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SAMPLING STRATEGIES FOR ESTIMATING STATUS AND COST OF WATERSHED MANAGEMENT POLICIES

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ABSTRACT

As the nation moves toward more specific programs for managing nonpoint sources in targeted watersheds, better information is needed to inform the public and decisionmakers about the current status of management practices in those watersheds and the cost of bringing sources into compliance with management policies. Improved methods for accomplishing those tasks are developed in this study. Particular attention is given to agricultural operations. It includes a review of the literature on costs of controlling nonpoint sources. Relative efficiencies of alternative statistical sampling methods, sample sizes, and confidence intervals are examined. Sampling strategies are examined in the context of the Neuse River Basin in North Carolina where specific management strategies have been adopted to reduce the flow of nutrients to the Neuse River estuary. It was found that samples stratified by size of agricultural operations could produce acceptable confidence intervals on estimated means of management practices and compliance costs with sample sizes that are small relative to the number of all operations in the watershed. Data from the Census of Agriculture supplemented with Monte Carlo simulation can be used to design the sample, and it was also found that land parcels as defined by tax records can be used as a sampling frame.

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SUMMARY AND CONCLUSIONS

Nonpoint source pollution from urban, agricultural, resource extraction and other land-disturbing activities has emerged as a significant source of water quality degradation. A large number of programs have been instituted at various levels of government to reduce the flow of pollutants from those sources using various means to reduce soil erosion, improve efficiencies of nutrient application, control the flow of stormwater runoff, and filter runoff through riparian buffers and vegetated filter strips. Most of these programs have been guided by goals to increase general use of preferred management practices, and participation has been largely voluntary. As states have moved to enhance water quality in particular watersheds, some have adopted enforceable policies that either require landowners to satisfy performance standards or mandate the use of specific management practices. Processes by which such policies are adopted are better informed if the present status of management practices in a watershed are known and the costs of bringing activities in the watershed into compliance with management policies have been estimated.

Those are not simple tasks for large scale watersheds. While much is known about activities in particular watersheds, routinely reported information does not include management practices. If the extent of management practices in a watershed is not known, the cost and effectiveness of alternative management policies are also unknown. For watersheds in which thousands of farming operations and cost urban developments are located, the time and expense necessary to obtain that information is not trivial.

This report explores relative efficiencies of alternative statistical sampling methods, sample sizes, and confidence intervals for estimating both the current status of management practices and the cost of bringing agricultural and urban activities into compliance with proposed watershed policies. It includes a review of the literature on costs of controlling nonpoint sources. Sampling strategies are examined in the context of the Neuse River Basin in North Carolina where specific management strategies have been adopted to reduce the flow of nutrients to the Neuse River Estuary. Strategies for agricultural areas are based for data for the entire basin; results for urban areas are based on an urban area around Raleigh, North Carolina.

Comparisons that go beyond broad generalities need to be based on an analysis of actual datasets. For farming operations, many county-level statistics are available from federal and state census reports, but data on individual farms and data on management practices relevant to water quality are not generally available. In the absence of a dataset of that kind, one was synthesized using Monte Carlo simulation techniques. The synthesized dataset was created so that it had the same statistics on number and sizes of farms, land use in farms, and crop production as those estimated by the Census of Agriculture and the Census of Forests for each of three geographic regions of the Neuse Basin. To introduce farm-to-farm variability, individual farm data were synthesized by allowing farm sizes to vary according to a uniform probability distribution within the size groups used in census reports. The synthesized dataset contained 5,772 farms with the same size distribution as that reported in the 1992 Census of Agriculture. Land uses within farms were then generated using triangular probability densities with mean values the same as those found in the census data. Probability distributions for stream densities were found for each region for 40-, 160-, and 640-acre blocks using the TIGER geographic files produced for the United States Bureau of the Census by the United States Geological Survey. Fractions of streams on individual farms that are protected by riparian buffers were generated using a triangular probability distribution with mean values dependent on the mix of cropland and forestland in the farms using a relationship previously established for the Neuse River Basin. Neither the fraction of harvested cropland on which controlled drainage is practiced nor how it varies from farm to farm is known. Considerable uncertainty about controlled drainage was introduced in the synthesized dataset by introducing two random variables. First, the probability that any one farm had any controlled drainage was varied from 0.2 in the Upper Region to 0.9 in the Lower Region. Then, if the farm had any controlled drainage, the fraction of harvested land covered by that practice was allowed to vary according to a uniform probability distribution over the range (0,1). That process likely introduced more variability in the dataset than actually exists in the field.

Wake County tax files are readily available and were used to evaluate alternative sampling strategies for urban areas. Those files were used to delineate an urban area that includes much of the municipalities of Raleigh, Cary, Garner, and other municipalities and surrounding areas. While that data does not include information about management practices relevant to water quality, it does information critical to estimating cost of management practices, namely land value. That variable was used as a surrogate for comparing sampling strategies.

Comparisons of sampling strategies on the agricultural data lead to different conclusions from those based on comparisons on urban data. Stratified random sampling is far more efficient than simple random sampling for the agricultural data; it is much less superior on the urban data.

For the agricultural data, an analysis of variance on all variables shows that variations between the nine size groups within regions clearly dominates variability between the three regions. For all of the variables, between size group variability also dominates variability within size groups within regions. Furthermore, that conclusion is largely unaltered when intervals over which random variables were allowed to vary are enlarged to substantially increase farm-to-farm variability. That finding is important because it indicates that even though farm-to-farm variability is not known, it is less important to design of a sampling strategy than is variation between size groups.

Results of the analysis of variance imply that stratified random sampling would be more efficient than simple random sampling if samples are stratified by size of farm. Differences between standard errors of estimates of mean values of the variables given the same sample size are substantial.

For all variables, confidence intervals about estimates of means are reasonably small for sample sizes in the range of 100 to 150. Confidence intervals for mean values of harvested cropland subject to riparian buffers, confidence intervals of $\pm$ 2 standard errors range from $\pm$ 7.7% of the mean for $n = 72$ to $\pm$ 5.3% for $n = 144$. Confidence intervals for mean values of harvested cropland subject to controlled drainage are larger, namely $\pm$ 31% for $n = 72$ and $\pm$ 21% for $n = 144$. Results for controlled drainage are based on very substantial farm-to-farm variability in the synthesized dataset.

Similar results were found when estimating mean values of cost for bringing farms into compliance with watershed policies. Farm-to-farm variability in costs are greater than those for land uses and management practices because there is added variability in unit costs of compliance. For the cases examined, it was found that quite reasonable estimates of mean values of costs to bring farms into compliance with goals for riparian buffers could be made from sample sizes as small as 100. For a sample of that size, the confidence interval of $\pm$ 2 standard errors as estimated from the synthesized dataset is $\pm$ 17.6% of the mean. For n = 200, the confidence interval is $\pm$11%. Larger confidence intervals were found for costs of meeting goals for controlled drainage, but even with the very large farm-to-farm variability in the synthesized dataset, the confidence interval is $\pm$28% of the mean for a sample of size 200.

Much of what is known about land use in a watershed is taken from confidential census records that cannot be accessed for purposes discussed in this study. Fortunately, agricultural land parcels as defined by county tax records, when grouped by identical names, were found to have a distribution by size groups that is quite similar to that of farms by size groups as reported in the Census of Agriculture. That finding suggests that county tax records can be used as a dataset from which to draw random samples. Stratification on size groups of parcels aggregated by identical owners should produce very similar results to those which would be found if the sample could be drawn the population of farms.

For urban areas, stratified sampling does not appear to offer as great an advantage as it did for agricultural data. Stratification by zoning classes would appear to be the most logical approach to improving efficiency when drawing samples in urban areas. An analysis of variance of land values reveals that variability within zoning classes tends to dominate variability between classes, providing a clue about relative efficiencies of stratified versus simple random sampling. Indeed, stratified sampling provides only 30-35% reduction in standard errors of estimates of mean land values relative to simple random sampling. Because of the large variability within zoning classes, sample sizes for urban areas may have to be larger than those for agricultural areas.

RECOMMENDATIONS

Findings from this study lead to several recommendations about methods for estimating the present status of management practices in urban and agricultural watersheds and the cost of bringing those operations into compliance with watershed policies. Included among those recommendations are:

* reasonable estimates of current status and cost of compliance can be achieved using random sampling with sample sizes being small relative to the number of farms and urban developments in a watershed;
* county tax records can and should be used as a dataset from which both agricultural and urban samples are drawn;
* agricultural samples should be stratified by size of operation, and size groups should be comparable to those used by the Census of Agriculture;
* unless better sources of information about farm-to-farm variability are available, synthesized datasets similar to that used in this study can be used to allocate the sample across size strata;
* for watersheds comparable in size and diversity to the Neuse River Basin, sample sizes of 100-200 should be sufficient to establish acceptably small confidence intervals on estimates of mean values for agricultural operations;
* stratification of samples by zoning classes should be used to improve efficiencies in urban areas even though their advantage is much less than for agricultural areas; and
* sample sizes of 200 or less should be sufficient to obtain reasonable estimates of cost for urban areas of the size and complexity of the area around Raleigh.

INTRODUCTION

Basinwide or watershed planning for reducing nonpoint sources of water pollution is a complex task involving a number of steps. Among them are:

(1) identification of and location of sources of pollution;

(2) characterization of the state of variables in the watershed that affect the generation, transport, and fate of pollutants;

(3) compilation of an inventory of existing management practices;

(4) formulation of management strategies;

(5) prediction of pollutant flows and their chemical, physical and biological effects on receiving streams; and

(6) estimation of the cost of implementing management strategies.

While a substantial body of literature has contributed to better understanding of several of those steps, two of them have received relatively little attention. First, all too frequently, watershed management strategies are based on inadequate intelligence about current conditions, particularly the status of land management practices. Substantial data are available about most watersheds in the United States, but critical information (like land management practices) needed to formulate and evaluate nonpoint source management strategies is frequently not known. Second, while information about costs and techniques for estimating cost for specific sites is available, existing techniques for estimating the cost of nonpoint source management programs at a watershed or basin scale are crude. Good estimates of cost at that scale depend not only on accurate costs of implementing the program at particular sites but also on reliable information about existing land management practices and what changes in practices will be required to achieve program objectives at a representative sample of all sites in the watershed. For a river basin divided into thousands of farms and other land parcels, complete enumeration of costs at all sites is a daunting task. It is also inefficient. Unless efficient methods of gathering data are employed, the cost of acquiring the needed information may be prohibitively expensive.

This report explores methods for gathering that information in a cost effective manner. It examines the use of stratified sampling techniques to achieve that goal. Available information on costs of management practices are reviewed. Selected characteristics of the Neuse River watershed in North Carolina of particular relevance to a basinwide nonpoint source strategy are described. That information is incorporated in a Monte Carlo simulation to create a dataset for designing and evaluating a sampling strategy. The relative efficiency and accuracy of stratified sampling are compared to those of the alternatives of complete enumeration and simple random sampling. A strategy for implementing the sampling program is then recommended.

Importance of the Problem

Probably the first national assessment of the quality of water in streams was that undertaken by the Federal Water Quality Administration (FWQA) in 1969. Although that assessment was based more on knowledge of state field personnel than on a rigorous statistical analysis of chemical, physical and biological data, and it reflects a sense of the priorities at the time. Results were published by FWQA's successor agency, the United States Environmental Protection Agency (USEPA), and indicated that 33% of all stream mileage was polluted to some degree (USEPA, 1971). Industrial sources were cited as the prime cause of pollution in 24% of degraded stream mileage; municipal sources in 22%; and agriculture in 11%.

That assessment had an impact on the structure of amendments to the Federal Water Pollution Control Act (FWPCA) of 1972. Nonpoint sources were explicitly recognized as being important in that statute, but the regulatory program was directed primarily at industrial and municipal sources. The statute also required USEPA, with help from the states, to produce a biennial assessment of water quality conditions, assessments commonly referred to as 305(b) reports after the section of the statute in which they were required.

Assessments subsequent to 1972 reflect a change in the relative importance of the classes of sources. The 1984 report (USEPA, 1985) ranked nonpoint sources as the leading cause of degradation, accounting for 39% of mileage in streams that were not fully supporting of their designated uses. Municipal sources were ranked second at 36%, and industrial sources third at 11%. These judgement-based assessments were no doubt influenced by progress in bringing industrial and municipal sources into compliance with requirements of the Clean Water Act, as the FWPCA became known after 1977.

The most recent assessment reflects an even greater importance attached to agricultural nonpoint sources relative to other causes. In its 1996 report to Congress, USEPA estimated that agriculture is the leading source of degraded streams, contributing to impairment of 25% of the stream miles surveyed. The next most important sources — municipal point sources, hydromodification, habitat modification, resource extraction, and urban stormwater — each contributed about 5%. Removal of streamside vegetation and industrial point sources each contributed about 3%. Similar findings are reported for degraded lakes (USEPA, 1997).

Nonpoint sources have been especially important in degradation of water quality in estuarine areas of the Middle and South Atlantic states, particularly in the Chesapeake Bay and the Neuse River of North Carolina. Sediment and excessive nutrient enrichment are significant problems in both systems. Sediment transported from upstream sources settles out in estuaries as rivers widen and velocities of flow are reduced. High loadings of phosphorous and nitrogen in shallow estuarine waters support high rates of algal biomass production, which, during biochemical oxidation, consumes all or most of the dissolved oxygen in portions of those systems. The Chesapeake Bay Program (CBP) established that 40% of the 1985 base load of 303 million pounds of nitrogen would have to be reduced to achieve water quality goals in the bay. Nearly 80% of that load was coming from nonpoint sources, and agricultural activities alone accounted for about 40% of the load (CBP, 1994). In the Neuse River, where excessive nutrients have led to large algal blooms over the past two decades, the North Carolina Department of Environment and Natural Resources (NCDENR) estimates that nitrogen loads from nonpoint sources account for about 71% of all nitrogen entering streams of the basin. About 40% of the total load is attributable to cultivated land (NCDENR, 1998).

Nonpoint Source Management Programs

All states have taken some steps to reduce nonpoint sources as required under Section 319 of the Clean Water Act as amended in 1987. Some states have been more aggressive than others, driven in part by the severity of events to which they have had to respond.

A survey conducted as part of this study sought to identify the types of programs various eastern states were using to address nonpoint sources. Questionnaires were sent to 31 states east of the Mississippi River. Responses to those questionnaires revealed wide variations from state to state. Programs in several states are used here to illustrate the variety of types of programs and priorities established in those states.

Massachusetts. Massachusetts appears to have placed greater emphasis on urban nonpoint sources than on agricultural sources. Long term strategies cited by the Department of Environmental Protection (MDEP) are based on several authorities, most of which are directed toward urban development activities. Those authorities are (MDEP, 1994):

* regulations for subsurface disposal of sanitary sewage;
* the soil erosion and sedimentation control law;
* control of stormwater runoff through the subdivision control law and control of roadway construction activity;
* the wellhead protection program;
* special estuarine programs to protect Buzzards Bay, Massachusetts Bay, Waquoit Bay, and Narragansett Bay programs;
* the Cape Cod Commission's sole source aquifer protection program; and
* the Watershed Protection Act of 1992 which established vegetative buffers and other land use restrictions in watersheds of the Massachusetts Water Resources Authority.

Agricultural sources received relatively little attention beyond existing federal and state financial and technical assistance programs. Priorities are established among watersheds, and programs are formulated for those receiving high priority. The program consists of an assessment and analysis of total maximum daily loads, targeting of sources, a technology transfer and training program, and monitoring and enforcement.

Subsequent to development of its nonpoint source strategy, Massachusetts passed a River Protection Act in 1996. Among its other provisions, that act established a 200-foot "riverfront area" or buffer that requires a permit before any alteration of the area can be undertaken. It also requires a 100-foot buffer of undisturbed vegetation around all streams.

Wisconsin. By contrast, Wisconsin's nonpoint source program as described by the Wisconsin Legislative Fiscal Bureau (1997) has a much greater emphasis on agriculture. The lead agency for water quality management is the Department of Natural Resources (DNR) and the Department of Agriculture, Trade and Consumer Protection (DATCP) is designated as lead agency for soil and water conservation policies. The program consists of three major elements:

* an NPS Pollution Abatement Grant Program;
* animal waste and nonpoint source regulatory authority; and
* DATCP's soil and water conservation programs.

The pollution abatement grant program is implemented through adoption of best management practices (BMP's) on priority watersheds. Some of those watersheds are specified by statute; others are designated by the Land and Water Conservation Board acting on recommendations from DNR and DATCP. Detailed program plans, including cost estimates, are then formulated for designated watersheds. BMP's identified either in statues or regulations include those for croplands, animal operations, and urban areas.

DNR has statutory authority to regulate waste management at large animal operations. It also has more general powers to order abatement of nonpoint source pollution that violates a water quality standard, significantly impairs aquatic habitat, restricts navigation, poses a threat to human health, or otherwise significantly impairs water quality.

New York. New York State's Department of Environmental Conservation (NYSDEC) has developed a broad based program that rest heavily on planning, technical assistance, and financial incentives (NYSDEC, 1997). Amendments to the NY State Environmental Conservation Law (Article 17) in 1989 created the NPS water pollution control cost-share Program. They also required the NYSDEC to produce an inventory and assign priorities to waterbodies affected by NPS pollution. Table 1 lists 27 federal, state and local programs that New York uses to provide a variety of incentives to alleviate problems identified in those watersheds.

Agricultural sources are prominent targets. The New York City Watershed Agricultural Program offers a range of technical assistance, financial assistance, technical training, and outreach programs with a goal of enrolling 85% of farms in the watersheds in the pollution abatement effort. A number of other financial assistance and technical assistance programs are offered through the Cooperative Extension Service and federal agricultural programs.

