Relationships Between Land Use, Land-Use Change, and Surface Water Quality Trends in Virginia

by

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(Abstract)

This research examines the relationships between land use and surface water quality trends in Virginia. Data from 168 surface water quality monitoring stations throughout Virginia were analyzed for trends for the period of 1978 to 1995. Water-quality data available at these stations included dissolved oxygen saturation (DO), biochemical oxygen demand (BOD), pH, total residue (TR), non-filterable residue (NFR), nitrate-nitrite nitrogen (NN), total Kjeldahl nitrogen (TKN), total phosphorus (TP), and fecal coliform (FC). A seasonal Kendall analysis was used to determine trends for each water-quality parameter at each station; this analysis produced an indicator (Kendall's tau) of improving or declining water quality. Median values for each water-quality variable were also determined at the monitoring stations.

Virginia land use was determined from the USGS Land Use Land Cover (LULC) data (1970s) and the Multi-resolution Land Characteristics (MRLC) data (1990s). Land-use variables included urban, forest, pasture, cropland, total agriculture, and urban change. These six variables were correlated with Kendall's tau to determine if relationships exist between water-quality trends and land use. Water-quality medians and land use were also correlated.

In general, highly forested watersheds in Virginia were associated with improving water quality over the 1978 to 1995 study period. These watersheds were also commonly associated with better water quality as measured by the water-quality medians. Watersheds with less agricultural land tended to be associated with improving water quality. Better water quality, as measured by the water-quality medians, was generally associated with watersheds possessing fewer urban acres. There were few significant relationships between water-quality medians and agricultural variables.

DEDICATION

For my parents, Jim and Lorrie Gildea.

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CHAPTER 1 - INTRODUCTION

INTRODUCTION

Water quality directly affects human and animal health, aquatic life, recreation, industry, and agriculture. As populations around the world increase, impacts on water quality become greater through more point and non point source pollution, and increased water use. It is important to monitor water quality to protect and preserve this essential resource. The Virginia Department of Environmental Quality (DEQ) and U.S. Geological Survey (USGS) monitor several hundred surface water-quality monitoring stations throughout Virginia. Data have been collected at some stations for a sufficient amount of time to allow for long-term water quality trend analyses. Analyses of long-term water quality trends allow for better water-quality protection planning. Patterns of improving or declining water quality are often studied to determine what factors have influenced the water-quality trend. Land use is one factor that may influence water-quality trends. Relationships between land use and water-quality trends have the potential to impact future land-use planning throughout Virginia.

Zipper et al. (1998) analyzed DEQ and USGS water-quality data to determine long-term water quality trends at 187 Virginia water-quality monitoring stations. Water-quality trends were evaluated to determine patterns of improving or declining water quality. Further research was proposed to determine if statistical associations exist between water-quality trends and variables representing watershed characteristics.

The objective of this research is to investigate statistical associations between water-quality trends and land use in Virginia. Water-quality trends for nine variables were determined at 187 Virginia water-quality monitoring stations by G.I. Holtzman and Patrick Darken (Zipper et al., 2000). A Seasonal Kendall analysis was used to determine water-quality trends. Water-quality variables included dissolved oxygen saturation (DO), biochemical oxygen demand (BOD), pH, total residue (TR), non-filterable residue (NFR), nitrate-nitrite nitrogen (NN), total Kjeldahl nitrogen (TKN), total phosphorus (TP), and fecal coliform (FC). Watersheds for each monitoring station were generated in Arc Info 7.2 using the USGS 1:250,000 scale Digital Elevation Models (DEMs) (Zipper et al., 2000).

Land use was determined from the USGS Land Use Land Cover (LULC) (U.S. Geological Survey, 1990) and the Multi-resolution Land Characteristics (MRLC) (U.S. Environmental Protection Agency, 1997) data. Both images were classified with an Anderson classification scheme (Anderson et al., 1976). A geographic information system (GIS) was used to determine land use (1990s), and urban land-use change (1978 to 1995), within the watersheds. Analyses were performed to determine the degree to which water-quality trends and land-use variables are correlated. Relationships were determined using Pearson's and Spearman's correlation procedures (Ott, 1993).

This research is one part of a report entitled "Analysis and Interpretation of Water-Quality Data to Enhance Clean Water Act Implementation: Final Report," (Zipper et al., 2000), which analyzed associations between water-quality trends and various watershed characteristics to enhance DEQ Clean Water Act activities. Relationships among water-quality trends and land use, agricultural, and socioeconomic variables were investigated.

ENVIRONMENTAL SETTING

Virginia has different landscapes ranging from flat lying coastal plains along the Atlantic Ocean to mountains in the west. The state is divided into five physiographic provinces (Figure 1-1) that distinguish the major landscapes. From east to west, these are the Coastal Plain, Piedmont, Blue Ridge, Ridge and Valley, and Appalachian Plateau. The Coastal Plain of Virginia is the most populated area of the state, and includes the cities of Virginia Beach, Norfolk, and the suburbs of Washington D.C. Sediments increase in thickness from the fall zone to the continental shelf, and are composed of a mixture of sand, clay, and silt. Many of the rivers and streams in this province are deep and slow moving, and influenced by ocean tides.

The Piedmont of Virginia has a more diverse landscape than the Coastal Plain. This area is defined by gently rolling hills and is underlain by igneous and metamorphic rocks (Roberts and Bailey, 2000). Land cover in the Piedmont is predominately a mixture of agriculture, forest, and urban land. Rivers in this area tend to be more shallow and faster than the Coastal Plain. Several of the river basins in the Piedmont province drain through the Coastal Plain and into the Chesapeake Bay.

The three western provinces are characterized by mountainous terrain. These include the Blue Ridge, Valley and Ridge, and Appalachian Plateau provinces. The continental divide runs through this area and divides water drainage into the Atlantic Ocean and Gulf of Mexico. Rivers flow through deep limestone valleys where karst topography influences surface and groundwater flow. Land cover in the mountainous provinces consists mostly of forest with smaller amounts of agriculture and urban land.

DEQ divides Virginia into thirteen major watersheds (Figure 1-2). These watersheds are subdivided into eight and fourteen digit hydrologic units by the U.S. Geological Survey. The New, Big Sandy, Clinch-Powell, and Holston rivers drain into the Ohio River, which then drains to the Mississippi and Gulf of Mexico. Two basins, the Chowan and Roanoke, drain into North Carolina and the Albemarle-Pamlico sound. The remaining major basins, the Potomac, Shenandoah and Upper Potomac, Rappahanock, York, James, Dismal Swamp, and Coastal Basins, drain into the Chesapeake Bay and Atlantic Ocean. Water quality in each basin is affected by watershed characteristics. These characteristics include, but are not limited to, land use and land cover, population, agriculture, geology, precipitation, atmospheric deposition, and vegetation.

Figure 1-1. Virginia Physiographic Provinces

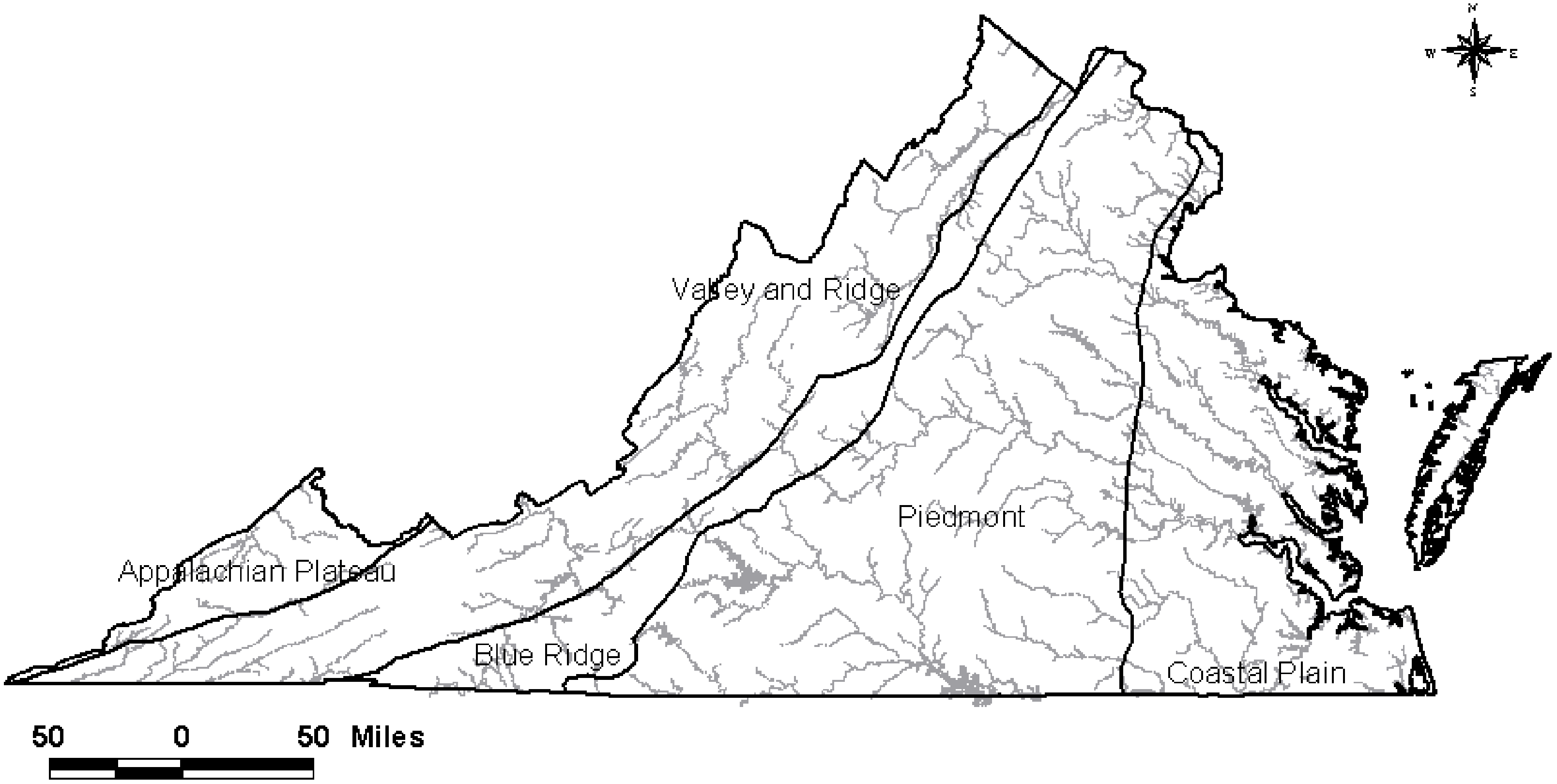
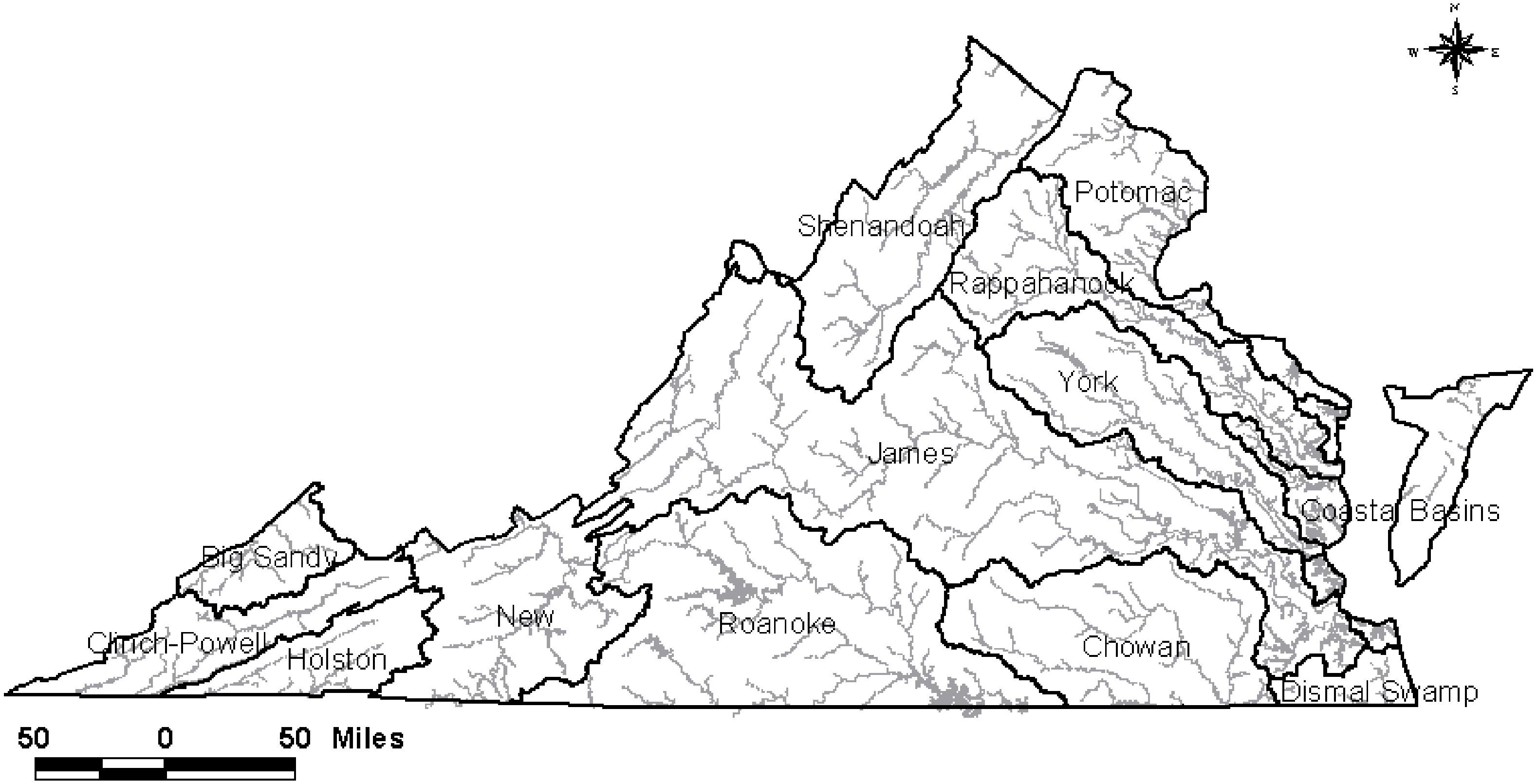


Figure 1-2. Major River Basins in Virginia, as Defined by Virginia Department of Environmental Quality



CHAPTER 2 - LITERATURE REVIEW

WATER-QUALITY TRENDS

Multi-basin studies of water-quality trends have only been performed in recent years due to earlier problems with lack of data, lack of accessible data, changing technologies, and sporadic data collections. These water-quality data problems were addressed by the U.S. government in the 1970s with the enactment of the Clean Water Act and federal regulations. A water-quality monitoring network was established to provide consistent data collection nationwide (Smith et al., 1987). Today, in addition to state and local water-quality monitoring data, data from the federal programs are available for long-term analyses.

Research has been performed to measure trends in the nation’s water quality. Over three hundred surface water-quality monitoring stations throughout the country were analyzed for trends from 1974 to 1981 (Smith et al., 1987). Water-quality variables included common constituents such as suspended sediment, dissolved oxygen, calcium, and magnesium. Nine trace elements were also analyzed for trend. A seasonal Kendall analysis, as described by Hirsh et al. (1982, 1991), was used to determine water-quality trends. P-values of less than 0.10 were considered statistically significant. Results indicated that the majority of stations did not exhibit statistically significant ($p<0.10$) water-quality trends. However, there were four times more significant increasing nitrate trends than significant decreasing nitrate trends. More significant increasing trends were also present in the sulfate, sodium, and chloride analyses. Significant increasing trends for nitrate, sulfate, sodium, and chloride indicate deteriorating water quality. Alkalinity, calcium, and fecal bacteria all exhibited more significant decreasing trends than significant increasing trends. Decreasing alkalinity, calcium, and fecal bacteria trends indicate improving water quality (Table 2-1).

The Virginia Department of Environmental Quality (DEQ) measures water-quality variables at stations throughout Virginia. Over twenty years of monthly data exist at many stations. DEQ measures several water-quality variables, nine of which were chosen by Zipper et al. (1998) to determine long-term water quality trends in Virginia. These variables included dissolved oxygen saturation (DO), biochemical oxygen demand (BOD), pH, total residue (TR), non-filterable residue (NFR), nitrate-nitrite nitrogen (NN), total Kjeldahl nitrogen (TKN), total phosphorus (TP), and fecal coliforms (FC). Trends were determined using a seasonal Kendall analysis. The seasonal Kendall analysis generated Kendall’s tau values, which represent trends in the water-quality data. DEQ personnel identified monitoring stations for the Zipper et al.

(1998) study based on availability of water-quality data and monitoring station locations that provide statewide geographic representation.

Overall, BOD, TP, FC, NFR, and DO exhibited more significant trends indicating improving water quality than deteriorating. NN and TKN each exhibited more significant trends indicating deteriorating water quality. Regional patterns of trends were found with most water-quality variables.

RELATIONSHIPS BETWEEN LAND USE AND WATER QUALITY

Several studies have been conducted to find relationships between land use and water quality. In 1977, Omernick conducted a nationwide study of water quality and watershed characteristics. The purpose of this study was to investigate relationships between nonpoint sources, land use, and stream nutrient levels (Omernick,1977). This study looked at watersheds across the United States that had few point sources and available aerial photography. Monthly water-quality data were collected for one year and included the variables total phosphorus, orthophosphorus, total nitrogen, and inorganic nitrogen. An arithmetic mean was then calculated per station for each parameter. Land use was classified using an Anderson level one classification scheme. Classes included forest, cleared, rangeland, agriculture, urban, wetland, and other. Omernick (1977) created graphs to display relationships between mean annual nutrient concentrations and land use.

Results from Omernick's (1977) research agreed with conventional expectations about land use and water quality. Streams draining watersheds that were predominately agricultural generally had higher nutrient concentrations than streams draining forested watersheds. Stream nutrient concentrations were also found to be proportional to the percent of agricultural land in the watershed. On average, total phosphorus concentrations were ten times higher in streams draining agricultural watersheds than forested watersheds.

Working with New York watersheds, Haith (1976) attempted to answer the question, "Do relationships exist between land use and water quality?" He proposed a correlation and multiple regression analysis of three water-quality variables and twelve land-use variables from watersheds in the central New York area. Land use was interpreted from 1968 and 1969 aerial photographs. Four primary land use classes and eight secondary classes were developed. Primary classes consisted of active agriculture (AG), forest (FR), residential (RS), and commercial/ industrial (CI). Secondary classes consisted of additional land uses that may affect water quality and included shoreline development (SH), open extractive industry (EXO), outdoor recreation (RC), transportation (TR), cropland agriculture (AC), high density residential (RH), medium density residential (RM), and low density residential (RL). Land use was reported as percent land use within a watershed.

The New York State Department of Environmental Conservation collected seasonal water-quality data including total nitrogen, total phosphorus, and total suspended solids for 1964 through 1967 (Haith, 1976). A mean concentration was calculated for each station and parameter during the four-year period. Haith then correlated the mean water-quality concentrations with percent land use (Table 2-3).

Most of the significant correlations were with nitrogen, although there was one significant correlation with total suspended solids and high density residential. In general, stream nitrogen levels were found to be negatively correlated with forest land and positively correlated with urban land and disturbed areas.

Haith (1976) also performed a multiple regression analysis to determine how land use affects water quality. Separate stepwise regressions were performed for total nitrogen and total suspended solids (Table 2-4). The total nitrogen multiple regression indicated that shoreline development, cropland agriculture, and transportation were the best variables for explaining nitrogen variation in the watersheds. Although forest land use was significantly correlated with stream nitrogen levels, forest land use was not selected for the nitrogen multiple regression. High-density residential land use was the only variable selected for the total suspended solids multiple regression.

Osborne and Wiley (1988) used a multiple regression analysis to demonstrate that urban land use is a major contributor of phosphorus and nitrogen to streams. Twenty-two water-quality monitoring stations in the Salt Fork watershed of eastern Illinois were studied. To determine land use, aerial photographs from 1983 were classified into six land-use classes including urban, agriculture, forest, water, wetlands, and barren land (Osborne and Wiley, 1988). Urban/agriculture and forest/agriculture ratios were calculated from the land-use data.

Nitrate and soluble reactive phosphorus were measured biweekly during 1984. Mean phosphorus and nitrogen concentrations were calculated at each station. A multiple regression analysis was performed using the urban/agriculture ratio, forest/agriculture ratio, and total watershed area as independent variables. Dependent variables were mean nitrate (NO_3) and mean soluble reactive phosphorus (SRP) concentrations. Multiple regression analyses were performed for different seasons and different watershed areas. Watershed areas were determined using stream buffers of various distances from the stream channel. Multiple regression results for the summer season and 100 foot watershed buffer are included in Table 2-5.

The urban-agriculture ratio explained the majority of variance for both nitrogen and phosphorus concentrations. Osborne and Wiley (1988) attributed this to low flow conditions in the summer months causing greater impact from urban point source pollution. The regression equations were then used to predict nitrogen and phosphorus concentrations in the Salt Fork watershed using various acres of urban, forest, and agricultural land use.

Another method for studying land use and water-quality relationships is to identify major pollutants associated with given land uses. Beaulac and Reckhow's 1982 study compares total phosphorus and total nitrogen exports from various land uses. They conducted a comprehensive review of various nutrient export studies in the United States and presented their findings according to land use (Beaulac and Reckhow, 1982). Several agricultural land uses were researched including animal feedlots, row crops, non-row crops, pasture, and mixed agriculture. Urban land uses were also considered. Feedlots and manure storage were the largest contributors of both nitrogen and phosphorus, while forest land contributed the least of each nutrient. Figures 2-1 and 2-2 list total nitrogen and total phosphorus exports from various land uses from highest to lowest.

Figure 2-1. U.S. Nitrogen Exports from Various Land Uses.

Feedlot and Manure Storage > Mixed Agriculture > Row Crops > Non Row Crops
> Urban > Pasture > Forest

Figure 2-2. U.S. Phosphorus Exports from Various Land Uses

Feedlot and Manure Storage > Row Crops > Urban > Mixed Agriculture
> Pasture > Non Row Crops > Forest

Source: Beaulac and Reckhow (1982)

Note: Data reported in Kilograms / Hectare / Year

SUMMARY

Several methods for determining land use and water-quality relationships were discussed in this report. Haith (1976), and Osborne and Wiley (1988), performed multiple regression analyses using land-use variables to describe variations in water quality. Beaulac and Reckhow determined that different amounts of nutrients are exported to streams from various land uses. Omernick (1977) found that streams draining various land uses have different amounts of nutrients. Results from both studies indicate that agricultural land contributes more nitrogen and phosphorus to streams than forest land. Patterns of water-quality trends were found in Virginia by Zipper et al. (1998), while Smith et al. (1987) found patterns of water-quality trends nationwide. Significant increasing nitrate trends outnumbered significant decreasing nitrate trends in Virginia and nationwide. More significant decreasing fecal coliform trends than significant increasing fecal coliform trends were exhibited in both the Zipper et al. (1998) and Smith et al. (1987) research.

Table 2-1. Statistically Significant ($p<0.10$) Water-Quality Trends in U.S. Rivers, 1974 to 1981.

Water-Quality Parameter	Number of Stations	No. of Stations w/ Significant Increasing Trends	No. of Stations w/ Significant Decreasing Trends
pH	290	70	54
Alkalinity as $CaCO_3$	289	18	75
Sulfate as SO_4	289	78	38
Nitrate	383	116	27
Phosphorus	381	43	50
Calcium	289	23	79
Magnesium	289	48	41
Sodium	289	100	27
Potassium	289	66	39
Chloride	289	101	34
Suspended Sediment	276	43	39
Fecal Coliform Bacteria	305	16	45
Fecal Streptococcus Bacteria	295	9	67
Dissolved Oxygen	369	63	41
Dissolved Oxygen Deficit	353	41	58

Source: Smith, Alexander, and Wolman, (1987)

Table 2-2. Surface Water Quality Trends in Virginia, 1966 to 1997 (number of stations).

Trend	DO	BOD	pH	TR	NFR	NN	TKN	TP	FC
Sig Inc	39	0	43	20	7	45	57	13	12
App Inc	18	1	10	11	7	12	31	9	17
No Trend	86	71	54	110	80	92	68	96	99
App Dec	13	28	20	21	37	14	9	30	10
Sig Dec	31	85	60	13	53	22	22	39	41
Totals	187	185	187	175	184	185	187	187	179

Sig Inc = significant increasing trend ($p<0.01$)
App Inc = apparent increasing trend ($0.01<p<0.1$)
No Trend = no apparent trend ($p>0.1$)
App Dec = apparent declining trend ($0.01<p<0.1$)
Sig Dec = significant declining trend ($p<0.01$)

Source: Zipper et al., (1998)

Table 2-3. Significant Correlations Between Land Use and Water-Quality Variables in New York.

Land Use	Total Nitrogen	Total Phosphorus	Total Suspended Solids
Active Agriculture (AG)	-	-	-
Forest (FR)	-0.77	-	-
Residential (RS)	0.57	-	-
Commercial/ Industrial (CI)	0.53	-	-
Shoreline Development (SH)	-	-	-
Open Extractive Industry (EXO)	0.69	-	-
Outdoor Recreation (RC)	0.53	-	-
Transportation (TR)	0.71	-	-
Cropland Agriculture (AC)	-	-	-
High Density Residential (RH)	0.48	-	0.79
Medium Density Residential (RM)	0.49	-	-
Low Density Residential (RL)	0.59	-	-

Source: Haith, (1976)

Table 2-4. Stepwise Regression Results for Nitrogen and Total Suspended Solids.

Water Quality Parameter	Regression Equation	R^2
Total Nitrogen (mg/L)	$N = 0.41 + 0.90TR + 0.027AC + 1.22SH$	0.886
Total Suspended Solids (mg/L)	$TSS = 18.8 + 50.2RH$	0.629

Source: Haith, (1976)

Table 2-5. Multiple Regression Results for Phosphorus and Nitrogen, Salt Fork Watershed, Illinois (Summer Season, 100ft Buffer).

Parameter	**Independent Variable Coefficients**			**Sum of Squares**	**R^2**
	AREA	**Urban / AG**	**Forest / AG**		
NO_3	9.5	26.8	0.23	40.5	0.902
SRP	43.9	51.5	0.15	99.4	0.961

Source: Osborne and Wiley, (1988)

Note: The authors did not report constants for the multiple regression equations.
Note: Area is in square miles.

CHAPTER 3 - LAND-USE DATA SOURCES

INTRODUCTION

Several land-use data sources exist for the state of Virginia. These sources differ in resolution, date of acquisition, sensors, data storage, classification, and availability. The objective of this research is to determine statistical relationships between land use and water-quality trends in Virginia. Relationships are to be determined between water-quality trends and land use (early 1990s), and between water-quality trends and land-use change (1970s - 1990s). Multiple data sources were evaluated to identify land use and land-use change data suitable for use in this research. This chapter describes the evaluation of Virginia land-use data sources.

NUMERICAL DATA

Introduction

Land-use data are available in either numerical or spatial format. Numerical land-use data consist of numerical tabulations of land use within an area and are generally prepared at the state or county level. Data are gathered through standard remote sensing (satellite or aerial photography) or surveying techniques. The land-use information is then made available in a numerical format for public use. Three numerical land-use data sources were evaluated in this research including the Virginia Forest Inventory and Analysis (FIA) (Johnson, 1992), Census of Agriculture (U.S. Department of Agriculture, 1999), and National Resources Inventory (NRI) (U.S. Department of Agriculture, 1987, 1994).

Virginia Forest Inventory and Analysis

The Virginia Forest Inventory and Analysis (FIA) is a government program that measures and categorizes forested areas in Virginia (Johnson, 1992). Inventories are performed by the U.S. Forest Service every five to ten years. The purpose of the FIA is to determine the amount of forest, forest species, increases or decreases in forest, and amount of harvested forest in Virginia (Gillespie, 1999). This program is part of a national effort to monitor forested areas on public and private lands. To estimate forest land, the FIA classified sample clusters systematically spaced on aerial photographs (Johnson, 1992). A subset of clusters was field checked to determine the classification accuracy. Acres of forest land were estimated for each county. Virginia Forest inventories were recently completed in 1977, 1986, 1992, and 1997.

In 1992, the FIA estimated approximately 15.6 million acres of forest land in Virginia (Johnson, 1992). This indicates that 63 percent of the state was forested in 1992. From 1977 to 1986, the FIA estimated a 457,000 acre loss of forest land in Virginia. However, a 54,000 acre increase in forest was estimated from 1986 to 1992. The net estimated loss of forest from 1977 to 1992 was approximately 403,000 acres (Appendix A-1).

To determine forest land-use change per county, each county must be evaluated individually. For example, Carroll County experienced a 23,000 acre loss of forest from 1977 to 1986. In 1992, Carroll County exhibited a 20,000 acre increase in forest from 1986. An analysis of forest change in Carroll County from 1977 to 1992 would indicate a 3,000 acre loss of forest, when in reality the FIA estimated that a much greater turnover occurred.

Figures 3-1 and 3-2 display percent of forest per county from the 1977 and 1992 Virginia FIA. Percent forest change from 1977 to 1992 is displayed in Figure 3-3.

Virginia FIA data were not an ideal land-use data source for this research. No other land uses other than forest were classified in the inventory. Data availability at the state level was adequate. However, because the FIA is conducted via a sampling procedure as opposed to estimating forest acres directly, data exhibit lower accuracy and broader confidence intervals at the county level than at the state level. Johnson (1992) reported county sampling errors from 2 to 20 percent depending on the size of the county and the amount of forest present. These data were more suited for forest area verification of other land-use data sources.

Census of Agriculture

Census of Agriculture data are also available in a numerical format (Appendix A-2). The purpose of the census is to obtain comprehensive data on agriculture production in all U.S. counties (U.S. Department of Agriculture, 1998). Unlike the FIA, census data are acquired through a census questionnaire that is mailed to individuals, businesses, and organizations associated with agriculture. In 1997, approximately 3.2 million people were asked to complete the Census of Agriculture questionnaire (U.S. Department of Agriculture, 1999). Due to sampling methodology, each Census of Agriculture statistic is an estimate that has a corresponding confidence interval and sample error. In addition to agricultural production, the Census of Agriculture reports acres of land use per county. Measured land-use classes include cropland, pasture, woodland, and other land (U.S. Department of Agriculture, 1999) (Appendix

B-1). Each class is also divided into subclasses such as harvested versus non-harvested cropland. Census of Agriculture land-use estimates are not complete for all of Virginia. Census questionnaires are only sent to agricultural businesses and farms. Land not in farms or is not reported by the census.

Several Census of Agriculture land-use classes were combined for the purpose of comparing similar classes among land-use datasets. Harvested cropland and other cropland were combined to compare cropland acres. This new class is referred to in this report as cropland_a. Pasture* was combined with pastured cropland to compare pasture acres. This new class is referred to in this report as pasture_a. The new pasture_a and cropland_a classes are similar to land-use data derived from remote sensing analyses and can be compared to other datasets in this report (Appendix A-3).

There are approximately 25.3 million acres of land in the state of Virginia (U.S. Department of Commerce, 1990). The 1992 Census of Agriculture estimated 2.8 million acres of cropland_a, which translates to 11 percent of the state (U.S. Department of Agriculture, 1999) (Figure 3-4). Virginia FIA estimated that 15.6 million acres of the state were forested in 1992. Only 2.6 million acres were reported as woodland (forest) by the Census. Differences in the forest data are due to different methods of data collection. The Census of Agriculture woodland land-use class only represents forest land on farms. Pasture_a accounted for 2.6 million acres of Virginia land (Figure 3-5).

Census of Agriculture land-use data were not comprehensive. Only 33 percent of land in Virginia was classified by the census. More than half the state was left unclassified. The county by county land use accuracy of the Census of Agriculture ultimately depends on the farmer’s knowledge of their farm land-use acreages. This is self-reported, unverified data. Statistical estimations are used for farms that do not respond to the questionnaires. The different cropland and pasture land-use classes appear to be relatively accurate estimations for agricultural land use in Virginia. Woodland and other land-use estimates are not comprehensive land use estimates and should not be interpreted as such.

National Resources Inventory

The Soil Conservation Service (SCS) began collecting data on agriculture and soil erosion in the mid 1930s (Nusser and Goebel,1997). Over the years, the extent of the program has grown to include more area and variables. In 1977, the federal government implemented the National Resources Inventory (NRI) to assess land use and land cover throughout the United States. This program is administered by the Natural Resources Conservation Service (NRCS, previously SCS) under the direction of the U.S. Department of Agriculture. Since 1977, an inventory has been completed every five years. Primary sampling units (PSUs) were established to facilitate data collection. One PSU is typically 160 acres and can range from 40 to 640 acres (Nusser and Goebel, 1997). PSU size depends land use homogeneity. A grid of primary sampling units was determined for the entire United States. Within each PSU, three previously located sample points are visited every five years. Goebel (1998) lists 11 main classes of data collected at each sample point.

- Soil characteristics and interpretation
- Earth cover (trees, shrub, grasses)
- Land cover and land use
- Erosion
- Land treatment (conservation tillage, irrigation, windbreaks)
- Vegetative conditions
- Conservation treatment needs
- Potential for crop conversion
- Extent of urban land
- Habitat diversity
- Land in the Conservation Reserve Program

This data is stored in the NRI database where statistical estimation procedures, described by Goebel and Baker (1987), are used to translate sample points into acres of land use per county.

NRI land-use data consist of cropland, pasture, forest, urban, and other (U.S. Department of Agriculture, 1994). This data, along with confidence intervals, are reported in numerical format at the county level and made available to the public. Definitions of each land-use class are included in Appendix B-2.

In 1992, the NRI estimated 2.9 million acres of cropland, 3.4 million acres of pasture, 13.5 million acres of forest, and 1.8 million acres of urban land in Virginia (U.S. Department of Agriculture, 1994) (Appendix A-4). This amounts to 100,000 acres more cropland and 800,000 acres more pasture than the Census of Agriculture. Virginia FIA reported 15.6 million acres of forest in 1992, 2.1 million acres more than the NRI. From 1982 to 1992, the NRI indicated that cropland exhibited the largest acreage change (Appendix A-5). Cropland decreased by 495,000 acres over this period according to NRI estimates (U.S. Department of Agriculture, 1987, 1994). Urban land increased by 426,000 acres, while forest and pasture displayed little change. Figures 3-6 through 3-9 display the 1992 NRI acres of urban, forest, pasture, and cropland per county. Land-use change (1982 – 1992) per county is displayed in Figures 3-10 through 3-13.

NRI data are not available to the public at the PSU level. Data are available in tabular format at the county level. Due to the large PSU sizes, confidence intervals and sample error are often high at the county level. The same NRI sample points are visited every five years, which results in a more accurate change detection analysis. As with the other numerical land-use data sources, these data are more suited for verification of other spatial data.

Numerical Data Comparisons

There are significant differences in the three numerical land-use data sources evaluated in this research. Each dataset was acquired through different methods and had unique land-use definitions. The FIA focuses on forest land and does not attempt to classify other land uses. Census of Agriculture data focuses on agricultural land. Due to sampling methods, several million acres of urban and forest land are not sampled by the Census of Agriculture. The NRI is comprehensive in its land use coverage. Large PSU sizes and few sampling points limit the accuracy of this dataset. Characteristics common to each dataset include tabular data format available at the county level, and high confidence intervals and low accuracy when working with small areas.

SPATIAL DATA

Introduction

Spatial land-use data are generally acquired through remote sensing techniques. Remotely sensed data include aerial photography and satellite imagery. These data are collected over a large area and are then manually or digitally processed and classified. A remotely sensed area is usually divided into cells that have a fixed length and width. The length and width of a cell is referred to as the image resolution. Spatial data differ from numerical data in that cells cover the entire area of interest and a sampling procedure is not required.

Resolution

The resolution of an image refers to the smallest area on the ground that a sensor can view at one time (Lillesand and Kiefer, 1994). Verbyla (1995) refers to resolution as the fineness of detail visible in an image. It is generally thought of as the pixel size of an image acquired through some means of remote sensing. Remote sensors have different resolutions, which can vary from less than one meter to over one kilometer. The Landsat Thematic Mapper satellites have a resolution of 30 meters, while NOAA AVHRR (Advanced Very High Resolution Radiometer) satellites have a resolution of over one kilometer (Verbyla, 1995).

Resolution is important because it determines the smallest area on the ground that can be distinguished on the image. An image with a small resolution will distinguish between more land-use classes and will have more pure pixels. Pure pixels are desirable because they represent only one land-use class (Hyde and Vesper, 1983). When an image has a large resolution, more mixed pixels occur because the cell is covering a larger area. Mixed pixels may have two or more land-use classes in the pixel area; however, the dominant class is generally reported in the land-use coverage.

Several studies have been completed to show the effects of different resolutions on an image. Hyde and Vesper (1983) worked with some of the early Landsat images that had a resolution of 80 meters and compared them to images with resolutions of 10, 20, 30, 40, and 60 meters. They found that mixed pixels were most prevalent in the Landsat 80 meter image, with the urban class having 100 percent mixed pixels. The percent of mixed urban pixels ranged from 81.3 percent in the 10 meter image to 100 percent in the 80 meter image. Urban areas tend to have mixed pixels due to the high spatial variability of urban land.

Cushnie (1987) showed that overall accuracy of an image increases as you increase spatial resolution. Accuracy is generally defined as the number of correctly classified cells divided by the total number of cells in an image. In a comparison of 5, 10, and 20 meter images, the 20 meter image had the highest accuracy. The increase in accuracy was most noticeable in urban areas and least noticeable in large agricultural areas. However, Moody and Woodcock (1995) demonstrated that while the accuracy of an image may increase with coarser resolutions, the proportions of land-use classes vary with different resolutions. As resolution increases, there is a tendency for rare or dispersed land cover classes to disappear from the image (Turner et al., 1989). Yang and Merchant (1997) compared 10 different resolutions of a Landsat Thematic Mapper scene and determined that land-use class areas significantly change with increasing resolution.

Land-Use Change

Land-use change detection generally involves a comparison of two remotely sensed images that are compatible with respect to scale, detail, accuracy, and classification (Campbell, 1996). Several change detection methods are available to enable a user to choose a method that is suitable for their image. Campbell (1996) describes seven of these methods including image algebra, postclassification comparison, multidate composites, spectral change vector analysis, binary change mask, on-screen digitization, and change detection by image display.

The postclassification method is ideal when two change detection images are from dissimilar sources, have different resolutions, or are spectrally unalike. This method first classifies each image separately, and then compares pixels to determine change. One advantage of the postclassification method is that the user can identify the original and new cell value. Howarth and Wickware (1981) used this technique with satisfactory results to determine land-use change in the Peace-Athabasca Delta.

Virginia GAP

The Virginia Gap Analysis Program (GAP) used 30 meter Landsat Thematic Mapper images to produce a land-use coverage of Virginia. Images from 1990 to 1994 were used to create the dataset. The mission of the national GAP program is to provide an assessment of native vertebrate species and natural land cover in the United States (Scott and Jennings, 1997). Several land-use classes were defined, which were then condensed into forest, agriculture, urban, and other for the purposes of this research.

The Virginia GAP reported 13.9 million acres of forest, 5.9 million acres of agricultural land, and 690,000 acres of urban land (Appendix A-6). Other land uses, including wetlands, water, and barren land, accounted for 1.8 million acres (Figure 3-14). A statewide analysis of the GAP coverage revealed that approximately 2.0 million acres of land were classified as “mixed” land use (Figure 3-15). Due to the mixed land-use class, this coverage was not considered for this research.

LULC

The U.S. Geological Survey used aerial photography to compile a Land Use Land Cover (LULC) dataset for the entire United States. Land use and land cover were manually interpreted from aerial photographs acquired between 1971 and 1982 that were taken at scales smaller than 1:60,000 (U.S. Geological Survey, 1990). The photographs were then interpreted, delineated, and stored in vector format at a scale of 1:250,000. LULC coverages were completed for the entire United States. Information classes were depicted using an Anderson level-two classification scheme (Appendix B-3). Four hectares is the minimum mapping area for urban and built-up land, water, confined feeding operations, other agricultural land, strip mines, quarries, gravel pits, and urban transitional areas. Sixteen hectares is the minimum mapping area for all other Anderson level-two information classes (U.S. Geological Survey, 1990). For the purpose of this study, level-two classes were condensed into level-one classes consisting of urban, forest, agriculture, wetlands, water, and barren land. Wetlands, water, and barren land were grouped together as “other” land.

The accuracies of four 1:250,000 scale LULC quadrangles were determined by Fitzpatrick-Lins (1980). These four quadrangles included Tampa, Florida, Portland, Maine, Charleston, West Virginia, and Greeley, Colorado (Fitzpatrick-Lins, 1980). Land use patterns in the Charleston, West Virginia quadrangle are similar to land use patterns in western Virginia and the accuracy assessment should apply to similar Virginia coverages. To determine map accuracy, 424 points in the Charleston quadrangle were checked for accuracy, and of those points, 393 were classified correctly. The total number of correctly classified points (393) divided by the total number of points (424) gives an overall map accuracy of 93 percent. The national overall Anderson level-two accuracy standard for the entire LULC dataset is 85 percent (Lillesand and Kiefer, 1994).

Fitzpatrick-Lins (1978) found that Anderson level-one classified aerial photography had a higher accuracy than the same photograph using level two. This would imply that the overall point-to-point accuracy of the LULC data used in this research is higher than 85 percent, as only level-one classes were used. Errors in the Virginia coverage occur where different land uses were combined due to the minimum mapping unit size of four or sixteen hectares. Other sources of error are due to the transformation from vector (lines and polygons) to raster (grid cells) format and classification errors. The national LULC coverage was compiled from aerial photographs spanning a range from 1971 to 1982, while water quality data used in this research begins in 1978 (U.S. Geological Survey, 1990). It is possible that in some locations the actual 1978 land use differed from the LULC-reported land use due to the broad range of dates.

An analysis of the LULC data reveals a total of 1.4 million acres of urban land, 7.1 million acres of agricultural land, 14.4 million acres of forest, and 1.3 million acres of other land (Appendix A-7). LULC data were an excellent source for determining land use in the late 1970s. A map of LULC land use is included as Figure 3-16.

LULC data for Virginia and surrounding states were downloaded from the EPA website at ftp://ftp.epa.gov/pub/spdata/EPAGIRAS/egiras/. Data were stored in ARC/ INFO export format and catalogued by USGS 1:250,000 scale quadrangles.

MRLC

The national Multi-Resolution Land Characteristics (MRLC) dataset was produced in the early 1990s to provide a current, accurate land use coverage with a 30 meter resolution (US Environmental Protection Agency, 1996). Landsat Thematic Mapper images from 1991 to 1993 were used to produce the MRLC coverages. Operational since 1982, the Landsat Thematic Mapper analyzes seven distinct bands of radiation (Table 3-1). These bands were then translated and interpreted into land-use classes using an unsupervised classification procedure. The MRLC Consortium used imagery from a range of dates during the 1991-to-1993 time frame in an effort to obtain cloud free, summer (leaves on) images. Images were corrected and projected to a Universal Transverse Mercator (UTM) Albers projection with a 1983 datum (US Environmental Protection Agency, 1997). Virginia and surrounding state coverages have been completed. A MRLC classification scheme was developed based on Anderson level-two classes (Appendix B-4). The MRLC and LULC datasets can be compared because of their similar classification schemes.

A comprehensive accuracy assessment for the MRLC coverage is not currently available. However, Vogelmann, Sohl, and Howard (1998) performed MRLC consistency checks for Delaware, Maryland, Pennsylvania, West Virginia, and Virginia. They realized that traditional accuracy assessments are not always feasible when dealing with large areas. MRLC data were compared to digital elevation models, population density, city lights, other aerial photographs, Census of Agriculture, LULC, National Wetlands Inventory (NWI), and Coastal Change

Analysis Program (C-CAP) data (Vogelmann, Sohl, and Howard, 1998). Similarities were found with almost all datasets. MRLC land area percentages were compared with National High Altitude Photography (NHAP), C-CAP data, 1992 Census of Agriculture data, and LULC data. NHAP photographs were 74 percent in agreement with MRLC data. C-CAP and LULC percentages also compared well, however, Census of Agriculture acreages were not well matched.

Possible errors were believed to occur in early releases of the MRLC coverage where grassy areas (lawns, golf courses, and parks) are classified as agricultural land. In later releases, the MRLC reclassified some areas in an effort to minimize these problems. A new class, urban grass, was added to the MRLC coverage (U.S. Geological Survey, 1999).

Image dates of acquisition were not always ideal for separating row crops and pasture, and could lead to misclassification of those areas (U.S. Geological Survey, 1999). The MRLC Consortium used images from multiple dates, when available, to try and reduce this error.

The MRLC reported 6.0 million acres of agricultural land and 15.6 million acres of forest in Virginia (Appendix A-8). Forest land closely corresponds with the 1992 FIA estimate. Total agricultural land consisted of 4.9 million acres of pasture and 825,000 acres of cropland. There were 863,000 acres of MRLC urban land in Virginia. This was 517,000 less urban acres than determined by LULC. MRLC data used a much finer resolution image that sensed more detail in the urban and suburban areas. In the LULC coverage, small parcels of forest and grasses within urban areas were included in the urban pixels due to the larger resolution. Different LULC and MRLC resolutions were causing a discrepancy between the coverages. Figure 3-17 depicts the Virginia MRLC land-use coverage.

MRLC data were downloaded from ftp://edcftp.cr.usgs.gov/pub/edcuser/vogel/states. Data were stored in flat file format and sorted by state. Virginia and surrounding states were downloaded. MRLC data released in May 1999 were used in this research.

Other Spatial Data Sources

There are several sources of spatial data. Unclassified spatial data is acquired from satellites every day. Verbyla (1995) outlines five common satellite sensors that are useful for land use mapping (Table 3-2). Aerial photographs are also abundant and can be flown on demand.

The U.S. government constructed a set of unclassified Landsat Multispectral Scanner (MSS) imagery called the North American Landscape Characterization (NALC). Each state has full NALC MSS coverage for 1973, 1986, and 1992 (plus or minus one year) (Lunetta et al., 1993). The NALC coverage was not considered in this research because the images are unclassified. Unclassified images are often difficult to classify and require an accuracy assessment. Also, multiple images can be difficult to register and may require spectral adjustments. For these reasons, unclassified imagery in general were not considered in this research.

LAND-USE COMPARISONS

In 1992, the NRI reported the largest amount of urban land. Urban land estimates ranged from 690,000 to 1.8 million acres in Virginia. NRI may be over estimating urban land because of statistical estimation error. Virginia GAP is underestimating urban land because many cells classified as “mixed” may belong to the urban class, e.g. low-density urban areas with full tree cover. The 1982 NRI and LULC were also compared. The two land-use data sources differed by 12,000 acres of urban land statewide. Between 1982 and 1992, the NRI reported a 425,000 acre increase in urban land. A comparison of the LULC and MRLC estimated a 517,000 acre loss of urban land between the late 1970s and early 1990s. This is not a logical estimate for urban land-use change due to the fact that once an area urbanizes, it usually does not revert back to some other land use. After analyzing the LULC and MRLC, it was apparent that these urban land use discrepancies were due to the different cell sizes of the two datasets.

MRLC and 1992 FIA forest data were very similar. Each estimated approximately 15.6 million acres of forest in Virginia. The Virginia GAP and 1992 NRI differed by 1.1 million acres of forest. Census of Agriculture forest estimates are significantly lower than all the other data sources. In 1977, the FIA estimated 16.0 million acres of forest, 1.6 million acres more than the LULC. These data were not as well matched as the FIA and MRLC. NRI reported the lowest forest estimate for that time period. An 81,000 acre loss of forest land was exhibited by the 1982 versus 1992 NRI data. The forest inventory estimated that a 400,000 acre loss of forest occurred from 1977 to 1992. However, a comparison of LULC and MRLC forest land revealed a 1.2 million acre increase in forest. This may be an indication of misclassified forest land or differences in resolution (30m vs. 16 hectares) in the MRLC and LULC.

Estimated acreages of agricultural land in Virginia ranged from 5.4 to 7.1 million acres. All six agricultural data sources fell within this range. The Virginia GAP and 1992 NRI differed by 422,000 agricultural acres. Surprisingly, the Census of Agriculture reported the smallest amount of agricultural land at 5.4 million acres. The next closest data source was the GAP at 5.9 million acres. Both the LULC and MRLC, and the 1982 and 1992 NRI, reported major losses in agricultural land from the late 1970s to the early 1990s.

Tables 3-3 and 3-4 compare the urban, forest, and agricultural land use acres from the various numerical and spatial data sources. The tables compare total state acres for each land use as reported by the land-use data source.

Several land-use data sources exhibited similar estimates at the state level. While statewide estimates may be similar, it was often found that county level comparisons were quite different. Tables 3-5 through 3-12 compare the various land-use data sources at the county level using eight Virginia counties. Counties were chosen to be evenly distributed throughout Virginia.

Early 1990s urban land estimates differed by as much as 97,000 acres in Fairfax County. NRI estimated more urban land than GAP or MRLC in all eight counties (Table 3-5). The large differences in urban land estimates illustrate the effects of different methods of acquisition among the land-use data sources.

FIA (1992) and MRLC forest estimates were similar at the state and county level. National forest lands are not sampled by the NRI. In counties with large tracts of national forests, such as Augusta County, large differences were exhibited between the NRI and other forest data sources. NRI generally estimated less forest than the FIA, GAP, and MRLC. Excluding the NRI and Census of Agriculture, forest estimates were generally similar among land-use datasets at the county level (Table 3-6).

