A LANDSCAPE ANALYSIS OF NEW YORK CITY'S WATER SUPPLY (1973-1998)

by

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Notice

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Project Summary

Title: A Landscape Analysis of New York City's Water Supply (1973-1998).

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Organization: Environmental Sciences Division, U.S. Environmental Protection Agency

Core Task Summary

Currently the city of New York is trying save taxpayers the cost of a billion dollar filtration system by protecting water quality through implementing a long-range watershed protection program. A large part of the watershed protection plan focuses on the solicitation for acquisition of 350 thousand acres of sensitive lands surrounding streams and rivers. The objective of this study is to explore relationships between changes in landscape and water quality degradation in the Catskill/Delaware basins. Together these basins supply 90% of New York City's drinking water. The goals of this study are 1) improvements in environmental risk assessment and 2) target watersheds and sub-watersheds influencing water quality in New York City's water supply system.

In this study, land use imagery will be acquired or generated for four dates, ranging from 1973 to 1998. Landsat TM imagery will be used to classify land use/ land cover for all dates except 1973, which will require the use of multispectral scanner (MSS) images from the North American Landscape Characterization (NALC) program. Landscape metrics believed to impact drinking water quality, such as proportion of land use, proportion of land use in and near riparian zones, length of roads near streams and crops on steep slopes. These landscape metrics will be calculated from the land use coverages for all sub-basins in the Delaware/Catskill watershed. Like many long term landscape analyses, this study will require comparisons between images having different resolutions. In order to better determine landscape change over a 25 year time span further evaluation of the multi-date and multi-resolution data sets will be conducted using paired Landsat TM and MSS imagery for one of four selected image dates.

Physical, chemical and biological water data will be collected from various database sources for the 70's 80's and 90's for streams and reservoirs. The main sources for the water quality parameters will be the NYCDEP, NYSDEC, USGS and EPA's EMAP and storage and retrieval data base STORET. Analyses may include 1) multi-variate and non-parametric procedures analyses to examine yearly and seasonal change in water quality and 2) stepwise regression, correlations and cluster analysis to find associations and relationships between land-use with water quality parameters.

From these analyses an expanded knowledge of the impacts of landscape proportion on water quality will be gained, and a set of landscape metrics important to surface water quality conditions will be calculated. These landscape metrics can then be used to target watersheds and sub-watersheds having landscape proportions strongly correlated with water quality degradation in the Catskill/Delaware basins. In addition to the area of this study there is the potential for application of this research in regions having similar landscape characteristics in the nearby states of Pennsylvania and New Jersey. This study is consistent with the goals and objectives of improved understanding of environmental risk, ecosystem research, assessment and restoration, as articulated by the 10 year strategic plan for the landscape science program (LEB Strategic Plan).

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List of Abbreviations

CREP	Conservation Reserve Enhancement Program
CWA	Clean Water Act
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
EPIC	Environmental Photographic Interpretation Center
EROS	Earth Resources Observation Systems
GIS	Geographic Information System
GPRA	Governmental Performance Results Act
LEB	Landscape Ecology Branch
MOA	Memorandum of Agreement
MRLC	Multi-Resolution Land Characteristics
MSS	Multispectral Scanner
NALC	North American Landscape Characterization
NERL	National Exposure Research Laboratory
NHAP	National High Aerial Photography
NYCDEP	New York City Department of Environmental Protection
NYSDEC	New York State Department of Environmental Conservation
ORD	Office of Research and Development
QA	Quality Assurance
STORET	STORage and RETrieval
TM	Thematic Mapper
USDA	United States Department of Agriculture
USGS	United States Geological Survey

Project Narrative

Goals and Objectives

The primary goal of this study is to improve risk assessment through the development of methods and tools for characterization of the relationship between landscape and water resource change. The relationship between landscape proportion and ecological and biological response has been established by a number of studies (Wiens and Milne, 1989; O'Neill et al., 1988; Graham et al.,1991). However, the existing studies are limited to a narrow set of landscapes features and tend to focus on percentages of near stream riparian land cover. The advent of geographic information systems and greater access to remote satellite imagery has enhanced landscape monitoring capabilities. Using land cover derived from satellite imagery with other spatial data and a GIS, it is now possible to generate landscape metrics that reflect changes in ecological processes (O'Neill et al.,1997).

Metrics such as proportion of land cover, topography and soils correlate well with stream and lake condition, suggesting a relationship between landscape proportion and water quality and quantity (Hunsaker and Levine, 1995). By further exploring this relationship an assessment of the vulnerability of land and water resources to stresses in the environment can be measured. Furthermore, once the information and techniques used in this study are validated through quality assurance and peer reviews, there will be a potential of utilizing the above techniques in similar types of watersheds in the region.

The main objectives of this study are to 1) generate a land cover database for the Catskill-Delaware basins spanning two and a half decades (1973 to 1998), 2) produce a landscape metric database for the watershed at the sub-basin level for each land cover image, 3) create water quality databases, which have been verified and checked against original agency sources and 4) relate water chemical (i.e. pH, NO_3-N, TP, chloride, and silica), physical (i.e. temperature and flow rate) and biological (i.e. microbial and macro-invertebrate) parameters to physiographic and landscape indices at the basin, sub-basin and near stream (100 and 500 meter) scale.

Because of changes in technology from the 1970's to the 1980's the resolution of satellite images has changed from 60 meters in the MSS images to 30 meters in the TM. Trying to evaluate landscape change across a 25 year time span, as has been proposed by this study, requires using both Landsat TM and MSS images. Therefore a secondary objective of this study will be to relate the land use\land cover classification of the MSS and TM imagery using paired imagery for one of the four selected image dates.

