EVALUATION OF THE ALBEMARLE-PAMLICO ESTUARINE STUDY AREA UTILIZING POPULATION, LAND USE AND WATER QUALITY INFORMATION

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ABSTRACT

The purpose of this project is to discover and project trends in population and land use in the Albemarle-Pamlico Estuarine Study (APES) area in order to determine where land use conversion may impact the environment. To reveal trends, land use and population data for subbasins throughout the 23,250 square miles study area are described using the State of North Carolina's Geographic Information System (GIS). Results of this study should be valuable in the development and implementation of a workable growth management strategy for both the entire APES basin and specific locations within the study area.

Land use/land cover information developed by Khorram et al. (1992) is a valuable tool in understanding the land use patterns and population trends throughout the APES area. However, based on other data sources and government officials' comments, errors are identified in the land use categories of urban and wetlands. Acreage appears to be underestimated up to 50% for both land uses. A method is developed to correct errors in the two land uses of urban and wetlands based on correlations with independent data sources and the resulting linear models.

Trend analysis for the period 1960 to 1990 indicates that the greatest population growth rate has been in the Neuse followed by the Tar-Pamlico, Pasquotank and White Oak Basins, while the Chowan and Lower Roanoke Basins have experienced little growth over the 30 year period. Description of individual county population growth rates shows that three distinct clusters of counties/cities —the Virginia Beach Area, the Raleigh/Durham Area and the Greenville/Morehead Area—are experiencing the greatest growth.

Land use information based on a modified LANDSAT classification scheme developed by Khorram et al. (1992) yields seven categories. These categories for the entire APES area are urban (4.8%), agriculture (28.1%), forest (28.4%), water

(14.6%), wetland (20.5%), shrub land (3.3%) and barren land (0.2%). The highest acreage of developed land is in the upper Neuse Basin and is related to the Raleigh metropolitan area. Wetlands are concentrated in the coastal counties/cities of the APES area. Forest wetlands make up approximately 70% of all the wetland types. The largest concentration of agricultural land is in the central portion of the Neuse and Tar-Pamlico Basins. Therefore, conversion of high percentage agriculture (>40%) and wetlands (>30%) is occurring in subbasins that also have a high percentage of development (>5%) and will cause conflicts in land use management.

The Albemarle Sound Basin is very rural, with only the Virginia Beach area experiencing any significant population growth. This growth is pushing south into the coastal portion of Dare County. There are 273 point sources of pollution in the basin; however, most facilities are very small and discharge less than 10,000 gallons per day of treated effluent. Nonpoint sources of pollution appear to have the greatest affect on the basin and total nitrogen and phosphorus loadings are the greatest for the Chowan River, particularly the Blackwater River tributary.

The Currituck Watershed is quite diverse, ranging from the urban characteristics of Virginia Beach in the north to the rural characteristics of Currituck National Wildlife Refuge in the south. There are 17 point sources in the watershed and none have any significant wastewater flow. Agriculture and urban runoff appear to be the largest contributors to water quality problems in the watershed, with total nitrogen and phosphorus loadings among the highest in the entire APES area. The high rate of growth in this area appears to be putting the urban and rural portions of the watershed on a collision course.

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I. BACKGROUND

I-A. Introduction

Population growth and development within the APES watershed has caused the greatest, single environmental impact on the estuarine system. Therefore, a better understanding of the human impact and where it is taking place will be invaluable in developing management strategies for both specific areas of concern and the entire APES area. An evaluation on a subbasin, basin and entire watershed scale is needed to define the extent of human impact on the existing natural resources.

The Albemarle-Pamlico Estuarine Study (APES) has funded many information acquisition projects over the last five years in the areas of resource critical areas, water quality, fisheries, and human environment (Steel and Scully, 1991). Most of these projects have transferred their data over to the APES's Geographic Information System (GIS) which was created through a subcontract with the State Center for Geographic Information and Analysis (CGIA). GIS has the ability to bring together (enter, display, edit, and manipulate) data based information with digital mapping (locational attributes). At the time of this study, the CGIA had or was creating all of the needed data bases. CGIA was able to combine the data layers in various ways to analyze the relationship among different layers in a visual as well as a statistical manner. A further explanation of the available data layers and a description of the actual GIS system components can be found in two other CGIA documents (SCGIA, 1990a and SCGIA, 1990b).

Interaction with and participation of the North Carolina Striped Bass Study Management Board (SBSMB), which is conducting a study of striped bass in Albemarle Sound and the Roanoke River Basin, has greatly facilitated the development of key data layers. Critical to the completion of successful management plans for both studies will be the evaluation of development trends through the utilization of land use information (Rader, 1987 and Brown, 1990).

I-B Purpose

The purpose of this project was to evaluate many other geographic data layers in relation to the existing land use data layer. The effort was to provide a better understanding of the potential effect human development is having on the APES invaluable estuarine system.

I-C. Study Area

The APES study area, as defined in this study, encompasses approximately 23,250 square miles and includes all or portions of 37 counties in eastern North Carolina and 13 counties and 7 independent cities in southeastern Virginia. There are 5 counties and 1 independent city along the coastline, 9 counties along the sounds, and 36 counties and 6 independent cities that lie in the upper drainage basin (Figure 1 and Appendix A). APES incorporates all or portions of 6 major river basins: the Chowan, Pasquotank, Lower Roanoke, Tar-Pamlico, Neuse, and White Oak (Figure 2). Each basin is divided into subbasins: Chowan, 13; Pasquotank, 8; Lower Roanoke, 3; Tar-Pamlico, 8; Neuse, 14; and White Oak, 5.

One approach in describing the APES area is through aquatic ecoregions as defined by Omernik (1987). Ecoregions identify areas of relatively homogeneous ecological systems. The concept was developed to provide a geographic framework for more efficient management of aquatic ecosystems and their components. Omernik defined ecoregions as perceived patterns of a combination of causal and integrative factors including land use, land surface form, potential natural vegetation, and soils. A map of the conterminous United States that defines 76 separate ecoregions was compiled by Omernik in 1986. The APES area is located in two ecoregions that are divided by a line running north and south and generally follows the western border of Isle of Wright, Hertford, Bertie, Martin, Beaufort, Craven and Jones Counties. The Southeastern Plain is the western ecoregion and is described as having a smooth to irregular plain land-surface form;

Figure 1. Map of Study Area

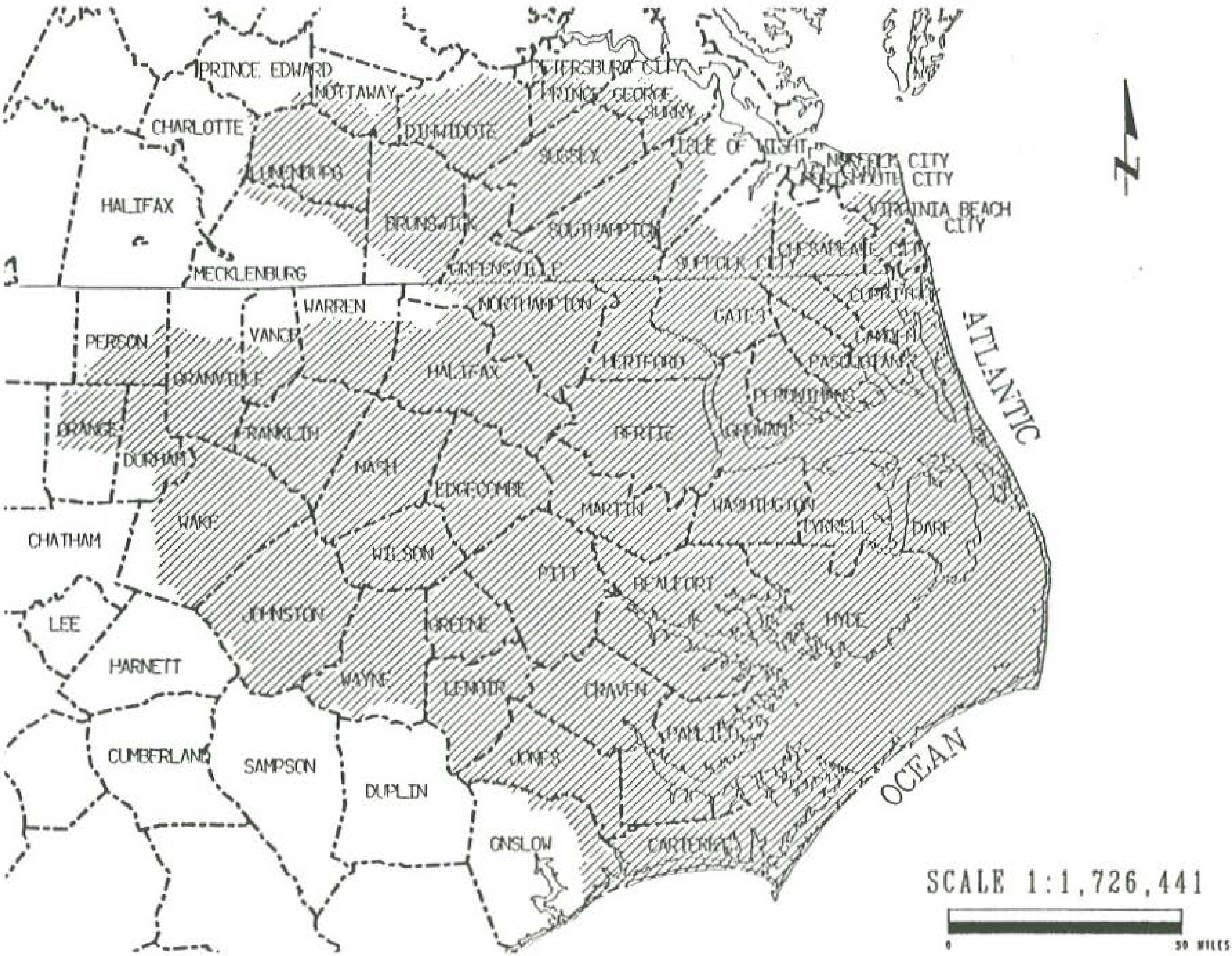


Figure 2. The Six APES Basins and Their Subbasins

oak/hickory/pine and southern mixed forest (beech, sweetgum, magnolia, pine, oak) as the potential natural vegetation; a mosaic of cropland, pasture, woodland, forest, and urban land use; and ultisol soils. The Middle Atlantic Coastal Plain is the eastern ecoregion that lies adjacent to the Atlantic Ocean and is described as having a flat plain land surface form; oak/hickory/pine, pocosin (pine, holly), southern floodplain forest (oak, tupelo, baldcypress), and southern mixed forest (beech, sweetgum, magnolia, pine, oak) as the potential vegetation; woodland, forest with some cropland and pasture, and swamp as the land use; and aquult soils.

II. METHODS OVERVIEW

II-A. Information Sources

This study builds upon two earlier APES projects on land use and population trends. The objective of an earlier project by Khorram et al. (1992) was to obtain current imagery (Winter 1987-88) from the LANDSAT 5 satellite and develop a land use/land cover classification scheme of the entire APES study area. There were 18 separate classifications developed with U.S. Geological Survey's Level I and II classification scheme as seen in Table 1. Accuracy for all Level I classes was 73 percent except urban or built up land, which was 46 percent accurate. The objective of the second project by Tschetter (1989) was to characterize the demographic trends and seasonal population of 33 counties in the North Carolina portion of the APES area. The investigator found that during the 1980's the highest rate of growth in recreational development was connected with private residential housing, motel rooms, and marinas. Peak seasonal population was the greatest in Dare County with four times more people living there in the summer than year-round.

The investigations of Khorram et. al (1992) and Tschetter (1989) were the starting point for an evaluation of the population and land use trends of the entire APES area. A GIS was utilized to combine the land use and population data layers for a number of different years.

II-B. Methods

The idea for determining the relative accuracy of the various classes of land cover/land use was to send the map products to federal, state and local officials who would utilize them for their every day work. These individuals were asked to determine the relative accuracy of these map products based on the officials' particular application. No statistical tests were preformed on the government officials' interpretation of land use maps provided to them for review because it

Table 1. Comparison of USGS and A/P Study Classification

USGS (Anderson et al., 1976)		A/P Study (Khorram et al., 1992)	
Level I	Level II	Level I	Level II
1. Urban or Built-up Land	11. Residential 12. Commercial and Services 13. Industrial 14. Transportation, Communications, and Utilities 15. Industrial and Commercial Complexes 16. Mixed Urban or Built-up Land 17. Other Urban or Built-up Land (Anderson et al.)	Urban or Built-up Land	Low Density Developed Medium Density Developed High Density Developed
2. Agricultural	21. Cropland 22. Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas 23. Confined Feeding Operations 24. Other Agricultural Land (Modified Anderson et al.)	Agriculture/Grasslands	Agriculture/Grass (21) Disturbed
3. Grassland (Herbaceous)	31. Herbaceous Grassland		
4. Forest Land	41. Deciduous Forest Land 42. Evergreen Forest Land 43. Mixed Forest Land (Anderson et al.)	Forest Land	Hardwood (41) Pine (42) Mixed P/H (43)
5. Scrub/Shrub	51. Deciduous Scrub/Shrub 52. Evergreen Scrub/Shrub 53. Mixed Scrub/Shrub (New Classes)	Shrub/Scrub	Low Density Vegetation

USGS (Anderson et al., 1976)		A/P Study (Khorram et al., 1992)	
Level I	Level II	Level I	Level II
6. Water (Deepwater)	61. Marine 62. Estuarine 63. Lacustrine 64. Riverine (Cowardin et al.)	Water	Water
7. Wetland	71. Estuarine Intertidal Herbaceous 72. Estuarine Intertidal Woody 73. Estuarine Intertidal Non-Vegetated 74. Palustrine Forested 75. Palustrine Scrub/Shrub 76. Palustrine Emergent 77. Palustrine Non-Vegetated (Cowardin et al.)	Wetland	Bottomland Hardwood (74) Riverine Swamp (72 and 74) Evergreen Hardwood/Conifer (74) Atlantic White Cedar (74) Low Pocosin (similar to 75) Low Marsh (71) High Marsh (71)
8. Barren Land	81. Dry Salt Flats 82. Beaches 83. Sandy Areas other than Beaches 84. Bare Exposed Rock 85. Strip Mines, Quarries, and Gravel Pits 86. Transitional Areas 87. Mixed Barren Land (Anderson et al.)	Barren Land	Sand (82 and 83)
9. Tundra	91. Shrub and Brush Tundra 92. Herbaceous Tundra 93. Bare Ground Tundra 94. Wet Tundra 95. Mixed Tundra (Anderson et al.)	N/A	
10. Perennial Snow or Ice	101. Perennial Snowfields 102. Glaciers (Anderson et al.)		

was felt that individual interpretation is hard to measure with statistical methods. This phase of the methods section was only to determine whether Level I or Level II classification scheme was the most usable form for this study.

The method was broken into three phases. Phase One was the creation of county land use maps from the existing LANDSAT classification scheme. These map products were sent to the U.S. Fish and Wildlife Service, state, and county officials to determine the relative accuracy of the defined land use classes. The land use maps were also used by the author during flights over the coastal and Raleigh metropolitan areas to further clarify classification errors. Phase Two was to determine a method to correct some of the relative errors in the existing classification. This was carried out by digitizing the corrections to the map products that were returned from the U.S. Fish and Wildlife Service, state, and county officials. The map information was also supplemented with other sources of information such as the U.S. Fish and Wildlife Service - National Wetland Inventory, U.S. Forest Service - Forest Inventory and Analysis, U.S. Bureau of Census - Census of Agriculture and U.S. Soil Conservation Service - National Resources Inventory and Hydric Soils in North Carolina Counties. Phase Three was identifying correlations between different data sets such as county census population and county acreage of developed land. If a strong correlation was found then a simple linear regression model was applied in order to predict the relationship between the two parameters. These models were used to correct some of the error in specific land use categories.

III. ENTIRE STUDY AREA

III-A. Map Development

There were two tasks involved in the development of land use and population maps for the entire APES area: (1) defining the actual drainage area; (2) digitizing all the basin and subbasin boundaries in order to determine the land use and population.

The first task was to define the study area. It was decided to include the entire drainage area of the Albemarle and Pamlico Sound system including Core and Bogue Sounds. The upper Roanoke Basin (above Roanoke Rapids Dam) and a portion of the White Oak Basin (lying southwest from Camp Lejeune Marine Base) were not included. The two areas were excluded for the following reasons: (1) the upper Roanoke River Basin covers approximately 8,370 square miles in Virginia/North Carolina and stretches over two-thirds the length of North Carolina. The combination of low growth, extensive reservoir systems, and distance from the sounds meant the cost/benefit ratio of including this portion of the Roanoke Basin was too low; and (2) a policy decision was made at the start of APES to have Carteret County as the furthest area south. However, due to the watershed approach used in this project to define the study area, all the subbasins in the White Oak Basin are included except the one furthest southwest, for which there was no compatible land use data.

The second task was to digitize all basins and subbasins so population and land use could be estimated. All North Carolina basins and subbasins were digitized by the Research Triangle Institute and compared closely with the U.S. Geological Survey subbasins in North Carolina. Virginia subbasin information was supplied by Information Support Systems Laboratory within Virginia Polytechnic Institute and State University and was based on Soil Conservation Service (SCS) information. Due to the large number of subbasins identified by SCS in the Virginia portion of the Chowan and Pasquotank Basins, subbasins were combined to create areas of similar sizes to subbasins identified in North Carolina. All subbasins were digitized from U.S. Geological Survey's 1:24,000 scale topographic maps. Specific subbasins were identified by a six number code that was broken into two digit sets. The first two digits identified the regional basin; the second two digits identified the basin; and the third two digits identified the subbasin. Codes used in this report were the same ones adopted by the North Carolina Division of Environmental Management.

III-B. Errors in the LANDSAT Data

The next task was to determine any errors in the LANDSAT land use data, to develop methods to correct for these errors, and define the unclassified data referred to as "mixed pixels". Khorram et al. (1992) found that the "urban or built up" land use category was only 46% accurate based on "user's accuracy" estimates and the accuracy of "forested wetlands" was unknown. The land use classification from 1987-88 developed by Khorram et al. (1992) will be referred to as the "LANDSAT" classification in this study. The Khorram classification was based on 1987-88 LANDSAT satellite imagery that was semi-automatically interpreted. The county map series was at a scale of 1:100,000 with a final resolution of 1 acre.

The first decision was to determine what land use classification scheme to be used. LANDSAT land use classification defined 18 separate classes that can be generally broken into similar U.S. Geological Level I and Level II groupings. The land use classification was based on LANDSAT data which Khorram classified mostly as land cover with some land use classes. There is a distinct difference between land cover and land use that should be understood. "Land cover" identifies the actual extent of vegetative and other cover types such as water that exists at any one time. "Land use" is an interpretation of the data as to the inferred use of the land. Therefore, interpretation of land use data is much more subjective and difficult to quantify than interpretation of land cover and is dependent on the background and knowledge of the individual interpreter.

To determine whether the 18 class scheme would serve the purposes of this analysis, a test run was conducted. County land use maps were produced with 18 classes and sent out to have the information on the maps verified. These maps were provided to officials of three National Refuges within the APES area. The Great Dismal Swamp National Wildlife Refuge staff reviewed the LANDSAT land use map of the refuge (Dave Brownlie, Forester, Great Dismal Swamp National Wildlife Refuge, Personal Communication, June 1991). This refuge is located on the border between North Carolina and Virginia just south of Portsmouth, Virginia. The refuge covers approximately 105,000 acres and is predominantly forested wetland. The staff felt there was good clarity among development, agriculture, water, and forest; however, the different forest cover types had serious reliability problems. A major problem was the misclassification of wetter deciduous stands like cypress/gum and maple/gum as pine/hardwood forest. A second land cover map was sent to Mattamuskeet and Swan Quarter National Wildlife Refuges personnel for their review (Kelly Davis, Wildlife Biologist, Mattamuskeet and Swan Quarter National Wildlife Refuges, Personal Communication, April, 1992). These two refuges are located entirely in Hyde County, North Carolina, and Swan Quarter is adjacent to the Pamlico Sound. These refuges together cover approximately 65,800 acres and are predominantly water, wetland, and forest. The staff found quite a few areas that were referred to as "mixed pixels" or unclassified sites that were actually open water or irregularly flooded brackish marshes. The staff also found several "White Cedar stands" that were actually marsh impoundment areas around Lake Mattamuskeet, and several "pine forests" that were actually mixed pine/hardwood or hardwood/cypress/pine forest. In general, both refuges indicated errors with the different forest and the mixed pixel classifications.

The Level II (18 classes) land cover maps were also sent early in the study to the counties that lie in the Currituck Sound Basin located south of Virginia Beach and adjacent to the Atlantic Ocean. Many map variations were sent to these county or state officials for their comment. The county or state officials could not evaluate all the classifications found in the Level II because of the time limitation and having little knowledge of a particular class such as wetlands.

Based on the comments by the U.S. Fish and Wildlife Service and county or state officials in the trial run, it was decided that the final map type to be sent to all county officials for comment would have the following attributes: LANDSAT land cover/land use data displayed at the USGS Level I with 6 categories shown in color, road network displayed from U.S Census TIGER files, map scale of 1:100,000, and modified Land Use Data Analysis (LUDA) land use data utilized to better define the urban or built up category.

LUDA was an early GIS effort started by U.S. Geological Survey in 1975 to define the land use for the entire United States (Kleckner, 1981). Source images were 1:56,000 color infrared photography and 1:80,000 black and white photography dating back to 1970. All the photography was manually photo-interpreted. The map series included 1:250,000 scale maps of North Carolina defining 37 uses based on the Level II classification system. Resolution was 10 acres for the urban or built up categories and 40 acres for the remaining classifications (Robert Johnson, U.S. Geological Survey, Personal Communication, Reston, Virginia. June, 1991).

In 1991 and 1992, the author flew over portions of the coastal and Raleigh metropolitan areas to further define possible errors with the LANDSAT land use data. A flight along the Outer Banks and inland around the estuarine portion of the study area was provided by the North Carolina Division of Marine Fisheries. The fight occurred in December, 1991. A second flight covering portions of Wake, Durham, and Orange Counties was provided by the North Carolina Wildlife Resources Commission, occurred in January, 1992. Both flights were conducted to verify the problems with the categories of urban or built up, wetland, and unclassified areas (mixed pixels). The urban or built up class appeared to be underestimated on the LANDSAT 1987-88 land use maps mainly due to forest crown cover that obscured the true land use on the ground. This changed the overall percentage of urban land from 2.5 on the original LANDSAT classification to 4.8 on the modified LANDSAT classification. High spectral reflectance of bare agricultural fields led them to be classified as developed areas. The problem with fields being identified as developed areas was especially evident in the LANDSAT scene that includes the Raleigh metropolitan area. During the flight reconnaissance and for the remainder of the study, a state topographic atlas for Virginia and North Carolina produced by DeLorme (1989 and 1992) was utilized to identify specific locations throughout the APES area. A comparison of LUDA, LANDSAT and corrected LANDSAT urban class acreage for 21 counties is presented in Appendix B.

The problems associated with the wetland class were found to be the result of interference from forest crown cover. Wetlands were erroneously classified as "forest". This changed the overall percentage of wetlands from 10.9 on the original LANDSAT classification to 20.5 on the modified LANDSAT classification. Open marsh and pocosin wetlands were usually accurately defined by the LANDSAT 1987-88 land use maps but closed forest canopy prevented standing water below the forest to be seen. Therefore these true wetland types were usually defined as forest. A comparison of LUDA, LANDSAT and National Wetland Inventory (NWI) wetland class acreage for 14 counties is presented in Appendix C.

The category of "mixed pixels" represents a grouping of land uses that could not be identified. This classification accounted for 0.3 percent of the original LANDSAT classification. Flights over the coastal and Raleigh metropolitan areas verified that in most cases mixed pixels were a mixture of standing water and wetland vegetation. The only exception to this observation was in Pasquotank County where poorly drained agricultural land had been defined as "mixed pixels" or "wetland".

These land use classification problems and others were identified at a workshop the author attended to verify remotely sensed land cover data for the Coastwatch Change Analysis Program of the National Oceanic and Atmospheric Administration (Burgess et al., 1992). The findings were categorized into four topics: classification error, cover versus land use, categorical resolution and change detection. Classification errors included "salt and pepper" effect of individual pixels, shadows and bare ground as urban areas, and problems with the degree of wetness during image acquisition. Cover versus land use describes the inherent problem of distinguishing between land uses and required ancillary information. Categorical resolution is related to spatial resolution and improper classification. Change detection describes the ability to detect a change but not necessary the nature of the change. From the author's own observations and the results of this workshop, methods were developed to overcome some of the problems associated with remotely sensed land cover data.

III-C. Land Use Map Corrections

Land use information was analyzed according to the Khorram et al. (1992) classification system but condensed from 18 to 7 categories (Table 2). Certain corrections were incorporated into some classes depending on the observed and reported error associated with each class. The LUDA data were used only to determine "developed land" because the information appeared to have the proper latitude/longitude coordinates and to be closer to the actual size of the land encompassed than the original 1987-88 LANDSAT data set. Corrected LANDSAT built up areas on the maps returned by the county or state officials were found to

Table 2.

LAND USE CLASSES FOR
THE ALBEMARLE-PAMLICO ESTUARINE STUDY*

Name	Description
Urban/Developed	Residential, commercial, and industrial development
Agriculture/Grass	Cropland and pasture, including bare and grass covered soil
Shrub Land	Area having some vegetative cover; can include old field, utility corridor and vegetative covered spoil pile
Barren Land	Bare, dry sandy soil; can include sand dune, bare sandy ridge and highly reflective agricultural soil
Forest	Stand of conifer, deciduous, and mixed conifer/deciduous with evergreen hardwood shrub
Wetland	Bottomland hardwood, Atlantic White Cedar, riverine swamp, low pocosin, irregularly flooded marsh and regularly flooded marsh
Water	Lake, reservoir, pond, estuary, sound and large stream or river

* a U.S. Geological Survey Level I classification scheme was used because a more detailed Level II scheme was not found to be reliable at a county scale

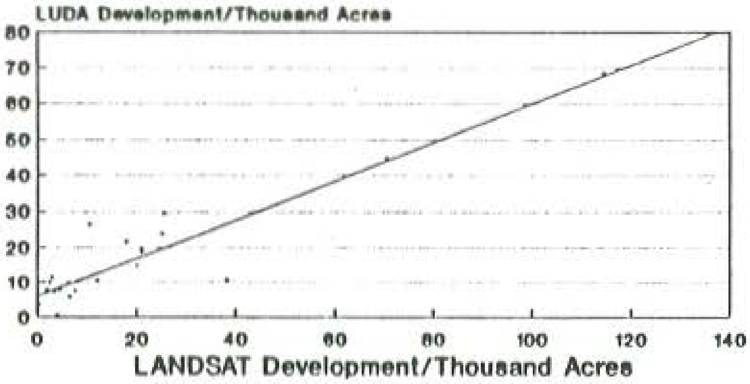
have a higher degree of correlation (R-squared of 0.9) with the LUDA "developed" category than LANDSAT maps (R-squared of 0.7). A linear regression model was used to predict built up land from the LUDA data (Figure 3). U.S. Fish and Wildlife Service's NWI data were used as a source of wetland acreage for the coastal plains of North Carolina (Wilen, 1990 and Burgess at al., 1992). Wetland acreage for twelve of the coastal counties was obtained from an article by Morehead (1992). There was a high correlation between LANDSAT and the NWI county wetland acres (R-squared of 0.9) and a simple linear regression model was used to predict wetland acres from the NWI values (Figure 4). The actual character of the "mixed pixel" class was determined by the U.S. Fish and Wildlife Service personnel and 2 overflights of the APES area to be predominantly wetlands. The "mixed pixel" figures were incorporated into the wetland classification. All the corrections to the original LANDSAT data lead to the development of 1990 land use statistics. These corrections were solely based on the information provided from the sources cited above and error statistics can not be provided for the various interpretations of the land use data set.

III-D. County Population Statistics

Population change data for the study area were compiled from U.S. Census data (U.S. Census Bureau, 1960, 1970, 1980, 1990). Compatible census data for Virginia for 1970 was not available for the basin evaluation but was presented on a county level. The data will first be presented on a county level and then presented on a basin and subbasin level.

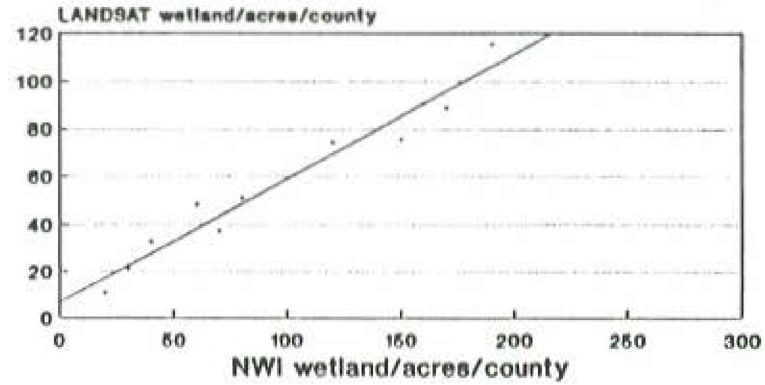
The 1990 census found the population of the U.S. to be almost 250 million people, an increase of 9.8% from the 1980 census. Since 1980, population in North Carolina had increased by 12.7%, and in Virginia by 15.7%. Over the same ten year period, the counties that make up the APES area grew, on average, 19.4%. This is double the national rate.