There were large differences in early 1990s cropland at the county level. MRLC reported less cropland than the Census of Agriculture, NRI, and GAP in all eight counties. However, MRLC generally reported more pasture per county than the other three data sources. Agricultural counties, such as Bedford and Augusta, tended to have more variation in the agricultural land-use estimates (Tables 3-7, 3-8, and 3-9). These large differences in county level land-use estimates are most likely due to methods of acquisition among the data sources. Even among spatial data sources, large discrepancies were reported.

NRI and LULC urban estimates compared well at the state and county level. NRI generally estimated more urban land than LULC, except for Isle of Wight County. The largest difference occurred in Fairfax County, which is one of the more urbanized counties in Virginia (Table 3-10). FIA generally estimated the most forest land among the late 1970s land-use data sources. LULC estimated 85,000 less acres of forest than the FIA in Halifax County. All other differences between the LULC and FIA in the eight counties were less than 85,000 acres (Table 3-11). Late 1970s NRI and LULC total agriculture estimates were similar at the state level and in all eight counties (Table 3-12).

CONCLUSIONS

A spatial dataset was desired to adequately represent the entire state and reduce sample errors. The MRLC was chosen for the 1990s land-use data. This coverage was preclassified and had Virginia statewide coverage. States surrounding Virginia were also completed and classified. MRLC forest land resembled the 1992 FIA estimates, which helped to verify the accuracy of forest acres. The LULC was chosen for the late 1970s coverage. This was the only 1970s spatial land-use data source available in a preclassified format. Discrepancies were found between the MRLC and LULC, particularly with urban land. To determine land-use change using the LULC and MRLC, data adjustments are necessary.

Table 3-1. Thematic Mapper Bands and Applications.

Band	Resolution	Spectral Definition (um)	Applications
1	30m	Blue-green 0.45–0.52	Penetration of clear water; bathymetry; mapping of coastal waters; chlorophyll absorption; coniferous vs. deciduous vegetation
2	30m	Green 0.52-0.60	Records green radiation reflected from healthy vegetation; plant vigor; reflectance form turbid water
3	30m	Red 0.63-0.69	Chlorophyll absorption important for plant-type discrimination
4	30m	Near Infrared 0.76-0.90	Indicator of plant cell structure; biomass; plant vigor; complete absorption by water facilitates delineation of shorelines
5	30m	Mid Infrared 1.55-1.75	Indicative of vegetation moisture content; soil moisture; soil mapping; differentiating snow from clouds; penetration of thin clouds
6	120m	Far Infrared 10.4-12.5	Vegetation stress analysis; soil moisture discrimination; thermal mapping; relative brightness temperature; soil moisture; plant heat stress
7	30m	Mid Infrared 2.08-2.35	Discrimination of rock types; alteration zones for hydrothermal mapping; hydroxyl ion absorption

Source: Campbell, (1996)

Table 3-2. Comparison of Landsat, Spot, and AVHRR Digital Scenes.

Satellite	Pixel Size	Number of Spectral Bands	Radiometric Resolution	Year of First Image
Landsat MSS	56 x 79 m	4	7-bit	1972
Landsat TM	30 x 30 m	7	8-bit	1982
SPOT HRV Multispectral	20 x 20 m	3	8-bit	1986
SPOT HRV Panchromatic	10 x 10 m	1	8-bit	1986
AVHRR	1.1 km	5	10-bit	1979

Source: Verbyla, (1995)

Table 3-3. Statewide Land-Use Comparisons for Early 1990s Data (Million Acres).

Land Use	1992 FIA	1992 Census of Agriculture	1992 NRI	GAP	MRLC
Urban	-	-	1.79	0.69	0.86
Forest	15.62	2.60	13.54	13.90	15.60
Pasture	-	2.62	3.44	2.28	4.91
Cropland	-	2.79	2.90	3.64	0.82
Total Ag	-	5.41	6.34	5.92	6.04

Note: Census of Agriculture forest land only represents forests on farms in Virginia.

Table 3-4. Statewide Land-Use Comparisons for the Late 1970s/ Early 1980s Data (Million Acres).

Land Use	1977 FIA	1982 NRI	LULC
Urban	-	1.37	1.38
Forest	16.02	13.62	14.41
Pasture	-	3.89	-
Cropland	-	3.40	-
Agriculture	-	6.79	7.11

Table 3-5. Urban Land Estimates for Eight Virginia Counties (Acres), Early 1990s.

County	FIA	Census	NRI	GAP	MRLC
Augusta	-	-	40,500	7,471	9,746
Bedford	-	-	29,900	4,547	5,699
Fairfax	-	-	181,200	94,036	84,659
Goochland	-	-	11,700	1,114	2,903
Grayson	-	-	8,500	564	1,699
Halifax	-	-	15,300	2,640	3,259
Isle of Wight	-	-	6,800	1,146	5,163
Wise	-	-	17,100	4,513	5,602

Table 3-6. Forest Land Estimates for Eight Virginia Counties (Acres), Early 1990s.

County	FIA	Census	NRI	GAP	MRLC
Augusta	346,217	49,124	123,700	301,401	349,532
Bedford	288,607	62,421	246,400	230,770	309,106
Fairfax	92,614	6,165	59,200	97,774	117,362
Goochland	130,505	19,390	114,900	111,352	120,520
Grayson	175,828	40,134	127,000	166,103	184,726
Halifax	352,976	105,998	321,700	264,224	326,599
Isle of Wight	114,511	22,944	121,600	68,305	79,733
Wise	178,535	3,885	128,200	185,115	207,345

Table 3-7. Cropland Estimates for Eight Virginia Counties (Acres), Early 1990s.

County	FIA	Census	NRI	GAP	MRLC
Augusta	-	82,231	68,900	175,655	19,776
Bedford	-	52,789	46,700	114,629	6,493
Fairfax	-	2,150	5,400	1,788	929
Goochland	-	18,020	22,100	16,407	4,964
Grayson	-	23,275	12,700	42,633	3,258
Halifax	-	62,692	103,200	81,815	22,216
Isle of Wight	-	56,596	48,600	51,103	21,244
Wise	-	2,348	8,400	8,519	787

Table 3-8. Pasture Estimates for Eight Virginia Counties (Acres), Early 1990s.

County	FIA	Census	NRI	GAP	MRLC
Augusta	-	148,267	174,800	49,236	198,991
Bedford	-	79,184	110,100	14,442	123,171
Fairfax	-	4,401	9,500	27,549	23,143
Goochland	-	12,210	18,200	22,931	31,525
Grayson	-	69,305	69,500	23,688	69,871
Halifax	-	51,398	42,100	31,578	91,573
Isle of Wight	-	4,567	6,500	17,453	49,941
Wise	-	6,707	65,600	18,712	8,454

Table 3-9. Total Agriculture Estimates for Eight Virginia Counties (Acres), Early 1990s.

County	FIA	Census	NRI	GAP	MRLC
Augusta	-	230,498	243,700	224,891	218,767
Bedford	-	131,973	156,800	129,072	129,664
Fairfax	-	6,551	14,900	29,337	24,072
Goochland	-	30,230	40,300	39,338	36,489
Grayson	-	92,580	82,200	66,321	73,128
Halifax	-	114,090	145,300	113,392	113,789
Isle of Wight	-	61,163	55,100	68,556	71,184
Wise	-	9,055	74,000	27,231	9,241

Table 3-10. Urban Land Estimates for Eight Virginia Counties (Acres), Late 1970s.

County	FIA	NRI	LULC
Augusta	-	32,800	26,111
Bedford	-	25,000	20,479
Fairfax	-	138,600	118,812
Goochland	-	7,500	6,161
Grayson	-	6,000	3,161
Halifax	-	13,700	4,794
Isle of Wight	-	4,900	10,392
Wise	-	14,600	5,883

Table 3-11. Forest Land Estimates for Eight Virginia Counties (Acres), Late 1970s.

County	FIA	NRI	LULC
Augusta	352,380	125,400	319,321
Bedford	297,686	247,500	261,163
Fairfax	123,051	86,000	84,601
Goochland	136,607	118,000	113,660
Grayson	160,484	132,200	133,620
Halifax	336,888	308,300	252,353
Isle of Wight	123,178	124,000	92,633
Wise	210,634	150,400	199,689

Table 3-12. Total Agriculture Estimates for Eight Virginia Counties (Acres), Late 1970s.

County	FIA	NRI	LULC
Augusta	-	249,300	236,462
Bedford	-	165,900	167,811
Fairfax	-	28,300	30,126
Goochland	-	45,400	47,827
Grayson	-	103,400	122,014
Halifax	-	166,100	218,756
Isle of Wight	-	55,500	68,525
Wise	-	14,700	8,753

Figure 3-1. 1977 Virginia Forest Inventory and Analysis

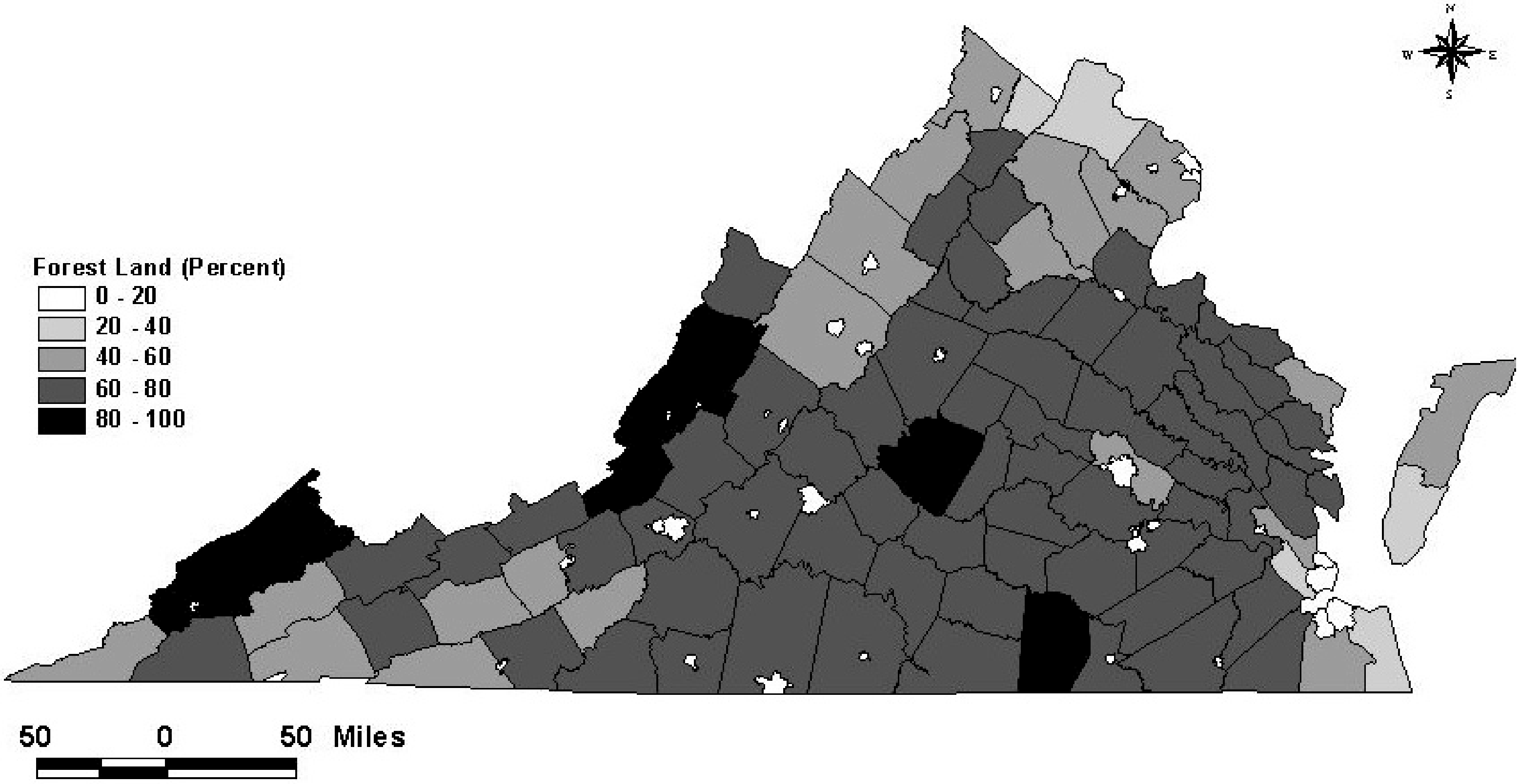


Figure 3-2. 1992 Virginia Forest Inventory and Analysis

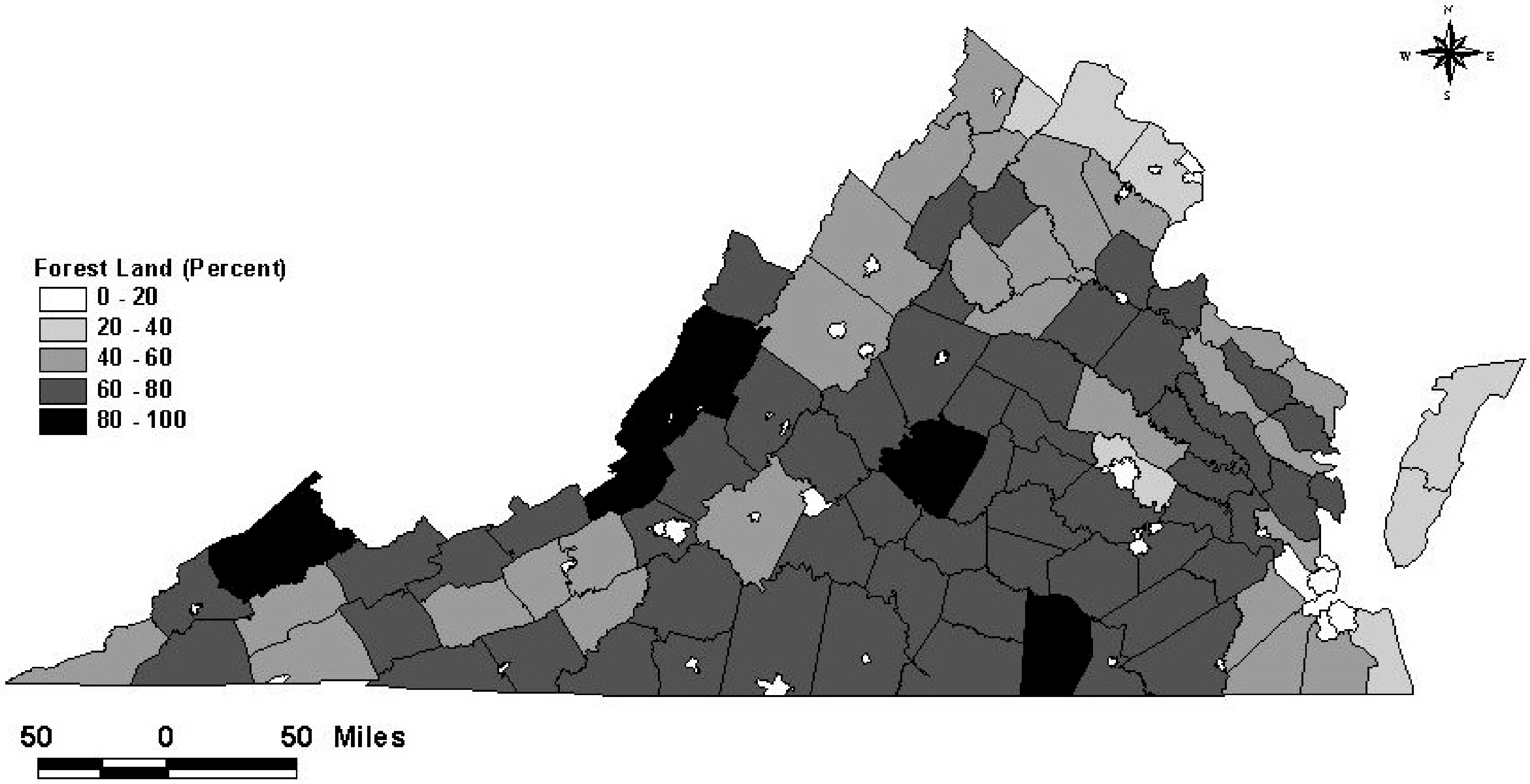


Figure 3-3. Virginia Forest Inventory Change Analysis - 1977 to 1992

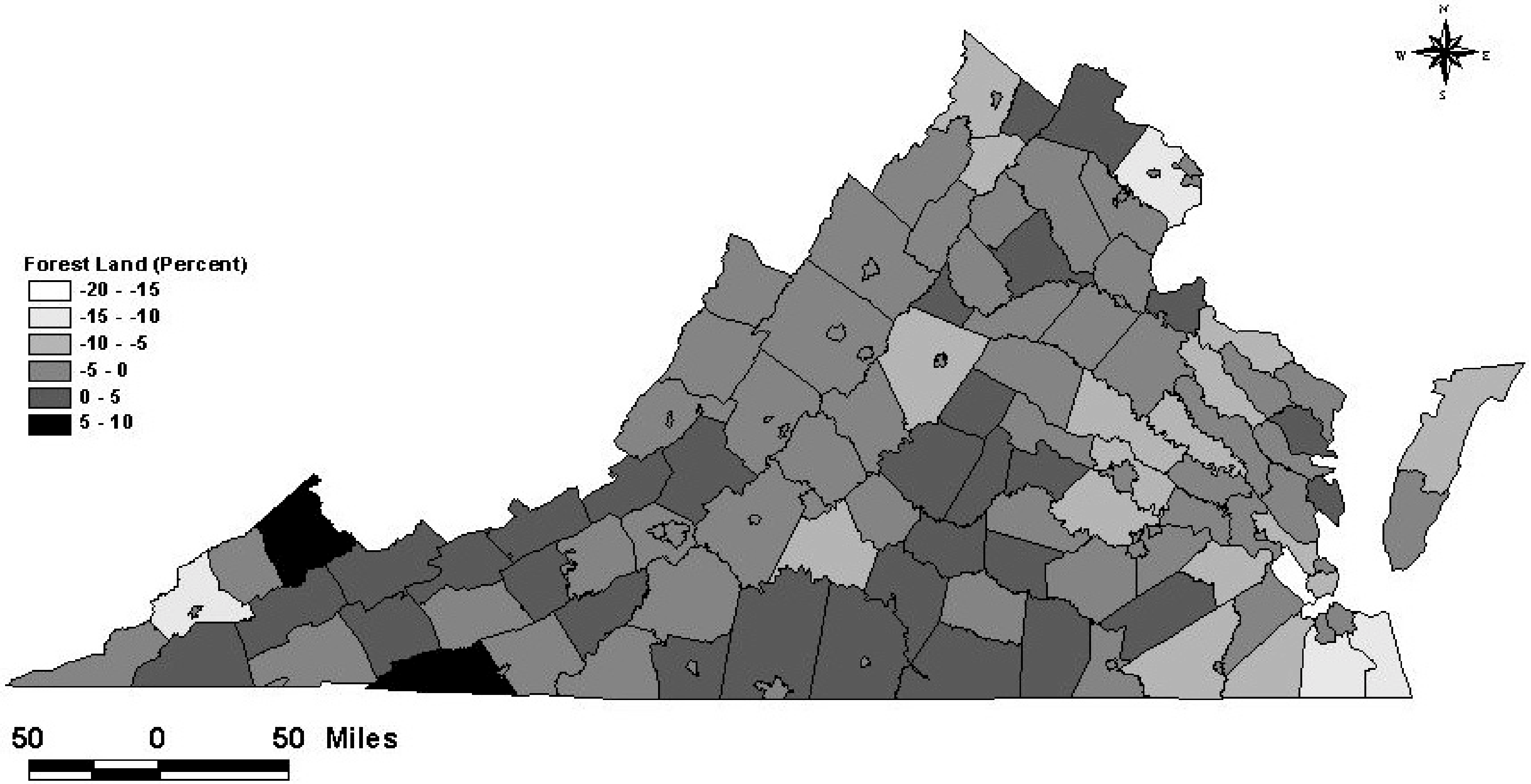


Figure 3-4. 1992 Census of Agriculture - Cropland [a]

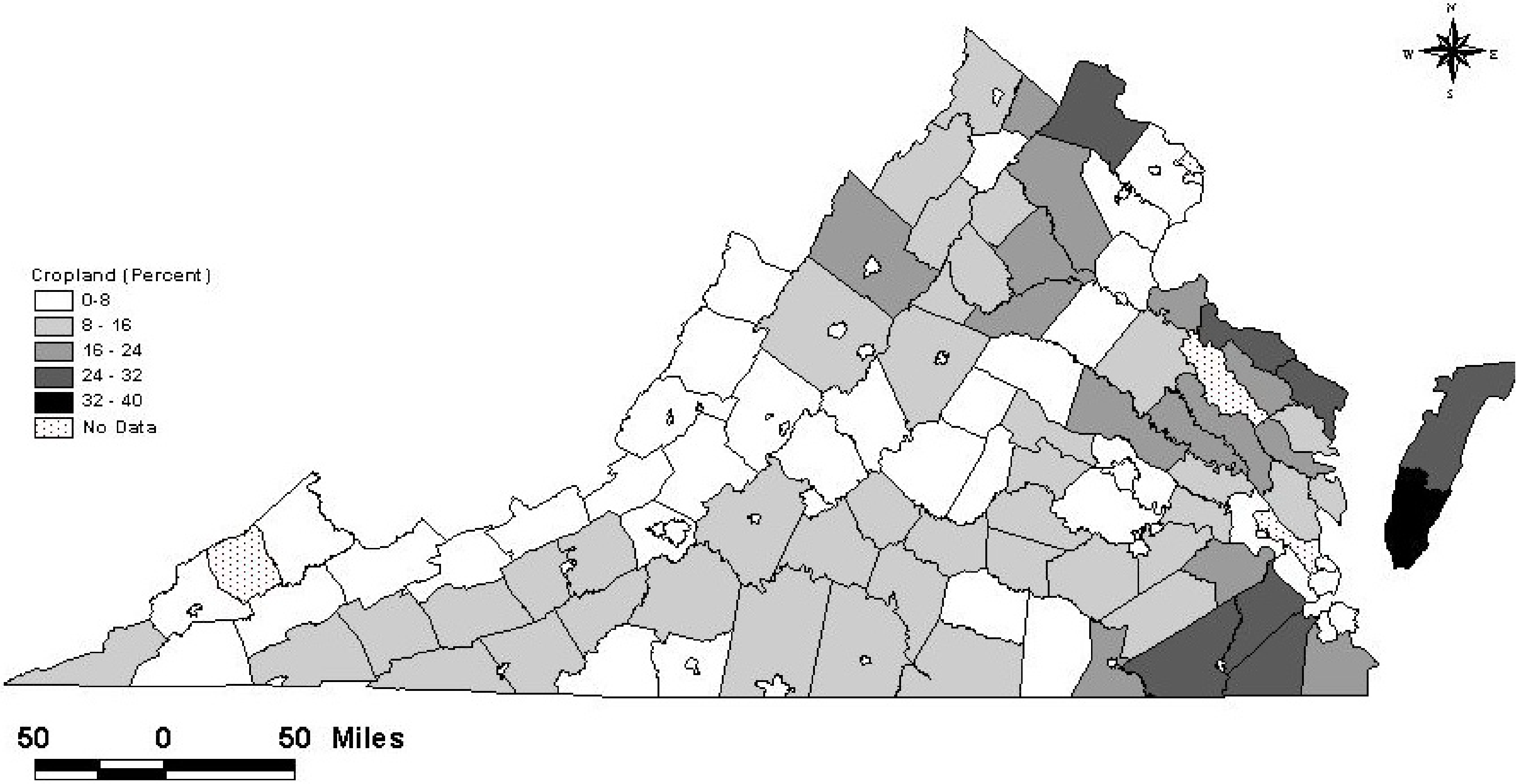


Figure 3-5. 1992 Census of Agriculture - Pasture [a]