Introduction

New York City Water Supply - Problems

Initially New York City's drinking water was supplied by public wells. The need for a greater water supply first became an issue in 1776, when the population swelled to 22,000 residents, resulting in construction of the city's first reservoir. Pollution of the well waters and increasing demand eventually led to the impoundment of the Croton river in 1842 and the construction of an elaborate aqueduct system to supply water from the Old Croton reservoir. The aqueduct could supply over 90 million gallons per day to the city, but eventually even this amount of water was not enough to supply the city's continued growth. New reservoirs and a second aqueduct system were constructed in Boyds Corner and Middle Branch and were put into service in 1890.

In an effort to insure the water supply into the future, the Catskill and Delaware systems were developed (Hecker, 1991, Weidner, 1974) (Figure 1). The construction of the impoundments, aqueducts and tunnels needed to supply the water to the city spanned a total of six decades (1905-1965). The six reservoirs are the Cannonsville, Pepacton, Schoharie, Neversink, Rondout and Ashokan (Figure 2). Together, these reservoirs provide 90% of the 1.4 billion gallons of drinking water consumed by New York City residence. Of the six reservoirs, Ashokan Reservoir is the oldest (1907) and largest reservoir with a water surface area of 12.8 square miles. The Schoharie reservoir which is located farther north and on higher ground (1,130 ft.) was constructed between 1917 and 1927 and is considerably smaller than the Ashokan with a water surface area of 1.8 square miles and a storage capacity of 22 billion gallons (Weidner, 1974). The first reservoir constructed as part of the Delaware water supply system was the Neversink. The Neversink was completed in 1950 and is located to the southeast of the Ashokan with a shoreline 17 miles long. The second reservoir the Rondout, was completed in 1951 and receives waters from the Neversink, Cannonsville and Pepacton, via the Delaware aqueduct, making it the keystone to the Delaware supply system (Figure 2).

With the development of the Catskill/Delaware systems, New York City's drinking water remains one of the cleanest in the nation. However, as a result of topographic constrains both agricultural and urban land use is concentrated close to rivers and streams. While the human population in the Catskill/Delaware watershed has increased only 17% in the past thirty years, the continued effluent inputs from waste treatment plants, non-point agricultural, and urban runoff increase the potential risk of contamination above acceptable water quality standards for drinking and habitat survival. The economy of the area depends largely on seasonal tourism and dairy farming (Stave, 1995), making fecal coliforms, nutrients and sedimentation levels a particular concern (Wall et al., 1998; Hansan, 1996).

New York City Water Supply - Solutions

Currently the city is trying to decrease the threat to its quality of water through the development and implementation of a long-range watershed protection program. The plan was signed in 1997 and unites efforts by the local communities, the city and state of New York, environmental groups, and the EPA to preserve the high quality of New York City's drinking water supply (Ashendorff et al., 1997, Okun et al., 1997). The plan includes upgrading current sewage treatment plants, implementing new watershed regulations, design and construction of a filtration system for the 10% of water supplied by the Croton system, and acquisition of land deemed critical to the preservation of high water quality in the Catskill/Delaware system.

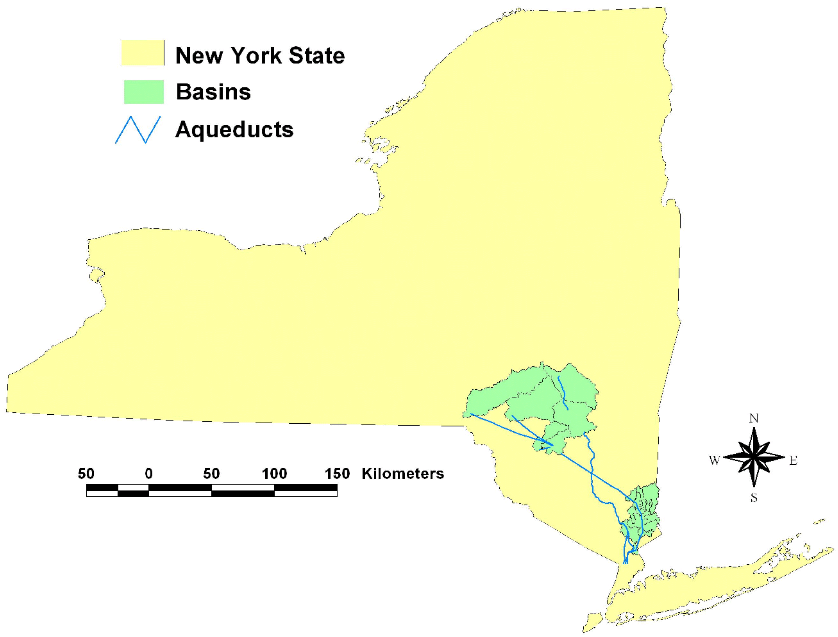

Figure 1. The New York City water supply system including the Catskill-Delaware and Croton watersheds.

