Alcoa Power Generating Inc.
Yadkin Division

Yadkin Project Relicensing (FERC No. 2197)

SEDIMENT FATE AND TRANSPORT REPORT

Draft Report

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EXECUTIVE SUMMARY

The Draft Sediment Fate and Transport Report presents the information that is publicly available on sediment fate and transport in the Yadkin-Pee Dee River basin. The area considered in this study is the river basin that drains to Winyah Bay, South Carolina and includes the Yadkin, Pee-Dee, Uwharrie, and Rocky rivers. The study was conducted in accordance with the Final Study Plan that was developed by Alcoa Power Generating Inc. (APGI) in consultation with the Water Quality Issue Advisory Group (IAG), supporting relicensing of the Yadkin Project. Specific objectives identified in the Final Study Plan included:

- identify the sources, estimate the current sediment load, and determine the physical characteristics of the sediments transported to and through the Yadkin Project reservoirs;
- estimate the volume of sediment trapped in the reservoirs and the deposition patterns; and
- evaluate the fate and transport of sediment qualitatively under existing and potential future operating scenarios

The study involved two separate components; 1) a literature search performed by Normandeau Associates to identify the body of research completed in this area, and 2) a review of historic survey data which is used to evaluate the patterns of sediment deposition within High Rock Reservoir based on changes in topography and bathymetry that have occurred since High Rock Dam was constructed.

In total, the study reviewed over a dozen articles and technical papers that have examined the issue of sediment and sedimentation in parts of the Yadkin-Pee Dee River Basin. As discussed in the reports and articles reviewed, the input of sediment, its transport, and its storage are dependent upon both natural conditions such as regional geology, hydrology and soils along with man's alteration of the landscape by development. The input, output and storage of sediment within parts of the Yadkin-Pee Dee River basin has been shown to vary both spatially and temporally in response to changes in both naturally occurring and imposed conditions. An understanding of the relationship between the naturally occurring conditions along with the potential impacts associated with any imposed changes (naturally or by man's actions) within the basin is essential in order to place the sediment issue into context.

The literature reviewed identifies that the major inputs of sediment to the Yadkin-Pee Dee River include soil erosion, streambank and channel erosion, and urban runoff. The reviewed literature indicates that the main source of sediment in the Yadkin-Pee Dee River is soil erosion. The rates of soil erosion within the Yadkin-Pee Dee River basin vary in response to the type of soil material and land use. In general, the soils found in the Piedmont physiographic province are typically fine grained (silt) and can be readily eroded when exposed to wind and water. Other natural factors contributing to the erosion of these soils include the humid climate and topographic relief found within the Piedmont physiographic province. Although many other rivers in North Carolina also have serious sedimentation problems, the Yadkin's combination of these factors together with land use patterns within the watershed, results in some of the highest erosion rates and sediment yields in North Carolina. The majority of the authors of the publications reviewed as part of the study concluded that the decline in agricultural land use for crop production since the 18th and early 19th centuries has resulted in a substantial decline in soil erosion and sediment input to the Yadkin-Pee Dee River. They also note that for those lands remaining in agricultural use soil erosion can be further reduced by implementing agricultural best management practices (BMPs).

Several of the authors also note that increasing development and urbanization may be causing a recent increase in sediment input to the Yadkin-Pee Dee River and may in the long run exceed the reductions associated with decreased cropland. Research has shown that development can result in increased runoff, higher soil erosion and sediment transport. Utilization of urban BMPs may reduce some of these impacts, but the benefits associated with implementation of urban BMPs may not be measurable for some time due to the time lag between land use changes and the basin's response. Recognizing this trend in its Basinwide Water Quality Plan (NCDNR 2003) for the Yadkin-Pee Dee River, the NCDNR has emphasized the need for the continued implementation of appropriate urban BMPs to reduce this growing source of sediment.

Overall, the findings of the reviewed research indicate that sediment transport in the Yadkin-Pee Dee River has decreased over the last several decades. This principal reason for this decreasing trend is the decline in the land area used for crop production and possibly the implementation of BMP to reduce soil erosion and stormwater runoff. Although this trend appears to be continuing, several of the streams and rivers within the Yadkin-Pee Dee River basin have been impaired by high sediment and turbidity levels (NCDNR 2003). Furthermore, several of the authors warn that the production of sediment associated with land development may ultimately cause sediment transport in the Yadkin-Pee Dee River to increase. If this occurs, any gains made in reducing sediment transport in the last decade basin could be reduced along with the continued impairment of the basins waters.

The study also concludes that storage of sediment in the basin naturally occurs within its streams and rivers and on their associated floodplains. The construction of dams and the operation of their associated reservoirs on the Yadkin-Pee Dee River has had an impact on the transport of sediment through the lower portion of the basin. The impoundment of water by High Rock, Tuckertown, Narrows, Falls, Tillery and Blewett Falls dams and the resulting reduction in water velocity at each reservoir have reduced the capacity of the Yadkin- Pee Dee River to transport its sediment, thereby leading to its deposition in each of the six impoundments.

The amount of sediment deposited in the reservoirs depends upon the amount of sediment supplied and the storage or residence time of the water in the impoundment. Several of the studies reviewed estimated the amount of sediment accumulated in the impoundments. The USDA (1979) estimated annual sediment accumulation in the Yadkin Project reservoirs ranged from 1,354,500 tons/year (903 ac. ft./yr) for High Rock Reservoir to 21,000 tons/year (14 ac. ft./yr) at Falls Reservoir, while the estimated annual loss in total storage capacity ranged from 0.36 percent in High Rock Reservoir to 0.05 percent in Narrows Reservoir. The lower capacity loss for Narrows and Falls reservoirs is due to the reduction in sediment transport by its accumulation in High Rock Reservoir. The analysis of the survey data available for High Rock Reservoir reveals that sedimentation has occurred since the construction of the dam in 1927. The bathymetry of the reservoir shows that sediment has accumulated in the upstream areas of the reservoir from Crane Creek upstream to the confluence of the Yadkin and South Yadkin rivers. The effect of 80 years of sediment accumulation has been quantified as a reduction of approximately 6 percent of total usable storage capacity in the upper 12 feet of the reservoir (typical drawdown of the reservoir).

Overall, changes in land use within the basin have had an effect on the input of sediment to the Yadkin-Pee Dee River and on the amount of sediment deposited in the Yadkin Project reservoirs. Although the decrease in cropland in the basin has resulted in a decline in sediment transport in the river, continued land development may represent a growing source of sediment. Only with the continued basinwide implementation and enforcement of appropriate BMPs and stormwater regulations will the input, transport and deposition of sediment in the Yadkin Basin continue to decline. Ultimately, the benefits of these actions will include the improvement of water quality and aquatic habitat in the basins waters.

1 INTRODUCTION

Through its Yadkin Division, Alcoa Power Generating Inc. (APGI), a wholly owned subsidiary of Alcoa Inc., has begun the process of preparing for the relicensing of the Yadkin Hydroelectric Project (FERC Project Number 2197), located on the Yadkin River in North Carolina. The watershed area above the lowest dam in the Project encompasses 4,190 square miles. This river is a part of the larger Yadkin - Pee Dee River Basin that extends from the eastern slopes of the Blue Ridge Mountains to the Atlantic coast. As part of this effort, APGI is collecting baseline information on resources at the Yadkin Project.

The Yadkin Project consists of a series of four reservoirs, dams, and powerhouses. From upstream to downstream the Project includes, High Rock Reservoir, Tuckertown Reservoir, Narrows Reservoir and Falls Reservoir (Figure 1 in Section 7). The High Rock Reservoir covers approximately 15,180 acres, has a shoreline length of 360 miles and is the largest of the four reservoirs. Tuckertown Reservoir covers 2,560 acres and has a shoreline length of 75 miles. Narrows Reservoir covers 5,355 acres and has a shoreline length of 115 miles. Falls Reservoir, the smallest of the four reservoirs covers 204 acres and has a shoreline length of 6 miles. Both High Rock and Narrows reservoirs and to a lesser extent Tuckertown are highly dissected with numerous side channels and bays. Forest and residential land uses dominate the shorelines of High Rock and Narrows reservoirs while the shoreline zone of Tuckertown and Falls reservoirs is mostly undeveloped and forested.

The Yadkin-Pee Dee River basin upstream of the Project is a significant source of sediment to the Project waters which can result in significant issues to water users throughout the river basin.

This report presents the information that is currently available on sediment fate and transport in the Yadkin-Pee Dee River basin. The information presented herein originates from two sources. First, a literature search was performed to identify the body of research completed in this area, and the studies are summarized in Section 3 of this report. In addition, survey data collected throughout the history of the Yadkin Project is presented in Section 4 to illustrate the changes in topography and bathymetry that have occurred since the Project was constructed. Finally, in Section 5 the collected body of information is used to meet, to the extent possible, the following objectives identified in the Final Study Plan:

- identify the sources, estimate the current sediment load, and determine the physical characteristics of the sediments transported to and through the Yadkin Project reservoirs;
- estimate the volume of sediment trapped in the reservoirs and the deposition patterns; and
- evaluate the fate and transport qualitatively under existing and potential future operating scenarios.

2 LITERATURE REVIEW APPROACH

2.1 PURPOSE

The purpose of this review is to provide a summary of existing literature on erosion, sediment transport and sedimentation in parts of the Yadkin – Pee Dee River basin. The results of this literature review will form the basis for an assessment of the impacts of Project operations on sediment transport into and through the Yadkin Project system.

2.2 SOURCES OF INFORMATION

Using publicly available information, a literature search on erosion, sediment transport and sedimentation in the Yadkin-Pee Dee River system was performed using GeoRef. GeoRef is a searchable electronic database that is maintained by the American Geological Institute (AGI). According to the AGI, GeoRef is the most comprehensive database of bibliographic information in the geosciences. This list of publications was supplemented by other publicly-available information and documents. Of particular interest to this study are reports of investigations performed by the U.S. Geological Survey (USGS), the North Carolina Department of Environment and Natural Resources (NCDENR) and research performed by Duke University. Additional information was provided by Dr. Daniel Richter of Duke University and copies of some of the publications were provided by Long View Associates.

The discussion of the literature reviewed is presented in chronological order so that the reader can follow the historical development of the erosion, sediment transport and sedimentation issues in parts of the Yadkin – Pee Dee River Basin and Yadkin Project over time. This approach allows for a critical review of the work performed and a means for following any trends in the research results. All of the publications cited in this review report are listed by author in the references (Section 6.0).

3 SEDIMENT TRANSPORT LITERATURE REVIEW

Comprehensive research on soil erosion and sediment transport on the Yadkin-Pee River began in 1970s and is continuing today. The initial research on sediment in the Yadkin-Pee Dee River was performed by the U.S. Department of Agriculture (USDA) in the late 1970s and was followed by several studies performed by the USGS in the 1980s. In the 1990s and early 2000s several investigations of erosion and sediment transport were performed by faculty and graduate students at Duke University. The results of these studies are summarized in the following sections. Any figures and tables referenced in this section are found at the end of this report in the appendices.

3.1 EROSION AND SEDIMENT INVENTORY SPECIAL REPORT

In 1979 the USDA published a "Special Report: Erosion and Sediment Inventory for the Yadkin-Pee Dee River Basin in North Carolina and South Carolina" (USDA 1979). This study represents the first comprehensive assessment of soil erosion, sediment transport and sedimentation in the Yadkin-Pee Dee River basin.

This study had multiple objectives, including the determination of the annual rates of soil erosion by source and land use, the transport of sediment through the drainage, its impact on water quality and on the major reservoirs located within the drainage basin. The overall approach used in this study was based on an agricultural and non-point pollution source study performed for the State of South Carolina. As noted in the report, seven hydrologic units of approximately 250,000 acres were selected to represent specific land resource areas in South Carolina. Two hydrologic units were selected in North Carolina. One of these (Unit 03-07-02) includes several counties found in the headwaters of the Yadkin Project. The total annual erosion for each source and land use was determined for each county or part of the county lying within the drainage basin. Annual erosion for each major sub basin was then extrapolated from the data and erosion rates were determined for each land resource area using similar methods.

The types of erosion evaluated were sheet and rill erosion, rural road associated erosion, urban and built-up erosion, gully and pit erosion and stream channel erosion. Wind erosion was not evaluated. The erosion rate for each of these was then estimated for each county in the drainage basin (refer to Table III in Appendix A) and compiled for each of the four Land Resource Areas (LRAs): Southern Piedmont, Georgia-Carolina Sand Hills, Southern Coastal Plain and Atlantic Coastal Flatwoods (refer to Table IV in Appendix A). The Yadkin Project is located within the Southern Piedmont LRA.

Sheet and rill erosion was estimated using the Universal Soil Loss Equation (USLE). A statistical sampling approach was used to estimate erosion within each of the hydrologic units. This sampling approach consisted of a random selected series of plots each containing 160 acres. Three points in each plot were sampled for land use and all factors in the soil loss equation. USDA technicians recorded data at approximately 600 points in each hydrologic unit. Land use was based on adjusted data of 1967 to make it current to April 1978. The data collected from all of the points were compiled for each hydrologic unit and the erosion rates were estimated for each land use, by county, in tons per acre per year.

The erosion associated with rural roads was also estimated based on a statistical sampling system. Each sampling point was considered as a 50 foot reach of road. The total mileage of each road type within the hydrologic unit was divided by the number of points sampled. The soil loss in tons per year was computed for each incremental length of road. At each sampling point the sum of the bank heights eroding, annual bank slope recession and volume weight of soil eroded was recorded. Since erosion would be greatest on dirt roads the width of the eroding roadbed was also recorded. The total annual erosion for each unit was then summarized for each road type.

Data were gathered for the hydrologic units by sampling points and observations to estimate erosion from urban and developed land. The average annual erosion rate from all sources by major land use type was estimated as: Piedmont - four tons per acre, Sand Hills and Coastal Plain - three tons per acre and Coastal Flatwoods one ton per acre. In this analysis it was assumed that approximately 50 percent of the urban and built-up area is covered by roof tops and concrete so the rate of erosion per acre was reduced by one half.

During the sheet and rill erosion survey USDA technicians collected erosion rate data on all significant gullies and pits encountered in each 160 acre sample plot. The erosion estimate was based on a measurement of the height of the bank and width of the eroding bed, length of the bank and eroding bed, annual recession of the bank and bed and of volume weight of the eroding soil in pounds per cubic foot. The total soil loss was then tabulated for all gullies and pits recorded in the hydrologic unit.

Stream channel erosion was estimated using information compiled for the Erosion and Sediment Inventory, Public Law 92-500, Section 208 reports for North and South Carolina. In North Carolina, two percent of the stream bank mileage was sampled for each county. In South Carolina, 1,000 foot sections of channel were sampled using a random pattern for each hydrologic unit. Technicians from both states determined if stream channel erosion was negligible, slight, moderate and/or severe based on the degree of bank recession. The average annual volume of soil eroded from stream channels was used to calculate an erosion rate in tons per mile and this was extrapolated along the drainage basin.

Estimates of sedimentation were made for the sub basins and the drainage areas of the major reservoirs found in the Yadkin-Pee Dee River basin. The gross annual erosion was calculated using the results of the erosion study. Average annual sediment yields were calculated using SCS engineering methods, which were not discussed. The average annual sediment concentrations were determined for points of interest using the calculated sediment available for transport above the point and the annual runoff flow for the drainage area.

Estimates of Soil Erosion

The erosion study results are summarized in Tables III through IV and in Figure II (in Appendix A). The estimated sheet and rill erosion for each of the major land use types varied in the Southern Piedmont, but was the highest when compared with the results for the Georgia-Carolina Sand Hills, Southern Coastal Plain and Atlantic Coastal Flatwood LRAs. Within the land use types, the estimated sheet and rill erosion was highest for cropland (10.7 tons per acre per year) while it was the lowest for forest land. The high sheet and rill erosion values for cropland reflect the erosiveness of the soils in this region, the land use management and the large amount of land used as cropland in this hydrologic unit.

The estimated erosion associated with rural roads was highest for the Southern Piedmont LRA. This value was 221 tons per mile per year. The estimated erosion associated with urban and built up land was also highest for the Southern Piedmont LRA. This value was 2.0 tons per acre per year.

The estimated gully and pit erosion for the Southern Piedmont LRA was 897.4 tons per mile per year. When compared with the three other LRAs this value was the less than Georgia-Carolina Sand Hills and the Southern Coastal Plain, but higher than the Atlantic Coastal Flatwoods. No explanation is provided in the report as to why the Georgia-Carolina Sand Hills have the highest gully and pit erosion rate.

For the four LRAs, the Southern Piedmont had the highest estimated stream channel erosion, 22.5 tons per year (Table IV in Appendix A). The estimated stream channel erosion decreased downstream and probably reflects a transition from higher gradient channels and drainages with moderate relief to an area having low gradient channels and drainages with low relief.

Overall, the SCS (1979) estimated that approximately 25,500,000 tons of soil is lost annually from all sources within the Yadkin-Pee Dee River Basin by erosion. Seventy four percent of this material originates in North Carolina, while 26 percent originates in South Carolina. Individual sources of erosion, ranked from highest to lowest were: 69 % cropland, 19 % rural road, 4 % urban and built up land, 4 % forest land, 2 % other land, 1 % pasture and hay land, 1 % stream channel and minor amounts from gully and pits.

When ranked by LRA, the areas having the highest to lowest estimated erosion were: Southern Piedmont, Georgia-Carolina Sand Hills, Southern Coastal Plain and the Atlantic Coastal Flatwoods. Since the Yadkin Project is located in the Southern Piedmont LRA, its drainages are experiencing the highest amounts of erosion in the Yadkin-Pee Dee drainage basin. Annual erosion rates in the Southern Piedmont LRA are roughly 85 % higher than the Georgia-Carolina Sand Hills, 180 % higher than the Southern Coastal Plain and 360 % higher than the Atlantic Coastal Plain (Table IV in Appendix A).

The average annual erosion rates for all sources is presented in Figure 11 in Appendix A. This figure clearly shows that the counties within the upper Yadkin River have the highest average annual erosion rates. In reviewing the data presented in Table III (Appendix A), which presents the gross erosion by land use, it is evident that the highest erosion rates are associated with croplands and rural roads. Due to the large amount of cropland and rural roads found within the counties in the upper Yadkin River, the estimated erosion rates are also high in these areas.

The report does note that “streams in the Piedmont Major Land Resource Area (MLRA) have the highest suspended sediment concentrations in the basin. This is due to its higher rates of erosion, swifter streams and higher content of silt and clay particles in the soil.” As noted in the report, the factors affecting sediment concentrations are the amount and the grain size of the material to be transported, the transport capacity of the stream and obstructions located in the stream. Reservoirs trap all of the material too large to be transported in suspension, which approximately equates to the bedload. Varying amounts of the suspended sediment are also trapped depending on the material size, reservoir capacity and stream inflow.

Estimates of Sedimentation

In the report, the gross erosion (tons/year) was estimated for each of the sub basins along the Yadkin-Pee Dee River (Table V in Appendix A). These included estimates for High Rock Reservoir, Tuckertown Reservoir, Narrows Reservoir and Falls Reservoir. These estimates were then used to calculate the annual sediment accumulation and annual capacity loss for the major impoundments in the drainage basin (Table VI in Appendix A). Lastly, the total sediment, bedload, suspended sediment and average suspended sediment concentration for selected points along the Yadkin-Pee Dee River were estimated (Table VII in Appendix A).

For the study area, the estimated annual sediment accumulation and annual capacity loss was:

Reservoir	Annual Sediment Accumulation	Annual Capacity Loss
High Rock	903 ac. ft.	0.36%
Tuckertown	86	0.20
Narrows	131	0.05
Falls	14	0.23

As shown in this table, High Rock has the highest annual sediment accumulation volume, which would be expected since it is the first reservoir on the Yadkin-Pee Dee River. Lower values are observed for the three downstream reservoirs. Due to the deposition of sediment in the Yadkin Project reservoirs, the estimated amount of sedimentation and average suspended sediment concentration decreases as you go downstream.

3.2 SEDIMENT CHARACTERISTICS OF NORTH CAROLINA STREAMS 1970-1979

Although published in 1993, this report by Clyde Simmons of the USGS provides a detailed analysis of erosion, sediment transport and sedimentation for North Carolina streams (including the Yadkin-Pee Dee River) for the period of 1970-1979. This report expands on the results of an earlier examination of the water-quality characteristics of streams in forested and rural areas of North Carolina by Simmons and Heath (1979 and 1982).

This report is based upon the analysis of sediment concentration data collected from a statewide monitoring network for the period of 1970 to 1979. A total of 152 stations were included in the analysis. The stations were grouped by physiographic province which included the Blue Ridge, Piedmont and the Coastal Plain (Figure 1 in Appendix B). The objectives of this study included; 1) an analysis of the effect of land use on characteristics of suspended-sediment transport, 2) a comparison of suspended sediment transport with selected basin characteristics and 3) the development of mathematical relations for estimating suspended-sediment yield for unmeasured basins.

In his assessment of the effects of land use on the characteristics of sediment transport, Simmons (1993) subdivided the sampling network into five classes:

- Forested basins representing background (pristine) conditions
- Forested basins having minor developments
- Rural basins affected by agriculture
- Rural basins heavily affected by nonagricultural activities
- Urban basins

For each of the classes Simmons (1993) calculated the estimated mean annual suspended-sediment discharge, the estimated mean annual suspended-sediment yield, maximum and minimum suspended-sediment concentration. He then evaluated the results within the classes, between classes and the physiographic provinces.

He then evaluated the relationship between several basin characteristics and suspended sediment. The basin characteristics examined included stream discharge, particle size, land use and gross erosion. This analysis was not based on a statistical comparison and is more of a qualitative assessment.

Lastly, Simmons (1993) developed equations for estimating suspended-sediment yield from rural and urban drainage basins. These equations were developed from a statistical analysis of selected drainage basin characteristics with suspended-sediment yield and suspended-sediment discharge. The basin characteristics examined included:

- Drainage area
- Channel slope
- Soil-infiltration ratio
- Average water discharge
- Percentage in forests
- Percentage in urban development
- Average percentage surface slope in basin
- Maximum observed stream velocity
- Rainfall factor
- Percentage of basin’s land area in row crops
- Water discharge for 2-year, 10-year and 25-year floods

The data were analyzed by multiple linear regressions using the Statistical Analysis System (SAS). To improve the reliability of the relationships Simmons (1993) developed the following guidelines:

- Drainage area should not exceed 400 sq. miles
- Individual analyses should be grouped by pre-dominant land-use category and soil class
- Basins containing major reservoirs and large-scale channelization should be omitted from analysis
- The independent variables that provide the highest correlation and smallest standard error of estimate were drainage area, average water discharge, 2-year flood and 10-year flood.
- Reliable predictive equations were possible for determining values of suspended-sediment discharge for specific land-use categories.
- Data in logarithmic format provided the best statistical results.

Additional statistical analyses were performed to compute correlation coefficients by soil class for rural-agricultural basins, by discriminant analysis and by least squares to fit general linear models.

Effects of Land Use on Characteristics of Sediment Transport

State wide the amount of sediment produced by a drainage basin is influenced by its extent of development and its physiographic setting. The highest estimated mean annual sediment yield was associated with urban land use (464 tons/ sq. mi) followed by rural with agricultural and nonagricultural land use (209 tons/sq. mi), rural with agricultural land use (174 tons/sq. mi), forested with minor development (132 tons/sq. mi) and forested (33 tons/sq. mi).

The forested drainage basins (seven total, none in the Yadkin Project basin) were selected as being representative of pristine or background conditions. Due to the high forest cover and limited ground disturbance, the principal source of sediment in these basins is thought to be the erosion of the stream channels and banks. Within this land use group the highest estimated sediment yields (44 tons/sq. mi) were in the Piedmont and Blue Ridge provinces, while the lowest (5.5 tons/sq. mi) were in the Coastal Plain. This difference is most likely due to the higher stream gradients in the Piedmont and Blue Ridge compared to the Coastal Plain. None of the forested drainage basins studied are located in the drainage of the Yadkin Project.

For those forested drainage basins (seven total, none in the Yadkin Project basin) with minor land development, unpaved roads and limited agricultural production the estimated sediment yield increases over the undisturbed forested condition. In these basins, the estimated sediment yield varied with physiographic province, with the Piedmont having the highest (178 tons/sq. mi) and the Coastal Plain having the lowest (60 tons/sq. mi). The difference in sediment yields by physiographic province and by land use (with or without minor development) is shown in Figure 11 (Appendix B).

Simmons (1993) also examined the sediment production from rural basins affected by agriculture and by a combination of agriculture and non-agricultural uses. He defined the rural basins as “those in which agricultural activities are the primary sources of fluvial sediments above background levels.” This is based on observations from field inspections that noted agricultural-type activities were the primary source of increased sediment loading to streams and rivers in these basins. A total of 83 basins were included in this group, 13 of which are located in the Yadkin Project drainage. By physiographic province the Piedmont drainages had the highest estimated sediment yield (239 tons/sq. mi) and the Coastal Plain drainages (29 tons/sq. mi) had the lowest. Simmons (1993) notes that the higher values for the Piedmont Province are most likely due to the location of the farmlands on floodplains. Due to the hilly nature of the Piedmont, most agricultural development has occurred on the floodplain in the valley bottoms. This concentration of farmland along streams and rivers has significantly decreased the transport distance between the source area and receiving area for sediment produced by farming.

For the rural basins affected by agriculture, Simmons (1993) shows the average annual suspended-sediment yield and average-sediment concentration for the major drainages in North Carolina in Figure 16 (Appendix B). Relative to the Yadkin Project this figure shows that the average suspended- sediment yield, for drainages 400 sq. miles or less, in the Upper Pee Dee River (Yadkin River) are the highest in the state. These high values reflect the erosivity of the soils, the relief in this physiographic province (Piedmont), the gradient of the streams and the impact of agricultural land use practices.

An additional 38 rural basins (two in the Yadkin Project basin) were evaluated where they had been affected by nonagricultural activities. These activities included highway construction, large-scale site development, urbanization and the presence of reservoirs. An increase in suspended sediment would be expected at development and highway construction sites in response to the removal of protected vegetations and the disturbance of erodable soils. For reservoirs, their impact would be the reduction of suspended sediment since they act as sediment traps.

Statewide the mean annual suspended sediment yield for the rural basins affected by nonagricultural activities was 209 tons/ sq. mi. By physiographic province it ranged from 302 tons/sq. mi. (Piedmont) to 64 tons/sq. mi. (Coastal Plain). A major influence on suspended sediment concentrations in these drainages is the presence of dams. As noted by Simmons (1993) sediment transport in 10 of the basins is affected by the trapping effects of upstream reservoirs. The inflow and storage characteristics for the reservoirs and their estimated trap efficiencies are summarized in Table 9 (Appendix B). Three of the basins are located in the Piedmont Province with the Yadkin-Pee Dee River being one of them. At these three basins the estimated mean annual suspended-sediment yield ranges from 12 tons/sq. mi. (Roanoke River at Roanoke Rapids) to 99 tons/sq. mi. (Reedy Fork near Gibsonville), which are well below the average of 302 tons/sq. mi. for the Piedmont. These low values reflect the storage of sediment in reservoirs upstream of these gaging stations.

A total of 17 basins (three in the Yadkin Project basin) were categorized as being urban. Two of the basins were located in the Coastal Province, 15 basins were located in the Piedmont Province and one basin was located in the Blue Ridge Province. In the urban basins land-use activities directly related to urban and municipal development are probably the primary sources of fluvial sediment (Simmons 1993). Increased sediment yield in these basins can result from the disturbance of erodable soils and the increased runoff from impervious surfaces, which increases flood flows and channel erosion.

The estimated mean annual suspended-sediment yield for the urban basins was highest in the Piedmont Province (515 tons/sq. mi) and lowest in the Coastal Plain Province (76.5 tons/sq. mi). The highest estimated value (1,500 tons/sq. mi) was for Irwin Creek, which flows through Charlotte (Figure 20 in Appendix B). For the Yadkin Project basin, estimates were made for Salem Creek, Muddy Creek and the South Fork of Muddy Creek, all of which originate in the Winston-Salem metropolitan area. These values ranged from 470 tons/sq. mi. for South Fork Muddy Creek to 410 tons/sq. mi. for Salem Creek, which are lower that the average for the Piedmont, but still an order of magnitude higher than those estimated for the Coastal Plain (Figure 20 in Appendix B).

Comparisons of Suspended-Sediment Transport Characteristics with Selected Basin Characteristics

Simmons (1993) discusses the relationship between suspended-sediment transport with selected basin characteristics such as stream discharge, suspended-sediment particle size, land use, the effects of stream-slope change across the Fall Line and gross erosion. Since the project area is above the Fall Line - the boundary between the Piedmont and the Coastal Plain physiographic provinces - his findings on this subject are not discussed in this review.

The relationship between stream discharge and suspended-sediment transport is illustrated by a graph of streamflow and suspended-sediment for the Yadkin River at Yadkin College (Figure 21 in Appendix B). This figure clearly shows that the concentration of suspended sediment increases with increasing streamflow. Simmons (1993) notes that in 80 percent of the basins studied the highest concentration of suspended sediment occurs immediately prior to maximum flow.

Simmons (1993) also evaluated the percentage of time required for suspended sediment transport. As summarized in Table 12 (Appendix B), for the three stations (numbers 78, 81 and 93) located in the Yadkin Project drainage basin, 50 percent of the sediment is transported during flows that occurred between 0.4 and 2.6 percent of the time during 1970 and 1979. For example, for the Yadkin River in Elkin, 50 percent of the suspended sediment was transported by flows that represented 2.4 percent of the total flow from 1970-1979. These data support the view that the greatest amount of suspended sediment is transported during high flow events.