Table 1. New York State Nonpoint Source Management Programs
(Source: New York State Department of Environmental Conservation)

Program Name	Plan-ning	Moni-toring	Regu-latory	Imple-ment.	Tech. ssist.	Finan-cial	Out-reach	Re-earch
Rotating Intensive Basin Studies		X						
Biological Stream Assessments		X						
Citizens Lake Assessments		X						
Lake Classification Inventory		X						
National Estuary Programs	X							
Management Conferences	X							
Great Lakes Programs	X							
Stream Classifications	X							
Shellfish Land Certiifcation	X							
Public Water Supply Program	X							
State Envrn Quality Review	X		X					
Wild, Recreational & Scenic Rivers	X							
Delaware River Basin Regulation	X		X					
Susquehanna River Basin Regulati	X		X					
Coastal Management Program			X					
Local Waterfront Revitalization			X					
South Shore Estuary Program	X							
Clean Lakes Program	X			X				
Water Resources Institute	X				X		X	
Water Resources Research						X	X	X
Resource Conservation & Develop	X			X	X	X		
Soil & Water Conservation Districts	X				X		X	
Nonpoint Source Cost-sharing						X		
Coastal NPS Program	X							
Water Week							X	
Clean Water/Clean Air Bond Act						X		
Pollution Prevention							X	

Maryland. Maryland, along with other signatories to the Chesapeake Bay Agreement, committed to a nutrient reduction program that would decrease the 1985 base load by 40% by the year 2000. Point sources accounted for 42% of the base load of nitrogen, nonpoint sources 58%, with agriculture accounting for 37%. Basin-specific strategies were then developed for each of the 10 tributary watersheds. Each strategy required:

* nutrient reduction technologies for all wastewater treatment plants with flows greater than 0.5 million gallons per day;
* full implementation and enforcement of all programs affecting nonpoint sources; and
* continuation of all other management options at least at current funding levels.

If those three actions were not sufficient to achieve 40% reduction, other actions were to be taken (Maryland Department of the Environment, 1995).

Maryland reinforced the tributary strategies by passing the Water Quality Improvement Act of 1998. It requires all agricultural operations with annual incomes of greater than $2500 or more than 8 animal units to formulate and implement a nutrient management plan by a given date. The act also covers nonagricultural operations that apply nutrients to more than 3 acres of land. Details of regulations to implement the act are still in the formulation stage (Maryland Cooperative Extension Service, 1998).

North Carolina. North Carolina's nonpoint source program, developed by the Department of Environment and Natural Resources (NCDENR), is an umbrella over a long list of individual programs involving local, state, and federal governments (NCDENR, 1996). Some of those are listed in Table 2. Priorities for implementation of those programs are established through a basinwide management approach begun in 1991. In that approach basinwide plans for each of the 17 basins in the state are being prepared and updated on a 5-year schedule.

Although considerable progress is being made under the umbrella of nonpoint source programs, a much more directed effort with specific targets to be achieved by specified dates is the Nutrient Sensitive Waters strategy adopted for the Neuse River Basin in 1997. Nutrient Sensitive Waters is a supplemental stream classification used by the state when it is necessary to

Table 2. North Carolina Nonpoint Source Management Programs
(Source: North Carolina Department of Environment and Natural Resources)

PROGRAM	MANAGEMENT AGENCIES Local	State	Federal
AGRICULTURE			
Agricultural Cost Sharing	SWCD	X	
Animal Waste Management	SWCD	X	X
Watershed Protection (PL 566)			X
Farm Bills			X
Pesticide controls			X
URBAN			
Urban stormwater programs	X	X	X
Water Supply Watershed Protection	X	X	
Pesticide controls			X
CONSTRUCTION AND MINING			
Sedimentation Pollution Control Act	X	X	
Coastal Area Management Act	X	X	
Mining Act of 1971		X	
ON-SITE WASTEWATER DISPOSAL			
Sanitary sewage system program	X	X	
SOLID WASTE PROGRAM			
Solid Waste Management Act of 1989	X	X	
Resource Conservation and Recovery Act			X
FORESTRY			
Forest practice guidelines		X	
National Forest Management Act			X
Forest Stewadship Program		X	
HYDROLOGIC MODIFICATION			
Section 404 of Clean Water Act		X	X
Dam Safety Permits		X	
WETLANDS			
Sections 404 and 401 of Clean Water Act		X	X
GROUNDWATER			
Wellhead protection program	X	X	
Underground storage tank programs		X	
GENERAL			
Section 319 of Clean Water Act		X	X
Coastal Zone Area Reauthorization Act		X	X
Stream classifications and standards		X	X

adopt nonpoint source regulations applicable to specific watersheds. Among the most significant provisions of that strategy were (NCDENR, 1997):

* a goal of reducing the annual load of nitrogen from both point and nonpoint sources by 30% of the 1991-1995 average to be achieved within 5 years of the effective date of the rule;

* a management program for point sources that:

    - set an upper limit of the collective mass loads from all dischargers with flows in excess of 0.5 million gallons per day;

    - established a nitrogen trading program; and

    - created an offset program that allows entry of new dischargers if they satisfy stringent effluent limits and acquire rights to discharge residual loads;

* an agricultural nitrogen load reduction of 30% of the 1991-1995 average to be achieved within 5 years of the effective date of the rule, where affected agricultural activities, including livestock operations, can comply either by participation in a collective local strategy or by installation and maintenance of specified best management practices;

* a requirement to protect and maintain existing forested riparian buffers;

* a mandatory nutrient management program for croplands, turfgrasses, golf courses and other recreational areas, and commercial fertilizer applicators; and

* expansion of coverage of urban stormwater management programs.

Even though the brief overviews of nonpoint source programs given here are selective and far from exhaustive, they cover a broad range of options that have been adopted by one or more states. For purposes of this report, it is convenient to catagorize them as being one of four types:

Type A - voluntary, using technical assistance, financial assistance, and/or outreach and public education to promote adoption of BMP's;

Type B - restrictions on new land development activities including, but not limited to, one or more of the following: sedimentation and erosion controls, stormwater management, protection of wetlands and riparian buffers, and density limits;

Type C - mandatory adoption of BMP's without a specified limit on nonpoint loads; and

Type D - mandatory of adoption of management practices sufficient to achieve a specified numerical limit on nonpoint source loads.

Type A is exemplified by traditional soil conservation, agricultural cost-sharing, and extension programs. Type B is exemplified by water supply watershed protection programs in Massachusetts and North Carolina. Type C would include stormwater management programs under the Clean Water Act and mandatory BMP's required under the Coastal Zone Reauthorization Act. Examples of Type D include the Maryland tributary strategies under the Chesapeake Bay program and North Carolina's nutrient sensitive waters strategy for the Neuse River Basin.

The primary objective of this report is to examine methods for estimating both the current status of management practices and basinwide costs of Type C and Type D policies. Estimating costs of Type C policies are actually much easier than for Type D. For Type C it is a relatively simple task to determine whether an operation has required management practices in place. Estimating cost of compliance for individual operations not in compliance is a matter of estimating the cost of adopting the necessary practices. For Type D policies, an extra step is required. Before costs can be estimated, effectiveness of each measure must be estimated and the number or extent of measures necessary to satisfy the numerical target must be calculated.

COSTS OF NONPOINT POLLUTION CONTROL PRACTICES

Information about cost of nonpoint source pollution control practices is limited and there are inconsistencies in methods for estimating costs. A few studies have examined costs and benefits of national programs for individual practices. A much larger body of literature reports results of applying particular practices in particular regions. Yet another body of literature draws on the second group of studies to estimate costs of a variety of practices in a particular region. Discussion of costs begins with a review of selected studies at the national level. Most of the discussion is devoted to a review of studies in the Chesapeake Bay area and North Carolina.

National Program Costs

Ribaudo et al (1994) estimate the cost and benefits of national programs to retire cropland from production for the purpose of improving water quality. They examine four different scenarios in which cropland is selected for retirement based on erosion level. The authors use the U.S. Agricultural Resource Model to evaluate the short-run economic effects of removing land from agricultural production and conclude that this change will increase crop prices, thereby reducing consumer plus producer surplus. Reductions in cropland acreage ranged from a low of 1% to a high of 11.6% over the four scenarios.

Ching-Cheng et al. (1994) analyze at the national and regional level the economic impacts of proposed regulations to limit cropland soil erosion to the lesser of soil loss tolerance or erosion occurring with conservation tillage. The authors use a multi-commodity agricultural sector model for their analysis. The model is a mathematical programming model that maximizes producer plus consumer surplus and simulates market equilibrium effects. Ching-Cheng et al. conclude that the proposed regulation would have a very limited effect on national market prices, food

consumption, and production. However, the proposed regulations would impose income losses on certain categories of producers from a reduction in land farmed, substitution of lower profit crops, and changes in yields and production costs. The estimated average loss per hectare in coastal areas in the U.S. is $3.30. The losses, however, vary widely by region, with the greatest losses occurring on highly erodible lands. Non-coastal producers also may experience losses, though their land is not directly affected by the proposed regulation. The study predicts, for example, a 4.2% decrease in net revenue for non-coastal farmers in the Southeast.

Szoege et al (1996) seek to estimate the cost-effectiveness of reducing nonpoint agricultural groundwater pollution in the United Kingdom through nutrient management and continuous cropping. To determine the cost of various management options, the authors simply calculated the payments made to farmers participating in pilot programs plus the administrative cost of the pilot programs.

Ribaudo (1998) brings together a number of recent evaluations of USDA agricultural nonpoint source pollution control programs. These evaluations do not attempt to calculate the cost of implementing BMP's, but they do shed some light on which practices have been most popular with farmers. The effect of a BMP on net revenue is one explanation for a farmer's decisions to adopt or not adopt the practice. Evaluations that Ribaudo reviews find that the most widely-adopted BMP's are those that have been found to increase net returns in many farming conditions: conservation tillage, nutrient management, and conservation rotations. Removing land from production, the construction of conservation structures, and the planting of less profitable crops have been less popular with farmers. Even cost sharing programs have not induced the majority of farmers to adopt these practices. For example, programs in Oregon and Michigan found that the level of cost-sharing offered to farmers was not sufficient to cover the capital costs of the preferred irrigation systems or the opportunity cost of vegetative buffers, respectively.

Stonehouse (1995) provides a comprehensive review of literature on the profitability of soil and water conservation measures in Canada. His conclusions are consistent with studies of U.S. agriculture, namely:

- Continuous cropping (which prevents soil erosion by providing more continuous land cover) is not unambiguously economically competitive with other cropping alternatives (such as summer fallowing). The desirability of continuous cropping depends on the particular crops, soils, and climate.

- Conservation tillage is often more profitable than conventional tillage because savings in labor, machinery operation, and machinery overhead exceed the increased cost in chemical herbicides. The net returns from conservation tillage, however, depend on the particular crops, soil type, climate, and field operations. For example, for monoculture crops on medium loam soils no-till is more profitable, whereas for sandy-loam or silt-loam soils, conventional tillage generates a higher return. Batie and Taylor (1989) reached similar conclusions for the United States; they found that the profitability of conservation tillage varied by region, by farm, and by management skill.
- Little study has been done of the profitability of conservation structures in Canada (such as tile drainage, tile outlet protection, terracing, drop structures, and grassed water ways). The few studies that Stonehouse cites conclude that the profitability of control structures depends on government subsidies, crops, and cropping practices. In the United States, Sun et al. (1996) simulate the effect of irrigation management on peanut farm yields for a representative farm in coastal Georgia. They conclude that irrigation management reduces yield variation from drought to non-drought years, but that irrigation management reduces net returns in favorable wet years.

Stonehouse does not address nutrient management in his review of BMP's. Sun et al, however, do study the profitability of nitrogen application. Their simulation suggests that expected net revenues on the representative peanut farm would drop if nitrogen application were reduced.

Chesapeake Bay Studies

Several studies have been directed toward estimation of costs for nonpoint source programs in the Chesapeake Bay area. Camacho (1992) used cost and longevity information extracted from the Chesapeake Bay Program's BMP database and from similar databases maintained by states in the bay area to construct estimates of unit costs for a variety of nutrient reduction technologies. Unit costs were derived by multiplying installation cost by a factor that adds in planning and technical assistance cost to get initial cost. Annual operation and maintenance costs (O&M) were estimated using factors taken from the Soil Conservation Service where annual O&M costs were stated as a percentage of installation cost. Initial costs were translated to equivalent annual cost using a discount rate of 10% and estimated economic lives of the technologies. Annualized initial costs were then added to O&M costs to get annual costs. Estimates for selected practices are given in Table 3.

Table 3. Unit Costs for Best Management Practices in The Chesapeake Bay Area (Source: Camacho, 1992)

Best Management Practice	No. of BMP's	BMP Life years	Annual Cost, $/ac/yr 25th%	Median	75th%
Strip-cropping	393	5	5.8	11.6	
Terraces	64	10	35.7	85.8	148
Sediment Retention and Water Control Structures	165	20	50.5	103	238
Permanent Vegetative Cover on Critical Areas	239	5	38.9	69.5	226
Nutrient Management		3		2.4	
Conservation Tillage		1		17.3	

Camacho's unit costs were used in conjunction with the Chesapeake Bay watershed model to estimate cost effectiveness of BMP's applied throughout the watershed. Results reported by Shulyer (1995) are for best available technology, but they are not site specific because they represent an effect averaged over diverse conditions in the watershed. Cost effectiveness of a range of technologies is given in Table 4.

Table 4. Cost-Effectiveness of Best Management Practices In Chesapeake Bay Area (Source: Shulyer, 1995)

Management Practice	Cost per lb of Nitrogen Reduction
Urban retrofit	$ 142.64
Forest	69.13
Farm plan	45.27
Highly erodible land	22.99
Pasture treatment	9.90
Lo Till	7.44
Animal waste	7.17
Nutrient management	0.61

Shabman and Smith (1998) developed a decision support system to provide landowners and policy makers with financial information associated with site-specific designs of riparian forested buffer systems. Their analysis includes not only costs for installation and maintenance of buffers but financial returns from harvesting portions of the buffers and income foregone from displacement of crop production. Site-specific topographic and soils information can be entered to generate appropriate designs and related costs. Returns to forestry production are based on production rates and net income in Virginia. Income foregone is estimated using farm enterprise budgets from the Virginia Agricultural Extension Service, using either field level values for yields and prices or default values based on Virginia agricultural statistics. Scenarios for farms representing three geographic regions of the state illustrate the use of the model. Results are dependent on variables such as stream length per field, soils, yields, buffer designs, and discount rates. Unit costs in dollars per acre per year for those three scenarios are summarized in Table 5. Costs are stated both in per acre of agricultural production and per acre of riparian buffer.

As it prepared its tributary strategies to achieve its nitrogen reduction goal for the Chesapeake Bay, Maryland estimated costs for a variety of urban and agricultural management practices (State of Maryland, 1996). For sediment and erosion control on land development

Table 5. Estimated Unit Costs for Forest Riparian Buffers For Representative Farms in Virginia (Source: Shabman and Smith, 1998)

Location	Cost ($) per acre of: Crop Production	Riparian Buffer
Inner Coastal Plain	2.23	128.64
Piedmont	2.05	159.73
Piedmont Valley and Ridge	0.86	106.46

sites, Maryland used an estimate of cost taken from a review of sediment control activities in North Carolina, about $2700 per acre of development. Using data from Maryland's cost-sharing program for stormwater, initial costs for stormwater management were estimated in the range of $1200-1400 per acre. Annual O&M costs were estimated to be 3% of construction costs. Conversions from existing dry ponds to wet ponds were estimated to be about $1,070 per acre. No conversions of initial costs to equivalent annual costs were made for these estimates. Estimates of cost for agricultural BMP's were based largely on Camacho (1992).

North Carolina Estimates

Tippett and Dodd (1995) made calculations for cost-effectiveness of agricultural management practices in the Tar-Pamlico Basin in North Carolina using data from North Carolina's Agriculture Cost Share Program. They ignored discounting when converting initial costs to annual costs, a method that in general will underestimate costs. A significant portion of that analysis was directed toward animal waste management. Other cost estimates were as shown in Table 6.

Table 6. Unit Costs of Best Management Practices
Tar-Pamlico Basin of North Carolina
(Source: Tippett and Dodd, 1995)

Management Practice	Annualized Cost per acre of production
Water control structures	$ 3.6
Grassed waterways	16.0
Diversions	32.7
Cropland conversion to grass	20.3
Cropland conversion to trees	14.1
Conservation tillage	10.0
Terraces	23.9
Vegetative filter strips	16.6
Field borders	2.4
Stripcropping	19.3

Noting that North Carolina did not have cost-sharing for nutrient management at the time of their analysis, Tippett and Dodd used Camacho's unit cost estimate of $2.40 per acre per year as a basis for arguing for greater attention to that practice. Among those practices for which efficiencies of nutrient reduction were available, water control structures were found to be the most cost-effective for reducing nitrogen. Nutrient management, vegetated filter strips and conservation tillage were also found to be highly ranked on the basis of cost-effectiveness. Except for water control structures, similar results were obtained for phosphorous reduction.

One of the difficulties in using any of these numbers is that they are not accompanied by careful descriptions of the technology to which they refer. The large discrepancy between the estimated cost of water control structures given by Tippett and Dodd and estimates for sediment retention and water control structures presented by Comacho may well be attributed to differences in technology.

The numbers used by Tippett and Dodd refer to practices supported under the North Carolina Agriculture Cost Share Program. Those numbers were updated for purposes of this report. A dataset compiled by the North Carolina Department of Environment and Natural Resources covers the period 1987-1998, and it includes useable data on 1672 structures on 299 farms. Summary statistics for the data are shown in Table 7. There it may be noted that the average cost of installing controlled drainage is $43.4 per acre of land served by the facility. If it

Table 7. Costs for Controlled Drainage in North Carolina
(Data from the North Carolina Department of Environment and Natural Resources)

	Mean	Standard Deviation
Acres per Farm	232	383
No. of Structures per Farm	5.59	6.46
Cost per Farm	$4267	$3965
Cost per Acre	$ 43.4	$ 66.7

is assumed that these facilities have a life of 20 years and the discount rate is 8% a year, then the equivalent annual value is $4.42 per acre per year. Table 7 also shows that costs are subject to large variability from one farm to another. Figure 1 illustrates the nature of that variability, with 25% of the farms having an initial cost of less than $15 per acre but another 25% having an initial cost of more than $52 per acre.

