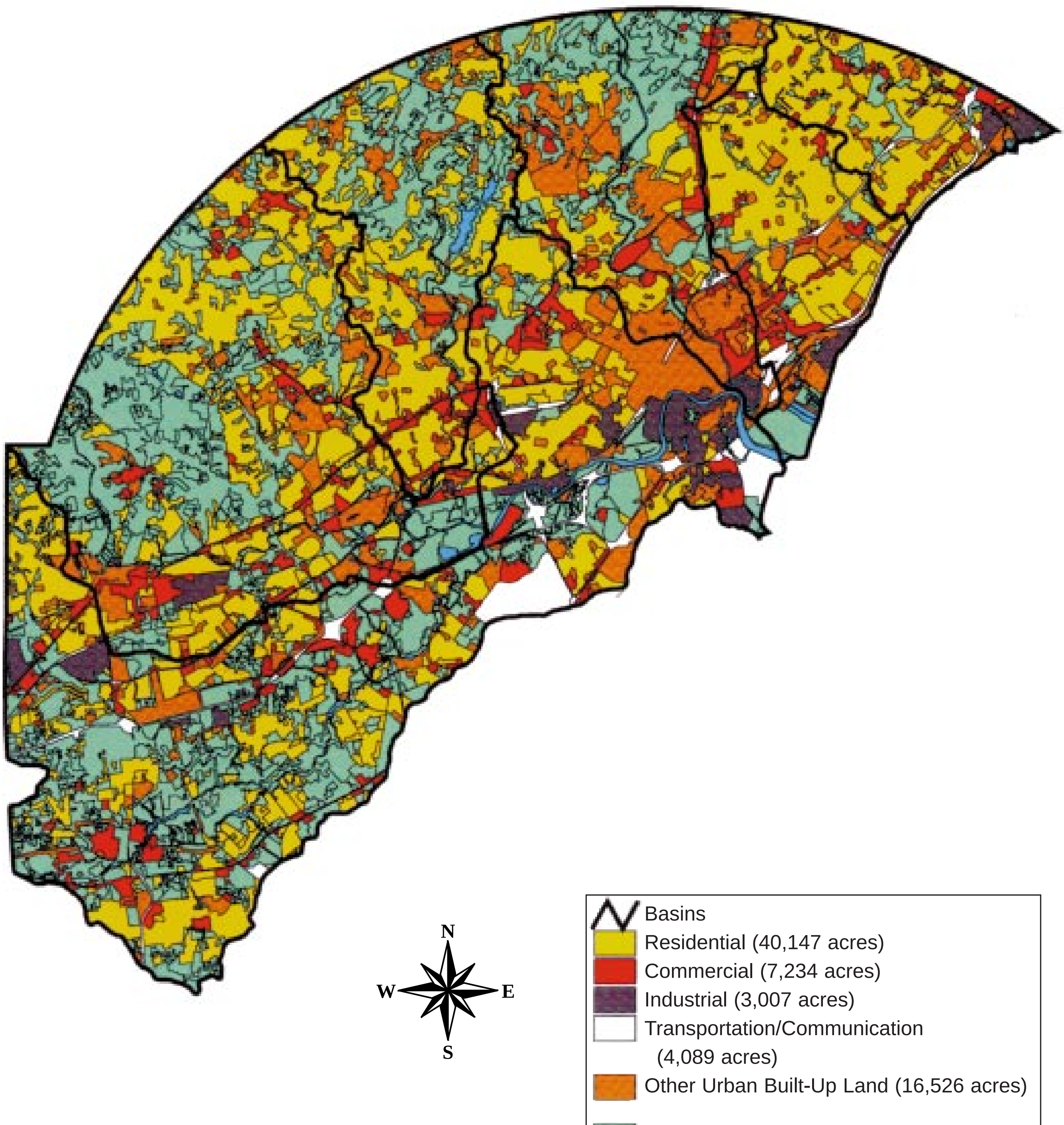
1992 Settlement Patterns
(from 1992 land use/land cover mapping)



