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EPA

# TMDL Case Study

# Albemarle/Pamlico Estuary

**Key Feature:** A nutrient screening approach that uses GIS technology to model watersheds within a large, multibasin area.

**Project Name:** Albemarle/Pamlico Nutrient Budgets
**Location:** EPA Regions III and IV, North Carolina and Virginia, Albemarle/Pamlico drainage
**Scope/Size:** Multibasin estuary, 30,880 mi$^2$
**Land Type:** Ecoregion 65, Southeastern plains; Ecoregion 63, Middle Atlantic coastal plain
**Type of Activity:** Agriculture, forestry, urban
**Pollutant(s):** Nitrogen and phosphorus
**TMDL Development:** PS, NPS
**Data Sources:** State, federal
**Data Mechanisms:** Modeling, GIS (ARC/INFO)
**Monitoring Plan:** No
**Control Measures:** No

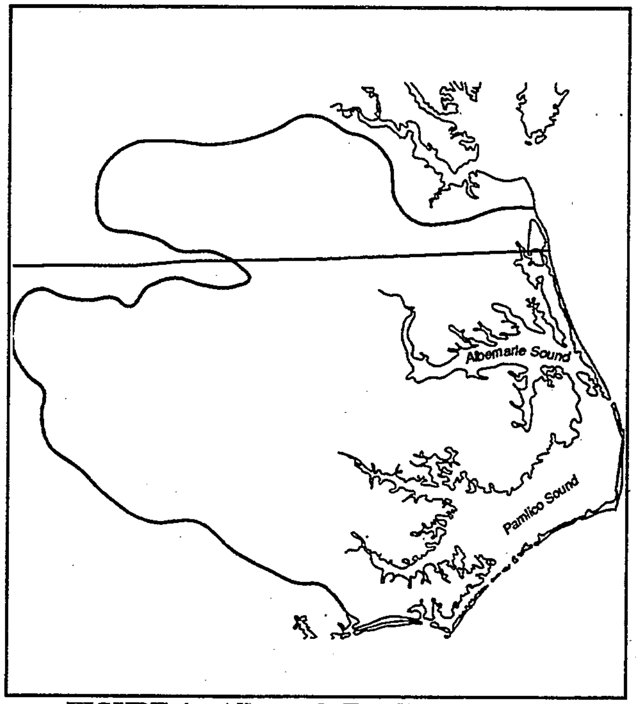

**FIGURE 1. Albemarle/Pamlico study area**

**Summary:** Over the past decade, North Carolina's Albemarle and Pamlico (A/P) Sounds (Figure 1) have experienced increasing water quality problems ranging from fish kills to declining populations of aquatic vegetation. In response to these and other problems, the A/P Estuarine Study was initiated to characterize the A/P basins and determine potential management strategies.

Excessive nitrogen and phosphorus loadings were identified early in the study as key factors impairing the health of the estuary. As a first step to address this problem, the North Carolina Department of Environment, Health, and Natural Resources, Division of Environmental Management (NCDEM) developed a modeling approach that is currently being used to screen the A/P watersheds for areas contributing excessive nutrients to surface waters. The approach uses LANDSAT imagery and geographic information system (GIS) technology to analyze land use within the basins, and then uses a combination of export coefficients and mass balances to calculate nutrient loadings from the 68 North Carolina watersheds and 44 Virginia watersheds within the study area. The output from this model allows relatively rapid graphical comparison of per-hectare loading values for various levels of spatial aggregation (basin, sub-basin, etc.). North Carolina intends to use this information to develop TMDLs as part of its new Basinwide Planning system. The process and technology used in the A/P Estuarine Study can help other states in the identification, prioritization, and targeting of critical areas for the TMDL process.

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## BACKGROUND

North Carolina's Albemarle and Pamlico basins comprise the second largest estuarine system in North America (Figure 1). With a total watershed area of 30,880 $mi^2$, the A/P basins are home to nearly 2 million permanent residents. The area is prized for its many recreational opportunities, including swimming, boating, fishing, and shellfish harvesting. The system is also a significant nursery area for East Coast fisheries. The A/P fisheries industry constitutes a substantial portion of the coastal and state economy, with an estimated value of processed fisheries products of $64.7 million in 1988. Table 1 summarizes the estimated commercial landings of the predominant estuarine-dependent finfish, crustaceans, and shellfish in the A/P area.

