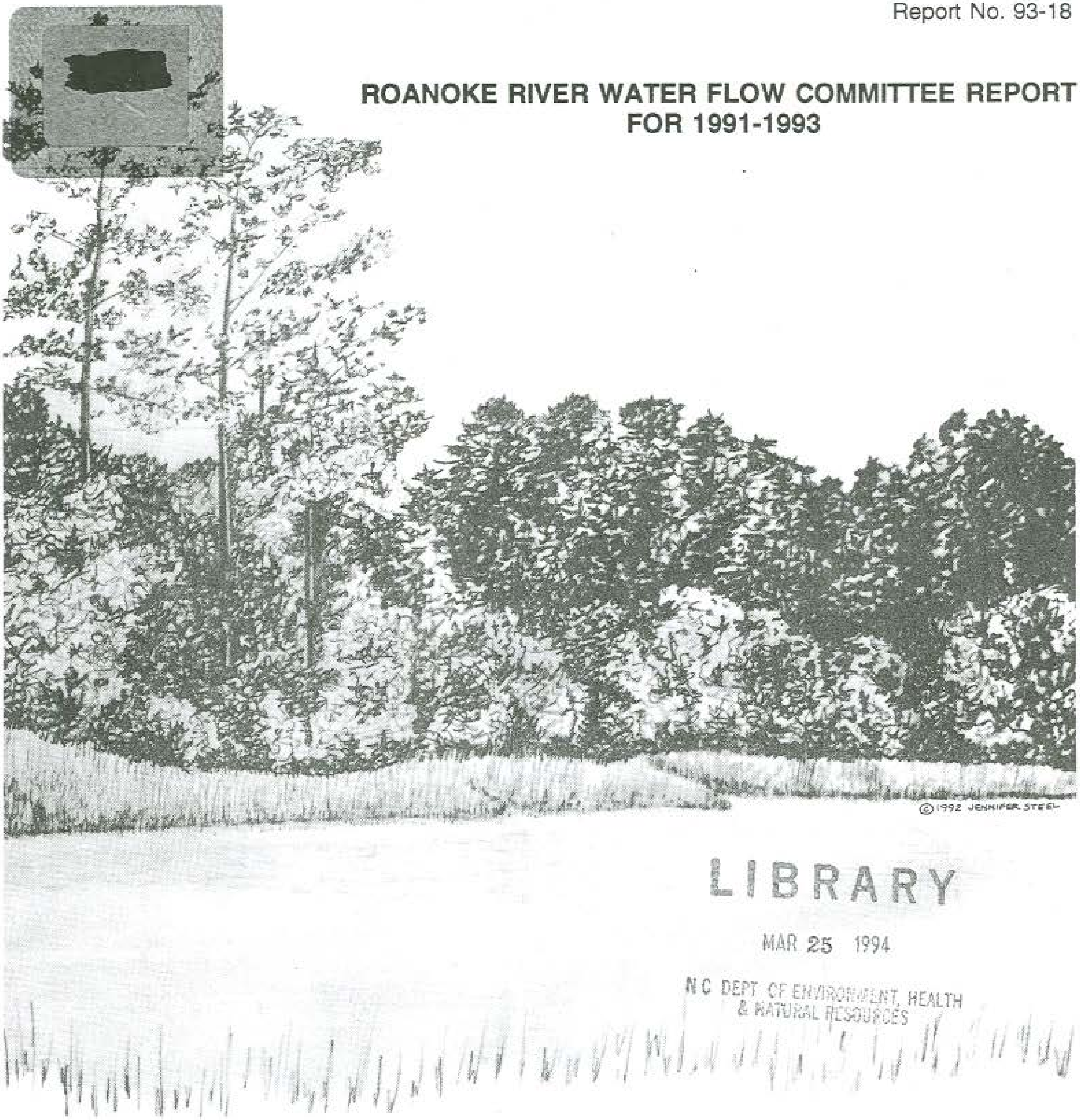
Report No. 93-18

ROANOKE RIVER WATER FLOW COMMITTEE REPORT FOR 1991-1993



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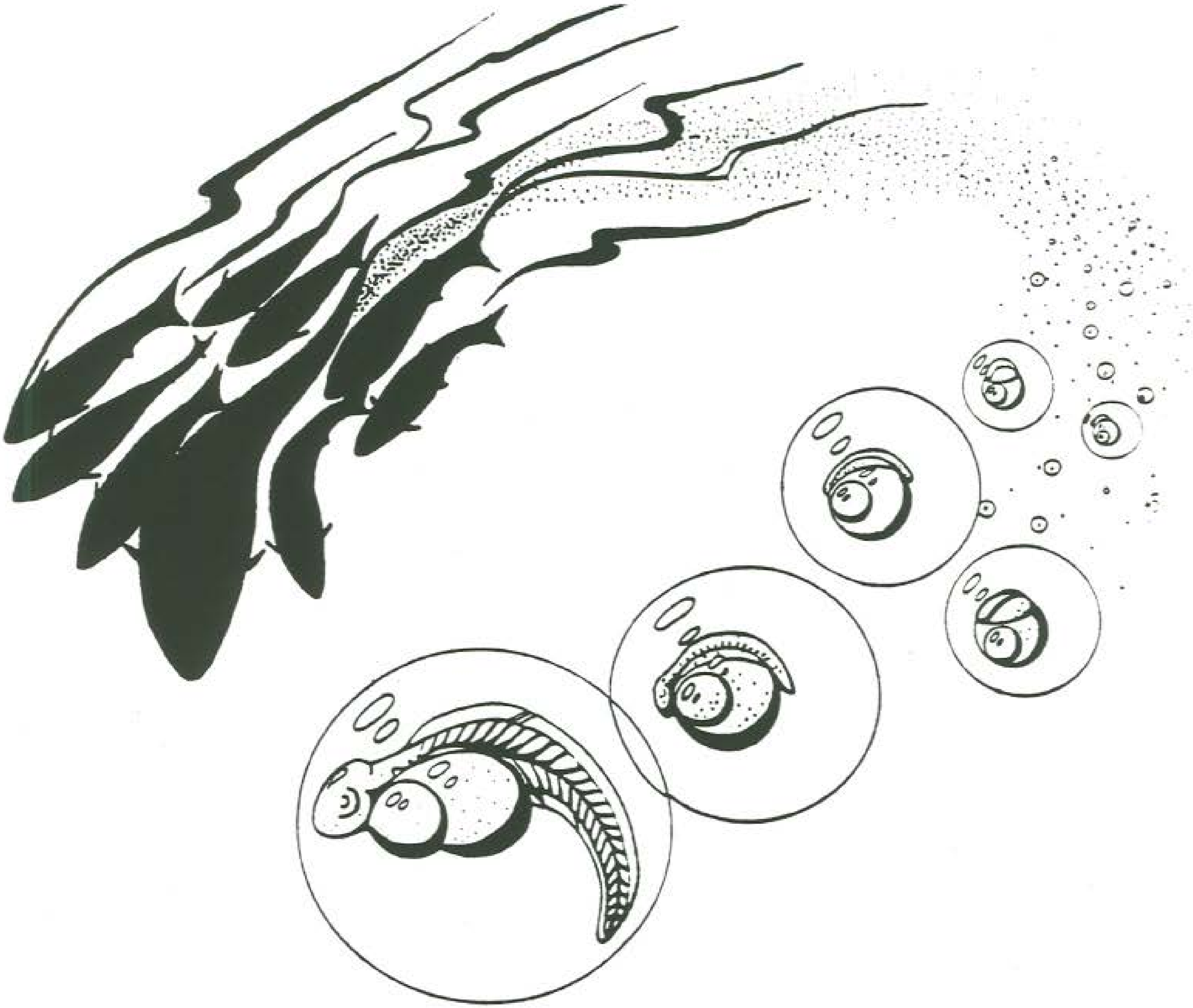

ROANOKE RIVER WATER FLOW COMMITTEE

REPORT FOR 1991-1993

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ROANOKE RIVER WATER FLOW COMMITTEE REPORT FOR 1991-1993

Edited by Roger A. Rulifson and Charles S. Manooch, III

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EXECUTIVE SUMMARY

A Committee of representatives from State and Federal agencies and State universities was formed in 1988 to gather information on natural resources of the lower Roanoke River watershed in North Carolina and to recommend a water flow regime that would be mutually beneficial to the resources and their users. A modified, trial flow regime was judged acceptable by the US Army Corps of Engineers and Virginia Power Company. The Committee suggested that the flow regime be evaluated over a four-year period (1989-1992), and that a report be issued each year during the study period. The trial period was extended to include 1993 by the US Army Corps of Engineers at the request of the North Carolina Wildlife Resources Commission.

The purpose of this Flow Report is to document hydrological events and reservoir operations for 1991-1993 in context with field research efforts and observations in the lower Roanoke River Basin on a number of watershed resources: fisheries (especially striped bass), wildlife, agriculture, and timber. This report differs from the three previous reports issued by the Flow Committee (Manooch and Rulifson 1989, Rulifson and Manooch 1990a, Rulifson and Manooch 1991) because it contains sections pertaining to abundance and habitat use of overwintering songbird and woodpecker communities, aquatic macroinvertebrate ecology and management relative to hydrology, public lands, heavy metal contaminants, Roanoke River time travel studies, relative abundance of finfish species other than striped bass, and susceptibility of larval fishes to entrainment by water withdrawal pipes. Following are summaries of the major sections contained herein. Each summary is presented as a separate paragraph.

FLOODPLAIN ECOLOGY. The lower Roanoke River floodplain is considered to be the largest intact, and least disturbed, bottomland forest ecosystem remaining in the Mid-Atlantic Region of the United States. The floodplain and adjacent uplands support at least 20 distinct natural communities, which contain a diverse assemblage of plants and animals. The floodplain has enormous biological significance and provides habitat for two federally-listed endangered animals, 15 state-listed animals, 13 state-listed plants, and a number of other rare species of flora and fauna.

FOREST RESOURCES. The forest vegetation types, prior to 1950, occurred as a function of natural variances associated with the River's hydrobiological regime. Floodplain species sorted themselves along a naturally occurring continuum of soil anaerobiosis (waterlogging). Because forested bottomlands of the Roanoke River are transitional in nature between the upland and aquatic zones, the complex and distinct layering forced by the hydrologic gradient (preimpoundment) provided many niches and habitats for a variety of wetland species, some of which are strictly limited to a wetland environment. Flood duration, frequency, and depth affected the vegetative communities which, in turn, affected animal community dynamics. The preimpoundment water regime was the most characteristic signature of the Roanoke River bottoms, and the alteration of that hydrology would likely have impaired some ecosystem functions. The asynchronous flows associated with an impounded river must disturb the hydrological, soil, physical, chemical, and biological properties of the bottomland system, eventually leading to a functional change. The consequences of altered hydroperiod in Roanoke bottomlands can be assumed to have long-term effects on existing vegetation and on regeneration of forest lands following harvest.

WATER QUALITY CONDITIONS. The North Carolina Division of Environmental Management (DEM) Water Quality Section maintains an extensive database containing water quality information for all waters of the State. Classifications and associated standards are assigned to waters based on their best usage. Ratings also are assigned to waterbodies to reflect the ability of the given waterbody to support its designated uses. Of the 2,414 Roanoke stream miles, only 15% are fully supporting, 19% are support-threatened, 47% are partially supporting, and 7% are not supporting. The remaining stream mileage was not evaluated. In 1993, there were 36 facilities with NPDES permits operating within the lower Roanoke River. Compliance is rated as very high, depending on year if weighted by flow. Compliance is somewhat lower if judged on a per effluent parameter limited basis. In order to properly determine the appropriate effluent limitations to be contained in permits for point sources of discharge to rivers, the capability to accept waste (assimilative capacity) must be determined. A revised (1990) water quality model has consistently predicted that the carbon biological oxygen demand (CBOD) capacity of the lower watershed is exhausted.

WATER QUALITY MONITORING. Ambient monitoring is conducted by the DEM at seven locations in the River from Roanoke Rapids Dam to the mouth of Batchelor Bay in Albemarle Sound. The most recent data summary shows consistently good water quality with the noteworthy exception of dissolved oxygen. In late spring, summer, and early fall the dissolved oxygen level drops below the swamp water standard of 4 mg/L for extended periods in the lower River. While some of these problems do occur during low flow periods, the problem is not just flow related. In fact, these low levels are predicted by the 1990 assimilative capacity calculations under a number of flow scenarios.

HYDROLOGY OF LOWER RIVER. A description of impoundments and reservoir operations including flood control, spawning flows, and minimum flow requirements are presented.

TIME TRAVEL STUDIES. Time of travel studies using dye were conducted from Roanoke Rapids to Plymouth. At Roanoke Rapids, velocity ranged from 0.8 mph at 1,000 cfs to 2.5 mph at 32,000 cfs. Under peaking (fluctuating flow) conditions, dye additions made during a low discharge could be overtaken by a later peaking discharge and the transit time shortened substantially. At flows of about 2,600 cfs, dye inserted at Oak City (River Mile 60) requires between 125 and 163 hours to reach Plymouth at River Mile 10. At about 5,600 cfs, the time of travel for dye is shortened to between 108 and 135 hours.

OVERWINTERING SONGBIRDS. Preliminary findings indicate that there is a consistent association between selected overwintering birds and large trees ($\geq$ 20 cm in diameter), and that selected plant species provide important foraging and resting substrate. These findings have important management implications for overwintering avifauna given current land and hydrological management practices on the Roanoke River. Forest and habitat management practices should be designed to maintain a patchwork of tree stands of different size classes, thereby ensuring the availability of large trees. Roanoke basin hydrological management schemes should take into consideration the potential long-term effects on plant population processes such as regeneration, recruitment, and tree mortality.

AQUATIC MACROINVERTEBRATE ECOLOGY. The key to long-term invertebrate management is to mimic natural (pre-impoundment) hydrology by creating a dynamic flow regime. Particular sites within the floodplain will vary in flood timing, rate, duration, and depth within a year among years. The vast Roanoke River floodplain under dynamic flooding will have prolonged foraging opportunities for waterbirds because the topographic/hydrologic interactions create hundreds of unique microwetlands.

PUBLIC LANDS. Efforts to protect large tracts of relatively intact forested wetlands of the Roanoke River floodplain have been underway since at least the late 1970s. Organizations and agencies involved in land acquisitions include the North Carolina Nature Conservancy, the North Carolina Wildlife Resources Commission, the North Carolina Natural Heritage Program, the North Carolina Wildlife Federation, the US Fish and Wildlife Service, Ducks Unlimited, the Sierra Club, the Bertie County Board of Commissioners, and the North Carolina Department of

Transportation. As of 1 September 1993, 28,617 acres of the Roanoke floodplain are owned by public and private conservation agencies. Following the completion of the current acquisition plan by Joint Venture Partners, a total of 53,000 acres will be under public protection.

COMMITTEE'S LONG-TERM RECOMMENDATION. The Committee recommended to the WRC that the present experimental flow regime be expanded by two weeks, to cover the dates 1 April through 30 June of each year. This extended flow regime would be continued for the next six years, 1994 through 2000, at which time the Federal Energy Regulatory Commission license expires and other flow alternatives, as described below, may be recommended. The Committee asked the WRC to stress to the Corps that the target flows during the expanded spawning window be the average daily flow values, rather than the upper and lower boundaries. The Committee also continued to recommend that the hourly variation in flow not exceed 1,500 cfs. The Committee further recommended to the WRC that it encourage the Corps and Virginia Power to consider a new annual (12-month) flow regime based on pre-impoundment (natural) flow conditions.

HEAVY METAL CONTAMINANTS. All 15 trace elements analyzed in this study are substantially enriched within bottom sediments at one or more sites in the vicinity of known point source discharges within the lower Roanoke and lower Chowan rivers and inner Albemarle Sound areas. Most sequestered trace elements are loosely bound to fine-grained sediments and consequently are potentially available to filter- and bottom-feeding organisms. Anthropogenic sources are largely responsible for trace element contamination within the sediments. NPDES permitted discharges appear to be the major contributors to enriched trace elements to bottom sediments. Nonpoint sources are also important, but are more diffuse and difficult to evaluate. Six areas of concern were identified: Welch Creek, inner Albemarle Sound, lower Roanoke River, Middle River, Cashie River, and lower Chowan River. Welch Creek is the most contaminated, but the problem appears to be relict.

HYDROLOGY. Flows during the period April through mid-June, 1991 were the 18th wettest on record. For this period, daily flows were within the flow regime 68% of the time. River flows during the period April through mid-June, 1992 were the 30th wettest on record. Daily flows from 1 April through 15 June were within the recommended flow regime 45% of the time. During 1993 spring flows were the 3rd wettest on record for April through mid-June. Flows exceeded the recommended upper flow boundary 54% of the time, and were within the upper and lower flow boundaries 46% of the time.

TIME SERIES ANALYSES. The extreme wet conditions of the early spring of 1991 resulted in so much water being stored that the outflow overwhelmed any pattern which might have been observed. The 1991 result was not consistent with findings in previous years; however, these results were consistent with the finding in the first report that bad spawning years are characterized by either very high or very low flows throughout the spawning season. Overall, the flows for 1992 were unstable due to significant rains during the spring. In terms of the models, the ARIMA models without the intervention variables were a random walk for the entire period (March through June) and similar to the models for other years for the Negotiated Period (1 April - 15 June). The model for the Negotiated Period had a positive AR1 parameter, indicating little day-to-day variation in flows. In the autoregressive analysis of the 1993 flows, significant monthly and daily coefficients in the models for daily data were conspicuous by their absence. Only in the daily model for the entire period were there significant coefficients which were not AR coefficients.

KERR RESERVOIR OPERATIONS IN HINDSIGHT. From a data collection standpoint, it was unfortunate that the entire five-year flow regime was relatively wet. Evaluating the Negotiated Flow Regime during drier times is needed.

WATER QUALITY DURING SPRING SPAWNING ACTIVITY. Several water quality parameters are influenced by changes in reservoir discharge. High flows early in the season are usually lower in water temperature and higher in dissolved oxygen. Substantial reduction in instream flow allows the water temperature to rise quickly and dissolved oxygen levels drop. Sudden and large increases in reservoir releases decrease water temperatures. Surface water pH normally remains above 7.0 throughout the spring.

ROANOKE STRIPED BASS SPORT HARVEST. In 1991, an estimated 74,596 angler-hours were spent to harvest 26,934 striped bass in the Roanoke River. In addition, more than 98,000 striped bass were caught and then released. In 1992, an estimated 49,277 angler-hours were exerted to harvest 13,372 striped bass. Approximately 24,000 were released. The recreational harvest in 1993 was estimated to be 14,327 fish (52,932 angler-hours). An additional 10,500 striped bass were released during the legal harvest season. After the season was closed to harvest (fishing is still allowed) more than 46,200 fish were caught and released. Males comprised 87% of 1,329 striped bass sampled during 1991. Males and females ranged in age from 2-8 years. Most were three years old. Males comprised 87% of the fish sampled in 1992, and 56% in 1993. During the two springs, males ranged from 2 to 5 years old; females 2 to 11. Most males were ages 3 and 4, while most females were 4 years old. The 1989 year class comprised 78 and 67% of the harvest in 1992 and 1993, respectively.