The suspended-sediment data were also examined to determine the grain-size distribution of this material. Simmons (1993) reports that the median grain size varied with physiographic province. The coarsest material (silt/sand) was found in the Blue Ridge, followed by clay/silt in the Piedmont and clay in the Coastal Plain. This distribution reflects both the source area and the average stream gradient/velocity. For the Piedmont, this province is transitional between the Blue Ridge (high relief and gradient) and the Coastal Plain (low relief and gradient). The Piedmont is also underlain by bedrock that weathers into silty/clay soil, so the median grain-size would be expected to be small. This soil texture is also highly erosive and can be readily transported by flowing water.

Using the suspended-sediment data, Simmons (1993) estimated the suspended-sediment discharge and sediment delivery ratio (SDR) for selected rural drainages (Table 16 in Appendix B). The SDR was calculated by dividing the annual suspended-sediment by gross erosion. The gross erosion data were obtained from the USDA Soil Conservation Service (now NRCS). The sediment-delivery ratio provides an estimate of the amount of sediment that is actually transported as sediment from the basin. Three of the selected drainages are located in the Yadkin Project basin including the Yadkin River at Patterson and at Elkin and Leonard Creek near Bethesda. The estimated SDR for these basins ranged from 0.15 to 0.37 which is in the range for the Piedmont basins.

Estimated Sediment Transport from Basins

Simmons (1993) developed regression equations for the estimation of annual suspended-sediment discharge for rural and urban basins. He found that the strongest statistical relationships were obtained when the data were grouped by soil class. Since the type of soil present in a drainage basin is one of the principal controls of soil erosion this approach was logical. For the rural basins he found that the best single variable for estimating annual suspended-sediment discharge was drainage basin area (refer to table 18 in Appendix B). He also developed regression equations using the best three variables, which included drainage basin area, average water discharge and the percentage of basin’s land in row crops. The use of these three variables increased the coefficient of determination (R^2) for each of the soil classes evaluated. For the urban basins he presents only one equation, based on drainage basin area, and that was for the soils found in the Piedmont Province. Several of these equations could be used to estimate the annual suspended-sediment discharge for rural and urban drainages located in the Yadkin Project basin. For the rural basins, however, these relationships have been recently revised (Calvo-Alvarado and Gregory 1997).

3.3 SOURCES, SINKS, AND STORAGE OF RIVER SEDIMENT IN THE ATLANTIC DRAINAGE OF THE UNITED STATES

In 1982, Robert Meade of the USGS published a comprehensive review article on the difficulty of predicting sediment movement on a river-basin scale (Meade 1982). In this article the author states that “the modeling of sediment movement on a river-basin scale is in a primitive state.” The prediction of sediment transport is difficult because of the numerous sources and sinks that are found within the drainages and the time scale that is used in any assessment. The factor of time complicates the ability to predict sediment transport because there can be a considerable lag from when the sediment is initially produced and when it reaches a stream to when it is transported through the system. He notes that "on a millennial or longer time scale, eroded upland soil may be the original source of sediment and the coastal zone may be the ultimate sink. At shorter time scales, the most important sources and sinks are the storage sites along the way between the uplands and the estuaries. The sediment moves in and out of storage in ways that we are not yet able to predict."

Meade reviewed existing information on erosion, sediment transport and sedimentation for the drainages located along the Atlantic coastline. His analysis was based on a review of academic and government research reports.

Meade outlined the difficulty of trying to predict the movement within a drainage basin. The major challenges to this undertaking is the lag between when erosion occurs and when it becomes transported by streams and rivers and the numerous in stream sources and sinks (storage) for sediment. In his paper he discussed the major sources of sediment and how they have changed over time, the major in stream sources and sinks of sediment, including the effects of reservoirs on sediment transport and lastly on how the coastal zone is the ultimate sediment sink.

In his discussion of the relationship between streamflow and sediment transport, Meade compares the discharge and sediment concentrations of the Yadkin-Pee Dee River with the Juniata River in PA, the Merrimack River in MA, and the Edisto River in SC. What differentiates the Yadkin-Pee Dee River from the others is the magnitude of sediment transported. The suspended sediment concentrations on the Yadkin-Pee Dee River were an order of magnitude higher than the three other drainages when measured at the same discharge (Figure 2 in Appendix C). He notes that "because of these consistently high concentrations, the sediment yields from the Piedmont are consistently the highest per unit area of any physiographic province on the Atlantic slope."

The original source of the sediment transported in the Atlantic drainages is soil erosion. He notes that land use within the drainages has contributed to soil erosion and that land use changes over time. The results of research by Trimble (1974) showed that intense crop farming in the Piedmont region contributed to excessive erosion. Other contributing factors to this erosion were the steep hillsides and the deep soils found in this region.

Meade also notes that that soil erosion in the southern Piedmont was recognized as a serious problem as by 1860, but that it most likely reached its peak by 1920 and has been declining in the last 50 years. He credits the implementation of soil-conservation practices in the 1930s as a contributing factor in the reduction of sediment yields. More importantly he notes that the decrease in farming, by about a third since the end of World War II, in North Carolina may be a more significant factor.

A significant sink for sediment in a drainage system are reservoirs. Even moderately sized reservoirs can trap large amounts of sediment. Based on a relationship between the storage capacity of reservoir and its drainage area (the capacity watershed ratio) developed by Brune (1953), Meade states that "a reservoir that is only large enough to hold one hundredth of the water that flows into to it can trap half the sediment that flows into its upper end. A reservoir that can retain a tenth of the annual water inflow can trap 80 to 90% of the inflowing sediment." Although Meade did not look at the Yadkin-Pee Dee River, he did present two examples. These included the Roanoke River at Scotland Neck, North Carolina (Kerr Reservoir) and the Santee River in South Carolina (Lake Marion and Lake Moultrie). At both of these locations the existing reservoirs effectively trap about 90% of the sediment flowing down the rivers. Thus, these facilities represent a significant sink for sediment being transported through their respective drainage basins.

3.4 WATER QUALITY OF THE YADKIN-PEE DEE RIVER SYSTEM, NORTH CAROLINA-VARIABILITY, POLLUTION LOADS AND LONG-TERM TRENDS

Douglas Harned and Dann Meyer of the USGS reported the results of their review of the water quality of the Yadkin-Pee Dee River in 1983 (Harned and Meyer 1983). The objectives of this study was to define the variation in water quality in the Yadkin-Pee Dee River basin, determine the pollutant load and determine any trends water quality. The report provides a comprehensive assessment of water quality conditions of the Yadkin-Pee Dee River up to the early 1980s. Relative to the Yadkin Project only the suspended sediment and turbidity sections of the report were reviewed.

Relative to sediment, Harned and Meyer (1983) looked at suspended sediment and turbidity in the Yadkin-Pee Dee River drainage. Their evaluation examined streamflow and suspended sediment data available from four monitoring stations: Yadkin River at Yadkin College, South Yadkin River near Mocksville, Rocky River near Norwood and the Pee Dee River near Rockingham. The Yadkin College station is located upstream of the Yadkin Project and data from this gage is representative of inflow sediment load. The South Yadkin River discharges into the Yadkin River upstream of High Rock Reservoir and represents a major tributary. The Rocky River is a tributary to the Yadkin Pee Dee River downstream of Tillery and thus, is located downstream of the Yadkin Project. The USGS gage in Rockingham, North Carolina is located downstream of the Yadkin Project and would represent the outflow from the dams. This gage would also include the effects of the Tillery Dam and the Blewett Falls dams, which are below the Yadkin Project (High Rock, Tuckertown, Narrows and Falls dams). A summary of the suspended sediment and turbidity data is presented in Table 2 (Appendix D).

As noted by Harned and Meyer (1983), little turbidity data are available for the Yadkin College and Norwood gaging stations, but the data are more complete for the Rockingham gage. Because these are the same gages that the suspended sediment data are taken from the same area is covered.

In their analysis of the suspended sediment data Harned and Meyer (1983) plotted the suspended sediment concentration and discharge data on log-log paper for three of the stations: Yadkin College, Rocky River, and Rockingham. A linear regression analysis was then performed to determine the statistical relationship between these variables. The suspended sediment data were then used to estimate the annual sediment transport at the four gaging stations for the period of 1974-1978. The suspended sediment load data were then used to calculate sediment volumes transported by the Yadkin-Pee Dee River.

The number of turbidity samples available for analysis ranged from two at the Rocky River gage in Norwood to 49 at the gage in Rockingham. Due to the limited amount of data no quantitative analysis was performed other than the basic statistics of mean and range.

As mentioned, Harned and Meyer (1983) developed linear regression equations for suspended sediment and discharge for the Yadkin River, the Rocky River and the Pee Dee River. The r values for these equations ranged from 0.56 for the Pee Dee River to 0.89 for the Rocky River. Results for the South Yadkin River at Mocksville were not discussed.

On the Yadkin River at Yadkin College and on the Pee Dee River at Rockingham the relationship between suspended sediment and discharge showed some interesting characteristics. For the Yadkin River, the concentration of suspended sediment plateaus at discharges above 7,500 cfs (Figure 9 in Appendix D). The authors believe that this suggests that the sediment supply potential has been almost reached. For the Pee Dee River, two clusters of data are observed, one at low discharge (300-1,000 cfs) and one at high discharge (7,000-30,000 cfs) (Figure 10 in Appendix D). The authors suggest that this clustering may be the result of flow regulation.

For the period of 1974 to 1978, the authors estimated the total annual load of suspended sediment in the Yadkin River (Yadkin College), South Yadkin River (Mocksville), Rocky River (Norwood) and Pee Dee River (Rockingham). They note that with the exception of the Pee Dee River the total sediment transport is roughly proportional to drainage area, with sediment yield greatest at Yadkin College and least at Rockingham (Table 3 in Appendix D). They also note that their estimates should be interpreted as minimum values because the sediment transported into the reservoirs hasn't been taken into account and bedload has not been estimated.

These data show that the suspended sediment input at Yadkin College is not matched by the suspended sediment output at Rockingham. This difference represents the amount of sediment deposited in the reservoirs. The authors estimate that approximately 1 million tons of sediment per year is deposited into the reservoirs by the three streams (Table 3 in Appendix D). This represents about 800 ac-ft/year or roughly 0.10 percent of the total volume of the reservoirs. Between 68 and 92 percent of this sediment is derived from the upper Yadkin River and the South Yadkin River, both of which drain into High Rock Reservoir. Thus, this reservoir is the most heavily loaded in the series of impoundments. Lastly, they note that about 27 percent of the sediment that enters the reservoir system is transported past the Rockingham station, so it can be concluded that the Yadkin-Pee Dee reservoirs capture at least 73 percent of the sediment that enters them.

The authors also compare their results with those presented by the SCS in 1979. The estimates by Harned and Meyer (1983) are lower than those reported by the SCS. They explain that this difference is due to the methods employed. The SCS performed an analysis of soil, erosion and land-use information to estimate erosion rates and amounts, while Harned and Meyer's (1983) study was based on the results of water quality samples, which would give a more reliable estimate of actual erosion, sediment transport and sedimentation on the Yadkin-Pee Dee River.

3.5 A SUSPENDED SEDIMENT BUDGET FOR SIX RIVER IMPOUNDMENTS ON THE YADKIN-PEE DEE RIVER

In 1993, Van Fischer, in partial fulfillment of the requirements for the Master of Environmental Management degree in the School of the Environmental at Duke University presented his Master's Project titled "A Suspended Sediment Budget for Six River Impoundments on the Yadkin-Pee Dee River" (Fischer 1993). The objective of his study was to extend the data analysis presented in Harned and Meyer's report (USGS 1983) on the water quality of the Yadkin-Pee Dee River and to estimate sediment transported during the fifteen year period of 1974 to 1988. In addition, the study presented a means to estimate the rate of sediment deposition and the rate at which the Yadkin-Pee Dee River reservoirs are filling with sediment.

Fischer (1993) based his study on streamflow and sediment concentration data taken from four gaging stations on the Yadkin-Pee Dee River. These gages included the Yadkin River at Yadkin College, South Yadkin River near Mocksville, Rocky River near Norwood and the Pee Dee River near Rockingham. The data collected at the Yadkin College station represents the inflow from the upper portion of the drainage basin. The South Yadkin River discharges into the Yadkin River upstream of High Rock Reservoir and represents its major tributary. The Rocky River is a tributary to the Yadkin-Pee Dee River downstream of Tillery and as a result is located downstream of the Yadkin Project. The USGS gage in Rockingham, North Carolina is located downstream of the Yadkin Project and represents the outflow of the Yadkin Project dams and the two dams (Tillery and Blewett Falls) located downstream.

The length of record and frequency of measurement of stream flow and sediment concentration varied at the sites:

Station	Record	Frequency
Yadkin College	1951 to 1988	Daily
Mocksville	1958 to 1968	Daily
Norwood	1976 to 1991	64 total
Rockingham	1976 to 1991	108 total

Fischer used a least squares regression analysis to estimate the daily suspended sediment yield at three of the four stations. This analysis was based on the relationship between suspended sediment concentrations and streamflow. For the Yadkin College gage, the daily streamflow and suspended sediment concentration measurements were used directly. To improve the regression for the Mocksville data set, Fischer divided the data into two seasonal periods: October to April (winter) and May to September (fall). The Norwood and Rockingham gages had relatively small data sets and they were not subdivided into seasons. For these three stations the suspended sediment and discharge values were log transformed and a linear regression analysis performed.

The Yadkin College data provided the best estimate of annual suspended sediment load for the years 1974 to 1988. He credits this to the availability of daily measurements, which minimized the error inherent in the regression analysis. Using these data he calculated that the mean suspended sediment yield for the Yadkin River at the Yadkin College station was 805,370 metric tons (887,754 tons) a year or 12,080,570 metric tons (13,316,325 tons) for the 15 year period. The drainage basin area above the Yadkin College gage is 5,905 sq. km. (2,280 sq. mi.), so on a unit area basis the sediment yield for the Yadkin River upstream of the impoundments is 136.4 metric tons/sq. km/year (389.4 tons/sq. mi./yr).

For the Mocksville, Norwood and Rockingham gages, Fischer's estimated suspended sediment yields were based on linear regressions on log transformed suspended sediment and discharge values. Based on this analysis he presented the following results:

Station	Sediment Load	Total Sediment Load (15 Years)
Mocksville	96,770 mt/yr	1,451,600 mt
Norwood	198,020 mt/yr	2,970,330 mt
Rockingham	419,760 mt/yr	6,296,360 mt

mt = metric tons

The cumulative flow measured at Yadkin College, Mocksville and Norwood only represents approximately 58 percent of the flow measured at the Rockingham gage. Mean discharge at these combined gages is 137 cu. m/sec (4,837 cu. ft./sec.) and the mean discharge at Rockingham over the 15 year period was 237 cu. m/sec. (8,369 cu. ft./sec), which leaves a deficit of 100 cu. m/sec (3,531 cu. ft./sec). This deficit represents the flow contributed by the Uwharrie and Little Rivers and numerous tributaries that aren't gaged. To estimate the sediment contributed by these tributaries he used an estimate of 105 mt/yr (115.7 tons) made by Simmons (1988) and he also summed the yield of Yadkin College, Mocksville and Norwood basins and divided by the drainage basin area for an estimated yield of 107 mt/yr (117.9 tons). So the missing sediment falls in the range of 790,020 (1,856,269 tons/sq.

mi./yr) to 805,070 mt/sq. km/yr (1,891,631 tons/sq.mi./yr) with an average of 797,550 mt/sq. km/year (1,873,962 tons/sq. mi./yr).

In reviewing the 15 year period of record Fischer (1993) notes that the annual suspended sediment yields varies from year to year. He concluded that this variation was due to "annual variations in the hydrologic cycle (precipitation)." No trend analysis or comparison with land use change was performed.

Fischer (1993) notes that in comparing the results for the Yadkin College and Rockingham gages that a large amount of the sediment is captured by the six impoundments. He estimates that the total of all suspended sediment inputs is approximately 1,897,710 mt/yr (2,091,832 tons) from 1974 to 1988 and that sediment discharge from the reservoirs at Rockingham was about 419,760 mt/yr (462,698 tons). Thus, net throughflow, approximately 1,480,210 mt (1,631,624 tons) of sediment, or 78% of input is deposited in the reservoirs on an annual basis.

He also estimated the amount of deposition in the reservoirs and the amount of time that it will take to fill the live portions of the reservoirs. Based on an estimated density of 1.165 mt/cu. m. (72.7 lbs/cu. ft) he estimated the volume of sediment deposited into the six reservoirs (total) for a year. Using this assumed density, the 1,480,210 mt/yr (1,631,625 tons) converts to 1,270,570 cu. m./yr (44,864,760 cu. ft/yr) of deposition. He then divided this value into the total volume of the reservoirs, 675 million cu. m.(23,834,745,763 cu. ft), to estimate the number of years that it would take to fill them. As a result, Fischer estimated that it would take 530 years to fill the reservoirs located on the Yadkin-Pee Dee River.

Fischer (1993) notes that his estimates should be considered conservative (low end of the range) since there are no data for bedload. He explains that bedload can account for 20 to 40 percent of the total sediment load in most drainages. Using an average value of 30 percent, he estimates that an additional 570,000 mt/year (628,307 tons) of sediment would discharge into the reservoirs. So the total sediment being retained by the reservoirs would be about 2,500,000 mt/yr (2,755,731 tons) or 85 percent of the total load.

3.6 DECREASES IN YADKIN RIVER BASIN SEDIMENTATION: STATISTICAL AND GEOGRAPHIC TIME-TREND ANALYSES, 1951 TO 1990

In 1995, Daniel Richter and Karl Korfmacher along with Robert Nau of Duke University published the findings of a comprehensive assessment of sedimentation in the Yadkin River basin for the period of 1951 to 1990 (Richter and others 1995)

The objective of this study was to evaluate 40-year time trends in sediment transport by the Yadkin River in North Carolina during a period in which this river basin was rapidly shifting from being dominated by agricultural uses to one with a mixture of land uses, including additional areas of low erosivity forest and pasture, and high erosivity urban and suburban development. The research tested the hypothesis that the transport of river sediment has decreased over the past 40 years.

This study had several tasks including; an analysis of 19th and 20th century land use changes, the development of a GIS Database, the estimation of gross soil erosion and the statistical and time trend analysis of the Yadkin River suspended sediment data collected at the USGS gaging station in Yadkin College, North Carolina.

Land Use Analysis

The analysis of land use change was performed on two different data sets. The first data sets examined were the USDA Forest Service Inventories for 1937-1990. Six different data inventories during this time period were reviewed to determine the change in four different land cover types: row crops, pasture, forest and urban-suburban. The second data sets examined were 20 US Department of Commerce Agricultural Censuses from 1870 to 1987 for the four major counties (Forsyth, Surry, Wilkes and Yadkin) in the basin. The emphasis in this review was documenting the change in the four major crops (corn, tobacco, wheat and soybeans) grown in these counties over time.

GIS Database

A GIS database was developed to perform the land-use trend analysis and to estimate gross erosion within the study area. The database was developed using information available at scales of 1:24,000 (1955 and 1988), 1:100,000 (1975) and 1:250,000 (1975). Base coverages created for the GIS analysis included:

Coverage	1;24,000	1;100,000	1:250,000
DEM	■		■
Slope	■		■
Aspect	■		■
Hydrology		■	
Watershed Boundary	■		■
General Soils			■
Roads	■	■	
Detailed Soils	■		
Land use-land cover	■		■

Datasets for each of the coverages were compiled using the best available information, typically from the 1:24,000 and 1:250,000 scale sources.

Using the 1:250,000 scale database a stratified image based on elevation, slope and proximity to rivers and streams was created. From this stratified image, 185 sampling points were randomly selected. Around each point a one sq. km. area was created and used as the sample area.

Gross Erosion Analysis of Rural Basin Areas

An analysis of gross erosion was performed to provide estimates of spatial changes in sediment sources and volume over time. Estimates of gross erosion were made at two scales. For 1975, the gross erosion estimates were made at a scale of 1:250,000 for the complete basin, while for the 1950s and late 1980s the estimates were made using the 185 sq. kilometer sample areas within the basin.

To estimate gross erosion the Universal Soil Loss Equation (USLE) was used. USLE can be mathematically expressed as:

$$A = R * K * LS * C * P$$

Where:

A = gross erosion from sheet and rill erosion

R = a measure of rainfall intensity

K = a soil erodibility factor

LS= combined length and steepness of slope

C = vegetative cover factor

P = conservation practice adjustment

The rainfall intensity was estimated using either long-term county R factors obtained from the USDA NRCS or a seasonally variable R factor derived from daily precipitation records. The K factors for the general soil coverage were calculated based on the distribution of the soils making up a given soil association in the STATSGO (State Soil Geographic) database. Individual K factors were taken from the USDA NRCS USLE Handbook and used to estimate area-weighted average K factors for soil associations. The LS factors were estimated from basin slope coverage data or calculated for each of the 185 sample areas. The C factors for various land use-land cover classes were assigned based on information provided from several NRCS district conservationists based in the study area. The P value was assumed to be equal to a value of one due to the lack of data for the 1955 database and the inability to detect any changes in conservation practices from aerial photography. The C-factors estimates were provided by county NRCS conservationists.

Statistical and Time Trend Analysis of Suspended Sediment Data

Daily suspended sediment data was obtained from the USGS for the gaging station located at Yadkin College for the period of 1951 to 1970. Statistical analyses performed on this data included: arithmetic means, discharge-weighted means, medians and frequency analyses. Analyses on transformed and untransformed data using daily, monthly and annual compilations of discharge, sediment concentration and sediment transport.

Several different approaches were used to evaluate the time trends of sediment transport over the 40-year record. These statistical methods included: the non-parametric Mann-Kendall tests of no trend used to test residuals that had low serial correlation; non-parametric seasonal Kendall tests were used for data with skewed distributions, seasonality and serial dependence; and confidence intervals of monotonic trends.

Changing Land Use in the Yadkin River Basin

The change in land use in the Yadkin River Basin was evaluated using USDA Forest Service Inventories (1937-1987) and USDC Agricultural Census (1870-1987). The results of the analysis of the Forest Service data are shown in Figure 5 (Appendix E). The most notable changes are the decreases in rowcrop land since the 1930s, from around 45 percent to 18 percent of the land area and the increase in the urban and residential uses from about 5 percent to 18 percent in the North Carolina Piedmont over five decades. Also, smaller increases in forest and pasture land were evident in the basin since the late 1930s.

The USDC Agricultural Census provides more specific information on the change in agricultural land use. The authors (Richter and others 1995) that the most significant trend is the reduction in the amount of land under cultivation. As shown in Figure 6 (Appendix E) the amount of cultivated land began to steady decline in the 1920s, with a short lived increase in the 1970s and 1980s. Since the 1920s the amount of cropland used for wheat, tobacco and corn production have significantly declined, while the amount of land used for soybean production increased and then remained stable. For additional information on the change in agricultural land use since the 1920s refer to Table 5 (Appendix E).

The authors (Richter and others 1995) note that the decline in the amount of land used for agricultural production has also led to a decrease in gross soil erosion. They also remark that "the sources of sediment in the Yadkin River are not simply decreasing but are rather shifting from being largely a result of agricultural activities to being a result of a variety of human activities, increasingly associated with urban and suburban development.'

GIS Analysis of Land Use-Land Cover

The second approach to estimating the change in land use was a GIS analysis. The land use-land cover data for 1955, 1975 and 1988 were classified into four groups; urban, agriculture, forest, water and other. The agriculture class was the sum of harvested cropland, other cropland and cropland pastured and other pastureland. The results of the GIS analysis and the USDC Agricultural Census are summarized in Table 7 (Appendix E). The GIS results show that agricultural use declined by 4 percent (27.28 percent to 23.27 percent) from 1955 to 1988. Comparatively the USDC Agricultural Census indicates that the decline in agricultural land use was even greater roughly nine percent (27.50 percent to 18.12 percent). The GIS analysis also showed that the greatest change in agricultural land use was in cultivated cropland, with combined rowcrop and covercrop areas decreasing by 39 percent between 1955 and 1988.

Gross Soil Erosion Rates from Rural Basin Areas

Estimates of gross soil erosion rates were made based on information derived from 1:250,000 scale and the 1:24,000 map coverage. For the 1;250,000 scale map coverage erosion rates were estimated holding the basin R factor constant and by varying the R factor by county. Of the 18 strata classes analyzed only four had annual erosion rates at or above the 11.2 Mg per hectare per year (4.1 tons/ac/yr) NRCS upper limit of tolerable erosion loss.

The 1:24,000 map coverage data and rainfall based R factors were used to estimate gross erosion rates for the 1950s (1953 to 19570 and the 1980s (1986-1990). The results of this analysis showed that between the 1950s and 1980s that simulated gross erosion rates from rural lands decreased by 17 percent or from 14.4 to 11.9 Mg per hectare per year (5.3 to 4.4 tons/ac/yr). The primary factor in reducing the aggregate erosion rate across the basin was the decline in land under cultivation for row crops.

The authors (Richter and others 1995) also modeled the impact of the implementation of Best Management Practices (BMPs) on erosion. They note that since the late 1980s BMPs have been implemented on nearly all farms in the Yadkin River basin and that gross erosion rates have been dramatically reduced. To assess the potential reduction in gross erosion by implementing these BMPs the estimates were recalculated using lower C values derived from discussions with NRCS personnel. With the R factor held constant and using the new C values the estimated gross erosion rate decreased by nearly 42 percent from 14.4 to 8.4 Mg per hectare per year (or 5.3 to 3.1 tons/ac/year).

Statistical Analysis of Yadkin River Suspended Sediment

The results of the statistical analysis of the 40 year suspended sediment concentration data record show that the Yadkin River transports a tremendous amount of sediment, annually about 819,000 Mg (742,997 tons). Per unit drainage basin area the mean annual suspended sediment yield is 1.39 Mg per hectare (0.5 tons/acre). During the period of 1951 to 1990 the daily median suspended sediment concentration was 70.0 mg/L, while the daily arithmetic mean was 150.6 mg/L (Table 19 in Appendix E). The statistics for daily suspended sediment concentration and sediment yield for each decade are presented in Tables 21 and 22 (Appendix E).

As noted by the authors (Richter and others 1995) the daily suspended sediment concentration and sediment yield data are highly skewed. Skewness is a measure of the symmetry of a distribution, with a normal distribution having a skewness of zero, whereas the results for the Yadkin River are positively skewed. This is explained by the fact that the bulk of the suspended sediment (71 percent) is transported by flows that occur about 10 percent of the time (36 to 37 high-flow days per year) and that about 26 percent of the annual transport occurred in three to four days per year (or one percent of the time).

As shown in Figure 12 (Appendix E) sediment transport by the Yadkin River varies highly from year to year. The variable nature of sediment transport is directly associated with discharge. As shown in Figure 13 (Appendix E), sediment transport increases with increasing discharge. This relationship between discharge and sediment transport was examined using linear regression techniques. As shown in Figure 14 (Appendix E) annual sediment transport and annual discharge are positively related and that 79 percent of the variation in sediment transport is associated with the variation in discharge.

Time Trend Analyses of Yadkin River Suspended Sediment

Since no obvious monotonic time trend was obvious in the suspended sediment data (Figure 13 in Appendix E) several statistical analyses were performed to remove the influence of the hydrologic variability and to identify any underlying trends. This analysis included the fitting of regression equations to sediment-hydrologic data and their time-ordered residuals and the testing of trends in the time-ordered residuals using the Mann-Kendall test.

Based on the results of this analysis sediment transport in the Yadkin River at Yadkin College is decreasing at a rate of about 6900 Mg per year (Figure 17 in Appendix E). The Sen-slope estimate indicated that sediment transport was decreasing significantly by about 7,789 Mg per year (2,860 tons/year) between 1951 to 1990 and is equivalent to 0.013 Mg per hectare per year (0.0047 tons/ac/yr).

Monthly suspended sediment data were also analyzed by regression methods and tested with the non-parametric seasonal Kendall test. The seasonal Kendall and Sen slope estimators of monthly sediment transport indicated that sediment transport was decreasing at about 0.0115 Mg per hectare (0.0042 tons/acre) of the 477 month record. This decrease in sediment transport is equal to about 0.46 Mg per hectare (0.17 tons/acre) over 40 years.

Daily log transformed suspended sediment concentration data were also evaluated using the statistical methods used in analyzing the annual and monthly data. The results of these analyses also indicated a decreasing slope of sediment concentration over time.

The authors (Richter and others 1995) also note that the production of sediment over the year changes in response to rainfall and runoff. The highest sediment transport (total sediment weight per month) is observed from February through June, coinciding with the months of highest runoff. The highest sediment concentrations (weight per unit discharge) typically occur from May through August. The seasonal differences in sediment concentration are believed to be due to the higher amounts of erosion that occur during the summer as a result of the intensity of convective summer storms.

Lastly, to determine whether sediment transport was decreasing in all months of the year the authors (Richter and others 1995) performed a Chi-square test. The results of this analysis indicated that negative trends in sediment transport during the period of 1951 to 1990 was present in all 12 months of the year and was most pronounced during June through August.

Changes in Land Use-Land Cover and Gross Soil Erosion and the Implications to Water Quality Management

The authors (Richter and others 1995) conclude that sediment transport is declining in the Yadkin River, although at a relatively slow rate. The estimated reduction in sediment transport over the 40 year period (1951 to 1990) is roughly 0.0115 Mg per hectare per year (0.004 tons/yr) which is equivalent to a reduction of 0.83 percent of the mean annual transport of 1.39 Mg per hectare (0.5 tons/yr). The data also indicated that the Yadkin River is transporting about 30 percent less suspended sediment on an annual basis than in 1951, when the study period began. Although these reductions are an improvement the amount of sediment being transported by the Yadkin River could be 10 times greater than what they were prior to forest clearing and agricultural development.

The authors (Richter and others 1995) also note that watershed management can play an important role in improving water quality conditions. The decline in agricultural land use coupled with the implementation of BMPs have greatly reduced the contribution of sediment from agricultural lands. The transition of land use from agricultural to urban is of particular concern. As urban development increases appropriate watershed management measures will need to be implemented to reduce this growing source of sediment. The control of this source is important considering the relatively slow recovery of the Yadkin River from the impact of historical land use change.