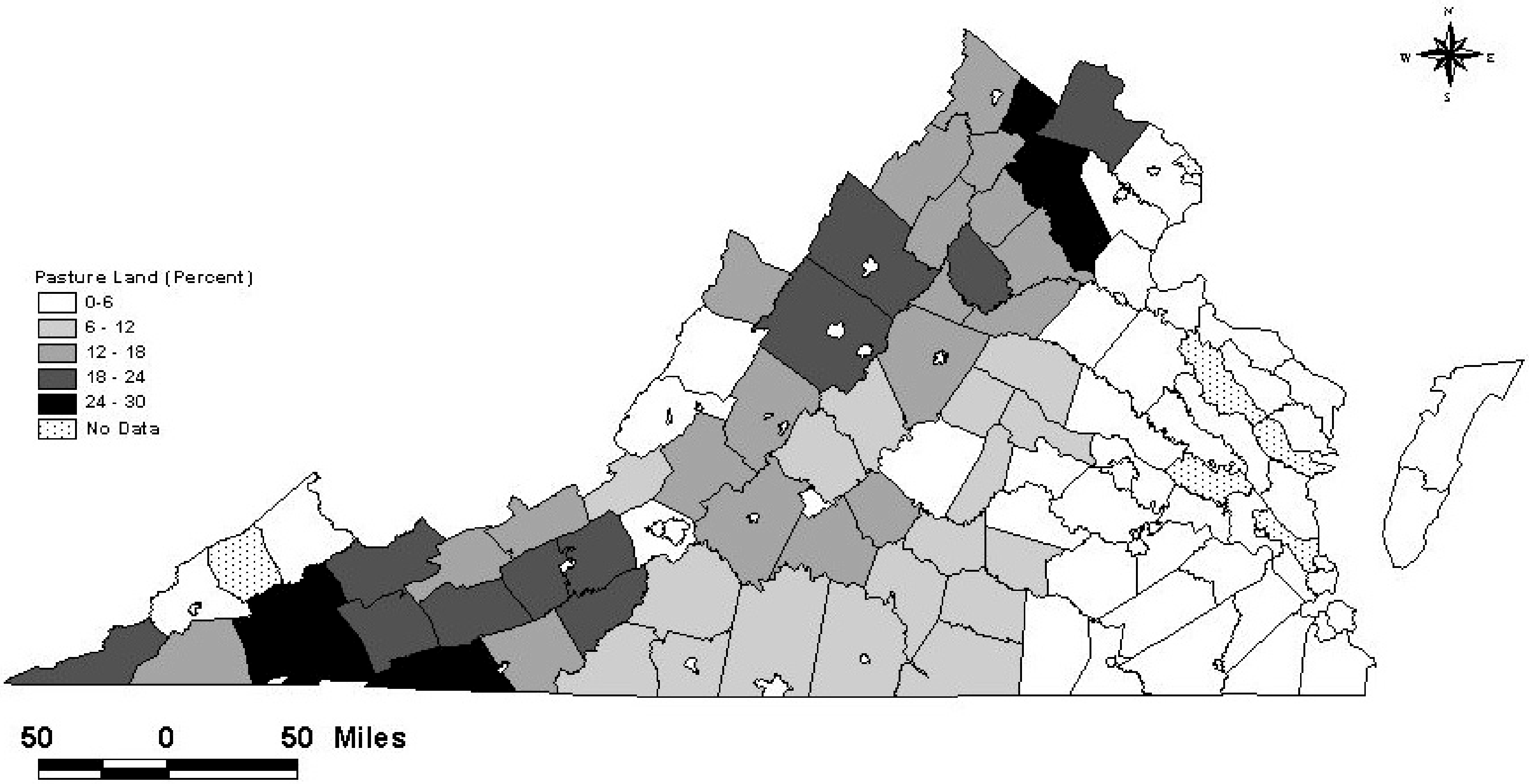


Figure 3-6. 1992 National Resources Inventory - Urban Land

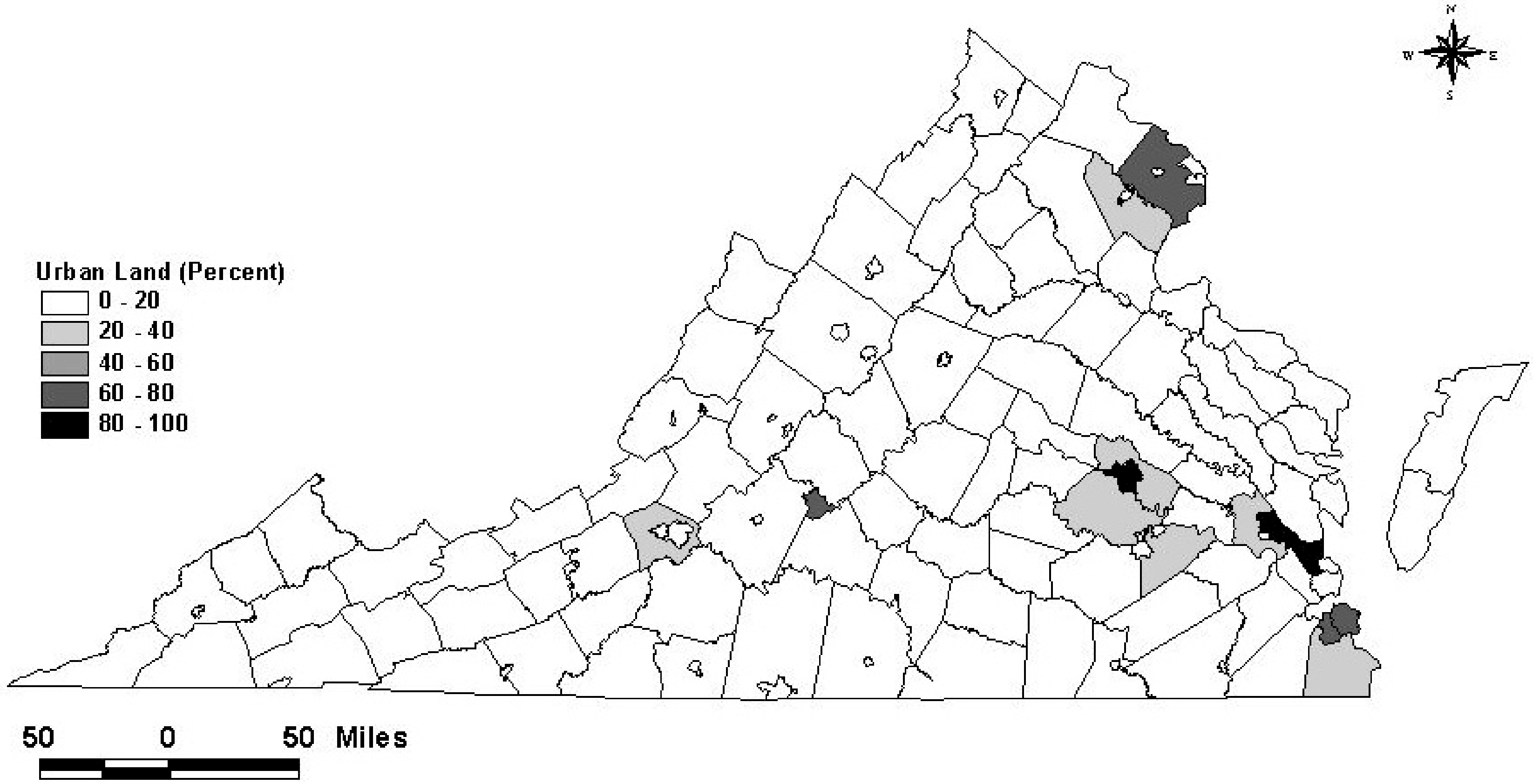


Figure 3-7. 1992 National Resources Inventory - Forest Land

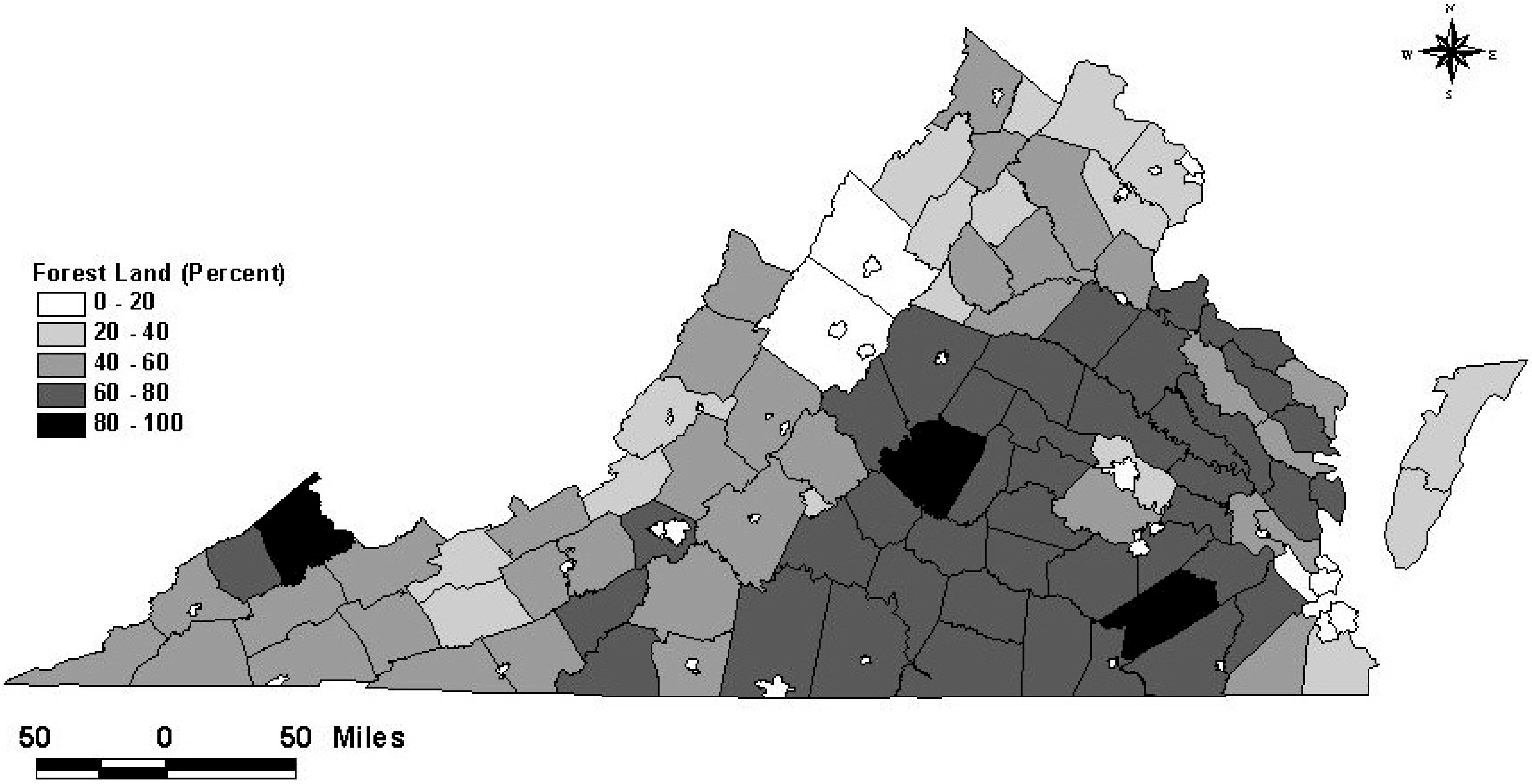


Figure 3-8. 1992 National Resources Inventory - Pasture Land

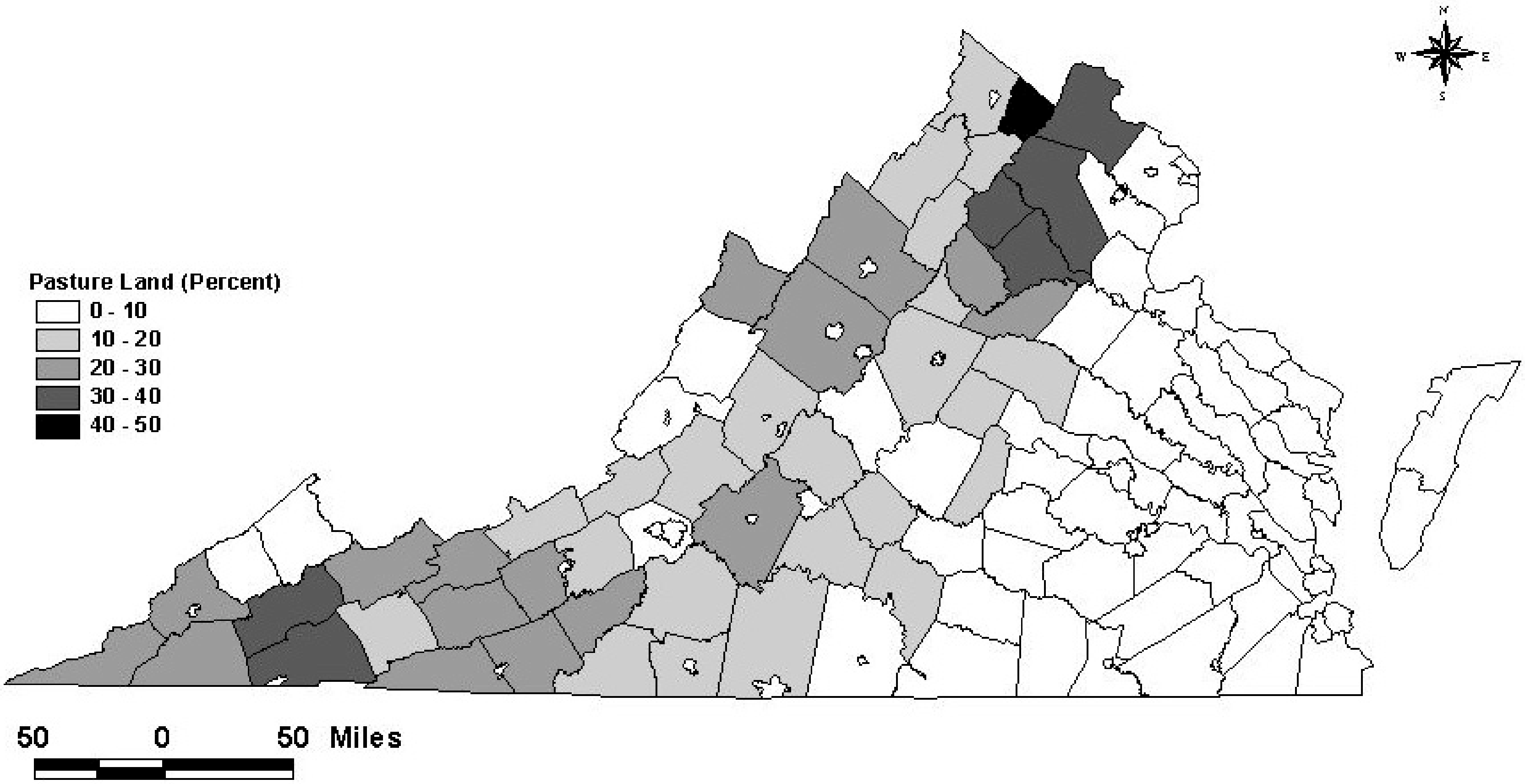


Figure 3-9. 1992 National Resources Inventory - Cropland

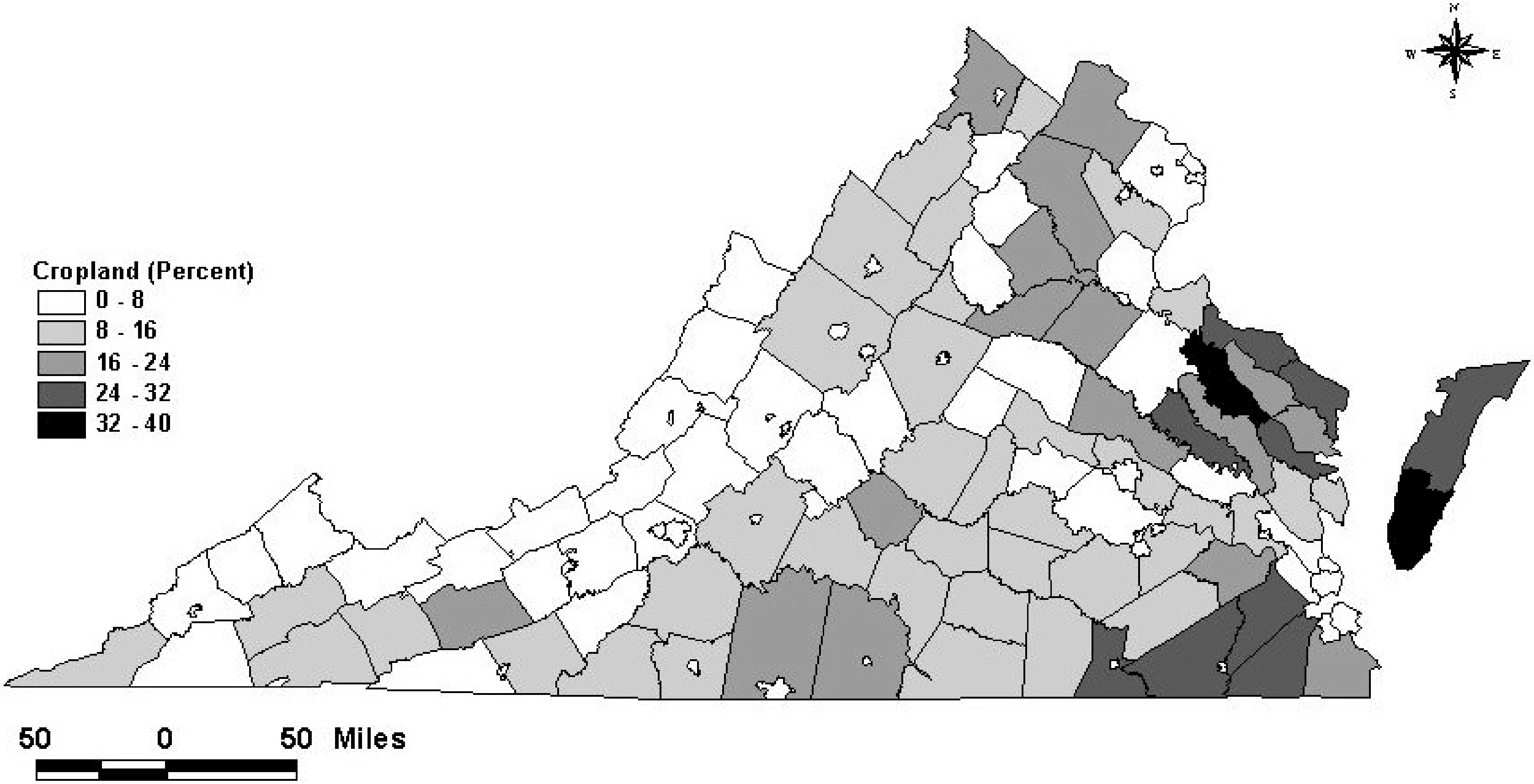


Figure 3-10. National Resources Inventory Urban Change - 1982 to 1992

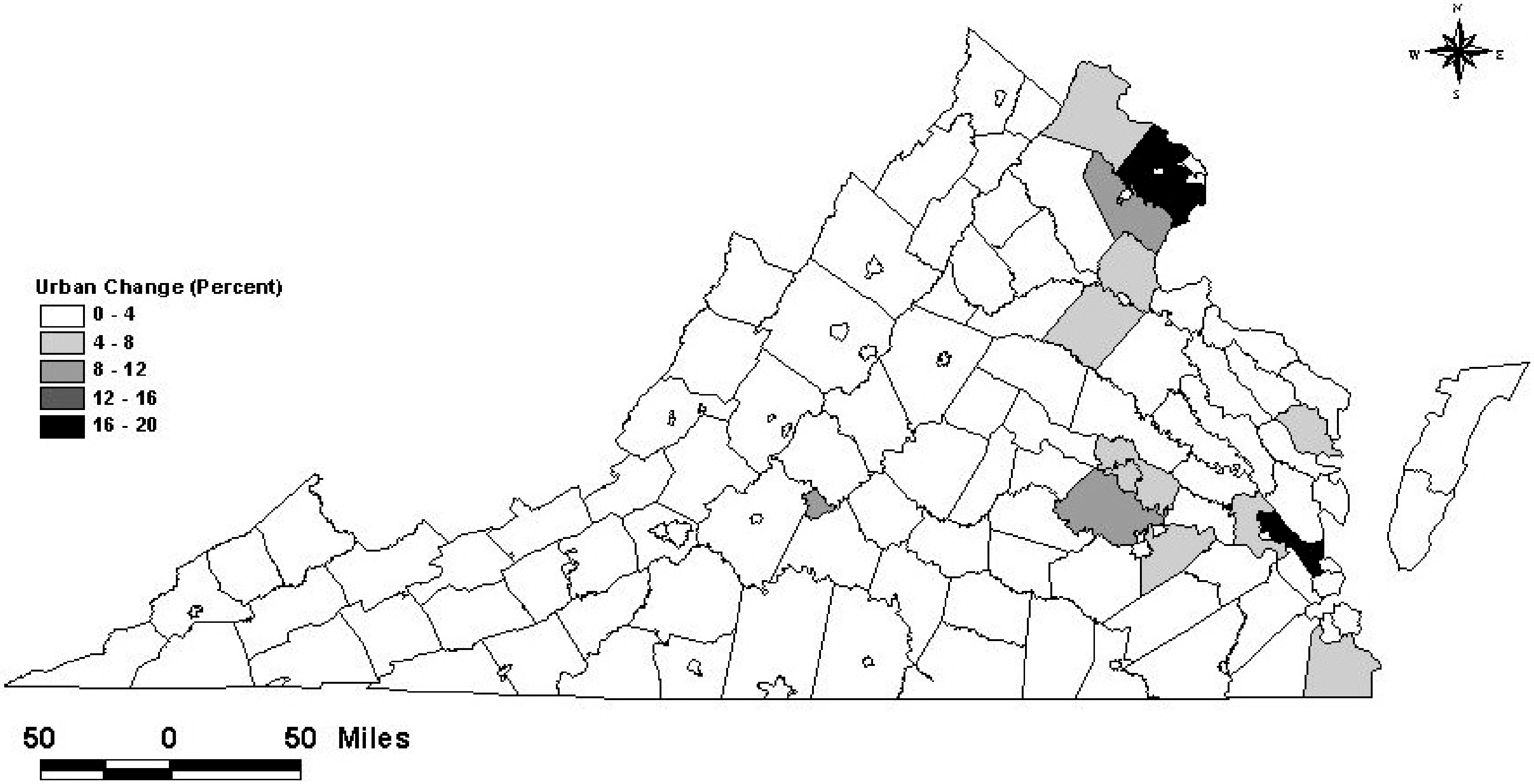


Figure 3-11. National Resources Inventory Forest Change - 1982 to 1992

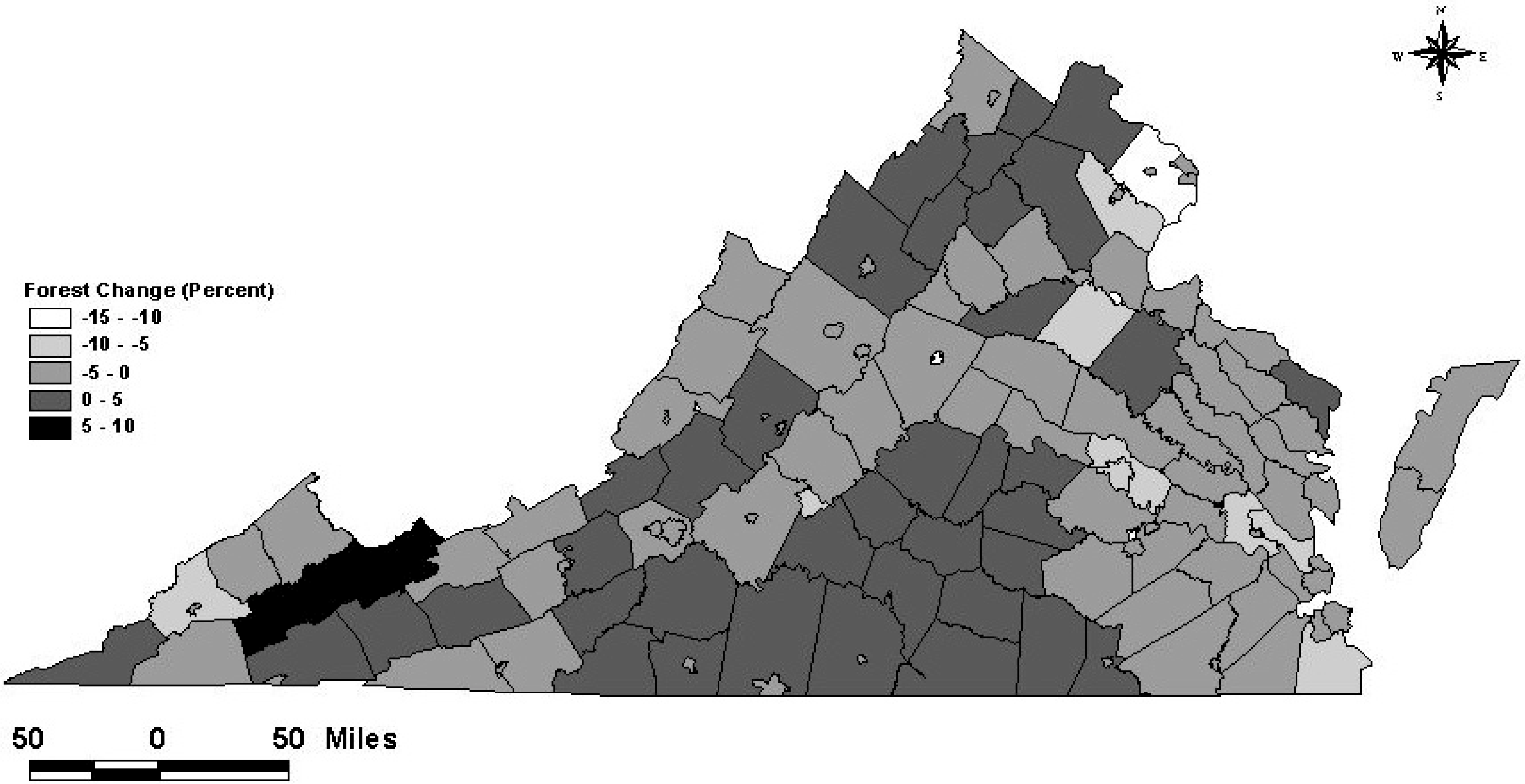


Figure 3-12. National Resources Inventory Pasture Change - 1982 to 1992

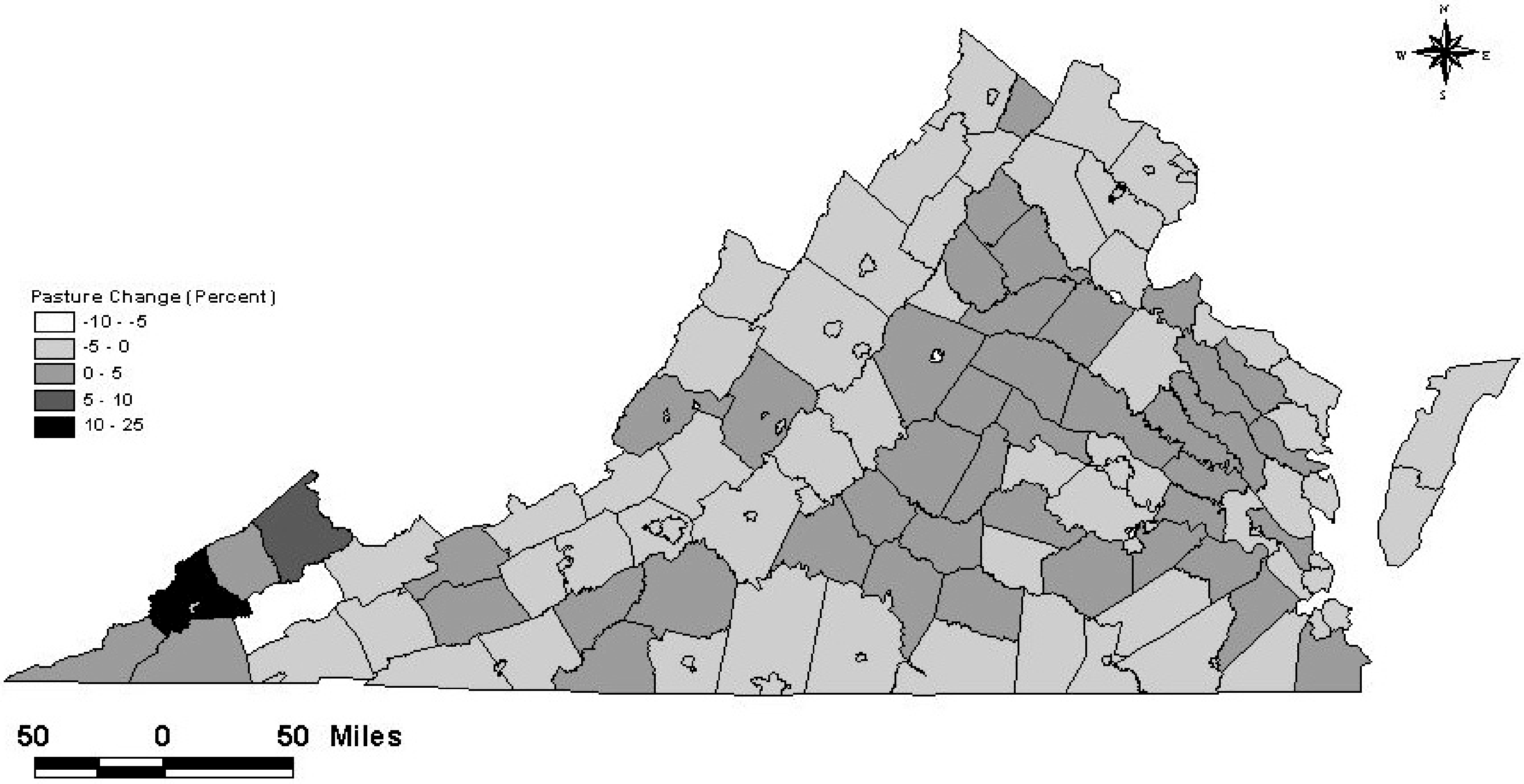


Figure 3-13. National Resources Inventory Cropland Change - 1982 to 1992

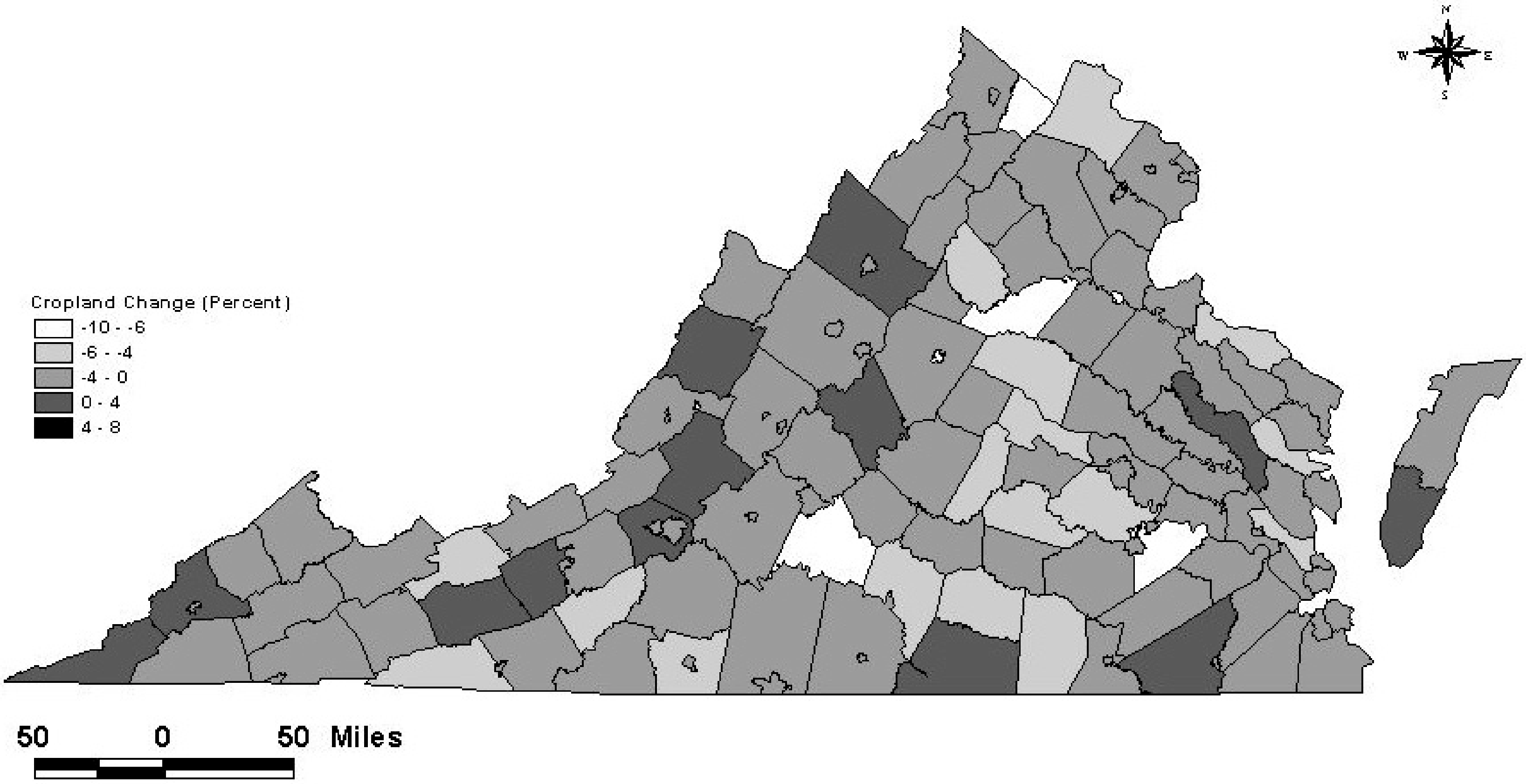


Figure 3-14. Virginia GAP, Early 1990s

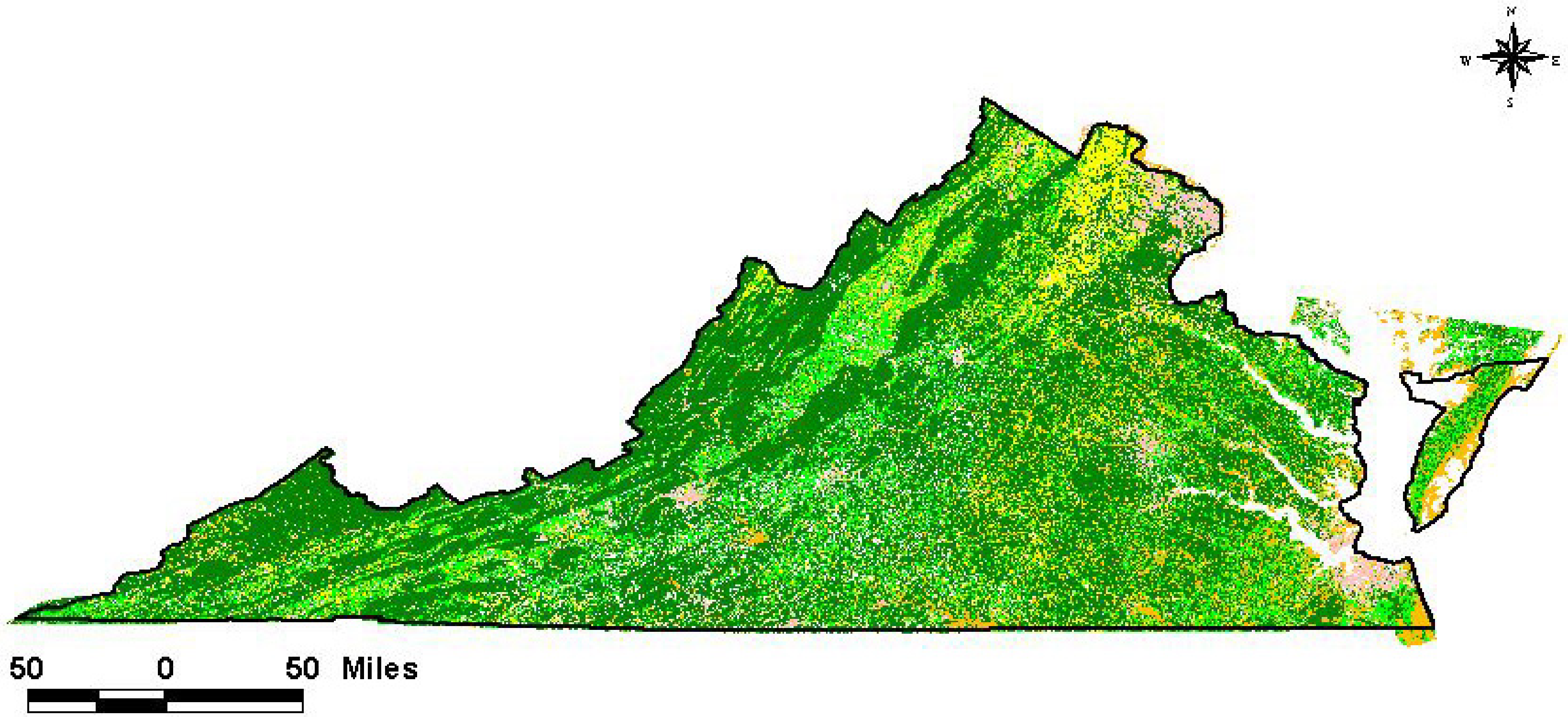


Figure 3-15. Virginia GAP Mixed Pixels, Early 1990s

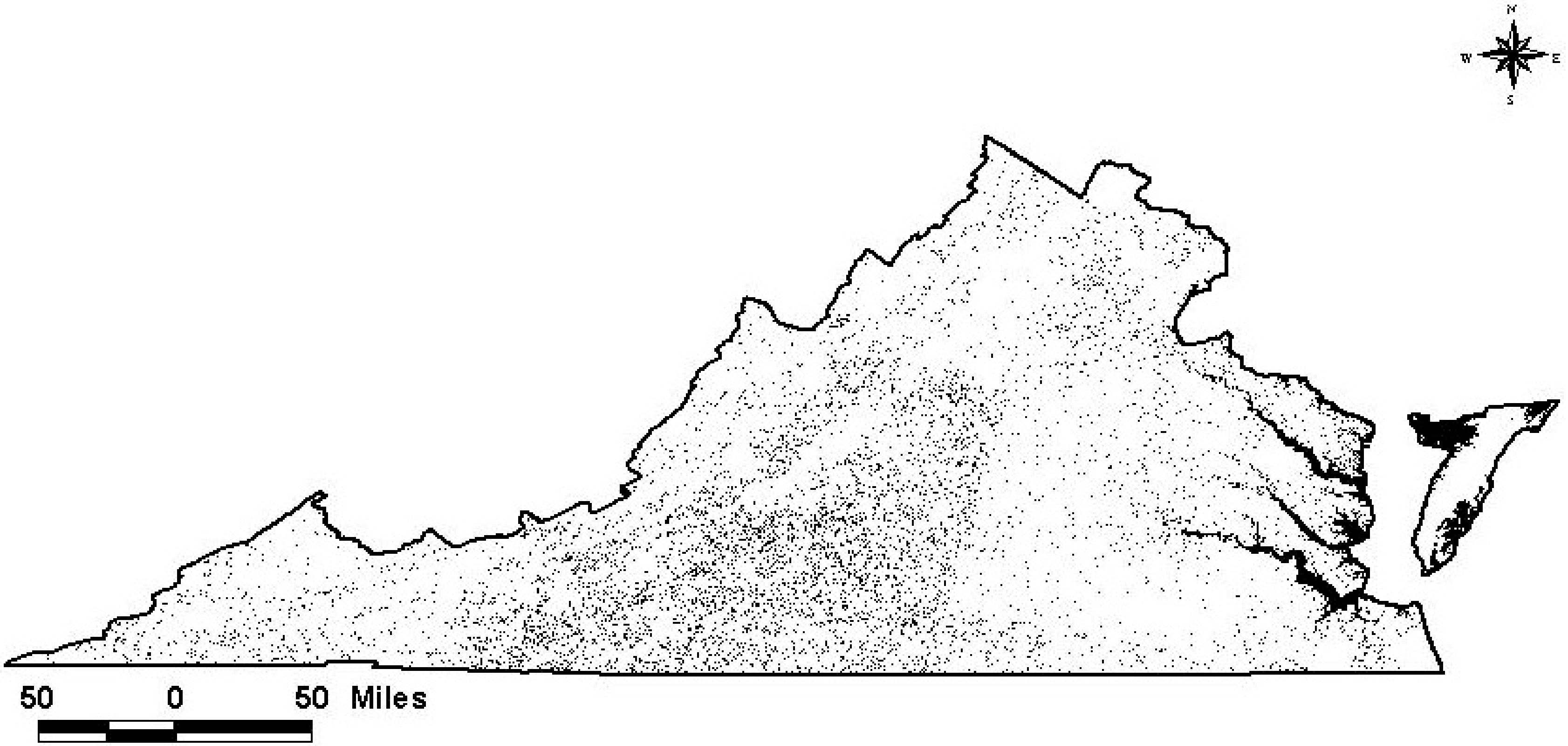


Figure 3-16. Virginia LULC, Late 1970s

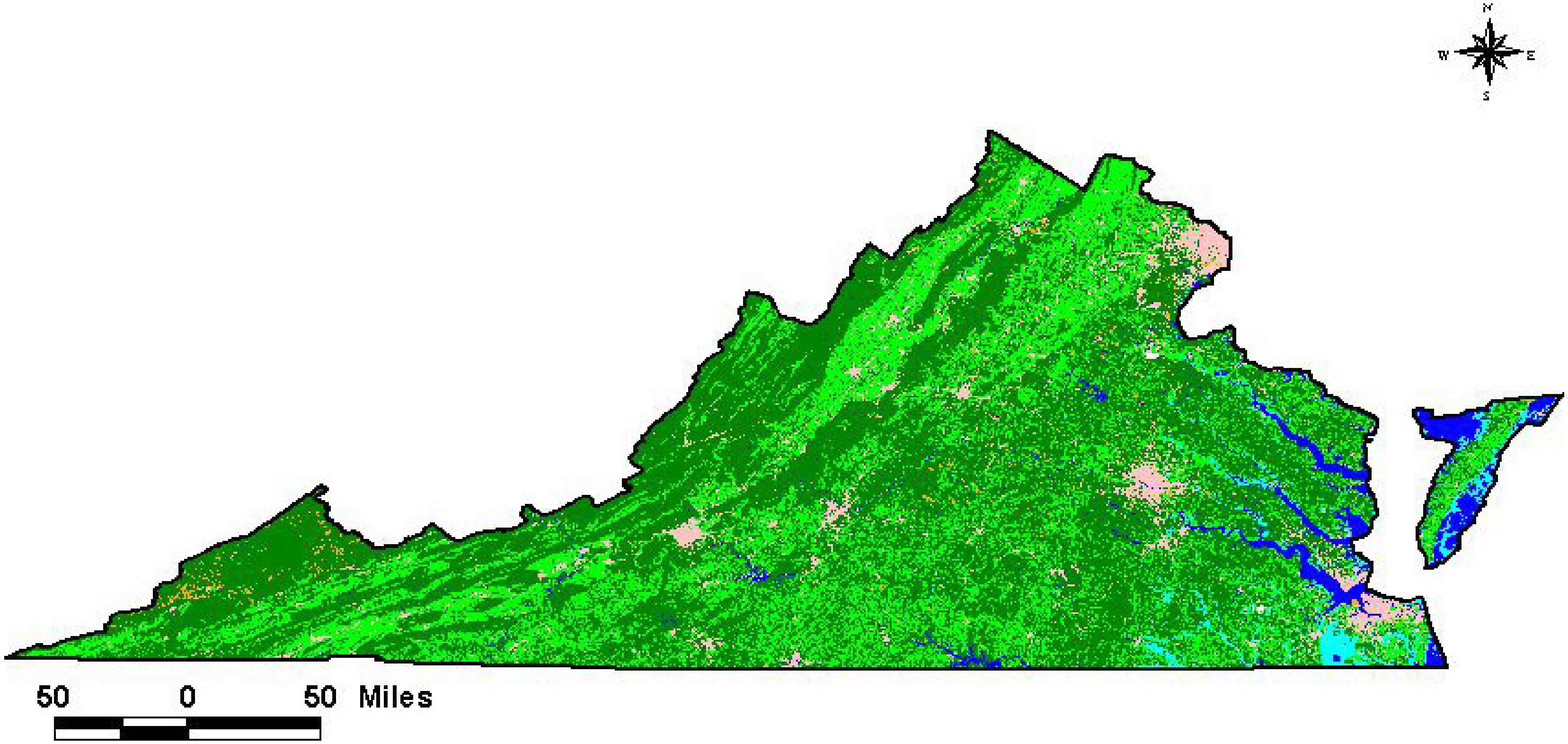
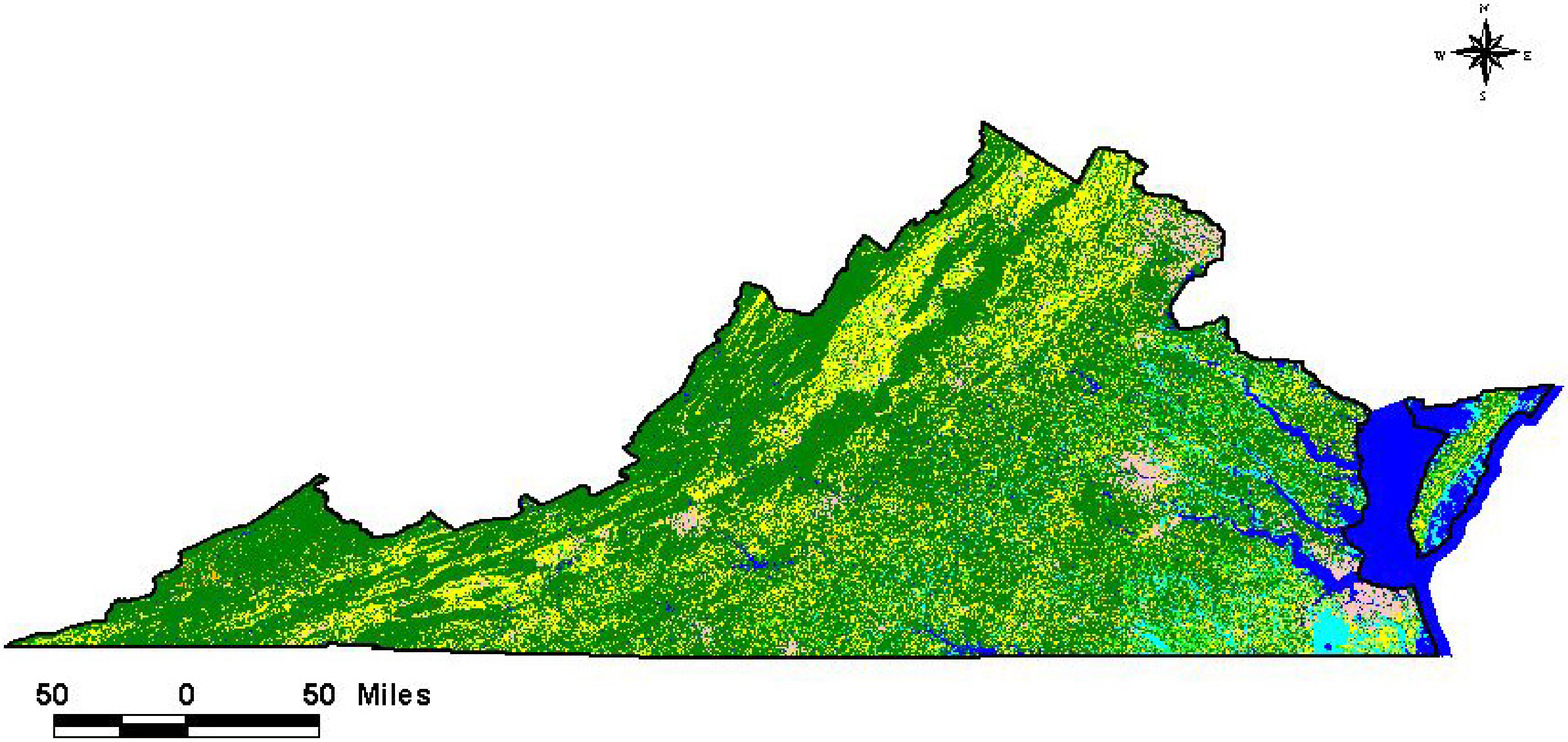


Figure 3-17. Virginia MRLC, Early 1990s



CHAPTER 4 - STATISTICAL RELATIONSHIPS BETWEEN LAND USE AND WATER-QUALITY TRENDS

INTRODUCTION

Land-Use Data

Two major sources of land-use data were utilized in this analysis. The U.S. Geological Survey's Land Use Land Cover (LULC) dataset (U.S. Geological Survey, 1990), compiled from aerial photographs in the late 1970s, and the Multi-Resolution Land Characteristics Consortium's (MRLC) land-use dataset (U.S. Environmental Protection Agency, 1997), compiled from satellite imagery in the early 1990s, were used in the land-use analysis. In the process of selecting land-use data, several data sources were considered including the Virginia Forest Inventory (Johnson, 1992), Census of Agriculture (U.S. Department of Agriculture, 1997), National Resources Inventory (NRI) (U.S. Department of Agriculture, 1987, 1994), North American Land Characterization (NALC) (Lunetta, 1993), Virginia GAP Analysis, MRLC and LULC. After evaluating the characteristics of each spatial dataset, the MRLC (1990s) and LULC (1970s) were chosen for use in this research. Each had multiple state coverage, were preclassified, used similar classification schemes, and allowed for the calculation of land-use change.

Other data sources used to verify the consistency of the LULC and MRLC included the Virginia Forest Inventory, Census of Agriculture, man-made features from Tiger Files (US Census Bureau, 1999), and the National Wetlands Inventory (NWI) (US Fish and Wildlife Service, 1999).

Water-Quality Data

Zipper et al. (1998) identified water-quality trends for nine variables at 187 monitoring stations throughout Virginia. These stations are part of the Virginia DEQ and USGS water-quality monitoring network. For this report, a subset of 168 stations was chosen from the 187 Zipper et al. (1998) stations. These stations possessed adequate data to perform water quality trend analyses from 1978 to 1995. Some watersheds were found to be quite small relative to the number of land-use cells within the watershed. Watersheds smaller than 4000 acres (1600 hectares) were eliminated from the analysis. Nine variables were analyzed including dissolved oxygen saturation (DO), biochemical oxygen demand (BOD), pH, total residue (TR), non-filterable residue (NFR), nitrate-nitrite nitrogen (NN), total Kjeldahl nitrogen (TKN), total phosphorus (TP), and fecal coliform (FC).

Water-quality trends at 168 stations were evaluated by G.I. Holtzman and P. Darken using the WQ1 SAS program (Zipper et al., 2000). The program used a Seasonal Kendall analysis as described by Hirsh et al. (1982, 1991) to evaluate water-quality trends. This procedure is used to detect monotonic trends in water-quality data. The Seasonal Kendall analysis is a robust procedure in that the analysis takes into account only whether the yearly change is positive or negative, and does not consider the magnitude of the change (Zipper et al., 1998). Month-to-month changes are also ignored due to the potential influence of seasonality. A Seasonal Kendall's tau is generated by the procedure.

Seasonal Kendall's tau is a nonparametric correlation coefficient that measures the relationship between a water-quality variable and time (Helsel and Hirsh, 1992). It is a weighted average of twelve rank-correlation coefficients (Kendall, 1970), one for each month of the year. The interpretation of Kendall's tau is similar to a Pearson's correlation coefficient. Both range from –1 to +1. "A tau of exactly -1 (+1) would be obtained only if there were, for each month of the year, a decrease (increase) from year to year for each year represented by available data," (Zipper et al., 1998). Tau values between –1 and +1 represent various strengths of the relationship between the water-quality variable and time. A tau of zero indicates that there is no identifiable relationship (Zipper et al., 2000). Kendall's tau values were generated for all nine water-quality variables at each station.

RESEARCH METHODS

Land-Use Data Modifications

LULC data were extracted and merged in ESRI's Arc View 3.1. Vector coverages for Virginia and surrounding states were converted to grid files with resolutions of 30 meters. These new coverages were then projected into geographic coordinates. MRLC data were also extracted and merged in Arc View 3.1. These data were in an Albers projection with a thirty-meter grid format. The projection was changed to a geographic coordinate system. An Anderson level-one classification scheme was used to reclassify both the LULC and MRLC data. LULC and MRLC level-one classes included urban, agriculture, forest, wetlands, barren, and water. MRLC agricultural land was also split into cropland and pasture.

Two MRLC coverages were required for the land-use data analysis. 1990s land use was determined with an unadjusted MRLC coverage. This coverage remained in the original format provided by EPA, and no adjustments were made other than reprojecting and reclassifying.

The MRLC and LULC coverages were used to determine land-use change from 1978 to 1995. Both coverages required adjustments before a direct comparison of land-use change could be made. Differences in the MRLC and LULC coverages originated from the two different methods of acquisition (satellite imagery vs. aerial photography) and cell sizes (30 meters vs. 16 hectares). A direct, non-adjusted comparison of the two coverages revealed numerous areas where the MRLC classified less urban area than the LULC. Since we are not aware of any large-scale conversions of urban land to agriculture and forest, we considered this to be an inaccurate result that reflected differences in classification methods and not actual changes in land use. For this reason, all urban land from the LULC coverage was copied into the MRLC coverage prior to the final analysis. Use of this procedure is based on the assumption that urban land uses expanded over the 1978-to-1995 period, and that once an area urbanizes, it does not revert back to an agricultural or forested land use.

MRLC classified a large amount of wetland area where the LULC coverage did not. Although some wetlands are being created in Virginia as a result of mitigation measures, the magnitude of difference between the two datasets caused us to conclude that this disparity also resulted from dissimilar methods of classification, as opposed to actual land-use change. MRLC data used National Wetlands Inventory (NWI) maps to help define wetland areas while the LULC did not (U.S. Geological Survey, 1999). Awareness and sensitivity to wetland issues increased substantially over the period spanned by these two datasets. This problem was remedied by copying wetland areas from the LULC and MRLC into both coverages to create equal wetland areas. A similar process was performed with the water class. We expect that the results of these procedures gave greater consistency to the land-use change estimates used in our analysis; wetland and water land-use variables were not used directly in our analyses.

When comparing LULC and MRLC forest and agricultural land, we suspected that there was confusion between the two land-use classes. Forest and agriculture land in Virginia tend to be mixed together. This pattern of land use creates difficulties when classifying remotely sensed images because many pixels are a mixture of two or more land-use classes. There was roughly a 1:1 change from forest to agriculture in the MRLC and LULC (Figure 4-1). This evidence supports our theory that forest and agriculture confusion has occurred. Both the LULC and MRLC determined different quantities of forest and agricultural land because of different resolution and data acquisition methods. Due to this characteristic, forest and agriculture land-use change were not considered in this research.

The barren land-use class was not used as a variable in this analysis. A barren land use, in many cases and in contrast to the other land uses, only occurs for a short term. Thus, any differences in the locations and occurrence of barren lands that may be observed between the late 1970s and the early 1990s may not represent a long term change in patterns of land use. Also, the Anderson level-one barren class is a mixture of classes including beaches, strip mines, clear cuts, and other transitional areas, each having different characteristics (Anderson et al., 1976). The occurrence of agricultural land, urban land, and forest land within watersheds in the late 1970s and early 1990s was found to be highly correlated, while the occurrence of barren land was not.

Figures 4-2 through 4-4 display the major urban, agricultural, and forested areas in Virginia. These maps were created from the unadjusted MRLC dataset. Most urban land is in the east, large forests dominate western Virginia, while agricultural land is dispersed throughout the state. Each pixel represents predominant land use within a 30m x 30m area.

Defining Variables to Represent Land Use and Land-Use Change

After analyzing the LULC and MRLC coverages, it was determined that six land-use variables would be used in the correlation analyses. Five land-use variables, including urban, forest, cropland, pasture, and total agriculture (cropland + pasture), were determined from the unadjusted MRLC (1990s) coverage. The only land-use change variable considered was urban change, which was determined from a comparison of the adjusted LULC and MRLC coverages.

To determine land use per watershed, Arc View shape files representing each watershed were overlain on the MRLC coverage. Watersheds for each monitoring station were delineated in Arc Info 7.2 using the USGS 1:250,000 digital elevation models (DEMs) (Zipper et al., 2000). Using a geographic information system (GIS), total watershed acres were calculated. Next, the *Histogram by Zone* function in Arc View 3.1 was used to determine the number of cells in each of the five major land-use classes within the watershed. These cell values were easily converted to acres based on each cell's representation of 30 x 30 meters. The number of land- use acres divided by the total acres within the watershed gives the percent land use within the watershed. An example calculation is included in Table 4-1.

Urban change was calculated using the adjusted MRLC and LULC coverages. Acres of urban land per watershed from the adjusted MRLC coverage were divided by acres from the adjusted LULC coverage to obtain a ratio of urban change from 1978 to 1995. Land-use and land-use change variables are further described in Table 4-2. Variables calculated for each watershed are included in Appendix C.

Data Adjustments

Many statistical procedures require their input data to have specific characteristics. In this research, Pearson's correlation was the primary analytical procedure for determining relationships between land use and water-quality trends. Pearson's correlation is a parametric procedure that requires a normal distribution and is sensitive to outliers (Ott, 1993). Upon evaluating the distributions of each land-use variable, it was discovered that some distributions required transformation to meet the requirements of Pearson's correlation.

To reduce the leverage of outliers, a Windsorizing procedure was implemented (Tukey, 1977). Windsorizing data involves choosing a quantile at the upper and lower ends of the data distribution. Data points above the upper quantile are changed to the value of the upper quantile, and points below the lower quantile are changed to the lower quantile. This method is used to reduce the leverage of outlier points without removing the points from the analysis. In this research, several land-use distributions required Windsorizing. We chose to use an upper quantile of 97.5% and a lower quantile of 2.5%. These two quantiles were determined to sufficiently reduce the leverage of outlier data points without affecting a large percentage of the data. Five land-use distributions required windsorizing including URBAN, CHGURB, CROPLAND, PASTURE, and TOTALAG. Figures 4-5 through 4-10 illustrate the effects of the windsorizing procedure on the land-use variable distributions.

Prior to analysis, severely non-normal land-use distributions were transformed by taking the LOG_{10} of the data. The LOG_{10} transformation was useful when data distributions were severely skewed; both the URBAN and CHGURB variables are examples of skewed distributions. Figures 4-5 and 4-6 display the URBAN and CHGURB land-use distributions before transformation and after. Both plots had several data points concentrated at the lower end of the data distribution. After taking the LOG_{10} of the data, the transformed distributions are less skewed, more normal, and better suited for the Pearson's correlation analysis. These data were also windsorized to reduce the influence of outliers. CHGURB was determined using a ratio rather than a difference so that a LOG_{10} transformation could be performed.

The forest distribution was relatively normal and no transformation was performed. Tables 4-3 and 4-4 list the transformations performed on each variable. For the remainder of this report, variables that have not been transformed are represented by capital letters (e.g. URBAN). Transformed variables are represented by capital letters with a subscript "t" (e.g. $URBAN_t$).

Correlations of Land Use and Water-Quality Trends

In order to investigate relationships between land use and water-quality trends (represented by Kendall's tau), and land-use change and water-quality trends (represented by Kendall's tau) during the period of 1978 to 1995, correlations were performed in SAS (SAS Institute, Research Triangle NC). Our research goal is to identify relationships between land use and water-quality trends that are representative of the entire dataset. To meet our research goal, correlations were performed using 168 water-quality monitoring stations, and their associated watersheds, distributed throughout Virginia.

Both Pearson's and Spearman's rank correlations were utilized in the correlation analysis. The primary statistical procedure was Pearson's correlation. A Pearson's correlation measures the strength of the relationship between two variables (Ott, 1993). Magnitudes of the data are considered in the relationship. Land-use data were transformed for the Pearson's analysis only. Spearman's correlation also measures the relationship between two variables. However, this procedure is based on the ranks of the data, and therefor does not consider magnitude. Land-use data were not transformed for the Spearman's analysis and water-quality trend data were not transformed for either analysis. Plots of selected relationships are included in the results.

Due to concern that results may be influenced by nested watersheds (that is, in certain areas of the state, many of the study watersheds overlie one another), a minimum overlap subset was identified. This subset includes 91 of the 168 watersheds analyzed in this study. These watersheds were chosen based on two criteria. First, the maximum amount of overlap between any two watersheds is 30 percent. Second, watersheds were selected to be as large as possible while maintaining adherence to the first criterion. A Pearson's correlation was performed with the minimum overlap subset of watersheds.

Correlations of Land Use and Water-Quality Medians

To help define relationships between land use and water-quality trends, the median values for each water-quality variable at each station were correlated with the land-use variables. Median values were calculated using the same water-quality data used to calculate the taus. Several of the median distributions were severely non-normal and required adjustments similar to the land-use distributions. Three different adjustments were made when applicable: Log_{10}, Windsorizing, and Log_{10}(Windsorized Data). Transformed data were used in the Pearson's median analysis only; Spearman's correlation did not require transformed data. Adjustments applied to the water-quality medians are included in Table 4-4.

BOD and TP medians possessed numerous tied values that produced severely non-normal distributions. In these two cases, only Spearman's correlation was performed. Transformations were not capable of sufficiently normalizing BOD and TP distributions to enable analysis with Pearson's correlation.

RESULTS

Statewide Land Use and Land-Use Change

Data describing statewide distribution of land-use and land-use change variables are listed in Table 4-5. The land-use change results were derived from the modified coverages, as discussed in the previous section. These results indicate that urban land use increased across the state between the late 1970s and early 1990s. According to MRLC, over half the state is forested and roughly 20 percent of the land is in agriculture.

An analysis of watershed land-use data indicated that several variables were highly correlated (Table 4-6). $PASTURE_t$ and $TOTALAG_t$ are highly correlated because the majority of the state's agricultural land is pasture. $URBAN_t$ exhibited a highly significant negative correlation with FOREST, as most of the state's urban areas and urban growth have occurred in watersheds that are not heavily forested. FOREST and $TOTALAG_t$, and FOREST and $PASTURE_t$ each exhibited a strong negative correlation.

Correlations With Water-Quality Trends and Medians

Pearson correlations for the 168 stations are listed in Table 4-7, and Spearman's rank correlations are listed in Table 4-8. For each land-use variable in the Pearson's correlation results, line one represents the Pearson's correlation coefficient (r) generated by SAS. Positive numbers represent a positive correlation between the land-use variable and the water-quality trend variable (Kendall's tau), while negative numbers represent a negative correlation. Line two represents the p-value, or the statistical significance of the Pearson's correlation coefficient. Line three represents the number of water-quality monitoring stations used to generate the correlation coefficient. The number of stations varies with each correlation because some water-quality variables were not available at certain stations during the 1978 to 1995 time period. The Spearman's correlation table is similar to the Pearson's table, except that the correlation coefficient reported in line one is the Spearman's rank correlation coefficient (Rho). Pearson correlations for the minimum overlap subset of monitoring stations are listed in Table 4-9. Correlations between water-quality medians and land-use variables are included in Tables 4-10 and 4-11.

In the following text, correlations are discussed and considered to be statistically significant only when p-values are less than .10 ($p<.10$). Relationships are considered to be highly significant only when p-values are less than .01 ($p<.01$). Tables 4-12 through 4-20 were created to compare the Pearson's, Spearman's, and minimum overlap correlations for each water-quality variable.

Biochemical Oxygen Demand (BOD): BOD trends tend to be negatively associated with forest land use. The scatterplot of BOD-tau vs. forest land use (FOREST) demonstrates that high forest land-use areas tend to be associated with declining BOD (Figure 4-11). This relationship has a Pearson's correlation coefficient of –0.26 and is highly significant ($p = 0.002$). Spearman's and minimum overlap correlations verified Pearson's result and were highly significant. The BOD-median analysis indicated that BOD-medians are negatively correlated with FOREST, indicating that lower BOD levels tend to occur in forested areas.

BOD-tau is weakly correlated with two of the three agricultural land uses. Both PASTURE_t and TOTALAG_t exhibited weak, positive correlations with BOD-tau in all three correlation analyses. PASTURE_t and TOTALAG_t are also highly correlated with one another. CROPLAND_t was positively correlated with BOD-tau in the Spearman's and minimum overlap analyses. The scatterplot of BOD-tau vs. TOTALAG illustrates that watersheds with fewer acres of agricultural land (including PASTURE) tend to associate with lower BOD-taus (Figure 4-12).

A positive statistical association between BOD-tau and $URBAN_t$ is present; however, it is not confirmed by the rank correlation. This relationship indicates that BOD tends to decrease in watersheds where there are fewer acres of urban land, which is complementary to the BOD-tau – FOREST relationship. $URBAN_t$ and FOREST have a strong negative correlation. BOD-medians also displayed a strong positive correlation with urban land use ($URBAN_t$). This supports the positive relationship with BOD-tau and $URBAN_t$.

The $CHGURB_t$ relationship with BOD-tau was negative. Spearman's correlation determined a stronger negative relationship than did Pearson's. CHGURB and BOD-medians were positively correlated using Spearman's correlation; however, the relationship was not significant at $p < 0.10$.

Dissolved Oxygen (DO): Correlations between DO-tau and all six land-use variables were extremely weak. The strongest DO-tau correlation occurred with $PASTURE_t$, and had a Pearson's correlation of –0.08 and p-value of 0.28 (Figure 4-13). This is a very weak correlation. Results were confirmed with the Spearman's and minimum overlap analyses. Scatterplots of DO-tau and land use generally reveal an evenly distributed cloud of points with no obvious relationships.

Several significant relationships were present between land use and DO-medians. The scatterplot of DO-medians vs. URBAN indicates that DO-medians are lower in watersheds with more urban land (Figure 4-14). The negative correlation between DO-median and $URBAN_t$ is confirmed by Pearson's and Spearman's correlations. $CHGURB_t$ was also negatively correlated with DO-median, however the Pearson correlation was not as significant.

FOREST exhibited a strong positive correlation with DO-medians, while $CROPLAND_t$ exhibited a strong negative correlation with DO-medians (Figures 4-15 and 4-16). Pearson and Spearman's correlations were highly significant ($p < 0.001$) for both the FOREST and $CROPLAND_t$ relationships with DO-medians.

Fecal Coliform (FC): FC-taus were correlated with several land-use variables. One of the strongest FC-tau relationships occurs as a positive correlation (Pearson's, rank, and minimum overlap) with FOREST. Many of the lowest FC-taus in this study occur in highly forested areas, particularly in southwest Virginia which has some of the highest amounts of forest in the state

(Figure 4-17).

Highly urbanized watersheds are among the state's least forested, and water-quality monitoring stations in Virginia’s urbanized areas tended to exhibit, on average, higher FC-taus than did stations in less-urbanized watersheds. This is consistent with the negative relationship of $URBAN_t$ and FOREST (Table 4-6). The FC-tau correlations with $URBAN_t$ were strongly influenced by monitoring stations located in southwest Virginia where there are fewer acres of urban land and FC-taus are lower. All three correlation methods confirmed the FC-tau and $URBAN_t$ relationship, however, correlations were not highly significant ($0.01 < p < 0.10$).

Significant positive correlations with FC-tau and two agricultural variables, $CROPLAND_t$ and $TOTALAG_t$, were present in the Pearson’s analysis. The minimum overlap analysis also indicated a strong positive correlation between $CROPLAND_t$ and FC-tau, but not $TOTALAG_t$. The Spearman’s correlation of FC-tau and TOTALAG was very weak ($p = 0.59$). FC-taus were low in southwest Virginia. All of the stations in the Big Sandy, Clinch-Powell, and Holston river basins exhibited FC-taus below zero. There is also a low percentage of cropland in southwest Virginia watersheds. The southwest Virginia stations strongly influenced the FC-tau vs. $CROPLAND_t$ correlation. Removal of the southwest Virginia stations produced a weak correlation between FC-tau and $CROPLAND_t$. Spearman’s correlation, which does not consider magnitude, also exhibited a non-significant correlation at $p < 0.10$.

Pearson’s and Spearman’s FC-med_t analyses exhibited few significant correlations. FOREST and FC-med_t were weakly correlated in the Pearson’s analysis, while CHGURB and FC-medians were weakly correlated in the rank correlation. Neither relationship was confirmed by the opposite correlation procedure.

Non Filterable Residue (NFR): NFR-tau exhibited two positive correlations with the agricultural variables $PASTURE_t$ and $TOTALAG_t$ (Figures 4-18 and 4-19). These relationships are consistent with conventional expectations: that agriculture can be a source of suspended solids. However, there were no significant relationships with $CROPLAND_t$ and NFR-tau. $PASTURE_t$ and $TOTALAG_t$ correlations with NFR-tau are consistent and highly significant throughout the Pearson’s, Spearman’s, and minimum overlap analyses. No other significant correlations existed with NFR-tau.

Two strong correlations were present with the NFR medians analysis. A strong positive relationship existed between NFR-med$_t$ and URBAN$_t$, and a negative relationship existed between NFR-med$_t$ and FOREST. The scatterplot of NFR-medians and FOREST indicates that high NFR medians tend to be associated with sparsely forested watersheds (Figure 4-20). The opposite is true for NFR medians and watersheds with more urban land (Figure 4-21). It was discussed earlier that FOREST and URBAN$_t$ are negatively correlated, and the NFR-med$_t$ relationships with FOREST and URBAN$_t$ support this finding.

Nitrate-Nitrite Nitrogen (NN): Few significant correlations existed between land use and NN-tau. Pearson's correlation revealed no significant correlations at $p < 0.10$ (Figures 4-22 and 4-23). CHGURB$_t$ and PASTURE$_t$ were significantly correlated with NN-tau in the Spearman's analysis.

NN-med$_t$ were positively correlated with URBAN$_t$ and negatively correlated with CHGURB$_t$. The NN-medians relationship with CHGURB was verified by Spearman's correlation.

pH: A Statistically significant positive correlation exists between pH-tau and forest land use (FOREST). Statistically significant negative correlations exist between pH-tau and urban land use (URBAN$_t$), pasture land use (PASTURE$_t$), and agricultural land use (TOTALAG$_t$). The relationship with forest land use is expressed most strongly. Several stations in the pH-tau analyses were suspected of having outlier data (1AFOU000.19, 9NEW081.72, 4ADAN075.22, 4ARNF013.66), yet significant rank correlations were found with URBAN, FOREST, PASTURE, and TOTALAG (Figure 4-24). PH-tau was significantly correlated with FOREST, PASTURE$_t$, and TOTALAG$_t$ in the minimum overlap analysis. There were no strong correlations ($p < 0.01$) between pH-tau and land use in any of the correlation analyses.

PH-medians were negatively correlated with URBAN$_t$ and positively correlated with FOREST (Figure 4-25). A strong negative correlation with pH-medians and CROPLAND$_t$ also existed. CHGURB$_t$ was negatively correlated with pH-medians in the Pearson's analysis but not Spearman's.

Total Kjeldahl Nitrogen (TKN): Several strong correlations were found with TKN-tau. FOREST is negatively correlated with TKN-tau. Watersheds with more acres of forest (Big

Sandy, Clinch-Powell, Holston basins) were generally associated with declining TKN, while watersheds with fewer acres of forest were generally associated with increasing TKN (Figure 4-26). Spearman's correlation also exhibited a strong relationship ($p<0.01$) between TKN-tau and FOREST. However, the minimum overlap correlation with FOREST and TKN-tau was only weakly significant ($p<0.10$).

$PASTURE_t$ and $TOTALAG_t$ were strongly correlated with TKN-tau, each having a p-value less than 0.01. The correlation coefficients are positive, indicating that watersheds with more agricultural areas tend to be associated with increasing TKN (higher TKN-taus) (Figure 4-27). Even though TKN-tau was correlated with two agricultural variables, it was not correlated with $CROPLAND_t$ in the Pearson's analysis. The relationships of $PASTURE_t$ and $TOTALAG_t$ to TKN-tau were highly significant ($p<.01$) in the Spearman's analysis and only weakly significant ($p<.10$) in the minimum overlap analysis. A significant positive correlation was found between CROPLAND and TKN-tau in the Spearman's analysis. This relationship was not confirmed by the Pearson's or minimum overlap analyses.

The TKN medians analysis gave results similar to the NFR medians analysis. TKN-med_t exhibited strong correlations with both $URBAN_t$ and FOREST. $URBAN_t$ was positively correlated with TKN-med_t and FOREST was negatively correlated with TKN-med_t. These were two of the strongest relationships in the median analyses.

Total Phosphorus (TP): Phosphorus is generally associated with agricultural land use and this was observed in the TP-tau correlations. TP-tau was positively correlated with $TOTALAG_t$ and $PASTURE_t$. These relationships were two of the strongest Pearson correlations found in the water-quality trend and land use analysis. Even with the removal of the outlier station 7HLD002.67, both $PASTURE_t$ and $TOTALAG_t$ remain strongly correlated with TP-tau ($p < 0.01$). TP-tau exhibited strong correlations ($p < 0.01$) with $PASTURE_t$ and $TOTALAG_t$ in the Spearman's and minimum overlap analyses. As displayed by the scatterplot of TP-tau vs. TOTALAG (Figure 4-28), watersheds with less agricultural land are associated with lower TP-taus, while areas with more agricultural land tend to be associated with higher TP-taus.

A significant negative correlation between TP-tau and CHGURB was present in the Spearman's analysis only.

The TP medians analysis gave few significant results. A Pearson's correlation procedure could not be used with the TP-median data due to numerous tied values in the data distribution. There was one significant Spearman's correlation between TP-medians and CROPLAND.

Total Residue (TR): Correlations of TR-tau with land use yielded results that are consistent with conventional expectations: positive correlations with urban land use and urban land-use change, and negative correlations with forest land use. The strongest Pearson correlation was the relationship between TR-tau and FOREST. After further inspection of the data, it seems that stations with high TR-tau values and low forest land-use values in the 5B watershed (Dismal Swamp basin) are influential in this relationship (Figure 4-29). High TR-tau values in the 5B watershed may be due to salt-water intrusion in the low-lying Dismal Swamp area. Removal of these stations resulted in a non-significant relationship between TR-tau and FOREST. There was also a non-significant relationship between TR-tau and FOREST in the Spearman's analysis.

TR-med$_t$ exhibited a statistically significant positive correlation with URBAN$_t$ and a statistically significant negative correlation with FOREST (Figure 4-25). Both were verified by the Spearman's analysis. CROPLAND$_t$ was negatively correlated with TR-med$_t$ in the Spearman's analysis but not Pearson's.

TR relationships were determined from 83 monitoring stations due to a lack of sufficient TR data at many monitoring stations. Correlations should be interpreted accordingly.

SUMMARY

Correlations With Respect to Land Use

Watersheds with less urban land (URBAN$_t$) tend to be associated with lower BOD and FC taus, and higher pH-taus. Watersheds with more urban land tend to be associated with higher TR-taus. BOD-tau was positively correlated with URBAN$_t$ in the Pearson's analysis, but not Spearman's. The TR-tau relationships with URBAN$_t$ may be due to the fact that many of Virginia's urban areas lie along the Atlantic Ocean or Chesapeake Bay. Salt water is a contributing factor to high TR values. This is confirmed by the strong positive correlation between URBAN$_t$ and TR-med$_t$. Also, total dissolved solids tend to increase downstream in rivers. Significant correlations existed between URBAN$_t$ and all water-quality medians except FC-med$_t$ and TP- medians. The URBAN$_t$ – NN-med$_t$ relationship was not verified by

Spearman's correlation. Spearman's analysis exhibited a strong correlation between URBAN and BOD-medians. This relationship could not be verified by Pearson's analysis because of the severely non-normal nature of the BOD-medians distribution.