ASSESSMENT OF STRIPED BASS SPAWNING STOCK. To examine changes in the relative abundance of striped bass collected by electrofishing among years, catch per unit effort data were analyzed. Results suggested that, by year class, striped bass are not present on the spawning grounds relative to their abundance in the population until at least age 4. To evaluate the changes in relative abundance of female among years a spawning index was developed. Index values have increased markedly from 1991 to 1993, mirroring increases observed in the estimates of striped bass egg production.

LANDINGS OF STRIPED BASS IN ALBEMARLE SOUND. Commercial fishermen landed 108,460 pounds of striped bass in Albemarle Sound in 1991, 100,549 pounds in 1992, and 83,735 pounds in 1993. Values of the annual totals were $155,538, $134,384, and $105,084 for 1991, 1992, and 1993, respectively. No commercial landings have been recorded in the Roanoke River for the period 1987-1993. Catches made by recreational anglers in the Sound were 14,869 fish in 1991, 10,542 in 1992, and 11,404 striped bass in 1993. Released fish totals by years were 43,175 in 1991, 42,165 in 1992, and 13,241 in 1993.

UPDATE ON STRIPED BASS REGULATIONS. Since 1990, more than 80 proclamations and other forms of regulations have been applied to recreational and commercial fishing for striped bass by the State of North Carolina.

STRIPED BASS SPAWNING IN ROANOKE RIVER. An estimated 1.84 billion eggs were spawned in 1991, the fifth largest number through that year since 1959. Approximately 55% of the eggs were viable. Spawning was related to water temperature, and more than 90% of the eggs were collected when water temperatures ranged from 18-24°C. An estimated 9.65 billion eggs were spawned in 1992 -- the largest spawn recorded to that date for Roanoke River striped bass. The viability was 46%. A positive correlation was observed for viability and water temperature; a negative correlation observed for viability and water velocity. Eggs were collected through 23 June, but spawning activity was observed through the end of June and perhaps into July due to the moderate water temperatures in 1992. Spawning in 1993 was again record-breaking as an estimated 23.9 billion eggs were produced. Viability was 49%. Over half of the eggs were deposited in the first spawning event of the season, which occurred with a sudden drop in reservoir discharge upstream.

JUVENILE STRIPED BASS ABUNDANCE. The Juvenile Abundance Index (JAI) for striped bass in the western Albemarle Sound is obtained each year by trawling at seven stations. The JAIs for 1991, 1992, and 1993 was 0.86, 2.57, and 44.54. The 1993 value is the highest ever recorded for the species in the Roanoke/Albemarle system.

AGE, GROWTH, AND SURVIVAL OF JUVENILE STRIPED BASS. Striped bass spawning in the Roanoke River can be manipulated by water releases from Roanoke Rapids Reservoir upstream. The spawning window is longer (80-100 days) than is currently managed (up to 76 days) by Virginia Power, the Corps, and WRC. Three years of data, 1990-1992, indicate that spawning activity late in the season accounts for over half of the successfully recruited juveniles in Albemarle Sound. Early spawning activity also may account for better than expected recruitment in some years. It is not known whether this phenomenon is correlated with environmental factors, age of spawning fish, or both. Since what constitutes optimal conditions is not known, the River flow should be managed to mimic historical river flows from 1 April to 30 June.

FOOD HABITS OF JUVENILE STRIPED BASS. Juvenile striped bass consumed a greater percentage of mysid shrimp than any other prey taxa. Invertebrates in general were more prevalent in the diet than were fish. There is insufficient evidence to determine any change in the benthic or epibenthic fauna that would be reflected in the diet. Determination of food availability, particularly invertebrate fauna, at the time of fish collection would indicate if the juvenile fish were limited by food.

RELATIVE ABUNDANCE OF OTHER FINFISH SPECIES. A remarkable increase in striped bass juvenile abundance has occurred since 1987. A major consideration is how other fish species have responded during this same period of time as measured by the annual trawling survey. To evaluate this, 10 species of finfish were selected and the annual catch rates, expressed as the number of fish/trawl, were plotted for 1982-1993. Of the 10 species evaluated, six had higher CPUE values for 1988-1993, the same time that CPUE was increasing for striped bass. However, of the six, only bay anchovy reflected a significant increase. It would appear that the revised flow regime (1988-1993) has not had a significant impact on the recruitment of these selected species. Unlike the striped bass, however, the selected species are not restricted to spawning in the Roanoke River.

CHLOROPHYLL *a* AND PHYTOPLANKTON. In general, spring 1991 chlorophyll *a* values were higher in the lower Roanoke River and western Albemarle Sound than in Batchelor Bay. A total of 154 phytoplankton species have been identified in the study. The phytoplankton group with the highest diversity is Bacillariophyceae. Phytoplankton biomass values for 1991 were similar to those reported for 1990, both of which were lower than those reported for the low flow years of 1985 and 1986. There is good evidence that this difference was caused by differences in River flow. This inverse River flow - algal biomass relationship appears to be common in riverine ecosystems.

ZOOPLANKTON. Several distinct zooplankton communities exist in the lower watershed and western Sound. Cladocerans dominate River zooplankton; copepods dominate Batchelor Bay samples; and cyclopoid copepods dominate samples in the western Albemarle Sound. Relative abundance of taxonomic groups in these locations is influenced by Roanoke River instream flow.

SUSCEPTIBILITY OF LARVAL FISHES TO ENTRAINMENT. Larval fish of seven taxa, including striped bass, common to the lower Roanoke River were analyzed for body dimensions. Results indicate that fish larvae of both resident and anadromous species are of entrainable size through 2-mm mesh wedge-wire screen. Since the young of these fish are common to the lower Roanoke River, the siting of intakes for water withdrawal pipes is critical.

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ROANOKE RIVER WATER FLOW COMMITTEE REPRESENTATIVES FOR 1991-1993

Members for 1991:

Mr. William Berry, N.C. Department of Parks and Recreation (Kerr Reservoir Parks)
Ms. Stephanie Spence Briggs, N.C. Division of Environmental Management (Water Quality)
Mr. Willard J. Cole, U.S. Fish and Wildlife Service (Fisheries)
Mr. Tom Ellis, N.C. Department of Agriculture (Agriculture)
Mr. Thomas C. Fransen, N.C. Division of Water Resources (Hydrology)
Ms. L.K. (Mike) Gantt, U.S. Fish and Wildlife Service Environmental Services (Fisheries/Wildlife)
Mr. Max Grimes, U.S. Army Corps of Engineers (Engineering/Hydrology)
Mr. Fred Harris, N.C. Wildlife Resources Commission (Fisheries)
Dr. William W. Hassler, Professor Emeritus, N.C. State University (Fisheries)
Mr. Lynn T. Henry, N.C. Division of Marine Fisheries (Fisheries)
Mr. Harrel B. Johnson, N.C. Division of Marine Fisheries (Fisheries)
Mr. James W. (Pete) Kornegay, N.C. Wildlife Resources Commission (Fisheries)
Dr. R. Wilson Laney, U.S. Fish and Wildlife Service Fisheries Resources Program (Fisheries/Wildlife)
Dr. Russ Lea, N.C. State University (Forest Resources)
Dr. Merrill Lynch, N.C. Nature Conservancy (Floodplain Ecology)
Dr. Charles S. Manooch, III, National Marine Fisheries Service (Fisheries)
Mr. George McCabe, Virginia Power Company (Hydropower)
Dr. Robert J. Monroe, Professor Emeritus, N.C. State University (Statistics)
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Dr. Roger A. Rulifson, East Carolina University (Fisheries/Water Quality)
Ms. Marsha E. Shepherd, East Carolina University (Databases)
Dr. L.H. (Buddy) Zincone, Jr., East Carolina University (Modeling)

Additional Member for 1992-1993:

Mr. Jerry Holloman, Manager, Roanoke River National Wildlife Refuge (Wildlife Habitat Management)

INTRODUCTION

The purpose of the Flow Report for 1991-1993 is to document hydrological events and reservoir operation in context with field research efforts and observations on a number of watershed resources: striped bass, wildlife, agriculture, and timber. In addition, this report summarizes the recommendations for springtime and yearly river flows after a five-year study. These recommendations were made to the three parties (NC Wildlife Resources Commission, US Army Corps of Engineers, and Virginia Power Company) involved in the 1971 Memorandum of Understanding which addressed river flows during the striped bass spawning period. All three parties are members of the Flow Committee and actively participated in developing committee recommendations.

These annual reports are to inform the reader of the objectives, activities, data analyses, and recommendations of an *ad hoc* Committee formed in 1988 to investigate the improvement of Roanoke River water flows below Roanoke Rapids Dam for striped bass (*Morone saxatilis*) and other downstream resources. Each of the reports contains similar, updated information such as egg production, egg viability, and juvenile abundance index for each year. In addition, we try to introduce new discussions each year. For example, in this year's report we have added sections on protection of public lands, assessment of contaminated sediments, assessment of the importance of the floodplain macro-invertebrate community, and juvenile abundance survey data trends for species other than striped bass. The Committee is composed of 26 representatives of State and Federal agencies, State universities, the North Carolina Nature Conservancy, and Virginia Power Company. In addition, the Committee seeks outside expertise in areas of reservoir management, operation of dams for power production, and statistical analysis and interpretation. A list of Committee members for 1991-1993 and their affiliations has been provided.

The Committee has a combined record of experience on the ecology and fisheries of the Roanoke watershed and Albemarle Sound totaling over 200 years and is committed to the protection and recovery of the striped bass population. The purpose of the Committee is to gather information on all resources of the lower watershed and recommend a flow regime that will be mutually beneficial to these resources and their downstream users. Striped bass as a resource has received the most attention because of its great social and economic importance to this region and to North Carolina; however, other resources such as wildlife, timber, and agriculture have been considered as well. The Committee recognizes the possibility that other factors such as water quality and intense fishing pressure may be contributing factors to a decline of the striped bass resource; however, the charge of the Committee was to examine only River flow.

The Committee's policy has been to examine Roanoke River flows in context with protection of wildlife and fishery resources irrespective of proposed or pending water use projects. This includes such projects as the Roanoke River National Wildlife Refuge under development by the US Fish and Wildlife Service, the proposed water withdrawal from Lake Gaston by the City of Virginia Beach, and proposed co-generation fossil fuel electrical generating facilities within the Basin, both above and below the Roanoke Rapids Dam.

A series of meetings held in 1988 resulted in the completion of the first formal Committee report that presented a detailed review and analysis of watershed hydrology and multi-use problems (Manooch and Rulifson 1989). A second Committee report (Rulifson and Manooch 1990a), in which data from springs of 1988 and 1989 were presented and compared, was issued in the spring of 1990, and a third report, which examined 1990 data, was published in August 1991 (Rulifson and Manooch 1991). All of the work presented in those documents was endorsed by the Committee. The US Army Corps of Engineers, Wilmington District, participated in all meetings and endorsed the recommendations of the Committee.

Although many data were compiled and analyses performed, more work is needed to fully comprehend the Roanoke River system. Work presented here is believed to be the first step toward understanding the interaction between the flow regime and the ecology of the River and floodplain.

DESCRIPTION OF THE WATERSHED

The Roanoke River, in northeastern North Carolina, flows through an extensive floodplain of national significance. This wetland area is considered to be the largest intact, and least disturbed, bottomland forest ecosystem remaining in the Mid-Atlantic Region (North Carolina Natural Heritage Program 1988). In addition to extensive mature bottomland hardwood and swamp forests, there are beaver ponds, blackwater streams, and oxbow lakes. Together, these habitats support a rich array of diverse and abundant wildlife species including waterfowl, fish, deer, turkeys, otters, bobcats, herons, egrets, and migratory songbirds (USFWS 1988).

The Roanoke River in Virginia and North Carolina drains an area of 9,666 square miles (Moody et al. 1985), arises in the Blue Ridge Mountains of central Virginia and flows east-southeast into north central North Carolina, and it empties into Albemarle Sound in the northeastern part of the State (Figure 1). Near the Virginia-North Carolina line, a series of dams was established between 1950 and 1963 for hydroelectric power and flood control from three reservoirs. These are the John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake, upstream to downstream, respectively. The John H. Kerr Dam and Reservoir is operated by the US Army Corps of Engineers for flood control, hydropower, and recreation. The dams at Lake Gaston and Roanoke Rapids Lake are owned and operated by Virginia Power Company and operated primarily for electric power generation. Below the dam at Roanoke Rapids, the River elevation drops from 50 feet at the dam to sea level as it enters Albemarle Sound. Downstream of the last dam (at Roanoke Rapids), the River meanders 137 miles through an extensive floodplain, approximately 70 air miles long and up to five miles wide, forming the border between Northampton and Halifax counties and Bertie and Martin counties (USFWS 1988).

The majority of the people in the Roanoke Valley live in the vicinity of the three reservoirs and in and around Roanoke Rapids and Weldon. Other major towns in North Carolina along the River's course include Halifax, Scotland Neck, Williamston, Jamesville, and Plymouth (Figure 2). The major industries are agriculture and forestry. The area consists of old plantations, some derived from the original royal grants, while "newer" ones are still over 100 years old. Very little population change has taken place within the Basin area.

The River is no longer used for commerce as in earlier days. In 1988, a high-rise bridge was constructed to replace a drawbridge for US Highway 17 at Williamston. Floodplain development is limited primarily to the Plymouth area, probably due to the history of rampaging floods along the Roanoke River prior to construction of the reservoirs. In addition, a few residences are located on the adjacent River bluffs in the upper half of the River in North Carolina.

Detailed information on the hydrology and watershed resources was presented in the Committee's initial report (Manooch and Rulifson 1989). Resources included forestry, agriculture, soils, flood plain habitats, wildlife, and fisheries. The appendices to the 1989 report provided a listing of fauna and flora of the lower Roanoke River watershed.

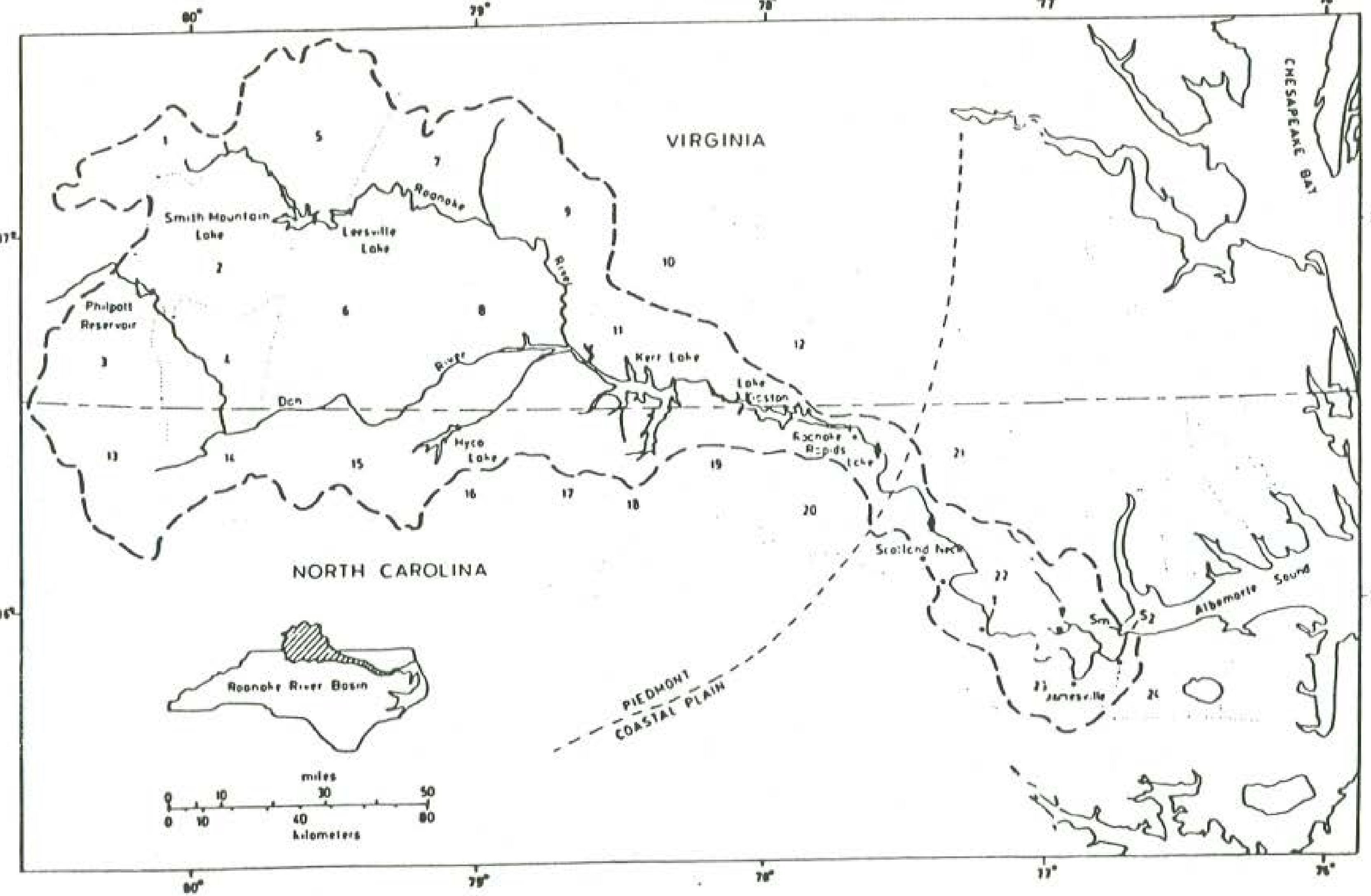

Figure 1. Drainage area of the Roanoke River Basin. Dashed line indicates approximate location of the Fall Line; diamonds= locations of USGS water quality and gaging stations; inverted triangle=USGS water quality station; T=upstream limit of tidal influence; S2=mean upstream intrusion limit of saltwater front (200 mg/L chloride); Sm=maximum upstream intrusion of saltwater front (Giese et al. 1979). Counties containing Roanoke watershed are enumerated.

List of Counties Enumerated in Figure 1.