3.7 WATER QUALITY AND QUANTITY TRENDS IN THREE SUB-BASINS OF THE YADKIN RIVER BASIN, NORTH CAROLINA

In 2000, Jamie Henkels, in partial fulfillment of the requirements for the Master of Environmental Management degree in the School of the Environmental at Duke University presented the findings of his Master's Project titled "Water Quality and Quantity Trends in Three Sub basins of the Yadkin River Basin, North Carolina" (Henkels 2000). Although not published, this presentation can be viewed at the The Forest, Soil and Water Lab web site at Duke University. (http://discus.env.duke.edu).

The purpose of Henkels (2000) research was to evaluate whether different sub basins of the Yadkin River are contributing different amounts of nonpoint pollution (sediment) and how is this related to land use. This investigation included an analysis of the relationship between hydrology and precipitation and the relationship between turbidity and streamflow.

Henkels (2000) study focused on three sub basins located in the Upper Yadkin River: the Mitchell River, Ararat River and Muddy Creek. Land use within the Mitchell River is primarily forested, the Ararat River basin is rural with agricultural land use, while Muddy Creek is largely developed and includes the western portion of Winston-Salem.

In this study, Henkels (2000) performed an analysis of the change in land use over time, the relationship between hydrology (runoff) and precipitation and the relationship between turbidity and streamflow.

For land use he examined the changes in land use in the three drainage basins over the years 1982, 1987 and 1992. The results of this analysis are presented as the percent change of county area for each of the following land use types: cropland, forestland, pastureland, rural and urban land.

In the hydrologic analysis, Henkels focused on the relationship between rainfall events and flow responses, the lag time of flow response after rainfall events and performs a comparison of lag time between the drainage basins. For this analysis he selected the study period of 1970 to 1998 and his sources of information included the USGS, the Surry County Soil and Water Conservation District (SWCD), North Carolina Dept. of Environment and Natural Resources, and the City of Winston-Salem. The first step in his analysis was to normalize the data for the purpose of comparing the data sets. He then determined the lag time between precipitation and runoff events for the Ararat River, Mitchell River and Muddy Creek. These data were analyzed by plotting the correlation coefficients of the time lags versus the time lag in days.

Lastly, he looked at the relationship between turbidity and streamflow. The study period for his analysis were from 1980-1998 for the Ararat River and from 1988-1991 for Muddy Creek. For his analysis he log transformed both the streamflow and turbidity data and then plotted the turbidity and flow values versus one another and performed a regression analysis. He did this for both the entire data set and then individually for Muddy Creek and the Ararat River.

The results of Henkels (2000) study were presented by topic. In his analysis of land use he lumped the drainages of the Mitchell and Ararat Rivers together since they are not urbanized. In these drainages the predominant land uses are cropland, forestland and pastureland (88 percent) with urban land use representing less than six percent of the county area. During the period of 1982 to 1992 the following trends in these drainage were noted; cropland decreased by 12 percent, forestland increased by three percent, pastureland increased by eight percent, rural land was unchanged and urban land increased by two percent.

For the Muddy Creek drainage the predominant land uses are forestland (40 percent) and urban land (25 percent). Over the period 1982 to 1992 the following trends were noted; cropland decreased by five percent, forestland decreased by three percent, pastureland and rural lands were unchanged and urban land increased by eight percent.

In his analysis of the drainages hydrology he examined the time lag between precipitation and streamflow. To analyze their relationship he plotted their correlation coefficients versus the lag time in days and found that; runoff reaches each stream in one day, the Ararat River has the highest correlation coefficient between these values and that the Mitchell River has the lowest one day correlation. The difference in the response between the Ararat and the Mitchell Rivers may be explained by the difference in their land use. The Ararat River is primarily agricultural while the Mitchell River is principally forested. When looked at on a decade basis, there was no significant difference for the Mitchell River and he credits this to little land use change over time. For the Ararat River only one significant difference was noted between 1970 and 1990. He provides no discussion of the results for Muddy Creek.

Lastly, he reported that in his analysis of turbidity and streamflow that when the log transformed turbidity and flow data are plotted, a relationship between the two variables is evident. In general, as flow increases turbidity is found to increase. When the two data sets are separated and replotted, the turbidity values for Muddy Creek are found to be significantly higher than that for the Ararat River.

This would suggest that the urbanization of the Muddy Creek watershed (Winston-Salem) is causing an increase in turbidity concentrations.

Henkels (2000) concludes that there haven't been any significant changes in flow regime in the three drainages studied during the last three decades, but that turbidity is now a greater problem in the urban watershed (Muddy Creek) than the agricultural watershed (Ararat). He also states that non-point source pollution continues to be a problem and that management strategies for the Yadkin River basin must shift in response to land use change from agricultural and forested to urban.

3.8 DYNAMIC MODELING OF LONG-TERM SEDIMENTATION IN THE YADKIN RIVER BASIN

In an article published in Advances in Water Resources, Jagdish Krishnaswamy, Michael Lavine, and Daniel Richter of Duke University and Karl Korfmacher of Denison University discuss the development of a statistical model to evaluate long-term sedimentation in the Yadkin River basin. The specific objectives of this study were to model the sediment response of the Yadkin basin using Bayesian dynamic linear regression models (DLMs) and to determine its ability to detect long term trends in basin sedimentation in response to land use changes. This paper expanded upon the approach taken by Richter and others (2000) in their report on the trends in land use and sediment transport in the Yadkin River basin.

The study focused on the upper Yadkin River Basin, upstream of the USGS gaging station in Yadkin College, North Carolina. As noted previously, this basin drains portions of the western piedmont and the Blue Ridge escarpment of North Carolina and Virginia. Since this gage is located upstream of the High Rock Reservoir the data do not reflect the effect of any of the Yadkin Project reservoirs, but documents sediment transport inflow into the project.

In the study, the authors (Krishnaswamy and others 2000) used Bayesian DLMs to evaluate the relationships between erosivity and streamflow with sediment concentrations and the relationship between rainfall and streamflow. The data used for the analysis included rainfall, streamflow and sediment concentration values for the period of January 1951 to September 1990. The streamflow and sediment concentration data were obtained from the USGS Yadkin College gage, while the rainfall data were taken from eight recording stations in the drainage basin. All data were aggregated to a monthly time step.

The following DLMs were developed as part of the study; 1) log sediment concentration and log erosivity, 2) log streamflow and log rainfall and 3) log concentration and log streamflow. The authors note that the advantage of using a DLM over a static linear regression is that the parameters evolve with time by incorporating new data and by discounting older data. Also, since the hydrologic system is non-stationary, the use of a static linear regression model is limited.

In this analysis the change in the slope coefficient (B) reflected physical changes underlying the relationship. For instance, an increase in the slope of the coefficient for erosivity over time may show a change in land use such as forest conversion, reforestation and/or urbanization. The study focused on the change in the slope parameter (B) for each of the relationships over time and then explained the reason for any observed changes.

Plots (Figures 4-6 in Appendix F) of the change in the coefficients for erodibility-sediment, flow-rainfall and flow-sediment relationships were presented. All three plots show a change occurring sometime in the late 1960s or early 1970s. For erosivity, a period of decreasing values between 1951 and 1973 is followed by a period of increasing values. Thus, there was an increase in sediment per unit basin hydrologic energy. This suggests an increase in basin erodibility. The relationship between flow and rainfall shows an increased flow per unit rainfall in the latter period, while for flow and sediment the slope increases to the early 1980s and then begins to decline.

The authors (Krishnaswamy and others 2000) explain that these changes are consistent with and are possibly explained by changes in land use throughout the basin starting in the late 1960s, which reversed the declining trends in basin erodibility and run-off. During the past three decades land use has changed from primarily rural/agricultural to a mixture of uses. For example, the area under row crops decreased by 5.9%, while urban development increased by 13%.

The decrease in the ability of rainfall to erode soils between 1951 and 1970 is most likely due to the regrowth of forests and pastures on abandoned agricultural lands. The more recent rising trend in erodibility and changes in the rainfall-flow processes may be related to the increase in urban areas and road construction. These types of land use generate impervious surfaces close to the main stem of the river leading to quick run-off and consequently erosion accelerated in the late 1960s to early 1980s. The increase in the availability of sediment between mid-1960s and early 1980s as reflected in the rising trend in the sediment coefficient is also attributed to the recent urban development.

The authors (Krishnaswamy and others 2000) then state that "the agricultural changes have substantially decreased gross soil erosion on extensive rural areas of agricultural land throughout the Piedmont region." They also repeat the findings of Richter and others (1995) in that "it is postulated that the sources of sediment in the Yadkin River are not simply decreasing but are rather shifting from being largely a result of a variety of human activities, increasingly associated with urban and suburban development". They also conclude that "the continued effects of urbanization in stabilizing the decline in overall basin surface erodibility and perhaps increasing sedimentation will perhaps be revealed by DLMs estimated in the near future" (Krishnaswamy and others 2000).

The authors (Krishnaswamy and others 2000) of this report use a more robust statistical method to analyze relationship between erosivity, streamflow and sediment concentrations in the Yadkin River than those used in the past (USDA 1979, Harned and Meyer 1983, Simmons 1993 and Richter and others 1995). Using this non-stationary approach they are able to show the variability and trends of these parameters over time. The changes in these parameters appear to be correlated to past changes in land use in the drainage basin, although they suggest that the positive effects of declining agricultural land may become offset by continuing development. The effect of this transition from agricultural to increasing urban land use as the sediment source is also cited in the following study.

3.9 CHANGES IN LAND USE AND WATER QUALITY IN THE YADKIN RIVER BASIN

In 2001, Carla Norwood, in partial fulfillment of the requirements for the Master of Environmental Management degree in the School of the Environmental at Duke University presented the findings of her Master's Project titled "Changes in Land Use and Water Quality in the Yadkin River" (Norwood 2001). Although not published, this presentation can be viewed at the The Forest, Soil and Water Lab web site at Duke University (http://discus.env.duke.edu). Norwood's study represents the most recent research of the sediment issue on the Yadkin River.

The objective of Norwood's study was to evaluate land use and sediment change in the Yadkin River Basin, over the period of 1951-2000, looking at what trends were evident and what relationships might be apparent. The study area included the Yadkin River Basin from its headwaters to the USGS gaging station in Yadkin College. Thus, the study area stops upstream of the High Rock reservoir and does not include any of the Yadkin Project reservoirs.

The study approach included a review of the changes in land use and sediment concentrations in the Yadkin River basin over time. Changes in land use were evaluated by reviewing the US Agricultural Census (1945-1997), US Census (1950-2000) and digital land use data (1975 and 2001) sets for four of the counties in the drainage basin (Forsyth, Surry, Wilkes and Yadkin).

In the second part of the study, Norwood (2001) evaluated the trend in suspended sediment concentrations recorded at the USGS Yadkin College gage. She looked at flow, sediment concentration and sediment transport for the period of 1951 to 2000. Daily sediment values were available for the period 1951-1995; no records were available for 1995 to 1996, while weekly values were available for 1996-2000. To fill the gap in 1995-1996, Norwood performed a log transformation on the flow and sediment data recorded for 1951-2000 and 1990-2000 and plotted log flow (X) vs. log sediment concentration (Y). She found that the 1990-2000 data had a stronger relationship and using this she was able to estimate the sediment concentrations in 1995-1996 based on the recorded flow data for this period.

Norwood (2001) then summarized the sediment concentration data computing a monthly mean and plotting it versus time. She noted that identifying a time trend in the data was difficult due to seasonality and its being skewed. To evaluate the trend she performed a seasonal trend decomposition with LOESS. This allowed for a nonparametric statistical test for trend and graphical analysis. By correcting for flow, she looked at the long term trend and seasonality components in sediment concentrations.

In the discussion of her results on land use change, Norwood presents several graphs that illustrate the change in land use over time and its potential contribution to sediment concentrations in the Yadkin River drainage. In one plot she shows that relative sediment contribution has changed over time:

Time	**Land Use**	**Sediment Contribution**
Pre-1700s	Native American Cultivation	Low
Late-1700s	Early Settlers	Medium
1880s	Cash Crops	Highest
1920s	Land Abandonment	High
1950s-Present	Urbanization?	High and Increasing

The decline of agriculture from the 1940s to late 1990s for the four counties studied is illustrated in a chart. Overall, the acreage in production decreases by roughly 100,000 acres or by over 40% during this time period. In addition, the greatest change occurs in the production of corn and wheat with both declining over this period.

Alternatively, the population in the four counties studied steadily increased from 1900 to 2000, with population going from around 100,000 to approximately 475,000. This represents an increase of roughly 3.8% per year. The greatest amount of growth was recorded in Forsyth County, which includes

Winston-Salem. This area experienced the greatest amount of urban development in the region from 1975 to 2001. Other major towns or cities are located within the upper Yadkin basin.

In her analysis of sediment transport Norwood found that when corrected for variation in flow the long term (1950-2000) concentration of sediment in the Yadkin River was found to decrease by 38% (63 to 39 mg/l). As shown by Norwood there is a strong seasonality to sediment concentrations for the Yadkin River. The highest concentrations occur in the summer (June, July and August), while the lowest concentrations occur in the late fall and early winter (November, December and January). For the period of record, the flow corrected concentration of sediment was also found to decrease.

Norwood (2001) presents a plot showing the proportional change in sediment concentration and percent land use for cash crops over the period of 1945 to 2000. During this period both the percent area under cultivation for crops and sediment concentration in the Yadkin River are found to decrease. In a second plot she includes the change in population density over time. While the density of population increased over time, the concentration of sediment in the Yadkin River fell.

Based on these findings Norwood suggests that the decline in sediment concentrations reflects the decline in agricultural use of land in the drainage basin and that sediment concentrations in the 1980s could be as ten times greater than those experienced pre-1800 settlement. This indicates that it may take a long time for the river to recover from past impacts. Norwood (2001) also notes that the impact from urbanization might be masked by the decline of agricultural land use. This is because the urbanized areas represent a relatively small area of the drainage basin. Lastly, she notes that there is a lag time between the change in land use type from agricultural to urbanized, so the impact of this change might not be observed until well into the future.

3.10 A RIVER IN JEOPARDY: THE YADKIN AND PEE DEE RIVERS OF NORTH CAROLINA

This report was prepared by members of Clean Water of North Carolina (CWFNC), which included Brad Carpenter, Scott Jackson and Hope Taylor-Guevara. The report was issued in October 2002.. As stated by the authors (Carpenter and others 2002) the purpose of this report was to “explore the impact human activity has on the Yadkin-Pee Dee watershed”. For this report the Yadkin-Pee Dee River was divided into three units: the Upper Yadkin, the South Yadkin and the Lower Yadkin.

The authors state that “the Yadkin River faces threats from several directions. Population growth and sprawl are the underlying causes of water quality problems. Sediment in muddy runoff comes from road and home construction, from the increased velocity of flow in urban areas and also from agricultural and timbering operations. Nutrients come mainly from wastewater treatment plants, fertilizer and animal wastes. Harmful bacteria are frequently associated with the nutrients. Toxic substances come from industrial sources, as do waste materials that add color to the water.” For these reasons a review of the existing conditions and actions that could be taken to improve the quality of the Yadkin-Pee Dee River was performed by CWFNC.

The review of this report was limited to the discussion of the issue of sediment and to the discussions of the Upper, Lower and South Yadkin drainages which are either upstream or include the Yadkin Project. The report is a compilation of existing material, relying particularly on the results of the Basinwide Water Quality Plan prepared for the Yadkin-Pee Dee River by the NCDNR Water Quality Section in 1998. This plan was recently revised and updated by the NCDNR in 2003. The report also is based on two earlier publications “A Citizens Report on the Mid-Yadkin River Basin” prepared in 1991 by the

Clean Water Fund of North Carolina (now Clean Water for North Carolina) and "A River Runs Through Us" which is a compilation of articles that appeared in the Salisbury Post in 1997.

The report "A River in Jeopardy" identifies sediment as the greatest threat to water quality in the Yadkin-Pee Dee River. The environmental impacts associated with high sediment loads is the deposition of sediment on streambeds, thus suffocating fish eggs, clogging fish gills, and reducing visibility for predators. Sediment can also carry bacteria, nutrients and toxins. Lastly, high concentrations of sediment may also increase the cost of water treatment for those communities using the Yadkin-Pee Dee River as a water supply.

The major sources of sediment in the Yadkin-Pee Dee River cited in the report include those that remove vegetation and expose bare ground such as: construction, urban runoff, golf courses, agriculture and livestock operations. The report notes that sources of sediment in the Yadkin-Pee Dee River have changed over the past century. Erosion from agriculture was at its highest in the 19^{th} and early 20^{th} centuries. In the late 20^{th} century decreasing amounts of land were in agricultural production. As a result, sediment levels in Southeastern rivers had declined to one third of their 1910 levels (Carpenter and others 2002). While sediment loads from agricultural lands have decreased increasing loads from construction and urban development may cause increased sediment loading to the river in the future.

To reduce the impact of erosion and sedimentation the authors (Carpenter and others 2002) recommend that riparian buffers and construction BMPs be employed. They also note that sediment is "not a long-lasting contaminant. If we can reduce the amount of new sediment entering the Yadkin-Pee Dee system, this river will improve as storms wash the existing sediments downstream."

Upper Yadkin Sub Basin

The report then examines the state of each of the three sub basins. The Upper Yadkin Sub Basin includes the uppermost portion of the Yadkin River above its confluence with the South Yadkin River. In the Upper Yadkin, the report notes that the estimated soil loss in this watershed has declined from 4.2 tons/acre/year in the 1970s to 3.7 tons/acre/year in the early 1990s. Of the sediment input to the Upper Yadkin River roughly 70 percent of it is captured and retained by the reservoirs located downstream in the Lower Yadkin Sub Basin.

Due to the high rates of soil erosion in the Upper Yadkin Basin several subdrainages have been impacted to the point of being considered impaired and are included on the states 303(d) list. These streams include Faulkner Creek (sediment) and Salem Creek (turbidity).

South Yadkin Sub Basin

The South Yadkin Sub Basin includes the watersheds of the South Yadkin River and Back Creek. The authors note that the study performed by the USDA in 1979 estimated that the South Yadkin Sub Basin lost 5.1 tons of sediment per acre per year in 1978, making this the most impaired sub basin at that time. They do not provide any information on any more recent estimates so any change in soil losses and sediment yield is not presented. Since there are no reservoirs on the South Yadkin Sub Basin near its outlet the sediment produced from this watershed is partially retained in the reservoirs located downstream in the Lower Yadkin Sub Basin.

The report notes that due to the high sediment production in this watershed that Fourth Creek has been impacted and is considered impaired due to high turbidity.

Lower Yadkin Sub Basin

The Lower Yadkin Sub Basin begins at High Rock Reservoir and ends at the South Carolina state line, so it includes the Yadkin Project. The report notes that the 1970s sediment analysis estimated that the Lower Yadkin Sub Basin lost 2.7 tons of sediment per acre per year, which is much less than the Upper Yadkin or the South Yadkin. The lower soil loss estimates are explained as being the result of the lower population of the Lower Yadkin and the higher proportion of forested land (Uwharrie National Forest).

Although the estimated rate of soil loss is less in this sub basin, several streams have been impacted and are considered impaired by the NCDNR. These include: Grants Creek (turbidity), McKee Creek (sediment) and the Rocky River (turbidity).

Based on their review of the exiting information on sediment in the Yadkin River the report authors make the following recommendation:

> "Substantial improvement in non-point source pollution control, particularly sediment. While sedimentation impacts due to farming have gradually diminished due to better practices and decreased farming in the basin, the Yadkin still runs brick red after any significant rainfall, and downriver habitats, water quality and reservoirs have been highly impacted. It will require economic incentives for farmers and developers, strict enforcement of sedimentation and erosion regulations for all sectors, and serious regional transportation and development planning to prevent further rapid degradation of the Yadkin's waters and quality of life in the basin."

3.11 YADKIN-PEE DEE RIVER BASINWIDE WATER QUALITY PLAN

In 2003, the North Carolina Department of Environment and Natural Resources, Division of Water Quality, Water Quality Section released the Yadkin-Pee Dee River Basinwide Water Quality Plan. This document is the first five year update of the plan originally issued in 1998. The Basinwide Water Quality Plan (BWQP) for the Yadkin-Pee Dee River provides a comprehensive overview of water quality issues in this basin. The BWQP was presented in the three sections: Section A General Basinwide Information, Section B Water Quality Data and Information by Sub basin and Section C Current and Future Water Quality Initiatives. Relative to the Yadkin Project, the BWQP was reviewed focusing on the sediment and turbidity issues.

In Section A the hydrology, land cover, population and growth trends in the basin along with its natural resources, water quality issues and the physical impacts to wetlands and streams are discussed. In the summary of water quality information for the Yadkin-Pee Dee River (Chapter 3) sediment loading was identified as a problem based on the results of the Lakes Assessment Program (LAP). The report states that "excess sediment reduces the storage of lakes over time, introduces nutrients, and reduces aesthetic appeal by giving the water a muddy appearance. Soils of the Yadkin-Pee Dee River basin are highly erodable. The most notable example of this problem can be seen in the upper end of High Rock Lake."(NCDNR 2003).

The Ambient Monitoring System (AMS) has reported turbidity as an issue in several watersheds. More than 10 percent of the samples collected at 11 stations in the Yadkin-Pee Dee River basin exceeded turbidity water quality standards within the most recent assessment period (1996 to 2001). The drainages where exceedances were reported in the Yadkin Project basin included: the Yadkin River (three different locations), Ararat River, South Yadkin River, Town Creek Arm of High Rock Reservoir and the Abbotts Creek Arm of High Rock Reservoir (two locations).

Turbidity was also identified as a water quality issue in the results of the Yadkin-Pee Dee River Basin Association Monitoring Program (YPDRBAM). More than 10 percent of samples exceeded turbidity water quality standards at 13 monitoring stations. The report notes that "turbidity at four mainstream Yadkin River monitoring locations exceeded the water quality standard in 13-21 percent of the samples collected. Water from both the South Yadkin River (mostly agricultural use) and the upper end of North Fork Crooked Creek (mostly developed/urban land use) exceeded turbidity standards in approximately 24 percent of the samples"(NCDNR 2003). Other streams located within the Yadkin Project basin reporting turbidity values greater than the water quality standard included: Dutchman Creek and Fourth Creek.

In Chapter 4 (Water Quality Issues), sedimentation is identified as one of the major contributors to habitat degradation in the Yadkin-Pee Dee River basin. The potential sources of sediment include those land-disturbing activities such as the construction of roads and buildings, crop production, livestock grazing and timber harvesting. The Plan notes that sediment produced from these activities may be deposited in streams smothering aquatic insects that fish feed on and may also bury fish spawning areas. Physically, sediment deposition may also fill river and streams decreasing their volume and increasing the frequency of floods (NCDNR 2003).

Suspended sediment can also impact the aquatic ecosystem by decreasing primary productivity (photosynthesis) by shading sunlight from aquatic plants. Suspended sediment can also affect various fish species including avoidance and redistribution, reduced feeding efficiency, respiratory impairment, reduced tolerance to diseases and toxicants and increased physiological stress. The removal of suspended sediment from water for its use as a drinking water supply is also costly (NCDNR 2003).

During basinwide monitoring performed by DWQ biologists in 1999, streambank erosion and sedimentation were reported throughout the Yadkin-Pee Dee River basin as being moderate to severe. Lower bioclassification ratings were assigned due to sedimentation covering substrate and or partially filling pools. In addition, unstable and/or eroding streambanks were also noted in the lower ratings (NCDNR 2003).

The BWQP outlines the actions that can be taken to reduce sediment production and transport in the watershed. These actions include:

- Implementation of Best Management Practices (BMPs)
- Development of stronger rules for sediment control
- Application of recent research results on sediment control
- Regulation of instream mining operations

In Section B of the BWQP, the water quality of each sub basin is discussed. A total of eight sub basins delineated in the BWQP fall within the Yadkin Project basin including:

Sub Basin Code	Basin Name
03-07-01	Upper Yadkin River and Kerr Scott Reservoir
03-07-02	Mitchell River, Fisher River and Deep Creek Watersheds
03-07-03	Ararat River Watershed
03-07-04	Muddy Creek, Grants Creek and High Rock Reservoir
03-07-05	Dutchman Creek Watershed
03-07-06	South Yadkin River Watershed
03-07-07	Abbotts Creek Watershed
03-07-08	Yadkin River below High Rock Dam (Narrows Reservoir)

For this review, only sediment and turbidity issues are discussed for each of these basins.

Upper Yadkin River

The Upper Yadkin River and Kerr Scott Reservoir drainage encompasses the head waters of the Yadkin River in the Blue Ridge and Piedmont physiographic provinces. This basin has a total area of 830 sq. mi., has a population density of 76 persons per sq. mi. and the majority of its land cover is forest or wetland (81 percent). Urban land cover is only 0.6 percent of the watershed.

The results of the AMP indicate that elevated turbidity values have been recorded at two locations on the Yadkin River (NC 268 and SR2327). Only one stream in this basin, an unnamed tributary to Mulberry Creek, is included in the State's 303(d) list of impaired waters and that was unrelated to sediment and turbidity.

Mitchell River, Fisher River and Deep Creek Watersheds

The Mitchell River, Fisher River and Deep Creek watersheds drainage an 822 sq. mi. area that has a population density of 111 persons per sq. mi. with the majority of its land cover as forest/wetland (59.4 percent) and pasture (32.2 percent). Urban land cover is only 1.2 percent of the watershed.

Elevated turbidity values have been reported for the Little Yadkin River and at three locations along the Yadkin River (SR 1605, SR 1003 and US 158) as part of the AMP. No waters in this sub basin are included on the State's draft 2002 303(d) list.

Ararat River Watershed

The Ararat River watershed drains part of southern Virginia and North Carolina. It includes 198 sq. mi. of land having a population density of 183 persons per sq. mi.. The majority of the land cover in this sub basin is either forest/wetland (59.1 percent) and pasture (32.7 percent). Urban land cover is 3.0 percent of the watershed.

Results of the AMP and the YPDRBAM indicate that elevated turbidity levels have been documented at two locations on the Ararat River (SR 2080 and SR 2044). Currently, portions of two streams in this sub basin, the Ararat River and Faulkner Creek, are included on the State's draft 303(d) list as impaired waters due to sediment problems.

Muddy Creek, Grants Creek and High Rock Reservoir

This sub basin is located entirely within the Piedmont physiographic province in North Carolina. It drains a total area of 730 sq. mi. having a population density of 461 persons per sq. mi.. Land cover is predominantly forest/wetland (55.9 percent) and pasture (31.7 percent). Located within this sub basin is

Winston-Salem and as a result the amount of urban land cover (6.0 percent) is higher than in the preceding sub basins.

The majority of the waters within this sub basin exhibit some level of impacts to water quality. Turbidity has been identified during the AMP and YPDRBAM as an issue on the Yadkin River at two locations (NC 150 and US 64), Grants Creek (near its mouth), Muddy Creek (SR1485) and in the Abbotts Creek Arm of High Rock Reservoir (NC 47 and SR 2295). Portions of two streams, Salem Creek and Grants Creek, are included on the State's draft 303(d) impaired waters list for turbidity.

Dutchman Creek Watershed

With a drainage area of 130 sq. mi. this sub basin is the smallest of the seven located within the Yadkin Project basin. The population density in this sub basin is 91 persons per sq. mi. while the principal land covers are forest/wetland (56.8 percent) and pasture (35.1 percent) along with cultivated cropland (5.5 percent).

Water quality is generally good to fair throughout this sub basin, although many streams are small and have not been monitored. Elevated turbidity values have been recorded on Dutchman Creek as part of the YPDRBAM and sedimentation has been noted as a problem in this drainage. As noted in the BWQP (NCDNR 2003) no waters in this sub basin are included in the State's draft 2002 303(d) list.

South Yadkin River Watershed

The South Yadkin River watershed includes a 907 sq. mi. area. The population density of this area is 104 persons per sq. mi. and the principal land use cover is forest/wetland (54 percent) and pasture (38 percent) with some cultivated cropland (6.2 percent).

The BWQP (NCDNR 2003) states that the water quality in this watershed cannot be generalized because of the wide variation in conditions between sub basins and within sub basins. Elevated turbidity values have been recorded on several streams within this watershed. The AMP has noted elevated turbidity values on the South Yadkin River (SR 1159) and Fourth Creek (SR 2308), while the YPDRBAM has recorded elevated turbidities on the South Yadkin River (US 601), Fourth Creek (SR 2308) and Second Creek (US 601). Due to the turbidity problems, Fourth Creek is included on the State's draft 2002 303(d) impairment list.

Abbotts Creek Watershed

The Abbotts Creek Watershed encompasses 237 sq. mi. and discharges into High Rock Reservoir, the uppermost reservoir of the Yadkin Project. This watershed includes the population centers Lexington, Thomasville and High Point which is reflecting in its high population density of 428 persons per sq. mi. The majority of the land cover is forest/wetland (56.5 percent) and pasture (31.8 percent) with a considerable amount of urban development (7.8 percent).

The water quality in the majority of the waters within this sub basin exhibit some level of impact. The results of the various water monitoring programs in the sub basin have identified turbidity as a problem in the Rich Fork (SR 2123). The BWQP (NCDNR 2003) notes that two streams, Brushy Creek and Hamby Creek, are included on the State's draft 2002 303(d) list due to impairment due to sedimentation.

Yadkin-Pee Dee River below High Rock Dam

This sub basin includes the Yadkin-Pee Dee River below High Rock Dam, Lick Creek, Narrows Reservoir, Mountain Creek and Tillery. Relative to the Yadkin Project this sub basin includes Tuckertown Reservoir, Narrows Reservoir and Falls Reservoir. The total area within this watershed is 294 sq. mi.. This area is relatively undeveloped with a population density of 68 persons per sq. mi.. The majority of land cover is forest/wetland (67.9 percent) and pasture (20.9 percent) and little urban development (0.8 percent).

Overall the water quality in this sub basin is considered generally good. Although three of these sub basins streams are included on the State's draft 2002 303(d) list, none have been included due to sediment or turbidity issues.