Watersheds with more urban growth (CHGURB_t) were associated with lower BOD-taus and higher TR-taus. Spearman's correlation also found significant negative relationships with CHGURB and FC, NN, and TP taus. CHGURB_t exhibited two significant correlations with DO-medians and NN-med_t that were verified by Pearson's and Spearman's analyses. CHGURB_t and pH-medians were significantly correlated in the Pearson's analysis, while FC-medians and NFR-medians were significantly correlated with CHGURB_t in the Spearman's analysis.

Several water-quality variables were correlated with FOREST. Negative correlations existed between FOREST and BOD, FC, TKN, and TR taus. Each of these relationships is indicative of improving water quality in highly forested watersheds in Virginia over the 1978 to 1995 study period. PH-tau was the only variable positively correlated with FOREST. FOREST exhibited significant correlations with all water-quality medians except NN-med_t. FC-medians and TP-medians were not significantly correlated with FOREST in the Spearman's analysis. The water-quality medians analyses generally indicated that better water quality is associated with highly forested watersheds.

Of the three agricultural variables, PASTURE_t and TOTALAG_t exhibited similar correlations with water-quality taus. This is expected as PASTURE_t and TOTALAG_t were highly correlated with one another. Both PASTURE_t and TOTALAG_t were positively correlated with BOD, NFR, TKN, and TP taus, and negatively correlated with pH-taus. PH-tau and TKN-tau correlations with agriculture indicate that watersheds with more agricultural land are generally associated with declining pH and TKN water quality. Low BOD, NFR, and TP taus were more associated with watersheds having lower amounts of agricultural land. CROPLAND_t and FC-tau exhibited a significant positive correlation in the Pearson's analysis. This relationship was not verified by the Spearman's analysis. There were not many strong correlations with agricultural land use and water-quality medians. The only relationships verified by the Pearson's and Spearman's analyses were CROPLAND_t and DO-medians, and CROPLAND_t and pH-medians. Spearman's correlation also found significant negative relationships between CROPLAND and NN, TP, and TR medians. Both PASTURE_t and TOTALAG_t were significantly correlated with DO-medians in the Spearman's analysis but not

Pearson’s.

Correlations With Respect to Water-Quality Trends

BOD and FC taus exhibited similar relationships with land-use variables. Both exhibited strong negative correlations with FOREST (forest land use); these relationships are confirmed by the Pearson’s, Spearman’s, and minimum overlap analyses. Both BOD-tau and FC-tau exhibit positive correlations with URBAN_t and one or more agricultural land-use variables, which are complementary to the FOREST relationship but more weakly expressed. PH exhibits a similar set of relationships, but of the opposite signs (i.e., a strong positive correlation with FOREST).

DO-tau and NN-tau correlations with land-use variables were very weak throughout the various analyses and most were not significant at $p < 0.10$. However, DO-medians had strong correlations with several land use variables. Higher DO-medians were associated with highly forested areas (positive correlation). Negative correlations existed between DO-medians and URBAN_t, CHGURB_t, and CROPLAND_t, indicating that high DO-medians are associated with watersheds that have less urban land, less urban change, and less cropland.

Similar relationships existed with NFR, TKN, and TP taus. All three were positively correlated with two agricultural variables: PASTURE_t and TOTALAG_t. NFR, TKN, and TP taus were strongly correlated ($p < 0.01$) with PASTURE_t and TOTALAG_t in the Pearson’s and Spearman’s analyses. These relationships indicate that watersheds with less agricultural land are associated with improving NFR and TP water quality. Watersheds with more agricultural land are associated with declining TKN water quality.

NFR, TKN, pH, and TR medians also displayed similar relationships with the land-use variables. These four water-quality medians were significantly correlated with URBAN_t and FOREST in the Pearson’s and Spearman’s analyses. Watersheds with less forest land were associated with higher NFR, TKN, and TR medians (negative correlations). Watersheds with more forest land were associated with higher pH-medians (positive correlation). An opposite relationship existed with URBAN_t and NFR, TKN, pH, and TR medians. Positive correlations existed with URBAN_t and NFR-med_t, TKN-med_t, and TR-med_t, and a negative correlation existed with URBAN_t and pH-medians.

NN-med_t and CHGURB_t, and pH-medians and CROPLAND_t, were significantly correlated in the Pearson’s and Spearman’s analyses. Watersheds with less urban change (CHGURB_t) were associated with higher NN-medians. High pH-medians were associated with watersheds that contained fewer acres of cropland.

Six relationships of water-quality taus and land use were highly significant ($p<0.01$) in the Pearson's, Spearman's, and minimum overlap analyses. These include the negative correlation of BOD-tau and FOREST, and the positive correlations of NFR-tau and $PASTURE_t$, NFR-tau and $TOTALAG_t$, TP-tau and $PASTURE_t$, TP-tau and $TOTALAG_t$, and TKN-tau and $PASTURE_t$. All six relationships were considered to be the most significant findings of the land use and water-quality trend analysis. Each relationship was verified by all three correlation techniques, were resistant to outlier influence, were significant at $p < 0.01$, and conformed to common expectations of water quality and land use relationships.

CONCLUSIONS

In general, highly forested watersheds in Virginia were associated with improving water quality with respect to BOD, FC, TKN, TR, and pH over the 1978 to 1995 study period. These watersheds were commonly associated with better water quality as measured by the water-quality medians for the variables DO, NFR, BOD, pH, TKN, and TR. Watersheds with less urban land tend to be associated with improving water quality with respect to BOD, FC, and pH, while watersheds with more urban land are associated with declining TR water quality. Better water quality, as measured by the water-quality medians (DO, NFR, NN, pH, TKN, and TR), was generally associated with watersheds possessing fewer urban acres. Improving BOD, NFR, and TP water quality tended to be associated with watersheds having fewer agricultural acres. Watersheds with more agricultural acres were associated with declining pH and TKN water quality. Urban and agricultural relationships were complementary to the forest relationships. There were few significant relationships between water-quality medians and agricultural variables.

Table 4-1. Calculation of Percent Land Use in Watershed 2CHK076.59.

	Urban	Forest	Pasture	Cropland	Total Agriculture	Total
Cells	12,970	51,474	11,671	2344	14,015	86,109
Acres	2,884	11,447	2,596	521	3,117	19,150
Percent	15.1	59.8	13.6	2.7	16.3	100

(Note: Barren, wetland, and water classes are not included in the table)
1 cell = 30m x 30m (900m^2)

Table 4-2. Land Use and Land-Use Change Variables for Watersheds Defined by Water-Quality Monitoring Stations.

Variable	Definition
URBAN	Urban land area, as percent of watershed
CHGURB	Change in urban land area, as a ratio of MRLC ÷ LULC
FOREST	Forest land area, as percent of watershed
PASTURE	Pasture land area, as percent of watershed
CROPLAND	Cropland area, as percent of watershed
TOTALAG	Sum of pasture and cropland, total agricultural land

Table 4-3. Land-Use Data Transformations.

Variable	Transformed Variable	Transformation Applied
URBAN	URBAN_t	$\mathrm{Log}_{10}(\mathrm{Windsorized}_{2.5,\,97.5}\ \mathrm{URBAN})$
CHGURB	CHGURB_t	$\mathrm{Log}_{10}\ (\mathrm{Windsorized}_{2.5,\,97.5}\ \mathrm{CHGURB})$
FOREST	N/A	None
PASTURE	$\mathrm{PASTURE}_t$	$\mathrm{Windsorized}_{2.5,\,97.5}\ (\mathrm{PASTURE})$
CROPLAND	$\mathrm{CROPLAND}_t$	$\mathrm{Windsorized}_{2.5,\,97.5}\ (\mathrm{CROPLAND})$
TOTALAG	$\mathrm{TOTALAG}_t$	$\mathrm{Windsorized}_{2.5,\,97.5}\ (\mathrm{TOTALAG})$

N/A - Not applicable

Table 4-4. Water-Quality Median Transformations.

Variable	Transformed Variable	Transformation Applied
BOD-medians	N/A	None
DO-medians	N/A	None
FC-medians	$\mathrm{FC\text{-}med}_t$	$\mathrm{Log}_{10}\ (\mathrm{FC\text{-}medians})$
NFR-medians	$\mathrm{NFR\text{-}med}_t$	$\mathrm{Log}_{10}\ (\mathrm{NFR\text{-}medians})$
NN-medians	$\mathrm{NN\text{-}med}_t$	$\mathrm{Windsorized}_{2.5,\,97.5}\ (\mathrm{NN\text{-}medians})$
pH-medians	N/A	None
TKN-medians	$\mathrm{TKN\text{-}med}_t$	$\mathrm{Log}_{10}\ (\mathrm{Windsorized}_{2.5,\,97.5}\ \mathrm{TKN\text{-}medians})$
TP-medians	N/A	None
TR-medians	$\mathrm{TR\text{-}med}_t$	$\mathrm{Log}_{10}\ (\mathrm{TR\text{-}medians})$

Note: Water-quality taus were not transformed.
N/A - Not applicable

Table 4-5. Land Use and Urban Land-Use Change Estimates for Virginia (1,000 acres)

	URBAN	FOREST	TOTAL AG	OTHER	TOTAL
MRLC	863	15,592	5,738	2,064	24,258
CHANGE	308	-	-	-	-

Other = water, wetlands, and barren
Change = Adjusted MRLC – Adjusted LULC
Note: Reported MRLC numbers were determined from the unadjusted MRLC coverage.

Table 4-6. Pearson Coefficients of Correlation Among Land-Use Variables.

Land Use	**URBAN$_t$**	**CHGURB$_t$**	**FOREST$_t$**	**PASTURE$_t$**	**CROPLAND$_t$**	**TOTALAG$_t$**
URBAN$_t$		**0.14**	**-0.74**	0.04	0.00	0.04
p-value		**0.07 ***	**0.000 ****	0.63	0.98	0.63
n		**168**	**168**	168	168	168
CHGURB$_t$	**0.14**		-0.10	-0.11	0.05	-0.09
p-value	**0.07 ***		0.20	0.17	0.52	0.24
n	**168**		168	168	168	168
FOREST$_t$	**-0.74**	-0.10		**-0.39**	**-0.14**	**-0.40**
p-value	**0.000 ****	0.20		**0.000 ****	**0.07 ***	**0.000** **
n	**168**	168		**168**	**168**	**168**
PASTURE$_t$	0.04	-0.11	**-0.39**		**0.19**	**0.98**
p-value	0.63	0.17	**0.000 ****		**0.01 ***	**0.000** **
n	168	168	**168**		**168**	**168**
CROPLAND$_t$	0.00	0.05	**-0.14**	**0.19**		**0.39**
p-value	0.98	0.52	**0.07 ***	**0.01 ***		**0.000** **
n	168	168	**168**	**168**		**168**
TOTALAG$_t$	0.04	-0.09	**-0.40**	**0.98**	**0.39**	
p-value	0.63	0.24	**0.000 ****	**0.000 ****	**0.000 ****	
n	168	168	**168**	**168**	**168**	

Note: For each pair of variables, numbers listed are the correlation coefficients; the coefficients p-value; and the number of observation pairs used to calculate the coefficient.

* = Significant at $0.01 < p < 0.10$

** = Significant at $p < 0.01$

Note: Land-use variables have been transformed using methods described in Table 4-3.

Table 4-7. Pearson Coefficients of Correlation Among Land-Use Variables and Water-Quality Trends (Kendall's Tau) for Virginia Monitoring Stations.

Land Use	**BOD**	**DO**	**FC**	**NFR**	**NN**	**PH**	**TKN**	**TP**	**TR**
URBAN$_t$	**0.16**	0.01	**0.21**	-0.06	0.13	**-0.15**	0.11	0.01	**0.31**
p-value	**0.04** *	0.88	**0.01** *	0.45	0.11	**0.06** *	0.17	0.95	**0.005** **
n	**149**	168	**155**	156	158	**168**	164	127	**83**
CHGURB$_t$	**-0.14**	0.03	-0.09	0.05	-0.09	0.05	0.05	-0.13	**0.25**
p-value	**0.10** *	0.68	0.25	0.56	0.25	0.56	0.55	0.14	**0.02** *
n	**149**	168	155	156	158	168	164	127	**83**
FOREST$_t$	**-0.26**	0.03	**-0.23**	0.05	0.03	**0.20**	**-0.21**	-0.08	**-0.35**
p-value	**0.002** **	0.71	**0.004** **	0.57	0.70	**0.01** *	**0.007** **	0.38	**0.001** **
n	**149**	168	**155**	156	158	**168**	**164**	127	**83**
PASTURE$_t$	**0.19**	-0.08	0.09	**0.24**	0.13	**-0.15**	**0.26**	**0.27**	-0.02
p-value	**0.02** *	0.30	0.28	**0.002** **	0.11	**0.05** *	**0.001** **	**0.002** **	0.88
n	**149**	168	155	**156**	158	**168**	**164**	**127**	83
CROPLAND$_t$	0.10	0.03	**0.24**	-0.03	0.01	-0.04	0.03	0.11	-0.16
p-value	0.24	0.71	**0.002** **	0.70	0.88	0.59	0.72	0.20	0.14
n	149	168	**155**	156	158	168	164	127	83
TOTALAG$_t$	**0.20**	-0.07	**0.13**	**0.22**	0.12	**-0.15**	**0.25**	**0.28**	-0.05
p-value	**0.01** *	0.36	**0.09** *	**0.006** **	0.15	**0.05** *	**0.002** **	**0.002** **	0.65
n	**149**	168	**155**	**156**	158	**168**	**164**	**127**	83

Note: For each pair of variables, numbers listed are the correlation coefficients; the coefficients p-value; and the number of observation pairs used to calculate the coefficient.

* = Significant at $0.01 < p < 0.10$

** = Significant at $p < 0.01$

Note: Land-use variables have been transformed using methods described in Table 4-3.

Table 4-8. Spearman Coefficients of Correlation Among Land-Use Variables and Water-Quality Trends (Kendall's Tau) for Virginia Monitoring Stations.

Land Use	**BOD**	**DO**	**FC**	**NFR**	**NN**	**PH**	**TKN**	**TP**	**TR**
URBAN$_t$	0.05	-0.02	**0.20**	-0.07	0.13	**-0.15**	0.08	0.03	**0.26**
p-value	0.51	0.82	**0.01** *	0.36	0.11	**0.05** *	0.31	0.72	**0.02** *
n	149	168	**155**	156	158	**168**	164	127	**83**
CHGURB$_t$	**-0.17**	0.08	**-0.18**	0.04	**-0.15**	0.01	0.01	**-0.18**	**0.19**
p-value	**0.04** *	0.31	**0.03** *	0.58	**0.06** *	0.90	0.95	**0.04** *	**0.09** *
n	**149**	168	**155**	156	**158**	168	164	**127**	**83**
FOREST$_t$	**-0.21**	0.03	**-0.20**	-0.01	-0.08	**0.19**	**-0.25**	-0.11	**-0.26**
p-value	**0.009** **	0.71	**0.01** *	0.87	0.33	**0.01** *	**0.001** **	0.22	**0.02** *
n	**149**	168	**155**	156	158	**168**	**164**	127	**83**
PASTURE$_t$	**0.16**	-0.07	0.02	**0.27**	**0.13**	**-0.17**	**0.24**	**0.26**	-0.04
p-value	**0.05** *	0.37	0.83	**0.001** **	**0.09** *	**0.03** *	**0.002** **	**0.003** **	0.69
n	**149**	168	155	**156**	**158**	**168**	**164**	**127**	83
CROPLAND$_t$	**0.18**	0.04	0.12	0.13	0.12	-0.10	**0.16**	0.11	**-0.19**
p-value	**0.03** *	0.63	0.13	0.11	0.15	0.20	**0.04** *	0.21	**0.09** *
n	**149**	168	155	156	158	168	**164**	127	**83**
TOTALAG$_t$	**0.15**	-0.07	0.04	**0.23**	0.13	**-0.17**	**0.21**	**0.26**	-0.07
p-value	**0.07** *	0.34	0.59	**0.003** **	0.11	**0.02** *	**0.007** **	**0.003** **	0.55
n	**149**	168	155	**156**	158	**168**	**164**	**127**	83

Note: For each pair of variables, numbers listed are the correlation coefficients; the coefficients p-value; and the number of observation pairs used to calculate the coefficient.

* = Significant at $0.01 < p < 0.10$

** = Significant at $p < 0.01$

Note: Land-use variables have been transformed using methods described in Table 4-3.

Table 4-9. Pearson Coefficients of Correlation Among Land-Use Variables and Water-Quality Trends (Kendall's Tau) for Minimum Overlap Analysis.

Land Use	BOD	DO	FC	NFR	NN	PH	TKN	TP	TR
URBAN$_t$	**0.25**	0.11	**0.23**	-0.06	**0.19**	-0.16	0.14	-0.01	**0.36**
p-value	**0.02** *	0.28	**0.03** *	0.60	**0.08** *	0.13	0.19	0.97	**0.01** *
n	**85**	91	**87**	88	**87**	91	88	65	**49**
CHGURB$_t$	-0.08	0.06	-0.04	0.10	-0.06	0.05	0.16	-0.17	**0.27**
p-value	0.48	0.55	0.69	0.38	0.55	0.63	0.13	0.18	**0.06** *
n	85	91	87	88	87	91	88	65	**49**
FOREST$_t$	**-0.33**	-0.04	**-0.26**	0.00	0.03	**0.21**	**-0.21**	-0.10	**-0.46**
p-value	**0.002** **	0.71	**0.01** *	0.98	0.76	**0.05** *	**0.05** *	0.42	**0.001** **
n	**85**	91	**87**	88	87	**91**	**88**	65	**49**
PASTURE$_t$	**0.19**	-0.08	0.11	**0.32**	0.10	**-0.19**	**0.28**	**0.39**	0.05
p-value	**0.09** *	0.47	0.32	**0.002** **	0.37	**0.06** *	**0.010** **	**0.001** **	0.72
n	**85**	91	87	**88**	87	**91**	**88**	**65**	49
CROPLAND$_t$	**0.18**	0.12	**0.29**	0.14	0.07	-0.06	-0.04	0.08	-0.20
p-value	**0.09** *	0.24	**0.007** **	0.20	0.51	0.59	0.73	0.54	0.17
n	**85**	91	**87**	88	87	91	88	65	49
TOTALAG$_t$	**0.22**	-0.05	0.16	**0.33**	0.11	**-0.19**	**0.24**	**0.40**	0.01
p-value	**0.05** *	0.63	0.13	**0.002** **	0.33	**0.07** *	**0.02** *	**0.001** **	0.93
n	**85**	91	87	**88**	87	**91**	**88**	**65**	49

Note: For each pair of variables, numbers listed are the correlation coefficients; the coefficients p-value; and the number of observation pairs used to calculate the coefficient.

* = Significant at $0.01 < p < 0.10$

** = Significant at $p < 0.01$

Note: Land-use variables have been transformed using methods described in Table 4-3.

Table 4-10. Pearson Coefficients of Correlation Among Land-Use Variables and Water-Quality Medians for Virginia Monitoring Stations.

Land Use	**DO**	**FC-med$_t$**	**NFR-med$_t$**	**NN-med$_t$**	**PH**	**TKN-med$_t$**	**TR-med$_t$**
URBAN$_t$	**-0.34**	0.01	**0.36**	**0.23**	**-0.21**	**0.59**	**0.48**
p-value	**0.000 ****	0.95	**0.000 ****	**0.003 ****	**0.008 ****	**0.000 ****	**0.000 ****
n	**168**	155	**156**	**159**	**168**	**164**	**83**
CHGURB$_t$	**-0.16**	0.12	0.12	**-0.18**	**-0.13**	0.08	0.15
p-value	**0.04 ***	0.12	0.12	**0.02 ***	**0.10 ***	0.34	0.17
n	**168**	155	156	**159**	**168**	164	83
FOREST$_t$	**0.53**	**0.16**	**-0.43**	-0.07	**0.30**	**-0.64**	**-0.61**
p-value	**0.000 ****	**0.05 ***	**0.000 ****	0.35	**0.000 ****	**0.000 ****	**0.000 ****
n	**168**	**155**	**156**	159	**168**	**164**	**83**
PASTURE$_t$	-0.07	-0.11	0.09	0.13	-0.04	0.06	-0.03
p-value	0.38	0.17	0.29	0.11	0.58	0.45	0.78
n	168	155	156	159	168	164	83
CROPLAND$_t$	**-0.30**	-0.06	-0.02	-0.02	**-0.27**	0.11	-0.09
p-value	**0.000 ****	0.47	0.82	0.76	**0.000 ****	0.16	0.42
n	**168**	155	156	159	**168**	164	83
TOTALAG$_t$	-0.13	-0.11	0.08	0.12	-0.10	0.08	-0.04
p-value	0.10	0.16	0.32	0.12	0.19	0.29	0.71
n	168	155	156	159	168	164	83

Note: For each pair of variables, numbers listed are the correlation coefficients; the coefficients p-value; and the number of observation pairs used to calculate the coefficient.

* = Significant at $0.01 < p < 0.10$

** = Significant at $p < 0.01$

Note: Land-use variables and water-quality medians have been transformed using methods described in Tables 4-3 and 4-4.

Table 4-11. Spearman Coefficients of Correlation Among Land-Use Variables and Water-Quality Medians for Virginia Monitoring Stations.

Land Use	**BOD**	**DO**	**FC**	**NFR**	**NN**	**pH**	**TKN**	**TP**	**TR**
URBAN$_t$	**0.38**	**-0.26**	0.00	**0.34**	0.13	**-0.18**	**0.55**	0.11	**0.41**
p-value	**0.000 ****	**0.001 ****	0.96	**0.000 ****	0.10	**0.02 ***	**0.000 ****	0.21	**0.000 ****
n	**149**	**168**	155	**156**	158	**168**	**164**	127	**83**
CHGURB$_t$	0.12	**-0.26**	**0.16**	**0.18**	**-0.20**	-0.12	0.06	-0.11	0.17
p-value	0.13	**0.001 ****	**0.05 ***	**0.02 ***	**0.01 ***	0.12	0.42	0.22	0.11
n	149	**168**	**155**	**156**	**158**	168	164	127	83
FOREST$_t$	**-0.31**	**0.47**	0.08	**-0.35**	-0.01	**0.33**	**-0.55**	0.02	**-0.38**
p-value	**0.000 ****	**0.000 ****	0.33	**0.000 ****	0.92	**0.000 ****	**0.000 ****	0.84	**0.000 ****
n	**149**	**168**	155	**156**	158	**168**	**164**	127	**83**
PASTURE$_t$	0.03	**-0.13**	-0.08	0.06	**0.15**	-0.04	0.03	0.01	-0.05
p-value	0.73	**0.08 ***	0.34	0.45	**0.06 ***	0.63	0.69	0.93	0.68
n	149	**168**	155	156	**158**	168	164	127	83
CROPLAND$_t$	-0.07	**-0.27**	-0.12	-0.04	**-0.14**	**-0.27**	0.11	**-0.19**	**-0.26**
p-value	0.38	**0.001 ****	0.15	0.61	**0.09 ***	**0.000 ****	0.18	**0.03 ***	**0.02 ***
n	149	**168**	155	156	**158**	**168**	164	**127**	**83**
TOTALAG$_t$	0.01	**-0.18**	-0.07	0.06	0.13	-0.10	0.06	-0.06	-0.05
p-value	0.88	**0.02 ***	0.41	0.49	0.11	0.20	0.46	0.51	0.65
n	149	**168**	155	156	158	168	164	127	83

Note: For each pair of variables, numbers listed are the correlation coefficients; the coefficients p-value; and the number of observation pairs used to calculate the coefficient.

* = Significant at $0.01 < p < 0.10$

** = Significant at $p < 0.01$

Note: Land-use variables and water-quality medians have been transformed using methods described in Tables 4-3 and 4-4.

Table 4-12. Correlation Coefficients Among Land-Use Variables and BOD-tau.

Variable	Pearson's R	Spearman's Rho	Minimum Overlap
URBAN$_t$, BOD	**0.16** *	0.05	**0.25** *
CHGURB$_t$, BOD	**-0.14** *	**-0.17** *	-0.08
FOREST, BOD	**-0.26** **	**-0.21** **	**-0.33** **
PASTURE$_t$, BOD	**0.19** *	**0.16** *	**0.19** *
CROPLAND$_t$, BOD	0.10	**0.18** *	**0.18** *
TOTALAG$_t$, BOD	**0.20** *	**0.15** *	**0.22** *

Table 4-13. Correlation Coefficients Among Land-Use Variables and DO-tau.

Variable	Pearson's R	Spearman's Rho	Minimum Overlap
URBAN$_t$, DO	0.01	-0.02	0.11
CHGURB$_t$, DO	0.03	0.08	0.06
FOREST, DO	0.03	0.03	-0.04
PASTURE$_t$, DO	-0.08	-0.07	-0.08
CROPLAND$_t$, DO	0.03	0.04	0.12
TOTALAG$_t$, DO	-0.07	-0.07	-0.05

Table 4-14. Correlation Coefficients Among Land-Use Variables and FC-tau.

Variable	Pearson's R	Spearman's Rho	Minimum Overlap
URBAN$_t$, FC	**0.21** *	**0.20** *	**0.23** *
CHGURB$_t$, FC	-0.09	**-0.18** *	-0.04
FOREST, FC	**-0.23** **	**-0.20** *	**-0.26** *
PASTURE$_t$, FC	0.09	0.02	0.11
CROPLAND$_t$, FC	**0.24** **	0.12	**0.29** *
TOTALAG$_t$, FC	**0.13** *	0.04	0.16

Note: Land-use variables have been transformed using methods described in Table 4-3.

* = Significant at $0.01 < p < 0.10$

** = Significant at $p < 0.01$

Table 4-15. Correlation Coefficients Among Land-Use Variables and NFR-tau.

Variable	Pearson's R	Spearman's Rho	Minimum Overlap
$URBAN_t$, NFR	-0.06	-0.07	-0.06
$CHGURB_t$, NFR	0.05	0.04	0.10
FOREST, NFR	0.05	-0.01	0.00
$PASTURE_t$, NFR	**0.24** **	**0.27** **	**0.32** **
$CROPLAND_t$, NFR	-0.03	0.13	0.14
$TOTALAG_t$, NFR	**0.22** **	**0.23** **	**0.33** **

Table 4-16. Correlation Coefficients Among Land-Use Variables and NN-tau.

Variable	Pearson's R	Spearman's Rho	Minimum Overlap
$URBAN_t$, NN	0.13	0.13	**0.19** *
$CHGURB_t$, NN	-0.09	**-0.15** *	-0.06
FOREST, NN	0.03	-0.08	0.03
$PASTURE_t$, NN	0.13	**0.13** *	0.10
$CROPLAND_t$, NN	0.01	0.12	0.07
$TOTALAG_t$, NN	0.12	0.13	0.11

Table 4-17. Correlation Coefficients Among Land-Use Variables and pH-tau.

Variable	Pearson's R	Spearman's Rho	Minimum Overlap
$URBAN_t$, pH	**-0.15** *	**-0.15** *	-0.16
$CHGURB_t$, pH	0.05	0.01	0.05
FOREST, pH	**0.20** *	**0.19** *	**0.21** *
$PASTURE_t$, pH	**-0.15** *	**-0.17** *	**-0.19** *
$CROPLAND_t$, pH	-0.04	-0.10	-0.06
$TOTALAG_t$, pH	**-0.15** *	**-0.17** *	**-0.19** *

Note: Land-use variables have been transformed using methods described in Table 4-3.

* = Significant at $0.01 < p < 0.10$

** = Significant at $p < 0.01$

Table 4-18. Correlation Coefficients Among Land-Use Variables and TKN-tau.

Variable	Pearson's R	Spearman's Rho	Minimum Overlap
URBAN$_t$, TKN	0.11	0.08	0.14
CHGURB$_t$, TKN	0.05	0.01	0.16
FOREST, TKN	**-0.21** **	**-0.25** **	**-0.21** *
PASTURE$_t$, TKN	**0.26** **	**0.24** **	**0.28** **
CROPLAND$_t$, TKN	0.03	**0.16** *	-0.04
TOTALAG$_t$, TKN	**0.25** **	**0.21** **	**0.24** *

Table 4-19. Correlation Coefficients Among Land-Use Variables and TP-tau.

Variable	Pearson's R	Spearman's Rho	Minimum Overlap
URBAN$_t$, TP	0.01	0.03	-0.01
CHGURB$_t$, TP	-0.13	**-0.18** *	-0.17
FOREST, TP	-0.08	-0.11	-0.10
PASTURE$_t$, TP	**0.27** **	**0.26** **	**0.39** **
CROPLAND$_t$, TP	0.11	0.11	0.08
TOTALAG$_t$, TP	**0.28** **	**0.26** **	**0.40** **

Table 4-20. Correlation Coefficients Among Land-Use Variables and TR-tau.

Variable	Pearson's R	Spearman's Rho	Minimum Overlap
URBAN$_t$, TR	**0.31** **	**0.26** *	**0.36** *
CHGURB$_t$, TR	**0.25** *	**0.19** *	**0.27** *
FOREST, TR	**-0.35** **	**-0.26** *	**-0.46** **
PASTURE$_t$, TR	-0.02	-0.04	0.05
CROPLAND$_t$, TR	-0.16	**-0.19** *	-0.20
TOTALAG$_t$, TR	-0.05	-0.07	0.01

Note: Land-use variables have been transformed using methods described in Table 4-3.

* = Significant at $0.01 < p < 0.10$

** = Significant at $p < 0.01$

Figure 4-1. Change in Forest vs. Change in Agriculture in Virginia Counties
Late 1970s - Early 1990s

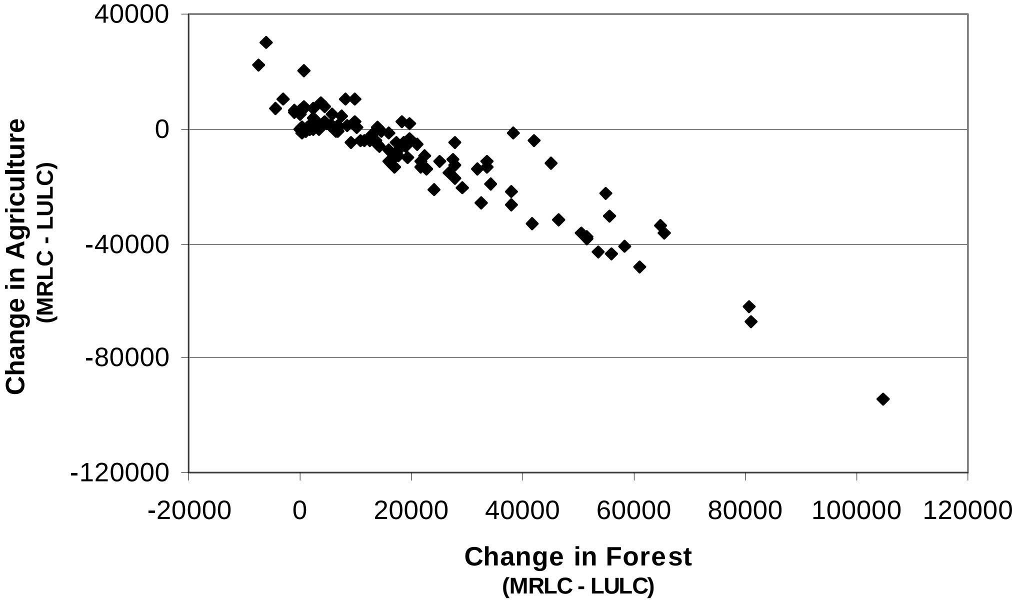


Figure 4-2. Virginia MRLC, Early 1990s - Urban Land

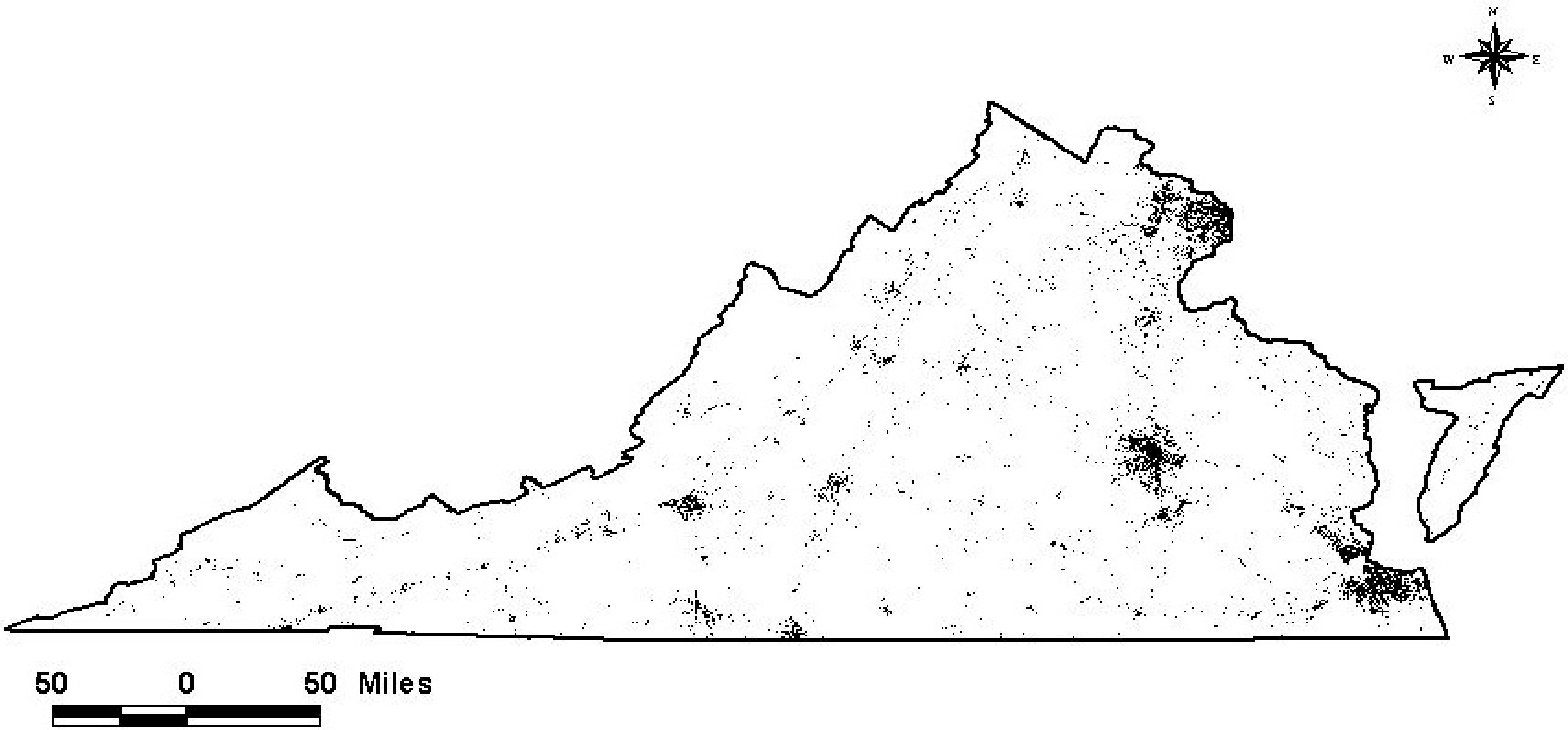


Figure 4-3. Virginia MRLC, Early 1990s - Forest Land

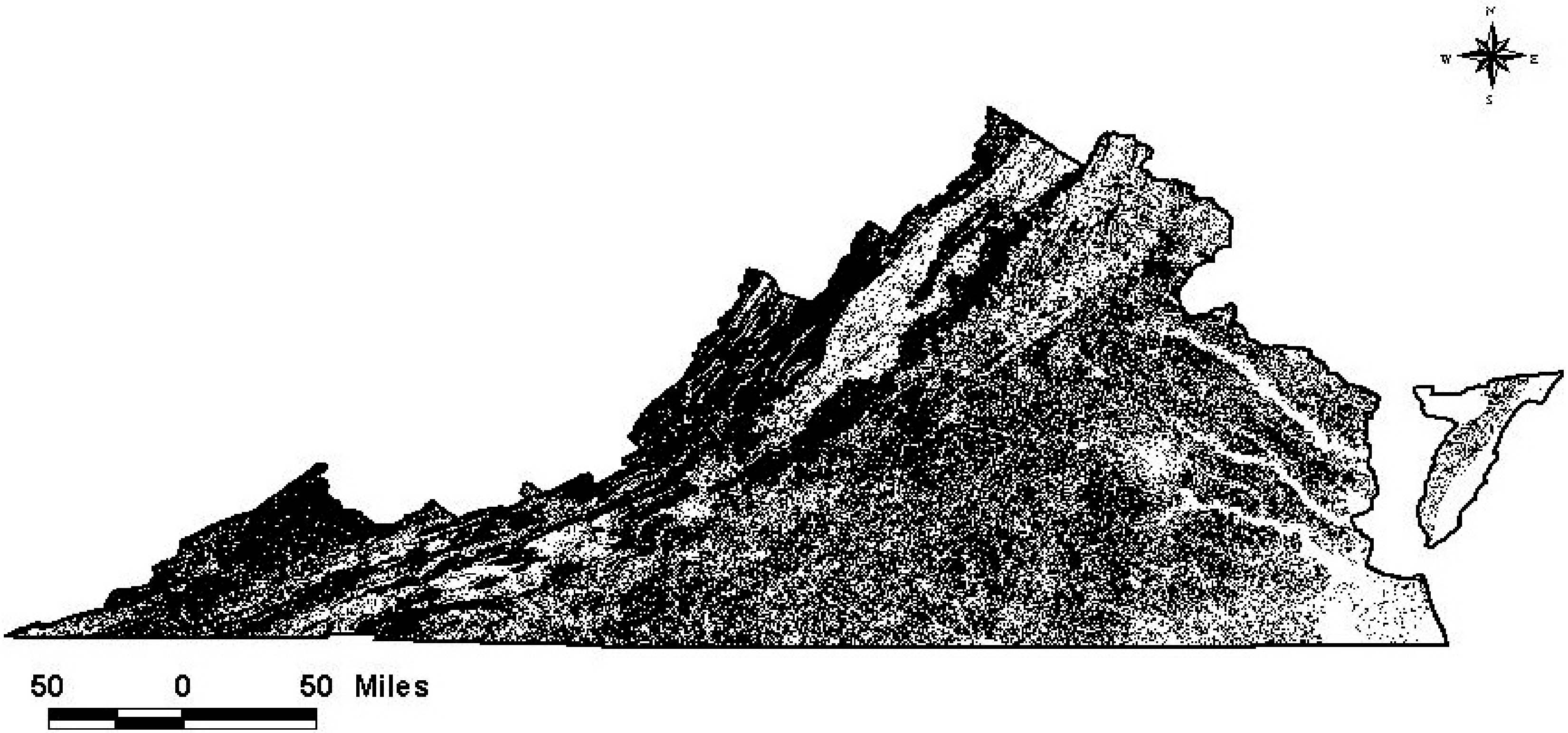


Figure 4-4. Virginia MRLC, Early 1990s - Agricultural Land

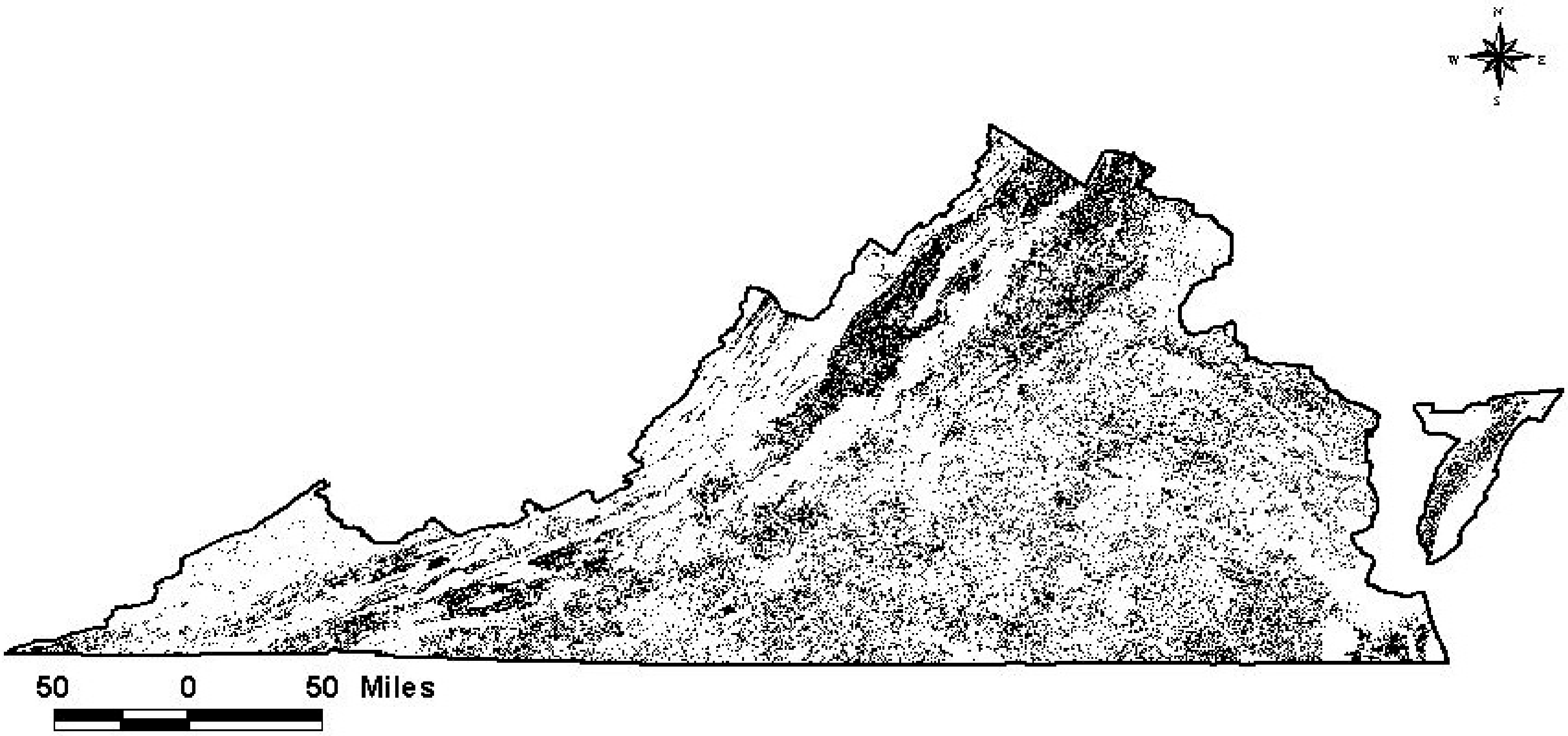


Figure 4-5. Distribution of Urban Land Use Variable (URBAN) Before and After Data Transformation.

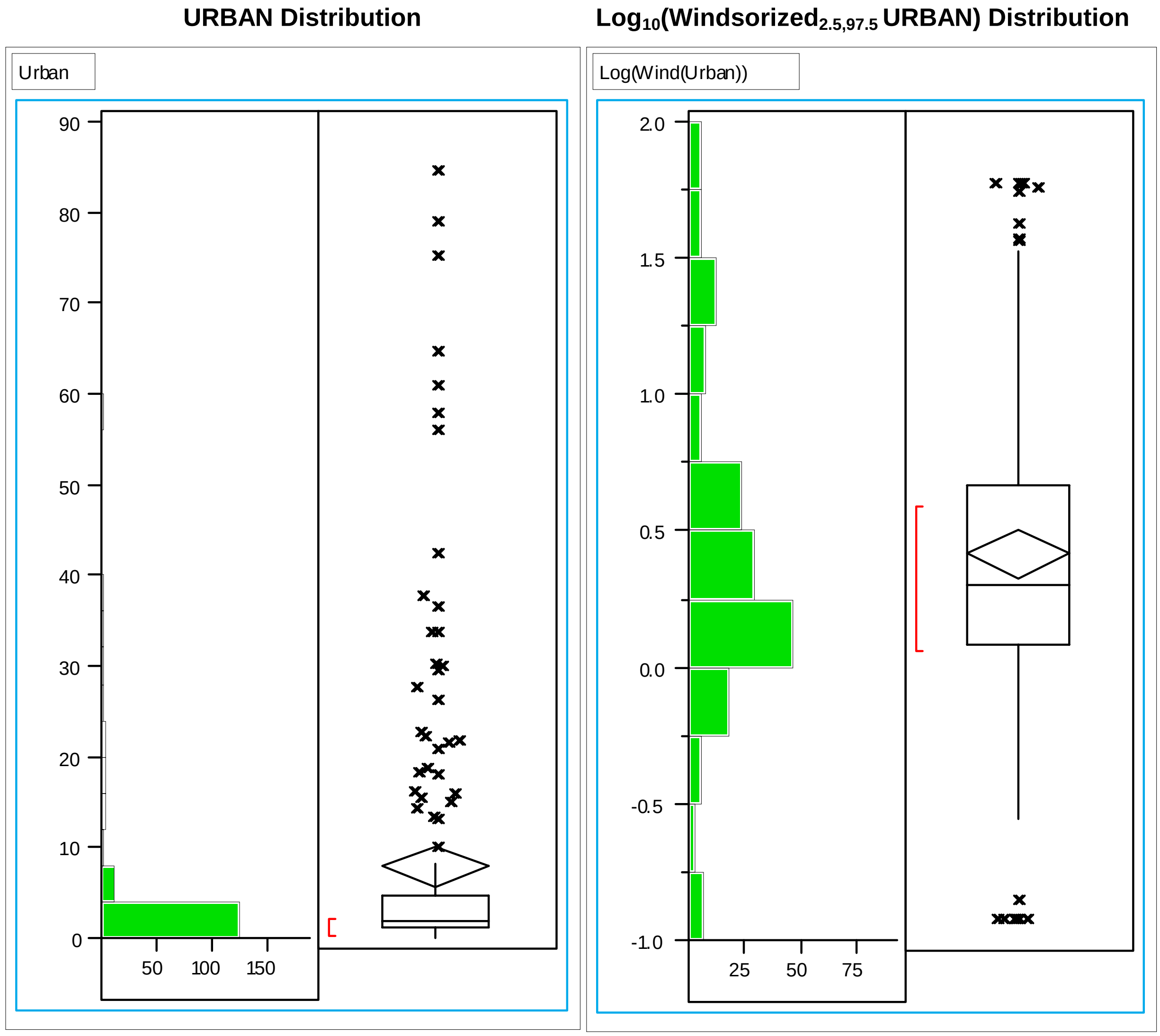
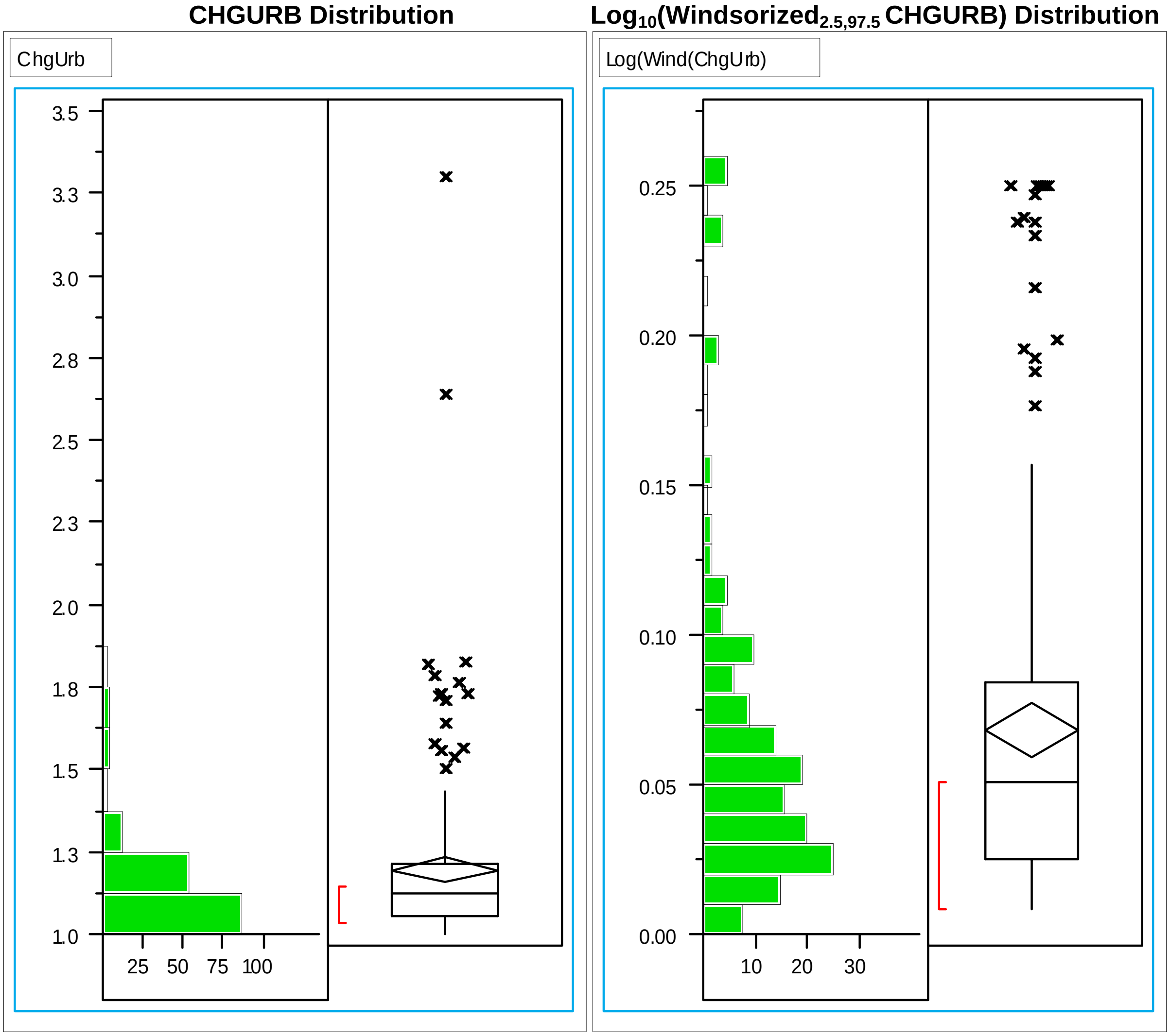


Figure 4-6. Distribution of Urban Change Land Use Variable (CHGURB) Before and After Data Transformation.