1-12 (Virginia)

1. Roanoke
2. Franklin
3. Patrick
4. Henry
5. Bedford
6. Pittsylvania
7. Campbell
8. Halifax
9. Charlotte
10. Lunenburg
11. Mecklenburg
12. Brunswick

13-24 (North Carolina)

13. Stokes
14. Rockingham
15. Caswell
16. Person
17. Granville
18. Vance
19. Warren
20. Halifax
21. Northampton
22. Bertie
23. Martin
24. Washington

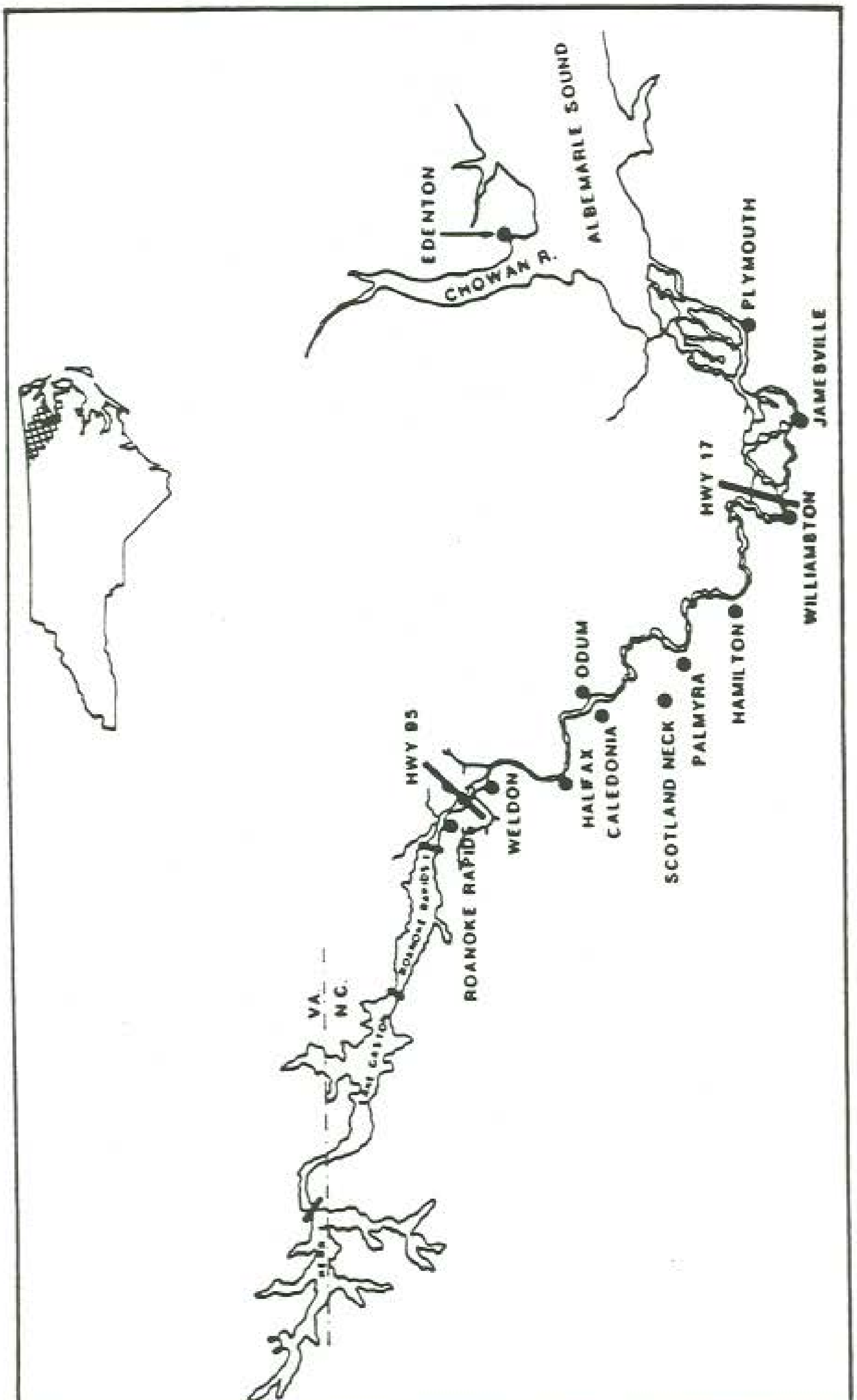

Figure 2. Lower Roanoke River watershed.

Geologic Framework of the Lower Roanoke River and Western Albemarle Sound

Stanley R. Riggs, Charles R. Klingman, and Robert A. Wyrick

The entire Roanoke River drainage basin encompasses approximately 9,666 square miles in 24 counties of North Carolina and Virginia, with another 8,694 square miles and 10 counties within the Albemarle Sound estuarine system. In terms of discussing the geologic setting, the Roanoke-Albemarle system can be divided into three distinctive parts: the upper Roanoke River, lower Roanoke River, and Albemarle Sound estuarine system (Figures 1 and 2). The upper Roanoke River (above the Roanoke Rapids Dam) constitutes the major portion of the River drainage system (87%) and is located within the Piedmont Province. The lower Roanoke River basin (below the Roanoke Rapids Dam to about 5 miles northeast of Plymouth) constitutes a much smaller portion of the River drainage basin (13%) and is totally within the Coastal Plain Province. The Roanoke River drains into the western end of Albemarle Sound, an extensive complex of fresh to brackish water estuaries. The Albemarle Sound estuarine system contains approximately 900 square miles of water, including seven major embayed lateral tributary estuaries and numerous small embayed lateral streams. These lateral streams drain the low, flat, swampy Coastal Plain and discharge relatively smaller amounts of sediment and acidic black-water into the Sound.

The Coastal Plain portion of the Roanoke-Albemarle drainage system can be further subdivided into two main geographic sections by the Suffolk Scarp. The Suffolk Scarp is a fossil barrier island sand ridge that was formed as an ocean shoreline during a previous interglacial period when sea level was considerably higher than present. This high sand ridge extends southward from Suffolk, Virginia, west of the Dismal Swamp to the eastern side of the lower Chowan River. Between Edenton and Eden House, the Scarp crosses the mouth of the Chowan River and western Albemarle Sound. The Scarp has been eroded from the Roanoke River floodplain, but it re-occurs just west of Plymouth where it continues southward along Highway 32 toward Washington.

The region west of the Suffolk Scarp is geomorphically much older than the Suffolk Scarp itself and the surface morphology to the east. Consequently, the western area has higher elevations with slightly rolling topography and moderately well-drained soils with a generally sandy texture. This higher upland topography forms the spectacular bluff shorelines along the Chowan River and western Albemarle Sound. Also, natural soil drainage is generally good west of the Scarp with many small farms growing crops like tobacco, where the relative net income per acre is high. East of the Scarp, elevations range from a maximum of 15 to 20 feet above sea level along the base of the Scarp, as the low, flat surface slopes gently eastward to the eastern end of the mainland with elevations of about one to two feet above sea level. The flat, poorly drained topography contains extensive swamps and pocosins composed of organic peat soils that generally thicken eastward. Non-swamp areas generally have fine-grained sandy soils with high organic and clay contents. Consequently, artificial drainage is required throughout this outer portion of the Coastal Plain. Resulting agriculture is characterized by large, row crop operations of mainly corn, wheat, and soybeans. Production of such crops is highly mechanized with relatively low net income per acre.

Albemarle Sound is the portion of the Roanoke River drainage system that has been flooded by the present level of the sea. Albemarle Sound is not directly connected to the ocean due to North Carolina's Outer Banks, a continuous barrier island without an ocean inlet in the Albemarle area. Albemarle Sound is dominated by large freshwater inflows and ranges from totally fresh water to slightly brackish water that is dominated by irregular, wind-driven tides with a very small lunar tidal component. Sediments presently being deposited within the estuarine system are generally derived from four sources.

1. The dominant sediment component is inorganic clay that comes from the suspended sediment load in the Roanoke River during flood stages and, to a lesser extent, the other smaller tributary systems.
2. Organic matter, an important secondary component (up to 20%) in some of the extensive mud deposits, is derived from storm flushing and erosion of marsh and swamp forest shorelines that occur throughout the estuarine system.
3. Most sand and some clay is derived from erosion of Quaternary sediment units that form sediment bank shorelines and underlie the shallow platform flanks of most of the estuarine area.
4. The outermost portion of Albemarle Sound is characterized with fine sands derived from the barrier islands by wind and storm overwash, as well as being transported into the estuary through former inlets in the barrier islands.

About 38% of the shoreline of the Albemarle Sound estuarine system is dominated by vegetation, whereas 62% is dominated by older Quaternary sediment banks (Bellis et al. 1975). Vegetation-dominated shorelines are characterized by marsh grasses (8%) in the middle and outer estuarine areas and by swamp forests (30%) in lateral tributaries and inner estuarine area around the mouth of the Roanoke River. These two types of original shorelines consist of thick peats with erosional scarps that drop abruptly into one to six feet of water on the estuarine side and lap onto the adjacent upland areas on the landward side. Quaternary sediment bluffs and high banks constitute about 19% of the Albemarle shorelines with the highest relief in the westernmost portion of the estuarine system; low bank shorelines are the most common, constituting about 43% of all shorelines and occurring throughout the estuarine system.

The upper Roanoke River Basin is situated within the Piedmont Province of Virginia and North Carolina (Figure 1). The Piedmont begins at the "Fall Line" which is a broad transition zone where the crystalline rocks of the Piedmont (i.e., the igneous and metamorphic rocks that cause the rapids in the Roanoke River at Roanoke Rapids) become buried by the marine sediments of the Coastal Plain. The Piedmont consists of very hilly topography and rolling ridges that rise gradually westward to 1,500 to 2,000 feet at the foot of the Blue Ridge and the beginning of the Appalachian Province. Most of this region is underlain by very old sequences of NE-SW trending crystalline rocks that are highly weathered to produce the red clay soils that dominate throughout much of the Piedmont.

The entire lower Roanoke River Basin and the Albemarle Sound estuarine system lie within the Coastal Plain Province (Figure 1). Consequently, this area is underlain by an eastward thickening wedge of sediments and sedimentary rocks deposited on top of the crystalline basement rocks similar to those in the Piedmont Province. Thick beds of marine sediments were deposited over the crystalline basement rocks during the past 150 million years as the ocean repeatedly covered the outer edge of the continent and formed the North Carolina Coastal Plain (Brown et al. 1972). Most of these subsurface sediment units have little direct effect upon the surficial processes.

Thinner beds of Quaternary sediments were deposited on the surface of the Coastal Plain during the past three million years (Riggs and Belknap 1988). This Quaternary history and the resulting surface veneer of unconsolidated sediments directly dictates the general characteristics of the Coastal Plain, including the regional morphology and character of the drainage systems and flooded estuaries, soil types, and potential land use. Quaternary sediments were deposited by the coastal system which rapidly migrated back and forth across the Coastal Plain-Continental Shelf as sea-level fluctuated in response to repeated episodes of glaciation and deglaciation. Within this rapidly changing coastal system, extremely varied sediments (including gravels, sands, clays, and peats in all possible combinations) were deposited in river, estuarine, barrier island, and continental shelf environments. The Quaternary sediments range from a few meters in thickness in places along the lower Roanoke River, up to 70 meters in the outer Albemarle area (Brown et al. 1972).

The modern surface sediments throughout the lower Roanoke River and inner Albemarle Sound areas consist of three general types. The first sediment type is a dark-colored, organic-rich mud that ranges up to 3 m thick and fills the deeper, basinal portions of the estuary and the shallow channel flanks within the river environments. This soft, very uniform, silty clay contains no sand laminae, has <10% organic matter, and tends to thin eastward through the estuarine system. The second sediment type consists of clean, fine to medium quartz sand, which only locally is coarse grained. These sands have the inverse distribution patterns of the muds. In the river system, sands occur within the channel, while in the estuarine system sands occur totally on the shallow perimeter platforms. The third sediment type consists of organic peat and clayey peat deposits that form within the extensive swamp forest wetlands that constitute a major environment within the Roanoke River system. This environment and associated sediments extend eastward and are terminated at the river mouth by the leading edge of estuarine drowning.

The distribution of each of these modern surface sediment types is directly related to their location within the river-estuarine system, location along the bathymetric profile, and the physical processes operating within different portions of the depositional system. Thus, surface sediment distribution within the lower Roanoke River (from Plymouth to the River mouth; Figure 2) consists of sand dominated channel deposits, mud dominated channel flanks, and peats in the adjacent swamp forests. Location and distribution of the sand and mud facies and the resulting lack of development of accretionary point bars, associated ridge and swale structures, and natural levee deposits all suggest the following conclusions.

1. The River channel has not in the recent past, and presently is not actively, meandering. The occurrence of several large meander patterns are thought to be inherited from a prior time and are incised into the present floodplain system. Sinha (1959) also found evidence to support this interpretation.

2. No active bedload is being transported downstream and discharged either into the floodplain swamp or into a deltiac lobe in Albemarle Sound. This is a consequence of upstream impoundment.

3. Sands within the Roanoke River channel occur as active bedforms, but represent relict lag deposits left behind from pre-man conditions and do not represent the changed pattern of sedimentation that has been dominant for the past three centuries. Energy levels remain high enough within the channel thalweg to winnow out all clays, but not to significantly transport the lag sand deposits.

4. Active accumulation of mud sediments along the channel flanks is probably a direct result of dam construction and subsequent total control of water discharge down the Roanoke. Absence of high-energy flood events that would normally flush the channel system on a periodic basis, has probably allowed for the long-term accumulation of these major channel flank mud deposits.

The sands that do exist within the River system tend to be very fine to fine grained with slight increases to medium sand downstream from Plymouth. The River course through much of its lower extent occurs within the Holocene floodplain. However, at towns such as Williamston, Jamesville, and Plymouth (Figure 2), the River channel occurs on the south side of its floodplain where it has eroded into older Quaternary sediments that confine the floodplain. The presence of this highland is the reason for the original site selection of these towns. Consequently, the sediment banks along the Plymouth shoreline present a local source for new and slightly coarser sand in the downstream portion of the River system as described by Erlich (1980).

Dramatic sediment changes occur within the transition zone from the Roanoke River system to the Albemarle estuarine system. Fine sands grade fairly abruptly into silty clays and to relatively pure clays within one mile seaward of the River mouth. A small lobe of fine sand extends from the mouth of the Roanoke River into Albemarle Sound, but is abruptly terminated or buried by subsequent deposition of estuarine muds. Within this transition zone, the floodplain swamp forest is being drowned and wave erosion is truncating the upper three to four feet of modern peat deposits. This results in a shallow, peat-floored platform that extends southeastward to sediment banks at Albemarle Beach and northwestward along the entire western side of Batchelor Bay to sediment banks at Black Walnut Point. Wave erosion of the high, sediment bank shorelines on both the north and south sides, supplies new sands to the shallow platform areas along these shoreline areas.

Sediments within the central basin of the inner Albemarle estuarine system are dominated by clays with sand to mud ratios of 1:99. Sand content only begins to increase significantly along the upward slope to the narrow, sand platform that occurs adjacent and parallel to the eroding sediment bank shorelines. These eroding sediment banks are the sole source for the thin, platform sands. Bellis et al. (1975) found that these sediment bank shorelines were eroding at rates that ranged from lows of less than one foot per year to highs of 13 feet per year with an average of 2.5 feet per year depending upon bank composition, orientation, and shape of the shoreline, water depth, and wind fetch. Within the shallower portions of the estuarine environments, the sediments are redistributed by periodic high-energy storms that winnow out the clays, and erode and redistribute the shoreline sands.

A contemporaneous couplet of river backfill deposits and estuarine deposits are interpreted to represent pre-man conditions within the Roanoke River drainage basin. The pre-man basinal sediments are dominated by black, organic-rich muds, which suggest that the pre-man drainage basin was extensively vegetated with only minor and local soil erosion taking place either during severe storms and flooding or following periods of fire within portions of the drainage basin. Based upon the general patterns of sediment distribution and their changes through time, we can develop several preliminary conclusions concerning the changing patterns of sediments in the inner estuarine environment around the mouth of the Roanoke River.

1. Rapid development by man of the Roanoke River drainage basin in the Piedmont Province of North Carolina and Virginia, starting in the early 18th century and continuing to the present, has had significant impacts on the changing character of bottom sediments.

2. This was a time of large-scale land clearing for logging, farming, and urban construction that opened the soil to major erosive forces and produced an extensive sediment load. This increased sediment supply of Piedmont derived, orange-colored, inorganic clays delivered to the estuarine system rapidly overwhelmed the normal processes of deposition of black, organic-rich mud sedimentation.

3. Sedimentation of the orange clays characterized most of the depositional history for about 250 years, however, the depositional rates were probably at maximum levels during the period from the end of the civil war to the 1950s.

4. In the 1950s a series of dams was constructed on the upper Roanoke River which controlled water discharge (Figure 2). Since their construction, rates of deposition have slowed and changed back to the pre-man sediment type of black organic-rich muds. These changes are partly in response to the dam impoundments trapping more sediment, but also due to increased awareness, laws, and practices to decrease amounts of upstream sediment pollution.

The complex, broad, shallow aquatic environments of Albemarle Sound extending many miles into the Coastal Plain are the direct consequences of a sea level that has been rising for the past 18,000 years. Sea level rise is the basic cause and storm wave energy is the force behind the high rates of shoreline erosion and recession that are ongoing throughout the North Carolina barrier islands (2 to 20 feet/year) and estuaries (1 to 5 feet/year). As sea level rises across the low sloping gradient of the outer Coastal Plain, the lower Roanoke River is flooded westward, shorelines of Albemarle Sound recede, and the land floods westward. The entire coastal system maintains its integrity through time as it migrates upward and landward with a systematic evolutionary succession. Sea level is still rising in North Carolina at the present rate of between 1 and 2.5 mm/year (4 to 10 inches/100 years) (Riggs et al. 1989; Fournet 1989). Depending upon the rate at which continued sea level transgression takes place, Figure 3 projects the position of the Albemarle Sound shoreline sometime between 100 and 500 years into the future.