In Section C, the BWQP (NCDNR 2003) reviews the current water quality initiatives underway in the Yadkin-Pee Dee River basin. It is noted that sedimentation and streambank erosion are two of the important water quality issues identified basinwide. To address these problems participants in five workshops held on the basin planning initiative recommended: better management of stormwater from developed areas, more enforcement of sediment/erosion control laws and ordinances and the widespread implementation of voluntary best management practices.

The BWQP then discusses the existing federal, state, regional and local initiatives in place to address water quality issues and also provides an overview of future water quality initiatives. One of the most important existing programs is the Agricultural Sediment Initiative (ASI). Beginning in 2000, the NC Association of Soil and Water Conservation Districts and the NC Soil and Water Conservation Commission started an effort to assess stream channels and watersheds of streams on the State's 2000 303(d) list due to sediment where agriculture was included as a potential source. The primary objective of the ASI was to assess the severity of sedimentation in the Yadkin-Pee Dee River watershed so that local strategies could be developed to address sedimentation problems (NCDNR 2003). A number of drainages within the Yadkin Project basin were identified for significant restoration and protection work including: Fourth Creek, Brushy Fork, the Ararat River and Faulkner Creek.

4 QUANTITATIVE SEDIMENT TRANSPORT AND SEDIMENTATION DATA

In this section the quantitative sediment transport and sedimentation data that is presented in the numerous papers discussed in the literature review are summarized for comparison and discussion. In addition to the data extracted from the literature review, data developed throughout the history of the Yadkin Project can also illustrate sediment deposition within the Yadkin Project. This section also presents this additional data, the methods used to calculate deposition, and where possible, compares the sediment deposition based upon the various sources.

4.1 SEDIMENT TRANSPORT

All of the quantitative data on sediment transport for the Yadkin-Pee Dee River from Kerr-Scott Reservoir to the USGS gage station a Rockingham, NC has been extracted from the literature reviewed in Section 3 of this report and is summarized in Table 4-1. The bedload and suspended sediment data for all reservoirs were taken from tables in "Erosion and Sediment Inventory for the Yadkin-Pee Dee River Basin in North and South Carolina" [USDA, 1979]. The suspended sediment load for each of the four USGS gage stations and the estimated sediment density used to convert the sediment data presented in Table 4-1 to ac-ft per year are from "A Suspended Sediment Budget for Six River Impoundments on the Yadkin-Pee Dee River" [Fischer 1993]. Table 4-1 also depicts the relative locations of major reservoirs and gage stations along the Yadkin-Pee Dee River and their drainage basin areas.

While the sediment transport data from the two sources is not directly comparable because the two studies do not provide estimates at any common locations, the data from the two sources appears to be relatively consistent. Average annual sediment load increases from upstream to downstream except at the reservoirs where a significant portion of the sediment is trapped. At High Rock Reservoir, the sediment transport entering the reservoir is estimated at 1,049 ac-ft per year (bedload plus suspended sediment) and downstream of Blewett Falls Dam the sediment transport leaving the reservoir is 141 ac-ft per year.

4.2 SEDIMENTATION VOLUME

With regard to sedimentation, the USDA study provides an estimate of the amount of sediment trapped in each reservoir in the Yadkin-Pee Dee River. This data is also summarized in Table 4-1 and reflects that the reservoirs trap 100 percent of the river's bedload and from 40 to 90 percent of the suspended sediment load. As seen in Table 4-1, the reservoir with the highest annual sediment accumulation is High Rock Reservoir. The reservoirs with the highest percent of sediment remaining in the reservoir are Kerr Scott, Narrows, and High Rock reservoirs.

Additional detail regarding sediment deposition in High Rock Reservoir is provided by several topographic and bathymetric surveys performed by the Yadkin Project at various times since 1917. The first survey was performed in 1917 prior to the construction of High Rock Dam and is documented on a set of 79 Tallassee Power Co. maps entitled "Topography and Property Survey – High Rock Basin." These maps depict the pre-impoundment topography of Yadkin River Basin from the confluence of the Yadkin/South Yadkin rivers downstream to the proposed location of High Rock Dam. A second topographic survey was performed in 1997, documenting the topography around High Rock Reservoir from 12 feet below normal full pool outwards to approximately one quarter mile beyond

Table 4-1. Comparison of USDA Sediment Analysis and USGS Sediment Measurements

Location of Reservoir or USGS Gage Station	Drainage Area sq mi	Entering/ Exiting Reservoir	UDSA Analysis[1]			USGS Measurements [2]
			Bedload t/yr ac-ft/yr	Suspended Sediment , ac-ft/yr and % Suspended Sediment Retained	Sediment Remaining in Reservoir (Bedload plus a portion of Suspended Sediment) ac-ft/yr	Suspended Sediment ac-ft/yr
Kerr Scott Reservoir	350	entering	19	78 (87%)	88	
		exiting	0	10		
Yadkin College Gage	2280					561
S. Yadkin Gage	306 (tributary)					67
High Rock Reservoir	3,973	entering	218	870 (79%)	903	
		exiting	0	185		
Tuckertown Reservoir	4,080	entering	16	248 (54%)	151	
		exiting	0	113		
Narrows Reservoir	4,180	entering	9	149 (82%)	131	
		exiting	0	27		
Falls Reservoir	4,190	entering	1	32 (41%)	14	
		exiting	0	19		
Tillery Reservoir	4,600	entering	28	129 (67%)	115	
		exiting	0	42		
Rocky River Gage	1372 (tributary)					138
Blewett Falls Reservoir	6,839	entering	33	171 (67%)	141	
		exiting	0	57		
Rockingham Gage	6,863					292

Notes:

1 Reservoir sedimentation data from Tables V to VII of the "Erosion and Sediment Inventory for the Yadkin-Pee Dee River Basin in North and South Carolina" (USDA 1979), Appendix A. The data was converted from tons/yr to ac-ft/yr using a density of 70.05 lbs/cu ft.

2 Gage Station suspended sediment values and the estimate of sediment density at 72.7 lbs/cu ft from "A Suspended Sediment Budget for Six River Impoundments on the Yadkin-Pee Dee River" (Fischer 1993). Values for suspended sediment at High Rock and Blewett have been estimated for this report by factoring the measured data as a function of contributing drainage basin area.

full pond contours. Continental Aerial Survey, Inc. (CAS) performed the aerial survey and prepared topographic maps with contours at 2 ft intervals.

Sedimentation Estimates Based on Surveys

A storage versus elevation curve for High Rock Reservoir was prepared at the construction of High Rock Dam based on the 1917 topographic survey. This curve shows the original 1917 storage-elevation relationship for elevations between 588.9 ft and 633.9 ft USGS. Following the 1997 aerial survey of High Rock Reservoir, the elevation-storage curve was revised to reflect the observed sediment deposition in the upper 12 feet. The digital topographic data was used to calculate surface areas at each 2-ft contour interval and a new storage volume was determined. The difference in storage volume between the original curve and the revised 1997 curve is 14,919 ac-ft, reflecting the deposition of sediment in that amount in the upper 12 ft of High Rock Reservoir between 1918 and 1997. This 14,919 ac-ft represents a loss of reservoir storage capacity of approximately 6 percent over 80 years, an average of 186 ac-ft/yr. While this is not directly comparable to the 903 ac-ft per year (1,049 ac-ft per year incoming minus 178 ac-ft per year released) total annual sedimentation estimated by the USDA, it is not inconsistent with that estimate.

4.3 SEDIMENTATION PATTERNS

Detail regarding High Rock Reservoir sedimentation patterns is provided by the 1917 and 1997 surveys. To illustrate sediment deposition patterns in High Rock Reservoir, the 1917 topographic maps showing the initial bathymetry of High Rock Reservoir and the 1997 bathymetry have been shaded to reflect reservoir water depths greater than and less than 10 ft. These maps, presented in Figures 4-1 through 4-6 in Section 7, show the area from Abbots Creek upstream to the confluence of the Yadkin and South Yadkin rivers. A comparison of the 1917 and 1997 figures reveals the pattern of sediment deposition during that period. In 1917, the area of the reservoir with water depths greater than 10 ft, denoted by red shading, includes the majority of the reservoir from High Rock Dam upstream to the confluence of the Yadkin and South Yadkin rivers. In 1997, while water depths of greater than 10 ft still extend upstream to the confluence of the Yadkin and South Yadkin rivers, these depths occur in a narrow channel, reflecting sediment deposition from Swearing Creek to the I-85 bridge. A comparison of the 1997 bathymetry (Figures 4-1 through 4-3 in Section 7) and the original 1917 bathymetry (Figures 4-4 through 4-6 in Section 7) shows the following trends in reservoir depths:

- A comparison of Figure 4-1 with Figure 4-4 (Section 7) reveals that from Abbots Creek to Crane Creek, the area of the reservoir with water depths greater than 10 feet, as depicted in red, is similar in 1917 and 1997.
- A comparison of Figure 4-2 with Figure 4-5 (Section 7) reveals that:
    - From Swearing Creek to just downstream of I-85, the reservoir area that was greater than 10 ft deep (depicted in red) in 1917 was less than 10 ft deep (depicted in pink) in 1997, indicating that reservoir water depths have decreased.
    - Sedimentation in the bend upstream of Swearing Creek has shifted the deepest portion of the reservoir (in red) to the west shoreline.

- From the Yadkin/South Yadkin river confluence to just downstream of the I-85 bridge, reservoir depths have remained greater than 10 feet in the center of the stream channel and less than 10 feet in the remaining stream channel. The deepest portion of the river has narrowed.
- A comparison of the outline of High Rock Reservoir at full pond reveals no substantial change in the shoreline between the 1917 survey and the 1997 survey. That is, if the current reservoir outline is laid over the 1917 outline, very little difference in the reservoir shape is evident.

4.4 EFFECTS OF SEDIMENT ON HABITAT

The preceding review of the literature turned up very little information, data or studies on the effects of sedimentation on aquatic habitats in the Yadkin Project reservoirs. However, as part of the relicensing effort, APGI has been conducting a number of studies of the Project reservoirs, including studies of aquatic habitats and wetlands. Specifically, the Wetland and Riparian Habitat Study is examining the distribution of wetlands and other important habitats throughout the Project reservoirs. Based on earlier mapping of wetlands done at the Project (Yadkin Inc., 1999), it is clear that some of the largest and most abundant wetlands on High Rock Reservoir are in the upper end of the reservoir and appear to have developed over time on sand bars and other sediment deposits. A more detailed analysis of these wetlands and the ongoing contribution that sediment may be having on their development will be discussed in the Wetland and Riparian Habitat Study Report.

Another study being conducted as part of the ongoing relicensing process, the Reservoir Fish and Aquatic Habitat Assessment will also provide some insight into the potential effects of sediments on fish habitats. As part of this study, NAI has mapped aquatic habitats throughout much of High Rock and Narrows reservoirs littoral zones. A key feature of the aquatic habitat maps will be the breakdown of habitats by general substrate types. This information will lend additional understanding to the patterns of sediment deposition within the reservoirs and how sediment may be impacting aquatic habitats.

4.5 EFFECTS OF SEDIMENT ON MUNICIPAL WATER SUPPLY INTAKES

There are four municipal water supply intakes located within the Yadkin Project. Salisbury-Rowan Utilities (SRU) operates a water supply intake located in the upper, riverine portion of High Rock, just upstream of the confluence of the Yadkin and South Yadkin rivers. The City of Albemarle operates intakes located on Tuckertown and Narrows reservoirs, and the City of Denton operates an intake located on Tuckertown Reservoir.

The literature review discussed previously in this report indicates that a majority of the sediment passes down the river during periods of high inflow associated with both spring runoff and summer thunderstorms. In terms of total volume, the highest amount of sediment occurs during the spring and in terms of concentration, the highest concentration occurs during summer storm events.

In a report entitled “Review of January 1998 Flood of Yadkin River” that was prepared by Stone and Webster Engineering, it was determined that the High Rock Reservoir elevation has little impact on water surface elevations at the Salisbury intake during periods of high flow. For river flows between 10,000 and 40,000 cfs at the confluence of the Yadkin and South Yadkin rivers, the range of increase in elevation at the intake, based on High Rock Reservoir elevation, varies from 0.50 ft to 0.07 ft, decreasing with increased flows. The report indicates this section of the Yadkin River behaves in a riverine manner during these periods with associated high flow velocities which carry most of the suspended sediment into the reservoir downstream of the I-85 bridges. Thus, the majority of the sediment load in the vicinity of the SRU intake passes by as suspended sediment in the water, and is unaffected by the operation of High Rock Reservoir.

According to SRU, suspended sediment in the river water can adversely affect the operation of the pumping system, increase system maintenance, and generally increase the cost of water processing. SRU indicates some sediment can also become deposited in the vicinity of the river intake structures and can affect these facilities. Recent discussions with SRU indicate the pump station has a sediment pumping system to control accumulation of sediment in the wet well of the pump station. SRU also indicates periodic dredging of sediment around the intakes has been effective in reducing clogging due to sediment deposition. A dredging operation exists in the area and has been beneficial to removal of sediment in the area of the intakes.

The municipal water supply intakes located on Tuckertown and Narrows reservoirs benefit from the High Rock Reservoir which traps much of the suspended sediment in the upper end of the Reservoir. The preceding literature review indicates that as much as 70 to 80% of the incoming sediment to High Rock is retained within the Reservoir. As a result, these facilities are generally much less affected by sedimentation during periods of normal flow conditions.

5 SYNTHESIS OF PREVIOUS INVESTIGATIONS

The preceding review of the literature on sediment in parts of the Yadkin-Pee Dee River basin shows that a significant amount of research has been performed on this important subject. As discussed in the reports and articles reviewed, the input of sediment, its transport or output and its storage are dependent upon both natural conditions such as regional geology, hydrology and soils along with man’s alteration of the landscape by development. The input, output and storage of sediment within the Yadkin-Pee Dee River basin has been shown to vary both spatially and temporally in response to changes in both naturally occurring and imposed conditions. An understanding of the relationship between the naturally occurring conditions along with the potential impacts associated with any imposed changes (naturally or by man’s actions) within the basin is essential in order to place the sediment issue into context.

5.1 EROSION

The inputs of sediment to the Yadkin-Pee Dee River include soil erosion, streambank and channel erosion and urban runoff. As discussed in the reviewed literature, the main source of sediment in the Yadkin-Pee Dee River is soil erosion. The rates of soil erosion within the Yadkin-Pee Dee River basin vary in response to the type of soil material and land use. In general, the soils found in the Piedmont physiographic province are typically fine grained (silt) and can be readily eroded when exposed to wind and water. Other natural factors contributing to the erosion of these soils include the humid climate and topographic relief found within the Piedmont physiographic province. The combination of these factors together with land use results in some of the highest erosion rates and sediment yields in North Carolina (Simmons 1993), the Atlantic Coast drainages (Meade 1982) and the United States (Renwick 1996).

In its inventory of soil erosion in the Yadkin-Pee Dee River Basin, the USDA (1979), estimated that the average annual soil erosion is 3.9 tons/acre or roughly 2,500 tons/sq. mi./year. In this analysis those counties having the greatest concentration of croplands also had the highest estimated erosion rates. Though estimates of the relative contribution to total erosion by croplands varies among the studies, they generally agree that croplands are significant producers of sediment due to the disturbance of the ground surface by tilling and because of the sheet and rill erosion produced by runoff.

Simmons (1993) found in his analysis of suspended sediment data for North Carolina that the basins located in the Piedmont physiographic province produced the highest sediment yields. He notes that that "the effects of intense rains combined with the province's steep gradients and highly erodable clayey soils produced some of the State's highest concentrations of fluvial sediment observed during this study." In his analysis of sediment yield and land use he found that the highest sediment yields were from those basins having a significant amount of land in urban use, 464 tons/sq. mi., followed by those rural basins with agricultural and non-agricultural land use, 209 tons/sq. mi. In the Piedmont physiographic province these values were slightly higher, 527 tons/sq. mi. for urban basins and 302 tons for rural basins with agricultural and non-agricultural land use. The high sediment production from urban basins is thought to be related to runoff generated from impervious cover and stream channel erosion. Simmons (1993) estimates are significantly lower than the USDA's (1979) because his are based on suspended sediment concentration data, which represents the portion of eroded material that is actually being transported by streams and rivers.

The studies performed by Richter and others (1995), Henkels (2000) and Norwood (2001) further examined the impact of land use on sediment production and how land use has changed over time. Overall, these studies have shown that since the early 1900s the amount of land used for agricultural purposes has declined. The decline in agricultural land use has also resulted in a decline in soil erosion and sediment production. Richter and others (1995) documented that cropland in the Yadkin River Basin (above Yadkin College) has decreased from 45 percent to 18 percent of the land area since the 1930s. In response to this decline, the estimated gross erosion in the basin, between the 1950s and 1980s, has decreased by 17 percent (Richter and others 1995). Norwood (2001) extended this analysis to the period 1951 to 2000, and found these land use trends are continuing. With the decline in cropland as a percentage of the basin area there was an associated decline in sediment in the Yadkin River.

Henkels (2000) analyzed change in water quality and quantity in the drainages of the Ararat, and Mitchell Rivers and Muddy Creek, tributaries to the Yadkin River. As part of this analysis Henkels (2000) looked at the changes in land use over a ten year period (1982 to 1992). He found that in the combined Ararat and Mitchell River basin the percentage of cropland had decreased by 12 percent, while in the Muddy Creek drainage it had decreased by five percent. In these drainages urban land use increased by two percent and eight percent, respectively. Although Henkels (2000) did not find any significant time trends in water quality or quantity he did note that turbidity values for Muddy Creek were significantly greater than for the Ararat River. He explained this difference as being reflective of the greater amount of urbanization in the Muddy Creek basin.

The majority of the authors of the publications reviewed concluded that the decline in agricultural land use for crop production has resulted in a substantial decline in soil erosion and sediment input to the Yadkin River. They also note that for those lands remaining in agricultural use soil erosion can be further reduced by implementing best management practices. This conclusion is supported by the results of a study performed by the USGS in northeastern Guilford County, North Carolina (Hill 1991). For the two test areas monitored, the area in which BMPs were employed had sediment yields about one seventh of the area where standard management practices were employed.

Overall the findings of the reviewed research appear to reach the same conclusion that the decline in land use for cropland has led to a decrease in gross erosion and sediment yield. Several of the authors also note that increasing development and urbanization may be causing a recent increase in sediment input to the Yadkin-Pee Dee River and may in the long run exceed the reductions associated with decreased cropland. The benefits associated with implementation of BMPs may not be measurable for some time due to the time lag between land use changes and the basin's response. As shown in the research performed by the USGS in Charlotte, North Carolina (Bales and others 1999) development can result in increased runoff, higher soil erosion and sediment transport. Recognizing this trend in its Basinwide Water Quality Plan (NCDNR 2003) for the Yadkin-Pee Dee River, the NCDNR emphasized the need for the continued implementation of appropriate BMPs to reduce this growing source of sediment.

5.2 SEDIMENT TRANSPORT

Several of the articles and reports reviewed evaluated sediment transport in parts of the Yadkin-Pee Dee River basin. These studies included an analysis of the relationship of sediment transport with land use, how these variables have changed over time and what other basin characteristics might affect sediment transport. The principal studies of sediment transport included those by Harned and Meyer (1983), Simmons (1993), Richter and others (1995) and Norwood (2001).

Harned and Meyer's (1983) study of the water quality of the Yadkin-Pee Dee River provided an overview of the transport of suspended sediment through the basin. The highest concentrations of suspended sediment were found in the Yadkin River at Yadkin College (158 mg/L) with slightly lower concentrations in the Rocky River at Norwood (149 mg/L) and much lower concentrations were observed in the Pee Dee River near Rockingham (33 mg/L). The significant decline in the concentration of suspended sediment between Yadkin College and Rockingham is due to the deposition of sediment in the six reservoirs between these stations. As part of their study, Harned and Meyers (1983) also evaluated the relationship between discharge and suspended sediment. They found that suspended sediment concentrations increase with increasing discharge. At the Yadkin College gaging station suspended sediment concentrations appear to plateau at discharges greater than 7,500 cfs, which suggests that at these flows sediment transport becomes supply limited - that is, the ability of the river to transport sediment is greater than the sediment available to it. At the Rockingham gaging station the suspended sediment data cluster into two groups at low flow and high flow. This distribution is most likely the result of the operations of the hydroelectric facilities upstream.

Simmons (1993) examined several factors that influence sediment production and transport. In addition to his detailed analysis of the relationship between land use and sediment yield (see previous section) he also examined the influence of stream discharge and particle size on sediment transport and developed mathematical relationships to estimate suspended-sediment transport from drainage basins. The relationship between stream discharge and suspended-sediment transport is direct, meaning that the more discharge the greater the suspended-sediment concentration and load. Also, the maximum suspended-sediment concentrations were typically found to occur just prior to the maximum flow during a runoff event for approximately 80 percent of the gaging stations.

Simmons (1979) also examined the frequency of flows required to transport suspended-sediment through selected drainages in North Carolina. For the Yadkin River and the South Yadkin River, he estimated that 50 percent of the total suspended-sediment transported in these drainages occurred over just 2.5 percent of the total time (92 days) during the 10 year period (1970-1979). This result is supported by Richter and others (1995) who determined that in the Yadkin-Pee Dee River 26 percent of total suspended sediment is transported at flows of less than 1 percent exceedance and 71 percent of total suspended sediment is transported at flows of less than 10 percent exceedance. This means that the bulk of the suspended sediment is transported during fairly infrequent storm events. During these events Simmons also found that in the Piedmont physiographic province the size of the suspended-sediment particles were typically silt and clay, which reflects the texture of the soils in this region.

The change in sediment transport over time was examined by several of the authors. The most comprehensive assessment of this was performed by Richter and others (1995). Through a linear regression analysis of the 40 year (1951-1990) discharge and suspended sediment records for the Yadkin College gage these researchers found that the transport of suspended sediment in the Yadkin River basin had decreased approximately 30 percent. The suspected reason for the decline in suspended sediment transport is believed to be associated with a significant decline in the amount of cropland in the basin. Norwood's (2001) update of this work confirmed the decline in suspended sediment concentrations and showed that this trend had continued through to 2000. She also noted that the amount of cropland within the basin had also continued to decline, but that there was an increase in urban land use which may represent a new source of sediment to the Yadkin River, though this may not be observed for some time due to the time lag between land use changes and the basin's response.

While the source of sediment entering the reservoirs is clearly from upstream sources, the determination that the majority of the total suspended-sediment transported occurs during the very high flow events suggests that the mode of reservoir operation may have an impact on sediment transport through the river basin. Reservoirs that operate as run-of-river would tend to pass the higher flow events and the suspended sediment load that is transported with them. In contrast, reservoirs such as High Rock that operate as store-and-release reservoirs store the majority of the inflows during high flow events, slowing transport of the sediment suspended within. The entrapment of a significant portion of the sediment load entering the reservoir system provides benefits to the lower river, which experiences far less sedimentation and turbidity. Moreover, the volume of sediment being trapped in High Rock Reservoir is estimated at less than one-half of one percent of the total reservoir volume annually.

5.3 SEDIMENTATION

The storage of sediment in the basin naturally occurs within its streams and rivers and on their associated floodplains. The construction of the dams and the operation of their associated reservoirs on the Yadkin-Pee Dee River has had an impact on the transport of sediment through the lower portion of the basin. The impoundment of water by High Rock, Tuckertown, Narrows, Falls, Tillery and Blewett Falls dams and the resulting reduction in water velocity at each reservoir have reduced the capacity of the Yadkin – Pee Dee River to transport its sediment, thereby leading to its deposition in each of the six impoundments.

The amount of sediment deposited in the reservoirs depends upon the amount of sediment supplied and the storage or residence time of the water in the impoundment. In the studies performed by the

USDA (1979), Harned and Meyer (1983), Simmons (1993) and Fischer (1993) they estimated the amount of sediment accumulated in the impoundments. In the USDA (1979) report (Table VI in Appendix A) the annual sediment accumulation in the Yadkin Project reservoirs ranged from 1,354,500 tons/year (903 ac.ft./yr) for High Rock Reservoir to 21,000 tons/year (14 ac. ft./yr) at Falls Reservoir, while the estimated annual loss in total storage capacity ranged from 0.36 percent in High Rock Reservoir to 0.05 percent in Narrows Reservoir. The lower capacity loss for Narrows Reservoir is due to the reduction in sediment transport by its accumulation in High Rock Reservoir.

Harned and Meyer (1983) noted that the suspended sediment load at the Yadkin College USGS gage is significantly higher than that reported for the USGS gage in Rockingham. The difference in suspended sediment concentrations between these two stations was assumed to be the result of the deposition of sediment in the six impoundments on the Yadkin-Pee Dee River. Based on these data they estimated that about 73 percent of the suspended sediment transported by the Yadkin-Pee Dee River is retained by the six reservoirs. This equates to approximately one million tons of sediment being deposited into the reservoirs each year. Volumetrically, this represents about 800 ac.ft./year or 0.10 percent of the total volume of the Reservoirs. Simmons (1993) did not provide an estimate for sediment accumulation in any of the Yadkin Project reservoirs.

Fischer (1993) estimated the total amount of sediment accumulating in six of the reservoirs (High Rock, Tuckertown, Narrows, Falls, Tillery and Blewett Falls) by taking the difference between the amount of sediment flowing into and out of the reservoirs. The difference between sediment input and output was 1,342,847 tons or about 78 percent of the total suspended load. If the bedload is considered, the total amount of sediment deposited in the reservoirs would increase to 2,268,000 tons/year or 85 percent of the total sediment load.

The authors note that estimating the sedimentation rates in the reservoirs is partly hindered by the lack of measured bedload. Fischer's (1993) estimate of sedimentation in the reservoirs is based on published values in the literature as opposed to the results of direct measurements in the Yadkin-Pee Dee River. Thus, sedimentation is probably underestimated in the majority of these analyses. The greatest impact would be in the estimation of the rate of sedimentation in High Rock Reservoir, where most of the bedload would be expected to be deposited.

The analysis of the survey data available for High Rock Reservoir reveals that sedimentation has occurred since the construction of the dam in 1917. The bathymetry of the reservoir shows that sediment has accumulated in the upstream areas of the reservoir between the I-85 bridge and Crane Creek. The effect of 80 years of sediment accumulation has been quantified as a reduction of approximately 6 percent of total usable storage capacity in the upper 12 feet of the reservoir.

As mentioned in the previous sections, changes in land use within the watershed have had an effect on the input of sediment to the Yadkin-Pee Dee River and on the amount of sediment deposited in the Yadkin Project reservoirs. Although the decrease in cropland in the basin has resulted in a decline in sediment transport in the river, continued land development may represent a growing source of sediment. Only with the continued basinwide implementation and enforcement of appropriate BMPs and stormwater regulations will reduce the input, transport and deposition of sediment in the Yadkin Basin continue to decline. Ultimately, the benefits of these actions will include the improvement of water quality and aquatic habitat in the basins waters.