Figure 3.
North Carolina Land Use: Development



1972 LUDA/1987-90 LANDSAT

Figure 4
North Carolina Land Use: Wetlands



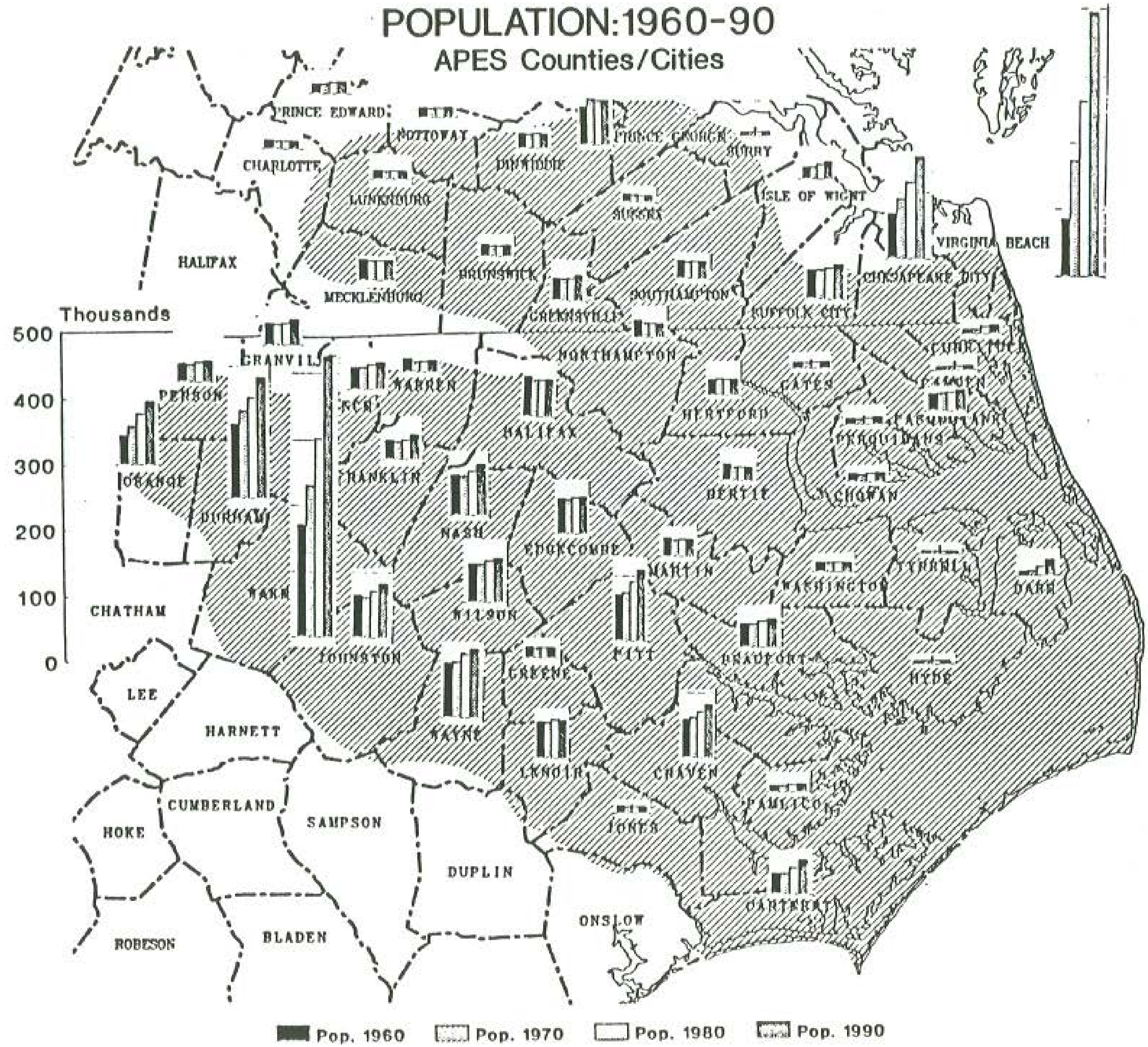
1982 NWI/1988 LANDSAT

1990 county population within the APES area ranged from a low of 3,856 in Tyrrell County to a high of 423,380 in Wake County. (Complete county/city population data for 1960, 1970, 1980, 1990, 2000 and 2010 can be found in Appendix D and the percent change statistics for each county/city can be found in Appendix E). When all the counties' population for 1960 through 1990 are displayed as bar charts a distinct pattern is evident (Figure 5). In very general terms the greatest population is in the counties that make up the southwestern portion of the study area and the lowest population is in the counties that make up the northeastern portion of the study area. The Virginia Beach metropolitan area is an exception.

When the rate of growth is compared for the three census periods in each county, the rapid expansion of more metropolitan areas become even more apparent (Figure 6). Growth occurs at the edge of the population centers and spills over into the surrounding areas. This is most evident in the Virginia Beach metropolitan area with the spill over into Currituck and Dare Counties. The same trend is seen in the Raleigh area with the spill over from Durham into Orange County. One isolated area also emerges as having fairly high growth rates: the counties of Pitt, Craven and Carteret. This third high growth area has not experienced the 50 and 60% average growth rates of the Virginia Beach and Raleigh regions but has seen continued growth in the 10 to 20% range. The highest growth rate average over the thirty year period is Virginia Beach at 68.9%, closely followed by Currituck County with 59.7%.

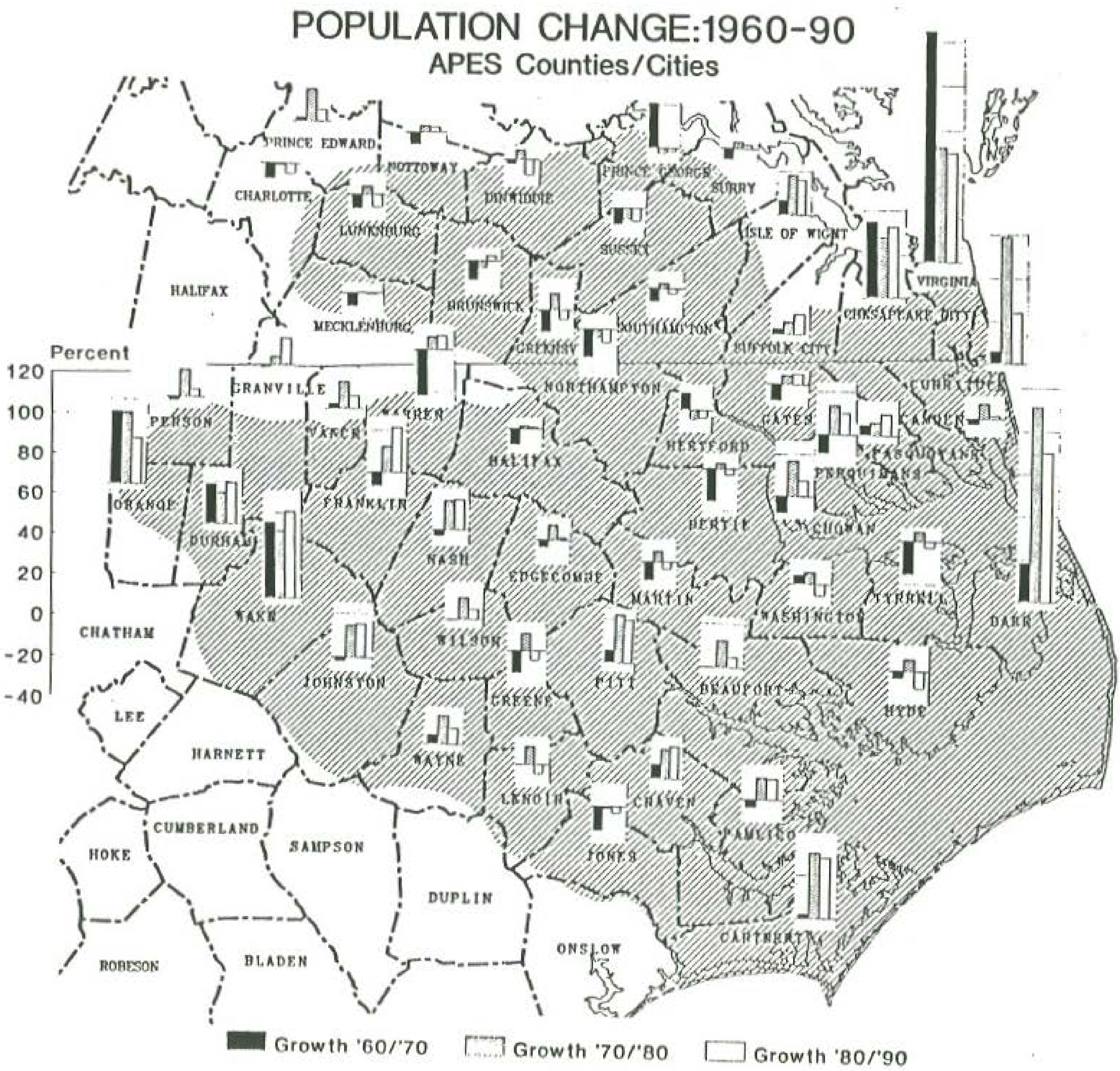
In contrast to the experience of the majority of counties in the study area are some parts of the region did not grow. Over the thirty year period Northampton County experienced an 8.0% population loss followed by Sussex County which lost 6.2% of its 1960 population. A total of 20 counties lost population over the thirty year period - Bertie, Greene, Halifax, Hertford, Hyde,

Figure 5.


POPULATION:1960-90
APES Counties/Cities
Thousands
500
400
300
200
100
0
PRINCE EDWARD
NOTTOWAY
CHARLOTTE
DINWIDDIE
PRINCE GEORGE
SURRY
ISLE OF WIGHT
SUSSEX
HALIFAX
MECKLENBURG
BRUNSWICK
SOUTHAMPTON
SUFFOLK CITY
CHESAPEAKE CITY
VIRGINIA BEACH
GRANVILLE
PERSON
WARREN
NORTHAMPTON
GATES
HERTFORD
ORANGE
DURHAM
FRANKLIN
NASH
EDGECOMBE
BERTIE
CHOWAN
CHATHAM
WAKE
WILSON
MARTIN
WASHINGTON
TYRRELL
DARE
JOHNSTON
GREENE
PITT
BEAUFORT
HYDE
LEE
HARNETT
WAYNE
LENOIR
CRAVEN
CUMBERLAND
SAMPSON
JONES
PAMLICO
HOKE
DUPLIN
CARTERET
ROBESON
BLADEN
ONSLOW
Pop. 1960
Pop. 1970
Pop. 1980
Pop. 1990

19

Figure 6.


POPULATION CHANGE:1960-90
APES Counties/Cities
Percent
120
100
80
60
40
20
0
-20
-40
PRINCE EDWARD
NOTTOWAY
CHARLOTTE
LUNENBURG
DINWIDDIE
PRINCE GEORGE
SURRY
SUSSEX
ISLE OF WIGHT
HALIFAX
MECKLENBURG
BRUNSWICK
GREENSV
SOUTHAMPTON
SUFFOLK CITY
CHESAPEAKE CITY
VIRGINIA
GRANVILLE
PERSON
VANCE
WARREN
NORTHAMPTON
HERTFORD
GATES
CURRITUCK
CAMDEN
PASQUOTANK
PERQUIMANS
CHOWAN
BERTIE
HALIFAX
ORANGE
DURHAM
FRANKLIN
NASH
EDGECOMBE
MARTIN
WASHINGTON
TYRRELL
DARE
WAKE
CHATHAM
JOHNSTON
WILSON
GREENE
PITT
BEAUFORT
HYDE
LEE
HARNETT
WAYNE
LENOIR
CRAVEN
JONES
PAMLICO
CARTERET
CUMBERLAND
HOKE
SAMPSON
DUPLIN
ONSLOW
ROBESON
BLADEN
Growth '60/'70
Growth '70/'80
Growth '80/'90

Jones, Martin, Northampton, Tyrrell, and Warren in North Carolina and Brunswick, Charlotte, Dinwiddle, Greenville, Lunenburg, Mecklenburg, Nottoway, Southhampton, Surry, and Sussex in Virginia. Most of these counties are located in the northern portion of the study area; 15 of the 20 are in the Chowan Basin and have shown little if any growth over thirty years. In summary, population growth within the APES area is not uniform; different parts of the areas face different challenges in dealing with population changes. For example, the Virginia Beach/Chesapeake City and Wake/Durham areas have both large population bases and continue to grow at rapid rates. On the other hand, the Washington/ Tyrrell/Hyde Counties and Nottoway/Lunenburg/ Brunswick Counties have small population bases and are not growing. Metropolitan areas are rapidly expanding outward while most rural areas are experiencing little if any growth based on the population census from 1960 to 1990.

III-E. Basin and Subbasin Population

The basin and subbasin population data were analyzed on the basis of density (persons per square mile [per./sq. mi.]) to compensate for shifts in tracts boundaries over time. A change in density is a surrogate for a change in population. The population densities for basins and subbasins in the APES area can be found in Appendix F. To provide some perspective on the densities that exist, the average density for the United States during the 1990 census was 69 per./sq. mi. During this same census the average density for North Carolina was 126 per./sq. mi. and Virginia was 152 per./sq. mi.

Subbasins will be identified by their six number code as seen in Figure 2. When Virginia subbasins are identified, they may have an extra letter after the six number code. The extra letter is needed in order to correspond with the North Carolina Division of Environmental Management's coding system that was used in this study.

The Chowan Basin is subdivided into 13 subbasins and only 3 subbasins are entirely located in North Carolina. Population densities in 1990 range from 25.1 to 86.8 per./sq. mi. The highest population density appears to be in Subbasin 03-01-04 and associated with the Town of Edenton (Figure 7).

The Pasquotank Basin is subdivided into 8 subbasins, and all but 2 subbasins are located entirely in North Carolina. Population densities in 1990 range from 2.2 to 184.1 per./sq. mi. The highest population density is in Subbasin 03-01-54A and associated with the Virginia Beach and Chesapeake City (Figure 8).

The Lower Roanoke Basin is subdivided into 3 subbasins, and 1990 per./sq. mi. varies from 32.6 to 107.0. The highest population density is in Subbasin 03-02-08 and associated with the City of Roanoke Rapids (Figure 9).

The Tar-Pamlico Basin is subdivided into 8 subbasins, and 1990 per./sq. mi. ranges from 3.4 to 222.5. The highest population density is in Subbasin 03-03-05 and associated with Greenville area (Figure 10). Review of the 1970 and 1980 census data reveals that growth has taken place in two upstream Subbasins (03-03-01 - Oxford/Louisburg areas and Subbasin 03-03-02 - Rocky Mount area). In the remaining subbasins (03-03-03, 03-03-04, 03-03-06, 03-03-07, and 03-03-08), little growth is taking place.

The Neuse Basin is subdivided into 14 subbasins, and 1990 per./sq. mi. range from 2.4 to 539.4. The highest population density is in Subbasin 03-04-02 and associated with the Raleigh area (Figure 11). A review of the 1980 and 1970 census data reveals that significant growth has taken place in 6 subbasins including 03-04-01 (Durham/N. Wake County), 03-04-02 (Raleigh area), 03-04-03 (Middle Creek area), 03-04-06 (Zebulon and West Goldsboro areas), 03-04-09 (South Greenville), and 03-04-10 (Havelock and New Bern areas). The remainder of the subbasins, 03-04-04, 03-04-05, 03-04-07, 03-04-08, 03-04-11, 03-04-12,