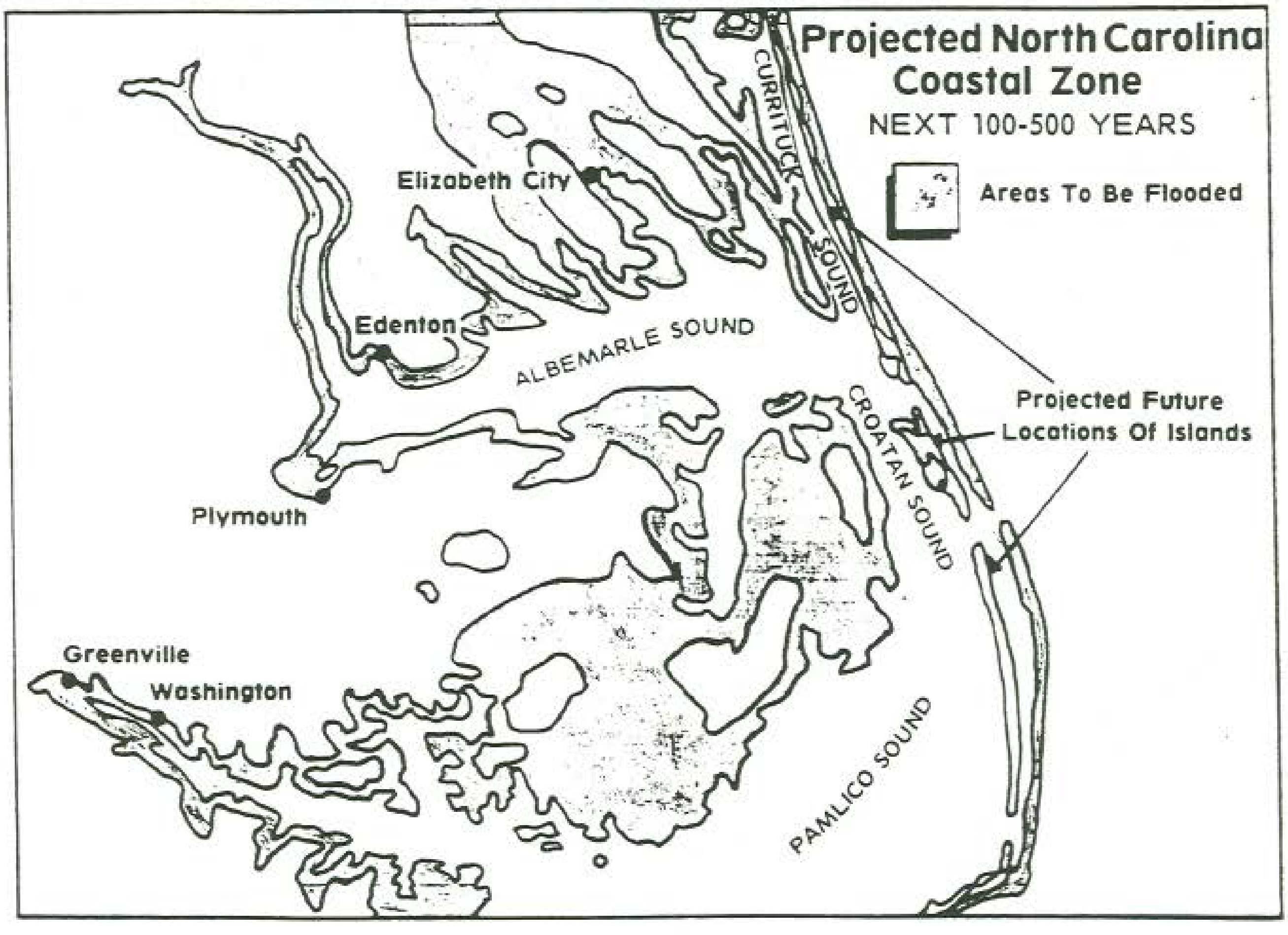

Figure 3. Map showing the interpreted location of Albemarle Sound and the Roanoke River at approximately 100 to 500 years in the future. The latter situation will occur in about 500 years if the present rate of rise in global sea level continues; however, if the "greenhouse effect" is real and if the rate of sea level rise increases, the situation outlined in this map could be realized in 100 to 300 years from now. Figure is modified from Riggs et al. (1978).

Floodplain Ecology of the Lower Roanoke River Basin

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Along its 137-mile course across the Coastal Plain, the Roanoke is characterized by an unusually wide, topographically diverse floodplain containing the sinuous, meandering brownwater River channel. The term brownwater refers to the fact that the Roanoke, like other southeastern rivers draining crystalline rocks in mountain regions, transports huge volumes of suspended silts, clays, and other sediments which it deposits during floods along its lower floodplain (see section by Riggs, Klingman, and Wyrick). Over the course of millennia the deposition of sediment associated with overbank flooding has formed an ecologically diverse and unusually wide floodplain containing at least 15 distinct natural communities and a large array of plants and animals, many of which have special adaptations to the flooding regime. An additional five natural communities occur along the upland margins of the floodplain (Table 1).

The forested floodplain along the lower Roanoke ranges up to five miles across and contains an estimated 150,000 acres of contiguous bottomland and swamp forest communities (Table 2). Other communities include excellent examples of basic mesic forest (G5T3 S1), Coastal Plain heath bluff (G4? S3?), tidal cypress-gum swamp (G3 S2), mesic mixed hardwoods forest (G5T4 S3), and Peatland Atlantic white cedar forest (G2 S2). Table 2 explains the ranking systems used to identify these communities. Most of the natural communities are represented by scattered old-growth forest remnants which contribute significantly to the floodplain's ecological diversity.

Table 1. Natural communities of the lower Roanoke River Basin, North Carolina (Schafale and Weakley 1990). Refer to Table 2 for ranking explanations.

Community type	Global Rank	NC Rank
* Mesic mixed hardwood forest, Coastal Plain subtype	C5T4	S3
* Basic mesic forest, Coastal Plain subtype	G4T3	S1?
Dry-mesic oak-hickory forest	G5	S5
Piedmont/Coastal Plain heath bluff	G4?	S3?
Piedmont/Coastal Plain acidic cliff	G4	S3?
Coastal Plain marl outcrop	G2	S1
* Coastal Plain levee forest, brownwater subtype	G5	S4
* Coastal Plain levee forest, blackwater subtype	G4	S2
* Cypress-Gum swamp forest, brownwater subtype	G5	S4
* Cypress-Gum swamp forest, blackwater subtype	G5	S4
* Coastal Plain bottomland hardwoods, brownwater subtype	G5	S3
* Coastal Plain bottomland hardwoods, blackwater subtype	G5	S3
* Coastal Plain semipermanent impoundment	G5	S3
* Oxbow Lake	G5	S3?
* Coastal Plain small stream swamp, blackwater subtype	G5	S5
* Coastal Plain small stream swamp, brownwater subtype	G4	S3
Low elevation seep	G4?	S3
* Tidal freshwater marsh	G4	S2?
* Tidal cypress-gum swamp	G3	S2?
* Peatland Atlantic white cedar forest	G2	S2

* Floodplain natural communities

Table 2. North Carolina and global rankings of contiguous bottomland and swamp forest communities.

North Carolina Rank

North Carolina ranks are based on The Nature Conservancy's system of measuring rarity and threat status. This system is now widely used by other agencies and organizations, as the best available scientific and objective assessment of a species' rarity at the state level.

S1 Critically imperiled in North Carolina because of extreme rarity (5 or fewer occurrences or very few remaining individuals) or because of some factor(s) making it especially vulnerable to extirpation in North Carolina.

S2 Imperiled in North Carolina because of rarity (6 to 20 occurrences or few remaining individuals) or because of some factor(s) making it very vulnerable to extirpation in North Carolina.

S3 Rare or uncommon in North Carolina (on the order of 21 to 100 occurrences).

S4 Apparently secure in North Carolina, with many occurrences.

S5 Demonstrably secure in North Carolina and essentially ineradicable under present conditions.

SH Of historical occurrence in North Carolina, perhaps not having been verified in the past 20 years, and suspected to be still extant.

Global Rank

Similar to North Carolina ranks, global ranks are assigned by a consensus of scientific experts, the various natural heritage programs, and The Nature Conservancy. They apply to the status of a species throughout its range, and are based on data on the species status rangewide. This system is now widely used by other agencies and organizations, as the best available scientific and objective assessment of a species' rarity throughout its range.

G1 Critically imperiled globally because of extreme rarity (5 or fewer occurrences or very few remaining individuals) or because of some factor(s) making it especially vulnerable to extinction.

G2 Imperiled globally because of rarity (6 to 20 occurrences or few remaining individuals) or because of some factor(s) making it very vulnerable to extinction throughout its range.

G3 Either very rare and local throughout its range or found locally (even abundantly at some of its locations) in a restricted range (e.g., a single physiographic region) or because of other factors making it vulnerable to extinction throughout its range; in terms of occurrences, in the range of 21 to 100.

G4 Apparently secure globally, though it may be quite rare in parts of its range, especially at the periphery.

G5 Demonstrably secure globally, though it may be quite rare in parts of its range, especially at the periphery.

One of the more significant natural communities along the lower Roanoke is the basic mesic forest. This community occurs on calcium-rich alluvium deposited during the Pleistocene and contains an unusual assemblage of disjunct, calciphilic herbs and shrubs with mountain or upper Piedmont affinities. Many of the herbs that occur here are unknown elsewhere in the Coastal Plain and are disjunct hundreds of miles from their primary Appalachian highland ranges. This Pleistocene relict flora includes at least eight plants considered rare, threatened, or endangered in North Carolina: wild hyacinth (*Camassia scilloides*), magnoliavine (*Schisandra glabra*), Atlantic isopyrum (*Isopyrum biternatum*), ginseng (*Panax quinquefolius*), veined skull-cap (*Scutellaria nervosa*), sessile-flowered trillium (*Trillium sessile*), a stinging nettle (*Urtica chamaedryoides*), and big shellbark hickory (*Carya laciniosa*).

Downstream, the River floodplain contains the most extensive examples of high-quality Coastal Plain levee forest, Coastal Plain bottomland hardwoods, and cypress-gum swamp forest remaining in the Mid-Atlantic Region (N.C. Natural Heritage Program 1988). These rich flood-plain forests contain significant wildlife values. The Roanoke River floodplain is regarded as among the best wild turkey (*Meleagris gallapavo*) habitats in North Carolina. Significantly, this population contains native birds and has not been restocked (USFWS 1981). The Roanoke River wetlands have also been designated among the key waterfowl wintering areas in the Atlantic-Eastern Gulf area by the USFWS (1981). Primary species utilizing the area for wintering are black ducks (*Anas rubripes*), wood ducks (*Aix sponsa*), and mallards (*Anas platyrhynchos*). The area also is of high value for wood duck production (USFWS 1981).

The lower Roanoke River floodplain also is a very significant area for nongame wildlife. For example, over 220 species of birds have been recorded in the floodplain including at least 90 breeding residents. This represents the highest breeding bird diversity known in the North Carolina Coastal Plain (N.C. Natural Heritage Program 1988). The floodplain contains at least eight heronries containing great blue herons (*Ardea herodius*) and great egrets (*Casmerodius albus*). This is almost a third of the inland heronries known in the State. Also notable are the disjunct breeding populations of cerulean warblers (G5 S3), Mississippi kites (G5 S1), and anhinga (G5 S2). The lower Roanoke contains one of the only three known nesting sites in North Carolina for the federally endangered bald eagle (*Haliaeetus leucocephalus*). Other birds of special concern include black vulture (*Coragyps atratus*), Cooper's hawk (*Accipiter cooperii*), and loggerhead shrike (*Lanius ludovicianus*). Special interest mammals include Rafinesque's big-eared bat (*Plecotus rafinesquii*) and black bear (*Ursus americanus*).

The lower portion of the Roanoke River floodplain adjacent to Albemarle Sound is characterized by a wide, perennially flooded, forested wetland underlain by some of the deepest peat deposits in North Carolina (Ingram 1987). This area contains several interesting natural communities including the globally endangered Atlantic white cedar forest and provides habitat for a remnant black bear population. This area also includes at least 20,000 acres of roadless cypress-gum swamp wilderness and is the most extensive example of this community known in the Carolinas (Lynch, unpublished data 1989).

There is enormous biological significance of this area: two federally endangered animals, 15 state-listed animals, 13 state-listed plants, and examples of at least 20 natural communities including the most extensive bottomland hardwood forests in the Mid-Atlantic, the globally endangered Atlantic white cedar forest, and the largest cypress-gum swamp wilderness in the Carolinas. In terms of quality, extent, and contiguity, the lower Roanoke's forested alluvial wetlands are unquestionably one of the best examples in the southeastern United States. Also, there are numerous plant species identified by the North Carolina Plant Watch List, which includes plant species that are rare or otherwise threatened with serious decline, but which have not yet been placed on the Rare Plant List of North Carolina.

Description of Floodplain Natural Communities

As mentioned in the previous section, at least 15 natural community types occur in the lower Roanoke River floodplain. An additional five occur in the uplands adjacent to the floodplain. The classification system used in this report is taken from Schafale and Weakley (1990), which is the official list used by the N.C. Natural Heritage Program. Their definition of natural community is as follows:

> *"a distinct and reoccurring assemblage of populations of plants, animals, bacteria, and fungi naturally associated with each other and their physical environment."*

The following is a brief description of the 20 natural communities which occur within the Coastal Plain section of the Roanoke River floodplain, its major tributaries, or its immediate environs.

Mesic Mixed Hardwood Forest, Coastal Plain Subtype

This community is the most important in the Roanoke system and occurs on mesic upland areas protected from fire. Along the Roanoke it commonly occurs on bluffs and on ravine slopes along the valley wall (dissected margin of the River floodplain). The community also occurs on high portions of alluvial terraces in the River floodplain.

The canopy is dominated by various mesophytic trees such as American beech, tulip poplar, white oak, sweetgum, swamp chestnut oak, cherrybark oak, and pignut hickory. American beech often forms almost pure stands on steep north-facing slopes along ravines. Understory species include hophornbeam, American holly, ironwood, flowering dogwood, and red maple.

On some sites the uncommon shrub *Stewartia malacodendron* is present. The shrub and herb layers range from sparse to dense and fairly diverse.

Basic Mesic Forest, Coastal Plain Subtype

This community is restricted along the Roanoke to a series of slopes adjacent to the floodplain between Weldon and Scotland Neck in Halifax and Northampton Counties. The community is characterized by unusually rich, high pH soils which probably originated from calcium-rich alluvium deposited by the Roanoke River.

Canopy trees include a mixture of mesophytic species such as American beech, bitternut hickory, Shumard's oak, swamp chestnut oak, and Florida (sugar) maple. Characteristic understory species include yellow buckeye, tall pawpaw, and spicebush. Herbs are generally very diverse and include a number of basophilic species such as *Camassia scilloides, Trillium sessile, Hybanthus concolor*, and others rare in the Coastal Plain.

Dry-Mesic Oak-Hickory Forest

This community occurs on upland slopes and flats adjacent to the River floodplain. On the topographic moisture gradient, the community is slightly more mesic than dry oak-hickory forest and slightly more xeric than mesic mixed hardwoods.

The forest is dominated by a mixture of oaks and hickories with white oak most prevalent with lesser amounts of black oak, southern red oak, mockernut hickory, tulip poplar, and blackgum. Common understory species include red maple, flowering dogwood, sourwood, and American holly.

This forest was once a common and widespread community type in the uplands but most sites have been cleared for agriculture or converted to pine plantations.

Piedmont/Coastal Plain Heath Bluff

This community occurs on steep slopes and bluffs, usually north-facing, exposed by undercutting of the River channel. The best example on the Roanoke is the Rainbow Banks area near Hamilton where exposed bluffs rise nearly vertically 60-75 feet above the River channel.

The canopy is open and relatively sparse. The shrub layer is characteristically dense and comprised primarily of mountain laurel although other species such as horsesugar and various blueberries also are common.

The community is subject to severe erosion caused by an unstable substrate of sandy sediments.

Piedmont/Coastal Plain Acidic Cliff

This community is limited to very steep, nearly vertical bluffs along undercut banks of the Roanoke River. The best example along the Roanoke River is the Rainbow Banks area near Hamilton, Martin County.

This community is characterized by a general lack of vegetation caused by the steepness of the underlying substrate. Various ferns and herbs occur in some areas. Mosses and lichens are also present.

Coastal Plain Marl Outcrop

This community is restricted to exposures of calcareous marl along certain bluffs undercut by the River channel. These marl exposures typically occur as a layer 5-15 feet thick underlain by sandy sediments. They occur in association with heath bluffs and acidic cliffs. The examples along the Roanoke are poorly developed vegetatively but contain interesting fossil assemblages of Miocene (Yorktown Formation) age.

Coastal Plain Levee Forest, Brownwater Subtype

This community occurs on natural levees adjacent to the Roanoke River channel. The levees are comprised of medium to coarse textured alluvial soils that are seasonally to intermittently flooded. Along the Roanoke, the highest, best-drained levees occur in the upstream portions of the River in Halifax and Northampton Counties. Downstream the levees typically are lower, flooded more frequently, and contain finer-textured sediments.

The canopy is dominated by a mixture of bottomland hardwoods such as sycamore, American elm, green ash, sugarberry, boxelder, water hickory, and sweetgum. Understory trees include tall pawpaw and ironwood. Vines are an abundant and conspicuous component of the community. The herb layer is commonly dense with many species of grasses, sedges, and forbs.

Coastal Plain Levee Forest, Blackwater Subtype

This community occurs on the natural levees of blackwater tributary streams. Examples in the Roanoke drainage area include the Cashie River and Gardner Creek. Levees along blackwater streams tend to be sandier, more acidic, and poorly developed compared with brownwater river systems.

Canopy trees common on blackwater levees include bottomland hardwoods such as laurel oak, overcup oak, willow oak, and river birch. Common understory trees are red maple and ironwood. Herbs are common and diverse and include a number of grasses, sedges, and forbs.

Cypress-Gum Swamp Forest, Brownwater Subtype

This community occurs in backswamps, sloughs, and other areas flooded for long periods throughout the Roanoke River floodplain.

The vegetation is dominated by two hydrophytic trees: water tupelo and baldcypress. Carolina water ash is a common understory species. Herbs are characteristically sparse owing to the frequent flooding.

This community is a common and well-known type in the Roanoke floodplain. In the more topographically diverse upper floodplain of Halifax and Northampton Counties, the cypress-gum swamp forest is more restricted to deeply flooded sloughs and backswamps. In the lower sections of the River downstream from Williamston, this type dominates large portions of floodplain.

Cypress-Gum Swamp Forest, Blackwater Subtype

This community occurs in frequently flooded sections of blackwater stream tributaries of the Roanoke River. The community is very similar to the brownwater cypress-gum swamp forest except for the increased dominance of swamp blackgum in the canopy. In many areas swamp blackgum replaces water tupelo in the canopy. The hydrology of blackwater swamp forests differ from brownwater in having more variable flow regimes and in having more acidic, nutrient-poor, sediment-depauperate water. Good examples of blackwater cypress-gum swamp forests occur in the Cashie River floodplain.

Coastal Plain Bottomland Hardwoods, Brownwater Subtype

This community occurs on abandoned natural levees, point bar ridges, terraces, and other relatively high portions of the Roanoke River floodplain, away from the active channel. The community is underlain by fine- to coarse-grained alluvial soils and is subject to occasional flooding, usually for brief periods.

The vegetation is comprised of a diverse mixture of bottomland hardwoods. Slight differences in flooding frequency and duration, and in soil texture cause a shift in the dominance of many species. Common trees include swamp chestnut, cherrybark, laurel, willow, and Shumard's oaks along with sweetgum, green ash, sugarberry, pignut, water and bitternut hickories, and American elm. Understory species include ironwood, deciduous holly, and American holly. Giant cane forms locally dense stands. The herb layer is generally sparse with various grasses, sedges, and forbs usually present.