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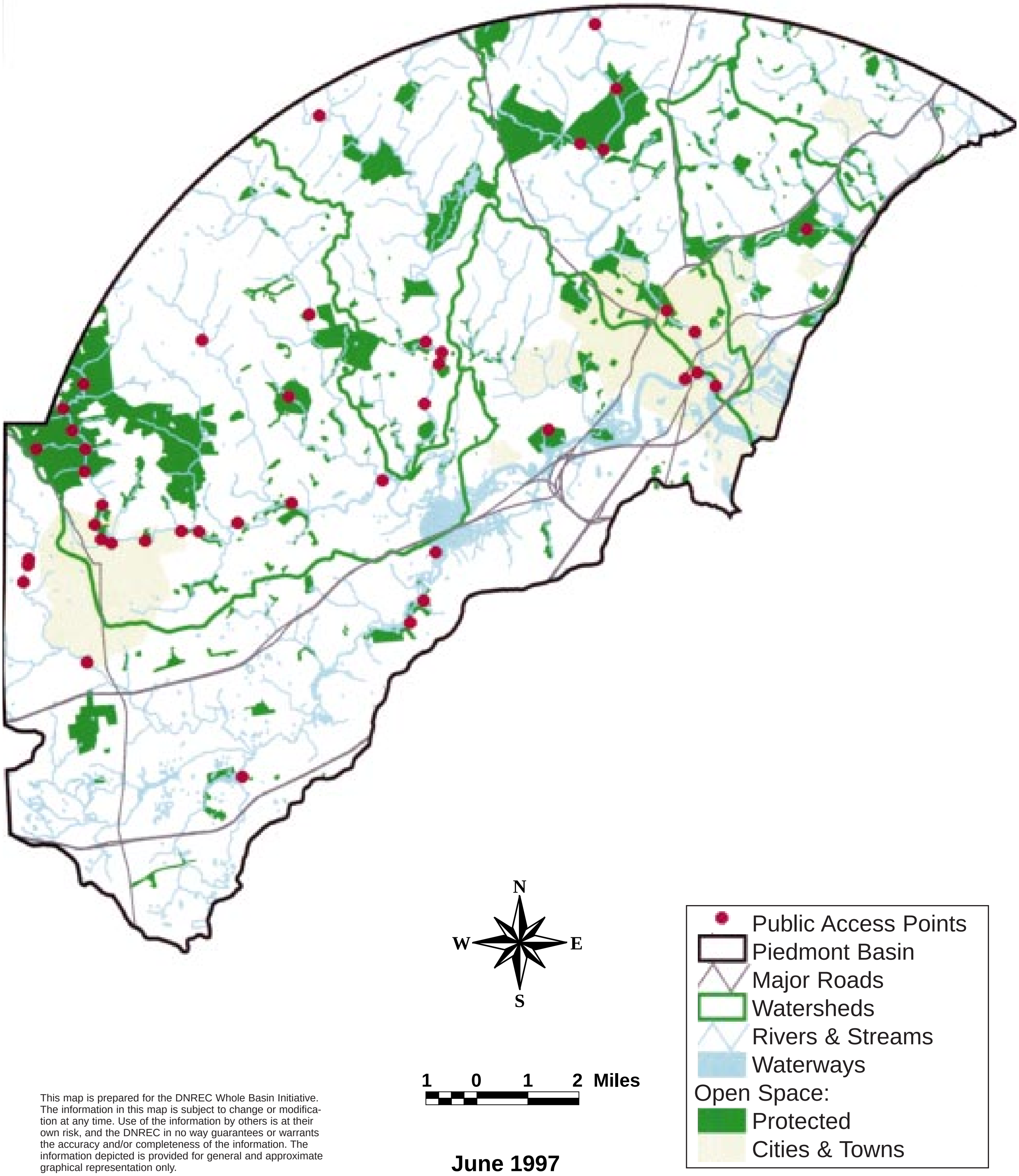
Open Space & Public Access



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