Figure 7
Chowan Basin Population Densities

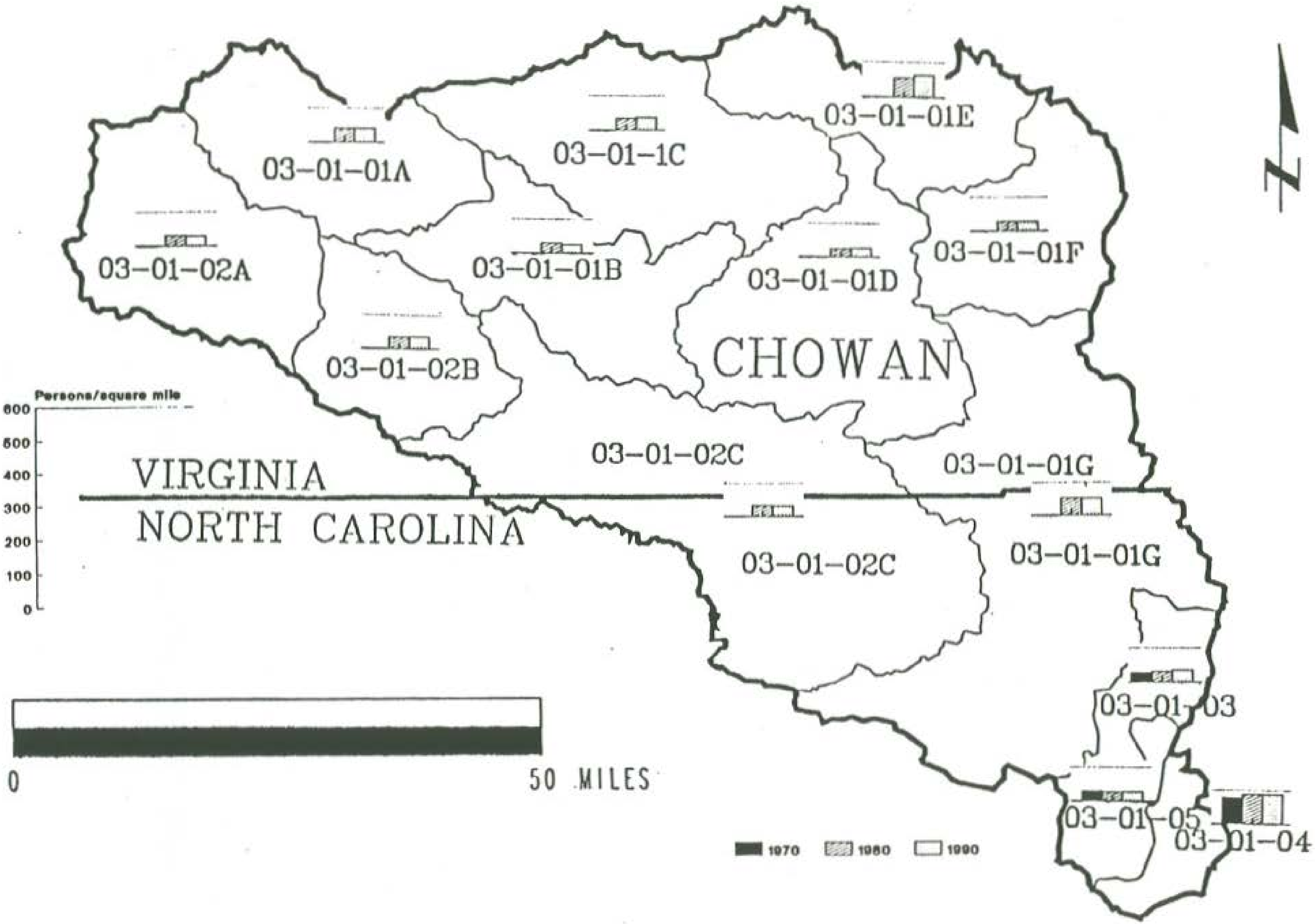


Figure 8.
Pasquotank Basin Population Densities

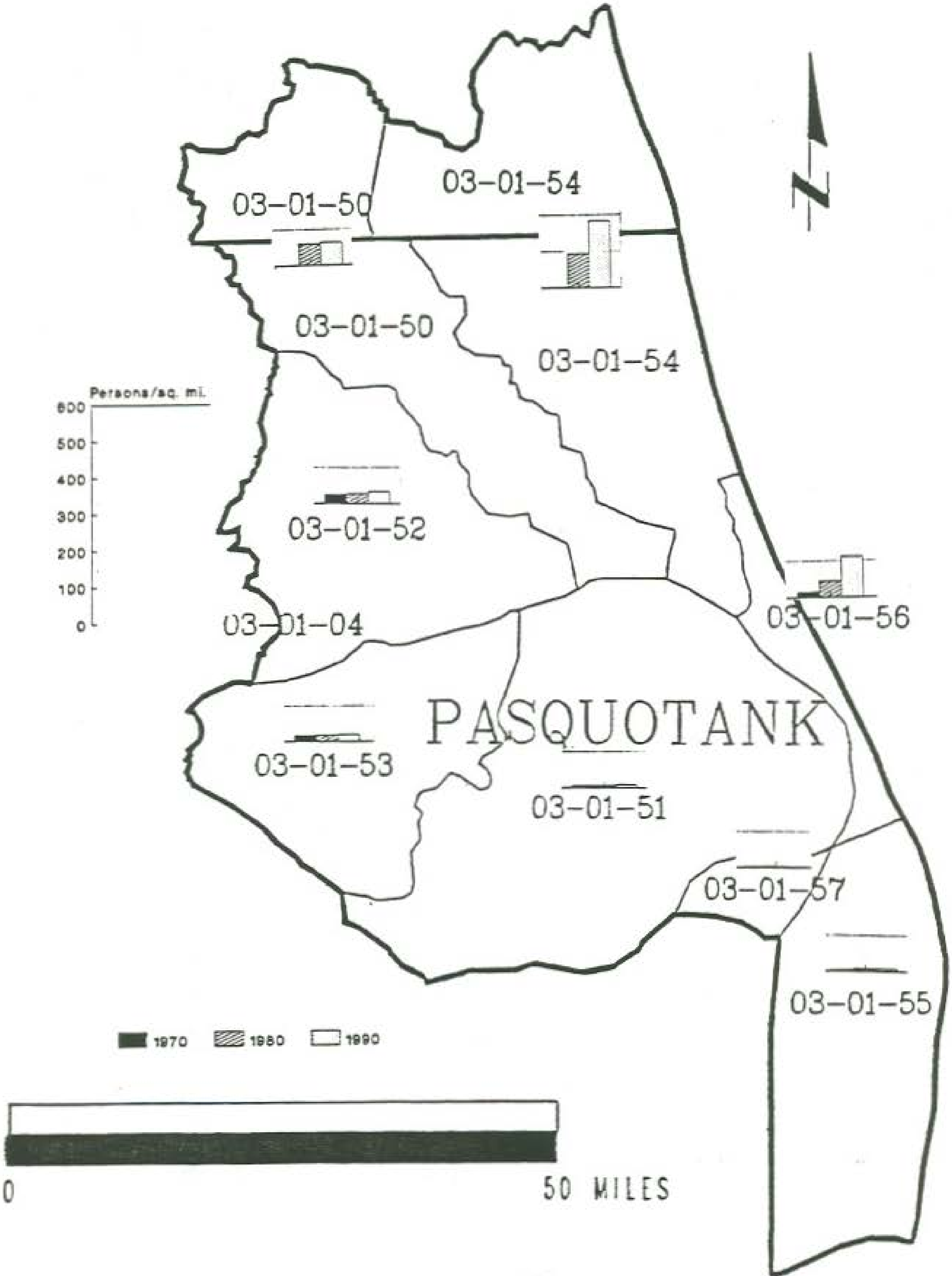


Figure 9.
L. Roanoke Basin Population Densities

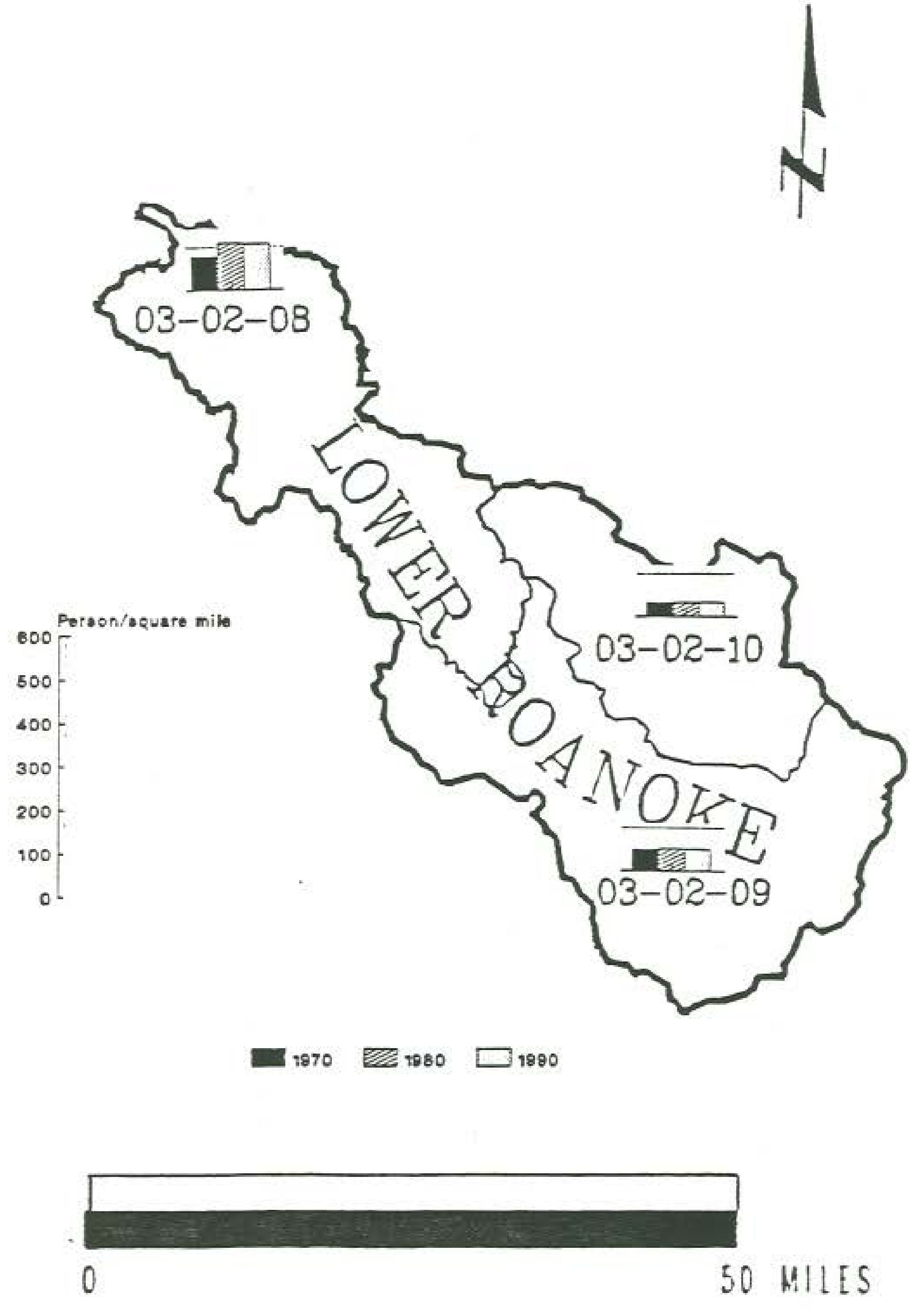


Figure 10.
Tar-Pamlico Basin Population Densities

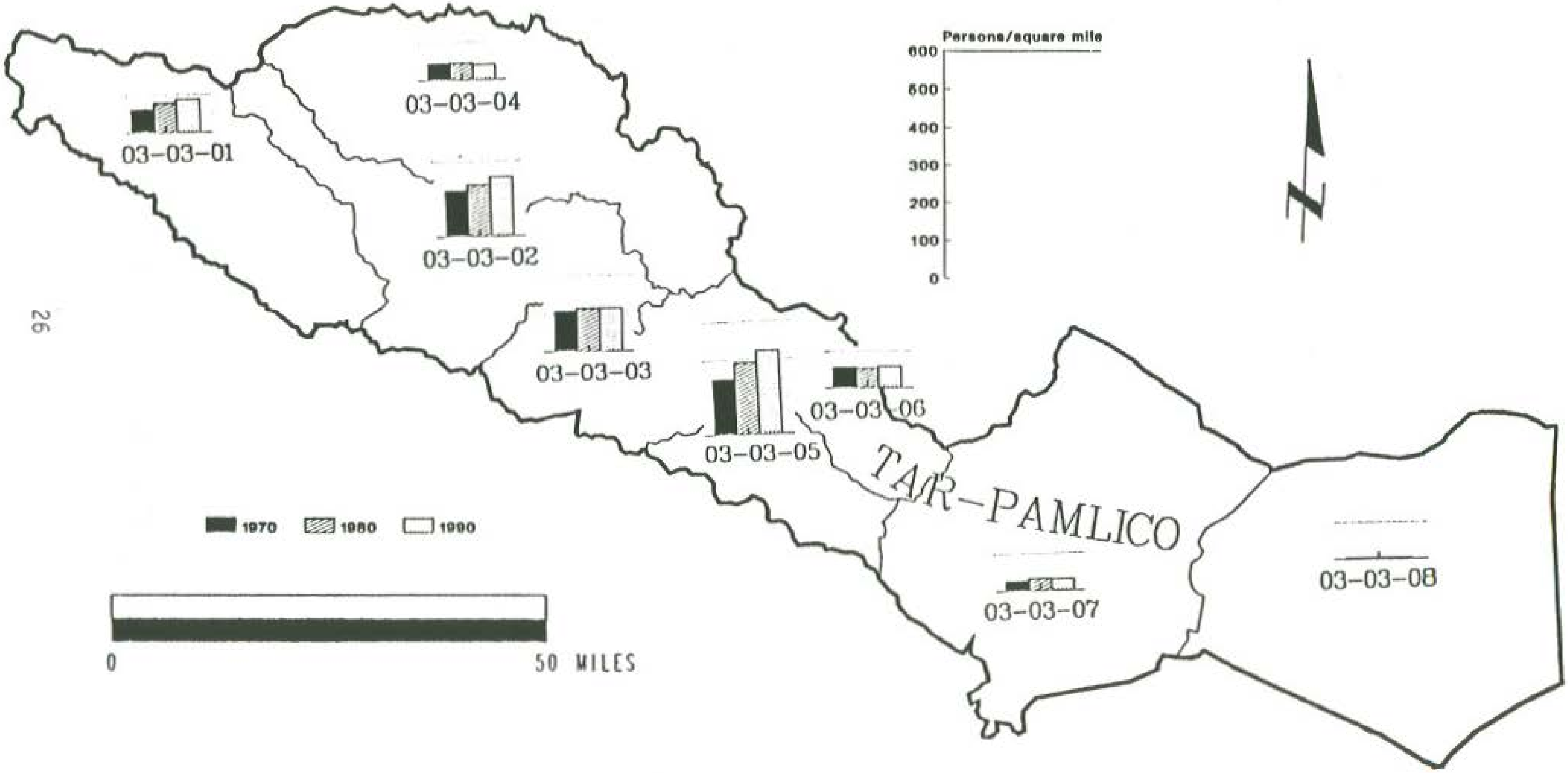
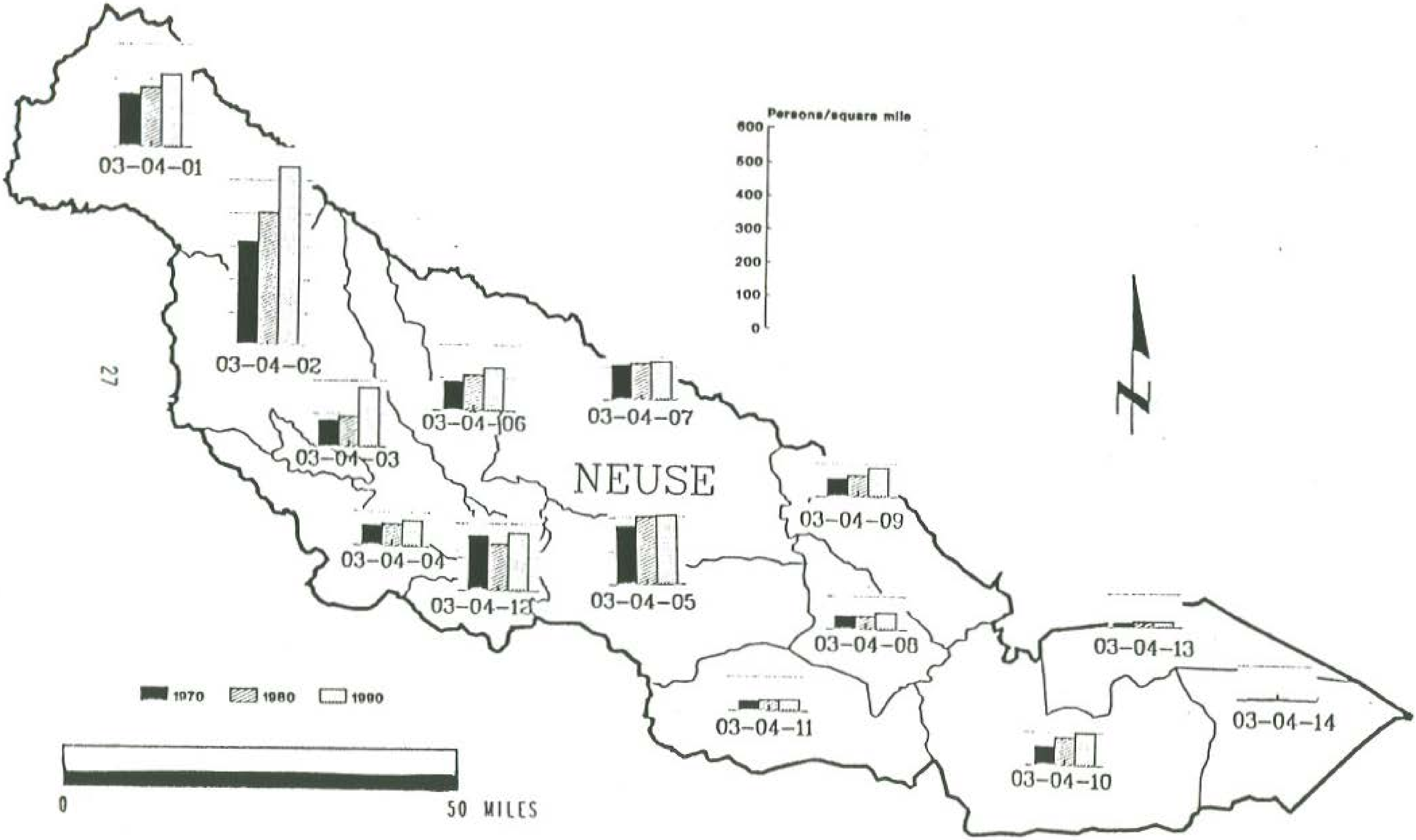


Figure 11.
Neuse Basin Population Densities



03-04-13, and 03-04-14, showed little or no growth during the 30 year period. Subbasin 03-04-14 (located on the eastern tip of Carteret County in the Cedar Island area and consisting mostly of open water and wetland) showed negative growth during this same period.

The White Oak Basin is subdivided into 5 subbasins, and all but one (Subbbasin 03-05-02) are within the study area. Population densities range from 15.2 to 170.9. The highest population density is in Subbasin 03-05-03 and associated with the Morehead City and Atlantic Beach areas (Figure 12). A review of the 1980 and 1970 census data indicates that the remaining subbasins (03-01-01, 03-05-04, and 03-05-05) showed no significant growth during the 30 year period.

Specific population patterns for the APES area can be observed from the subbasin population densities that are equal to or greater than 69 per./sq. mi. (Figure 13). The Chowan Basin has higher density only in the most downstream subbasin (03-01-04) associated with the City of Edenton, and the Pasquotank Basin is experiencing a great deal of growth associated with the Outer Banks (03-03-54 and 03-03-56) in the areas of Nags Head and Duck. The Lower Roanoke Basin is experiencing growth in the upstream subbasin (03-02-08) related to City of Roanoke Rapids and the Tar-Pamlico Basin is experiencing growth in the four upstream subbasins (03-02-01, 03-02-02, 03-02-03 and 03-02-05) associated with Cities of Oxford, Louisburg, Rocky Mount, Tarboro and Greenville areas. The Neuse Basin is experiencing rapid growth particularly in the eight upstream subbasins (03-04-01, 03-04-02, 03-04-03, 03-04-04, 03-04-05, 03-04-06, 03-04-07 and 03-04-12) associated with the Cities of Durham, Raleigh, Smithfield, Wilson and Goldsboro areas. There is also growth taking place in lower basins (03-04-09 and 03-04-10) associated with the Cities of Greenville, Havelock, and New Bern. While the data do not show subbasin census tracts it is logical to

Figure 12.
White Oak Basin Population Densities

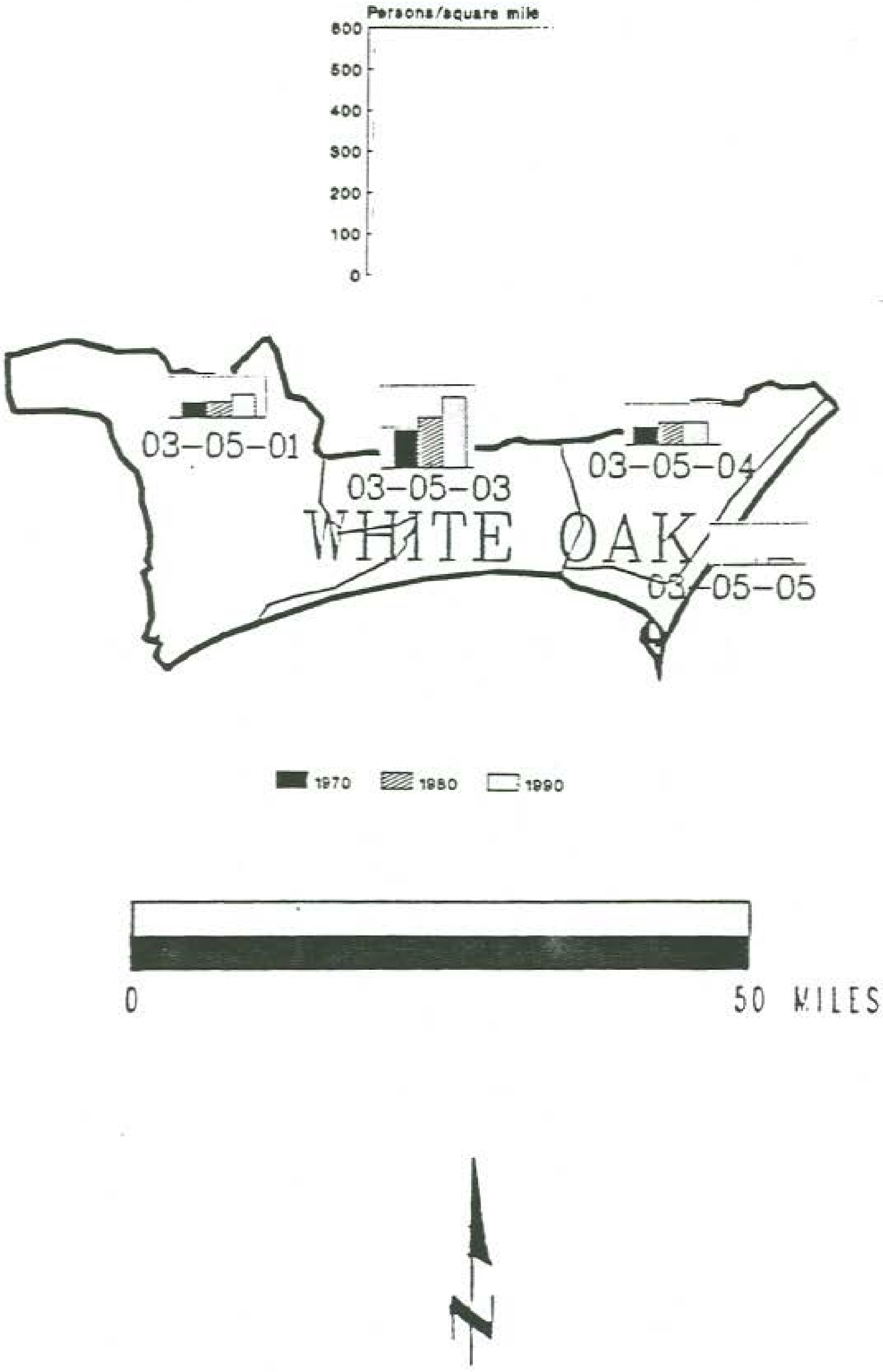


Figure 13. Population Density by Subbasin: 1990

assume that the growth in these indicated subbasins is not occurring throughout each subbasin but is localized.

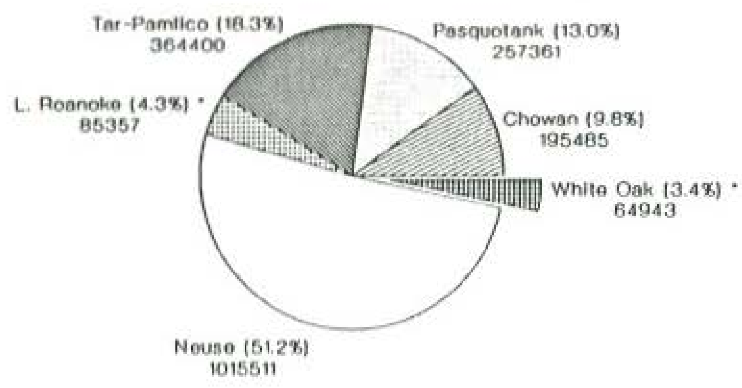
In summary, the APES region population data for the census years of 1970, 1980, and 1990 were evaluated on a subbasin level. Both county and basin/subbasin data were reviewed to determine trends in the population of the APES area in 1990. The population of the study area was almost 2 million people with 53.1% residing in the Neuse Basin which occupies only 26.8% of the land area (Figures 14 and 15). Together the Chowan, Tar-Pamlico, and Neuse Basins comprised 72% or 16,937 square miles of the APES area. Average population density for the basins ranged from 136.5 per./sq. mi. in the Neuse to 40.1 per./sq. mi. in the Chowan.

Generally, the region with the greatest population is located in the North Carolina Piedmont. The one exception is the Virginia Beach metropolitan area located in the extreme northeastern corner of the study area adjacent to the Chesapeake Bay. In contrast, the Chowan Basin located in the northeastern portion of the study area, 71% of the counties lost population over the 30 year period from 1960 to 1990. This basin is heavily engaged in the agriculture and forest product industries. A large population base is not needed to maintain these commercial activities and the basin has remained rural. The trends indicate that the metropolitan areas of Raleigh and Virginia Beach will continue to expand downstream in their respective basins and most rural areas will remain the same or lose population in the future.

III-F. Land Use Statistics: Basins

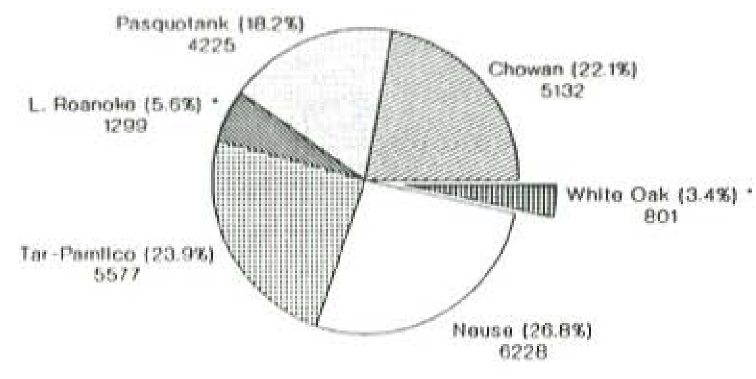
There were seven classes with the following percentages: urban (4.8%), agriculture (28.1%), forest (28.4%), water (14.6%), wetland (20.5%), shrub land (3.3%), and barren land (0.2%) (Figure 16). However, the class of water is not a true land use and will be discussed separately from the other six land use classes.

Figure 14.
APES Basin Populations in 1990



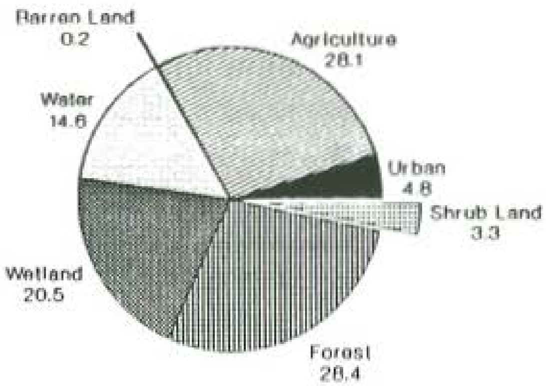
* Only a portion of these basins

Figure 15.
Area of APES Basins in Square Miles



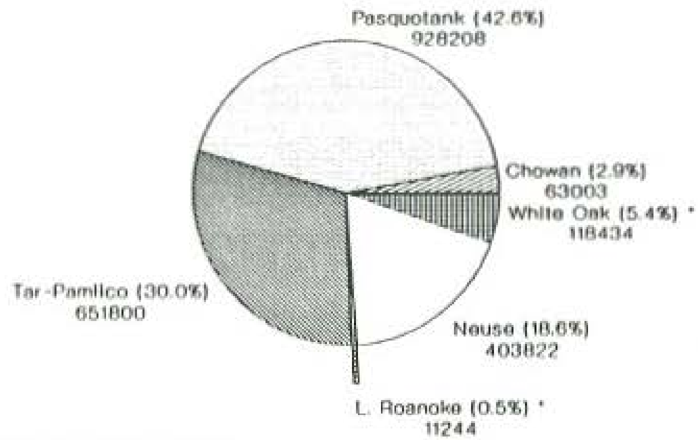
* Only a portion of these basins

Figure 16.
LAND USE/LAND COVER: 1987-1990



Modified 1987-88 LANDSAT Data

Figure 17.
Water Acreage for Each Basin: 1987-1990



*** Only a portion of these basins**

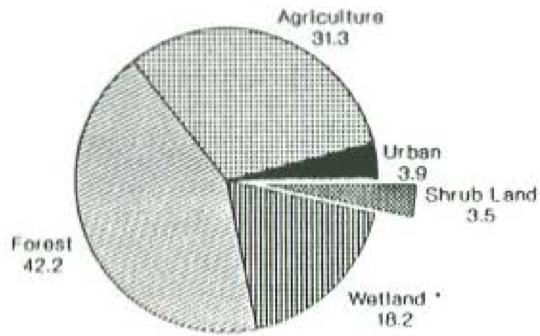
In general, the study area is rural in nature with less than 5% of the total area developed. More than 50 percent of the total APES acreage is in the categories of agriculture and forest.

When each basin is compared to the other five basins, the Pasquotank Basin has the largest percentage of water (928,208 acres) in the APES area (Figure 17). This fact is not surprising because this basin lies entirely in the coastal plain and encompasses many water bodies including 4 sounds, 7 rivers, 5 lakes and 1 bay. The basin with the second largest number of acres of water (403,822) is the Tar-Pamlico and includes 3 rivers, 17 bays and 1 sound. Because of the amount of water found in these basins there is a higher potential that land based pollution will reach the aquatic environment especially the estuarine areas. The remaining discussion in this section (III-F) and the next section (III-G) will not include the class water as part of the analysis.

Urban use ranges from 3.9% in the Chowan Basin to 8.8% in the Neuse Basin. Agriculture ranges from 12.0% in the White Oak Basin to 37.7% in the Tar-Pamlico Basin. Forest ranges from 16.5% in the White Oak Basin to 42.2% in the Chowan Basin. Wetlands range from 18.2% in the Chowan Basin to 57.2% in the White Oak Basin. Shrub Land ranges from 1.4% in the Pasquotank Basin to 6.3% in the Lower Roanoke Basin. Barren Land ranges from 0.0% in the Chowan and Lower Roanoke Basins to 0.8% in the Pasquotank and White Oak Basins. Figures 18-23 provide the 1990 land use for each basin.

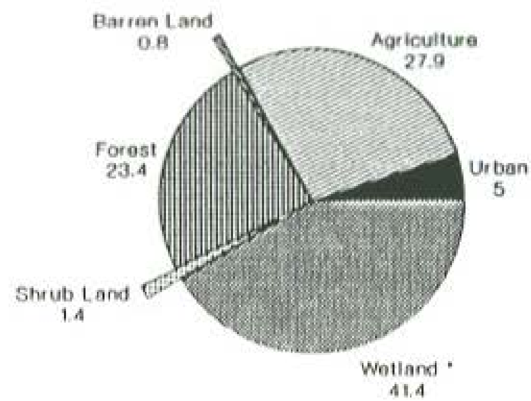
In general, while similar percentages of land uses exist in all the basins there are some clear exceptions. For instance, the Pasquotank and White Oak Basins are dominated by wetlands -- 41.4 and 57.2% respectively. The rural Chowan Basin has a high percentage (74.0%) of forest and agriculture land use while both the Neuse and White Oak basins are relatively developed. The White Oak has a low

Figure 18.
Chowan Basin Land Use: 1987-1990



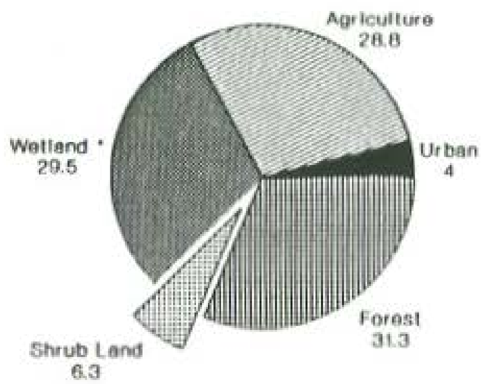
* does not include water

Figure 19.
Pasquotank Basin Land Use: 1987-1990



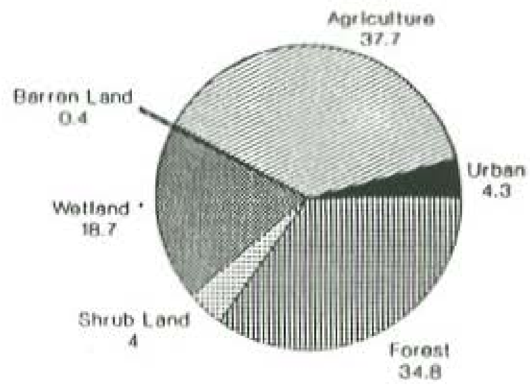
* does not include water

Figure 20.
L. Roanoke Basin Land Use: 1987-1990



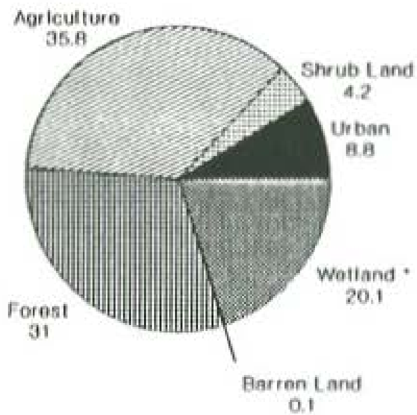
* does not include water

Figure 21.
Tar-Pamlico Basin Land Use: 1987-1990



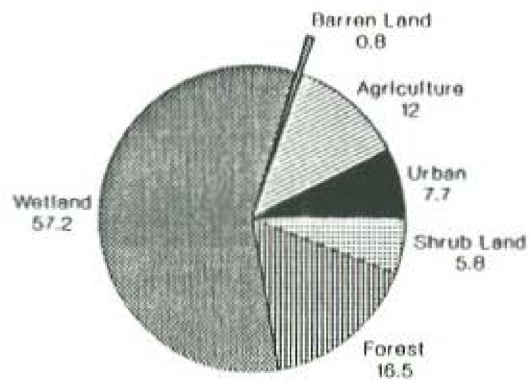
* does not include water

Figure 22.
Neuse Basin Land Use: 1987-1990



* does not include water

Figure 23.
White Oak Basin Land Use: 1987-1990



* does not include water

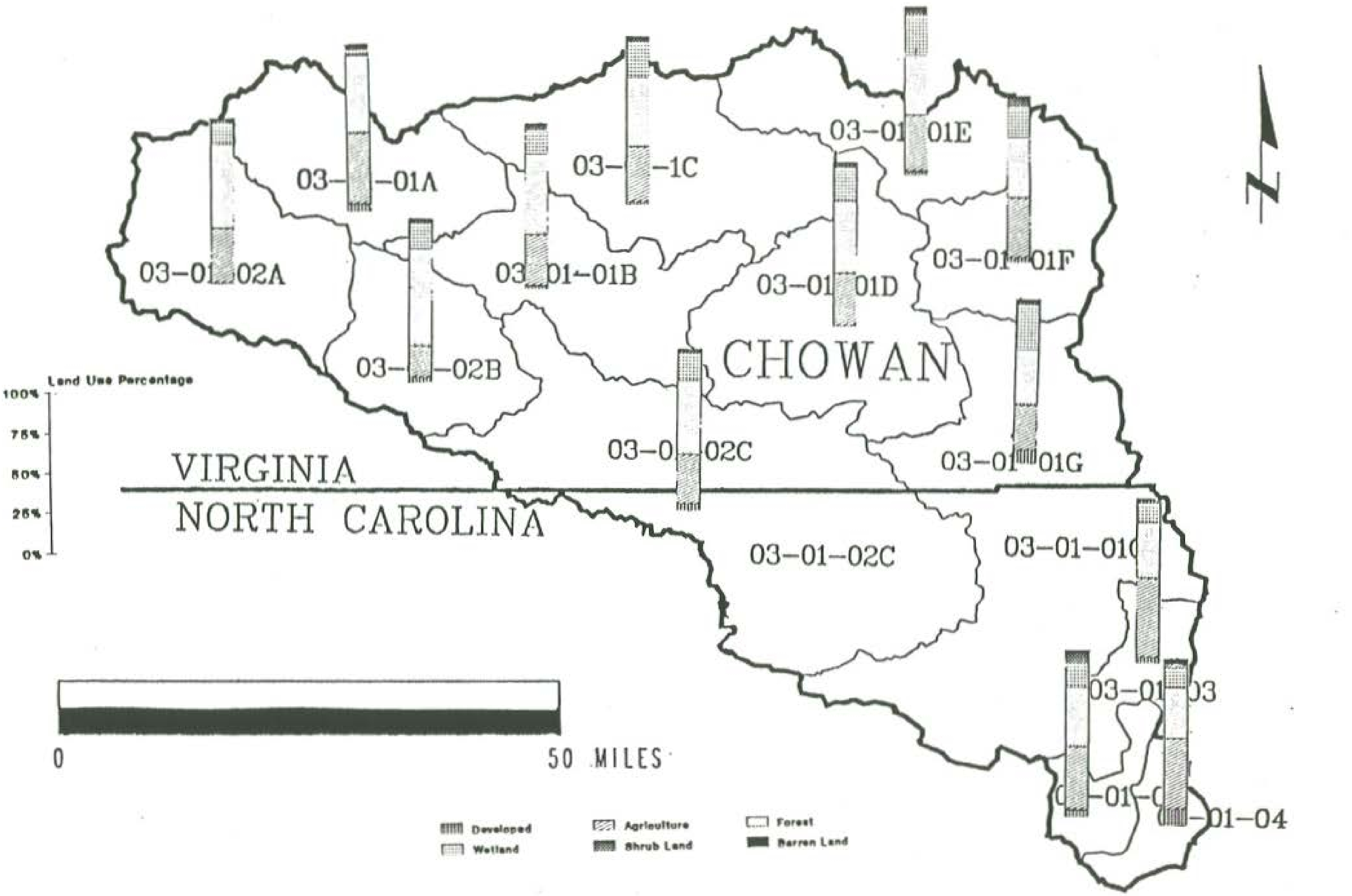
percentage of agricultural land, which may be due to the high percentage of land in the wetland category. The percentage of shrub land is the highest in the White Oak and Lower Roanoke Basins and may reflect the high pocosins in the White Oak and young pine plantations in the Lower Roanoke. The percentage of barren land is the highest in Pasquotank and White Oak Basins and appears to be mainly associated with sandy beaches along the Outer Banks. This category also includes highly reflective soil associated with the many scarps (old shorelines) located along the Coastal Plain of North Carolina. A listing of all the land uses including water with their associated percentages and acres for each basin and subbasin can be found in Appendix G.

III-G. Land Use Statistics: Subbasins

A graphical comparison has been made of land uses in subbasins within each basin (Figures 24-29). The sizes of these subbasins vary from 51 to 1225 square miles, with the average size being 455 square miles.

The Chowan Basin has 13 subbasins that drain three main tributaries of the Blackwater, Nottoway and Meherrin Rivers. Each subbasin in the Chowan Basin can be described from a land use perspective as seen in Figure 24. Overall, the headwater portion of the basin is very rural with more than 70 percent of the land use in forest and agriculture. The urban land use varies from 1.3 to 10.0 percent and becomes more prominent near the river mouth. Agriculture is fairly consistent through out the basin with percentages ranging between 26.4 and 47.9 except for Subbasin 02B with 19.0%. The forest classification is also consistent through out the basin and ranges from 29.8 to 59.4. Wetlands range from 3.1 to 26.7% and increases downstream to a maximum in Subbasin 01G where the Blackwater and Nottoway Rivers merge to form the Chowan River at the state line between North Carolina and Virginia. Shrub land coverage ranges from 2.2 to 7.1 percent and appears to have the greatest acreage in a north-south band in the middle of the

Figure 24.
Chowan Subbasin Land Use: 1987-90



basin (Subbasins 01F, 01G and 050). Barren land is seen only in the downstream subbasins (030, 040, and 050) near the river's mouth and is probably associated with the highly reflective soil along the cliffs and scarps found in this region of the basin.

The Pasquotank Basin has 8 subbasins that drain the Yeopim/ Perquimans Rivers, Pasquotank River, North River/Currituck Sound, Scuppernong River Area/Alligator River Area, Stumpy Point Bay, Nags Head Outer Banks Area, and Cape Hatteras Outer Bank Area. Each of the subbasins in the Pasquotank Basin can be described from the land use perspective as seen in Figure 25. In general, the basin has its greatest urban percentage and its lowest agriculture and forest percentage along the Outer Banks. Wetlands are highest in the subbasins associated with the Dismal Swamp and Albemarle-Pamlico Peninsula. Urban land use varies from 0.6 to 30.0 percent and becomes very prominent along the Outer Banks (especially in subbasins 550 and 560). Agriculture is fairly constant in the western subbasins (29.7 to 38.9%) but decreases to less than 12 percent in the Outer Banks subbasins (550, 560, and 570). Forest class is consistent (19.4 to 21.5 percent) in the western subbasins but, increases to more than 70 percent in Subbasin 570. Wetlands ranges from 22.4 to 52.8 percent and predominate in the Subbasins of 50A, 510 and 54A. These subbasins are part of the Great Dismal Swamp and Albemarle-Pamlico Peninsula, and both are known for the extensive forested wetlands that are defined in this report as wetlands. Shrub land ranges from 0.3 to 2.6 percent and is considered a minor land use. Barren land has the highest percentage (8.0 to 9.0 percent) in Subbasin 550 and 560 and probably indicating the sandy beaches along the Outer Banks.