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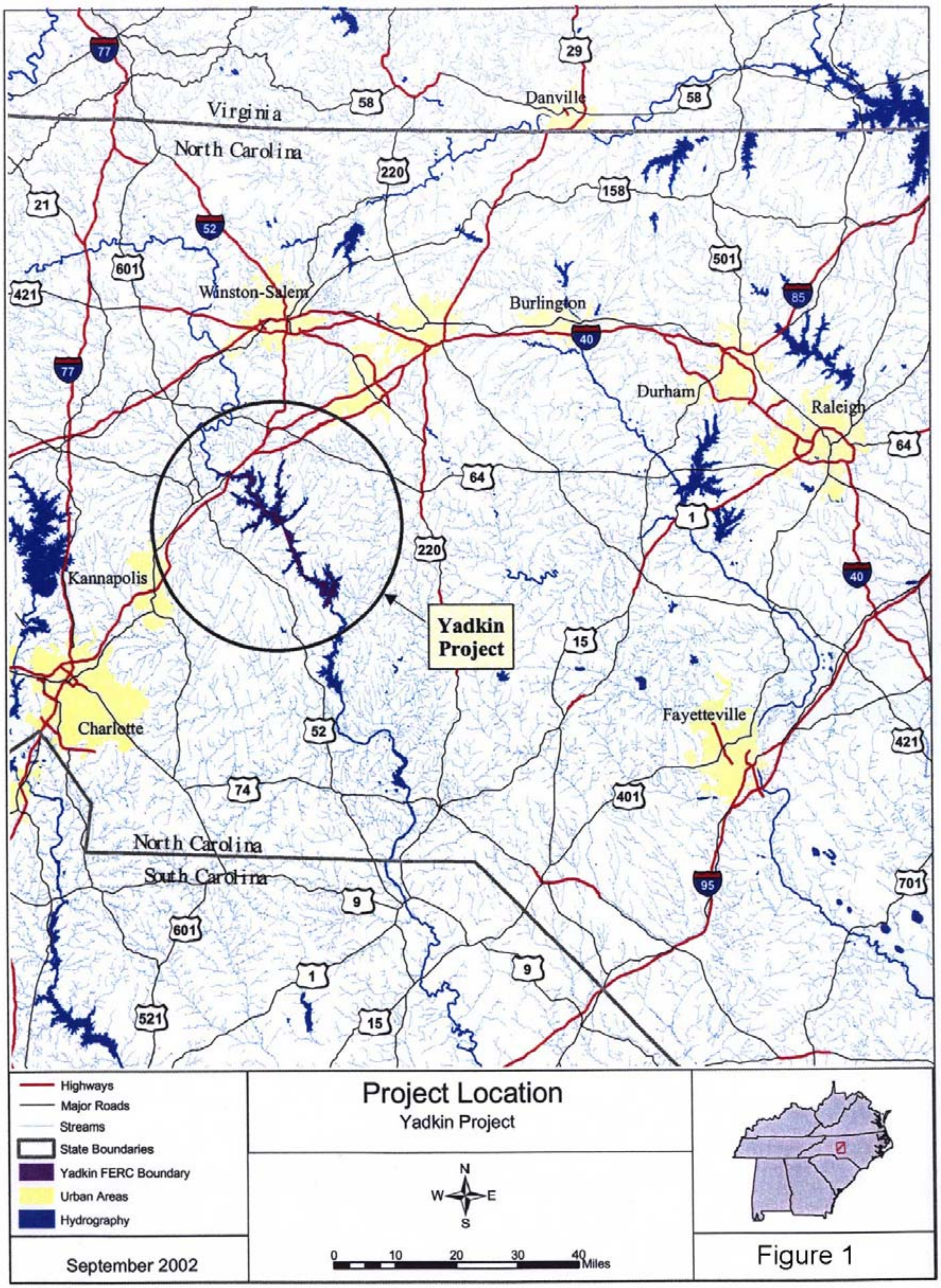
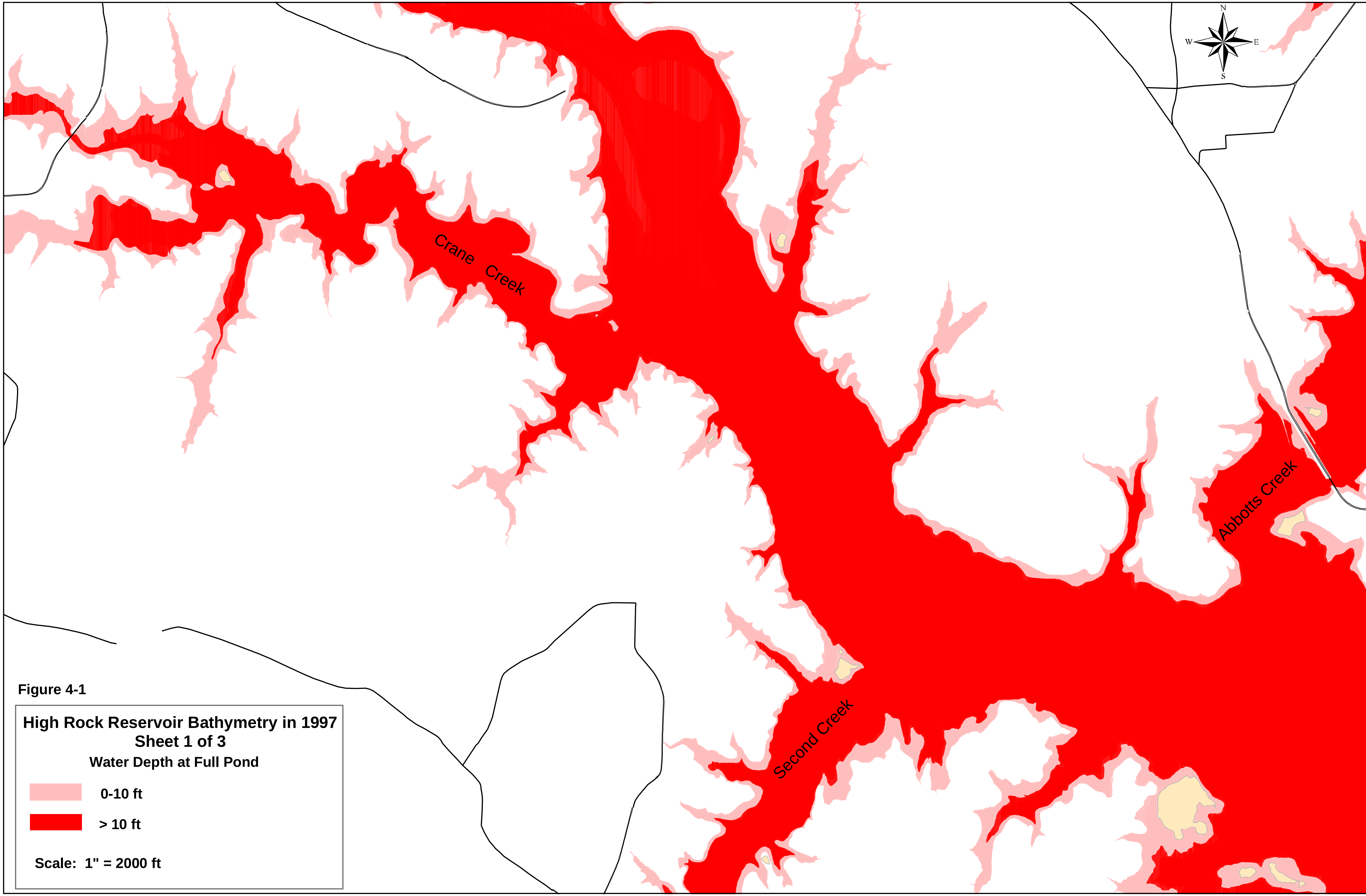
7 LIST OF FIGURES

Figure 1 Location Map of Upper Yadkin River and the Yadkin Project




N
W
E
S
Crane Creek
Abbotts Creek
Second Creek
High Rock Reservoir Bathymetry in 1997
Sheet 1 of 3
Water Depth at Full Pond
0-10 ft
> 10 ft
Scale: 1" = 2000 ft
Figure 4-1

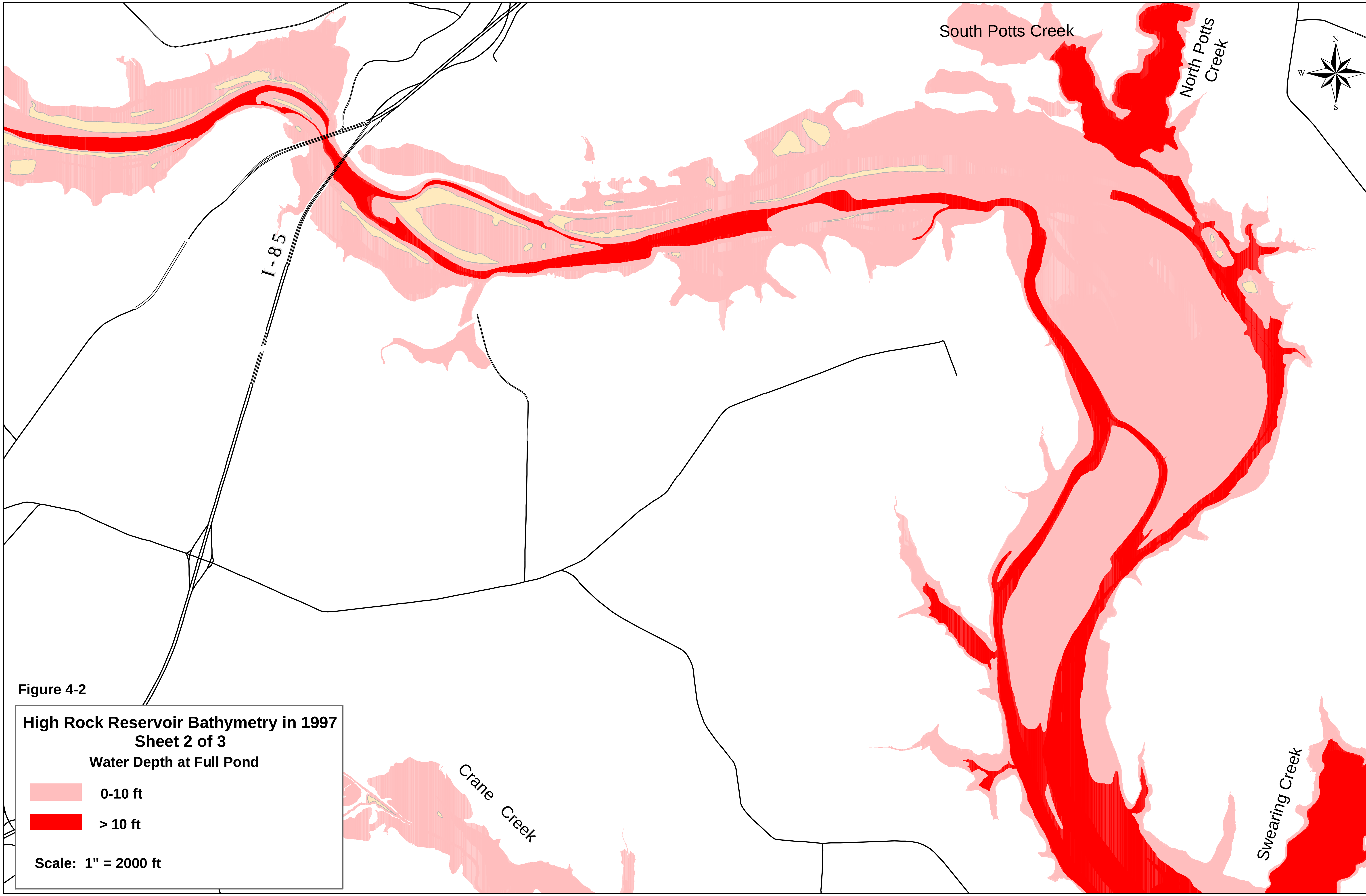
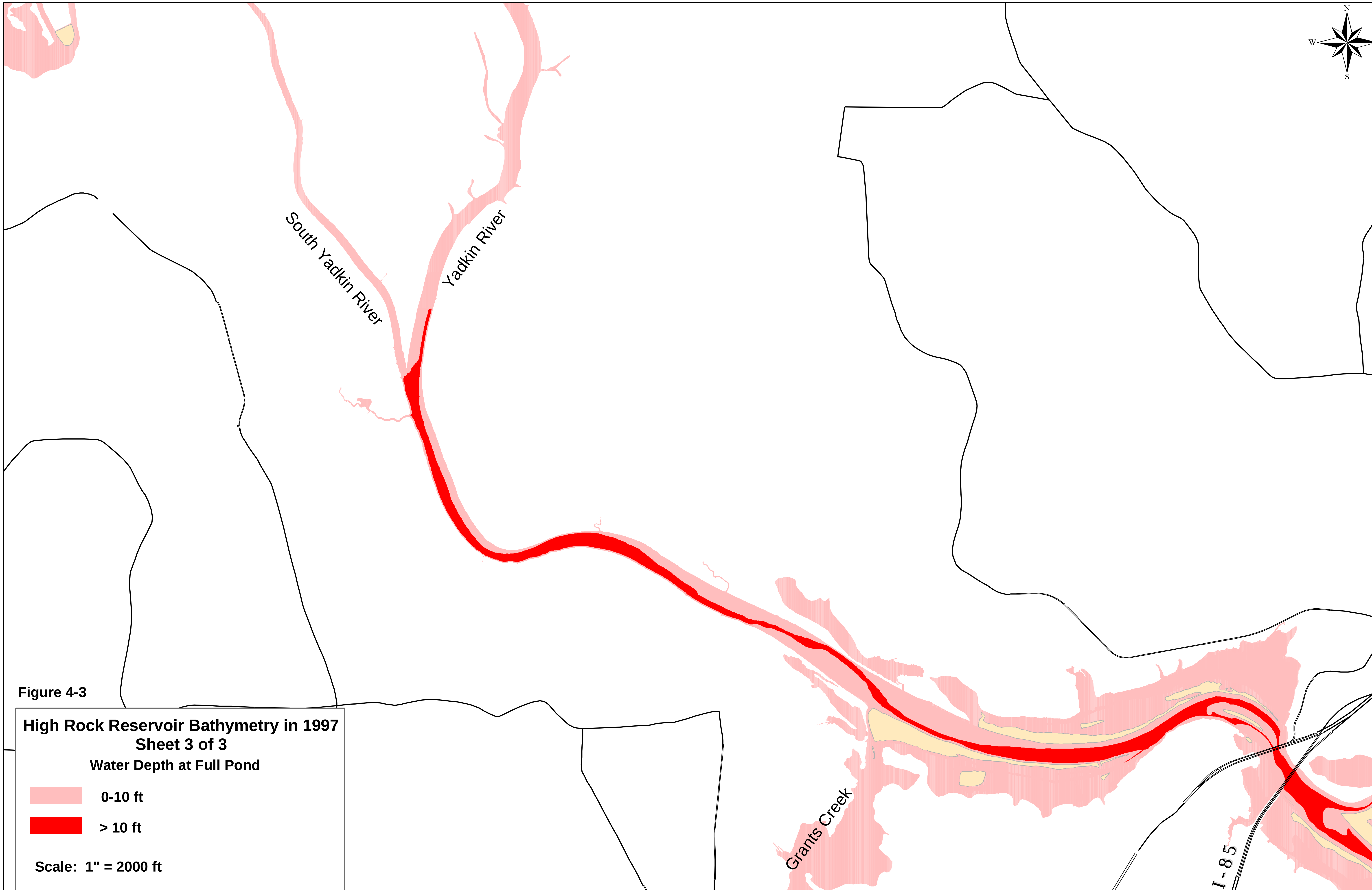

South Potts Creek
North Potts Creek
I-85
Crane Creek
Swearing Creek
N
E
S
W
High Rock Reservoir Bathymetry in 1997
Sheet 2 of 3
Water Depth at Full Pond
0-10 ft
> 10 ft
Scale: 1" = 2000 ft

Figure 4-2


N
S
E
W
South Yadkin River
Yadkin River
Grants Creek
I-85
Figure 4-3
High Rock Reservoir Bathymetry in 1997
Sheet 3 of 3
Water Depth at Full Pond
0-10 ft
> 10 ft
Scale: 1" = 2000 ft

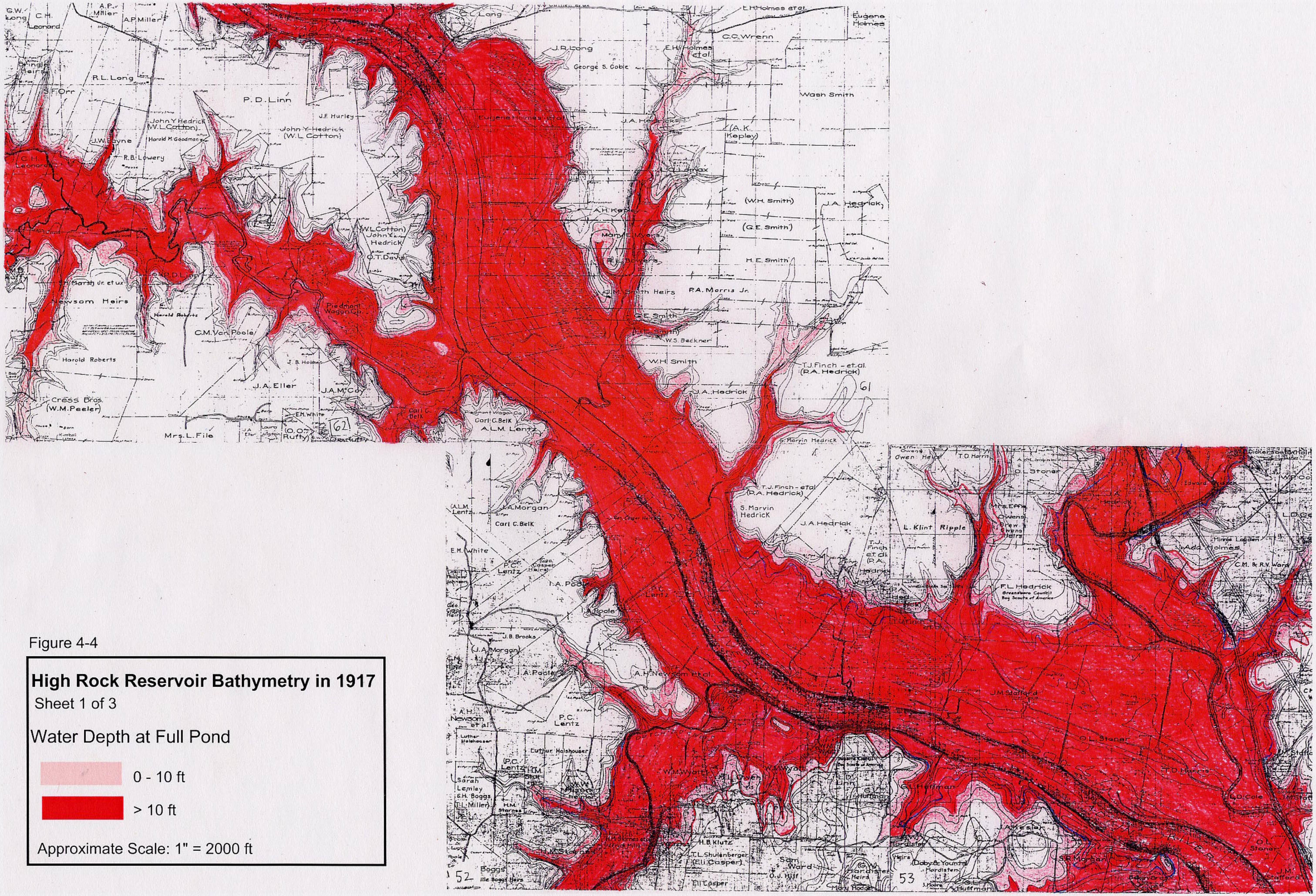


Figure 4-4

High Rock Reservoir Bathymetry in 1917

Sheet 1 of 3

Water Depth at Full Pond

0 - 10 ft

> 10 ft

Approximate Scale: 1" = 2000 ft

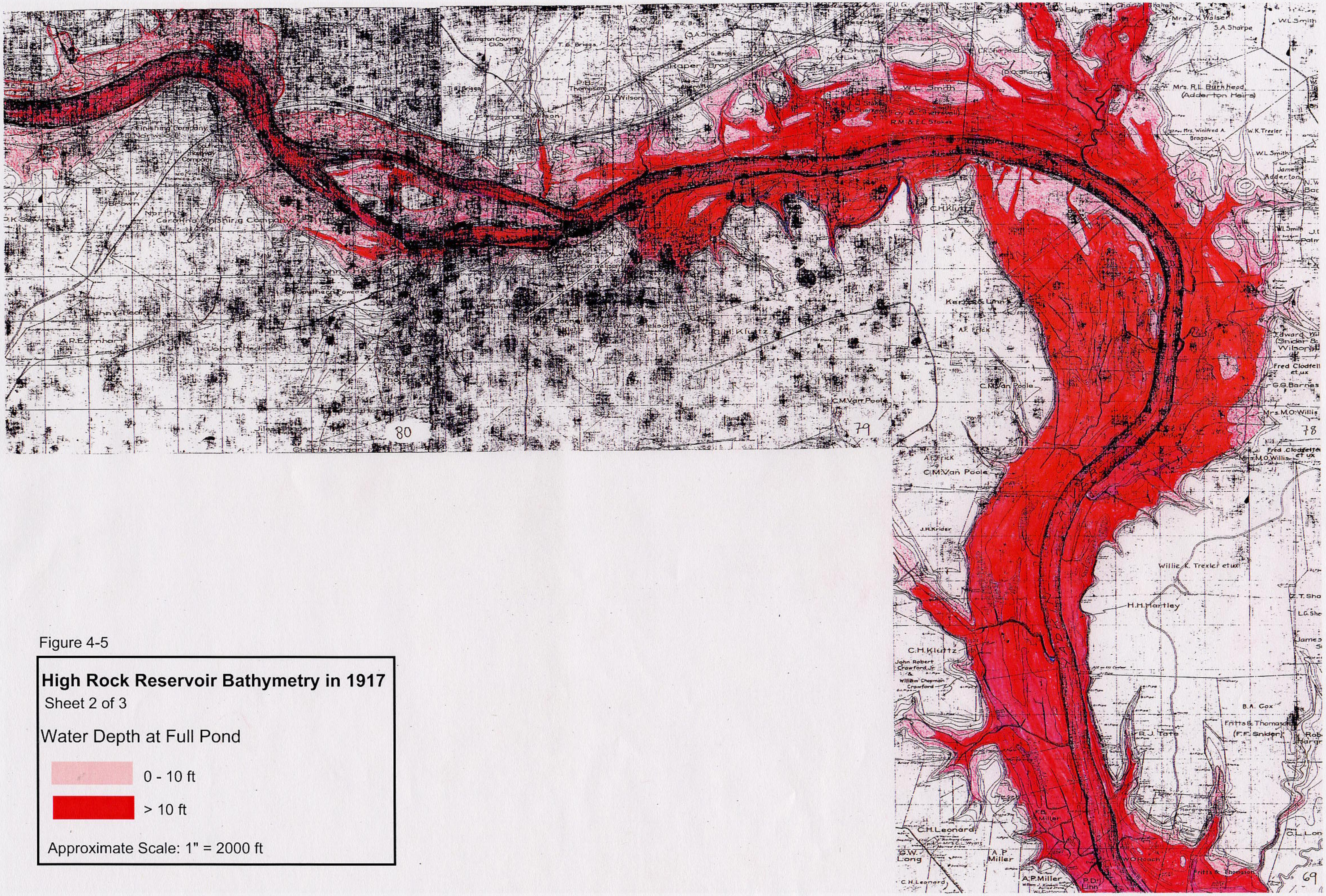


Figure 4-5

High Rock Reservoir Bathymetry in 1917

Sheet 2 of 3

Water Depth at Full Pond

0 - 10 ft

> 10 ft

Approximate Scale: 1" = 2000 ft

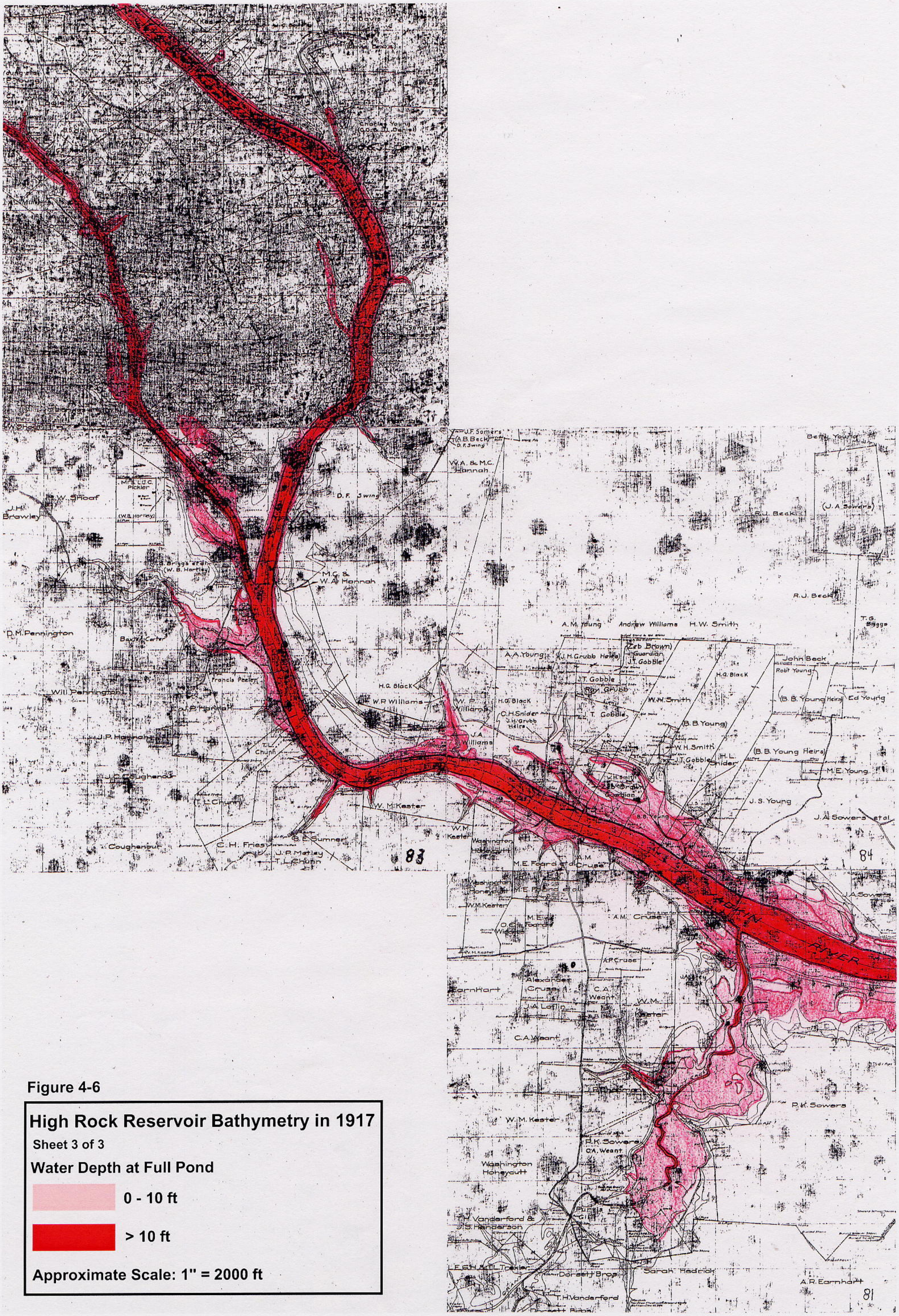


Figure 4-6

High Rock Reservoir Bathymetry in 1917

Sheet 3 of 3

Water Depth at Full Pond

	0 - 10 ft
	> 10 ft

Approximate Scale: 1" = 2000 ft

APPENDIX A

Figures and Tables
Erosion and Sediment Inventory for the Yadkin-Pee Dee River Basin in North and South Carolina

USDA 1979

TABLE III: GROSS EROSION TONS 1/ PER YEAR - COUNTY OR PART COUNTY 2/

YADKIN-PEE DEE RIVER BASIN

State/County	Sheet and Rill: Cropland	Sheet and Rill: Pasture & Hayland	Sheet and Rill: Forest Land 3/	Sheet and Rill: Urban	Sheet and Rill: Other Land	Other Erosion Sources: Rural Road Associated	Other Erosion Sources: Gully & Pit	Other Erosion Sources: Stream Channel	County Totals	Average Erosion Rate/Acre All Sources
NORTH CAROLINA										
Alexander	178,574	4,508	10,894	4,010	130	79,390	678	1,499	279,683	4.17
Alleghany	7,743	382	3,353	178	296	8,164	Minor	298	20,414	1.46
Anson	488,368	5,440	45,999	17,009	7,079	120,443	1,645	4,218	690,201	2.03
Bladen	72,202	513	3,223	7,106	226	43,385	Minor	1,205	127,860	0.67
Brunswick	81,792	47	10,858	1,900	2,269	2,555	Minor	927	100,348	0.32
Cabarrus	558,760	8,580	26,364	64,800	965	68,959	465	35,955	764,848	3.31
Caldwell	80,377	2,788	15,448	9,954	7,138	13,546	762	1,516	131,529	1.73
Columbus	328,172	3,555	7,920	7,005	16,410	96,775	Minor	5,106	464,943	0.86
Cumberland	13,650	75	41	282	271	2,781	Minor	238	17,338	2.11
Davidson	997,948	15,518	48,844	74,675	115,854	416,064	3,629	3,982	1,676,514	4.66
Davie	593,976	9,888	19,963	32,785	20,264	175,848	1,696	9,212	863,632	5.16
Forsyth	584,512	6,899	21,097	58,914	49,178	191,880	1,843	8,036	922,359	5.06
Guilford	3,933	206	524	25,280	3,045	Urban	Minor	187	33,175	2.02
Hoke	207,270	1,157	2,233	3,493	732	23,182	645	702	239,414	2.43
Iredell	1,088,648	25,382	38,764	30,731	5,980	435,935	3,104	8,111	1,636,655	5.30
Mecklenburg	145,919	1,866	11,959	39,380	1,053	11,715	Minor	4,320	216,212	2.38
Montgomery	272,052	2,166	57,995	14,640	660	48,530	556	13,036	409,635	1.53
Moore	103,360	821	3,671	7,695	2,893	16,740	960	7,207	143,347	1.51
Randolph	288,723	1,794	41,489	27,480	550	48,460	431	7,287	416,214	1.95
Richmond	392,480	3,651	11,249	20,190	5,710	73,696	3,053	2,997	513,026	1.70
Robeson	583,882	4,400	6,582	41,539	8,189	100,689	Minor	2,352	747,633	1.24
Rowan	1,145,428	17,611	41,297	58,263	14,544	324,243	3,373	8,166	1,612,925	4.95
Scotland	313,104	2,015	3,365	8,996	66,259	37,961	1,331	467	433,498	2.14
Stanley	753,502	10,518	29,349	32,600	629	72,714	521	3,084	902,917	3.58
Stokes	134,453	1,573	7,510	2,723	6,877	39,895	454	2,034	195,519	4.32
Surry	982,463	20,590	50,224	30,790	14,038	420,631	3,334	4,284	1,526,354	4.60
Union	893,650	12,477	30,019	25,520	1,780	81,880	559	7,874	1,053,759	3.80
Watauga	43,998	4,077	6,447	2,943	1,138	41,220	378	348	100,549	2.67
Wilkes	512,247	18,145	97,318	49,375	65,467	548,770	4,883	14,301	1,310,506	2.71
Yadkin	868,289	11,770	26,954	20,323	19,711	248,966	2,163	2,311	1,200,487	5.63
NORTH CAROLINA TOTAL	12,719,475	198,412	680,953	720,579	439,335	3,795,017	36,463	161,260	18,751,494	

TABLE IV: AVERAGE 1/ EROSION RATES BY LAND RESOURCE AREAS

YADKIN-PEE DEE RIVER BASIN

Land Resource Area	Cropland	Pasture & Hayland	Forest Land 2/	Urban	Other Land	Gully & Pit	Rural Road Associated	Stream Channel	All Sources
	(Tons Per Acre Per Year) 3/					(Tons Per Mile Per Year) 4/			(Tons Per Acre Per Year)
Southern Piedmont	10.7	0.4	0.3	2.0	2.2	897.4	221.0	22.5	3.7
Georgia-Carolina Sand Hills	8.0	0.3	0.05	1.5	1.3	1,584.0	170.0	17.2	2.0
Southern Coastal Plain	3.1	0.3	0.09	1.5	1.6	1,162.0	117.0	12.9	1.3
Atlantic Coastal Flatwoods	2.9	0.02	0.04	0.5	0.12	Minor	14.0	Minor	0.8

1/ Extrapolated from Table II.
2/ Extrapolated from Table II data furnished by the U.S. Forest Service.
3/ To convert to metric tons per hectare per year, multiply by 0.37.
4/ To convert to metric tons per kilometer per year, multiply by 1.46.
SOURCE: SCS River Basin Staff, except as shown in footnote 2.