CHGURB Distribution

$\text{Log}_{10}(\text{Windsorized}_{2.5,97.5}$ CHGURB) Distribution

Figure 4-7. Distribution of Forest Land Use Variable (FOREST) – No Data Transformations Required.

FOREST Distribution

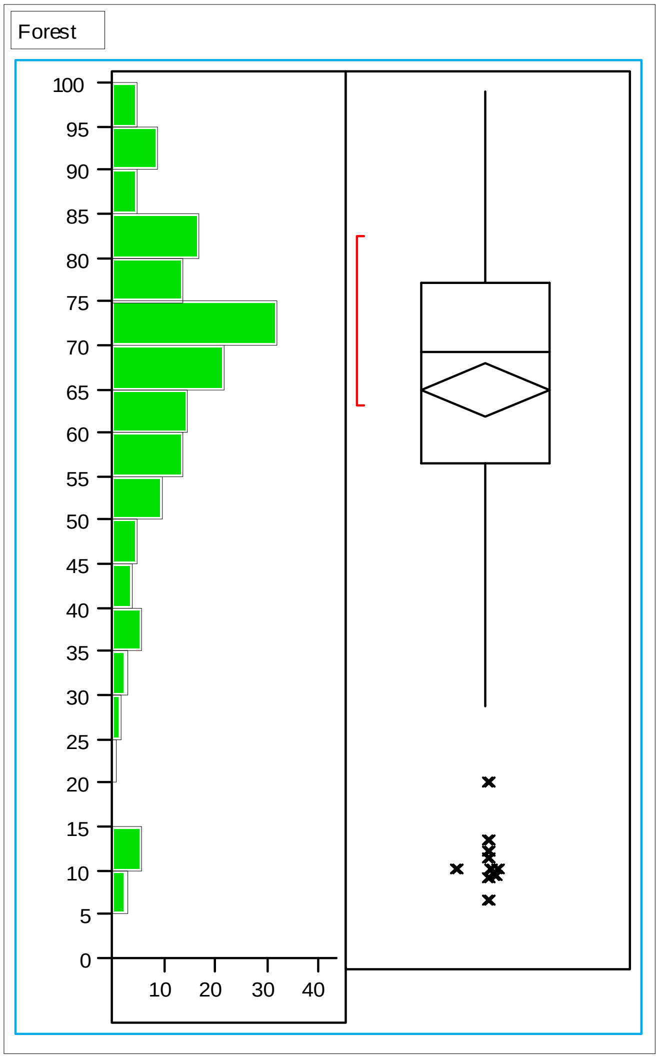
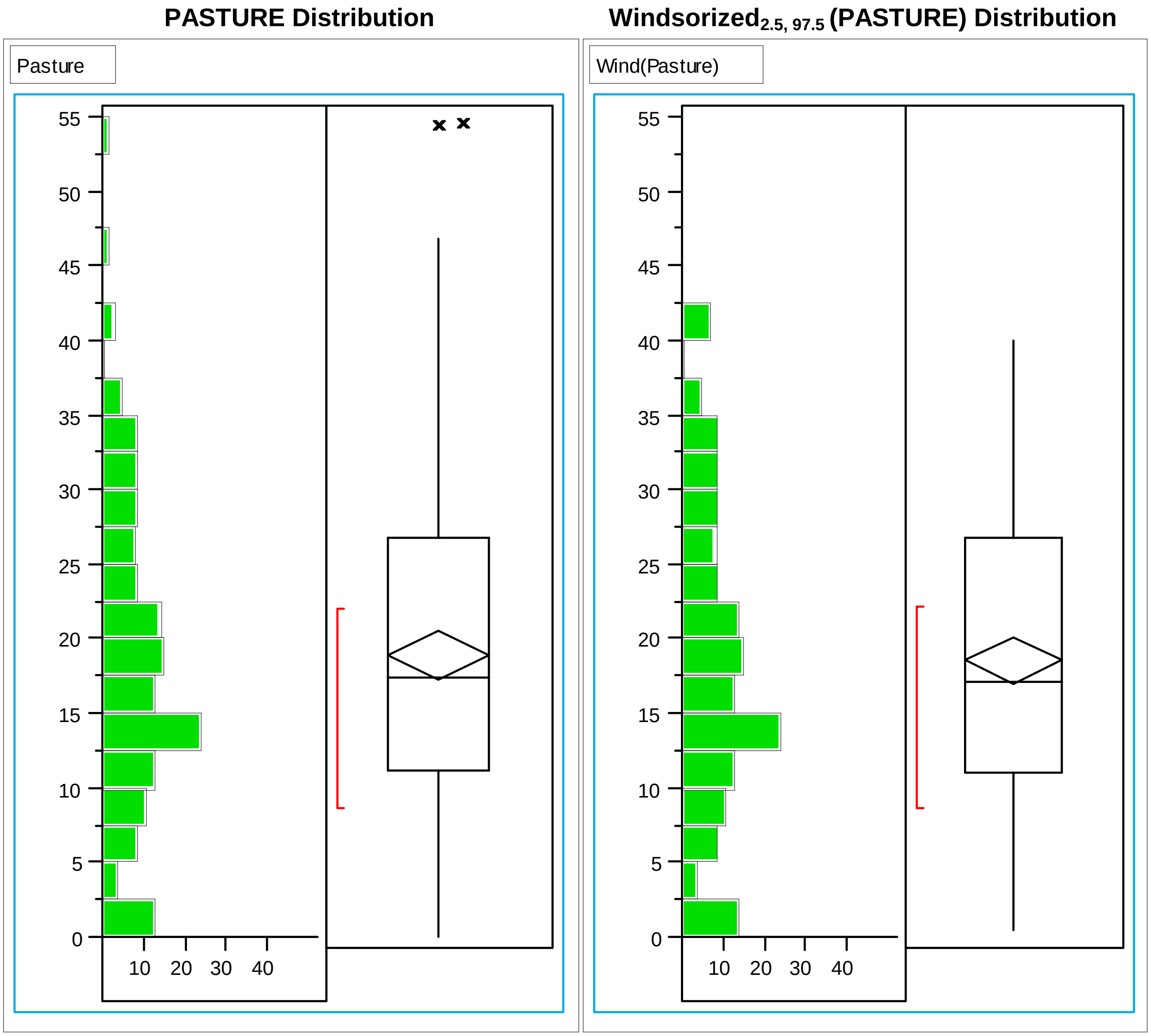


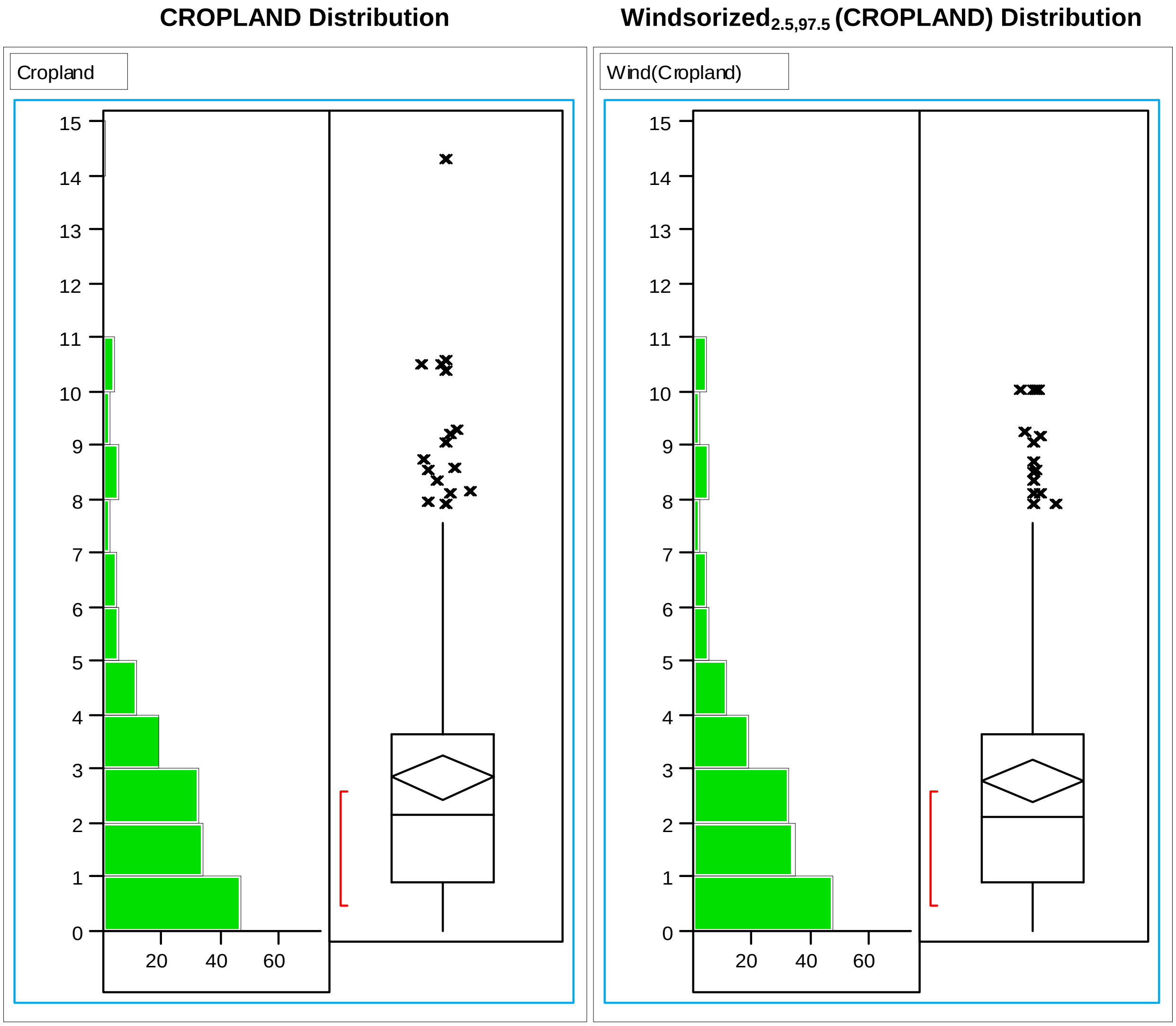
Figure 4-8. Distribution of Pasture Land Use Variable (PASTURE) Before and After Data Transformation.



PASTURE Distribution

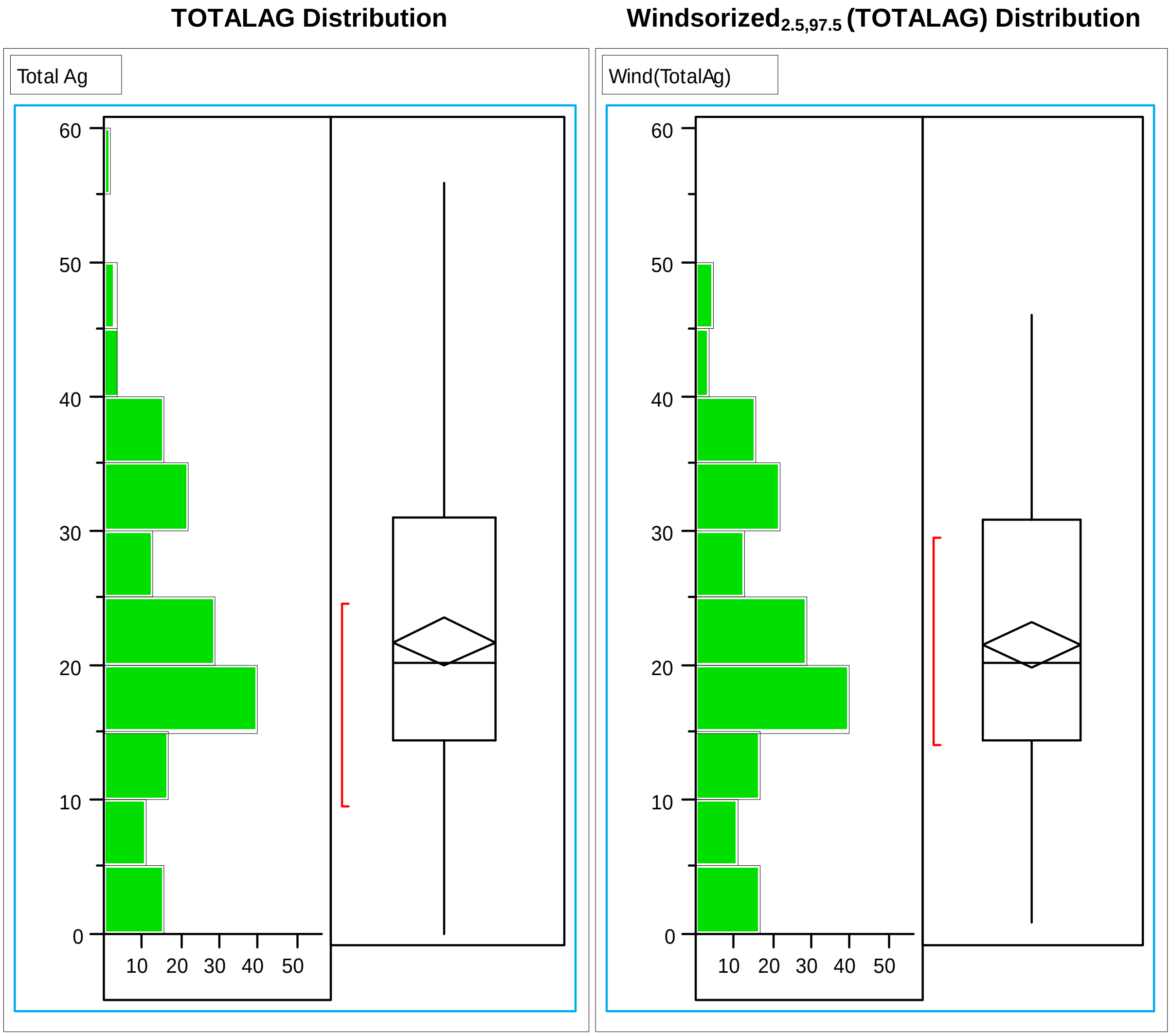
Windsorized$_{2.5,\ 97.5}$ (PASTURE) Distribution

Figure 4-9. Distribution of Cropland Land Use Variable (CROPLAND) Before and After Data Transformation.



CROPLAND Distribution **Windsorized$_{2.5,97.5}$ (CROPLAND) Distribution**

Figure 4-10. Distribution of Agricultural Land Use Variable (TOTALAG) Before and After Data Transformation.



TOTALAG Distribution

Windsorized$_{2.5,97.5}$ (TOTALAG) Distribution

Figure 4-11. BOD-tau vs. FOREST

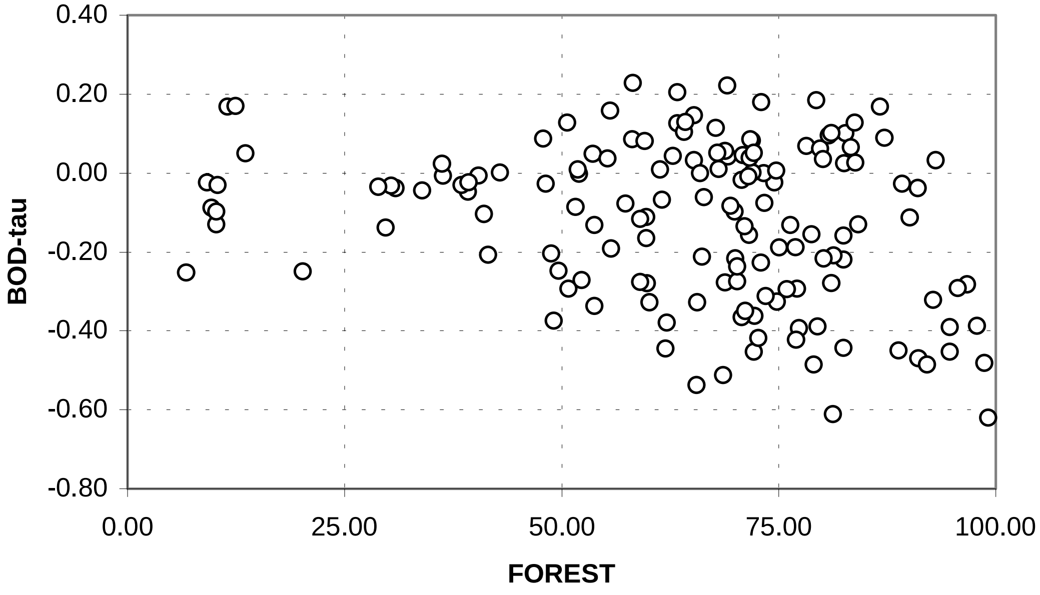


Figure 4-12. BOD-tau vs. TOTALAG

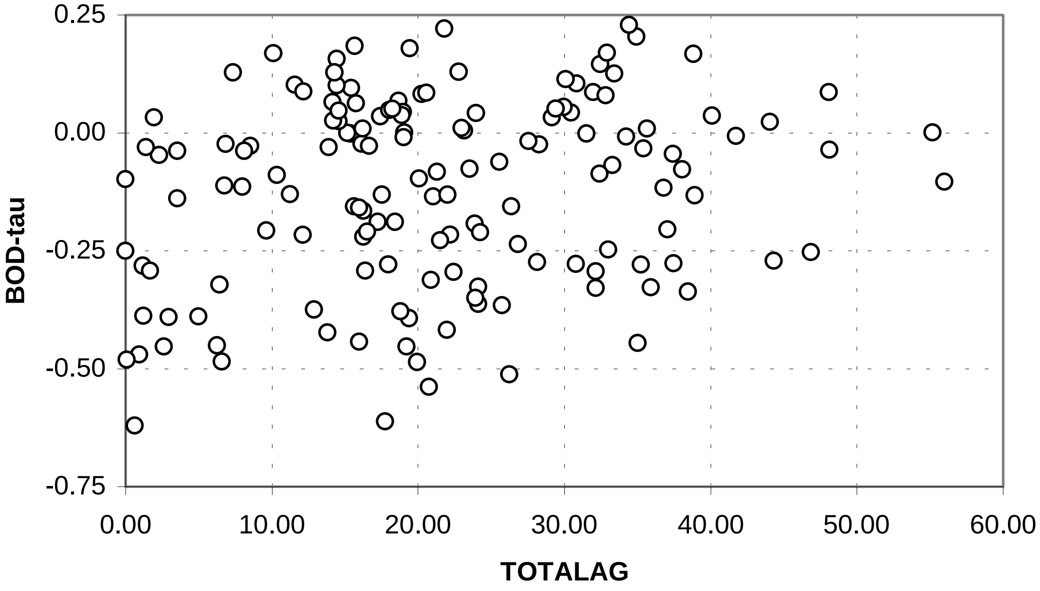


Figure 4-13. DO-tau vs. PASTURE

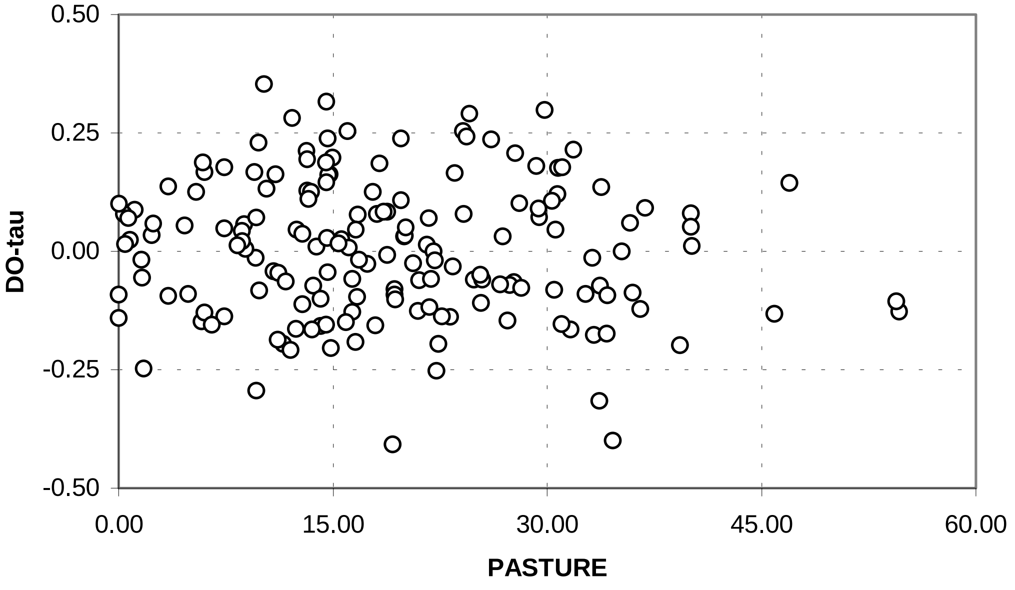


Figure 4-14. DO-medians vs. URBAN

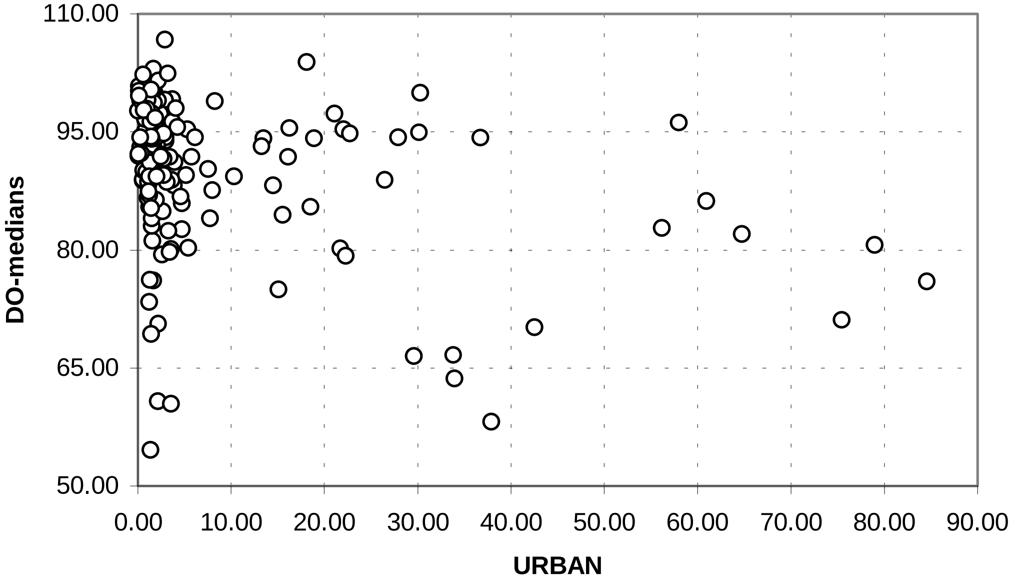


Figure 4-15. DO-medians vs. FOREST

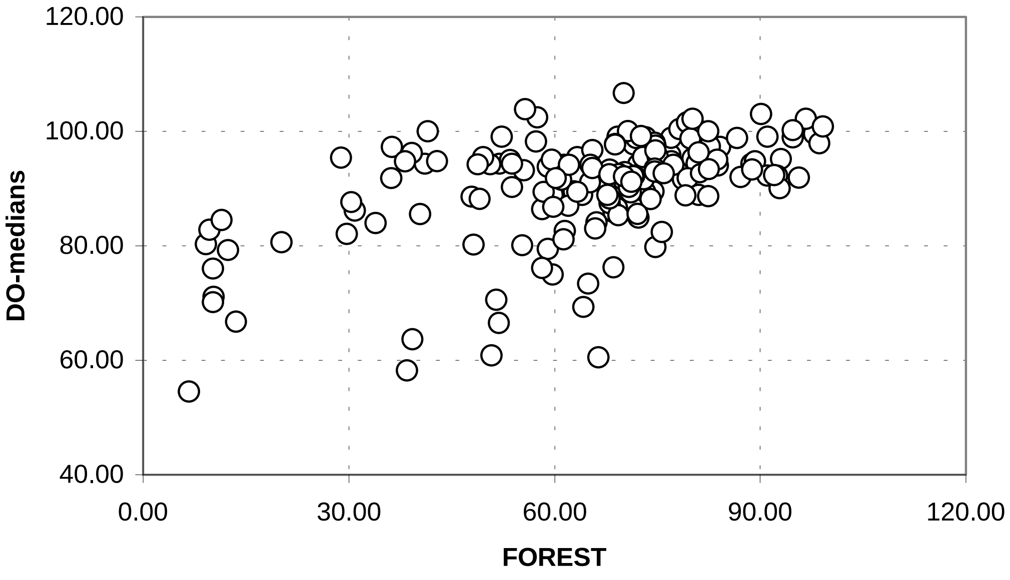


Figure 4-16. DO-medians vs. CROPLAND

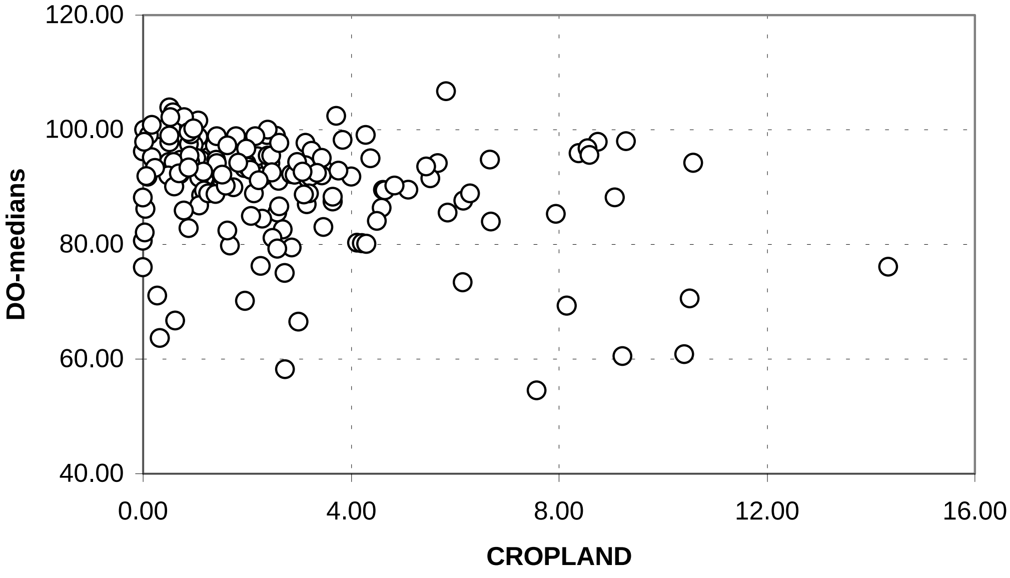


Figure 4-17. FC-tau vs. FOREST

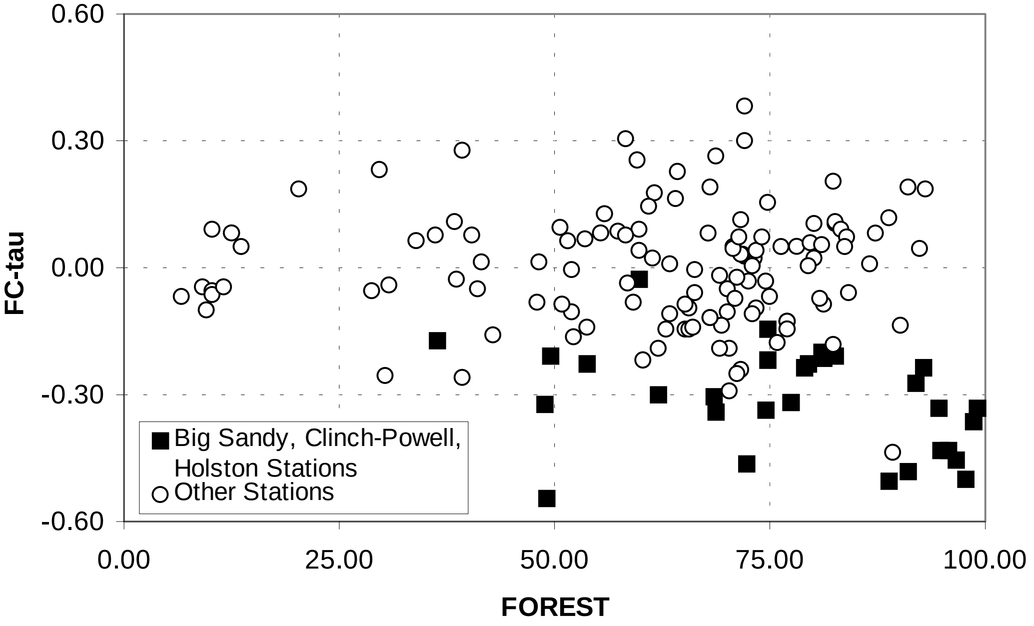


Figure 4-18. NFR-tau vs. PASTURE

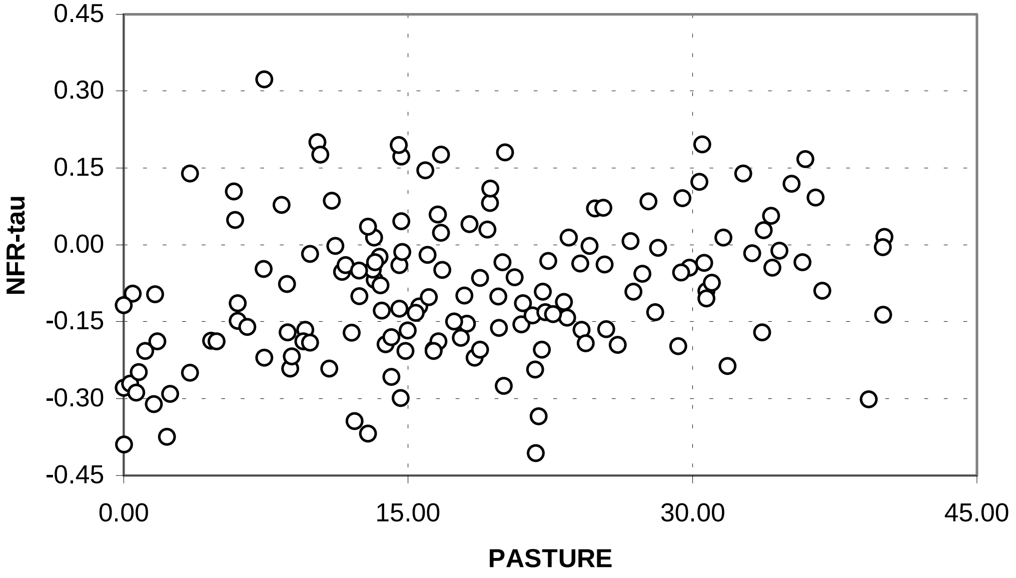


Figure 4-19. NFR-tau vs. TOTALAG

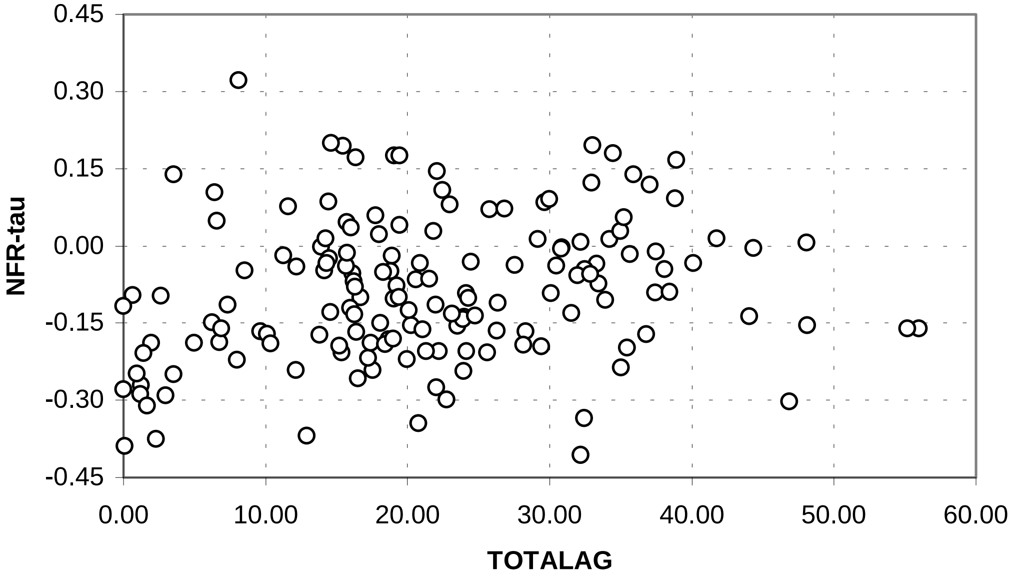


Figure 4-20. NFR-medians vs. FOREST

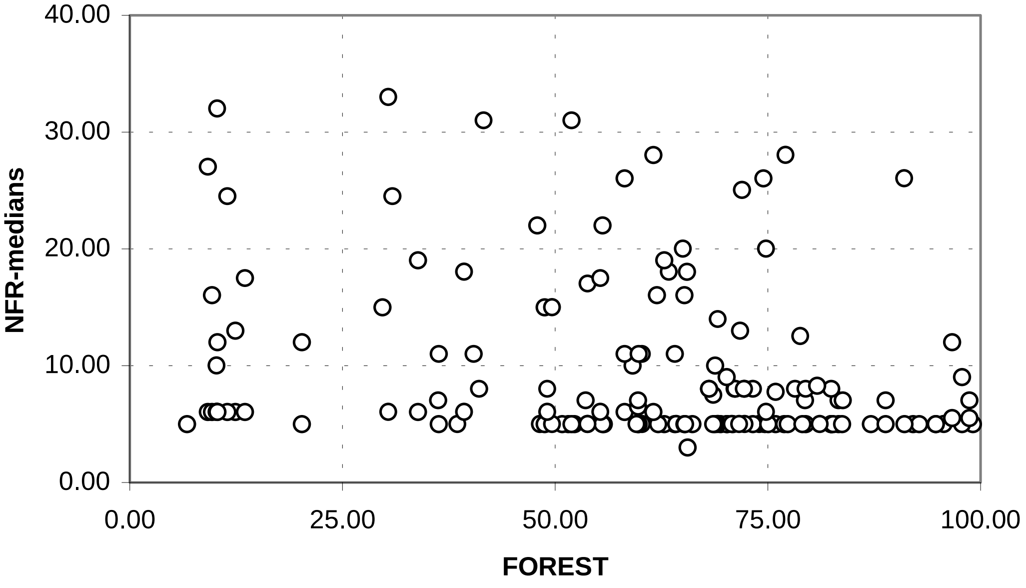


Figure 4-21. NFR-medians vs. URBAN

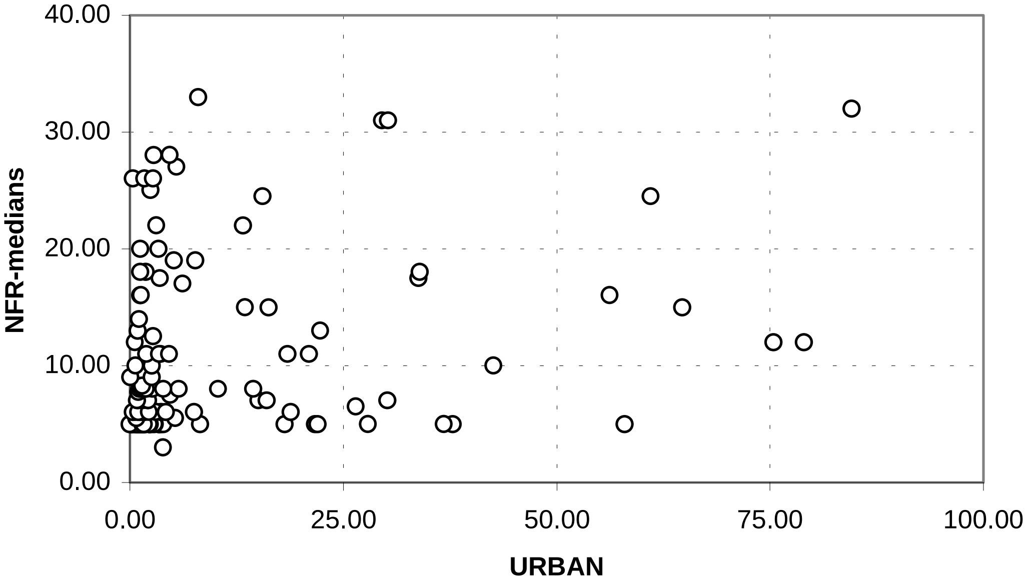


Figure 4-22. NN-tau vs. CROPLAND

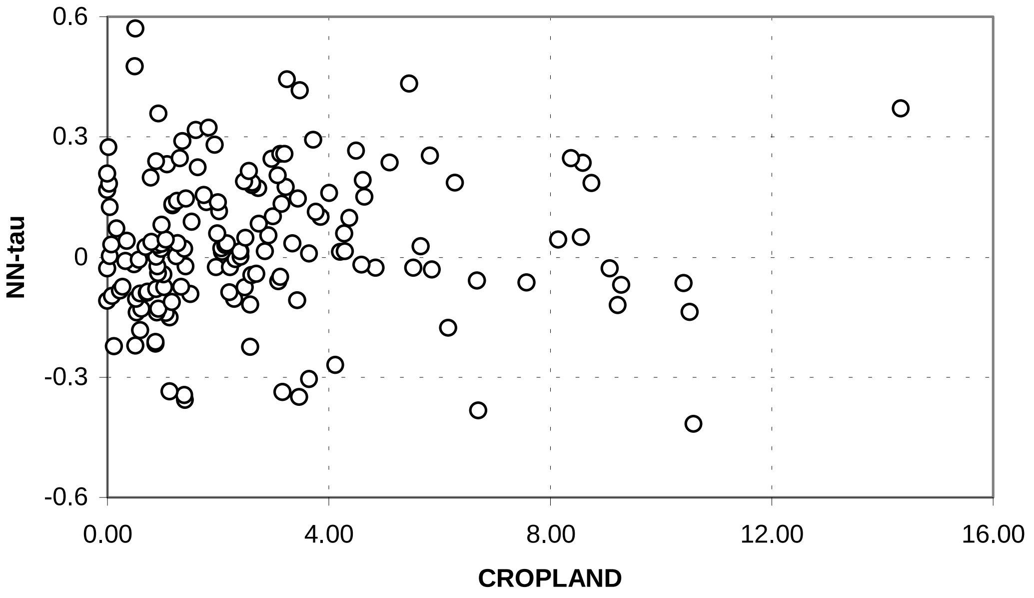


Figure 4-23. NN-tau vs. TOTALAG

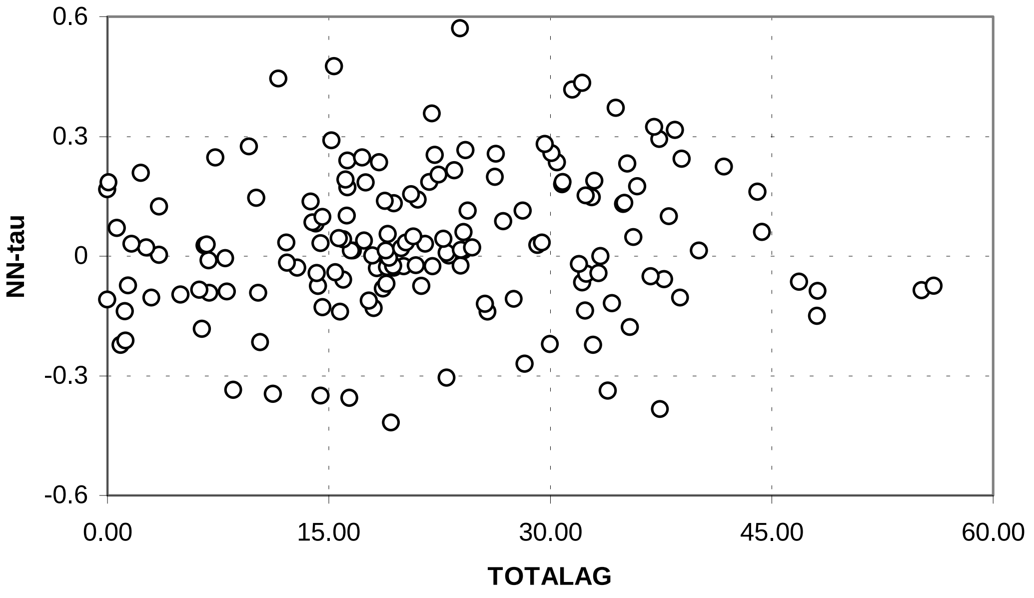


Figure 4-24. PH-tau vs. TOTALAG

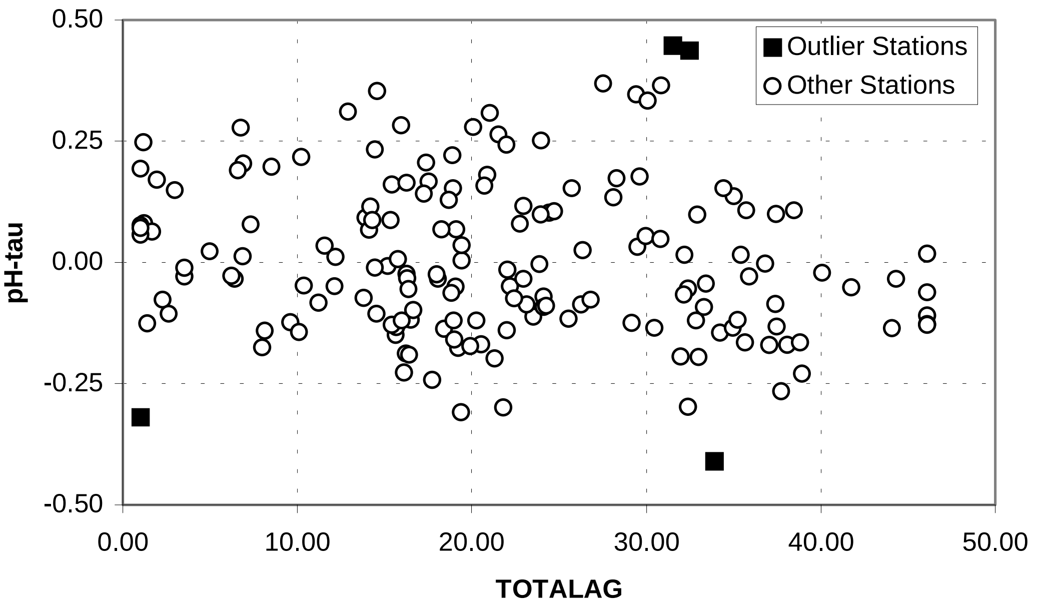


Figure 4-25. PH-medians vs. FOREST

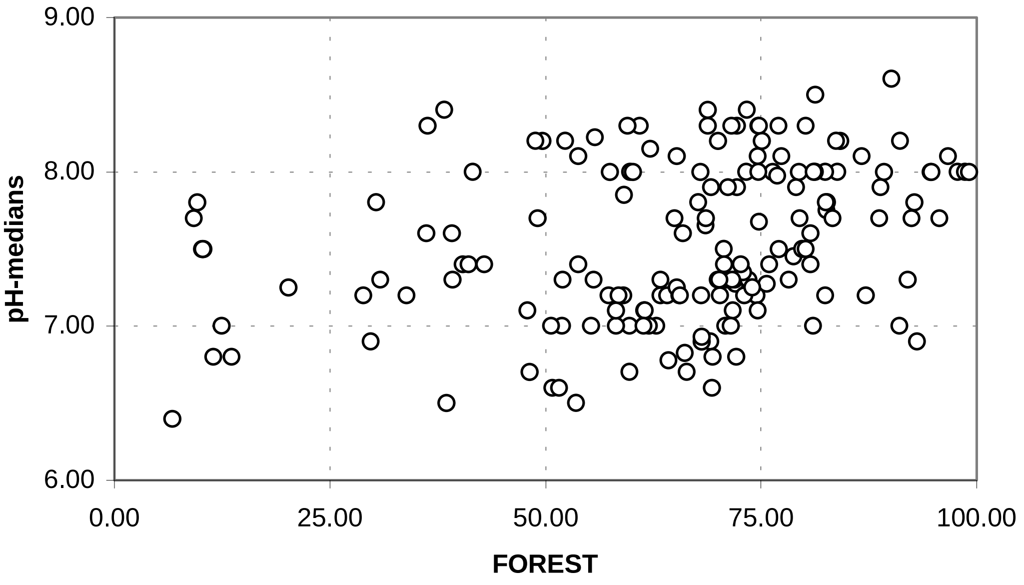


Figure 4-26. TKN-tau vs. FOREST

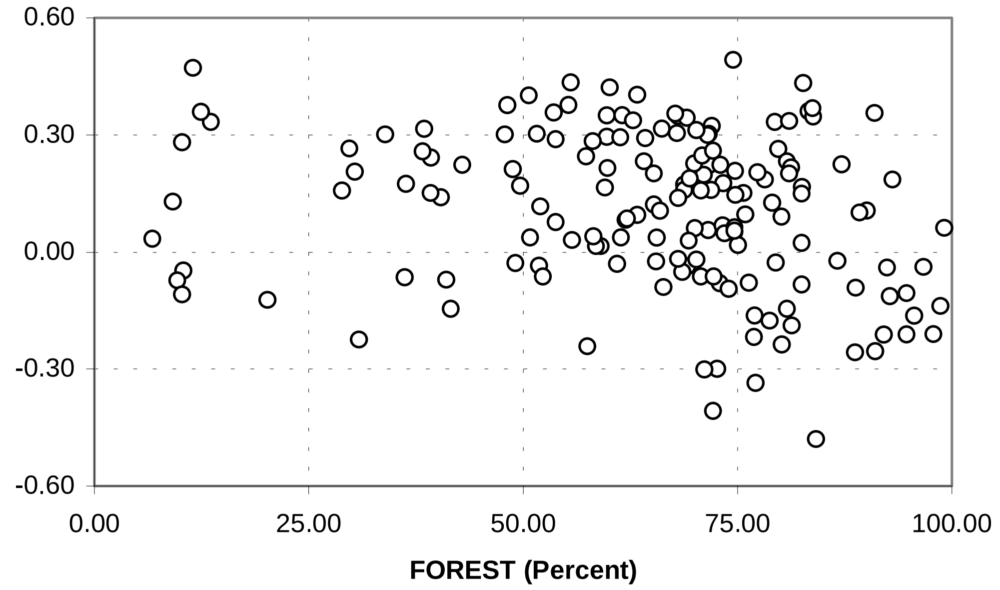


Figure 4-27. TKN-tau vs. TOTALAG

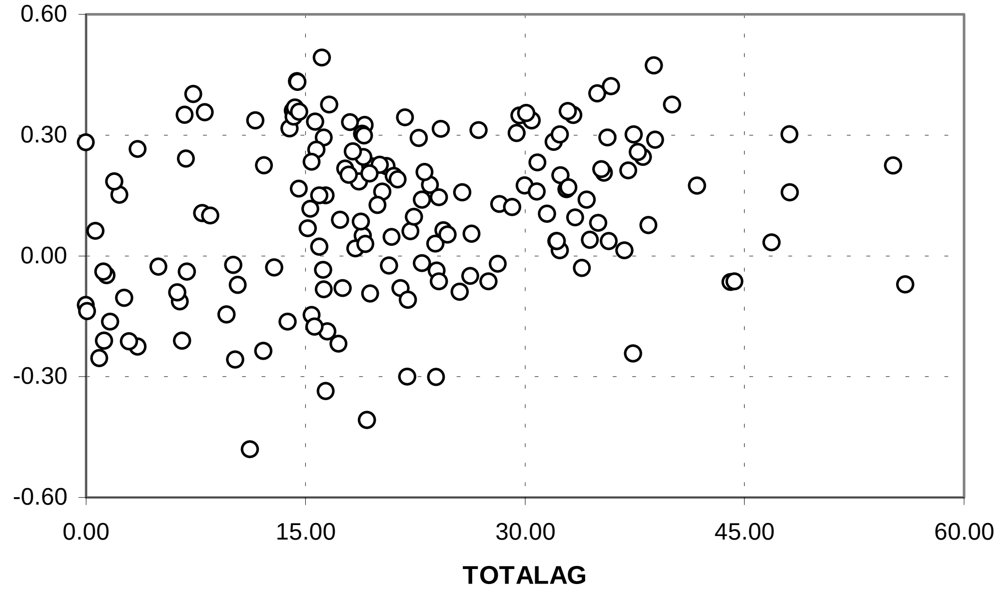


Figure 4-28. TP-tau vs. TOTALAG

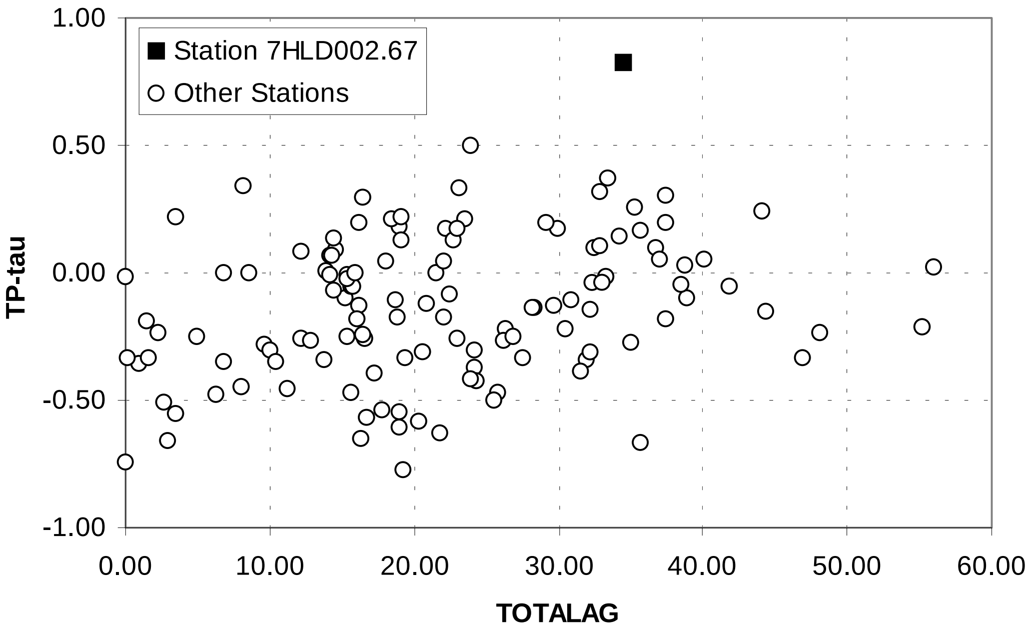


Figure 4-29. TR-tau vs. FOREST

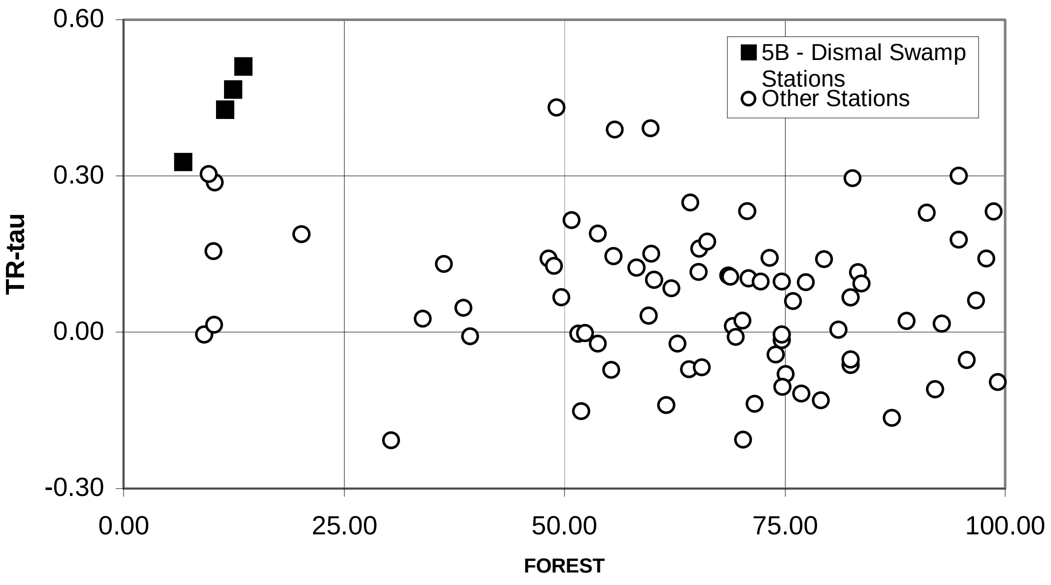
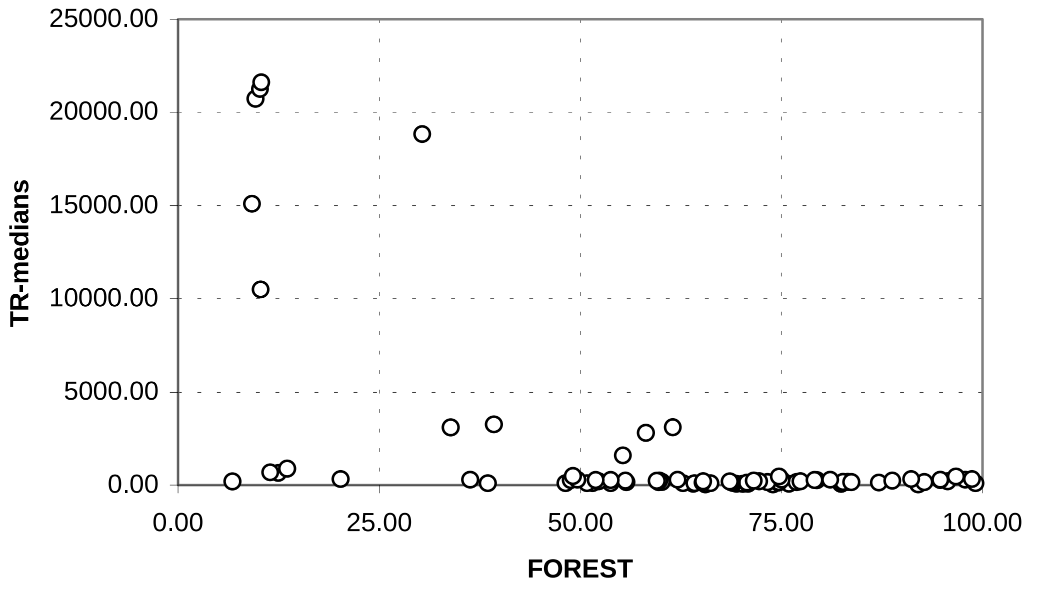


Figure 4-30. TR-medians vs. FOREST



CHAPTER 5 - CONCLUSIONS

The objective of this research is to determine statistical relationships between land use and water-quality trends in Virginia. Relationships were determined between water-quality trends and land use (early 1990s), and between water-quality trends and land-use change (1970s - 1990s). Water-quality trends for nine variables were determined at 168 Virginia water-quality monitoring stations by G.I. Holtzman and Patrick Darken using a seasonal Kendall analysis (Zipper et al., 2000). Water-quality variables included dissolved oxygen saturation (DO), biochemical oxygen demand (BOD), pH, total residue (TR), non-filterable residue (NFR), nitrate-nitrite nitrogen (NN), total Kjeldahl nitrogen (TKN), total phosphorus (TP), and fecal coliform (FC).

