A Landscape Assessment of the Catskill/Delaware Watersheds 1975-1998

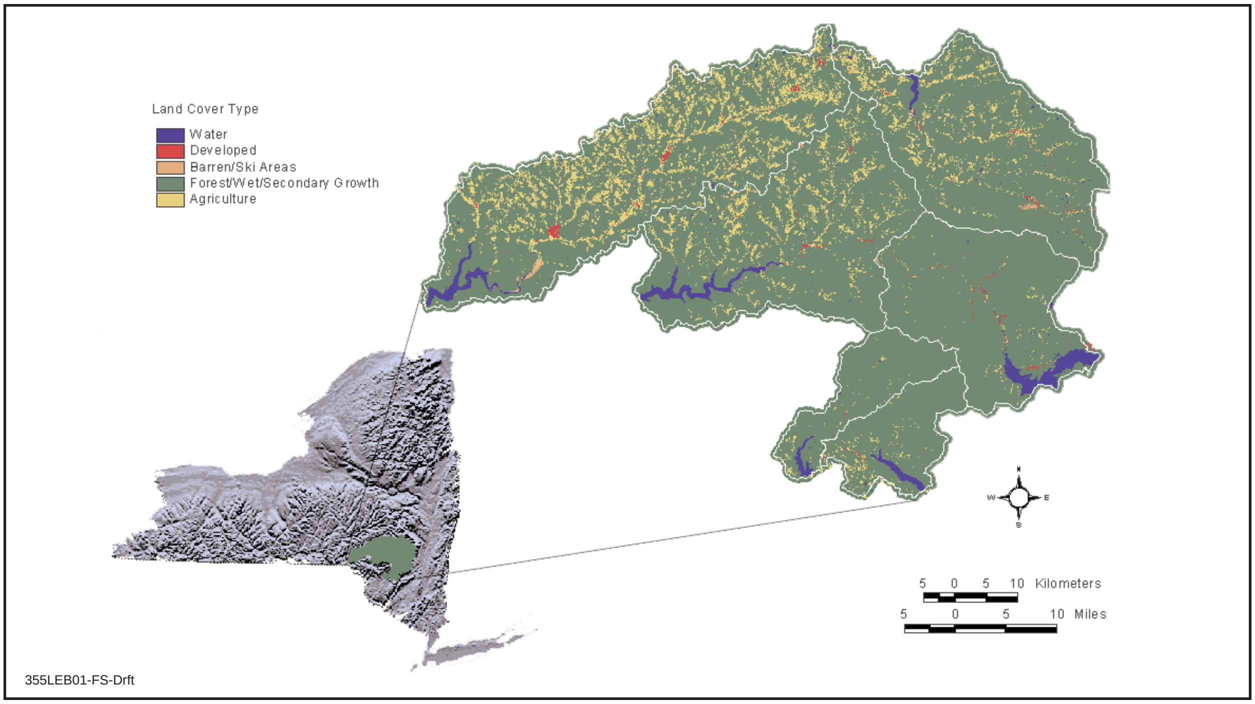
New York City's Water Supply Watersheds

The U.S. Environmental Protection Agency's (EPA) Office of Research and Development (ORD), National Exposure Research Laboratory's (NERL) Landscape Ecology Branch has published the report, “A Landscape Assessment of the Catskill / Delaware Watersheds (1975-1998) - New York City's Water Supply Watersheds.” This report represents a large-scale environmental assessment of potential risks to water resources from multiple landscape stressors in the Catskill / Delaware water supply watersheds. The streams of the Catskill / Delaware watersheds flow into a set of reservoirs which supply drinking water to New York City. Two decades of landscape and water quality data collected from within the watersheds were examined for trends over time and for meaningful relationships between land use and surface water conditions.

Background

The 1980s witnessed increased interest in protecting whole ecosystems from chronic environmental problems. However, the resulting regulations and standards were often separated in relation to specific materials or media such as water, air, or soil. Current thinking is evolving toward examination of critical environmental problems over larger spatial scales and assessment of cumulative risk resulting from multiple stresses or stressors. In response to this need, a landscape-scale research program was initiated by the EPA in 1992. The landscape-scale assessment approach was applied to a set of community-based watersheds in southeastern New York State. The streams of the Catskill / Delaware watersheds flow into six reservoirs which supply 90% of New York City's drinking water. The water supplied from these reservoirs has, to date, required only minor treatment to be suitable for drinking.

Location and Land Cover of the Catskill/Delaware Watersheds in New York State



A Landscape Assessment of the Catskill/Delaware Watersheds 1975-1998

Background *(continued)*

To continue supplying high quality drinking water and to avoid the need for a multibillion dollar water filtration system, New York City implemented a long-term land management strategy. Upgrades to sewage treatment plants and purchase of more lands are key components to pollutant reduction and continued non-filtration. The purpose of this study was to provide information that may assist in the protection of the Catskill/Delaware water supply to managers, policy makers, and the general public.

The Assessment

Elevation data and satellite images were used to assess the landscape of the Catskill/Delaware watersheds. The elevation of the area is diverse and includes some of the highest mountains in the State. The landscape has changed little in the past two decades, forest cover remains the dominant vegetation in the area. Compared to other watersheds within Region 2, States of New York and New Jersey, the environmental disturbance within the Catskill/Delaware watersheds is low. Population has only increased by about 15% (between 1970 and 1995), from 53 to 64 thousand people. However, as a result of topographic constraints, the majority (90%) of urban development and agricultural land use is located near streams.

A wide variety of landscape measurements were evaluated in this study. Those most related to water quality were percentage agriculture, urban, bare ground, agriculture on erodible soils, agriculture on steep slopes and stream density. The relationship between land use and surface water pollutant levels were statistically analyzed. This analysis indicated that the amount and location of human use in the landscape has direct consequences to surface water condition. For example, release of agricultural fields from farming during the past two decades has returned a small percentage of land to secondary growth forest, resulting in a 2% net increase in forest cover. The effect of this land cover change was a decrease in nutrient contribution to the water.

The results of this study suggest that targeting "at risk" watersheds for enrollment in land use management programs may have a greater overall impact on pollution reduction than random areawide enrollment programs. Balancing water quality protection and economic growth requires a great deal of thought, coordination, and cooperation. As demonstrated by this study, human use of the landscape has direct consequences on water quality resources. Even changes as small as 2% may be of importance. Whether or not the change is beneficial to the water supply rests on the choices made by those living in the area. Economic and social incentives encouraging forestry, agriculture and urban planning and management geared for specific pollutant problems can all help facilitate the continued success of New York City's long-term watershed management plans for the Catskill/Delaware water supply watersheds.

Products of this Study

- A land cover database with imagery from the mid 1970s, mid 1980s, early 1990s, and late 1990s.
- A set of landscape measures (metrics) for each image date compiled into an easy to use format within a Geographical Information System.
- A set of supplemental geographic data on elevation, watershed boundaries, surface geology, aqueducts and tunnels, stream drainage, city and state owned lands, sewage treatment plants, roads, and population data.
- Landscape models for surface water total nitrogen, total phosphorus and fecal coliform bacteria.
- EPA reports, fact sheets and journal publications summarizing the study and its findings.

An electronic version of the report is available at (http://www.epa.gov/nerlesd1/land-sci/ny.htm).

Technical questions and requests for hard copies of the report should be directed to Megan Mehaffey, Ph.D., U.S. Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Environmental Sciences Division, Landscape Ecology Branch, 944 E. Harmon, Las Vegas, NV 89119.

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United States
Environmental Protection
Agency

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EPA/600/R-01/075
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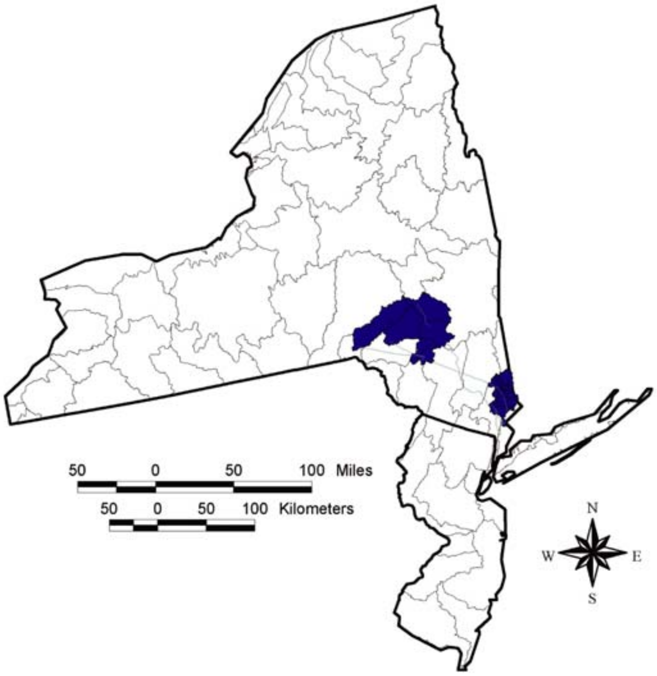

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Notice

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Appendices

Abbreviations

ATtILA - Analytical Tools Interface for Landscape Assessments
ß - Magnitude of the Coefficients
BMP - best management practice
CI - confidence interval
CD -Catskill/Delaware
DEM - digital elevation model
DLG - digital land graph
EPA - U.S. Environmental Protection Agency
EPIC - Environmental Photographic Interpretation Center
EROS - Earth Resources Observation Systems
FAD - filtration avoidance determination
FC - fecal colifom bacteria
GIS - geographic information system
HUC - hydrologic unit code
LEB - Landscape Ecology Branch
MCL - water maximum contaminant levels
MOA - Memorandum of Agreement
MRLC - Multi-Resolution Land Characteristics
MSS - multispectral scanner
N-index - natural vegetation index
NALC - North American Landscape Characterization
NAPP -National Aerial Photography Program
NDVI - normalized-difference vegetation index
NERL - National Exposure Research Laboratory
NHAP - National High Altitude Photography
NLCD - National Land Cover Data
NRCS - Natural Resource Conservation Service
NYCDEP - New York City Department of Environmental Protection
NYSDEC - New York State Department of Environmental Conservation
ORD - Office of Research and Development
Partial R^2 - partial coefficient of multiple determination
QA - quality assurance
R^2 - coefficient of multiple determination
RF3 - River Reach File, Version 3
STATSGO - State Soil Geographic Data Base
SSURGO - Soil Survey Geographic Data Base
TM - Thematic Mapper
TMDL - total maximum daily load
TN - total nitrogen
TP - total phosphorus
U-Index - human use index
USDA - United States Department of Agriculture
USGS - United States Geological Survey
VIF - variance inflation factor
WSPA - Walton Sewage Treatment Plant (upstream)
WSPB - Walton Sewage Treatment Plant (downstream)

% - percent
CFU - colony forming units
cm - centimeter
ft - foot
g - grams
ha - hectare
in - inch
km - kilometer
L - liter
m - meter
*u*g - microgram
mi - mile
ml - milliliter
mg - milligram
mm - millimeter
sec - second

Acknowledgments

The authors would like to thank all the people who have participated in the creation of this study. Special thanks goes to the staff of the New York City Department of Environmental Protection (NYCDEP). In particular, Michael Principe who was willing to consider our proposed study and authorize the use of the NYCDEP water chemistry data; Barbara Dibler who willing shared her knowledge of GIS, the watershed, and its community whenever we visited; and David Lipsky who provided and compiled editorial comments which made this report more complete. We thank the Delaware County U.S. Department of Agriculture (USDA) Farm Service Association and its staff for sharing their collective knowledge of the farming practices within the watershed. We also send our thanks to Jeff Gratz and New York City Watershed Team members who provided input that helped in the completion of this report. In addition, we thank David Braun and Colin Apse from the Nature Conservancy, Neversink River Program, who provided extensive editorial comments which strengthened this final product. A special thanks also to Donna Sutton from Lockheed Maritn Technical Services who provided the final polish with her technical edits. Last, but certainly not least, we would like to thank all the staff of the Landscape Ecology Branch, our family, and friends, many of whom provided invaluable assistance in the production, assessment, processing, analyzing, and editing of this report. Without the above mentioned people this study could not have been completed.

Executive Summary

Together the six reservoirs located in the Catskill/Delaware watersheds supply 90% of New York City's drinking water. The 4,100 km^2 (1,583 mi^2) Catskill/Delaware watersheds are located in the southeast corner of New York State, 160 km (100 mi) northwest of New York City. The study summarized here provides (1) regional and local scale data that will assist land managers, policy makers, and the general public in making informed decisions on environmental and water resource issues; and (2) data analyses that help direct future land cover and land use practices critical to maintaining water quality.

The first chapter of the report gives an overview of regional and watershed land cover allowing the reader to compare environmental conditions of the Catskill/Delaware water supply watersheds to other areas within Region 2. The remainder of this report takes a closer look at landscape change, water quality, and land use relationships and trends through time in the Catskill/Delaware watersheds.

There are six watersheds contained within the CD water supply area, each ending in a manmade reservoir. The topography of the area is diverse and, except for the Adirondacks to the north, has the greatest elevation in the state. The landscape of the Catskill/Delaware watersheds has changed little in the past two decades, with forest cover remaining the dominant vegetation in the area. Historically, the Catskill/Delaware watersheds have been dominated by northern hardwoods, including maple, birch, and beech trees. Much of the area was logged prior to the mid-1800s. Today, secondary forest consisting of evergreen and deciduous species covers about 90% of the watersheds. Human use ranges from 0 to 40% of the subwatershed areas, and averages 11% across the entire Catskill/Delaware watersheds. Compared to other watersheds within Region 2, such as those near the Great Lakes and Long Island, which have human use percentages reaching 80%, the environmental disturbance within the Catskill/Delaware watersheds is low. Population has increased by only 15% from 53 to 64 thousand people between 1970 and 1995. However, as a result of topographic constraints, the majority (90%) of urban and agriculture land use is located within a 120-m (395-ft) riparian buffer. The highest amount of human use is located in the less rugged terrain of the northwest and the lowest is in the southeast watersheds.

Only one reservoir, the Cannonsville, exceeds State and Federal total maximum daily load (TMDL) standards for phosphorus. However, all six reservoirs and one stream are currently included on the State 303d list for sediment, phosphorus, or pathogens levels. At lower levels, nitrogen and phosphorus do not pose a threat to either human health or aquatic habitat. However, when the nutrient levels are enriched, eutrophication can occur resulting in algal blooms. Excessive algal growth can disrupt stream habitat, deplete oxygen levels, and raise turbidity, odor, and color to unacceptable levels. When present in the water, fecal coliforms indicate contamination by warm-blooded animal waste. Human health is affected by other pathogens, which may be excreted along with the fecal coliforms, such as bacteria, protozoa, and viruses. In many cases, excessive nutrient and fecal coliform levels are the result of nonpoint pollution related to land use and land use practices. Modifying these practices can improve water quality conditions. However, in a few cases spikes can result from unexpected sources such as migratory bird populations or accidental spills.

Total nitrogen, phosphorus, and fecal coliform data were selected for study because of public concern about the 303d listing of the water supply reservoirs for nutrients and pathogens and the potential linkages to land use. Like patterns of human use, average water quality measurements of nitrogen, phosphorus, and fecal coliforms are highest in the northwest and lowest in the southeast of the Catskill/Delaware watersheds. Monthly averages of nitrogen, phosphorus, and fecal coliform, in general, do not exceed ambient water quality standards. However, in watersheds having the most human use, a few water sampling sites have median and average values that approach or slightly exceed current standards. These are most frequently at sites downstream of sewage treatment facilities.

Multiple regression analysis is used to examine the relationship of landscape metrics to surface water concentrations of total nitrogen, total phosphorus, and fecal coliform. The percentages of agriculture and urban development in the subwatersheds are significantly related to all three water quality measurements. Agriculture is the dominant human use in the subwatersheds and riparian buffer. Results from the regression analyses suggest that as the percentages of agriculture and urban development increase, surface water concentrations of total nitrogen, total phosphorus, and fecal coliform can also be expected to increase. Three other metrics having a significant relationship to water quality parameters, but explaining only a small portion of overall variability in water quality, are percent bare ground, percent agriculture on steep slopes, and percent agriculture on erodible soils within the subwatersheds. Therefore, increases in the percentage of these land uses associated with increased erosion may result in elevating total nitrogen, total phosphorus, and fecal coliform levels in surface water.

Release of agricultural fields from farming has returned a small percentage of land to secondary growth forest. During the past two decades this change has resulted in a 2% net increase in forest cover. The effect of this land cover change is evident in the decreasing contribution of agriculture to total nitrogen concentrations within the surface water from 1987 to 1998. The direction of change in surface water and landscape condition indicates that those measurements of land use significant to single date comparisons are also important to trends in time.

These results suggest targeting the farms in a subwatershed having high percentages of land use types associated with water quality degradation may achieve greater overall pollution reduction to the water supply than random areawide enrollment in farm management programs. Selecting Best Management Programs to initiate would then depend on which pollutant is of highest priority for that subwatershed. Farmers within subwatersheds nearest to the reservoirs and having low stream density should be encouraged to preserve wetland and riparian areas through enrollment in wetland reserve and forest easement programs. These efforts would help buffer streams and reservoirs from nonpoint pollution via runoff from barnyards, pastures, and crop fields.

Another key component to determining water quality is the percent of urban land use within the subwatershed. The current regulations proposed in the Memorandum of Agreement for improving exiting treatment plant performance and restricting new waste treatment plants should help reduce point source inputs in the Catskill/Delaware watersheds. However, in addition to waste treatment plant inputs, high percentages of impervious surfaces have increased discharge rates, sedimentation, and pollutant runoff in a number of the subwatersheds. An urban planning program that helps landowners develop best management practices for golf courses, parks, backyard gardens, and lawns could help address some of the current impacts. Offsetting future land uses will most likely require increasing the percentage of forest cover, particularly in the riparian buffer. One way to help promote more riparian forest is by increasing the setbacks requirements for human use from 30 to 60 or 120 m.

Balancing water quality protection and economic growth requires a great deal of thought, coordination, and cooperation. As demonstrated by the results of this study, human use of the landscape has direct consequences on water quality resources. Even changes as small as 2% can have an effect. Whether or not the change is beneficial to the quality of water supplied by the Catskill/Delaware watersheds, rests on the choices made by those living in the area. Economic and social incentives which encourage forestry, agriculture and urban planning and management for specific subwatershed needs within the Catskill/Delaware watersheds can help facilitate the continued success of long-term watershed management plans set forth in the Memorandum of Agreement.

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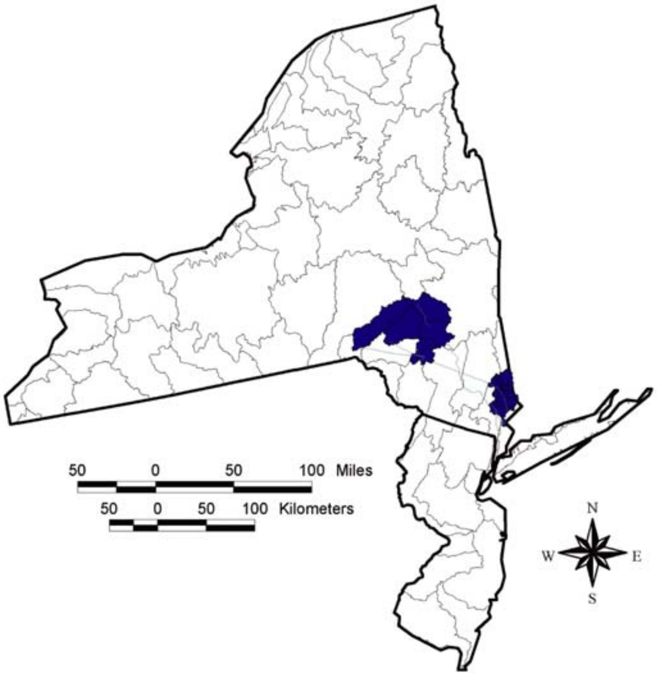

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Chapter 1. Introduction

Objectives

The study reported here takes advantage of a set of new technologies for assessing environmental conditions at a landscape scale (Jones et al.,1997). The focus of this report is the watersheds of the Catskill/Delaware (CD) water supply system located in Region 2 of the U.S. Environmental Protection Agency's (EPA)(Figure 1.1). These watersheds and their reservoirs provide the majority of the drinking water for New York City. High speed computers, satellite imagery and historical databases with extensive spacial and temporal coverage now facilitate analyses of regional issues such as the status of the CD water supply system over time.

The purpose of this document is to provide (1) regional and local scale data that will assist land managers, policy makers, and the general public in making informed decisions on environmental and water resource issues; and (2) data analyses that help direct future land cover and land use practices critical to maintaining water quality. In this report the six watersheds making up the CD water supply system will be called the CD watersheds and Region 2 refers to the states of New York and New Jersey (although Region 2 also includes Puerto Rico, the U.S. Virgin Islands, and seven tribal Nations, only data related to the two states was used in the study of the CD watersheds). This study was conducted by the Landscape Ecology Branch of the EPA Office of Research and Development.

Overview

Selection of an area for study often depends on the local population's concern for a specified resource. In this case one of the major concerns for millions of people living in Region 2 is maintaining quality water for recreational, agricultural, and consumption purposes. One means of monitoring water quality is through the use of Total Maximum Daily Loads (TMDL; EPA, 1991). A TMDL is the amount of pollutants a water body can receive and still meet water quality standards set by States, territories, and Native American tribes. Water bodies that are not attaining water quality standards with technology based controls alone are placed on the State 303d list for TMDL determination. Almost 90% of all watersheds within New Jersey have more than a quarter of the water bodies on the 303d listing. In New York, less then 10% of the watersheds have more than a quarter of the water bodies listed as impaired; the other 90% list between 0 to 25%

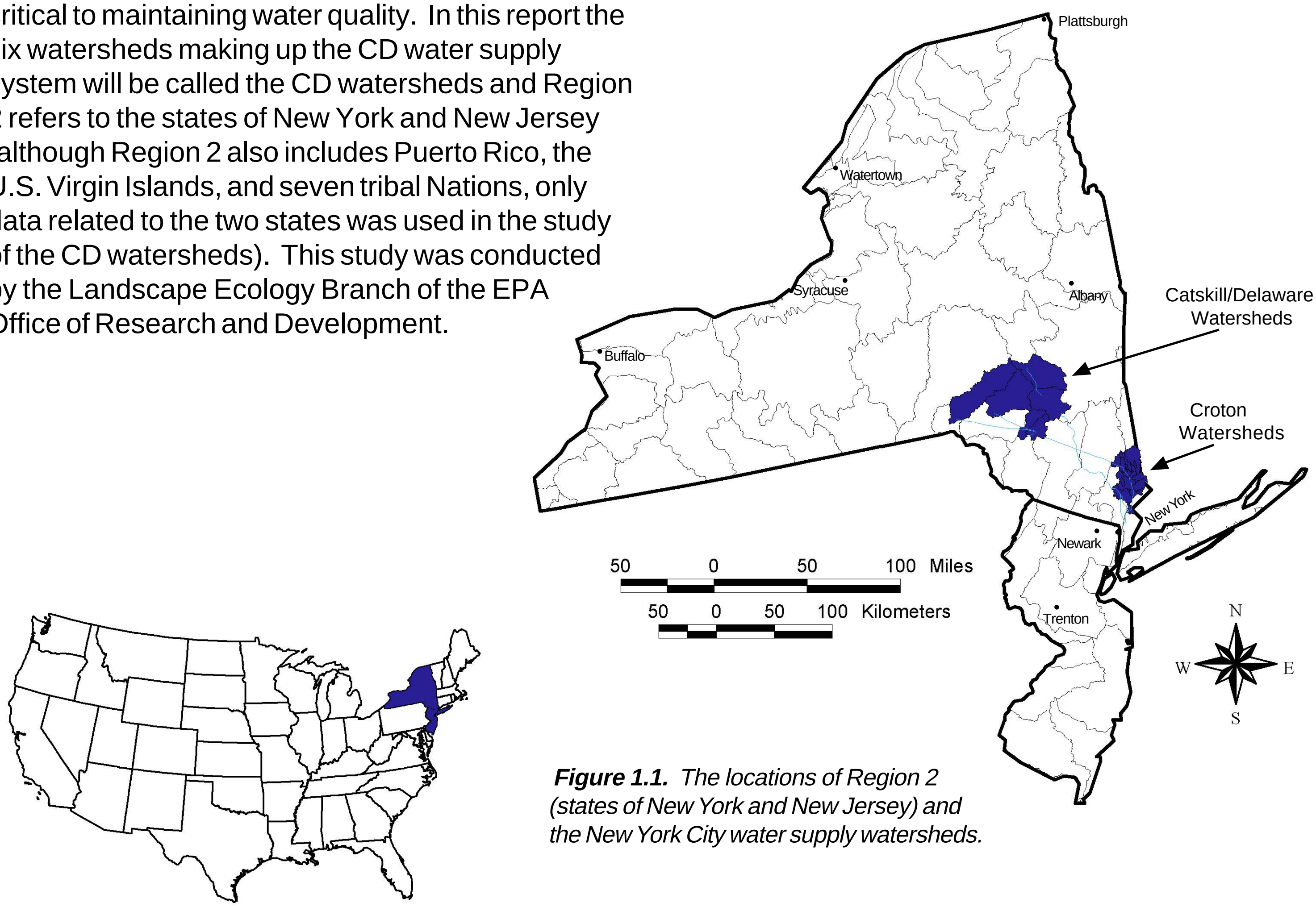


Figure 1.1. *The locations of Region 2 (states of New York and New Jersey) and the New York City water supply watersheds.*

(Figure 1.2). The majority of listings are the result of five pollutants: pH, pathogens, organic matter content, nutrients and sediments. Low pH is generally attributable to acid rain, while organic matter content, sediment, nutrients, and pathogens tend to be related to land use and erosion (EPA, 1998a). Nutrients and pathogens account for the impairment of close to 1,700 stream miles and 100,000 acres of Region 2 lakes, estuaries, and wetlands. Several of these impaired water bodies are located within the CD watersheds.

The six reservoirs in the CD watersheds provide over a billion gallons of water daily to New York City and other nearby communities. Therefore, the 303d listing of all six of these reservoirs for phosphorous or pathogen impairment is of particular concern to people living within New York City. Potential sources of impairment are municipal treatment plant effluent, stream bank erosion, and urban and agricultural runoff.

Most drinking water sources require filtration and treatment with chlorine before public consumption is allowed. New York City drinking water supplied by the older Croton water supply system currently requires filtering (Figure 1.3). According to the EPA, urban development and higher growth rates in the Croton watersheds would overwhelm any watershed management options for protecting the drinking water coming from its reservoirs (Brown, 2000). However, water coming from the CD water supply reservoirs, which supply 90% of New York City's drinking water, is currently under an exemption granted by an EPA filtration avoidance determination (FAD; Brown, 2000). The FAD is a conditional exemption from having to build a filtration plant required by the federal government.

In order to avoid filtration in the future, the city must implement a series of watershed protection measures aimed at preserving water quality in the CD watersheds. In 1997 a watershed Memorandum of Agreement (MOA) negotiated by the local communities, New York City, New York State, environmental groups, and the EPA was signed. The MOA lays out a series of plans for preserving high quality drinking water. These plans include upgrading current sewage treatment plants, implementing new watershed regulations, designing a potential filtration system, and acquiring critical lands (MOA, 1997).

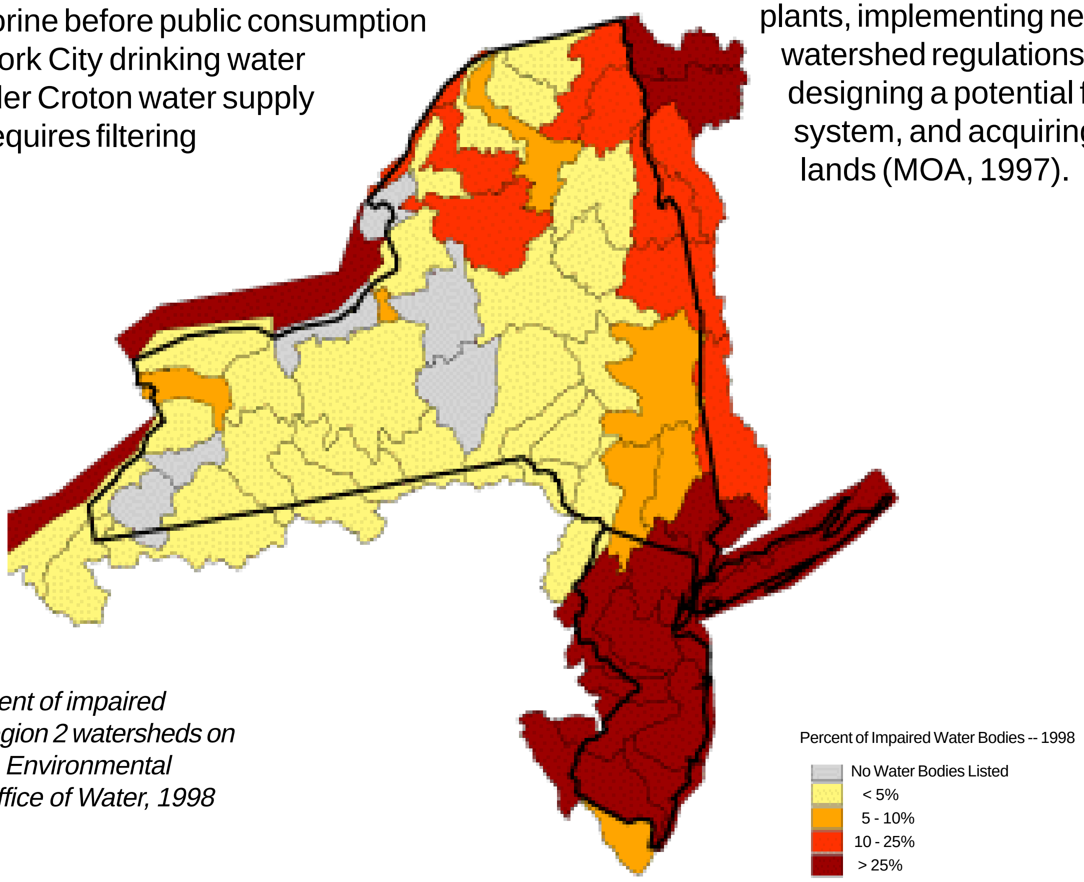


Figure 1.2. *The percent of impaired waterbodies within Region 2 watersheds on the 303d list. Source: Environmental Protection Agency, Office of Water, 1998 State 303d listings.*

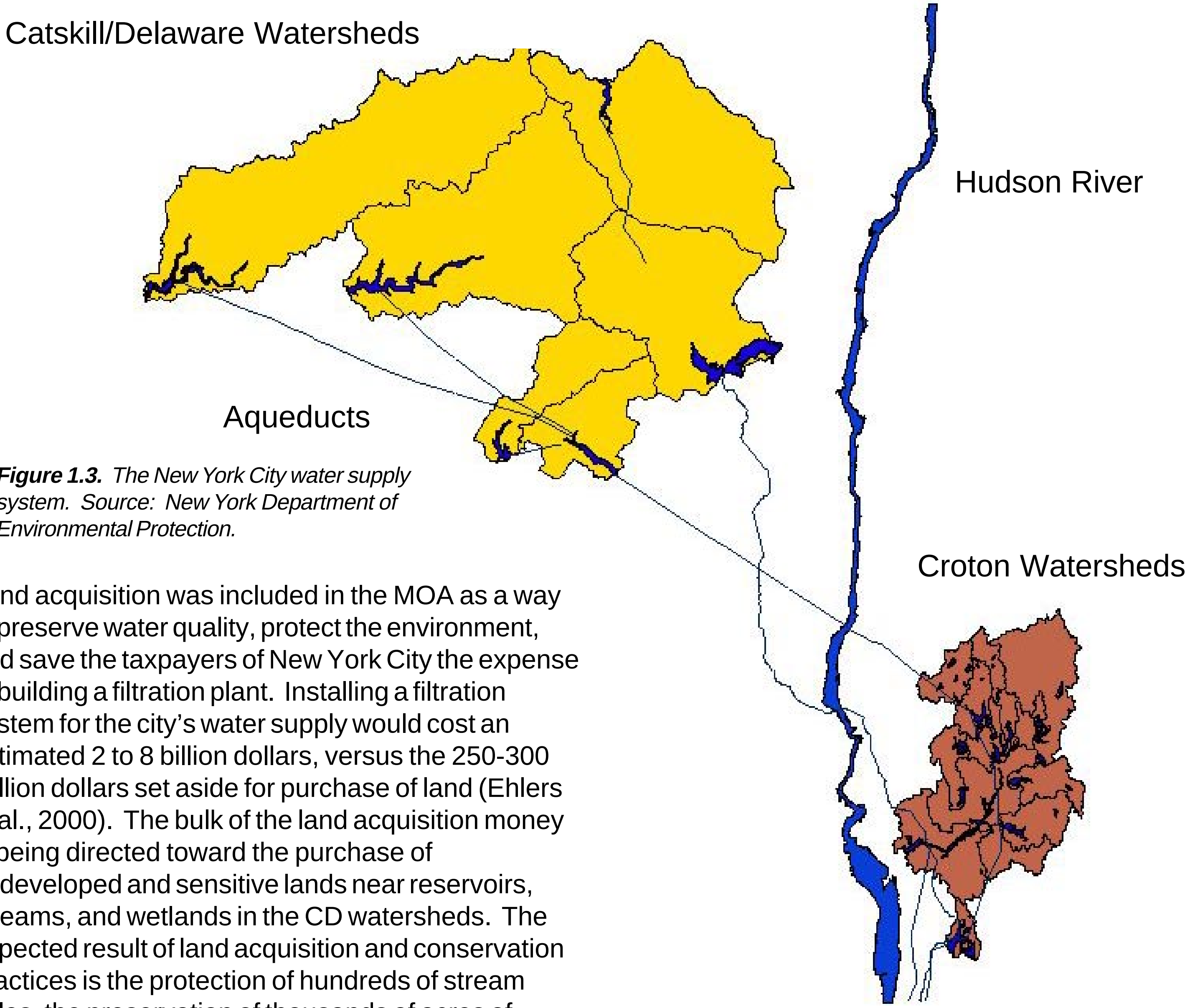


Figure 1.3. *The New York City water supply system. Source: New York Department of Environmental Protection.*

Land acquisition was included in the MOA as a way to preserve water quality, protect the environment, and save the taxpayers of New York City the expense of building a filtration plant. Installing a filtration system for the city's water supply would cost an estimated 2 to 8 billion dollars, versus the 250-300 million dollars set aside for purchase of land (Ehlers et al., 2000). The bulk of the land acquisition money is being directed toward the purchase of undeveloped and sensitive lands near reservoirs, streams, and wetlands in the CD watersheds. The expected result of land acquisition and conservation practices is the protection of hundreds of stream miles, the preservation of thousands of acres of natural areas, and continued high water quality without the cost of a multi-billion dollar filtration system.

There have been numerous studies investigating how human use impacts water quality. For example, the contribution of pollution by runoff after a rainfall event can be lowered by increasing riparian buffer forest cover (Correll, 1997). Watersheds with high percentages of bare ground and anthropogenic cover increase runoff energy and decrease delivery time of pollutants to water bodies (Fennessy and Cronk, 1997). In general, previous studies have made use of landscape and water data from a single snapshot in time (e.g., mid-1990s) to establish the influence of the landscape on pathogens and nutrient loads to streams (Jones et al., 2001; Mehaffey et al., 2001). However, they fail to establish any long-term trends. Prior research has also been focused in areas of the country with very different biophysical and land use patterns than those found within Region 2 and the CD watersheds. In this study relationships between landscape and water quality in the CD watersheds are investigated using both snapshots in time and long term trends analyses.

Layout

This chapter describes the report objectives and layout and provides an overview of environmental and water resource concerns within the study area. Chapter 1 is followed by a description of the biophysical setting of the Catskill/Delaware watersheds in Region 2. Chapter 2 is designed to help readers orient themselves by using familiar landmarks such as state boundaries, lakes, and mountain ranges. Chapter 2 also introduces the reader to potentially unfamiliar concepts and terminology in landscape ecology such as topography, land cover, stream connectivity, and watershed. The basic methodology of determining land cover from satellite imagery and assessing its accuracy, the calculations of the landscape metrics, and the procedures used to evaluate the data are set forth in Chapter 3. For further information on methodologies, the reader is referred to the Appendices, List of References, and Books for Interested Readers found at the end of the report. Chapter 4 contains landscape metric maps of Region 2 and CD watersheds. The intent of this chapter is to provide a quick view of how land cover and land use in the CD watersheds ranks when compared to the surrounding region. In addition, this chapter shows how assessments of environmental condition change with watershed size. The reader can observe how the amount and type of information change between the larger regional watersheds and community level subwatersheds.

In the fifth chapter the focus is narrowed to the CD watersheds. This chapter shows the reader the location and amount of landscape change that has occurred during the past two decades. As in the case of the preceding chapters, Chapter 6 gives the reader an idea of how water quality conditions differ across the CD watersheds. Like landscape, water quality condition can vary over time as well as space. Therefore, Chapter 6 presents an evaluation of both spatial and temporal affects on the three water quality measurements. Additional water quality details, data, and graphs are provided in the appendices.

Chapter 7 brings the water quality and landscape data together using a statistical procedure called a stepwise regression. Results from the analyses of 32 subwatersheds are presented so the reader can see which measures of landscape condition are important to water quality. The regression models are then applied to all of the CD water supply area to approximate water quality condition in each of the subwatersheds. In addition to the regression analyses, Chapter 7 provides a table of water quality, land use, and land cover trends over time for those sites used in the regression analyses. In the final chapter (Chapter 8) a synopsis of the results from Chapters 3, 4, 5, 6, and 7 is provided along with a set of recommendations.

This report is meant to provide information that can be used by a wide variety of audiences. In general as readers progress through the chapters they will find that the terminology and analyses become more complex and technical in the later half of the report. However, a summary section is provided at the end of each chapter and the final discussion in Chapter 8 points out relevant findings from the study.

Road construction on State Highway 10 in the town of Bloomville, Cannonsville watershed.

Chapter 2. The Biophysical Setting

This chapter contains an overview of the biophysical setting of Region 2 and the Catskill/Delaware watersheds including topography, soils, streams, watershed boundaries, and land cover. Besides providing a means of orienting the reader and describing the area of study, these biophysical data are necessary for calculating a number of the landscape metrics presented in Chapter 4.

Land Cover and Topography

The mountains, valleys, plateaus, and coastal areas form distinctive physical and biological characteristics within Region 2 (Figure 2.1). The northwest has a lower elevation and is bounded on the north and west by the Great Lakes. Heading east from the banks of the Great Lakes, the terrain rises to the plateaus of central New York. Variations in soil moisture, pH, and cation exchange capacity are related to elevation and other soil physical properties, such as clay and organic contents. Specific topography, elevation, and soil physical and chemical properties dictate the distribution of both natural vegetation and human utilization of the land (Larcher, 1995). The plateaus provide a gently sloping area made up of high organic matter glacial till soils, well suited for the cultivation of crops and urban development (Figure 2.2). To the northeast and southeast of the plateau, elevation rises, culminating in the Adirondack and Catskill Mountains, respectively. The low organic matter soils of the Adirondack and Catskill mountain ranges make them less desirable for agricultural use (Figure 2.3a). Left relatively undisturbed by humans, the high elevation areas within Region 2 contain the northern hardwood forest with its distinctive maple, birch, beech, and hemlock trees. The CD watersheds lie within the plateau and Catskill Mountains and are part of both the Delaware and Hudson river basins.

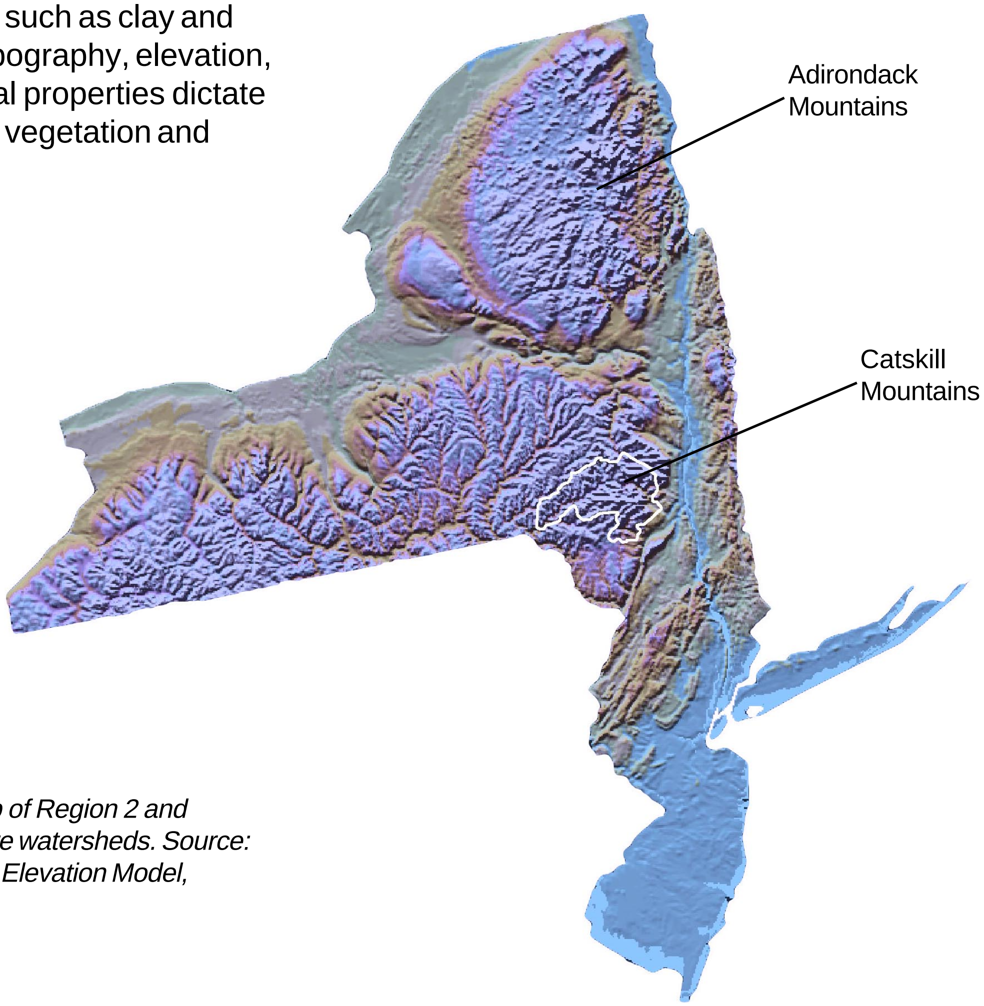


__Figure 2.1.__ Shaded relief map of Region 2 and location of the Catskill/Delaware watersheds. Source: U.S. Geological Survey, Digital Elevation Model, 1:24,000 scale.

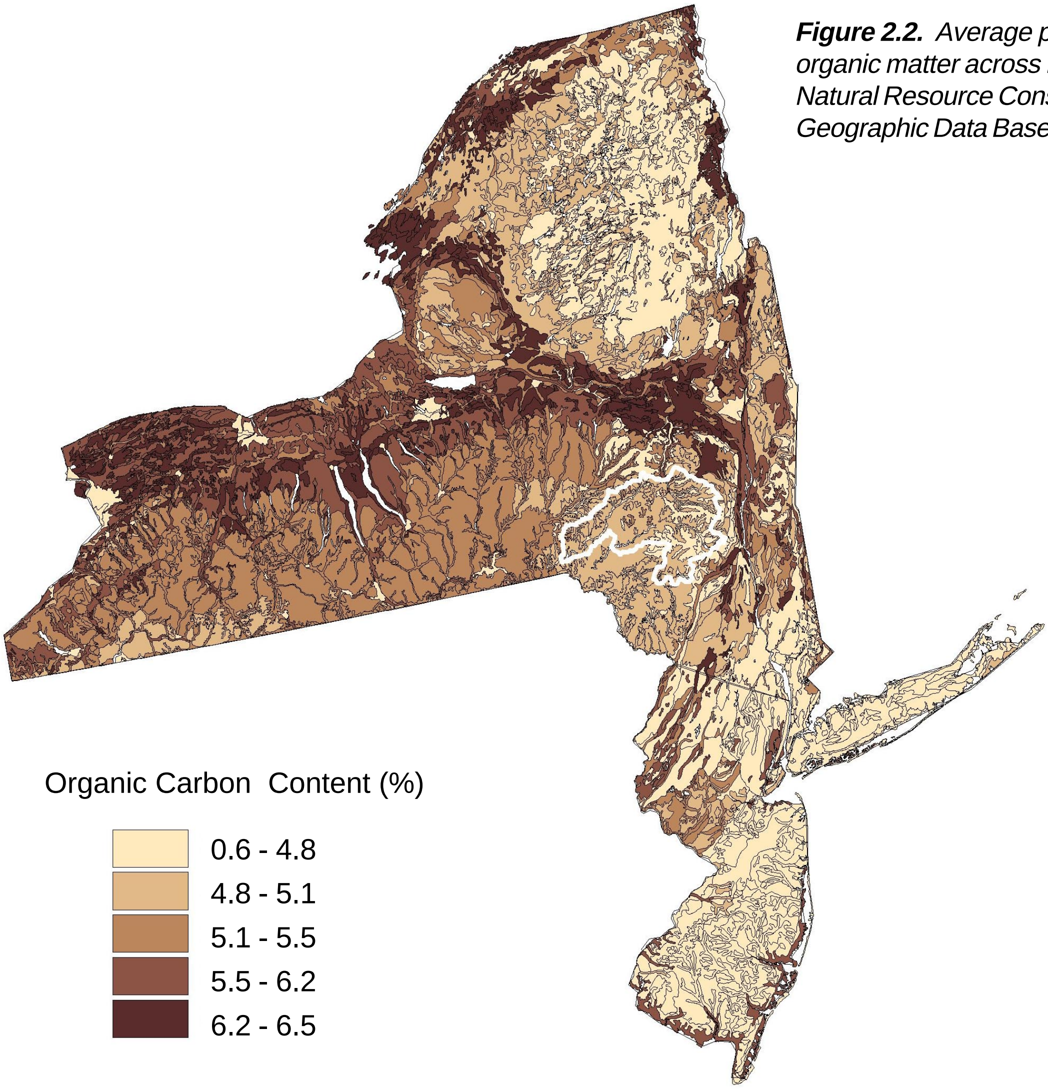


***Figure 2.2.** Average percent soil total organic matter across Region 2. Source: Natural Resource Conservation, State Soil Geographic Data Base.*

The 4,100 km^2 (1,583 mi^2) CD watersheds are located in the southeast corner of New York State, 160 km (~100 mi) northwest of New York City. Historically, the CD watersheds were dominated by northern hardwood forest, much of which was logged prior to the mid-1800s (van Valkenburg, 1996). The transfer of ownership of 14,000 ha (~34,600 acres) of forest land back to New York State in 1884 was the starting point for the development of the Catskill Park. In the decades since the park's inception the forest has rebounded from its previous losses and now consists of a mixture of hardwood, deciduous, and evergreen trees covering 285,507 ha (705,500 acres). The extensive forest cover in the CD watersheds reflects the benefit of the park's presence and relatively low human use (Figure 2.3b). The greatest amount of human use such as (1) agriculture (row crop and pasture), (2) bare ground (ski areas, fallow fields, and quarries), and (3) development (low intensity residential, golf courses, and lawns) occurs in the northwestern CD watersheds.

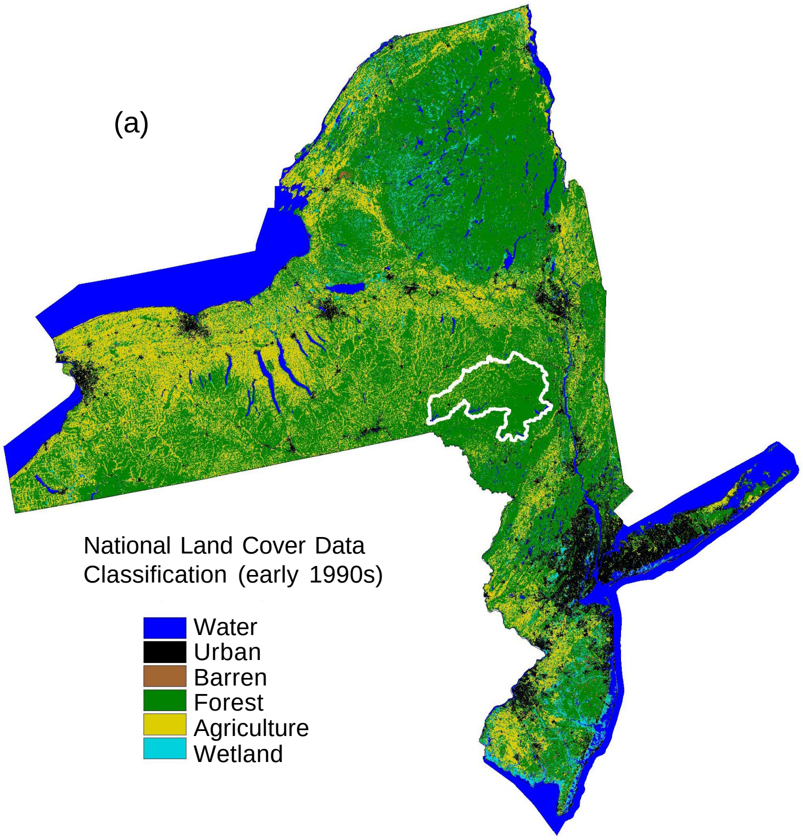
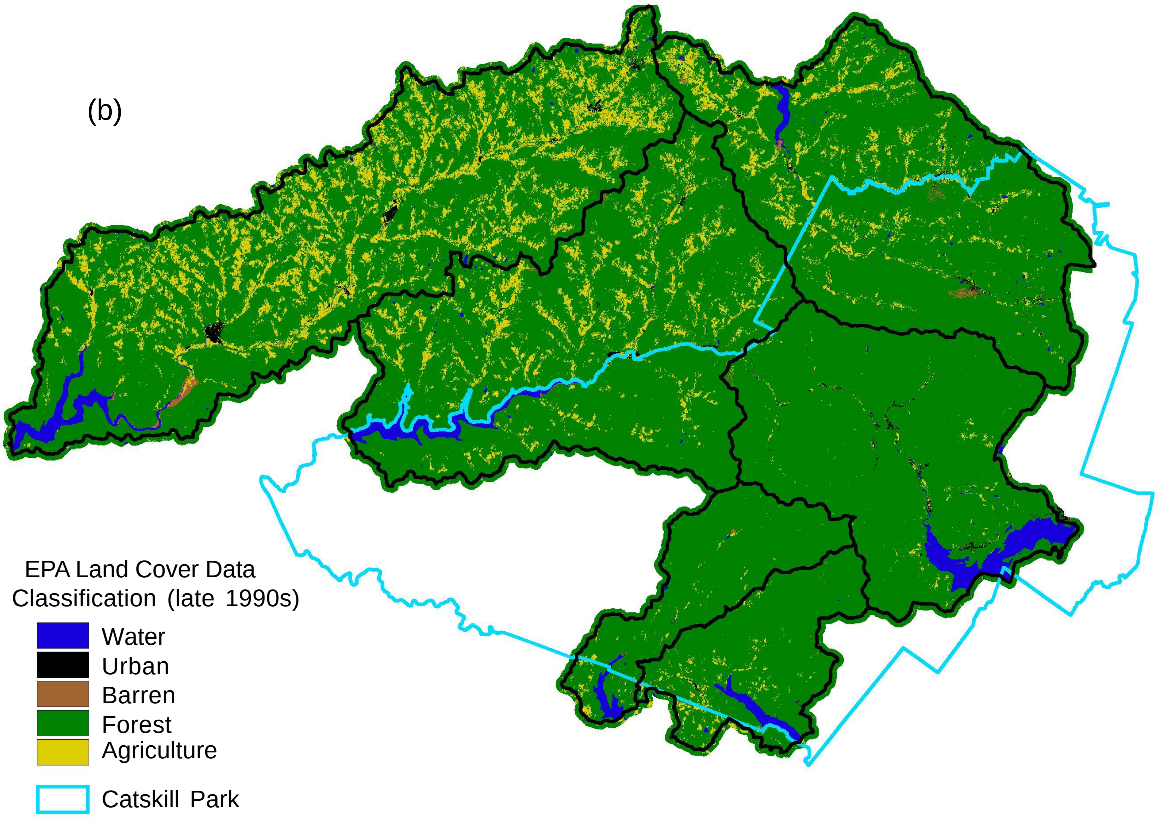


Figure 2.3. *Land cover/use in **(a)** Region 2 and **(b)** the Catskill/Delaware watersheds. Sources: Source:Multi-Resolution Land Characteristics (MRLC) Program, derived from Landsat Thematic Mapper (TM) data, 30-m resolution and the Environmental Protection Agency, Landscape Ecology Branch, derived from Landsat Thematic Mapper (TM) data, 30-m resolution.*



The topography of the CD water supply area is diverse and except for the Adirondacks to the north has the greatest elevation in New York State (Figure 2.4). The area is divided into two main water supply systems -- the Delaware (Cannonsville, Pepacton, Neversink and Rondout watersheds) and the Catskill (Ashokan and Schoharie watersheds). The watersheds which feed the Cannonsville and Pepacton reservoirs are located at the southeastern edge of New York State's central plateau region and have a gently rolling landscape. Glacial till dominates their geology, making large portions of the Cannonsville and Pepacton watersheds suitable for agriculture (Miller, 1970). The Ashokan and Schoharie watersheds are within the Catskill Mountains and the Rondout and Neversink at the mountains southern edge. These four watersheds are more rugged with shallow soils (1 m or ~3 ft) and large portions of exposed bedrock.