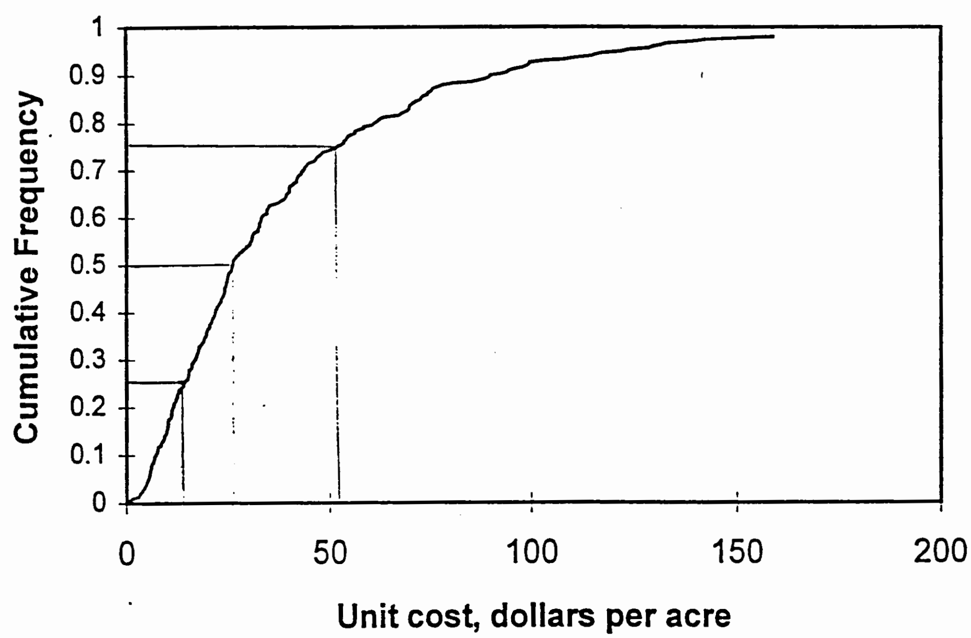

Figure 1. Distribution of Unit Costs for Controlled Drainage

Conceptual Bases for Estimating Costs

As evidenced from the literature, unit costs are reported in a variety of forms including installation costs and annual costs, sometimes including discounting of future costs, sometimes not. Shabman and Smith (1998) outline the basic concepts for estimating the cost of adopting management practices. Their framework, while stated in the context of a particular management practice, is generally applicable to most practices. The full cost of implementing a best management practice would include the following:

(1) initial cost to establish the practice;

(2) annual costs to operate and maintain the practice;

(3) financial opportunity costs resulting from any income-producing activity that is displaced or preempted by adoption of the practice; and

(4) financial returns that may result from adoption of the practice that would not otherwise accrue to the operation.

Shabman and Smith state that for a forested riparian buffer, first costs would include such items as site preparation, planting, and possibly fencing to keep animals off of streambanks. Opportunity cost would be the change in net income to property resulting from displacement of cropland. If the buffer is periodically harvested, net income from harvesting would be deducted from costs.

For controlled drainage, there would be the first cost of installation and annual costs of operation and maintenance. If crop yield is increased as a direct result of installing controlled drainage, net income from the increased yield would be deducted from costs.

Those two cases can be extended to any management practice. Let n be economic life of capital investments in years; let r be the interest rate; let c_0 be the initial cost of facilities; let c_i be the operation and maintenance cost in the i^{th} year; let y_i be the loss of income due to crop displacement in year i; and let z_i be the incremental income less other incremental costs assignable to the management practice in year i. Then, the net present value of all costs over the economic life of the investment is:

$$PV(cost) = c_0 + \sum_{i=1}^{i=n}(c_i + y_i - z_i)/(1+r)^i.$$

That cost can also be stated as equivalent annual cost (EAC) as follows:

$$EAC = PV(cost)/[\sum_{i=1}^{i=n} 1/(1+r)^i]$$

These expressions include all costs regardless of who bears them. If financial assistance is offered through cost-sharing or other programs, then the cost to an owner is reduced, but any reduction of cost to the owner is borne by the program.

CASES: NEUSE RIVER WATERSHED AND THE RALEIGH URBAN AREA

Sampling strategies for both rural and urban areas within watersheds are considered in this study. Land uses and management practices for these two types of areas are quite different, and sampling strategies for the two cases are likely to be quite different. The rural area selected for this study comprises the agricultural lands in the Neuse River Basin of North Carolina, and the urban area is the City of Raleigh and its environs located within the Neuse Basin.

Neuse River Watershed

Watersheds or riverbasins come in a wide variety of sizes, climatic conditions, topography, soils, and land uses. Some are small, relatively homogeneous, and subject to little development pressures. Others are large, cover several geographical regions, and are subject to a great mix of land uses. There is probably nothing such as a "typical" watershed. This study was undertaken to examine one of a particular class of watersheds, those in the South Atlantic water resource region where watersheds originate along the eastern continental divide or the Piedmont and flow southeasterly to the Atlantic Ocean. Of particular interest are those that flow into shallow estuarine areas that are quite sensitive to loads of nitrogen and phosphorous, periodically producing excessive algal growth. These include most streams that discharge to the Chesapeake Bay, the Albemarle and Pamlico Sounds of North Carolina, and embayments along the Gulf Coast. Even the characteristics of these watersheds display considerable variability, and there is considerable variability within some of them.

The Neuse Basin is one of those watersheds, and, as discussed earlier, it is an important watershed for which an advanced management program has been adopted. Although it may not be typical of others in its class, it is not so unique that results based on it cannot be transferred to many other basins within its class. At the watershed-level scale, special attention is given to the problem of estimating the cost of management programs directed at agricultural operations, the largest single class of sources of nutrients. Because watersheds of this size contain a large number of individual farming operations, an efficient strategy must rely on statistical sampling. Logical sampling frames are either farms or parcels defined by ownership, but characteristics of farms and parcels, including soils, topography, size, land use within them, and management practices, are highly variable throughout the watershed. The magnitudes of those variations are examined in this section to better inform the process of selecting an efficient sample from which to estimate those characteristics that most directly affect cost.

Geographic and Physical Setting. The Neuse River Basin, shown in Figure 2 and located entirely within North Carolina, covers an area of about 6,200 square miles, about 600 of which is open water. The mainstem of the Neuse River begins at the confluence of the Flat and Eno Rivers near Durham from which it flows as a freshwater stream about 200 miles until it becomes influenced by tidal action near Streets Ferry upstream of New Bern. Over 3,000 miles of freshwater tributaries contribute flow to the stream.

Originating as it does in the Piedmont region of the state, the mainstem of the river has a gentle slope, dropping from about 240 feet above mean sea level (MSL) at the upper end to 15 feet above MSL at Kinston, about 150 miles downstream. A considerable break in grade occurs around Smithfield. From Smithfield to the upper end, the channel slope averages 0.06%, the reach from Smithfield to Kinston, the slope averages about 0.017%. The river begins to experience tidal fluctuations at a point midway between Kinston and New Bern where it drops to just a few feet above sea level.

Streamflow per unit of drainage area is relatively constant in freshwater portions of the basin constant area. At the United States Geological Survey's Northside gage, the uppermost mainstem gage, flow averaged 0.970 cubic feet per second (cfs) per square mile over the 535 sq. mi. of drainage area over water years 1927-1979. At the most downstream gage (near Kinston, drainage area: 2692 semi), flow averaged 1.056 cfs per semi over water years 1930-1989.

Several impoundments regulate portions of those flows. Single purpose reservoirs on tributary streams serve Hillsborough, Durham, and Wilson as public water supplies. The largest impoundment, Falls Lake (built and operated by the U.S. Army Corps of Engineers) is a multipurpose facility, providing flood control, a public water supply for Raleigh, and augmentation of low flows. The safe yield for water supply is 86 million gallons a day during the worst period of record. The Corps is committed to maintenance of a low flow of 100 cfs at the Clayton gage. Smithfield and Goldsboro also use the Neuse as a run-of-the-river supply.

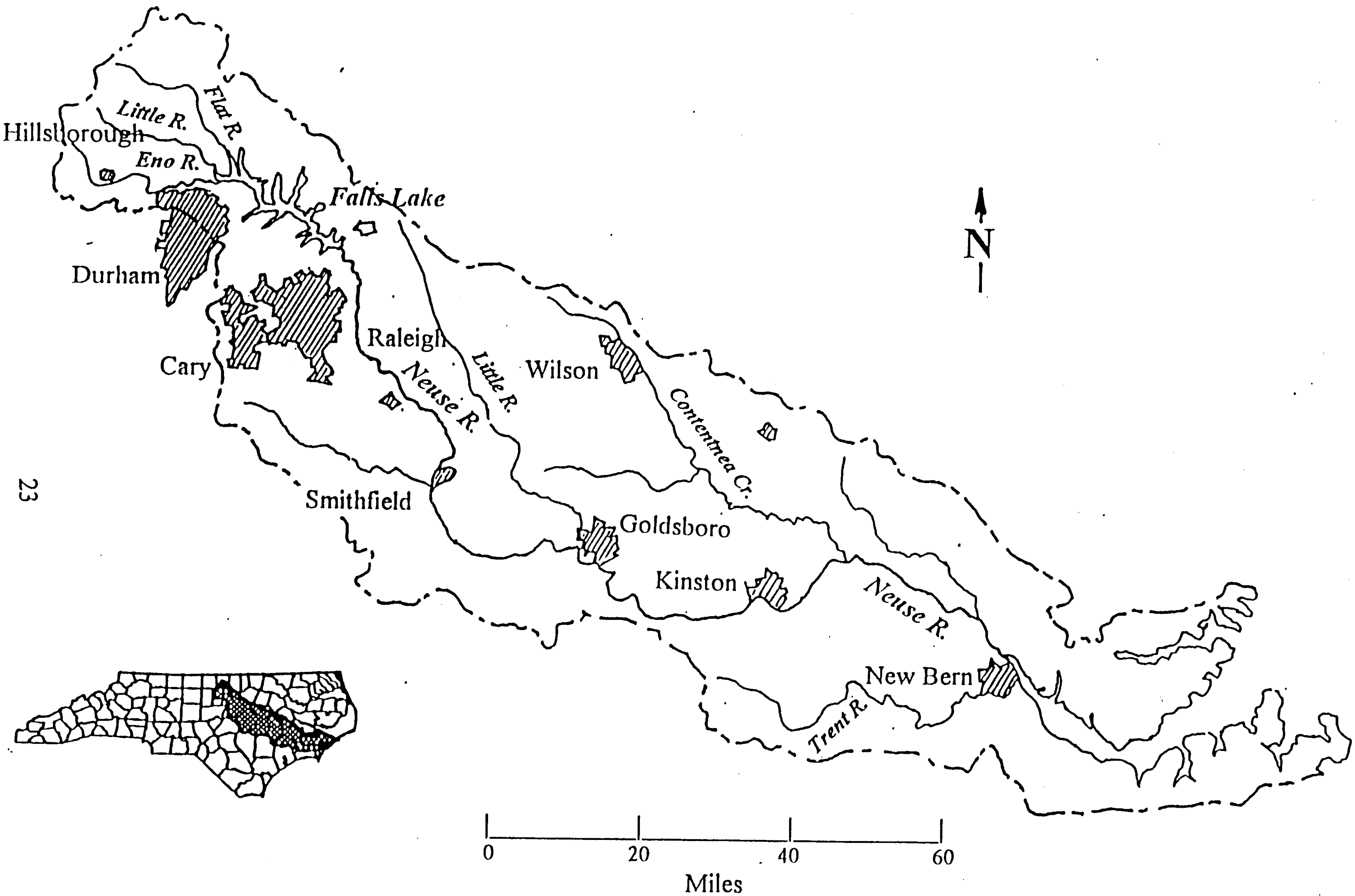

Figure 2. Neuse River Basin

Soils. Soils in the basin, shown in Figure 3 are quite variable. Brackish and freshwater marsh soils (Map Unit 7 in Figure 3) occupy the extreme lower end of the basin, and soils in much of the lower basin are thick, dark, and rich in organics (Units 4 & 5). Many of those are poorly drained. In the middle of the basin, the most extensive soils are those with fine-loamy subsoils. Upper portions of the basin are characterized by felsic crystalline terrains and volcanics. Running through the Coastal Plain region are the large river valley and floodplain soil systems that are different from adjacent uplands.

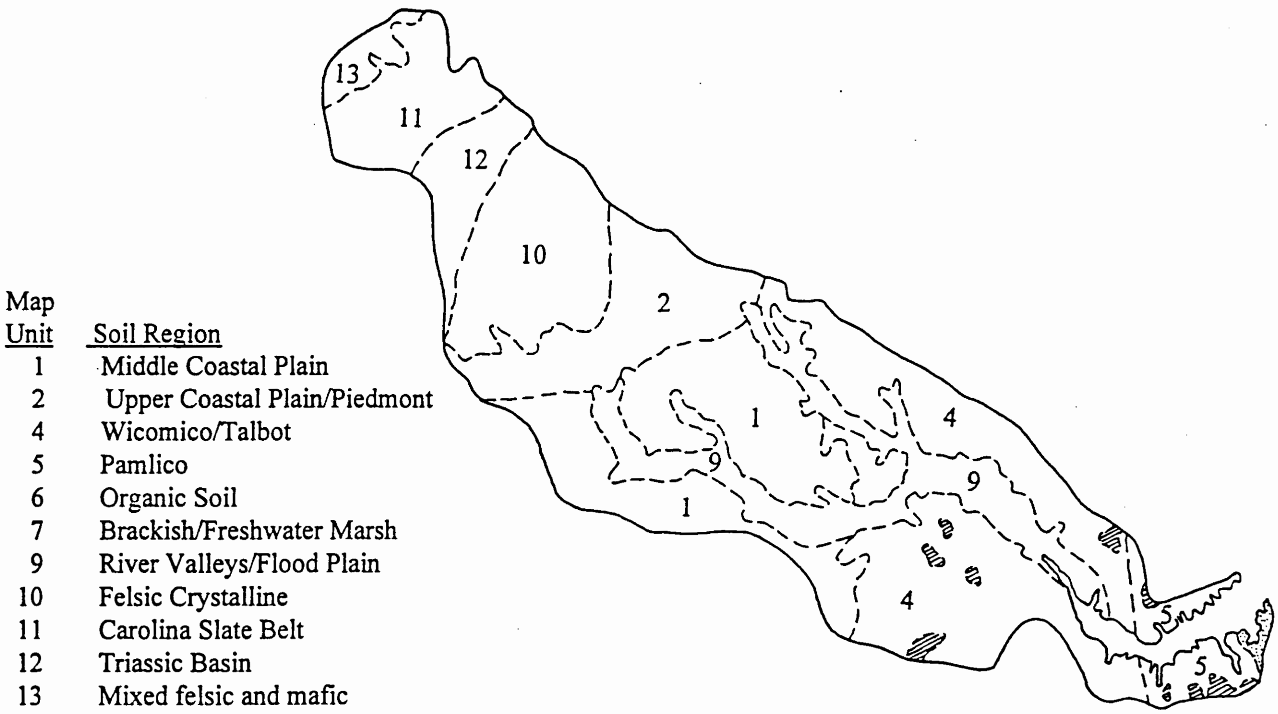

Figure 3. Generalized Soils of the Neuse River Basin

Differences in soils and slopes suggest that the basin consists of several regions, and for purposes of this discussion, it is divided into four areas, referred to as the Upper, Middle, and Lower Basins, and that portion of the basin which drains directly to the river below the most nutrient-sensitive portion of the estuary. The four regions cover approximately 25, 38, 25, and 12% of the basin, respectively.

Population. The basin covers portions of 19 counties, substantial portions of 12 counties. Just over one million persons resided in the basin in 1990, about two-thirds of them in the Raleigh-Durham metropolitan area in Durham and Wake Counties. Wake County, the county with by far the largest population, grew 40.5% from 1980 to 1990 to a population of 432,000. Other counties located predominantly in the basin with populations over 65,000 are Johnston (Smithfield), Wayne (Goldsboro), Wilson (Wilson), and Craven (New Bern). The distribution of the 1990 population by census tracts is shown in Figure 4.

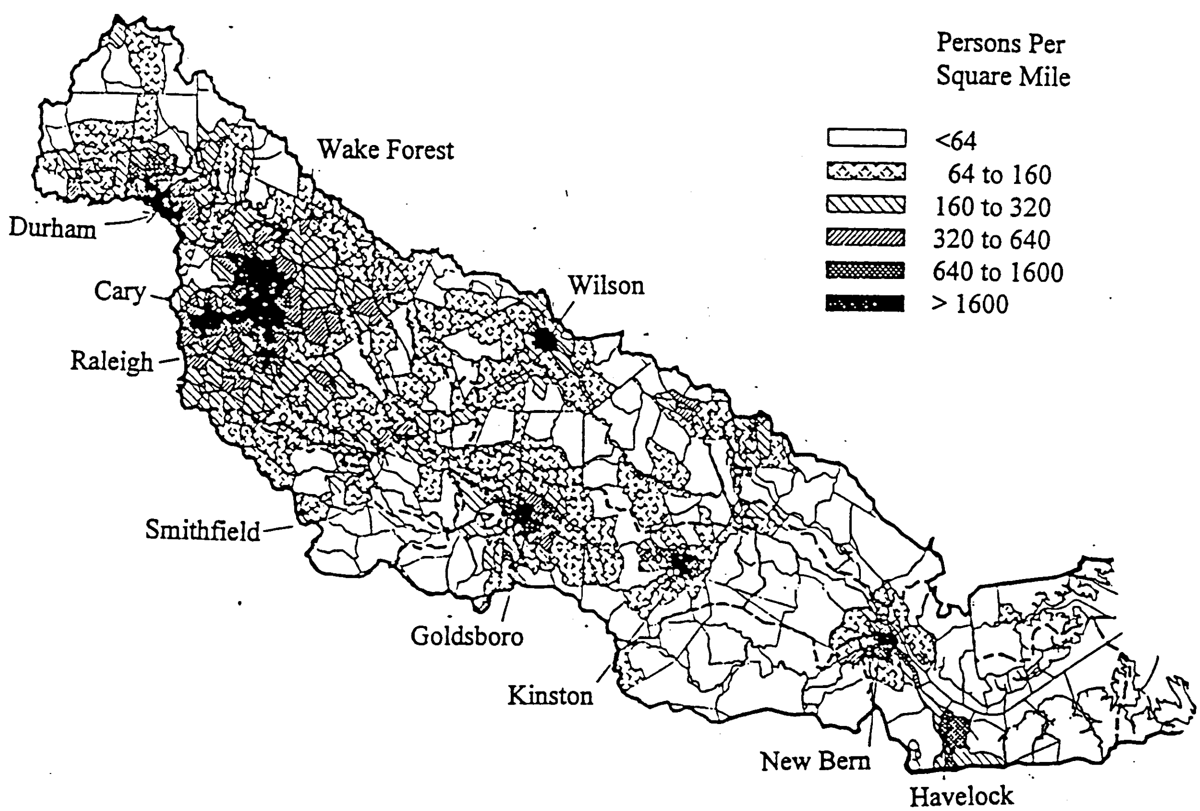

Figure 4. Distribution of Population in the Neuse River Basin
(Source: NC Dept. of Environment and Natural Resources, 1993)

Land Use. Table 8 shows the distribution of uses to which the 5,560 square miles of land area in the basin are put. Land use-land cover data for subbasins were used to estimate approximate land use distributions for the Upper, Middle, and Lower Basin areas.