Bottomland hardwoods are a conspicuous feature of the Roanoke floodplain, particularly in the upper and middle sections of the River upstream from Williamston. In this area, the community occupies sizable portions of the floodplain and, along with cypress-gum swamp forest, is the dominant vegetation feature.

Coastal Plain Bottomland Hardwoods, Blackwater Subtype

This community occurs on abandoned natural levees, point bar ridges, and other elevated portions on the floodplains of blackwater tributary streams. These areas tend to flood occasionally for relatively brief periods. The canopy is dominated by various combinations of bottomland hardwoods including laurel, overcup, water and willow oaks, red maple, and sweetgum. Understory trees include red maple, American holly, and sweetbay magnolia. The herb layer is usually poorly developed.

Examples of blackwater River bottomland hardwoods are located mainly along the Cashie River upstream from Windsor. The community is not well known but is believed to be generally less diverse than those associated with brownwater rivers.

Coastal Plain Semipermanent Impoundment

This community includes beaverponds, blocked embayments and old millponds that contain permanent or semi-permanent standing water. Most in the Roanoke River area are active beaverponds. Beaverponds occur within the River floodplain and on a number of tributary streams.

A diversity of floating or submergent aquatic plants are associated with this aquatic community. Baldcypress and/or water tupelo may occur in areas naturally flooded before impoundment and standing dead trees are often present in areas not subject to prolonged flooding prior to impoundment. A very localized variant of this community occurs along tributary streams in the upper portion of the River where natural levees have acted as dams, restricting or preventing water flow. Examples of these embayed streams include the lower portions of Sweetwater and Conoho Creeks in Martin County.

Oxbow Lake

This community is associated with abandoned River channels which have permanent nonflowing water. Various aquatic plants are associated with these sites including water lilies.

The only example of an oxbow lake in the Roanoke River floodplain is located near Hamilton, Martin County. This lake was created about 50 years ago when the River cut a new channel during a major flood.

Coastal Plain Small Stream Swamp, Blackwater Subtype

This community occurs in the floodplains of small blackwater tributary streams which are too small to distinguish fluvial features. The hydrology of these swamps varies from intermittent to seasonally flooded.

The vegetation tends to consist of hydrophytic trees such as baldcypress, swamp blackgum, and others. The shrub layer ranges from sparse to dense and almost pocosin-like.

Coastal Plain Small Stream Swamp, Brownwater Subtype

This community occurs on the floodplains of small brownwater streams in which separate fluvial features and associated vegetation zones are too small or poorly developed to be distinguishable at a natural community level. The forest is flooded at least occasionally.

The canopy is variable and dominated by combinations of baldcypress, water tupelo, and various bottomland hardwoods such as swamp chestnut oak, cherrybark oak, laurel oak, water oak, willow oak, sweetgum, sycamore, river birch, green ash, black willow, and swamp cottonwood.

This community differs from the blackwater subtype in having higher pH soils, finer sediments, and the general lack of pocosin shrubs. This community occurs along tributary streams in the upper portion of the Roanoke watershed which drain Piedmont areas.

Low Elevation Seep

This community occurs at seepages and springs at the bases of slopes or edges of floodplains. Along the Roanoke it occurs primarily in areas of steep ravines and bluffs in highly dissected topography. The seep community is highly localized and usually occurs at the contact zone where an impervious clay zone causes lateral seepage of groundwater.

The vegetation associated with seeps consists of a number of wetland herbs and ferns such as *Saururus cernuus*, *Impatiens capensis*, *Osmunda cinnamomea*, *Osmunda regalis*, and *Boehmeria cylindrica*. These species also occur in swamps or an understory community.

Tidal Freshwater Marsh

This community occurs along the margins of the main Roanoke River channel and its distributaries in the lower portion of the Basin from Plymouth downstream to Albemarle Sound. The marsh usually occurs as only a very narrow fringe along the channel margins. The marsh occurs in the lower Roanoke River area which is subject to wind tides from Albemarle Sound.

The marshes are dominated by the tall grass, *Zizaniopsis miliacea*, but also include cattail (*Typha latifolia*), pickerelweed (*Pontederia cordata*), and other forbs and sedges.

Tidal Cypress-Gum Swamp

This community occurs in the lowermost portion of the Roanoke River adjacent to Albemarle Sound where there is wind tide influence.

The canopy is dominated by a mixture of baldcypress, water tupelo, swamp blackgum, and red maple with occasional loblolly pine. The shrub layer ranges from open to dense. The tidal cypress-gum swamp is distinguished from other cypress-gum swamps by having tidal flooding predominate over river flooding as the main source of wetness. The boundary between the two types of cypress-gum swamp is difficult to delineate along the lower Roanoke. The presence of dead-end tidal creeks indicate tidal influence and are useful in helping to identify areas dominated by tidal cypress-gum swamp.

Peatland Atlantic White Cedar Forest

This community is limited in the Roanoke River Basin to the extreme lower portion of the River floodplain near Albemarle Sound where there are extensive deposits of organic soil underlain by sandy mineral soils.

The community is dominated by open to dense stands of Atlantic white cedar in association with other trees and shrubs associated with peat wetlands. Other species include loblolly and pond pines, red maple, swamp blackgum, sweetbay magnolia, redbay, baldcypress, fetterbush, titi, and gallberries. The shrub layer is typically very dense and pocosin-like. Bamboovine (*Smilax laurifolia*) is a common and conspicuous vine.

The white cedar stands in the lower Roanoke occur in interior portions of the floodplain away from the channels. At most only a hundred acres or so of this community type is present in the area. It is one of the rarest communities in the Roanoke Basin.

Description of Forest Resources

Forest management activities play a major role in developing the structure of the Roanoke River floodplain forest communities. Some old-growth tracts occur along the entire floodplain. Forest tracts upstream from Williamston, NC are those most altered by silvicultural practices. Silvicultural practices include: clear-cutting of mature stands for natural regeneration, conversion of mixed bottomland forests to short-rotation sycamore (*Platanus occidentalis*) and sweetgum (*Liquidambar styraciflua*). In addition, some tracts at the highest elevations are clear-cut, drained, and converted to pine plantations.

Because forested bottomlands of the Roanoke River are transitional in nature between the upland and aquatic zones, the complex and distinct layering forced by the hydrologic gradient (preimpoundment) provided many niches and habitats for a variety of wetland species. Some of these species are strictly limited to a wetland environment. Flood duration, frequency, and depth affected the vegetative communities, which in turn, affected animal community dynamics (Crow and MacDonald 1979, Fredricson 1979, Weller 1979, Bedinger 1981, McKnight et al. 1981, Sather and Smith 1984, Mitsch and Gosselink 1986, Mitchell 1989). The preimpoundment water regime was the most characteristic signature of the Roanoke River bottoms, and the alteration of the hydrology would likely have impaired some ecosystem functions. Larsen (1988) and Suurballe (1988) support that the depth, duration, flow, periodicity, and chemistry of the water are the most important determinants of wetland functions. The hydrology directly controls the functions of groundwater discharge or recharge, streambank stabilization, sedimentation, nutrient cycling, and food chain support (Sather and Smith 1984, Larsen 1988, Leibowitz et al. 1988, Niering 1988). Furthermore, the soils of the bottomlands, with their chemical and physical properties driven by preimpoundment conditions, were the site of critical nutrient transformations which were the basis for the functions of nutrient cycling and transformations through many of the trophic levels.

Since postimpoundment, wetland vegetation is largely determined by the interactions of hydrology, soils, and seedbank. Agencies and organizations endeavoring to develop management practices for the Roanoke River are handicapped by the lack of quantitative research that simultaneously explores a number of specific functions for specific sites along the River's reach. A holistic approach for assessing ecosystem disturbance and recovery is appropriate because of complex linkages between and within abiotic and biotic components of riverbottom forests. Maltby (1988) stated that morphological similarity under postimpoundment conditions does not necessarily imply functional performance. The asynchronous flows associated with an impounded river must disturb the hydrological, soil physical, chemical, and biological properties of the bottomland system, eventually leading to a functional change.

The most valuable function the bottomlands of the Roanoke River perform is probably the amelioration of upslope practices to adjacent watercourses. Undisturbed bottomlands have the greatest potential for retention of water, nutrients, and chemicals due to the maintenance of favorable conditions for physical, chemical, and biological processes. Biological processes such as nutrient uptake and storage by vegetation, maintenance of viable soil microbial populations, and maintenance of good hydrologic properties through the incorporation of organic matter are the most critical processes protecting water quality.

The floodplain forests of the Roanoke River Bottom are composed of generally recognized management types which are a function of cutting practices, hydrological conditions from upstream impoundments, and timber market conditions. What is recognizable in forest form, therefore, is strongly related to the degree to which the above factors influence stand dynamics. The following management types can be found on the Roanoke River bottomlands (Cobb 1990).

Tupelo Gum/Bald Cypress Backswamp

The tupelo gum (*Nyssa aquatica*) / bald cypress (*Taxodium distichum*) backswamps are some of the most unique community types in the River bottomland. The prolonged flooding which occurs in sloughs and ponds, provides standing water which persists throughout the summer. Whenever these forest communities dry out, a diverse assemblage of herbaceous plants emerge as ground cover and include: march purslane (*Ludwigia palustris*), smartweeds (*Polygonum* sp.), grasses, false nettle (*Boehmeria cylindrica*), purple mecardonia (*Mecardonia acuminata*), marsh mermaid weed (*Prosperpinaca palustris*), parrot's feather (*Myriophyllum brasiliense*), lizard's tail (*Saururus cernuus*), broadleaf arrowhead (*Sagittaria latifolia*), and horse nettle (*Solanum carolinense*).

The understory layer is dominated by bald cypress, red maple (*Acer rubrum*), and ash (*Fraxinus* sp.). In addition, pepper-vine (*Ampelopsis aborea*), rattan-vine (*Berchemia scandens*), ironwood (*Carpinus carolina*), tupelo gum, sycamore, swamp cottonweed (*Populus heterophylla*), overcup oak (*Quercus lyrata*), common greenbriar (*Smilax rotundifolia*), poison ivy (*Toxicodendron radicans*), American elm (*Ulmus americana*), and grape (*Vitis* sp.) contribute to the understory.

Bottomland Hardwoods

This type is dominated by overstory hardwood species such as oaks, gums, ashes, maples, elms, and ironwood. Dominant species in the herbaceous layer include: false nettle, giant cane (*Arundinaria gigantea*), poison ivy, lizard's tail, Japanese honeysuckle (*Lonicera japonica*), Virginia creeper (*Parthenocissus quinquefolia*), and horse nettle.

The woody species are rich in diversity and are dominated by maples (*Acer negundo, A. rubrum*), deciduous holly (*Ilex decidua*), and ironwood. Water hickory (*Carya aquatica*), hackberry (*Celtis occidentalis*), green hawthorn (*Crataegus viridis*), persimmon (*Diospyros virginiana*), swamp chestnut oak (*Quercus michauxii*), water oak (*Quercus nigra*), black willow (*Salix nigra*), bald cypress, American elm, grape, and muscadine (*Vitis rotundifolia*) also are common.

Levee Gallery Forests

The levee forests in the Roanoke River bottoms can occur on naturally deposited ridges in the bottomland or on spoil piles from dredging of the River channel. The overstory of this habitat is dominated by paw paw (*Asimina triloba*), hackberry, American elm, maples, sweetgum, ironwood, and bitternut hickory (*Carya cordiformis*). Sycamore, river birch, green ash, and swamp cottonwood are common on well-drained sandy soils adjacent to the River channel.

The herbaceous layer in this type is dominated by *Smilax* sp., poison ivy, smartweed, giant cane, and common greenbriar.

Second Terrace

These forests are usually in an area that is bounded by the bottomland hardwood type at lower elevations and agricultural and pine forest areas adjoining on the upland. The overstory is composed of ironwood, sweetgum, American elm, sugar maple (*Acer saccharum*), water oak, red maple, beech (*Fagus grandifolia*), and hickories. Redbud, flowering dogwood (*Cornus florida*), loblolly pine (*Pinus taeda*), black oak (*Quercus velutina*), and swamp chestnut oak are also a minor component of this type.

The understory components of this type are rich and varied depending on the amount of disturbance received from the adjoining upland land practices. Herbaceous dominants include

Elephantopus tormentosus, common trumpet creeper, poison ivy, pepper-vine, mosses, sedges (*Carex intumescens*, *Cyperus* sp.), bedstraws (*Galium* sp., *G. circaezans*), lespedezas (*Lespedeza bicolor*, *L. cuneata*), Japanese honeysuckle, wood sorrel (*Oxalis stricta*), blackberry (*Rubus argutus*), common greenbriar, catbriars (*Smilax bona-nox*, *S. walteri*), and fescue.

Within this type there are mixed pine/hardwood stands, loblolly pine plantations, and hardwood plantations of sycamore, greenash, and sweetgum. The understory plants are typically related to the level of management disturbance, light, and soil tillage.

Hydrology of the Lower Roanoke River

Tom Fransen

Description of Impoundments

The lower Roanoke River is regulated by a series of impoundments: John H. Kerr Reservoir, Gaston Lake, and Roanoke Rapids Reservoir. The original Steering Committee for Roanoke Rapids studies documented the specifications of the various projects in the report prepared by Fish (1959). The following information is from that study.

John H. Kerr Dam

Originally known as the "Buggs Island Project," the John H. Kerr Dam was built at RM 179 within the State of Virginia. The site is approximately 44 miles upstream from Roanoke Rapids and about 20 miles above the North Carolina-Virginia border. The project was approved by the U.S. Congress under the auspices of the Flood Control Act of 1944. The primary purposes of the project were flood control and production of hydroelectric power. Also recognized by the Congressional authorization were incidental downstream benefits including flood protection to additional hydroelectric plants, pollution abatement, navigation, and fish and wildlife conservation.

Construction of the John H. Kerr project was initiated by the U.S. Army Corps of Engineers (COE) in February 1946. The first power was generated in December 1952, and flood control measures were used in the spring of 1953. The dam created a lake 39 miles long, with a shoreline of 800 miles and a surface area of 48,900 acres at the normal summer water-surface elevation of 300 feet above sea level. At this elevation, water depth at the powerhouse is 112 feet. Water storage in the impoundment includes 1,046,000 acre-feet for power production, and an additional 1,278,000 acre-feet available for flood control. The Kerr powerhouse contains seven generators with a total capacity of 204,000 kilowatts. Power production is primarily during peak energy demands. Some water is always released during off-peak periods. Power production contributes to the Southeastern Power Pool and is marketed by the Southeastern Power Administration.

Roanoke Rapids Dam

On 6 October 1948, the Virginia Electric and Power Company (VEPCO), now known as Virginia Power -- a subsidiary of Dominion Resources -- applied to the Federal Power Commission (FPC) for a license to construct the Roanoke Rapids Dam at RM 137. The license was granted to VEPCO by the FPC's Opinion and Order Number 204, effective on 1 February 1951, giving permission to build VEPCO Project 2009 (the Roanoke Rapids project). The FPC envisioned that the Roanoke Rapids project would act as a re-regulator of river flow, providing a continuous 2,500 cfs downstream so that the John H. Kerr could be used as a peak energy facility without serious harm to future navigation below Weldon. However, the 2,500 cfs minimum continuous flow was not required because the navigation from Palmyra to Weldon was of no consequence at the time, nor did it appear as a distinct possibility in the future. Even so, the Federal Government did reserve the right to require a continuous flow up to 2,500 cfs below the Roanoke Rapids project for navigation. Additionally, the FPC stated that the water release requirements during off-peak hours for pollution abatement and preservation of fish life were the same as for the Buggs Island project. Therefore, VEPCO's proposed Roanoke Rapids project could relieve the Buggs Island project of the off-peak water release burden.

The gates of the Roanoke Rapids project were closed on 25 June 1955, and power generation by VEPCO began in July 1955. The lake created by the dam is nine miles long, with a surface area of 4,900 acres at the normal power-pool elevation of 132 feet. At this elevation, water depth is approximately 60 feet. The dam impounds 85,000 acre-feet solely for use in power production. Operation of the Roanoke Rapids powerhouse is closely coordinated with the Kerr powerhouse so that fluctuation of the water surface elevation in the Roanoke Rapids Reservoir seldom exceeds three feet. The Roanoke Rapids powerhouse contains four adjustable blade propeller-type turbines driving four identical generators with a combined capacity of 100,000 kilowatts. Power production is primarily during peak energy periods, with firm power obtained from maintenance of minimum discharge during off-peak hours.

Gaston Dam

Gaston Dam and Reservoir, the newest of the three impoundments, was constructed in 1963 by VEPCO between the Kerr Dam and Roanoke Rapids Dam at RM 145.5. The normal power-pool elevation is 200 feet, resulting in a lake 34 miles in natural river channel between Kerr Dam and the head of Roanoke Rapids Reservoir. The surface area of Lake Gaston is approximately 20,300 acres with a capacity of 400,000 acre-feet and a depth of about 90 feet. An additional three feet of flood control storage (about 63,000 acre-feet) is available. Close coordination of the three powerhouses is required to minimize the change in elevation of Gaston surface waters. Private shoreline development and heavy recreational use have become increasingly important to lake Gaston since its construction.

The Gaston powerhouse is equipped with three fixed-blade propeller turbines, and one adjustable-blade turbine, driving four generators with a total capacity of 225,000 kilowatts. Power production occurs primarily during peak energy demand.

Reservoir Operation

The flow regime in the Roanoke River is dictated by the releases from the Roanoke Rapids power plant. The release from the dam is dependent upon the release from lake Gaston. These two projects have limited storage and therefore are driven by releases from Kerr Reservoir. The release is a function of the lake level in Kerr (as defined by the Guide (Rule) Curve, Figure 4) and power demands or commitments to supply power and energy.

Kerr operation distributes higher winter runoff to the spring and more importantly decreases the peaks of flood events. The storage available at Kerr dictates the operation of all three reservoirs on a weekly basis. That is, the storage available for release is known for any given point in time and a determination made as to the amount of water available for power generation for the upcoming week. Forecasted higher flows or flood events will at times modify the release schedule. On an hourly basis, the operation of Roanoke Rapids has control of flows in the lower Roanoke River.