December 1979

TABLE V: GROSS EROSION BY SUBBASIN

YADKIN-PEE DEE RIVER BASIN

Subbasin Unit Number	Evaluation Point	Unit Area (Sq.Mi.)	Gross Erosion (Tons/Yr.)
NORTH CAROLINA			
03-07-01	Lake Kerr-Scott	350.0	539,885
	basin outlet	818.5	1,341,515
03-07-02	Deep Creek Watershed	27.9*	100,580*
	Little River Watershed	7.1*	19,617*
	basin outlet	1,572.6	3,663,414
03-07-03	Stewarts Creek Watershed	15.5*	45,719*
	basin outlet	208.2	597,637
03-07-04	Salem Lake	25.0	80,960
	High Rock Lake	701.7	2,171,794
	basin outlet	701.7	2,171,794
03-07-05	Dutchman Creek Watershed	29.9*	99,596*
	basin outlet	154.4	510,284
03-07-06	Third Creek Watershed	26.6*	85,110*
	basin outlet	963.1	3,148,511
03-07-07	Lexington-Thomasville Reservoir	70.3	209,663
	basin outlet	254.4	699,893
03-07-08	Tucker Town Lake	158.0	336,244
	Badin Lake	82.6	182,742
	Falls Lake	10.0	21,929
	Lake Tillery	108.5	190,051
	basin outlet	359.1	730,966
03-07-09	Asheboro City Lake	16.3	20,342
	basin outlet	369.4	522,383
03-07-10	Blewett Falls Lake	387.6	495,077
	basin outlet	387.6	495,077
03-07-11	Cannon Lake	18.0	57,024
	Lake Fisher	16.0	50,680
	Concord Lake	4.7	9,956
	basin outlet	272.7	573,042
03-07-12	Lake Stewart	34.8	84,673
	basin outlet	439.0	1,005,794
03-07-13	basin outlet	319.4	698,070
03-07-14	Lake Monroe	40.0	88,320
	Lake Lee	50.3	11,062
	basin outlet	433.1	955,235
03-07-15	basin outlet	346.7	349,032
03-07-16	Ledbetter Lake	83.0	90,304
	Everetts Mill Pond	39.0	42,432
	basin outlet	310.9	348,646
03-07-17	basin outlet	123.5	159,270
03-07-50	basin outlet	264.3	278,618
03-07-51	basin outlet	529.8	438,142
03-07-52	basin outlet	157.7	180,006
03-07-53	basin outlet	426.9	304,743
03-07-54	basin outlet	217.4	172,307
03-07-55	basin outlets	397.2	476,788
03-07-56	Lake Waccamaw	61.6	33,905
	basin outlet	187.4	96,375
03-07-57	basin outlet	579.7	239,317
03-07-58	basin outlet	279.5	141,064
03-07-59	basin outlets	280.7	55,425
SOUTH CAROLINA			
03-07-02	basin outlet	375.5	76,465
03-07-04	basin outlets	101.6	32,784
03-07-06	basin outlet	124.5	21,515
03-07-08	basin outlet	269.8	133,979
03-07-10	basin outlet	533.4	382,093
03-07-12	basin outlet	718.4	834,350
03-07-14	basin outlet	413.0	412,964
03-07-15	basin outlet	125.8	61,967
03-07-16	basin outlet	465.5	229,384
03-07-18	basin outlet	573.2	316,768
03-07-20	basin outlet	361.1	324,861
03-07-22	basin outlet	129.8	94,324
03-07-24	basin outlet	818.0	684,683
03-07-25	Lake Robinson	141.0	129,043
	basin outlet	478.0	560,410
03-07-26	basin outlet	971.1	1,070,373
03-07-28	basin outlet	366.4	369,558
03-07-30	basin outlet	416.8	532,985
03-07-32	basin outlet	193.0	265,422
03-07-34	Site No. 1, Hills Creek	8.4	7,688
	basin outlet	356.2	380,208

* Total above all reservoirs

SOURCE: SCS River Basin Planning Staff.

December 1979

TABLE VI: ANNUAL STORAGE CAPACITY LOSS IN MAJOR RESERVOIRS

YADKIN-PEE DEE RIVER BASIN

Reservoir Identification	Subbasin	Drainage Area (Sq.Mi.)	Original Capacity (Ac.Ft.)	Annual Sediment Accumulation (Ac.Ft.)	Annual Capacity Loss (%)
NORTH CAROLINA					
Kerr-Scott Lake	03-07-01	350.0	153,000	88	0.06
Salem Lake	03-07-04	25.0	356	11	3.09
High Rock Lake	03-07-04	4,506.0	254,000	903	0.36
Lexington-Thomasville	03-07-07	70.3	6,522	39	0.60
Tucker Town Lake	03-07-08	4,120.0	43,000	86	0.20
Badin Lake	03-07-08	4,180.0	279,000	131	0.05
Falls Lake	03-07-08	4,190.0	6,120	14	0.23
Lake Tillery	03-07-08	4,600.0	168,000	115	0.07
Asheboro City Lake	03-07-09	16.3	38,000	5	0.01
Blewett Falls Lake	03-07-10	6,830.0	97,000	147	0.15
Concord Lake	03-07-11	4.7	1,201	3	0.25
Lake Fisher	03-07-11	16.0	3,377	12	0.36
Cannon Lake	03-07-11	18.0	4,140	13	0.31
Lake Stewart	03-07-12	34.8	1,382	15	1.10
Lake Monroe	03-07-14	40.0	1,228	15	1.22
Lake Lee	03-07-14	50.3	1,380	7	0.51
Everetts Mill Pond	03-07-16	39.0	433	5	1.15
Ledbetter Lake	03-07-16	83.0	1,750	10	0.57
SOUTH CAROLINA					
Lake Robinson	03-07-25	141.0	31,000	16	0.05
Hills Creek, Site No. 1	03-07-34	8.4	1,846	7	0.38

TABLE VII: SEDIMENT YIELDS, BEDLOAD AND SUSPENDED, FOR SELECTED POINTS

YADKIN-PEE DEE RIVER BASIN

Subbasin	Location of Evaluation	Total Sediment Tons/Year	Bedload Tons/Year	Suspended Sediment Tons/Year	Total Stream Flow Tons/Year	Average Suspended Sediment Concentration Parts Per Million
NORTH CAROLINA						
03-07-01	Kerr-Scott Lake	148,468	29,694	118,774	508,374,720	234
	Lake outlet	14,847	-	14,847	508,374,720	29
	Subbasin outlet	203,776	40,755	163,021	1,188,870,595	137
03-07-02	Deep Creek Watershed (13 sites)*	4,023	805	3,219	2,522,304	1,276
	Deep Creek Watershed (site outlets)*	402	-	402	2,522,304	159
	Little River Watershed (2 sites)*	4,512	902	3,610	3,026,765	1,193
	Little River Watershed (site outlets)*	451	-	451	3,026,765	149
	Subbasin outlet	769,057	153,811	615,246	1,796,687,585	342
03-07-03	Stewarts Creek Watershed (1 site)*	17,373	3,475	13,898	20,261,331	686
	Stewarts Creek Watershed (site outlet)*	1,737	-	1,737	20,261,331	86
	Subbasin outlet	156,783	31,357	125,426	271,626,048	462
03-07-04	Salem Lake	29,146	5,829	23,317	28,919,520	806
	Lake outlet	11,658	-	11,658	28,919,520	403
	High Rock Lake	1,659,924	331,985	1,327,939	5,212,454,284	255
	Lake outlet & subbasin outlet	282,187	-	282,187	5,212,454,284	54
03-07-05	Dutchman Creek Watershed (7 sites)*	6,118	1,224	4,894	4,375,980	1,118
	Dutchman Creek Watershed (site outlets)*	612	-	612	4,375,980	140
	Subbasin outlet	124,514	24,903	99,611	157,120,404	634
03-07-06	Third Creek Watershed (11 sites)*	3,559	712	2,847	2,776,437	1,110
	Third Creek Watershed (site outlets)*	356	-	356	2,776,437	200
	Subbasin outlet	740,347	148,069	592,278	1,114,095,588	600
03-07-07	Lexington-Thomasville Reservoir	67,092	13,418	53,674	71,538,630	800
	Reservoir outlet	8,051	-	8,051	71,538,630	200
	Subbasin outlet	151,365	30,273	121,092	258,882,324	500
03-07-08	Tucker Town Lake	403,235	24,210	379,025	5,375,116,800	70
	Lake outlet	172,844	-	172,844	5,375,116,800	32
	Badin Lake	240,459	13,523	226,936	5,453,395,200	42
	Lake outlet	40,878	-	40,878	5,453,395,200	7
	Falls Lake	50,307	1,886	48,421	5,466,441,600	9
	Lake outlet	28,675	-	28,675	5,466,441,600	5
	Lake Tillery	239,414	42,148	197,266	6,001,344,000	33
	Lake outlet & subbasin outlet	64,642	-	64,642	6,001,344,000	11
03-07-09	Asheboro City Lake	7,730	1,546	6,184	16,586,595	373
	Lake outlet	387	-	387	16,586,595	23
	Subbasin outlet	140,420	28,084	112,336	375,908,532	299
03-07-10	Blewett Falls Lake	310,868	49,892	260,976	7,960,489,272	33
	Lake outlet & subbasin outlet	87,043	-	87,043	7,960,489,272	11
03-07-11	Concord Lake	4,331	866	3,465	4,741,932	731
	Lake outlet	217	-	217	4,741,933	46
	Lake Fisher	19,512	3,902	15,610	16,142,746	967
	Lake outlet	1,096	-	1,096	16,142,746	68
	Cannon Lake	21,669	4,334	17,335	18,160,589	955
	Lake outlet	1,083	-	1,083	18,160,589	60
	Subbasin outlet	140,175	28,035	112,140	275,132,920	408
03-07-12	Lake Stewart	29,636	5,927	23,709	35,110,472	675
	Lake outlet	6,520	-	6,520	35,110,472	186
	Subbasin outlet	379,241	75,848	303,393	717,948,611	423

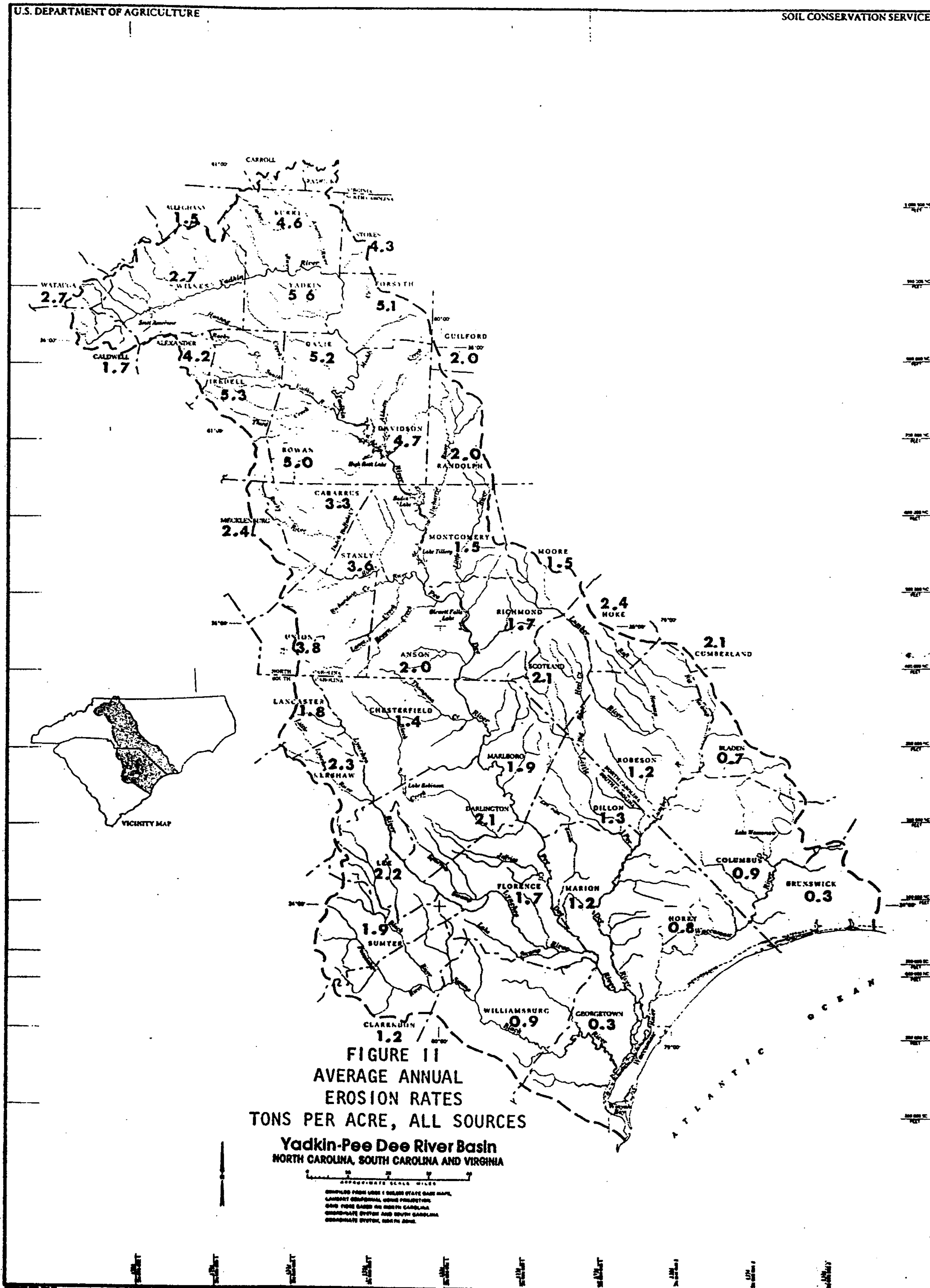


FIGURE 11
AVERAGE ANNUAL
EROSION RATES
TONS PER ACRE, ALL SOURCES

APPENDIX B

Figures and Tables
Sediment Characteristics of North Carolina Streams, 1970–1979

Simmons 1993

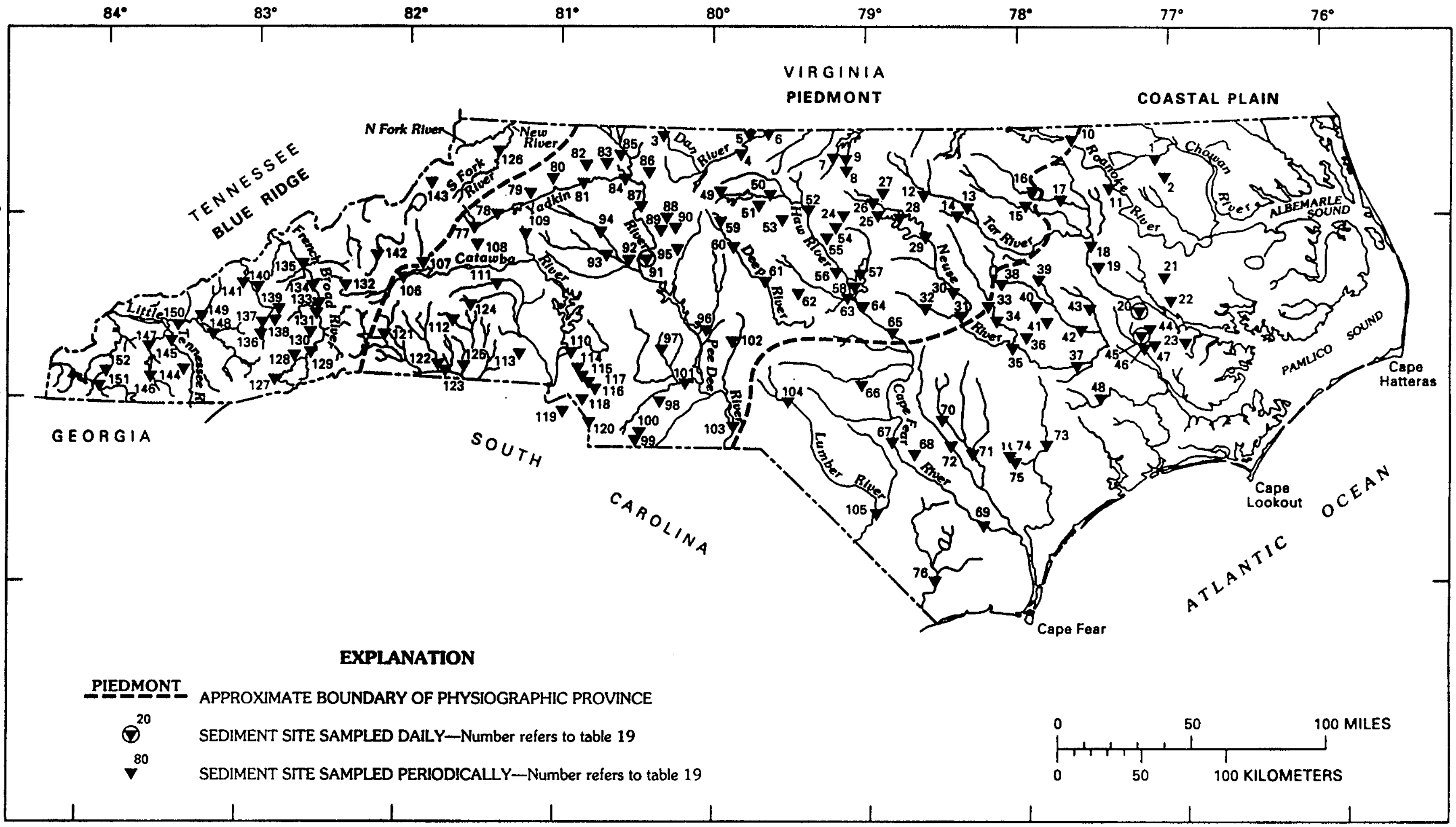


Figure 1. Locations of sediment-sampling sites in North Carolina.

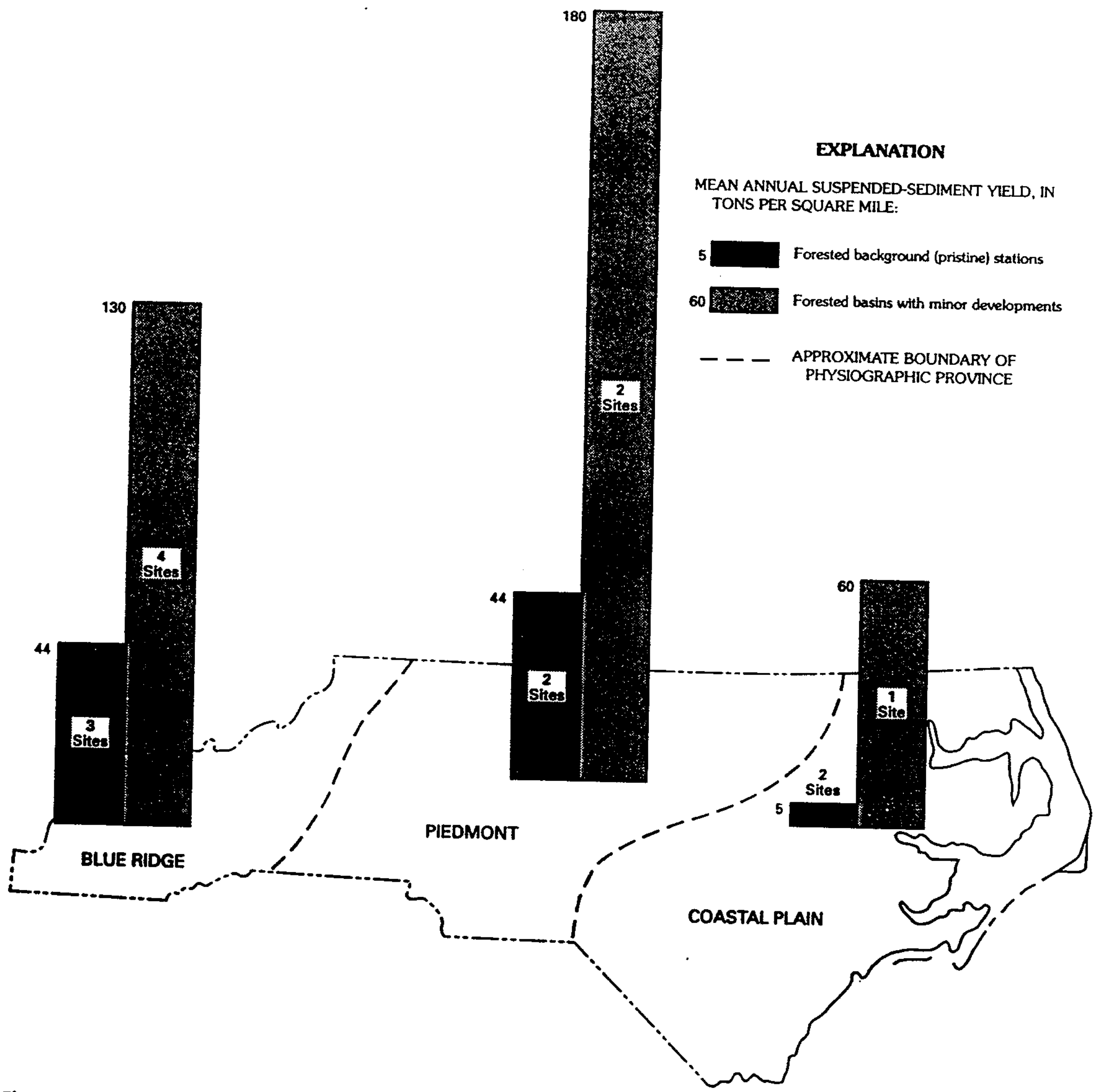


Figure 11. Comparisons of mean annual suspended-sediment yields for forested basins with and without minor development.

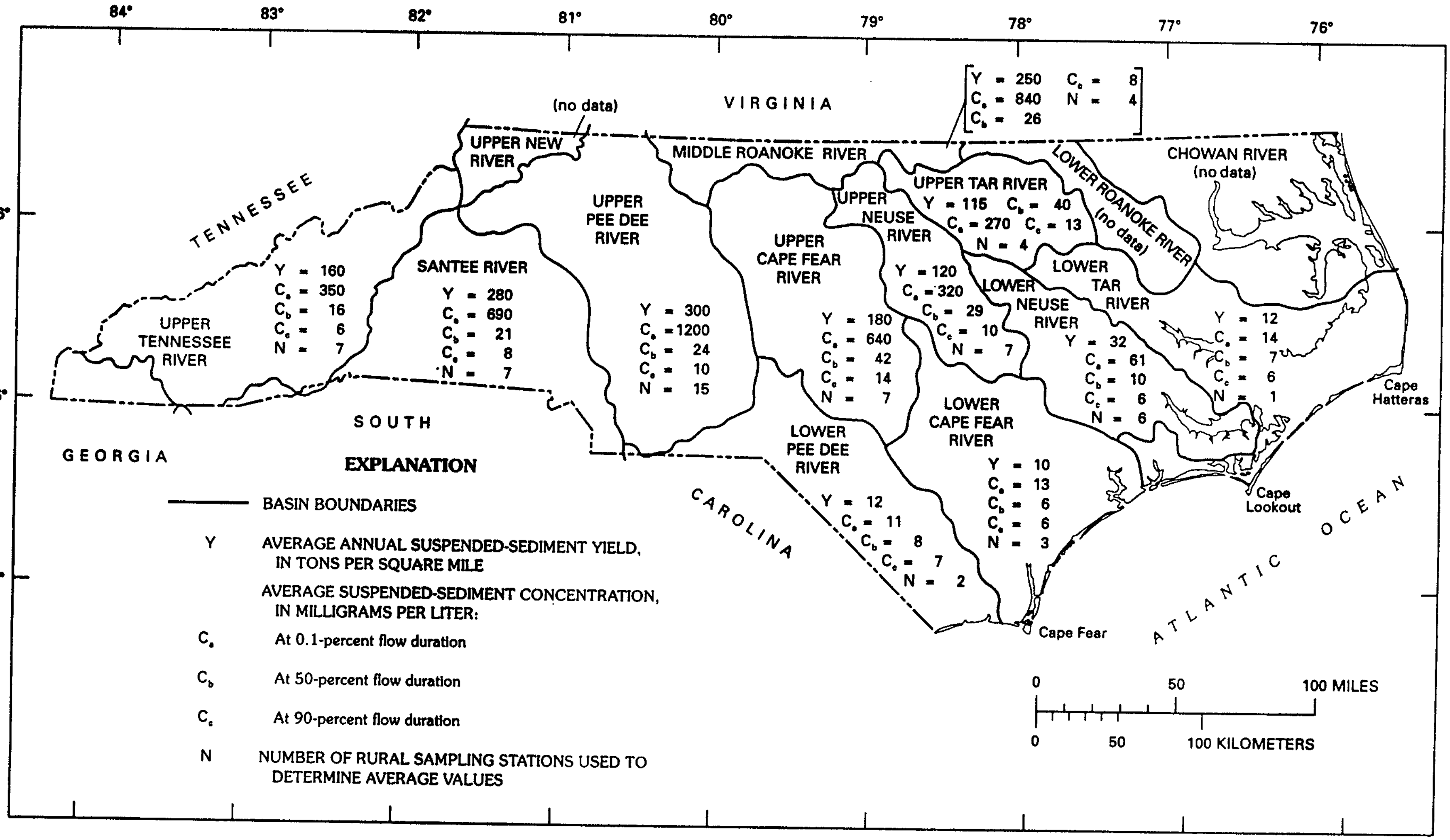


Figure 16. Selected suspended-sediment characteristics, by major river basin, for predominantly rural basins affected by agriculture.

Table 9. Estimated trap efficiencies and related information for major reservoirs affecting suspended-sediment sampling sites, 1970–79

Site number (fig. 1)	Name	Reservoir inflow and storage characteristics				
		Reservoir name	Distance upstream from sampling site (miles)	Normal capacity[1] (cubic feet)	Estimated average annual water inflow (cubic feet)	Estimated trap efficiency[2] (percent)
10	Roanoke River at Roanoke Rapids	Roanoke Rapids Lake	3	3×10^9	210×10^9	52
10	Roanoke River at Roanoke Rapids	Lake Gaston	12	22×10^9	210×10^9	86
11	Roanoke River near Scotland Neck	Lake Gaston	34	22×10^9	210×10^9	86
38	Contentnea Creek near Lucama	Buckhorn Reservoir	1	69×10^6	5×10^9	53
50	Reedy Fork near Gibsonville	Lake Brandt	14	290×10^6	2×10^9	90
103	Pee Dee River near Rockingham	Blewett Falls Reservoir	3	4×10^9	255×10^9	60
137	West Fork Pigeon River below Lake Logan near Waynesville	Lake Logan	3	90×10^6	5×10^9	58
139	Pigeon River at Canton	Lake Logan	11	90×10^6	5×10^9	58
147	Nantahala River at Nantahala	Nantahala Lake	12	6×10^9	16×10^9	95
148	Tuckasegee River at Dillsboro	Dillsboro Powerplant	1	Unknown	25×10^9	Unknown
151	Hiwassee River above Murphy	Chatuge Lake	22	10×10^9	14×10^9	97

[1]Capacity at usable storage.
[2]Estimated from Brune (1953, fig. 6).

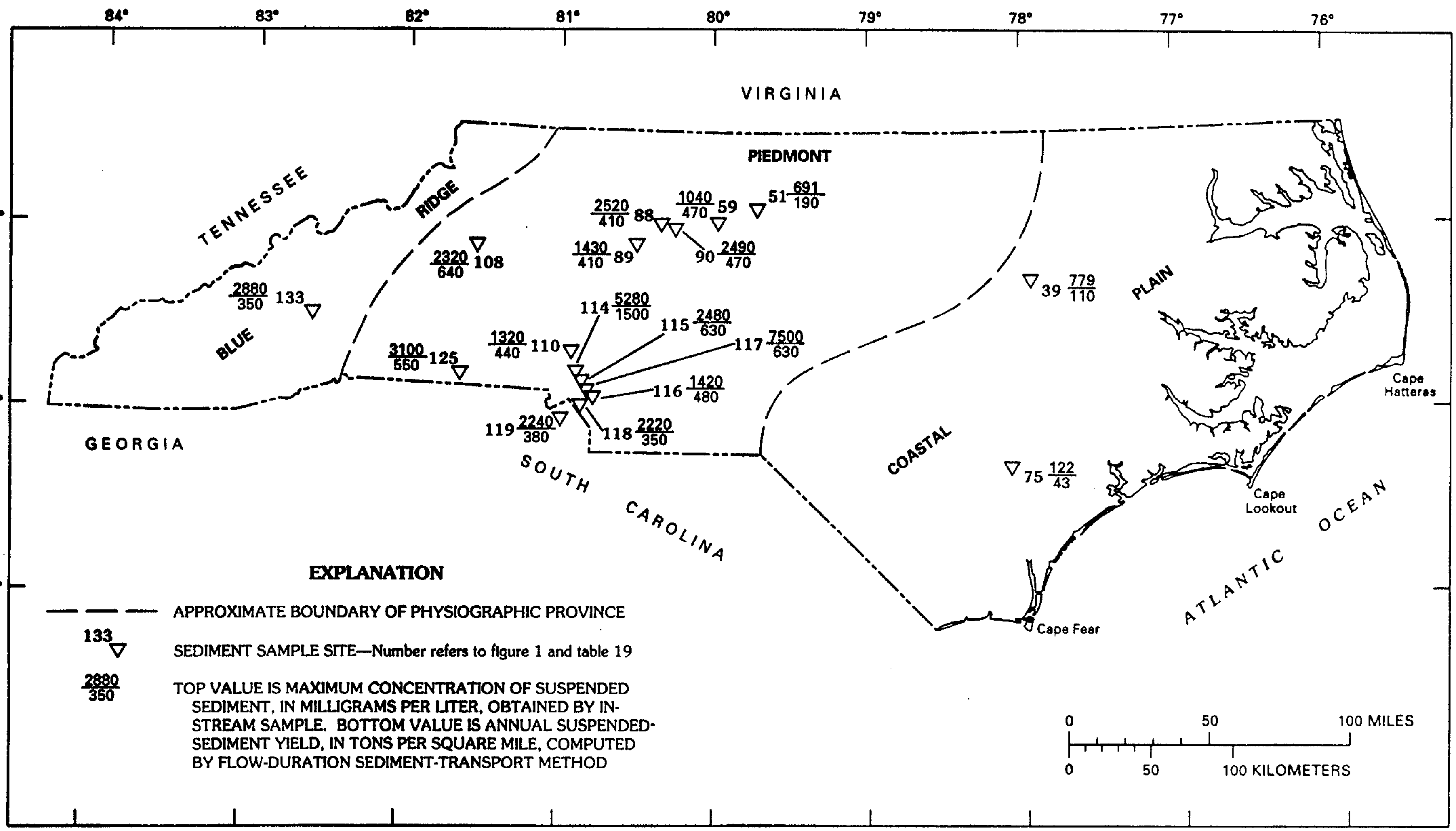


Figure 20. Maximum observed concentration of suspended sediment and mean annual yield at urban sampling sites.