Table 8. Land Uses in Neuse Basin
(Based in part on data from Neuse River Basinwide Water Quality Management Plan NCDEHNR, 1993)

Use	Entire Basin	Upper Basin	Middle Basin	Lower Basin
Agriculture	38.7	35.2	48.6	37.7
Forest	37.8	40.6	36.6	38.3
Urban	5.7	10.5	7.1	1.1
Wetland	13.1	8.2	5.1	15.2
Other	4.7	5.5	2.6	7.7

There are considerable differences in land uses from one part of the watershed to another. As expected from population data, the Upper Basin is much more urbanized than the other areas. A much larger share of the Middle Basin is used for agriculture than are the Upper and Lower areas. The percentage of land in forests is subject to relatively small variability.

Use of Land in Farms. A significant portion of agricultural and forest lands are included in farming operations as defined by the United States Bureau of the Census. To characterize farms and the use of land in farms in the basin, 1992 Census of Agriculture county-level data were used. Data for Durham, Orange and Wake Counties were used to characterize the Upper Basin. To characterize the Middle Basin, data from all counties that are partly in that region were used, and the Lower Basin was characterized using data from Craven, and Lenoir Counties. That data show the amount of land in farms varies considerably from one region of the basin to another, 21% in the Upper Basin, 63% in the Middle Basin, and 20% in the Lower.

Uses of land within farms also varies across the three regions. Census data divides farm land into three mutually exclusive categories, namely cropland, woodland, and other. Several subcategories under cropland include harvested cropland, grazing, and other cropland. Distributions of lands in farms across theses categories and subcategories are shown in Table 9 for the three regions. In the Upper and Lower regions, cropland accounts for 52-55% of farmland while it accounts for nearly 74% in the Middle. Grazing accounts for a much larger share in the Upper region than in either of the other two.

Table 9. Uses of Land in Farms
(Estimated using data from the 1992 Census of Agriculture)

	Upper		Middle		Lower	
	% of farmland	% of cropland	% of farmland	% of cropland	% of farmland	% of cropland
Cropland	55.2		73.7		69.0	
Harvested		60.9		83.6		84.0
Grazing		21.4		4.0		1.8
Other		17.7		12.4		14.2
Woodland	34.6		21.2		16.0	
Other	10.2		5.2		15.0	

Farms by Size. Numbers of farms by size categories are also available from the Census of Agriculture. Those distributions are shown in Figure 5. There it may be noted that the three distributions follow the same general pattern with the largest fraction in each area being in the size range of 10-49 acres. The Upper Basin does have a larger share of smaller farms and a smaller share of larger farms than the Middle Basin, and the relationship exists between the Middle and Lower Basins. Average sizes of farms in each region can be approximated from those distributions, and with those values, the numbers of farms in each region can be estimated as given in Table 10.

Parcels. Much of what we know about agricultural operations in a basin comes from agricultural census data based on farm units. Unfortunately, for those seeking information on management practices and other information not included in a census, the list of farm units from which census data is compiled is not public information. In order to collect that data, the Bureau of the Census has assured respondents that information about individual farms will not be disclosed.

Table 10. Estimated Average Size and Number of Farms

Region	Area, sq.mi.	% of Land in Farms	Average Farm Size, acres	No. of Farms
Upper	1390	21.2	156	1209
Middle	2110	63.2	220	3879
Lower	1390	20.3	264	684
Total	4890	39.1	212	5772

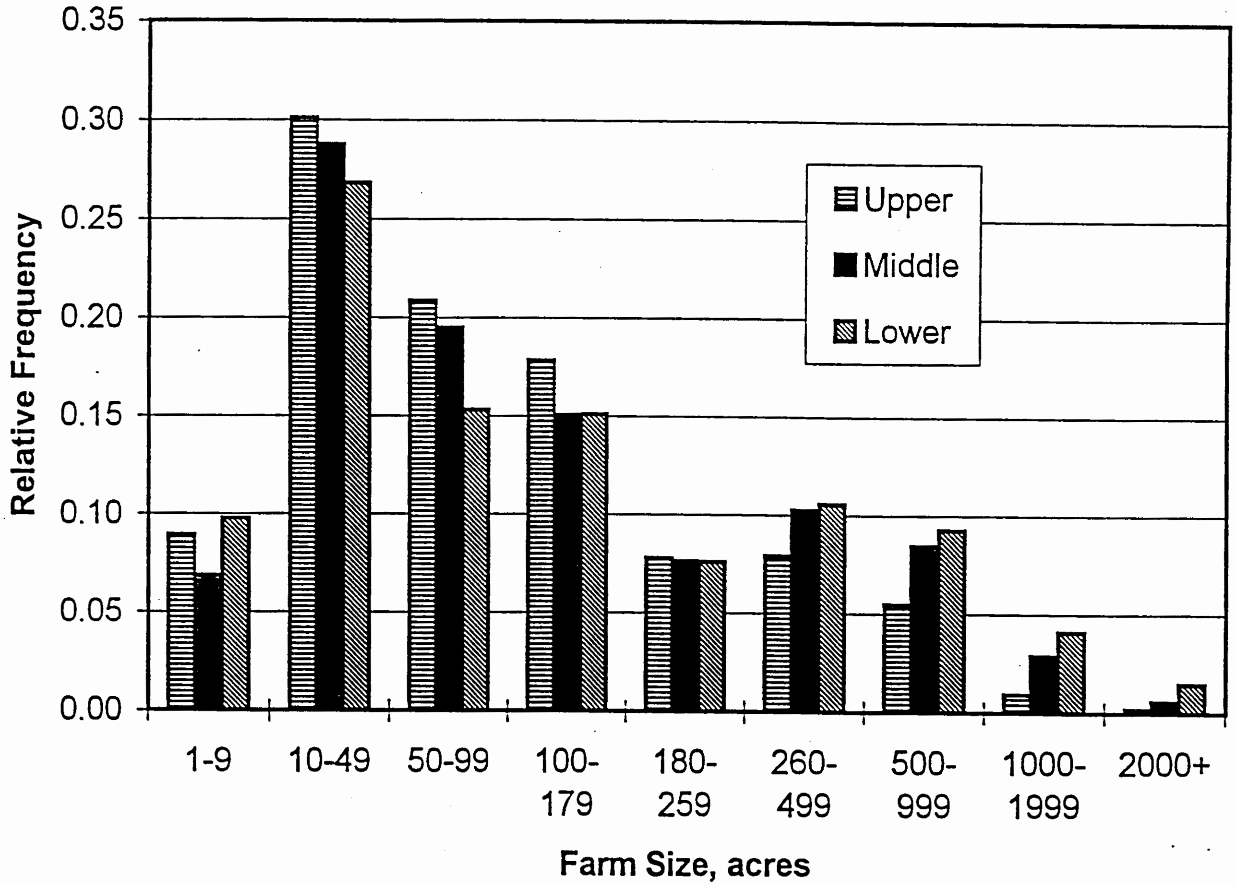

Figure 5. Distributions of Farms by Size by Region

In making estimates of lands under various management practices, it would be preferable to draw from the same sampling frame as that used for the agricultural census, but given the confidentiality of that list, the next best lists that are available may be county tax roles. There may be special lists of farms in some states from which a true random sample could be drawn, but those must be used with considerable care. For instance, one possibility in North Carolina would be the list of farms who participate in North Carolina's Agriculture Cost Share Program. While it covers a large number of farms, it includes only those who have voluntarily participated in the cost sharing program. It has the potential of a significant bias because of its somewhat selective nature.

Tax roles on the other hand are exhaustive in their coverage. Furthermore, it is generally possible to separate agricultural lands from other lands. In North Carolina, all counties distinguish agricultural lands from other lands on tax roles, because (at least in part) most agricultural lands are eligible for use value assessment instead of market value assessments applied to other properties. In North Carolina use values are used to assess farm units, horticultural units, and forest units consisting of one or more parcels, one of which must meet certain size restrictions, and the units must meet certain gross income requirements. One of the parcels in a farm unit must be at least 10 acres; one of the horticultural units must be a least 5 acres, and one of the forest units must be 10 acres.

Tax offices of all counties in the Neuse Basin were contacted regarding the availability of these records. All are readily available, although a modest charge is required in most counties to cover the cost of data processing.

Assessments of this type are not unique to North Carolina. Ten other randomly selected states were contacted during this study to inquire about their tax codes and land records. All of them (AL, CA, CO, IL, IA, MN, MO, OH, UT, WA) had tax evaluation practices that took account of agricultural uses. All of them had site addresses, owners addresses, acreage and tax value.

Characteristics of those parcels in two counties --Wake and Craven-- in the Neuse Basin were determined from those records. There were 4,717 parcels in Wake County in 1998 that were labeled as being in some type of agricultural use. Included in those were 2,861 parcels over 5 acres used for cropland and 748 over 5 acres in forests. Those two groups are distributed by size as shown in Figure 6.

If a sample of farms is selected using tax-record parcels as the sampling frame, it will be useful to know how parcels are related to farms. The tax data do not indicate explicitly how parcels are aggregated into farm units. One indirect approach, subject to some error, was to group all those parcels for which names of the owner are identical and refer to them as GPIO's (groups of parcels with identical owners). Even if two parcels have the same owner, it does not necessarily follow that the two parcels are in the same farm unit, nor is it necessary for two parcels in a farm unit to have the same owner. A single owner may have multiple farms, and it is quite common for one owner to rent to another. Nonetheless, some insight into grouping of parcels in farms can be gained from comparing the distributions of farms and GPIO's by size. Size groups were selected to be comparable to those for which farm data are reported, namely <10, 10-50, 50-100, 100-180, 180-260, 260-500, 500-1000, and >1000 acres.

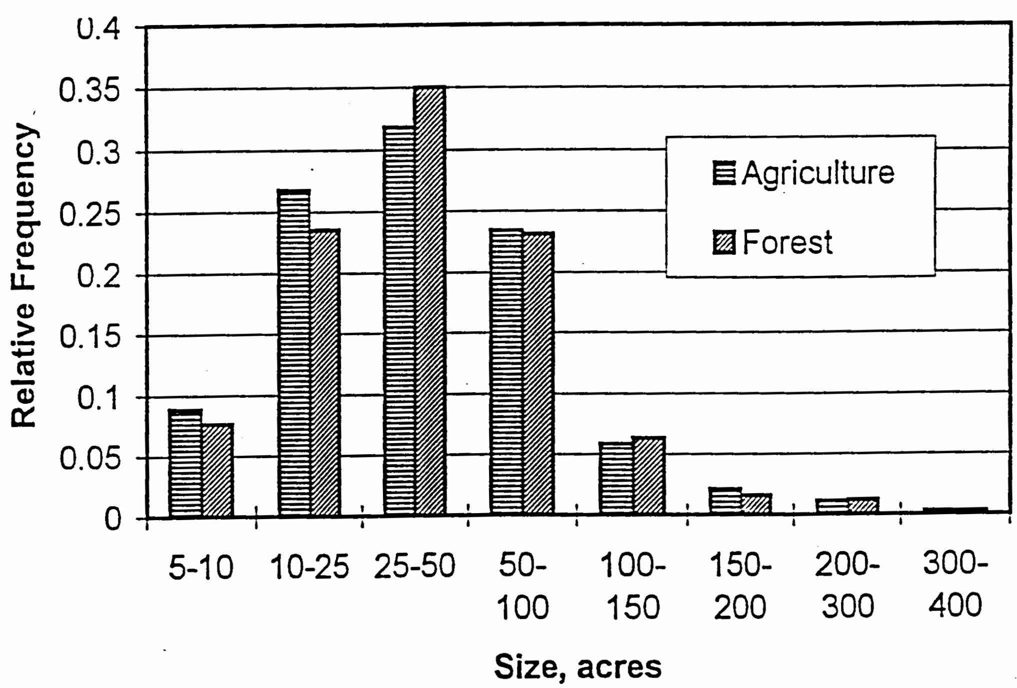

Figure 6. Distributions of Agricultural and Forest Parcels by Size in Wake County

Comparative data for Wake County are shown in Figure 7. In Wake County, no two tracks having identical owners were found to have a combined area of less than 10 acres and no group of two or more tracks with identical owners was found to have an area greater than 1000 acres. It may be noted that the two distributions are quite similar.

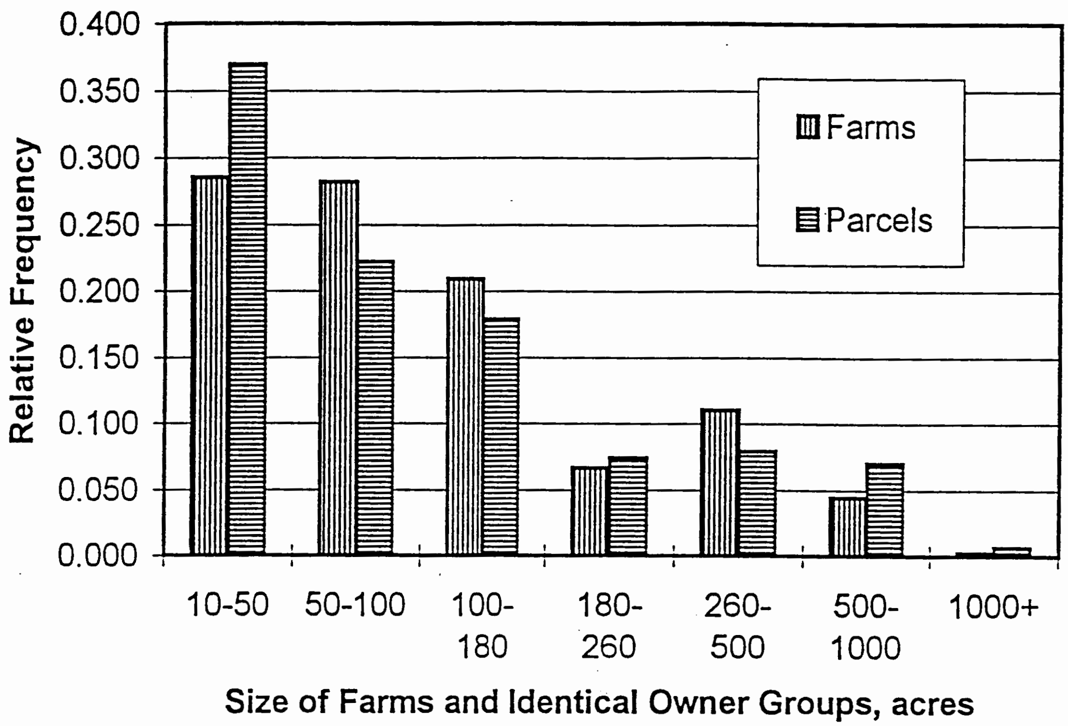

Figure 7. Distributions of Farms and GTIO's by Size in Wake County

An analysis of Craven County in the lower portion of the basin showed similar results. In that county there were 3,391 parcels in 1998 equal to or greater than 5 acres. The distribution of those parcels by size, shown in Figure 8, indicates a similar distribution to that in Wake County, but somewhat larger frequency of parcels in the 10-25 acre range and a somewhat smaller frequency in the 25-50 acre range. Of the parcels or groups of parcels having a combined area of less than 10 acres, only 9% contained 2 or more parcels. Only 8 groups with identical owners were found to have an area greater than 1000 acres. Comparative distributions of GTIO's and farms shown in Figure 9 where it again may be noted that the two distributions are quite similar.