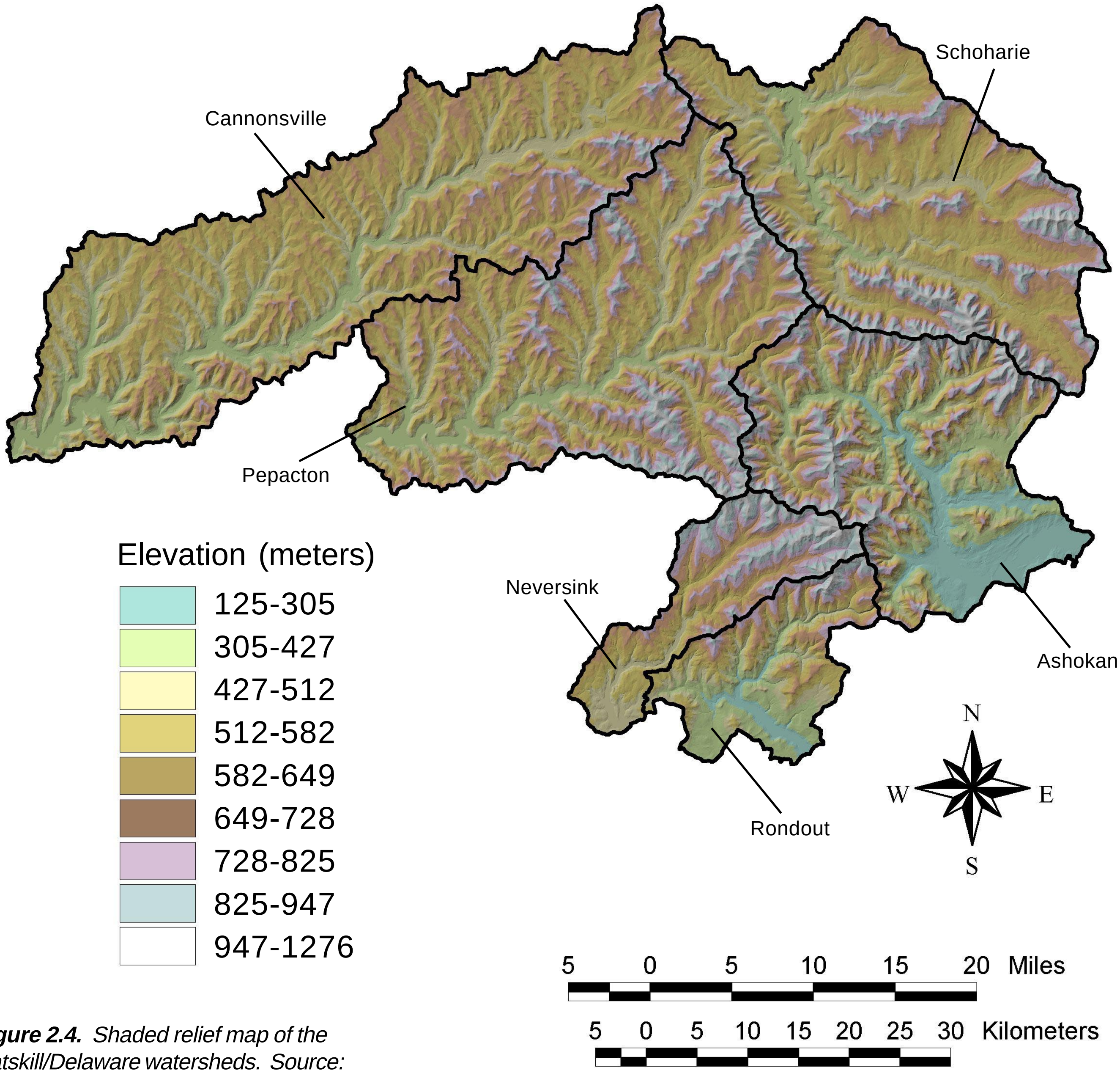


Figure 2.4. *Shaded relief map of the Catskill/Delaware watersheds. Source: U.S. Geological Survey, Digital Elevation Model, 10-m.*

Streams

Streams and rivers direct the flow of water across the landscape and are a dominant feature of Region 2. They provide necessary resources to plants, nearby riparian habitat and wildlife, and humans (Petts, 1994). In the past, city life and commerce had a more direct connection to the rivers, resulting in many of the Nation's cities being located on or near major rivers. Today, streams and rivers continue to play an important role as a source of drinking water, irrigation, recreation, and transportation. The landscape surrounding the streams and rivers provides a system rich in diversity and productivity of plant and animal species. At the same time, these areas are recognized as a primary resource for human use. The result is a conflict between agricultural and urban development and the need for a healthy, diverse, and stable system. The stream networks contributing to or receiving contributions from the CD watersheds can be seen in the EPA River Reach File (RF3) map, which is derived from the U.S. Geological Survey (USGS) Digital Line Graph - streams at a scale of 1:100,000 (Figure 2.5).

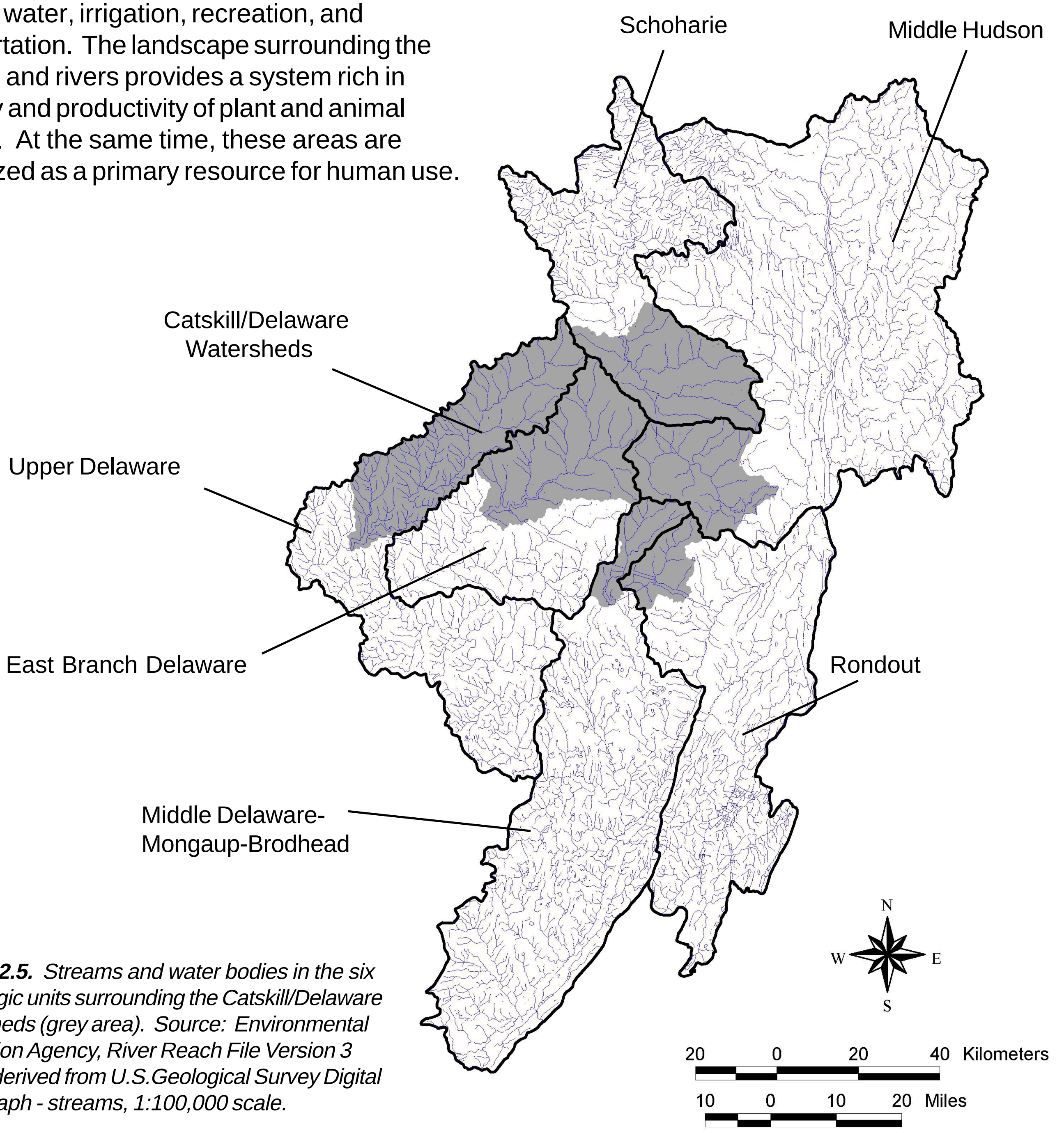


Figure 2.5. *Streams and water bodies in the six hydrologic units surrounding the Catskill/Delaware watersheds (grey area). Source: Environmental Protection Agency, River Reach File Version 3 (RF3), derived from U.S.Geological Survey Digital Line Graph - streams, 1:100,000 scale.*

The flow and drainage of streams in the CD watersheds split the area into six large contributing areas with reservoirs as end points. The streams and reservoirs of the CD watersheds in turn are connected to three larger river basins. The Cannonsville, Pepacton, and Neversink watersheds all lie within the upper, middle and east Delaware hydrologic units, Rondout watershed within the Rondout hydrologic unit, Ashokan watershed within the Middle Hudson hydrologic unit, and Schoharie watershed within the Schoharie hydrologic unit (Figure 2.5).

The stream map, developed by the New York City Department of Environmental Protection (NYCDEP) using USGS 1:24,000 quads, shows the prominent streams feeding the CD water supply reservoirs, including the East and West Delaware, Esopus, Neversink, Rondout and Schoharie (Figure 2.6). The difference in stream density between the Region 2 RF3 and the NYCDEP stream map is due to an increase in resolution (i.e., 1:100,000 and 1:24,000).

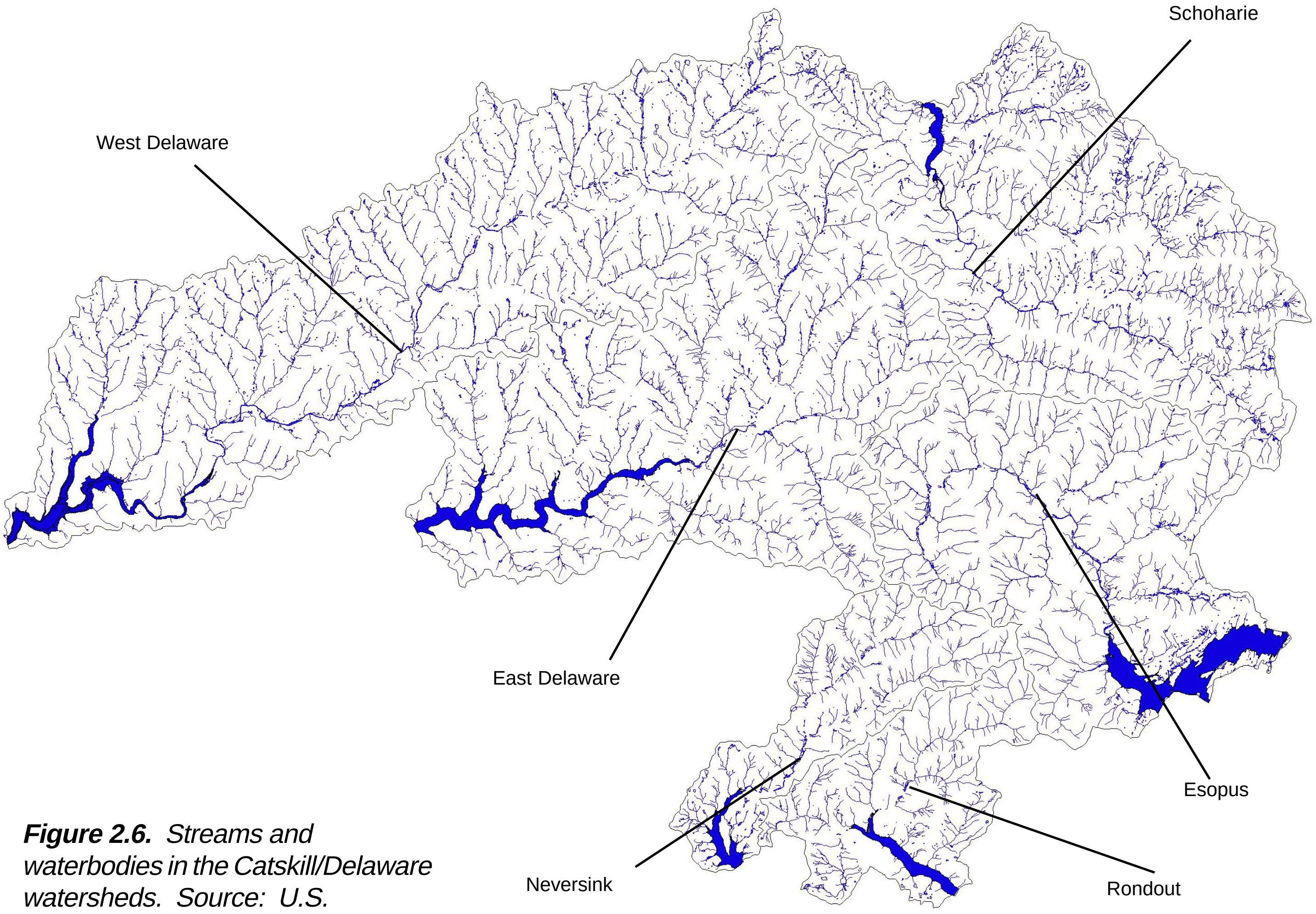


Figure 2.6. *Streams and waterbodies in the Catskill/Delaware watersheds. Source: U.S. Geological Survey 1:24,000 scale, modified by New York City Department of Environmental Protection.*

Watersheds

A watershed is a natural unit of land that captures rainfall, snow, or other forms of precipitation which drain or infiltrate to streams and ground water. The amount of water entering and leaving a watershed plays a crucial role in defining characteristics and change within an ecosystem. Therefore, a watershed provides a limited and contained unit of measure for evaluating landscape and water relations (Aber and Melillo, 1991). A hydrologic unit (HUC) represents all or part of a surface drainage area, a combination of drainage areas, or a distinct hydrologic feature. A subset of USGS national eight-digit hydrologic cataloging units is used to summarize landscape metrics for Region 2 (Figure 2.7; Table 2.1).

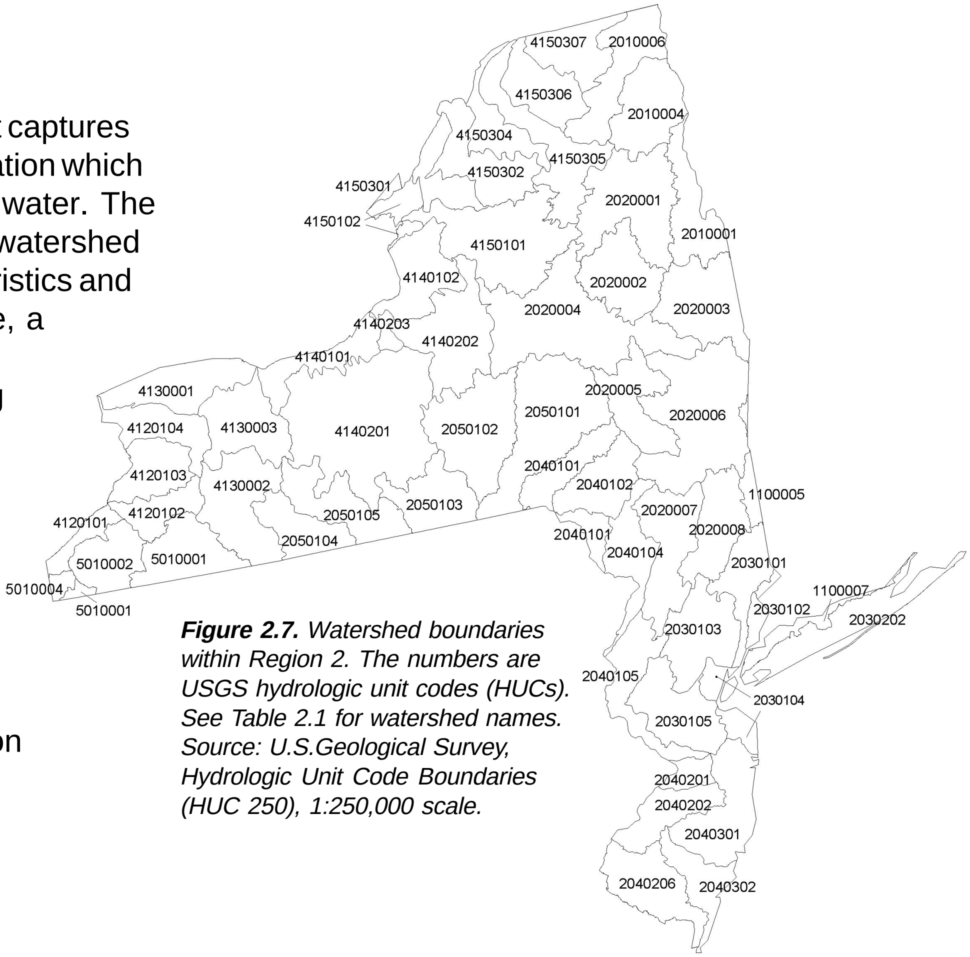


Figure 2.7. *Watershed boundaries within Region 2. The numbers are USGS hydrologic unit codes (HUCs). See Table 2.1 for watershed names. Source: U.S.Geological Survey, Hydrologic Unit Code Boundaries (HUC 250), 1:250,000 scale.*

Table 2.1. Regional Hydrologic Unit Code Numbers and Names (HUCs in blue surround the Catskill/Delaware watersheds).

1100005	Housatonic	2050101	Upper Susquehanna
1100006	Saugatuck	2050102	Chenango
1100007	Long Island Sound	2050103	Owego-Wappasening
2010001	Lake George	2050104	Tioga
2010004	Ausable	2050105	Chemung
2010006	Great Chazy-Saranac	4120101	Chautauqua-Conneaut
2020001	Upper Hudson	4120102	Cattaraugus
2020002	Sacandaga	4120103	Buffalo-Eighteenmile
2020003	Hudson-Hoosic	4120104	Niagara
2020004	Mohawk	4130001	Oak Orchard-Twelvemile
2020005	Schoharie	4130002	Upper Genesee
2020006	Middle Hudson	4130003	Lower Genesee
2020007	Rondout	4140101	Irondequoit-Ninemile
2020008	Hudson-Wappinger	4140102	Salmon-Sandy
2030101	Lower Hudson	4140201	Seneca
2030102	Bronx	4140202	Oneida
2030103	Hackensack-Passaic	4140203	Oswego
2030104	Sandy Hook-Staten Island	4150101	Black
2030105	Raritan	4150102	Chaumont-Perch
2030202	Southern Long Island	4150301	Upper St. Lawrence
2040101	Upper Delaware	4150302	Oswegatchie
2040102	East Branch Delaware	4150303	Indian
2040104	Middle Delaware-Mongaup-Brodhead	4150304	Grass
2040105	Middle Delaware-Musconetcong	4150305	Raquette
2040201	Crosswicks-Neshaminy	4150306	St. Regis
2040202	Lower Delaware	4150307	English-Salmon
2040206	Cohansey-Maurice	5010001	Upper Allegheny
2040301	Mullica-Toms	5010002	Conewango
2040302	Great Egg Harbor	5010004	French

Source: U.S.Geological Survey, Hydrologic Unit Code Names and Numbers (HUC 250), 1:250,000 scale.

The HUCs are fairly consistent in size across the country making comparisons of land cover between different regions possible. However, the map of HUCs within New York and New Jersey illustrates one of the problems with using naturally defined units such as watersheds to assess conditions within state boundaries. The HUCs which cross state lines are divided and therefore metrics calculated for these partial watersheds may not accurately represent the watershed system as a whole.

A separate group of GIS-delineated watersheds was used for the CD watersheds. These watersheds were created using elevation to determine boundaries or ridge tops which divide water flow to a main drainage point (stream, river, or water body). The watersheds consist of six drainage areas, each ending in a manmade reservoir, and 79 subwatersheds developed by NYCDEP from 30-m digital elevation models (DEM; Figure 2.8; Table 2.2). These NYCDEP watersheds were used in conjunction with land cover data to conduct the landscape assessment presented in Chapter 4.

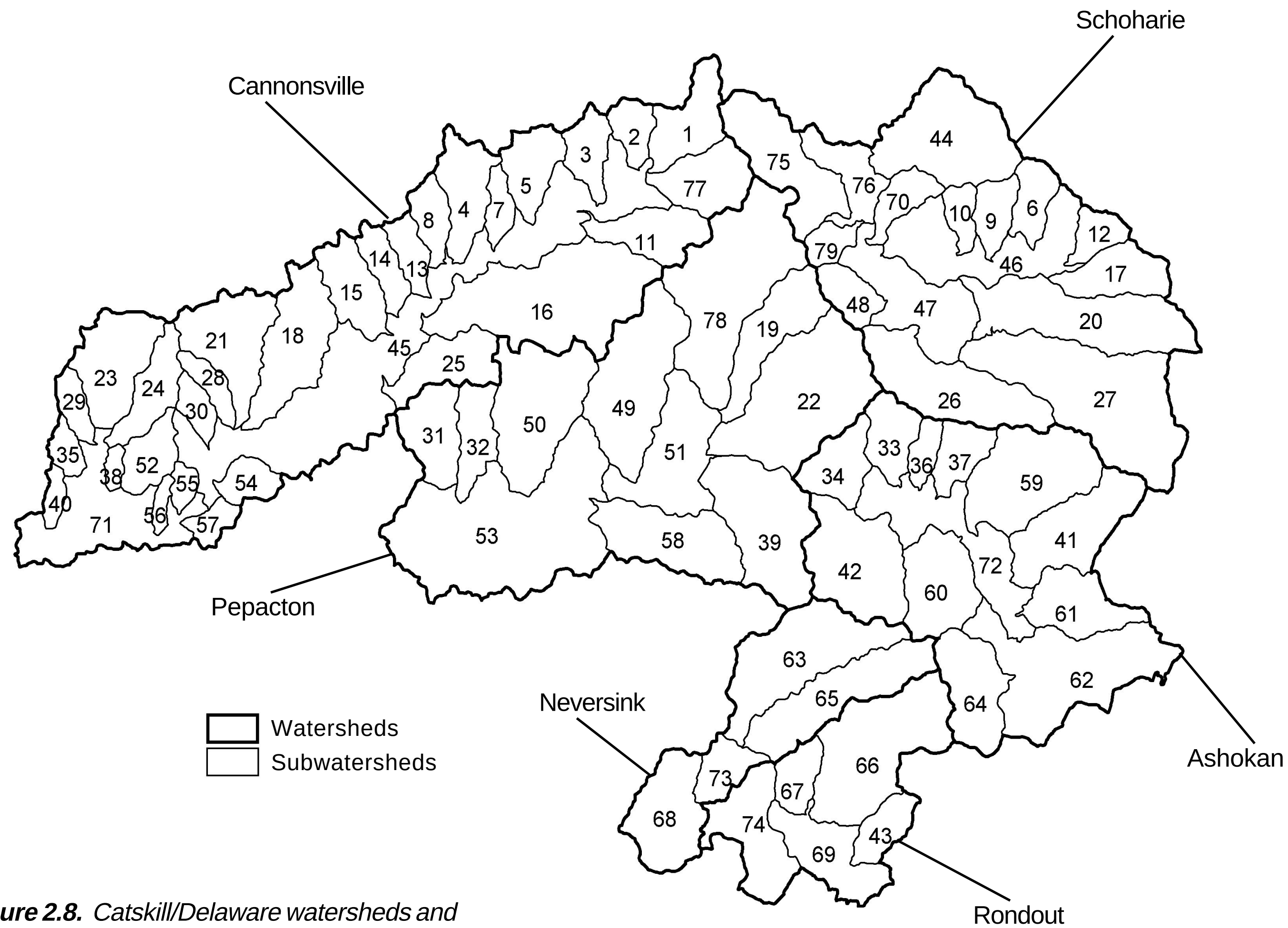


***Figure 2.8.** Catskill/Delaware watersheds and subwatersheds. Numbers correspond to subwatershed names in Table 2.2. Source: New York City Department of Environmental Protection created from U.S. Geological Survey, Digital Elevation model, 30-m data.*

Table 2.2. Catskill/Delaware Subwatershed Names with Numbers Corresponding to Figure 2.8

1	West Branch Delaware Headwaters	41	Beaver Kill
2	Lake Brook	42	Esopus Creek Headwaters
3	Betty Brook	43	Trout Creek - Rondout
4	Elk Creek	44	Manor Kill
5	Wright Brook	45	West Branch Delaware River
6	Mitchell Hollow	46	Batavia Kill - Schoharie
7	Kidd Brook	47	Schoharie Creek
8	Falls Creek	48	Little West Kill
9	North Settlement	49	Platte Kill
10	Sutton Hollow	50	Tremper Kill
11	Rose Brook	51	East Branch Delaware River
12	Silver Lake	52	Dryden Brook
13	Steele Brook	53	Pepacton Reservoir
14	Peaks Brook	54	Beers Brook
15	Platner Brook	55	Wakeman Brook
16	Little Delaware River	56	Fish Brook
17	Batavia Kill Headwaters	57	Chase Brook
18	East Brook	58	Mill Brook
19	Batavia Kill - Pepacton	59	Stony Clove Creek
20	East Kill	60	Woodland Creek
21	West Brook	61	Little Beaverkill
22	Bush Kill_Pepacton	62	Ashokan Reservoir
23	Trout Creek_Cannonsville	63	West Branch Neversink River
24	Loomis Brook	64	Bush Kill - Ashokan
25	Bagley Brook	65	East Branch Neversink River
26	West Kill	66	Rondout Creek
27	Schoharie Creek Headwaters	67	Sugarloaf Brook
28	Third Brook	68	Neversink Reservoir
29	Sherruck Brook	69	Rondout Reservoir
30	Pines Brook	70	Huntersfield Creek
31	Terry Clove (Bryden Hill)	71	Cannonsville Reservoir
32	Fall Clove (Brydon Lake)	72	Esopus Creek
33	Bushnellsville Creek	73	Neversink River
34	Birch Creek	74	Chestnut Creek
35	Dry Brook - Cannonsville	75	Bear Kill
36	Peck Hollow	76	Schoharie Reservoir
37	Broadstreet Hollow	77	Town Brook
38	Chamberlain Brook	78	East Branch Delaware Headwaters
39	Dry Brook - Pepacton	79	Johnson Hollow Brook
40	Johnny Brook		

Chapter 3. Methodology

This chapter discusses the various data sources and methods used to assess landscape and water quality conditions in Region 2 and CD watersheds. The methods in this chapter cover landscape classification, landscape metrics calculation, an EPA-delineation of select subwatersheds, statistical procedures for determining spatial and temporal trends, and relationships between landscape and water quality data. Also included in this chapter is information on data sources and the importance of the three water quality parameters selected for analsysis.

Regional Classification

The Region 2 land cover data are based primarily on images taken in the early 1990s by the Landsat satellite (Thematic Mapper; TM). Different surfaces reflect different amounts of light at various wavelengths; therefore, it is possible to classify land cover types from satellite measurements of reflected light (Figure 3.1; Lillesand and Kieffer, 1994). Regional land cover maps of data are prepared by the Multi-Resolution Land Characteristics (MRLC) Consortium, a multi-agency sponsored mapping program. The land cover data is at a 30-meter resolution. The National Land Cover Data (NLCD) classification for Region 2 consists of 18 land cover classes which, for the purpose of this study, were consolidated into six dominant categories (Table 3.1). Consolidation into six classes also improved the overall accuracy of the land cover classes by eliminating identification error inherent in interpreting satellite imagery. For example, the identification of forest cover is fairly straight forward. However, splitting the forest into subsets of hand-planted evergreen, orchard, and decidous trees, and forested wetlands increases the possiblility for classification error.

Figure 3.1. *Illustration of differential light reflectance properties for sediments suspended in water and land surfaces over a portion of Long Island Sound. These images can be manipulated in various ways to extract information about the Earth's surface. Source: North American Landscape Characterization Program.*

Table 3.1. Aggregation of the National Land Cover Data (NLCD) Regional Land Cover Classes

Open Water	Water
Low Intensity Residential	
High Intensity Residential	
High Intensity Commercial	Urban
Cultivated	
Pasture	
Row Crops	
Small Grains	
Urban Grass	Agriculture
Deciduous Forest	
Evergreen Forest	
Mixed Forest	Forest
Bare Rock	
Quarries	
Transitional	
Bare Soil	Barren
Woody Wetland	
Emergent Wetland	Wetland

Catskill/Delaware Classification

To evaluate landscape condition and change in the CD water supply watersheds, land cover data sets were produced for four time periods: 1975, 1985, 1991, and 1998. The EPA Landscape Ecology Branch and Lockheed Martin Environmental Services jointly prepared the CD land cover data. The mid-1970s classification has a spatial resolution of 60 m (Landsat multispectral scanner; MSS); however, the mid-1980s, early-1990s, and late-1990s classifications have a spatial resolution of 30 m (Landsat TM). The data from each image were grouped into one of five categories: water, forest, agriculture, urban, and bare ground. Wetlands were exclude due to their minimal presence in the area and the inability to accurately classify them without extensive ground truthing. The classifications were assessed to have an overall accuracy near 90%. The accuracy assessment was conducted by the EPA Landscape Ecology Branch Environmental Photographic Interpretation Center (LEB-EPIC) in Reston, Virginia. A more detailed description of the classification technique and accuracy assessment can be found in Appendix A.

EPA-Delineated Subwatersheds

A second set of CD subwatersheds, delineated by the EPA Landscape Ecology Branch, was used for assessing relationships between the landscape and water quality. Unlike the NYCDEP subwatersheds shown in Figure 2.8, the 32 EPA watersheds are based on modeling flow accumulation to a select set of water sampling locations using 10-m DEMs (Figure 3.2; more detailed information can be found in Appendix A). For landscape and water quality relationship analyses, the sampling sites had to be located off main stream tributaries or at headwaters and have no nearby upstream sewage treatment plant. Half of the 32 EPA-delineated subwatersheds match the NYCDEP boundaries, but the remaining half are either smaller or larger in size.

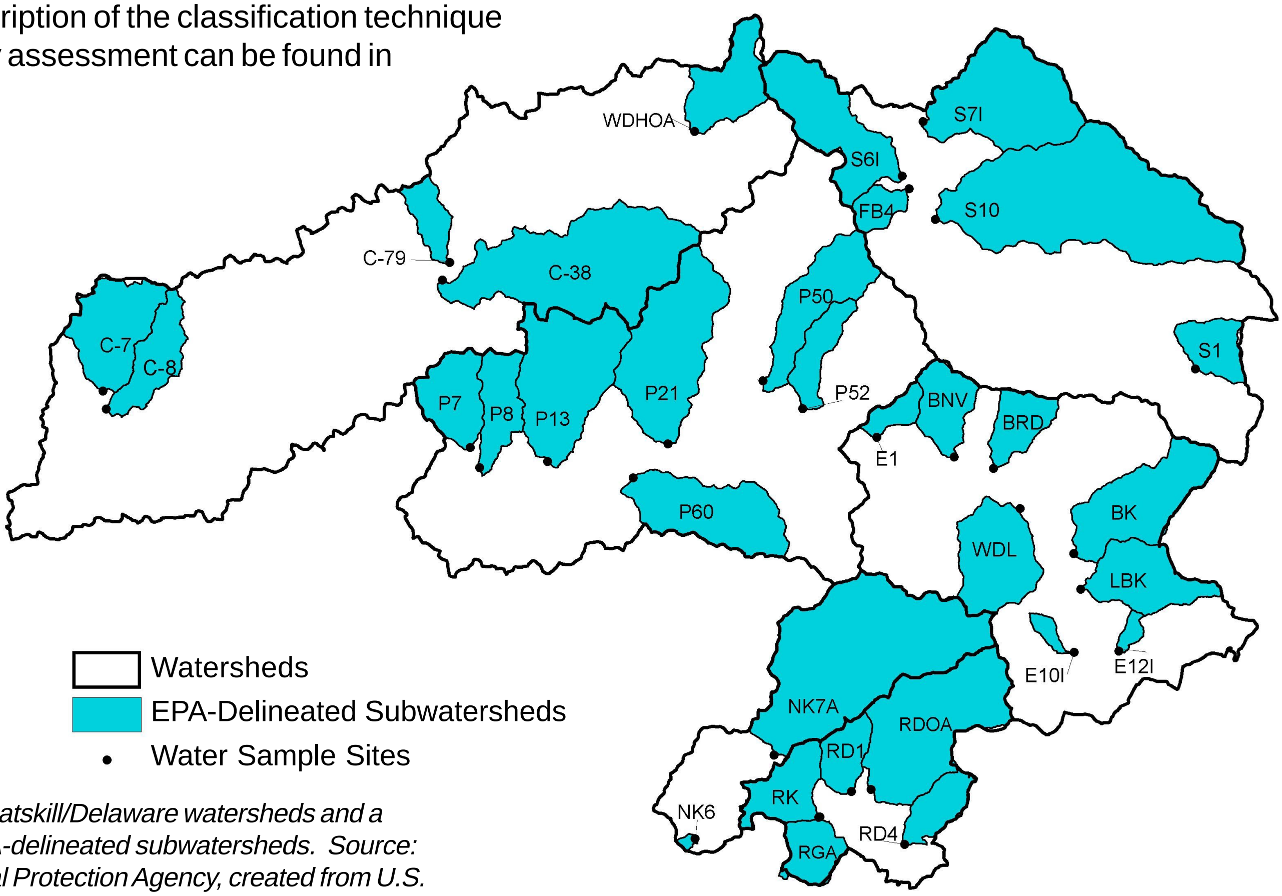


Figure 3.2. Catskill/Delaware watersheds and a subset of EPA-delineated subwatersheds. Source: Environmental Protection Agency, created from U.S. Geological Survey, Digital Elevation model, 10-m data.

Landscape Metrics

Landscape metrics are defined as measurements that describe the condition of an ecosystem or one of its critical components (O'Neill et al., 1992). The primary uses of a metric are to characterize current status and to track or predict significant change in environmental conditions (Hunsaker et al., 1996). Calculation of these metrics requires the aid of a geographical information system (GIS). Two GIS techniques mentioned in this report include overlaying and clipping (ESRI, 1992). These methods combine two or more data themes to extract a new set of information. For example, by placing a watershed boundary on top of a land cover map, the proportion of a specific land use within a watershed can be determined (Figure 3.3). Land cover change was determined by comparing land cover maps from two different dates on a pixel-by-pixel basis. Landscape change metrics were then determined based on the differences between the maps using the previously mentioned overlaying and clipping techniques.

Once the metrics were calculated, maps showing the relative ranking of watersheds or subwatersheds to each other were produced (Figure 3.4a and b). The watersheds or subwatersheds were ranked by equal interval value ranges for a given landscape metric. All watersheds or subwatersheds within the same data range were colored with one of five colors to represent least (green) to most (red) altered environmental condition. The interval should be read as 60 through 75, 75.01 to 80, and etc. These types of maps, based on ranking, are useful for comparing relative conditions across the Region 2 watersheds and the CD subwatersheds, but are not meant to give details about specific locations. More information on individual metrics discussed in this report are located in Appendix A, and a fuller definition of landscape metrics can be found in the "Mid-Atlantic Atlas" (Jones et al., 1997). The landscape metric maps are presented in Chapter 4 and landscape change maps in Chapter 5.

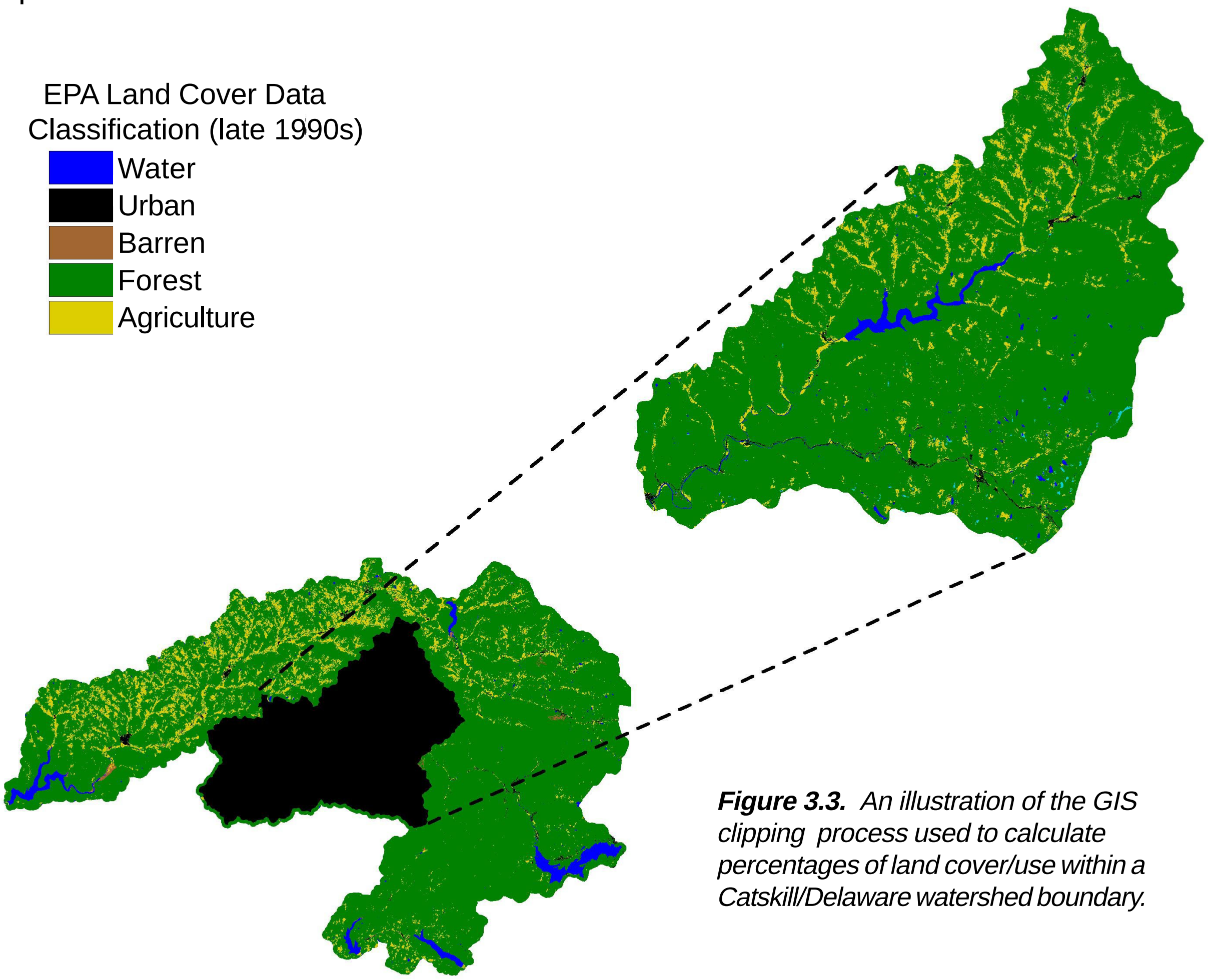


Figure 3.3. *An illustration of the GIS clipping process used to calculate percentages of land cover/use within a Catskill/Delaware watershed boundary.*

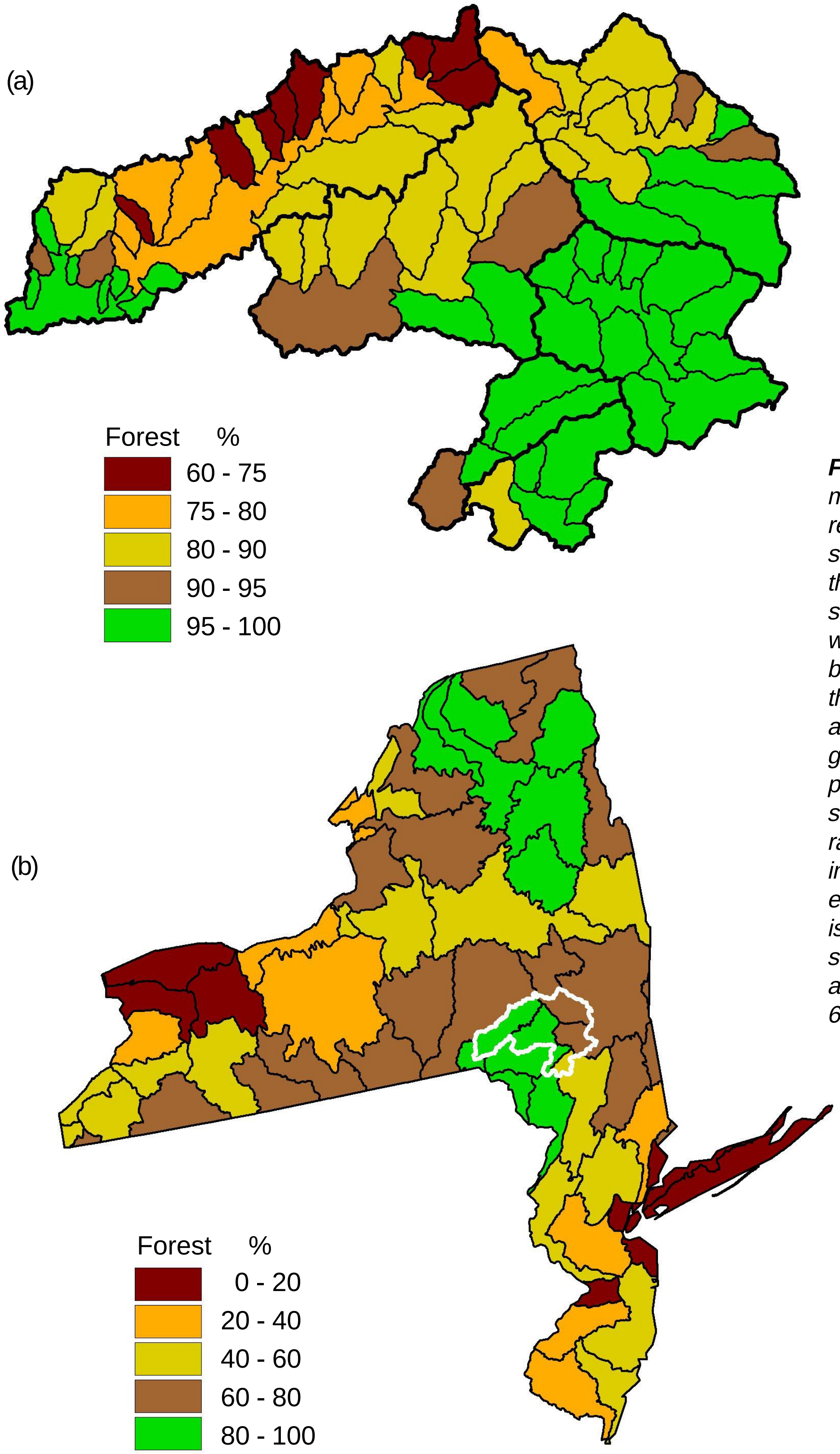


Figure 3.4. *An illustration of the maps that appear in the following report. The maps were color coded to show land cover/use percentages in the **(a)** Catskill/Delaware subwatersheds and **(b)** Region 2 watersheds. The effect of scale can be seen in the differences between the Catskill/Delaware subwatershed and regional watershed maps. A greater amount of information is provided by using the smaller subwatershed size. The map colors range from green to red, respectively indicating least to most altered environmental condition. The ranking is relative to the watersheds or subwatersheds within the study area.The interval should be read as 60 through 75, 75.01 to 80, and etc.*

Surface Water Quality Measurements

The NYCDEP monitors the water supply on behalf of the millions of city and state residents who use close to 3.8 billion liters (1 billion gallons) daily. The monitoring program includes numerous sampling stations within the many streams and reservoirs of the CD watersheds (NYCDEP, 1997a). Water quality data have been collected since the early 1900s at a number of these sampling stations, but only the most recent data is available in digital format. The database made available for this study from the NYCDEP contains biweekly surface water measurements from 1987 to 1998. Three water quality variables (total nitrogen, total phosphorus, and fecal coliform bacteria) were chosen for study based on regional and local concerns and on their relationship to landscape condition. Total phosphorous and total nitrogen are measured on grab samples. Fecal coliform bacteria are measured by placing water from a grab sample on a cultural medium and counting the number of colonies present following incubation (NYCDEP, 1997a).

Nitrogen and phosphorus are two essential nutrients required by terrestrial and aquatic organisms. These nutrients enter the water from both natural and human sources. Natural sources of these materials include the soil, animal waste, organic decay, and biologic conversion by bacteria. Human sources include nonpoint runoff of fertilizer and point source effluent inputs. At lower levels nutrients pose a minimal threat to human and aquatic health. However, anthropogenic inputs of nitrogen and phosphorous can raise nutrient concentrations to levels where consumption can result in potential health risks such as “blue baby” syndrome in infants (EPA, 1998b). Acceptable water standards established by New York and EPA are shown in Table 3.2. In addition to health risks, human-induced increases in nutrient levels speed up the natural process of stream and lake eutrophication, resulting in undesirable algal blooms. Excessive algal growth disrupts stream habitat, decreases oxygen availability, and raises turbidity, odor, and color to

Table 3.2. Drinking and Ambient Water Quality Standards for Nitrogen, Phosphorus, and Fecal Coliform Bacteria

	Drinking Water		Ambient Water	
Variable	EPA	NY State*	EPA	NY State
Nitrogen (mg/L)			0.7 **	“Not in an amount allowing growth of algea, weeds and slimes that will impair water for best use.”
Nitrate	10	10		
Nitrite	1	1		
Nitrate+Nitrite	10	10		
Phosphorus (mg/L)	N/A	N/A	0.1	“Not in an amount allowing growth of algea, weeds and slimes that will impair water for best use.”
Fecal Coliform Bacteria (CFU/100ml/month)	Zero	Zero	~ 200	200 - 2000

* = New York State Department of Health sets drinking water standards; New York State Department of Environmental Conservation sets ambient water quality standards

** = Ambient nitrogen standards have not yet been developed by EPA; the standard is general and based on a ratio of 7:1 (N:P) accepted as optimal for growth of aquatic plants.

unacceptable levels (Harris,1997). When plants and algae die their remains gradually sink and are consumed by aerobic bacteria. Gradually oxygen levels decrease and the water becomes anoxic. Under these conditions anaerobic bacteria flourish producing foul-smelling compounds such as hydrogen sulphide and ammonia. The process of algal bloom and decay can also result in an increase in disinfection by-products as greater amounts of organic carbon interact with chlorine.

Fecal coliforms are bacteria which occur naturally in human and animal intestinal tracts. Bacteria can enter streams from surface water runoff, treatment and septic system discharge, recreational use by humans, and use by wildlife and domestic animals (Fisher et al., 2000). When present in the water, fecal coliform bacteria indicate contamination by warm-blooded animal waste. Human health effects are related to other pathogens which may be excreted along with the fecal coliform bacteria, such as bacteria, protozoa, and viruses. These pathogens can cause outbreaks of hepatitis, typhoid fever, dysentery, diarrhea, and cholera.

Data Evaluation

In order to accomplish the following analyses, different groups of sites were used. That is to say sites used for analysis 1 may or may not be used for analyses 2 and 3. A more extensive discussion of the statistical techniques described in this report is presented in Appendix A. Results from the analyses described here are presented in Chapters 6 and 7.

Data Sources

Data sources include (1) EPA for the classified satellite imagery, select watershed delineations, and RF3 files; (2) NYCDEP for watershed and subwatershed boundaries and surface water chemical and biological data; (3) USGS for DEM, HUC, and stream discharge data; (4) Northeastern Regional Climate Center for precipitation data; and (5) Natural Resource Conservation Service (NRCS) for State Soil Geographic Data Base (STATSGO) and Soil Survey Geographic Data Base (SSURGO) soils data. Using these data, three types of statistical analyses were conducted.

Hiking trail and tributary near Bull Run, Rondout watershed.

Data Analyses

1) An average across the most recent 5 years of water data (1994 -1998) at each sample site (number of sites = 84) was used to examine the spatial trends in total nitrogen, phosphorus, and fecal coliform bacteria.

2) To study temporal variation of rainfall, discharge, and water quality, three sites (one water quality, one flow, and one rainfall) were selected in each of the six watersheds. These were the only sites where all three samples were taken within close proximity to each other (Figure 3.5). The discharge sites were located within a 1.5-km radius of a water quality sampling site. Precipitation sites were within a 1- to 22-km radius (average of 10 km or ~6 mi) of the water quality and discharge sample sites. Due to changes in total phosphorus collection methodology and limited total nitrogen data, temporal analysis includes only those measurements occurring between 1990 through 1998. However, fecal coliform bacteria data were from 1987 to 1998. Sampling times and frequency differed among the precipitation, discharge, and concentration data sets. Therefore, in order to relate the data for time series analyses, monthly averages were calculated synchronizing in time the precipitation, discharge, and concentration data (Box and Jenkins, 1976).