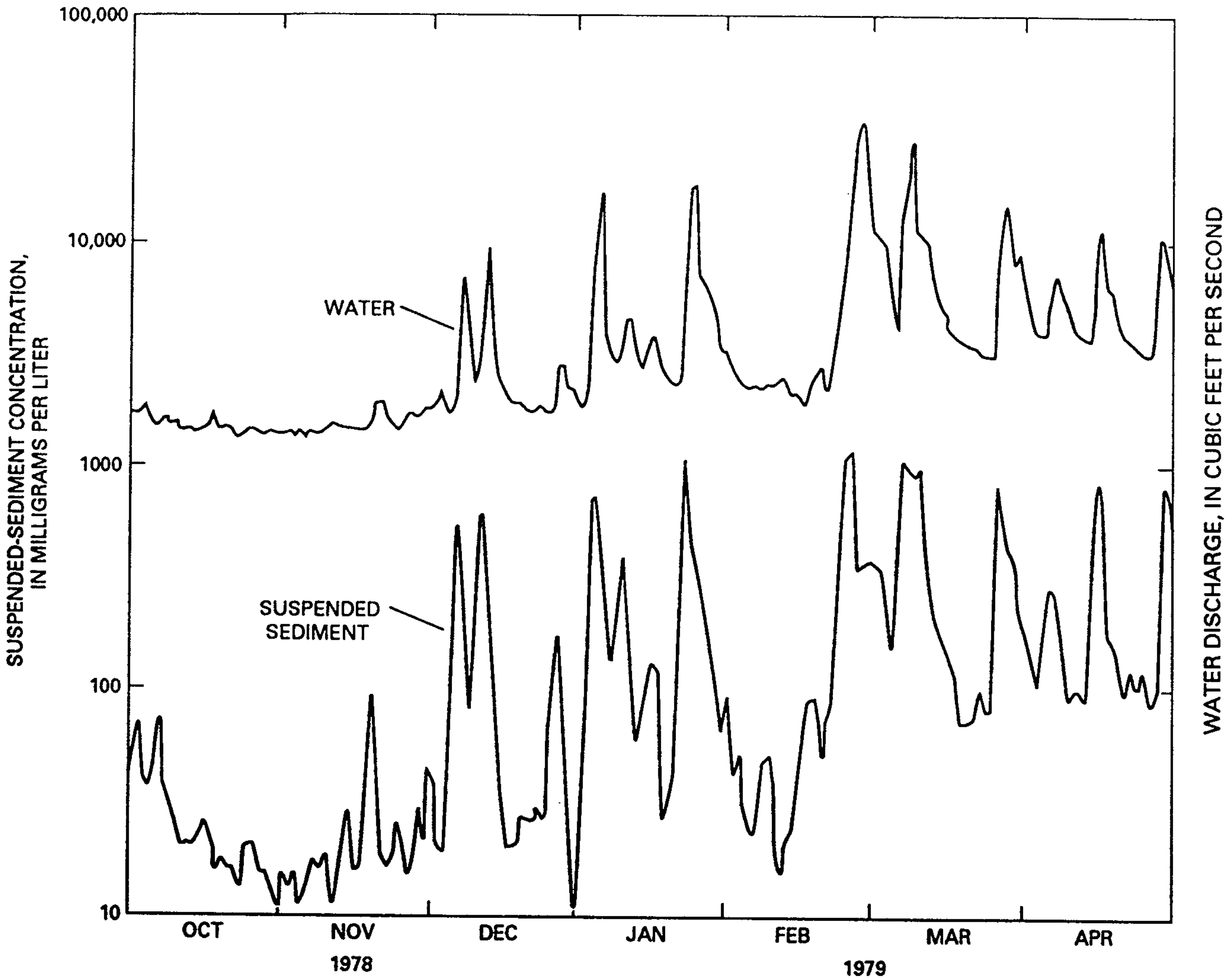


Figure 21. Streamflow and suspended-sediment concentration for Yadkin River at Yadkin College, October 1978–April 1979.

Table 12. Estimated percentage of time required for higher flows at selected stations to transport 25 and 50 percent of sediment and water during 1970–79

Site number (fig. 1)	Name	Drainage area (square miles)	Percentage of time required for higher flows to transport 25 and 50 percent of suspended sediment and water discharge during 1970–79			
			25 percent of total transport		50 percent of total transport	
			Sediment	Water	Sediment	Water
	Blue Ridge Province					
127	French Broad River at Rosman	67.9	0.2	9	0.7	30
130	Mills River near Mills River	66.7	.2	9	2.0	24
131	French Broad River at Bent Creek	676	.5	7	3.9	22
138	East Fork Pigeon River near Canton	51.5	.2	7	.6	20
143	Watauga River near Sugar Grove	92.1	.4	3	3.0	17
149	Oconaluftee River at Birdtown	184	.2	6	1.5	22
	Piedmont Province					
4	Dan River near Wentworth	1,053	0.3	4	0.9	17
7	Hyco Creek near Leasburg	45.9	.2	1	.8	6
12	Tar River near Tar River	167	.4	1	1.6	4
25	Eno River near Durham	141	.2	1	.8	6
32	Middle Creek near Clayton	83.5	.8	2	4.5	10
49	Reedy Fork near Oak Ridge	20.6	.1	2	.4	13
55	Cane Creek near Teer	33.7	.4	1	1.5	5
56	Haw River near Bynum	1,277	.3	2	.9	9
61	Deep River at Ramseur	349	.2	1	.7	6
65	Cape Fear River at Lillington	3,464	.7	3	2.2	10
78	Elk River at Elkville	48.1	.1	3	.4	19
81	Yadkin River at Elkin	869	.5	6	2.4	24
93	South Yadkin River near Mocksville	306	.7	3	2.6	17
97	Big Bear Creek near Richfield	55.6	.1	1	.6	4
111	Henry Fork near Henry River	83.2	.1	4	.4	17
122	Second Broad River at Cliffside	220	.1	5	.4	22
	Coastal Plain Province					
17	Fishing Creek near Enfield	526	0.8	3	3.0	11
18	Tar River at Tarboro	2,183	2.3	4	7.2	13
23	Durham Creek at Edward	26.0	1.5	2	8.1	9
43	Little Contentnea Creek near Farmville	93.3	1.1	3	4.6	8
45	Creeping Swamp near Vanceboro	27.0	.4	2	2.4	4
71	Black River near Tomahawk	676	3.9	6	13	18
72	South River near Parkersburg	379	3.4	5	13	16
76	Waccamaw River at Freeland	680	4.2	4	14	15
105	Lumber River at Boardman	1,228	5.5	6	17	20

Table 16. Gross erosion and sediment-delivery ratio values for selected basins

[mi², square mile; tons/yr, tons per year. Predominant land-use symbols: R, rural-agricultural; N, rural affected by nonagricultural development; D, forested with minor development; U, urban; F, forested (pristine)]

Site number (fig. 1)	Name	Physiographic province	Drainage area (mi²)	Suspended-sediment discharge (tons/yr)	Gross erosion[1] (tons/yr)	Sediment delivery ratio[2]	Predominant land use
8	Double Creek near Roseville	Piedmont	7.47	3,100	22,400	0.14	R
13	Tar River at Louisburg	Piedmont	427	30,000	774,000	.03	R
18	Tar River at Tarboro	Coastal Plain	2,183	93,000	4,520,000	.02	R
26	Little River near Orange Factory	Piedmont	80.4	11,000	144,000	.08	R
27	Flat River at Bahama	Piedmont	149	28,000	262,000	.11	R
29	Neuse River near Falls	Piedmont	772	140,000	990,000	.14	N
43	Little Contentnea Creek near Farmville	Coastal Plain	93.3	3,300	130,000	.03	R
49	Reedy Fork near Oak Ridge	Piedmont	20.6	5,200	66,300	.08	R
58	Haw River near Haywood	Piedmont	1,689	280,000	1,060,000	.26	N
61	Deep River at Ramseur	Piedmont	349	62,000	603,000	.10	R
62	Tick Creek near Mount Vernon Springs	Piedmont	15.5	4,200	47,200	.09	R
63	Deep River at Moncure	Piedmont	1,434	190,000	2,080,000	.09	R
64	Buckhorn Creek near Corinth	Piedmont	76.3	5,800	41,000	.14	D
65	Cape Fear River near Lillington	Piedmont	3,464	420,000	5,710,000	.07	R
66	Flat Creek near Inverness	Coastal Plain	7.63	460	1,600	.29	D
69	Cape Fear River near Kelly	Coastal Plain	5,255	290,000	7,040,000	.04	R
77	Yadkin River at Patterson	Piedmont	28.8	11,000	30,000	.37	R
81	Yadkin River at Elkin	Piedmont	869	300,000	1,440,000	.21	R
95	Leonard Creek near Bethesda	Piedmont	5.16	2,000	13,500	.15	R
99	Lanes Creek near Trinity	Piedmont	4.92	1,100	22,400	.05	R
101	Rocky River near Norwood	Piedmont	1,372	270,000	4,030,000	.07	R
108	Lower Creek at Lenoir	Piedmont	28.1	18,000	28,400	.63	U
110	Long Creek near Paw Creek	Piedmont	16.4	7,200	13,900	.52	U
113	Long Creek near Bessemer City	Piedmont	31.8	11,000	76,600	.14	R
123	Broad River near Boiling Springs	Piedmont	875	340,000	1,070,000	.32	N
124	First Broad River near Casar	Piedmont	60.5	15,000	167,000	.09	R
129	French Broad River at Blantyre	Blue Ridge	296	78,000	254,000	.31	R
135	French Broad River at Marshall	Blue Ridge	1,332	670,000	1,860,000	.36	N
145	Little Tennessee River at Needmore	Blue Ridge	436	110,000	1,120,000	.10	N
146	Nantahala River near Rainbow Springs	Blue Ridge	51.9	3,000	46,300	.06	F

[1]Waller, E.R., Jr., U.S. Department of Agriculture, Soil Conservation Service, Raleigh, N.C., written commun., 1984.

[2]Ratio of suspended-sediment discharge to gross erosion.

Table 18. Relations for estimating suspended-sediment discharge from rural-agricultural and urban basins by soil class (unchannelized basins ranging in size from 1 to 400 square miles)

[SEDQ, annual suspended-sediment discharge; DA, drainage area; AVGQ, average water discharge; ROW, percentage of basin's land area in row crops]

Condition	Soil class (fig. 4)	Regression equation	R^2	Standard error of estimate (percent)
		Rural basins		
Best single variable	1, 3, 4	$SEDQ = 52.9\ DA^{0.801}$	0.776	74
	10, 13	$SEDQ = 204\ DA^{1.00}$	.951	35
	11	$SEDQ = 279\ DA^{0.893}$	.957	25
	14	$SEDQ = 258\ DA^{0.952}$	.560	66
Best three variables	1, 3, 4	$SEDQ = 88.4\ DA^{2.84}\ AVGQ^{-2.20}\ ROW^{0.252}$	0.823	72
	10, 13	$SEDQ = 203\ DA^{0.689}\ AVGQ^{0.335}\ ROW^{0.0035}$	.952	35
	11	$SEDQ = 31.0\ DA^{2.23}\ AVGQ^{1.18}\ ROW^{0.459}$	.966	25
	14	$SEDQ = 1{,}980\ DA^{2.43}\ AVGQ^{-1.37}\ ROW^{-0.543}$	.661	65
		Urban basins		
Best single variable	10, 13	$SEDQ = 671\ DA^{0.909}$	0.885	46

APPENDIX C

Figure

Sources, Sinks, and Storage of River Sediment in the Atlantic Drainage of the United States

Meade 1982

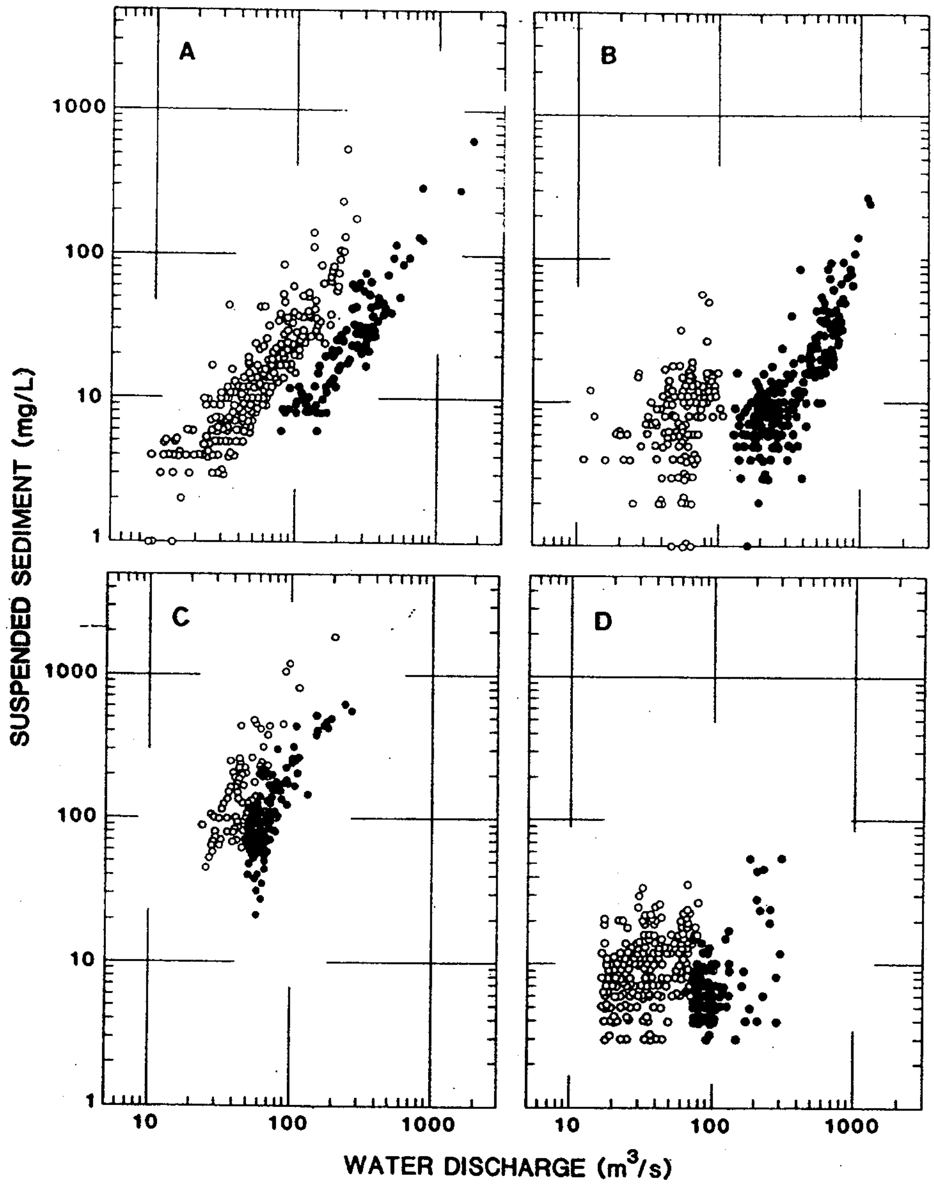


FIG. 2.—Relations between daily concentration of suspended sediment and daily mean discharge of water in rivers draining different physiographic provinces of the Atlantic slope during the 1970 water year. Data from U.S. Geological Survey (1974, p. 94–95, 143–144; 1975, p. 50–51, 503–504). Seasonal differences are indicated by open circles (warm season) and dark circles (cool season). *A*. Juniata River at Newport, Pennsylvania, in the Valley and Ridge Province; cool season was February through mid-May. *B*. Merrimack River at Lowell, Massachusetts, in central New England; cool season was November through mid-June. *C*. Yadkin River at Yadkin College, North Carolina, in the southern Piedmont Province; cool season was mid-December to mid-May; warm-season data from mid-May through early August only. *D*. Edisto River near Givhans, South Carolina, in the southern Coastal Plain; cool season was mid-December to mid-April.

Appendix D

Water Quality of North Carolina Streams, Chapter E: the Yadkin-Pee Dee River

Harned and Meyer 1983

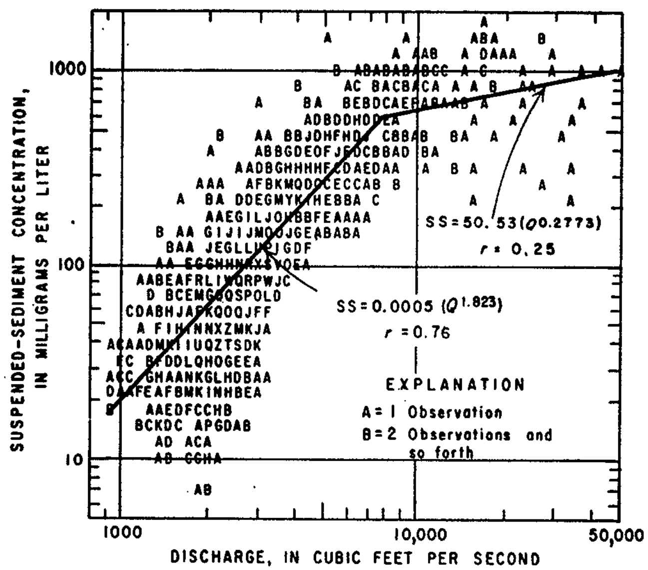


Figure 9. Suspended-sediment concentration versus discharge for the 1974–78 water years at the Yadkin River at Yadkin College (r= correlation coefficient).

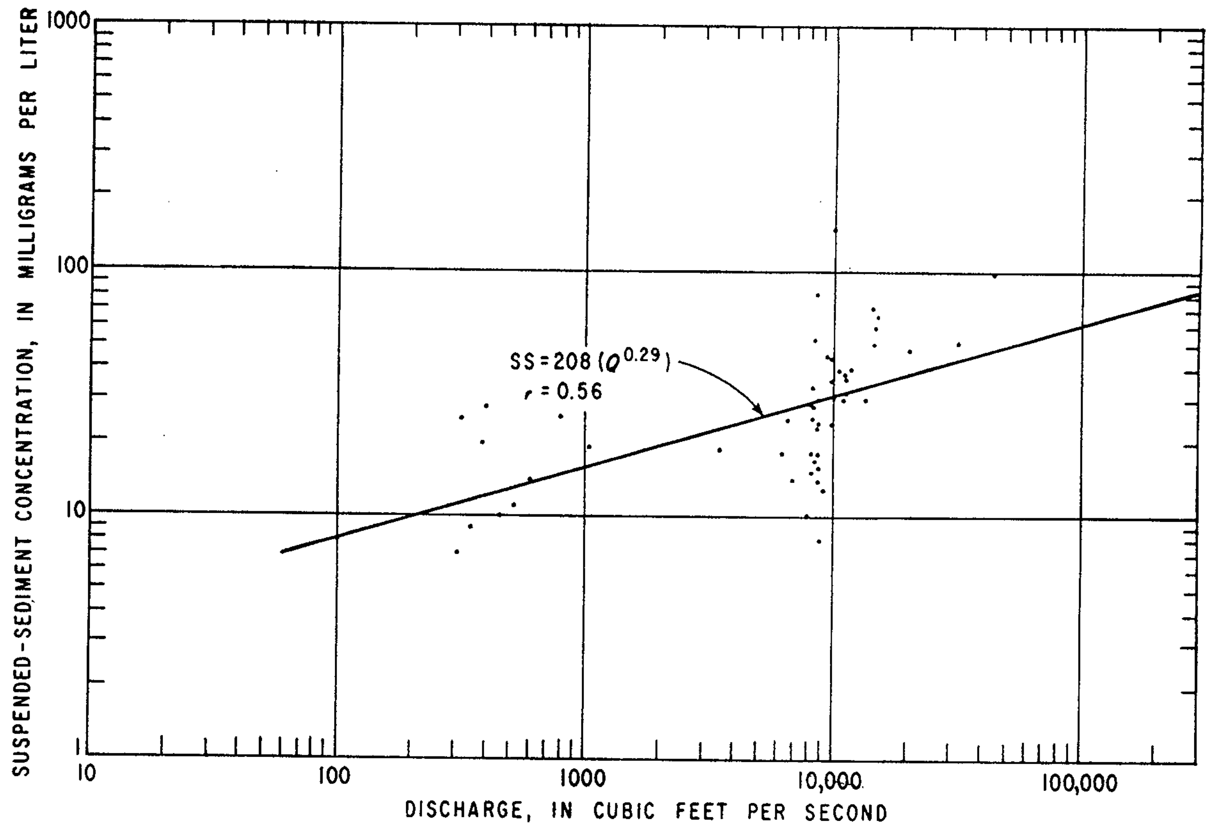


Figure 11. Suspended-sediment concentration (SS) versus discharge (Q) for the 1974–78 water years at the Pee Dee River near Rockingham (r= correlation coefficient).

Table 2. Summary statistics of physical characteristics of the Yadkin River at Yadkin College, the Rocky River near Norwood, and the Pee Dee River near Rockingham (water years 1970–78, unless indicated otherwise)

Physical parameter	Yadkin River at Yadkin College: Mean and 95-percent confidence interval[1]	Yadkin: Range	Yadkin: Number of samples	Rocky River near Norwood: Mean and 95-percent confidence interval[1]	Rocky: Range	Rocky: Number of samples	Pee Dee River near Rockingham: Mean and 95-percent confidence interval[1]	Pee Dee: Range	Pee Dee: Number of samples	U.S. E.P.A. Criteria (1976)
Discharge[2] at time of sampling (ft^3/s)	4,800 (3,800–5,800)	950–41,100	135	5,800 (3,100–8,600)	69–29,100	40	10,300 (8,600–12,000)	309–57,600	97	----------
Discharge daily values (ft^3/s)	2,970	177–80,200	[3]50 yr	1,330	17–10,500	[3]49 yr	7,997	58–276,000	[3]56 yr	----------
Temperature (°C)	16.4 (15.3–17.5)	2.0–28.0	141	14.6 (12.0–17.2)	0.5–33.0	45	18.5 (17.4–19.7)	2.0–30.0	151	----------
Dissolved oxygen (mg/L)	8.9 (8.6–9.2)	2.1–13.7	128	10.0 (9.2–10.7)	6.0–15.1	42	8.3 (7.9–8.7)	3.8–16.2	134	Freshwater aquatic life: 5.0 mg/L minimum.
pH[4]	6.4 (6.4–6.5)	5.7–7.5	94	6.7 (6.4–7.3)	5.5–8.0	39	6.5 (6.3–6.6)	5.3–8.0	156	Domestic water supply 5.9 pH units. Freshwater aquatic life: 6.5–9 pH units.
Suspended sediment (mg/L)	158 (147–169)	7.0–1,670	1,461	149 (91–207)	3–538	29	33 (26–40)	7–147	53	----------
Turbidity (JTU)[5]	31.5 (—)	9.0–57.0	4	62.2 (—)	5.0–93.0	2	27.2 (19.6–34.8)	1.0–120.0	49	----------

[1] The 95-percent confidence interval means that with 95-percent confidence, we estimate the mean to fall within the given range (in parentheses), assuming that the number of samples is large enough, and that the samples are randomly collected.
[2] Discharge measurements made during water-quality sampling, used in all water-quality calculations.
[3] Years given are period of record.
[4] Means are calculated from mean hydrogen-ion concentration.
[5] JTU is Jackson Turbidity Unit.

Table 3. Annual suspended-sediment transport and estimates of minimum sediment deposition in the Yadkin-Pee Dee lakes

Water year	Station	Mean annual discharge (ft^3/s)	Annual sediment transport (tons)	Sediment remaining in lakes: Yadkin College + Mocksville + Norwood − Rockingham =			
				Tons	Acre-feet	Percentage of lake volume	Percentage
1974	Yadkin College	4,000	1,462,000				
	Mocksville	404	44,000	1,273,000	974	0.12	22
	Norwood	1,218	130,000				
	Rockingham	9,516	363,000				
1975	Yadkin College	3,919	1,522,000				
	Mocksville	487	180,000	1,558,000	1,192	.15	28
	Norwood	2,492	453,000				
	Rockingham	13,000	597,000				
1976	Yadkin College	2,711	714,000				
	Mocksville	273	15,000	590,000	451	.06	26
	Norwood	868	73,000				
	Rockingham	6,683	212,000				
1977	Yadkin College	2,743	608,000				
	Mocksville	312	53,000	622,000	476	.06	35
	Norwood	1,661	302,000				
	Rockingham	8,428	341,000				
1978	Yadkin College	3,840	1,423,000				
	Mocksville	457	122,000	1,408,000	1,078	.13	25
	Norwood	1,791	324,000				
	Rockingham	10,630	461,000				
Mean				1,090,200	834	.10	27

APPENDIX E

Decreases in Yadkin River Basin Sedimentation: Statistical and Geographic Time-Trend Analyses, 1951 to 1990

Richter, Korfmacher and Nau 1995

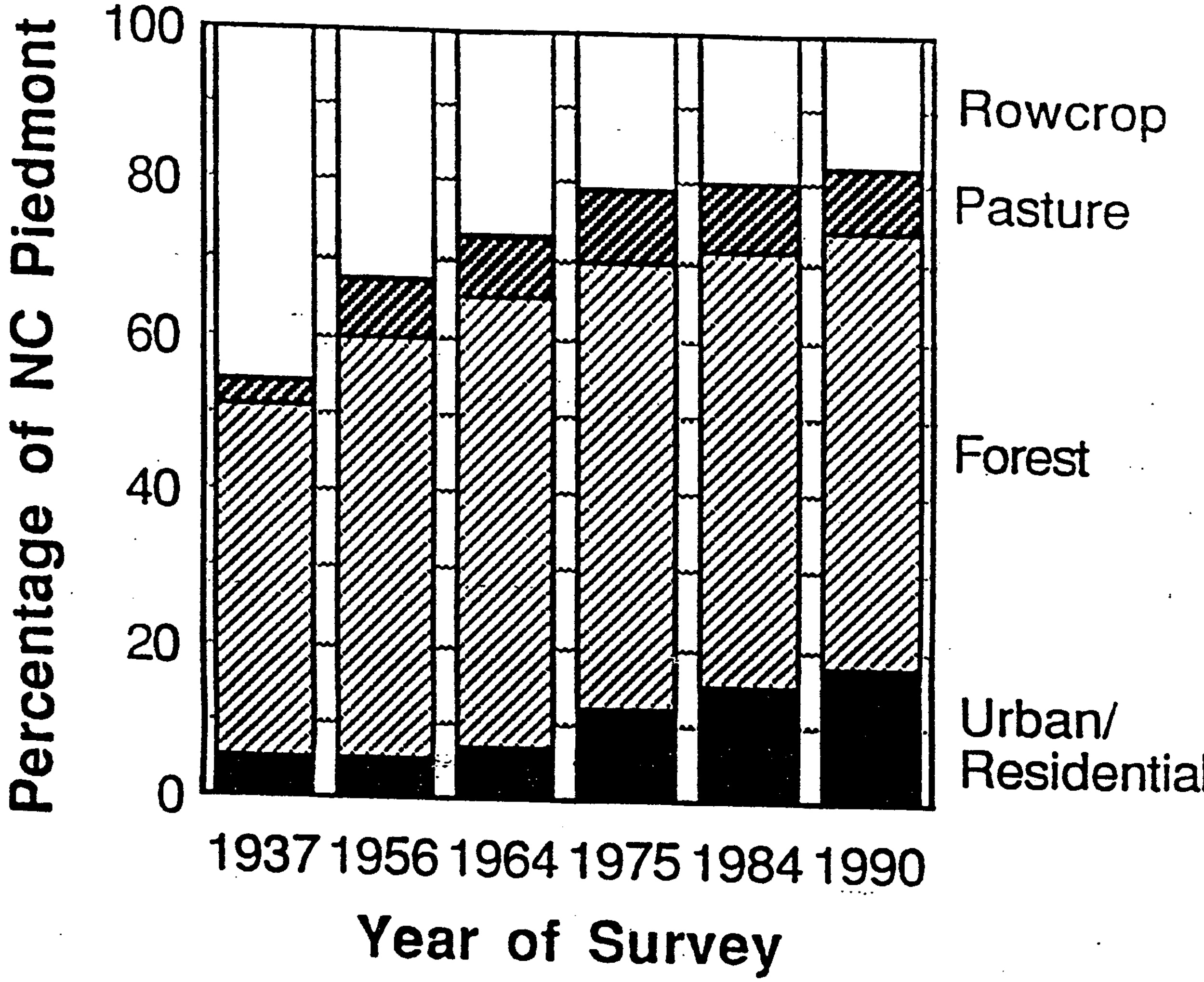


Figure 5. General land uses (1937-1990) of the North Carolina Piedmont, based on six forest inventories of the U.S. Department of Agriculture Forest Service (Brown, 1991).