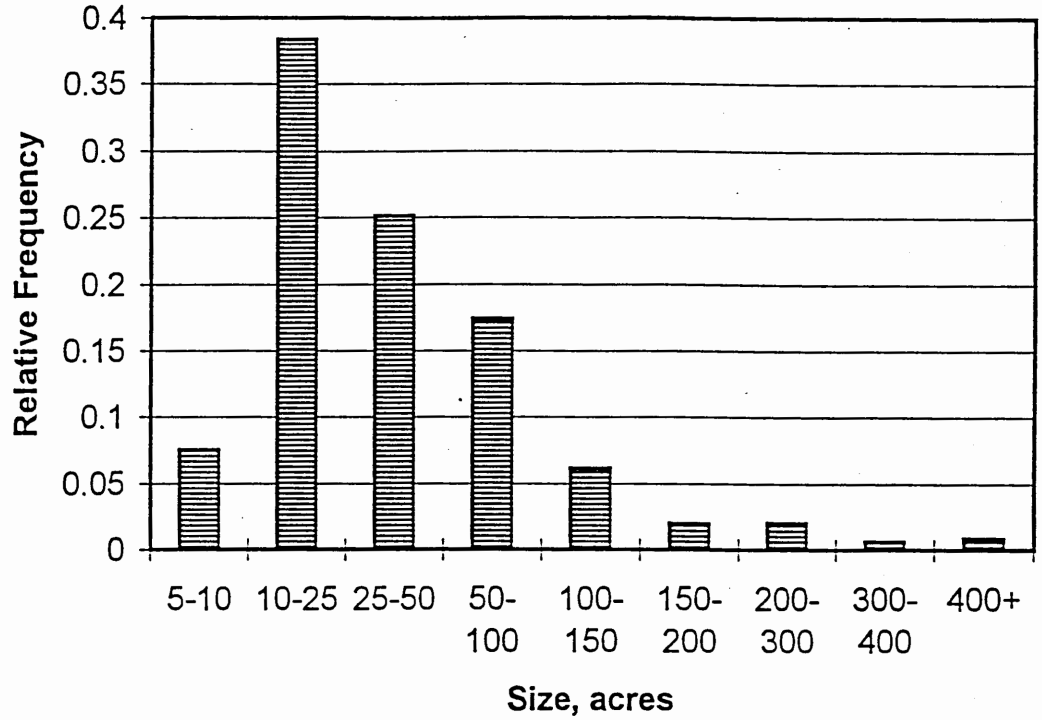

Figure 8. Distribution of Agricultural Parcels by Size in Craven County

<u>Crops</u>. Crops grown on these lands are quite variable across the Upper, Middle, and Lower Basins. Nearly 93% of all harvested cropland in the basin is used to raise either soybeans (36%), corn (27%), tobacco (11%), wheat (10%), hay (7%), or cotton (2%). Shares of total harvested cropland for each major crop in each of the three regions are shown in Figure 10. There it may be noted that hay is the largest crop produced in the Upper Basin where farms are smaller on average and a larger portion of cropland is in pasture. Corn production varies from 9% of total acreage in the Upper Basin to 36% in the Lower. Wheat production accounts for a much larger share in the Upper Basin than in the Lower. Soybean shares are about the same in the Middle and Lower Basin. Tobacco shares are different, but not greatly so, across the three regions.

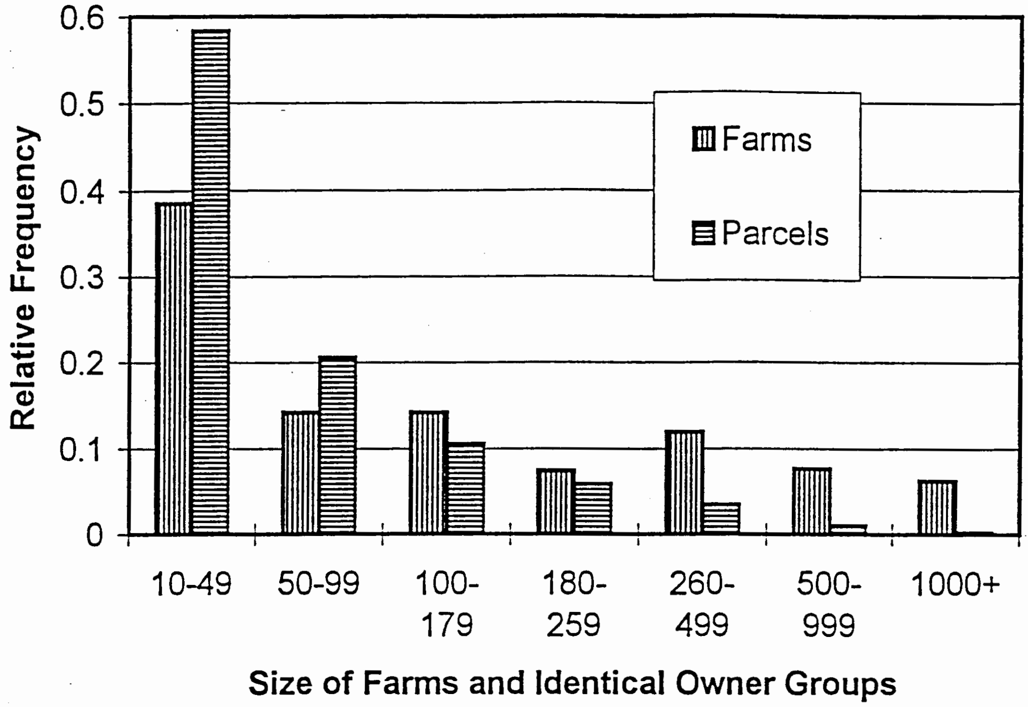

Figure 9. Distributions of Farms and GTIO's by Size in Craven County

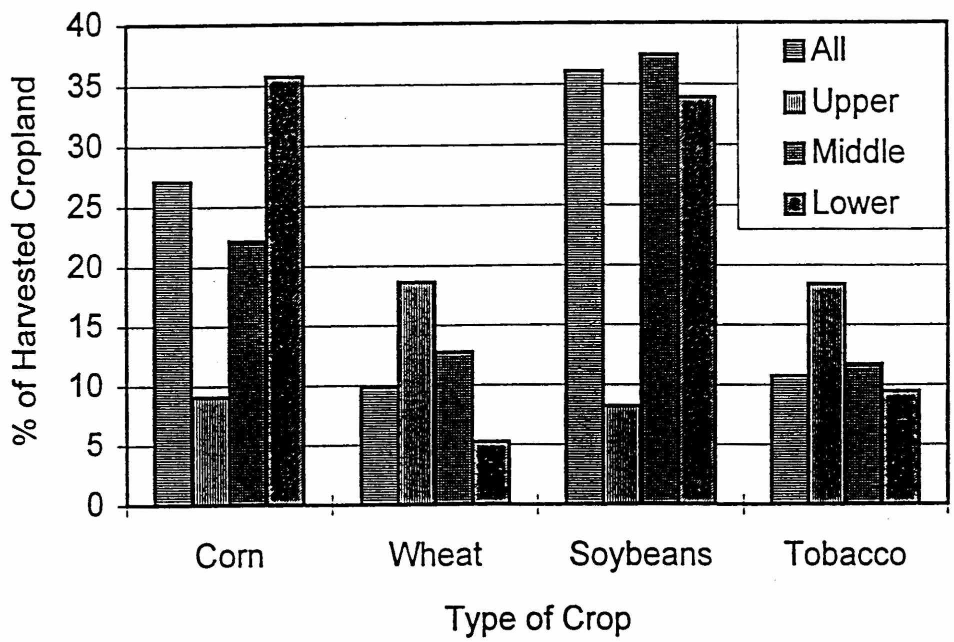

Figure 10. Percentage of Harvested Cropland in Selected Crops

Stream Density. Another factor relevant to estimating the cost of managing runoff from land-using activities is stream density. Relative frequency distributions for each of the Upper, Middle, and Lower regions of the basin for 40-acre and 160-acre parcels are shown in Figures 11 and 12. Distributions were estimated by placing a 4-mile by 4-mile square grid, divided into 256 40-acre blocks in each region and calculating lengths of stream segments that fall within each block. Stream segments were taken from the TIGER files prepared for the Bureau of the Census by the United States Geological Survey. For each region there are 256 observations on each 640-acre tract. Spatial correlation between stream lengths within adjacent 40-acre blocks was estimated using Moran's I auto correlation coefficient of lag one. That analysis revealed very small correlation between adjacent parcels. It is particularly noteworthy that the distributions do not vary greatly from one region to another.

Stream Buffers. The extent to which riparian buffers exist along those streams is dependent on land use and location in the basin (Komives, 1996). A random sample of 200 points on streams in the Neuse Basin was used for analysis. Those points were selected on stream segments in the 1992 TIGER files mentioned earlier. Those points were then located on 1:24,000 scale orthophotoquads taken during the 1980-83 time frame. Land use within a 2000-foot radius of each point was classified as either agricultural, forest, or developed. A comparison of the orthophotoquads and more recent 1988 aerial photographs indicated very little change had occurred in either land uses or buffers within that 5-8 year period.

Komives found that 81% of stream edges in the sample had forested buffers of at least 50 feet. Some variation existed from one region to another. The Upper Basin was 87% buffered, the Middle Basin 77%, and the Lower Basin 83%.

Percentages also varied by mix of land uses. For the 65 observations that were predominantly agricultural use, 62% of the streams were buffered. For 14 observations in predominantly developed areas, 55% of stream edges were buffered. A good predictor of extent of buffering is the percentage of land that is either agricultural or developed. That relationship is shown in Figure 13.

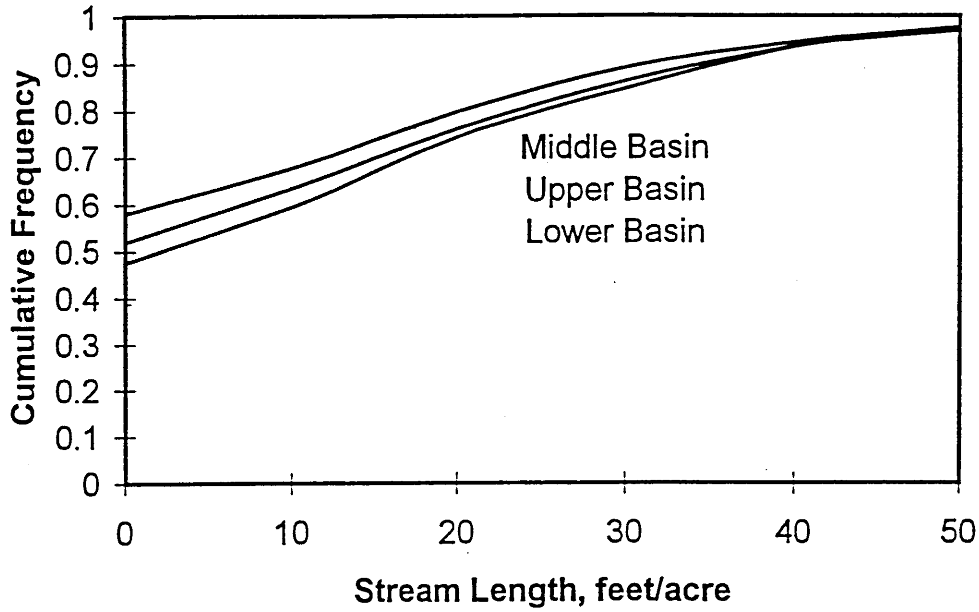

Figure 11. Stream Density on 40-acre Blocks

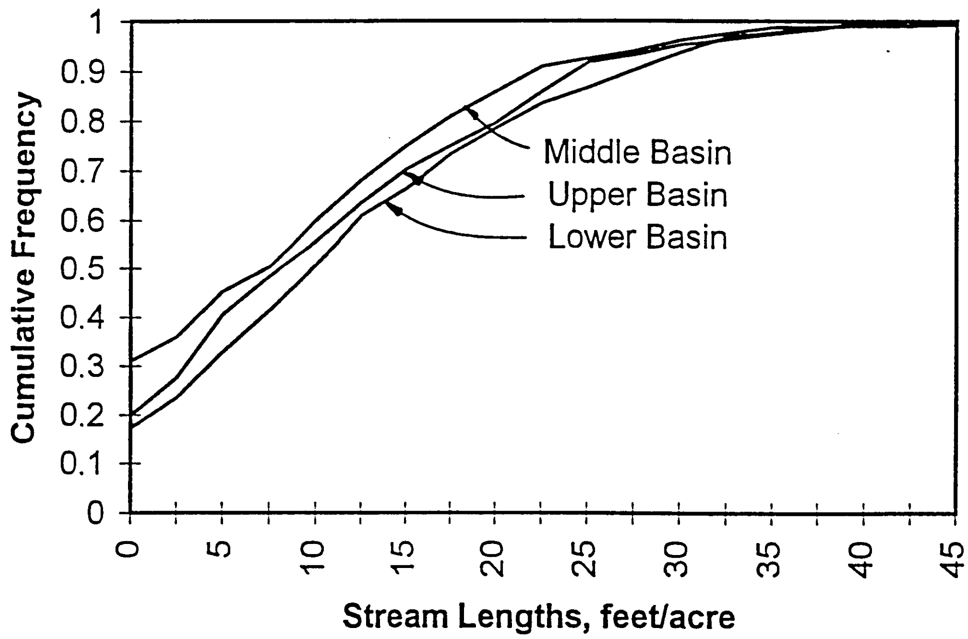

Figure 12. Stream Densities on 160-acre Blocks

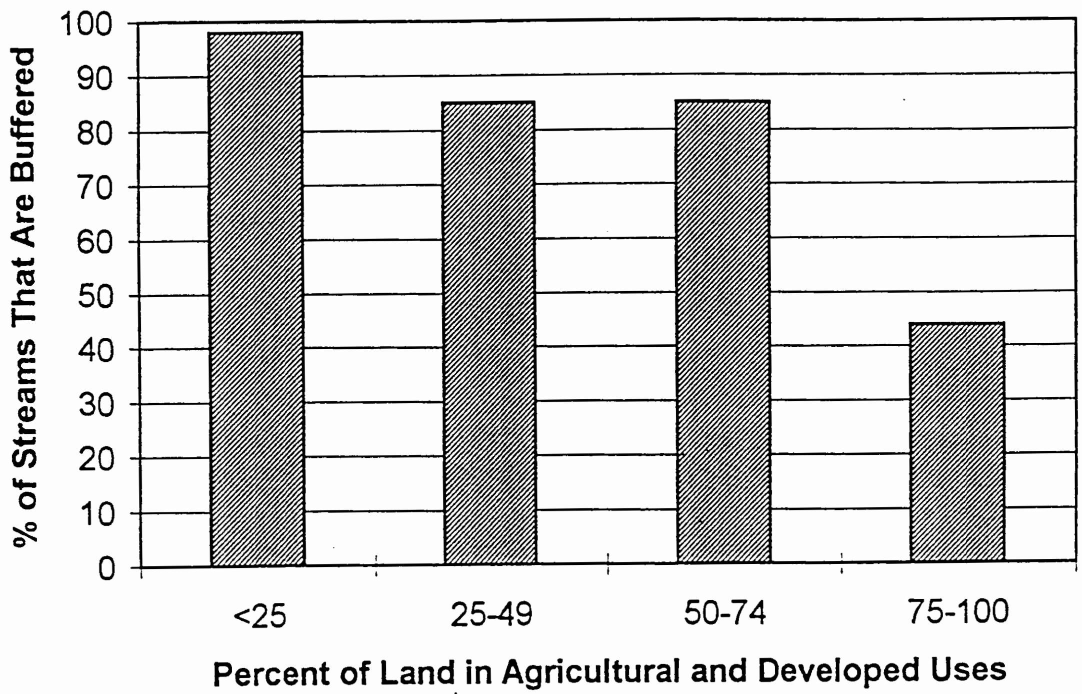

Figure 13. Percentage of Streams that are Protected by Forested Buffers

Raleigh Urban Area

Unlike the agricultural area, detailed land use information for the urban area is available at the parcel level. Tax files maintained by Wake County contain extensive information about each parcel -- 87 fields of data. Among those data most relevant to this analysis are:

* location information (street address and state planar coordinates of the centroid)
* no. of housing units
* acreage
* land value
* zoning
* value of buildings
* type and use

That and other information about the area information was used to delineate an urban area shown in Figure 14 that includes most of the municipalities of Raleigh, Cary, Garner,

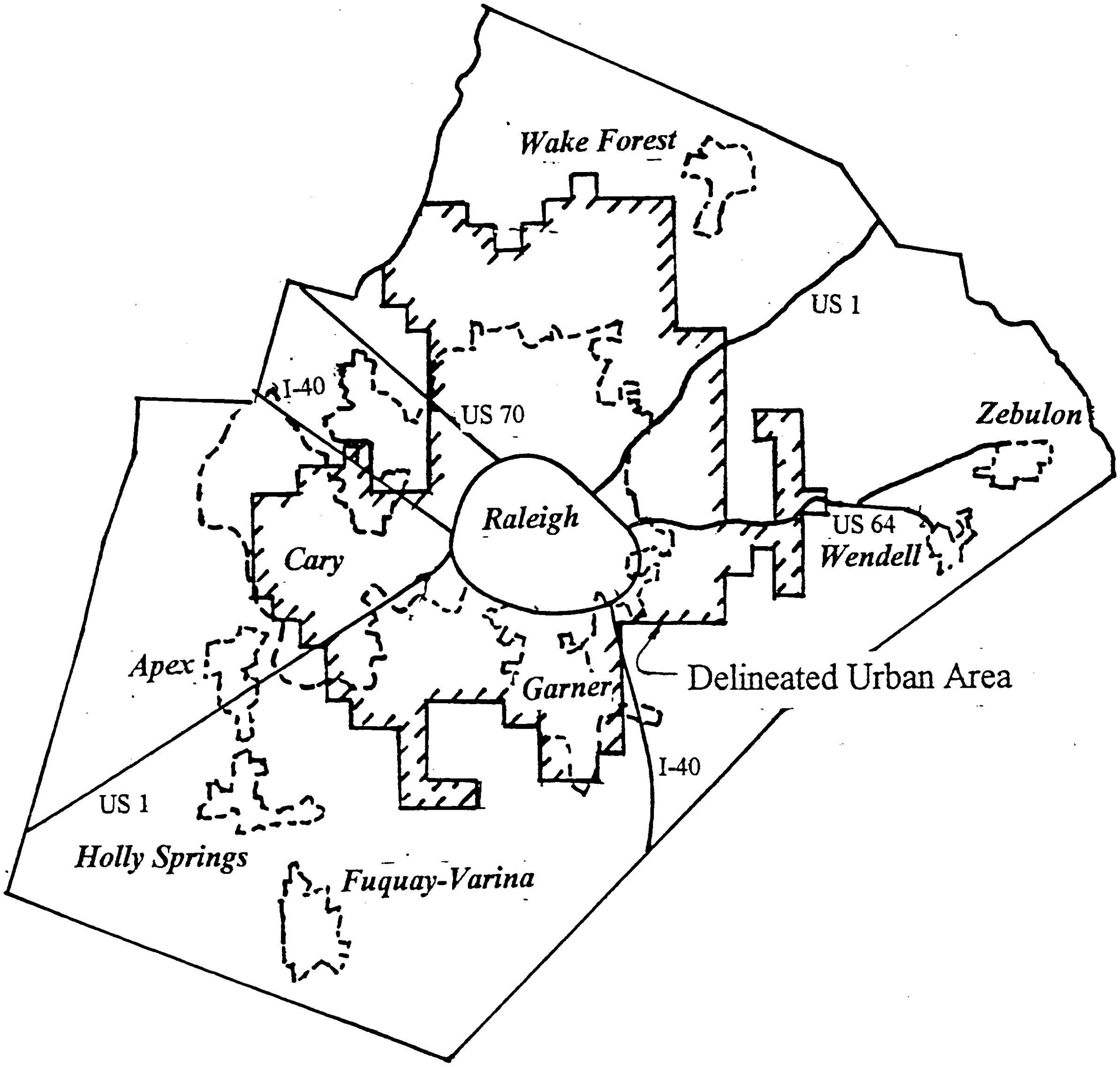

Figure 14. Delineated Urban Area Around Raleigh

and Wendell. Parcels were assigned to grid cells approximately one mile square (5000 ft. X 5000 ft to be exact), and boundaries of the area were established primarily by those cells where housing densities exceeded 0.2 units per acre of residential land.