Changes in total nitrogen, total phosphorus, and fecal coliform bacteria over time were analyzed using auto-regression analyses. This type of analysis addresses serial correlation effects that can

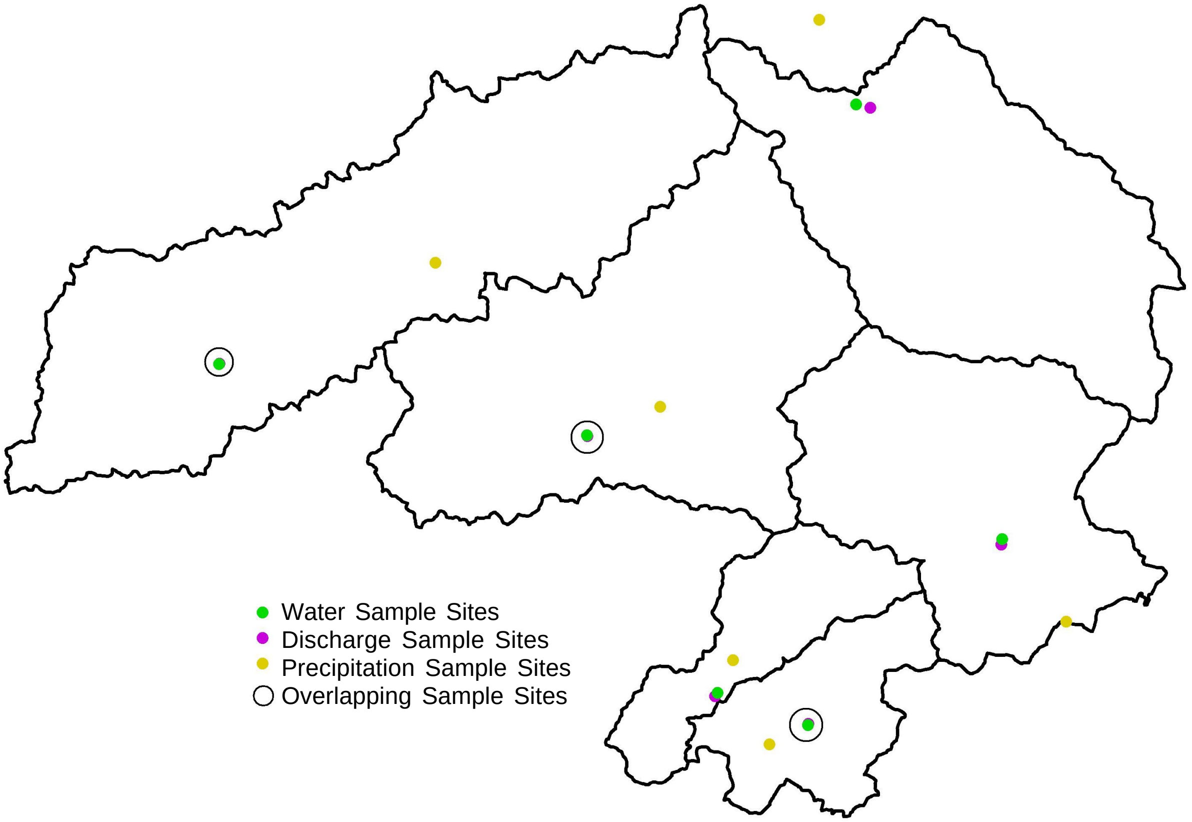


Figure 3.5. *Location of the rainfall, discharge, and water quality sample sites used to examine temporal variation in each of the Catskill/Delaware watersheds.*

result from temporal data (SAS,1990). Monthly data from 33 sites were used to characterize these trends. Prior to auto-regression analyses, data were log-transformed to homogenize and stabilize dependent variances. The spatial and temporal analyses results are discussed in Chapter 6.

3) Stepwise multiple regression analyses were conducted on three sets of landscape and water quality data to determine the contribution of various land uses, measured as landscape metrics, to surface water total nitrogen, phosphorus, and fecal coliform bacteria (SAS, 1990). Water quality data from 32 selected water sampling sites (Figure 3.2) and the landscape metric percentages for the watersheds were used in the regression analyses.

The total nitrogen, phosphorus, and fecal coliform bacteria data were averaged over the years around the imagery as follows: average water data from 1994 to 1998 were paired with the late 1990s land cover classification; average water data from 1989 to 1993 were paired with the early 1990s land cover classification; average water data from 1987 to 1988 were paired with the mid-1980s land cover classification. The water data were log transformed to eliminate seasonal effects and linearize the relationship with landscape metrics (Jones et al., 2001).

Prior to stepwise regression, pairwise correlations were examined to detect any high colinearity (similarity) between the landscape metrics (Griffith and Amerhein, 1997). Inclusion of highly similar landscape metrics can interfere with regression analyses, resulting in unreliable predictions of the landscape relationships to water quality (Berry and Felman, 1985). When two landscape metrics were determined to be highly correlated, one was excluded from the regression analysis. A further set of statistical tests was conducted to determine data normality, randomness, and outliers (Madanskey, 1988).

In order to validate the final stepwise regression models, a set of four surface water sample sites and their corresponding land cover percentages were withheld from the regression model. Model accuracy was determined by how well the withheld site means fit within the 95% confidence interval of model predicted values from subwatersheds having comparable land use. The results from the model validation and predictions are presented in Chapter 7.

Chapter 4. Land Cover/Use

In this chapter a number of landscape metrics are used to assess environmental conditions in Region 2 and Catskill/Delaware watersheds. Each metric is discussed separately with maps illustrating the relative ranking of the watersheds or subwatersheds. The metrics and the accompanying interpretation are not exhaustive but focus on those expected to be relevant to water quality.

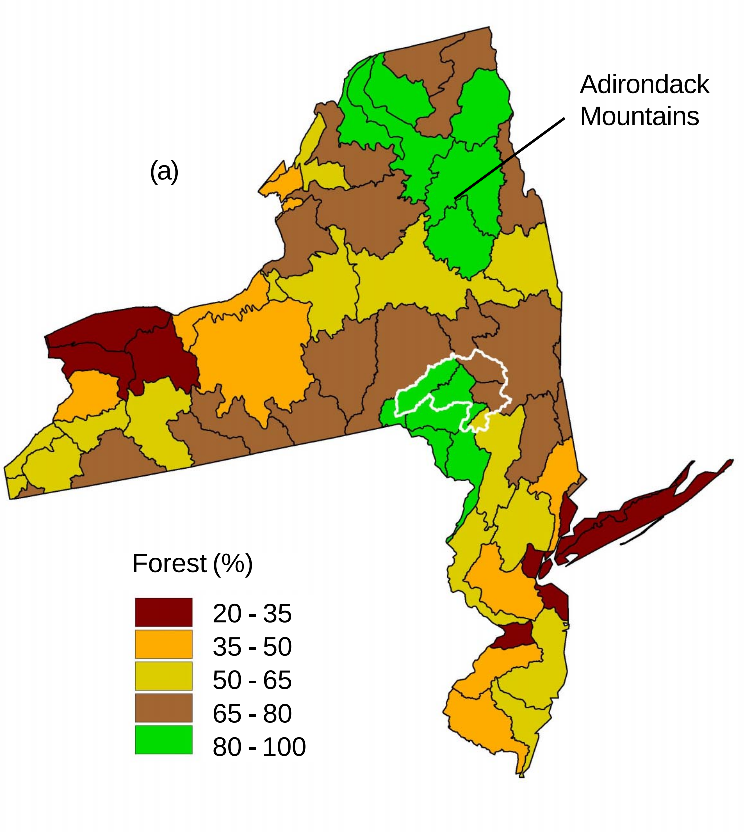


***Figure 4.1.** Percentage of forested land cover in **(a)** Region 2 watersheds and **(b)** the Catskill/Delaware subwatersheds. The metrics were calculated as total area divided by total watershed*

Forest Land Cover

Trees are an important element of both natural and human-dominated landscapes. Forests provide benefits to humans and wildlife such as wood fiber, outdoor recreation, habitat, and regulation of hydrologic flow. The proportion of forest cover can influence rainfall impacts and surface runoff properties within a watershed. The deeper roots and higher water interception in forested soil helps reduce runoff and erosion into surface water (Novotny and Olem, 1994).

Historic patterns of land use, development, and forest regrowth in Region 2 have created the present distribution of forest from what once was essentially all forest (Forman, 1995a). For most of Region 2, forest remains the dominant land cover type covering approximately 60% of the area. The watersheds in the interior portions of the Adirondack Mountains approach complete forest cover (97%; Figure 4.1a; Table B-1). These watersheds contain large tracts of interior forest, providing habitats for a variety of wildlife species. The lowest percentage of forest cover is about 21% in the more developed coastal watersheds to the east. Forests within these watersheds would be smaller and farther apart having a greater proportion of edge than interior forest habitat.

Like the Appalachian watersheds, the CD watersheds are dominated by evergreen and deciduous forest with an average cover of 89%. The forest cover largely consists of secondary regrowth. With the exception of the subwatersheds surrounding the Cannonsville Reservoir, the general spatial distribution (from lowest to highest percentage of forest cover) is from northwest to southeast (Figure 4.1b; Table C-1). Three of the six watersheds (Ashokan,

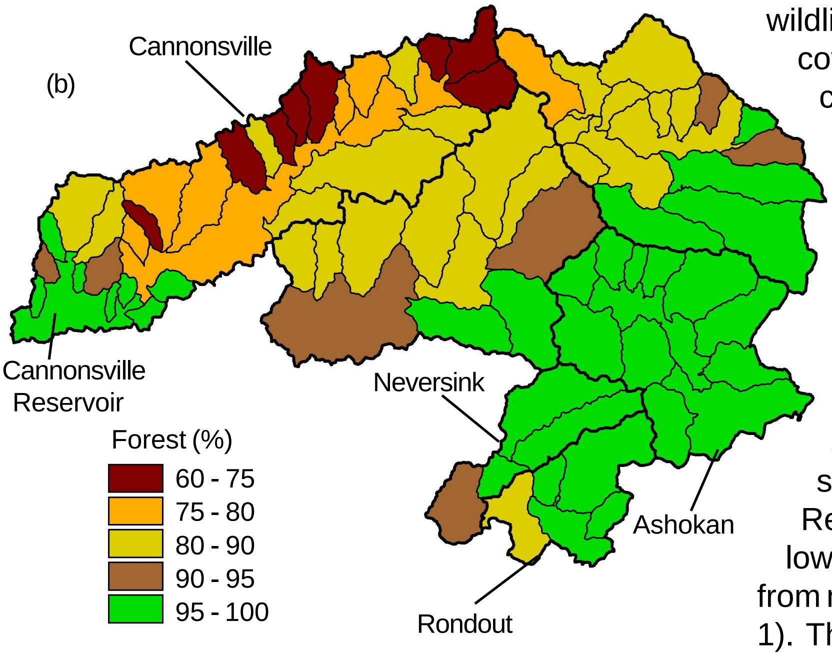


Table 4.1. Late 1990s Land Cover/Use Percentages in the Catskill/Delaware Watersheds

Watershed	Forest (%)	Urban (%)	Agriculture (%)	Barren (%)	U-Index (%)	Ag Slope >5% (%)
Cannonsville	80	1	19	< 1	20	13
Schoharie	91	< 1	8	< 1	9	4
Pepacton	90	< 1	9	< 1	10	7
Ashokan	98	1	1	< 1	2	< 1
Neversink	98	< 1	2	< 1	2	1
Rondout	96	< 1	4	0	4	3

Neversink, and Rondout; Table 4.1) have forest cover averages greater than 95%, and roughly half of all the CD subwatersheds have greater than 90% forest cover. Only eight subwatersheds have forest cover under 75%; all are located within the Cannonsville watershed.

Agriculture

According to the United States Department of Agriculture Statistics Service, approximately 8 million acres are dedicated to the production of livestock, grain, and specialty crops within New York and New Jersey (USDA, 1999). Production from these lands includes around 80-million bushels of grain, 300-million pounds of meat, and 1.5-billion gallons of milk. From these numbers it is easy to see that livestock play a major role in the commerce and community structure within Region 2. In order to support the high production of both forage (grass) and grain crops (corn and wheat), tons of fertilizer are applied every year. Despite the obvious production and greening benefits gained by the application of fertilizer, there is the potential for negative repercussions on water quality from nutrient runoff (Heathwaite et al., 1990). Due to its influence on society and the environment, agriculture is an important land use for Region 2.

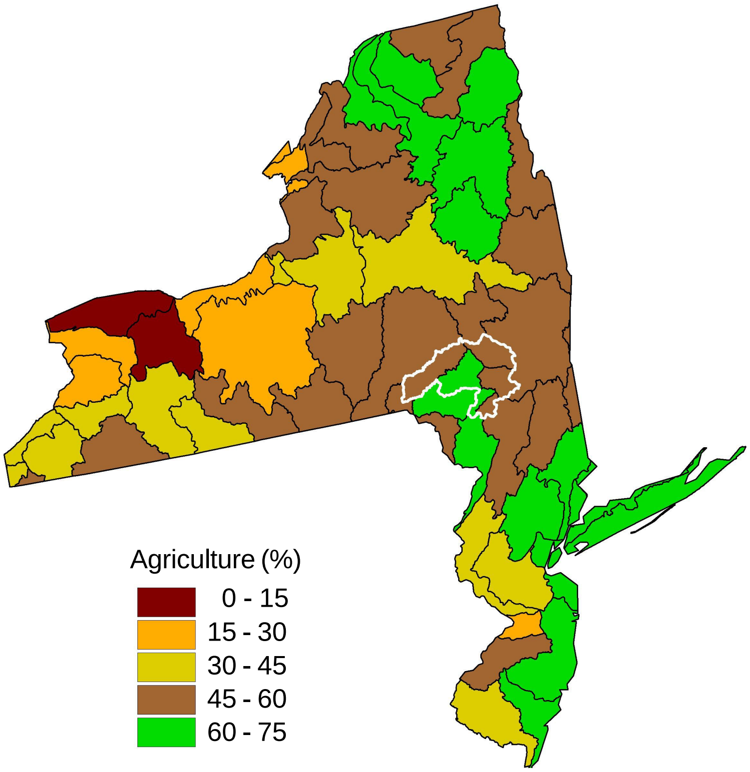


Figure 4.2. *Percentage of agriculture land cover in Region 2 watersheds The metrics were calculated as total agriculture area divided by total watershed area.*

The percentage of land devoted to agriculture averages 25% across all watersheds in the two states, with a range from 1 to 75% (Figure 4.2; Table B-1). However, the median percentage of agricultural land use across all watersheds is equal to the average percentage of agriculture, suggesting a fairly even distribution across Region 2. The location and type of farming practiced can be tied directly to the biophysical and climatic settings of the area. Steep slopes, shallow soils, and a shorter growing season tend to limit the mountainous parts of Region 2 to raising livestock. However, the gently rolling lands of the western plateau provide fertile ground for cultivation of field crops.

Compared to Region 2, the percentage of land in agriculture is not as large in the CD watersheds (Figure 4.3; Table C-1). However, the average percentage of agriculture across all CD watersheds is 10%, making it the most common human use of the land in the area. Most farming in this area consists of pastures for livestock and hay production and is concentrated in the northwest. Close to 20% of the Cannonsville watershed is devoted to agricultural use with eight subwatersheds having the highest percentages of agriculture (over 25%) in all the CD watersheds. The Pepacton and Schoharie watersheds average about 10% agriculture in the watersheds and subwatersheds. The remaining watersheds (Neversink, Rondout, and Ashokan) average 3% or less total agricultural.

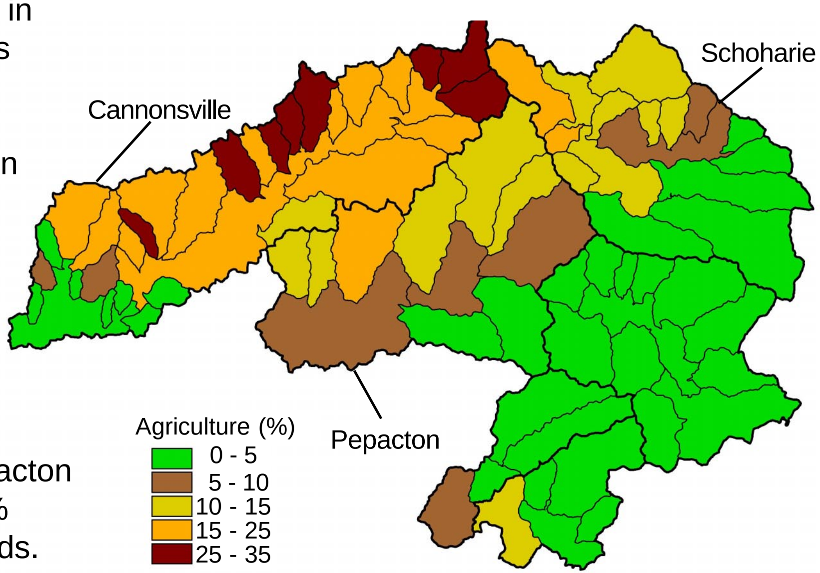


Figure 4.3. *Percentage of agriculture land cover in the Catskill/Delaware subwatersheds. The metrics were calculated as total agriculture area divided by total watershed area.*

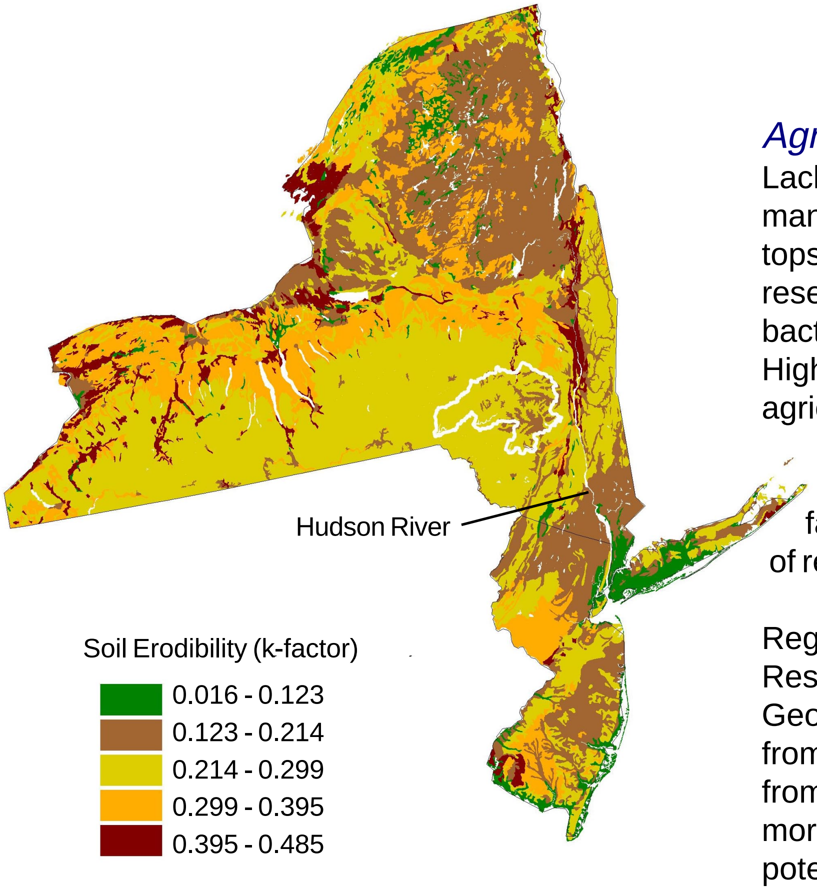


Figure 4.4. *Average soil erodability factor (k-factor) for Region 2. Source: Natural Resource Conservation Service, State Soil Geographic Data Base.*

Agriculture on Erodible Soils

Lack of vegetative cover and poor land management practices result in the transport of topsoil to streams and reservoirs. Sediments fill in reservoirs and carry nutrients and fecal coliform bacteria which impairs water quality in streams. Highly erodible soils are of particular concern, since agriculture on these soils results in a higher rate of soil erosion (Johnes and Heathwaite, 1997). The potential for erosion, expressed as the k-factor, is used to evaluate the relative erodibility of regional and CD water supply watershed soils.

Regional soil k-factors are derived from the Natural Resource Conservation Service (NRCS) State Soil Geographic (STATSGO) database and they range from 0 to 0.49 (Figure 4.4). The k-factor is derived from soil texture and slope conditions. A k-factor of more than 0.3 is an indication of high erosion potential (Brady, 1990). In New York the most erodible soils are located in the northwest and around the Hudson River, while in New Jersey the potential for erosion is the highest in the southwestern part of the state.

In the CD watersheds the soil k-factors are derived from the finer scale NRCS Soil Survey Geographic (SSURGO) database, which provided a better spatial estimate of soil erosion potential. The most erodible soils in the watershed are located on hill slopes or on valley floors near streams. To evaluate the watershed's relative risk for soil loss, metrics for agriculture on erodible soils and agriculture on slopes >5% were calculated by overlaying the SSURGO and elevation data.

In the CD watersheds, close to half of the total agriculture acreage is located on hill slopes greater than 5%. Subwatersheds with the greatest proportion of agriculture on slopes greater than 5% corresponded with those having the highest overall percentage of total agriculture (Figure 4.3; Figure 4.5a; Table C-1). Greater than one third of the total agriculture within the CD watersheds is located on soils having a k-factor greater than 0.3. The greatest percentage of agriculture on highly erodible soils is located in the subwatersheds around the Schoharie Reservoir and the West Branch of the Delaware River (Figure 4.4b; Table C-2).

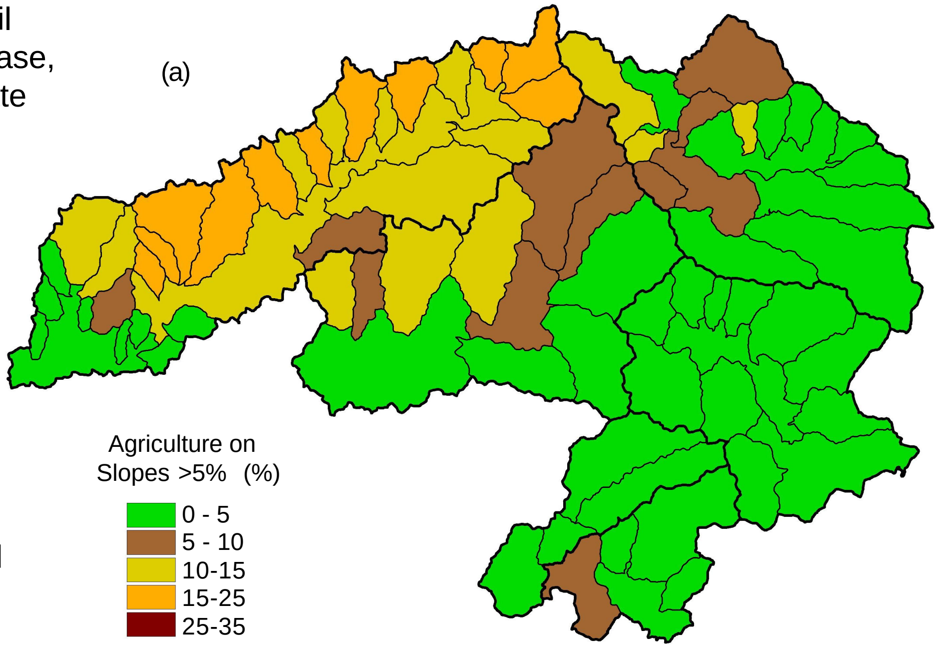
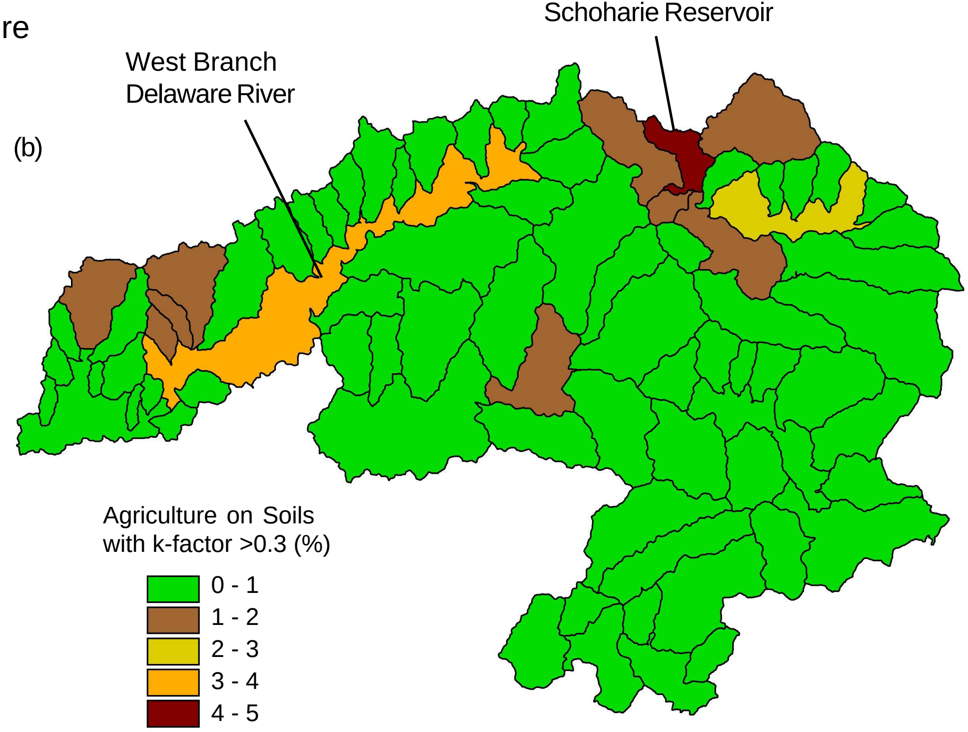


Figure 4.5. *Percentage of Catskill/Delaware subwatersheds with agricultural land use on* ***(a)*** *slopes >5% or* ***(b)*** *soils with k-factor values >0.3. The metrics were calculated by overlaying maps of slope and land cover and dividing the area of agricultural use on slopes >5% or agriculture on highly erodible soils (k >0.3) by the total subwatershed area.*



Roads

Roads are necessary to connect people with towns, recreational sites, agricultural fields, and ecological communities. The influence of a given road on the surrounding environment extends for some distance, depending on road size, surface type, traffic volume, and type of use (Forman and Deblinger, 2000). The construction and maintenance of roads can cause permanent stress (altered flow and sediment deposition) on nearby streams. The impervious nature of road surfaces and the ditches built to channel water off roads influence the rate of water runoff which can carry salt, petroleum products, antifreeze, and other vehicle-related chemicals into nearby streams. Another influence roads may have is the enhancement or impairment of species migration and habitat (Dijak and Thompson, 2000). Road density and number of roads crossing streams are important measurements to include in an environmental assessment. The road metrics are calculated from 1:100,000 USGS Digital Land Graph (DLG) data.

A map of relative road density is used to indicate total number of roads in Region 2 watersheds (Figure 4.6; Table B-1). There are about 240,000 km of roads in Region 2, with the highest road density 10 km/km^2 (16 mi/mi^2) located around the Long Island Sound. For the most part, the rest of Region 2 watersheds have road densities between 1 and 2 km/km^2.

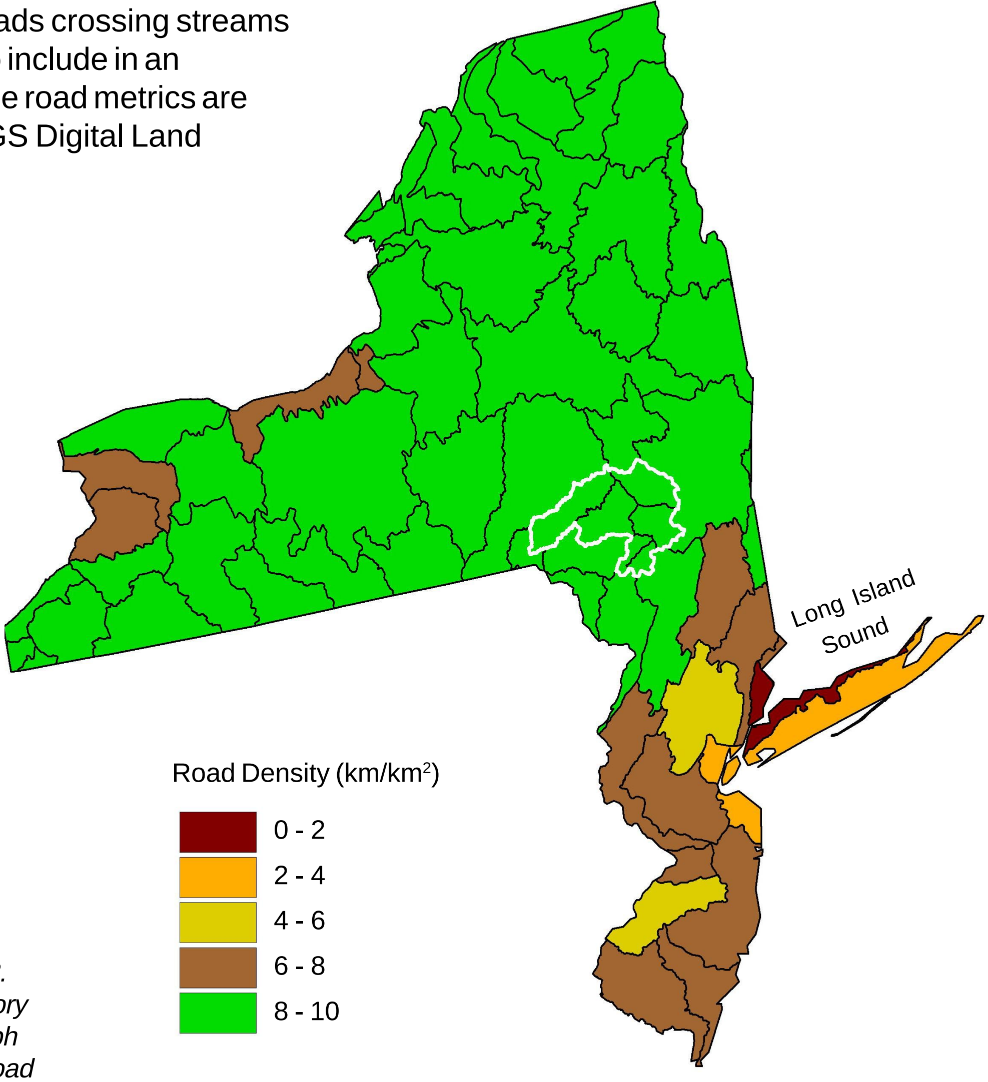


Figure 4.6. *Road density in Region 2. The metric was based on road catagory classes 1-4 (USGS Digital Land Graph data) and is calculated as length of road per total watershed area.*

The distribution of roads appears to be fairly even across the CD watersheds, with the majority of the subwatersheds averaging between 0.9 and 1.5 km/km^2 (1.5 to 2.4 mi/mi^2; Figure 4.7; Table C-2). There are 4,000 km (2,485 mi) of roads in the CD watersheds. The topography forces many of the roads to run parallel to the stream where the land surface is flatter. Road density within a 60-m buffer from streams varied from 0 to 0.5 kilometer of road per kilometer of stream. Invariably these roads end up intersecting with the numerous streams. In each of the three watersheds (Cannonsville, Pepacton and Schoharie; Figure 4.8) there are over 1,000 places each where roads intersect or cross streams. Seven subwatersheds within the Cannonsville watershed have stream crossing densities greater than one crossing per kilometer of stream (1.61 crossing/mi; Figure 4.8; Table C-2). The Ashokan watershed has the second highest number of stream crossings and one of the four subwatersheds with the highest density of crossings.

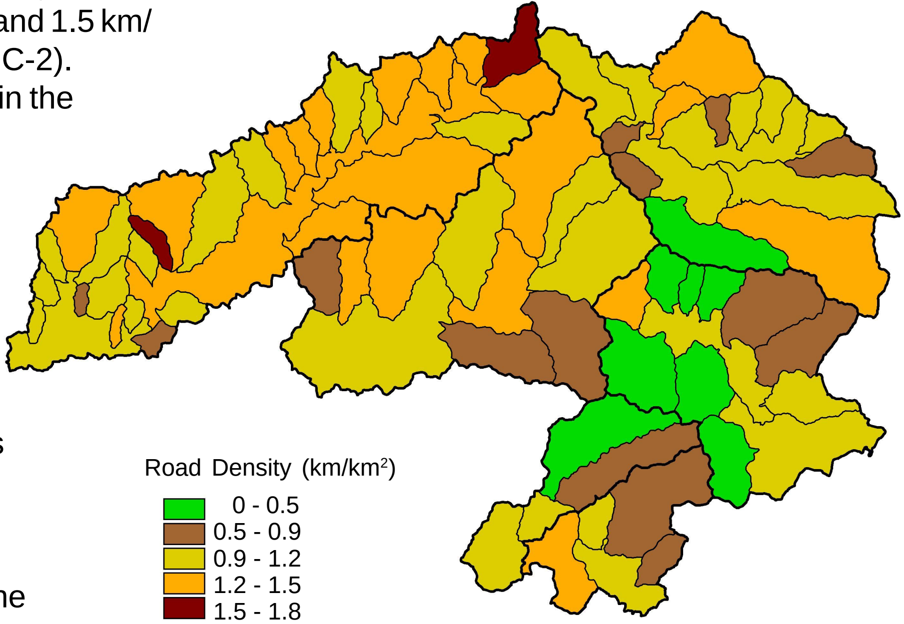


Figure 4.7. *Road density in the Catskill/Delaware subwatersheds. The metric was calculated as length of road (km) per total subwatershed area (km^2).*

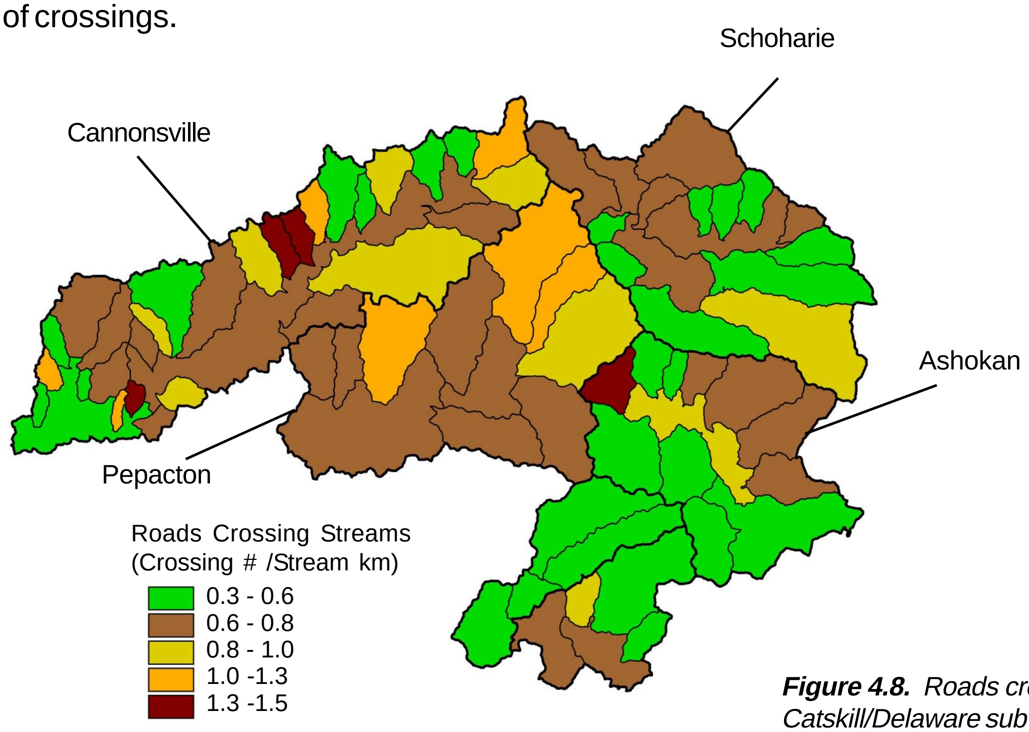


Figure 4.8. *Roads crossing streams in the Catskill/Delaware subwatersheds. The metric was calculated as total number of crossings per total length of stream in the subwatershed (km).*

Population Growth and Urban Development

According to the United States Bureau of the Census, the population in 1990 was estimated at close to 18 million for New York and 7.7 million for New Jersey (U.S. Census, 1990). When converted to population density, there were 380 people per square mile for New York and just over 1,026 per square mile for New Jersey. As of 1990 close to 10 million people resided in the city of New York and surrounding areas. The population density in the watersheds surrounding New York City is orders of magnitude higher than in the rest of the state, where there is considerably lower density. This diverse pattern is reflected in the map of urban development (Figure 4.9; Table B-1). Urban development averages 10% of the total area, with the higher concentrations located in watersheds containing the major cities of New York, Newark, and Trenton. In these metropolitan-dominated watersheds, urban development is as high as 70%, while many of the watersheds in the mountainous regions of New York approach near zero development. This unequal distribution of development results in a median value of about 4% urban development for the watersheds of Region 2.

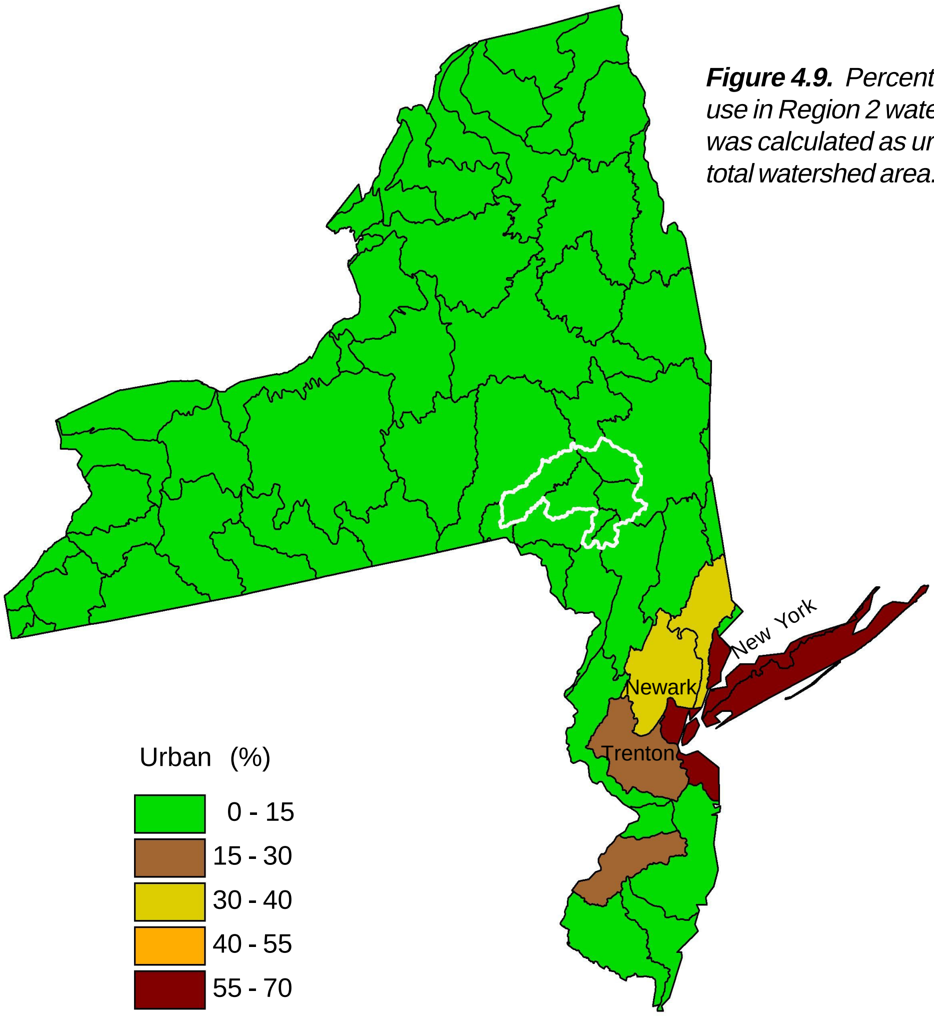


Figure 4.9. *Percentage of urban land use in Region 2 watersheds. The metric was calculated as urban area divided by total watershed area.*

From 1970 to 1995, population in the CD watersheds increased by only 15% from 53 to 64 thousand people (Figure 4.10). Urban land use averages less than 1% of the total area and consists of small residential towns. The urban development in the area is focused around agriculture in the west and tourism in the east (Stave, 1995). This has led to pockets of growth near the reservoirs, ski resorts, and areas of high agricultural production. The greatest amount of urban land use in the Schoharie and Pepacton watersheds is located within subwatersheds containing ski resorts and other tourist attractions (Figure 4.11; Table C-1). In the Cannonsville watershed, average urban land use in the subwatersheds ranges from 0 to 3.7%. The majority of the urban land use in the Ashokan watershed is located around and upstream of the reservoir. The remaining watersheds (Neversink and Rondout) have minimal urban land use.

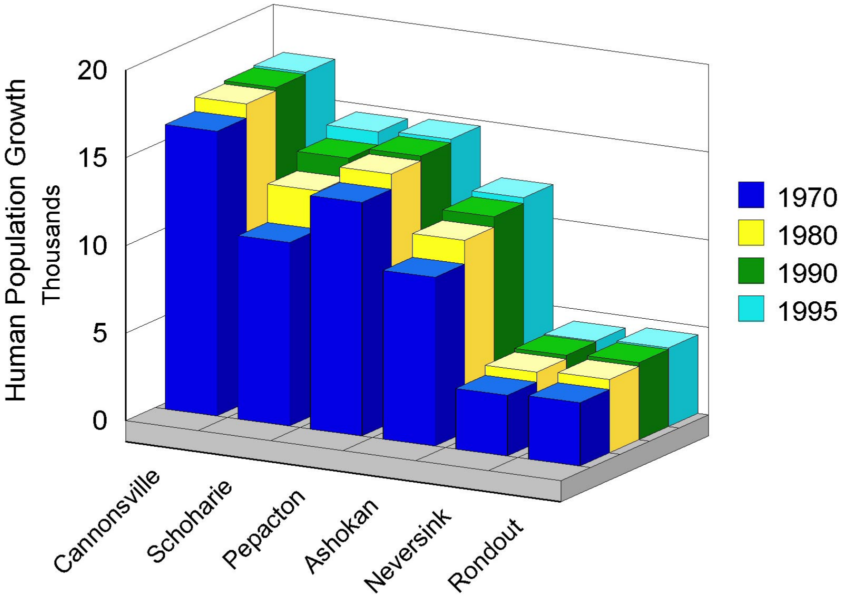


Figure 4.10. *Population change within the Catskill/ Delaware watersheds. County level census data were modified using 1990 estimates of within-watershed population. Source: U.S. Census Bureau county data 1970 to 1995 modified using New York City Department of Environmental Protection 1990 estimated within-watershed population totals.*

As a result of topographic constraints, much of the human use within the watersheds has concentrated close to rivers and streams. Therefore, while the human population only marginally increased in the past 30 years, the location of urban use near watershed streams increases the potential for continued effluent from waste treatment plants, nonpoint agricultural, and urban runoff to enter streams.

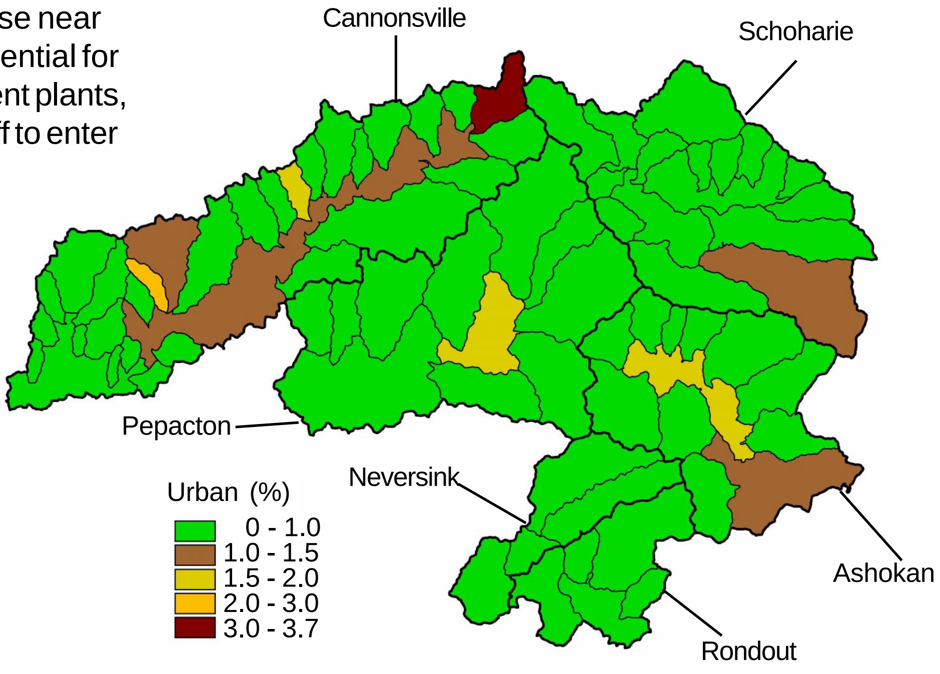


Figure 4.11. *Percentage of urban land use in the Catskill/Delaware subwatersheds having urban land use. The metric was calculated as total urban area divided by total subwatershed area.*

Human Use Index

While the proportion of developed land use gives an indication of urban development within an area, a more accurate picture of human influence on the landscape can be mapped with the human use index (U-index). The human use index combines the proportions of agriculture, barren, and urban land use into a single measure. By looking at watershed patterns of the U-index, it is possible to identify those areas which have experienced the greatest land conversion from natural vegetation cover (O'Niel et al., 1988).

The highest U-index for Region 2 is about 78% and the lowest is 1.5% with a median value of 34% (Figure 4.12; Table B-1). Agriculture is the dominant component of the U-index in watersheds located outside major metropolitan areas. In contrast, the watersheds located in close proximity to Long Island Sound have a U-index dominated by urban. The lowest U-index values are in watersheds containing the Adirondack and Catskill Mountains. The soils of these watersheds are generally too shallow for agriculture and difficult to build homes on due to topography.

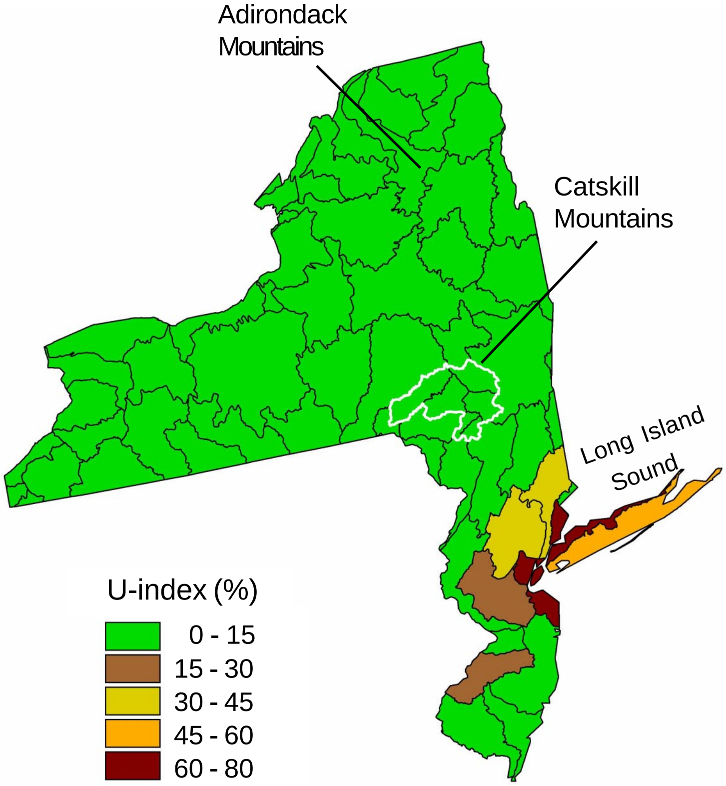


Figure 4.12. *Percentage of watershed in human land use in Region 2. The U-index was calculated as total urban and agricultural area divided by total watershed area.*

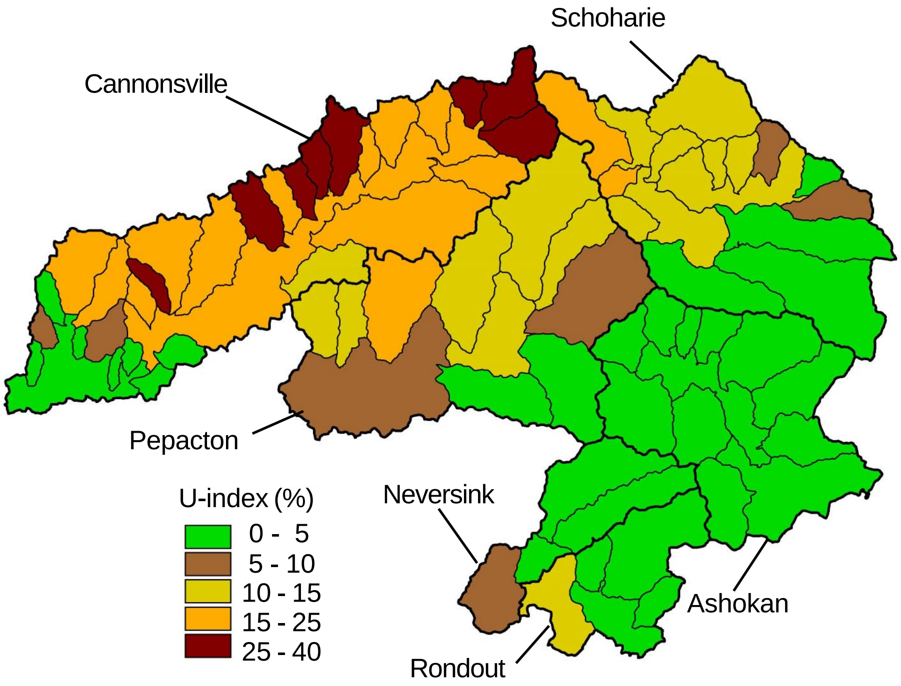


Figure 4.13. *Percentage of the Catskill/Delaware subwatersheds in human land use. The metric was calculated as total urban, agricultural, and barren area divided by total subwatershed area.*

The higher percentages of agricultural and barren lands in the Cannonsville, Pepacton, and Schoharie watersheds resulted in higher U-index values than for the other three subwatersheds (Table 4.1). Although the Ashokan has the highest percentage of urban use, its U-index is similar to that of the Neversink and Rondout watersheds. With the exception of two subwatersheds, one in Schoharie and one in Pepacton, the U-index rankings remain identical to those for subwatershed total agriculture (Figures 4.3 and 4.13; Table C-1).