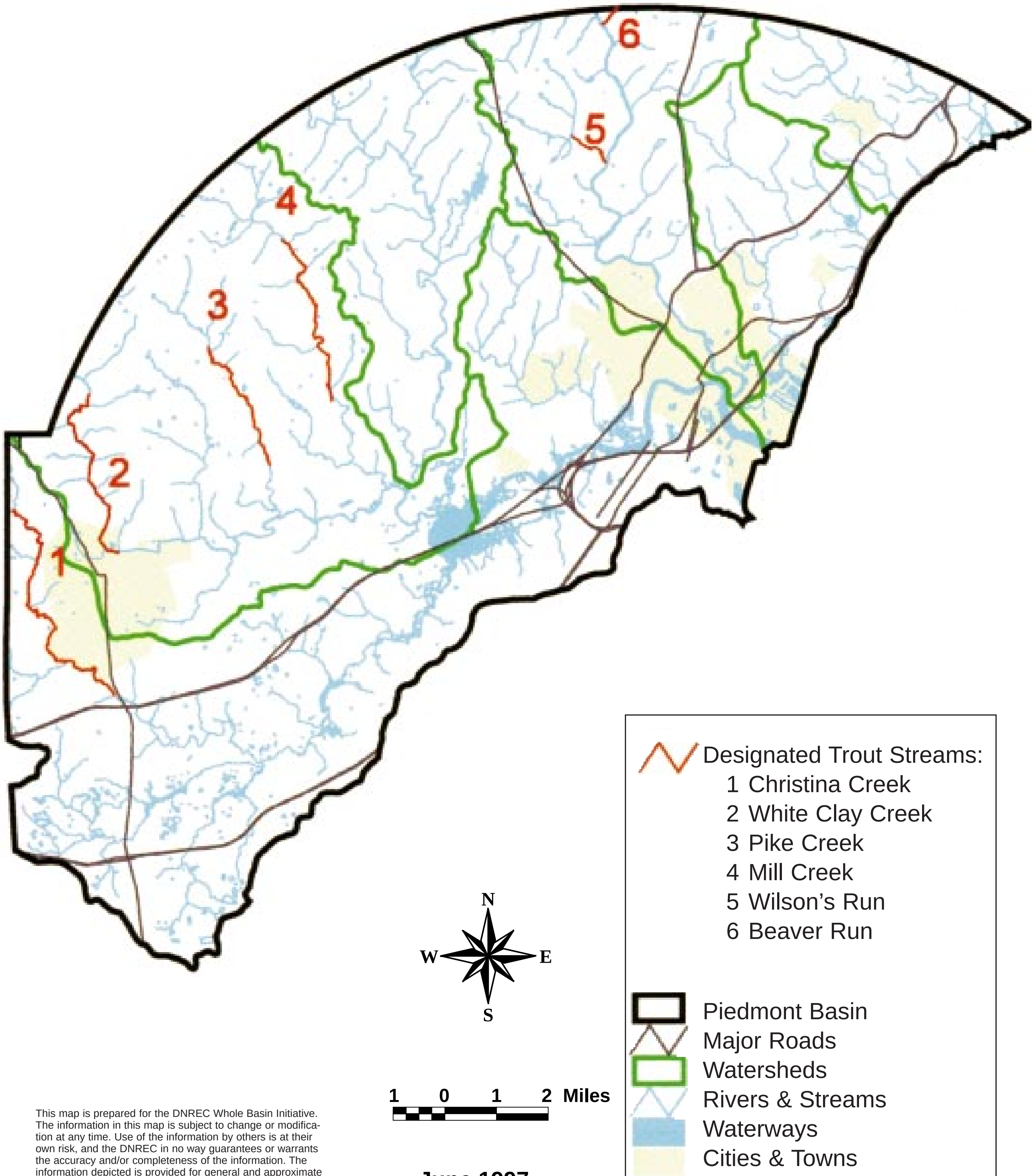
Designated Trout Streams



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