Approximately 176,000 housing units are located in the delineated urban area which covers 620 square miles, almost 400,000 acres. There are about 138,000 land parcels. At least 57% of the land is zoned for some kind of residential use; another 24% is zoned for office and institutional use; more than 9% is zoned for industrial use, and about 2.3% is zoned for business and commercial uses. Given state government buildings and a large land-grant university within the area, an unusually large portion of land in Raleigh is zoned for institutional use.

Land parcels in the delineated area fall in 86 different zoning classes, the large number of classes resulting from different classification systems used by the several cities and Wake County. Over 80% of the land area and 83% of the parcels fall one of the 11 classes shown in Table 11.

Of special interest to the estimation of cost of best management practices in urban areas is the value of land displaced that BMP's displace. Both average and standard deviations of those values can be calculated from the Wake County data, and results are reported in Table 11 by zoning classification. It may be noted that there is considerable variation from class to class, ranging from $46,900 per acre for R-40W lands to $178,000 for Organizational and Institutional lands. Standard deviations in that table show a high level of variability of values within each class.

Table 11. Land and Land Value by Zoning Class in Delineated Urban Area

Zoning Class	No. of Parcels	Area acres	% of Total Area	Land Value, $1000/acre Mean	Land Value, $1000/acre Standard Deviation
O&I-1	1115	85611	21.49	178.0	129.6
R-10	8334	41634	10.45	152.5	131.2
R-40W	7193	39121	9.82	46.9	49.6
R-30	17261	38148	9.58	120.1	103.6
R-4	28380	31635	7.94	88.5	75.5
I-1	2113	23835	5.98	103.5	81.8
R-6	18898	17502	4.39	145.2	119.4
R-12	22512	15005	3.77	97.1	76.5
I-2	446	11932	3.00	75.6	60.8
R-8	6750	9904	2.49	131.3	88.7
R-40	2539	7218	1.81	49.7	53.9
Other	22167	76860	19.29	100.7	122.4

DESIGN OF SAMPLING STRATEGIES

Data given in the previous discussion indicate that much is known about the nearly 5,800 farms in the Neuse Basin and the 137,000 parcels of land in the urban area, but more specific information is needed to estimate the likely effectiveness of alternative management policies and the cost of implementing them in a particular watershed. Two levels of data are needed. First, at the most basic level, information is needed on the current status of management practices within the watershed or urban area. If the objective is to reduce nutrient loads to some specified level, then it is imperative that the present status of management practices in the watershed be known. Riparian buffers, stormwater management, nutrient management, controlled drainage, and other technologies may have considerable potential to reduce nutrient loads, but if those practices are already in wide use in an area, their potential for further reduction are limited. Second, information is needed about what management practices are needed and what it would cost to bring individual operations into compliance with watershed policies.

The purpose of this section is to examine relative efficiencies of alternative strategies for obtaining the needed information. A brief discussion of what information is needed to determine the status of management practices is followed by a discussion of problems in estimating cost of compliance under alternative watershed goals. For agricultural areas, data from the previous section and a few plausible assumptions are used to synthesize a data dataset of individual farms. These data are used to evaluative relative efficiencies of alternative sampling strategies to estimate means and confidence intervals about the status of management practices and cost of compliance. Relationships between confidence intervals and sample sizes are also examined. Because the population of all farms is not publicly available information, the use of land parcel records from tax files as a means of obtaining samples of farms is explored. The analysis concludes with an examination of sampling strategies for urban areas. Data reported in the previous section for the Raleigh urban area are used to compare sampling strategies and sample size-confidence interval relationships.

Cost of Achieving Compliance

Estimation of costs for achieving watershed management goals is policy dependent. Although there may be many variations, four policy options are discussed here to highlight some differences in estimation of costs. One type, probably the most commonly encountered, is **voluntary** programs that use educational approaches, technical assistance, and financial incentives to promote adoption of best management practices. To determine the cost of fully funding those programs, one would need to specify the desired coverage of programs, likely rates of participation in response to the incentives, and the cost of implementing preferred practices.

Another type includes programs that **mandate particular management practices**, such as riparian buffers, urban stormwater management, or nutrient management. Estimating cost for these types of programs may be the simplest of the four options considered here. It would require knowledge about the present status of management practices, the difference between some specified level of coverage and present status, and the cost of eliminating that difference.

A third type would be policies mandating **performance standards** applicable to specified geographic areas within a large watershed, say small watersheds, or even individual farms or subdivisions. An example would be a policy that required all farm or urban activities in a given watershed to reduce nutrient runoff in some base year by a stated percentage. Particular methods for achieving performance standards may be suggested but not prescribed. Estimating the cost of achieving performance standards would require preparation of site-specific plans and estimation of related cost. Cost-effective mixes of management practices necessary to satisfy standards could not be specified in advance of plan preparation.

Possibly the most difficult task of estimating cost would be associated with policies that mandate **watershed-level performance standards,** allowing all urban areas and agricultural operations in the watershed to collaborate in achieving the standard at lowest cost. Policies of this general type were permitted for nutrient management in the Neuse River Basin where municipal and industrial dischargers and agricultural operations were allowed to form coalitions. Individual dischargers were allowed to either participate in a coalition where nutrient trading is permitted or meet technology-based effluent limits. Agricultural operations were permitted to either participate in a local-area (usually county) plan or adopt specified management practices. Nutrient trading among local areas was also considered. Costs for this kind of policy would depend on site-specific plans for each farm and optimum-seeking behavior among all nutrient generators. Although he treated each county as a single farm, Schwabe (1996) used a linear programming model to maximize returns across farms (counties) to select the optimum mix of technologies within each farm (county). Applying that model with even several hundred spatial units at the watershed or county level would be a costly undertaking.

Agricultural Areas

Status of Management Practices. Regardless of which type of policy is adopted, a starting point for estimating cost is information about the status of management practices in the watershed. Although relevant practices will vary by state, it would appear from the review of policies in the first section of this report that the set of practices is reasonably consistent from state to state. At a minimum, it would be desirable to know for each farm:

* its size;
* land uses by woodlands, pasturelands, and cultivated cropland, and other uses;
* crop production;
* length of streams transecting or bordering the farm; and
* how much of each type of land is covered by each of several management practices, including some indicator about the quality of those practices.

In addition to the basic data, other information about individual farms might be appropriate, including physical factors affecting choice and cost of practices and attributes of owners and operators, such as their educational backgrounds, sources of technical assistance, and attitudes about various management practices and implementation incentives.

Synthesized Dataset. Despite an abundance of information about farming operations in the Neuse Basin as discussed earlier in this report, some data of crucial importance to estimation of costs of water quality management programs are not available. Furthermore agricultural census data provide very little information about farm-to-farm variability -- information that is crucial to design of sampling strategies.

With a few reasonable assumptions, it is possible to synthesize a dataset on characteristics of individual farms that can provide substantial insights about the size and structure of statistical samples that can be used to provide the needed information. The dataset was constructed in such a manner that it has the same average values for selected attributes as those for the Neuse Basin as described in the previous section of this report. It has the same number of farms distributed by size and region, the same mean values of land use in farms, the same stream densities, and the same fraction of streams that are buffered as those in the Neuse Basin. Very little quantified information is available about the use of controlled drainage in the basin, but that information has been added using a model based on subjective judgement. Farm-to-farm variability has been added to the data set by generating random observations on individual farms using a set of assumed probability distributions. Selection of some of those distributions is somewhat arbitrary, but, as noted later, an analysis of the data indicates that the lack of prior information is not likely to affect designs for the statistical sample.

The synthesized dataset contains data for 5,772 individual farms, distributed by size and region as shown in Table 12. Data for each farm include:

(1) size of farm;

(2) amount of cropland;

(3) amount of harvested cropland;

(4) amount of harvested cropland draining to buffered streams;

(5) amount of harvested cropland subject to controlled drainage;

(6) amount of woodland;

(7) length of streams;

(8) length of stream bordered by riparian buffer.

The size of each farm in each region was generated as a uniform random variable within given size ranges. Cropland in each farm was generated by multiplying size of farm by a fraction, z_{Crop}, generated as a random variable from a triangular distribution. That distribution was constructed as shown in Figure 15. The mean, μ, was estimated from data in Table 10 for the region in which the farm was located. The base of the triangular distribution was specified as

Table 12. Number of Farms in Synthesized Dataset by Size and Region

Size, Acres	Upper Basin	Middle Basin	Lower Basin
1-9.9	108	266	67
10-49.9	364	1116	184
50-99.9	252	756	105
100-179.9	215	586	103
180-259.9	94	296	52
260-499.9	96	398	72
500-999.9	66	328	63
1000-1999.9	11	111	28
$\geq$ 2000	3	22	10
Total	1209	3879	684

being $2\alpha\mu$ where α is a parameter that can be varied to examine the sensitivity of results to a range of values. Four different datasets were generated using values of $\alpha = 0.25, 0.50, 0.75$, and 1.0. Since z_{Crop} cannot exceed 1.0, if $\mu(1+\alpha) > 1$ the upper limit is set equal to 1 corresponding to a value of $\alpha = (1/\mu)-1$ and the lower limit was set equal to $(2\mu-1)$. Likewise, since z_{Crop} cannot be less than 0, if $\mu(1-\alpha) < 0$ the lower limit is set equal to 0 corresponding to a value of $\alpha = 1$, and the upper limit was set equal to 2μ.

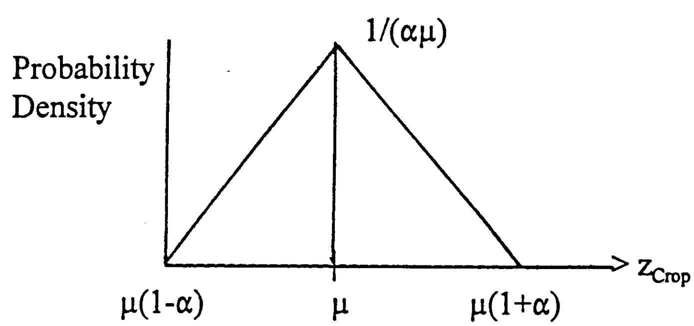

Figure 15. Triangular Distribution for Random Variability about Mean

Values of harvested cropland on each farm were generated in a manner identical to that of cropland. The amount of woodland was taken to be the difference between farm size and cropland.

Length of stream in each farm was generated using randomly generated lengths from the distribution functions in Figures 11 and 12. Distributions for 40-acre tracts were used for farms of less than 50 acres. Distributions for 160-acre tracts were used for farms between 50 and 260 acres, and distributions for 640 acres were used for farms greater than 260 acres.

The percentage of streams on a farm that are buffered was generated using a random variable generated from a triangular distribution as described earlier where the mean was estimated from a relationship derived by Komives (1996), specifically:

$$\% \text{ buffered} = 93 - 0.5*(\% \text{ of farm in cropland}).$$

Komives examined only land use within a 2000-foot radius of selected points on streams in the Neuse Basin, not land use in the farm in which the point was located. In the absence of other information, however, the relationship is applied here to each farm.

There is very little data on the extent to which controlled drainage is used in the watershed. It is known that the practice is much more widespread in the Lower Basin than the other two basins, and very little is used in the Upper Basin in the Piedmont. For the limited purposes of creating a dataset, coverage by controlled drainage was generated by multiplying harvested cropland by a random variable, z_{CD}, where the probability of z_{CD} being 0 is as follows:

Region	$Pr\{ z_{CD} = 0\}$
Upper	0.8
Middle	0.4
Lower	0.1

A random variable was generated to determine if coverage was either zero or greater than zero. If greater than zero, then the coverage was generated by a uniform random variate over the range (0,1).

Standard Deviation of Attributes. With the model specified in this manner, Monte Carlo techniques were used to generate synthetic datasets for the range of α values stated previously. Among the most important information relevant to sample design to be obtained from those datasets are the standard deviations of farm variables. They are given in Table 13 for the smallest (0.25) and largest (1.0) values of α. There it may be noted that the choice of values for α has relatively little effect on those standard deviations (no effect on length of streams which is independent of α). That table also shows the pronounced effect of size group on the magnitude of standard deviations. Standard deviations about regional means in the Middle and Lower Basin are similar; those in the Upper Basin are considerably smaller.

Analysis of Variance. Another method for determining relative importance of the several sources of variability in the data is an analysis of variance (ANOVA). That analysis is intended to reveal relative magnitudes of several sources of variability for each variable. Those sources include variations due to differences between the three regions, variations due to differences between the nine size categories of farms within each region, and differences due to random variability within regions and within size categories. Variability due to each of those sources can then be compared to total variability to gain some insight as to the relative importance of each source.

Total variability can be measured by the sum of squares about the grand mean. If x_{ijk} is the kth observation of a given variable in the jth size range in the ith region, and if $x_{\bullet\bullet\bullet}$ is the grand average of all observations over all sizes and regions, then the total sum of squares is

$$TSS = \Sigma_i \Sigma_j \Sigma_k (x_{ijk} - x_{\bullet\bullet\bullet})^2. \qquad (1)$$

If $x_{i\bullet\bullet}$ is the regional mean value of x in region i, then a measure of the variability due to differences between regions is

$$SSBR = \Sigma_i \Sigma_j \Sigma_k (x_{i\bullet\bullet} - x_{\bullet\bullet\bullet})^2 = \Sigma_i \; n_i (x_{i\bullet\bullet} - x_{\bullet\bullet\bullet})^2 \qquad (2)$$

where n_i is the number of observations in region i, including those in all size ranges.

Table 13. Standard Deviations for Selected Attributes
Of Farms in Synthesized Dataset

Size Group acres	Crop-land acres	Harvested Cropland: Total acres	Harvested Cropland: Buffered acres	Harvested Cropland: Controlled Drainage acres	Stream Length 1000 feet	Buffered Streams 1000 feet
			Alpha = 0.25			
1-9	1.98	1.60	0.82	0.83	0.35	0.22
10-49	8.67	7.68	4.22	5.88	1.74	1.05
50-99	12.96	13.24	6.79	14.05	2.18	1.34
100-179	22.85	23.83	12.08	25.60	3.93	2.45
180-259	30.30	32.79	16.31	41.83	6.08	3.73
260-499	64.19	65.11	33.90	74.21	3.01	2.01
500-999	133.23	131.29	68.60	148.78	6.94	4.59
1000-1999	275.64	262.71	130.89	295.81	12.39	8.25
2000+	416.75	382.75	200.36	470.15	13.45	11.93
Region						
1	151.52	92.95	59.68	23.61	8.51	5.55
2	266.75	223.78	124.39	108.76	10.94	6.20
3	233.42	183.99	122.88	103.07	13.61	9.23
Grand	197.89	165.11	93.87	91.68	8.10	4.92
			Alpha = 1.0			
1-9	2.11	1.71	0.90	0.84	0.35	0.23
10-49	9.57	8.30	5.29	6.01	1.74	1.11
50-99	15.58	14.93	10.22	14.27	2.18	1.50
100-179	28.33	27.56	18.67	26.00	3.93	2.75
180-259	41.51	40.15	28.98	43.00	6.08	4.19
260-499	77.84	73.99	52.37	75.54	3.01	2.79
500-999	161.73	150.67	103.03	151.04	6.94	5.94
1000-1999	343.12	314.73	211.46	300.34	12.39	11.15
2000+	569.57	476.50	358.92	490.85	13.45	20.61
Region						
1	167.73	106.50	61.80	25.12	8.51	5.66
2	269.12	225.90	131.47	110.11	10.94	6.57
3	249.40	197.13	117.52	103.15	13.61	9.64
Grand	205.08	170.52	100.67	92.88	8.10	5.36

If $x_{ij\bullet}$ is the average value of x in the ith region and jth size range, averaged over all observations in that region and size range, then a measure of variability due to differences between the size range within regions is:

$$SSBSWR = \Sigma_i \Sigma_j \Sigma_k (x_{ij\bullet} - x_{i\bullet\bullet})^2 = \Sigma_i \Sigma_j n_{ij} (x_{ij\bullet} - x_{i\bullet\bullet})^2 \qquad (3)$$

where n_{ij} is the number of observations in the jth size range in region i.