Several land-use data sources were evaluated to determine the optimal land-use data for Virginia. Three numerical land-use data sources were considered in the evaluation. Each dataset was acquired through different methods and had unique land-use definitions. The Virginia Forest Inventory (FIA) focused on forest land and did not attempt to classify other land uses. Census of Agriculture data focused on agricultural land only. Due to sampling methods, several million acres of urban and forest land are not sampled by the Census of Agriculture. The National Resources Inventory (NRI) is comprehensive in its land use coverage. Large PSU sizes and few sampling points limit the accuracy of this dataset at the county level. Characteristics common to each dataset include tabular data formats available at the county level, and high confidence intervals and low accuracy when working with small areas. These three numerical land-use data sources were used to verify the spatial data evaluated in this research.

A spatial dataset was desired to adequately represent land-use data in Virginia. The Virginia GAP, MRLC, and LULC coverages were evaluated. The MRLC was chosen to represent 1990s land-use data in Virginia. This coverage was preclassified and had Virginia statewide coverage. States surrounding Virginia were also completed and classified. MRLC forest land resembled the 1992 FIA estimates, which helped to verify the accuracy of forest acres. The LULC was chosen for the late 1970s coverage. This was the only spatial land-use data source for the late 1970s available in a preclassified format. Discrepancies were found between the MRLC and LULC, particularly with urban land. To determine land-use change using the LULC and MRLC, data adjustments were necessary.

Relationships were determined between land use and water-quality trends (represented by Kendall’s tau), and between urban land-use change and water-quality trends (represented by

Kendall’s tau), using Pearson’s and Spearman’s correlation procedures. In general, highly forested watersheds in Virginia were more associated with improving water quality with respect to BOD, FC, TKN, TR, and pH over the 1978 to 1995 study period. These watersheds were commonly associated with better water quality as measured by the water-quality medians for the variables DO, NFR, BOD, pH, TKN, and TR. Watersheds with less urban land tend to be associated with improving water quality with respect to BOD, FC, and pH, while watersheds with more urban land are associated with declining TR water quality. Better water quality, as measured by the water-quality medians (DO, NFR, NN, pH, TKN, and TR), was generally associated with watersheds possessing fewer urban acres. Improving BOD, NFR, and TP water quality tended to be associated with watersheds having fewer agricultural acres. Watersheds with more agricultural acres were associated with declining pH and TKN water quality. Urban and agricultural relationships were complementary to the forest relationships. There were few significant relationships between water-quality medians and agricultural variables.

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Appendix A

Appendix A-1. Virginia Forest Inventory and Analysis Data (Acres) (Johnson, 1992).

				Change Analysis		
County	**1977**	**1986**	**1992**	**1977 to 1986**	**1986 to 1992**	**1977 to 1992**
Accomack	117,115	104,715	96,630	-12,400	-8,085	-20,485
Albemarle	320,656	290,860	293,436	-29,796	2,576	-27,220
Alleghany	255,511	251,501	254,026	-4,010	2,525	-1,485
Amelia	170,920	167,507	169,531	-3,413	2,024	-1,389
Amherst	234,862	221,538	226,454	-13,324	4,916	-8,408
Appomattox	155,561	155,856	153,357	295	-2,499	-2,204
Augusta	352,380	345,921	346,217	-6,459	296	-6,163
Bath	309,093	302,052	306,266	-7,041	4,214	-2,827
Bedford	297,686	287,093	288,607	-10,593	1,514	-9,079
Bland	174,198	178,055	179,477	3,857	1,422	5,279
Botetourt	251,840	245,026	253,975	-6,814	8,949	2,135
Brunswick	290,505	287,198	290,950	-3,307	3,752	445
Buchanan	271,215	287,004	290,585	15,789	3,581	19,370
Buckingham	298,646	299,235	301,661	589	2,426	3,015
Campbell	222,295	208,415	205,236	-13,880	-3,179	-17,059
Caroline	263,294	262,658	261,702	-636	-956	-1,592
Carroll	186,936	164,004	184,058	-22,932	20,054	-2,878
Charles City	87,739	86,139	85,042	-1,600	-1,097	-2,697
Charlotte	207,387	214,857	209,194	7,470	-5,663	1,807
Chesapeake	130,445	115,140	101,569	-15,305	-13,571	-28,876
Chesterfield	216,119	193,898	189,813	-22,221	-4,085	-26,306
Clarke	34,386	40,601	39,987	6,215	-614	5,601
Craig	177,625	175,307	179,276	-2,318	3,969	1,651
Culpeper	107,768	106,997	114,304	-771	7,307	6,536
Cumberland	132,352	135,560	133,642	3,208	-1,918	1,290
Dickenson	178,990	186,145	175,390	7,155	-10,755	-3,600
Dinwiddie	246,833	239,824	244,769	-7,009	4,945	-2,064
Essex	107,164	95,625	98,013	-11,539	2,388	-9,151
Fairfax	123,051	99,337	92,614	-23,714	-6,723	-30,437
Fauquier	191,790	180,056	175,188	-11,734	-4,868	-16,602
Floyd	138,718	134,179	143,873	-4,539	9,694	5,155
Fluvanna	134,086	132,590	137,348	-1,496	4,758	3,262
Franklin	295,868	286,692	284,099	-9,176	-2,593	-11,769
Frederick	144,055	130,947	129,262	-13,108	-1,685	-14,793
Giles	170,925	176,181	176,775	5,256	594	5,850
Gloucester	96,044	99,488	94,613	3,444	-4,875	-1,431
Goochland	136,607	123,054	130,505	-13,553	7,451	-6,102
Grayson	160,484	161,648	175,828	1,164	14,180	15,344

Appendix A-1. Virginia Forest Inventory and Analysis Data (Acres) (Johnson, 1992).

				Change Analysis		
County	**1977**	**1986**	**1992**	**1977 to 1986**	**1986 to 1992**	**1977 to 1992**
Greene	66,770	64,253	68,858	-2,517	4,605	2,088
Greensville	138,074	139,144	135,286	1,070	-3,858	-2,788
Halifax	336,888	348,892	352,976	12,004	4,084	16,088
Hampton city	6,523	6,334	4,342	-189	-1,992	-2,181
Hanover	198,812	184,587	178,376	-14,225	-6,211	-20,436
Henrico	72,119	66,929	59,637	-5,190	-7,292	-12,482
Henry	171,834	178,116	179,127	6,282	1,011	7,293
Highland	196,394	195,822	196,294	-572	472	-100
Isle of Wight	123,178	117,676	114,511	-5,502	-3,165	-8,667
James City	66,453	64,104	64,973	-2,349	869	-1,480
King and Queen	160,961	153,245	152,722	-7,716	-523	-8,239
King George	72,191	73,029	72,837	838	-192	646
King William	125,112	113,537	111,822	-11,575	-1,715	-13,290
Lancaster	51,686	52,896	52,501	1,210	-395	815
Lee	167,562	156,526	157,865	-11,036	1,339	-9,697
Loudoun	111,726	101,055	118,338	-10,671	17,283	6,612
Louisa	234,104	232,229	228,537	-1,875	-3,692	-5,567
Lunenburg	211,760	208,183	209,807	-3,577	1,624	-1,953
Madison	129,859	118,289	120,511	-11,570	2,222	-9,348
Mathews	34,106	35,237	34,787	1,131	-450	681
Mecklenburg	249,169	262,562	265,852	13,393	3,290	16,683
Middlesex	53,831	51,470	49,882	-2,361	-1,588	-3,949
Montgomery	149,767	146,183	145,464	-3,584	-719	-4,303
Nelson	239,432	223,672	233,316	-15,760	9,644	-6,116
New Kent	101,407	102,268	98,183	861	-4,085	-3,224
Newport News	15,665	10,908	7,934	-4,757	-2,974	-7,731
Northampton	32,202	29,932	30,967	-2,270	1,035	-1,235
Northumberland	69,188	67,888	67,886	-1,300	-2	-1,302
Nottoway	137,206	140,994	137,331	3,788	-3,663	125
Orange	132,334	120,565	125,848	-11,769	5,283	-6,486
Page	126,866	120,991	121,531	-5,875	540	-5,335
Patrick	226,264	225,130	220,534	-1,134	-4,596	-5,730
Powhatan	126,358	127,998	132,471	1,640	4,473	6,113
Prince Edward	163,327	160,816	166,832	-2,511	6,016	3,505
Prince George	120,644	119,262	118,271	-1,382	-991	-2,373
Prince William	115,122	121,061	114,923	5,939	-6,138	-199
Pulaski	116,113	117,241	118,971	1,128	1,730	2,858
Rappahannock	106,495	105,446	103,499	-1,049	-1,947	-2,996

Appendix A-1. Virginia Forest Inventory and Analysis Data (Acres) (Johnson, 1992).

				Change Analysis		
County	**1977**	**1986**	**1992**	**1977 to 1986**	**1986 to 1992**	**1977 to 1992**
Richmond	79,027	76,818	76,279	-2,209	-539	-2,748
Roanoke	114,748	102,107	110,833	-12,641	8,726	-3,915
Rockbridge	257,335	243,783	253,650	-13,552	9,867	-3,685
Rockingham	312,794	308,742	306,177	-4,052	-2,565	-6,617
Russell	159,563	166,872	174,359	7,309	7,487	14,796
Scott	230,907	229,142	237,082	-1,765	7,940	6,175
Shenandoah	193,432	185,674	191,246	-7,758	5,572	-2,186
Smyth	176,947	172,534	177,224	-4,413	4,690	277
Southampton	263,927	241,634	240,553	-22,293	-1,081	-23,374
Spotsylvania	187,532	184,537	175,636	-2,995	-8,901	-11,896
Stafford	125,121	120,200	118,956	-4,921	-1,244	-6,165
Suffolk city	163,455	147,230	143,645	-16,225	-3,585	-19,810
Surry	134,945	124,910	124,151	-10,035	-759	-10,794
Sussex	248,554	250,306	250,668	1,752	362	2,114
Tazewell	204,713	207,118	213,914	2,405	6,796	9,201
Virginia Beach	60,778	47,785	40,727	-12,993	-7,058	-20,051
Warren	85,334	79,845	78,281	-5,489	-1,564	-7,053
Washington	190,137	194,164	189,483	4,027	-4,681	-654
Westmoreland	88,496	76,613	75,785	-11,883	-828	-12,711
Wise	210,634	190,561	178,535	-20,073	-12,026	-32,099
Wythe	148,697	145,345	144,321	-3,352	-1,024	-4,376
York	38,742	34,510	32,849	-4,232	-1,661	-5,893
Totals	16,024,469	15,567,803	15,621,428	-456,666	53,625	-403,041

Change Analysis:
(+) = increasing forest land
(-) = decreasing forest land

Appendix A-2. Census of Agriculture Data for Virginia (Acres) - 1992

County	Harvested Cropland	Cropland (pastured)	Other Cropland	Total Cropland	Total Woodland	Other Land	Pasture*	Total Pasture
Accomack	69,420	1,050	1,953	72,423	15,150	3,995	1,349	2,804
Albemarle	39,675	44,023	4,174	87,872	73,736	26,959	19,937	77,152
Alleghany	3,139	4,929	925	8,993	13,932	2,885	1,746	10,193
Amelia	21,464	9,699	4,556	35,719	28,762	5,930	3,490	18,382
Amherst	13,293	20,604	1,364	35,261	38,045	16,990	14,673	49,796
Appomattox	19,270	20,403	2,406	42,079	27,817	8,795	6,286	35,586
Arlington	(D)	-	(D)	(D)	(D)	-	-	-
Augusta	78,525	59,798	3,706	142,029	49,124	96,289	88,469	167,756
Bath	6,103	7,925	1,003	15,031	23,741	8,238	6,376	16,707
Bedford	49,258	50,449	3,531	103,238	62,421	34,848	28,735	105,774
Bland	10,249	13,106	955	24,310	37,198	20,260	17,849	41,408
Botetourt	18,689	21,216	1,468	41,373	30,025	25,435	23,067	53,700
Brunswick	18,902	9,531	6,978	35,411	43,398	5,868	2,074	17,005
Buchanan	733	1,285	407	2,425	5,006	1,196	499	3,285
Buckingham	14,459	15,464	2,006	31,929	29,017	5,088	2,845	25,207
Campbell	31,178	28,492	5,247	64,917	52,510	17,047	13,185	56,648
Caroline	29,631	3,777	2,299	35,707	14,060	1,837	591	5,734
Carroll	24,435	34,684	2,504	61,623	29,638	21,904	18,983	64,847
Charles City	16,605	931	565	18,101	9,038	1,688	441	1,720
Charlotte	19,138	17,560	13,513	50,211	47,135	15,598	11,868	41,399
Chesterfield	5,569	2,198	1,153	8,920	7,187	1,285	232	3,740
Clarke	24,571	16,810	2,222	43,603	5,884	18,839	16,310	35,198
Craig	7,533	9,165	882	17,580	19,589	8,282	7,303	20,419
Culpeper	44,440	22,838	5,286	72,564	24,376	18,355	14,815	42,273
Cumberland	12,321	15,352	2,858	30,531	24,728	6,410	4,607	24,409
Dickenson	(D)	(D)	600	(D)	(D)	1,962	1,485	4,695
Dinwiddie	26,967	6,061	6,425	39,453	38,244	8,257	4,541	16,026
Essex	34,612	(D)	(D)	38,648	13,001	4,631	743	2,414
Fairfax	1,675	2,829	475	4,979	6,165	4,570	1,572	4,736
Fauquier	69,265	44,161	6,169	119,595	50,426	65,512	56,902	112,782
Floyd	25,619	30,467	2,034	58,120	36,617	21,772	18,013	60,830
Fluvanna	11,337	10,708	1,527	23,572	26,143	8,611	6,811	21,697
Franklin	43,391	33,671	5,595	82,657	64,920	18,900	12,786	64,034
Frederick	34,585	20,999	2,910	58,494	21,493	18,155	14,242	40,972
Giles	8,063	21,131	1,282	30,476	27,547	15,074	13,250	44,779

Appendix A-2. Census of Agriculture Data for Virginia (Acres) - 1992

County	Harvested Cropland	Cropland (pastured)	Other Cropland	Total Cropland	Total Woodland	Other Land	Pasture*	Total Pasture
Gloucester	16,401	635	889	17,925	5,283	1,270	146	1,961
Goochland	15,817	9,268	2,203	27,288	19,390	4,764	2,942	15,132
Grayson	21,588	42,397	1,687	65,672	40,134	30,514	26,908	88,657
Greene	8,474	8,521	1,148	18,143	13,135	5,766	3,825	15,109
Greensville	25,482	1,626	5,386	32,494	17,235	1,645	815	5,123
Halifax	36,971	32,689	25,721	95,381	105,998	31,473	18,709	69,650
Hanover	47,097	11,405	2,561	61,063	27,886	7,333	4,075	19,437
Henrico	10,057	3,095	1,316	14,468	7,064	2,669	188	4,033
Henry	9,365	13,767	2,386	25,518	15,553	7,897	6,815	26,938
Highland	9,438	22,461	862	32,761	38,870	25,279	23,410	60,245
Isle of Wight	53,206	3,281	3,390	59,877	22,944	3,426	1,286	6,811
James City	4,215	519	239	4,973	3,412	1,174	243	1,045
King and Queen	33,598	1,325	2,209	37,132	13,669	1,707	471	3,910
King Geroge	17,767	2,332	2,354	22,453	9,335	5,989	3,315	6,489
King William	36,189	1,617	2,422	40,228	12,015	7,083	5,985	9,010
Lancaster	11,882	576	1,255	13,713	5,037	907	422	1,304
Lee	20,275	36,323	4,563	61,161	43,219	24,916	20,059	73,050
Loudoun	69,572	42,754	12,656	124,982	36,103	34,391	26,156	76,347
Louisa	21,646	15,328	2,820	39,794	31,462	10,171	7,255	28,231
Lunenburg	13,987	13,532	8,106	35,625	43,121	6,854	3,645	26,160
Madison	28,844	20,517	1,793	51,154	28,208	21,240	18,446	45,285
Mathews	3,958	352	451	4,761	921	470	226	654
Mecklenburg	35,407	33,198	14,430	83,035	67,310	17,513	9,586	61,105
Middlesex	12,336	1,010	1,236	14,582	4,772	2,153	(D)	2,869
Montgomery	20,482	24,528	1,776	46,786	28,573	23,555	21,378	57,030
Nelson	12,947	17,796	1,770	32,513	29,017	11,151	9,094	34,677
New Kent	11,489	678	690	12,857	5,097	413	(D)	1,610
Northampton	41,617	354	2,656	44,627	6,205	1,637	565	1,169
Northumberland	30,066	1,408	2,271	33,745	6,388	1,157	582	4,073
Nottoway	13,830	12,194	4,738	30,762	27,453	5,776	2,734	20,712
Orange	31,888	24,398	3,721	60,007	32,945	14,748	11,912	41,592
Page	18,506	16,575	1,883	36,964	12,547	15,345	12,589	33,755
Patrick	14,833	13,971	4,864	33,668	37,670	8,111	5,182	28,426
Pittsylvania	59,095	47,029	25,314	131,438	132,774	32,852	18,088	98,535
Powhatan	12,312	5,631	1,394	19,337	18,381	5,462	3,464	11,954
Prince Edward	15,175	13,705	4,914	33,794	29,349	5,441	3,568	23,188

Appendix A-2. Census of Agriculture Data for Virginia (Acres) - 1992

County	Harvested Cropland	Cropland (pastured)	Other Cropland	Total Cropland	Total Woodland	Other Land	Pasture*	Total Pasture
Prince George	22,057	2,549	3,685	28,291	15,965	4,633	695	4,475
Prince William	12,565	7,486	1,852	21,903	6,310	4,760	3,596	12,081
Pulaski	16,520	18,243	882	35,645	11,724	24,434	21,785	45,045
Rappahannock	17,515	16,585	1,704	35,804	27,582	15,591	13,461	35,907
Richmond	25,614	559	2,128	28,301	9,114	1,525	87	1,481
Roanoke	5,179	6,010	667	11,856	9,365	3,703	2,647	10,904
Rockbridge	25,887	32,253	3,155	61,295	41,587	38,884	35,484	82,359
Rockingham	85,802	58,782	3,955	148,539	37,846	49,689	41,737	112,726
Russell	20,095	33,659	1,856	55,610	50,437	54,926	49,916	108,791
Scott	19,767	30,415	4,673	54,855	52,935	26,401	20,319	69,210
Shenandoah	39,087	30,545	3,682	73,314	27,179	24,901	21,064	56,908
Smyth	21,918	30,920	2,604	55,442	28,584	35,947	33,185	77,859
Southampton	91,366	6,408	9,413	107,187	64,706	6,576	3,944	15,608
Spotsylvania	15,502	7,804	2,332	25,638	21,003	6,263	3,792	15,084
Stafford	6,939	3,371	632	10,942	7,878	1,287	781	6,539
Surry	29,195	1,094	2,212	32,501	15,287	4,982	3,863	6,090
Sussex	40,157	2,046	7,893	50,096	26,562	6,078	4,628	9,516
Tazewell	17,270	25,967	1,083	44,320	42,445	51,766	45,024	89,821
Warren	9,592	11,366	322	21,280	9,062	8,625	6,998	21,137
Washington	37,786	49,231	7,295	94,312	48,074	47,676	41,597	107,377
Westmoreland	33,890	978	3,480	38,348	14,555	3,386	2,129	4,280
Wise	2,142	4,446	206	6,794	3,885	2,568	2,261	7,886
Wythe	33,940	38,337	2,798	75,075	26,052	30,239	26,925	75,433
York	994	(D)	(D)	1,369	694	295	97	484
Chesapeake	43,836	1,156	2,762	47,754	5,793	743	145	1,505
Suffolk	58,554	2,042	3,504	64,100	15,020	3,927	2,042	5,600
Virginia Beach	34,870	885	3,171	38,926	3,198	1,208	217	1,576
Virginia	2,449,013	1,524,399	338,428	4,311,840	2,600,441	1,384,730	1,100,248	3,285,065

(D) - Withheld to avoid disclosing data for individual farms.
Pasture* - Total pasture, not counting pastured cropland and woodland.

Appendix A-3. Census of Agriculture Data for Virginia (Acres) - 1992.

County	Pasture$_a$	Cropland$_a$	Land in Farms	Total Acres
Accomack	2,399	71,373	91,568	290952
Albemarle	63,960	43,849	188,567	462561
Alleghany	6,675	4,064	25,810	285367
Amelia	13,189	26,020	70,411	228372
Amherst	35,277	14,657	90,296	304164
Appomattox	26,689	21,676	78,691	213571
Arlington	(D)	(D)	(D)	16563
Augusta	148,267	82,231	287,442	621893
Bath	14,301	7,106	47,010	340403
Bedford	79,184	52,789	200,507	483100
Bland	30,955	11,204	81,768	229551
Botetourt	44,283	20,157	96,833	347327
Brunswick	11,605	25,880	84,677	362345
Buchanan	1,784	1,140	8,627	322494
Buckingham	18,309	16,465	66,034	371771
Campbell	41,677	36,425	134,474	322881
Caroline	4,368	31,930	51,604	340878
Carroll	53,667	26,939	113,165	304981
Charles City	1,372	17,170	28,827	116783
Charlotte	29,428	32,651	112,944	304019
Chesapeake	1,301	46,598	54,290	218035
Chesterfield	2,430	6,722	17,392	272453
Clarke	33,120	26,793	68,326	113045
Craig	16,468	8,415	45,451	211245
Culpeper	37,653	49,726	115,295	243948
Cumberland	19,959	15,179	61,669	191053
Dickenson	(D)	(D)	(D)	212901
Dinwiddie	10,602	33,392	85,954	322406
Essex	(D)	(D)	56,280	164980
Fairfax	4,401	2,150	15,714	253168
Fauquier	101,063	75,434	235,533	416197
Floyd	48,480	27,653	116,509	244145
Fluvanna	17,519	12,864	58,326	183955
Franklin	46,457	48,986	166,477	442955
Frederick	35,241	37,495	98,142	265333
Giles	34,381	9,345	73,097	229056
Gloucester	781	17,290	24,478	138617

Appendix A-3. Census of Agriculture Data for Virginia (Acres) - 1992.

County	Pasture[a]	Cropland[a]	Land in Farms	Total Acres
Goochland	12,210	18,020	51,442	182051
Grayson	69,305	23,275	136,320	283305
Greene	12,346	9,622	37,044	100233
Greensville	2,441	30,868	51,374	189094
Halifax	51,398	62,692	232,852	520830
Hanover	15,480	49,658	96,282	302569
Henrico	3,283	11,373	24,201	152403
Henry	20,582	11,751	48,968	244721
Highland	45,871	10,300	96,910	266165
Isle of Wight	4,567	56,596	86,247	202169
James City	762	4,454	9,559	91464
King and Queen	1,796	35,807	52,508	202424
King Geroge	5,647	20,121	37,777	115209
King William	7,602	38,611	59,326	176288
Lancaster	998	13,137	19,657	85216
Lee	56,382	24,838	129,296	279776
Loudoun	68,910	82,228	195,476	332747
Louisa	22,583	24,466	81,427	318394
Lunenburg	17,177	22,093	85,600	276341
Madison	38,963	30,637	100,602	205730
Mathews	578	4,409	6,152	54845
Mecklenburg	42,784	49,837	167,858	399348
Middlesex	(D)	13,572	21,507	83393
Montgomery	45,906	22,258	98,914	248473
Nelson	26,890	14,717	72,681	302324
New Kent	(D)	12,179	18,367	134294
Northampton	919	44,273	52,469	132724
Northumberland	1,990	32,337	41,290	123079
Nottoway	14,928	18,568	63,991	201428
Orange	36,310	35,609	107,700	218710
Page	29,164	20,389	64,856	199133
Patrick	19,153	19,697	79,449	309224
Pittsylvania	65,117	84,409	297,064	621345
Powhatan	9,095	13,706	43,180	167230
Prince Edward	17,273	20,089	68,584	225797
Prince George	3,244	25,742	48,889	169990
Prince William	11,082	14,417	32,973	216594

Appendix A-3. Census of Agriculture Data for Virginia (Acres) - 1992.

County	Pasture$_a$	Cropland$_a$	Land in Farms	Total Acres
Pulaski	40,028	17,402	71,803	205167
Rappahannock	30,046	19,219	78,977	170623
Richmond	646	27,742	38,940	122544
Roanoke	8,657	5,846	24,924	160427
Rockbridge	67,737	29,042	141,766	383789
Rockingham	100,519	89,757	236,074	544773
Russell	83,575	21,951	160,973	303787
Scott	50,734	24,440	134,191	343421
Shenandoah	51,609	42,769	125,394	327832
Smyth	64,105	24,522	119,973	289349
Southampton	10,352	100,779	178,469	384171
Spotsylvania	11,596	17,834	52,904	256576
Stafford	4,152	7,571	20,107	172804
Suffolk	4,084	62,058	83,047	256051
Surry	4,957	31,407	52,770	178628
Sussex	6,674	48,050	82,736	314082
Tazewell	70,991	18,353	138,531	332650
Virginia Beach	1,102	38,041	43,332	158927
Warren	18,364	9,914	38,967	136783
Washington	90,828	45,081	190,062	361091
Westmoreland	3,107	37,370	56,289	146686
Wise	6,707	2,348	13,247	258155
Wythe	65,262	36,738	131,366	296487
York	(D)	(D)	2,358	67593
Virginia	2,624,647	2,787,441	8,297,011	24,900,924

(D) - Withheld to avoid disclosing data for individual farms.

Pasture$_a$ = Pasture + pastured cropland.

Cropland$_a$ = Harvested cropland + other cropland.

Appendix A-4. National Resources Inventory (NRI) Data for Virginia, 1982 and 1992
(U.S. Department of Agriculture, 1987, 1994).

	1982 (Acres)				1992 (Acres)			
County	**Cropland**	**Pasture**	**Forest**	**Urban**	**Cropland**	**Pasture**	**Forest**	**Urban**
Accomack	83,600	700	113,700	13,800	78,100	700	112,300	16,500
Albemarle	52,900	71,200	289,800	28,000	51,900	72,600	282,000	33,400
Alleghany	3,200	11,200	118,200	10,700	3,000	11,700	112,700	13,200
Amelia	45,700	10,800	162,200	3,300	33,600	18,100	164,700	4,000
Amherst	20,400	42,500	167,100	8,400	19,100	42,500	167,000	9,500
Appomattox	37,900	28,100	134,000	4,600	34,200	28,200	138,300	5,400
Augusta	71,700	177,600	125,400	32,800	68,900	174,800	123,700	40,500
Bath	12,400	13,600	137,100	200	15,000	11,800	137,000	200
Bedford	51,000	114,900	247,500	25,000	46,700	110,100	246,400	29,900
Bland	11,500	46,600	92,800	2,800	1,800	53,700	91,800	3,800
Botetourt	14,400	47,100	183,100	7,600	20,800	40,900	184,800	9,300
Brunswick	53,200	7,000	277,900	2,900	36,000	5,300	281,500	3,300
Buchanan	600	5,500	286,000	6,200	0	29,800	279,500	7,900
Buckingham	39,200	18,200	301,700	700	30,100	19,500	308,800	1,100
Campbell	54,700	38,100	202,000	16,500	33,900	45,000	206,600	18,500
Caroline	26,400	11,700	213,600	4,600	23,100	6,500	216,900	7,900
Carroll	39,700	69,200	161,100	17,300	37,400	66,500	154,500	21,400
Charles City	19,700	800	87,600	500	17,800	2,600	84,800	2,400
Charlotte	53,900	29,600	202,500	4,100	36,100	39,900	204,200	4,900
Chesapeake	51,200	1,600	63,600	31,500	46,300	2,800	50,400	48,500
Chesterfield	32,500	19,300	153,200	58,500	18,700	17,400	141,300	84,700
Clarke	25,100	51,500	27,200	3,600	18,000	54,500	29,100	4,800
Craig	7,800	25,400	58,700	800	7,600	24,500	59,000	900
Culpeper	46,000	74,100	110,400	7,200	43,600	74,800	106,900	9,300
Cumberland	28,900	23,700	130,600	3,300	18,200	28,300	133,900	3,900
Dickenson	4,400	13,600	162,900	4,700	3,800	19,900	159,200	6,100
Dinwiddie	61,500	4,700	230,600	1,400	49,900	6,300	229,000	2,500
Essex	57,300	900	96,100	3,500	55,500	1,600	92,500	4,400
Fairfax	12,700	15,600	86,000	138,600	5,400	9,500	59,200	181,200
Fauquier	78,600	134,700	165,200	18,700	70,000	126,200	171,800	28,000
Floyd	29,100	57,600	140,500	2,800	17,600	58,500	148,200	4,400
Fluvanna	12,800	20,600	137,700	8,300	8,600	22,100	137,200	11,200
Franklin	60,700	82,000	250,900	16,400	51,200	85,800	254,600	18,200
Frederick	43,700	50,500	135,300	19,200	42,600	48,600	131,700	23,500
Giles	1,000	44,200	118,500	2,800	1,000	40,900	117,400	3,900

Appendix A-4. National Resources Inventory (NRI) Data for Virginia, 1982 and 1992
(U.S. Department of Agriculture, 1987, 1994).

	1982 (Acres)				1992 (Acres)			
County	**Cropland**	**Pasture**	**Forest**	**Urban**	**Cropland**	**Pasture**	**Forest**	**Urban**
Gloucester	23,200	5,700	99,800	8,300	21,600	3,500	98,600	13,400
Goochland	30,200	15,200	118,000	7,500	22,100	18,200	114,900	11,700
Grayson	24,300	79,100	132,200	6,000	12,700	69,500	127,000	8,500
Greene	13,700	17,700	41,000	9,800	12,100	17,400	38,400	12,500
Greensville	49,200	1,300	132,500	5,300	47,400	1,200	132,900	6,600
Halifax	120,100	46,000	308,300	13,700	103,200	42,100	321,700	15,300
Hanover	64,800	15,500	187,200	20,000	52,700	19,500	185,800	28,200
Henrico	13,500	8,100	69,900	43,700	13,100	4,200	60,100	55,800
Henry	37,400	30,500	134,500	36,800	27,600	27,700	139,600	40,100
Highland	1,000	66,700	139,200	700	1,000	65,600	135,600	900
Isle of Wight	50,500	5,000	124,000	4,900	48,600	6,500	121,600	6,800
James City	10,200	2,100	60,000	15,100	9,100	1,300	53,900	21,600
King and Queen	31,800	800	146,900	2,100	32,700	1,800	143,600	3,800
King George	17,100	5,000	77,900	4,100	16,800	7,000	74,300	6,900
King William	49,000	800	109,900	3,300	48,500	1,700	107,600	4,800
Lancaster	16,100	1,100	59,600	3,800	13,900	1,000	57,200	7,800
Lee	23,300	54,100	151,700	7,100	23,400	63,300	156,900	8,800
Loudoun	83,400	125,900	84,500	15,900	64,400	115,700	100,100	34,900
Louisa	36,900	20,800	237,300	11,500	18,100	33,600	233,300	16,000
Lunenburg	43,700	20,600	194,500	4,600	28,300	21,400	196,600	5,200
Lynchburg city	0	300	12,700	17,900	0	0	10,600	20,600
Madison	24,700	46,400	91,700	4,300	15,000	56,600	88,100	6,000
Mathews	8,700	1,700	37,000	3,900	7,800	1,500	37,000	5,500
Mecklenburg	51,100	38,300	255,800	7,600	51,400	19,400	257,000	11,000
Middlesex	25,800	1,900	48,300	5,500	22,000	3,400	47,600	7,400
Montgomery	14,800	48,400	135,300	18,300	9,600	43,900	141,900	22,200
Nelson	12,000	29,900	235,800	2,400	12,300	29,300	235,100	3,200
New Kent	5,900	0	110,300	4,100	5,400	700	106,400	7,300
Northampton	46,500	0	48,700	8,100	47,000	0	48,500	9,800
Northumberland	42,200	800	62,200	2,400	39,100	700	63,500	5,800
Nottoway	23,200	13,900	126,200	4,200	17,800	11,600	133,200	5,000
Orange	53,000	52,900	95,100	10,800	35,800	61,300	98,600	15,100
Page	18,300	43,000	62,600	3,600	16,200	38,000	63,800	6,300
Patrick	32,500	37,300	219,600	2,500	25,300	39,900	223,000	3,500
Pittsylvania	138,700	81,100	368,700	36,100	118,700	77,600	378,900	41,100

Appendix A-4. National Resources Inventory (NRI) Data for Virginia, 1982 and 1992 (U.S. Department of Agriculture, 1987, 1994).

	1982 (Acres)				1992 (Acres)			
County	**Cropland**	**Pasture**	**Forest**	**Urban**	**Cropland**	**Pasture**	**Forest**	**Urban**
Powhatan	15,400	15,600	119,300	11,200	12,200	15,600	119,500	13,900
Prince Edward	35,100	18,100	156,600	8,200	28,500	21,900	157,600	9,100
Prince George	27,100	6,100	120,000	24,000	15,100	11,700	112,300	34,100
Prince William	21,600	30,800	63,600	62,800	18,900	20,700	46,700	82,600
Pulaski	5,700	58,900	98,300	12,000	8,400	55,400	97,300	13,800
Rappahannock	14,500	47,300	65,800	6,700	7,800	52,300	66,000	7,600
Richmond	30,000	2,600	80,700	1,300	27,000	3,500	78,000	2,200
Richmond city	0	0	6,200	32,200	0	0	3,300	35,000
Roanoke	2,400	19,700	125,200	40,000	3,500	15,200	121,700	46,400
Rockbridge	39,800	68,800	189,300	10,500	28,100	74,800	189,700	13,800
Rockingham	81,500	139,300	105,200	22,700	82,400	135,100	105,600	26,900
Russell	26,900	118,500	136,200	11,000	25,500	98,900	153,500	12,500
Scott	27,100	61,000	197,700	6,900	23,500	70,800	196,300	8,400
Shenandoah	38,500	67,000	125,000	8,300	37,700	65,100	125,100	10,100
Smyth	27,200	61,200	105,500	14,000	23,700	54,400	117,500	16,500
Southampton	101,000	12,400	257,200	8,600	101,800	12,300	254,200	9,700
Spotsylvania	51,800	13,200	173,400	10,100	44,500	25,000	156,500	21,000
Stafford	12,000	13,500	87,000	16,500	10,500	13,500	84,300	25,000
Suffolk city	75,200	8,900	118,000	12,100	71,000	8,000	111,700	15,300
Surry	34,100	0	133,000	4,300	31,700	1,300	131,100	7,100
Sussex	41,000	2,500	260,100	4,300	40,700	1,000	259,100	5,300
Tazewell	20,600	94,300	178,800	12,400	11,400	82,500	199,400	15,700
Virginia Beach	38,100	1,600	41,700	49,400	23,100	300	31,700	75,800
Warren	12,400	26,300	65,400	4,900	9,800	21,900	66,800	9,600
Washington	42,700	119,900	150,800	19,600	34,900	118,200	155,100	23,500
Westmoreland	41,800	1,700	91,500	2,900	35,300	1,700	89,900	5,100
Wise	4,300	10,400	150,400	14,600	8,400	65,600	128,200	17,100
Wythe	42,000	87,000	94,200	7,300	48,500	88,000	100,800	9,500
York	3,800	0	33,800	62,300	500	500	27,600	73,400
Totals	3,395,800	3,388,900	13,619,500	1,368,300	2,900,600	3,443,200	13,538,300	1,794,000

Appendix A-5. National Resources Inventory (NRI) Data for Virginia, 1982 to 1992 Change in Land Use (U.S. Department of Agriculture, 1987, 1994).

County	Cropland	Pasture	Forest	Urban
Accomack	-5,500	0	-1,400	2,700
Albemarle	-1,000	1,400	-7,800	5,400
Alleghany	-200	500	-5,500	2,500
Amelia	-12,100	7,300	2,500	700
Amherst	-1,300	0	-100	1,100
Appomattox	-3,700	100	4,300	800
Augusta	-2,800	-2,800	-1,700	7,700
Bath	2,600	-1,800	-100	0
Bedford	-4,300	-4,800	-1,100	4,900
Bland	-9,700	7,100	-1,000	1,000
Botetourt	6,400	-6,200	1,700	1,700
Brunswick	-17,200	-1,700	3,600	400
Buchanan	-600	24,300	-6,500	1,700
Buckingham	-9,100	1,300	7,100	400
Campbell	-20,800	6,900	4,600	2,000
Caroline	-3,300	-5,200	3,300	3,300
Carroll	-2,300	-2,700	-6,600	4,100
Charles City	-1,900	1,800	-2,800	1,900
Charlotte	-17,800	10,300	1,700	800
Chesapeake	-4,900	1,200	-13,200	17,000
Chesterfield	-13,800	-1,900	-11,900	26,200
Clarke	-7,100	3,000	1,900	1,200
Craig	-200	-900	300	100
Culpeper	-2,400	700	-3,500	2,100
Cumberland	-10,700	4,600	3,300	600
Dickenson	-600	6,300	-3,700	1,400
Dinwiddie	-11,600	1,600	-1,600	1,100
Essex	-1,800	700	-3,600	900
Fairfax	-7,300	-6,100	-26,800	42,600
Fauquier	-8,600	-8,500	6,600	9,300
Floyd	-11,500	900	7,700	1,600
Fluvanna	-4,200	1,500	-500	2,900
Franklin	-9,500	3,800	3,700	1,800
Frederick	-1,100	-1,900	-3,600	4,300
Giles	0	-3,300	-1,100	1,100

Appendix A-5. National Resources Inventory (NRI) Data for Virginia, 1982 to 1992 Change in Land Use (U.S. Department of Agriculture, 1987, 1994).

County	Cropland	Pasture	Forest	Urban
Gloucester	-1,600	-2,200	-1,200	5,100
Goochland	-8,100	3,000	-3,100	4,200
Grayson	-11,600	-9,600	-5,200	2,500
Greene	-1,600	-300	-2,600	2,700
Greensville	-1,800	-100	400	1,300
Halifax	-16,900	-3,900	13,400	1,600
Hanover	-12,100	4,000	-1,400	8,200
Henrico	-400	-3,900	-9,800	12,100
Henry	-9,800	-2,800	5,100	3,300
Highland	0	-1,100	-3,600	200
Isle of Wight	-1,900	1,500	-2,400	1,900
James City	-1,100	-800	-6,100	6,500
King and Queen	900	1,000	-3,300	1,700
King George	-300	2,000	-3,600	2,800
King William	-500	900	-2,300	1,500
Lancaster	-2,200	-100	-2,400	4,000
Lee	100	9,200	5,200	1,700
Loudoun	-19,000	-10,200	15,600	19,000
Louisa	-18,800	12,800	-4,000	4,500
Lunenburg	-15,400	800	2,100	600
Lynchburg city	0	-300	-2,100	2,700
Madison	-9,700	10,200	-3,600	1,700
Mathews	-900	-200	0	1,600
Mecklenburg	300	-18,900	1,200	3,400
Middlesex	-3,800	1,500	-700	1,900
Montgomery	-5,200	-4,500	6,600	3,900
Nelson	300	-600	-700	800
New Kent	-500	700	-3,900	3,200
Northampton	500	0	-200	1,700
Northumberland	-3,100	-100	1,300	3,400
Nottoway	-5,400	-2,300	7,000	800
Orange	-17,200	8,400	3,500	4,300
Page	-2,100	-5,000	1,200	2,700
Patrick	-7,200	2,600	3,400	1,000
Pittsylvania	-20,000	-3,500	10,200	5,000
Powhatan	-3,200	0	200	2,700

Appendix A-5. National Resources Inventory (NRI) Data for Virginia, 1982 to 1992 Change in Land Use (U.S. Department of Agriculture, 1987, 1994).

County	**Cropland**	**Pasture**	**Forest**	**Urban**
Prince Edward	-6,600	3,800	1,000	900
Prince George	-12,000	5,600	-7,700	10,100
Prince William	-2,700	-10,100	-16,900	19,800
Pulaski	2,700	-3,500	-1,000	1,800
Rappahannock	-6,700	5,000	200	900
Richmond	-3,000	900	-2,700	900
Richmond city	0	0	-2,900	2,800
Roanoke	1,100	-4,500	-3,500	6,400
Rockbridge	-11,700	6,000	400	3,300
Rockingham	900	-4,200	400	4,200
Russell	-1,400	-19,600	17,300	1,500
Scott	-3,600	9,800	-1,400	1,500
Shenandoah	-800	-1,900	100	1,800
Smyth	-3,500	-6,800	12,000	2,500
Southampton	800	-100	-3,000	1,100
Spotsylvania	-7,300	11,800	-16,900	10,900
Stafford	-1,500	0	-2,700	8,500
Suffolk city	-4,200	-900	-6,300	3,200
Surry	-2,400	1,300	-1,900	2,800
Sussex	-300	-1,500	-1,000	1,000
Tazewell	-9,200	-11,800	20,600	3,300
Virginia Beach	-15,000	-1,300	-10,000	26,400
Warren	-2,600	-4,400	1,400	4,700
Washington	-7,800	-1,700	4,300	3,900
Westmoreland	-6,500	0	-1,600	2,200
Wise	4,100	55,200	-22,200	2,500
Wythe	6,500	1,000	6,600	2,200
York	-3,300	500	-6,200	11,100
Totals	-495,200	54,300	-81,200	425,700

(+) = increasing land use from 1982 to 1992

(-) = decreasing land use from 1982 to 1992

Appendix A-6. Virginia GAP Analysis Data for Virginia (Acres), Early 1990s.

County	Urban	Pasture	Cropland	Total Ag	Forest	Other	Mixed	Total
Accomack	1,474	0	68,081	68,081	90,726	140,367	55,070	355,719
Albemarle	5,130	22,391	92,414	114,806	257,652	9,776	46,874	434,236
Alexandria	7,710	209	21	230	1,018	67	352	9,378
Alleghany	2,648	3,609	8,783	12,392	233,962	5,420	12,253	266,677
Amelia	354	33,576	26,973	60,549	139,061	8,878	3,776	212,619
Amherst	3,125	5,752	45,861	51,613	196,080	5,411	28,530	284,759
Appomattox	1,597	7,962	43,132	51,095	114,094	5,968	25,901	198,654
Arlington	11,336	680	378	1,058	2,145	251	925	15,714
Augusta	7,471	49,236	175,655	224,891	301,401	11,175	38,023	582,961
Bath	641	6,261	17,942	24,203	276,909	7,664	10,361	319,778
Bedford	4,547	14,442	114,629	129,072	230,770	17,508	74,573	456,470
Bedford city	950	42	635	678	1,222	44	1,189	4,083
Bland	382	10,720	29,005	39,725	163,889	1,255	6,808	212,058
Botetourt	6,396	11,299	50,289	61,589	216,902	10,995	28,802	324,684
Bristol city	3,524	525	648	1,173	1,476	324	377	6,874
Brunswick	2,913	35,431	35,019	70,450	224,151	26,192	11,433	335,138
Buchanan	716	3,345	2,349	5,693	283,125	4,821	4,427	298,783
Buckingham	1,125	15,397	40,301	55,698	241,635	14,874	34,281	347,614
Buena Vista	1,081	62	494	556	1,828	324	289	4,078
Campbell	6,135	17,328	74,916	92,244	142,420	7,657	51,611	300,067
Caroline	2,851	23,656	32,912	56,567	197,627	53,697	11,590	322,332
Carroll	1,469	22,609	45,098	67,708	162,339	6,427	43,298	281,240
Charles City	255	4,823	15,357	20,180	73,062	12,832	14,477	120,806
Charlotte	844	19,297	54,814	74,111	148,353	25,126	33,710	282,144
Charlottesville	2,712	292	429	721	913	250	1,565	6,161
Chesapeake	24,297	7,586	44,188	51,774	67,108	47,189	15,955	206,322
Chesterfield	13,459	12,415	17,858	30,273	191,424	12,886	12,098	260,139
Clarke	1,578	33,570	26,921	60,492	38,977	3,705	3,555	108,307
Clifton Forge	656	7	36	43	745	167	178	1,790
Colonial Heights	1,956	295	352	647	1,410	331	279	4,623
Covington	1,020	38	93	131	529	685	268	2,633
Craig	200	4,579	16,857	21,436	162,064	1,908	10,260	195,868
Culpeper	5,119	81,482	21,271	102,753	106,122	4,180	12,145	230,320
Cumberland	264	26,652	16,190	42,842	113,177	17,794	3,555	177,632
Danville	9,261	823	1,426	2,250	10,616	997	2,769	25,892

Appendix A-6. Virginia GAP Analysis Data for Virginia (Acres), Early 1990s.