Riparian Land Cover/Use

Nonpoint source pollution continues to be a concern to regional and local water resource managers. Since the 1970s, research has shown a link between near stream vegetation and water quality measurements (Karr and Schlosser, 1978). A designated distance from a stream is called a riparian buffer. Natural vegetation in the riparian buffer can provide an effective barrier to stream bank erosion and runoff of water pollutants such as excess fertilizer. In addition, riparian vegetation supports a variety of valuable plant and wildlife species (Lowrance, 1997). Characterization of riparian conditions over the entire region can help to identify watersheds that might benefit from riparian improvements.

The relative amount of forest and human use in a 60-m riparian buffer (each side of streams) within Region 2 watersheds can be seen in Figure 4.14 and Table B-2. The ranking of all riparian land cover/use metrics is similar to the total watershed assessment, with only slightly lower proportions in the riparian buffer area (Tables B-1 and B-2). The range of human use within the 60-m buffer is between 2 and 70%. Human use averages 30% of the total riparian area, with agriculture land use accounting for close to three quarters of that amount. In the more mountainous areas where human use is concentrated in the flatter flood plains, a larger proportion of the total agricultural acreage within the watershed is located within 60 m of the stream.

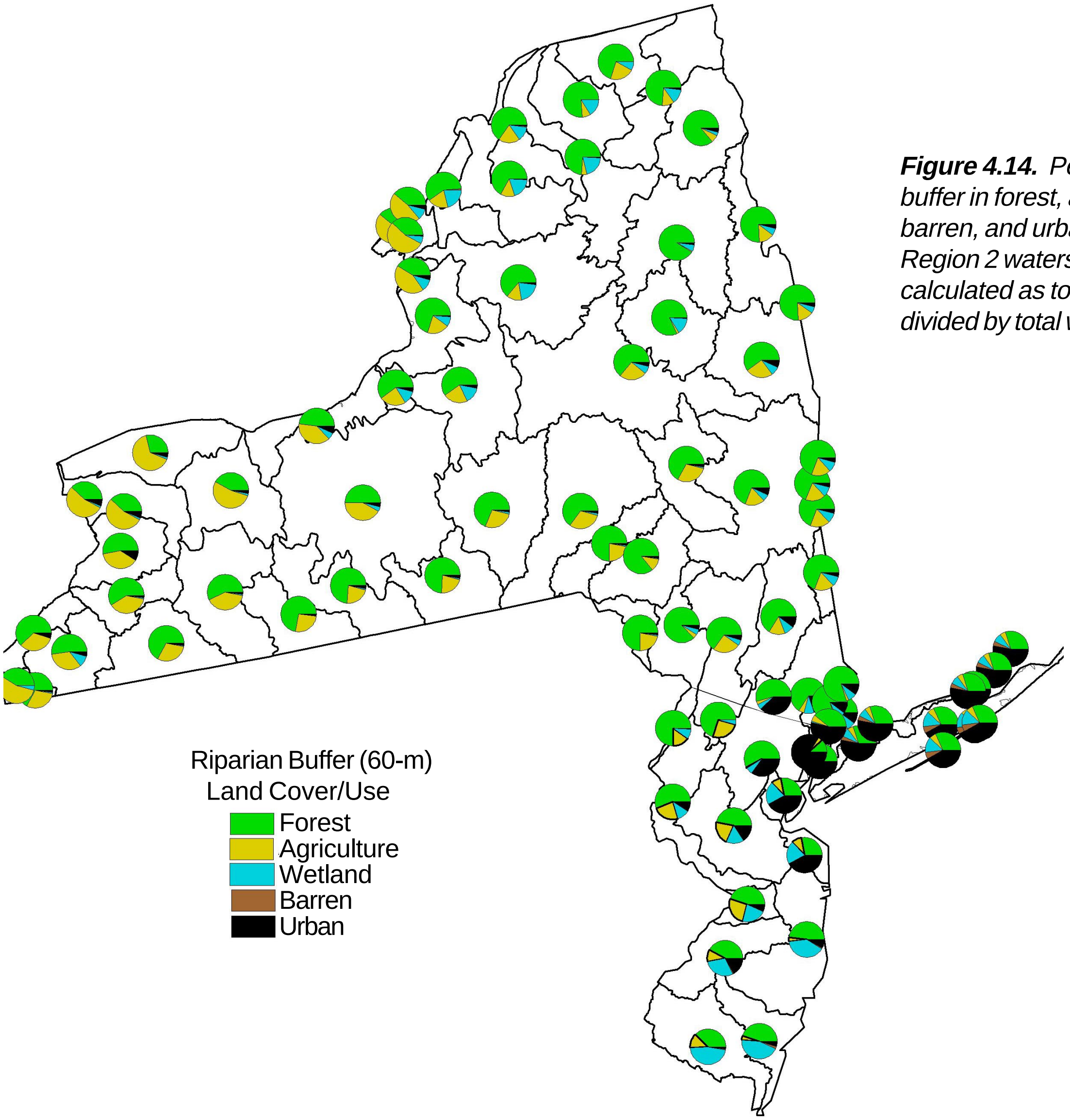


Figure 4.14. *Percentage of the riparian buffer in forest, agriculture, wetland, barren, and urban land cover/use in the Region 2 watersheds. The metrics were calculated as total land cover/use area divided by total watershed area.*

In the CD watersheds there are around 7,000 km (4,350 mi) of streams. Buffer distances of 30, 60, and 120 m on both sides of the streams are used to calculate land cover/use metrics. The average riparian forest cover within the subwatersheds is about 5% lower than that of the whole subwatershed. Table 4.2 gives the average land cover percentages for the CD subwatersheds and 60- and 120-m riparian buffers. Forest cover percentages did not vary between 30 and 120 m. The lower forest cover in the riparian is, for the most part, due to greater proportions of agriculture. The flatter topography surrounding the streams is often the only place available for agricultural production, particularly row crops. The percentage of agriculture in the riparian buffers ranges between 15 and 44%. The agriculture in the CD riparian buffer often makes up between 10 to 100% of the total subwatershed agriculture. The lowest forest and highest agricultural riparian coverage are in the subwatershed of the Cannonsville and Pepacton watersheds (Figure 4.15; Table C-3). The riparian human use index is mostly related to percent total agriculture in the subwatersheds. However, in the Ashokan and Schoharie watersheds the most eastern subwatersheds have high percentages of urban development which placed them into a lower U-index ranking.

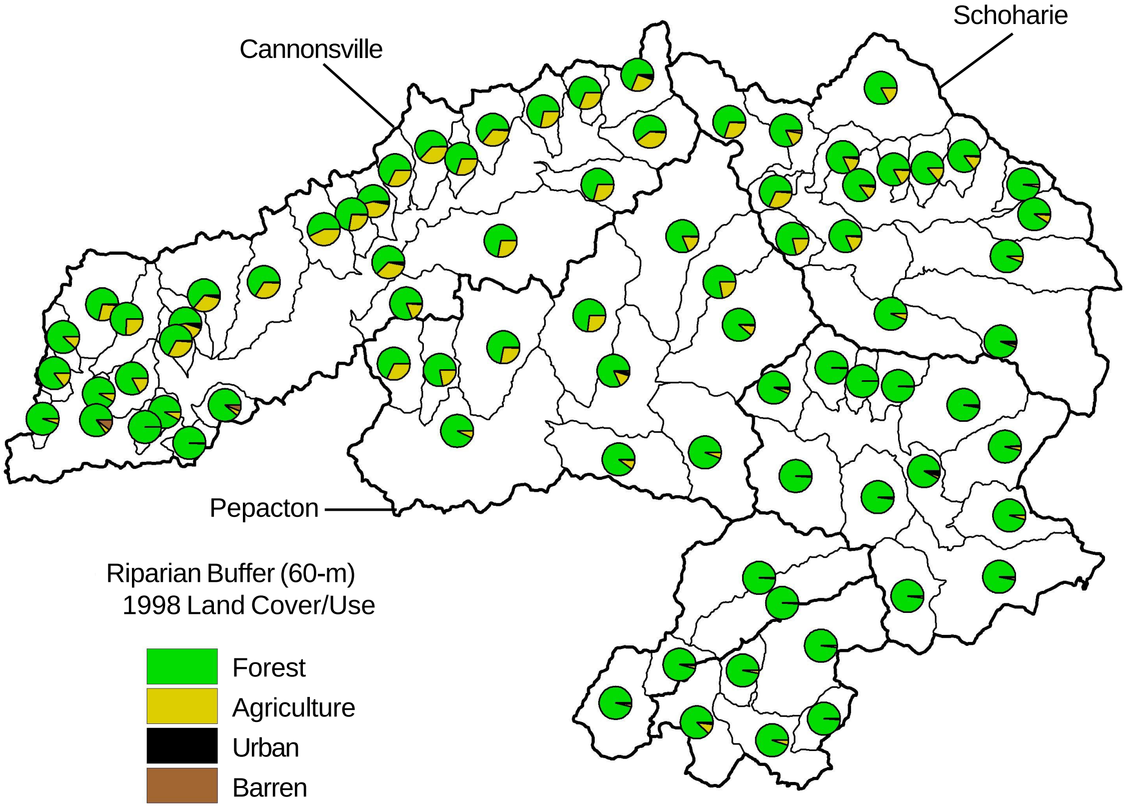


Figure 4.15. *Percentage of the riparian buffer in forest, agriculture, urban, and barren land cover/use in the Catskill/Delaware subwatersheds . The metrics were calculated as total land cover/use area within a 60-m buffer divided by total subwatershed area.*

Table 4.2. Descriptive Statistics for the Catskill/Delaware Subwatersheds and Riparian Buffers

Metric	Mean	Median	Minimum	Maximum
Subwatersheds				
Forest (%)	89	90	64	100
Urban (%)	< 1	< 1	0	2
Agriculture (%)	10	9	< 1	35
Barren (%)	< 1	0	0	3
U-Index (%)	11	10	< 1	36
Ag. (%) on Slope 5%	7	5	< 1	24
Ag. (%) on Slope 15%	< 1	< 1	0	1
Stream Length (m)	86,833	63,192	5,017	416,591
Stream Density (km/km^2)	2	2	1	3
Road Length (m)	51,920	38,240	2,678	298,501
Road Density (km/km^2)	1	1	< 1	2
Xing Count (#)	60	41	3	282
Riparian Buffers				
Forest (60 m) (%)	84	85	54	100
Agriculture (60 m) (%)	15	13	< 1	44
Urban (60 m) (%)	1	< 1	0	6
Barren (60 m) (%)	< 1	0	0	11
U-Index (60 m) (%)	17	15	< 1	47
Road Near Stream (60 m) (m/m)	< 1	< 1	< 1	< 1
Forest (120 m) (%)	84	86	53	100
Agriculture (120 m) (%)	15	14	< 1	44
Urban (120 m) (%)	1	< 1	0	5
Barren (120 m) (%)	< 1	0	0	7
U-Index (120 m) (%)	16	14	< 1	47

Landscape Summary

There is a wide range of land use across Region 2 watersheds. The variability in the regional landscape is the result of the interactions between topography, soil, climate, vegetative land cover, and human use. The coastal areas of New Jersey contain both large amounts of urban development and wetland habitat, while upstate New York has large tracts of forest interspersed with small farm community towns. The Long Island Sound area is largely dominated by cities and a vast number of interlacing roads, while the northwest has a large agricultural base. The mountainous areas, including the CD watersheds, are dominated by forest cover with small pockets of rural towns and agriculture located within the riparian buffer.

In the CD watersheds the human use, which is dominated by agriculture, is highest in the northwest watersheds and lowest in the southeast watersheds. The lowest overall forest cover is within the subwatersheds of the Cannonsville watershed, while the Rondout and Neversink have forest cover approaching 100%. The mountainous topography creates a situation where close to half of the total agricultural acreage is found on slopes greater than 5%. The amount of human use in the riparian buffer is also influenced by topography. The results from the 60- and 120-m buffer assessment indicate that riparian land use/cover parallels the watershed as a whole, having slightly greater percentages of agriculture and urban development.

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New York City's Water Supply Watersheds

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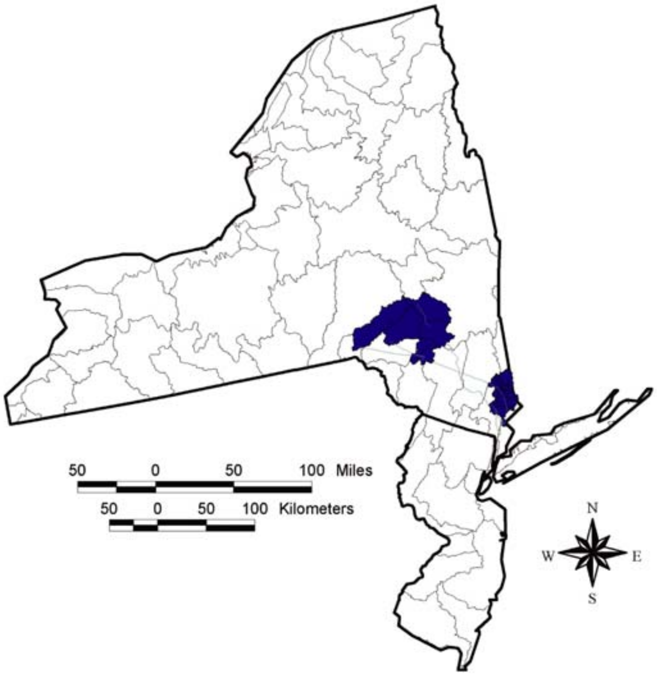
D.W. Ebert[1], K.B. Jones[1], and A. Rager[3]



[1] U.S. Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Environmental Sciences Division, Las Vegas, Nevada

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Chapter 5. Landscape Change

The landscape is transformed from one cover type to another by a number of different mechanisms. Human-induced changes (suburbanization, farming, and logging) and natural changes such as fires and flooding are the most common drivers of land cover change over time (Forman, 1995b). This chapter provides an assessment of the land cover and land use changes which have taken place in the CD watersheds across a 25-year time span.

Change in the Watershed

Between the mid-1970s and the late 1990s, a total of 8% of the CD watersheds changed from one cover type to another. The majority of the change is from agriculture to forest (5% of the area) or forest to agriculture (3% of the area). During the past two decades many acres of pasture have been released allowing forest regrowth to occur and resulting in a 2% net increase in secondary forest cover across the watersheds. The decrease in percent agriculture within the CD watershed is reflected in other related metrics, such as the human use index, percent agriculture on erodible soil, and agriculture on slopes greater than 5, 10, and 15% (Table 5.1). The next largest change, following agriculture and forest, is an increase in urban development of less than 1% across the watersheds (Figure 5.1b). The majority of the change in urban development occurred between the mid-1970s and the mid-1980s which corresponds to increases in population.

The rate of change was fairly consistent throughout the two decades, with the exception of a slight increase in change from agriculture to forest during the mid-1980s to the early 1990s (Figures 5.1a and c). The CD watersheds which had the greatest percentage of change from agriculture to forest classification are the Cannonsville, Pepacton, and Schoharie. Vegetation change between the mid-1970s and the late 1990s in these three watersheds resulted in a net increase of forest cover by 5, 3, and 2%, respectively (Table 5.2).

Table 5.1. Change in Agriculture Metrics in the Catskill/Delaware Watersheds (mid-1970s to late 1990s)

	Agriculture k >0.3		Agriculture Slope >5%		Agriculture Slope >10%		Agriculture Slope >15%	
Watershed	km^2	%	km^2	%	km^2	%	km^2	%
Cannonsville	0.24	0.02	46.00	3.92	21.00	1.74	6.00	0.49
Pepacton	0.58	0.06	12.00	1.28	4.00	0.37	0.48	0.05
Ashokan	0.40	0.06	20.00	3.03	9.00	1.34	2.00	0.25
Neversink	0.02	0.01	0.05	0.02	0.05	0.02	0.02	0.01
Schoharie	0.00	0.00	1.00	0.13	0.25	0.03	0.16	0.02
Rondout	0.00	0.00	0.59	0.24	0.42	0.17	0.01	0.00

The only watershed showing a net loss in forest cover is the Ashokan (Table 5.2). With the exception of one subwatershed, which had no change between the mid-1970s and the late 1990s, all of the Ashokan subwatersheds lost forest cover during the past two decades (Figure 5.2). The loss of forest in the Ashokan and its subwatersheds is likely related to increases in urban development (Figure 5.1b).

Barn, hayfield, and row crops in Cannonsville near Hobart.

Outside of the Ashokan, there are only three other subwatersheds which have a net loss in forest cover across time, one each in the Cannonsville, Schoharie, and Rondout (Figure 5.2). The Cannonsville subwatershed forest loss is the result of increases in urban and agriculture land use, while the Schoharie subwatershed lost forest as the result of urban growth and increases in bare ground (ski resort development) (Figure 5.1b, c, and d). Loss of forest cover in the Rondout reservoir subwatershed is also caused by urban growth.

Strip cropping (corn, alfalfa, pasture) in Cannonsville, North of New Delhi.

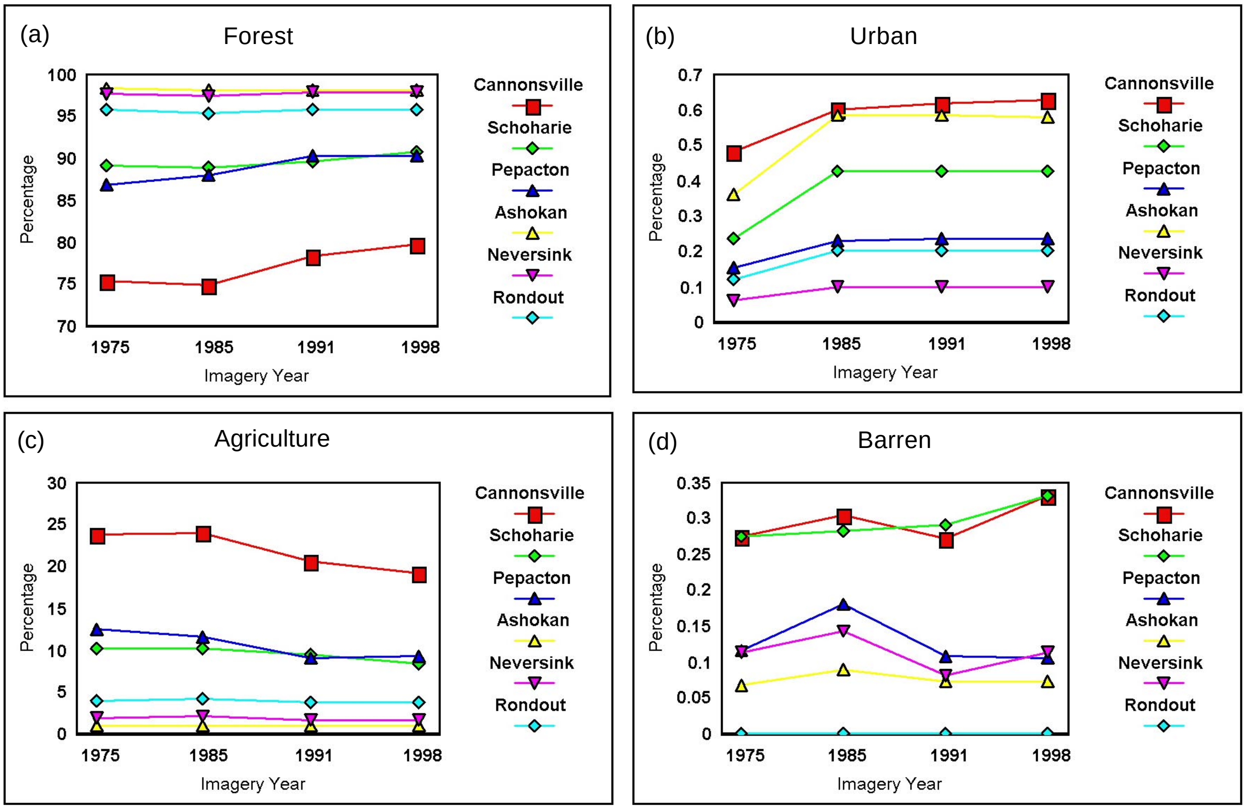


Figure 5.1. *Change in percent* ***(a)*** *forest,* ***(b)*** *urban,* ***(c)*** *agriculture, and* ***(d)*** *barren in the Catskill/Delaware watersheds from mid-1970s to late 1990s.*

Table 5.2. Land Cover/Use Change (mid-1970s to late1990s) in the Catskill/Delaware Watersheds

Watershed	Total Change		Ag to Forest		Forest to Ag		Net Change to Forest	
	km^2	%	km^2	%	km^2	%	km^2	%
Cannonsville	162	14	107	9	55	5	52	5*
Schoharie	53	7	33	4	19	2	14	2
Pepacton	80	9	55	6	24	3	32	3
Ashokan	5	1	2	< 1	3	< 1	-1	<1
Neversink	4	2	2	1	2	1	0	0
Rondout	8	3	4	2	4	2	0	0

* Seeming inaccuracies in net change results are the result of rounding.

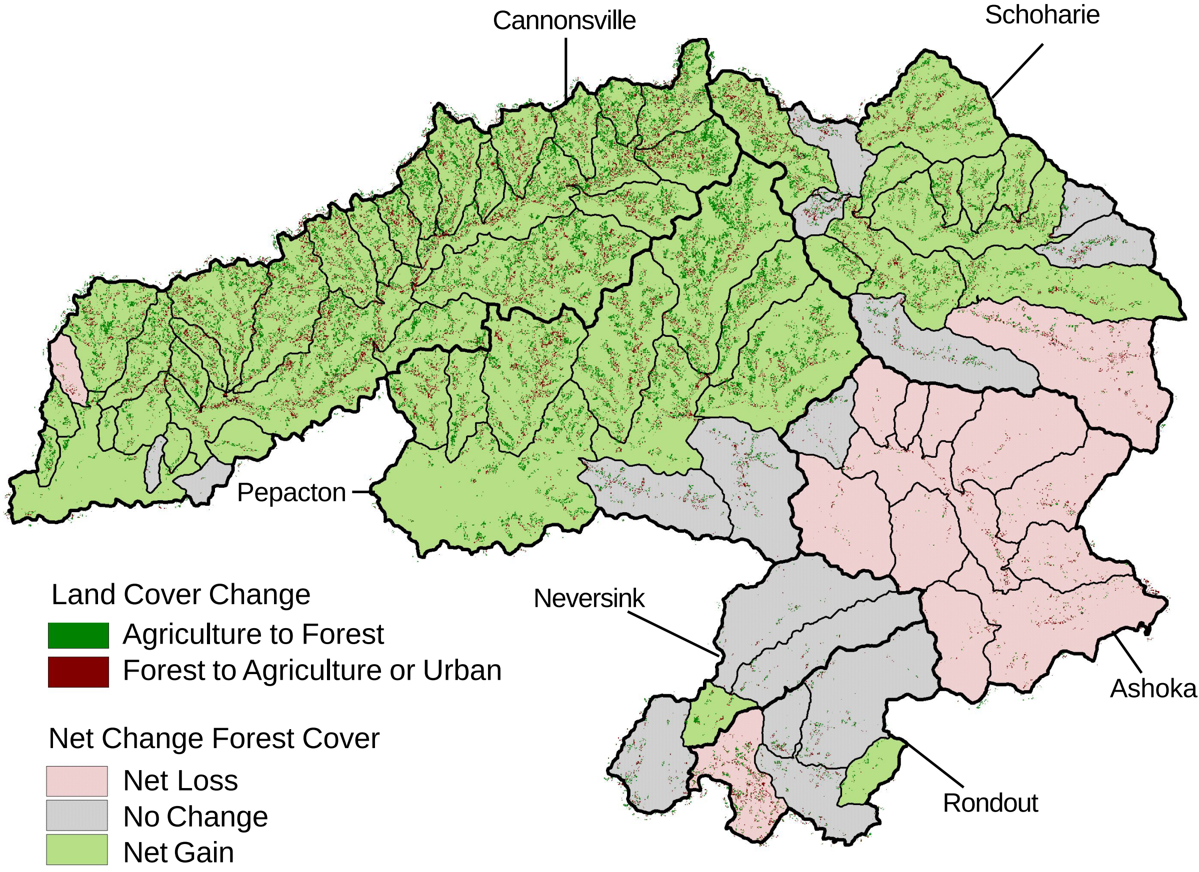


Figure 5.2. *Vegetation change between forest cover and agricultural or urban land use from mid-1970s to late 1990s in the Catskill/Delaware watersheds. The metrics were calculated as total net change divided by subwatershed area.*

Change in the Riparian Buffer

A riparian buffer can carry out the functions of filtering and sequestering nonpoint pollution. However, when riparian vegetation is replaced by agricultural or urban development, the natural buffering capacity is lost and it becomes a potential source of nutrient, bacterial, chemical, and erosional pollution (Lowrance et al., 1984). Riparian buffer make up a large proportion of the CD watersheds. As a result of high stream density, an average of 44% of the land is located within 120 m of a stream. Therefore, a large percentage (68%) of the total vegetation change observed between the mid-1970s and the late 1990s took place within riparian buffers.

Riparian buffer changes are greatest in the Cannonsville, Pepacton, and Schoharie watersheds, resulting in net gains in the amount of forest cover in the 60-m riparian from 2 to 4% (Table 5.3). The largest increases in forest cover occurred between the mid-1980s and the early 1990s (Figure 5.3a). In the Cannonsville watershed the amount of forest gain in the riparian buffer was slightly lower than the watershed as a whole, suggesting that more conversion from agriculture to forest occurred farther than 60 m from streams.

A decreasing trend in riparian agriculture occurred during the same 10 years (mid-1980s to early 1990s) as forest increases, followed by a leveling off (Figure 5.3c). The percentage change in bare ground fluctuated between each of the four time periods with no obvious trend across time (Figure 5.3d). Urban development increases in the riparian buffer of the CD watersheds were greatest between the mid-1970s and the mid-1980s paralleling watershed results (Figure 5.3b).

When assessing riparian buffer changes at the subwatershed scale, the range of gains and losses is considerably larger than suggested by the change in the watershed. Changes in the subwatershed riparian buffer range from forest cover losses of 3% to gains of 14% (Figure 5.4). In five of the CD subwatersheds forest percentages remained the same or decreased in the 120-m buffer over time (Figure 5.4); however, these same subwatersheds were shown to have an increase in percent forest cover across the whole area (Figure 5.2). Four Cannonsville subwatersheds had the highest net gains in riparian forest cover. All of the subwatersheds in the Ashokan had net decreases in riparian forest cover with time, which is most likely related to urbanization along major roads paralleling nearby streams.

Table 5.3. Total Land Cover, Agriculture (Ag), and Forest Change in the Catskill/Delaware Watersheds Riparian Buffer (60-m) from mid-1970s to late 1990s

	Total Change		Ag to Forest		Forest to Ag		Net Change to Forest	
Watersheds	km^2	%	km^2	%	km^2	%	km^2	%
Cannonsville	95	20	59	11	36	8	22	4*
Schoharie	37	10	22	5	15	4	7	2
Pepacton	50	13	34	8	16	4	18	4
Ashokan	4	2	2	1	2	1	0	0
Neversink	2	2	1	1	1	1	0	0
Rondout	5	4	2	2	2	2	0	0

* seeming inaccuracies in net change results are the result of rounding

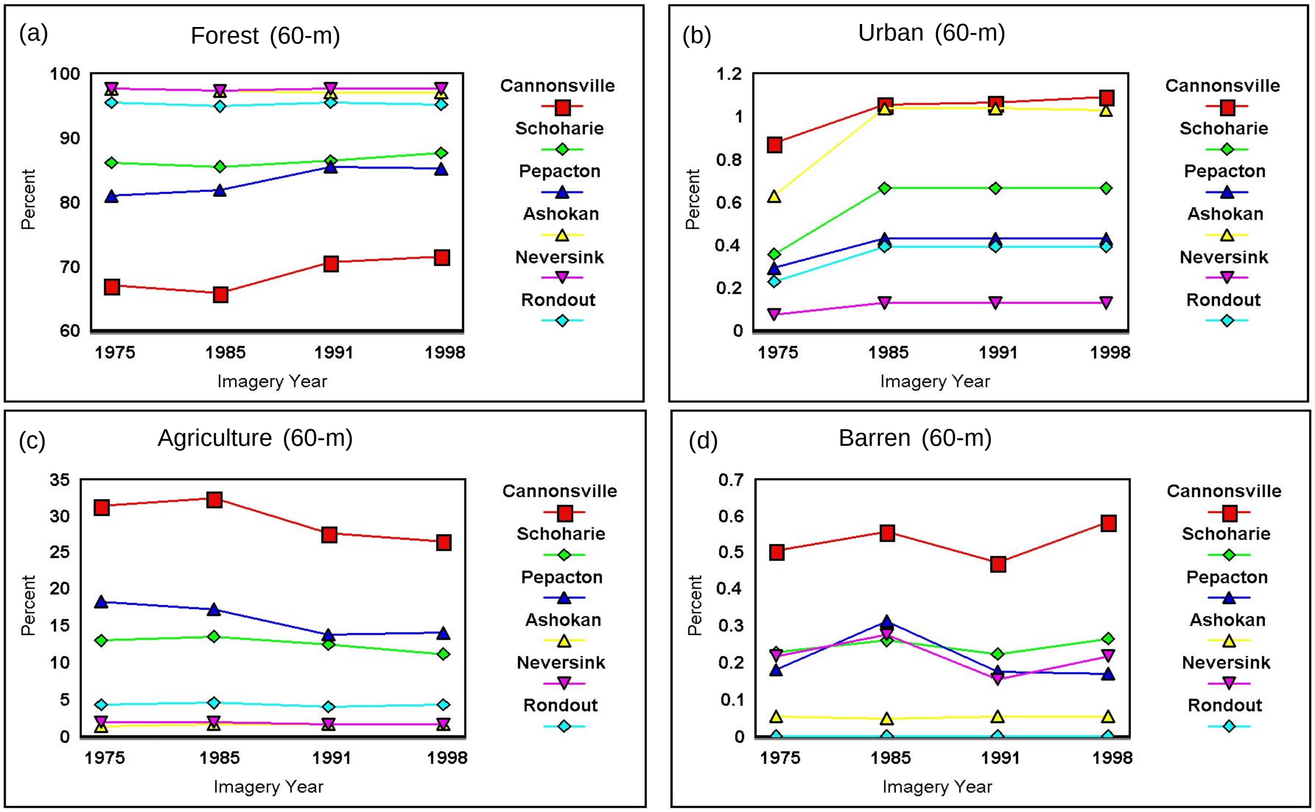
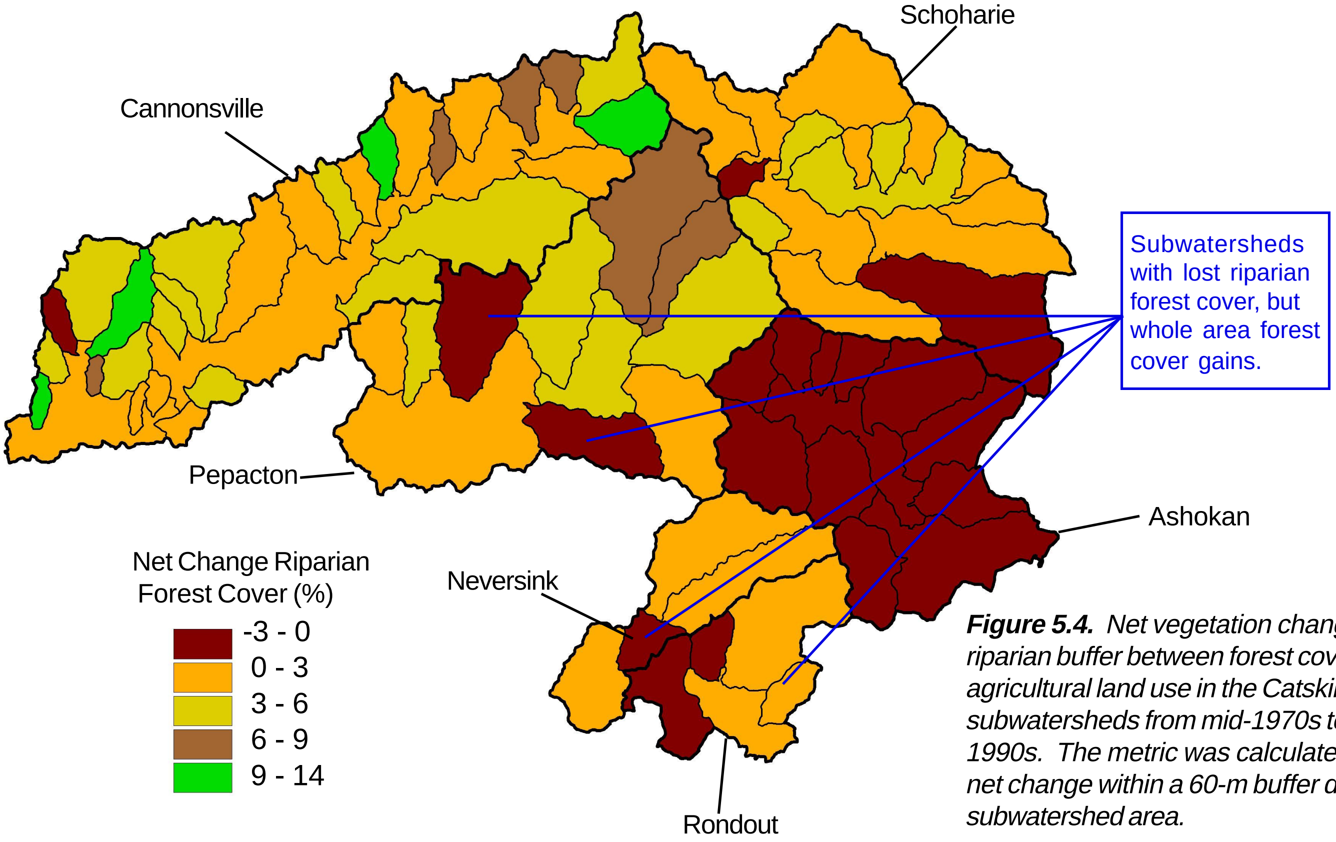


Figure 5.3. *Change in riparian buffer (60 m) percent* ***(a)*** *forest,* ***(b)*** *urban,* ***(c)*** *agriculture, and* ***(d)*** *barren in the Catskill/Delaware watersheds from mid-1970s to late 1990s.*



Subwatersheds with lost riparian forest cover, but whole area forest cover gains.

Figure 5.4. *Net vegetation change in the riparian buffer between forest cover and agricultural land use in the Catskill/Delaware subwatersheds from mid-1970s to late 1990s. The metric was calculated as total net change within a 60-m buffer divided by subwatershed area.*

Landscape Change Summary

Across all six watersheds there was a total of 2% gain in forest cover. The majority of the change was between agriculture land use and forest land cover, with only a small portion of forest loss as a result of urbanization. The increases in urban percentages occurred during the period of greatest population increase from the mid-1970s to the mid-1980s. A majority of the forest increases were between the mid-1980s and the early 1990s, with a further small increase between the early 1990s and the late 1990s. The Cannonsville watershed had the greatest number of subwatersheds showing a net gain in forest cover percentages, while the Ashokan was the only watershed to have an overall loss in forest cover with time. All but one of the subwatersheds in the Ashokan lost forest cover during the past two decades. Most of the losses in the Ashokan were the result of increased urban development between the mid-1970s and the mid-1980s and increased agriculture land use between the mid-1980s and the early 1990s. In general, changes occurring in the riparian buffer parallel watershed and subwatershed results. Forest cover gains in the subwatershed riparian buffers ranged between 1 and 14% and are mostly the result of shifts from agriculture to forest. Riparian forest losses ranged between 0 and 3%, with the highest losses occurring in the Ashokan subwatershed buffer.

Tributary of the East Branch Delaware River in the Pepacton.

Chapter 6. Surface Water Quality

A large portion of the water collected in the reservoirs of the CD watersheds is supplied by surface water runoff. The biophysical setting within the watershed influences the quantity and quality of surface water entering the streams and reservoirs (Herlihy et al., 1998). The rate of water runoff depends on properties such as forest, slope, and water-holding capacity (Nash et al., 1992 and 1999). Therefore, amounts of surface water total nitrogen, phosphorus, and fecal coliform bacteria are expected to be strongly affected by topography, soil, and vegetative cover (Slaymaker, 2000). In this chapter, spatial and temporal variation of the three measurements of water quality are examined. An average across the most recent five years of water data (1994 -1998) at all water sample site is used for spatial estimates. Temporal patterns of fecal coliform bacteria, total nitrogen and total phosphorous, discharge, and precipitation are determined using 8 to 10 years of data.

Spatial Variation

Like many of the landscape metrics, water quality measurement averages (1994-1998) of fecal coliform bacteria, total nitrogen, and total phosphorus are highest in the northwest and lowest in the southeast in the CD watersheds (Figures 6.1a, b, and c). The lowest average concentrations of total nitrogen, phosphorus, and fecal coliform bacteria counts are found within the Catskill Park boundary and other areas of low human use (Figure 2.3b). Median fecal coliform bacteria counts ranged from 0 to 200 CFU/100 ml. Maximum fecal coliform bacteria counts are sometimes greater than 10,000 CFU/100 ml at sites in the Ashokan, Cannonsville, Pepacton, and Schoharie watersheds (Table D-3). Sites having the highest average, median, and maximum total nitrogen content are located on the West Branch Delaware river in the Cannonsville watershed. Three sites in the Cannonsville watershed have greater than 1.5 mg/L median total nitrogen concentrations and are located on the upper portion of the West Branch Delaware river (Figure 6.1b). Total phosphorus median concentration values ranged from 3 to 111 *u*g/L across the watersheds. Similar to total nitrogen, the highest phosphorus average, median, and maximum values are found in the Cannonsville and Schoharie watersheds (Table D-1).

In general the average and median total nitrogen, phosphorus, and fecal coliform bacteria did not exceed state and federal surface water standards. However, in watersheds having the most human use (i.e., Cannonsville, Schoharie, and Pepacton), a few water sampling sites have maximum values that approach or slightly exceed established standards. Often these sites are located downstream of point sources, such as sewage treatment facilities, dairy farms, and landfills. The NYCDEP monitors both upstream and downstream of treatment plants to determine general effectiveness of each treatment plant (Figure 6.2). Furthermore under the MOA the NYCDEP is committed to upgrading all wastewater treatment plants in order to meet phosphorus effluent discharge limits and remove the presence of protozoan pathogens.

Over 70% of the monitored point source sites have greater median nutrient concentrations and fecal coliform bacteria counts downstream. Upstream and downstream differences are greatest in the Cannonsville and Schoharie watershed sites for all three water parameters (Table 6.1). Differences in median values for the selected treatment plant sites in each watershed ranged from 0.08 to 0.38 mg/L nitrogen, 6 to 82 *u*g/L phosphorus, and -8 to 20 CFU/100 ml fecal coliform bacteria. These results suggest that until treatment plant upgrades are implemented by the NYCDEP, nutrients and fecal coliform bacteria contributions from effluent will continue to be a problem for a number of streams in the CD watersheds.

Temporal Variation

Climate in the CD watersheds includes mild summers and cold winters. Yearly precipitation (rainfall and snowfall) can average as much as 1650 mm (65 in.), with snowfall accounting for up to 18% of the yearly total (Murdoch and Barnes, 1996). Over time, precipitation rates vary, and in turn influence discharge, surface water runoff, nutrients,

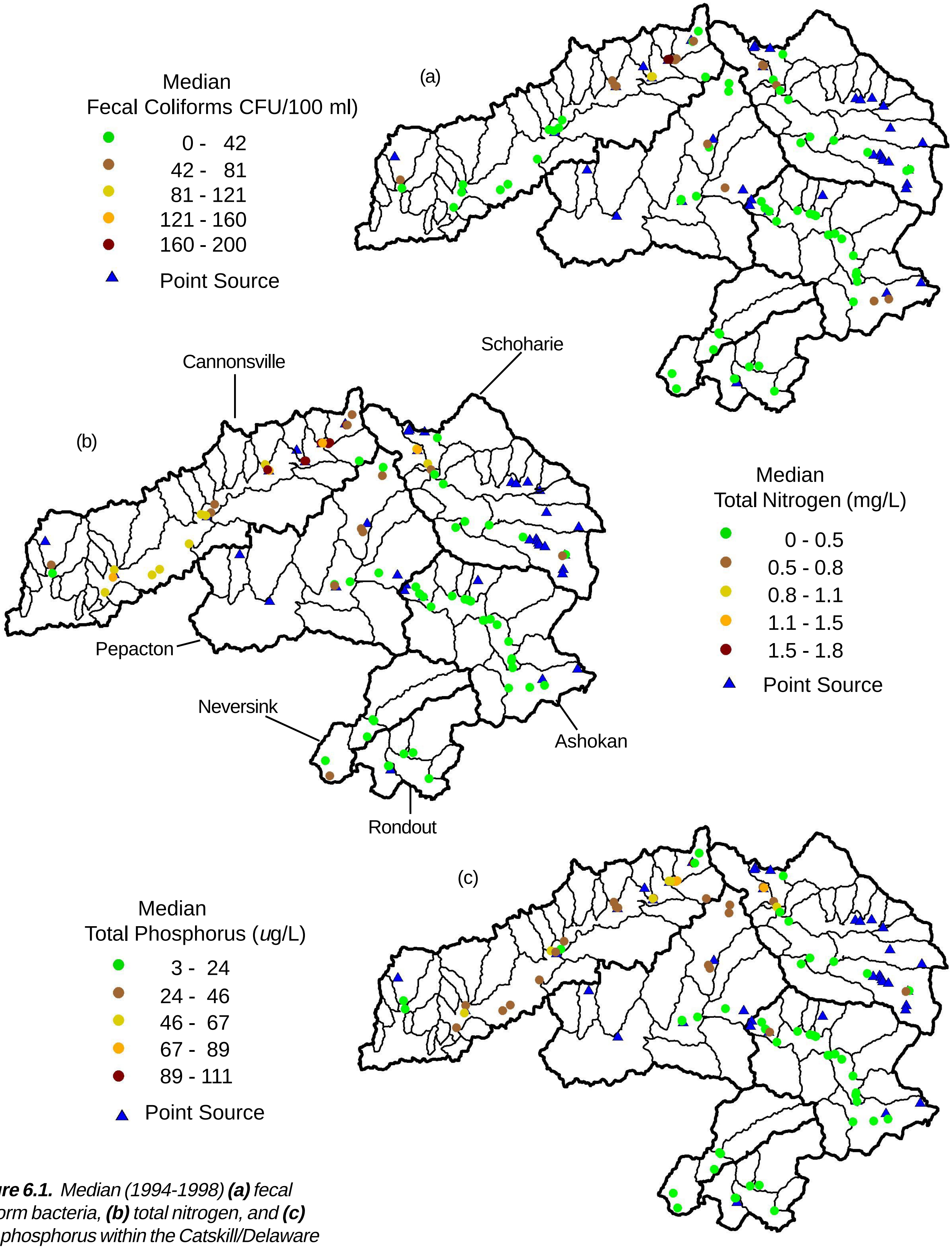


Figure 6.1. *Median (1994-1998)* ***(a)*** *fecal coliform bacteria,* ***(b)*** *total nitrogen, and* ***(c)*** *total phosphorus within the Catskill/Delaware subwatersheds.*

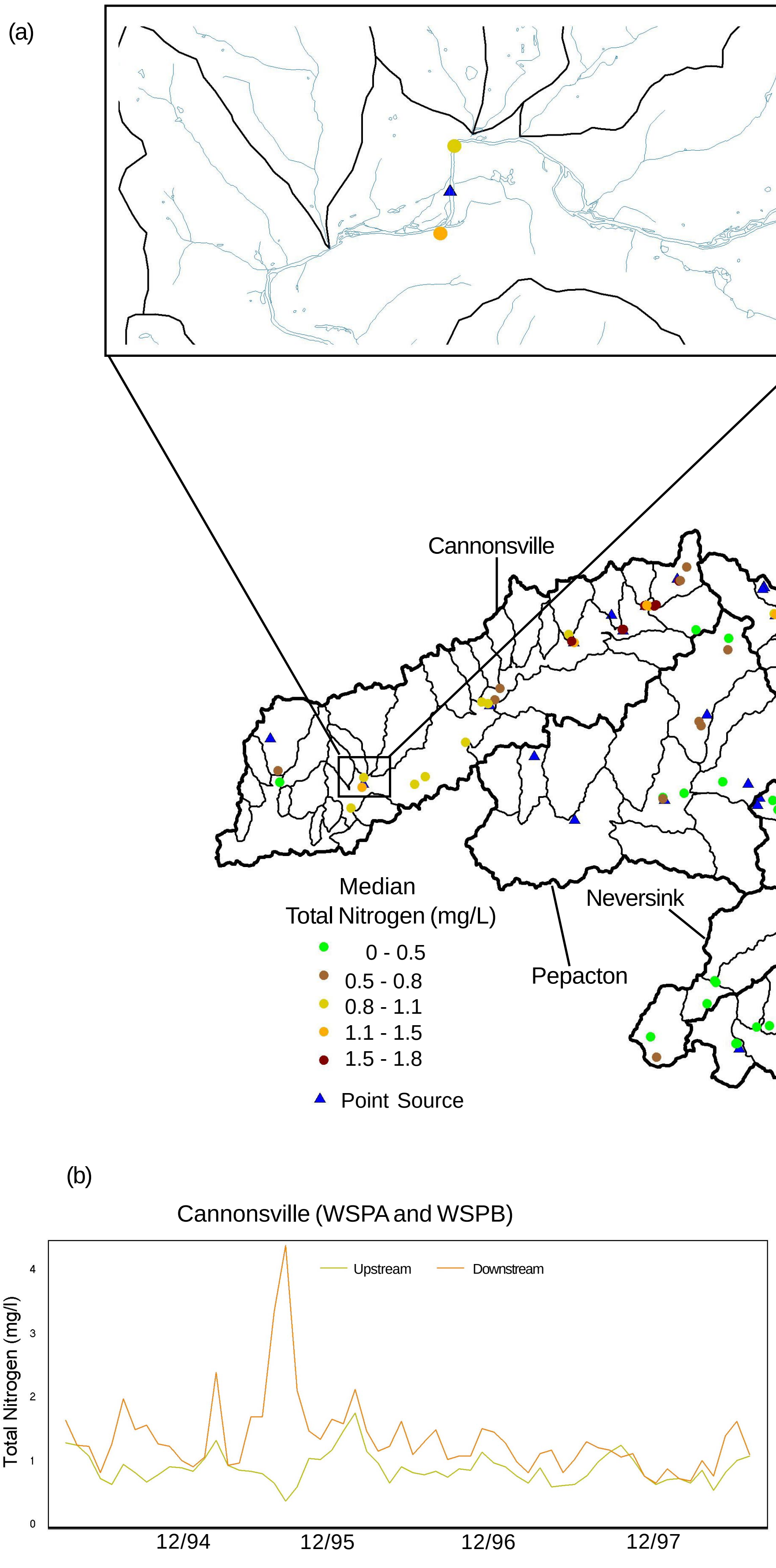


Figure 6.2. *The upstream (WSPA) and downstream (WSPB) of the Walton Sewage Treatment Plant (WSPA) surface water sample site* ***(a)*** *location and median total nitrogen and* ***(b)*** *average monthly total nitrogen from 1994 to 1998.*

Table 6.1. Mean and Median Total Nitrogen, Total Phosphorous, and Fecal Coliform Bacteria (1994-1998) in Surface Water Sample Sites Upstream and Downstream of Sewage Treatment Plants in the Catskill/Delaware Watersheds

			Total Nitrogen (mg/L)		Total Phosphorus (*u*g/L)		Fecal Coliform B (CFU/100 ml)	
Watersheds*	Site	Stream Location	Mean	Median	Mean	Median	Mean	Median
Ashokan	E3	Upstream	0.27	0.29	15.95	14.00	14.38	6.00
	E15	Downstream	0.36	0.37	28.57	23.00	19.42	10.00
Cannonsville	WSPA	Upstream	0.94**	0.92	31.17	28.00	94.76	20.00
	WSPB	Downstream	1.39	1.30	102.76	110.00	197.44	40.00
Pepacton	PMSA	Upstream	0.37	0.38	16.85	15.00	93.30	28.00
	PMSB	Downstream	0.50	0.49	27.87	25.00	75.80	20.00
Rondout	RGA	Upstream	0.35	0.36	12.37	11.00	82.00	24.50
	RGB	Downstream	0.44	0.44	17.96	17.00	97.76	22.00
Schoharie	S1	Upstream	0.35	0.36	14.71	11.00	30.19	4.00
	S2	Downstream	0.73	0.60	48.20	37.00	47.23	12.00

* there are no sewage treatment plants with up and downstream monitoring in the Neversink watershed
** red color = close to or exceeding federal and state surface water standards

and fecal coliform bacteria input to streams. Examining long-term precipitation and surface water measurements provides a picture of trends and changes over time.

Rainfall and Discharge

The average monthly rainfall in the CD watersheds from 1987 through 1998 ranges between 79 and 112 mm (3.1 and 4.4 in.) with the highest monthly rainfall average occurring in the Neversink watershed (Table 6.2). Variation in the amount of rainfall is random and does not change with time at any of the six rain gauge sites selected for temporal analysis.

The highest average monthly discharge occurs at the stream gauge in the Ashokan watershed. However, the widest range of discharge occurs at the stream gauge in the Cannonsville watershed. In contrast to rainfall, a significant 12-month cyclical pattern occurs in discharge with time at all six stream gauges selected for temporal analysis (Figures D-1, 3, 5, 7, 9 , and 11). The maximum discharge measurements are generally seen during the months of April and May. Since discharge tends to be skewed by large storm events the median values are lower than the mean.

Peaks and depressions in monthly discharge are synchronized with rainfall (Figures D-1, 3, 5, 7, and 11). Cross correlation between discharge and rainfall indicates that discharge has an immediate response to rainfall. The instantaneous affect of rainfall on discharge suggests that flow and precipitation sample sites are sufficiently close together to insure that distance between sites is not impacting the relationship between rainfall and discharge.