Finally, a measure of variability due to random variation within regions and within size groups, called the error sum of squares (ESS), is:

$$ESS = \Sigma_i \Sigma_j \Sigma_k (x_{ijk} - x_{ij\bullet})^2. \qquad (4)$$

It can be shown that the total sum of squares given in (4.1) is the sum of the sum of squares between regions given in (4.2), the sum of squares between size ranges within regions given in (4.3), and the error sum of squares in (4.4), or

$$TSS = SSBSWR + SSBR + SSE. \qquad (5)$$

Analysis of variance results for datasets generated with α values of 0.25 and 1.0 are shown in Figures 16 and 17. Sums of squares for the various components are expressed as fractions of TSS. Several observations about those two figures are noteworthy. First, the general pattern of the ANOVA's is relatively insensitive to the choice of α. There are some differences between the two sets of results, but they have the same general pattern. Second, for all variables except controlled drainage, the sum of squares between sizes within regions (SSBSWR) tends to dominate other components accounting for 65-95% of total variability even with distributions covering a wide range of values (α = 1.0). For distributions covering lesser ranges (α = 1.0), SSBSWR accounts for 85-95% of total variability. For the case of controlled drainage, random variation within sizes and regions (SSE) is larger than SSBSWR, but regional differences remain relatively small. The conclusion to be drawn from this analysis and the table of standard deviations is that variability due to differences in size groups is a dominant factor in characteristics of these farms. Regional differences are relatively small by comparison. Failure to account for differences in sizes can lead to inefficient designs.

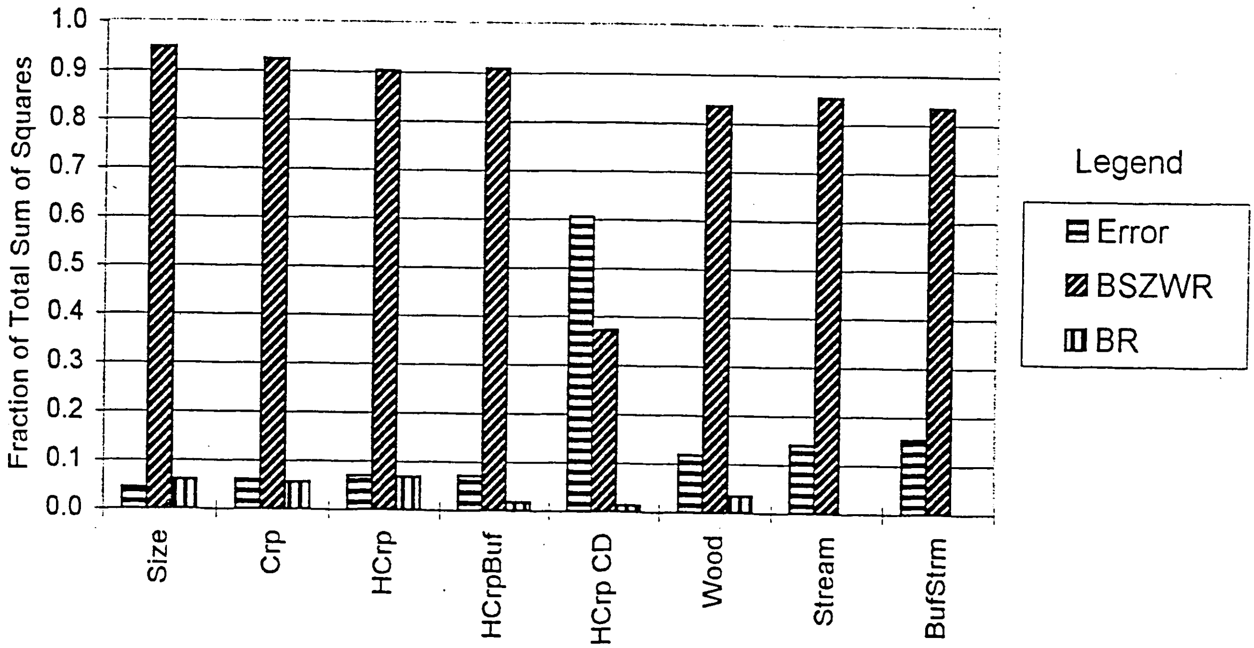

Figure 16. Analysis of Variance for Alpha = 0.25

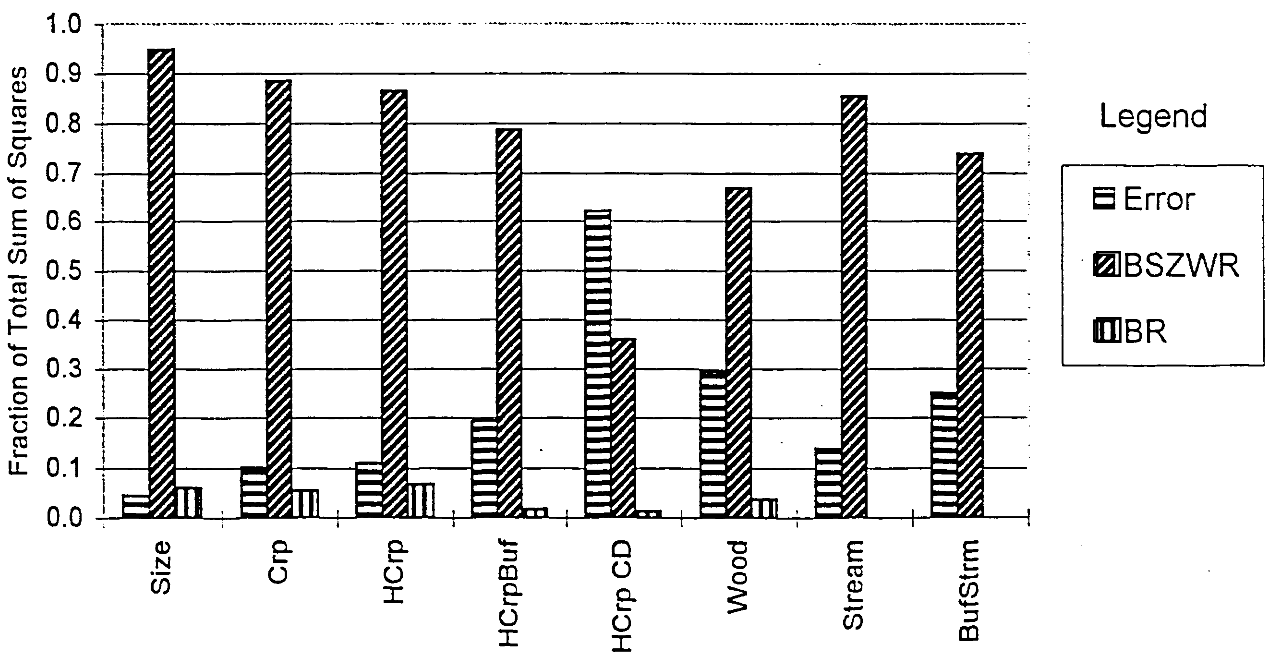

Figure 17. Analysis of Variance for Alpha = 1.0

Simple Random Sampling Versus Stratified Random Sampling

Sampling for Management Practices. Stratification on the sample based on size of farm is one method for improving efficiency. To illustrate the point, consider a basin containing 1000 farms in which the number of acres covered by a particular management practice (MP) is unknown. To obtain an exact estimate of that quantity, we would have to survey all 1000 acres. If we are willing to accept something less than an exact number, however, we could do that with far less effort. Let the number of acres covered by that MP in a farm be X. If we estimate the average value of X for the farms, then the total acres number of acres in the basin covered by this MP is 1000 times that average. Let the number of acres subject to this MP be distributed as follows: half of the farms are in the size range of 0-100 acres, 30% in the size range 100-300 acres, and 20% are in the size range of 300-600 acres. Within each size range, let the coverage of the given MP be uniformly distributed. If that is the case, then the average value of X for the first range is 50, for the second range 200, and for the third range, 450. For all 1000 farms, the average value is:

$$\mu = 0.5x50 + .3x200 + .2x450 = 175 \text{ acres.}$$

Variances within the three ranges are 833.3, 3333.3, and 7500. The variance over the full range $\sigma_x^2 = 26{,}042$, the standard deviation being $\sigma_x = 161.4$ acres.

Now, if we draw a simple random sample from the population of all farms and estimate the average for that sample, the standard error of the estimated mean would be:

$$S.E.(_{ran}) = \sigma_x/\sqrt{n} = 161.4/\sqrt{n}. \qquad (6)$$

For n = 30, the standard error would be 29.5, and the 95% confidence interval would be about $\pm$ 2x29.5 or $\pm$ 57 acres about the estimated mean.

An alternative and much more efficient strategy would be to use stratified random sampling, taking advantage of our knowledge that there is considerable variability in x solely due to the size of farms. If the sample of size n is stratified with n_1 taken from the first size range, n_2 taken from the second range, and n_3 from the third ($n_1+n_2+n_3 = n$), then it can be shown (Cochran, 1977) that the standard error of the estimated mean is:

$$S.E.(_{st}) = [\Sigma N_h(N_h-n_h)S_h^2/n_h]^{1/2}/N \qquad (7)$$

where N is the number of farms (N=1000), N_h is the number of farms in the hth strata, and S_h^2 is the variance within the hth strata. For this example, (7) becomes

$$S.E.(_{st}) = [500(500-n_1)833.3/n_1 + 300(300-n_2)3333.3/n_2 + 200(200-n_3)7500/n_3]^{1/2}/1000.$$

It can also be shown (Cochran, p.1977) that the standard error is minimized if the sample is stratified so that

$$n_h \text{ is approximately equal to } nN_hS_h/\Sigma N_hS_h. \qquad (8)$$

For this example, with $n = 30$, then $n_1 = 9$, $n_2 = 10$, and $n_3 = 11$, and the standard error becomes 8.80. With stratified sampling then, the standard error is only 30% of the standard error for random sampling, and the 95% confidence interval is $\pm$ 2x8.80 or $\pm$ 17.6 acres about the estimated mean, much narrower than the $\pm$ 57.0 acres for simple random sampling.

This example illustrates two key points. First, if one can accept some uncertainty in the estimate of basinwide characteristics, the task of making that estimate can be substantially reduced. Instead of surveying all 1000 farms in the basin to get a precise estimate of an average of 175 acres per farm covered by the MP, with a sample of only 30 farms, an estimate can be made with 95% confidence that the true value lies within $\pm$ 17.6 acres of the value estimated from the sample. That standard error can be reduced even further with a larger sample but one that is still much smaller than 1000. Second, stratified random sampling is far more efficient than simple random sampling if it is known that data are stratified by a given characteristic.

For the Neuse Basin, the number of size groups can be reduced. The smallest farms less than 10 acres in size can be ignored, and because of the relatively small number of large farms, the two groups of largest farms, those larger than 1000 acres, can be combined into a single group. The number of farms and standard deviations for the three management practices for the seven remaining strata are show in Table 14.

Table 14. Number of Farms and Standard Deviations for Selected Variables by Size Strata

		Standard Deviations		
Size Strata, acres	Number of Farms	Buffered Cropland, acres	Cropland with Controlled Drainage, ac.	Buffered Streams, 1000 feet.
10-49.9	1664	4.22	5.88	1.05
50-99.9	1113	6.79	14.05	1.34
100-179.9	904	12.08	25.60	2.45
180-259.9	442	16.31	41.83	3.73
260-499.9	566	33.90	74.21	2.01
500-999.9	457	68.60	148.78	4.59
1000+	185	186.85	339.83	12.19
All strata	5331	114.9	97.67	6.54

Means values for the three variables are:

Croplands with riparian buffers:	66.25 acres
Croplands with controlled drainage:	33.65 acres
Streams with riparian buffers:	4.31 thousand feet.

For a sample size of 100, the optimal distributions of the sample over the strata for the three variables were calculated using (8). Results are shown in Table 15. There it may be noted that distributions for the first two variables are quite similar; the one for the third variable is considerably different. Thus, if the same sample of farms is used to estimate mean values for the three variables, then some combinations of those distributions would have to be selected. One could use either a distribution like the first two and allow inefficiency in the third, or select some weighted combination of the three, allowing somewhat less inefficiencies in all three.

Table 15. Optimal Distribution of Sample of Size 100

Size Strata, acres	Buffered Cropland	Cropland with Controlled Drainage	Buffered Streams
10-49.9	6	4	14
50-99.9	7	7	12
100-179.9	9	9	17
180-259.9	6	8	13
260-499.9	16	18	9
500-999.9	27	28	17
1000+	29	26	18

If the distribution of the sample for buffered cropland is used for all three variables, the resulting standard errors of the means would be 2.13, 4.39, and 0.278, respectively. If the sample distribution is selected to minimize the standard error of cropland with controlled drainage, the standard error for that variable would be 4.36 instead of 4.39 for the first distribution. If the distribution is selected to minimize the standard error of buffered streams, its value would be 0.232 instead of 0.278. Therefore, selecting an optimal distribution for buffered cropland and using the same distribution for the other two variables causes only modest increases in standard errors for estimates of the other two means. Those standard errors are still considerably smaller than those resulting from simple random sampling. In this case, standard errors of means for the three variables using simple random sampling are 11.5, 9.77, and 0.645.

Standard errors for a range of sample sizes are given in Table 16 for both stratified sampling and simple random sampling. For stratified sampling, samples were distributed across size strata using the relationship cited previously. Two observations are noteworthy in that table. First, stratified random sampling is far more efficient than simple random sampling. For the same size sample, standard errors of estimated means are far smaller for stratified samples than with simple random sampling. The other observation is that with samples as small

Table 16. Standard Errors for Estimates of Means of Selected Variables for Stratified and Simple Random Sampling for Various Sample Sizes

	Stratified Sampling			Simple Random Sampling		Buffered
	Cropland with	Buffered	Buffered	Cropland with	Buffered	
	Cropland,	Controlled	Streams,	Cropland,	Controlled	Streams,
n	acres	Drainage, ac.	1000 feet.	acres	Drainage, ac.	1000 feet.
36	3.65	7.50	0.485	19.2	16.3	1.09
72	2.54	5.23	0.331	13.5	11.51	0.77
144	1.75	3.61	0.230	9.58	8.14	0.55
288	1.66	2.42	0.159	6.77	5.76	0.39

as 72, relatively small confidence intervals surround estimated means. For buffered croplands, confidence interval of $\pm$ 2 standard errors for n = 72 is $\pm$ 5.08 acres or $\pm$ 7.7% of the mean of 66.25 acres. For a sample of size 144, that confidence interval is reduced to $\pm$ 5.3%. The confidence interval for cropland with controlled drainage are some what larger. For n = 72, $\pm$ two standard errors is $\pm$ 31% of the mean. For n = 144, it is $\pm$ 21% of the mean.

Sampling for Compliance Costs. A similar analysis was made to determine effects of sampling methods and sampling sizes on costs to bring farms into compliance with a mandatory management practice policy. Estimates were made using policies that mandate specified coverages of riparian buffers and controlled drainage on croplands. Estimates were made for 75 and 100% coverage of riparian buffers and 50 and 75% coverage of controlled drainage.

Cost of implementing a mandatory management practice policy on an individual farm is the product of the area necessary to bring that farm into compliance with the policy and the cost per unit area. Both of those variables can be treated as random variables. Let A_i be the acreage of harvested cropland in farm i; let F be the fraction of that land stated in the policy that must be covered by a given practice; X_i is the amount of land in farm i already covered by the management practice; and G_i is the amount needed to bring the farm into compliance. G_i can be calculated as follows:

$$G_i = \begin{cases} 0 & \text{for } X_i \geq FA_i \\ FA_i - X_i & \text{for } X_i < Fa_i \end{cases} \quad (9)$$

Then, if the unit cost for that farm is U_i, the total cost for bringing that farm into compliance is U_iG_i.

Previous studies of unit costs reviewed in earlier sections of this report suggest that they are highly variable from one farm to another. Results presented by Comacho (1992) indicate that unit costs come from a skewed distribution for which 75th percentile values range from 1.7 to 3.3 times median values. The distribution of unit costs for controlled drainage structures in the Neuse River Basin shown in Figure 1 has a mean of \$43.4 per acre, a standard deviation of 66.7, and the 75th percentile value is approximately twice the median value. North Carolina's Agriculture Cost Share (NCACS) program has only limited data for vegetative filter strips. These data contain only 15 projects over the period 1989-1997; the mean first cost of those projects was \$32.41 with a standard deviation of \$47.7. For this data, like that for controlled drainage, the 75th percentile value is approximately twice the median value.

Very little information about farm-to-farm variability of unit costs specific to riparian buffers was found, but if they vary like other unit costs for management practices, variability can be represented by a log-normal distribution. Let the mean of the distribution be \$3.6 per acre with a standard deviation of \$5.45 ($\mu_{\ln x} = \ln 3$ and $\sigma_{\ln x} = 0.6$). The density function for that distribution is shown in Figure 18. The distribution of unit costs for controlled drainage used in this analysis is that for the NCACS program shown in Figure 1.

Random values of unit costs were generated from these distributions for each farm in the data set, and those values were used in (9) to calculate a compliance cost for each farm for specified coverages of riparian buffers and controlled drainage. Standard deviations of compliance costs were calculated for each size strata, and optimal distributions of samples across strata were calculated using (8). Those distributions for sample sizes of 50, 100, and 200 are shown in Table 17 for 100% coverage by buffers and 75% coverage by controlled drainage.