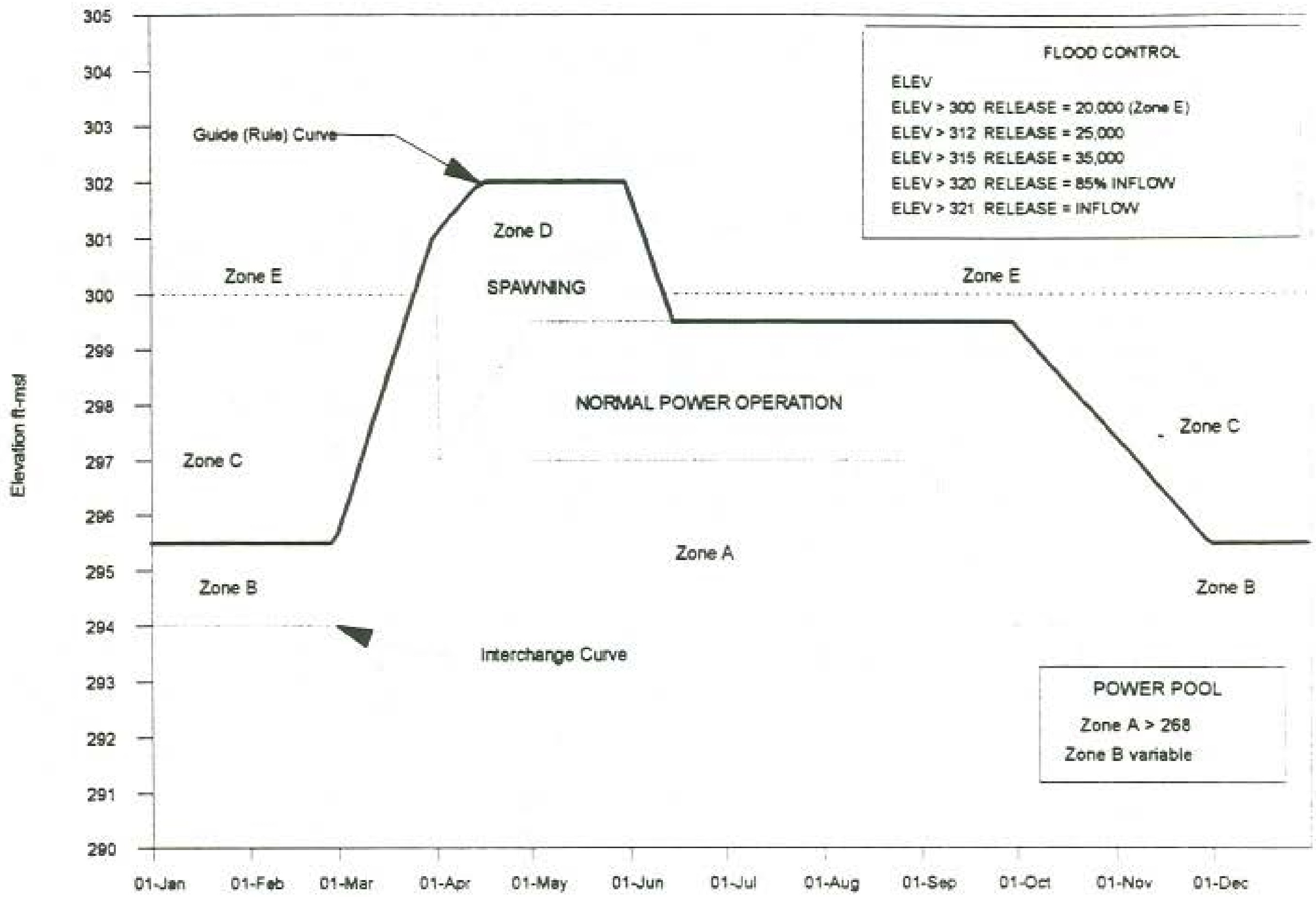

Figure 4. John H. Kerr Reservoir guide curves.

Flood Control

Flood control is accomplished by reserving the 1.2-million acre-feet storage space for containment of Kerr inflow during periods of excessive run-off. Below the dam, the River need only carry the run-off entering the watershed downstream in addition to that amount released as part of flood control operations. As soon as downstream conditions permit, the excessive inflow is released from the storage space in the reservoir at the fastest rate possible but still maintaining the River within certain stages downstream. This procedure may result in prolonged flooding of downstream areas, with the flooding period much longer in duration than that observed under pre-impoundment conditions.

The potential for flood control varies with the seasons and in coordination with the two primary purposes of the project. This planned seasonal fluctuation in reservoir surface elevation is known as the "Guide Curve" for power generation (Figure 4). The surface water elevation of 300 feet is known as the "maximum power-pool elevation." During the usually wet months of November through January, a target water surface of 295.5 feet above sea level exists to provide maximum volume of flood water storage while maintaining sufficient height for efficient power generation. Inflow conditions dictate the magnitude and duration of deviations from target elevations. Generally the COE operates the project to bring the lake elevation to the target elevation as quickly as possible, consistent with flood control and power production objectives. During

March the surface elevation is raised so that by 1 April the reservoir surface is between elevation 299.5 and 302.0. This elevation zone is to provide additional storage for spawning flows from April to June. The normal upper target elevation for power operations is 299.5 from April to September. The elevation target is lowered from 299.5 to 295.5 during October and November to restore flood control storage.

Associated with specific elevation zones are maximum releases from Kerr powerhouse or dam. These zones are given in Figure 4. Zone "C," for example, is between elevations 295.5 and 300.0 from December through March. If lake elevation is within this zone, then the Corps would normally release 8,500 cfs. Zone "E" is between elevations 300.0 and 312.0 feet msl and is the first flood control zone (except during the striped bass spawning period). In this zone Kerr would normally release 20,000 cfs. Figure 5 shows that maximum recorded controlled flows at Roanoke Rapids seldom exceed 35,000 cfs (equivalent to Zone "G", elevations 315 to 320 msl at Kerr). For 90% of the time and for most of the year the flows are below 20,000 cfs (i.e., Kerr elevations below or in Zone "E").

The Kerr Reservoir Guide Curve was developed from the water requirement to meet contracts for the sale of power, receipts of which are used to reimburse the Federal Treasury for 80% of its investment in the Kerr project over a 50-year period. This Guide Curve cannot be significantly altered without affecting flood control objectives or the existing power contracts and thus the reimbursement schedule to the Treasury by the terms specified in the Congressional authorization of the project. Agreements, such as the existing 1971 Memorandum of Understanding on Spawning Flows (MOU), may however be developed that could enhance the flow regime downstream of the projects for the benefit of flood control or power production. However, more analysis is needed to determine necessary adjustments to enhance the regime and magnitude of impacts.

Spawning Flows

The MOU on striped bass spawning flows was signed in 1971 and began the spring of 1972. The purpose of the MOU was to establish a plan for the reregulation of water from John H. Kerr Reservoir for the protection of the striped bass in the lower Roanoke River. The agreement is between Dominion Resources (then VEPCO), the U.S. Army Corps of Engineers Wilmington District (Corps), and the North Carolina Wildlife Resources Commission (WRC). A copy of the (MOU) agreement is in Appendix B.

The MOU provides for releases from Kerr Dam to maintain a minimum 13-foot stage at Weldon, NC. The releases are to start at 8 a.m. on 26 April and continue throughout the spawning period, but not later than 15 June of each year, unless otherwise requested by the WRC. These augmentation flows will be provided <u>only if Kerr Reservoir has storage available</u>.

The Guide Curve has a zone specified for providing additional water storage for release from April into June to benefit spawning activity of fish. The time and duration of the spawning release is dictated primarily by the availability of the additional storage and the inflows received during the spawning period.

There are many years when the full spawning water storage is not achieved;, however, some storage is still available for release during critical periods. Conversely, exceeding the target elevation may result in too much storage which, according to Corps rules, should be evacuated as quickly as possible to restore flood control capabilities. Therefore, storage over elevations of 305.0 feet msl will probably result in excessive flows with respect to the striped bass spawning cycle.

Minimum Flow Requirements/Targets

The Federal Energy Regulatory Commission (FERC) license for Gaston/Roanoke Rapids project requires a seasonal varying minimum release. A FERC license was granted to VEPCO and became effective 1 February 1951 for 50 years (License Number 2009); this license expires in the year 2001. The relicensing of a project like Gaston/Roanoke Rapids can take a long time and Virginia Power started the process in 1993.

The releases from Roanoke Rapids Dam determine the hour by hour flow in the lower Roanoke River. However, the storage available in Kerr Reservoir controls the amount of water released for the week. The Corps has operational guidelines (Figure 4) for Kerr Reservoir that include the target minimum flows. Table 3 summarizes the FERC required flows and the Corps' target flows along with the Committee's flow regime.

The impact caused by the regulation is to shift the spring flood waters to later in the year. The winter and spring flows (November through April) are reduced, followed by higher, more stable flows in the summer and fall (July through October). Also, the flow regulation causes an increase in the minimum flows. The unregulated daily minimum is 818 cfs (529 MGD) on 15 November 1970. Even though flow regulation increases the daily minimum flow, the amount of time at low flows increases.

A common measure of low flows is the 7Q10, the lowest average flow over seven consecutive days which is likely to occur once in a 10-year period. The unregulated 7Q10 is 955 cfs (617 MGD). As seen in Table 3, the regulated flows will always exceed the 7Q10 as long as the FERC minimums are being met.

In summary, the flows in the lower Roanoke River are regulated by upstream reservoirs. The reservoir regulation stores the winter and spring floods for use later in drier periods of the year. The impact on low flows caused by this regulation is an increase in the magnitude of minimum flows, but also increases in the amount of time at low flows.

Table 3. Roanoke River minimum flows.

	FERC Minimum release Roanoke Rapids		Kerr Reservoir Target releases		Roanoke River Lower limit		Flow Committee Target release	
	cfs	(MGD)	cfs	(MGD)	cfs	(MGD)	cfs	(MGD)
Jan	1,000	(646)	1,000	(646)				
Feb	1,000	(646)	1,000	(646)				
Mar	1,000	(646)	1,000	(646)				
Apr 1-15	1,500	(970)	2,000	(1,293)	6,600	(4,266)	8,500	(5,495)
Apr 16-30	1,500	(970)	5,700	(3,749)	5,800	(3,749)	7,800	(5,042)
May 1-15	2,000	(1,293)	5,700	(3,685)	4,700	(3,038)	6,500	(4,202)
May 16-31	2,000	(1,293)	5,700	(3,685)	4,400	(2,844)	5,900	(3,814)
June 1-15	2,000	(1,293)	5,700	(3,685)	4,000	(2,856)	5,300	(3,426)
June 16-30	2,000	(1,293)	2,000	(1,293)				
July	2,000	(1,293)	2,000	(1,293)				
Aug	2,000	(1,293)	2,000	(1,293)				
Sep	2,000	(,1293)	2,000	(1,293)				
Oct	1,500	(970)	1,500	(970)				
Nov	1,000	(646)	1,000	(646)				
Dec	1,000	(646)	1,000	(646)				

Note: FERC license requires a minimum of 2,000 cfs will be furnished as early as 1 April, but not later than 15 April, and to continue for at least 60 days, but no longer than 70 days.

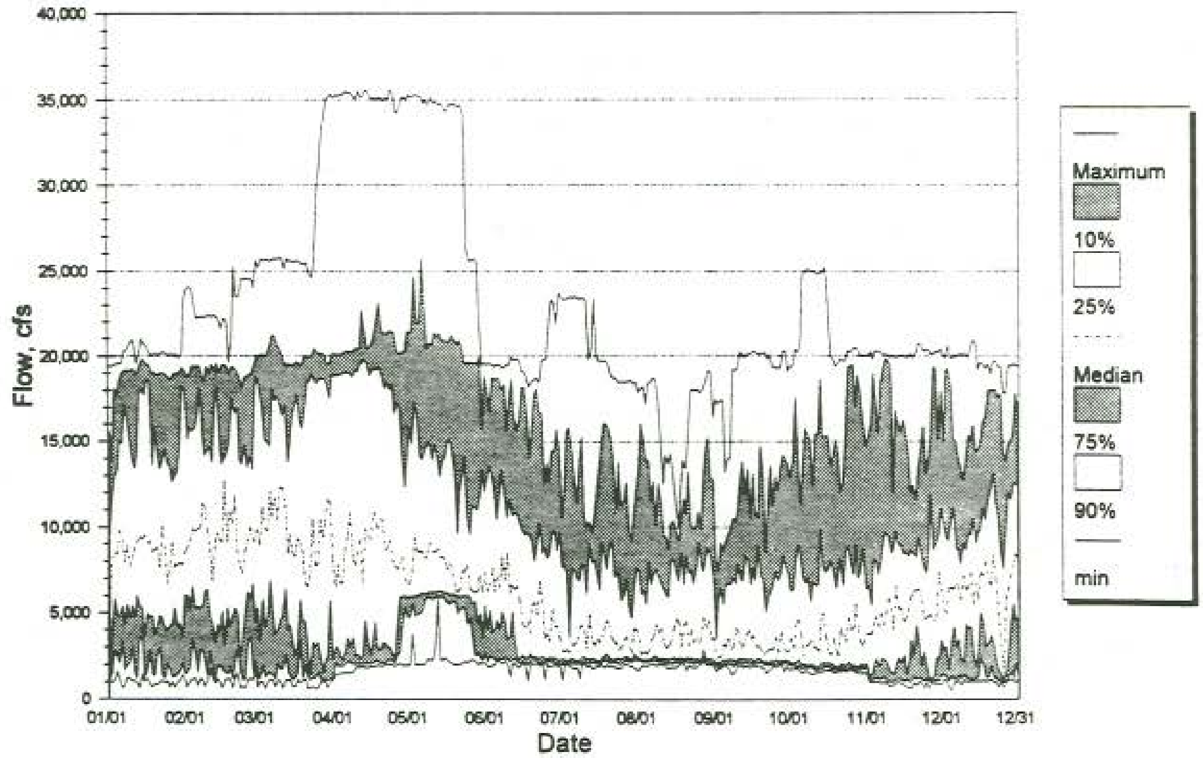

Figure 5. Range of daily flows of the lower Roanoke River measured at Roanoke Rapids for the period of October 1955 through September 1992.

Roanoke River Time of Travel Studies

Robert Herrmann

Roanoke Rapids, at river mile (RM) 134 is the nearest upstream location where river discharge is continuously gaged (US Geological Survey Station 02080500). To estimate the flows in the lower river near Plymouth, time of travel information was developed for the gaged discharge at Roanoke Rapids.

Rates of water mass movement in the river from the Roanoke Rapids station to Scotland Neck (RM 100) were previously investigated in the late 1950s (Fish 1959). In this reach of the river, where the average stream gradient is 1.0 ft/mi., average velocities ranged from 0.8 mph at a flow of 1,000 cfs to 2.5 mph at 32,000 cfs (Table 4). Farther downstream, below Oak City (RM 60), the stream gradient is significantly less, 0.05 ft/mi. and there is tidal influence. The relationship between discharge and stream velocity in the Roanoke Rapids/Scotland Neck section of the river is shown in Figure 6.

Water mass travel time information for the low gradient section of the river from Oak City to Plymouth was obtained from dye studies in 1980. Dye additions (15 to 20 liters of rhodamine WT) were made on four different occasions in 1980 to measure the rate of water movement. On 22 July, the dye was added at Williamston (RM 37) at the Highway 13 bridge. On 16 and 25 August, and on 15 September, dye was added at the Highway 11 bridge, near Oak City. During July of 1980, the USGS installed a river height gage at the latter location, enabling us to determine the flow at the time of the dye additions.

An Isco sampler was located on the river at the Weyerhaeuser Paper Mill at Plymouth to monitor the downstream passage of the dye slug. Sampling frequency was 2.5 hours. The fluorescence of the water samples was measured with a Turner Model III Fluorometer. Time of travel results for the four study dates are shown in Figures 7-10. For the 22 July dye addition, the minimum travel time (dye leading edge) from Williamston to the Plymouth mill (27 miles) was 30 hours; the dye peak arrived 33.5 hours after the addition (Table 5). These travel times translate to river velocities of 0.9 mph and 0.8 mph, respectively. The flow at Roanoke Rapids associated with this dye addition was 9,800 cfs (July 16-17). Based on previous travel time data (Fish 1959), the average velocity is 1.4 mph in the Roanoke Rapids/Scotland Neck reach. Assuming this velocity persisted downstream to Williamston, an additional 2.9 days, for a total of 4.3 days for the dye peak would be required for the water to cover the 125 miles from the USGS gaging station to the mill.

For the 16 August dye addition, when the flow at Oak City was 5,700 cfs, the minimum travel time to the mill (50 miles) was 108 hours, and the dye peak arrived 135 hours after the addition. The maximum and average river velocities over this distance were 0.45 mph and 0.37 mph. The average velocity below Roanoke Rapids associated with a flow of 5,700 cfs was 1.1 mph. The estimate for the total travel time from the gaging station to the mill for the 16 August study was 8.4 days.

Both the 25 August and 15 September dye additions at Oak City were made at flows of 2,600 cfs; however, the time of travel to the mill differed considerably between the studies. For the 25 August addition, the leading edge of the dye reached the mill in 125 hours, with the peak at 135 hours. Travel velocities were 0.40 mph and 0.37 mph, respectively. The minimum travel time for the 15 September dye dump was 144 hours, while the time to the dye peak was 158 hours. The corresponding velocities for these travel times were 0.35 mph and 0.32 mph. The average water velocity below Roanoke Rapids associated with a discharge of 2,600 cfs was 0.9 mph. Therefore, the total travel time for Roanoke Rapids to the mill was 9.0 days for 25 August, and 10.0 days for 15 September. The slower travel time for the lower river on the latter date may have been caused by river backup conditions caused by easterly winds.

The relationship between river discharge at Roanoke Rapids (range 2,600 cfs-8,200 cfs) and at Oak City to the nominal river time of travel estimates is shown in Figure 11. Note that the rate of travel is faster for the entire river than for the lower river only. These relationships were developed from dye additions made during stable flow conditions below Roanoke Rapids Dam. However, under peaking (fluctuating flow) conditions, dye additions made during a low discharge could be overtaken by a later peaking discharge and the transit time shortened substantially. Conversely, a dye addition during a peaking flow might be slowed in transit by the major reductions in flow accompanying water storage at Roanoke Rapids Dam (usually occurring on the weekends).

Table 4. Roanoke River velocities and time of travel studies, Roanoke Rapids to Scotland Neck.