The Lower Roanoke Basin has 3 subbasins that drain the lower portion of the Roanoke River including the Cashie River. Figure 26 provides an overview of the various land uses for each subbasin. Urban land use varies from 2.3 to 7.0 percent and is highest in the upper subbasin (080) which is associated with the

Figure 25.
Pasquotank Subbasin Land Use: 1987-90

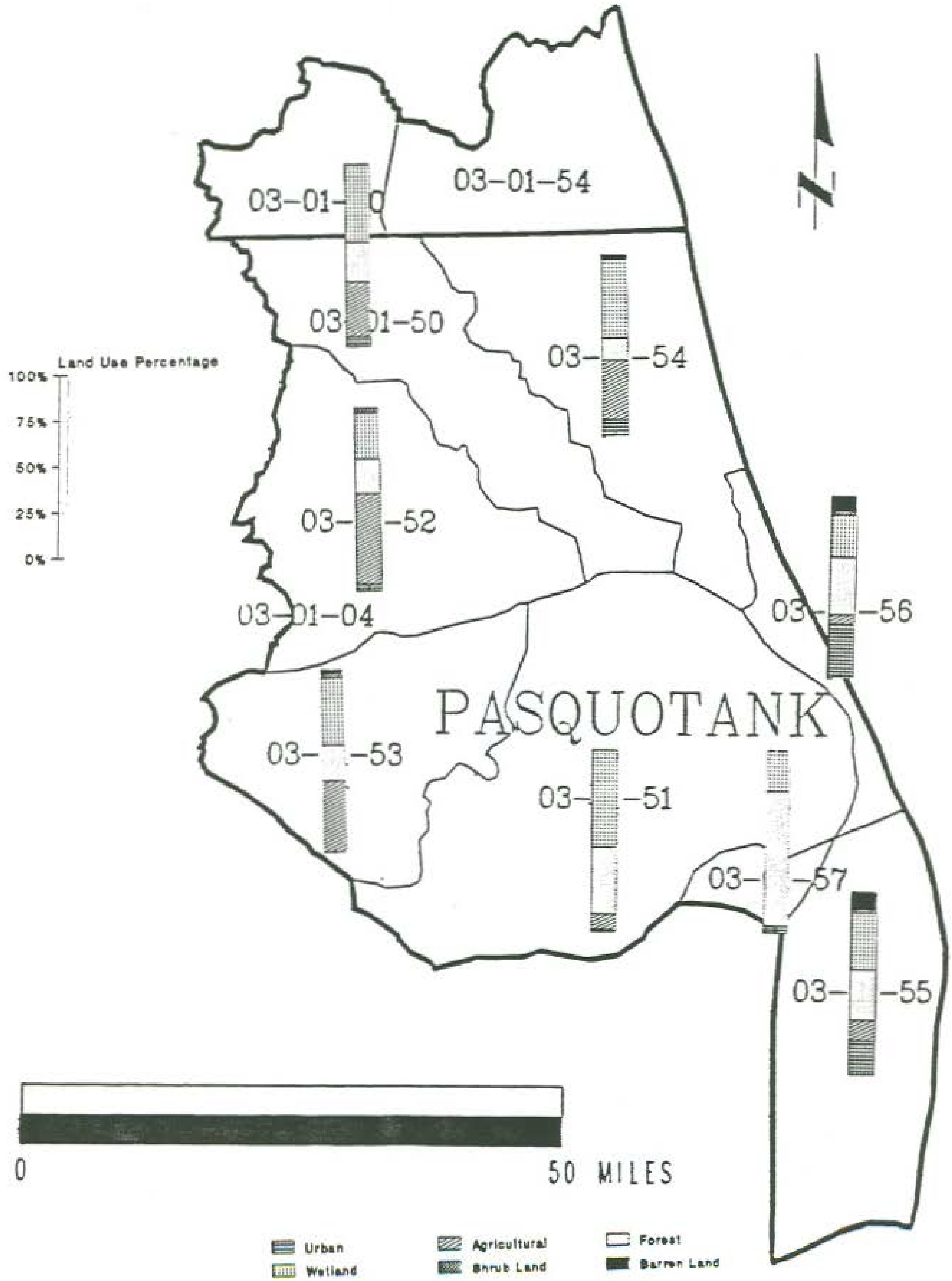
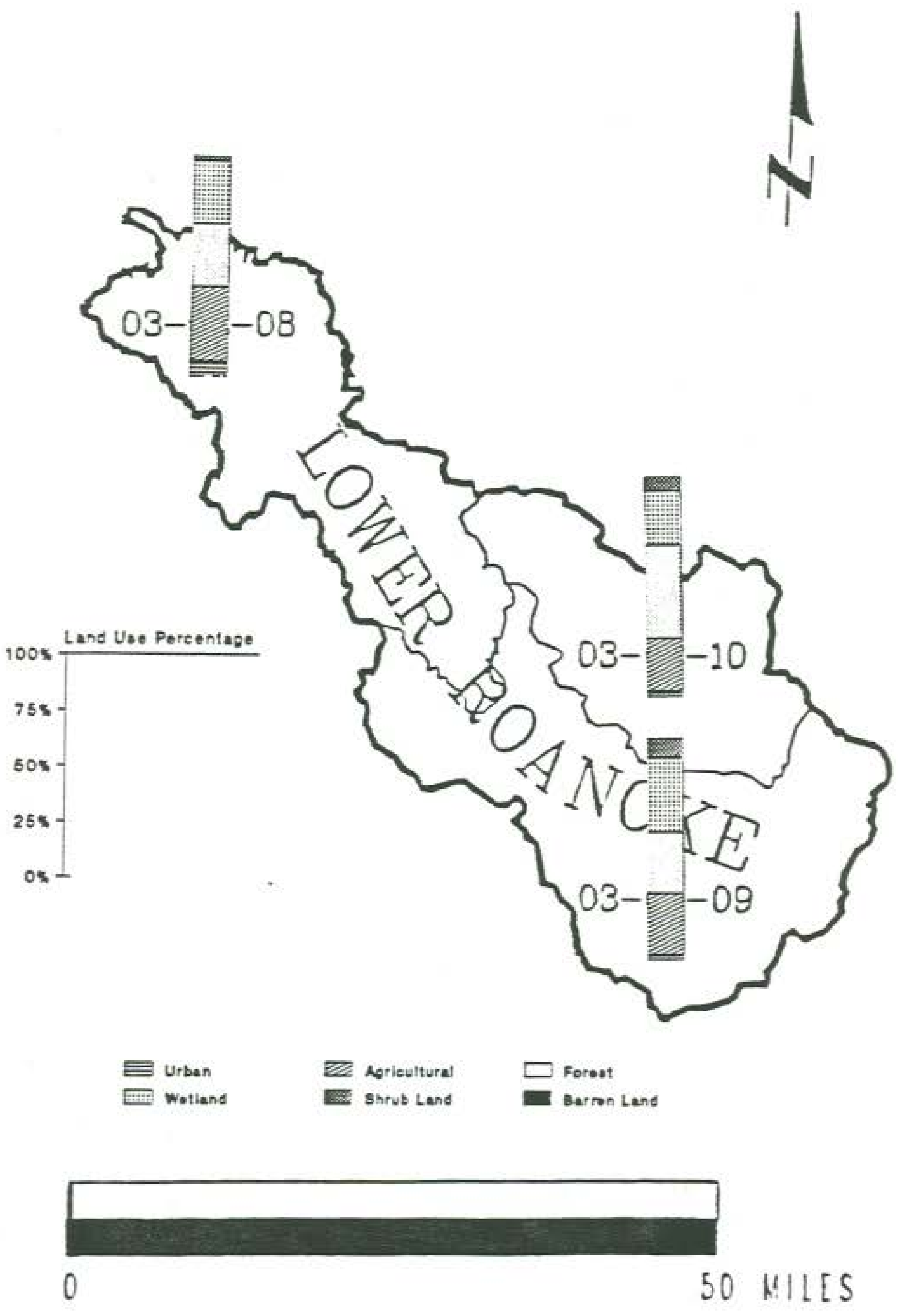


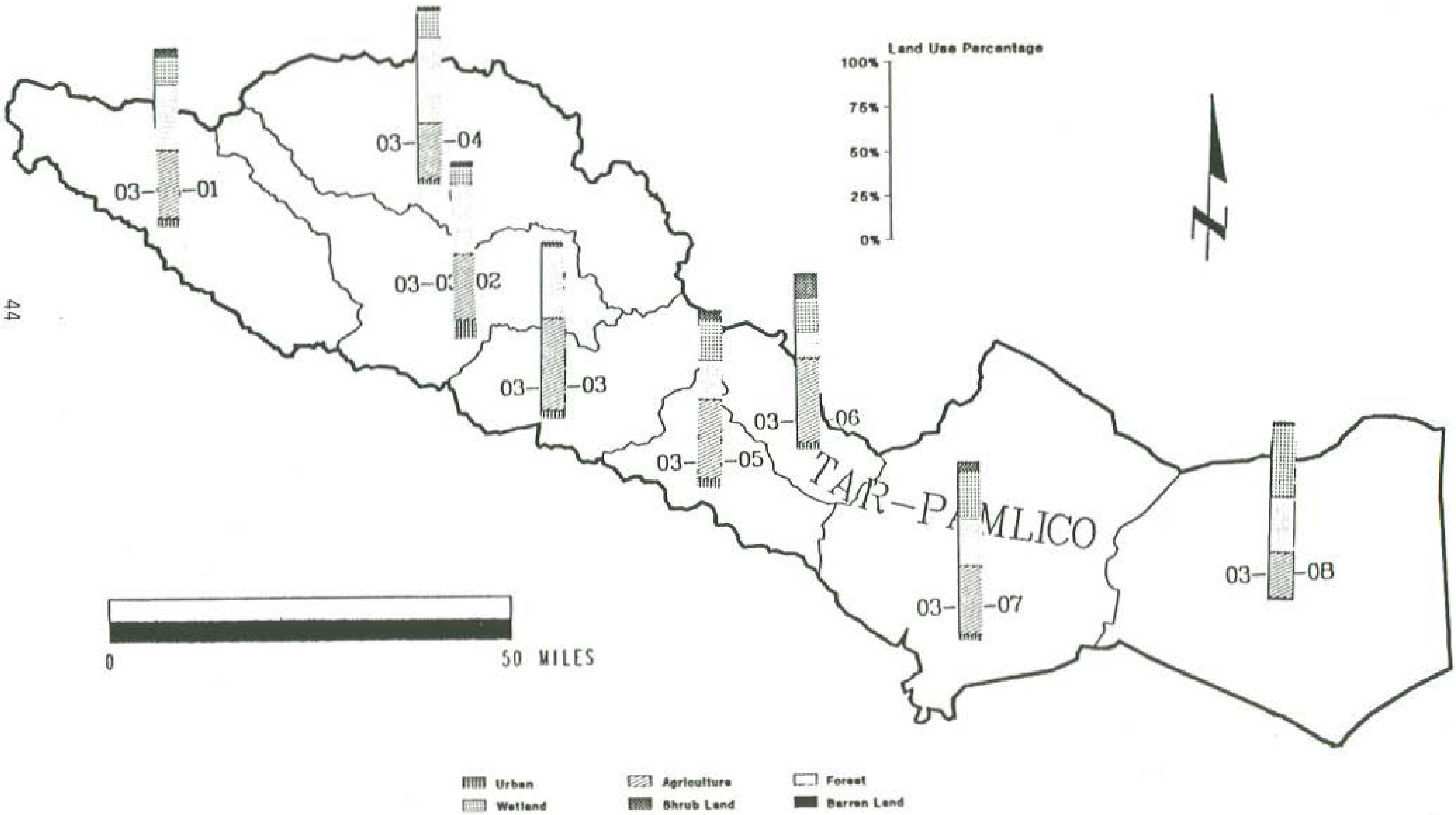
Figure 26.
L. Roanoke Subbasin Land Use: 1987-90



City of Roanoke Rapids. Agriculture is fairly consistent at 23.6 to 33.7 percent throughout the basin. Forest percentages are very close for Subbasins 080 and 090 (27.6 to 28.4) but Subbasin 100 has 41.9 percent forest cover. Wetlands range from 24.6 to 33.5 percent, with the majority located at the most downstream subbasin (090). Shrub land varies from 2.7 percent in the upper subbasin to between 7.2 and 8.9 percent in the two lower subbasins. The high percentage of shrub land in the lower subbasins may be associated with the tracts of young pine plantations that are being grown there. Barren land is not evident in two of the subbasins and only accounts for 0.1 percent in the remaining subbasin. In summary, the Lower Roanoke Basin is very rural in nature, with more than 60 percent of the area in agriculture or forest land. Wetlands is the only remaining large class and accounts for more than 29 percent. The highest urban percentage is only 7 percent and is located in the upper subbasin.

The Tar-Pamlico Basin has 8 subbasins that drain the Tar River into the Pamlico River at Washington, NC, and then into the Pamlico Sound. Figure 27 provides an overview of the percentage of land use in each subbasin. Urban land use varies from 1.1 to 10.2 percent with the highest percentage occurring in subbasin 03-01-02 associated with the Cities of Henderson and Rocky Mount. Agriculture land cover is fairly evenly distributed and ranges from 25.4 to 51.5 percent. Forest land use is also consistent only varying from 22.2 to 47.6 percent except for Subbasin 03-01-06 which drops to 14.8 percent. Wetlands vary quite a bit throughout the subbasins, with the percent ranging from 1.7 to 40.4. Shrub land is united (below 7 percent) in all subbasins except for subbasin 03-03-06 where the percentage is 15.6. This high percent of shrub land may be associated with high pocosin vegetation. The only barren land that is identified in the Tar-Pamlico Basin is in the last two downstream subbasins which have 0.8 and 1.5 percent, most likely associated with bare sand. In summary, the highest percent of urban, forest and agriculture classes lie in the upstream subbasins while the highest percent of water, wetland and barren land classes lie in the downstream

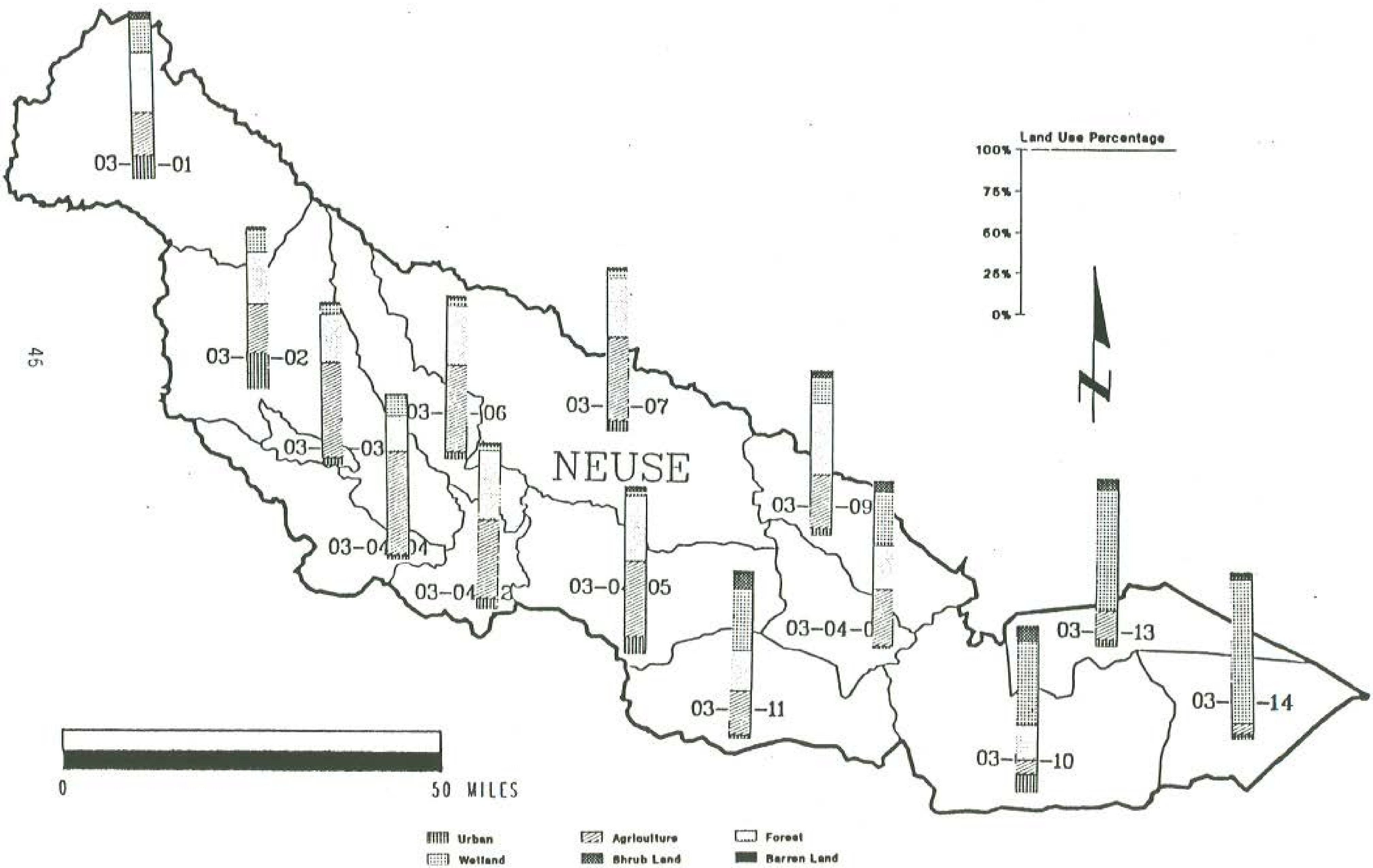
Figure 27.
Tar-Pamlico Subbasin Land Use; 1987-90



subbasins. Only shrub land has a significant percentage in the middle of the basin and may be associated with high pocosin vegetation.

The Neuse Basin has 14 subbasins that drain to the Neuse River, which empties into the Pamlico Sound. Figure 28 provides an overview of the land use in each subbasin. The urban land vary from 1.5 to 22.3 percent, with the highest percentage in the 8 upstream subbasins. Agriculture land use varies considerably, from 25.4 to 61.8, with the highest percent found in the upper two-thirds of the basin. The lowest agriculture percent, less than 8 percent, is in the last three subbasins downstream. Forest class follows the same pattern as agriculture with the highest percentage in the 10 upstream subbasins and the lowest percentage in the 4 downstream subbasins. Wetlands class varies from 2.8 to 85.6 with the highest percent associated with the 4 downstream subbasins that make up the estuary and sound portion of the Neuse Basin. The 3 subbasins that make up the upper portion of the basin also have wetland areas that vary from 6.3 to 20.2 percent and are probably associated with the many water bodies found here including Falls Lake. Shrub land is below 7 percent for all except 2 downstream subbasins where pocosin vegetation raised the percentage to between 8 and 11. Barren land constitutes less than 0.5 percent for all but the most downstream subbasin (03-04-14), and the higher percentage is probably associated sandy beaches of the barrier islands. A review of the Neuse Basin finds land use patterns similar to those of the Tar-Pamlico Basin with urban, agriculture and forest having the highest percentages in the upper two-thirds of the basin. The high percentage of urban land use can be directly related to the high population densities found earlier in this portion of the Neuse Basin. The lower one-third of the basin had the highest percentages of water, wetland, shrub land, and barren land which indicates little of man's activity and low population densities. Therefore, most of man's direct impact to this basin will result from upstream activities affecting downstream resources.

Figure 28.
Neuse Subbasin Land Use: 1987-90



The White Oak Basin has 5 subbasins, but only 4 are within the APES study area as defined earlier in the text. Three of the four subbasins are adjacent to the Atlantic Ocean and the remaining subbasin (03-04-04) is adjacent to Core and Back Sounds. Figure 29 provides an overview of the percentage of land use in each subbasin. Urban land use is the highest in subbasins 03-05-03 and 03-05-04 with 17.0 and 13.4 percent. This buildup is associated with Newport, MoreheadCity, Bogue Banks and Cape Carteret for subbasin 03-05-03 and Beaufort and Harkers Island for subbasin 03-05-04. Agricultural land use did not show very much variation (8.7 to 17.7%) among the subbasins. The forest lands are similar to agriculture with little variation and ranges from 8.3 to 24.7 percent, except for subbasin 03-05-05 which has none. This subbasin has no forest because it consists of only Shackleford and Core Banks. Wetlands range from 43.1 to 58.6 percent and is dominant throughout the subbasins. Shrub land remains constant through the subbasins and range from 4.4 to 10.3. Shrub land appears to be associated with the many pocosins that are found in this portion of the study area. Barren land is less than 0.8 percent of all subbasins except 03-05-05 which has 28.0 percent, related to bare sand along the uninhabited barrier islands. In summary, the White-Oak subbasins can be broken into two subsets with the more mainland subbasins as one unit and subbasin 03-05-05 acting as a barrier island unit. The highest urban, agriculture, forest, wetland and shrub land percentages occur in the 3 mainland type subbasins while the barrier island subbasin has the highest barren land percentage.

III-H. Intrabasin Comparison

Another way to analyze the land use data set is to examine a particular land use across all subbasins in the APES area to begin to identify potential conflicts of land use. Urban land comprises 5 percent or more of the area in the Chowan subbasins 03-01-01G and 03-01-04 (8 to 10 percent); in the Pasquotank subbasins 03-01-50, 03-01-54, 03-01-55 and 03-01-56 (5 to 18 percent); in the

Figure 29.
White Oak Subbasin Land Use: 1987-90

Lower Roanoke subbasin 03-02-08 (7 percent); in the Tar-Pamlico subbasins 03-03-02 and 03-03-05 (5 to 10 percent); in the Neuse subbasins 03-04-01, 03-04-02, 03-04-05, 03-04-07, 03-04-10 and 03-04-12 (6 to 22 percent); and in the White-Oak subbasins 03-05-03 and 03-05-04 (13 to 17 percent). In general, the high percent of development is in subbasins adjacent to the Atlantic Ocean and in headwater and upstream subbasins. This is particularly true for the Lower Roanoke, Tar-Pamlico and Neuse Basins. The Chowan Basin is the only exception. Figure 30 shows the location of development by subbasin in the APES area.

The agricultural lands comprise 40 percent or more of the acreage in the Chowan subbasin 03-01-01A, 03-01-03 and 03-01-04 (42.7 to 47.9 percent); Pasquotank subbasin 03-01-52 (49.3 percent); Tar-Pamlico subbasins 03-03-03, 03-03-05 and 03-03-06 (43.9 to 51.5 percent); and in the Neuse Basin subbasins 03-04-03, 03-04-04, 03-03-05, 03-04-06, 03-04-07 and 03-04-12 (45.0 to 61.8 percent). Most of this agricultural land is found in the central portion of the APES area with the exception of the Chowan Basin where one subbasin was located in the extreme headwaters of the basin. The largest acreage of agricultural land is in the Neuse Basin with over 1.2 million acres.

The forest lands comprise 40 percent or more of the acreage in the Chowan subbasins 03-01-01A, 03-01-01B, 03-01-01C, 03-01-01D, 03-01-01E, 03-01-02A, 03-01-02B and 03-01-02C (41.3 to 59.4 percent); in the Pasquotank subbasin 03-01-57 (73.6 percent); in the Roanoke subbasin 03-02-10 (41.9 percent); in the Tar-Pamlico subbasins 03-03-02, 03-03-03 and 03-03-04 (40.0 to 47.4 percent); and in the Neuse subbasin 03-04-09 and 03-04-12 (41.7 to 43.5 percent). The Chowan has the highest percentage of forest with over 1.3 million acres followed by the Tar-Pamlico with 1.0 million acres. All of the forest acreage in both basins is located in the upper or headwater portion.

Figure 30. Urban Land Use ≥ 5%: 1990

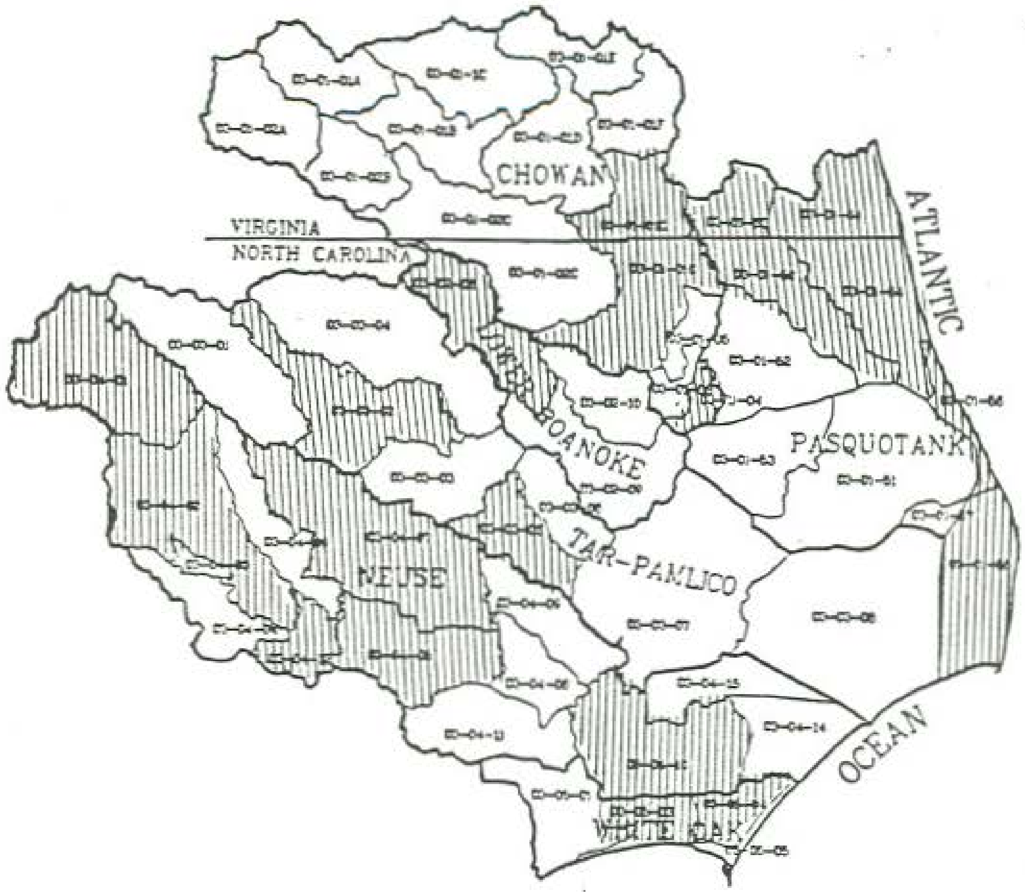
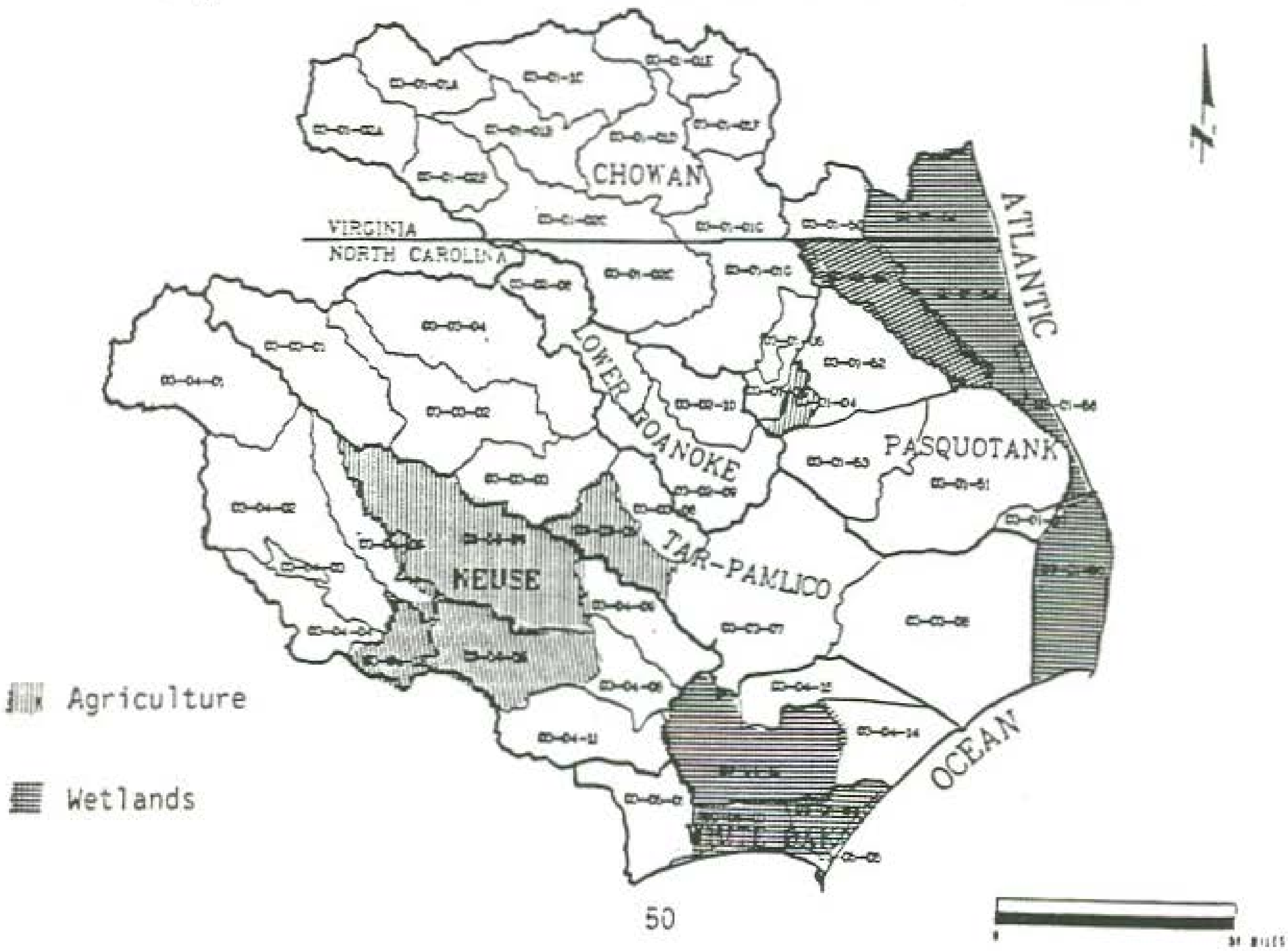


Figure 31. Areas of Potential Conflicts Between Urban and Other Uses



The wetlands comprise 30 percent or more of the acreage in the Pasquotank subbasins 03-01-50, 03-01-51, 03-01-53, 03-01-54, 03-01-55 and 03-01-56 (30.9 to 52.8 percent); in the Lower Roanoke subbasin 03-02-09 (33.5 percent); in the Tar-Pamlico subbasin 03-03-08 (40.4 percent); in the Neuse subbasins 03-03-08, 03-04-10, 03-03-11, 03-04-13 and 03-04-14 (31.3 to 85.6 percent); and in the White-Oak subbasins 03-05-01, 03-05-03, 03-05-04 and 03-05-05 (43.1 to 58.6 percent). Most of these wetlands are located in the Coastal Plain and much of the lands are associated with the extensive Great Dismal Swamp, Alligator River National Wildlife Refuge, Pocosin Lakes National Wildlife Refuge, Roanoke River National Wildlife Refuge, Roanoke River Wetlands, Bachelor Bay Gameland, J & W Dismal Swamp, Mattamuskeet National Wildlife Refuge, Swan Quarter National Wildlife Refuge, Big Pocosin, Gum Swamp, Light Ground Pocosin, Hofmann State Forest and Gameland, Croatan National Forest and Cedar Island National Wildlife Refuge. All eight coastal subbasins and their six adjacent subbasins have greater than 30 percent wetlands. Approximately 70 percent of the wetland category that lie in the APES area are forested, according to the LUDA, LANDSAT and NWI wetland data sets.