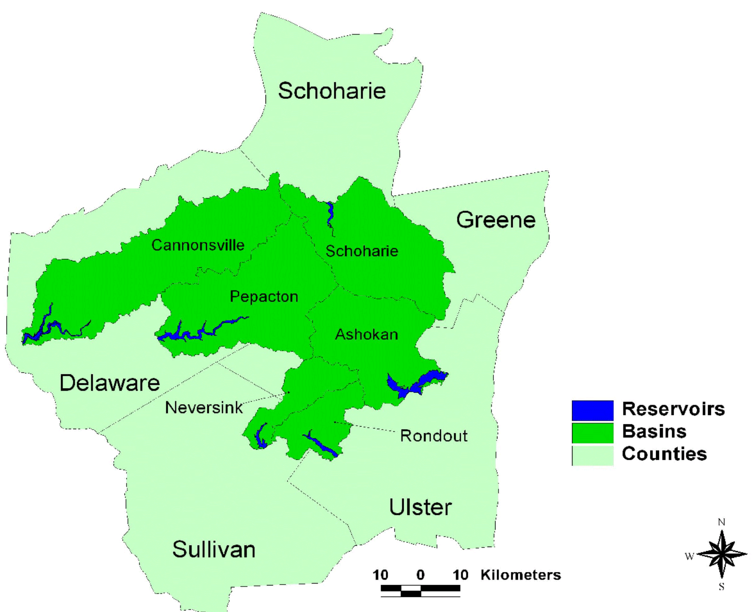

Figure 2. The five reservoir basins and surrounding counties of the Catskill-Delaware watershed.

Land acquisition was selected, partly to protect the environment, but also as a means to save the taxpayers of New York state billions of dollars. Installing a filtration system for the city's water supply would cost an estimated 2-8 billion dollars, versus the 250-300 million dollars set a side for purchase of land (MOA, 1997, Featherstone, 1996). The majority (90%) of money spent for land acquisition will be used in the Catskill/Delaware basins. The city has set as its goal, the solicitation of 350 thousand acres of land (MOA, 1997). Under the agreement the State Department of Environmental Conservation issued a permit to acquire land through outright purchase and conservation easement. Priority is being given to purchase of undeveloped land around reservoirs, streams and wetland areas. Secondary land acquisition will focus on the purchase of sensitive lands surrounding streams and rivers. In conjunction with the watershed protection program, the city of New York is working with the Watershed Agriculture Council and the United States Department of Agriculture in developing a Conservation Reserve Enhancement Program (CREP) to help protect, restore and manage these sensitive lands. The program pays farmers to remove sensitive lands from production and apply conservation practices in place of agriculture. A total of 3,000 acres of highly erodible land and 2,000 acres of riparian buffer lands have been targeted for protection under CREP. The expected result of land acquisition and conservation practices is the protection of over 165 stream miles, the preservation of thousands of acres of natural areas, and continued high water quality without the cost of a $6 billion filtration system (Featherstone, 1996, Murphy et al., 1995).

Technical Approach

Human activity in a watershed can lead to a number of changes in the landscape including 1) conversion of natural land cover to urban and agricultural, use 2) changes to soil infiltration, compaction and erosion rates, and 3) alteration of hydrologic pathways. Forested riparian zones act as a buffer, which help diminish excessive runoff of water and pollutants such as fertilizer, pesticides, and other chemicals (Manlanson, 1993; Finlayson, 1991). When forests are removed, the potential for flow of pollutants into streams is greatly increased. Fertilizers, pesticides and other pollutants can be transported into streams that flow through or very close to agricultural or urban land more easily than streams that flow through forest (Osborne and Wiley, 1988, Lowrance et al., 1984). Roads near streams increase the amount of impervious surface altering runoff rates (Forman and Alexander, 1998). Frequent driving can deposit small amounts of gasoline, oil, antifreeze and other chemicals, which are washed away during precipitation events. Salt applied during winter is another potential source of pollution where streams are in close proximity to roads. Agricultural has the potential to increase soil erosion. When cropping takes place on soils with a 3% or greater slope there is an increased likelihood of erosion (Lowrance, 1986). Studying the relationship between land use and water quality can help target landscape proportions with a potential to either contribute or prevent undesired impacts. By doing so the relationships between landscape proportion and water quality in the Catskill/Delaware basins, the potential areas of risk to New York City's drinking-water supply system can be evaluated. The databases generated from this study can then be used to prioritize and target basins, subbasins and near stream sites in need of preservation and restoration in the Catskill/Delaware watersheds.

Site Characteristics

Physiography and Land Use

The 5000 square kilometer Catskill/Delaware watersheds are located in the southeast corner of New York State, 160 kilometers northwest of New York City. The topography of the area is diverse and except for the Adirondacks to the north has the greatest elevation in the State (Figure 3). The bedrock geology of the area is sedimentary, consisting of sandstone, shale and conglomerates formed during the

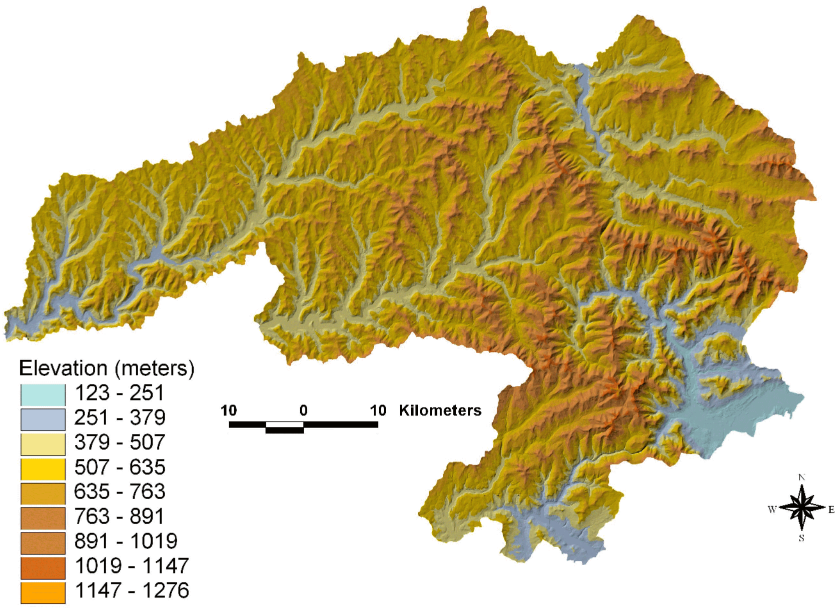

Figure 3. Painted shaded relief showing elevational topography of the Catskill-Delaware watershed.