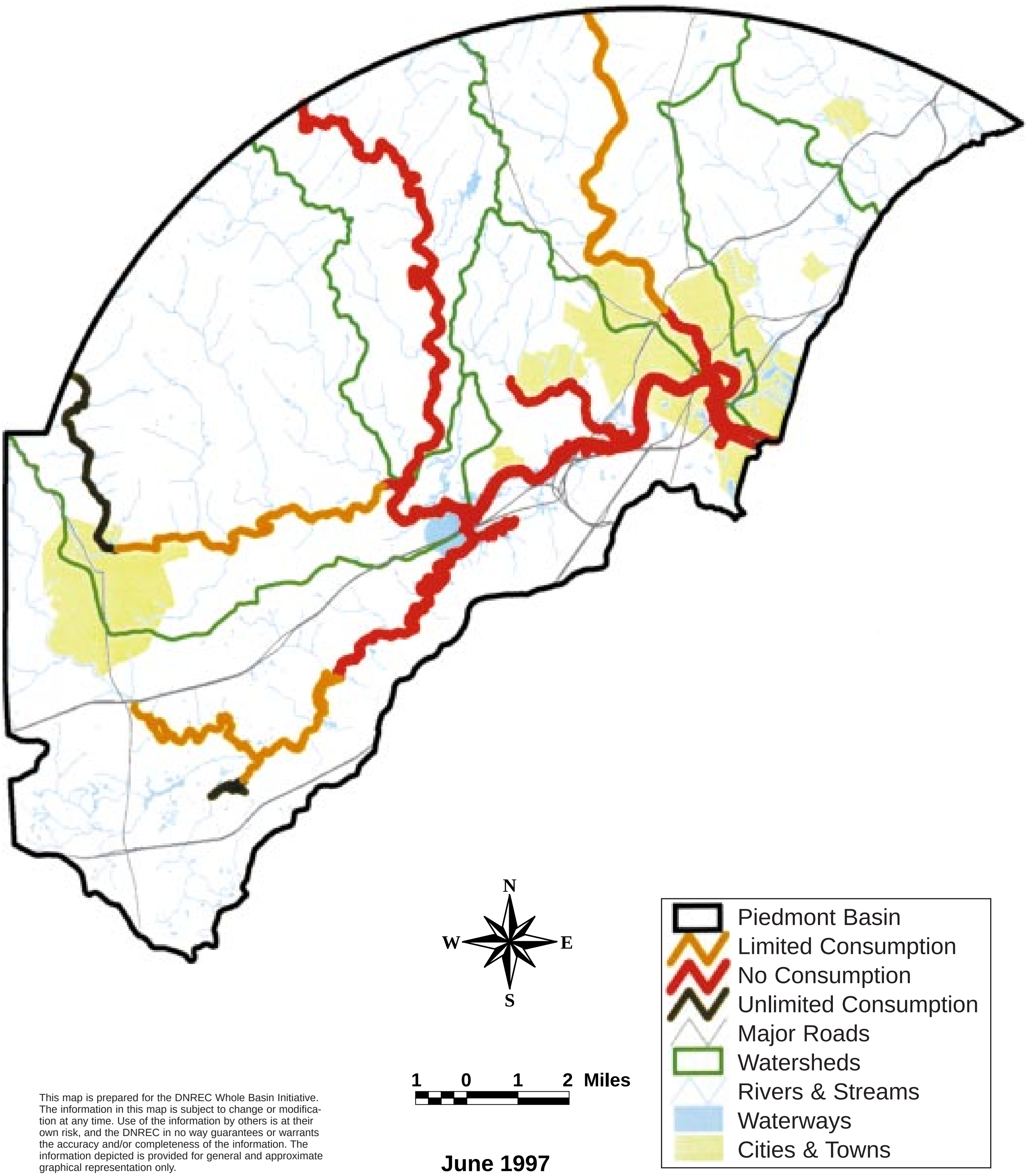
Fish Consumption Advisory



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