In recent years, the quality of this valuable resource has been declining because of human waste contamination, draining of wetlands, increased near-stream development, and agricultural and urban runoff. Effects are being seen in the form of declining populations of submerged aquatic vegetation, decreasing shellfish yields, skin and shell diseases on aquatic organisms, and extensive algal blooms.

In response to these problems, and in light of the system's high recreational and commercial values, the A/P system was designated as an estuary of national significance in 1987 and was selected to be studied as part of EPA's National Estuary Program. The resulting A/P Estuarine Study was initiated as a cooperative program between EPA and the State of North Carolina's Department of Environment, Health, and Natural Resources (DEHNR). Its purpose is to evaluate the nature of the basins' environmental problems and to determine how the estuaries can best be preserved and managed.

## ASSESSING AND CHARACTERIZING THE PROBLEM

The 1991 Status and Trends report for the A/P Estuarine Study stated that accelerated eutrophication resulting from nitrogen and phosphorus loadings is a significant cause of water quality degradation in many tributaries to the A/P estuary. In particular, the study found that nuisance algal blooms, anoxic events, and some fish kills have been associated with nutrient loading to the estuary (Steel, 1991). As a first step toward controlling nutrient loadings, the A/P Study developed a screening approach designed to narrow the focus of future nonpoint source (NPS) control efforts. The approach consists of developing nutrient budgets within the 68 sub-basins composing the North Carolina portion of the A/P study area (Research Triangle Institute, 1992a). These budgets will then serve as a tool for screening out critical areas of high nutrient loading. The information gained from this process is valuable for TMDL development and for targeting BMP cost share funding to areas causing the greatest nutrient loadings.

### *Calculating the Nutrient Budget*

The approach, which uses export coefficients and mass balance models to estimate nitrogen and phosphorus budgets for A/P sub-basins, can be separated into point and nonpoint source calculations.

**TABLE 1.** Commercial landings of estuarine-dependent finfish, crustaceans, and shellfish in North Carolina, 1986-1990, in thousands of pounds (Steel, 1991)

| Species | 1986 | 1987 | 1988 | 1989 | 1990 |
|---|---|---|---|---|---|
| Finfish | | | | | |
| Atlantic croaker | 9,425 | 7,289 | 8,434 | 6,824 | 5,731 |
| Flounder | 8,845 | 7,984 | 10,265 | 7,555 | 5,137 |
| Atlantic Menhaden | 66,378 | 55,499 | 73,716 | 66,750 | 71,647 |
| Striped bass | 189 | 262 | 116 | 101 | 114 |
| Crustaceans | | | | | |
| Blue crab | 23,755 | 32,424 | 35,604 | 34,725 | 38,002 |
| Shrimp | 6,162 | 4,416 | 8,139 | 8,923 | 7,802 |
| Shellfish | | | | | |
| Clams | 1,356 | 1,207 | 940 | 1,295 | 1,334 |
| Oyster | 745 | 1,426 | 913 | 530 | 323 |
| Bay scallops | 306 | 155 | 39 | 84 | 62 |

**TABLE 2.** LANDSAT Land Use/Cover Types

| |
|---|
| Water |
| Developed |
| Agriculture |
| Low density vegetation |
| Pine forest |
| Bottomland swamp |
| Mixed and hardwood |
| Shadow |
| Marsh |
| Atlantic white cedar |

Point source discharge data for the A/P study area were obtained from Discharger Monitoring Reports through NCDEM and the Virginia Water Control Board. Recent (1989-90) nitrogen and phosphorus inputs were calculated by using the median value of monthly records of flow and concentration data from point source dischargers. The data were transferred to a digital map in a GIS by using the latitude/longitude values included for each discharger. By overlaying watershed boundaries onto this map, point source discharges of nitrogen and phosphorus were assigned to each of the 68 A/P sub-basins.