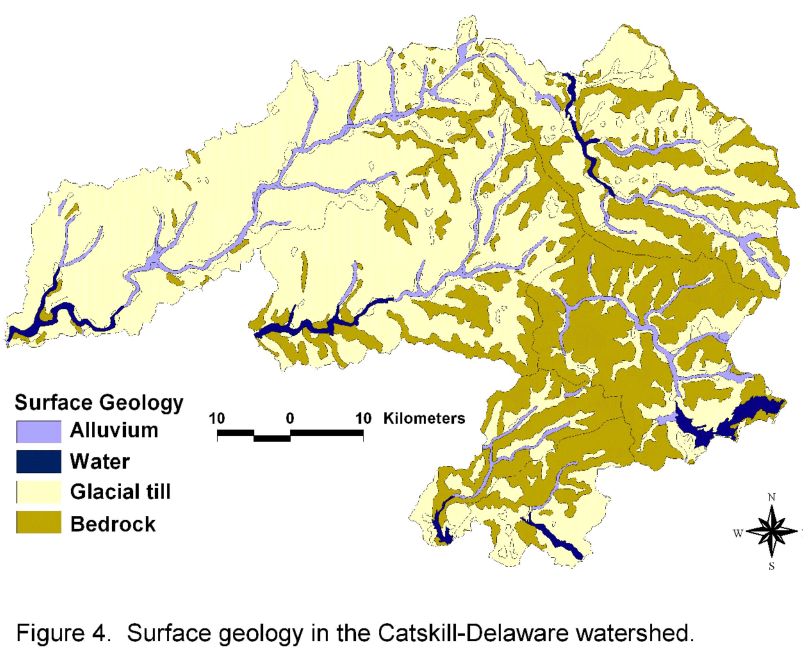

Figure 4. Surface geology in the Catskill-Delaware watershed.

Devonian time period (Miller, 1970). The bedrock is exposed or within one meter of the surface in about 30% of the watershed area. Of the remaining surface geology almost 60% is glacial till (Figure 4). The watershed is bisected by numerous creeks, streams and rivers including the Delaware, Schoharie, and the Neversink. The alluvial deposition and out wash from these major rivers and their tributaries accounts for the remaining 10% of the watersheds surficial geology. The direction of hydrologic flow and drainage end points (the six reservoirs) split the Catskill/Delaware watersheds into six basins.

Historically, the Catskill/Delaware watershed was dominated by northern hardwoods, including maple, birch and beech trees. Other species present, but in smaller numbers were white/red pine, hemlock, elm and ash (van Valkenburg, 1996). Much of the area was logged prior to the mid-1800's. However, due to the need to eliminate a substantial debt owed by Ulster County, lands currently owned by the county were conveyed back to the state in 1884. With the transfer of ownership, 34,000 acres of forest was brought under state protection and the Catskill Park and Preserve was born. In the decades since the Preserve's inception, the forest has rebounded from its previous losses and is once again made up of a mixture of hardwoods, deciduous and evergreens trees (van Valkenburg, 1996). Today, the Catskill Park covers 705,500 acres or more than 40% of the Catskill/Delaware watershed. The watershed as a whole has benefitted by the Park's presence and remains relatively undisturbed, having a forest cover near 90% in five of the six basins as of 1991 (Figure 5). Together, the urban and agriculture land use makes up 10% of the watershed. Nine percent can be classified as farming, pasture and recreational (i.e. golf and lawns) and one percent as urban or commercial (Figure 6). The low urban and agricultural land use in the watershed is related not only to presence of the Park and Forest Preserve, but also to low population growth. From 1970 to 1995, population in the five counties containing the Catskill/Delaware watershed increased by only 20%, shifting the population density from 150 to 180 people per square mile.

Data Collection and Analytical Methods

Landscape Classification

We will use land use data that is derived from satellite imagery for regional and larger areas to calculate most landscape metrics, and is generally derived from. In this study, land use will be acquired or generated for four dates, ranging from 1973 to 1998. Landsat TM imagery will be used for all dates except 1973, where multispectral scanner (MSS) from the North American Landscape Characterization (NALC) program will be used. The study area is contained completely within one scene, Landsat Worldwide Reference System 2 (WRS) path 14, row 31.

Like many long term landscape analyses, this study will require comparisons between images having different resolutions. In order to better determine landscape change over a 25 year time span further evaluation of the multi-date and multi-resolution data sets will be conducted using paired Landsat TM and MSS imagery for one of the four selected image dates. Re-sampling techniques such as nearest neighbor, bilinear and cubic convolution will be evaluated, as well as re-sampling to 120, 60, and 30 meter resolutions. The effects of this re-sampling will be demonstrated and evaluated to develop a standard method for measuring landscape change in a multi-date, multi-resolution data set.