County	Urban	Pasture	Cropland	Total Ag	Forest	Other	Mixed	Total
Dickenson	617	7,944	4,481	12,425	170,568	6,618	7,516	197,744
Dinwiddie	1,676	26,771	39,662	66,433	203,067	22,763	5,214	299,152
Emporia	1,398	322	421	743	979	641	326	4,087
Essex	1,007	9,545	33,907	43,453	85,556	18,976	21,906	170,898
Fairfax	94,036	27,549	1,788	29,337	97,774	6,422	17,998	245,567
Fairfax city	587	52	0	52	164	2,791	28	3,621
Falls Church	94	0	0	0	13	910	202	1,220
Fauquier	6,440	152,181	28,925	181,107	181,624	2,586	22,411	394,167
Floyd	316	10,337	51,166	61,503	122,117	3,173	37,766	224,875
Fluvanna	679	14,318	21,479	35,796	115,549	10,141	11,330	173,495
Franklin	4,840	9,312	63,421	72,733	251,149	25,588	66,012	420,322
Franklin city	610	596	915	1,511	1,335	675	353	4,484
Frederick	8,867	61,009	29,936	90,945	137,576	6,663	8,751	252,802
Fredericksburg	2,395	1,201	90	1,291	2,303	143	172	6,305
Galax city	830	553	287	840	1,695	247	1,160	4,772
Giles	2,584	6,585	24,473	31,058	159,505	5,503	15,259	213,910
Gloucester	1,432	8,070	12,442	20,512	70,065	30,566	34,918	157,493
Goochland	1,114	22,931	16,407	39,338	111,352	16,868	4,374	173,045
Grayson	564	23,688	42,633	66,321	166,103	5,099	24,101	262,188
Greene	530	14,491	11,235	25,726	65,017	1,607	1,466	94,346
Greensville	2,582	15,776	25,256	41,032	89,163	35,280	6,282	174,339
Halifax	2,640	31,578	81,815	113,392	264,224	43,825	60,858	484,939
Hampton	17,264	1,378	882	2,260	1,618	7,332	6,594	35,067
Hanover	6,521	37,952	44,098	82,049	156,287	29,116	8,590	282,563
Harrisonburg	5,150	1,959	1,400	3,359	1,053	612	387	10,560
Henrico	22,919	10,377	23,122	33,499	65,065	14,104	9,043	144,629
Henry	7,842	4,500	11,141	15,641	154,967	12,336	35,358	226,144
Highland	139	36,543	23,093	59,636	179,125	1,933	9,443	250,276
Hopewell	2,870	395	467	862	1,794	216	595	6,336
Isle of Wight	1,146	17,453	51,103	68,556	68,305	44,151	29,980	212,136
James City	2,101	3,826	8,171	11,998	51,028	17,853	23,739	106,719
King and Queen	483	5,507	32,105	37,613	121,048	26,407	8,882	194,433
King George	1,827	16,775	5,584	22,359	68,360	7,731	12,275	112,553
King William	886	8,817	30,572	39,389	92,819	27,982	9,326	170,402
Lancaster	1,064	3,062	15,795	18,856	42,806	10,301	31,491	104,518
Lee	2,747	15,293	65,956	81,249	149,491	7,181	16,896	257,563
Lexington	635	24	211	235	95	197	302	1,465

Appendix A-6. Virginia GAP Analysis Data for Virginia (Acres), Early 1990s.

County	Urban	Pasture	Cropland	Total Ag	Forest	Other	Mixed	Total
Loudoun	22,114	176,270	10,109	186,378	91,305	7,693	9,363	316,853
Louisa	3,253	25,631	34,064	59,695	205,943	28,646	7,940	305,477
Lunenburg	607	36,349	32,960	69,309	160,183	18,036	6,789	254,924
Lynchburg	7,895	1,237	4,261	5,498	6,728	1,090	8,192	29,404
Madison	1,350	32,558	36,099	68,657	117,170	3,119	3,251	193,547
Manassas	4,236	1,187	33	1,220	549	39	20	6,065
Manassas Park	740	80	2	81	299	6	5	1,133
Martinsville	2,528	30	73	104	2,829	297	741	6,499
Mathews	795	3,255	3,146	6,401	14,503	24,221	16,474	62,394
Mecklenburg	8,408	45,292	71,710	117,002	178,524	63,440	32,224	399,597
Middlesex	1,015	6,947	12,907	19,854	41,585	9,296	26,815	98,565
Montgomery	7,407	11,922	45,990	57,912	133,952	4,808	26,421	230,500
Nelson	1,136	6,632	41,069	47,701	205,069	5,331	23,763	283,000
New Kent	425	4,581	11,222	15,803	86,230	20,695	9,787	132,940
Newport News	13,453	2,240	2,738	4,978	12,090	7,331	26,194	64,047
Norfolk	24,720	646	253	899	671	4,596	6,916	37,802
Northampton	536	0	38,703	38,703	31,544	74,080	65,437	210,299
Northumberland	1,490	4,774	34,074	38,848	55,547	7,708	25,895	129,488
Norton	533	218	75	293	2,852	549	112	4,339
Nottoway	1,784	31,934	21,465	53,399	112,560	15,520	3,777	187,039
Orange	2,422	46,837	29,326	76,163	111,239	8,019	8,147	205,990
Page	2,230	24,167	26,608	50,775	125,192	6,644	4,544	189,386
Patrick	818	9,917	22,275	32,192	205,729	11,863	34,992	285,593
Petersburg	3,826	1,427	1,177	2,604	5,990	698	630	13,748
Pittsylvania	6,641	41,522	113,436	154,958	316,070	22,882	75,067	575,618
Poquoson	1,099	289	96	385	864	6,093	4,644	13,085
Portsmouth	12,610	466	412	877	958	3,672	5,533	23,651
Powhatan	390	19,415	13,780	33,195	106,109	13,353	2,974	156,021
Prince Edward	1,661	23,884	30,832	54,716	122,833	17,061	13,206	209,477
Prince George	2,434	15,289	19,549	34,838	107,371	8,619	13,120	166,381
Prince William	24,815	48,714	4,429	53,143	115,932	4,500	11,769	210,158
Pulaski	4,628	10,099	50,120	60,219	101,946	11,607	16,399	194,799
Radford	1,770	238	424	662	1,994	479	1,114	6,018
Rappahannock	531	28,549	22,720	51,269	105,648	1,341	2,181	160,970
Richmond	855	6,144	26,348	32,492	59,770	17,580	18,679	129,375
Richmond city	17,566	800	3,118	3,919	11,403	2,441	1,862	37,191
Roanoke	10,429	3,888	13,910	17,798	99,061	3,542	17,669	148,499

Appendix A-6. Virginia GAP Analysis Data for Virginia (Acres), Early 1990s.

County	Urban	Pasture	Cropland	Total Ag	Forest	Other	Mixed	Total
Roanoke	14,773	1,003	2,121	3,125	3,318	1,536	2,729	25,481
Rockbridge	4,236	13,739	86,388	100,127	219,042	7,335	27,982	358,721
Rockingham	10,130	85,529	102,616	188,145	284,794	13,087	18,247	514,404
Russell	2,111	41,048	48,675	89,723	170,073	6,830	12,649	281,386
Salem	4,408	535	619	1,154	1,470	389	1,144	8,564
Scott	2,476	22,345	52,436	74,781	210,676	8,348	20,222	316,504
Shenandoah	5,987	53,354	51,100	104,455	183,828	6,706	8,868	309,843
Smyth	2,610	28,795	43,088	71,882	180,531	3,352	8,062	266,437
South Boston	817	71	107	178	1,332	514	441	3,282
Southampton	2,758	29,340	91,694	121,033	156,417	66,108	8,350	354,666
Spotsylvania	5,160	33,217	14,076	47,293	165,128	20,018	9,550	247,150
Stafford	7,005	23,556	965	24,521	116,175	6,317	14,223	168,241
Staunton	3,308	698	4,071	4,769	1,296	492	1,874	11,739
Suffolk	4,646	16,524	55,123	71,647	93,303	56,483	20,186	246,265
Surry	287	8,674	31,736	40,410	91,153	30,435	21,323	183,609
Sussex	951	16,699	42,075	58,774	174,360	53,774	3,613	291,471
Tazewell	3,154	24,840	46,933	71,773	219,313	3,895	9,354	307,490
Virginia Beach	37,655	2,886	32,332	35,219	34,088	63,088	10,146	180,195
Warren	3,887	17,911	15,188	33,098	83,392	5,837	4,717	130,931
Washington	4,299	38,955	88,009	126,964	179,051	8,281	15,329	333,924
Waynesboro	3,182	454	2,438	2,892	1,047	738	648	8,507
Westmoreland	2,516	15,329	29,241	44,570	67,154	17,358	18,649	150,246
Williamsburg	789	329	156	486	3,004	554	346	5,179
Winchester	3,238	743	359	1,102	544	408	286	5,579
Wise	4,513	18,712	8,519	27,231	185,115	13,589	8,287	238,736
Wythe	3,360	26,268	78,952	105,220	136,831	6,153	22,232	273,797
York	3,622	4,082	3,240	7,323	36,996	11,188	20,791	79,920

Other = Barren, wetlands, and water

Appendix A-7. USGS Land Use Land Cover (LULC) Data for Virginia, Late 1970s (Acres).

County	Urban	Agriculture	Forest	Other	Total
Accomack	12,111	94,994	85,232	161,227	353,565
Albemarle	25,996	140,024	265,184	2,139	433,344
Alexandria city	8,897	0	235	246	9,378
Alleghany	7,504	18,126	239,568	1,479	266,677
Amelia	1,505	64,532	143,915	2,664	212,617
Amherst	12,727	52,679	217,334	2,018	284,758
Appomattox	6,515	54,011	136,829	1,299	198,654
Arlington	15,242	0	287	185	15,714
Augusta	26,111	236,462	319,321	1,013	582,906
Bath	3,722	32,506	283,300	173	319,701
Bedford	20,479	167,811	261,163	7,017	456,470
Bedford city	2,753	882	434	16	4,083
Bland	2,046	51,375	158,602	36	212,058
Botetourt	17,037	73,866	231,960	1,822	324,684
Bristol city	4,280	1,138	1,304	149	6,871
Brunswick	7,016	65,392	260,121	2,599	335,127
Buchanan	1,460	2,539	279,787	14,996	298,783
Buckingham	5,164	72,266	258,358	11,826	347,613
Buena Vista city	1,523	664	1,835	55	4,078
Campbell	22,542	93,694	182,803	1,026	300,064
Caroline	8,341	56,066	240,858	17,036	322,300
Carroll	4,580	135,300	138,859	2,501	281,240
Charles City	669	21,976	79,888	18,273	120,806
Charlotte	3,307	97,476	177,071	4,242	282,097
Charlottesville city	5,727	161	273	0	6,161
Chesapeake city	36,505	47,100	49,047	73,665	206,317
Chesterfield	30,522	23,331	191,233	15,042	260,127
Clarke	887	69,657	36,412	1,351	108,306
Clifton Forge city	1,109	0	680	0	1,790
Colonial Heights city	2,516	410	844	852	4,623
Covington city	1,600	394	639	0	2,633
Craig	613	29,427	165,757	71	195,868
Culpeper	12,546	121,883	93,095	2,791	230,315
Cumberland	3,148	50,612	119,110	4,758	177,627
Danville city	12,347	2,838	9,966	741	25,892

Appendix A-7. USGS Land Use Land Cover (LULC) Data for Virginia, Late 1970s (Acres).

County	Urban	Agriculture	Forest	Other	Total
Dickenson	690	3,040	189,602	4,411	197,744
Dinwiddie	6,738	61,071	226,603	4,570	298,981
Emporia city	1,966	716	1,194	212	4,087
Essex	2,082	43,226	100,811	24,778	170,897
Fairfax	118,812	30,126	84,601	12,029	245,567
Fairfax city	3,488	45	269	0	3,802
Falls Church city	1,182	38	0	0	1,220
Fauquier	30,943	203,634	158,503	856	393,937
Floyd	1,127	110,362	113,302	57	224,848
Fluvanna	6,408	40,541	122,437	4,110	173,495
Franklin	12,895	137,305	260,058	10,058	420,316
Franklin city	1,701	1,239	1,015	529	4,484
Frederick	5,242	102,812	141,334	3,414	252,802
Fredericksburg city	3,026	1,535	1,458	131	6,151
Galax city	2,727	1,448	597	0	4,772
Giles	3,599	36,426	170,354	3,531	213,910
Gloucester	4,287	29,955	88,780	34,464	157,487
Goochland	6,161	47,827	113,660	5,396	173,044
Grayson	3,161	122,014	133,620	3,388	262,184
Greene	5,114	30,081	57,050	2,099	94,345
Greensville	4,314	47,990	103,507	18,528	174,339
Halifax	4,794	218,756	252,353	9,037	484,939
Hampton city	18,032	2,525	6,137	8,374	35,067
Hanover	24,089	82,930	167,391	8,045	282,454
Harrisonburg city	5,631	3,590	1,143	197	10,560
Henrico	46,132	27,268	60,841	10,379	144,620
Henry	17,778	51,568	155,457	1,340	226,143
Highland	864	63,158	186,255	0	250,276
Hopewell city	3,970	167	1,831	368	6,336
Isle of Wight	10,392	68,525	92,633	40,387	211,938
James City	4,598	14,144	60,822	27,155	106,719
King and Queen	1,546	36,628	142,308	13,950	194,432
King George	6,723	30,015	65,737	10,049	112,523
King William	1,699	42,729	107,862	18,113	170,402
Lancaster	3,894	24,578	49,241	26,804	104,517
Lee	3,661	96,280	152,801	4,821	257,563
Lexington city	1,275	128	62	0	1,465

Appendix A-7. USGS Land Use Land Cover (LULC) Data for Virginia, Late 1970s (Acres).

County	Urban	Agriculture	Forest	Other	Total
Loudoun	13,663	217,422	83,599	2,150	316,834
Louisa	8,507	68,872	219,627	8,132	305,139
Lunenburg	2,972	81,467	169,903	442	254,785
Lynchburg city	17,481	2,429	9,198	295	29,403
Madison	9,198	75,979	108,269	101	193,547
Manassas city	2,874	2,192	648	351	6,065
Manassas Park city	508	280	249	96	1,133
Martinsville city	4,669	293	1,537	0	6,499
Mathews	1,988	16,136	29,229	15,040	62,394
Mecklenburg	9,693	159,503	196,796	33,596	399,588
Middlesex	3,121	24,786	47,497	23,157	98,562
Montgomery	12,553	71,968	144,455	1,524	230,500
Nelson	8,418	52,842	220,516	1,224	283,000
New Kent	3,013	19,842	90,800	19,266	132,920
Newport News city	19,726	2,089	14,483	27,743	64,041
Norfolk city	30,935	152	589	6,126	37,802
Northampton	4,485	57,685	26,786	119,690	208,646
Northumberland	5,038	43,363	64,057	17,011	129,470
Norton city	575	0	2,993	771	4,339
Nottoway	9,775	48,425	126,927	1,331	186,457
Orange	9,345	87,421	106,425	2,761	205,952
Page	15,145	55,383	116,149	2,709	189,386
Patrick	2,630	74,097	207,085	1,766	285,578
Petersburg city	6,806	2,056	4,750	136	13,748
Pittsylvania	11,828	238,683	319,848	5,244	575,604
Poquoson city	891	1,614	1,716	8,864	13,085
Portsmouth city	14,513	1,687	735	6,716	23,651
Powhatan	3,084	37,017	111,967	3,952	156,020
Prince Edward	6,834	66,123	135,676	844	209,477
Prince George	5,722	38,460	109,711	12,484	166,377
Prince William	38,846	53,267	108,352	9,688	210,153
Pulaski	10,871	73,578	104,255	6,095	194,799
Radford city	2,436	974	2,169	439	6,018
Rappahannock	5,192	58,954	96,669	147	160,962
Richmond	3,570	34,071	71,689	20,042	129,372
Richmond city	30,886	66	3,617	2,620	37,191
Roanoke	19,884	21,770	106,343	502	148,499

Appendix A-7. USGS Land Use Land Cover (LULC) Data for Virginia, Late 1970s (Acres).

County	**Urban**	**Agriculture**	**Forest**	**Other**	**Total**
Roanoke city	21,335	1,924	1,981	241	25,481
Rockbridge	13,591	109,336	233,833	1,835	358,595
Rockingham	31,851	194,137	287,298	1,112	514,399
Russell	5,010	102,451	169,203	4,685	281,348
Salem city	6,750	512	1,302	0	8,564
Scott	4,649	77,939	233,525	391	316,504
Shenandoah	19,966	114,465	172,768	2,618	309,817
Smyth	11,561	95,805	158,278	794	266,437
South Boston city	1,915	289	1,078	0	3,282
Southampton	7,288	124,535	180,276	38,888	350,987
Spotsylvania	6,528	58,737	167,201	11,516	243,982
Stafford	19,136	29,306	109,176	10,162	167,780
Staunton city	5,774	4,440	1,385	140	11,739
Suffolk city	24,129	69,835	87,869	64,428	246,261
Surry	1,232	42,305	115,342	24,727	183,606
Sussex	5,155	63,082	203,150	20,074	291,462
Tazewell	9,716	100,810	192,326	4,638	307,490
Virginia Beach city	44,009	42,015	32,091	62,020	180,136
Warren	15,378	39,345	70,461	5,661	130,846
Washington	13,778	151,768	166,660	1,688	333,894
Waynesboro city	4,723	2,626	1,124	34	8,507
Westmoreland	8,715	47,402	77,937	16,190	150,244
Williamsburg city	1,858	72	3,122	127	5,179
Winchester city	3,296	2,256	27	0	5,579
Wise	5,883	8,753	199,689	24,404	238,729
Wythe	8,756	131,713	131,363	1,965	273,797
York	11,060	5,814	42,642	20,402	79,918
Totals	1,380,509	7,106,630	14,409,350	1,346,684	24,243,172

Other = water, wetlands, and barren land

Appendix A-8. MRLC Data for Virginia, Early 1990s (Acres) (May 1999 Release).

County	Urban	Pasture	Cropland	Total Ag	Forest	Other	Total
Accomack	5,589	53,851	32,751	86,602	92,101	171,427	355,719
Albemarle	9,352	95,391	3,900	99,291	316,660	8,933	434,236
Alexandria	7,216	267	8	276	1,492	395	9,378
Alleghany	3,056	11,877	2,887	14,764	245,610	3,247	266,677
Amelia	650	42,764	5,930	48,694	149,979	13,295	212,619
Amherst	4,188	37,170	1,865	39,035	235,172	6,365	284,759
Appomattox	2,339	38,031	2,384	40,415	145,311	10,590	198,654
Arlington	12,141	0	0	0	3,406	166	15,714
Augusta	9,746	198,991	19,776	218,767	349,532	4,917	582,961
Bath	806	22,433	1,713	24,146	289,868	4,957	319,777
Bedford	5,699	123,171	6,493	129,664	309,106	12,002	456,470
Bedford city	1,155	1,154	45	1,199	1,708	22	4,083
Bland	859	36,458	4,422	40,881	169,315	1,004	212,058
Botetourt	5,468	56,869	3,139	60,008	253,651	5,557	324,684
Bristol	3,683	545	39	583	2,503	104	6,874
Brunswick	3,277	52,286	13,074	65,360	234,104	32,397	335,138
Buchanan	1,076	2,426	2,182	4,608	288,154	4,945	298,783
Buckingham	1,551	40,991	2,575	43,565	282,149	20,348	347,613
Buena Vista	1,001	608	13	622	2,321	135	4,078
Campbell	8,635	66,556	7,435	73,991	206,037	11,405	300,067
Caroline	4,643	30,519	25,335	55,854	220,192	41,643	322,332
Carroll	3,304	91,888	4,579	96,467	179,702	1,768	281,240
Charles City	524	14,926	6,719	21,645	71,329	27,308	120,806
Charlotte	1,309	55,718	7,256	62,974	193,760	24,102	282,144
Charlottesville	3,393	307	17	324	2,348	95	6,161
Chesapeake	30,156	54,588	7,195	61,783	15,253	99,129	206,322
Chesterfield	29,343	19,277	6,783	26,060	187,031	17,705	260,139
Clarke	700	59,317	2,883	62,200	44,017	1,390	108,307
Clifton Forge	624	46	10	56	1,067	43	1,790
Colonial Heights	2,287	271	84	355	1,016	965	4,623
Covington city	1,212	246	61	306	965	149	2,633
Craig	245	18,783	4,934	23,717	170,901	1,005	195,868
Culpeper	4,559	92,718	7,742	100,460	121,088	4,212	230,319
Cumberland	1,062	29,760	2,218	31,977	129,969	14,623	177,632
Danville city	11,154	2,362	521	2,884	10,828	1,027	25,892

Appendix A-8. MRLC Data for Virginia, Early 1990s (Acres) (May 1999 Release).

County	Urban	Pasture	Cropland	Total Ag	Forest	Other	Total
Dickenson	429	4,406	1,837	6,242	184,621	6,451	197,744
Dinwiddie	4,469	38,215	22,334	60,549	216,007	18,128	299,152
Emporia city	1,421	485	353	839	1,240	588	4,087
Essex	1,807	27,205	17,835	45,040	91,292	32,760	170,898
Fairfax	84,659	23,143	929	24,072	117,362	19,475	245,567
Fairfax city	2,465	167	0	167	1,157	12	3,802
Falls Church	870	0	0	0	346	4	1,220
Fauquier	11,050	169,053	7,272	176,325	203,243	3,548	394,166
Floyd	333	64,304	9,815	74,119	149,085	1,339	224,875
Fluvanna	1,701	26,806	1,577	28,383	132,255	11,157	173,495
Franklin	4,562	89,348	10,759	100,107	301,505	14,148	420,322
Franklin city	1,482	1,116	53	1,170	1,189	643	4,484
Frederick	4,459	81,026	6,136	87,162	157,640	3,541	252,802
Fredericksburg	2,280	1,140	87	1,226	2,258	541	6,305
Galax	1,889	1,222	76	1,298	1,543	42	4,772
Giles	2,625	26,148	5,488	31,636	175,735	3,914	213,910
Gloucester	2,385	19,361	5,691	25,052	84,643	45,413	157,493
Goochland	2,903	31,525	4,964	36,489	120,520	13,132	173,045
Grayson	1,699	69,871	3,258	73,128	184,726	2,634	262,188
Greene	1,562	21,748	1,943	23,691	67,994	1,099	94,346
Greensville	2,435	24,284	22,727	47,011	84,295	40,598	174,339
Halifax	3,259	91,573	22,216	113,789	326,599	41,292	484,939
Hampton	18,502	1,795	135	1,930	5,911	8,725	35,067
Hanover	14,268	57,231	25,303	82,534	161,835	23,926	282,563
Harrisonburg	4,424	2,850	587	3,437	2,075	625	10,560
Henrico	41,379	21,532	6,886	28,418	58,759	16,073	144,629
Henry	13,945	32,564	3,827	36,391	170,699	5,109	226,144
Highland	141	46,927	2,250	49,177	199,713	1,246	250,276
Hopewell	3,436	406	10	415	1,788	697	6,336
Isle of Wight	5,163	49,941	21,244	71,184	79,733	56,056	212,136
James City	4,374	11,161	1,709	12,870	56,339	33,136	106,719
King and Queen	1,029	23,966	14,780	38,746	130,930	23,728	194,433
King George	2,820	17,835	8,052	25,887	69,765	14,081	112,553
King William	1,257	26,038	16,290	42,328	98,302	28,515	170,402
Lancaster	2,141	16,407	3,916	20,323	51,350	30,704	104,518
Lee	1,960	49,564	3,428	52,993	201,520	1,090	257,563
Lexington	780	287	6	293	379	13	1,465

Appendix A-8. MRLC Data for Virginia, Early 1990s (Acres) (May 1999 Release).

County	Urban	Pasture	Cropland	Total Ag	Forest	Other	Total
Loudoun	13,343	161,348	6,830	168,178	125,693	9,639	316,853
Louisa	3,110	52,053	5,069	57,123	219,912	25,333	305,477
Lunenburg	1,233	48,431	5,613	54,044	182,628	17,020	254,924
Lynchburg	9,871	3,368	104	3,472	15,586	475	29,404
Madison	2,023	56,953	6,653	63,607	126,256	1,662	193,547
Manassas	4,117	781	80	861	819	267	6,065
Manassas Park	743	84	0	84	302	3	1,133
Martinsville	3,812	180	9	189	2,412	86	6,499
Mathews	1,027	8,143	1,746	9,889	25,326	26,152	62,394
Mecklenburg	5,367	98,218	9,316	107,535	227,132	59,563	399,597
Middlesex	1,872	19,555	3,509	23,064	46,636	26,993	98,565
Montgomery	9,018	55,766	8,068	63,834	155,470	2,177	230,500
Nelson	2,036	36,484	1,894	38,378	237,082	5,504	283,000
New Kent	1,821	12,085	5,719	17,805	85,402	27,913	132,940
Newport News	17,989	2,519	118	2,637	13,645	29,776	64,047
Norfolk	27,580	1	0	1	2,178	8,043	37,802
Northampton	2,071	31,275	18,245	49,520	32,840	125,868	210,299
Northumberland	2,674	32,001	4,022	36,023	69,296	21,495	129,488
Norton	398	44	0	44	3,518	379	4,339
Nottoway	5,164	35,708	4,413	40,121	129,478	12,276	187,039
Orange	3,202	66,071	4,496	70,567	126,674	5,547	205,990
Page	5,195	46,924	3,568	50,492	130,794	2,905	189,386
Patrick	1,560	45,818	7,308	53,126	226,914	3,993	285,593
Petersburg	5,354	1,774	405	2,179	5,942	273	13,748
Pittsylvania	6,867	128,605	33,909	162,514	383,031	23,206	575,618
Poquoson	876	721	27	749	2,265	9,195	13,085
Portsmouth	13,177	857	24	880	1,948	7,646	23,651
Powhatan	1,273	25,426	4,668	30,093	113,278	11,376	156,021
Prince Edward	2,661	38,930	2,224	41,154	152,080	13,581	209,477
Prince George	4,998	23,216	11,310	34,527	110,648	16,209	166,381
Prince William	25,424	45,795	2,476	48,270	121,323	15,140	210,158
Pulaski	6,622	59,554	7,469	67,023	115,082	6,072	194,799
Radford city	1,889	892	89	981	2,925	223	6,018
Rappahannock	1,247	47,621	983	48,604	110,215	905	160,970
Richmond	2,052	26,900	8,672	35,572	64,439	27,312	129,375
Richmond city	26,020	1,499	190	1,689	6,784	2,698	37,191
Roanoke	10,777	18,229	2,085	20,314	115,978	1,429	148,499

Appendix A-8. MRLC Data for Virginia, Early 1990s (Acres) (May 1999 Release).

County	Urban	Pasture	Cropland	Total Ag	Forest	Other	Total
Roanoke	15,088	2,871	31	2,902	6,962	529	25,481
Rockbridge	4,560	91,519	3,031	94,549	256,084	3,528	358,721
Rockingham	11,272	167,101	20,573	187,674	311,339	4,119	514,404
Russell	3,046	58,446	4,497	62,943	211,310	4,087	281,386
Salem	4,475	1,267	14	1,281	2,689	120	8,564
Scott	1,897	34,666	2,254	36,920	276,582	1,104	316,504
Shenandoah	8,058	98,420	7,581	106,001	192,026	3,758	309,843
Smyth	6,546	59,951	2,811	62,762	196,332	798	266,437
South Boston	1,409	196	57	253	1,285	335	3,282
Southampton	4,061	80,550	52,857	133,407	140,290	76,907	354,666
Spotsylvania	6,340	36,691	12,362	49,054	173,746	18,011	247,150
Stafford	9,461	23,430	5,032	28,462	113,187	17,131	168,241
Staunton	3,453	4,534	180	4,713	3,415	157	11,739
Suffolk	12,617	61,030	16,999	78,029	65,645	89,974	246,265
Surry	737	26,497	14,058	40,555	99,212	43,106	183,609
Sussex	2,831	32,658	26,929	59,587	183,144	45,909	291,471
Tazewell	5,133	71,487	6,536	78,023	221,770	2,564	307,490
Virginia Beach	46,316	30,458	3,847	34,305	21,459	78,116	180,195
Warren	6,008	33,013	916	33,929	88,059	2,936	130,931
Washington	8,084	83,789	4,091	87,880	235,751	2,209	333,924
Waynesboro	3,338	2,222	511	2,733	2,252	184	8,507
Westmoreland	3,491	34,500	12,551	47,051	74,469	25,235	150,246
Williamsburg	1,401	351	24	375	3,073	330	5,179
Winchester	2,846	1,387	202	1,589	1,096	47	5,579
Wise	5,602	8,454	787	9,241	207,345	16,548	238,736
Wythe	5,462	105,655	13,369	119,024	146,986	2,325	273,797
York	6,849	5,556	422	5,978	42,921	24,172	79,920
Totals	863,208	4,913,741	824,570	5,738,311	15,592,356	2,064,131	24,258,005

Other = Barren, wetlands, and water

Appendix B

Appendix B-1. Census of Agriculture (1992) Land-Use Class Definitions (U.S. Department of Agriculture, 1999).

Cropland Used Only for Pasture and Grazing (cropland – pastured) – This category includes land used only for pasture or grazing which could have been used for crops without additional improvement. Also included was all cropland used for rotation pasture. However, cropland which was pastured before or after crops were harvested was to be included as harvested cropland rather than cropland for pasture or grazing.

Cropland$_a$ – (Harvested cropland) + (Other Cropland)

Harvested Cropland – This category includes land from which crops were harvested or hay was cut, and land in orchards, citrus groves, Christmas trees, vineyards, nurseries, and greenhouses. Land from which two or more crops were harvested was counted only once. Land in tapped maple trees is included in woodland not pastured.

Other Cropland – This category includes cropland not harvested and not grazed which was used for cover crops or soil-improvement crops, land on which all crops failed, land in cultivated summer fallow, idle cropland, and land planted in crops which were to be harvested after the census year.

Total Cropland – This category includes land from which crops were harvested or hay was cut; land in orchards, citrus groves, vineyards, nurseries, and greenhouses; cropland used only for pasture or grazing; land in cover crops, legumes, and soil improvement grasses; land on which all crops failed; land in cultivated summer fallow; and idle cropland.

Pasture* – (Pasture and rangeland other than pastured cropland or pastured woodland)

Pasture$_a$ – (Pasture*) + (pastured cropland)

Total Pasture – Pasture, pastured cropland, and pastured woodland**.**

Other Land – This category includes land in house lots, barn lots, ponds, roads, ditches, wasteland, etc. It includes those acres the farm operation not classified as cropland, pastureland, or woodland.

Woodland, Pastured – This category includes all woodland used for pasture or grazing during the census year. Woodland or forest land pastured under a per-head grazing permit was not counted as land in farms and, therefor, was not included in woodland pastured.

Woodland, Total – This category includes natural or planted woodlots or timber tracts, cutover and deforested land with young growth which has or will have value for wood products, and woodland pastured. Land covered by sagebrush or mesquite was to be reported in cropland harvested, and land in tapped maple trees reported as woodland not pastured.

Land Area (Total Acres) – The approximate land area of counties and States represents the total land area as determined by records and calculations as of January 1, 1997. These data are updated periodically; however, the acreages shown for 1997 are the same as in 1992.

Appendix B-2. National Resources Inventory Land Use Definitions (U.S. Department of Agriculture, 1994).

Cropland - A land cover/use category that includes areas used for the production of adapted crops for harvest. Two subcategories of cropland are recognized: cultivated and noncultivated. Cultivated cropland comprises land in row crops or close-grown crops and also other cultivated cropland, for example, hayland or pastureland that is in a rotation with row or close-grown crops. Noncultivated cropland includes permanent hayland and horticultural cropland.

Pastureland - A land cover/use category of land managed primarily for the production of introduced forage plants for livestock grazing. Pastureland cover may consist of a single species in a pure stand, a grass mixture, or a grass-legume mixture. Management usually consists of cultural treatments: fertilization, weed control, reseeding or renovation, and control of grazing. For the NRI, includes land that has a vegetative cover of grasses, legumes, and/or forbs, regardless of whether or not it is being grazed by livestock.

Forest Land - A land cover/use category that is at least 10 percent stocked by single-stemmed woody species of any size that will be at least 4 meters (13 feet) tall at maturity. Also included is land bearing evidence of natural regeneration of tree cover (cut over forest or abandoned farmland) and not currently developed for nonforest use. Ten percent stocked, when viewed from a vertical direction, equates to an areal canopy cover of leaves and branches of 25 percent or greater. The minimum area for classification as forestland is 1 acre, and the area must be at least 100 feet wide.

Urban and Built-Up Areas - A land cover/use category consisting of residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; other land used for such purposes; small parks (less than 10 acres) within urban and built-up areas; and highways, railroads, and other transportation facilities if they are surrounded by urban areas. Also included are tracts of less than 10 acres that do not meet the above definition but are completely surrounded by Urban and built-up land. Two size categories are recognized in the NRI: areas of 0.25 acre to 10 acres, and areas of at least 10 acres.

Barren Land - A land cover/use category used to classify lands with limited capacity to support life and having less than 5 percent vegetative cover. Vegetation, if present, is widely spaced.

Primary Sample Unit (PSU) - An area of land, typically square to rectangular in shape, that is approximately 40, 100, 160, or 640 acres in size. Within the PSU, sample points are assigned. Certain data elements are collected for the entire PSU, while others are collected at the PSU points. The size of the PSU is based on the shape, size, and complexity of the resources being inventoried. In 34 states, PSU’s are often 160-acre square parcels measuring 0.5 mile on each side. In the western United States, PSU’s are often 40-acre or 640-acre square areas; the 40-acre units are used in most irrigated areas, and the larger PSU’s are used in relatively homogeneous areas containing large tracts of rangeland, forest land, or barren land. In the 13 northeastern states, PSU’s are defined to be 20 seconds of latitude by 30 seconds of longitude, ranging from 97 acres in Maine to 114 acres in southern Virginia. In Louisiana and parts of northwestern Maine, PSU’s are 0.5 kilometer squares (61.8 acres).

Appendix B-3. Anderson Level-Two Land-Use Classes for LULC Data (Anderson et al., 1976).

1 Urban or Built-Up Land
- 11 Residential
- 12 Commercial Services
- 13 Industrial
- 14 Transportation, Communications
- 15 Industrial and Commercial
- 16 Mixed Urban or Built-Up Land
- 17 Other Urban or Built-Up Land

2 Agricultural Land
- 21 Cropland and Pasture
- 22 Orchards, Groves, Vineyards, Nurseries
- 23 Confined Feeding Operations
- 24 Other Agricultural Land

3 Rangeland
- 31 Herbaceous Rangeland
- 32 Shrub and Brush Rangeland
- 33 Mixed Rangeland

4 Forest Land
- 41 Deciduous Forest Land
- 42 Evergreen Forest Land
- 43 Mixed Forest Land

5 Water
- 51 Streams and Canals
- 52 Lakes
- 53 Reservoirs
- 54 Bays and Estuaries

6 Wetland
- 61 Forested Wetlands
- 62 Nonforested Wetlands

7 Barren Land
- 71 Dry Salt Flats
- 72 Beaches
- 73 Sandy Areas Other than Beaches
- 74 Bare Exposed Rock
- 75 Strip Mines, Quarries, and Gravel Pits
- 76 Transitional Areas
- 77 Mixed Barren Land

8 Tundra
- 81 Shrub and Brush Tundra
- 82 Herbaceous Tundra
- 83 Bare Ground
- 84 Wet Tundra
- 85 Mixed Tundra

9 Perennial Snow and Ice
- 91 Perennial Snowfields
- 92 Glaciers

Appendix B-3. Anderson Level-Two Land-Use Classes for LULC Data (Anderson et al., 1976).

Urban/ Built Up Land - Areas of intensive use with much of the land covered by structures. Cities, towns, developments, transportation, power lines, communications facilities, shopping centers, mills, industrial complexes.

Agricultural Land - Land used primarily for production of food and fiber.

Rangeland - Land where the potential natural vegetation is predominately grasses, grasslike plants, forbs, or shrubs.

Forest Land - Lands having a tree crown aerial density of 10 percent or more, are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime.

Water - Streams, sloughs, estuaries, canals, and other moving bodies of water one-eighth of a statute mile in width and greater, and lakes, reservoirs, ponds, and other permanent bodies of water 40 acres in area and greater.

Wetland - Areas where the water table is at, near, or above the land surface for a significant part of most years. Aquatic or hydrophytic vegetation are usually present.

Barren Land - Land with limited ability to support life and in which less than one-third of the area has vegetation or other cover. An area of thin soil, sand, or rocks. Land altered by man, which may be reasonably inferred that it will be returned to its original use, is not included in the barren category.

Tundra - Treeless regions beyond the limit of the boreal forest and above the altitudinal limit of trees in high mountain ranges. Vegetation is low, dwarfed, and often forms a complete mat.

Perennial Snow or Ice - Land having a perennial cover of snow or ice due to environmental conditions.

Appendix B-4. Modified Anderson Level-Two Land-Use Classes for MRLC Data (U.S. EPA, 1996).

Water
11 Open Water
12 Perennial Ice/Snow

Developed
21 Low Intensity Residential
22 High Intensity Residential
23 Commercial/ Industrial/Transportation

Barren
31 Bare Rock/Sand/Clay
32 Quarries/Strip Mines/Gravel Pits
33 Transitional

Forested Upland
41 Deciduous Forest
42 Evergreen Forest
43 Mixed Forest

Shrubland
51 Shrubland

Non-natural Woody
61 Orchards/Vineyards/Other

Herbaceous Upland
71 Grasslands/Herbaceous

Herbaceous Planted/Cultivated
81 Pasture/Hay
82 Row Crops
83 Small Grains
84 Fallow
85 Urban/Recreational Grasses

Wetlands
91 Woody Wetlands
92 Emergent Herbaceous Wetlands

Appendix B-4. Modified Anderson Level-Two Land-Use Classes for MRLC Data (U.S. EPA, 1996).

Bare Rock/Sand: Includes areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, and other accumulations of rock without vegetative cover, with the exception of such rock exposures in tundra regions.

Bare Soil - Areas within planted or cultivated regions that have been tilled or plowed and do not exhibit any visible cover of vegetation.

Deciduous Shrublands - Areas in which 75% or greater of the shrub cover present is characterized Shrubland by individuals that simultaneously shed their foliage in response to an unfavorable season.

Deciduous Forest - Areas dominated by trees in which 75% or more of the tree cover present is characterized by individuals that shed foliage simultaneously in response to an unfavorable season.

Emergent - Non-woody vascular perennial vegetation where the soil or substrate is Herbaceous Wetlands - periodically saturated with or covered with water as defined by Cowardin et al (1970).

Evergreen Shrubland - Shrublands in which 75% or greater of the shrub cover present is characterized by individuals that maintain their leaves all year. Canopy is never without green foliage.

Evergreen Forest - Areas dominated by trees in which 75% or more of the tree cover present is characterized by individuals that maintain their leaves all year. Canopy is never without green foliage.

Grasslands - Areas comprised of natural upland herbaceous vegetation dominated by (Natural/Seminatural) graminoids, typically utilized by grazing animals. Examples include the large areas of private and public rangeland of the western half of the United States.

High Intensity - Includes heavily built-up urban centers and large constructed surfaces in **Developed** - Suburban and rural areas with a variety of different land uses. Contains areas in which a significant land area is covered by concrete and asphalt or other constructed materials. Vegetation occupies less than 20 percent of the landscape. Examples of such areas include apartment complexes, skyscrapers, shopping centers, factories, industrial complexes, airport runways, and interstate highways.

High Intensity - Includes heavily built-up urban centers where people reside. Examples include **Residential -** apartment complexes and row houses. Vegetation occupies less than 20 percent of the landscape. Constructed materials account for 80-100 percent of the total area.

High Intensity - Includes all highly developed lands not classified as High Intensity Residential. **Commercial/Industrial -** Commercial and Industrial land use may be included but not specifically classified in this category.

Low Intensity - Land includes areas with a mixture of constructed materials and vegetation or **Residential -** other covers. Constructed materials account for 30-80 percent of the total area.

Mixed Shrubland - Areas dominated by shrubland where neither deciduous nor evergreen species represent more than 75% of the cover present.

Mixed Forest - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75% of the cover present.

Open Water - All areas of open water with less than 25% cover of trees, shrubs, persistent emergent plants, emergent mosses, lichens, or other land cover.

Other Grasses - Vegetation planted in developed settings, for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns and golf courses.

Pasture/Hay - Grasses, legumes, or grass-legume mixtures planted or intensely managed for livestock grazing or the production of seed or hay crops.

Appendix B-4. Modified Anderson Level-Two Land-Use Classes for MRLC Data (U.S. EPA, 1996).

Perennial Ice/Snow - Areas covered year-round with snow and ice.
Planted/Cultivated - Orchards, vineyards, and tree plantations planted for the production of fruit, nuts,
Woody - fiber(wood), or ornamental.
Quarries/Strip - Areas of extractive mining activities with significant surface expression.
Mines/Gravel Pits
Row Crops - All areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, cotton.
Small Grains - All areas used for the production of graminoid crops such as wheat and rice.
Transitional Bare - Areas dynamically changing from one land cover to another, often because of land use activities. Examples include transition phase between forest and agricultural land, temporary clearing of Woody or Herbaceous vegetation.

Woody Wetlands - Areas of forested and shrubland vegetation where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al., (1970).

Appendix C

Appendix C-1. Land-Use Variables Defined for Each Watershed.

Station	Basin	URBAN	CHGURB	FOREST	PASTURE	CROPLAND	TOTALAG
1A01646580	Potomac	3.20	1.16	57.51	33.68	3.72	37.40
1ABRB002.15	Potomac	18.50	1.74	40.45	31.63	2.59	34.21
1ADIF000.86	Potomac	27.89	1.12	52.02	14.86	0.50	15.36
1AFOU000.19	Potomac	78.99	1.02	20.23	0.00	0.00	0.00
1AGOO002.38	Potomac	1.91	1.14	41.10	54.64	1.34	55.98
1AGOO022.44	Potomac	1.71	1.07	42.91	54.44	0.73	55.17
1AHUT000.01	Potomac	64.71	1.03	29.74	3.49	0.04	3.53
1ALIF000.19	Potomac	60.97	1.01	30.86	3.49	0.05	3.54
1ANEA000.57	Potomac	30.28	1.29	41.58	9.59	0.02	9.61
1APIM000.15	Potomac	58.00	1.05	39.19	2.29	0.00	2.29
1AQUA004.46	Potomac	2.65	1.05	93.08	1.78	0.17	1.95
1ATUS000.37	Potomac	16.09	1.54	36.24	40.06	4.01	44.07
1AUMC004.43	Potomac	2.74	1.05	74.49	11.53	4.61	16.14
1BCDR013.29	Upper Potomac and Shenandoah	3.94	1.77	76.38	8.78	8.75	17.53
1BHKS000.96	Upper Potomac and Shenandoah	3.79	1.02	76.91	8.87	8.38	17.25
1BLEW002.91	Upper Potomac and Shenandoah	1.88	1.06	72.20	8.64	10.59	19.23
1BNFS000.57	Upper Potomac and Shenandoah	0.99	1.05	71.61	23.22	3.13	26.35
1BNFS010.34	Upper Potomac and Shenandoah	2.20	1.05	73.39	20.97	2.56	23.52
1BNFS081.42	Upper Potomac and Shenandoah	2.90	1.05	70.07	16.37	5.84	22.20
1BNFS093.53	Upper Potomac and Shenandoah	2.88	1.02	69.21	21.58	2.39	23.97
1BNTH014.08	Upper Potomac and Shenandoah	10.31	1.08	73.29	13.82	1.36	15.18
1BSHN022.63	Upper Potomac and Shenandoah	8.24	1.06	76.99	12.02	1.79	13.81
1BSSF003.56	Upper Potomac and Shenandoah	1.52	1.05	81.32	14.12	2.41	16.53
1BSSF054.20	Upper Potomac and Shenandoah	5.28	1.06	80.20	10.86	1.28	12.13
1BSTH007.80	Upper Potomac and Shenandoah	2.37	1.06	84.22	9.84	1.39	11.23
1BSTH027.85	Upper Potomac and Shenandoah	0.38	1.08	86.69	8.66	1.42	10.08
1BSTY001.22	Upper Potomac and Shenandoah	18.13	1.03	55.75	23.38	0.50	23.89
2-02035000	James	1.44	1.06	80.79	14.51	0.92	15.43
2-02041650	James	4.03	1.24	74.66	9.64	9.29	18.93
2-APP001.53	James	2.47	1.21	72.01	16.75	2.32	19.07

Appendix C-1. Land-Use Variables Defined for Each Watershed.

Station	Basin	URBAN	CHGURB	FOREST	PASTURE	CROPLAND	TOTALAG
2-APP012.79	James	1.26	1.12	71.98	18.10	2.16	20.26
2-APP050.23	James	0.91	1.09	71.74	18.82	1.74	20.56
2-APP110.93	James	1.40	1.08	71.13	19.78	1.26	21.04
2-APP118.04	James	1.12	1.09	73.05	18.25	1.18	19.44
2-BEN001.42	James	5.44	1.13	9.20	24.16	4.12	28.28
2-BLY000.65	James	29.57	1.17	51.92	13.23	3.00	16.23
2-BUF002.10	James	1.43	1.04	78.22	17.80	0.89	18.69
2-CHK002.17	James	13.30	1.15	55.59	10.98	3.46	14.44
2-CHK032.77	James	21.70	1.15	48.20	12.45	4.21	16.66
2-CHK062.57	James	37.86	1.14	38.52	11.17	2.74	13.91
2-CHK076.59	James	15.06	1.83	59.78	13.55	2.72	16.28
2-CRE002.37	James	1.66	1.03	90.11	7.41	0.58	7.98
2-CWP002.58	James	0.29	1.15	88.74	9.64	0.59	10.23
2-EBE000.40	James	75.41	1.24	10.37	1.14	0.27	1.41
2-FAC000.85	James	36.75	1.21	50.70	6.03	1.32	7.34
2-FAC012.96	James	26.46	1.42	59.76	4.62	2.14	6.76
2-JKS000.38	James	0.91	1.07	89.27	7.39	1.13	8.52
2-JMS021.04	James	3.39	1.12	74.78	14.64	1.68	16.32
2-JMS055.94	James	3.31	1.12	75.70	14.77	1.63	16.40
2-JMS074.44	James	2.80	1.11	77.12	14.98	1.41	16.39
2-JMS099.30	James	2.75	1.09	78.79	14.56	1.09	15.65
2-JMS110.30	James	2.16	1.07	79.39	14.63	1.06	15.68
2-JMS117.35	James	1.72	1.08	79.79	14.70	1.06	15.76
2-JMS157.28	James	1.44	1.06	80.79	14.51	0.92	15.43
2-JMS189.31	James	1.35	1.06	82.57	13.63	0.93	14.56
2-JMS229.14	James	1.50	1.06	82.69	13.48	0.98	14.46
2-JMS258.54	James	1.41	1.06	83.33	13.16	0.98	14.14
2-JMS275.75	James	0.87	1.05	83.83	13.20	1.02	14.22
2-JMS282.28	James	0.88	1.05	83.74	13.28	1.02	14.30
2-LAF000.00	James	56.20	1.18	9.69	9.50	0.88	10.37
2-MCM005.12	James	1.78	1.44	70.72	24.85	0.89	25.74
2-MRY000.46	James	1.25	1.05	74.72	22.26	0.88	23.14
2-MRY038.10	James	0.46	1.03	82.47	15.61	0.36	15.96
2-NAN002-77	James	8.00	1.13	30.38	29.25	6.16	35.42
2-NAN019.14	James	7.70	1.13	33.93	30.74	6.70	37.44
2-PCT002.46	James	30.18	1.79	53.58	10.20	4.38	14.58
2-POT000.12	James	0.08	1.06	92.47	5.42	1.50	6.92
2-RVN001.64	James	2.99	1.06	73.55	19.98	0.91	20.89
2-RVN015.97	James	3.34	1.06	72.95	20.62	0.91	21.52
2-RVN033.65	James	3.66	1.05	72.65	21.06	0.93	21.98
2-SBE001.53	James	42.55	1.31	10.22	20.05	1.96	22.01

Appendix C-1. Land-Use Variables Defined for Each Watershed.