Nonpoint source loadings were calculated in two ways. First, export coefficients were used to calculate loadings from each land use in each sub-basin of the study area. This was accomplished by overlaying data from a 1987/88 LANDSAT land use/cover study with digitized watershed boundaries to determine the area of each land use within each watershed. A literature review of export coefficients was then used to determine low, most likely, and high values of nutrient export for each land use/cover category. Multiplying land use areas by the appropriate export coefficients yielded nitrogen and phosphorus loading values by land use for each sub-basin. Table 2 summarizes the land use/cover categories used in the study. Figure 2 shows a GIS-generated map of relative nitrogen loadings for the Tar-Pamlico Basin.

A mass balance approach was also used to calculate nonpoint source loadings. This approach attempts to account for and balance the input, output, and storage of nutrients in the system. Because of data limitations, this approach was used only for agricultural areas in the 16 gaged watersheds of the A/P study area. Inputs for the mass balance included fertilizer, precipitation, livestock wastes, and nitrogen fixation. Outputs included the nutrients in harvested crops, soil fixation, denitrification, loss to swamp forests, and river export.

Numerous data sources and several assumptions were required to prepare the mass balance for the agricultural areas. Fertilizer inputs were assumed to be equal to the amount recommended by the Agricultural Extension Service for a particular crop. The distribution of each crop type in each sub-basin was determined by overlaying county and watershed boundaries onto the LANDSAT cover information and then combining this information with county-level agricultural statistics. In each county, the proportion of LANDSAT agricultural land attributed to any crop was determined by the average proportion of county agricultural land planted with that crop during the period 1987-89. In areas where one county is in multiple sub-basins, the crop acreages were allocated to each sub-basin assuming the crops were uniformly distributed within the county.

Point estimates of atmospheric nitrogen loading were obtained from EPA's Regional Atmospheric Deposition Model (RADM). The GIS was used to map these points and interpolate contours for wet and dry deposition.

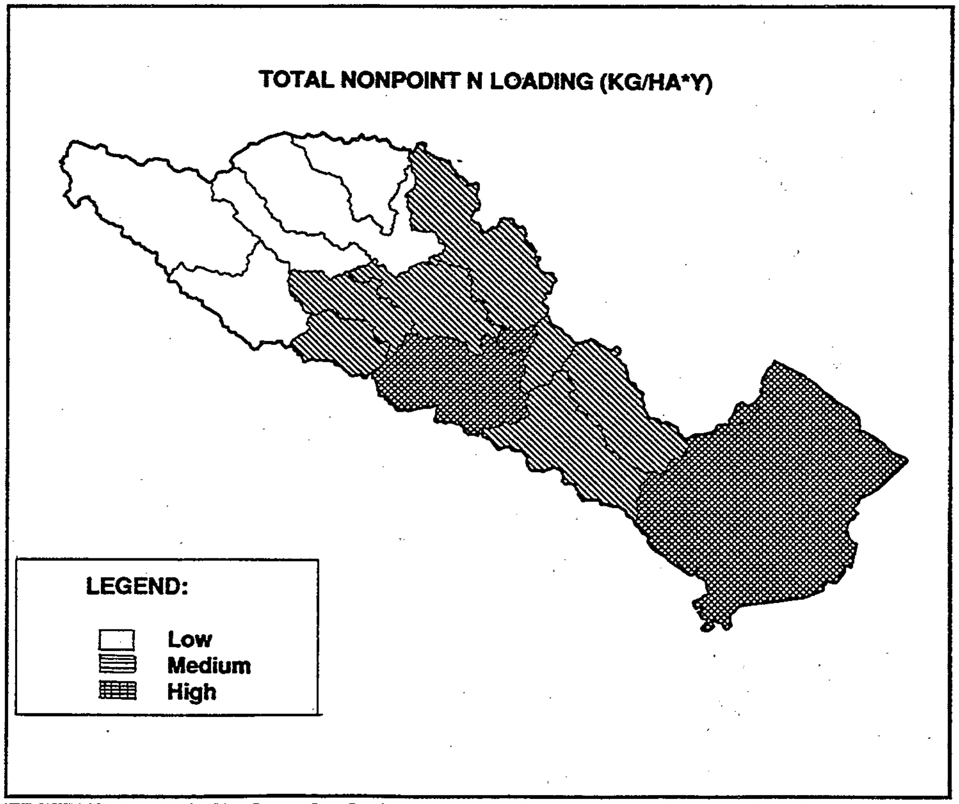


**FIGURE 2. GIS display of relative nitrogen loadings in the Tar-Pamlico basin**

These maps were overlaid on the A/P sub-basin maps, and area-weighted averages were calculated for each deposition type.