Coverages available from the New York Department of Environmental Protection for the study area include basin and sub-basin boundaries, topography, soils, roads, streams (including lake shorelines), and water sampling site locations. Land use data for 1989/91 from the Multi-Resolution Land Characteristics program (MRLC), a consortium of four federal agencies, was acquired from the EROS Data Center. This data set was generated using an unsupervised classification technique. Clusters of spectrally similar areas were grouped and manually assigned a land use class with the aid of National High Aerial

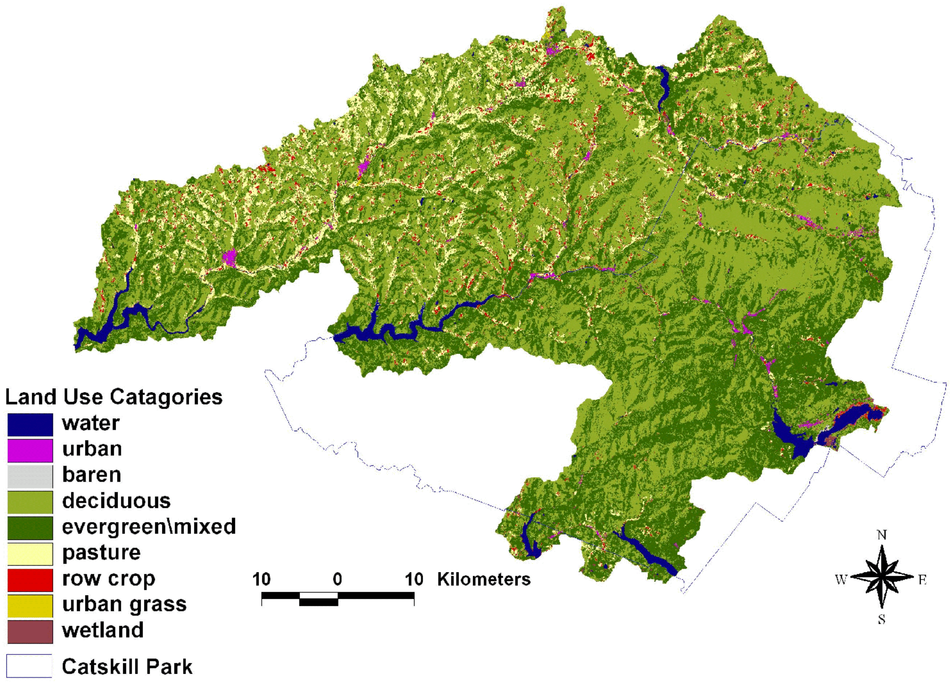

Figure 5. Land use (1991) and Catskill Park boundary in the Catskill-Delaware watershed.

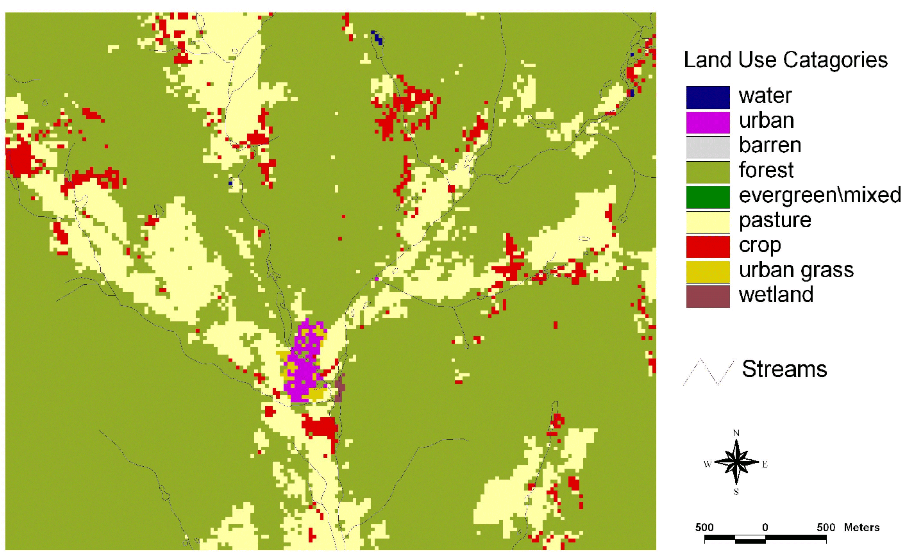

Figure 6. Land use (1991) near town of Trout Creek in Catskill-Delaware watershed.

Photography program (NHAP) aerial photos. Areas that contained more than one land use class were labeled with the aid of ancillary data such as population or elevation (EROS Data Center 1998). For use in this study the final MRLC image classification will be aggregated to six classes for use in metric calculations (Table 1).

Land use will be derived from the three additional scenes (7/7/1973, 9/21/1984, and 7/26/98) using supervised and unsupervised classification. Unsupervised analysis will include dividing the image into100 clusters of spectrally similar areas which will then be manually assigned a land use class with the aid of National High Aerial Photography program (NHAP) aerial photos, and yearly farm crop data collected by the Agricultural Farm Association of New York. Two ground truthing site visits, one summer and one fall, will be conducted to verify classification. Areas that contain more than one land use class will be labeled with the aid of ancillary data such as population, elevation, and site survey. Training sites of known land use will be identified to define spectral characteristics for each class. Training sites will be selected separately for each image with the aid of aerial photography and other ancillary data. Each pixel in the image will then be assigned to the class it most closely resembles using a maximum likelihood statistical algorithm (Lee and Marsh, 1995; Lillesand and Kieffer, 1994). The classification will consist of six categories: water, forest, barren, agriculture, urban (residential and commercial), and cloud/shadow (Wickham and Norton, 1994). If possible, agriculture will be separated into row crops and pasture.