Station	Basin	URBAN	CHGURB	FOREST	PASTURE	CROPLAND	TOTALAG
2-SFT004.92	James	3.68	1.58	81.06	8.33	3.25	11.57
2-TYE000.30	James	0.99	1.04	80.17	16.60	0.79	17.39
3-01668000	Rappahanock	1.45	1.05	61.45	33.28	2.45	35.73
3-GRT001.70	Rappahanock	0.04	1.04	87.17	11.70	0.49	12.19
3-HOK000.74	Rappahanock	4.68	2.65	61.55	30.60	2.70	33.30
3-RAP006.53	Rappahanock	22.03	1.03	28.89	45.92	2.21	48.13
3-ROB001.90	Rappahanock	2.21	1.01	63.37	31.02	2.40	33.42
3-RPP017.72	Rappahanock	2.56	1.10	59.11	34.60	2.86	37.47
3-RPP025.52	Rappahanock	1.31	1.10	68.58	27.22	2.26	29.49
3-RPP080.19	Rappahanock	0.35	1.10	91.05	7.40	0.72	8.12
3-RPP147.10	Rappahanock	2.97	1.03	59.06	33.68	3.13	36.81
3-THO006.50	Rappahanock	3.42	1.03	57.34	34.21	3.85	38.06
3-TOT005.11	Rappahanock	3.52	1.07	55.32	35.79	4.29	40.08
4ABAN005.58	Roanoke	5.13	1.16	62.84	25.38	5.10	30.47
4ABWR019.75	Roanoke	3.59	1.06	64.11	24.56	6.29	30.84
4ABWR032.32	Roanoke	1.69	1.09	68.08	27.68	1.95	29.63
4ADAN015.30	Roanoke	3.09	1.24	47.93	46.96	1.12	48.08
4ADAN055.69	Roanoke	1.84	1.24	65.55	12.18	8.55	20.73
4ADAN059.80	Roanoke	1.24	1.25	62.03	31.87	3.15	35.02
4ADAN075.22	Roanoke	1.30	1.25	65.23	29.85	2.61	32.46
4AHYC002.70	Roanoke	1.96	1.12	58.18	27.37	4.60	31.97
4APGG008.42	Roanoke	2.00	1.12	58.50	27.76	4.65	32.41
4ARNF013.66	Roanoke	2.19	1.30	60.97	30.73	3.17	33.89
4AROA018.04	Roanoke	1.57	1.14	61.38	33.15	2.49	35.65
4AROA059.12	Roanoke	1.23	1.07	63.34	33.78	1.18	34.96
4AROA192.55	Roanoke	0.67	1.08	68.84	29.47	0.51	29.98
4AROA202.20	Roanoke	0.75	1.09	59.58	29.40	3.44	32.85
4AROA227.42	Roanoke	0.77	1.34	65.28	23.50	5.66	29.16
4ASRE007.90	Roanoke	1.23	1.25	70.77	24.10	3.44	27.53
4ASRE033.19	Roanoke	1.19	1.29	70.26	24.37	3.77	28.14
4ASRE043.54	Roanoke	3.86	1.56	74.03	10.36	9.08	19.44
4ATKR000.69	Roanoke	4.24	1.08	75.09	9.82	8.59	18.41
5ABLW009.14	Chowan	2.16	1.17	50.83	21.75	10.42	32.16
5ABLW022.84	Chowan	2.20	1.17	51.57	21.88	10.52	32.40
5ABLW074.66	Chowan	3.52	1.29	66.39	16.35	9.22	25.57
5AMHN052.34	Chowan	1.04	1.19	69.11	19.19	2.62	21.82
5ANTW003.30	Chowan	1.43	1.18	64.24	14.61	8.15	22.76
5ANTW075.48	Chowan	1.60	1.11	70.00	14.55	5.53	20.08
5ANTW078.20	Chowan	1.58	1.11	70.90	14.13	4.84	18.98
5ANTW105.67	Chowan	2.34	1.10	71.66	16.04	2.85	18.89
5ANTW109.02	Chowan	2.36	1.10	71.52	16.10	2.92	19.02

Appendix C-1. Land-Use Variables Defined for Each Watershed.

Station	Basin	URBAN	CHGURB	FOREST	PASTURE	CROPLAND	TOTALAG
5BNLR005.56	Dismal Swamp	15.53	1.83	11.50	36.52	2.30	38.81
5BNLR013.61	Dismal Swamp	33.85	3.31	13.57	17.44	0.62	18.06
5BNTW011.90	Dismal Swamp	1.34	1.02	6.78	39.29	7.57	46.87
5BWNC001.73	Dismal Swamp	22.32	1.37	12.45	30.35	2.58	32.93
6AKOX008.11	Big Sandy	0.10	1.12	97.85	0.36	0.87	1.24
6ALEV130.00	Big Sandy	0.55	1.57	96.72	0.66	0.53	1.20
6AMCR007.46	Big Sandy	0.29	1.65	94.75	2.45	0.51	2.97
6ARSS025.40	Big Sandy	0.14	1.73	94.77	1.66	0.98	2.63
6BBER001.14	Clinch-Powell	14.49	1.26	49.10	12.89	0.00	12.89
6BCLN211.00	Clinch-Powell	1.49	1.21	77.37	17.97	1.42	19.38
6BCLN315.11	Clinch-Powell	2.65	1.12	72.26	22.06	2.08	24.14
6BGUE006.50	Clinch-Powell	5.71	1.32	79.47	4.89	0.09	4.98
6BNFC003.80	Clinch-Powell	0.61	1.35	92.82	5.82	0.60	6.42
6BPOW143.53	Clinch-Powell	2.07	1.27	88.84	6.00	0.23	6.24
6BPOW180.78	Clinch-Powell	1.03	1.40	91.13	0.81	0.12	0.93
6BPWL001.49	Clinch-Powell	1.42	1.15	95.69	1.60	0.07	1.67
6BSRA001.11	Clinch-Powell	0.99	1.31	98.68	0.05	0.03	0.07
6BSTO004.56	Clinch-Powell	0.11	1.71	99.14	0.48	0.17	0.65
6CBEV015.27	Holston	16.26	1.21	49.65	30.52	2.48	33.00
6CBEV021.07	Holston	6.13	1.17	53.83	35.96	2.96	38.92
6CBVD000.07	Holston	0.70	1.17	92.07	5.89	0.70	6.58
6CLTL000.26	Holston	18.85	1.12	62.14	16.81	2.00	18.81
6CMFH005.00	Holston	4.58	1.15	59.85	34.16	1.08	35.24
6CMFH026.00	Holston	4.73	1.14	68.61	25.47	0.78	26.25
6CNFH008.78	Holston	0.63	1.13	81.25	16.57	1.17	17.74
6CNFH039.18	Holston	0.51	1.16	81.08	16.72	1.25	17.98
6CNFH059.65	Holston	0.54	1.16	79.10	18.53	1.39	19.93
6CNFH080.43	Holston	0.76	1.16	74.78	22.13	1.99	24.12
6CNFH083.32	Holston	0.56	1.19	74.66	22.40	2.02	24.43
6CNFH085.20	Holston	0.28	1.17	74.67	22.66	2.06	24.72
6CNFH097.67	Holston	0.00	1.00	68.84	28.20	2.62	30.82
6CSFH073.62	Holston	0.96	1.14	82.50	15.39	0.88	16.27
6CWLF001.46	Holston	13.48	1.08	48.81	35.23	1.84	37.06
6CWLF006.55	Holston	21.04	1.08	36.35	40.13	1.63	41.76
7-BRK004.14	Coastal Basins	33.96	1.73	39.29	6.53	0.33	6.86
7-HLD002.67	Coastal Basins	1.69	1.05	58.21	20.11	14.33	34.44
7-NEW001.92	Coastal Basins	84.62	1.16	10.26	0.00	0.00	0.00
8-01673000	York	1.16	1.09	68.13	19.33	3.64	22.97
8-01674500	York	1.45	1.25	69.34	11.15	7.95	19.09
8-MPN094.79	York	1.21	1.15	72.15	12.41	5.86	18.27
8-NAR005.42	York	1.06	1.10	69.44	18.82	2.49	21.30

Appendix C-1. Land-Use Variables Defined for Each Watershed.

Station	Basin	URBAN	CHGURB	FOREST	PASTURE	CROPLAND	TOTALAG
8-PMK056.87	York	1.45	1.08	66.20	19.77	4.50	24.27
8-PMK082.34	York	1.16	1.09	68.13	19.33	3.64	22.97
8-YRK011.14	York	1.25	1.12	64.99	15.91	6.15	22.06
9-BST029.71	New	3.44	1.50	60.18	32.68	3.22	35.90
9-CST010.45	New	7.55	1.12	53.82	36.86	1.60	38.46
9-LVR001.34	New	1.83	1.13	65.60	26.72	5.45	32.17
9-NEW030.15	New	1.57	1.19	68.00	26.07	3.35	29.42
9-NEW081.72	New	1.50	1.19	65.99	28.05	3.48	31.53
9-NEW098.32	New	1.36	1.20	67.75	26.89	3.20	30.10
9-NEW148.23	New	0.98	1.22	75.96	19.36	3.08	22.44
9-NEW187.46	New	1.11	1.28	82.47	12.89	3.09	15.99
9-PBC002.69	New	2.55	1.08	70.22	25.31	1.53	26.84
9-PKC004.65	New	3.93	1.11	71.21	21.71	2.22	23.93
9-RDC009.00	New	2.93	1.21	52.32	40.05	4.28	44.33
9-STE002.41	New	22.74	1.24	38.29	31.06	6.68	37.73

Appendix C-2. Kendall's Tau Values for 168 Virginia Water Quality Monitoring Stations.

Station	BOD-tau	DO-tau	FC-tau	NFR-tau	NN-tau	pH-tau	TKN-tau	TP-tau	TR-tau
1A01646580	.	-0.32	.	.	0.29	-0.09	-0.24	-0.18	.
1ABRB002.15	-0.01	-0.16	0.08	0.01	-0.12	-0.15	0.14	0.15	.
1ADIF000.86	0.00	-0.20	0.00	-0.21	0.48	0.09	0.12	-0.25	.
1AFOU000.19	-0.25	-0.14	0.19	-0.28	0.17	-0.32	-0.12	-0.74	0.19
1AGOO002.38	-0.10	-0.13	-0.05	-0.16	-0.07	-0.11	-0.07	0.02	.
1AGOO022.44	0.00	-0.11	-0.16	-0.16	-0.09	-0.06	0.22	-0.21	.
1AHUT000.01	-0.14	-0.09	0.23	-0.25	0.00	-0.03	0.26	-0.55	.
1ALIF000.19	-0.04	0.14	-0.04	0.14	0.12	-0.01	-0.23	0.22	.
1ANEA000.57	-0.21	-0.01	0.01	-0.17	0.27	-0.12	-0.15	-0.28	.
1APIM000.15	-0.05	0.03	-0.26	-0.37	0.21	-0.08	0.15	-0.23	.
1AQUA004.46	0.03	-0.25	0.19	-0.19	.	0.17	0.19	.	.
1ATUS000.37	0.02	0.08	0.08	-0.14	0.16	-0.14	-0.06	0.24	.
1AUMC004.43	-0.02	-0.20	-0.03	-0.05	0.19	-0.23	0.49	0.19	.
1BCDR013.29	-0.13	0.06	0.05	-0.24	0.18	0.17	-0.08	.	.
1BHKS000.96	-0.19	0.01	-0.13	-0.22	0.25	0.14	-0.22	-0.39	-0.12
1BLEW002.91	-0.45	0.04	0.38	-0.08	-0.42	-0.18	-0.41	-0.77	.
1BNFS000.57	-0.16	-0.14	-0.24	-0.11	0.26	0.03	0.06	-0.22	-0.14
1BNFS010.34	-0.08	-0.13	-0.10	-0.16	0.21	-0.11	0.18	0.21	.
1BNFS081.42	-0.22	-0.06	-0.10	-0.21	0.25	-0.05	0.06	0.17	.
1BNFS093.53	0.04	0.01	-0.02	-0.14	0.01	0.25	-0.04	.	.
1BNTH014.08	0.00	0.01	0.02	-0.19	0.29	-0.01	0.07	-0.10	0.14
1BSHN022.63	-0.42	-0.21	-0.13	-0.17	0.14	-0.07	-0.16	-0.34	.
1BSSF003.56	-0.21	-0.16	-0.09	-0.26	0.01	-0.12	-0.19	-0.26	.
1BSSF054.20	-0.22	-0.04	0.02	-0.24	0.03	-0.05	-0.24	-0.26	.
1BSTH007.80	-0.13	-0.08	-0.06	-0.02	-0.35	-0.08	-0.48	-0.46	.
1BSTH027.85	0.17	0.02	0.01	-0.17	0.15	-0.14	-0.02	-0.31	.
1BSTY001.22	-0.19	-0.03	0.13	-0.14	0.57	0.00	0.03	0.50	0.39
2-02035000	.	-0.15	.	.	.	0.16	-0.15	-0.01	.
2-02041650	.	-0.29	.	.	-0.07	0.15	0.05	0.18	.

Appendix C-2. Kendall's Tau Values for 168 Virginia Water Quality Monitoring Stations.

Station	BOD-tau	DO-tau	FC-tau	NFR-tau	NN-tau	pH-tau	TKN-tau	TP-tau	TR-tau
2-APP001.53	0.00	0.08	0.03	0.18	0.00	-0.05	0.32	0.13	.
2-APP012.79	0.08	0.08	0.03	-0.15	0.03	-0.12	0.16	-0.58	.
2-APP050.23	0.09	0.08	0.03	-0.06	0.16	-0.17	0.22	-0.31	.
2-APP110.93	-0.14	0.24	-0.25	-0.16	0.14	0.31	0.20	.	.
2-APP118.04	0.18	0.19	-0.11	0.04	0.13	0.00	0.22	-0.33	.
2-BEN001.42	-0.02	0.08	-0.04	-0.17	-0.27	0.17	0.13	-0.14	0.00
2-BLY000.65	0.01	0.13	-0.10	-0.07	0.10	-0.19	-0.03	-0.13	-0.15
2-BUF002.10	0.07	0.13	0.05	-0.18	-0.08	0.13	0.19	-0.10	.
2-CHK002.17	0.16	0.16	.	0.09	-0.35	-0.01	0.43	-0.07	0.15
2-CHK032.77	-0.03	0.05	0.01	-0.10	0.01	-0.10	0.38	-0.57	0.14
2-CHK062.57	-0.03	-0.05	-0.03	0.00	0.08	0.09	0.32	0.00	0.05
2-CHK076.59	-0.16	-0.17	0.09	-0.08	0.17	-0.02	0.29	-0.65	0.39
2-CRE002.37	-0.11	0.05	-0.14	-0.22	-0.01	-0.18	0.11	-0.44	.
2-CWP002.58	.	0.07	0.12	.	-0.09	0.22	-0.26	.	.
2-EBE000.40	-0.03	0.09	-0.05	-0.21	-0.07	-0.13	-0.05	-0.19	0.29
2-FAC000.85	0.13	0.17	0.09	-0.11	0.25	0.08	0.40	.	.
2-FAC012.96	-0.11	0.05	0.04	-0.19	0.03	0.28	0.35	0.00	.
2-JKS000.38	-0.03	0.18	-0.43	-0.05	-0.34	0.20	0.10	0.00	.
2-JMS021.04	.	-0.04	.	0.17	.	-0.03	.	.	.
2-JMS055.94	.	0.16	.	.	.	-0.19	0.15	0.29	.
2-JMS074.44	-0.29	0.20	-0.15	-0.17	-0.36	-0.06	-0.34	-0.24	.
2-JMS099.30	-0.16	0.32	.	-0.04	.	-0.15	-0.18	-0.47	.
2-JMS110.30	0.18	0.24	0.01	0.05	0.04	-0.13	0.33	-0.06	.
2-JMS117.35	0.06	0.16	0.06	-0.01	-0.14	0.01	0.26	-0.05	.
2-JMS157.28	0.10	0.19	-0.07	0.19	-0.04	-0.13	0.23	-0.03	.
2-JMS189.31	0.02	-0.07	0.10	-0.13	-0.13	-0.11	0.17	0.09	.
2-JMS229.14	0.10	0.13	0.11	-0.02	0.03	0.23	0.43	0.14	0.30
2-JMS258.54	0.07	0.21	0.09	-0.05	0.08	0.07	0.36	0.07	0.11
2-JMS275.75	0.03	0.19	0.07	0.01	-0.04	0.11	0.35	-0.01	.
2-JMS282.28	0.13	0.11	0.05	-0.03	-0.08	0.09	0.37	0.07	0.09
2-LAF000.00	-0.09	0.17	-0.10	-0.19	-0.22	-0.05	-0.07	-0.35	0.30
2-MCM005.12	-0.37	-0.06	0.05	0.07	-0.14	0.15	0.16	-0.47	.
2-MRY000.46	0.01	-0.25	0.16	-0.13	0.00	-0.09	0.21	0.33	-0.02
2-MRY038.10	-0.16	0.03	0.21	-0.12	0.04	0.28	0.15	0.00	-0.06
2-NAN002-77	-0.03	0.18	-0.25	-0.20	-0.18	0.01	0.21	.	-0.21
2-NAN019.14	-0.05	0.18	0.06	-0.09	-0.38	0.10	0.30	0.19	0.03
2-PCT002.46	0.05	0.35	0.07	0.20	0.10	0.35	0.36	.	.
2-POT000.12	.	0.13	0.04	.	-0.09	0.20	-0.04	.	.
2-RVN001.64	-0.31	0.03	0.04	-0.03	-0.02	0.18	0.05	-0.12	.
2-RVN015.97	-0.23	-0.03	0.00	-0.06	0.03	0.26	-0.08	0.00	.
2-RVN033.65	-0.42	-0.06	-0.03	-0.11	0.36	0.24	-0.30	0.05	.
2-SBE001.53	-0.13	0.03	-0.07	-0.28	-0.03	-0.14	-0.11	-0.18	0.16

Appendix C-2. Kendall's Tau Values for 168 Virginia Water Quality Monitoring Stations.

Station	BOD-tau	DO-tau	FC-tau	NFR-tau	NN-tau	pH-tau	TKN-tau	TP-tau	TR-tau
2-SFT004.92	0.10	0.01	0.05	0.08	0.44	0.03	0.34	.	.
2-TYE000.30	0.04	0.05	0.11	-0.19	0.04	0.21	0.09	.	.
3-01668000	.	-0.18	.	.	.	0.11	0.04	0.17	.
3-GRT001.70	0.09	-0.06	0.08	-0.04	-0.02	0.01	0.22	0.08	-0.16
3-HOK000.74	-0.07	0.05	0.18	-0.03	-0.04	-0.09	0.35	-0.01	-0.14
3-RAP006.53	-0.04	-0.13	-0.05	-0.15	-0.09	0.02	0.16	.	.
3-ROB001.90	0.13	-0.15	-0.11	-0.07	0.00	-0.04	0.10	0.37	.
3-RPP017.72	-0.28	-0.40	.	-0.01	.	-0.13	.	0.30	.
3-RPP025.52	.	-0.15	.	.	.	0.03	.	.	.
3-RPP080.19	-0.04	-0.14	0.19	0.32	-0.09	-0.14	0.36	0.34	.
3-RPP147.10	-0.12	-0.07	-0.08	-0.17	-0.05	0.00	0.01	0.10	.
3-THO006.50	-0.08	-0.09	0.09	-0.04	0.10	-0.17	0.24	.	.
3-TOT005.11	0.04	0.06	0.08	-0.03	0.01	-0.02	0.38	0.05	-0.07
4ABAN005.58	0.04	-0.11	-0.15	-0.04	0.24	-0.13	0.34	-0.22	-0.02
4ABWR019.75	0.10	0.29	0.17	0.00	0.19	0.37	0.23	-0.11	-0.07
4ABWR032.32	.	-0.06	0.19	0.09	0.28	0.18	0.35	-0.13	.
4ADAN015.30	0.09	0.15	-0.08	0.01	-0.15	-0.13	0.30	-0.24	.
4ADAN055.69	-0.54	0.28	-0.10	-0.34	0.05	0.16	-0.02	.	.
4ADAN059.80	-0.45	0.21	-0.19	-0.24	0.13	0.14	0.08	.	.
4ADAN075.22	0.15	0.30	-0.14	-0.05	-0.04	0.44	0.20	0.10	0.12
4AHYC002.70	0.09	-0.07	0.08	-0.06	-0.02	-0.19	0.28	-0.34	.
4APGG008.42	.	0.21	-0.03	.	0.15	-0.05	0.01	.	.
4ARNF013.66	.	0.12	0.15	-0.10	-0.34	-0.41	-0.03	.	.
4AROA018.04	0.01	-0.01	0.02	-0.02	0.05	-0.17	0.29	-0.66	.
4AROA059.12	0.20	0.14	0.01	0.03	0.13	-0.13	0.40	-0.27	.
4AROA192.55	0.06	0.07	0.26	0.09	-0.22	0.05	0.17	0.18	.
4AROA202.20	0.08	0.09	0.25	-0.05	0.15	-0.12	0.16	0.32	0.03
4AROA227.42	0.03	0.17	-0.09	0.01	0.03	-0.13	0.12	0.20	0.16
4ASRE007.90	-0.02	0.25	0.05	-0.04	-0.11	0.37	-0.06	-0.33	0.23
4ASRE033.19	-0.27	0.24	-0.19	-0.19	0.11	0.13	-0.02	-0.14	-0.21
4ASRE043.54	.	0.13	0.07	0.18	-0.03	0.04	-0.09	.	-0.04
4ATKR000.69	-0.19	0.23	-0.07	-0.19	0.24	-0.14	0.02	0.21	-0.08
5ABLW009.14	-0.29	-0.12	-0.09	-0.41	-0.07	-0.07	0.04	-0.31	0.22
5ABLW022.84	-0.09	-0.06	0.06	-0.33	-0.14	-0.30	0.30	-0.04	0.00
5ABLW074.66	-0.06	-0.13	0.00	-0.21	-0.12	-0.12	-0.09	-0.50	.
5AMHN052.34	0.22	-0.41	-0.19	0.03	0.19	-0.30	0.34	-0.63	0.01
5ANTW003.30	0.13	0.03	0.23	-0.30	0.04	0.08	0.29	0.13	0.25
5ANTW075.48	-0.10	0.15	-0.05	-0.13	-0.03	0.28	0.23	.	.
5ANTW078.20	0.04	-0.10	-0.07	-0.18	-0.03	-0.12	0.25	-0.55	0.10
5ANTW105.67	0.04	0.25	0.11	-0.02	0.01	0.22	0.30	-0.18	.
5ANTW109.02	-0.01	0.01	0.07	-0.10	0.06	-0.16	0.30	-0.60	.
5BNLR005.56	0.17	-0.12	-0.04	0.09	-0.10	-0.17	0.47	0.03	0.43

Appendix C-2. Kendall's Tau Values for 168 Virginia Water Quality Monitoring Stations.

Station	BOD-tau	DO-tau	FC-tau	NFR-tau	NN-tau	pH-tau	TKN-tau	TP-tau	TR-tau
5BNLR013.61	0.05	-0.03	0.05	-0.15	-0.13	-0.03	0.33	0.05	0.51
5BNTW011.90	-0.25	-0.20	-0.07	-0.30	-0.06	-0.13	0.03	-0.33	0.33
5BWNC001.73	0.17	0.11	0.08	0.12	-0.22	0.10	0.36	0.11	0.47
6AKOX008.11	-0.39	0.08	-0.50	-0.27	-0.21	0.08	-0.21	.	0.14
6ALEV130.00	-0.28	0.07	-0.45	-0.29	-0.14	0.25	-0.04	.	0.06
6AMCR007.46	-0.39	0.06	-0.33	-0.29	-0.10	0.15	-0.21	-0.66	0.30
6ARSS025.40	-0.45	-0.06	-0.43	-0.10	0.02	-0.11	-0.10	-0.51	0.18
6BBER001.14	-0.37	0.04	-0.55	-0.37	-0.03	0.31	-0.03	-0.26	0.43
6BCLN211.00	-0.39	-0.16	-0.32	-0.10	-0.02	-0.31	0.20	.	0.10
6BCLN315.11	-0.36	0.00	-0.46	-0.20	0.01	-0.07	-0.06	-0.37	0.10
6BGUE006.50	-0.39	-0.09	-0.23	-0.19	-0.10	0.02	-0.03	-0.25	0.14
6BNFC003.80	-0.32	-0.15	-0.24	0.10	-0.18	-0.03	-0.11	.	0.02
6BPOW143.53	-0.45	-0.13	-0.51	-0.15	-0.08	-0.03	-0.09	-0.48	0.02
6BPOW180.78	-0.47	0.02	-0.48	-0.25	-0.22	0.08	-0.25	-0.35	0.23
6BPWL001.49	-0.29	-0.02	-0.43	-0.31	0.03	0.06	-0.16	-0.33	-0.05
6BSRA001.11	-0.48	0.10	-0.37	-0.39	0.18	0.19	-0.14	-0.33	0.23
6BSTO004.56	-0.62	0.02	-0.33	-0.10	0.07	0.06	0.06	.	-0.10
6CBEV015.27	-0.25	-0.08	-0.21	0.20	0.19	-0.20	0.17	-0.03	0.07
6CBEV021.07	-0.13	-0.09	-0.23	0.17	0.24	-0.23	0.29	-0.10	0.19
6CBVD000.07	-0.48	0.19	-0.27	0.05	0.03	0.19	-0.21	.	-0.11
6CLTL000.26	-0.38	-0.02	-0.30	-0.05	0.14	-0.06	0.09	.	0.08
6CMFH005.00	-0.28	-0.17	-0.03	0.06	0.23	-0.12	0.21	0.26	0.15
6CMFH026.00	-0.51	-0.06	-0.31	-0.16	0.20	-0.09	-0.05	-0.27	0.11
6CNFH008.78	-0.61	-0.19	-0.21	0.06	-0.11	-0.24	0.22	-0.54	.
6CNFH039.18	-0.28	-0.10	-0.20	0.02	0.00	-0.03	0.20	.	0.00
6CNFH059.65	-0.49	0.08	-0.24	-0.22	0.02	-0.17	0.13	.	-0.13
6CNFH080.43	-0.33	-0.02	-0.22	-0.09	0.06	-0.09	0.15	-0.30	-0.10
6CNFH083.32	.	-0.20	-0.33	-0.03	0.11	0.10	0.06	.	0.10
6CNFH085.20	.	-0.14	-0.15	-0.14	0.02	0.11	0.05	.	0.00
6CNFH097.67	-0.28	-0.08	-0.34	-0.01	0.18	0.05	0.16	.	0.11
6CSFH073.62	-0.22	0.02	-0.21	-0.13	0.24	0.16	-0.08	.	0.07
6CWLF001.46	-0.20	0.00	-0.32	0.12	0.32	-0.17	0.21	0.05	0.13
6CWLF006.55	-0.01	0.01	-0.17	0.02	0.22	-0.05	0.17	-0.05	0.13
7-BRK004.14	-0.02	-0.16	0.28	-0.16	-0.01	0.01	0.24	-0.35	-0.01
7-HLD002.67	0.23	0.05	0.30	0.18	0.37	0.15	0.04	0.82	0.12
7-NEW001.92	-0.10	-0.09	0.09	-0.12	-0.11	0.07	0.28	-0.01	0.01
8-01673000	.	-0.08	.	.	-0.31	0.12	-0.02	0.17	.
8-01674500	.	-0.19	.	.	.	0.07	0.03	0.22	.
8-MPN094.79	0.05	-0.16	0.30	-0.05	-0.03	0.07	0.26	.	.
8-NAR005.42	-0.08	-0.01	-0.14	-0.21	-0.08	-0.20	0.19	.	-0.01
8-PMK056.87	-0.21	0.11	-0.06	-0.10	0.27	-0.09	0.31	-0.43	0.17
8-PMK082.34	0.01	-0.09	-0.12	0.08	0.01	-0.03	0.14	-0.26	.

Appendix C-2. Kendall's Tau Values for 168 Virginia Water Quality Monitoring Stations.

Station	BOD-tau	DO-tau	FC-tau	NFR-tau	NN-tau	pH-tau	TKN-tau	TP-tau	TR-tau
8-YRK011.14	.	-0.15	.	0.15	.	-0.02	.	.	.
9-BST029.71	-0.33	-0.09	-0.22	0.14	0.18	-0.03	0.42	.	0.10
9-CST010.45	-0.34	0.09	-0.14	-0.09	0.32	0.11	0.08	-0.05	-0.02
9-LVR001.34	-0.33	-0.07	-0.15	0.01	0.43	0.02	0.04	-0.14	-0.07
9-NEW030.15	0.05	0.24	-0.12	-0.20	0.03	0.35	0.30	.	.
9-NEW081.72	0.00	0.10	-0.14	-0.13	0.42	0.45	0.11	-0.39	.
9-NEW098.32	0.11	0.03	0.08	-0.09	0.26	0.33	0.35	.	.
9-NEW148.23	-0.29	-0.10	-0.18	0.11	0.20	-0.07	0.10	-0.08	0.06
9-NEW187.46	-0.44	-0.11	-0.18	0.04	-0.06	-0.12	0.02	-0.18	-0.05
9-PBC002.69	-0.24	-0.05	-0.29	0.07	0.09	-0.08	0.31	-0.25	0.02
9-PKC004.65	-0.35	0.07	-0.02	-0.24	-0.03	0.10	-0.30	-0.42	.
9-RDC009.00	-0.27	0.05	-0.17	0.00	0.06	-0.03	-0.06	-0.15	0.00
9-STE002.41	.	0.18	0.11	.	-0.06	-0.27	0.26	.	.

Appendix C-3. Median Values for 168 Virginia Water Quality Monitoring Stations.

Station	BOD	DO	FC	NFR	NN	pH	TKN	TP	TR
1A01646580	.	102.4	.	.	1.20	8.00	0.50	0.06	.
1ABRB002.15	2.00	85.5	100.0	11.0	0.70	7.40	0.50	0.10	.
1ADIF000.86	1.00	94.3	200.0	5.0	0.88	7.30	0.30	0.10	.
1AFOU000.19	5.00	80.7	175.0	12.0	1.93	7.25	6.00	0.10	320.0
1AGOO002.38	2.00	94.3	100.0	8.0	1.37	7.40	0.50	0.10	.
1AGOO022.44	1.00	94.8	100.0	5.0	0.89	7.40	0.30	0.10	.
1AHUT000.01	7.00	82.1	100.0	15.0	0.40	6.90	10.00	0.10	.
1ALIF000.19	4.00	86.2	100.0	24.5	1.39	7.30	1.40	0.10	.
1ANEA000.57	4.00	100.0	100.0	31.0	1.04	8.00	1.10	0.10	.
1APIM000.15	1.00	96.2	300.0	5.0	1.48	7.60	0.30	0.10	.
1AQUA004.46	1.00	95.2	100.0	5.0	.	6.90	0.20	.	.
1ATUS000.37	3.00	91.8	100.0	7.0	3.25	7.60	1.20	0.10	.
1AUMC004.43	3.00	89.5	100.0	26.0	0.06	7.20	0.90	0.10	.
1BCDR013.29	1.00	97.9	100.0	5.0	0.46	8.00	0.10	.	.
1BHKS000.96	1.00	95.9	200.0	5.0	1.25	7.98	0.20	0.10	147.0
1BLEW002.91	1.00	94.2	1,200.0	8.0	1.85	8.30	0.30	0.10	.
1BNFS000.57	1.00	97.7	100.0	5.0	1.20	8.30	0.30	0.10	212.0
1BNFS010.34	1.00	99.0	100.0	5.0	1.38	8.40	0.30	0.10	.
1BNFS081.42	1.00	106.7	100.0	5.0	2.58	8.20	0.30	0.10	.
1BNFS093.53	1.00	99.1	100.0	5.0	0.89	7.90	0.20	.	.
1BNTH014.08	1.05	89.4	362.5	8.0	2.54	8.00	0.40	0.20	169.5
1BSHN022.63	1.00	98.9	100.0	5.0	1.01	8.30	0.40	0.10	.
1BSSF003.56	1.00	100.0	100.0	5.0	1.13	8.50	0.40	0.10	.
1BSSF054.20	1.00	95.3	100.0	5.5	1.63	8.30	0.40	0.20	.
1BSTH007.80	1.00	97.3	200.0	5.0	1.70	8.20	0.50	0.10	.
1BSTH027.85	1.00	98.9	100.0	6.0	0.69	8.10	0.20	0.10	.
1BSTY001.22	1.00	103.9	100.0	5.0	1.72	8.23	0.30	0.20	178.0
2-02035000	.	94.4	.	.	.	7.40	0.40	0.11	.
2-02041650	.	98.0	.	.	0.13	7.10	0.40	0.04	.
2-APP001.53	2.00	91.9	100.0	25.0	0.30	7.28	0.70	0.10	.
2-APP012.79	1.00	98.9	100.0	5.0	0.17	7.30	0.40	0.10	.
2-APP050.23	1.00	89.9	200.0	13.0	0.24	7.10	0.30	0.10	.
2-APP110.93	1.00	89.4	200.0	8.0	0.17	7.30	0.20	.	.
2-APP118.04	1.00	91.6	100.0	5.0	0.17	7.20	0.20	0.10	.
2-BEN001.42	2.00	80.3	79.0	27.0	0.10	7.70	0.80	0.10	15,084.0
2-BLY000.65	6.00	66.5	500.0	31.0	0.80	7.00	5.30	0.29	274.0
2-BUF002.10	1.00	100.4	100.0	8.0	0.19	7.30	0.20	0.10	.
2-CHK002.17	2.00	93.2	.	22.0	0.31	7.30	0.60	0.10	219.0
2-CHK032.77	1.40	80.2	100.0	5.0	0.06	6.70	0.50	0.10	88.0
2-CHK062.57	2.00	58.2	100.0	5.0	0.09	6.50	0.50	0.10	111.0

Appendix C-3. Median Values for 168 Virginia Water Quality Monitoring Stations.

Station	BOD	DO	FC	NFR	NN	pH	TKN	TP	TR
2-CHK076.59	2.00	75.0	100.0	7.0	1.46	6.70	0.70	0.10	157.0
2-CRE002.37	1.00	103.1	100.0	5.0	0.35	8.60	0.10	0.10	.
2-CWP002.58	.	94.3	100.0	.	0.10	7.70	0.10	.	.
2-EBE000.40	1.00	71.1	100.0	12.0	0.23	7.50	0.80	0.10	21,600.0
2-FAC000.85	1.00	94.3	100.0	5.0	0.23	7.00	0.40	.	.
2-FAC012.96	2.00	88.9	100.0	6.5	0.09	7.00	0.40	0.10	.
2-JKS000.38	2.00	94.8	300.0	5.0	0.25	8.00	0.40	0.40	.
2-JMS021.04	.	79.7	.	20.0	.	7.68	.	.	.
2-JMS055.94	.	82.4	.	.	.	7.28	0.73	0.12	.
2-JMS074.44	3.60	94.8	100.0	28.0	0.48	7.50	1.10	0.10	.
2-JMS099.30	1.70	91.6	.	12.5	.	7.45	0.60	0.15	.
2-JMS110.30	1.00	101.6	100.0	7.0	0.26	8.00	0.30	0.10	.
2-JMS117.35	1.00	98.7	100.0	6.0	0.27	7.50	0.30	0.10	.
2-JMS157.28	1.50	94.4	100.0	8.3	0.29	7.60	0.30	0.11	.
2-JMS189.31	1.00	96.3	100.0	6.0	0.29	7.75	0.28	0.10	.
2-JMS229.14	2.00	97.4	100.0	6.0	0.32	7.80	0.30	0.20	154.5
2-JMS258.54	2.00	94.1	300.0	7.0	0.25	7.70	0.30	0.15	153.0
2-JMS275.75	2.00	94.0	100.0	7.0	0.19	8.00	0.30	0.20	.
2-JMS282.28	1.00	95.1	100.0	5.0	0.21	8.20	0.20	0.20	168.0
2-LAF000.00	1.00	82.8	23.0	16.0	0.16	7.80	0.70	0.10	20,746.0
2-MCM005.12	1.00	100.0	200.0	5.0	0.37	7.50	0.20	0.10	.
2-MRY000.46	1.00	97.5	100.0	5.0	0.35	8.30	0.20	0.10	154.0
2-MRY038.10	1.00	100.0	100.0	5.0	0.13	8.00	0.10	0.10	70.0
2-NAN002-77	2.00	87.6	17.0	33.0	0.12	7.80	0.70	.	18,835.5
2-NAN019.14	3.00	84.0	1,500.0	19.0	0.08	7.20	1.20	0.20	3,100.0
2-PCT002.46	1.00	95.0	200.0	7.0	0.18	6.50	0.40	.	.
2-POT000.12	.	92.2	100.0	.	0.11	7.70	0.10	.	.
2-RVN001.64	1.00	94.3	100.0	6.0	0.54	7.30	0.30	0.10	.
2-RVN015.97	1.00	95.5	100.0	5.0	0.55	7.35	0.30	0.10	.
2-RVN033.65	2.00	99.2	100.0	5.0	0.59	7.40	0.40	0.10	.
2-SBE001.53	1.00	70.2	130.0	10.0	0.27	7.50	0.89	0.10	21,245.0
2-SFT004.92	2.00	96.4	100.0	6.0	0.08	7.00	0.40	.	.
2-TYE000.30	1.00	102.2	100.0	5.0	0.12	7.50	0.20	.	.
3-01668000	.	94.1	.	.	.	7.10	0.35	0.04	.
3-GRT001.70	2.00	92.0	100.0	5.0	1.58	7.20	0.50	0.10	119.0
3-HOK000.74	2.00	82.6	160.0	28.0	0.10	7.10	0.70	0.10	3,100.0
3-RAP006.53	1.00	95.4	100.0	5.0	0.58	7.20	0.30	.	.
3-ROB001.90	1.00	95.5	400.0	5.0	0.61	7.20	0.20	0.10	.
3-RPP017.72	1.00	79.5	.	10.0	.	7.85	.	0.04	.
3-RPP025.52	.	76.2	.	.	.	7.65	.	.	.
3-RPP080.19	2.00	92.3	100.0	26.0	0.44	7.00	0.55	0.10	.
3-RPP147.10	1.00	93.9	170.0	5.0	0.44	7.20	0.20	0.10	.

Appendix C-3. Median Values for 168 Virginia Water Quality Monitoring Stations.

Station	BOD	DO	FC	NFR	NN	pH	TKN	TP	TR
3-THO006.50	1.00	98.3	100.0	5.0	0.35	7.20	0.20	.	.
3-TOT005.11	2.00	80.1	100.0	17.5	0.07	7.00	0.60	0.10	1,604.0
4ABAN005.58	1.00	89.5	100.0	19.0	0.17	7.00	0.30	0.10	84.5
4ABWR019.75	1.00	88.9	300.0	11.0	0.56	7.20	0.30	0.10	67.3
4ABWR032.32	.	93.3	300.0	8.0	0.61	7.20	0.30	0.10	.
4ADAN015.30	1.00	88.6	100.0	22.0	0.39	7.10	0.40	0.12	.
4ADAN055.69	1.00	96.8	200.0	18.0	0.30	7.20	0.30	.	.
4ADAN059.80	1.00	87.0	100.0	16.0	0.30	7.00	0.30	.	.
4ADAN075.22	1.00	91.2	200.0	16.0	0.31	7.25	0.30	0.10	117.0
4AHYC002.70	2.00	86.4	100.0	11.0	0.19	7.00	0.40	0.10	.
4APGG008.42	.	89.4	100.0	.	0.24	7.20	0.20	.	.
4ARNF013.66	.	91.5	400.0	6.0	0.80	8.30	0.20	.	.
4AROA018.04	1.00	81.2	100.0	5.0	0.22	7.00	0.30	0.10	.
4AROA059.12	1.00	89.4	100.0	18.0	0.26	7.30	0.30	0.10	.
4AROA192.55	2.00	97.8	100.0	10.0	0.90	8.30	0.50	0.10	.
4AROA202.20	1.00	95.1	252.5	5.0	0.46	8.30	0.20	0.10	214.0
4AROA227.42	1.00	94.1	200.0	5.5	0.44	8.10	0.20	0.10	192.0
4ASRE007.90	1.05	92.0	100.0	6.0	0.32	7.40	0.40	0.20	122.0
4ASRE033.19	1.00	92.9	200.0	5.0	0.13	7.20	0.20	0.10	56.0
4ASRE043.54	.	88.2	100.0	3.0	0.14	7.25	0.20	.	45.0
4ATKR000.69	1.00	95.7	1,000.0	6.0	1.05	8.20	0.20	0.10	280.0
5ABLW009.14	1.00	60.8	100.0	5.0	0.29	6.60	0.60	0.10	105.0
5ABLW022.84	1.40	70.6	100.0	5.0	0.17	6.60	0.60	0.10	104.0
5ABLW074.66	2.00	60.5	100.0	5.0	0.18	6.70	1.00	0.10	.
5AMHN052.34	1.00	86.6	100.0	14.0	0.11	6.90	0.40	0.10	84.0
5ANTW003.30	1.00	69.3	100.0	5.0	0.14	6.78	0.50	0.10	90.0
5ANTW075.48	1.00	91.5	100.0	5.0	0.13	7.30	0.30	.	.
5ANTW078.20	1.00	90.3	100.0	5.0	0.12	7.00	0.30	0.10	78.0
5ANTW105.67	1.00	92.2	100.0	5.0	0.13	7.30	0.30	0.10	.
5ANTW109.02	1.00	92.1	100.0	5.0	0.14	7.00	0.30	0.10	.
5BNLR005.56	2.00	84.5	100.0	24.5	0.09	6.80	1.10	0.10	681.5
5BNLR013.61	2.00	66.7	100.0	17.5	0.15	6.80	1.10	0.15	866.0
5BNTW011.90	2.00	54.6	100.0	6.0	0.07	6.40	1.20	0.10	194.5
5BWNC001.73	3.00	79.3	100.0	13.0	0.06	7.00	1.05	0.20	662.0
6AKOX008.11	1.00	99.6	800.0	9.0	0.36	8.00	0.20	.	292.0
6ALEV130.00	1.70	102.3	800.0	12.0	0.34	8.10	0.20	.	441.5
6AMCR007.46	1.00	99.0	1,600.0	5.0	0.27	8.00	0.20	0.10	279.5
6ARSS025.40	1.00	100.3	400.0	5.0	0.24	8.00	0.20	0.10	252.0
6BBER001.14	3.30	88.2	1,900.0	8.0	1.01	7.70	1.50	0.30	485.0
6BCLN211.00	1.00	94.1	100.0	5.0	0.57	8.10	0.20	.	197.0
6BCLN315.11	2.00	84.9	500.0	8.0	0.61	7.90	0.30	0.10	193.0
6BGUE006.50	1.80	91.8	700.0	8.0	0.70	7.70	0.35	0.10	255.0

Appendix C-3. Median Values for 168 Virginia Water Quality Monitoring Stations.

Station	BOD	DO	FC	NFR	NN	pH	TKN	TP	TR
6BNFC003.80	1.00	90.1	200.0	6.0	0.46	7.80	0.20	.	152.5
6BPOW143.53	1.00	93.3	100.0	7.0	0.60	7.90	0.20	0.10	225.0
6BPOW180.78	1.50	99.1	1,400.0	6.0	0.60	8.20	0.20	0.10	314.0
6BPWL001.49	1.90	92.0	2,200.0	6.0	0.32	7.70	0.30	0.10	193.0
6BSRA001.11	1.10	97.9	2,700.0	7.0	0.48	8.00	0.20	0.10	341.0
6BSTO004.56	1.00	100.8	200.0	5.0	0.20	8.00	0.10	.	92.0
6CBEV015.27	2.00	95.5	4,200.0	15.0	1.42	8.20	0.30	0.10	294.0
6CBEV021.07	2.00	94.3	700.0	17.0	1.40	8.10	0.20	0.10	271.0
6CBVD000.07	1.00	92.4	170.0	5.0	0.24	7.30	0.10	.	41.0
6CLTL000.26	2.40	94.2	3,300.0	6.0	1.60	8.15	0.30	.	305.0
6CMFH005.00	1.70	86.8	400.0	11.0	1.21	8.00	0.30	0.10	213.5
6CMFH026.00	1.85	85.9	600.0	7.5	1.10	7.70	0.30	0.10	195.0
6CNFH008.78	1.00	92.7	200.0	5.0	0.34	8.00	0.20	0.10	.
6CNFH039.18	1.15	89.0	100.0	5.0	0.44	8.00	0.20	.	277.5
6CNFH059.65	1.00	88.8	100.0	5.0	0.49	7.90	0.20	.	266.0
6CNFH080.43	1.15	96.6	100.0	5.0	0.61	8.30	0.30	0.10	470.0
6CNFH083.32	.	93.5	100.0	5.0	0.61	8.10	0.20	.	136.0
6CNFH085.20	.	93.0	200.0	5.0	0.61	8.00	0.20	.	131.0
6CNFH097.67	1.30	97.7	200.0	5.0	0.71	8.40	0.20	.	143.0
6CSFH073.62	1.10	93.4	300.0	5.0	0.50	7.80	0.10	.	83.0
6CWLF001.46	1.80	94.2	900.0	15.0	1.91	8.20	0.30	0.20	270.0
6CWLF006.55	2.00	97.3	400.0	11.0	1.90	8.30	0.30	0.20	280.0
7-BRK004.14	2.00	63.7	430.0	18.0	0.06	7.30	1.00	0.10	3,254.0
7-HLD002.67	4.00	76.2	540.0	26.0	3.30	7.10	2.40	0.50	2,801.5
7-NEW001.92	2.50	76.0	350.0	32.0	0.06	7.50	1.00	0.10	10,486.0
8-01673000	.	87.5	.	.	0.24	6.90	0.43	0.06	.
8-01674500	.	85.3	.	.	.	6.60	0.45	0.05	.
8-MPN094.79	1.00	85.5	100.0	5.0	0.07	6.80	0.40	.	.
8-NAR005.42	1.00	92.6	100.0	5.0	0.14	6.80	0.30	.	53.0
8-PMK056.87	1.00	84.1	100.0	6.0	0.40	6.83	0.40	0.10	83.0
8-PMK082.34	1.00	88.3	100.0	8.0	0.23	6.93	0.40	0.10	.
8-YRK011.14	.	73.4	.	20.0	.	7.70	.	.	.
9-BST029.71	1.45	91.8	600.0	11.0	0.90	8.00	0.20	.	162.0
9-CST010.45	3.45	90.3	300.0	6.0	0.47	7.40	0.70	0.30	83.0
9-LVR001.34	1.10	93.6	400.0	5.0	0.47	7.20	0.20	0.10	36.0
9-NEW030.15	1.00	92.5	100.0	5.0	0.71	8.00	0.20	.	.
9-NEW081.72	1.00	83.0	100.0	5.0	0.70	7.60	0.20	0.10	.
9-NEW098.32	1.00	88.9	100.0	5.0	0.39	7.80	0.30	.	.
9-NEW148.23	1.00	92.7	200.0	7.8	0.51	7.40	0.20	0.10	57.0
9-NEW187.46	1.10	88.7	200.0	8.0	0.51	7.20	0.20	0.10	51.0
9-PBC002.69	1.50	92.1	600.0	9.0	0.61	7.30	0.30	0.20	67.0
9-PKC004.65	3.00	91.2	100.0	8.0	0.45	7.90	0.50	0.10	.

Appendix C-3. Median Values for 168 Virginia Water Quality Monitoring Stations.

Station	**BOD**	**DO**	**FC**	**NFR**	**NN**	**pH**	**TKN**	**TP**	**TR**
9-RDC009.00	1.70	99.1	200.0	5.0	0.71	8.20	0.30	0.10	192.0
9-STE002.41	.	94.8	100.0	.	1.11	8.40	0.30	.	.

Vita

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Objective Environmental scientist; interests in water and land resources, geographic information systems.

Education **M.S. Environmental Science and Engineering, May 2000**
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Thesis Title: Relationships Between Land Use and Water-Quality Trends in Virginia.

B.S. Environmental Sciences, May 1998, Cum Laude
Virginia Polytechnic Institute and State University, Blacksburg, VA
Minor: Chemistry GPA: 3.51

Cooperative Education – Hydrologist
U.S. Geological Survey – Water Resources Division, Richmond, VA (01/97-08/97)

- Created maps using Arc/ Info and Arc View on a Unix system.
- River and groundwater sampling, watershed delineation.
- Performed hydrologic analysis of Yorktown Naval Weapons Station.
- Interpreted well logs and constructed aquifer framework.
- Co-authored report, "Geohydrology of the Shallow Aquifer System, Naval Weapons Station Yorktown, Yorktown, VA."

Experience **Graduate Research Assistant**
05/98-05/00 *Virginia Tech Department of Crop and Soil Environmental Sciences*

- Served as GIS specialist on a team research project.
- Compiled land-use data for Virginia using a GIS.
- Analyzed Virginia water-quality data.
- Co-authored report, "Analysis and Interpretation of Water-Quality Data to Enhance Clean Water Act Implementation."

10/97-05/98 **GIS Specialist**
Virginia Tech Department of Crop and Soil Environmental Sciences

- Maintained department GIS lab.
- Compiled and created Virginia data layers.
- Assisted with department GIS projects.
- Co-authored report, "Long-Term Water Quality Trends in Virginia's Waterways."

Computer Skills Arc View 3.2 - Spatial Analyst, Network Analyst, and Image Analyst; Arc Info 7.2; Erdas Imagine; Idrisi; QUAL2E; SAS 6.12; MS Office; Corel Draw; Adobe Photoshop

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