For determining livestock inputs, county livestock inventory data were averaged for the period 1987-1989. Per-animal nutrient generation values were then used to calculate total production. Based on literature review and professional judgment, the values 3, 5, and 10 percent were chosen as the low, most likely, and high scenarios for the proportion of animal waste nutrients actually entering the stream. A uniform distribution of livestock was assumed in allocating county loading values to each sub-basin.

Nitrogen fixation rates (inputs) for soybeans and peanuts (the dominant leguminous crops) were determined from the literature. Denitrification (output) was assumed to be 15 percent of applied fertilizer nitrogen, also according to the literature. Nutrients lost to harvesting were determined by multiplying county crop production data by the nutrient content of each crop as found in the literature. Allocations to sub-basins were made as discussed for fertilizer and livestock.

Calculation of losses to wetlands was limited to the portion of agricultural land whose drainage passes through wetlands before entering a stream. Based on the literature, wetlands were assumed to drain areas 3, 5, or 11 times their size. These areas were calculated for each sub-basin and the portions of agricultural nutrients from these areas were reduced by 64 percent for nitrogen and 43 percent for phosphorus (Kuenzler and Craig, 1986).

Average annual total nitrogen (TN) export and total phosphorus (TP) export were estimated for gaged watersheds. These estimates were based on STORET daily average flow and concentration data for the 1987-89 water years. Average loading (flux) was calculated according to the equation:

$$W = w * \frac{Q}{q}$$

where

W = average flux (kg/y);
w = mean of measured flux[a];
Q = mean of daily average flow; and
q = mean of measured flow[a].

[a] on days when nutrients were sampled

To complete the agricultural mass balance, a storage term was calculated as the difference between total inputs and outputs. The nutrient mass contained in the storage term was assumed to be associated with soil, groundwater, and biomass.

To reduce GIS programming time and enable modelers to use conventional personal computers, both GIS (ARC/INFO) and spreadsheets (Excel) were used to perform file manipulations and data analysis. The modelers chose to use spreadsheet programs whenever possible and reserved the GIS for spatial analyses that involved watershed and county boundaries and land use cover data.

## *Targeting and Prioritizing*

Nutrient loadings for each of the 68 sub-basins in the North Carolina portion of the A/P study area were summarized into charts depicting the data at various levels of spatial aggregation. Graphical analyses of nutrient loadings at each level were then used to compare relative impacts between basins, sub-basins, or land uses within a sub-basin.

### Basin Scale

Figure 3 depicts per-hectare nonpoint nitrogen loadings for each basin in the North Carolina portion of the A/P study area. This presents a spatial perspective that the state can use to identify critical areas for the TMDL process. Specifically, for a state implementing basinwide water quality management, this information allows basins to be prioritized according to their relative loadings. This would help ensure that resources such as monitoring staff, modelers, and funding to implement best management practices (BMPs) are distributed in the most cost-effective manner. In this example, the Chowan, Tar-Pamlico, and Neuse basins show relatively high areal loading values. These basins can then be selected for analysis at the sub-basin, or watershed, scale.

### Watershed Scale

Figure 4 shows the nonpoint nitrogen and phosphorus loading from each of the 68 sub-basins within the North Carolina portion of the A/P study area. Since the units have been converted to per hectare values, they allow comparison of the relative impacts of each sub-basin within the study area. For the TMDL process, this type of information can assist states in targeting critical watersheds on a regional basis. In essence, this can help to ensure that the areas selected for TMDL development are critical not only on a local scale, but on a regional scale as well.