Discharge (cfs)	Roanoke Rapids	Weldon	Scotland Neck	Nominal average
Channel cross-section velocities (mph):				
1,000	--	--	[2]0.8	0.8
5,000- 6,000	[1]0.9 [2]1.0	-- --	[1]1.5 [2]1.3	1.18
10,680	[1]1.4	[1]1.2	[1]1.6 [2]1.7	1.4
15,000- 16,200	[1]1.8	--	[1]1.6 [2]2.5	1.9
32,000	[1]2.5	--	--	2.5
Channel longitudinal velocities via dye (mph):				
7,000	--	[1]1.1	1.3	1.2

[1]Fish (1959)
[2] USGS, 6/29/79

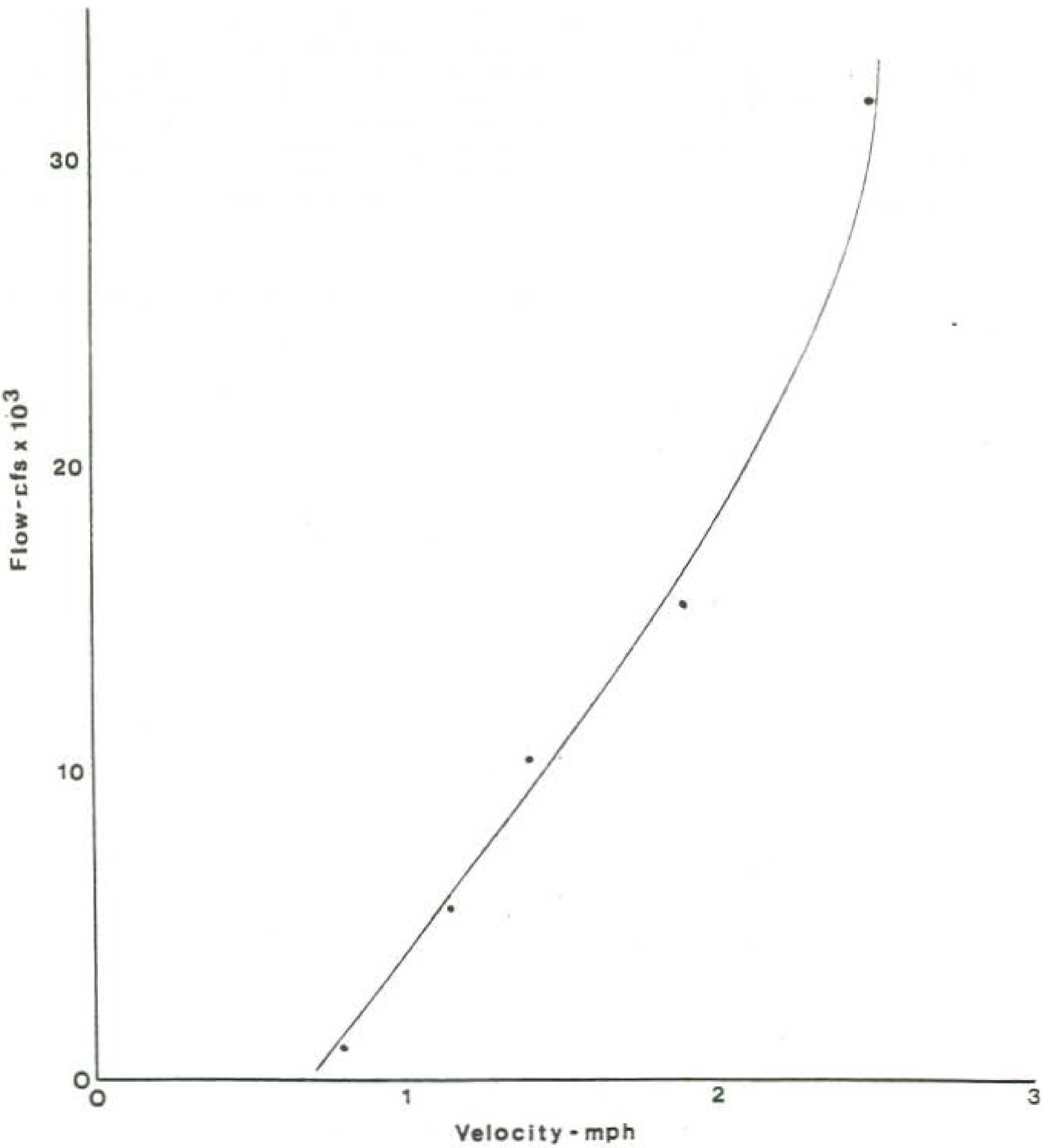

Figure 6. The relationship between Roanoke River velocities (mph) and discharge (cfs) for Roanoke Rapids to Scotland Neck.

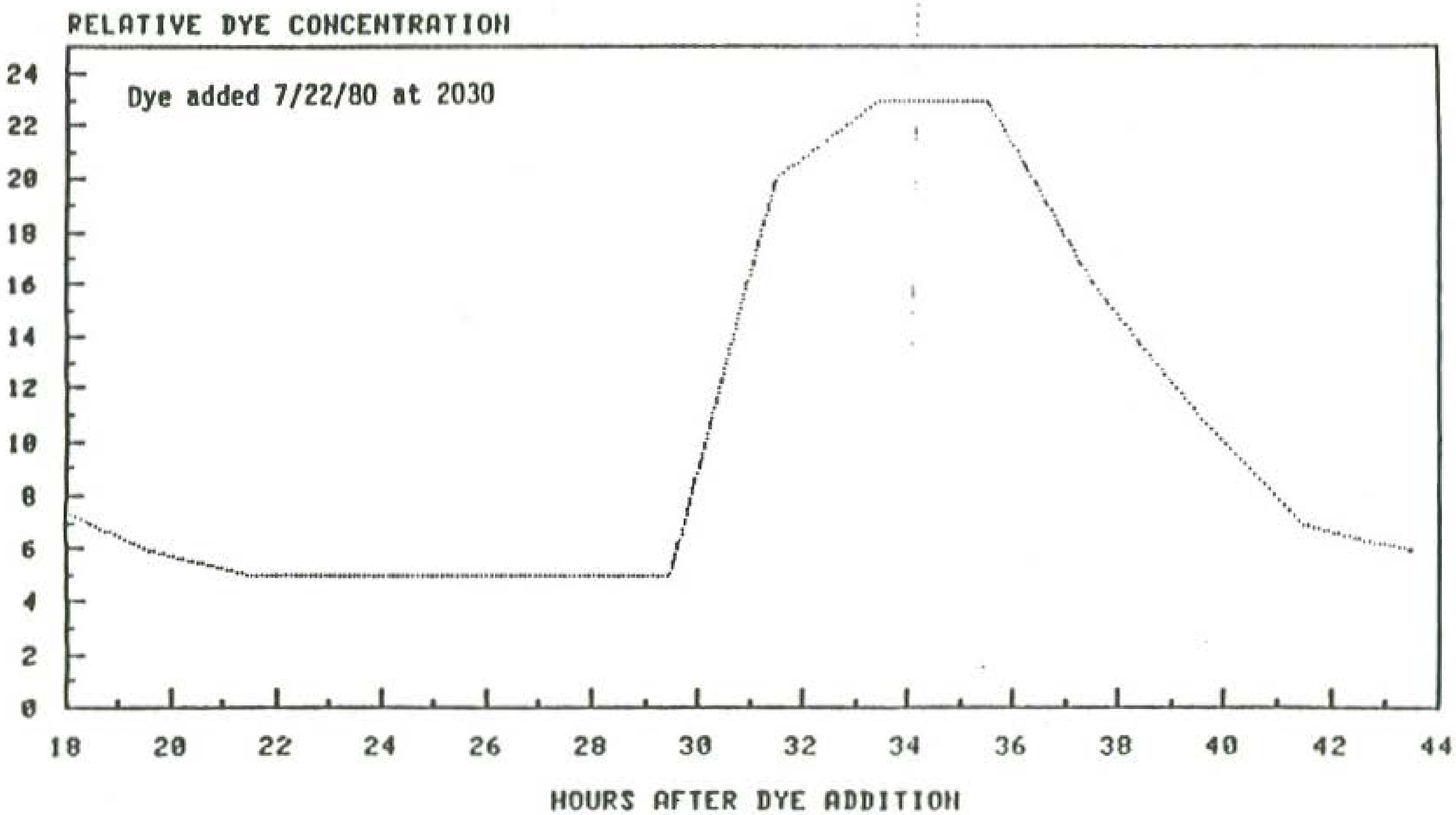

Figure 7. Travel time of dye in the Roanoke River released at Williamston, NC, at Highway 13 bridge (RM 37) and monitored at the Weyerhaeuser pulp mill at Plymouth, NC (RM 10) starting on 22 July 1980 at a river discharge of 9,850 cfs.

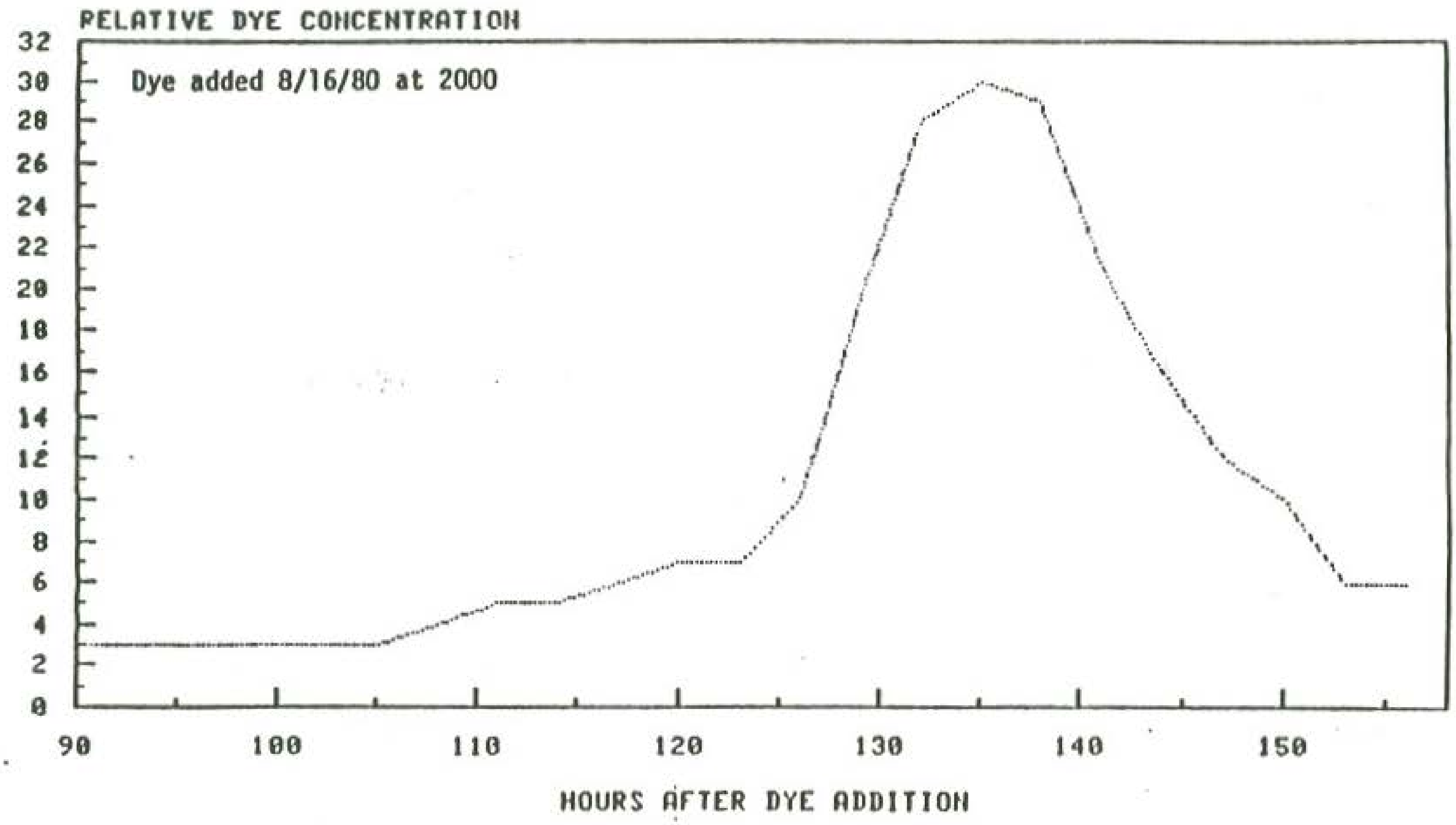

Figure 8. Travel time of dye in the Roanoke River released at Oak City, NC at Highway 11 bridge (RM 60) and monitored at the Weyerhaeuser pulp mill at Plymouth, NC (RM 10) starting on 16 August 1980 at a river discharge of 5,650 cfs.

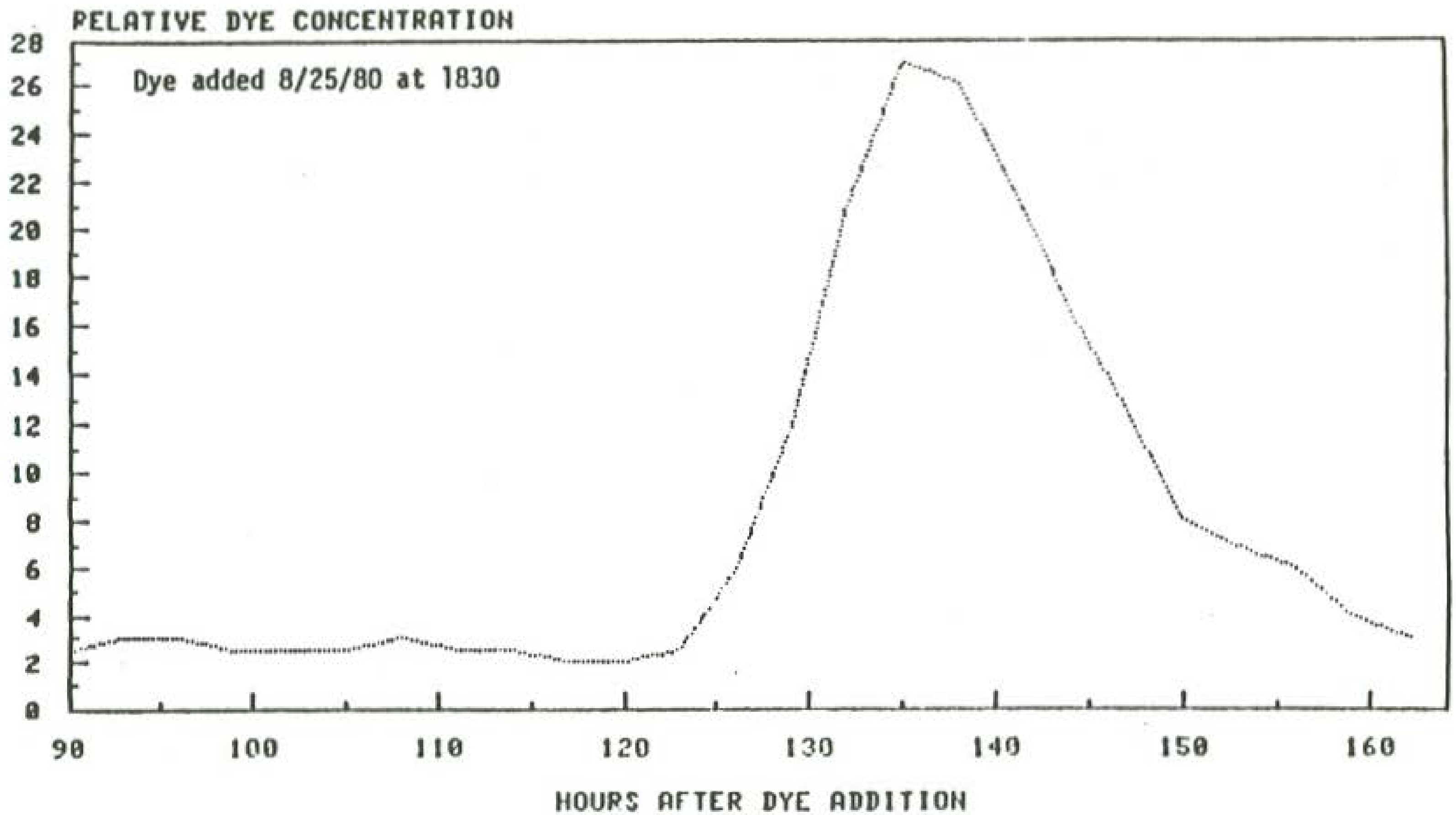

Figure 9. Travel time of dye in the Roanoke River released at Oak City, NC at Highway 11 bridge (RM 60) and monitored at the Weyerhaeuser pulp mill at Plymouth, NC (RM 10) starting on 25 August 1980 at a river discharge of 2,615 cfs.

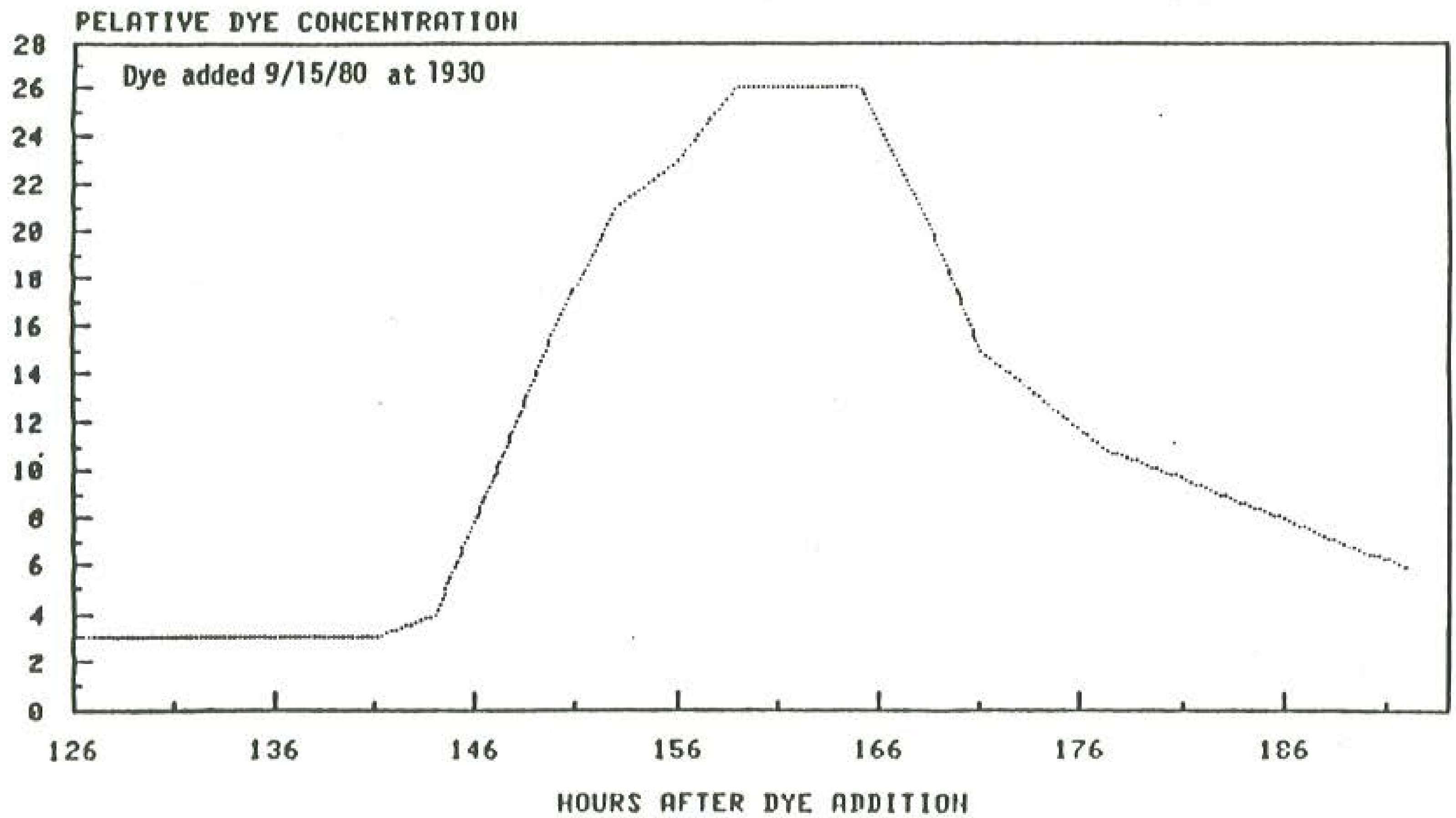

Figure 10. Travel time of dye in the Roanoke River released at Oak City, NC at Highway 11 bridge (RM 60) and monitored at the Weyerhaeuser pulp mill at Plymouth, NC (RM 10) starting on 15 September 1980 at a river discharge of 2,615 cfs.