Table 6.2. Descriptive Statistics for Monthly Precipitation(1987-1998), Discharge (1987-1998), Total Nitrogen (1990-1998), Total Phosphorus (1990-1998), and Fecal Coliform Bacteria (1987-1998) at Select Surface Water Sample Sites in the Catskill/Delaware Watersheds

Watershed	Variable	Mean	Median	Minimum	Max
Ashokan	Precipitation (mm)	101.09	101.60	10.41	262.38
	Discharge (ft^3/sec)	735.22	517.00	149.47	2,927.60
	Total Nitrogen (mg/L)	0.17	0.17	0.02	0.60
	Total Phosphorus (*u*g/L)	11.44	10.00	6.00	30.00
	Fecal Coliform (CFU/100ml)	28.22	4.00	2.00	210.00
Cannonsville	Precipitation (mm)	93.22	81.79	9.40	224.03
	Discharge (ft^3/sec)	583.06	326.00	27.58	2,756.60
	Total Nitrogen (mg/L)	0.99	0.92	0.43	1.82
	Total Phosphorus (*u*g/L)	31.49	27.00	11.50	86.50
	Fecal Coliform (CFU/100ml)	86.21	20.00	1.50	853.33
Neversink	Precipitation (mm)	112.78	100.58	12.70	259.33
	Discharge (ft^3/sec)	195.08	117.00	19.26	898.77
	Total Nitrogen (mg/L)	0.31	0.29	0.12	0.86
	Total Phosphorus (*u*g/L)	5.61	4.00	2.00	107.00
	Fecal Coliform (CFU/100ml)	8.52	3.00	1.00	78.33
Pepacton	Precipitation (mm)	85.60	84.07	3.05	213.36
	Discharge (ft^3/sec)	54.67	34.00	2.47	257.73
	Total Nitrogen (mg/L)	0.42	0.36	0.13	0.91
	Total Phosphorus (*u*g/L)	10.34	8.00	2.00	127.67
	Fecal Coliform (CFU/100ml)	27.86	7.00	1.00	302.00
Rondout	Precipitation (mm)	97.79	91.69	5.59	271.53
	Discharge (ft^3/sec)	103.80	64.00	8.86	442.77
	Total Nitrogen (mg/L)	0.32	0.30	0.07	0.88
	Total Phosphorus (*u*g/L)	7.06	5.00	2.00	98.00
	Fecal Coliform (CFU/100ml)	23.13	8.00	1.00	404.00
Schoharie	Precipitation (mm)	79.25	76.20	2.03	261.87
	Discharge (ft^3/sec)	49.02	23.00	1.60	296.57
	Total Nitrogen (mg/L)	0.25	0.24	0.03	0.51
	Total Phosphorus (*u*g/L)	13.21	11.00	5.00	36.00
	Fecal Coliform (CFU/100ml)	80.46	16.00	1.00	2,816.25

Total Nitrogen

The Cannonsville sample site has the highest monthly mean, median, minimum, and maximum nitrogen value for the sampling period (Table 6.2). The Pepacton site had the second highest recorded mean, median, and maximum monthly nitrogen value. The average monthly nitrogen values at the other water chemistry sample sites range between 0.17 and 0.32 mg/L. The median values are similar to the means suggesting a fairly evenly distributed set of data.

Trends analyses for four of the six water chemistry sites indicate an overall decrease in monthly nitrogen values since 1990 (Figures D-2, 8, 10, and 12). However, no significant change in time took place at the Ashokan and Neversink sites. The rate of change in nitrogen at these sample sites is slight and remains near the average throughout time.

A 12-month cyclic pattern in monthly total nitrogen is present at all six water chemistry sample sites, with maximum values generally occurring during the winter and spring months (Appendix D-1, 3, 5, 7, 9, and 11). The Ashokan water chemistry sample site was the only site that didn't show an immediate nitrogen concentration response to greater discharge. Nitrogen concentrations at the other five sites respond quickly to changes in discharge, suggesting that nitrogen contributions from the surrounding landscape are expected to increase during high rainfall and snowmelt events.

Total Phosphorus

The Cannonsville water chemistry sample site has the highest mean and median monthly total phosphorus (31.49 *u*g/L) concentrations, which are more than twice those of the other five sites (Table 6.2). The Ashokan and Schoharie site had the second highest average total phosphorus concentration (11.44 and 13.21 *u*g/L). The lowest average monthly phosphorus concentration values are at the Neversink and Rondout sites. Median total phosphorus values are only slightly lower than mean values and the relative ranking of the water chemistry sites is the same as for the means.

Total phosphorus concentration significantly increases over time at the Ashokan and Schoharie sample sites (Figures D-2 and 12). However, the monthly total phosphorus concentrations at the Cannonsville and Neversink watershed sites decrease (Figures D-2 and 6). The remaining water chemistry sample sites did not show any significant trends in time.

Time series analyses indicated no significant cyclic pattern in monthly total phosphorus at any of the six water chemistry sample sites. There is a slight delay in response (1 to 2 months) of phosphorus concentrations to discharge at the Schoharie and Ashokan sites. At the site in the Cannonsville watershed there is an immediate total phosphorus to discharge response (Figure D-1). The other three sites did not show any significant response to discharge. The lack of a consistent response to discharge suggests that monthly total phosphorus concentrations were less tightly coupled to surface water runoff than total nitrogen.

Fecal Coliform Bacteria

Monthly fecal coliform bacteria counts over the sampling period are highest at the Cannonsville site, with the widest range of values at the Schoharie sample site. The average and maximum monthly counts at the Neversink site are more than two times lower than the other five sites. Like discharge data, the fecal coliform bacteria counts peak a few times a year with the majority of the counts being lower. This type of skewed data results in the lower median values seen in Table 6.2.

The only site to show any significant decreasing trend in monthly fecal coliform bacteria counts is the one located in the Schoharie watershed (Figure D-12). A slight negative slope can be seen at the other five sites, however the trend is not significant.

Only the Ashokan and Neversink sample sites have a significant 12-month cyclic pattern (Figures D-3 and 5). However, all the watershed sample sites have higher values of surface water fecal coliform bacteria during the summer months (e.g., July and August) and lower values in winter (November and December). Fecal coliform bacteria have a delayed response (1 to 5 months) to discharge in all but the Schoharie sample site, which did not respond to changes in discharge. These results suggest a potential dilution effect in spring followed by higher reproduction rates in the warm summer months when discharge is low.

Water Quality Summary

Average monthly measurements of fecal coliform bacteria, total nitrogen, and total phosphorus appear to be greatest in the northwest watersheds where human use is higher and least in the southeast watersheds where human use is lower. Point source contributions are influencing downstream sample sites by increasing nutrient concentrations and, to a lesser degree, fecal coliform bacteria counts.

There is an overall decreasing trend in monthly total nitrogen concentrations with time at four of the six water chemistry sample sites selected for temporal analysis. There doesn’t appear to be any consistent trend in monthly total phosphorus concentrations. The Cannonsville sample site, which has the highest average nutrient concentrations, is the only site where a decreasing trend over time is observed for both total nitrogen and phosphorus. Fecal coliform bacteria counts are highest in the warm summer months for all sample sites and did not change over time at five of the six sample sites. Only the Schoharie watershed sample site has a significant decreasing trend with time in fecal coliform bacteria.

Total nitrogen concentrations have a strong 12-month cyclical pattern and an instant response to the rate of discharge. Maximum values are often seen during the spring and winter months. The relationship between peak total nitrogen levels and discharge suggests that a greater contribution from surrounding landscape occurs as a result of increases in surface runoff during high rainfall and snowmelt. Total phosphorus and fecal coliform bacteria are less influenced by discharge and surface water runoff than total nitrogen. There is, however, a slight seasonal effect on fecal coliform bacteria with higher values occurring during the summer months (July and August).

Chapter 7. Landscape and Water Relationships

An imprint of landscape condition is collected and transported to the streams via surface runoff. The impact of land cover and use can be seen in the measurements of nutrient concentrations and fecal coliform bacteria counts. The previous chapters present an overview of spatial and temporal aspects of landscape and water parameters. This chapter focuses on relationships between landscape and water quality data within the 32 EPA delineated subwatersheds within the CD watersheds (Figure 2.8). The following subsections discuss regression analyses on the mid-1980s, early 1990s, and late 1990s data, as well as trends across the three time periods.

Regression Models

The riparian metrics are highly correlated with whole watershed metrics and were therefore eliminated from the regression. The forest cover metric was also eliminated, since in the CD watersheds the percent of forest is simply the inverse of the percentage of agriculture and other land uses make up only a small percentage of the area. Of the remaining landscape metrics calculated, multiple regression analyses for total nitrogen, total phosphorus, and fecal coliform bacteria indicated seven that are significant to the final models. In general, metrics in the final model which are an estimate of land use are positively related to water quality measurements (Table 7.1). Therefore, the greater the percentage of land use in the watershed, the more total nitrogen, total phosphorus, and fecal coliform bacteria present in the surface water. Two measurements of land use that are positively related to water quality, and consistently present in all three models, are percent agriculture and percent urban development. The combined effect of these two land uses strongly influences water quality measurements, explaining between 25 and 75% of the model variation (Partial R^2).

By examining the magnitude of the coefficients (ß), an indication of how contributions of a particular land use change between time periods can be determined. For example, the contribution of percent agricultural land use to each of the surface water quality measurements decreases with time from the mid-1980s to the late 1990s. Three land use measurements having for the most part a weaker positive relationship to water quality and explaining only 3 to 46% of the variability are percent barren, percent agriculture on steep slopes, and percent agriculture on erodible soils in the subwatersheds. The inclusion of these metrics in the regression models indicates that land uses which affect the rate of erosion, also affect concentrations of total nitrogen and total phosphorus and counts of fecal coliform bacteria in surface water. The only metric consistently having a negative relationship to measurements of surface water total nitrogen, total phosphorus, and fecal coliform bacteria was stream density. The negative value of the stream density metric most likely reflects the affect of water volume flowing through the streams. As stream density increases, the quantity of water reaching a site increases, diluting nutrient concentrations.

Total Nitrogen

Since total nitrogen measurements did not begin until 1990, the regressions were run for only the early 1990s and late 1990s time periods. The landscape measurements in the nitrogen regression model are strongly related (79%) to surface water total nitrogen concentrations (Table 7.1). Stream density, percent agriculture, and percent urban land use are the dominant landscape metrics in the subwatersheds for both time periods. More than half of the nitrogen variability is explained by the percentage of agriculture land use in the subwatersheds. However, the contribution of agriculture and urban land use, as indicated by the magnitude of their coefficients (ß), decreases with time. The relationship between stream density and total nitrogen concentration indicates that subwatersheds having greater stream mileage per hectare would be expected to have a lower average total nitrogen. The other two land uses which are significant, but explain only small amounts of the variability in the average total nitrogen concentration data, are percent agriculture on erodible soils and percent barren within the subwatersheds. In the early 1990s the percentage of

Table 7.1. Regression Model Estimates (ß), Partial R^2 and Model R^2 for Landscape Metrics and Surface Water Total Nitrogen, Total Phosphorus, and Fecal Coliform Bacteria for mid-1980s, early 1990s, and late 1990s

Regression Models	Mid-1980s ß	Mid-1980s Partial R^2 (%)	Early 1990s ß	Early 1990s Partial R^2 (%)	Late 1990s ß	Late 1990s Partial R^2 (%)
Log Total Nitrogen						
Stream Density	-	-	0.921	9.6	0.840	7.2
Agriculture	-	-	0.046	59.3	0.039	64.9
Urban	-	-	0.312	6.2	0.256	4.0
Ag. on Erodible Soil	-	-	0.182	4.3	-	-
Barren	-	-	-	-	1.018	3.0
Model R^2				79.4		79.1
Log Total Phosphorous						
Stream Density	-	-	0.574	3.0	0.928	7.0
Agriculture	0.052	50.5	0.047	69.5	0.032	43.1
Urban	-	-	0.233	4.3	0.362	5.4
Ag. on Erodible Soil	-	-	-	-	0.426	7.6
Model R^2		50.5		76.8		63.1
Log Fecal Coliform Bacteria						
Erodible Soil	0.271	16.6	0.206	8.5	0.132	3.3
Urban	0.409	15.9	0.428	10.5	0.389	12.2
Agriculture	0.043	31.0	0.048	48.4	0.046	12.7
Ag. on Slopes >15%	-	-	1.099	5.1	1.494	46.1
Model R^2		63.5		72.5		74.3

agriculture on erodible soil has a weak relationship to total nitrogen and by the late 1990s it is not included as part of the model. The percent of barren in the subwatersheds was only important in the late 1990s nitrogen model. Those subwatersheds having the highest amount of barren land cover have a greater amount of total nitrogen in the stream.

Total Phosphorous

As in the case of average total nitrogen, the percentage of agriculture in the subwatersheds has the strongest relationship to total phosphorus concentrations in all three time periods, explaining 43 to 70% of the variability. In the mid-1980s the percentage of agriculture in the subwatersheds is the only variable with a strong relationship to total phosphorous (51%). However, from mid-1980s to late 1990s the influence of percent total agriculture in the model (ß) decreases and other metrics, such as percent agriculture on erodible soils, stream density, and urban development make a more significant contribution. In the early and late 1990s, stream density, percent agriculture, and urban development in the subwatersheds explain more than a half of the variability in total phosphorus concentration. A fourth metric, percentage of the subwatersheds having agriculture on erodible soil, explains an additional 8% of the variability in the late 1990s model.

Fecal Coliform Bacteria

There are four significant measures of land cover and land use included in the fecal coliform bacteria model. These landscape measurements have a strong relationship to fecal coliform bacteria counts explaining 64 and 74% of the variation in the data. Fecal coliform bacteria is positively related to percent erodible soil, urban development and agriculture within the subwatersheds. Unlike total nitrogen and phosphorous, the influence (ß) of percent urban and percent agricultural in the fecal coliform bacteria model remains the same across time periods. However, the total model variability explained by percent agriculture within the subwatersheds ranges from 13 to 48%. In the early 1990s fecal coliform bacteria responded positively to the percentage of agriculture on slopes greater than 15% within the subwatersheds. The amount of variability percent agriculture on very steep slopes explains increases from 5 to 46% between the early and late 1990s. The overall contribution of this metric, as indicated by the larger coefficient, also increases with time.

Model Application

Using the late 1990s regression models, an estimate was made of potential total nitrogen, phosphorus, and fecal coliform bacteria contributions for all 79 subwatersheds based on the late 1990s land cover (Figure 7.1). The spatial distribution of human use is the most important factor affecting the maps of watershed pollution potential. The highest level of estimated nutrients and fecal coliform bacteria are located within Cannonsville subwatersheds. The West Branch Delaware River subwatershed has the greatest fecal coliform bacteria and total phosphorus measures due to the influence of the percentage of urban and agriculture on slopes >15% within the subwatershed. A similar effect of urban land use on fecal coliform bacteria and phosphorus can be seen in the lower ranking of the Ashokan subwatersheds. The subwatersheds around the Cannonsville Reservoir have the highest nitrogen content as a result of the high percentage of transitional land upstream of the lake.

The accuracy of applying stepwise regression models to other subwatersheds was tested by examining water sample data from four sites not used to develop the models. The observed nitrogen, phosphorus, and fecal coliform bacteria means from the new sites are all within the 95% confidence intervals of predicted values from subwatersheds having comparable landscape metrics (Table 7.2; Figure 7.2).

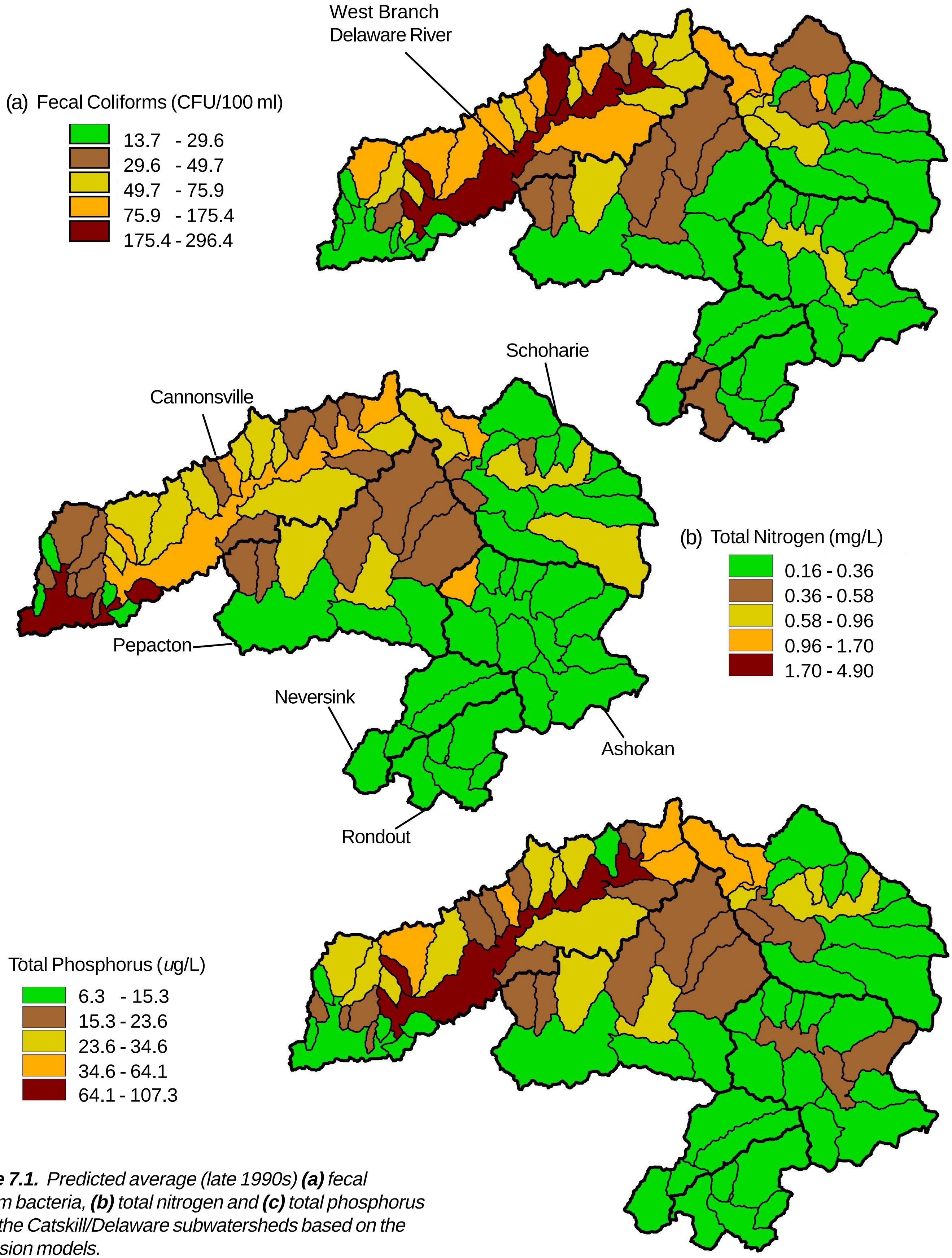


Figure 7.1. *Predicted average (late 1990s)* ***(a)*** *fecal coliform bacteria,* ***(b)*** *total nitrogen and* ***(c)*** *total phosphorus within the Catskill/Delaware subwatersheds based on the regression models.*

Table 7.2. Average Observed Total Nitrogen (TN), Total Phosphorus (TP), and Fecal Coliform Bacteria (FC) from Four Surface Water Sample Sites not used in the Landscape Models Compared with Model Predicted Upper and Lower 95% Confidence Interval (CI) Values from Subwatersheds having Similar Land Cover Percentages

Model Site	Lower 95% CI		Upper 95% CI		New Site	Observed	
	---mg/L---					---mg/L---	
	TN	log(TN)	TN	log(TN)		TN	log(TN)
BRD*	0.13	2.03	0.42	0.87	NWBR**	0.29	1.24
C-38	0.63	0.47	2.23	0.80	CWB	0.92	0.08
E12I	0.16	1.82	0.69	0.37	SCL	0.30	1.20
NK7A	0.13	2.01	0.43	0.85	NEBR	0.25	1.39
	---*u*g/L---					---*u*g/L---	
	TP	log(TP)	TP	log(TP)		TP	log(TP)
BRD	3.82	1.34	22.87	3.13	NWBR	3.91	1.36
C-38	1.27	0.24	104.58	4.65	CWB	34.85	3.55
E12I	6.49	1.87	59.74	4.09	SCL	20.49	3.02
NK7A	1.13	0.12	21.54	3.07	NEBR	3.50	1.25
	---CFU/100 ml---					---CFU/100 ml---	
	FC	log(FC)	FC	log(FC)		FC	log(FC)
BRD	4.10	1.41	47.94	3.87	NWBR	9.48	2.25
C-38	55.70	4.02	796.32	6.68	CWB	347.76	5.85
E12I	4.57	1.52	52.98	3.97	SCL	21.09	3.05
NK7A	4.53	1.51	52.46	3.96	NEBR	8.64	2.16

* The four model sites and their corresponding subwatershed locations can be seen in Figure 3.2.

** The four new sites and their corresponding subwatersheds are NWBR (West Branch Neversink River), CWB(Wright Brook), SCL (Stony Clove Creek), NEBR (East Branch Neversink River); their location within the Catskill/Delaware watersheds can be seen in Figure 2.8.

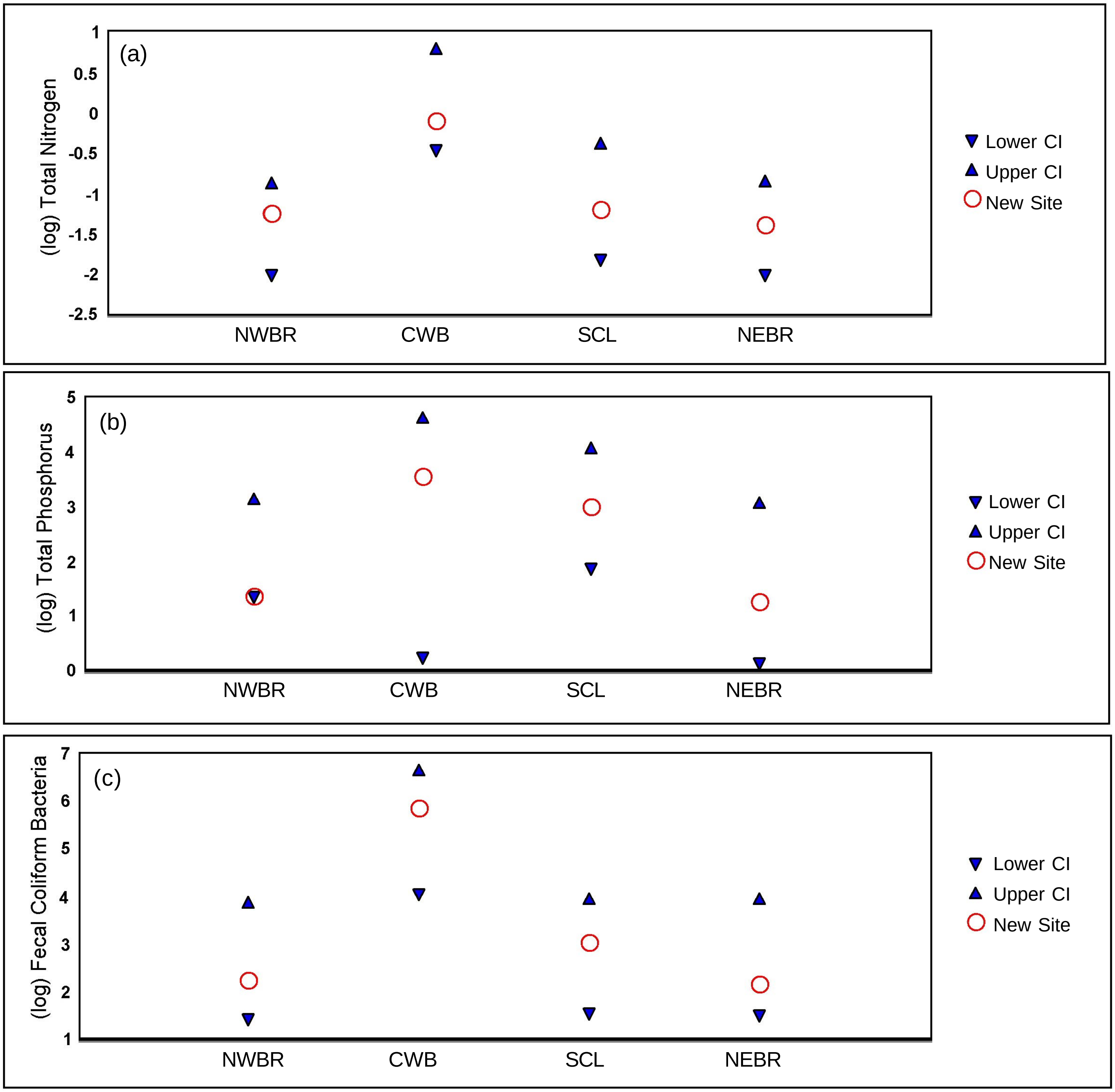


Figure 7.2. *Average observed* ***(a)*** *total nitrogen (TN),* ***(b)*** *total phosphorus (TP), and* ***(c)*** *fecal coliform bacteria (FC) from four surface water sample sites not used in the landscape models. The four new sites and their corresponding subwatersheds are NWBR (West Branch Neversink River), CWB (Wright Brook), SCL (Stony Clove Creek), NEBR (East Branch Neversink River) and their location within the Catskill/Delaware watersheds can be seen in Figure 2.8. The new site values (new site) fall within the 95% confidence intervals (CI) of the predicted model value from subwatersheds having similar land cover percentages.*

Trends in Water and Landscape

The general direction of change in surface water nitrogen, phosphorus, fecal coliform bacteria, and landscape metric percentages with time indicates that those land uses shown to be significant for single-point-in-time comparisons (i.e., the late 1990s image data compared with 1994 -1998 water data) are also important to change through time (mid-1980s to late 1990s) comparisons of water and landscape data.

Decreasing trends through time of percent agriculture land use and increasing trends through time of percent forest cover within the subwatersheds tend to coincide with decreasing total nitrogen concentrations (Table 7.3). In five subwatersheds total nitrogen decreases, while percent agriculture increases and percent forest decreases. However, in three of these subwatersheds, percent agriculture on erodible or sloped soils has decreased, suggesting the possibility of decreased nutrient runoff to streams from these types of farm fields (Table 7.4).

From 1990 to 1998 only four water chemistry sample sites showed a decreasing trend in total phosphorus concentration with time (Table 7.3). In these four subwatersheds there is a decrease in the percentage of total agriculture and an increase in percent forest cover. In all but one of these subwatersheds there was also an increase in riparian forest cover and a decrease in the amount of agriculture on sloped soils. Nine sites had slight increasing trends in total phosphorus which appear to be related to greater percentages of human use, particularly in the riparian buffer.

As seen in the regression analyses, fecal coliform bacteria trends across time appear to be related to changes in human use practices and their location within the subwatersheds. In subwatersheds having significant increases in fecal coliform bacteria levels with time, there are also increasing trends in the percentage of agriculture on erodible soils, slopes >15%, and in the riparian zone within the subwatersheds.

Relationship Summary

Landscape metrics that have a strong positive relationship with concentrations of total nitrogen, total phosphorus, or fecal coliform bacteria are percent urban and total agriculture within the subwatersheds. These two land use measurements also show up as being important in an assessment of trends with time. The smaller contribution of percent agriculture to surface water nutrient concentrations in the late 1990s regression is reflected in the percent forest cover gains and agriculture losses through time. However, in a few subwatersheds changes in land use within the 60- and 120-m riparian buffer zones appear to be more related to trends in water quality.

Stream density was the only landscape measurement included in the regression models with an inverse relationship to all three water quality measurements. As the number of streams per area increases, the amount of water flowing past the sampling point increases resulting in a dilution of surface water nutrients and fecal coliform bacteria. Three other metrics having a slight positive relationship with water quality measurements in the regression models are percent bare ground, percent agriculture on slopes >15%, and percent erodible soils within the subwatersheds. The association between trends in time of landscape percentages and total nutrients concentration data was less obvious then in the regression. However, trends in fecal coliform bacteria and percentage of human use within the watershed show a similar pattern to that seen in the regression models.

Despite decreasing trends at a majority of the water chemistry sample sites in the northwest CD watersheds (Cannonsville, Pepacton, and Schoharie), predicted levels of total nitrogen, total phosphorus, and fecal coliform bacteria within these subwatersheds are higher than those in the southeast as a result of the greater percentage of human use.

Table 7.3. Trends in Total Nitrogen (1990-1998), Total Phosphorus (1990-1998), Fecal Coliform Bacteria (1987-1998), and Landscape Metrics (1987-1998) in 32 Catskill/Delaware Subwatersheds

Watershed	Site	TN	TP	FC	FOR	AGT	ERD	SL5	SL10	SL15	URB	BAR	U_IN
Ashokan	bk	⬜	🟨	⬜	🟨	🟨	🟩	🟩	🟩	🟩	⬜	⬜	🟨
Ashokan	bnv	🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟨	⬜	⬜	🟩
Ashokan	brd	🟩	🟨	⬜	🟩	🟩	🟨	🟩	🟩	🟩	🟨	⬜	🟩
Ashokan	e1	🟩	🟨	⬜	🟩	🟩	🟨	🟩	🟩	🟨	🟨	⬜	🟩
Ashokan	e10i	🟩	🟨	⬜	🟩	🟩	🟨	🟨	🟨	🟩	⬜	⬜	🟩
Ashokan	e12i	⬜	⬜	⬜	🟨	🟨	🟩	🟨	🟨	🟨	⬜	⬜	🟨
Ashokan	lbk *	⬜	🟨	⬜	🟩	🟩	🟨	🟩	🟩	🟩	🟨	⬜	🟩
Ashokan	wdl	🟩	🟨	⬜	🟨	🟨	🟩	🟨	🟨	🟨	🟨	⬜	🟨
Cannonsville	c-38	⬜	⬜	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟨	⬜	🟩
Cannonsville	c-7 *	⬜	⬜	⬜	🟩	🟩	🟨	🟩	🟩	🟩	⬜	⬜	🟩
Cannonsville	c-79	🟩	⬜	⬜	🟩	🟩	🟨	🟩	🟩	🟩	⬜	🟨	🟩
Cannonsville	c-8	⬜	⬜	🟨	🟩	🟩	🟨	🟩	🟩	🟩	⬜	⬜	🟩
Cannonsville	wdhoa	⬜	⬜	⬜	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟨	🟩
Neversink	nk6	🟩	⬜	⬜	🟨	🟨	🟩	🟩	🟩	🟨	⬜	⬜	🟨
Neversink	nk7a *	⬜	🟩	⬜	🟩	🟩	🟩	🟨	🟨	🟨	⬜	🟩	🟩
Pepacton	p13	🟩	⬜	🟨	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟩
Pepacton	p21	🟩	🟩	⬜	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟨	🟩
Pepacton	p50	🟩	⬜	⬜	🟨	🟨	🟨	🟨	🟨	🟨	🟨	⬜	🟨
Pepacton	p52	🟩	⬜	⬜	🟩	🟩	🟨	🟩	🟩	🟩	⬜	⬜	🟩
Pepacton	p60 *	🟩	⬜	⬜	🟨	🟨	🟨	🟨	🟨	🟨	⬜	⬜	🟨
Pepacton	p7	🟩	⬜	⬜	🟩	🟩	🟨	🟩	🟩	🟩	⬜	⬜	🟩
Pepacton	p8	🟩	⬜	⬜	🟩	🟩	🟨	🟩	🟩	🟩	⬜	⬜	🟩
Rondout	rd1	🟩	🟩	⬜	🟩	🟩	🟨	🟩	🟩	🟩	🟨	⬜	🟩
Rondout	rd4	⬜	🟩	⬜	🟩	🟩	🟨	🟩	🟩	🟩	🟨	⬜	🟩
Rondout	rdoa *	🟩	⬜	⬜	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟨	🟩
Rondout	rga	🟩	⬜	⬜	🟩	🟩	🟨	🟩	🟩	🟩	⬜	⬜	🟩
Rondout	rk	🟩	⬜	🟨	🟩	🟩	🟨	🟩	🟩	🟨	🟨	🟨	🟩
Schoharie	fb4	🟩	⬜	⬜	🟩	🟩	🟨	🟩	🟩	🟨	⬜	⬜	🟩
Schoharie	s1	🟩	🟨	🟩	🟨	🟨	🟨	🟩	🟩	🟩	⬜	⬜	🟩
Schoharie	s10	⬜	⬜	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟨	🟩
Schoharie	s6i	🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟨	🟩
Schoharie	s7i *	🟩	⬜	🟩	🟩	🟩	🟨	🟩	🟩	🟩	⬜	⬜	🟩

* = sites also used in time series cross-correlation analysis with discharge and precipitiation; green = positive change (*i.e.*, increasing forest cover, decreasing land use, decreasing nutrient concentrations, and decreasing fecal coliform bacteria counts), gold = negative (*i.e.,* decreasing forest cover, increasing land use, increasing nutrient concentrations, and increasing fecal coliform bacteria counts), grey = no change; TN =Total Nitrogen; TP=Total Phosphorus; FC= Fecal Coliform Bacteria; FOR=Forest; AGT=Agriculture; ERD=Agriculture on Erodible Soils; SL5, SL10, and SL15=Agriculture on 5%, 10%, and 15% slope; URB=Urban; BAR=Barren; U_IN= U-Index.

Table 7.4. Trends in Total Nitrogen (1990-1998), Total Phosphorus (1990-1998), Fecal Coliform Bacteria (1987-1998), and Riparian Landscape Metrics (1987-1998) in 32 Catskill/Delaware Subwatersheds

Watershed	Site	TN	TP	FC	FOR 60m	AGT 60m	URB 60m	BAR 60m	U_IN 60m	FOR 120m	AGT 120m	URB 120m	BAR 120m	U_IN 120m
Ashokan	bk	⬜	🟨	⬜	🟨	🟨	⬜	⬜	🟨	🟨	🟨	🟨	⬜	🟨
Ashokan	bnv	🟩	🟨	🟩	🟨	🟨	🟨	⬜	🟨	🟨	🟨	🟨	⬜	🟨
Ashokan	brd	🟩	🟨	⬜	🟩	🟩	🟨	⬜	🟩	🟨	🟨	🟨	⬜	🟨
Ashokan	e1	🟩	🟨	⬜	🟨	🟨	🟨	⬜	🟨	🟨	🟨	⬜	⬜	🟨
Ashokan	e10i	🟩	🟨	⬜	🟩	🟩	🟨	⬜	🟩	🟩	🟩	🟨	⬜	🟩
Ashokan	e12i	⬜	⬜	⬜	🟩	🟨	⬜	⬜	🟩	🟨	🟨	⬜	⬜	🟨
Ashokan	lbk *	⬜	🟨	⬜	🟩	🟩	🟨	⬜	🟩	🟩	🟩	🟨	⬜	🟩
Ashokan	wdl	🟩	🟨	⬜	🟨	🟨	🟨	⬜	🟨	🟨	🟨	🟨	⬜	🟨
Cannonsville	c-38	⬜	⬜	⬜	🟨	🟨	🟨	⬜	🟨	🟩	🟩	🟨	⬜	🟩
Cannonsville	c-7 *	⬜	⬜	⬜	🟩	🟨	🟨	⬜	🟨	🟨	🟨	🟨	⬜	🟨
Cannonsville	c-79	🟩	⬜	⬜	🟨	🟨	⬜	🟩	🟨	🟩	🟩	⬜	🟨	🟩
Cannonsville	c-8	⬜	⬜	🟨	🟩	🟩	⬜	⬜	🟩	🟩	🟩	🟨	⬜	🟩
Cannonsville	wdhoa	⬜	⬜	⬜	🟩	🟩	🟨	⬜	🟩	🟩	🟩	🟨	⬜	🟩
Neversink	nk6	🟩	⬜	⬜	🟩	🟩	🟨	⬜	🟩	🟩	🟩	🟨	⬜	🟩
Neversink	nk7a *	⬜	🟩	⬜	🟩	🟩	⬜	🟨	🟩	🟩	🟩	🟨	🟨	🟩
Pepacton	p13	🟩	⬜	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Pepacton	p21	🟩	🟩	⬜	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	⬜	🟨
Pepacton	p50	🟩	⬜	⬜	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	⬜	🟨
Pepacton	p52	🟩	⬜	⬜	🟨	🟨	🟨	⬜	🟨	🟨	🟨	🟨	⬜	🟨
Pepacton	p60 *	🟩	⬜	⬜	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	⬜	🟨
Pepacton	p7	🟩	⬜	⬜	🟨	🟨	🟨	⬜	🟨	🟨	🟨	🟨	⬜	🟨
Pepacton	p8	🟩	⬜	⬜	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	⬜	🟨
Rondout	rd1	🟩	🟩	⬜	🟨	🟨	⬜	⬜	🟨	🟩	🟩	⬜	⬜	🟩
Rondout	rd4	⬜	🟩	⬜	🟩	🟩	🟨	⬜	🟩	🟩	🟩	🟨	⬜	🟩
Rondout	rdoa *	🟩	⬜	⬜	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	⬜	🟨
Rondout	rga	🟩	⬜	⬜	🟨	🟨	⬜	⬜	🟨	🟨	🟨	🟨	⬜	🟨
Rondout	rk	🟩	⬜	🟨	🟨	🟨	⬜	🟩	🟨	🟨	🟨	🟨	🟨	🟨
Schoharie	fb4	🟩	⬜	⬜	🟨	🟨	⬜	⬜	🟨	🟩	🟩	⬜	⬜	🟩
Schoharie	s1	🟩	🟨	🟩	🟨	🟨	⬜	⬜	🟨	🟨	🟨	🟨	⬜	🟨
Schoharie	s10	⬜	⬜	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟩
Schoharie	s6i	🟩	🟨	🟩	🟩	🟩	⬜	🟨	🟩	🟩	🟩	⬜	🟩	🟩
Schoharie	s7i *	🟩	⬜	🟩	🟩	🟩	⬜	⬜	🟩	🟩	🟩	🟨	⬜	🟩

* = sites also used in time series cross-correlation analysis with discharge and precipitiation; green = positive change (*i.e.*, increasing forest cover, decreasing land use, decreasing nutrient concentrations, and decreasing fecal coliform bacteria counts), gold = negative (*i.e.,* decreasing forest cover, increasing land use, increasing nutrient concentrations, and increasing fecal coliform bacteria counts), grey = no change; TN =Total Nitrogen; TP=Total Phosphorus; FC= Fecal Coliform Bacteria; FOR=Forest; AGT=Agriculture; URB=Urban; BAR=Barren; U_IN= U-Index.

Chapter 8. Conclusion

This final chapter provides a synopsis of the landscape and water quality results. A summary of land use metric percentages and trends and how they are related to water quality is presented. The summary section is followed by a set of recommendations that have been developed based on the results from this assessment and with regard to current and proposed future management practices.

Summary

Region 2 hydrologic units surrounding the CD watersheds are in excellent environmental condition. The forest cover in these HUCs is high and land use is minimal (30% total agriculture, 15% urban; Figures 4.2 and 4.8). In the smaller CD subwatersheds agriculture land use percentages range from 0 to 35% (Figure 4.3). However, due to low population growth rates, percentages of urban development in the CD subwatersheds only reach 3.7%. Percentages of riparian land use at the regional scale are slightly lower than in the CD watersheds and have a smaller range than the subwatersheds. Agriculture and urban land use make up from about 0 to 47% of the 60-m riparian buffer in the CD subwatersheds (Table 4.2).

Water quality in the streams of the CD watersheds remains high with only a few cases of exceedance of federal surface water requirements. However, despite the continued high quality of water in the streams of CD watersheds, point source (i.e., treatment plants) and nonpoint source (near-stream land use) impacts to stream condition remain a concern for New York City. A recent mid-course report by the EPA recommended that the city upgrade 34 sewage treatment plants and acquire more “crucial” land during the years remaining under the FAD (EPA, 2000).

In addition to inputs from waste treatment plant facilities and land use, impacts to the CD water supply watershed streams are also related to terrain influences on runoff. The steep slopes result in very rapid water flow across the landscape and into the streams. Therefore, nitrogen in the surrounding landscape will be carried quickly in runoff to streams either in solution or transported in the sediment. Stream total phosphorus concentrations do not appear to respond to rainfall-induced increases in discharge as rapidly as nitrogen. This delay in response to rainfall events suggests that base flow and ground water play an important role in total phosphorus contributions to the streams. Fecal coliform bacteria levels in the streams do not respond to increases in discharge from rainfall, but instead peak during the warm summer months when water temperature is high, flow is low, and recreational and animal usage is the greatest.

Much of the past research has investigated the relationships between landscape and water quality by examining water quality response to a degradation in ecological condition. In this study we have demonstrated that the same linkage between landscape and water quality holds true under improving ecological conditions. In the CD watersheds, releasing agricultural fields from farming has returned a small percentage (2%) of land to secondary growth forest. With the exception of a few subwatersheds the increase in forest cover took place in the northwest. Since the majority of the agriculture in the study area is located within 240 m of a stream, much of the 2% change is located within the riparian buffer.

Pepacton Reservoir, Pepacton watershed.

Agriculture land use is the major contributor to concentrations of total nitrogen and total phosphorus in the streams, but its influence is reduced as percentages within the watershed decrease. The effect of decreasing agriculture and increasing forest cover percentages is evident in the lower agriculture contribution to surface water nutrient concentration seen in the late 1990s regression analyses and in the decreasing trends in total nitrogen across time at many of the water chemistry sample sites. In subwatersheds where there are no trends in agricultural land use or forest cover, surface water nutrient concentrations remain unchanged across time.

Changes in total agriculture land use and forest cover appear to have less influence on fecal coliform bacteria trends. Fecal coliform bacteria are more affected by percentage of agriculture land use on slopes greater than 15% in the watershed. The influence of this type of land use on fecal coliform bacteria increases as total agriculture percentages decrease in the watershed. These results suggest that nitrogen and phosphorus concentrations are strongly related to land use proportions, while fecal coliform bacteria counts are related more to land use location within the watershed.

In general, application of the late 1990s regression models demonstrated that the western watersheds, which have the greatest percentage of human use, would be expected to have higher stream total nitrogen, total phosphorus, and fecal coliform bacteria counts. A number of subwatersheds stand out as being at risk from single or multiple land uses (Figure 8.1). The landscape conditions in these subwatersheds have a high potential for impacts to water quality.

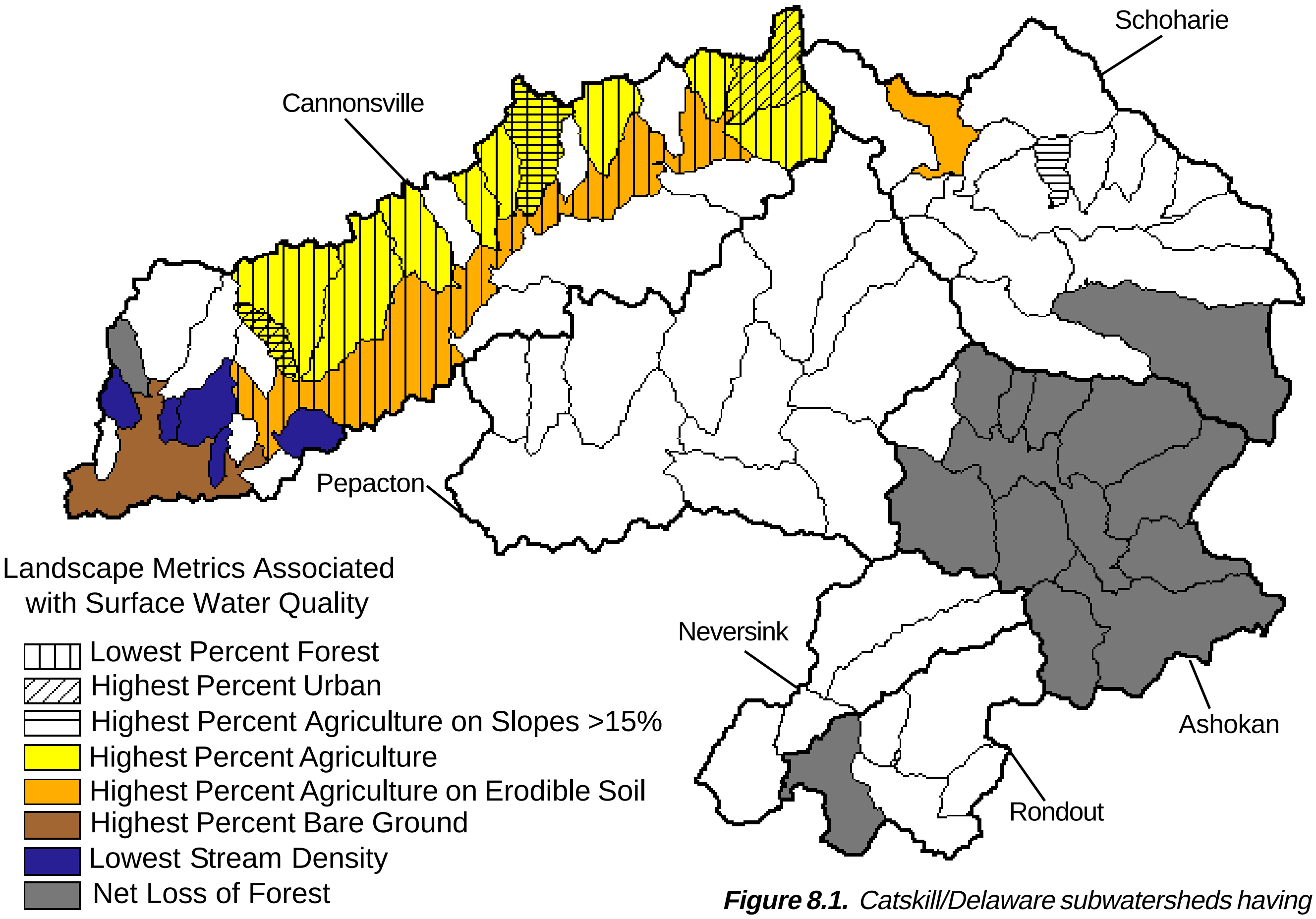


Figure 8.1. *Catskill/Delaware subwatersheds having landscape metrics associated with water quality degredation.*

Recommendations

Agriculture is the greatest human use of the land occurring in the CD watersheds and one of the most likely factors affecting water quality. Agricultural land use can result in nonpoint pollution via runoff from barnyards, pastures, and crop fields. Agricultural practices can also lead to stream sedimentation by increasing erosion rates. In response to potential risks to the water supply, the Watershed Agriculture Council began promoting whole farm planning. The planning process is voluntary and implements farm-specific best management practices (BMPs). Since farming is important to the economic viability of the area, continued education and enrollment of the land owners in these types of programs offers an attractive way of reducing nonpoint source pollution to surface waters (Addiscott, 1997). However, results from this study suggest that in addition to farm-specific criteria, the Watershed Agriculture Council may also want to consider gearing its programs toward subwatershed specific needs.

Targeting the farms in an at risk subwatershed, may achieve greater overall pollution reduction to the water supply than random areawide enrollment. For example, the subwatersheds of Third Brook and Elk Creek have a high potential for pollution by nitrogen, phosphorus, and fecal coliform bacteria (Figure 7.1). Outreach in these subwatersheds might want to focus on farms with cropping or pasture taking place on steep slopes or erodible soils. Subwatersheds having a low stream density and in close proximity to a reservoir are more likely to contribute nutrients to the reservoirs. Encouraging farmers within this type of subwatershed to preserve wetland and riparian areas through enrollment in wetland reserve and forest easement programs would help buffer streams and reservoirs from nutrient runoff impacts.

While comprising a much smaller percentage of the CD watersheds than agriculture, urban land use remains one of the key components in determining water quality. The current regulations proposed in the MOA for improving exiting treatment plant performance and restricting new waste treatment plants should help reduce point source inputs in the CD watersheds. However, in addition to waste treatment plant inputs, high percentages of impervious surfaces and agriculture have increased discharge rates, sedimentation, and pollutant runoff in a number of the subwatersheds. Only after the current impacts are alleviated in the at-risk subwatersheds can planning for future offset needs be implemented.

An urban planning program that helps landowners develop BMPs for golf courses, parks, backyard gardens, and lawns could help address some of the current impacts. Offsetting future land uses will most likely require increasing the percentage of forest cover, particularly in the riparian buffer. One way to help promote more riparian forest is by increasing the setback requirements for human use from 30 to 60 or 120 m. Another recommendation would be for the Watershed Agriculture Council's Forestry Program to set up a model forest in the riparian buffer of one of the more urbanized areas. The study area would provide an excellent opportunity for education outreach and green space for the nearby community.

Balancing water quality protection and economic growth requires a great deal of thought, coordination, and cooperation. Targeting watersheds and farms for possible BMP implementation depends on which pollutant is of highest priority to the community. Numerous groups depend on the water from the CD watersheds for drinking, irrigation, recreational use, and livestock production. As demonstrated by the results of this study, human use of the landscape has direct consequences on water quality resources. Even changes as small as 2% can have an effect. Whether or not the change is beneficial to the quality of water in the CD water supply rests on the choices made by those living in the area. Economic and social incentives which encourage forestry management, and agriculture and urban planning for specific subwatershed needs within the CD watersheds can help facilitate the continued success of long-term watershed management plans set forth in the MOA.

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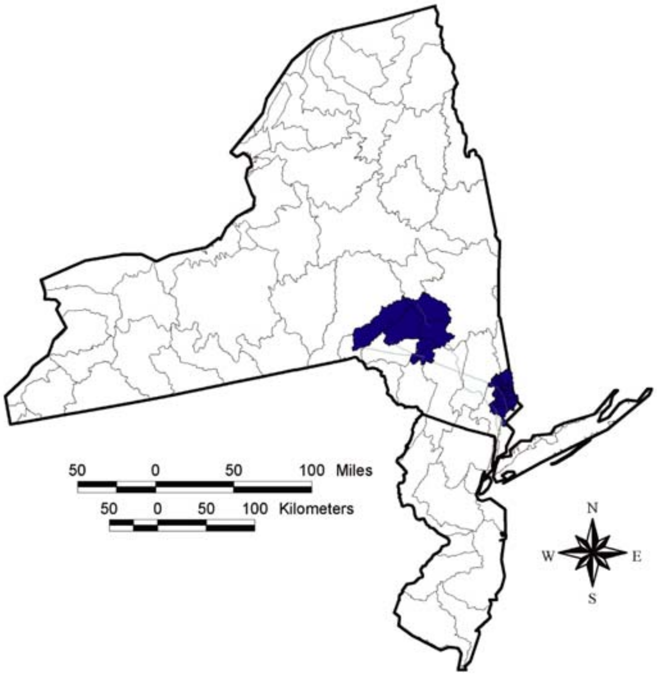

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Appendix A. Methodology Details

This appendix gives greater details on the methods used to classify imagery, assess the accuracy of the classification, delineate watersheds, calculate the reported landscape metrics, and analyze the data.

Image Classification

The land cover classifications for this study were produced using a modified version of the binary change mask technique (Yuan et al., 1998). Land cover data sets for the Catskill/Delaware watersheds were produced for four time periods:

1. mid-1970s,
2. mid-1980s,
3. late-1980s/early-1990s, and
4. late-1990s.

The land cover classification for the mid-1970s was produced from Landsat MSS images acquired in 1973, 1975, and 1976 (Table A-1). The MSS images acquired in the 1970s contained severe banding and/or line dropouts in band 1. Therefore, the bands 2 (red), 3 (mid-infrared), and 4 (mid-infrared) from one leaf-on and one leaf-off scene were combined into a six-band multi-date mid-1970s image. Since the 1975 image contained clouds, the final classified image also contained a “cloud” category. This cloud class was used as a mask to create another 6-band image using bands 2, 3, and 4 of the leaf-off image (1976) and the secondary leaf-on image (1973).

Land cover classification data for the other three time periods were produced using Landsat TM images. Composite images were created for mid-1980s, early-1990s, and late-1990s by combining Landsat TM bands 3 (red), 4 (infrared), and 7 (mid-infrared) from the leaf-off and leaf-on imagery to create a six-band multi-date image for each time period. These bands were chosen because they represent most of the variation within the scene. Then any clouded areas in the image were masked out. A cloud mask was used to create a second 6-band image from bands 3, 4, and 7 of the April 17, 1985, and June 10, 1987 images.