The shrub land comprises 5 percent or more of the acreage in the Chowan subbasins 03-01-01G and 03-01-05 (5.8 to 7.1 percent); in the Lower Roanoke subbasins 03-02-09 and 03-02-10 (7.2 to 8.9 percent); in the Tar-Pamlico subbasins 03-03-05 and 03-03-06 (6.2 to 15.6 percent); in the Neuse Basin subbasins 03-04-01, 03-04-08, 03-04-10, 03-04-11 and 03-01-13 (5.0 to 11.0 percent); and in the White-Oak subbasins 03-05-03 and 03-05-04 (5.5 to 10.3 percent). Except for Subbasin 03-04-01, located in the headwater portion of the Neuse Basin, shrub land generally follow the Suffolk Scarp from north to south and widens in the southern portion of the study area.

More than 0.5 percent the acreage in the Chowan subbasin 03-01-04 (2.0 percent); in the Pasquotank subbasins 03-01-51, 03-01-53, 03-01-54, 03-01-55 and 03-01-56 (0.5 to 9.8 percent); in the Tar-Pamlico subbasin 03-03-07 and 03-03-08 (0.8 to 1.5 percent); in the Neuse subbasin 03-04-14 (2.0 percent) and in the White-Oak subbasin 03-05-03 and 03-05-05 (0.7 to 28.0 percent) is barren. Many of these subbasins are located adjacent to the Atlantic Ocean, and the barren land comprised of bare, sandy areas of the barrier islands. The remaining clump of barren land class is centered in the Chowan, Washington, Beaufort and Craven Counties and mainly consists of bare, sandy agricultural land.

The final step in identifying subbasins with a high percentage of a land use type is to overlay land use maps onto one base map. In certain subbasins, the demand for land for urban growth has the potential of creating conflicts, particularly with the conversion of wetlands or agricultural land to urban uses. Land can be broken into developed and resource lands. Developed land is land with residential, commercial or industrial uses. Resource land is land with agriculture, forest, water, wetland, shrub land or barren cover or use. Detailed land use coverage data from Maryland for four separate years starting in 1973 show that as developed land increases, agricultural and forest lands are reduced about equally. (Maryland Office of Planning, 1989).

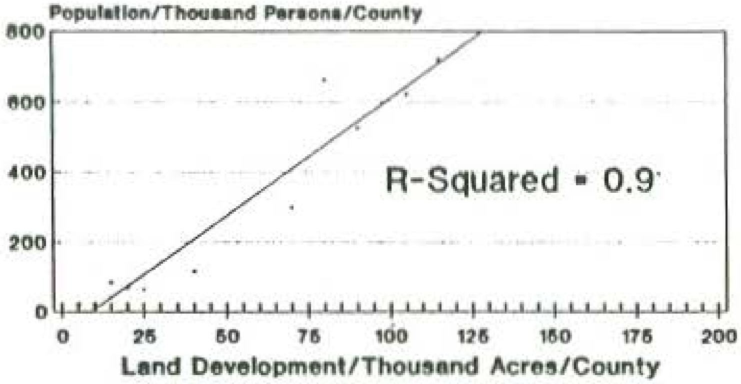
Most subbasins with agricultural land of 40 percent or greater (13 subbasins) are adjacent to subbasins that include development acreage over 5 percent and are found in the Chowan, Pasquotank, Tar-Pamlico and Neuse Basins. These subbasins form a 30 to 50 mile wide corridor that runs from the Dismal Swamp in the northeast and broadens to the swamps and pocosins associated with the Neuse River in the southwest of the APES area. Due to the higher value of land for development there is a potential for this agricultural land to be developed at a rapid rate. The greatest conflict over converting agricultural land to developed land will be in the Neuse Basin in the central subbasins of 03-04-05, 03-04-07 and 03-04-12. Conflicts in the Chowan and Tar-Pamlico Basins will occur in the subbasins of 03-01-04 and 03-03-05. There will also be conflict over conversion of wetlands. Wetland conversion will occur mainly in the Pasquotank, Neuse and White-Oak Basins. Subbasins include 03-01-50, 03-01-54, 03-01-55, 03-01-56, 03-04-10, 03-05-03 and 03-05-04. The key to the conflict will be if these lands are actually wetlands from a regulatory perspective. In summary, conversion of high percentage agricultural lands (>40%) and wetlands (>30%) is occurring in subbasins that also have a high percentage of development (>5%) (Figure 31). Special attention should be given to these potential land use conflicts and more planning should be undertaken to identify these areas in more detail and provide more effective management strategies.

III-I. Population Versus Developed Land

If a strong correlation between high population density and high percentage of urban land can be shown, then a powerful planning tool can be created to predict the amount of developed land from existing or projected density for the APES area.

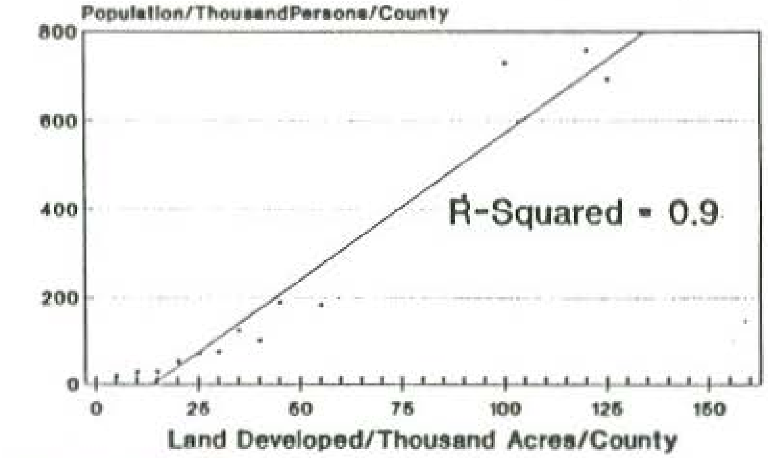
The APES area has only one recent comprehensive land use data base (LANDSAT) and does not correlate well with the category of urban or built up land based on government reviewers' comments and other sources of urban land use data. Therefore, another source of long term land use data is needed to determine if the relation between population density and developed land is statistically sound. Land use data from the State of Maryland has been gathered since 1973 and has been taken as frequently as every five years during the past 15 year period (Maryland State Planning Office, 1991). During this period, total developed land acreage had a high statistical correlation with the population for each county in Maryland. Three periods of land use data (1973, 1981, and 1990) had high statistical correlations (R-squared value of greater than 0.9). Because of the high correlation, a simple regression model was developed for the 1973 and 1990 data and the results were very similar for both periods (Figures 32 and 33). During this period, for every 200,000 increase in population between 39,000 and 43,000

Figure 32.
Land Consumption: MD 1970/73



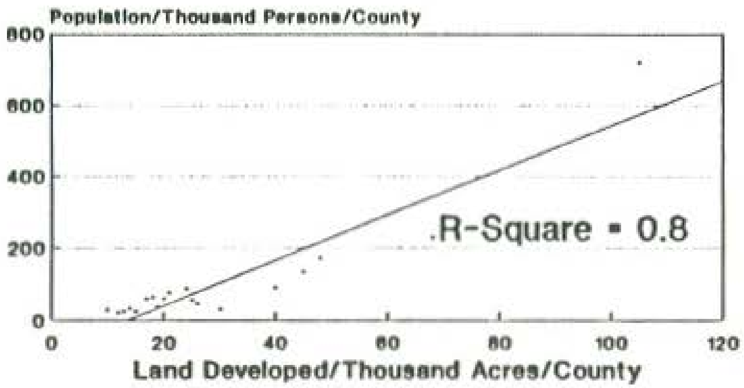
1970 Census/1973 Land Use

Figure 33.
Land Consumption: MD 1990/90



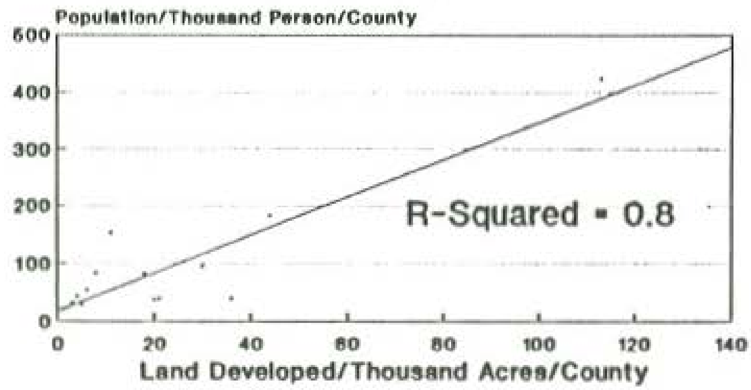
1990 Census/1990 Land Use

Figure 34.
Land Consumption: NC 1970/72



1970 Census/1972 Land Use

Figure 35.
Land Consumption: NC 1990/90



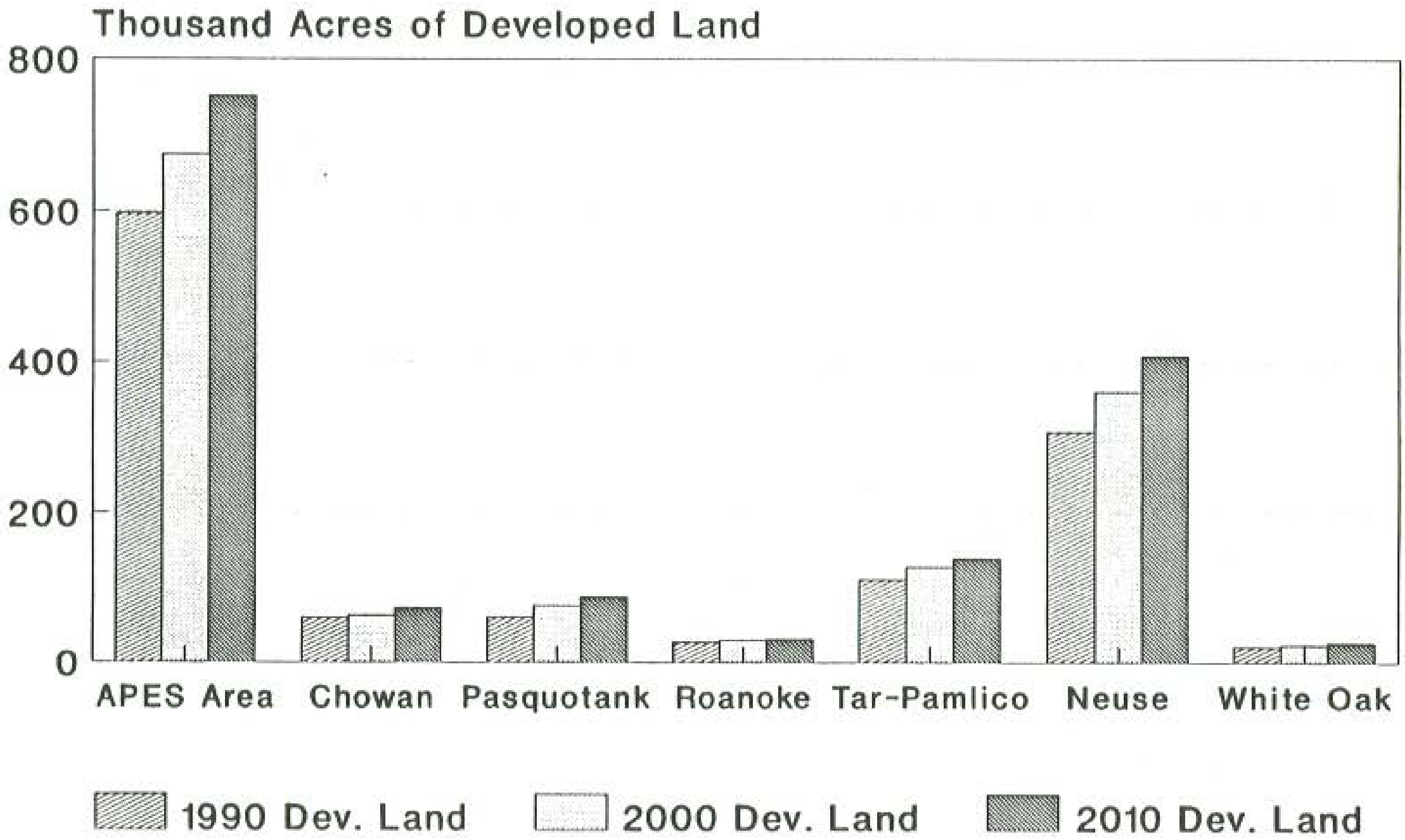
Census 1990/1990 Land Use

acres of land were developed. This relationship held for the Maryland data set, and similar land use and population data exist for Eastern Maryland and Eastern North Carolina. Therefore, could the same relationship be established with the limited land use data sets in North Carolina? The earlier LUDA data set had a high statistical correlation with developed land, but how could the existing LANDSAT accuracy for developed land be improved? LANDSAT land use maps of 21 counties in the APES area were sent to county planners or other county officials for their review. Each official was asked to shade in the extent of development that took place in his county up through 1990 and change any land use that was not properly classified. The returned maps were digitized, and new acreage for developed land was obtained for each county. Both the LUDA and the corrected LANDSAT land use maps were compared to the population census data in the same manner as the Maryland information. Both correlations had a R-squared value of greater than 0.8. Again, a simple linear regression model was developed for each correlation and the results were very similar for both 1970 and 1990 (Figures 34 and 35). A population of 200,000 people was equated to between 45,000 and 60,000 acres of developed land.

Based on the relationship established between population and developed land, the number of acres of developed land can be estimated even if land use information is not available. The method utilizes projected population for counties within the basin. A particular subbasin population is estimated by taking the weighted population based on the percentage of the county that falls within a certain subbasin. The resulting population figure for the subbasin is entered into the model equation (based on the information from the 1987-1990 data bases) to determine the amount of developed land.

The resulting developed land pattern is similar to that of population. Developed land for the entire study area for 1990 is 597,000 acres, with the Neuse Basin having the largest share at 306,000 acres and the White Oak Basin the least, at 21,000 acres. Using this method, it is projected that by 2010, approximately 752,000 acres of the study area will be developed land. The Neuse River Basin will continue to have the most developed land with 407,000 acres and the White-Oak Basin will have the least with 26,000 acres (Figure 36). It appears that by 2010 the Pasquotank Basin will out pace the Chowan Basin in the amount of developed land and contain the third largest acreage behind the Neuse and Tar-Pamlico Basins. As population grows in the APES area, land development will continue to increase mainly at the expense of agriculture, wetland and forest. Based on communication with county planners in Maryland, Virginia and North Carolina, about 80 percent of the developed land is for residential development and the remaining 20 percent is commercial, industrial and other forms of development. Urban development produces more runoff as the impervious surface increases and concentrates the pollutant. Impervious surfaces resist the movement of water through them (infiltration) resulting in more of the water running over their surface. This movement of water, referred to as surface runoff, picks up many pollutants that remain on the impervious surfaces as water moves across the surface. Pollutant loads in the Tidewater Virginia area were estimated by Cohn-Lee and Cameron (1992) to be up to 26 times higher than municipal wastewater treatment plants and up to 1200 times higher than the largest factory in the same area. Therefore, knowing where and what type of development might take place will provide good insight into what water quality impact the developed area may have on the surrounding environment.

Figure 36.
Estimate of Developed Land by Basin



NC & VA Census/LANDSAT+

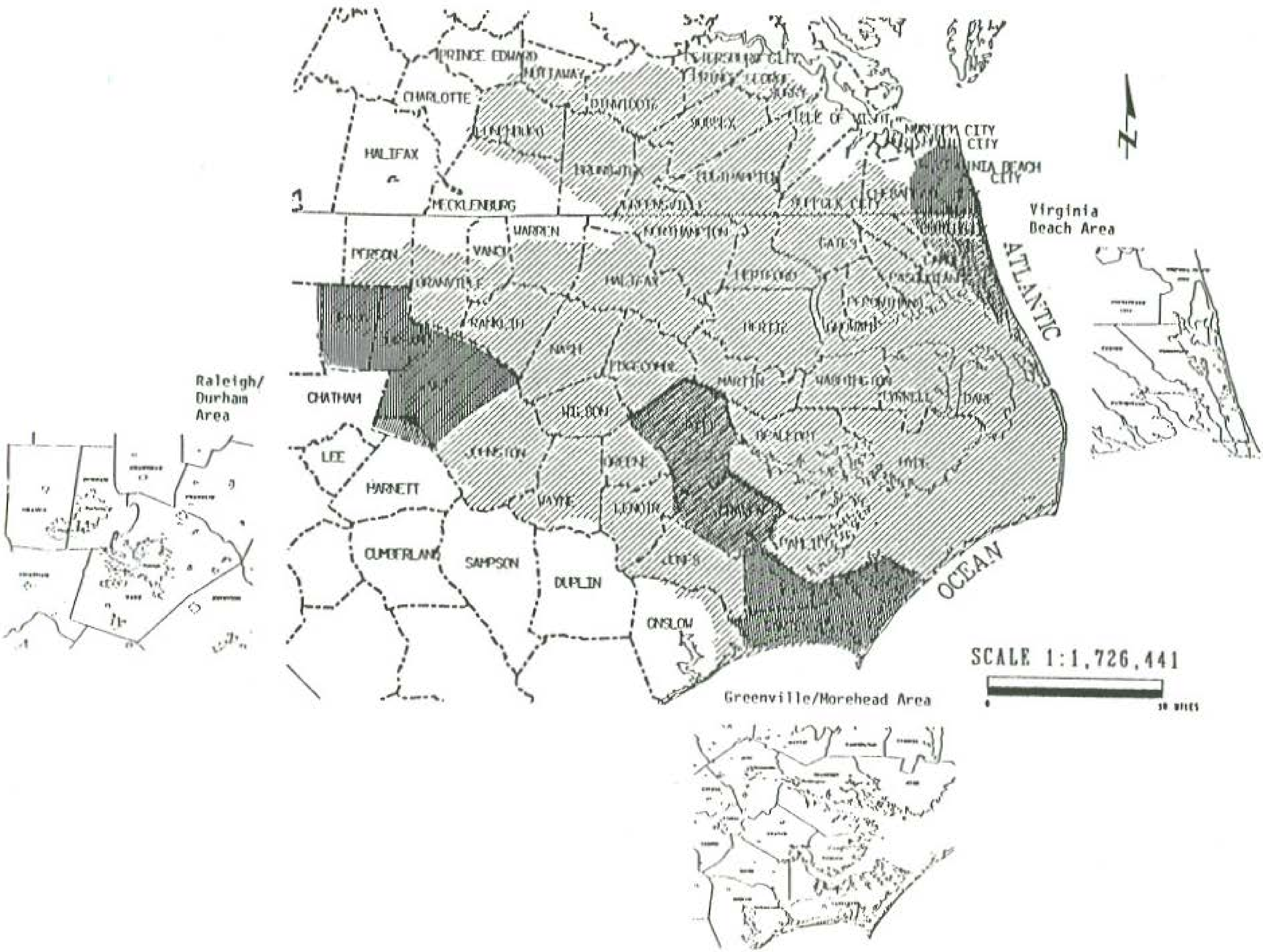
IV. HIGH GROWTH AREAS

The following information is a review of the population and land use trends that have occurred in the three high growth areas of the APES region. These areas include the Virginia Beach area, Raleigh/Durham area and Greenville/Morehead area. As indicated in the earlier section on population trends, these three areas had the highest average population growth of the entire study area based on U.S. Census data. Their growth rates ranged from 15.8 to 43.4 percent for the last 30 years. These figures represent the entire county population and land use that make up the three focus areas. Figure 37 shows the location of the three growth areas in the APES area.

IV-A. Virginia Beach Area

The Virginia Beach area is located in the Coastal Plain physiographic region adjacent to the Atlantic Ocean and occupies the far northeastern portion of the APES area. This area includes the independent cities of Virginia Beach and Chesapeake located in Virginia and Currituck and Dare Counties in North Carolina. Due to data limitations, it is only possible to focus on the Currituck Sound Watershed that encompasses all of Currituck County but only portions of Chesapeake, Virginia Beach, Camden County and Dare County. Currituck is the largest county and makes up 44.5 percent of the five-county/independent city focus area. This is followed by Virginia Beach contributing 27.5 percent, Chesapeake providing 23.9 percent, Dare County adding 3.8 percent and Camden County only having 0.1 percent of the land area. From a watershed perspective, these jurisdictions are located in the Pasquotank Basin but the northern portion of Chesapeake and Virginia Beach lies in the Chesapeake Bay Basin. A portion of all five independent cities/counties including a tiny portion of Camden County lies in the Currituck Sound Watershed and is part of the Subbasin 03-01-54. The Currituck Sound Watershed is made up of four sub-watersheds referred to as Back

Figure 37. Location of the Three Growth Areas



Bay, North Landing River, Northwest River and Currituck Sound. The drainage area of all four sub-watersheds is approximately 730 square miles.

The 1990 Census data for the entire independent cities/counties within the Virginia Beach Area includes 393,069 for Virginia Beach, 151,976 for Chesapeake, 22,746 for Dare County, 13,736 for Currituck County and 5,904 for Camden County. Rates of population growth over the past 30 years are Virginia Beach—68.9 percent; Dare—59.7 percent; Chesapeake—31.8 percent; Currituck County—29.5 percent and Camden County—1.9 percent. Average growth rates for the next 20 years (excluding Camden County) are projected to be between 15.7 and 34.8 and to remain above the state average for both North Carolina and Virginia. Figures 3 and 4 presented earlier in the population section of this report showed that the Virginia Beach area has both the largest population and highest growth rate in the APES area. A comparison of persons/square mile in the Currituck Sound Watershed for 1980 and 1990 reveals that Virginia Beach has the highest density, increasing from 184 to 533 persons/square mile in 10 years. Chesapeake's person/square mile increased from 126 to 184. Dare County's density increased from 76 to 109 and Currituck's increased from 27 to 32 during the same 10 year period. The population trend indicates very rapid growth taking place in the Virginia Beach area, especially southward into the Currituck Sound Watershed.

Land use for the Virginia Beach area (Currituck Sound Watershed) in 1990 was made up of urban (8.6%), agriculture (31.7%), forest (14.7%), wetland (39.1%) and range & barren lands (2.3%). The amount of water in the watershed is 127,000 acres and includes Back Bay, Currituck Sound and their tributaries. Due to their small land area (30 sq. mi.), Dare and Camden Counties did not significantly contribute to any land use percentage except for Dare County's urban acreage. The largest amount of urban land was in Virginia Beach and Chesapeake City (22,000 acres or 75% of the total). Most of this development is located along the northern basin boundary and in the vicinity of Great Bridge, Stumpy Lake and Dam Neck. A second area of development is located in northern Dare County in the vicinity of Southern Shores. Agricultural acreage was similar for Virginia Beach, Chesapeake City and Currituck County ranging from 33,000 to 40,000 acres. Most of the agricultural acreage is found in the northern portion of the watershed. A similar pattern is evident for forest land in the three dominant jurisdictions, and forest acreage ranges from 15,000 to 17,000 acres. The greatest wetland acreage of 57,000 acres lies in Currituck County followed by Chesapeake City and Virginia Beach with 40,000 acres each. Most of the wetlands are found along the shoreline of Back Bay, Currituck Sound and their tributaries. Range and barren land did not contribute more than 2500 acres for any jurisdiction in the watershed.

A comparison of 1972 versus 1990 land use data can only be made for urban land based on information supplied by officials from the cities/counties within the Currituck Sound Watershed. Urban land use has almost doubled in 18 years to approximately 30,000 acres. Currituck County had the largest increase in acreage of 2.8 times and followed by Dare County with 2.7 times. Urban acreage in Virginia Beach increased 1.9 times and in Chesapeake, 1.5 times. Camden County did not have any urban land for either 1972 or 1990 within the Currituck Sound Watershed. However, the largest number of urban acres still remain in Virginia Beach and Chesapeake. The population data for the same period support the urban land trend.

The population and limited land use data indicate that the Virginia Beach area is rapidly growing with little signs of slowing based on the projected growth rate over the next 20 years. The most rapid development in all five cities/counties is taking place in the northern portion of the basin within Virginia Beach and Chesapeake.

IV-B. Raleigh/Durham Area

The Raleigh/Durham area is located in the Piedmont physiographic region of North Carolina and occupies the far western portion of the APES area. The area includes the cities of Raleigh, Durham and Chapel Hill located in the counties of Wake, Durham and Orange. Only the northern portion of Orange County (49% of the county) is included in this section because county officials could review only this portion of the county. Wake is the largest county and makes up 63.4 percent of the three county focus area. This is followed by Durham County, contributing 22.1 percent, and Orange County with the remaining 14.5 percent of the land area. When the three counties are combined they cover approximately 1350 square miles. From a watershed perspective, these counties occupy the Neuse Basin, but the southern portion of all three counties lies in the Cape Fear Basin. The two subbasins that are found in the Neuse Basin cover Orange, Durham and the northern section of Wake County (Subbasin 04-04-01) and almost all of Wake County (Subbasin 04-04-02). These subbasins include all the tributaries of the Eno and Little Rivers that drain into the Falls of the Neuse Lake. Falls Lake flows into the Neuse River where Crabtree and Swift Creeks become part of the river below Raleigh. The drainage area for the two Neuse subbasins is approximately 580 square miles.

The 1990 population for the Raleigh/Durham area included 423,380 for Wake County, 181,835 for Durham County and 93,851 for Orange County. More than 50 percent of the total population of these three counties resides in the three major cities of Raleigh, Durham and Chapel Hill. Rates of population growth over the last 30 years are Wake County—35.8 percent; Durham County—17.6 percent; and Orange County—29.9 percent. Average growth rates for the next 20 years are projected to be between 8.6 and 18.3 percent. Figures presented earlier in the population section of this report determined that the Raleigh/Durham area had the second highest population and growth rates in the study area. A comparison of persons/square mile for 1970 and 1990 reveals that Durham County has the highest density, increasing from 444 to 609 persons/square mile (per./sq. mi.) in 20 years. Wake's per./sq. mi. density increased from 268 to 495 and Orange County's increased from 144 to 236 (69 to 115 per./sq. mi. northern portion of county). The population trend indicates the major growth is occurring in an eastern and southern direction from Raleigh and a northern direction from both Durham and Hillsborough.

Land use for the Raleigh/Durham area in 1990 was made up of urban (33.9%), agriculture (22.8%), forest (33%), wetland (7.1%) and range & barren lands (2.8%). The amount of water in the study area is 16,000 acres and increased 4-fold with the completion of Falls of Neuse and B. E. Jordan Reservoirs. The largest amount of urban land is in Durham and Wake Counties (270,000 acres or more than 90% of the total). Most of this development has occurred in southern Durham County near the Research Triangle Park and north of Interstate 440 in Raleigh. Most of the agricultural acreage is found in the northern portion of Orange and Durham Counties and in the eastern and southern portion of Wake County. Agricultural acreages range from 23,000 in Durham County to 134,000 in Wake County. The highest amount of forest acreage appears to be upstream of the Falls Reservoir with county acreages ranging from 50,000 in Orange County to 174,000 in Wake County. The greatest wetland acreage of 32,000 acres lies in Wake County followed by Durham and Orange County with approximately 14,000 acres each. Most of the wetlands are associated with riparian areas adjacent to tributaries of the Neuse River and the greatest concentration is in northern and eastern Wake County. Range and barren land contributes 24,000 acres for all three counties and is probably associated with disturbed land mainly in Wake County.

A comparison of 1972 versus 1990 land use data can only be made for urban land based on information supplied by officials from the counties within the Raleigh/Durham area. Urban land use has almost triped in 18 years to approximately 288,000 acres. Orange County urban acreage increased 4.1 times, Wake County by 2.9 times, and Durham County by 1.9 times. However, the largest number of urban acres still remain in Wake County and it contributes 64% of the total urban acreage. The population data for the same period support the urban land trend.