Figure 5 shows nitrogen loadings from sub-basins within the Chowan Basin. As a TMDL prioritization tool, this

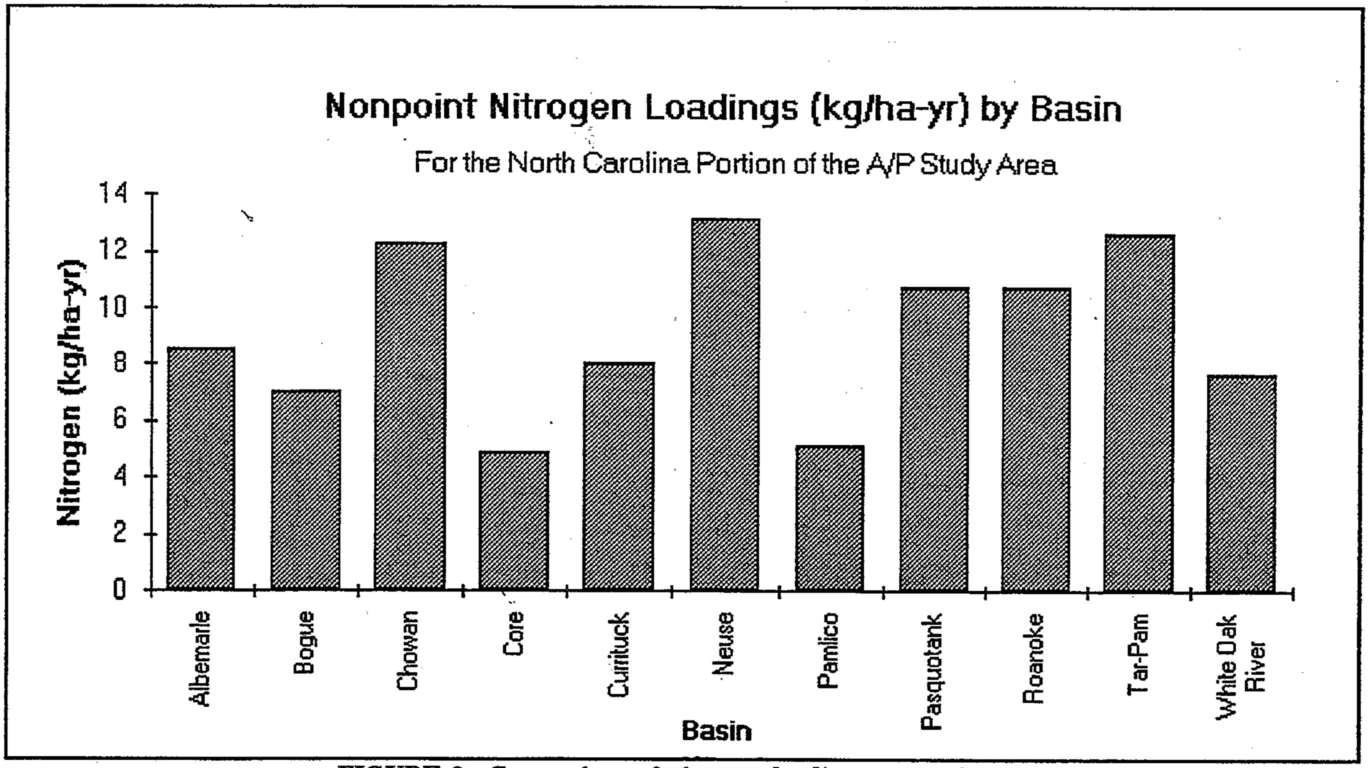


**FIGURE 3. Comparison of nitrogen loadings among basins**

perspective allows ranking of the severity of watershed loadings within a basin that has already been identified as having critical loadings. Chowan Sub-basin 4, for example, shows a particularly high loading rate. Moving one spatial level lower, a State could then target the specific land uses within this watershed for BMP implementation.

Figure 6 shows the total NPS nitrogen loads from each LANDSAT cover category in Chowan Sub-basin 4. This type of information is useful in targeting land uses for management practices and justifying controls to the affected public (e.g., row-crop farmers).