Table 1. Aggregation of MRLC Land Use Classes

MRLC Class	Aggregated Class
Open Water	Water
Low Intensity Residential High Intensity Residential High Intensity Commercial/Industrial/Transportation	Urban
Pasture/Hay Row Crops Other Grasses (e.g. parks, lawns, golf courses)	Agriculture
Evergreen Forest Deciduous Forest Mixed Forest Woody Wetlands Emergent Herbaceous Wetlands	Forest
Quarries/Strip Mines/Gravel Pits Transitional	Barren

Landscape Metrics

Landscape metrics of characteristics believed to have a relationship to drinking water quality will be calculated for six basins (average area 700 km^2) and 79 sub-basins (average area 50 km^2) in the Delaware/Catskill watershed. Five metrics were chosen based on results of a previous study in the Mid-Atlantic region; these metrics are proportion of the six land cover/use categories listed above within the watershed, basins and sub-basins, proportion of land use in and near (100 meter buffer) stream riparian zones, length of roads near streams, proportion of agriculture on steep slopes, proportion of agriculture on highly erodible soils and Normalized Difference Vegetation Index (NDVI) (Lyon et al. 1998, Jones et al. 1997).

The NDVI is a measure of relative greenness of an area (Lyon et al. 1998; Davenport and Nicholson, 1993). NDVI will be calculated from the MSS and TM satellite spectral reflectance data in the red and infrared wavelengths. NDVI values range between 0 and 1 with high values indicating healthy vegetation and low values bare ground, pavement or water. Positive changes in NDVI between dates will indicate a gain in greenness, while negative changes will indicate a loss. Difference of temporal satellite images usually have an approximately normal distribution. We will use two standard deviations from the mean, which will capture 95% of the values (McClave and Dietrich 1979), to detect change/no change in greenness.

Because the potential natural vegetation of the Catskill/Delaware watershed is almost entirely forest (Kuchler, 1964), the proportion of other land use provides general information on the extent of disturbance in each sub-basin. This metric will be generated by overlaying the land use with sub-basin boundaries. Proportions of each land use will then be calculated by sub-basin. Water will be excluded from total sub-basin area when calculating proportions. Total human use, or U-index (O'Neill, 1988), will be calculated by summing the proportions of agriculture, urban, and non-natural barren (e.g., mines or gravel pits) land use by sub-basin.

Forested riparian zones provide a buffer, which help diminish excessive runoff of water and pollutants such as fertilizer, pesticides, and other chemicals (Manlanson 1993, Finlayson 1991). When forests are removed, the potential for flow of pollutants into streams is greatly increased. Fertilizers, pesticides and other pollutants can be transported into streams that flow through or very near agricultural or urban land uses more easily than streams that flow through forest Osborne and Wiley, 1988; Lowrance et al., 1984). Two sets of metrics will be generated for this group, the proportion of stream length adjacent to each land use type by sub-basin and the proportion of each land use within 100 meters of streams by sub-basin. Both sets of metrics will be calculated by overlaying land cover with streams (or buffered streams), and then overlaying the result with sub-basin boundaries. Water will again be excluded when calculating proportions.

Roads near streams can affect water quality in several ways (Forman and Alexander 1998). The impervious surface increases the rate of water runoff, which can increase sediment loadings in streams. Everyday driving can deposit small amounts of gasoline, oil, antifreeze and other chemicals, which are washed away during precipitation events. Salt applied during winter is another potential source of pollution where streams are in close proximity to roads. This metric will be calculated by creating a 30-meter buffer around streams, and then overlaying with roads. The metric will be reported as total length of roads in meters within the buffer per kilometer of stream length by sub-basin.

Soil erosion can result in transport of nutrients and sediment to the surface water. Agricultural practices have the potential to increase soil erosion. Erosion potential is related to the steepness of slopes in agricultural use and soil type (Comeleo et al., 1996; Lowrance, 1986). The threshold for increased erosion is a 3% slope (USDA 1951). Percent slope will be generated from 30-meter Digital Elevation Model (DEM) data. This will be overlaid with land use to determine overlap of steep slopes and agriculture to create an metric of the percentage of land with agriculture (crop or pasture) on slopes greater than three percent by sub-basin.

The State Soil Geographic Soil Maps (STATSGO) and Data Base provides an erodibility factor (k-factor) which quantifies the susceptibility of soil particles to detachment and movement by water under fallow field conditions (USDA 1994). Erodibility data will be aggregated following the methods described in the STATSGO data use information report (USDA 1994) The aggregated k-factors will then be overlaid with land use to determine overlap of highly erodible soils and agriculture. The metric created will be a measure of the percentage of land with agriculture (crop and pasture) on highly erodible soils.

Water Quality

In order to describe the water quality in the Catskill/Delaware watershed data will be collected from the 70's, 80's and 90's for streams and reservoirs (Figure 7). The main source for the chemical and physical water quality parameters will come from the NYCDEP, NYSDEC, USGS and EPA's EMAP and the storage and retrieval data base called STORET. STORET is a repository for water parameter data for the contiguous United States. Many organizations contribute to the data base including federal, state, interstate, universities, contractors, individuals and water laboratories. The station operators include USGS, the regional and environmental research laboratories from the EPA, and the NYSDEC. The NYSDEC will supply separate databases containing 49 benthic sample locations with data, spanning a time period from 1984 to 1997 (Figure 8). Benthic data prior to 1984 will be collected from the NYSDEC 20-year trend report published in 1993 (Bode et al., 1993). The NYCDEP has a large data base dating back to 1908 containing numerous water chemical, physical and biological parameter.