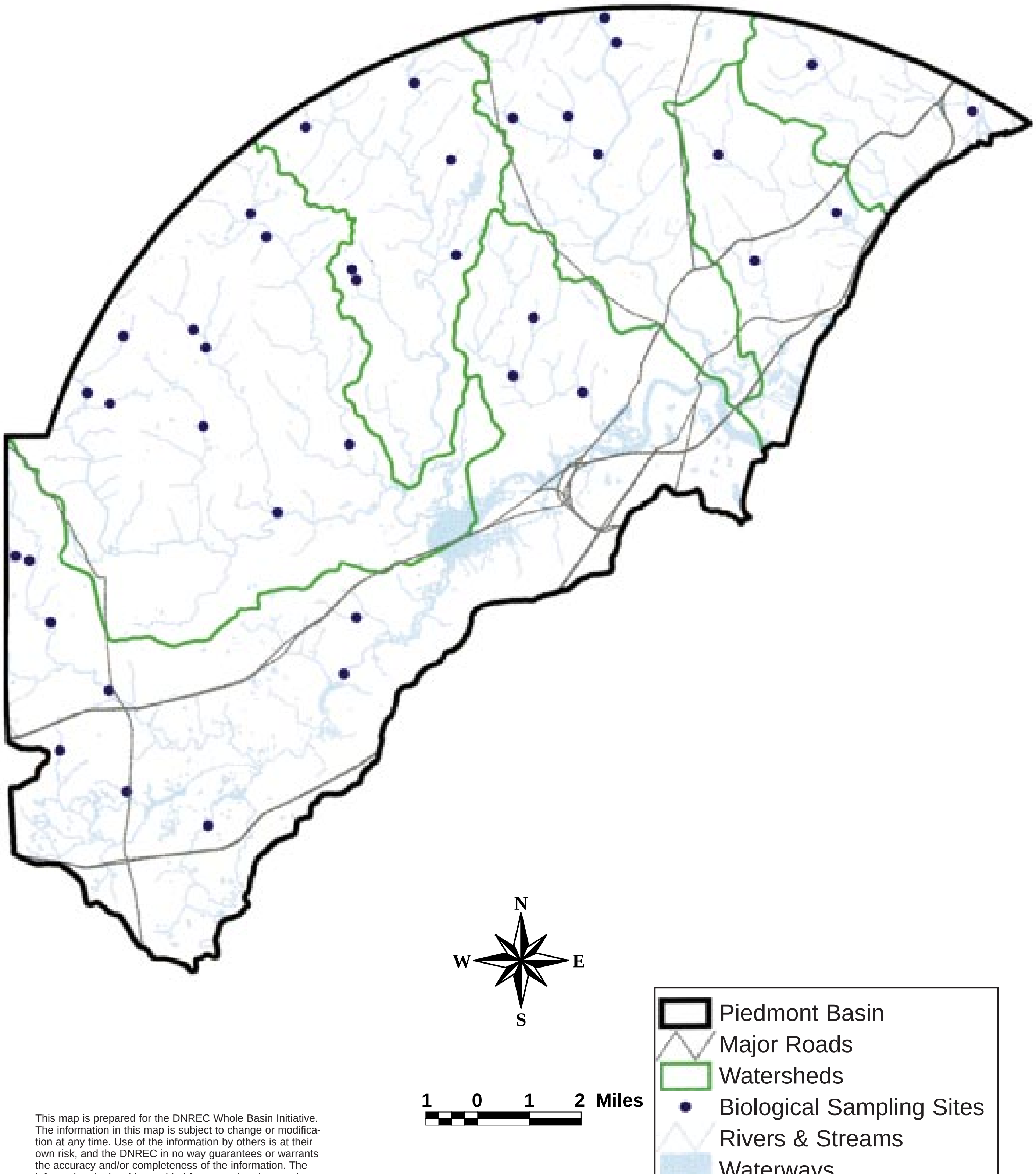
Biological Habitat Sampling Sites



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