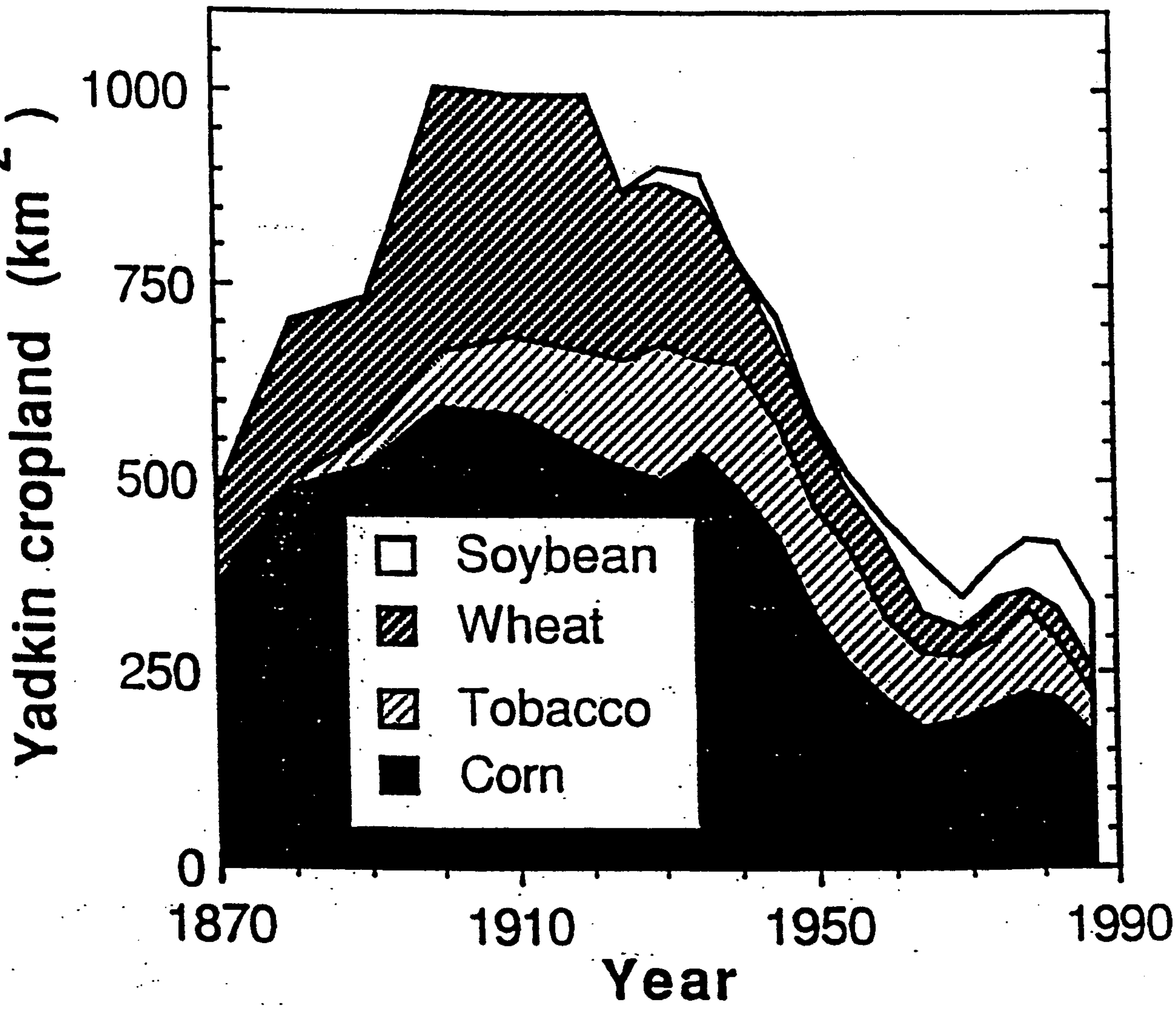


Figure 6. Time trends of land use in the U.S.A.'s southern Piedmont for major crops of the Yadkin River basin (1870-1987), based on 20 U.S. Department of Commerce Census of Agriculture inventories (Bureau of the Census, 1987).

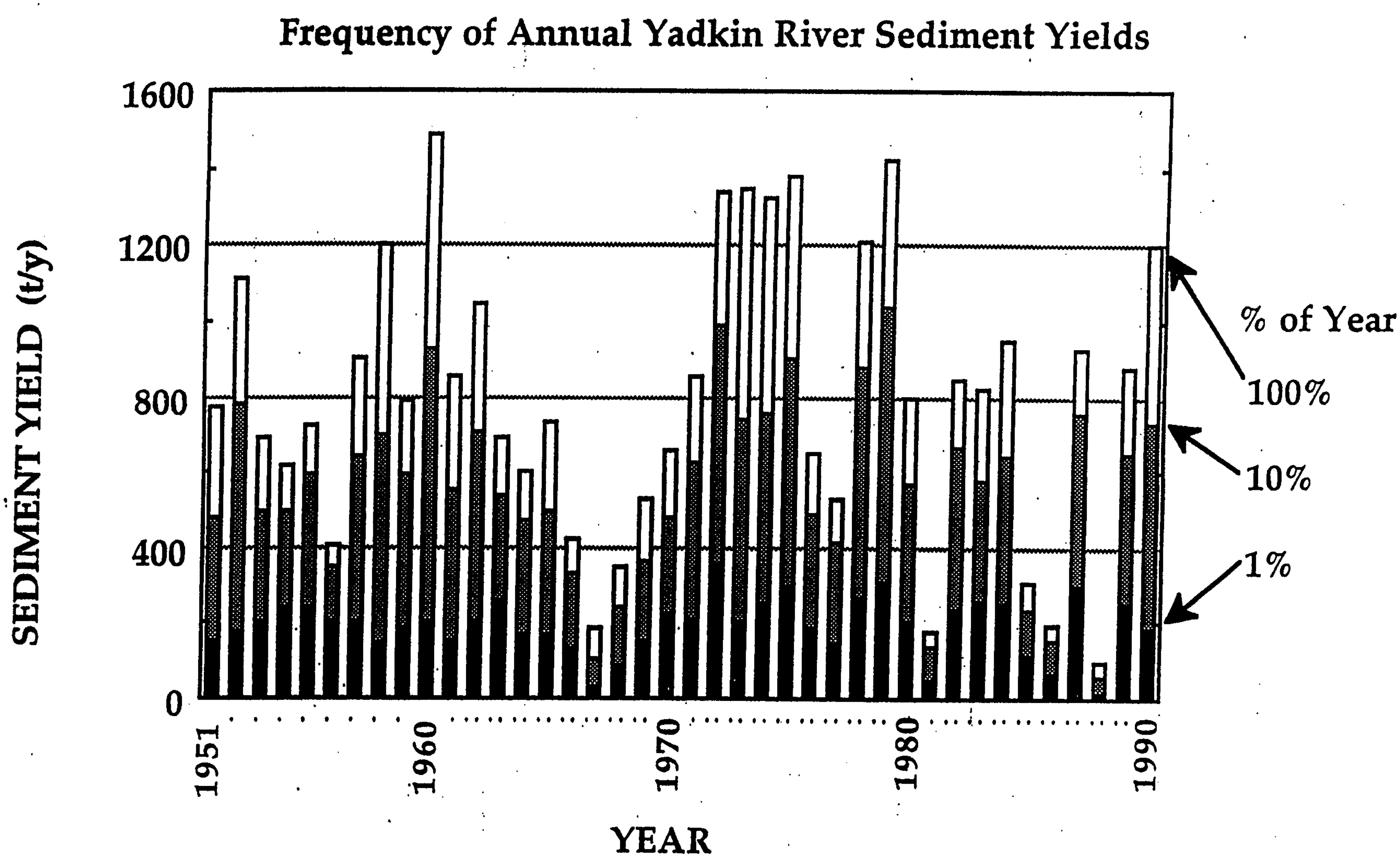


Figure 12. Frequency analysis of Yadkin River sediment transport or yields illustrated by year 1951-1990. Black bars represent the volume of sediment transported during the top 3 to 4 events (1%) of a year and grey bars represent the volume of sediment transported during the top 36 to 37 events (10%) of a year. Cumulative, annual totals (100%) are represented by all three sections.

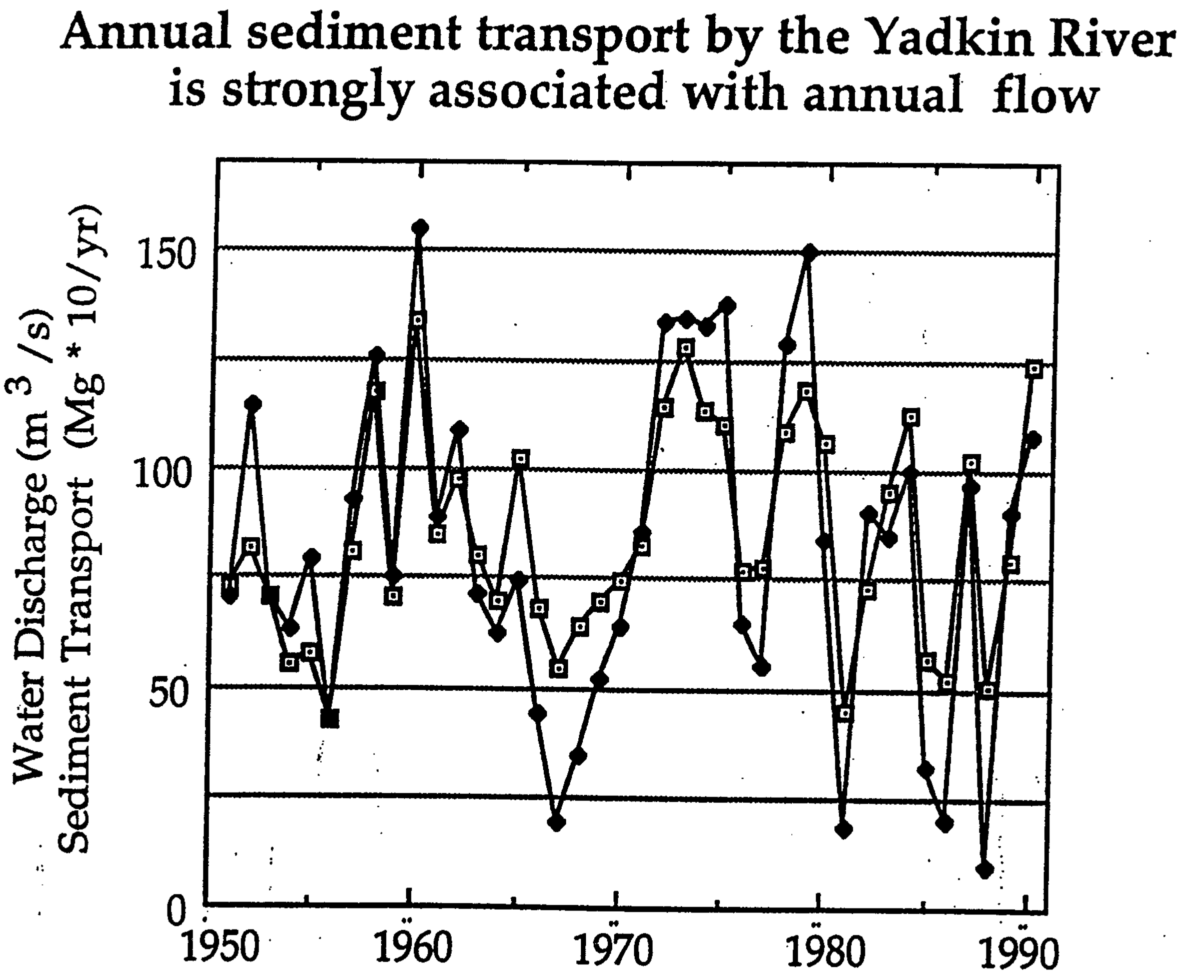


Figure 13. The association of annual suspended sediment transport and discharge in the Yadkin River. Sediment transport is illustrated by filled diamonds and discharge by open squares.

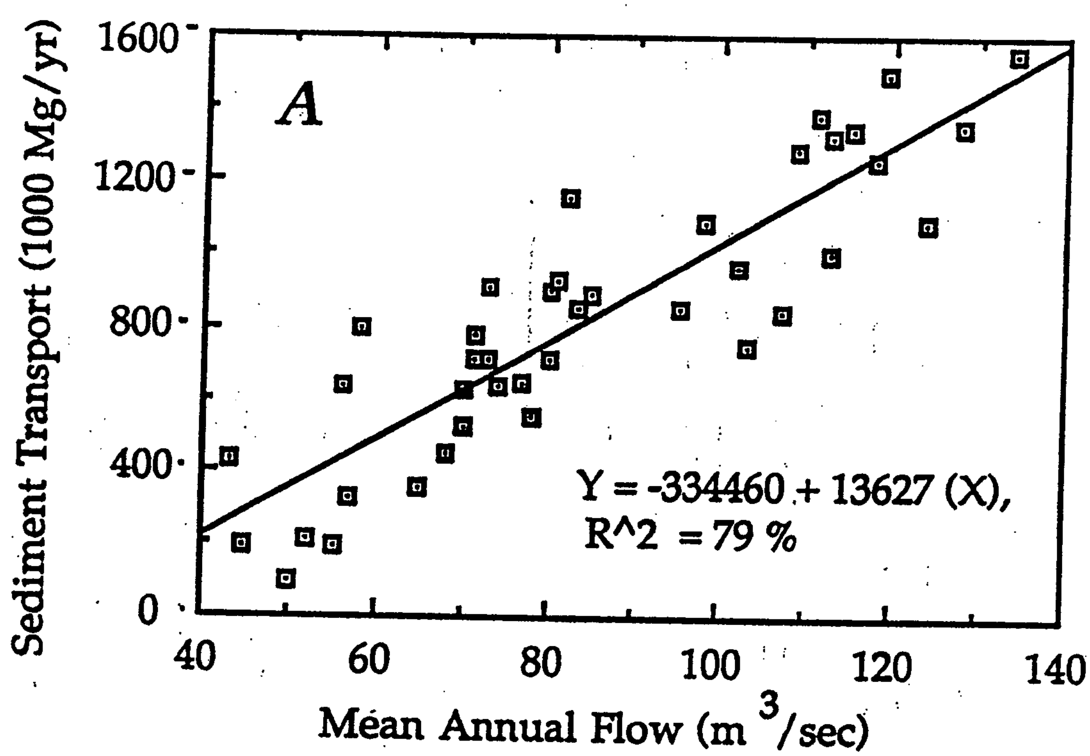


Figure 14. Linear regression of annual discharge and sediment transport in the Yadkin River.

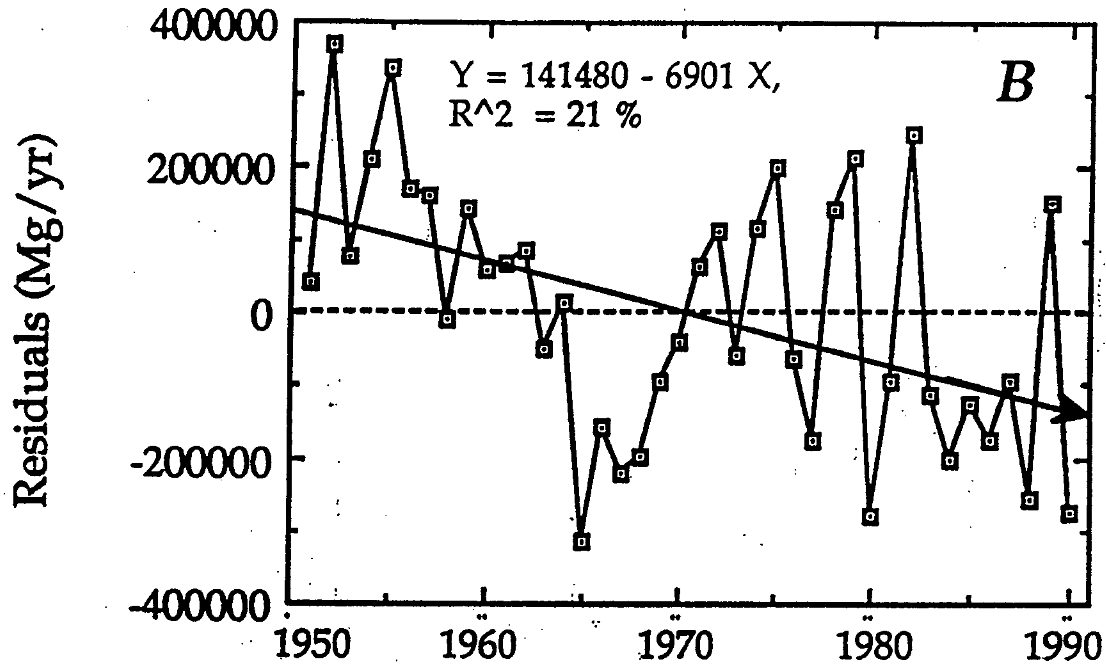


Figure 17. Time-ordered residuals of linear regression illustrated in Figure 14 illustrating significant improvement of 6901 Mg/yr less sediment being transported by the Yadkin River since 1951.

Table 5. Summary of four-county land use statistics for the Yadkin River basin (Bureau of the Census, 1987).

Attribute	Unit	1987	1982	1978	1974	1969	1964	1959	1954	1950	1945	1940	1935	1930	1925
Farms	Number	4298	5130	5571	5975	7714	9081	10726	14460	16019	15418	16258	16828	15577	15920
Farmland Area	1000 ha	164	182	191	197	241	280	307	351	387	390	411	431	410	428
Farmland/County Land	%	31.2	34.4	36.1	37.1	45.4	52.4	57.5	65.8	72.4	73.1	77.0	85.2	81.0	84.6
Mean Farm Area	ha	38.2	35.4	34.4	33.0	31.2	30.8	28.6	24.3	24.1	25.6	25.3	25.6	26.3	26.9
Total Cropland Area	1000 ha	85.3	90.5	93.0	90.4	98.9	94.9	101.8	116.6	130.3	142.0	165.2	161.4	153.4	138.3
Harvested Cropland	1000 ha	46.1	51.6	52.2	47.6	43.4	54.7	65.8	79.8	81.7	98.1	99.1	102.9	98.3	98.6
Grazing Cropland	1000 ha	-	27.6	27.2	29.9	30.0	14.6	8.9	12.1	13.1	13.8	30.1	24.2	21.7	24.2
Harvested/Farm Area	%	28.1	28.4	27.3	24.2	18.0	19.6	21.4	22.7	21.1	23.9	24.1	23.9	24.0	23.0
Specific Harvested Crops															
Corn	1000 ha	9.02	15.46	19.21	17.98	16.35	15.24	18.56	22.26	27.24	36.02	41.52	45.49	42.45	43.63
Tobacco	1000 ha	4.54	6.60	9.00	7.22	6.85	8.16	9.07	13.09	12.27	12.95	13.88	10.20	14.93	12.10
Soybean	1000 ha	6.75	7.59	5.80	4.36	3.62	6.06	1.95	1.84	1.29	2.55	-	2.35	1.78	-
Hay	1000 ha	16.89	13.70	14.25	12.09	10.22	16.23	21.00	27.15	25.21	22.66	15.82	14.49	7.85	9.59
Harv'd Crops w/o hay	1000 ha	29.24	37.86	37.99	35.51	33.20	38.49	44.80	52.70	56.54	76.50	83.33	88.42	90.41	89.03

Table 7. Distribution of general land use for the 185 sample areas in 1955, 1975, and 1988, and a comparison with the total basin coverage estimates of land use in 1975. 1955 and 1988 estimates based on aerial photography. 1975 data are from 1:250,000 U.S.G.S. Land Use/Land Cover (LULC) data. Combined cropland and pasture areas from the 1987 U.S.D.C. Agriculture Census and the 1987 N.R.C.S. Natural Resource Inventory (NRI) data for Forsyth, Surry, Wilkes, and Yadkin counties are provided for comparison.

	GIS Stratified Sample						Total Basin	
Land Use	1955		1975		1988		1975	
Class	km^2	%	km^2	%	km^2	%	km^2	%
Urban	12.3	6.63	15.7	8.68	22.1	11.94	461.4	7.82
Agriculture	50.5	27.28	51.8	28.63	43.5	23.27	1798.0	30.50
Forest	110.3	59.60	112.6	62.24	109.5	59.20	3596.0	60.99
Water	0.6	0.30	0.5	0.28	1.0	0.56	21.2	0.36
Other	11.5	6.22	0.3	0.16	9.3	5.04	19.4	0.33
Total	185.0		181.0		185.0		5896.0	
U.S.D.C.	U.S.D.C. Agriculture Census						N.R.C.S. NRI	
Ag Census/	1954		1974		1987		1987	
N.R.C.S. NRI	km^2	%	km^2	%	km^2	%	km^2	%
Agriculture	1469	27.50	905	17.05	958	18.12	1692	31.85

Table 19. Statistical summary of 40-yr daily data of suspended sediment at the Yadkin College, North Carolina sampling station in the Yadkin River (1951-1990).

Attribute	Log Transformation	Daily Discharge (m3/s)	Suspended Sediment Concentration (mg/L)	Suspended Sediment Yield (Mg/d)
Sample size	-	14516	14516	14516
Arithmetic mean	No	84.68	150.6	2244.5
Mean Nat. Log	Yes	4.200	4.340	6.090
Standard deviation	No	87.210	223.23	7373.1
Standard error	No	0.7200	1.850	61.20
Coeff. of variation, %	No	103.0	148.2	328.5
Coeff. of variation, %	Yes	15.04	26.2	27.2
Minimum	-	9.34	1	2.72
Lower quartile	-	44.46	35	136.1
Median	-	62.86	70	367.4
Upper quartile	-	92.60	160	1188.4
Upper 10%	-	145.00	379	4599.0
Upper 1%	-	470.10	1100	37830
Maximum	-	1868.92	2970	165,110
Skewness	No	5.99	3.64	7.87
Skewness	Yes	0.70	0.24	0.50
Kurtosis	No	58.86	19.07	84.30
Kurtosis	Yes	1.57	-0.21	0.10

Table 21. Statistical summary of daily suspended sediment concentration at Yadkin College, North Carolina in the Yadkin River arranged by decade.

Attributes	Log Transformation	Sediment Concentration (mg/L) 1950s	1960s	1970s	1980s
Sample size	-	3559	3652	3653	3652
Arithmetic mean	No	181.11	133.52	174.43	114.14
Mean of Nat. Log	Yes	4.41	4.31	4.60	4.04
Standard deviation	No	268.70	193.42	222.78	193.91
Coeff. of variation, %	No	148.4	144.9	127.7	169.9
Coeff. of variation, %	Yes	29.1	24.0	22.6	27.4
Minimum	-	1	4	7	2
Lower quartile	-	35	38	46	26
Median	-	80	68	91	48
Upper quartile	-	203	135	203	112
Upper 10%	-	486	312	433	277
Upper 1%	-	1260	1000	1100	955
Maximum	-	2970	2100	2210	2480
Skewness	No	3.30	3.78	2.88	4.89
Skewness	Yes	0.020	0.35	0.27	0.52
Kurtosis	No	15.75	19.21	10.62	35.01
Kurtosis	Yes	-0.35	0.07	-0.44	-0.03

Table 22. Statistical summary of daily sediment transport or yield at Yadkin College, North Carolina in the Yadkin River arranged by decade.

Attributes	Log Transformation	Sediment Yield (Mg/d) 1950s	1960s	1970s	1980s
Sample size	-	3559	3652	3653	3652
Arithmetic mean	No	2459.9	1699.1	3036.2	1788.0
Mean Nat. Log	Yes	6.043	6.011	6.594	5.729
Standard deviation	No	7333.9	5859.9	9017.8	6844.7
Coeff. of variation, %	No	298.1	344.9	297.0	382.8
Coeff. of variation, %	Yes	30.8	24.3	23.2	28.7
Minimum	-	2.72	14.51	31.75	8.26
Lower quartile	-	116.1	147.9	233.1	92.5
Median	-	385.56	337.5	594.2	215.9
Upper quartile	-	1388.0	850.5	1905.1	841.0
Upper 10%	-	5361.5	3048.1	6232.4	3302.2
Upper 1%	-	39009	28214	46811	31025.7
Maximum	-	97,976	114,305	165,108	125,192
Skewness	No	6.22	9.03	7.23	9.13
Skewness	Yes	0.23	0.73	0.78	0.78
Kurtosis	No	48.36	110.81	72.49	105.71
Kurtosis	Yes	-0.25	0.64	0.07	0.27

APPENDIX F

Figures

Dynamic Modeling of Long-Term Sedimentation in the Yadkin River Basin

Krishnaswamy, Lavine, Richter and Korfmacher 2000

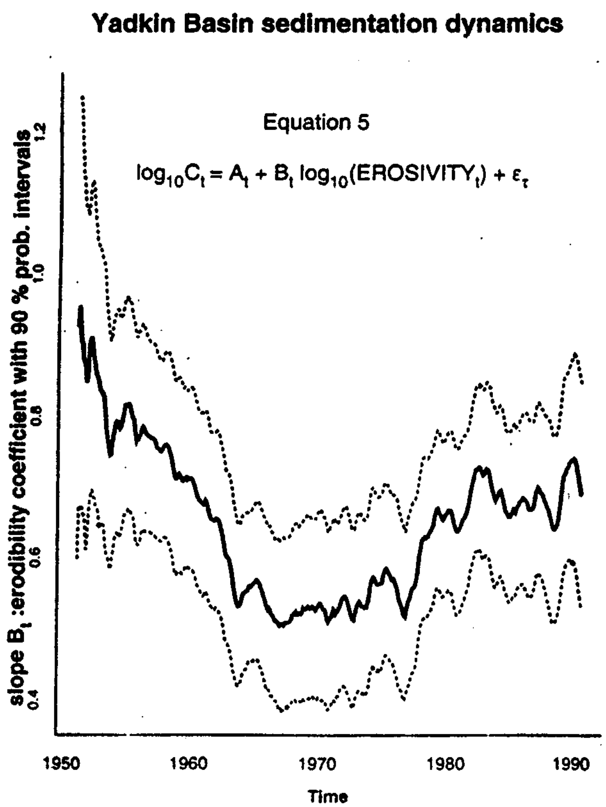


Fig. 4. Time-series of dynamic erodibility coefficient with 90% probability intervals: slope of log rainfall erosivity in regression of log volume-weighted sediment concentration with log rainfall erosivity as independent variable.

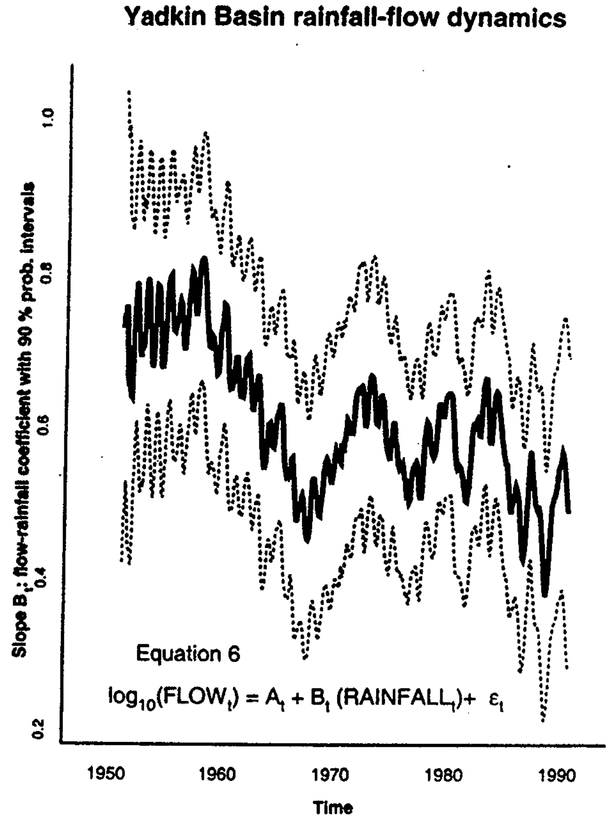


Fig. 5. Time-series of dynamic flow coefficient with 90% probability intervals: slope of rainfall in regression of log flow with log rainfall as independent variable.

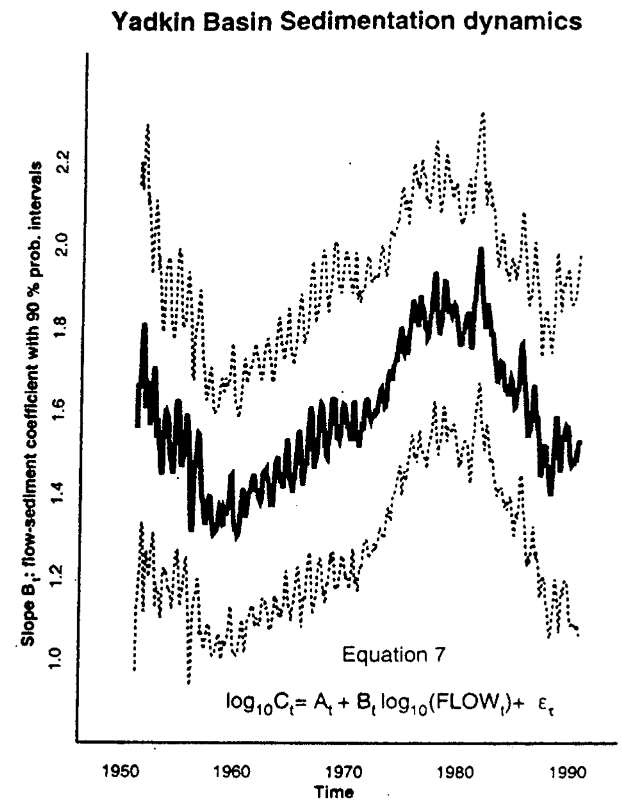


Fig. 6. Time-series of dynamic sediment coefficient with 90% probability intervals: slope of log flow in regression of log flow with log rainfall as independent variable.