Fifty spectral classes were generated from the six-band multi-date images using unsupervised classification. Using 20 National High Altitude Photography (NHAP) and 21 National Aerial Photography Program (NAPP) photographs distributed throughout the study area as reference, each spectral cluster was compared to the land cover type in the six-band multi-date image. Spectral clusters were tentatively labeled as one of five land cover types or as mixed between two or more land cover types. The five land cover types are (1) water, (2) developed, (3) barren/ski area/ transitional, (4) forest/forested wetlands/secondary forest, and (5) agricultural. Pixels that were spectrally confused or mixed between or among land cover types were assigned into land cover types

Table A-1. Images Used in Land Cover Classifications of Catskill/Delaware Watersheds

Classification Time Period	Leaf-Off Image Date	Leaf-On Image Date
Mid-1970s	3/23/1976*	7/7/1973* 8/2/1975*
Mid-1980s	4/17/1985	7/21/1984 6/10/1987
Early-1990s	4/28/1989	6/21/1991
Late-1990s	4/15/1996	7/26/1998

*Landsat MSS Scene. All other scenes are Landsat TM.

using a series of GIS decision rules. GIS data assembled for this land cover classification project include: (1) a 10-m resolution Digital Elevation Model (DEM) resampled to 30- and 60-m resolutions; (2) data derived from the DEMs (i.e., slope, aspect, hillshade); (3) population density; (4) road density; (5) distance from major roads; (6) City Lights data; (7) distance from streams; (8) bedrock geology; (9) surficial geology; (10) soils; and (11) Normalized-Difference Vegetation Index (NDVI).

The remaining confused pixels were resolved interactively by the analyst. In most cases, the analyst compared the confused clusters to the raw satellite image or to aerial photographs and manually assigned the pixels to a land cover type.

Because a spectral signature for barren ground is so difficult to discern in this region, the barren areas were edited manually with the aid of air photo and satellite image interpretation. Ski areas were identified from tourist maps of the region. Because the ski area texture was easy to distinguish in the leaf-off scene, the analyst was able to screen-digitize their boundaries and include them in the classified image. The transitional areas within flood plains were added through use of a flood plain mask. The flood plain mask was created by screen digitizing all areas upstream from the upstream margin of the reservoir that: (1) were in flat areas (slope <5%) and (2) appeared on the images to include braided streams. All confused pixels or forest pixels within the flood plain were defined as transitional. The three classified images for both the mid-1970s and mid-1980s were merged to create a final image for each of these two time periods.

To facilitate post-classification change comparisons between the mid-1970s and the other land cover data sets, the 1980s and 1990s land cover data were resampled to 60-m resolution. Resampling only slightly alters the land cover totals (Table A-2).

Table A-2. Catskill/Delaware Watersheds Land Cover Area (ha) 30-m versus 60-m Resolution

Land Cover	Mid-1970s	Mid-1980s	Late-1980s/Early-1990s	Late-1990s
30 meter				
Water	——-	10,709	10,894	10,819
Developed	——-	1,809	1,826	1,832
Barren	——-	838	722	827
Forest	——-	374,111	381,027	382,904
Agricultural	——-	50,722	43,442	41,064
60 meter				
Water	10,537.92	10,706	10,894	10,820
Developed	1,230.84	1,807	1,826	1,835
Barren	724.32	846	724	834
Forest	374,254.92	374,083	381,027	382,898
Agricultural	51,626.88	50,798	43,447	41,034

Accuracy Assessment

Accuracy assessment points were chosen using a stratified random sample technique (Fitzpatrick-Lins, 1981, Skirvin *et al.*, 2000). The total number of samples was determined using equation 1. This is the minimum number of samples required using binomial probability theory.

$$n = (z/e)^2 * p * q \qquad (1)$$

where:
n = total number of samples
e = allowable error
p = expected accuracy
q = 1 - p
z = standard normal score for the 95% two-tail confidence level (1.96)

In this study, p was 0.75 and e was 0.05, or $n = (1.96/0.05)^2 * 0.75 * 0.25 = 288.12$ (rounded up to 289). These 289 samples were apportioned among the five land cover classifications according to area, but with a minimum of at least 25 samples per class (Table A-3). Because the amount of change in the area was very small, the area proportions for the early 1990s were used for all dates.

Sample points were randomly selected within the correct cover type with one restriction. The sample had to be located in the center of a homogeneous area (defined as a 90-m by 90-m or larger neighborhood) made up of a single land cover type. The same point locations were used for all dates.

Aerial photographs and other available independent imagery was used as reference or "truth" to determine the accuracy of the Landsat classifications. In order to minimize error due to landscape change, the acquisition dates of the reference data were within two years of the acquisition of the Landsat data. The error matrices which follow compare the classifications from the satellite data and the manually interpreted photographs (Tables A-4 to A-7). Reading across the rows shows the number of points in each class according to the satellite classification; reading down the columns shows the number of points in each class according to the photographic interpretation. Values along the diagonal are in agreement, numbers off the diagonal disagree. Producer's accuracy is a measure of omission error and relates to how well an area can be classified. Producer's accuracy is the total number of pixels within a class (on the diagonal) correctly identified, divided by the column total or total number of that category. The user's accuracy is the total number of correct in a class (on the diagonal), divided by the row total or total number classified in the category. User accuracy is a measure of commission and indicates the probability that what is classified in the image is on the ground. Overall accuracy was quite high for all four dates. Two other measures of accuracy conducted on the error matrix data were the Cohen Kappa and Kendall's Tau-B, which include omission and commission errors (Congalton, 1991).

Table A-3. Calculated and Actual Number of Samples Used in the Accuracy Assessment

Land Cover Class	Calculated number of samples	Actual number of samples
Water	8	25
Developed	1	25
Barren	1	25
Forest	250	250
Agriculture	30	30

Table A-4. Mid-1970s Classification Error Matrix

	Photography					
Satellite	Water	Developed	Barren	Forest	Ag	User Accuracy
Water	25	0	0	0	0	100%
Developed	0	15	0	2	0	88%
Barren	0	0	18	0	5	78%
Forest	0	12	0	234	11	91%
Ag	0	5	0	6	22	67%
Producer Accuracy	100%	47%	100%	97%	58%	

Overall accuracy = 314/355 = 0.8845
Cohen = 0.7614
Kendall’s Tau B = 0.6665

Table A-5. Mid-1980s Classification Error Matrix

	Photography					
Satellite	Water	Developed	Barren	Forest	Ag	User Accuracy
Water	25	0	0	0	0	100%
Developed	0	18	1	4	0	78%
Barren	0	0	18	1	4	82%
Forest	0	3	3	235	9	94%
Ag	0	2	0	2	30	88%
Producer Accuracy	100%	78%	82%	97%	70%	

Overall accuracy = 326/355 = 0.9183
Cohen = 0.83502
Kendall’s Tau B = 0.7925

Table A-6. Early 1990s Classification Error Matrix (69 missing points due to lack of adequate photography - 9 water, 11 developed, 13 barren, 28 forest, and 8 ag)

	Photography					
Satellite	Water	Developed	Barren	Forest	Ag	User Accuracy
Water	16	0	0	0	0	100%
Developed	0	11	0	3	0	79%
Barren	0	0	11	1	0	92%
Forest	0	5	0	216	1	97%
Ag	0	3	0	0	19	86%
Producer Accuracy	100%	58%	100%	98%	95%	

Overall accuracy = 273/286 = 0.9545
Cohen = 0.8833
Kendall’s Tau B = 0.8240

Table A-7. Late 1990s Classification Error Matrix

	Photography					
Satellite	Water	Developed	Barren	Forest	Ag	User Accuracy
Water	25	0	1	0	0	96%
Developed	0	19	0	4	2	76%
Barren	0	0	18	1	4	78%
Forest	0	7	1	240	11	93%
Ag	0	3	0	0	19	86%
Producer Accuracy	100%	66%	90%	98%	53%	

Overall accuracy = 321/355 = 0.9042
Cohen = 0.7986
Kendall’s Tau B = 0.7106

Watershed Delineation

The subwatershed boundaries, or the area contributing to the sample point location, were produced using 10-m digital elevation data (U.S. Geological Survey, DEM) and Arc/Info Grid software. Small errors (sinks) in the DEM were filled to ensure a continuous drainage network and flow accumulation, and direction grids were created.

Drainage channels were then generated using cells with flow accumulations over 900 (i.e., cells into which at least 900 other cells or 9 hectares drained). When water sample point coordinates were imprecise, sample points were manually moved to overlay a best approximation of the appropriate drainage channel. This step was necessary to properly generate contributing areas. In most cases, a location description was available and used to move points to their "correct" locations. When that was not possible, points were moved to the closest point on a drainage. Finally, the watershed command in Grid was used to produce contributing areas for each sample point.

Landscape Metrics

The majority of the landscape metrics used in this report were calculated with the Analytical Tools Interface for Landscape Assessments (ATtILA), an ArcView extension developed by the EPA Landscape Ecology Branch. Those not calculated by ATtILA will be noted in the following descriptions. ATtILA is available free of charge by emailing ebert.donald@epa.gov. Using ATtILA requires ArcView software and the Spatial Analyst extension, both are commercial products available from Environmental Systems Research Institute (ESRI; www.esri.com).

Forest, agriculture, urban, and barren land cover.
These landscape metrics were all calculated using overlay techniques. To determine the proportion of land cover in an area (watershed or subwatershed), the boundary for that area was used to clip the data. Recall that the land cover data were in a raster or grid cell format. The clipped boundary was overlaid on the land cover classification, and any cell whose center was within the boundary was included in the analysis for that area. To compute the proportion of land cover, wetlands, for example, the number of wetland cells inside the boundary was divided by the total number of cells inside the boundary minus those cells classified as water. This process was repeated for forest, total agriculture, barren, pasture, crop, and urban land covers.

Human use index.
The calculations for the human use index used the same method as above, but the numerator was changed to include two or more land cover types. For the human use index (U_Index), the metric was calculated by dividing the number of cells with agriculture or urban within a given watershed by that watershed's total number of non-water land cover cells. For natural vegetation index (N-Index), the numerator was defined as the number of cells within the watershed with forest, wetlands, or barren land cover.

Forest, agriculture, urban, and barren, land cover within 30-, 60-, and 120-m buffer of streams.
First, stream data were converted to a raster format using 30 meter cells so they lined up with the land cover. Then they were buffered on each side by 30, 60, and 120 m (one, two, and four cells). Land cover cells that were inside these expanded areas were then extracted from the initial land cover grid and placed into separate riparian zone land cover grids. Finally the watershed and subwatersheds boundaries were overlaid with the riparian zone land cover data. For each watershed, metrics were calculated as the number of cells of a particular land cover (e.g., wetlands) within that watershed's particular buffer zone (e.g., 120 meters) divided by the number of nonwater land cover cells within the respective buffer zone.

Human use index within 30-, 60-, and 120 m buffer of streams.
The calculations for the human use index along streams used the same method as for land cover along streams, but the numerator was changed to include two land cover types: agriculture and urban. For each of the riparian buffers, the metric was

calculated by dividing the number of cells with agriculture or urban land cover within a buffer zone for a given watershed by the total number of nonwater land cover cells for that buffer zone.

Agriculture on slopes >5%, >10%, and >15% slope.
A grid of slope measurements was queried to see where slopes were >5%, >10%, and >15%. At these locations, the land cover data were examined and the cells classified as agriculture were extracted into a slope-dependent agriculture land cover grid. Next, the boundary for each watershed and subwatershed was overlaid on this grid and, for each area, the number of cells representing agriculture on slopes >5%, >10%, and >15% was determined. This figure was then divided by the total number of nonwater land cover cells within the boundary to calculate the metric.

Stream length and density.
The streams map was overlaid with the watershed and subwatershed boundaries and the streams were clipped along the boundaries. All stream segments within a given boundary were then measured and summed for the stream length metric. Distances were reported in kilometers. Stream length was then divided by the total area, in square kilometers, of the respective watershed for the stream density metric.

Road length and density.
Road length and density calculations were similar to those of stream length and density. Road length is the total length of roads in kilometers within the watershed while road density is road length divided by the area of the watershed in square kilometers.

Roads crossing streams.
To find where roads crossed streams, the roads map was overlaid with the streams map, and any point where roads and streams intersected was used in the metric. The intersection points were then overlaid with the watershed and subwatershed boundaries and the number of points per area was summed. That figure was then normalized by dividing by the total length of streams in kilometers located within the watershed.

Roads within 60 m of streams.
First the streams were buffered to a distance of 60 m. Next, the roads were clipped by the buffer boundaries and only segments found within the buffer zone were used for the metric. The lengths of these road segments, in kilometers, were summed for each watershed and subwatershed. Lastly, the total length of roads for each particular watershed was standardized by dividing it by that watershed's total length of streams, also in kilometers.

Soil Erodibility, Total Organic Carbon, Soil Clay Content (non-ATtILA).
The tables and soil polygon coverages from the USDA-NRCS SSURGO data base were used to generate an average for each of the soil measurements which were then weighted by percent of the polygon area and upper soil layer depth (see SURRGO instruction manual). The average was then associated to its corresponding soil polygon. The polygon coverages for each soil metric were then converted to a 30-m grid and overlaid with the boundary for each watershed and subwatershed. To compute the soil metrics the sum of cell values inside the watershed and subwatershed boundaries were divided by the total number of cells inside the boundary.

Agriculture on Erodible Soils (non-ATtILA).
A grid of k-factor measurements was queried to see where erodibility was greater than or equal to 0.3. At these locations, the land cover data were examined and the cells classified as agriculture were extracted into an erodible-dependent agriculture land cover grid. Next, the boundary for each watershed and subwatershed was overlaid on this grid and, for each area, the number of cells representing agriculture on erodible soils greater than or equal to 0.3 was determined. This figure was then divided by the total number of nonwater land cover cells within the boundary to calculate the metric.

Agriculture in Watershed Located within the Riparian Zone (non-ATtILA).
The percent of total watershed agriculture located within the riparian zone was determined by taking the

area of riparian agriculture (see above) and dividing it by the area of total agriculture within the watershed.

Statistical Analyses

Time series analysis, ARIMA/SAS program, was used to explore the cyclic behavior of water quality, discharge, and precipitation data. The correlogram is an ARIMA output that shows the behavior of the data with time. Water quality, discharge, and precipitation data were collected by different agencies, at different times and frequencies during the months of this study; therefore monthly averages were generated for each data set for use in the analyses.

The monthly averages for water quality were also used to assess trends in time. When assessing temporal measurements, serial correlation in the errors may occur and effect the standard error of the coefficient. Therefore, autoregression (PROC AUTOREG/SAS), which can account for residual serial correlation, was used to determine trends. The model is described as:

$$(2)\quad Y = \beta_0 + \beta_i x + \varphi_1 R_k$$

Where Y is the dependent or predicted value (i.e., total nitrogen), β and φ are regression coefficients, x is time, R is the residual, and k is the lag time. By using a stepwise selection option to select residuals of any lag that contribute significantly, autoregression can fit the errors to the model. If the lag residuals are independent, they will not be added to the model.

Relationships between landscape metrics and water quality data were explored using a stepwise multiple regression technique (PROC REG/SAS). Regression consists of means of dependent values determined by an independent value (Steel and Torrie, 1980). Multiple regression allows for analysis of the relationship between a dependent variable (i.e., average total nitrogen) and many independent variables (landscape metric percentages). However, in order to conduct such an analysis, data must meet a set of basic assumptions (homogeneity of variances and normal distributions). While there are nonparametric procedures available that do not require meeting the above assumptions, they work best on data sets having a sample size less than 10 and may not extract as much information as a valid parametric data analysis (Steel and Torrie, 1980).

Prior to the regression analyses pairwise correlations were used to detect any high colinearity between the landscape variables. A correlation cutoff value of | 0.85 | was used to determine if the landscape metrics were too closely related. High colinearity causes the coefficient to be unstable within the model, making it unreliable in predicting the contribution of landscape metrics on the water quality parameters. When two landscape metrics were correlated |> 0.85 |, one of the metrics was excluded from the regression analysis. Log-transformed total nitrogen, total phosphorous, and fecal coli data were used to linearize the relationship with landscape metrics. The residuals for the final model were checked for outliers, randomness, and normality. Cook's D test was used to detect outliers. To test model stability a variance inflation factor (VIF) was calculated during the multiple regression analysis. If the VIF exceeds 10, then inclusion of a variable in the final model must be justified.

Results of the regression model are interpreted using the magnitude of their coefficients (β) and R^2 values, which indicated the contribution of individual landscape metrics in the model to the variation in water quality, and total R^2 values, which give an idea of the ability of the models to explain variation.

Appendix B. Regional Watershed Landscape Metrics

Table B-1. Land Cover/Use (early 1990s) for the EPA Region 2, 8-Digit Watersheds

HUC	N-Index (%)	Forest (%)	Wetland (%)	Urban (%)	Pasture (%)
1100005	76.97	74.06	2.90	2.40	16.52
1100006	82.72	79.18	3.54	13.00	2.01
1100007	22.26	21.43	0.83	69.80	1.09
2010001	80.54	79.23	1.31	2.24	12.14
2010004	90.70	89.57	1.12	1.22	4.03
2010006	82.94	77.80	5.14	1.83	7.75
2020001	98.59	96.95	1.65	0.51	0.20
2020002	97.60	92.89	4.71	0.71	1.05
2020003	64.05	61.38	2.66	6.15	20.96
2020004	62.91	59.52	3.39	6.13	24.91
2020005	77.30	76.75	0.55	1.09	17.08
2020006	73.15	71.30	1.85	8.35	13.38
2020007	71.29	68.70	2.60	4.77	17.78
2020008	70.75	67.56	3.19	11.51	13.79
2030101	69.30	66.28	3.02	24.24	3.83
2030102	25.44	25.10	0.34	66.73	0.51
2030103	51.56	46.45	5.10	42.67	1.87
2030104	27.25	21.85	5.40	60.11	6.49
2030105	46.58	41.04	5.54	22.34	24.11
2030202	28.54	26.57	1.98	58.85	4.14
2040101	82.19	81.86	0.33	0.66	14.62
2040102	93.36	93.16	0.20	0.53	4.34
2040104	91.57	89.60	1.97	2.97	3.06
2040105	57.08	53.12	3.96	8.96	26.30
2040201	39.98	32.37	7.61	13.19	33.48
2040202	44.79	35.53	9.26	29.02	15.93
2040206	48.12	40.72	7.40	6.65	22.77
2040301	73.30	59.58	13.71	12.16	5.60
2040302	66.51	55.56	10.95	9.92	5.74
2050101	70.68	69.79	0.89	1.34	24.04
2050102	70.75	70.06	0.69	1.57	21.95
2050103	72.29	72.12	0.17	3.48	20.38
2050104	68.89	68.77	0.12	0.80	24.55
2050105	68.62	68.34	0.28	2.87	21.42
4120101	52.21	51.90	0.31	3.44	31.23
4120102	56.39	56.09	0.29	1.07	35.85
4120103	42.82	42.60	0.22	12.10	36.20

Blue HUCs = Watersheds surrounding the New York City supply watersheds

Crop (%)	Total Ag. (%)	Barren (%)	U-Index (%)	Road Length (m)	Road Density (km/km²)
3.42	20.32	0.32	23.03	819,565.78	1.43
0.58	4.26	0.01	17.28	352,689.86	2.82
1.05	6.99	0.95	77.74	6,362,652.39	8.10
4.91	17.18	0.04	19.46	2,597,430.99	1.13
3.68	7.89	0.19	9.30	2,912,002.47	1.05
7.11	15.05	0.18	17.06	2,982,493.97	1.03
0.47	0.68	0.21	1.41	3,188,419.45	0.74
0.56	1.66	0.03	2.40	1,718,242.00	0.63
8.26	29.78	0.02	35.95	5,558,674.05	1.68
5.32	30.90	0.06	37.09	10,072,620.88	1.50
4.22	21.57	0.05	22.70	3,055,777.05	1.27
3.72	18.30	0.20	26.85	11,413,186.04	1.84
5.03	23.83	0.11	28.71	5,826,959.64	1.85
2.34	17.55	0.19	29.25	6,121,631.55	2.52
0.78	6.37	0.10	30.70	6,970,869.21	3.85
0.20	7.81	0.02	74.56	3,549,940.48	9.45
0.42	5.68	0.10	48.44	15,415,997.38	5.24
1.55	12.38	0.27	72.75	8,338,286.06	7.30
4.55	30.84	0.24	53.42	9,555,411.38	3.42
3.47	11.49	1.12	71.46	19,219,451.69	6.89
2.33	17.13	0.01	17.81	3,018,618.96	1.30
1.68	6.11	0.01	6.64	2,403,224.74	1.11
1.70	5.40	0.06	8.43	3,055,590.12	1.52
6.20	33.74	0.23	42.92	6,174,342.61	2.63
10.76	46.49	0.34	60.02	1,940,712.14	3.00
6.22	25.00	1.19	55.21	8,099,793.23	4.42
9.71	44.61	0.62	51.88	5,871,971.23	2.18
2.24	12.79	1.75	26.70	9,501,064.02	3.04
4.10	21.93	1.64	33.49	3,925,393.29	2.52
3.58	27.97	0.01	29.32	7,123,367.50	1.36
5.16	27.57	0.10	29.25	5,779,477.46	1.40
2.78	24.20	0.02	27.71	3,661,074.65	1.56
5.31	30.25	0.06	31.11	2,494,621.01	1.36
6.10	28.47	0.04	31.38	4,464,783.38	1.69
12.19	44.22	0.14	47.79	1,428,990.80	1.80
6.20	42.43	0.12	43.61	1,946,842.95	1.37
6.43	45.02	0.06	57.18	4,750,118.20	2.46

Table B-1 (continued). Land Cover/Use (early 1990s) for the EPA Region 2, 8-Digit Watersheds

HUC	N-Index (%)	Forest (%)	Wetland (%)	Urban (%)	Pasture (%)
4120104	30.50	29.59	0.90	12.42	41.44
4130001	23.73	22.70	1.04	3.92	47.71
4130002	60.23	59.91	0.31	0.89	30.74
4130003	31.88	31.22	0.67	4.82	43.80
4140101	43.78	41.04	2.75	9.57	34.79
4140102	73.08	68.04	5.03	0.84	21.61
4140201	42.60	40.98	1.62	4.16	38.59
4140202	65.65	58.13	7.51	3.74	23.33
4140203	61.65	56.21	5.44	4.93	25.06
4150101	83.42	72.29	11.13	0.88	12.28
4150102	39.14	35.40	3.74	1.41	52.69
4150301	45.60	42.23	3.37	2.43	46.08
4150302	84.03	74.25	9.78	0.43	13.19
4150303	72.09	63.77	8.32	0.47	23.24
4150304	84.75	80.49	4.25	0.87	11.94
4150305	93.89	85.46	8.43	0.63	4.08
4150306	91.36	84.00	7.37	0.21	6.82
4150307	76.58	71.24	5.33	0.67	19.52
5010001	80.41	80.00	0.41	1.03	15.40
5010002	58.28	54.66	3.61	2.26	31.90
5010004	55.64	53.61	2.03	0.55	37.56

Crop (%)	Total Ag. (%)	Barren (%)	U-Index (%)	Road Length (m)	Road Density (km/km^2)
12.62	56.73	0.35	69.50	4,901,419.39	2.57
23.22	72.12	0.23	76.27	4,368,403.88	1.66
7.71	38.87	0.01	39.77	5,055,149.99	1.46
17.58	63.10	0.20	68.12	5,355,459.99	1.89
9.12	46.55	0.09	56.22	4,402,852.02	2.43
4.25	25.99	0.10	26.93	2,959,807.26	1.18
13.26	53.17	0.08	57.40	15,965,159.51	1.78
6.53	30.37	0.25	34.35	5,318,815.68	1.41
7.04	33.36	0.06	38.35	695,004.34	2.01
2.63	15.02	0.68	16.58	4,405,838.34	0.88
6.42	59.45	0.01	60.86	1,115,646.50	1.33
5.39	51.73	0.24	54.40	165,591.55	1.20
1.91	15.16	0.38	15.97	2,191,387.56	0.82
2.80	26.08	1.35	27.91	1,446,399.88	0.98
2.19	14.24	0.14	15.25	1,655,811.15	0.99
1.03	5.20	0.28	6.11	2,466,381.39	0.75
1.28	8.11	0.31	8.64	2,020,860.31	0.93
2.97	22.61	0.14	23.42	2,108,333.08	1.03
2.75	18.51	0.05	19.59	4,150,871.85	1.56
6.61	39.41	0.05	41.72	2,848,904.92	1.46
5.77	43.81	0.00	44.36	353,299.53	1.22

Table B-2. Riparian Buffer (60m) Land Cover/Use (early 1990s) for the EPA Region 2, 8-Digit Watersheds

HUC	Stream Length (m)	Stream Density (km/km2)	N-Index (%)	Forest (%)	Wetlands (%)
1100005	402,588.43	0.71	77.25	68.67	8.58
1100006	139,828.37	1.13	87.38	79.23	8.15
1100007	220,821.48	0.32	40.95	30.13	7.78
2010001	1,076,898.25	0.47	81.34	75.46	5.88
2010004	1,172,848.61	0.42	89.43	86.03	3.40
2010006	1,569,841.24	0.54	86.91	74.26	12.66
2020001	2,530,329.75	0.59	97.51	91.02	6.49
2020002	1,902,101.64	0.70	96.83	81.84	14.99
2020003	1,574,346.74	0.48	68.19	60.20	8.00
2020004	5,454,127.58	0.81	71.04	64.21	6.84
2020005	1,473,805.06	0.61	68.63	67.31	1.32
2020006	3,335,542.50	0.54	74.27	68.52	5.75
2020007	1,684,439.24	0.32	71.43	66.95	4.48
2020008	1,809,946.15	0.74	74.26	65.60	8.66
2030101	1,585,754.50	0.47	40.31	35.95	4.34
2030102	262,010.21	0.71	40.08	38.79	1.27
2030103	1,156,958.88	0.41	60.64	55.21	5.43
2030104	950,255.82	0.93	48.08	27.46	20.59
2030105	2,421,022.98	0.87	63.64	47.15	16.50
2030202	980,786.39	0.37	51.34	31.55	13.76
2040101	1,358,908.20	0.59	76.26	75.40	0.85
2040102	979,925.94	0.45	87.04	86.31	0.73
2040104	1,145,453.46	0.34	87.33	80.41	6.92
2040105	2,063,088.82	0.88	65.81	55.07	10.74
2040201	712,134.67	1.10	66.11	44.46	21.65
2040202	2,246,462.23	1.23	70.63	41.99	28.63
2040206	4,986,824.18	1.85	83.49	37.59	45.86
2040301	5,563,562.45	1.78	86.98	48.45	38.51
2040302	2,155,799.29	1.39	89.72	45.33	44.39
2050101	3,667,424.33	0.70	66.73	64.53	2.20
2050102	3,074,667.92	0.74	71.00	69.19	1.81
2050103	2,024,411.84	0.86	74.28	73.71	0.56
2050104	754,002.36	0.41	72.07	71.71	0.36
2050105	1,663,626.49	0.63	74.34	73.51	0.83
4120101	434,306.00	0.55	62.30	61.88	0.42
4120102	947,026.94	0.67	60.13	59.26	0.86

Blue HUCs = Watersheds surrounding the New York City supply watersheds

Urban (%)	Pasture (%)	Crop (%)	Total Ag. (%)	Barren (%)	U-Index (%)
4.05	13.91	3.67	17.57	0.18	21.80
10.63	0.72	0.90	1.62	0.00	12.25
53.37	0.98	4.05	5.04	3.68	59.05
3.79	8.55	5.63	14.18	0.08	18.05
2.85	3.03	4.46	7.48	0.24	10.57
2.44	4.62	5.89	10.51	0.13	13.09
0.93	0.25	1.03	1.28	0.28	2.49
1.39	0.80	0.97	1.76	0.01	3.17
6.76	15.92	9.10	25.02	0.03	31.81
4.22	20.53	4.16	24.69	0.05	28.96
2.51	21.85	6.96	28.80	0.06	31.37
7.92	12.63	4.98	17.61	0.15	25.68
2.49	20.36	5.01	25.37	0.02	27.88
10.65	11.17	3.76	14.93	0.16	25.74
30.63	1.47	2.21	3.68	0.03	34.33
54.05	0.63	5.24	5.87	0.02	59.92
35.47	0.55	1.57	2.12	0.01	37.60
41.69	5.33	3.28	8.61	0.07	50.35
15.08	18.16	2.86	21.02	0.26	36.36
42.78	1.89	3.89	5.78	6.13	48.66
1.82	18.23	3.57	21.80	0.01	23.63
2.19	7.81	2.96	10.77	0.00	12.96
2.48	6.65	2.97	9.62	0.03	12.14
9.60	20.11	3.25	23.36	0.19	33.15
7.51	22.03	3.95	25.98	0.16	33.64
17.11	8.44	2.37	10.81	0.76	28.69
3.06	9.00	3.97	12.97	0.51	16.50
8.55	2.29	1.28	3.57	0.92	13.02
4.17	1.83	1.94	3.77	2.34	10.28
2.37	26.50	4.40	30.89	0.00	33.27
2.26	20.87	5.74	26.62	0.13	29.00
3.63	18.49	3.60	22.08	0.01	25.72
2.15	18.60	7.07	25.66	0.11	27.93
3.76	16.89	4.99	21.88	0.03	25.66
4.31	24.08	8.94	33.01	0.38	37.70
1.68	31.62	6.52	38.14	0.06	39.87

Table B-2 (continued). Riparian Buffer (60m) Land Cover/Use (early 1990s) for the EPA Region 2, 8-Digit Watersheds

HUC	Stream Length (m)	Stream Density (km/km2)	N-Index (%)	Forest (%)	Wetlands (%)
4120103	1,616,498.49	0.84	53.78	53.38	0.40
4120104	1,569,370.17	0.83	39.82	38.25	1.57
4130001	2,438,611.62	0.93	30.87	28.96	1.91
4130002	2,324,509.38	0.67	58.50	57.14	1.36
4130003	2,510,899.36	0.88	43.69	42.10	1.59
4140101	1,467,445.66	0.82	53.87	48.22	5.64
4140102	2,443,500.89	0.98	79.55	69.82	9.40
4140201	7,555,960.27	0.84	54.07	50.36	3.71
4140202	3,163,041.44	0.84	74.26	59.60	14.65
4140203	289,294.53	0.84	72.10	59.83	12.27
4150101	4,330,523.65	0.86	84.42	64.44	19.99
4150102	623,373.50	0.71	48.45	39.30	9.15
4150301	92,056.46	0.77	49.13	39.21	9.92
4150302	2,457,122.13	0.92	86.17	66.82	19.34
4150303	1,361,924.01	0.92	80.23	59.70	20.54
4150304	141,852.20	0.08	78.09	65.00	13.08
4150305	2,759,552.41	0.84	94.30	74.43	19.87
4150306	2,098,149.72	0.97	91.86	76.18	15.68
4150307	1,617,949.30	0.80	77.18	69.57	7.61
5010001	1,564,807.07	0.59	68.27	66.84	1.43
5010002	1,048,013.86	0.54	62.63	52.21	10.42
5010004	256.24	0.00	45.19	41.35	3.85

Urban (%)	Pasture (%)	Crop (%)	Total Ag. (%)	Barren (%)	U-Index (%)
7.71	32.47	6.01	38.48	0.02	46.22
5.99	41.83	12.05	53.87	0.31	60.18
3.59	46.66	18.54	65.20	0.34	69.13
1.67	30.50	9.32	39.82	0.01	41.50
3.27	39.80	13.19	52.99	0.06	56.31
7.47	29.10	9.54	38.65	0.02	46.13
0.91	16.80	2.73	19.54	0.33	20.45
3.73	32.04	10.10	42.14	0.06	45.93
3.49	17.76	4.40	22.16	0.09	25.74
3.62	17.94	6.20	24.14	0.15	27.90
0.89	11.98	2.41	14.39	0.30	15.58
2.28	43.02	6.24	49.26	0.01	51.55
3.78	39.10	8.00	47.10	0.00	50.87
0.37	11.71	1.44	13.15	0.31	13.83
0.53	17.27	1.34	18.61	0.63	19.77
1.40	17.61	1.90	19.51	1.00	21.91
0.73	3.77	0.90	4.68	0.29	5.70
0.26	6.68	0.96	7.65	0.24	8.14
1.01	19.49	2.29	21.78	0.03	22.82
1.75	24.67	5.27	29.94	0.04	31.73
3.39	26.41	7.55	33.96	0.03	37.37
0.00	48.08	6.73	54.81	0.00	54.81

Appendix C. Catskill/Delaware Subwatershed Landscape Metrics

Table C-1. Land Cover/Use (late 1990s) for NYCDEP Subwatersheds

Watershed	Subwatershes	Forest (%)	Urban (%)
Ashokan	Ashokan Reservoir	97.08	1.22
Ashokan	Beaver Kill	98.25	0.26
Ashokan	Birch Creek	96.58	0.29
Ashokan	Broadstreet Hollow	99.77	0.08
Ashokan	Bush Kill_Ash	99.14	0.07
Ashokan	Bushnellsville Creek	99.49	0.05
Ashokan	Esopus Creek	96.46	1.92
Ashokan	Esopus Creek Headwaters	99.54	0.05
Ashokan	Little Beaverkill	97.99	0.11
Ashokan	Peck Hollow	99.94	0.03
Ashokan	Stony Clove Creek	98.98	0.70
Ashokan	Woodland Creek	99.26	0.41
Cannonsville	Bagley Brook	88.35	0.34
Cannonsville	Beers Brook	95.58	0.01
Cannonsville	Betty Brook	80.70	0.12
Cannonsville	Cannonsville Reservoir	95.55	0.01
Cannonsville	Chamberlain Brook	96.97	0.00
Cannonsville	Chase Brook	99.61	0.00
Cannonsville	Dry Brook_Can	93.60	0.00
Cannonsville	Dryden Brook	90.06	0.00
Cannonsville	East Brook	75.24	0.56
Cannonsville	Elk Creek	72.55	0.18
Cannonsville	Falls Creek	72.34	0.15
Cannonsville	Fish Brook	99.68	0.00
Cannonsville	Johnny Brook	95.60	0.00
Cannonsville	Kidd Brook	77.46	0.00
Cannonsville	Lake Brook	74.49	0.04
Cannonsville	Little Delaware River	81.76	0.05
Cannonsville	Loomis Brook	80.57	0.01
Cannonsville	Peaks Brook	83.17	0.03
Cannonsville	Pines Brook	79.02	0.15
Cannonsville	Platner Brook	71.75	0.04
Cannonsville	Rose Brook	83.35	0.02
Cannonsville	Sherruck Brook	95.34	0.01
Cannonsville	Steele Brook	63.99	1.53
Cannonsville	Third Brook	70.54	2.31
Cannonsville	Town Brook	72.51	0.50
Cannonsville	Trout Creek_Can	80.83	0.33
Cannonsville	Wakeman Brook	96.34	0.00
Cannonsville	West Branch Delaware Headwaters	70.74	3.24
Cannonsville	West Branch Delaware River	75.50	1.42
Cannonsville	West Brook	75.34	1.36
Cannonsville	Wright Brook	75.26	0.24

Agriculture (%)	Barren (%)	U_index (%)	Ag. Slope 3% (%)	Ag. Slope 5% (%)	Ag. Slope 10% (%)	Ag. Slope 15% (%)
1.70	0.00	2.92	0.68	0.40	0.04	3.70
1.49	0.00	1.75	0.45	0.31	0.03	1.87
1.78	1.35	3.42	1.50	1.16	0.11	6.17
0.15	0.00	0.23	0.11	0.06	0.00	2.56
0.80	0.00	0.86	0.25	0.20	0.06	7.74
0.46	0.00	0.51	0.32	0.23	0.05	10.20
1.62	0.00	3.54	0.43	0.19	0.03	2.00
0.41	0.00	0.46	0.17	0.10	0.03	6.52
1.90	0.00	2.01	1.06	0.61	0.03	1.32
0.03	0.00	0.06	0.03	0.03	0.00	0.00
0.32	0.00	1.02	0.15	0.06	0.00	1.33
0.32	0.00	0.74	0.32	0.27	0.10	31.94
11.30	0.00	11.65	10.51	8.90	0.29	2.61
2.38	2.03	4.42	2.09	1.99	0.39	16.38
19.19	0.00	19.30	15.92	10.88	0.14	0.74
1.55	2.88	4.45	0.74	0.59	0.04	3.15
3.03	0.00	3.03	2.89	2.35	0.13	4.15
0.29	0.10	0.39	0.18	0.13	0.00	0.00
6.40	0.00	6.40	6.18	4.97	0.09	1.36
9.94	0.00	9.94	9.02	7.12	0.21	2.08
24.21	0.00	24.76	21.27	16.75	0.36	1.47
27.27	0.00	27.45	23.37	18.09	1.15	4.22
27.51	0.00	27.66	20.94	13.29	0.38	1.37
0.32	0.00	0.32	0.31	0.29	0.06	18.18
4.40	0.00	4.40	4.24	3.67	0.14	3.15
22.54	0.00	22.54	18.98	12.69	0.16	0.71
25.48	0.00	25.51	21.36	15.43	0.21	0.84
18.16	0.03	18.24	16.53	14.10	0.57	3.14
19.42	0.00	19.43	17.56	13.79	0.16	0.84
16.80	0.00	16.83	15.63	12.91	0.43	2.56
20.83	0.00	20.98	19.80	16.37	0.19	0.93
28.21	0.00	28.25	25.69	20.71	0.56	1.99
16.63	0.00	16.65	15.33	13.23	0.49	2.97
4.65	0.00	4.66	4.35	3.90	0.12	2.58
34.48	0.00	36.01	31.60	24.37	0.21	0.60
27.15	0.00	29.46	25.35	21.61	0.86	3.16
26.99	0.00	27.49	24.24	18.39	0.19	0.72
18.84	0.00	19.17	15.55	12.76	0.39	2.08
3.66	0.00	3.66	3.54	3.04	0.52	14.24
25.58	0.44	29.26	21.61	15.39	0.19	0.74
22.47	0.61	24.50	15.40	12.11	0.61	2.74
23.31	0.00	24.66	21.07	17.50	0.27	1.15
24.50	0.00	24.74	21.17	17.37	0.64	2.62

Table C-1(continued). Land Cover/Use (late 1990s) for NYCDEP Subwatersheds

Watershed	Subwatershed	Forest (%)	Urban (%)
Neversink	East Branch Neversink River	99.27	0.02
Neversink	Neversink Reservoir	93.76	0.17
Neversink	Neversink River	97.97	0.37
Neversink	West Branch Neversink River	99.34	0.02
Pepacton	Batavia Kill_Pep	87.92	0.07
Pepacton	Bush Kill_Pep	92.52	0.34
Pepacton	Dry Brook_Pep	96.85	0.01
Pepacton	East Branch Delaware Headwaters	87.72	0.40
Pepacton	East Branch Delaware River	88.30	1.57
Pepacton	Fall Clove (Brydon Lake)	87.91	0.00
Pepacton	Mill Brook	95.19	0.00
Pepacton	Pepacton Reservoir	94.85	0.00
Pepacton	Platte Kill	86.36	0.14
Pepacton	Terry Clove (Bryden Hill)	85.18	0.03
Pepacton	Tremper Kill	83.25	0.11
Rondout	Chestnut Creek	88.56	0.82
Rondout	Rondout Creek	98.76	0.03
Rondout	Rondout Reservoir	96.56	0.02
Rondout	Sugarloaf Brook	97.47	0.00
Rondout	Trout Creek_Ron	98.81	0.16
Schoharie	Batavia Kill Headwaters	94.80	0.50
Schoharie	Batavia Kill_Sch	89.36	0.97
Schoharie	Bear Kill	77.30	0.41
Schoharie	East Kill	95.49	0.05
Schoharie	Huntersfield Creek	89.10	0.70
Schoharie	Johnson Hollow Brook	82.59	0.10
Schoharie	Little West Kill	88.23	0.00
Schoharie	Manor Kill	88.06	0.10
Schoharie	Mitchell Hollow	90.26	0.53
Schoharie	North Settlement	89.28	0.03
Schoharie	Schoharie Creek	86.28	0.31
Schoharie	Schoharie Creek Headwaters	95.78	1.03
Schoharie	Schoharie Reservoir	87.71	0.10
Schoharie	Silver Lake	97.78	0.07
Schoharie	Sutton Hollow	85.51	0.09
Schoharie	West Kill	96.90	0.14

Agriculture (%)	Barren (%)	U_index (%)	Ag. Slope 3% (%)	Ag. Slope 5% (%)	Ag. Slope 10% (%)	Ag. Slope 15% (%)
0.72	0.00	0.73	0.38	0.22	0.02	2.28
5.78	0.29	6.24	4.18	2.52	0.04	0.72
1.66	0.00	2.03	0.75	0.56	0.01	0.49
0.51	0.13	0.66	0.28	0.19	0.04	8.23
12.01	0.00	12.08	10.36	8.26	0.18	1.50
7.08	0.05	7.48	6.35	5.00	0.15	2.16
3.13	0.01	3.15	2.87	2.55	0.15	4.90
11.71	0.17	12.28	10.16	8.20	0.25	2.16
9.59	0.55	11.70	7.46	5.99	0.18	1.88
12.09	0.00	12.09	10.92	9.55	0.46	3.79
4.78	0.03	4.81	4.41	3.92	0.19	3.96
5.10	0.05	5.15	4.34	3.75	0.11	2.44
13.48	0.03	13.64	12.00	10.10	0.29	2.14
14.79	0.00	14.82	13.18	11.28	0.16	1.06
16.43	0.20	16.75	14.87	12.81	0.52	3.17
10.62	0.00	11.44	9.23	7.02	0.29	2.75
1.21	0.00	1.24	0.98	0.87	0.16	13.60
3.42	0.00	3.44	2.46	1.86	0.06	2.16
2.53	0.00	2.53	2.45	2.19	0.38	15.09
1.04	0.00	1.19	0.98	0.74	0.08	7.97
4.69	0.00	5.20	3.09	1.70	0.03	0.74
8.92	0.74	10.64	5.58	3.31	0.11	1.21
21.90	0.40	22.70	18.13	13.04	0.24	1.09
4.35	0.00	4.40	2.72	1.46	0.08	1.77
10.20	0.00	10.90	8.54	5.91	0.08	0.78
17.31	0.00	17.41	15.05	10.45	0.15	0.85
11.77	0.00	11.77	10.84	9.12	0.72	6.12
11.85	0.00	11.95	8.50	5.28	0.08	0.67
9.21	0.01	9.74	6.92	3.60	0.03	0.30
10.69	0.00	10.72	8.46	4.99	0.01	0.08
13.42	0.00	13.72	9.40	6.00	0.11	0.85
2.20	0.99	4.22	1.36	0.84	0.05	2.44
10.48	1.71	12.29	5.82	2.97	0.03	0.35
2.15	0.00	2.22	1.67	0.81	0.03	1.24
14.39	0.00	14.49	12.67	10.47	0.85	5.89
2.96	0.00	3.10	2.07	1.42	0.05	1.65

Table C-2. Land Cover/Use (late 1990s) for NYCDEP Subwatershed

Watershed	Subwatershed	Stream Length (m)	Stream Density (km/km^2)
Ashokan	Ashokan Reservoir	236,472.49	2.07
Ashokan	Beaver Kill	87,682.90	1.36
Ashokan	Birch Creek	43,566.26	1.33
Ashokan	Broadstreet Hollow	32,903.30	1.37
Ashokan	Bush Kill_Ash	68,945.73	1.35
Ashokan	Bushnellsville Creek	36,037.53	1.25
Ashokan	Esopus Creek	145,232.58	1.93
Ashokan	Esopus Creek Headwaters	124,789.41	1.62
Ashokan	Little Beaverkill	86,289.58	2.00
Ashokan	Peck Hollow	18,180.59	1.40
Ashokan	Stony Clove Creek	112,696.97	1.35
Ashokan	Woodland Creek	72,092.69	1.36
Cannonsville	Bagley Brook	59,966.30	1.49
Cannonsville	Beers Brook	20,802.59	1.18
Cannonsville	Betty Brook	45,258.23	1.92
Cannonsville	Cannonsville Reservoir	129,582.55	1.56
Cannonsville	Chamberlain Brook	5,016.57	0.87
Cannonsville	Chase Brook	17,305.40	1.40
Cannonsville	Dry Brook_Can	12,665.03	1.11
Cannonsville	Dryden Brook	29,032.21	1.17
Cannonsville	East Brook	105,940.01	1.64
Cannonsville	Elk Creek	60,715.53	1.53
Cannonsville	Falls Creek	35,698.30	1.77
Cannonsville	Fish Brook	5,552.47	0.90
Cannonsville	Johnny Brook	12,903.40	1.53
Cannonsville	Kidd Brook	18,519.02	1.37
Cannonsville	Lake Brook	32,235.66	1.80
Cannonsville	Little Delaware River	185,751.76	1.37
Cannonsville	Loomis Brook	47,632.98	1.48
Cannonsville	Peaks Brook	29,547.02	1.47
Cannonsville	Pines Brook	19,683.96	1.45
Cannonsville	Platner Brook	63,192.03	1.75
Cannonsville	Rose Brook	54,493.07	1.42
Cannonsville	Sherruck Brook	19,466.33	1.36
Cannonsville	Steele Brook	22,822.39	1.30
Cannonsville	Third Brook	22,234.98	1.55
Cannonsville	Town Brook	55,254.10	1.33
Cannonsville	Trout Creek_Can	95,303.20	1.72
Cannonsville	Wakeman Brook	11,327.33	1.40
Cannonsville	West Branch Delaware Headwaters	90,718.00	2.25
Cannonsville	West Branch Delaware River	416,590.83	1.80
Cannonsville	West Brook	104,496.50	1.79
Cannonsville	Wright Brook	55,917.49	1.78

Road Length (m)	Road Density (km/km^2)	Xing Density #/km^2	Xing Count #	Avg K Factor	Ag. Erod.Soil (%)
117,848.79	1.03	0.49	117.00	0.13	0.09
48,606.89	0.75	0.68	60.00	0.15	1.05
47,737.76	1.46	1.40	61.00	0.12	0.11
7,683.27	0.32	0.76	25.00	0.11	0.00
24,162.24	0.47	0.38	26.00	0.08	0.00
10,982.76	0.38	0.58	21.00	0.12	0.00
78,080.36	1.03	0.88	128.00	0.18	0.67
33,330.21	0.43	0.54	68.00	0.10	0.53
42,379.49	0.98	0.67	58.00	0.14	0.50
2,677.97	0.21	0.39	7.00	0.10	0.00
57,041.55	0.68	0.77	87.00	0.13	0.06
23,109.41	0.43	0.57	41.00	0.12	0.14
47,882.64	1.19	0.60	36.00	0.17	0.07
15,210.95	0.86	0.96	20.00	0.13	0.04
27,901.75	1.18	0.49	22.00	0.18	0.02
78,563.26	0.94	0.32	42.00	0.17	2.92
3,582.07	0.62	0.60	3.00	0.15	0.00
8,784.48	0.71	0.64	11.00	0.10	0.02
10,280.64	0.90	1.11	14.00	0.16	0.09
21,516.45	0.87	0.76	22.00	0.18	0.05
71,313.12	1.10	0.66	70.00	0.19	1.75
42,989.34	1.08	0.59	36.00	0.19	0.04
27,472.42	1.37	1.04	37.00	0.21	0.03
7,532.16	1.21	1.08	6.00	0.11	0.00
7,646.26	0.91	0.54	7.00	0.17	0.02
12,198.37	0.90	0.43	8.00	0.19	0.08
23,256.23	1.30	0.56	18.00	0.20	0.12
159,981.51	1.18	0.94	174.00	0.17	1.06
33,591.61	1.04	0.69	33.00	0.20	0.30
24,196.36	1.21	1.32	39.00	0.18	0.00
13,315.06	0.98	0.66	13.00	0.18	0.72
39,199.48	1.08	0.90	57.00	0.19	1.67
33,675.80	0.88	0.68	37.00	0.16	1.00
13,361.88	0.93	0.46	9.00	0.18	0.32
24,450.21	1.40	1.45	33.00	0.19	0.00
21,990.07	1.54	0.81	18.00	0.20	1.62
49,778.22	1.19	0.89	49.00	0.19	1.83
65,114.57	1.18	0.70	67.00	0.21	1.71
8,885.15	1.10	1.50	17.00	0.13	0.01
72,722.98	1.81	1.18	107.00	0.19	0.34
298,500.62	1.29	0.68	282.00	0.18	23.63
77,464.70	1.33	0.53	55.00	0.19	0.66
38,240.43	1.22	0.80	45.00	0.18	0.34

Table C-2 (continued). Land Cover/Use (late 1990s) for NYCDEP Subwatershed

Watershed	Subwatershed	Stream Length (m)	Stream Density (km/km^2)
Neversink	East Branch Neversink River	108,378.99	1.52
Neversink	Neversink Reservoir	130,633.17	2.31
Neversink	Neversink River	45,441.25	2.04
Neversink	West Branch Neversink River	165,942.92	1.88
Pepacton	Batavia Kill_Pep	74,385.65	1.49
Pepacton	Bush Kill_Pep	180,148.23	1.47
Pepacton	Dry Brook_Pep	133,710.32	1.52
Pepacton	East Branch Delaware Headwaters	220,033.86	1.71
Pepacton	East Branch Delaware River	121,440.47	1.74
Pepacton	Fall Clove (Brydon Lake)	39,362.33	1.36
Pepacton	Mill Brook	96,061.28	1.46
Pepacton	Pepacton Reservoir	265,614.93	1.40
Pepacton	Platte Kill	132,276.77	1.44
Pepacton	Terry Clove (Bryden Hill)	52,400.40	1.34
Pepacton	Tremper Kill	120,691.35	1.39
Rondout	Chestnut Creek	105,188.13	1.92
Rondout	Rondout Creek	153,335.83	1.49
Rondout	Rondout Reservoir	78,387.51	1.67
Rondout	Sugarloaf Brook	30,189.48	1.45
Rondout	Trout Creek_Ron	41,233.63	1.89
Schoharie	Batavia Kill Headwaters	66,358.29	1.83
Schoharie	Batavia Kill_Sch	149,826.80	1.89
Schoharie	Bear Kill	119,202.62	1.78
Schoharie	East Kill	198,895.30	2.12
Schoharie	Huntersfield Creek	41,975.89	2.05
Schoharie	Johnson Hollow Brook	18,349.53	1.36
Schoharie	Little West Kill	25,857.43	1.22
Schoharie	Manor Kill	211,693.52	2.37
Schoharie	Mitchell Hollow	60,260.81	2.68
Schoharie	North Settlement	39,450.17	1.93
Schoharie	Schoharie Creek	138,926.22	2.07
Schoharie	Schoharie Creek Headwaters	286,894.52	2.01
Schoharie	Schoharie Reservoir	74,125.57	2.32
Schoharie	Silver Lake	37,015.50	2.18
Schoharie	Sutton Hollow	20,004.26	1.45
Schoharie	West Kill	125,589.98	1.55