The population and land use data indicate that the Raleigh/Durham area is rapidly growing but shows some signs of slowing, with a projected rate of growth of only 12 percent for the next twenty years. However, over 30 percent of the Raleigh/Durham area is already urbanized or developed according to the 1990 land use information.

IV-C. Greenville/Morehead Area

The Greenville/Morehead area is located in the Coastal Plain physiographic region of North Carolina and occupies the southern portion of the APES area. This area includes Morehead City, Havelock, New Bern and the southern portion of Greenville located in the counties of Carteret, Craven and Pitt. Carteret is the largest county and makes up 43.0 percent of the three county focus area. This is followed by Craven County contributing 30.2 percent and Pitt County with the remaining 26.8 percent of the land area. When the three counties are combined they cover approximately 2440 square miles. From a watershed perspective, these counties occupy the Neuse Basin, but the northeastern half of Pitt County is in the Tar-Pamlico Basin. Also a tiny portion of Craven County below New Bern and almost two-thirds of Carteret County lies in the White Oak Basin. The four subbasins that are found in the Neuse Basin cover Pitt County and the northern portion of Craven County (Subbasin 03-04-09), middle portion of Craven County

(Subbasin 03-04-08), lower portion of Craven County and a tiny section of northern Carteret County (Subbasin 03-04-10), and the remaining northern portion of Carteret County (Subbasin 03-04-14). These subbasins drain all the small tributaries to the Neuse River and the Neuse Estuary. The drainage area of the four subbasin is approximately 1370 square miles.

Population based on the 1990 Census data for the Greenville/Morehead area is 107,924—Pitt County; 81,613—Craven County; and 52,556—Carteret County. When the populations for the three major cities are combined they make up 34 percent of the total population for the three county area. Rates of population growth over the last 30 years are Carteret County—20.0 percent; Pitt County—15.8 percent; and Craven County—11.6 percent. Average growth rates for the next 20 years are projected to be from 6.7 to 21.8 percent. Figures presented earlier in the population section of this report determined that the Greenville/Morehead area had the third highest population and growth rates in the study area. A comparison of per./sq.mi. for 1970 and 1990 reveals that Pitt County has the highest density, increasing from 113 to 165 persons/square mile (per./sq. mi.) in 20 years. Craven's per./sq. mi. density increased from 92 to 120, and Carteret County's increased from 61 to 102.

Land use for the Greenville/Morehead area in 1990 was made up of urban (6.7%), agriculture (24.8%), forest (30.6%), wetland (30.5%) and range & barren lands (7.3%). The amount of water in the study area is 38,000 acres and includes portions of the Tar River, Neuse River, Pamlico Sound, Core Sound, Back Sound, Bogue Sound and their tributaries. The largest amount of urban land is located in Craven County. Both Craven and Pitt Counties had similar urban acreage ranging from 22,000 to 30,000. Most of this development has occurred in the southern Greenville, southeastern New Bern and Cape Carteret/Morehead areas. Most of the agricultural acreage is found in Pitt County and the northern portion of Craven County. There is one other area of high agricultural acreage in Carteret County referred to as Open Ground Farms and containing approximately 40,000 acres. Agricultural acreages range from 51,000 in Carteret County to 174,000 in Pitt County. The highest concentration of forest acreage appears to be in northeastern Pitt and Craven Counties along with the central portion of Carteret County. County acreages range from 80,000 in Carteret County to 170,000 in Craven County. The greatest wetland acreage (144,000 acres) lies in Carteret County. Craven County has the next largest acreage of wetlands with 137,000 followed by Pitt County with approximately 80,000 acres. A large acreage of wetlands are concentrated in southwestern Craven and western Carteret Counties. Range and barren lands (probably pocosins inland and bare sand along the Core Banks coastline) contribute 87,000 acres for all three counties.

A comparison of 1972 versus 1990 land use data can only be made for urban land based on information supplied by officials from the counties within the Greenville/Morehead area. Urban land use has increased by almost 50 percent in 18 years to 79,000 acres. Acreage of urban land in Carteret County increased by 1.7 times, Pitt County by 1.4 times and Craven County by 1.2 times. The urban acreage is similar for all three counties and ranges between 21,000 and 30,000 acres.

The population and land use data indicate that the Greenville/Morehead area is growing at a rate higher than the state average. Little signs of slowing are evident by the average projected growth rate of 14 percent for the next twenty years in these three counties. However, the growth is isolated to three separate areas including southern Greenville, southeastern New Bern and along the shoreline of Bogue Sound from Cape Carteret to Morehead City.

V. ALBEMARLE SOUND BASIN

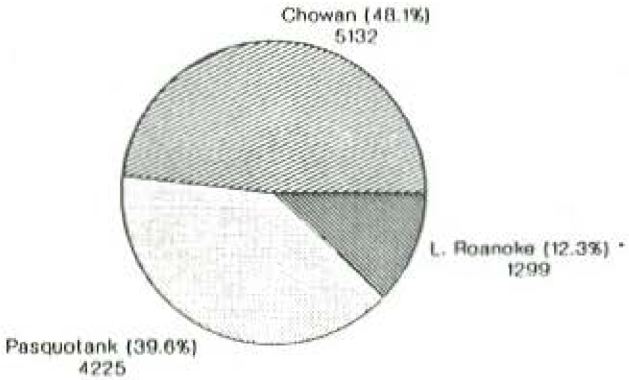
The Albemarle Sound Basin has been treated somewhat differently than the other basins in the APES area because the North Carolina Striped Bass Study Management Board requested a more detailed analysis of this basin. This analysis includes sections on point and nonpoint sources of major nutrients, water quality trends and potential impacts on striped bass.

V-A. Characteristics

Albemarle Sound Basin encompasses the entire northern portion of the APES area and includes southeastern Virginia and northeastern North Carolina. This basin covers all or portions of 31 counties and the independent cities of Virginia Beach, Chesapeake, Suffolk, Franklin, Emporia and Petersburg in Virginia and the cities and towns of Roanoke Rapids, Elizabeth City and Edenton in North Carolina (Figure 38). The basin is made up of three smaller basins including Chowan, Pasquotank and Lower Roanoke and covers approximately 10,500 square miles. This figure does not include the upper Roanoke Basin (9,500 square miles) that is not part of this study. The major tributaries that drain into the Albemarle Sound are the Roanoke and Chowan Rivers. These two rivers provide more than 80 percent of all the freshwater that enters the sound. The other smaller tributaries that surround the sound (in clockwise order) include the Yeopim, Perquimans, Pasquotank, North, Currituck, Alligator and Scuppernong Rivers. The largest basin is the Chowan contributing 48.2 percent of the total area followed closely by the Pasquotank with 39.6 percent. The Lower Roanoke basin is the smallest with only 12.2 percent or 1300 square miles of drainage area to the Albemarle Sound (Figure 39).

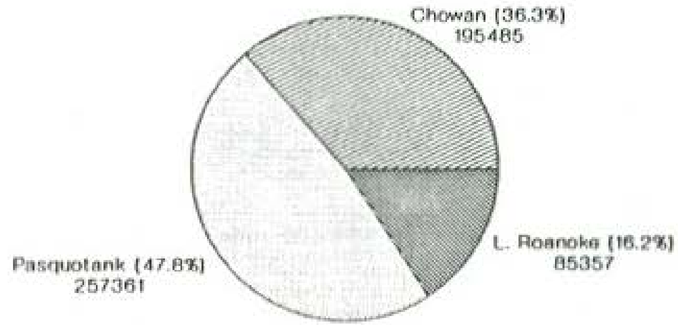
Figure 38. Location of Albemarle Sound Basin

Figure 39.
Albemarle Sound Subbasins in Square Mile



* Only a portion of this basin

Figure 40.
Albemarle Sound Subbasins Pop. 1990



* Only a portion of this basin

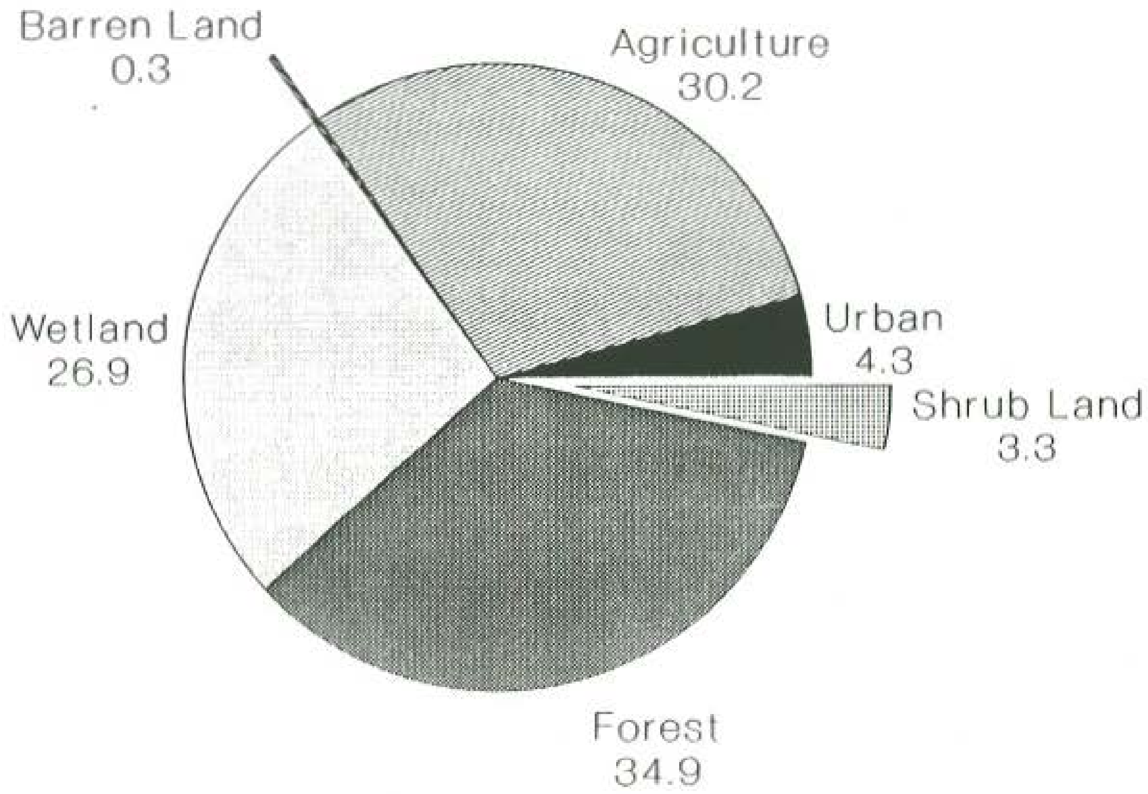
V-B. Population Trends

The 1990 population census figures reveal that approximately 538,000 people reside in the Albemarle Sound Basin, of that number, 47.8 percent live in the Pasquotank Basin. The Chowan Basin provides 36.3 percent, and the remaining 16.2 percent is from the Lower Roanoke Basin (Figure 40). Projections of population for each county were provided by the States of Virginia and North Carolina for the years 2000 and 2010 (North Carolina Data Center, 1991 and Virginia Employment Commission, 1991). These figures indicate that the greatest rate of growth continues to be in the Pasquotank Basin with the coastal jurisdiction of Virginia Beach, Currituck and Dare leading the way with rates between 21.7 and 40.0 percent. Just the opposite is occurring in the Chowan Basin. One-half of the 21 counties in the Chowan Basin have growth rates of less than 5 percent for the year 2000 or 2010. Persons/square mile (per./sq. mi.) data reveal similar conditions, trend to growth rate with most of the subbasins having densities of less than 69 per./sq. mi., which is below the national average. The subbasins in North Carolina portion of the Albemarle Sound Basin that have densities above 69 per./sq. mi. are around Edenton, Elizabeth City, Roanoke Rapids and the along the Outer Banks. Virginia subbasins with densities greater than 69 per./sq. mi. include Petersburg, Chesapeake and Virginia Beach area. The Albemarle Sound Basin is quite diverse from a population standpoint because of the largely rural Chowan and Lower Roanoke Basins and the heavily urbanized area of the northern portion of the Pasquotank Basin.

V-C. Land Use Classification

Land use information was obtained from LANDSAT data and modified using other data sources as indicated in an earlier section. The Albemarle Sound Basin is made up of developed (4.3%), agriculture (30.2%), forest (34.9%), wetland (26.9%), shrub land (3.3%) and barren land (0.3). Figure 41 shows the land use for the Albemarle Sound Basin. However, the category of water is not included

Figure 41.
Albemarle Sound Basin Land Use (%)



modified 1987/90 LANDSAT

because it is not a true land use and will be discussed separately. Water is an important category in the Albemarle Sound Basin because there are more than one million acres. This is also an important element in land cover because of the directlink with water quality concerns. The Pasquotank Subbasin has the more than 92% of all the water in the entire Albemarle Basin and should be of concern from a water quality stand point because of the high ratio of water to land combined with high population densities in certain subbasins.

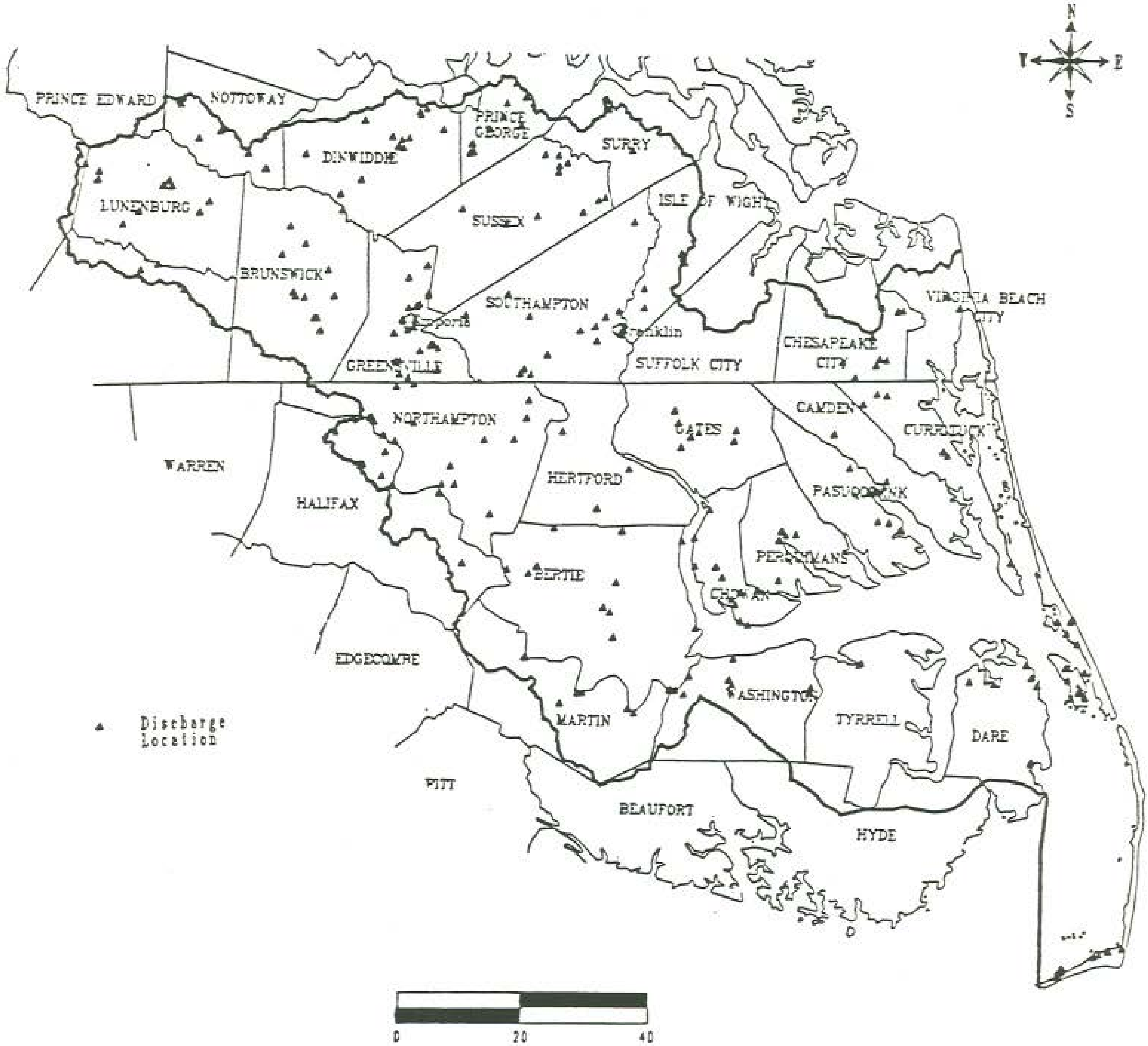
Developed land ranges from 3.9 to 5.0 percent for all three of the smaller basins that make up the Albemarle Sound Basin. Forest land represents only thirty-five percent of the total basin acreage because approximately 70 percent of the wetlands are forested wetlands. If the forest and wetlands categories are combined to include forested wetlands under the forest category the percentage jumps to 61.8. Agricultural acreage only varies from 27.9 to 31.8% in all three subbasins. Shrub land ranges from 1.4 to 6.3 percent, are mainly found in the Lower Roanoke Basin, and appear to be young pine plantations. Barren land is less than 1 percent, has the highest percentage (0.8) in the Pasquotank Basin, and is probably associated with sandy beaches along the Outer Banks. A comparison with two other sources of land use information for the APES area (Stanley, 1989 and Harned et. al., 1990) reveal comparable percentages for similar land use types. For a more detailed review of each basin refer to the Entire Study Area section of this report.

V-D. Point and Nonpoint Sources of Major Nutrients

The amount of nutrients in water, mainly elements of nitrogen and phosphorus, can cause what is referred to as cultural eutrophication and is the direct result of man's activities within a watershed. Eutrophication or nutrient enrichment can manifest itself in many ways such as algal blooms, fish kills, and a shift in the food chain composition to less desirable species. These factors cause many water quality problems such as low dissolved oxygen and high pH, chlorophyll-a and nutrient levels. The three main sources for nutrient loading to the waters of a basin are point, non-point and atmospheric deposition. In most cases point or non-point sources are the dominant source of nutrient loading.

Point sources can contribute significant amounts of nutrients and other contaminants to aquatic systems. Point sources discharge wastewater through a pipe or other direct conveyance to a water body. In the Albemarle Sound Basin there are 273 point source dischargers of treated effluent, including 41 dischargers in the Lower Roanoke Basin, 165 in the Chowan Basin and 67 in the Pasquotank Basin. Only 23 facilities are considered major (discharging more than 1 million gallons per day [MGD] or being in a special use category). Large facilities are usually municipalities or industries. The largest dischargers are three pulp and paper mills that have a combined design flow of 165 MGD and are located on the Blackwater and Roanoke Rivers. Most of the dischargers are spread throughout the basin and are very small (less than 10,000 gallons per day). The only exception to this pattern is in the case of cities and towns where the dischargers are usually clustered. This is evident in Edenton, Elizabeth City, Roanoke Island, Kill Devil Hills, Cape Hatteras and Roanoke Rapids in North Carolina and Franklin, Emporia, Lawrenceville, Petersburg and Blackstone in Virginia (Figure 42). Point source loadings were estimated for the APES area by Dodd et al. (1992). Only the large facilities had self monitoring data for the major nutrients of Total Nitrogen (TN) and Total Phosphorus (TP) measured as kilograms per hectare per year (kg/ha/yr). The estimates show the Chowan River with 691,065 kg/ha/yr TN and 2,174,621 kg/ha/yr TP; the Lower Roanoke River with 821,021 kg/ha/yr TN and 145,226 kg/ha/yr TP; and the Albemarle Sound with 18,791 kg/ha/yr TN and 1,874 kg/ha/yr TP. From the limited data available it appears that the highest point source loadings to the Albemarle Sound are coming from the Chowan River and one point source.

Figure 42. Point Source Locations in the Albemarle Sound Basin



Nonpoint sources can also be an important source of nutrients and other contaminants. Nonpoint sources are diffuse and are usually a result of overland water flow that picks up contaminants from the land it crosses in reaching a water course. Therefore, contaminants in nonpoint source loadings are related to land use or land cover type. Dodd et al. (1992) have also taken the land use/land cover data from the LANDSAT imagery in 1987 and 1988 and developed loadings for each basin in the APES area. They found that non-point sources were the dominant source of nutrient loading to the three basins in the Albemarle Sound Basin. The areal loadings from runoff measured as kilogram per hectare per year (kg/ha/yr) were for total nitrogen (TN) and total phosphorus (TP). The results indicated the Chowan River had 5.48 kg/ha/yr TN and 0.49 kg/ha/yr TP; the Roanoke River had 5.07 kg/ha/yr TN and 0.45 kg/ha/yr TP; the Albemarle Sound had 5.41 kg/ha/yr TN and 0.49 kg/ha/yr TP. The highest loadings are coming from the Chowan River and in particular from the Blackwater River with loadings of 5.46 kg/ha/yr TN and 0.49 kg/ha/yr TP. This river and the Nottoway River merge at the North Carolina and Virginia state line and become the Chowan River. This high loading situation is compounded by the long freshwater replacement time in the Albemarle Sound that ranges from 2 to 3.5 months (G.S. Janowitz, Department of Marine, Earth and Atmospheric Sciences, N.C. State University, Personal Communication, Raleigh, North Carolina) and allows these nutrients to build up further before being moved out of this Sound system. Therefore, the more point and nonpoint sources that exist, the more loading of nutrients and other potential contaminants that enter water bodies within the APES area. The origin of these point and nonpoint sources of pollution can be directly linked to increases in population and land use conversion.

V-E. Water Quality Trends

The water quality trends in the Albemarle Sound Basin will be described by determining the locations where water quality parameters have one of the following characteristics: appear to be higher/lower than normal, above water quality standards, or above detection limits. Trends only reflect locations of the highest number of potential pollutants that are based on literature sources. Information came from two Virginia and six North Carolina documents. The sources include: Virginia Water Quality Assessment for 1992: 305b Report to EPA and Congress, Virginia Water Control Board (1992); Comprehensive Review of Selected Toxic Substances - Environmental Samples in Virginia, Tinger et. al. (1990); Albemarle-Pamlico Estuarine Study: Fish Tissue Baseline Study 1989, North Carolina Division of Environmental Management (1991); Albemarle-Pamlico Estuarine Study: Synoptic Survey Data Review - July 25, 1989, North Carolina Division of Environmental Management (1990a), Water Quality Progress in North Carolina: 1988-1989 305(b) Report, North Carolina Division of Environmental Management (1990b); Historical Trends in Land Use, Nutrient Production, Water Quality and Fisheries in the Albemarle-Pamlico Estuarine System, Stanley (1989), Water-Quality Trends and Basin Activities and Characteristics for the Albemarle-Pamlico Estuarine System, North Carolina and Virginia, Harned et al. (1990) and Watershed Planning in the Albemarle-Pamlico Estuarine System: Report 3 - Toxics Analysis, Cunningham et al. (1992). The above sources provide water quality data in the form of water column, sediment and fish tissue parameters.

Water column data indicates high values for chlorophyll-a, total nitrogen, aluminum, copper, zinc and fecal coliform. Low values for pH and dissolved oxygen are also observed. Most of the high chlorophyll-a, and total nitrogen are associated with the Chowan River and the western Albemarle Sound. Aluminum was detected only in the Chowan and Roanoke Rivers and was usually associated with geologic sources. Copper and zinc are found in the Chowan River and its two tributaries, the Nottoway and Meherrin Rivers. The copper concentrations appear more frequently in the Meherrin River than any other basin. High fecal coliform and low pH and dissolved oxygen are found in the Meherrin, Nottoway and Blackwater Rivers. Dissolved oxygen is typically a problem in the lower reaches of these watershed and the upper Chowan River during the summer months when there is little water flow. Most of this water column data indicate that many of these problems are found more frequently in the Chowan Basin.

The second area described is sediment data. High sediment concentrations for copper, chromium, lead, nickel, zinc and mercury were found mostly in the Albemarle Sound as a result of the intensive sampling effort by Stan Riggs of East Carolina University. Lead was identified in the sediment from Edenton Bay, Pasquotank River, upper Chowan River and Scuppernong River. Mercury and zinc were both found in the sediments of Pasquotank River, but only mercury was found at the mouth of Roanoke River. Chromium, copper, nickel, zinc and mercury were found in the sediments of Welch's Creek which for many years received the effluent from a large industry on the Lower Roanoke River. The "hot spots" for high metal concentrations in the sediments appear to be locations such as boat marinas, towns, military installations and industries. These type of intensive human activities have been shown to produce pollutants such as heavy metals (Riggs et al., 1989).

The final area of water quality to describe will be fish tissue. Dioxin was found in the tissue of fish in the entire Chowan River, western Albemarle Sound and lower portion of the Roanoke River. Due to the large area and numbers of fish in which dioxin was detected, the States of North Carolina and Virginia issued a fish consumption advisory. The source of the dioxin is presumed to be the two pulp and paper mills located on the lower Roanoke River and headwaters of the Chowan River. Mercury in fish tissue was found in the upper Chowan and lower Blackwater Rivers. Also the Meherrin River fish had elevated levels of copper, chromium and DDE (DDT metabolizes to DDE) while the Blackwater River fish sample contained only DDE. Mercury was also found in many locations in the upper Roanoke Basin above the Roanoke Rapids Dam but was not detected in fish tissue in the lower portion of the Roanoke River. The fish tissue information, aside from dioxin, points to the Chowan River and its major tributaries as having the most problems with pollutants.

In general, water quality problems in the Albemarle Sound Basin as measured by the water column, sediment and fish tissue parameters point to the Chowan and Roanoke Rivers. The majority of the land area, point sources and freshwater flow are in these two basins. However, the Chowan River does not have all the upstream dams that the Roanoke River has and the Chowan has a lower population for the entire basin. Such dams appear to act as settling basins and reduce the amount of pollutant loading downstream. The Roanoke Basin also has the advantage of being mostly in the Piedmont physiographic region and where higher elevation produces greater water flow rates. In contrast, the Chowan Basin is mostly located in the Coastal Plain physiographic region with much flatter terrain and low flow rates.

V-F. Potential Impact on Striped Bass

Striped bass are anadromous species and utilize the upper Roanoke River around the Weldon area for spawning and the mouth of the Roanoke River as a nursery area (U.S. Fish and Wildlife Service, 1992). They are most susceptible to detrimental environmental effects during spawning and early larval development. Therefore, most of the water quality information will be focused on the Lower Roanoke Basin. Based on the information presented so far in this report concerning population and land use trends, the areas of spawning and nursery activities do not appear to be directly impacted by man's activities. However, there do appear to be two potential indirect impacts. First there is the increasing amount of development occurring around the City of Roanoke Rapids, only 3 miles upstream from Weldon. The City of Roanoke Rapids had a 1990 population of 15,722 and is the largest city within a 35 mile radius. Since the city is adjacent to the Roanoke River, runoff from development activities has the potential of reaching the river and impacting the spawning area just downstream. The second potential impact is also connected with the City of Roanoke Rapids. A paper mill operates at Roanoke Rapids with a wastewater design flow of 28 million gallons per day. Studies in Europe and Canada using fish as biomarkers below paper mills have shown that this type of effluent causes significant changes in the biochemical pathways in fish and may be affecting the reproductive and immune systems (R. DiGiulio, Duke University, Personal Communication, January, 1993). If this is the case, eggs and early larval striped bass just downstream in the spawning area may be affected by the effluent but show no physical signs of any problems.

Dioxin has been found in a number of fish taken from the Chowan and Roanoke Rivers and the western Albemarle Sound (Cunningham et al., 1992). The U.S. Fish and Wildlife data cited in Cunningham et al. (1992) indicated that contamination of fish with dioxin might pose a hazard to wildlife and also to humans based on the health advisory that is posted by both the State of North Carolina and Virginia for this area. Dioxin pollution is of concern because the striped bass nursery area is at the mouth of the Roanoke River and in the cone of contamination. Also, due to the sluggish nature of the Albemarle Sound, water residence time of greater than three months allows more time for pollutants to build up and interact with the surrounding fish community.