Compiling water quality data from a number of different sources can lead to problems of consistency and comparability, due to differences in measurement and analysis methods. In the course of our data compilation we anticipate specific problems will be encountered including: 1) differences in methodologies between agencies and with time, 2) changes in detection limits of chemicals and metals over time, making comparison to earlier samples difficult, 3) sample sites monitored for short time spans (1 to 3 years) rather than continuously, 4) some sites sampled more frequently than others, 5) discontinuation of monitoring and initiation of new sites in different location. Together these problems could result in insufficient temporal and spatial sampling sites to fully characterize the relationships between changes in watershed metrics and water quality.

For this study, we will use chemical, physical and biological water quality parameters from a total of 248 water sample stations and 49 benthic sample stations located throughout the Catskill/Delaware watershed. Because climate influences both the physical and chemical properties of surface water rainfall, snow pack and temperature data will be collected for the surrounding area from stations monitored by the North East Regional Climate Center and deposition data from five nearby National Atmospheric Deposition stations. The collection of water quality data from these sample sites spans a 25 year time period (1973-1994). Most of the data collected from the stations have already been published by the controlling agencies, either as reports or journal articles.

Changes in the amounts of the chemical constituents of the surface water may indicate human impacts or simply a shift in stream flow or water temperature (Gray, 1994). Nutrients such as nitrogen and phosphorous are essential to the metabolic reactions of plants and animals and can be growth limiting factors. However, when present in large quantities, nutrient inputs can result in water eutrophication. While natural occurrences, such as fire, can cause an “algal bloom,” most eutrophication is the result of human induced enrichment, especially changes in atmospheric deposition. When calcium availability from bedrock is limited and deposition is high, nitrate concentrations, declining forests, and acidic surface water can be in-part related to an overall low surface water calcium value. Similar to nitrogen and phosphorous, chloride and silica both occur in nature but documented increases at a point location or across time may be tied to impacts from waste water treatment (Taras et al., 1971). Oxygen and pH

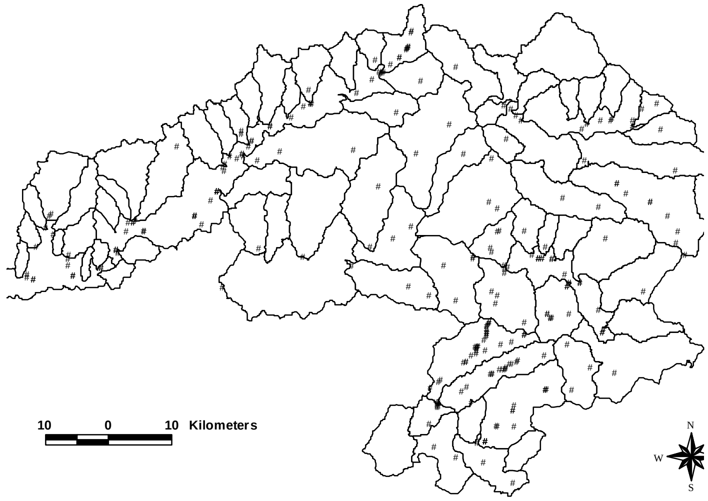

Figure 7. STORET water quality sites in the Catskill/Delaware watershed.

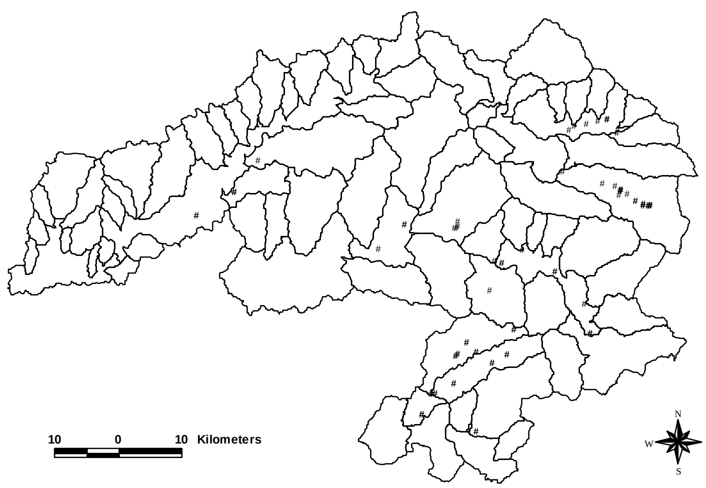

Figure 8. Benthic sample site locations in the Catskill/Delaware watershed.

levels are good secondary metrics of human induced impacts. Most natural waters have pH levels between 4 and 9. Departure from normal pH levels could indicate acid or basic contributions by industrial waste. Water physical parameters important to the evaluation of chemical changes are stream flow, temperature and suspended sediments. These physical factors can influence oxygen levels, nutrient loading, turbidity and habitat suitability. The primary concern of water pollution is its effect on living organisms including humans. Aquatic organisms are often the first to experience the impacts of changes in water quality and therefore can act as metrics of stress. Benthic macro-invertebrates have proven especially valuable for this purpose (Abel, 1989; Hilsenhoff, 1982). Shifts in macro-invertebrate communities from pollution intolerant to pollution tolerant species indicate a decrease in water quality (Rosenberg and Resh, 1993). Data to be used for evaluating changes in water quality are species richness, diversity, ratios of sensitive to nonsensitive species, total individual numbers and percent model affinity (compares known non-impacted site communities to sample locations) (Novak and Bode, 1992). Other biological parameters of concern are include changes in Fecal Coliforms counts resulting from the direct discharge of human and animal sewage into the water. A high Fecal Coliforms count by itself is not pathogenic but can be an indication of other disease causing organisms such as bacteria, viruses and parasites.