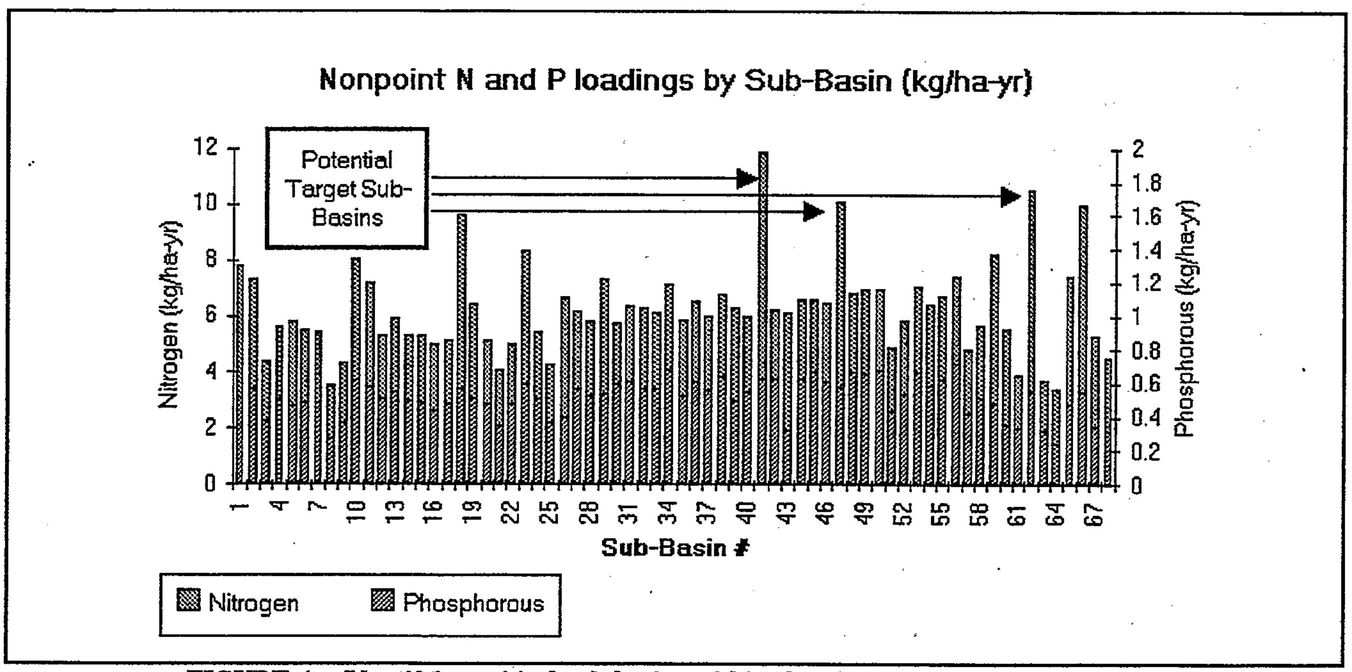


**FIGURE 4. Identifying critical sub-basins within the Albemarle/Pamlico study area**

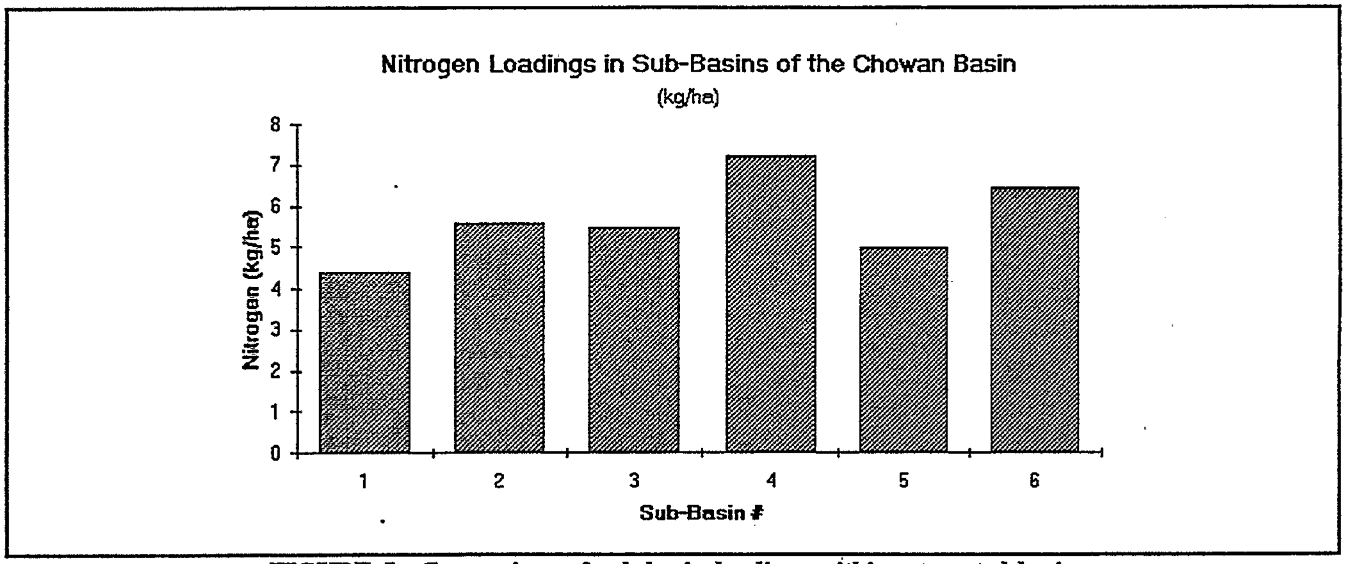


**FIGURE 5. Comparison of sub-basin loadings within a targeted basin**

## FOLLOW-UP

As part of its new Basinwide Planning process, North Carolina intends to use the information obtained from the A/P screening to target areas for TMDL development. Watersheds showing high nitrogen and phosphorus loadings, especially those nearest the estuaries, will be selected for special management attention. The Tar-Pamlico Basin, in the central portion of the study area, has already been targeted for PS/NPS trading of nitrogen loads.

Once critical watersheds have been identified, other small-scale nutrient and sediment models can be used to assist in determining the optimum BMP scenarios to reach desired reduction limits. The Nomini Creek TMDL Case Study (#4) discusses the use of watershed-scale models with a GIS in order to quantify loads and identify critical nonpoint source areas.

The A/P modeling tools are currently being used to develop and test nutrient control and population growth scenarios across the A/P basins. Additional GIS tools are being developed by NCDEM to help decision makers analyze the water quality impacts of nonpoint source controls. For example, GIS technology is being used to provide maps highlighting areas of critical nitrogen and phosphorus loadings. For TMDL targeting, these maps