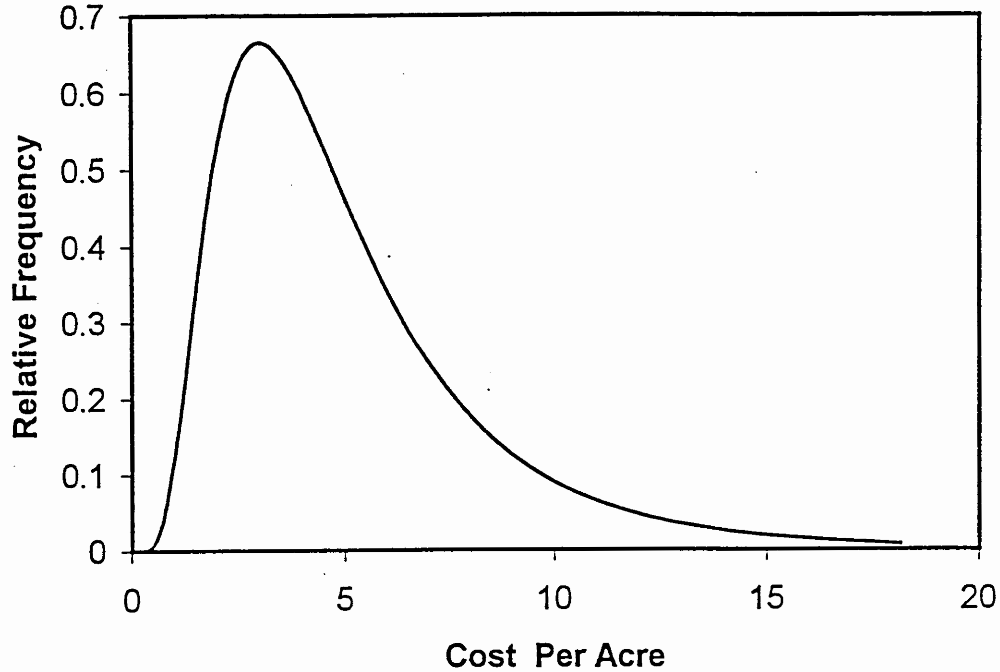

Figure 18. Density Function for Unit Costs of Riparian Buffers

Table 17. Optimal Allocations of Samples Across Size Strata

Size Size Strata, acres	Buffered Cropland			Controlled Drainage		
	n=50	n=100	n=200	n=50	n=100	n=200
10-49.9	2	5	9	2	4	9
50-99.9	3	6	13	4	7	14
100-179.9	5	10	20	5	11	21
180-259.9	4	8	16	4	8	16
260-499.9	8	15	31	9	18	35
500-999.9	13	26	52	14	29	58
1000+	15	30	59	12	23	47

There it may be noted that allocations to minimize standard errors of cost estimates of riparian buffers are nearly the same as those for controlled drainage.

Sampling distributions shown in Table 17 for buffered cropland were then used in a Monte Carlo simulation to estimate standard errors of cost estimates for the given sample sizes. The sampling process was replicated 500 times for each sample size, resulting in 500 estimates of sample means. Standard errors were estimated by calculating standard deviations of the 500 sample means.

The reader is reminded that absolute magnitudes of the numbers are not important because samples were drawn from a synthesized dataset. The important relationship is the magnitude of standard errors relative to means. For this case, the mean values are \$187.2 per farm for 100% coverage by riparian buffers and \$338.3 per farm for 75% coverage by controlled drainage. Standard errors are given in Table 18. They again demonstrate the relative efficiency of stratified sampling based on size of farm. For both riparian buffers and controlled drainage standard errors of estimates with stratified sampling are substantially smaller than those for simple random sampling. Results in Table 18 also indicate that relatively small standard errors of estimates are possible for costs of riparian buffers for relatively small samples. Reasonably reliable estimates may be obtained with sample sizes as small as 50 or 100. For n=100, a confidence interval of ± 2 standard errors is ± 17.6% of the mean. Standard errors for controlled drainage costs are larger. Even with n = 200 standard errors are about 14% of mean values.

Table 18. Standard Errors of Cost Estimates

	Simple Random Sampling	Stratified Random Sampling
Riparian Buffers		
n = 50	57.82	21.18
n = 100	42.06	16.45
n = 200	28.13	10.54
Controlled Drainage		
n = 50	189.57	93.05
n = 100	116.18	65.41
n = 200	93.40	47.10

The larger standard errors for mean values of cropland covered by controlled drainage and the cost of bringing farms into compliance with basinwide policies can be attributed to two factors. First, variability introduced in generating the synthesized dataset was quite large. For 80% of the farms, the fraction of harvested cropland covered by controlled drainage was allowed to vary according to a uniform distribution over the interval (0,1). That introduced considerable variability, possibly much greater than that which might be found in the field. Second, the distribution of unit costs based on data from the NCACS program shows considerable variation. Further investigation may be warranted as to why those costs are so highly variable.

Stratified Sampling Using Parcels. Analysis based on farms provides considerable insight about the design of samples, but as noted previously, the sampling frame for farms is not available because of confidentiality. Fortunately, land parcels as defined for purposes of property tax files can be used as a sampling frame. As shown earlier for each of two counties, when parcels with identical owner names were grouped, the aggregated parcels (GPIO's) were distributed by size groups in a manner similar to the distribution of farms in the Census of Agriculture. Data from the Census of Agriculture are used to stratify the sample across size groups of agricultural operations, but so long as GPIO's have similar distributions, little loss of efficiency should be expected when drawing the sample from GPIO's.

An example is given to illustrate the point. Let conditional probabilities of farm size strata given the size of a GPIO be as given in Table 19. An interpretation of that table is as follows. Given that the sizes of all GPIO are known in advance, a GPIO can be selected at random from one of the strata, say the first. Then there is a 65% chance that GPIO is part of a farm in the size range 10-49.9, a 20% chance that it is part of a farm in the size range 50-99.9, a 10% it is in a farm in the 100-179.9 stratum, etc.

With this set of conditional probabilities, it is then possible to use Monte Carlo techniques to generate a large number of realizations of sample distributions across farm size strata for a given distribution of samples across GPIO strata. In this example, the optimal sample distribution for buffered cropland given in Table 15 is used to select 1000 samples, each of size 100, from the GPIO strata. In each sample there are 6 GPIO's randomly selected from the first strata, 7 from the second, 9 from the third, ..., 29 from the seventh. For each GPIO, a corresponding farm size

Table 19. Conditional Probabilities of Farm Size Given the Size of A Parcel in a Group of Parcels with Identical Owners

GPIO	Farm Size Strata						
Strata	10-49.9	50-99.9	100-179.9	180-259.9	260-499.9	500-999.9	1000+
10-49.9	0.65	0.20	0.10	0.04	0.03	0.02	0.01
50-99.9	0	0.65	0.20	0.09	0.03	0.02	0.01
100-179.9	0	0	0.65	0.20	0.08	0.05	0.02
180-259.9	0	0	0	0.65	0.25	0.08	0.02
260-499.9	0	0	0	0	0.75	0.20	0.05
500-999.9	0	0	0	0	0	0.75	0.25
1000+	0	0	0	0	0	0	1.00

stratum is generated using the table of conditional probabilities given above. Thus, for each sample taken from the GPIO strata, there is a corresponding sample across farm strata, but the number of samples in the farm strata are not necessarily the same as those in the GPIO strata. Using the distribution of a sample across farm strata, the standard error for that sample can be calculated using the relationship

$$S.E.(_{st}) = [\Sigma N_h(N_h-n_h)S_h^2/n_h]^{1/2}/N.$$

That process can be repeated 1000 times, and the standard error of each sample can be divided by the standard error for an exact match between GPIO's and farms. The cumulative frequency of those ratios is shown in Figure 19 where it may be noted that for 95% of the samples, the standard error is less than 1.15 times the standard error for an exact match.

Estimation of Costs for Selected Farms. To this point the discussion has focused entirely on the process of how to select a relatively small sample of agricultural operations from which the status of management practices and cost of compliance for an entire watershed can be inferred. But once a sample has been selected, a number of procedural questions remain about how to measure the status of practices and compliance costs for those operations. Details of how to

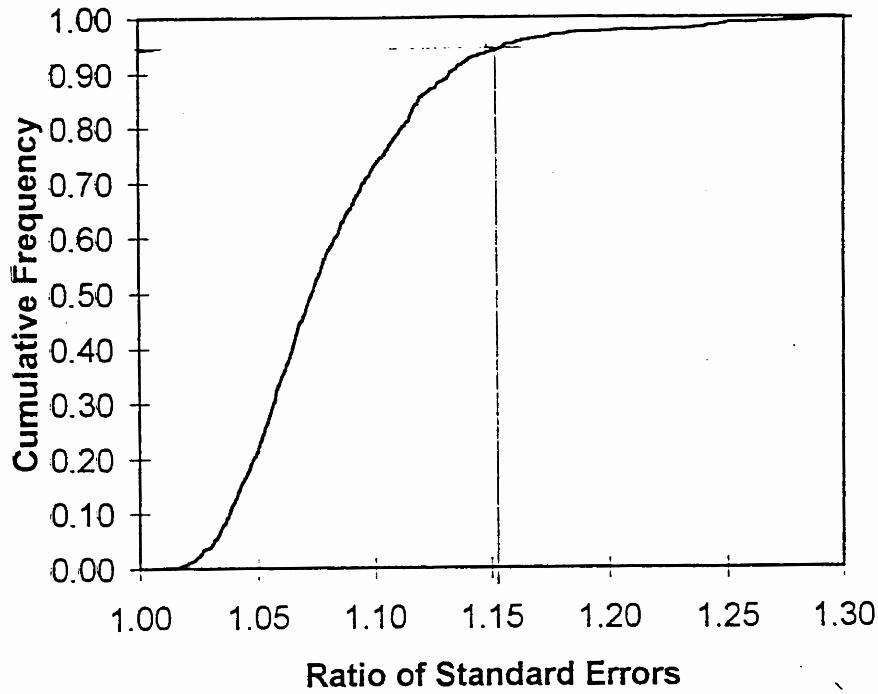

Figure 19. Ratios of Standard Errors Using Samples from GPIO's to Those Using Farms

accomplish this task will vary from one watershed to another and possibly from one farm to another, depending on how much information is in a tax file, if and when a management plan had already been prepared for an operation, availability of recent areal photographs, and other data.

Among the earliest steps to be taken in the process would be to establish watershed management goals in sufficient clarity and detail so that field personnel can determine their implications for individual agricultural operations. Among the tasks that may be necessary to complete that step would be establishment of what management practices are to be included in the survey and analysis.

While the sample may be designed and selected by a state or regional management agency, determination of the current status of management practices and cost of compliance for individual operations in the sample should be done by personnel in local offices of the Natural

Resources Conservation Service, Soil and Water Conservation Districts, or other agencies with personnel trained and certified in the design of agricultural management plans. After an operation has been selected, a portfolio of information about it should be compiled from publicly available sources. It is possible that tax information may be sufficient to fully describe its location. If so, it should be possible to obtain from secondary sources information about soils, streams, and other natural resource characteristics of the operation. If recent management plans are available, field personnel may be able to compile all necessary information from those sources. Information not available from those sources would have to acquired through interviews with owners or managers of an operation.

Estimation of the cost of compliance for an operation given knowledge about the present status of relevant management practices will depend on particular provisions of watershed management policies. If information from a previously formulated management plan is not available for a particular operation, at least two methods could be used to make those estimates. One approach would be to determine the areas or activities that would have to be covered by specific management practices to bring the operation into compliance, then apply generalized unit costs similar to those reviewed in earlier in this report. The other would be to design an operation-specific management plan from which more detailed estimates of quantities of materials and labor and their costs could be estimated. The first of these two options would clearly be less expensive than the second. In either case, it would be desirable to assign some measure of uncertainty to the cost estimates.

Urban Areas

Like the case of agricultural areas, estimation of the cost of BMP's in urban areas depends on the nature of the policy -- whether it is voluntary or mandatory, whether it mandates particular technologies or not, or whether it is based on performance standards. Selection of a sample of land parcels in urban areas would appear to be much simpler than for farms. Modern tax files, such as those in Wake County, provide a ready-made sampling frame, and data contained in those files provide very good descriptors of the parcels. Although those files generally do not provide information about best management practices, some information about the extent to which various practices have been installed may be compiled from a history of development and ordinances under which development occurred. One characteristic of BMP's in urban areas that may be quite different from rural areas is that BMP's may not be on site. For instance, stormwater management may have been designed to serve entire subdivisions, not individual lots. Similarly, facilities to manage stormwater in highly developed business districts are most likely to be off site.

Despite some differences, the general problem of estimating cost of a proposed policy in urban areas is not very different from that in agricultural areas. First, it is necessary to determine the extent to which a proposed policy exempts existing development. Second, it is necessary to determine the extent to which existing practices already conform to proposed policy, and, third, it is necessary to determine the effect of a proposed policy on existing and future development.

Statistical sampling can be quite useful in the second and third steps. To provide reliable information about the current status of BMP's, one may have to examine only a small number of the nearly 138,000 parcels in the urban area. Likewise, that same sample may be sufficient to determine estimates of cost for the entire urban area that are within acceptable error bounds.

For purpose of this report, assume that the proposed policy consists of two parts: (a) protection of existing riparian buffers along all streams in developed portions of the urban area; and (b) protection of existing or establishment of new riparian buffers along all lands within the area that will be developed in the future. The cost of the proposed policy in existing areas would be the opportunity cost associated with removing those lands from future development possibilities. In many instances, that cost may be zero. If a parcel is fully developed under existing zoning restrictions, then adding an additional restriction has no effect on its value. In other instances protection of an existing buffer on parcel could have significant opportunity cost. For lands to be developed in the future, the cost would include the opportunity cost of the land and, if an acceptable buffer does not already exist, the cost of establishing one.

Considerable insight to the design of sampling strategies for such policies can be gained from an analysis of land values in the area. In this section, land values are used to explore the relationship between confidence intervals and sample sizes and to compare relative efficiencies of simple random sampling with stratified sampling.

Land values of special interest are for parcels that are adjacent to streams. Those values may be very different from values of all parcels in the urban area given in Table 11. To examine those values for this investigation, a sample of 1000 parcels adjacent to streams was selected for analysis. That sample was selected as follows:

- lengths and cumulative lengths of all stream segments in the TIGER files for Wake County were calculated;
- 1000 stream locations were selected at random by multiplying the total length of streams by uniform distributed random numbers and using the cumulative lengths to determine which segment and the location along that segment corresponds to each random length; and,
- for each stream location, the land parcel with the nearest centroid was identified.

Those 1000 parcels fell into 41 different zoning classes. Average values for these parcels are substantially lower than that for all parcels in the urban area. Those adjacent to streams have an estimated average value of $62,200 per acre, while the all-parcel average is $107,610 per acre. Values for both sets of parcels are subject to very large variability. The standard deviation for those adjacent to streams is $89,400; for all parcels it is $102,300.

Analysis of Variance . As noted in the previous section, there is substantial variation in those values among parcels within each zoning classes. There is also considerable variation between classes. As is the case with agricultural areas, an analysis of variance can be useful in determining relative magnitudes of those different sources of variations to guide selection of sampling strategies.

In this case, there are only two sources of variability -- within classes and between classes. If x_{ij} is the value of a variable for the jth parcel in class i, and if x_{**} is the grand average of all observations over all parcels and classes, then the total sum of squares is

$$TSS = \Sigma_i \Sigma_j (x_{ij} - x_{**})^2. \qquad (10)$$

If x_{i*} is the mean value of x in zoning class i, then a measure of the variability within classes is:

$$SSWC = \Sigma_i \Sigma_j (x_{ij} - x_{i*})^2 \qquad (11)$$

and the variability due to differences between classes is

$$SSBC = \Sigma_i \Sigma_j (x_{i*} - x_{**})^2 = \Sigma_i \; n_i (x_{i*} - x_{**})^2 \qquad (12)$$

where n_i is the number of observations in class i. It can also be shown that

$$TSS = SSWC + SSBC \qquad (13)$$

For the 1000 parcels adjacent to streams, results of the ANOVA indicate that a large portion of the variability in land values (62%) occurs within zoning classes, and variability between classes accounts for only 38% of the total. As a consequence, it is likely that stratification based on zoning class will have less effect in improving efficiency of sampling relative to simple random sampling than is the case with agricultural operations.

Simple versus Stratified Sampling. Since the standard deviation of land values in the urban area for parcels adjacent to streams is $89,400 per acre, the standard error of the mean for simple random sampling is:

$$S.E.(\_{ran}) = \sigma_x/\sqrt{n} = 89.4/\sqrt{n} \text{ in units of \$1000/acre.} \qquad (14)$$

That value ranges from 16.3 down to 6.32 as the sample size increases from 30 to 200. With a mean value of 62.2 ($1000/acre), the standard error would vary from 26.2% to 7.01% of the mean for sample sizes over that range..

For stratified sampling, the number of strata can be reduced to a reasonable number by grouping some of the zoning classes. For this analysis, six strata were defined, statistics for which are given in Table 20. Two of the largest zoning classes, R-30 and R-4, were treated as individual strata. Four office and institutional classes were assigned to a third stratum, two industrial zones were assigned to a fourth, and three residential classes with similar means and standard deviations, R-40, R-40W, and R-80W were assigned to the fifth. The remaining 30 classes were grouped in an "Other" strata. The first five strata account for 66% of the parcels; the "Other" stratum included 34%.

Results of using Expression (8) to determine optimal distribution of samples across strata and Expression (7) to calculate the corresponding standard error leads to results given in Table 21.

There it may be noted that the use of stratified sampling can lead to reductions in standard errors of 12.3% for n equal to 30, increasing to 21.3% for n equal to 200.

If confidence intervals are set at ± 2.0 times the standard error, the confidence interval for n equal to 100 is ± 29% of the mean. For n equal to 200, the confidence interval is about ± 16% of the mean.

Table 20. Numbers of Parcels, Means and Standard Deviations For Six Strata of Parcels Adjacent to Streams

Zoning Class(es)	No. of Parcels	Mean	Standard Deviation
Office/Institutional	58	165.78	118.04
R-40/R-40W/R-80W	120	28.45	35.39
R-30	192	53.90	95.71
R-4	223	40.98	45.75
Industrial	63	84.99	84.14
Other	344	70.67	100.24
All	1000	62.19	89.35

Table 21. Optimal Distribution of Samples Across Strata And Standard Errors of Means for Urban Areas

Zoning Class(es)	Sample Size for Each Strata n=30	n=50	n=100	n=150	n=200
Office/Institutional	3	4	9	13	17
R-40/R-40W/R-80W	2	3	7	10	13
R-30	2	3	5	8	11
R-4	7	12	23	35	46
Industrial	4	6	13	19	26
Other	12	22	43	65	87
Standard Errors					
Stratified sampling	14.3	10.9	7.49	5.92	4.95
Simple	16.3	12.6	8.93	7.30	6.32

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