Road Length (m)	Road Density (km/km^2)	Xing Density #/km^2	Xing Count #	Avg K factor	Ag. Erod.Soil (%)
39,687.72	0.56	0.33	36.00	0.09	0.00
48,652.88	0.86	0.32	42.00	0.21	0.07
21,720.62	0.97	0.46	21.00	0.18	0.11
45,205.66	0.51	0.40	67.00	0.09	0.08
57,495.34	1.15	1.01	75.00	0.16	1.17
134,357.50	1.10	0.87	156.00	0.15	1.86
67,552.57	0.77	0.63	84.00	0.10	0.03
159,140.27	1.24	1.13	248.00	0.16	4.59
97,339.32	1.39	0.77	93.00	0.16	1.97
41,738.32	1.44	0.69	27.00	0.16	0.17
42,148.52	0.64	0.72	69.00	0.13	0.16
187,232.40	0.99	0.67	177.00	0.15	0.14
86,926.08	0.95	0.78	103.00	0.16	0.87
29,223.83	0.75	0.69	36.00	0.17	0.07
128,724.97	1.48	1.06	128.00	0.17	0.33
79,756.08	1.46	0.75	79.00	0.20	0.33
62,597.20	0.61	0.38	58.00	0.10	0.79
54,762.73	1.17	0.66	52.00	0.16	0.67
22,633.55	1.09	0.96	29.00	0.12	0.03
16,932.17	0.77	0.34	14.00	0.12	0.00
21,288.62	0.59	0.51	34.00	0.13	1.05
81,799.98	1.03	0.69	103.00	0.16	12.75
78,009.50	1.17	0.76	90.00	0.18	3.13
81,538.71	0.87	0.50	100.00	0.14	4.91
27,180.78	1.32	0.76	32.00	0.14	0.03
11,217.64	0.83	0.60	11.00	0.18	0.17
15,989.86	0.75	0.58	15.00	0.14	0.00
105,587.30	1.18	0.72	153.00	0.18	6.31
24,416.04	1.08	0.46	28.00	0.16	1.35
18,392.87	0.90	0.58	23.00	0.16	0.14
73,561.68	1.10	0.72	100.00	0.16	0.56
171,184.13	1.20	0.83	237.00	0.14	0.40
34,637.75	1.09	0.63	47.00	0.23	2.24
17,661.51	1.04	0.62	23.00	0.11	0.04
8,398.24	0.61	0.50	10.00	0.16	0.25
32,729.92	0.40	0.54	68.00	0.14	0.77

Table C-3. Land Cover/Use (late 1990s) for NYCDEP Subwatershed Riparian Buffers

Watershed	Subwatershed	Roads (road m/stream m)	Forest (%)	Agriculture (%)
Ashokan	Ashokan Reservoir	0.06	96.67	1.92
Ashokan	Beaver Kill	0.12	95.65	3.62
Ashokan	Birch Creek	0.22	94.17	3.70
Ashokan	Broadstreet Hollow	0.12	99.29	0.41
Ashokan	Bush Kill_Ash	0.07	98.41	1.47
Ashokan	Bushnellsville Creek	0.16	98.59	1.22
Ashokan	Esopus Creek	0.13	92.13	3.63
Ashokan	Esopus Creek Headwaters	0.09	98.60	1.28
Ashokan	Little Beaverkill	0.06	96.04	3.64
Ashokan	Peck Hollow	0.08	99.74	0.12
Ashokan	Stony Clove Creek	0.12	96.98	0.90
Ashokan	Woodland Creek	0.10	98.53	0.30
Cannonsville	Bagley Brook	0.11	80.89	17.81
Cannonsville	Beers Brook	0.28	88.69	5.36
Cannonsville	Betty Brook	0.05	72.58	27.33
Cannonsville	Cannonsville Reservoir	0.07	84.75	4.53
Cannonsville	Chamberlain Brook	0.24	92.32	7.68
Cannonsville	Chase Brook	0.23	98.79	0.78
Cannonsville	Dry Brook_Can	0.38	85.36	14.64
Cannonsville	Dryden Brook	0.17	82.34	17.64
Cannonsville	East Brook	0.13	65.55	33.37
Cannonsville	Elk Creek	0.09	62.35	37.15
Cannonsville	Falls Creek	0.15	67.77	31.89
Cannonsville	Fish Brook	0.20	99.90	0.10
Cannonsville	Johnny Brook	0.04	95.07	4.93
Cannonsville	Kidd Brook	0.07	70.97	29.03
Cannonsville	Lake Brook	0.06	68.55	31.44
Cannonsville	Little Delaware River	0.12	72.47	27.41
Cannonsville	Loomis Brook	0.12	73.39	26.60
Cannonsville	Peaks Brook	0.23	72.90	27.02
Cannonsville	Pines Brook	0.21	67.55	31.85
Cannonsville	Platner Brook	0.16	57.17	42.72
Cannonsville	Rose Brook	0.11	70.96	28.98
Cannonsville	Sherruck Brook	0.12	88.72	11.25
Cannonsville	Steele Brook	0.25	53.48	43.45
Cannonsville	Third Brook	0.09	53.48	41.17
Cannonsville	Town Brook	0.10	59.22	39.60
Cannonsville	Trout Creek_Can	0.10	72.29	26.70
Cannonsville	Wakeman Brook	0.23	91.22	8.78
Cannonsville	West Branch Delaware Headwaters	0.15	69.14	25.40
Cannonsville	West Branch Delaware River	0.11	61.87	34.80
Cannonsville	West Brook	0.09	64.29	33.46
Cannonsville	Wright Brook	0.11	65.13	34.13

60 m			120 m				
Urban (%)	Barren (%)	U-Index (%)	Forest (%)	Agriculture (%)	Urban (%)	Barren (%)	U-Index (%)
1.41	0.00	3.33	96.46	1.99	1.55	0.00	3.54
0.73	0.00	4.35	96.08	3.29	0.63	0.00	3.92
1.01	1.13	5.83	95.07	2.83	0.71	1.39	4.93
0.31	0.00	0.71	99.43	0.37	0.20	0.00	0.57
0.12	0.00	1.59	98.41	1.46	0.13	0.00	1.59
0.19	0.00	1.41	98.74	1.12	0.14	0.00	1.26
4.25	0.00	7.87	92.76	3.28	3.96	0.00	7.24
0.12	0.00	1.40	98.96	0.93	0.11	0.00	1.04
0.32	0.00	3.96	96.38	3.40	0.22	0.00	3.62
0.14	0.00	0.26	99.84	0.07	0.09	0.00	0.16
2.12	0.00	3.02	97.55	0.85	1.60	0.00	2.45
1.17	0.00	1.47	98.50	0.44	1.06	0.00	1.50
1.30	0.00	19.11	80.97	18.08	0.95	0.00	19.03
0.03	5.92	11.31	89.73	5.52	0.01	4.73	10.27
0.09	0.00	27.42	73.23	26.61	0.16	0.00	26.77
0.04	10.69	15.25	88.84	3.84	0.03	7.30	11.16
0.00	0.00	7.68	90.85	9.15	0.00	0.00	9.15
0.00	0.44	1.21	99.26	0.49	0.00	0.25	0.74
0.00	0.00	14.64	86.22	13.78	0.00	0.00	13.78
0.02	0.00	17.66	83.08	16.91	0.01	0.00	16.92
1.08	0.00	34.45	66.95	31.99	1.06	0.00	33.05
0.50	0.00	37.65	62.71	36.86	0.43	0.00	37.29
0.34	0.00	32.23	67.09	32.61	0.30	0.00	32.91
0.00	0.00	0.10	99.83	0.17	0.00	0.00	0.17
0.00	0.00	4.93	93.28	6.72	0.00	0.00	6.72
0.00	0.00	29.03	71.58	28.42	0.00	0.00	28.42
0.02	0.00	31.45	69.59	30.40	0.01	0.00	30.41
0.10	0.01	27.53	72.25	27.66	0.09	0.01	27.75
0.01	0.00	26.61	73.03	26.95	0.02	0.00	26.97
0.08	0.00	27.10	73.91	26.01	0.08	0.00	26.09
0.60	0.00	32.45	69.45	30.18	0.37	0.00	30.55
0.10	0.00	42.83	59.62	40.29	0.09	0.00	40.38
0.06	0.00	29.04	71.04	28.91	0.05	0.00	28.96
0.03	0.00	11.28	90.16	9.82	0.02	0.00	9.84
3.07	0.00	46.52	53.43	43.77	2.80	0.00	46.57
5.34	0.00	46.52	55.77	39.40	4.83	0.00	44.23
1.18	0.00	40.78	59.11	39.76	1.13	0.00	40.89
1.01	0.00	27.71	72.09	27.12	0.80	0.00	27.91
0.00	0.00	8.78	91.86	8.14	0.00	0.00	8.14
5.45	0.02	30.86	66.22	28.48	5.24	0.06	33.78
2.33	1.00	38.13	61.78	34.97	2.40	0.85	38.22
2.26	0.00	35.71	65.82	32.04	2.14	0.00	34.18
0.75	0.00	34.87	64.42	35.04	0.54	0.00	35.58

Table C-3 (continued). Land Cover/Use (late 1990s) for NYCDEP Subwatershed Riparian Buffer

Watershed	Subwatershed	Roads (road m/stream m)	Forest (%)	Agriculture (%)
Neversink	East Branch Neversink River	0.04	98.77	1.18
Neversink	Neversink Reservoir	0.04	95.98	3.10
Neversink	Neversink River	0.05	96.41	2.35
Neversink	West Branch Neversink River	0.06	98.93	0.92
Pepacton	Batavia Kill_Pep	0.13	78.29	21.56
Pepacton	Bush Kill_Pep	0.13	88.90	10.01
Pepacton	Dry Brook_Pep	0.12	94.67	5.31
Pepacton	East Branch Delaware Headwaters	0.17	81.69	17.48
Pepacton	East Branch Delaware River	0.13	82.50	12.25
Pepacton	Fall Clove (Brydon Lake)	0.08	78.26	21.74
Pepacton	Mill Brook	0.11	91.07	8.80
Pepacton	Pepacton Reservoir	0.13	93.16	6.61
Pepacton	Platte Kill	0.12	73.35	26.39
Pepacton	Terry Clove (Bryden Hill)	0.11	67.47	32.50
Pepacton	Tremper Kill	0.17	73.03	26.10
Rondout	Chestnut Creek	0.10	88.28	10.00
Rondout	Rondout Creek	0.08	98.36	1.57
Rondout	Rondout Reservoir	0.06	95.26	4.73
Rondout	Sugarloaf Brook	0.11	96.65	3.35
Rondout	Trout Creek_Ron	0.03	99.22	0.44
Schoharie	Batavia Kill Headwaters	0.09	90.17	8.50
Schoharie	Batavia Kill_Sch	0.08	84.96	12.95
Schoharie	Bear Kill	0.10	70.36	28.64
Schoharie	East Kill	0.06	94.07	5.78
Schoharie	Huntersfield Creek	0.09	82.15	16.54
Schoharie	Johnson Hollow Brook	0.09	67.80	31.73
Schoharie	Little West Kill	0.10	78.48	21.52
Schoharie	Manor Kill	0.09	82.83	16.97
Schoharie	Mitchell Hollow	0.05	85.23	13.73
Schoharie	North Settlement	0.06	86.30	13.68
Schoharie	Schoharie Creek	0.11	82.84	16.48
Schoharie	Schoharie Creek Headwaters	0.10	94.39	3.24
Schoharie	Schoharie Reservoir	0.06	81.42	15.37
Schoharie	Silver Lake	0.07	96.62	3.37
Schoharie	Sutton Hollow	0.07	82.88	16.92
Schoharie	West Kill	0.08	93.89	5.71

60 m			120 m				
Urban (%)	Barren (%)	U-Index (%)	Forest (%)	Agriculture (%)	Urban (%)	Barren (%)	U-Index (%)
0.06	0.00	1.23	98.80	1.17	0.04	0.00	1.20
0.05	0.86	4.02	95.30	4.04	0.14	0.53	4.70
1.24	0.00	3.59	96.59	2.59	0.82	0.00	3.41
0.04	0.11	1.07	98.94	0.86	0.04	0.16	1.06
0.15	0.00	21.71	78.95	20.94	0.10	0.00	21.05
1.00	0.09	11.10	89.10	10.03	0.79	0.08	10.90
0.02	0.00	5.33	94.11	5.87	0.01	0.01	5.89
0.78	0.04	18.31	81.04	18.21	0.69	0.06	18.96
3.12	2.14	17.50	82.33	13.61	2.75	1.31	17.67
0.00	0.00	21.74	78.88	21.12	0.00	0.00	21.12
0.00	0.13	8.93	90.95	8.97	0.00	0.08	9.05
0.01	0.22	6.84	92.59	7.28	0.01	0.13	7.41
0.15	0.11	26.65	74.92	24.92	0.09	0.06	25.08
0.03	0.00	32.53	69.86	30.11	0.03	0.00	30.14
0.48	0.39	26.97	72.92	26.42	0.31	0.36	27.08
1.72	0.00	11.72	87.99	10.61	1.40	0.00	12.01
0.07	0.00	1.64	98.38	1.55	0.06	0.00	1.62
0.01	0.00	4.74	94.90	5.08	0.02	0.00	5.10
0.00	0.00	3.35	96.62	3.38	0.00	0.00	3.38
0.35	0.00	0.78	99.00	0.72	0.28	0.00	1.00
1.33	0.00	9.83	91.30	7.73	0.97	0.00	8.70
1.80	0.29	15.04	84.52	13.52	1.64	0.32	15.48
0.80	0.20	29.64	69.39	29.55	0.72	0.34	30.61
0.10	0.00	5.88	94.08	5.75	0.08	0.00	5.82
1.31	0.00	17.85	82.52	16.24	1.23	0.01	17.48
0.47	0.00	32.21	67.47	32.24	0.28	0.00	32.53
0.00	0.00	21.52	79.77	20.23	0.00	0.00	20.23
0.19	0.00	17.17	83.53	16.31	0.16	0.00	16.47
1.01	0.02	14.77	85.07	14.03	0.89	0.01	14.93
0.03	0.00	13.70	85.66	14.32	0.02	0.00	14.34
0.68	0.00	17.16	81.25	18.17	0.58	0.00	18.75
1.83	0.54	5.61	94.30	3.43	1.62	0.65	5.70
0.11	3.09	18.58	81.57	15.42	0.13	2.88	18.43
0.02	0.00	3.38	96.34	3.54	0.11	0.00	3.66
0.20	0.00	17.12	83.18	16.64	0.19	0.00	16.82
0.41	0.00	6.11	94.43	5.29	0.29	0.00	5.57

Appendix D. Catskill/Delaware Water Quality Site Data

Table D-1. Water Quality Site (NYCDEP) Locations, Universal Transverse Mercator, Zone 18

Site ID	East	North
BK	559828.0000	4654984.0000
BNV	549624.0000	4663216.0000
BRD	552984.0000	4662264.0000
C-38	506530.5669	4679843.2085
C-7	476891.1730	4668863.8763
C-79	505888.0000	4678360.0000
C-8	477144.0000	4667312.0000
CWB	515708.6336	4687062.0322
DCDA	537098.5521	4686561.6626
DCDB	536992.6968	4685034.5965
DLTA	504096.0000	4678048.0000
DLTB	501946.5070	4672671.2628
DTPA	504960.0000	4677832.0000
DTPB	504096.0000	4678048.0000
E1	543008.0000	4664912.0000
E10I	559876.0000	4646540.0000
E12I	563694.0000	4646651.0000
E13I	566337.0000	4647044.0000
E15 ▲	544432.0000	4663072.0000
E16I	560597.0000	4650248.0000
E3 ▲	543690.0000	4663662.0000
E4	545768.0000	4661264.0000
E5	551928.0000	4662648.0000
E6	555432.0000	4658816.0000
E7	557768.0000	4658048.0000
E8I	560360.0000	4651420.0000
EDRA	533114.9768	4675425.8023
EDRB	533404.2858	4674867.9339
FB4	545768.0000	4686144.0000
LBK *	560432.0000	4651912.0000
NEBR	535421.0000	4640609.0000
NK4	526660.0000	4633360.0000
NK6	527456.0000	4630636.0000
NK7A *	534216.0000	4637744.0000
NWBR	535216.0000	4640829.0000
P13	514864.0000	4662852.0000
P21	525168.0000	4664360.0000
P50	533286.6324	4669748.1698
P52	536684.0000	4667360.0000
P60 *	522204.0000	4661456.0000
P7	508264.0000	4664036.0000
P8	509072.0000	4662312.0000
PAKA	536336.0000	4667420.0000
PDRY	531138.5807	4665843.3747
PMSA ▲	528309.3125	4665306.0000
PMSB ▲	528289.0625	4665100.5000
PQTPA	516456.0000	4685984.0000
PQTPB	516124.4594	4686128.7061
PSR	532754.0000	4687688.0000
RD1	540828.0000	4634648.0000
RD4	545384.0000	4630144.0000
RDOA *	542528.0000	4634804.0000
RGA ▲	538132.0000	4632468.0000
RGB ▲	538216.0000	4632444.0000
RK	538048.0000	4632432.0000
S1 ▲	570219.0000	4670748.0000
S10	548000.0000	4683528.0000
S2 ▲	569624.0000	4670552.0000
S3	562456.0000	4673912.0000
S4	551880.0000	4676756.0000
S5I	546408.0000	4685240.0000
S6I	545192.0000	4687216.0000
S7I *	546960.0000	4691880.0000
S8	543192.0000	4689852.0000
S9	543408.0000	4689720.0000
SCL	556540.0000	4659032.0000
SCL-2	558692.0000	4661528.0000
SEK	556288.0000	4676072.0000
SKTPA	523072.5161	4687746.2624
SKTPB	522888.0000	4687744.0000
SWK	550264.0000	4675624.0000
WDBN	486661.0535	4663857.3569
WDHOA	527432.0000	4691048.0000
WDHOB	525854.2826	4690943.4654
WDHOM	526152.0312	4690952.4186
WDL	555240.0000	4658804.0000
WDLFA	496600.0000	4668072.0000
WDLFB	495180.0000	4667036.0000
WDSTA	531480.0000	4696072.0000
WDSTB	530445.7912	4694226.3687
WDSTM	530626.6374	4694248.7434
WSPA ▲ *	488360.0000	4667984.0000
WSPB ▲	488144.0000	4666630.0000

Blue = Regression Sites, Red = Model Validation Sites, * = Temporal Analysis Sites, ▲ = Treatment Plant Monitoring Sites

Table D-2. Waste Treatment Plant Site (NYCDEP) Locations, Universal Transverse Mercator, Zone 18

Waste Treatment Plant Site	East	North
Stamford WWTP	530176.4375	4694662.0000
Golden Acres #3	541752.6133	4693620.6482
Golden Acres #2	541819.3398	4693531.6797
Golden Acres #1	541601.3666	4693295.9128
Rondevous Restaurant	544584.7063	4693191.9704
Village of Hobart PCF	525960.1875	4691003.0000
SEVA Institute #003 (Seasonal)	521385.8438	4689844.0000
SEVA Institute #002 (Seasonal)	521385.8438	4689844.0000
Grand Gorge STP	543299.6875	4689790.0000
South Kortright Center for Boys	522924.3750	4687750.5000
Penn Quality Meats Coop., Inc.	516363.0000	4686133.0000
Thompson House Inc. (Seasonal)	563306.1875	4684079.0000
Frog House Restaurant, The	560306.5625	4683997.0000
Snowtime	561174.1250	4683760.0000
Crystal Pond (Seasonal Limits)	565422.1875	4682566.0000
Mountain View Estates	566674.8500	4678561.6800
Delhi V (Seasonal Limits)	505155.5938	4677788.5000
Roxbury Run Village	534148.8750	4676537.0000
Harriman Lodge (Seasonal)	572548.3125	4675906.5000
Forester Motor Lodge	564769.4375	4673765.5000
Colonel Chair Estates-Block 8 (#002)	563623.5625	4673599.5000
Camp Loyaltown (Seasonal)	564986.9375	4673456.5000
Delaware Boces	475840.0000	4673336.0000
Liftside	565238.5625	4673025.5000
Hunter Highlands WPC	565357.2500	4672693.5000
Whistle Tree Development	566392.1250	4672392.5000
Camp Nubar (Seasonal)	511080.8750	4670944.5000
Tannersville STP	569957.3750	4670883.5000
Latvian Church Camp (Seasonal)	569710.8125	4668260.5000
Elka Park (Seasonal)	569536.7500	4667481.5000
Walton (V) WWTP	488293.8125	4667303.5000
Regis Hotel (Seasonal)	539654.7500	4667283.5000
Camp Timber Lake (Seasonal)	554277.7500	4666270.5000
Belleayre Mtn. Ski Center (#001)	541161.0000	4665415.5000
Margaretville STP	528504.5017	4665120.1691
Belleayre Mtn. Ski Center (#002)	540910.5625	4664426.0000
Pine Hill STP	544289.7500	4663302.5000
Onteora Jr-Sr High School (Seasonal)	560543.2500	4650587.5000
Grahamsville STP	538449.5625	4631957.5000
Camp Tai Chi (Seasonal)	516484.2500	4662472.5000
Maverick Inn	572291.3702	4650220.0711
EG&G Rotran	565977.4165	4648349.2190

Table D-3. Site Locations for Water Quality, Discharge, and Precipitation, Universal Transverse Mercator, Zone 18

Precipitation Sample Sites	East	North
ARKVILLE 2 W	528927.9128	4664055.6651
CLARYVILLE	535657.1646	4640769.9485
DELHI 2 SE	508249.4957	4677324.9605
GRAHAMSVILLE	539016.6823	4633015.5705
LANSING MANOR	543583.9998	4699663.0166
SHOKAN BROWN STA	566307.9964	4644320.7990

Discharge Sample Sites	East	North
01365000	542602.0000	4634887.0000
01350080	548300.0000	4691581.0000
01414500	522256.0000	4661379.0000
01362500	560353.0000	4651393.0000
01435000	533991.0000	4637431.0000
01423000	488397.0938	4668024.0000

Water Quality Sample Sites	East	North
S7I	546960.0000	4691880.0000
WSPA	488360.0000	4667984.0000
P60	522204.0000	4661456.0000
LBK	560432.0000	4651912.0000
NK7A	534216.0000	4637744.0000
RDOA	542528.0000	4634804.0000

Table D-4. Descriptive Statistics for 32 Water Quality Sites in the Catskill/Delaware Watersheds

Site	Year	TN	TP	FC	TN	TP	FC	TN	TP	FC
			Minimum			Maximum			Mean	
		mg/L	*u*g/L	CFU/100ml	mg/L	*u*g/L	CFU/100ml	mg/L	*u*g/L	CFU/100ml
BK	1987-1988		0.00	2.00		35	720		8.92	49.30
	1990-1994	0.05	4.00	2.00	0.84	30	1,700	0.22	10.19	22.32
	1995-1998	0.01	3.00	1.00	0.44	55	880	0.18	11.35	28.38
BNV	1987-1988		0.00	2.00		2500	430		205.54	59.78
	1990-1994	0.16	0.40	1.00	1.62	30	1,200	0.52	13.08	41.26
	1995-1998	0.06	6.00	1.00	0.72	68	320	0.34	16.15	11.08
BRD	1987-1988		0.00	2.00		30	700		12.85	32.68
	1990-1994	0.06	4.00	2.00	1.21	34	380	0.45	13.09	18.04
	1995-1998	0.03	6.00	1.00	0.95	107	228	0.34	23.32	18.34
C-38	1987-1988	0.00	22.60	2.00	0.00	65	240	0.00	41.43	69.91
	1990-1994	0.39	6.00	2.00	1.54	458	1,390	0.80	40.66	76.56
	1995-1998	0.15	7.00	1.00	1.65	287	2,560	0.72	34.61	86.97
C-7	1987-1988		14.40	2.00		73	680		26.11	100.81
	1990-1994	0.35	4.00	2.00	0.87	244	4,100	0.58	21.31	260.31
	1995-1998	0.23	2.00	1.00	1.02	134	3,000	0.56	16.76	323.44
C-79	1987-1988		10.80	4.00		139	490		28.68	99.75
	1990-1994	0.23	7.00	2.00	1.13	385	1,440	0.73	26.24	78.17
	1995-1998	0.11	3.00	1.00	1.41	184	2,900	0.53	19.70	94.89
C-8	1987-1988		10.80	2.00		51	200		19.64	25.77
	1990-1994	0.12	4.00	2.00	0.84	66	1,240	0.49	18.01	42.44
	1995-1998	0.07	2.00	4.00	0.82	59	2,020	0.39	14.39	84.26
E1	1987-1988		5.00	2.00		35	750		13.15	21.29
	1990-1994	0.03	4.00	2.00	0.88	37	350	0.32	13.33	14.66
	1995-1998	0.05	6.00	1.00	0.49	52	396	0.23	15.90	22.04
E10I	1987-1988		0.00	2.00		35	200		8.92	12.64
	1990-1994	0.02	4.00	2.00	0.84	40	660	0.28	9.65	17.99
	1995-1998	0.02	5.00	1.00	0.43	27	216	0.18	10.78	11.09
E12I	1987-1988		0.00	2.00		55	600		13.55	86.32
	1990-1994	0.07	5.00	2.00	0.67	50	9,600	0.29	14.60	252.48
	1995-1998	0.09	6.00	2.00	0.80	153	11,100	0.29	16.94	232.45
FB4	1987-1988		30.00	4.00		75	2,800		55.86	252.78
	1990-1994	0.19	5.00	4.00	1.07	184	6,000	0.65	57.92	297.55
	1995-1998	0.06	19.00	1.00	1.53	462	20,000	0.54	64.94	320.91
LBK	1987-1988		0.00	2.00		35	670		9.92	48.18
	1990-1994	0.02	4.00	2.00	0.47	75	1,100	0.18	12.07	27.83
	1995-1998	0.03	5.00	1.00	0.91	26	1,100	0.18	11.69	27.26

Table D-4 (continued). Descriptive Statistics for 32 Water Quality Sites in the Catskill/Delaware Watersheds

Site	Year	TN	TP	FC	TN	TP	FC	TN	TP	FC
			Minimum			Maximum			Mean	
		mg/L	*u*g/L	CFU/100ml	mg/L	*u*g/L	CFU/100ml	mg/L	*u*g/L	CFU/100ml
NK6	1987-1988		16.40	2.00		59	84		37.33	18.38
	1990-1994	0.60	8.00	1.00	1.11	220	1,500	0.84	25.48	62.52
	1995-1998	0.29	7.00	1.00	1.23	45	2,000	0.67	20.50	76.47
NK7A	1987-1988	11.40	1.00			22	54		14.61	8.46
	1990-1994	0.11	2.00	1.00	1.34	107	130	0.38	7.77	7.25
	1995-1998	0.10	2.00	1.00	0.65	22	194	0.28	4.36	10.08
P-13	1987-1988		10.80	4.00		65	580		22.75	78.32
	1990-1994	0.22	7.00	1.00	1.52	183	890	0.63	21.30	94.59
	1995-1998	0.14	5.00	1.00	1.13	124	2,000	0.49	17.56	141.90
P-21	1987-1988		10.80	2.00		63	740		25.28	91.73
	1990-1994	0.31	5.00	1.00	1.24	126	535	0.68	21.43	62.49
	1995-1998	0.26	4.00	1.00	1.16	118	10,400	0.56	17.97	142.76
P-50	1987-1988		11.40	4.00		46	272		19.17	47.24
	1990-1994	0.09	3.00	2.00	1.06	92	765	0.51	19.34	51.28
	1995-1998	0.06	3.00	1.00	1.00	116	330	0.32	17.43	40.89
P-52	1987-1988		10.80	2.00		26	234		16.76	36.59
	1990-1994	0.04	2.00	1.00	0.63	109	710	0.28	14.12	29.79
	1995-1998	0.05	2.00	1.00	0.63	42	416	0.21	8.42	21.29
P-60	1987-1988		10.60	2.00		27	200		15.02	33.27
	1990-1994	0.19	2.00	1.00	0.95	370	880	0.53	15.08	33.48
	1995-1998	0.07	2.00	1.00	1.19	76	560	0.38	9.33	25.40
P-7	1987-1988		16.40	5.00		79	500		35.68	130.65
	1990-1994	0.40	8.00	2.00	1.26	169	1,640	0.72	27.22	85.60
	1995-1998	0.16	6.00	1.00	1.10	96	1,580	0.60	21.72	110.34
P-8	1987-1988		11.30	2.00		77	288		27.35	70.05
	1990-1994	0.26	5.00	1.00	1.15	111	1,700	0.58	18.52	75.29
	1995-1998	0.07	3.00	1.00	0.95	114	2,000	0.48	17.91	82.88
RD1	1987-1988		10.60	2.00		38	85		18.39	24.16
	1990-1994	0.06	2.00	1.00	0.57	80	760	0.27	15.21	29.38
	1995-1998	0.05	2.00	1.00	0.49	50	400	0.23	11.54	28.12

Table D-4 (continued). Descriptive Statistics for 32 Water Quality Sites in the Catskill/Delaware Watersheds

Site	Year	TN	TP	FC	TN	TP	FC	TN	TP	FC
			Minimum			Maximum			Mean	
		mg/L	ug/L	CFU/100ml	mg/L	ug/L	CFU/100ml	mg/L	ug/L	CFU/100ml
RD4	1987-1988		10.30	1.00		20	82		14.68	10.76
	1990-1994	0.01	2.00	1.00	0.55	65	280	0.14	9.26	13.28
	1995-1998	0.02	2.00	1.00	0.35	87	580	0.13	7.05	19.90
RDOA	1987-1988		0.00	1.00		27	70		14.47	17.72
	1990-1994	0.12	2.00	1.00	1.28	98	380	0.44	10.21	20.40
	1995-1998	0.06	2.00	1.00	0.68	123	800	0.28	6.44	27.26
RGA	1987-1988		10.60	2.00		27	210		16.15	50.85
	1990-1994	0.21	3.00	2.00	0.68	59	1,000	0.42	12.53	52.87
	1995-1998	0.08	2.00	1.00	0.68	51	1,000	0.36	12.14	77.28
RK	1987-1988		10.80	4.00		35	216		18.01	32.12
	1990-1994	0.28	2.00	2.00	0.66	97	296	0.44	14.76	32.72
	1995-1998	0.17	4.00	1.00	0.74	43	1,000	0.40	12.64	74.98
S1	1987-1988		0.00	2.00		20	1,100		12.07	74.10
	1990-1994	0.18	5.00	2.00	0.80	81	620	0.41	12.50	26.04
	1995-1998	0.09	5.00	1.00	0.84	79	570	0.35	14.77	21.63
S10	1987-1988		11.00	2.00		45	4,500		24.43	193.52
	1990-1994	0.10	5.00	2.00	0.65	159	3,300	0.33	18.30	107.47
	1995-1998	0.03	6.00	1.00	0.88	131	2,750	0.28	23.68	51.19
S6I	1987-1988		16.00	5.00		99	11,000		54.92	424.52
	1990-1994	0.28	13.00	2.00	1.74	121	29,000	1.02	53.34	285.33
	1995-1998	0.30	9.00	1.00	1.85	188	4,000	0.85	45.52	116.77
S7I	1987-1988		10.00	2.00		78	2,400		39.43	220.38
	1990-1994	0.07	4.00	2.00	0.51	100	11,000	0.28	19.53	129.86
	1995-1998	0.03	5.00	1.00	0.61	51	220	0.24	14.25	17.67
WDHOA	1987-1988		28.90	8.00		152	3,250		92.17	498.32
	1990-1994	1.37	35.00	4.00	11.80	590	3,260	2.59	114.21	259.95
	1995-1998	0.92	29.00	1.00	3.23	280	4,000	1.81	86.90	260.23
WDL	1987-1988		0.00	2.00		36	270		13.71	19.70
	1990-1994	0.07	5.00	2.00	1.16	31	780	0.38	11.86	20.44
	1995-1998	0.03	5.00	1.00	0.51	42	142	0.25	14.16	19.26

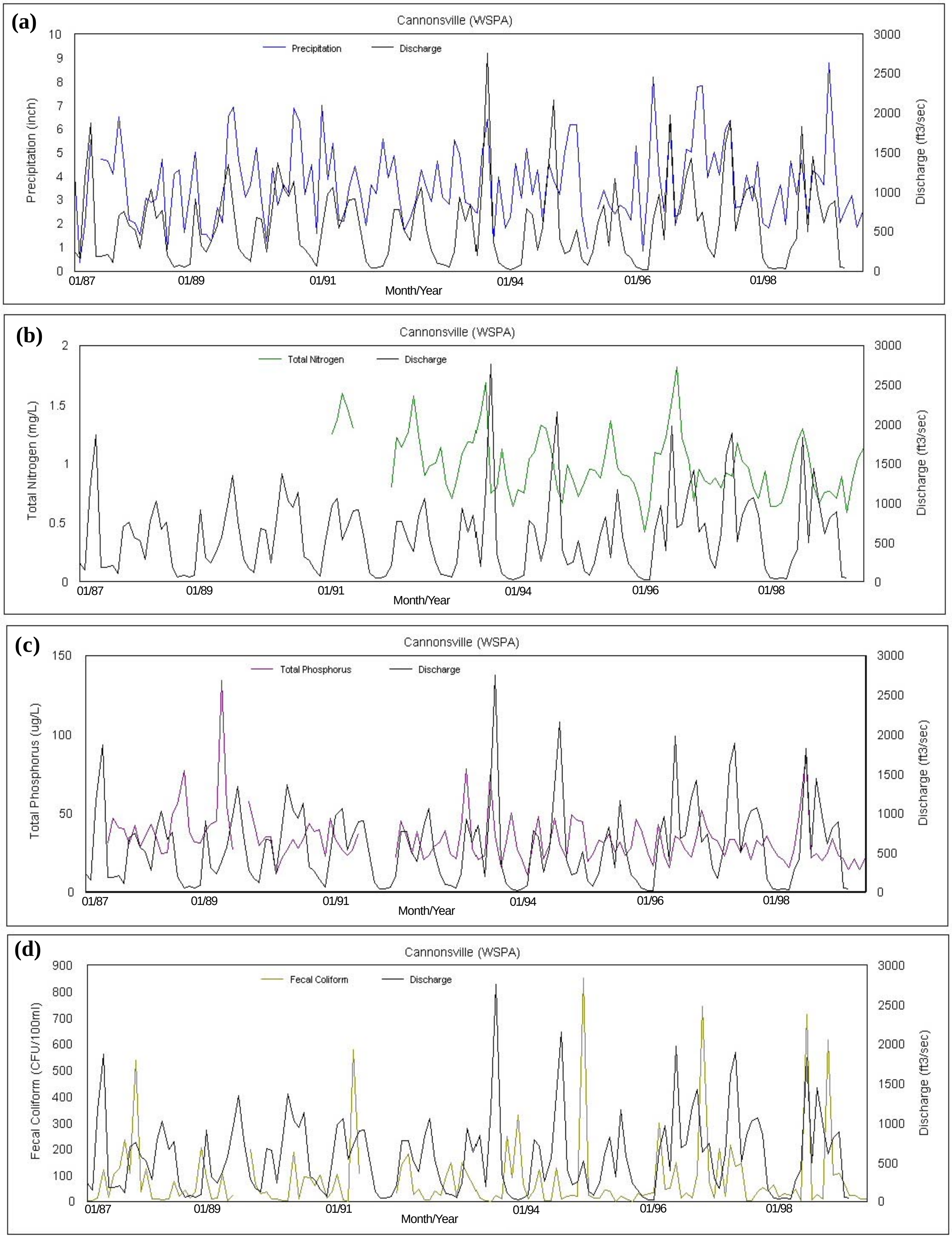


***Figure D-1.** Average monthly (1987-1998) discharge and **(a)** precipitation, **(b)** total nitrogen, **(c)** total phosphorus, and **(d)** fecal coliforms at the Cannonsville water quality trend sites.*

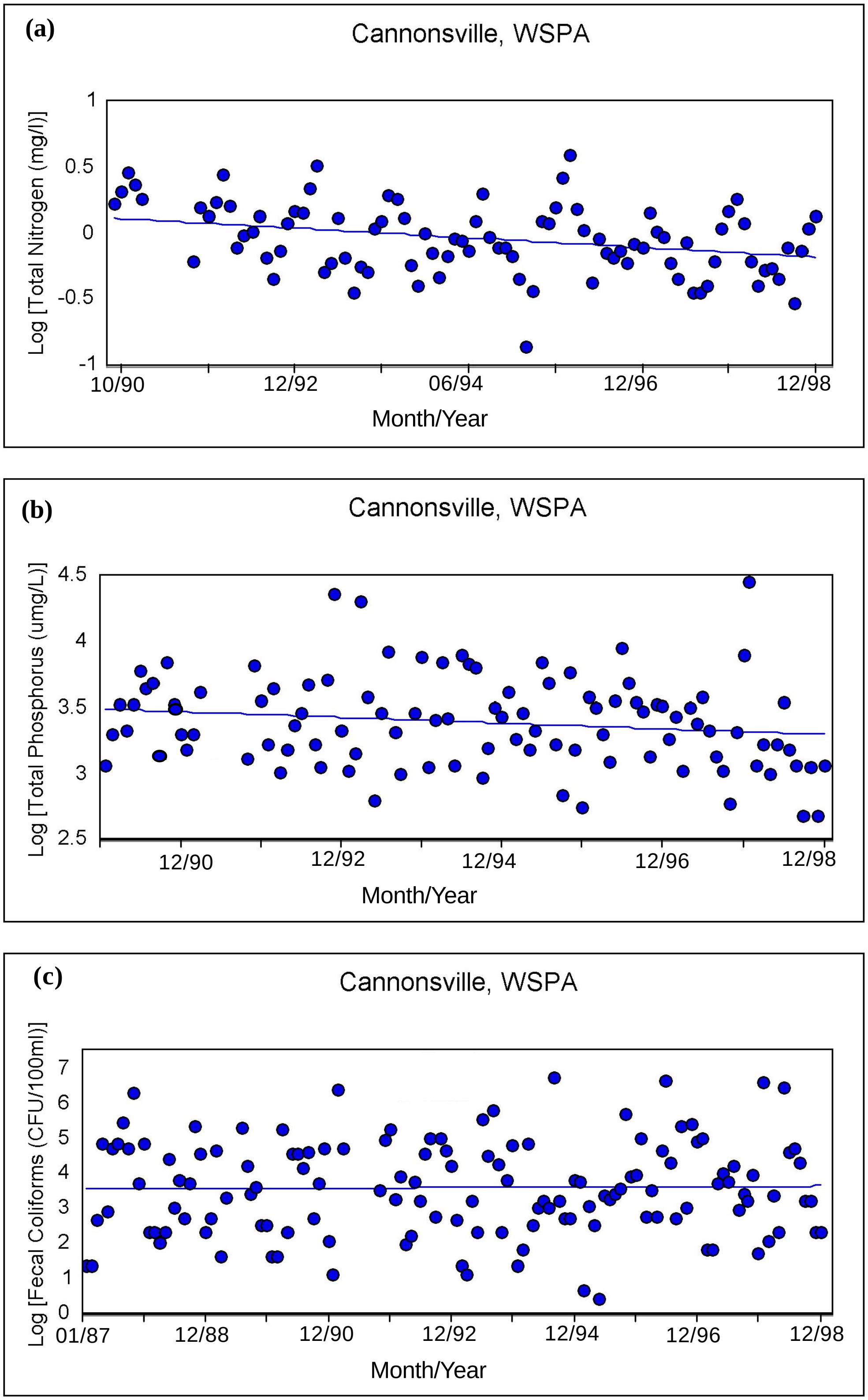


Figure D-2. *Average monthly* ***(a)*** *total nitrogen (1990-1998),* ***(b)*** *total phosphorus (1990-1998), and* ***(c)*** *fecal coliforms (1987-1998) at the Cannonsville water quality trend site. The blue line shows the overall trend with time.*

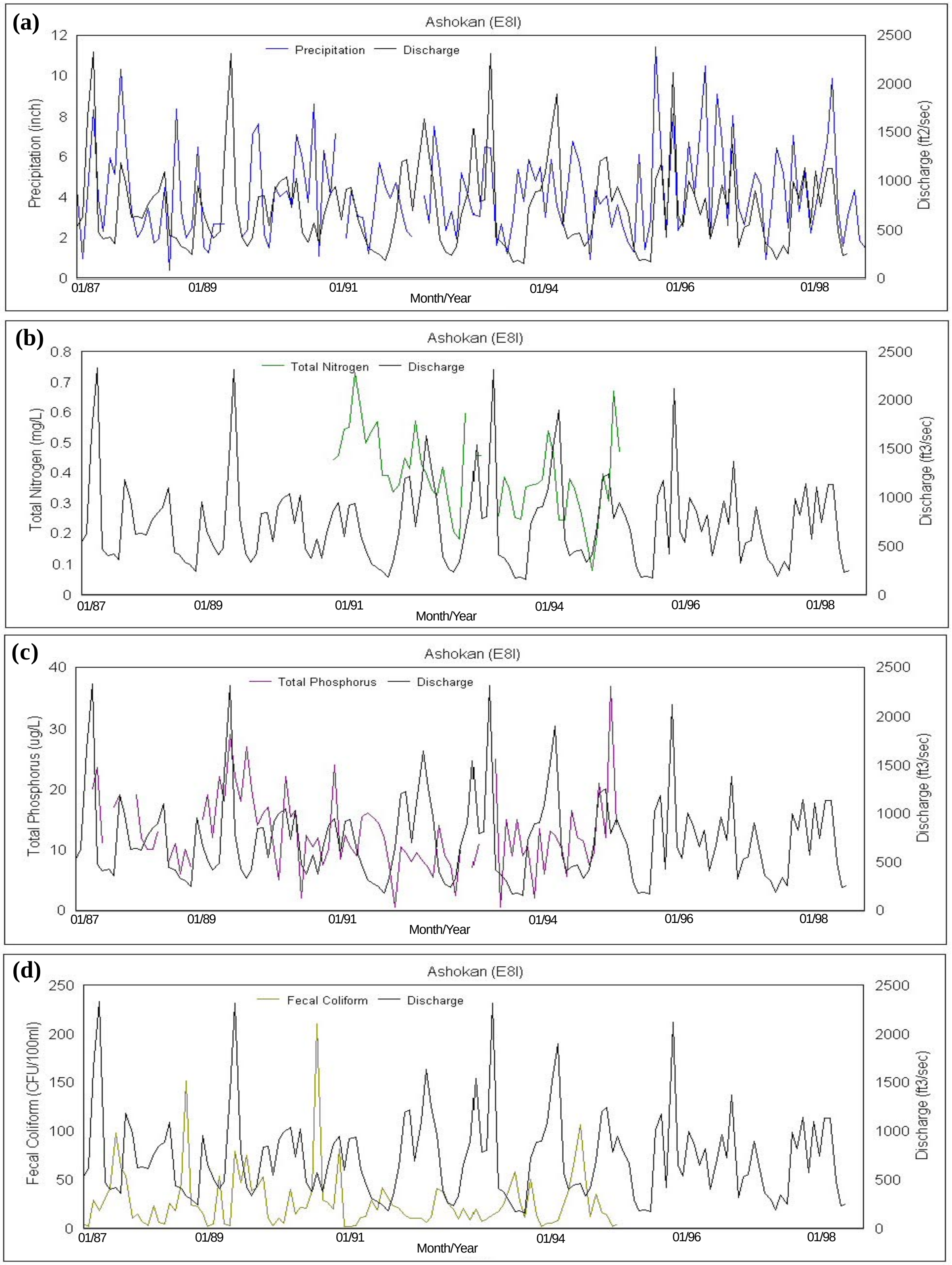


Figure D-3. *Average monthly (1987-1998) discharge and **(a)** precipitation, **(b)** total nitrogen, **(c)** total phosphorus, and **(d)** fecal coliforms at the Ashokan water quality trend sites.*

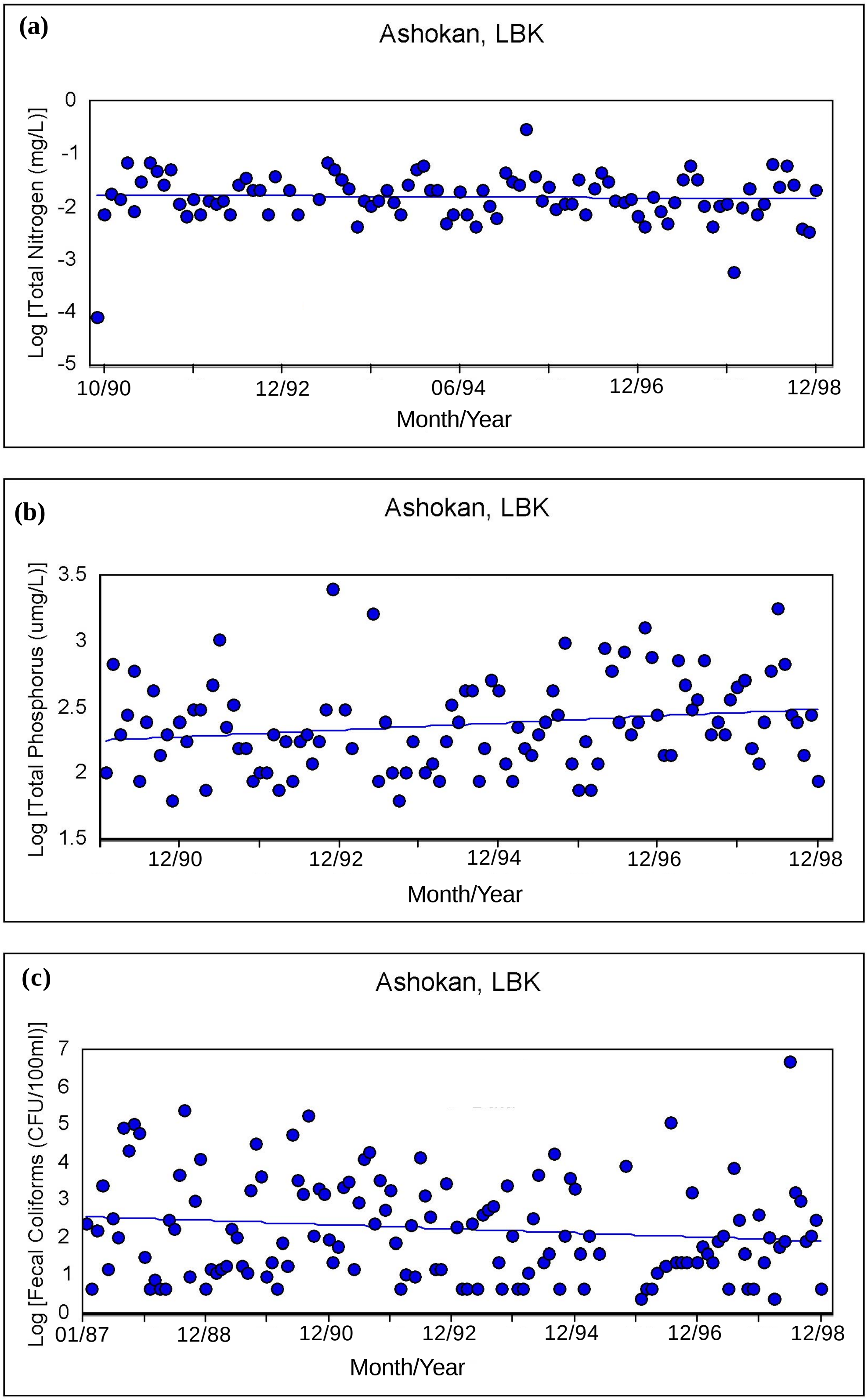


Figure D-4. *Average monthly* ***(a)*** *total nitrogen (1990-1998),* ***(b)*** *total phosphorus (1990-1998), and* ***(c)*** *fecal coliforms (1987-1998) at the Ashokan water quality trend site. The blue line shows the overall trend with time.*

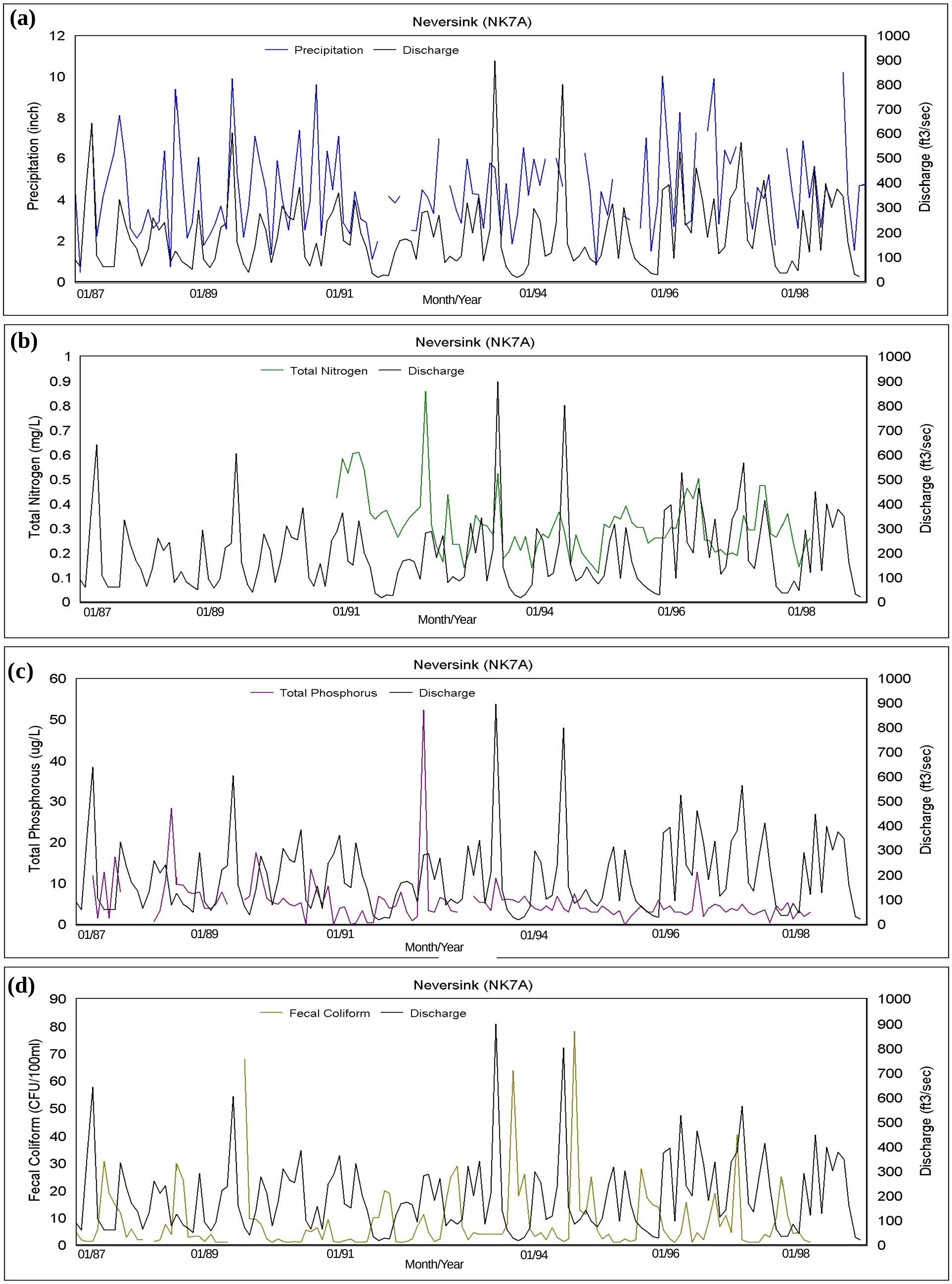
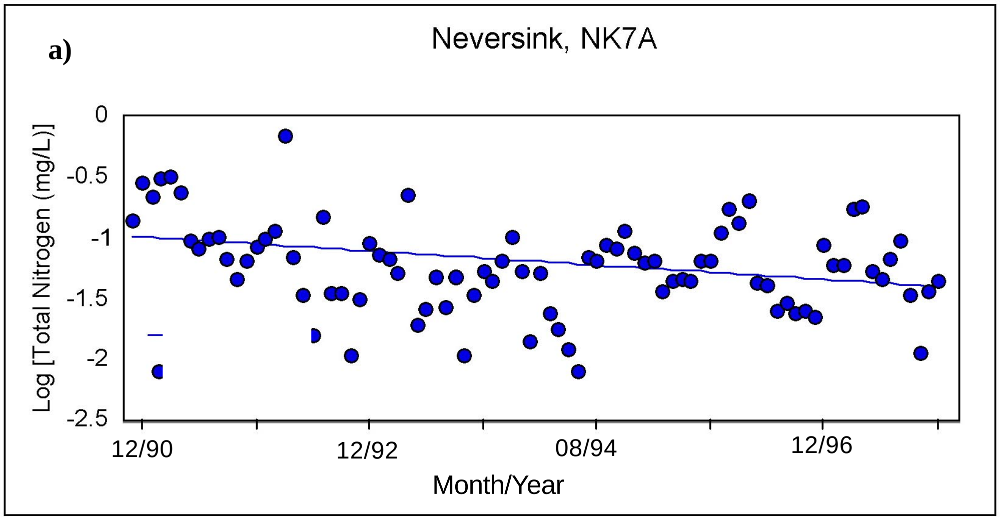
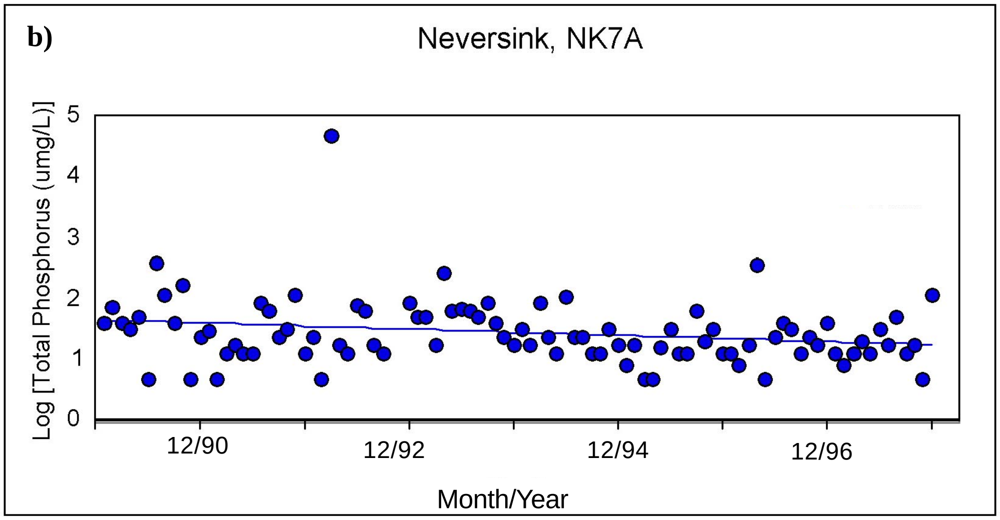