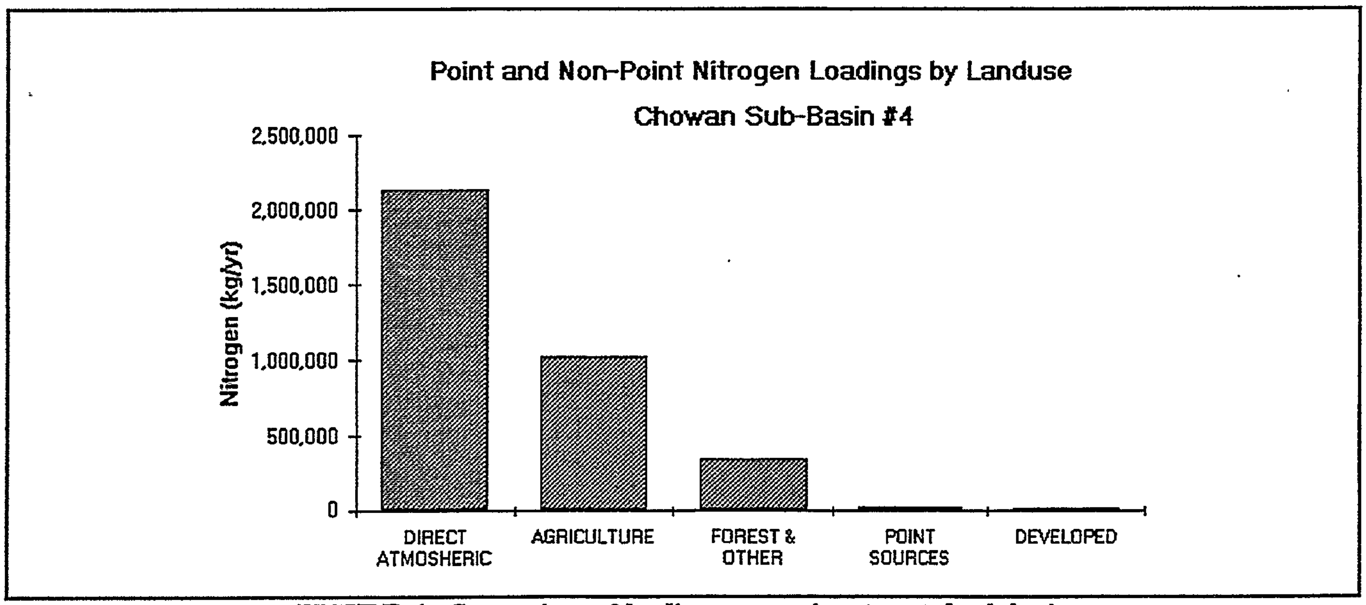


**FIGURE 6. Comparison of loading sources in a targeted sub-basin**

will be combined with maps showing other variables of concern, such as public interest, aesthetic value, or fragility of a particular system. A GIS can then generate a master targeting map, showing areas where multiple water quality concerns overlap (Figure 7). Similar critical area maps are being developed for the A/P study using a variety of GIS data layers.

GIS technology is also expected to play a role in illustrating the need for controls to the agricultural community and municipal dischargers. In addition, the GIS will be used to study the use of riparian buffer protection and restoration to supplement on-the-farm BMPs, which alone may not achieve the desired nitrogen and phosphorus reductions in A/P watersheds.

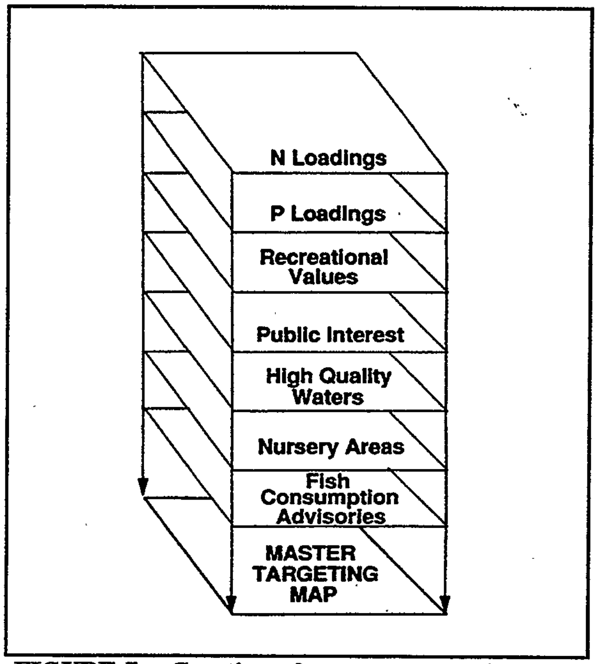


**FIGURE 7. Creation of a master targeting map**

The A/P databases and modeling results are being incorporated into "sub-basin profiles," which summarize the characteristics of each sub-basin (e.g., land use, point sources, crop statistics, livestock operations, pollutant loading characteristics). This information has also been compiled into a PC data base, which will allow NCDEM users to have desktop access to watershed data that were previously available only through a mainframe or a GIS.

## CONSIDERATIONS

Other rural NPS models have been linked with GISs, but many are data-intensive and storm-event-driven. AGNPS, which is best suited for modeling small watersheds, is one example of such models. The approach used in the A/P study was chosen specifically for its ability to handle a large multibasin area, while still providing output for screening at the sub-basin level. It is important to note that the A/P nutrient screening approach estimates annual loadings, a feature that is suitable within a long-term context for nutrient management of basins draining to estuaries and lakes. Data requirements are such that small watersheds or large basins can be screened and management scenarios can be tested (e.g., combinations of BMPs and PS control strategies).

The A/P approach is, however, more data-intensive than some screening models. Where nationally available data were out-of-date or unreliable (e.g., land use/cover information, some agricultural statistics) the latest data were acquired (e.g., the 1987-88 LANDSAT imagery and state-maintained crop statistics) to ensure that screening results would be credible to the decision makers and to other stakeholders as well.

## REFERENCES

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Steel, J., ed. 1991. *Albemarle-Pamlico Estuarine System, technical analysis of status and trends.* A/P Estuarine Study Report 90-01.

This case study was prepared by Research Triangle Institute, Research Triangle Park, NC, in conjunction with EPA Office of Wetlands, Oceans, and Watersheds, Watershed Management Section. To obtain copies, contact your EPA Regional 303(d)/TMDL Coordinator.