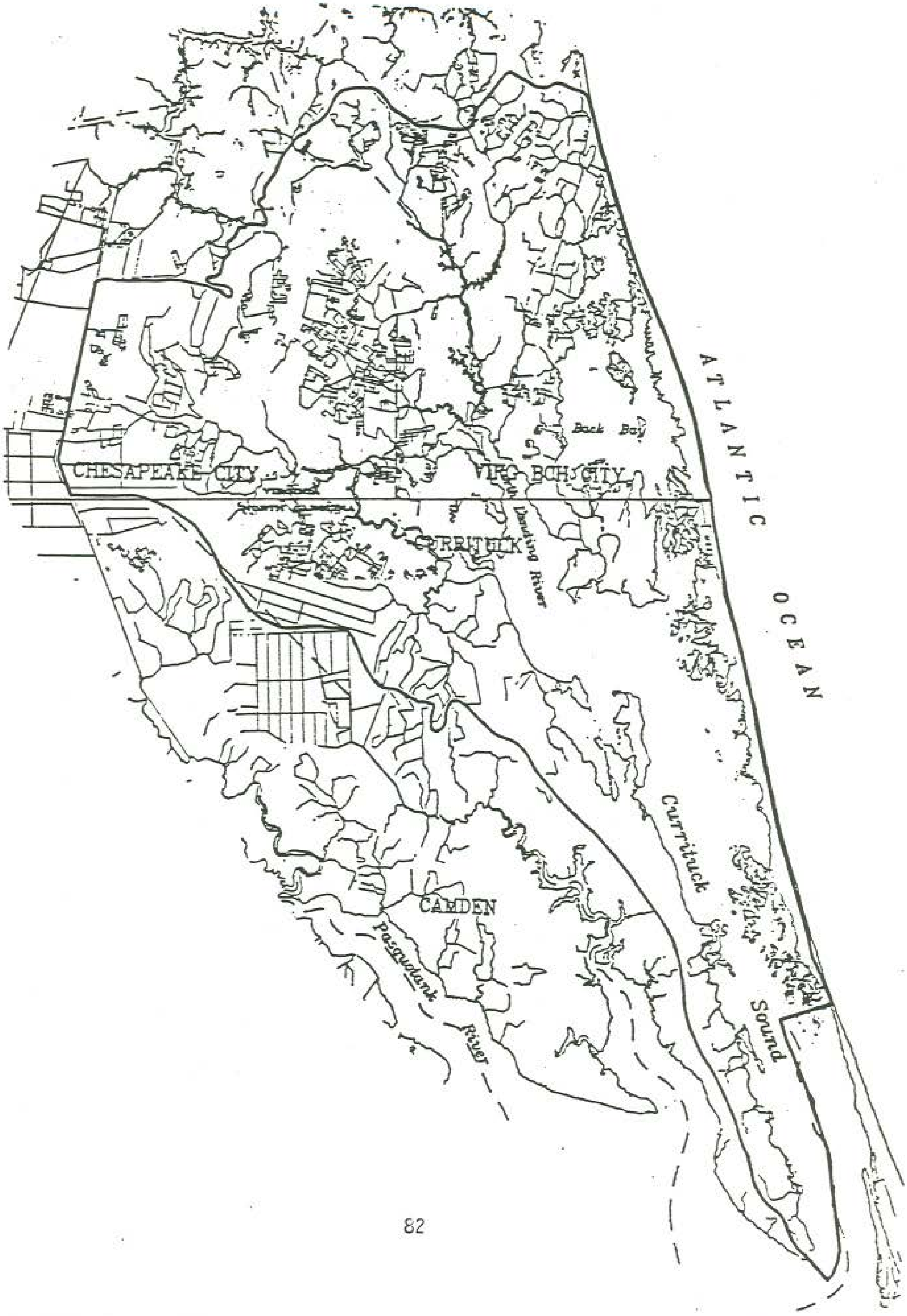
The Chowan and Roanoke Rivers are two bodies of water in the Albemarle Sound system having the greatest frequency of water quality problems as determined from water column, sediment and fish tissue data. This is not surprising because these two subbasins drain approximately 70% of the Albemarle Sound Basin and supply 80% of the flow. With the ever increasing coastal population that is expanding inland from the Outer Banks to the surrounding tributaries of the Albemarle Sound, more and more sources of pollution will be created. These additional sources of pollution will cause further water quality problems and impact the striped bass population that utilize the Lower Roanoke River Basin for spawning and early development.

VI. CURRITUCK SOUND WATERSHED

VI-A. Characteristics

The Currituck Sound and its tributaries are a subbasin of the Pasquotank Basin, however for the purposes in this report will be referred to as the "Currituck Sound Watershed". Currituck Sound Watershed is located adjacent to the Atlantic Ocean in southeastern Virginia and northeastern North Carolina. This basin covers all or portions of five counties including Virginia Beach City and Chesapeake City in Virginia and Dare, Camden and Currituck in North Carolina (Figure 43). This entire watershed covers approximately 732 square miles and spans north to south from Oceania Naval Air Station in the City of Virginia Beach to Point Harbor in Currituck County, a distance of approximately 49 miles. The major water bodies that drain into Currituck Sound and their sub-watersheds size are Back Bay with 118 square miles, North Landing River with 178 square miles, and Northwest River with 196 square miles. The Currituck Sound is a separate sub-watershed and covers the largest area of the four sub-watersheds with 240 square miles. Water flow is normally in a southerly direction; however, due to little topographic relief (average of 15 to 18 feet) and shallow water depths (average 4 to 5 feet) the flow can be northward depending on the prevailing winds (Adams, 1984 and Mann, 1984). The residence time from Back Bay to the mouth of Currituck Sound ranges from 18 to 77 months if only freshwater replacement is considered and approximately 2 months if wind-driven replacement is considered only (G.S. Janowitz, Department of Marine, Earth and Atmospheric Sciences, N.C. State University, Personal Communication, September, 1992, Raleigh, North Carolina). Currituck Sound and Back Bay can be characterized as a fresh/brackish estuary dominated by wind tides as seen by the difference in residence time for freshwater versus wind tides.

Figure 43. Location of the Currituck Watershed



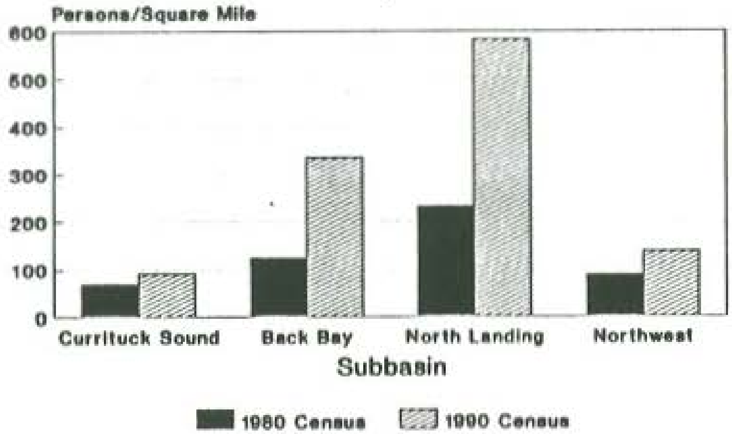
Due to prevailing conditions in the Currituck Sound Watershed many unusual terrestrial and aquatic habitats have been created. The Virginia Division of Natural Heritage identifies the Virginia portion of the Currituck Sound Watershed as having some of the premier unspoiled natural areas in the state. Approximately 20,000 acres of these special habitats have been set aside and protected in the form of Back Bay National Wildlife Refuge, Mackay Island National Wildlife Refuge, Currituck National Wildlife Refuge, False Cape State Park, Northwest River Marsh Gamelands, North Landing River Preserve, Northwest River Park, North River Gameland, Trojan - Pocahontas Waterfowl Management Area and Currituck Banks National Estuarine Research Reserve. However, according to an investigation by Frost (1990) of the counties in the Albemarle Sound area, there are many unique habitats in the Currituck Sound area that are not unprotected. Because of the development pressures on this basin, special habitats that remain unprotected may be degraded or destroyed if steps are not taken to protect these areas from encroachment.

VI-B. Population Trends

The 1990 census figures for each of the five counties within the Currituck Sound Watershed will provide some insight on where the largest population areas are in the watershed and were future population growth will occur. However, the figures given will be larger than the actual population that resides in the watershed because only a portion of each county lies in the boundaries. The two leading populations are in the independent cities of Virginia Beach and Chesapeake with a combined population of over 309,000. The counties of Dare, Camden and Currituck have a combined population of just over 22,000. Four of the five counties have growth rates over 15 percent since 1980, making this area one of the fastest growing areas in Virginia and North Carolina. One early observation from the figures is that the two Virginia counties have a population base (13 to 25 times) greater than the two North Carolina counties. Chesapeake and Virginia Beach are much more urbanized than Dare and Currituck Counties. Based on figures provided in the Roy Mann Report (1984) the City of Virginia Beach is one of the fastest growing coastal cities in the United States. However, the actual growth rate in the North Carolina countries appears to be an average of 13 percent higher than the state wide average. Tschetter (1989), in characterizing the demographic trends of the North Carolina portion of the A/P Study area, showed growth rates highest in the coastline counties of Carteret, Currituck, and Dare. He also noted that Currituck and Dare counties have the largest recreational infrastructure and that Currituck County is really part of the Virginia Beach metropolitan area. The existing growth rates added to the growth rate projections indicate that coastal counties will experience rates of growth at or above 10 percent at least through the year 2000. This projection appears to hold true for the counties making up the Currituck Sound Watershed particularly in North Carolina. Since most of the development in Virginia Beach has taken place in the northern districts, the Back Bay area has escaped development pressure so far. However, the vacant buildable property in the northern districts is becoming scarce and the only sizable buildable property in the City of Virginia Beach is south in the Currituck Sound Watershed (Mann, 1984 and Clayton Bernick, City of Virginia Beach, Personal Communication, June, 1991, Virginia Beach, Virginia).

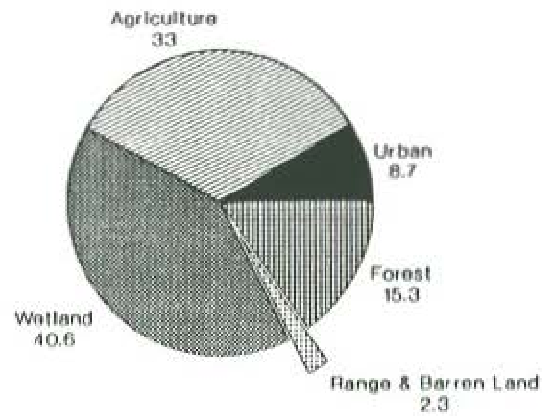
Population for 1980 and 1990 will now be presented for sub-watersheds. The 1970 census data for the Virginia portion of the watershed cannot be presented because it was found not to be compatible with the 1970 census data from North Carolina. The population for the entire watershed in 1990 was 157,620 and this was a 2.2 times increase over the 1980 population. Population for each sub-watershed will be presented in persons/square mile format because of the change in census tract size from one census to the next. In 1990 the persons/square mile for the sub-watersheds ranged from 91 to 582, with the highest density being in the North Landing River Sub-Watershed (Figure 44). There has been a 2.5 times increase in persons/square since 1980 in this sub-watershed, primarily located in the Great Bridge area of Virginia Beach. The lowest population

Figure 44.
Currituck Sound Watershed Densities



1980/1990 Census

Figure 45.
Currituck Sound Land Use (%)



Watershed Land Use: 1987-90

was in the Currituck Sound Sub-Watershed which increased only 1.3 times increase since 1980. The second highest population density, of 335 was in the Back Bay Sub-Watershed, followed by Northwest River with 138 persons/square mile. The sub-watershed of North Landing and Back Bay have been experiencing rapid growth since 1980 and the highest growth for all of Virginia Beach is occurring in the planning areas of Kempsville, Holland and Courthouse-Sandbridge which lie in these two sub-watersheds (City of Virginia Beach, 1991). Both the Northwest and Currituck Sound Sub-Watersheds have not seen the development pressures present in the other two sub-watersheds, this is probably a result of much less growth in these areas.

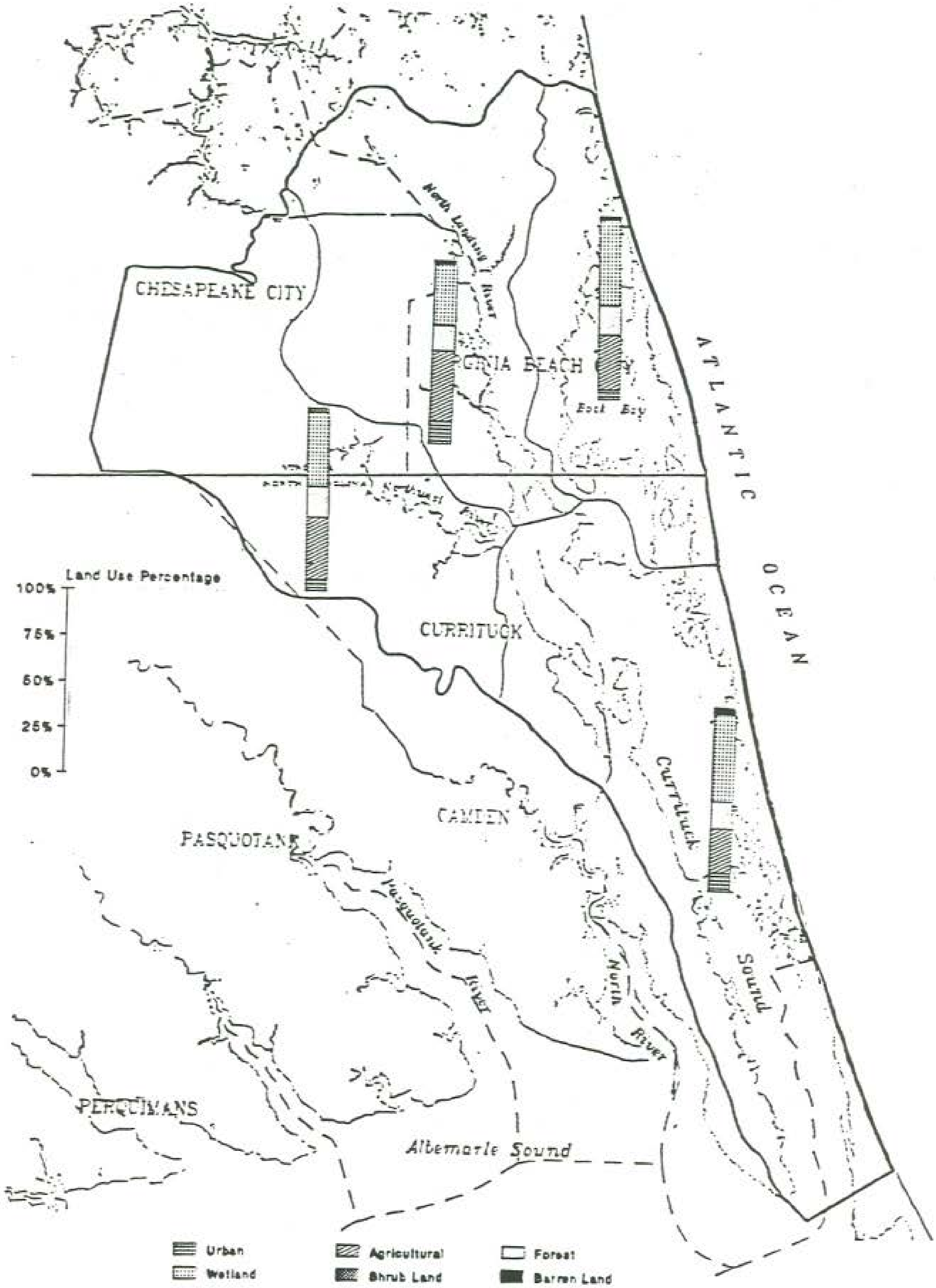
The population trend for the Currituck Sound Watershed indicates rapid population expansion southward from the Virginia Beach area into the North Landing and Back Bay Sub-Watersheds. The Outer Banks area of Dare and Currituck Counties in the Currituck Sound Watershed is also experiencing expansion northward based on density trends (1.3 times the population of 1980) but not on the same scale as that of Virginia Beach. Future rates of growth are expected to drop some but to remain higher than the average growth rates for both North Carolina and Virginia.

VI-C. Land Use Trends

Land use information was obtained from the LANDSAT data base. Maps of land use were sent to county officials in the Currituck Sound Watershed in the same manner as described earlier for the three focus areas in this report except in this section only subbasin information will be presented. Land use for the Currituck Sound Watershed in 1990 is made up of urban (8.7%), agriculture (33.0%), forest (15.3%), wetland (40.6%) and range & barren lands (2.3%). Figure 45 shows the land use for Currituck Watershed. The amount of water in the watershed is 85,000 acres and includes Back Bay, Currituck Sound and their tributaries. The largest amount of urban land is in North Landing Sub-Watershed (13,000 acres or 45% of the total). Most of this development is located along the northern basin boundary and in the vicinity of Stumpy Lake. A second area of development is located in Currituck Sound Sub-Watershed in the vicinity of Southern Shores. Agricultural acreage is 42,000 for both North Landing and Northwest Sub-Watersheds. Currituck Sound and Back Bay Sub-Watersheds also has similar agricultural acreages ranging from 14,000 to 15,000. Most of the agricultural acreage is located in the northern half of North Landing and Northwest Sub-Watersheds. A similar pattern is evident for forest land and the highest acreage is in the Northwest Sub-Watershed with 20,000. The greatest wetland acreage of 50,000 acres lies in Northwest followed by North Landing, Currituck Sound and Back Bay Sub-Watershed having between 22,000 and 37,000 acres each. Sixty-three percent of the wetlands are found along the Northwest and North Landing Rivers and their tributaries. Range and barren land contribute 7900 acres and the greatest percentage of range land is located in Northwest and North Landing. Just the opposite is true for barren land with Currituck Sound and Back Bay having the greatest percent. Figure 46 shows the land use for each sub-watershed in the Currituck Sound Watershed.

A comparison of 1972 versus 1990 land use data can only be made for urban land based on information supplied by officials from the cities/counties within the Currituck Sound Watershed. Urban land use has almost doubled in 18 years to 30,000 acres. Currituck Sound Sub-Watershed has the largest increase in acreage of 2.5 times and followed by both North Landing and Northwest Sub-Watershed with 1.8 times. Back Bay Sub-Watershed has 1.6 times increase in urban acreage. However, the largest number of urban acres still remain in North Landing Sub-Watershed. Population data for the same period supports this trend.

Figure 46.
Currituck Sub-Watershed Land Use



VI-D. Point and Nonpoint Sources of Major Nutrients

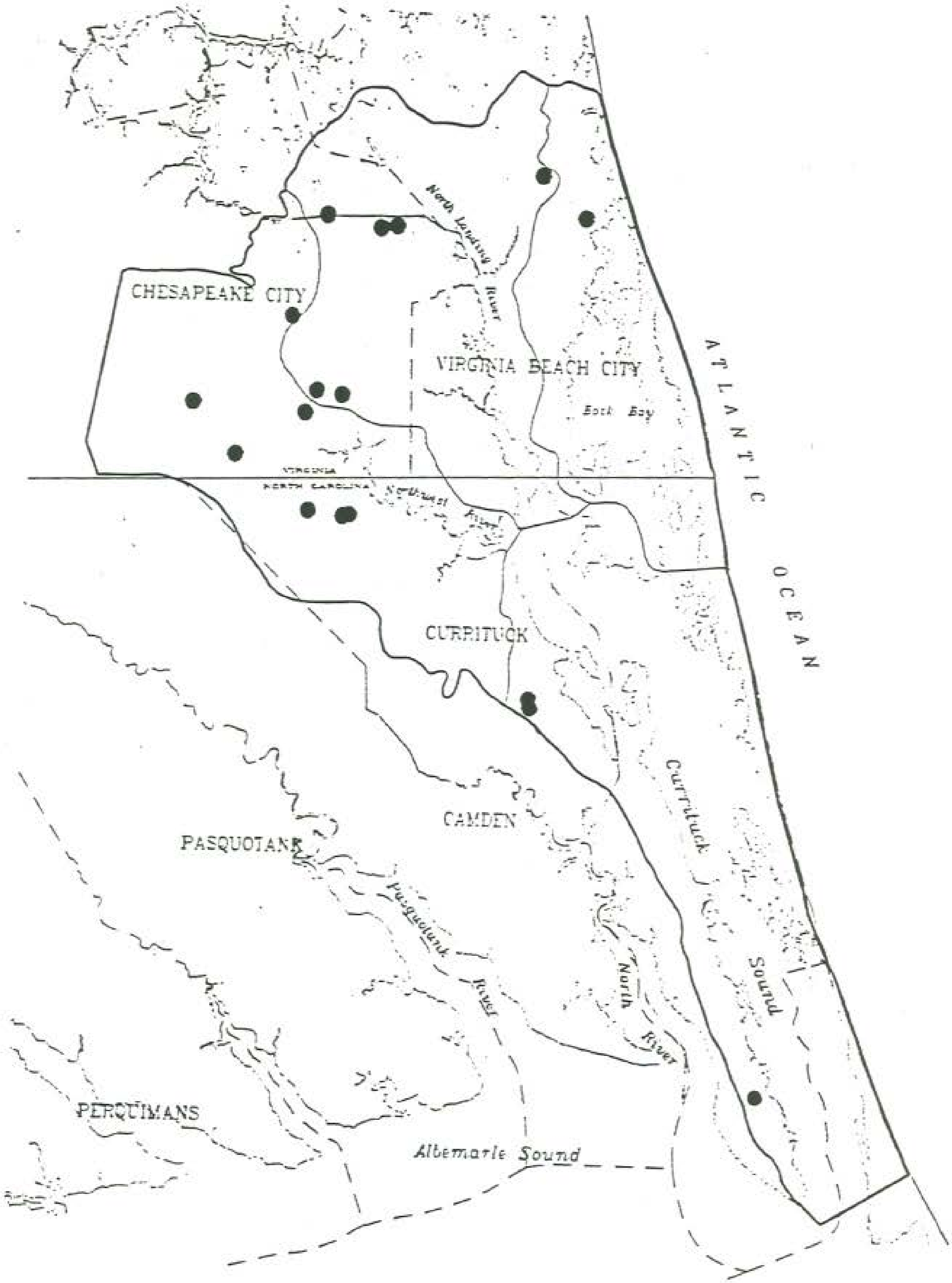
The two major sources of pollution are usually point and nonpoint sources. In the Currituck Sound Watershed there are 17 point source dischargers, including 1 discharger in Back Bay Sub-Watershed, 6 dischargers in North Landing River Sub-Watershed, 7 dischargers in Northwest River Sub-Watershed and 3 dischargers in Currituck Sound Sub-Watershed (Figure 47). All of the point sources dischargers are less than 0.5 MGD and form a crescent starting in Currituck (in Currituck County) and extending around to Sandbridge (in Virginia Beach). These facilities are not considered to be a major contributor to the nutrient loading of the watershed because of their small discharge rate. However, nonpoint sources are a different matter.

Nonpoint sources can be an important source of nutrients and other contaminants. Dodd et al. (1992) have taken the land use /land cover data from the LANDSAT scenes in 1987 and 1988 and developed loadings for each basin in the APES area. They found that nonpoint sources were responsible for the highest loadings in the Currituck Sound Watershed and Neuse River Basin. The areal loadings from runoff measured as kilogram per hectare per year (kg/ha/yr) were for Total Nitrogen (TN) and Total Phosphorus (TP). The Currituck Sound Watershed had loadings of 6.07 kg/ha/yr TN and 0.57 kg/ha/yr TP compared to the adjacent Albemarle Sound with lower values of 5.41 kg/ha/yr TN and 0.49 kg/ha/yr TP.

VI-E. Water Quality Trends

The water quality trends in the Currituck Sound Watershed will be described by determining the locations where water quality parameters have one of the following characteristics: appear to be higher/lower than normal, above water quality standards, or above detection limits. Trends only reflect locations of the highest number of potential pollutants determined from literature sources. Information came from three Virginia and two North Carolina documents. The

Figure 47. Currituck Sound Watershed Point Source Locations



sources include: Virginia Water Quality Assessment for 1992: 305b Report to EPA and Congress, Virginia Water Control Board (1992); Comprehensive Review of Selected Toxic Substances - Environmental Samples in Virginia, Virginia State Water Control Board, Tinger et. al. (1990); Multivariate Analysis of Spatiotemporal Water Quality Patterns of Back Bay, Virginia, Alden, (1989); Albemarle-Pamlico Estuarine Study: Fish Tissue Baseline Study 1989, North Carolina Division of Environmental Management (1991); and Albemarle Watershed Planning in the Albemarle-Pamlico Estuarine System: Report 3 - Toxics Analysis, Cunningham et al. (1992).

Water column data indicate high values for suspended solids, pH, total nitrogen, total phosphorus, dissolved oxygen and fecal coliform. Some of the highest values for suspended solids for the entire APES study area have been recorded in the Currituck Sound and Back Bay. At the mouth of Currituck Sound, high total nitrogen concentrations were found along with high pH values. Total nitrogen and phosphorus concentrations were significantly higher in Nawney Creek, a tributary to Back Bay, than other surrounding tributaries. The source of these high nutrients is believed to be the runoff from agricultural and residential development in the Back Bay Sub-Watershed. Low dissolved oxygen is a problem during the summer months in sections of the Northwest and North Landing River Sub-Watershed. This situation is not unusual during the summer months in coastal plain tributaries when low flow conditions exist. High fecal coliform counts have been reported in the North Landing Sub-Watershed around Stumpy Lake and probably a result of urban runoff.

Sediment data is very limited at the present time but when Dr. Stan Riggs, East Carolina University, completes his investigation of the Currituck Sound a better idea of the extent of heavy metal contaminant will be available. The information currently available is from one location in the North Landing River Sub-

Watershed that had detectable levels of lead, cadmium and mercury in the sediment.

One other water quality concern should be mentioned. A shellfish ban is in effect off the coast of Virginia from Red Wing Lake to the North Carolina/Virginia state line. The contamination is associated with the buffer zone surrounding the discharge from the HRSD - Atlantic STP naval facility and nonpoint source pollutants. However, this contamination is offshore and not directly connected with the Currituck Sound Watershed.

In general, the water quality data for the Currituck Sound Watershed is quite limited, and more water quality information was available for the Back Bay area than any other location. The best way to summarize the water quality is to paraphrase some of the conclusions reached by the Roy Mann (1984) report prepared for the City of Virginia Beach concerning a management plan for Back Bay. These conclusions are not just for Back Bay but can be applied to the entire Currituck Sound Basin. "Due to little elevation, the watershed tributaries only have a minor contribution to the water flow except during periods of heavy precipitation. Each tributary is sensitive to even small introductions of pollutants and the dominant sources of nonpoint pollution are urban and agricultural runoff. Water quality needs to be improved in the tributary streams or the rural character and wildlife habitats will be threatened."

VII. CONCLUSIONS AND RECOMMENDATIONS

The first thing that should be considered when studying the Albemarle-Pamlico Estuarine Study area is the sheer size. This study area is almost twice the size of the State of Maryland and contains the second largest estuarine system on the east coast of the United States. Approximately two million people are living in this study area, making the population density a little higher than 70 per./sq.mi. This population density is low compared to the average density of 126 per./sq. mi. for the State of North Carolina. However there are portions of the study area that have seen population growth as high as 68 percent during a ten year period. Therefore, gaining a better understanding of the population and land use dynamics of the system is critical to the proper management of these vast natural resources.

Land use/land cover information provided by the LANDSAT satellite was a valuable tool in understanding the land use patterns and population trends throughout the APES area. However, the relative accuracy based on federal, state and county officials' comments after reviewing the map products lacked the detail needed below the regional level (multiple counties). The USGS Level I land use classification was found to be the most suitable format for the multiple levels of government. The largest errors were found in the categories of urban and wetlands. Acreage appeared to be underestimated by up to 50% for both categories based on comparison with other data sources. The LANDSAT satellite imagery provides reasonable information from a land cover stand point but when evaluating land use, such as the urban category, more detailed interpretation is needed by individuals familiar with the area.

RECOMMENDATION: **Land use information provided by LANDSAT or any other remote sensing platform should be supplemented with other sources of information which cover the same land use category. Reliance on human interpretation is still**

required over computer methods especially in the case of urban land use. If any change analysis is required of the land use data only the same format and platform should be used to eliminate as many inherent errors as possible.

Most of the APES area is rural especially the Chowan and Lower Roanoke Basins. The Chowan Basin has 22 percent of the total APES acreage but only 11 percent of the population. At the other extreme is the Neuse Basin which contains only 27 percent of the total acreage but more than 50 percent of the population.

Land use in the APES area is estimated to be 4.8 percent urban or built up, 28.1 percent agriculture, 28.4 percent forest, 14.6 percent water, 20.5 percent wetlands, 3.3 percent shrub land and 0.2 percent barren land. Potential conflicts are evident in most of the coastal subbasins between wetlands and uses for development purposes. There are other potential conflicts in some subbasins of the Neuse, Tar-Pamlico, Chowan and Pasquotank Basins between agricultural use and uses for development purposes.

RECOMMENDATION: **The location and acreage of all wetlands should be accurately defined and the most valuable wetlands protected. Because of the limited land on the barrier islands of North Carolina, more comprehensive management strategies should be focused on these areas to resolve the many land use conflicts that exist. Further study is needed on the large acreage of agricultural land in the central Neuse and Tar-Pamlico Basins and ways of protecting these areas from rapid conversion to developed land.**

The three areas in the Albemarle-Pamlico Estuarine Study that have had high growth rates are the Virginia Beach area, the Raleigh/Durham area and the Greenville/Morehead area. The Virginia Beach area had the highest growth rate (43.4 percent for the past 30 years) of all three areas from a county wide perspective, but the Raleigh/Durham area had the highest growth (27 percent for the last 30 years) from a basin wide perspective. Virginia Beach and the Raleigh/Durham areas are projected to have growth rates over the next 20 years that are above the state average for Virginia and North Carolina.

RECOMMENDATION: **More attention should be focused on density control and stormwater runoff in these high growth areas because of the runoff problem that is created with the increase in impervious surfaces. The Virginia Beach area is of particular concern because of the high potential of direct land use conflicts between natural resources and urban development.**

Population in 1990 for the Albemarle Sound Basin is just over 500,000 people. The highest population is in the Pasquotank Basin, closely followed by the Chowan Basin. Growth projections to the year 2010 indicate that the Pasquotank Basin will continue to lead in growth especially in the coastal city of Virginia Beach and counties of Currituck and Dare. Land use for 1990 was similar to the entire APES area with only slightly higher acreage for wetlands and lower acreage for urban or built up areas. There are 273 point source dischargers of wastewater in the Albemarle Sound Basin and most of the dischargers are scattered through out the basin and had daily flows of less than 10,000 gallons. Nonpoint source loading of nutrients are the highest in the Chowan River and particularly the Blackwater River. Water quality data indicate that the Chowan and Roanoke Rivers have more potential pollutant problems than any other water bodies in the Albemarle Sound Basin. Potential impact to striped bass come in the form of heavy metals in the water column and sediments. Dioxin in fish tissue from the Chowan and Lower Roanoke Rivers is also evident. Of particular concern is the potential impact of a paper mill and surrounding development in Roanoke Rapids that is just upstream of the major spawning area for striped bass in North Carolina.