Statistical Analysis

Water quality data will be divided into four time groups corresponding to available landscape imagery, with four years of water quality data on either side of the imagery date. For example if the land use image is from 1990, then water quality data from 1986 to 1994 will be used in the statistical comparisons with the landscape metrics data. An analysis of variance (ANOVA) and Tukey's HSD test of means will be conducted to determine significant differences ($P \leq 0.05$) between land cover-use and landscape metrics by basins (SAS 1990). Assuming that sufficient data is available for analysis a 1) multi-variate and non-parametric analyses to examine yearly and seasonal changes in water quality data; and 2) step-wise regression, correlations and cluster analysis will be conducted to determine the extent of influence of the surrounding land-use and landscape metrics on yearly and seasonal water quality parameters.

Potential for Reducing Uncertainty and Meeting Program Goals

Any task undertaken in the EPA has as one of its primary goals the reduction of uncertainty in exposure assessment. The goals of this study align with the goals and objectives, of the 10 year strategic plan for the landscape science program (LEB Strategic Plan), which in turn follow the guidelines set forth by the NERL strategic Research Plan, the Strategic Plan for the Office of Research and Development (ORD Strategic Plan) and the ORD Ecological Research Strategy. All of these plans are driven by a need to respond to national goals such as the Governmental Performance Results Act (GPRA) or to specific legislative mandates, like amendments to the Clean Water Act (CWA). The sub-task set forth in this document complies with the goals of GPRA, Objective 8.1.1, to improve the understanding of environmental risk and innovative addressing of environmental problems, particularly in the area of ecosystem research, assessment and restoration.

To date, only limited analysis has been conducted in comparing landscape proportions to surface water conditions in the Catskill/Delaware watershed. The USGS recently published a report on water quality in the Hudson River Basin (1992-1995) an area that overlaps part of this study site (Wall et al. 1998). The study's main focus is water quality parameters obtained from throughout the basin. Some attempt is made at discussing connections between results from the water quality sampling and nearby land use. Similar comparisons between land use and water quality were made in a 20 year study of benthic and chemical water parameters for the state of New York by the NYSDEC (Hansen, 1996). The USGS is currently undertaking a study of the Delaware River basin which may include a greater analysis of land use, but the project is only in its initial stages and data has yet to be collected or analyzed.

The research done by the agencies collecting the water quality data is an important step in understanding changes in the water quality with time. However, while landscape proportions are often mentioned as a potential contributing factor to changes in water quality, only limited attempts have been made at relating land use to water quality. One such study is being conducted at Cornell University's School of Agriculture. This study focuses on modeling soil erosion effects on phosphorous loadings within the Cannonsville Reservoir. The purpose of this sub-task is to expand the on the previous set of studies by correlating changes in landscape proportion and water quality over varying scales and over a 25 year time period.

Results will then be used to construct a set of landscape metrics, such as proportion of land cover, topography and soils erodibility, which correlate well with stream and lake condition in the Catskill/Delaware basins. An evaluation of each metric can then be conducted at the basin, subbasin and near stream scale. This diagnostic methodology can be used to develop necessary protocols needed to maintain or restore and target sites within other New York watersheds and in regions having similar landscape characteristics (i.e., Pennsylvania and New Jersey).

Quality Assurance

The quality assurance (QA) for this project will include statistical and comparative procedures. These will include a computer audit for all water quality and landscape data. Comparisons to original data from contributing agencies will insure that no errors occurred during data transfer either to STORET or to local computers stations. To test the validity of statistical inferences of the fitted model we will check the model residuals for outliers, normality and homoscedasticity. Methods such as Cook's D test and uni-variate analysis will be used to test whether the residuals meets the basic assumptions (Madansky 1988). Statistical analysis of data will include a search for outliers via descriptive statistics, uni-variate analysis, and residual comparisons with Cook's D test. Accuracy assessment of the land cover will be performed at the Environmental Photographic Interpretation Center (EPIC) in Reston, Virginia. High resolution imagery and photographs of the study area will be used to generate a "truth" land cover. An error matrix will be generated by comparing the "truth" to the derived land cover. In addition to these procedures, an in-lab review of the project plan will be conducted as an initial screening for the project goals and objectives. A second review by the Division Director will follow. Once the project plan has obtained the necessary signatures it will be submitted to at least three outside EPA readers and review by 05/99.

Anticipated Products and Results

1) This project will produce an expanded knowledge of the impacts of landscape and landscape change on water quality. A set of landscape metrics will be evaluated for their importance to and correlation with surface water conditions. These land cover-use and landscape metrics can then be used to compare basins, subbasins and near stream sites relative to each other for the purpose of targeting sites for maintenance or restoration in the Catskill/Delaware watersheds.

2) Water quality data will be compiled from various sources including STORET, USGS, EPA and NYSDEC. The final database will contain site name, location, chemical, physical and benthic values. The databases will be quality checked and then converted to a format for statistical and ArcInfo/ArcView analysis.

3) The project will produce a land cover database spanning three decades with scenes from 1973, 1984,1987,1991, and1998. Geographic data to be collected includes NYDEP watershed and sub-watershed boundaries, elevation (30 meter DEM), surface geology, aqueduct and tunnel locations, streams (based on 1:24,000 scale USGS, improved by DEP), city and state owned lands, and roads. The EPA, EROS data center and USGS will supply land cover/land use data derived from MRLC, MSS (60 meter resolution)and landsat TM (30 meter resolution). In addition to the water quality and coverage data bases, a set of four landscape metric groups will be developed (see above methods for details).

4) Two journal articles are expected to be produced as a result of the project they are 1) Analysis of Landscape and Water Quality in the New York Catskill-Delaware watersheds and 2)Twenty-five Years of Landscape Change in the Catskill/Delaware Basins.

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