Figure D-5. *Average monthly (1987-1998) discharge and **(a)** precipitation, **(b)** total nitrogen, **(c)** total phosphorus, and **(d)** fecal coliforms at the Neversink water quality trend sites.*





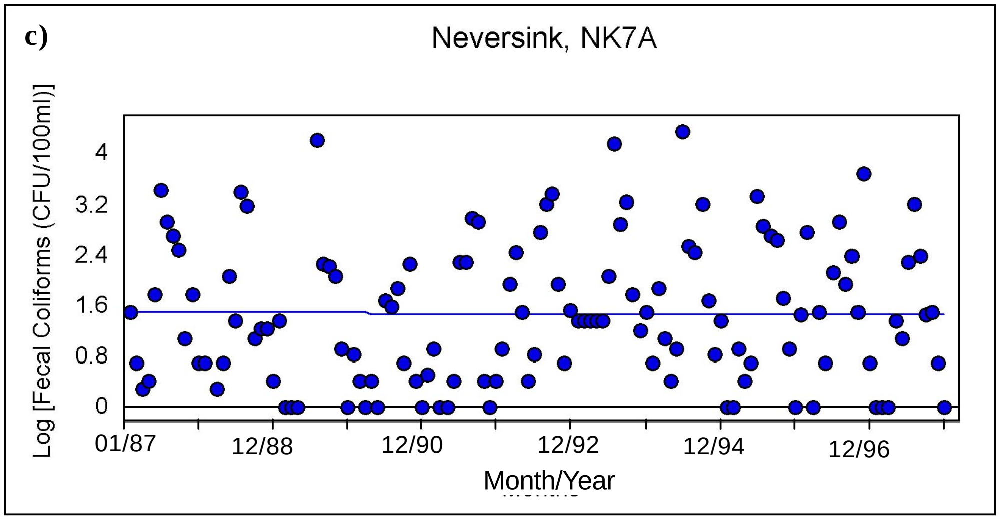


Figure D-6. *Average monthly **(a)** total nitrogen (1990-1998), **(b)** total phosphorus (1990-1998), and **(c)** fecal coliforms (1987-1998) at the Neversink water quality trend site. The blue line shows the overall trend with time.*

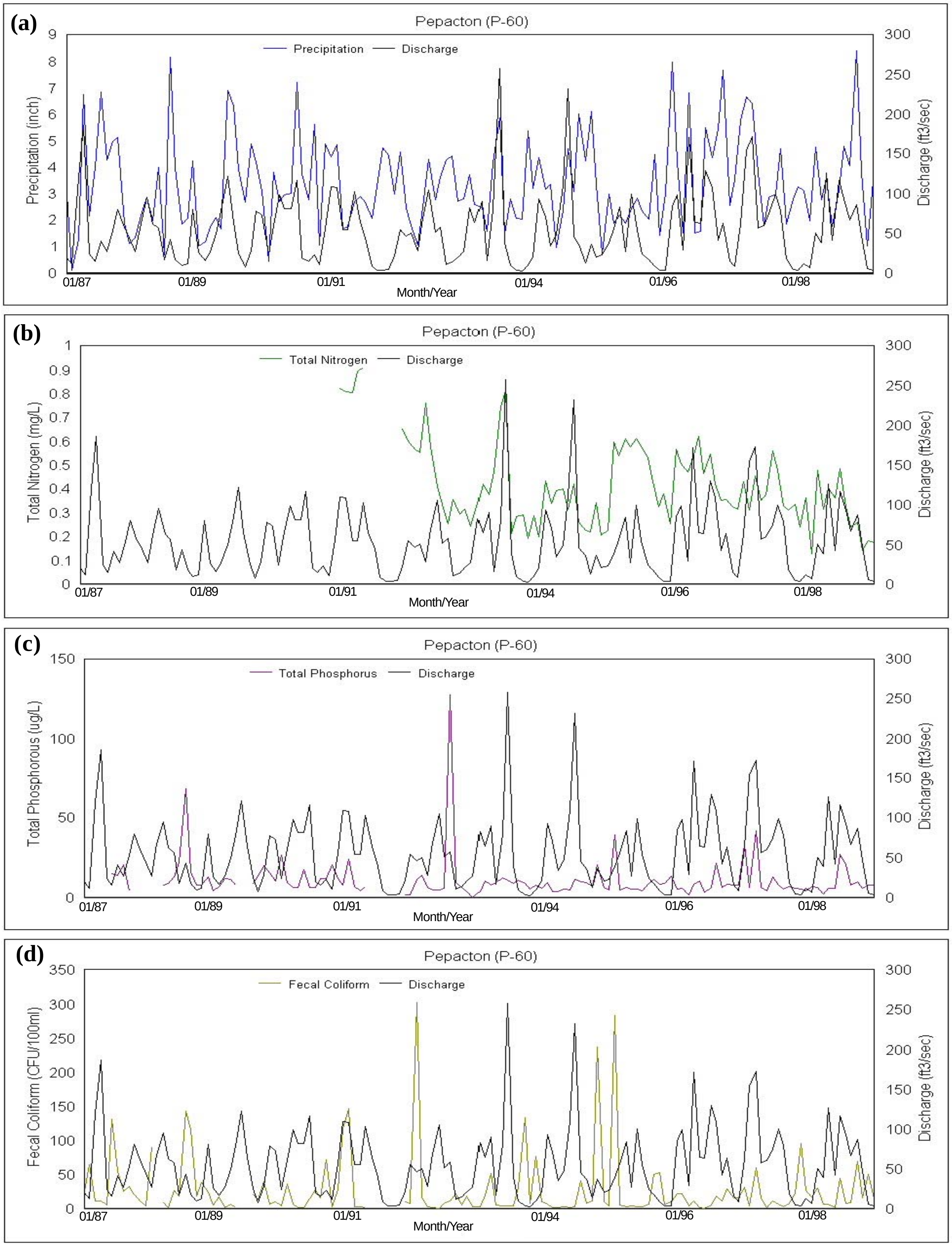


Figure D-7. *Average monthly (1987-1998) discharge and* ***(a)*** *precipitation,* ***(b)*** *total nitrogen,* ***(c)*** *total phosphorus, and* ***(d)*** *fecal coliforms at the Pepacton water quality trend sites.*

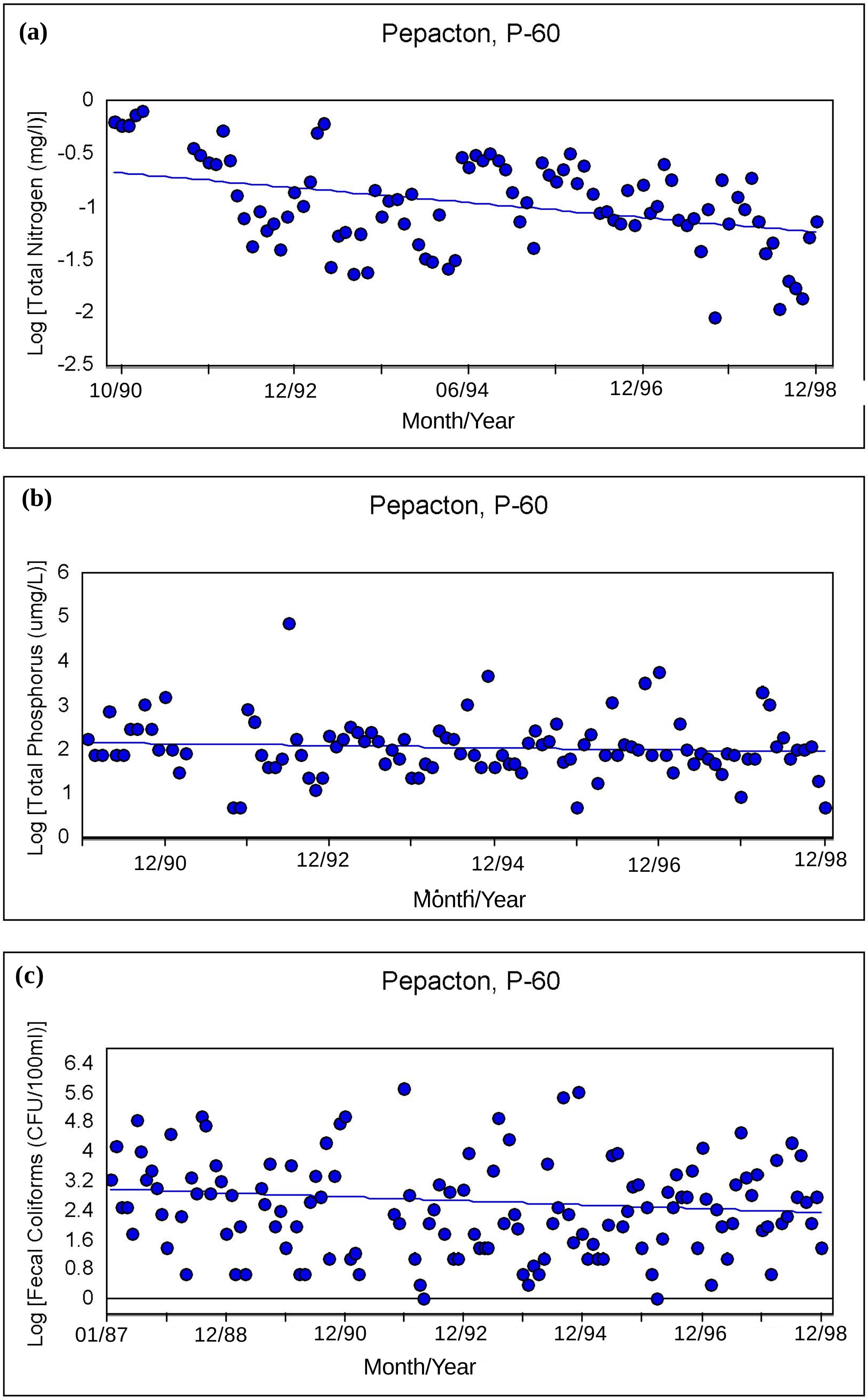


Figure D-8. *Average monthly* ***(a)*** *total nitrogen (1990-1998),* ***(b)*** *total phosphorus (1990-1998), and* ***(c)*** *fecal coliforms (1987-1998) at the Pepacton water quality trend site. The blue line shows the overall trend with time.*

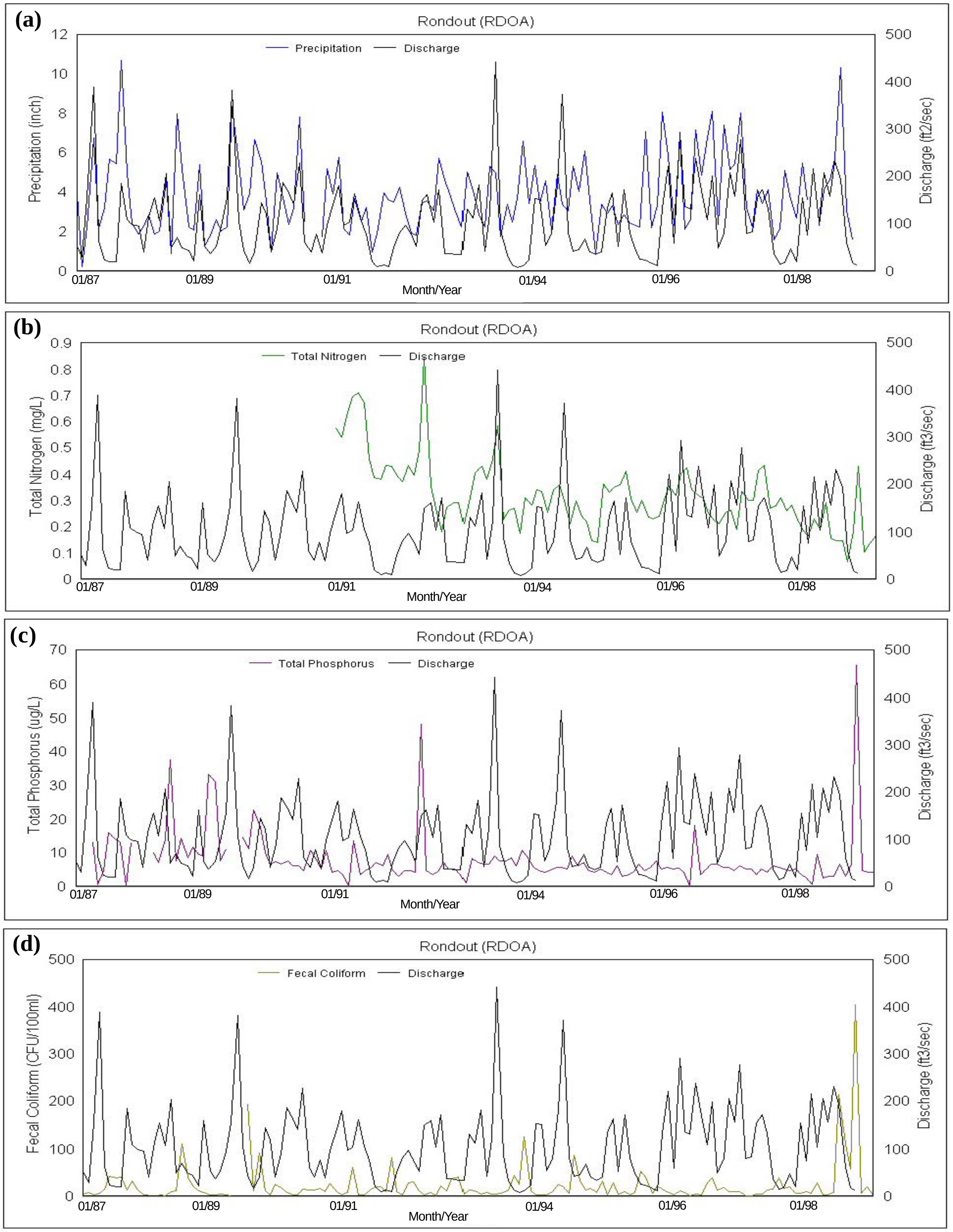


Figure D-9. *Average monthly (1987-1998) discharge and* ***(a)*** *precipitation,* ***(b)*** *total nitrogen,* ***(c)*** *total phosphorus, and* ***(d)*** *fecal coliforms at the Rondout water quality trend sites.*

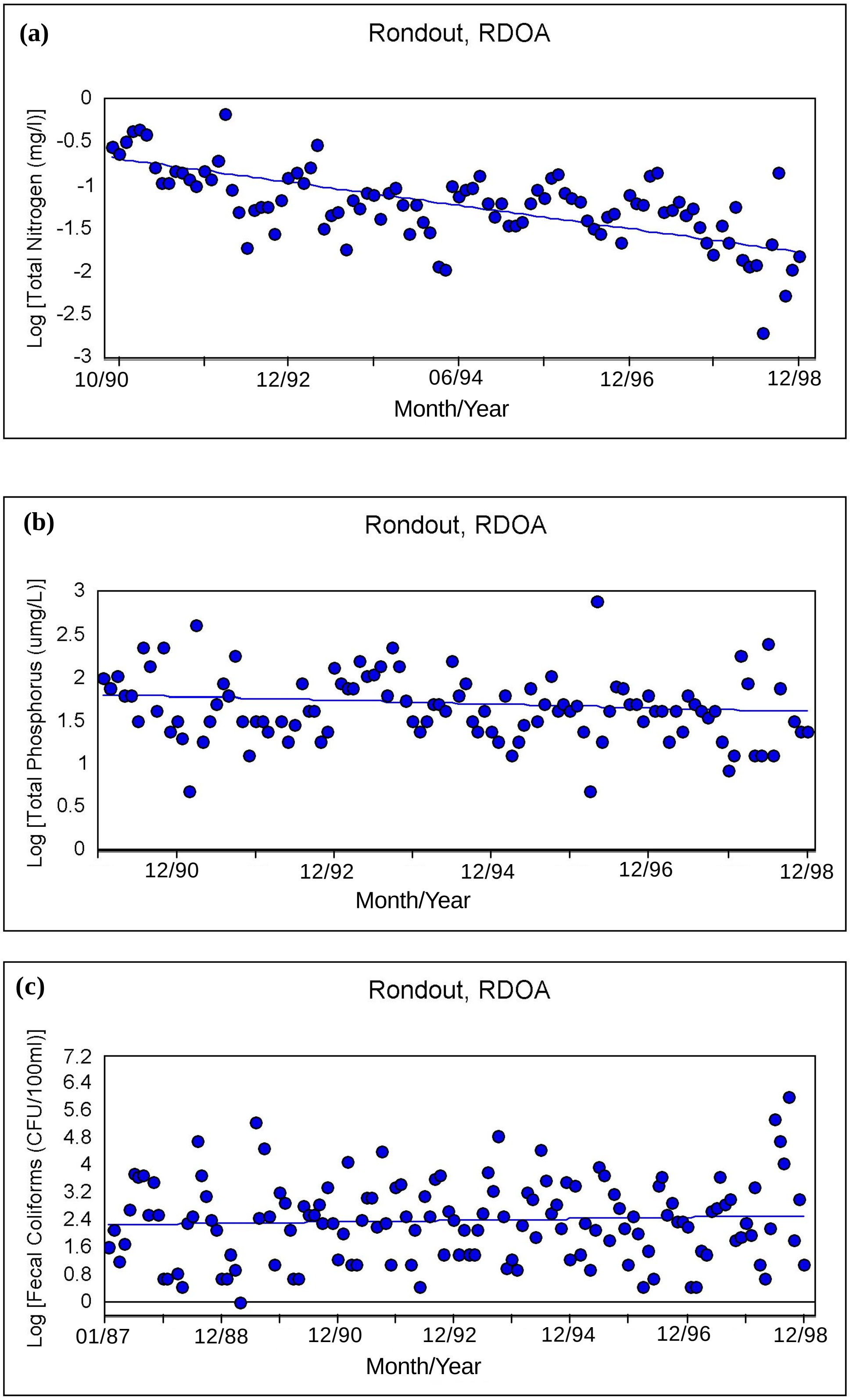


Figure D-10. *Average monthly* ***(a)*** *total nitrogen (1990-1998),* ***(b)*** *total phosphorus (1990-1998), and* ***(c)*** *fecal coliforms (1987-1998) at the Rondout water quality trend site. The blue line shows the overall trend with time.*

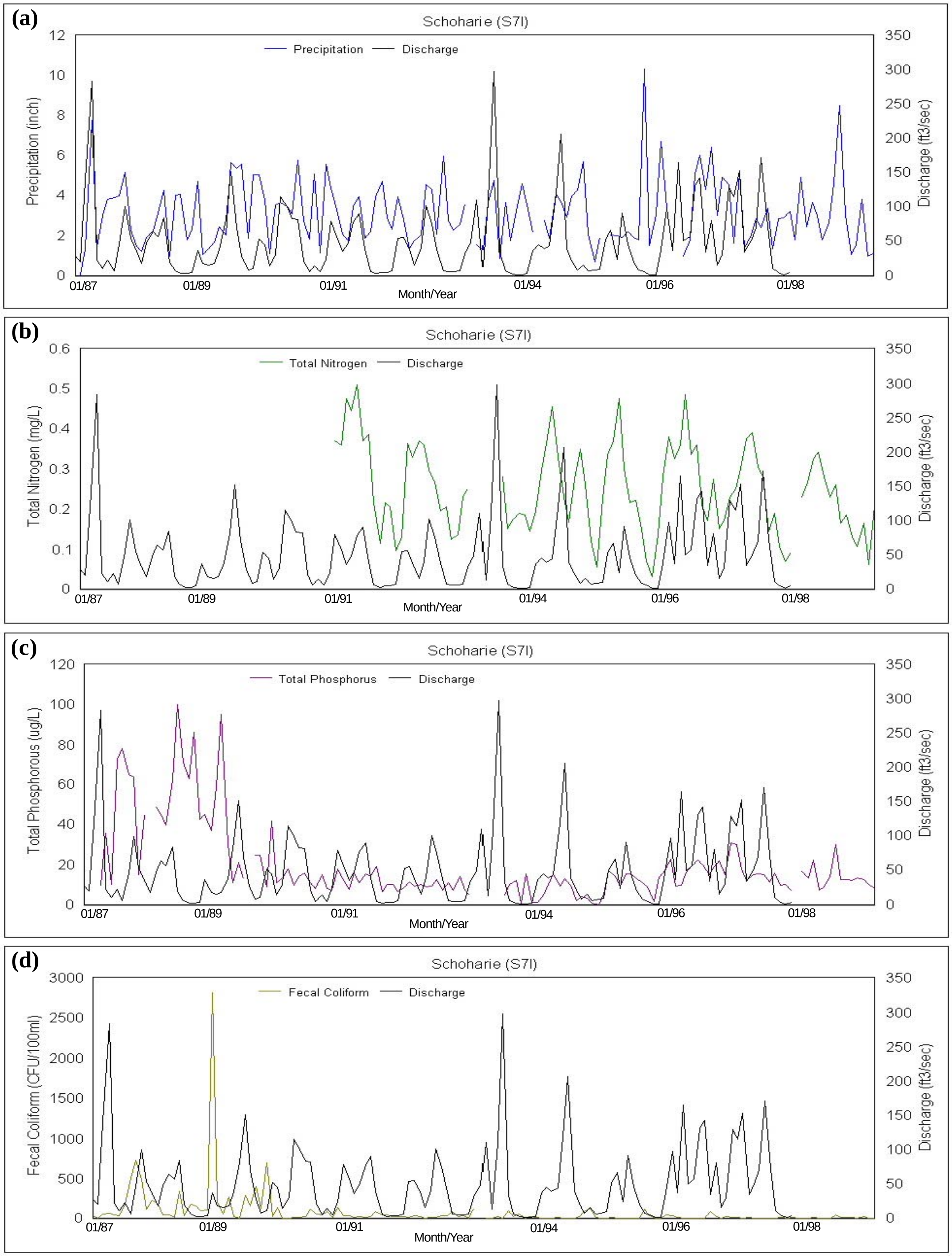


Figure D-11. *Average monthly (1987-1998) discharge and* ***(a)*** *precipitation,* ***(b)*** *total nitrogen,* ***(c)*** *total phosphorus, and* ***(d)*** *fecal coliforms at the Schoharie water quality trend sites.*

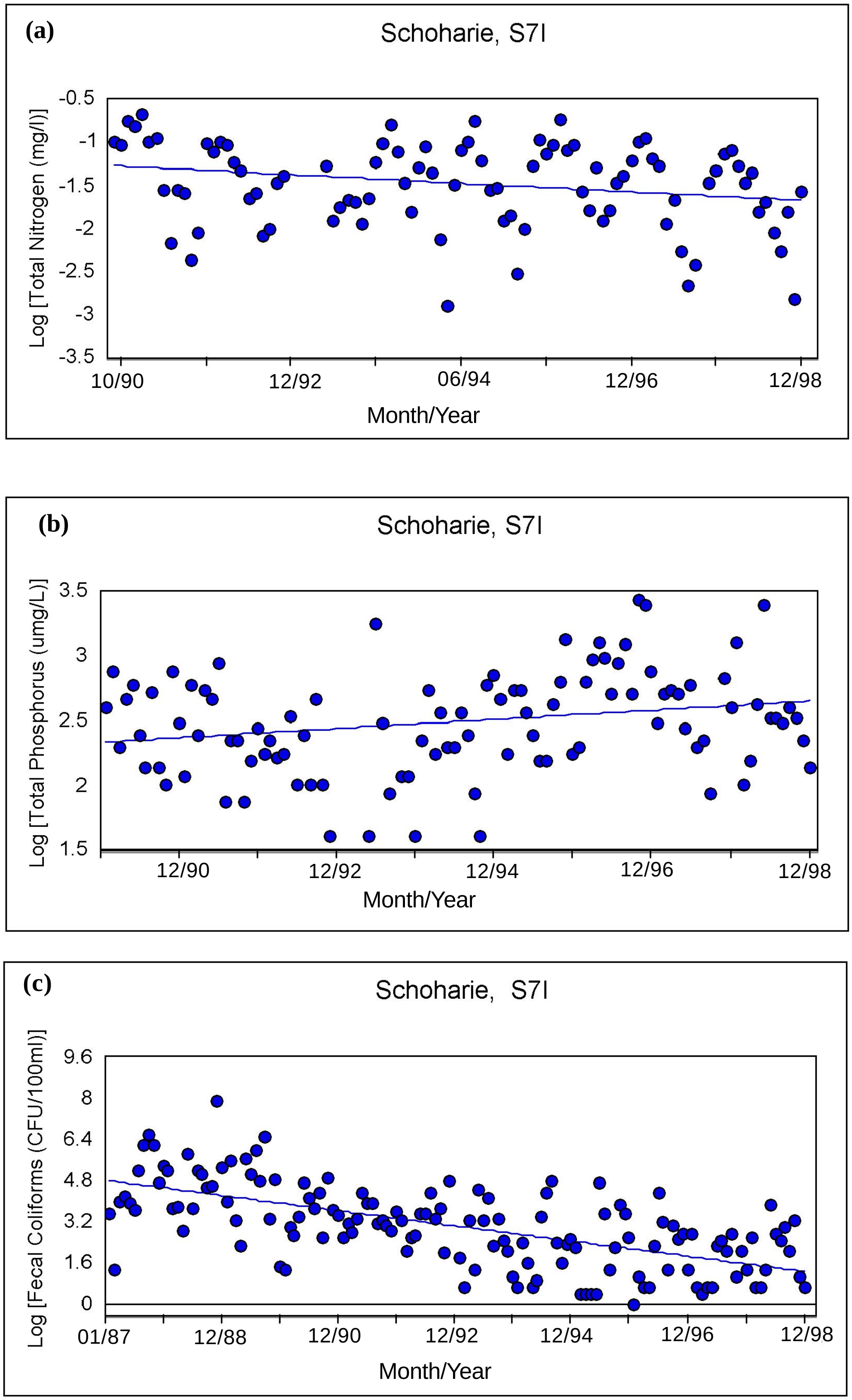


Figure D-12. *Average monthly* **(a)** *total nitrogen (1990-1998),* ***(b)*** *total phosphorus (1990-1998), and* ***(c)*** *fecal coliforms (1987-1998) at the Schoharie water quality trend site. The blue line shows the overall trend with time.*

Glossary

303D List
List of impaired waters (stream segments, lakes) that the Clean Water Act requires all states to submit for EPA approval every two years.

Acid Rain
A complex chemical and atmospheric phenomenon that occurs when emissions of sulfur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the original sources, and then deposited on earth in either a wet or dry form. The wet forms, popularly called “acid rain,” can fall as rain, snow, or fog. The dry forms are acidic gases or particulates.

Ambient
Outdoor.

Anion
A negative ion.

Anthropogenic
Relating to, or resulting from the influence of human beings on nature.

Biophysical
The geology, hydrology, soil, elevation, rainfall, temperature, plants and animals present in an area of study.

Cation
A positive ion.

Cation Exchange Capacity
The maximum number of moles of proton charge dissociable from unit mass given conditions of temperature and pressure.

Correlation Coefficient
A correlation coefficient is a number between -1 and 1 which measures the degree to which two variables are linearly related. If there is perfect linear relationship the correlation coefficient will be 1 or -1. A correlation coefficient of 0 means that there is no linear relationship between the variables.

Deciduous
Falling off or shed seasonally or at a certain stage of development in the life cycle.

Ecosystem
Community of different species interacting with one another and with the chemical and physical factors making up the nonliving environment.

Effluent
Wastewater, treated or untreated, that flows out of a treatment plant, sewer, or industrial outfall. Generally refers to wastes discharged into surface waters.

Estuaries
Regions of interaction between rivers and near shore ocean waters, where tidal action and river flow create a mixing of fresh and salt water. These areas may include bays, mouths of rivers, salt marshes, and lagoons. These brackish water ecosystems shelter and feed marine life, birds, and wildlife.

Eutrophication
A process whereby a water body becomes enriched by increased amounts of nutritive compounds such as nitrogen and phosphorus, resulting in the over production of plant life. Human activities can accelerate the process.

Fallow Fields
Cultivated land that is allowed to lie idle during the growing season; the tilling of land without sowing it for a season.

Fecal Coliform
Bacteria found in the intestinal tracts of mammals. Their presence in water or sludge is an indicator of pollution and possible contamination by pathogens.

Filtration Avoidance Determination (FAD)
A watershed protection agreement to protect the source of New York City's drinking water supply. The City will undertake measures to ensure continued protection of water quality within the watershed without filtration.

Geographic Information System (GIS)
A system, usually computer based for the input, storage, retrieval, analysis and display of interpreted geographic data. The data base is typically composed of map-like spatial representations, often called coverages or layers. These layers may involve a three-dimensional matrix of time, location and attribute or activity. A GIS may include digital line graph (DLG) data, digital elevation models (DEM), geographic names, land-use characterizations, land ownership, land cover, registered satellite and/or aerial photography along with any other associated or derived geographic data.

Glacial Till
Accumulations of unsorted, unstratified mixtures of clay, silt, sand, gravel, and boulders.

HUC
Hydrologic Unit Code, used by the U.S. Geological survey to reference hydrologic accounting units throughout the United States. Can be used interchangeably with watershed.

Human Use Index
The proportion of an area that is urbanized or used for agriculture is a measure of human use known as the U-index.

K-Factor
A measure of erodibility for a standard condition. It represents both the susceptibility of soil to erosion and the rate of runoff in a standard unit plot condition.

Land Cover/Use
Dominant vegetative, water, or urban cover in an area.

Landscape
A conceptual unit for the study of spatial patterns in the physical environment and influence of these patterns on important environmental resources.

Landscape Metrics
Refers to landscape measurements which are used as independent variables in the landscape indicator models to be developed. A landscape metric typically is based on one spatial measure or aspect; examples include population density, human use index, road density, and proportion of watershed with crops on steep slopes.

Median Value
The median is the value halfway through a data set, below and above which there lies an equal number of data values.

MRLC
Multi-Resolution Land Characteristics Consortium is a consortium of federal agencies that pool financial resources in order to acquire satellite-based remote sensor data in a cost effective manner, for their environmental monitoring programs.

Multispectral Scanner (MSS)
The MSS is a nonphotographic imaging system which utilizes an oscillating mirror and fiber optic sensor array. The mirror sweeps from side to side, transmitting incoming energy to a detector array which sequentially outputs brightness values (signal strengths) for successive pixels, one swath at a time. The forward motion of the sensor platform carries the instrument to a position along its path where an adjacent swath can be imaged. The MSS simultaneously senses radiation using an array of six detectors in each of four spectral bands from 0.5 to 1.1 micrometers.

Multiple Regression
The multiple regression is used to find a linear relationship between a response variable and several possible predictor variables.

N-Index
The proportion of an area that is in forest, grassland, wetland, and shrub cover and is a measure of natural vegetation.

NLCD
National Land Cover Data is one of the projects sponsored by the MRLC. The project objective was production of land-cover data for the conterminous United States using Landsat 5 Thematic Mapper (TM) satellite data and production of general land cover classes.

Nonpoint Source Pollution
Pollution sources which are diffuse and do not have a single point of origin or are not introduced into a receiving stream from a specific outlet. The pollutants are generally carried off the land by storm water runoff. The commonly used categories for nonpoint sources are: agriculture, forestry, urban, mining, construction, dams and channels, land disposal, and saltwater intrusion.

Nutrient
Any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus in wastewater, but is also applied to other essential and trace elements.

Organics
Referring to or derived from living organisms; in chemistry, any compound containing carbon.

Pathogens
Microorganisms that can cause disease in other organisms or in humans, animals and plants. They may be bacteria, viruses, or parasites and are found in sewage, in runoff from animal farms or rural areas populated with domestic and/or wild animals, and in water used for swimming. Fish and shellfish contaminated by pathogens, or the contaminated water itself, can cause serious illnesses.

pH
The negative common logarithm of free-proton activity.

Pixel
A contraction of the phrase “picture element.” The smallest unit of information in an image or raster map. Referred to as a cell in an image or grid.

Point Sources
A stationery location or fixed facility from which pollutants are discharged or emitted. Also, any single identifiable source of pollution, e.g., a pipe, ditch, ship, ore pit, factory smokestack.

Pollution
Generally, the presence of matter or energy whose nature, location or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the manmade or man-induced alteration of the physical, biological, and radiological integrity of water.

Regression Analysis
A regression is an algebraic expression of the relationship between two (or more) variables. A regression analysis indicates the extent a prediction or association of response variables can be made using an independent set of predictor variables .

Reservoir
Any natural or artificial holding area used to store, regulate, or control water.

Riparian Buffer Zone
Riparian buffer zones are an arbitrary delineation of the ecotone between terrestrial and aquatic ecosystems.

Riparian Ecosystem
A system located within close proximity to aquatic or subsurface water, having a high water table, distinct vegetation and soil characteristics. Riparian ecosystems are uniquely characterized by the combination of high species diversity, density, and productivity. There is a continuous exchange of energy nutrients and species between the riparian, aquatic, and upland terrestrial ecosystems.

Riparian Zone
The area of vegetation located on the bank of a natural watercourse, such as a river, where the flows of energy, matter, and species are most closely related to water dynamics. The "riparian zone" can specifically refer to the linear corridors associated with streams and streamside vegetation.

Scale
The spatial or temporal dimension over which an object or process can be said to exist. The spatial, attribute, and temporal parameters associated with making an observation or measurement, usually including resolution, extent, window size, classification system (nomenclature), and lag. The way in which objects, parts of objects, or processes are related as the scale of measurement changes. The amount of information or detail about an area.

Sediments
Soil, sand, and minerals washed from land into water usually after rain. They fill in reservoirs, rivers and harbors, destroying fish-nesting areas and holes of water animals, and clouding the water so that needed sunlight might not reach aquatic plants. Farming, mining, and building are activities that expose sediment materials, allowing them to be washed off the land after rainfalls.

Soil Moisture
The percent of the soil volume containing water.

Soil Porosity
The pores (cracks and spaces) in rocks or soil, or the percentage of the rock's or soil's volume not occupied by the rock or soil itself.

Spatial Resolution
The "grain" size of a set of imagery and is dependent on the sensor being used, the structure of the ground area being sensed. The higher the resolution, the more detail captured, the smaller the area covered within a pixel.

Stepwise Regression
A regression where the "best" model is developed in stages using a list of several potential explanatory variables. The variable having the strongest explanatory power is used first, then the second, until no more variables having a significant contribution are left.

Stream Connectivity
The flow of water from headwater drainages to larger watershed streams. The movement of water from one place to another via streams.

Stream Density
The amount of streams per total area of a watershed.

Subwatersheds
The drainage area of off mainstream tributaries, generally including first and second order streams.

Suburbanization
The outward expansion of cities resulting in the conversion of rural land to urban developments, rights-of-way, highways, and airports

Surface Water Runoff
Sheet flow across the landscape that usually occurs during and immediately following rainfall or spring thaw.

Temporal Data
Information or measurements gathered over time.

Terrestrial
Pertaining to land.

Thematic Mapper (TM)
The TM is a nonphotographic imaging system which utilizes an oscillating mirror and seven arrays of detectors which sense electromagnetic radiation in seven different bands. The thematic mapper sensor is a derivative of the multispectral scanner (MSS) generation of scanners, achieving greater ground resolution, spectral separation, geometric fidelity, and radiometric accuracy.

TMDL
Total maximum daily loads. TMDL is a calculation of the amount of pollutant a water body can receive and still meet standards set forth in the Clean Water Act.

Topography
The configuration of a surface including its relief and the position of its natural and manmade features.

U-Index
The proportion of an area that is urbanized or used for agriculture and is a measure of human use.

Urban Development
Rate of growth of an urban center.

Water Holding Capacity
The point at which a soil becomes saturated with water and ready downward drainage will occur with the addition of more water.

Water Quality Standards
Specific standards for water condition which, if reached, are expected to render a body of water suitable for its designated use. The criteria are based on the level of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Watershed
A watershed is a natural unit of land that captures rainfall, snow or other forms of precipitation, which then drain or infiltrate to streams and ground water.

Watershed Pollution Potential
The amount of pollution predicted to enter stream water as a result of landscape proportions within a watershed. The potential is predicted based on a set of metrics known to significantly contribute water quality.

Wetland
An area of land located at the junction of upland terrestrial and aquatic ecosystems having water present at the surface or within the root zone, anoxic soils, and hydrophytic plants.

References

Aber, J.D., and J.M. Melillo. 1991. Terrestrial Ecosystems. Saunders College Publishing, Orlando, Florida, USA. pp1-429.

Addiscott, T.M. 1997. A critical review of the value of buffer zone environments as a pollution control tool. Pp236-242. *In*: N.E. Haycock, T.P. Burt, D.W.T. Goulding, and G. Pinay (eds.), Buffer Zones: Their Processes and Potential in Water Protection. Quest Environmental.

Berry, W. D., and S. Felman. 1985. Multiple Regression in Practice. Sage Publications, Beverly Hills, California, USA.

Box, G.E.P., and G.M. Jenkins. 1976. Time series analysis: Forecasting and control. Holden-Day, SanFransico, California, USA.

Brady, N.C. 1990. The Nature and Properties of Soils. Macmillan Publishing Company, New York, New York, USA.

Brown, J.L. 2000. Protecting the source. Civil Engineering. 70:50-55.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing Environment. 37:35-46.

Correll, D.L. 1997. Buffer zones and water quality protection: general principles. Pp 7-20. *In*: N.E. Haycock, T.P. Burt, D.W.T. Goulding and G. Pinay (eds.), Buffer Zones: Their Processes and Potential in Water Protection. Quest Environmental.

Dijak, W.D., and F.R. Thompson. 2000. Landscape and edge effects on the distribution of mammalian predators in Missouri. Journal of Wildlife Management. 64:209-216.

Ehlers, L.J., M.J. Pfeffer, and C.R. O'Melia. 2000. Management work. Environmental Science and Technology/News. 34:465-471.

EPA (U.S. Environmental Protection Agency). 1991. Guidance for Water Quality Based Decisions: The TMDL Process. EPA 440-/4-91-001. U.S. Environmental Protection Agency, Washington, DC, USA.

EPA. 1998a. National Water QualityInventory: 1996 Report to Congress, EPA 841-R-97-008, Office of Water, U.S. Environmental Protection Agency, Washington, DC, USA.

EPA. 1998b. Clean Water Action Plan - Restoring and protecting America's waters. EPA-840-R-98-001 U.S. Environmental Protection Agency.

EPA. 1999. USDA-National Agriculture Statistics Service (NASS). Available at http://www.nass.usda.gov/.

EPA (Environmental Protection Agency). 2000. Assessing New York City's Watershed Protection Program. The 1997 Filtration Avoidance Determination Mid-Course Review for the Catskill/Delaware Water Supply Watershed. Region 2 Report.

ESRI (Environmental System Research Institute). 1992. Understanding GIS: The ARC/INFO Method.

Fennessy, M.S., and J.K. Cronk. 1997. The effectiveness and restoration potential of riparian ecotones for the management of nonpoint source pollution, particularly nitrate. Critical Reviews in Environmental Science and Technology. 27:285-317.

Fisher, D.S., J.L. Steiner, D.M. Endale, J.A. Stuedemann, H.H. Schomberg, A.J. Franzluebbers, and S.R. Wilkinson. 2000. The relationship of land use practices to surface water quality in the Upper Oconee Watershed of Georgia. Forest Ecology and Management. 128:39-48.

Fitzpatrick-Lins, K. 1981. Comparison of sampling procedures and data analysis for land use and land cover maps. Photogrammetric Engineering and Remote Sensing. 47:343-351.

Forman, R.T.T. 1995a. Some general principles of landscape and regional ecology. Landscape Ecology 10:133-142.

Forman, R.T.T. 1995b. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge, Massacussetts, USA. Pp 632.

Forman, R.T.T., and R.D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (U.S.A.) suburban highway. Conservation Biology. 14:36-46.

Griffith, D. A., and C.G. Amerhein. 1997. Multivariate Statistical Analysis for Geographers. Prentice Hall, New Jersey, USA.

Harris, G.P. 1997. Algal biomass and biogeochemistry in catchments and aquatic ecosystems: scaling of processes, models and empirical tests. Hydrobiologia (The Hague). 349:19-26.

Herlihy, A.T., J.L. Stoddard, and C.B. Johnson. 1998. The relationship between stream chemistry and watershed land cover data in the mid-Atlantic region, U.S. Water, Air and Soil Pollution. 105:377-386.

Heathwaite, A.L., T.P. Burt, and S.T. Trudgill. 1990. The effect of land use on nitrogen, phosphorus and suspended sediment delivery to streams in a small catchment in Southwest England. *In*: Thomas, J.B. (ed.) Vegetation and Erosion: Processes and Environments, John Wiley, Chichester, U.K. Pp 161-178.

Hunsaker, C.T., P.M. Schwartz, and B.L. Jackson. 1996. Landscape characterization for watershed management. Pp 206-208, *In*: Watershed ’96. WaterEnviron. Fed., Alexandria, Virginia, USA.

Johnes, P.J., and A.L. Heathwaite. 1997. Modelling the impact of land use change on water quality in agricultural catchments. Hydrological Processes. 11:269-286.

Jones, K.B., A.C. Neale, M.S. Nash, R.D. Van Remortel, J.D. Wickham, K.H. Ritters, and R.V. O’Neill. 2001. Predicting nutrient and sediment loadings to streams from landscape metrics: A multiple watershed study from the United States. Landscape Ecology, 16:301-312.

Jones, K.B., K.H. Ritters, J.D. Wickham, R.D. Tankersly, R.V. O’Neill, D.J. Chaloud, E.R. Smith, and A.C.

Neale. 1997. An Ecological Assessment of the United States Mid-Atlantic Region. EPA/600/R-97/130, U.S. Environmental Protection Agency. Office of Research and Development, Washington, DC, USA.

Karr, J.R., and I.J. Schlosser. 1978. Water resources and the land-water interface. Science. 201:229-234.

Lillesand, T.M., and R.W. Kiefer. 1994. Remote Sensing and Image Interpretation. John Wiley and Sons, Inc., New York, New York, USA.

Larcher, W. 1995. Physiological Plant Ecology. Ecophysiology and Stress Physiology of Functional Groups. Third Edition. Springer-Verlag, New York, New York, USA, 506pp.

Lowrance., R. 1997. The potential role of riparian forest as buffer zones. pp128-132. *In*: N.E. Haycock, T.P. Burt, D.W.T. Goulding and G. Pinay(eds.), Buffer Zones: Their Processes and Potential in Water Protection. Quest Environmental.

Lowrance, R., R.L. Todd, J. Fail Jr., O. Hendrickson Jr., R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. Bioscience. 34:374-377.

Madansky, A. 1988. Prescriptions for Working Statisticians. Spring Verlag, New York, New York, USA.

Mehaffey, M.H., T.G. Wade, M.S. Nash, and C.M. Edmonds. 2001. Analysis of land cover/use and water quality in the New York Catskill/Delaware watersheds. Managing for Ecosystem Health. In press.

Miller, W.J. 1970. The Geological History of New York State. Kennilcat Press. Port Washington, New York, USA.

MOA. 1997. Watershed Memorandum of Agreement. NYCDEP Office of Watershed Communications, Kingston, New York, USA.

Murdoch, P.S., and C.R. Barnes. 1996. Stream acidification in the Catskill Mountains of New York. U.S. Geological Survey, Open-File Report 96-221. pp1-14.

Nash, M.S., A. Toorman, P.J. Wierenga, A. Gutjahr and G.L. Cunningham. 1992. Estimation of vegetation cover in an arid rangeland based on soil moisture using co-kriging. Soil Science. 154: 25-36.

Nash, M.S., W.G. Whitford, A.D. Soyza and J. Vanzee. 1999. Livestock activity and Chihuahuan desert annual plant communities: boundary analysis of disturbance gradients. Ecological Application 9:814-823.

Novotny, V., and H. Olem. 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York, USA.

NYCDEP 1997a. Water Quality Surveillance Monitoring. Valhalla, N.Y., USA

NYCDEP 1997b. Appendices Water Quality Surveillance Monitoring. Valhalla, N.Y., USA

NYCDEP 1997c. Supplement to Appendices Water Quality Surveillance Monitoring. Valhalla, N.Y., USA

O'Neill, R.V., J.R. Krummel, R.H. Gardner, G. Sugihara, B. Jackson, D.L. DeAngelis, B.T. Milne, M.G. Turner, B. Zygmunt, S.W. Christensen, V.H. Dale, and R.L. Graham. 1988. Indices of landscape pattern. Landscape Ecology, 1(3):153-162.

O'Neill, R.V., C. Hunsaker, D. Levine. Monitoring challenges and innovative ideas. 1992. pp. 1443-1460. D.H. McKenzie, D.E. Hyatt, and V.J. McDonald (eds.), Ecological Indicators. Elsevier, New York, USA.

Petts, G.E. 1994. Rivers: dynamic components of catchment ecosystems. *In*: Petts, G.E. and P. Calow (eds.),
The Rivers Handbook Volume Two, Blackwell, Oxford, UK. Pp3-22.

SAS 1990. SAS/SAT User's Guide, Version 6, Fourth Edition, Vol. 2, SAS Institute Inc., Cary, North Carolina, USA.

Skirvin, S.M., S.E. Drake, J.K. Maingi, S.E. Marsh, W.G. Kepner. 2000. An Accuracy Assessment of 1997 Landsat Thematic Mapper Derived Land Cover for the Upper San Pedro Watershed (U.S./Mexico). EPA - 600-R-00-097. U.S. Environmental Protection Agency.

Slaymaker, O. 2000. Research developments in the hydrological sciences in Canada (1995-1998): surface water quality and ecology. Hydrological Processes. 14:1539-1550.

Stave, K.A. 1995. Resource Conflict in New York City's Catskill Watersheds: A Case for Expanding the Scope of Water Resource Management. American Water Resources Association. 95:61-67.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. Second Edition. McGraw-Hill, New York, NY, USA.

U.S. Census (United States Bureau of the Census). 1990. 1990 U.S. Census of Population and Housing: New York State. Washington, DC, USA.

USDA (U.S. Department of Agriculture). 1999. National Agriculture Statistical Service Website, www.usda.gov/nass/pubs.

van Valkenburg, N.J. 1996. The Forest Preserve of New York State in the Adirondack and Catskill Mountains: A Short History, Purple Mountain Press, New York, New York, USA.

Yuan, D., Elvidge, C.D., and Lunetta, R.S., 1998. Survey of Multispectral Methods for Land Cover Change Analysis in Remote Sensi

Books for Interested Readers

Aber, J. D. and J. M. Melillo. Terrestrial Ecosystems. Saunders College Publishing.

Brady, N.C. 1990. The Nature and Properties of Soils. Macmillan Publishing Company, New York, New York, USA.

Forman, Richard T. T. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge

Forman, R.T.T. & Gordon, M. Landscape Ecology. John Wiley and Sons.

Lampert, W. and Sommer U. Limnoecology: The Ecology of Lakes and Streams. Translated by J.F. Hensley, Oxford University Press.

Ludwig, J.A. and Reynolds, J.F. Statistical Ecology: A Primer on Methods and Computing.John Wiley and Sons.

Lillesand, T.M. and Kieffer, R.W. 1994. Remote Sensing and Image Interpretation. 3rd Ed. John Wiley and Sons

Miller, W.J. 1970. The Geological History of New York State. Kennilcat Press. Port Washington, New York, USA.

Pomeroy, L.R. and Alberts J.J. Concepts of Ecosystem Ecology. Springer-Verlag.

Sheskin, D.J. Handbook of Parametric and Non-Parametric Statistical Proceedures. Second Edition Chapman and Hall/CRC, Florida, USA,

Stiling, P. Ecology: Theories and Applications, 3rd edition. Prentice-Hall

Turner, M. G., and R. H. Gardner. Quantitative methods in landscape ecology. Springer-Verlag.

van Valkenburg, N.J. 1996. The Forest Preserve of New York State in the Adirondack and Catskill Mountains: A Short History, Purple Mountain Press, New York, New York, USA.

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