RECOMMENDATION: **Since 50 percent of all the freshwater flow into the Pamlico Sound comes from the Albemarle Sound and the majority of this flow originates with the Roanoke and Chowan Basins, more attention should be given to where growth and types of land use conversion for this entire drainage area are taking place. Special attention should be devoted to evaluating the relation between paper mill effluent and striped bass utilizing a biomarker technique. The focus area should be in the vicinity of Weldon, North Carolina.**

The highest population growth for the entire APES area is in the Currituck Sound which is a watershed of the Pasquotank Basin. North Landing and Northwest River Sub-Watersheds have the highest growth in the Currituck Sound Watershed. Land use in these western subbasins contain the highest urban/built up acreage. The eastern sub-watersheds of Back Bay and Currituck Sound have approximately 15,000 acres that are managed for natural resource protection. There are only 17 point source dischargers in the Currituck Sound Watershed and all are considered to be minor facilities because of their low discharge rate. Currituck Sound has the highest nonpoint source nutrient loading of any watershed in the entire APES area. Water quality data indicate some of the highest suspended solids values are from Currituck Sound and Back Bay. Nutrients, pH, dissolved oxygen and fecal coliform problems appear to be related to nonpoint sources of agriculture and development.

RECOMMENDATION: Due to number and acreage of unique habitats that are located in the Currituck Sound Watershed, special attention should be given to the type of land conversion and where it is taking place in relation to the natural area. More basic studies are needed to better identify and understand all of the components that make up this watershed. Special buffer zones should be established around protected areas to prevent encroachment from urban development. Other priority non-protected unique habitats should come under protection as soon as possible.

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Appendix A:

ALBEMARLE-PAMLICO ESTUARINE STUDY AREA

North Carolina Study Area
(including 37 counties)

COASTLINE (5)	SOUND (9)	UPLAND (23)	
Carteret	Beaufort	Craven	Martin
Currituck	Bertie	Durham	Nash
Dare	Camden	Edgecombe	* Northhampton
Hyde	Chowan	Franklin	* Orange
* Onslow	Pamlico	Gates	* Person
	Pasquotank	* Granville	Pitt
	Perquimans	Greene	* Vance
	Tyrell	* Halifax	* Wake
	Washington	Hertford	* Warren
		* Johnson	* Wayne
		* Jones	Wilson
		* Lenoir	

Virginia Study Area
(including 13 counties/6 independent cities)

COASTLINE (1)	UPLAND (18)	
* Virginia Beach City	* Brunswick	* Mecklenburg
	* Charlotte	* Nottoway
	* Chesapeake City	* Prince Edward
	* Dinwiddle	* Prince George
	* City-Petersburg	* City-Petersburg
	Greenville	Southampton
	City-Emporia	City-Franklin
	* Isle of Wight	* Suffolk City
	* Lunenburg	* Surry
		Sussex

* only a portion of the county or city is in the study area

Appendix B: Comparison of LUDA, LANDSAT and Modified Landsat Developed Class Acreages

County	LANDSAT	LUDA	Modified LANDSAT
Beaufort	4411	18611	0
Bertie	970	11841	0
Camden	685	3445	618
Carteret	5553	29461	25466
Chowan	860	7721	4720
Craven	8062	23706	25677
Currituck	1581	5644	6622
Dare	2390	18709	20925
Durham	43674	44556	70756
Gates	488	10553	851
Hertford	623	12955	0
Hyde	1349	3206	0
Lenoir	714	14669	19715
Onslow	14806	0	0
Pamlico	6219	7287	0
Pasquotank	2576	10321	11942
Perquimans	1513	7511	7539
Pitt	1915	21385	18026
Tyrrell	264	442	4323
Washington	531	2860	0
Wake	113195	68421	114742
Brunswick	650	7643	2042
Dinwiddle	2298	7313	3306
Isle Wight	2072	11271	3261
Southhampton	1448	9795	3130
Suffolk City	2356	26265	10528
Surry	1652	1336	512
Sussex	2012	5617	2278
Totals	224867	392544	356979

Appendix C: Comparison of LUDA, LANDSAT and NWI Wetland Class Acreages

County	LANDSAT	LUDA	NWI (ha.)	NWI (acres)
Beaufort	74147	73240	49002	121084
Bertie	76722	8644	48853	120716
Camden	34774	76751	32756	80940
Carteret	115345	141867	75791	187280
Chowan	10648	11102	7444	18394
Craven	88579	90081	69049	170620
Currituck	50866	75427	33454	82665
Dare	84944	184385	86344	213356
Gates	48214	53325	24250	59922
Hertford	32693	32396	15206	37574
Hyde	81826	190537	94299	233013
Onslow	90352	105367	64944	160477
Pamlico	82622	87153	46976	116078
Pasquotank	21074	42336	12812	31658
Perquimans	22140	22289	8790	21720
Tyrrell	75666	140766	59669	147442
Washington	37331	31078	26535	65568
Totals	1027943	1366744		1868506
Percentage	55	73		100

Appendix D: APES Population Data by County/City: 1960-2010

County/City	1960 Pop.	1970 Pop.	1980 Pop.	1990 Pop.	2000 Pop.	2010 Pop.
Beaufort - NC	36014.0	35980.0	40355.0	42283.0	46368.0	48558.0
Bertie - NC	24350.0	20528.0	21024.0	20388.0	21079.0	20696.0
Camden - NC	5598.0	5453.0	5829.0	5904.0	6250.0	6362.0
Carteret - NC	30940.0	31603.0	41092.0	52556.0	66377.0	77876.0
Chowan - NC	11729.0	10764.0	12558.0	13506.0	14999.0	15846.0
Craven - NC	58773.0	62554.0	71043.0	81613.0	96376.0	106996.0
Currituck - NC	6601.0	6976.0	11089.0	13736.0	18516.0	22542.0
Dare - NC	5935.0	6995.0	13377.0	22746.0	31050.0	41283.0
Durham - NC	111995.0	132681.0	152235.0	181835.0	196483.0	214757.0
Edgecombe - NC	54226.0	52341.0	55988.0	56558.0	63739.0	65996.0
Franklin - NC	28755.0	26820.0	30055.0	36414.0	43852.0	49743.0
Gates - NC	9254.0	8524.0	8875.0	9305.0	10941.0	11682.0
Granville - NC	33110.0	32762.0	34043.0	38345.0	44807.0	48813.0
Greene - NC	16741.0	14967.0	16117.0	15384.0	16708.0	16529.0
Halifax - NC	58956.0	54354.0	55076.0	55516.0	58018.0	57633.0
Hertford - NC	22718.0	24439.0	23368.0	22523.0	24294.0	24032.0
Hyde - NC	5765.0	5571.0	5873.0	5411.0	5748.0	5806.0
Johnston - NC	62936.0	61737.0	70599.0	81306.0	93431.0	103063.0
Jones - NC	11005.0	9779.0	9705.0	9414.0	10632.0	10893.0
Lenoir - NC	55276.0	55204.0	59819.0	57274.0	59806.0	57906.0
Martin - NC	27139.0	24730.0	25948.0	25078.0	27793.0	27880.0
Nash - NC	61002.0	59122.0	67153.0	76677.0	80565.0	85506.0
Northampton - NC	26811.0	23099.0	22195.0	20798.0	21984.0	21283.0
Onslow - NC	82706.0	103126.0	112784.0	149838.0	147086.0	161255.0
Orange - NC	42970.0	57567.0	77055.0	93851.0	101241.0	110511.0
Pamlico - NC	9850.0	9467.0	10398.0	11372.0	11451.0	11766.0
Pasquotank - NC	25630.0	26824.0	28462.0	31298.0	33934.0	35790.0
Perquimans - NC	9178.0	8351.0	9486.0	10447.0	12764.0	14244.0
Person - NC	26394.0	25914.0	29164.0	30180.0	33600.0	34972.0
Pitt - NC	69942.0	73900.0	90146.0	107924.0	114212.0	122871.0
Tyrrell - NC	4520.0	3806.0	3975.0	3856.0	4462.0	4729.0
Vance - NC	32002.0	32691.0	36748.0	38892.0	42550.0	44186.0
Wake - NC	169082.0	229006.0	301429.0	423380.0	501347.0	592773.0
Warren - NC	19652.0	15340.0	16232.0	17265.0	16902.0	16894.0
Washington - NC	13488.0	14038.0	14801.0	13997.0	14165.0	13459.0
Wayne - NC	82059.0	85408.0	97054.0	104666.0	98138.0	95376.0
Wilson - NC	57716.0	57486.0	63132.0	66061.0	68296.0	69038.0
Brunswick - VA	17779.0	16172.0	15632.0	15987.0	16600.0	17100.0
Charlotte - VA	13368.0	12366.0	12266.0	11688.0	11500.0	11500.0
Chesapeake City - VA	66400.0	89580.0	114486.0	151976.0	188000.0	221000.0
Dinwiddie - VA	22183.0	21668.0	22602.0	20960.0	22100.0	23100.0
Greenville - VA	16155.0	14904.0	15743.0	14159.0	17800.0	20900.0
Isle of Wight - VA	17164.0	18285.0	21603.0	25053.0	33000.0	39100.0
Lunenburg - VA	12523.0	11687.0	12124.0	11419.0	12500.0	12800.0
Mecklenburg - VA	31428.0	29426.0	29444.0	29241.0	30200.0	30600.0
Nottaway - VA	15141.0	14260.0	14666.0	14993.0	15300.0	15600.0
Prince Edward - VA	14121.0	14379.0	16456.0	17320.0	19500.0	20900.0
Prince George - VA	57020.0	68573.0	66788.0	65780.0	70500.0	72100.0
Southhampton - VA	27195.0	25462.0	26039.0	25414.0	26300.0	26600.0
Suffolk City - VA	43975.0	45024.0	47621.0	52141.0	62100.0	69700.0
Surry - VA	6220.0	5882.0	6046.0	6145.0	7100.0	7600.0
Sussex - VA	12411.0	11464.0	10874.0	10248.0	10000.0	10000.0
Virginia Beach City - VA	84215.0	172106.0	262199.0	393069.0	500000.0	610000.0
Totals (pop.)	1868116.0	2081145.0	2438871.0	2913190.0	3303264.0	3678145.0

Appendix E: APES Percent Change in Population by County/City: 1960-2010

County/City	% Grow 60/70	% Grow 70/80	% Grow 80/90	% Grow 90/200	% Grow 200/201	% Grow Avg.
Beaufort - NC	-0.1	12.2	4.8	9.7	4.7	7.8
Bertie - NC	-15.7	2.4	-3.0	3.4	-1.8	0.2
Camden - NC	-2.6	6.9	1.3	5.9	1.8	4.0
Carteret - NC	2.1	30.0	27.9	26.3	17.3	25.4
Chowan - NC	-8.2	16.7	7.5	11.1	5.6	10.2
Craven - NC	6.4	13.6	14.9	18.1	11.0	14.4
Currituck - NC	5.7	59.0	23.9	34.8	21.7	34.8
Dare - NC	17.9	91.2	70.0	40.0	29.6	57.7
Durham - NC	18.5	14.7	19.4	8.1	9.3	12.9
Edgecombe - NC	-3.5	7.0	1.0	12.7	3.5	6.1
Franklin - NC	-6.7	12.1	21.2	20.4	13.4	16.8
Gates - NC	-7.9	4.1	4.8	17.6	6.8	8.3
Granville - NC	-1.1	3.9	12.6	16.9	8.9	10.6
Greene - NC	-10.6	7.7	-4.5	8.6	-1.1	2.7
Halifax - NC	-7.8	1.3	0.8	4.5	-0.7	1.5
Hertford - NC	7.6	-4.4	-3.6	7.9	-1.1	-0.3
Hyde - NC	-3.4	5.4	-7.9	6.2	1.0	1.2
Johnston - NC	-1.9	14.4	15.2	14.9	10.3	13.7
Jones - NC	-11.1	-0.8	-3.0	12.9	2.5	2.9
Lenoir - NC	-0.1	8.4	-4.3	4.4	-3.2	1.3
Martin - NC	-8.9	4.9	-3.4	10.8	0.3	3.2
Nash - NC	-3.1	13.6	14.2	5.1	6.1	9.7
Northampton -	-13.8	-3.9	-6.3	5.7	-3.2	-1.9
Onslow - NC	24.7	9.4	32.9	-1.8	9.6	12.5
Orange - NC	34.0	33.9	21.8	7.9	9.2	18.2
Pamlico - NC	-3.9	9.8	9.4	0.7	2.8	5.7
Pasquotank - N	4.7	6.1	10.0	8.4	5.5	7.5
Perquimans - N	-9.0	13.6	10.1	22.2	11.6	14.4
Person - NC	-1.8	12.5	3.5	11.3	4.1	7.9
Pitt - NC	5.7	22.0	19.7	5.8	7.6	13.8
Tyrrell - NC	-15.8	4.4	-3.0	15.7	6.0	5.8
Vance - NC	2.2	12.4	5.8	9.4	3.8	7.9
Wake - NC	35.4	31.6	40.5	18.4	18.2	27.2
Warren - NC	-21.9	5.8	6.4	-2.1	-0.0	2.5
Washington - N	4.1	5.4	-5.4	1.2	-5.0	-0.9
Wayne - NC	4.1	13.6	7.8	-6.2	-2.8	3.1
Wilson - NC	-0.4	9.8	4.6	3.4	1.1	4.7
Brunswick - VA	-9.0	-3.3	2.3	3.8	3.0	1.4
Charlotte - VA	-7.5	-0.8	-4.7	-1.6	0.0	-1.8
Chesapeake Cit	34.9	27.8	32.7	23.7	17.6	25.5
Dinwiddie - VA	-2.3	4.3	-7.3	5.4	4.5	1.8
Greenville - V	-7.7	5.6	-10.1	25.7	17.4	9.7
Isle of Wight	6.5	18.1	16.0	31.7	18.5	21.1
Lunenburg - VA	-6.7	3.7	-5.8	9.5	2.4	2.4
Mecklenburg -	-6.4	0.1	-0.7	3.3	1.3	1.0
Nottaway - VA	-5.8	2.8	2.2	2.0	2.0	2.3
Prince Edward	1.8	14.4	5.3	12.6	7.2	9.9
Prince George	20.3	-2.6	-1.5	7.2	2.3	1.3
Southhampton -	-6.4	2.3	-2.4	3.5	1.1	1.1
Suffolk City -	2.4	5.8	9.5	19.1	12.2	11.6
Surry - VA	-5.4	2.8	1.6	15.5	7.0	6.8
Sussex - VA	-7.6	-5.1	-5.8	-2.4	0.0	-3.3
Virginia Beach	104.4	52.3	49.9	27.2	22.0	37.9
Totals (pop.)	11.4	17.2	19.4	13.4	11.3	15.3

Appendix F: Population Densities for Basins and Subbasins: 1970-1990

Basin	Subbasin Number	1970 Pop./Person	1980 Pop./Person	1990 Pop./Person	1970 Pop./Mi.2	1980 Pop./Mi.2	1990 Pop./Mi.2	Total Acres	Total Sq. Mi.
Chouan	03-01-01A	N/A	13680.0	13512.0	N/A	41.8	41.2	209792.0	327.8
Chouan	03-01-01B	N/A	10892.0	9198.0	N/A	29.8	25.1	234304.0	366.1
Chouan	03-01-01C	N/A	16250.0	17919.0	N/A	34.2	37.7	304448.0	475.7
Chouan	03-01-01D	N/A	11748.0	12905.0	N/A	24.1	26.5	312128.0	487.7
Chouan	03-01-01E	N/A	15787.0	18292.0	N/A	54.7	63.3	184832.0	288.8
Chouan	03-01-01F	N/A	9466.0	9647.0	N/A	27.2	27.8	222464.0	347.6
Chouan	03-01-01G	N/A	47822.0	47582.0	N/A	51.8	51.6	590656.0	922.9
Chouan	03-01-02A	N/A	11555.0	10969.0	N/A	30.3	28.7	244352.0	381.8
Chouan	03-01-02B	N/A	9564.0	9984.0	N/A	34.7	36.3	176256.0	275.4
Chouan	03-01-02C	N/A	30970.0	30660.0	N/A	32.5	32.2	608960.0	951.5
Chouan	03-01-03	3488.0	3918.0	4465.0	28.3	31.8	36.2	78976.0	123.4
Chouan	03-01-04	6738.0	7745.0	7682.0	76.1	87.5	86.8	56640.0	88.5
Chouan	03-01-05	2732.0	2564.0	2670.0	28.7	26.9	28.0	60928.0	95.2
Total Chouan	-------------------	N/A	191969.0	195495.0	N/A	39.0	40.1	3284736.0	5132.4
Pasquotank	03-01-50A	N/A	38021.0	40658.0	N/A	58.3	62.4	417088.0	651.7
Pasquotank	03-01-51	5370.0	6317.0	6263.0	5.4	6.3	6.3	638080.0	997.0
Pasquotank	03-01-52	13589.0	15191.0	18175.0	25.2	28.1	33.7	345472.0	539.8
Pasquotank	03-01-53	7843.0	8432.0	8756.0	17.0	18.3	19.0	295168.0	461.2
Pasquotank	03-01-54A	N/A	83740.0	165341.0	0.0	93.3	184.1	574656.0	897.9
Pasquotank	03-01-55	1621.0	3605.0	3817.0	3.2	7.1	7.6	323008.0	504.7
Pasquotank	03-01-56	1529.0	4800.0	12216.0	13.8	43.4	110.4	70848.0	110.7
Pasquotank	03-01-57	140.0	189.0	135.0	2.2	3.0	2.2	39936.0	62.4
Total Pasquotank	-------------------	N/A	160303.0	257361.0	N/A	32.2	53.4	2704256.0	4225.4
Roanoke	03-02-08	35358.0	49207.0	48215.0	78.5	109.2	107.0	288320.0	450.5
	03-02-09	26683.0	27954.0	27148.0	49.2	51.6	50.1	346944.0	542.1
	03-02-10	9703.0	10121.0	9994.0	31.6	33.0	32.6	196480.0	307.0
Total L. Roanoke	-------------------	71744.0	87282.0	85357.0	53.1	64.6	63.2	831744.0	1299.6
Tar-Pamlico	03-03-01	40340.0	51578.0	57604.0	60.8	77.7	86.8	424896.0	663.9
	03-03-02	76302.0	87693.0	100822.0	119.6	137.4	158.0	408384.0	638.1
	03-03-03	43902.0	47492.0	48234.0	103.5	112.0	113.8	271360.0	424.0
	03-03-04	37388.0	38891.0	35608.0	41.8	43.5	39.8	572160.0	894.0
	03-03-05	43223.0	56627.0	65867.0	146.0	191.3	222.5	189440.0	296.0
	03-03-06	13634.0	13054.0	14226.0	56.0	53.6	58.4	155904.0	243.6
	03-03-07	30296.0	38886.0	37857.0	25.4	32.6	31.8	762624.0	1191.6
	03-03-08	3864.0	4115.0	4182.0	3.2	3.4	3.4	784576.0	1225.9
Total Tar-Pamlico	-------------------	288949.0	338336.0	364400.0	69.5	81.4	89.3	3569344.0	5577.1
Neuse	03-04-01	116323.0	134700.0	163228.0	150.7	174.5	211.5	493888.0	771.7
	03-04-02	226555.0	291204.0	390804.0	312.7	402.0	539.4	463680.0	724.5
	03-04-03	10017.0	12023.0	23461.0	76.2	91.5	178.5	84096.0	131.4
	03-04-04	16093.0	17937.0	20974.0	57.8	64.4	75.3	178240.0	278.5
	03-04-05	85772.0	100279.0	101418.0	172.2	201.3	203.6	318848.0	498.2
	03-04-06	27337.0	34218.0	40906.0	86.4	108.1	129.3	202496.0	316.4
	03-04-07	102787.0	110422.0	115397.0	102.1	109.6	114.6	644608.0	1007.2
	03-04-08	8793.0	9147.0	11620.0	38.1	39.6	50.3	147840.0	231.0
	03-04-09	17646.0	21581.0	29073.0	53.0	64.9	87.4	212928.0	332.7
	03-04-10	38818.0	58596.0	67708.0	55.4	83.6	96.6	448384.0	700.6
	03-04-11	12357.0	14152.0	14466.0	27.9	31.9	32.6	283776.0	443.4
	03-04-12	29446.0	25323.0	31126.0	163.3	140.4	172.6	115392.0	180.3
	03-04-13	3446.0	4647.0	4521.0	12.5	16.8	16.3	177024.0	276.6
	03-04-14	1128.0	1357.0	809.0	3.4	4.0	2.4	215104.0	336.1
Total Neuse	-------------------	696518.0	835666.0	1015511.0	93.7	109.5	136.5	3986304.0	6228.6
White Oak	03-05-01	14273.0	14826.0	21403.0	37.2	38.6	55.8	245696.0	383.9
	03-05-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	03-05-03	17765.0	23759.0	33277.0	91.2	122.0	170.9	124608.0	194.7
	03-05-04	7193.0	9270.0	9477.0	42.1	54.3	55.5	109312.0	170.8
	03-05-05	41.0	50.0	786.0	0.8	1.0	15.2	33088.0	51.7
Total White Oak	-------------------	39272.0	47905.0	64943.0	42.8	54.0	74.3	512704.0	801.1
Grand Total APES	-------------------	N/A	1661461.0	1983057.0	N/A	65.5	76.1	14889088.0	23264.2

Appendix G: APES Land Use Acreage for Basins and Subbasins: 1987-1990

Subbasin	Urban	Agriculture	Forest	Water	Wetland	Shrub Land	Barren Land	Total (acres)	Total (sq. mi.)
CHOWAN BASIN									
03-01-01A	10097.0	89091.1	96992.5	521.5	6509.1	6178.3	0.0	209784.5	327.8
03-01-01B	5193.0	72300.0	113517.0	629.7	33713.5	8300.4	0.0	234314.4	366.1
03-01-01C	5102.2	99090.1	125763.0	1379.4	61770.6	10924.6	2.6	304429.3	475.7
03-01-01D	3950.1	99566.2	134364.5	1107.4	63370.9	9650.0	0.2	312097.3	487.7
03-01-01E	4719.7	62447.7	66378.3	945.1	44795.6	5546.0	1.2	184834.4	288.8
03-01-01F	7924.0	86226.3	86977.6	770.9	45092.5	9970.7	0.2	222441.2	347.6
03-01-01G	45097.1	149633.5	104400.9	9966.0	151272.1	32910.2	44.6	590661.4	922.9
03-01-02A	3071.0	79533.0	123040.5	210.5	31499.6	6205.7	0.2	244368.5	381.8
03-01-02B	6415.0	33096.1	105740.0	129.6	20029.4	5919.4	0.0	176239.5	275.4
03-01-02C	24562.0	109256.6	274164.9	2136.5	102542.3	14367.3	0.0	609948.4	951.5
03-01-03	2919.7	30603.9	21092.9	15070.5	7749.4	1455.1	90.9	78977.4	123.4
03-01-04	3660.5	15823.9	10070.2	20130.3	4246.3	1174.0	749.9	56659.3	88.5
03-01-05	2352.4	19760.1	10220.5	9509.2	7210.0	3627.6	223.2	60919.0	95.2
Total Chowan Basin (acre	126434.5	1020124.5	1363032.4	63005.2	587037.9	114326.1	1116.0	3280674.6	5132.3
Percentage	3.8	31.3	41.5	1.9	17.9	3.5	0.0	100.0	0.0
PASQUOTANK BASIN									
03-01-50A	19039.6	105420.0	76405.4	61740.7	149605.4	4700.5	62.3	417062.7	651.7
03-01-51	9904.0	40609.5	167955.0	176743.5	243007.2	1029.0	2000.7	638097.7	997.0
03-01-52	9030.4	125343.4	40370.1	91040.0	63050.4	6503.9	447.0	345484.0	539.8
03-01-53	1369.6	84099.7	42364.2	76762.0	80004.4	4507.1	4375.0	295162.8	461.2
03-01-54A	41540.0	135156.7	49499.2	157037.8	100529.4	6910.0	3956.2	574637.8	897.9
03-01-55	3667.3	2265.3	5532.5	302916.5	6207.5	427.3	1960.2	322904.6	504.7
03-01-56	7409.3	1209.5	7666.9	46181.0	5603.8	513.8	2115.8	70860.1	110.7
03-01-57	883.1	0.0	17747.7	15705.0	5415.5	63.5	0.0	39914.8	62.4
Total Pasquotank Basin	88732.1	495064.9	415541.5	928208.1	735903.6	25723.1	15013.2	2704186.3	4225.3
Percentage	3.3	18.3	15.4	34.3	27.2	1.0	0.6	100.0	0.0
LOWER ROANOKE BASIN									
03-02-08	19836.3	95695.0	80706.0	4380.4	80189.1	7539.7	0.0	288346.5	450.5
03-02-09	7761.7	94301.5	94129.0	6207.7	114010.0	30346.2	215.0	346971.9	542.1
03-02-10	5303.7	46122.3	81964.0	656.1	48241.4	14191.9	0.0	196480.2	307.0
Total L. Roanoke Basin	32901.7	236118.0	256800.6	11244.2	242440.5	52077.8	215.0	831798.6	1299.7
Percentage	4.0	28.4	30.9	1.4	29.1	6.3	0.0	100.0	0.0
TAR-PAMLICO BASIN									
03-03-01	19843.5	164547.4	154692.7	1313.1	65554.7	18935.4	0.0	424886.8	663.9
03-03-02	41412.9	151053.0	160392.8	2446.0	43044.0	10030.2	0.0	408380.5	638.1
03-03-03	11919.0	139407.3	109056.3	512.4	4716.5	4970.9	0.0	271302.4	424.0
03-03-04	17396.6	179109.4	271902.4	533.0	86744.4	16354.9	0.0	572142.7	894.0
03-03-05	9692.9	82294.0	41639.0	1706.5	42453.0	11540.3	0.0	189413.7	296.0
03-03-06	5544.9	73003.4	23027.9	85.4	29078.5	24375.0	0.0	155915.1	243.6
03-03-07	17222.2	243398.1	171407.5	123599.7	168674.6	28814.0	9554.0	762620.9	1191.6
03-03-08	2074.4	66719.2	81959.2	521523.3	106253.7	3103.8	2121.6	784555.2	1225.9
Total Tar-Pamlico Basin	125906.4	1100282.6	1014957.8	651800.2	546541.4	110132.5	11676.4	3569297.3	5577.0
Percentage	3.5	30.8	28.4	18.3	15.3	3.3	0.3	100.0	0.0
NEUSE BASIN									
03-04-01	67406.2	122439.3	171141.4	11270.6	97290.1	24360.5	0.0	493908.1	771.7
03-04-02	102603.0	130213.0	145082.4	3199.7	64061.6	9663.7	0.0	463704.2	724.5
03-04-03	3640.6	40370.3	24735.3	369.5	5305.9	1653.5	0.0	84083.1	131.4
03-04-04	4736.5	109520.3	30922.1	934.0	21712.9	2305.0	0.0	178210.8	270.3
03-04-05	32693.6	142615.6	122259.2	1009.2	8773.2	10661.4	24.4	318036.6	498.2
03-04-06	8896.1	186450.0	73189.1	659.9	9790.1	3518.1	0.0	202504.1	316.4
03-04-07	39146.2	327714.9	231624.4	2510.4	32199.3	11418.0	0.0	644613.2	1007.2
04-04-08	2133.1	49007.8	30610.3	1829.3	45246.5	9909.3	490.9	147814.2	231.0
03-04-09	8820.8	68715.9	92560.3	169.2	33924.5	9546.2	0.0	212944.9	332.7
03-04-10	29633.9	23027.5	56453.5	121170.6	189415.5	27461.2	437.7	440394.9	708.6
03-04-11	9563.6	73631.4	68630.4	750.5	103641.0	31766.0	262.7	283761.6	443.4
03-04-12	7013.5	52595.2	47107.6	2453.7	4107.6	2102.9	0.0	115382.5	180.3
03-04-13	3310.9	15332.7	0.0	88942.7	62987.6	6114.0	333.3	177029.2	276.6
03-04-14	1423.2	3001.6	0.0	167744.0	40537.2	1449.7	965.7	215122.2	336.1
Total Neuse Basin	316309.2	1281495.1	1110334.0	403822.1	720293.0	151508.5	2517.7	3986301.6	6228.6
Percentage	7.9	32.1	27.9	10.1	18.1	3.8	0.1	100.0	0.0
WHITE OAK BASIN									
03-05-01	5116.9	25951.1	55118.4	22371.3	126612.7	10311.4	233.3	245714.7	383.9
03-05-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
03-05-03	16439.0	8400.3	9295.7	27092.0	56695.1	5275.3	656.2	124612.4	194.7
03-05-04	8793.4	11663.6	0.0	43506.5	38040.2	6798.1	82.2	109304.0	170.8
03-05-05	0.0	1364.3	699.8	24663.4	3634.1	372.3	2365.1	33099.0	51.7
Total White Oak Basin	30348.9	47387.3	65113.9	118434.0	225352.1	22757.1	3336.8	512738.1	801.1
Percentage	5.9	9.2	12.7	23.1	44.0	4.4	0.7	100.0	0.0
GRAND TOTAL (Acres)	720632.8	4180423.2	4226500.2	2176511.0	3058368.5	484605.1	33875.1	14880996.7	23264.1
PERCENTAGE (Land Area)	4.8	28.1	28.4	14.6	20.5	3.3	0.2	100.0	0.0