Table 5. Roanoke River dye time of travel (in hours), Oak City (RM 60) to Plymouth at RM 10. The 22 July study was from Williamston (RM 37) (in hours) to Plymouth. River flow (cfs) measured at RM 134.

Date	River flow (cfs)	Time of dye arrival at Plymouth (hours after addition)		
		Leading edge	Mean	Median
22 July 1980	9,850	30	35	36
16 August 1980	5,650	108	135	132
25 August 1980	2,615	125	138	142
15 September 1980	2,615	144	163	169

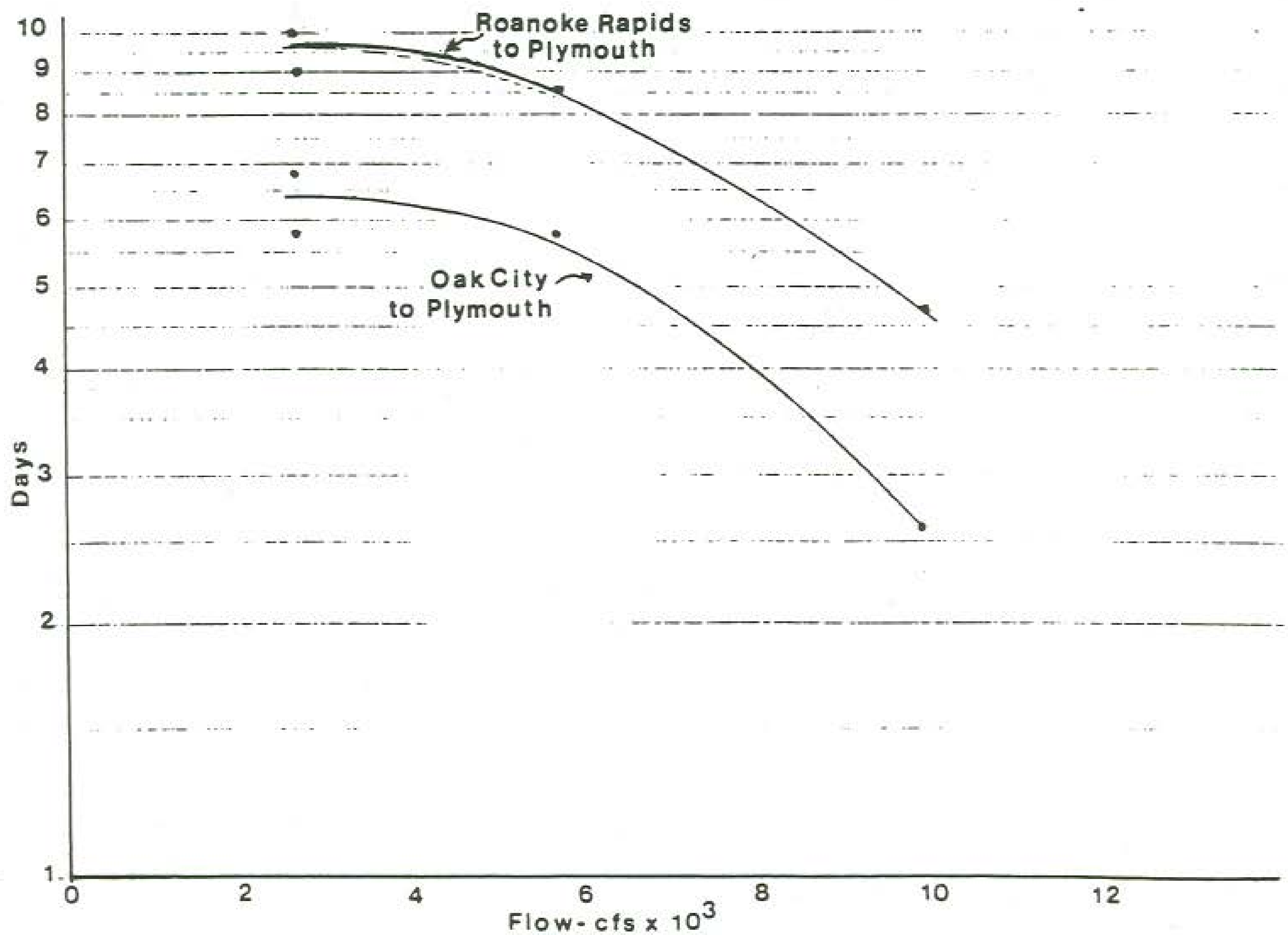

Figure 11. The relationship between Roanoke River discharge (range 2,600-8,200 cfs) at Roanoke Rapids (RM 134) and at Oak City (RM 60) to the nominal estimates of river time of travel during stable flow conditions.

Water Quality of the Lower Roanoke River Basin

Jim Mulligan, Carol Metz, David Holsinger, Ruth Swanek, Don Safrit, Jay Sauber, Norm Bedwell, and Sandra Gillaspie

The North Carolina Division of Environmental Management (DEM) Water Quality Section maintains an extensive database containing water quality information for all waters of the State. This information is obtained through monitoring and research by DEM and other agencies, and through public and interagency workshops. This database includes both chemical and biological ambient monitoring data, reports of various incidents (i.e., fish kills, oil spills, and algal blooms), and water quality ratings based on both monitoring data and best professional judgment. Likely sources of pollution are identified, when possible, for all impaired stream mileage.

Classifications and associated standards are assigned to waters based on their best usage (Briggs 1991). In accordance with the North Carolina Administrative Code Sections 15A NCAC 2B .0211(b)(2) and 15A NCAC 2B .0212(b)(2), all waters of the State must, at a minimum, be suitable for aquatic life propagation and maintenance, wildlife, and secondary recreational uses including boating and wading. Additional and more stringent standards may apply to waters with classifications more protective than Classes C or SC. Any source of water pollution that precludes any of the designated uses will be considered to be violating a water quality standard.

Ratings are assigned to waterbodies to reflect the ability of the given waterbody to support its designated uses. A waterbody that fully supports its uses is rated as supporting (S). A waterbody rated as support-threatened (ST) is characterized by either improving or worsening water quality, but continues to fully support its uses. A waterbody that supports some of its uses, but not all, is rated as partially supporting (PS). If a waterbody does not support any of its designated uses, it is considered to be nonsupporting (NS). When there are no data available on which to base a use support rating, it is listed as nonevaluated (NE) (DEHNR 1991).

In addition to maintaining this water quality database, DEM and other agencies have implemented aggressive management programs for better control of both point and nonpoint sources of pollution.

The Roanoke River Basin encompasses 3,603 square miles in 17 counties located in the Piedmont and inner Coastal Plain regions of the State. It also includes an additional 4,783 square miles in the mountain and Piedmont regions of Virginia. The Basin in North Carolina is divided into two drainage areas: the Dan River and the Roanoke River. The Roanoke River below Roanoke Rapids is characterized by variable water levels and flow rate fluctuations due to changes in discharge rates from upstream dams. Altogether, there are 2,414 stream miles in North Carolina's portion of the Roanoke River Basin (DEHNR 1991).

Use Support

Use support assessments for North Carolina's freshwater streams and rivers for 1989 through 1991 are listed in Appendix A. Overall, 65% of the streams supported, 23% partially supported, and 5% did not support their designated uses. Seven percent of the streams were not evaluated. River basins with the highest percentage of supporting freshwater streams were the Savannah, Little Tennessee, Hiwassee, New, and Broad. Basins with the lowest percentage of supporting freshwater streams were the Pasquotank, the Chowan, and the Roanoke.

Of the 2,414 Roanoke stream miles, only 15% are fully supporting, 19% are support-threatened, 47% are partially supporting, and 7% are not supporting (Appendix A).

Across North Carolina, nonpoint sources were identified as a source of use support impairment in 79% of the PS and NS streams or 22% of the total stream miles. Point sources were identified as sources in 12% of the PS and NS streams or 3% of the total stream miles. In the Roanoke point sources represent nearly 8% of the use support impairment. Throughout the state, agricultural runoff was the most widespread probable source and accounted for 56% of use support impairment in the PS and NS streams or 15% of the total stream miles. Urban runoff was the next most widespread probable source (13% of PS and NS stream miles or 4% of total miles), followed by construction (10%PS, NS and 3% total), and land disposal (5% PS, NS and 1% total). In the Roanoke, agricultural runoff was 30% of use support impairment (Appendix A).

Throughout the state, sediment was identified as the most widespread cause of use support impairment (38% of PS and NS stream miles and 10% of total miles), followed by fecal coliform bacteria (6% PS, NS and 2% total), and low dissolved oxygen/biochemical oxygen demand, toxicants, and nutrients (all at 5% PS, NS and 1% total) In terms of total Roanoke river miles, use support impairment was caused primarily by sediment (14%), followed by nutrients (7%), toxicants (6%), and fecal coliform bacteria (4%). Low dissolved oxygen and dioxin each represented about 2% of use support impairment of the watershed.

A stream segment by stream segment breakdown of the ratings for the Roanoke River and tributaries appears in Appendix A.

Agriculture Nonpoint Source Control Programs

There are a number of active programs to control agricultural pollutants (see Appendix A). Some are state and federal regulatory, or quasi-regulatory control mechanisms, including the Pesticide Law of 1971, the new turbidity water quality standard, a more stringent fecal coliform standard, National Pollution Discharge Elimination System (NPDES) permit requirements for certain concentrated animal feeding operations, and the Conservation Title of the Food Security Act of 1985. Each of these initiatives has application in the Roanoke River watershed, where nonpoint sources (85%) far outweigh point sources (15%) in terms of impaired river miles. Of all the basin's nonpoint sources, agriculture is the major contributor, so all of the control programs are important to Roanoke River water quality.

The North Carolina Agriculture Cost Share Program is a major nonpoint source control program. In 1984, the General Assembly budgeted approximately $2 million to assist landowners in 16 counties within the "Nutrient Sensitive Waters" (NSW) watersheds including the Roanoke River to implement BMPs for agricultural and silvicultural activities. These funds were increased in May 1987 to include 17 additional coastal counties by the passage of a General Statute formally creating the Agriculture Cost Share Program for Nonpoint Source Pollution Control (NCACSP). In 1989 the NCACSP became a statewide program. The NCACSP will pay a farmer 75% of the average cost of implementing approved BMPs and offer technical assistance to the landowners or users which would provide the greatest benefit for water quality protection. The primary purpose of this voluntary program is water quality protection.

The local Soil and Water Conservation District Boards, under the administration of the N.C. Soil and Water Conservation Commission (SWCC), are responsible for identifying treatment areas, allocating resources, signing contractual agreements with landowners, providing technical assistance for the planning and implementation of BMPs, and generally encouraging the use of appropriate BMPs to protect water quality. The criteria for allocating funds to a district are "based on the identified level of agricultural-related NPS pollution problems and the respective district's BMP installation goals and available technical services as demonstrated in the district's annual strategy plan" (NCAC Title 15, Chapter 6, Section 6E). This local participation is crucial to the success of the program.

The DEHNR-Division of Soil and Water Conservation (DSWC) provides staff, administrative and technical support to the SWCC. The DSWC also coordinates the efforts of various associated Program committees and acts as the clearinghouse for district strategy plans, contracts, etc. A legislated Technical Review Committee meets quarterly "to review the progress of the Program" (G.S. 143-215.74B) and to make technical recommendations to the Commission.

Technical assistance for the implementation of approved BMPs is provided to the districts through a 50:50 cost share provision for technical positions to be filled at the district level. The USDA-Soil Conservation Service also provides technical assistance.

The current statewide budget to share MBP costs (75:25) with landowners is approximately $6.7 million. The budget to share the cost of providing technical assistance with districts is approximately $1.3 million. Additional support for administration and staff is provided by local governments.

The Cost Share Program has had considerable application in the Roanoke River basin. Annual activity summary reports are provided for 1991, 1992, and a partial year for 1993 (see tables in Appendix A).

The North Carolina Pesticide Law of 1971 provides another major component of agricultural nonpoint source pollutant control. In 1971 the General Assembly created and authorized the North Carolina Pesticide Board to regulate the use, application, sale, disposal, and registration of pesticides for the protection of the health, safety, and welfare of the people and for the promotion of a healthy and safe environment. Some of the responsibilities of the Pesticide Board and the North Carolina Department of Agriculture include registering all pesticides prior to distribution and sale in N.C., sampling pesticides to insure that all products are up to guaranteed analysis and unadulterated by any other pesticide, sampling pesticides at time of application to insure that the applicator is following label instructions, certifying the competency of applicators and dealers of restricted use pesticides.

The Pesticide Section of the North Carolina Department of Agriculture conducts mandatory annual inspections of all aircraft used in pesticide application and conducts random inspections of ground application equipment and chemigation (application of pesticides through irrigation systems) systems. These inspections are intended to encourage proper calibration and use of equipment in order to avoid excessive application rates and accidental spills from faulty systems. Stop use orders are issued for noncompliance with the regulations.

Inspections are also required for bulk storage tanks prior to filling. All commercial pesticide storage facilities are required to have an approved Pre-fire Plan. In addition, each large commercial storage facility is required to develop and maintain an Emergency Contingency Plan. This plan describes the actions facility personnel shall take to respond to fires, explosions, spills, or any other sudden or gradual release of pesticides or pesticide-contaminated materials to air, soil, or surface waters. The Contingency Plan is designed to minimize hazards to human health and the environment.

Penalties can be assessed to careless pesticide applicators. Enforcement of the law is based on where the pesticide is deposited rather than just where it is applied. For example, if a pesticide is found in a stream as a result of wind drift, the applicator is subject to legal action.

The Raleigh Office staff of the NCDA Pesticide Section is comprised of 20 employees. There are 10 inspectors who conduct field-level compliance monitoring and investigation services. The annual budget for pesticide control and analytical work is $1.4 million.

In 1976, the North Carolina Pesticide Board adopted regulations governing the disposal of pesticides. These regulations make it illegal in North Carolina to dispose of hazardous waste (which includes certain pesticides) in sanitary landfills. While households and farms which generate less than 220 pounds of hazardous waste and less than 2 pounds of acutely hazardous waste are exempt from federal disposal requirements, the regulations prohibiting the disposal of these wastes in sanitary landfills still applies to them. The option to use commercial hazardous waste disposal companies is too expensive and most companies will not pick up small quantities. As a result of this dilemma, the NCDA created the Pesticide Disposal Program in 1980 through appropriations from the General Assembly.

The goal of the Program is to provide an available, affordable, and environmentally acceptable mechanism in which any homeowner, farmer, or institution can dispose of unwanted or unusable pesticides. It is mandatory, however, that all pesticide products are labeled correctly before NCDA will pick them up. An EPA permitted hazardous waste treatment or disposal facility (TSD) requires proper identification before the products can be disposed.

The Food and Drug Division of the North Carolina Department of Agriculture administers the Pesticide Disposal Program. The same staff used for enforcing the North Carolina Pesticide Law of 1971 are used in the Disposal Program.

There is considerable effort towards nonpoint source control through education and research. Crop and animal production programs are administered under the research and education activities of the N.C. Agricultural Research Service and the N.C. Cooperative Extension Service. The research and education efforts are broad and include areas such as variety development, crop fertilizer requirements, soil testing, integrated pest management, animal housing, animal waste management, machinery development, and irrigation. Guidelines for most agricultural enterprises have been developed and made available to farmers. A more intensified water quality emphasis is being incorporated in these areas and many other projects undertaken by Research and extension. The local contact that county Cooperative Extension agents have with farmers and homeowners provides an excellent opportunity for dialogue and education in nonpoint source pollution control. This network of contacts can be used to inform people about BMPs and to provide some structure for a general NPS education program.

The management of animal waste has recently received additional emphasis. North Carolina has adopted the federal water quality protection regulation that applies to animal feeding operations (15A NCAC2H.0122-.0123 and General Statute 143-215(e)). Under the regulation, concentrated animal feeding operations which discharge to waters of the State are considered a point source and are regulated by the Division of Environmental Management under the National Pollution Discharge Elimination System. The Director of DEM may designate any animal feeding operation as concentrated on the basis of size or on a case-by-case basis (regardless of size) if it is determined to be discharging to surface waters. Currently, DEM inspects animal waste facilities only in response to citizen complaints or detected water quality problems. If a farmer is not in compliance and needs to modify his operation, appropriate agricultural agencies are notified as a source of technical assistance. In effect, the regulation prohibits the discharge of animal waste without a permit from DEM. Any farmer who directly discharges waste from a lagoon (through a pipe or overflow) or fails to control stormwater runoff from a storm event less intense than the 25-year, 24-hour storm is in violation of the regulation and subject to enforcement action. Enforcement action could also be initiated if a water quality standard is contravened.

The current policy statement in the regulations for waste not discharged to surface waters deems animal waste management systems to be permitted without any minimum standards or conditions. This means a farmer does not have to make a formal permit application to DEM since the permit is automatically issued to all treatment works and disposal systems for animal waste by virtue of the policy statement. However, a proposal to amend the existing nondischarge regulation for animal operations is currently under consideration. The proposed amendments would require animal waste management plans to be developed for new, expanded, and existing animal operations >100 animal units in order to be deemed permitted. The standards and specifications of the USDA-Soil Conservation Service would be the minimum criteria used for plan approval by the local soil and water conservation districts.

Depending on the nature of a violation caused by an animal operation, there may or may not be a grace period given to a farmer to come into compliance before a penalty is assessed. For example, a grace period of 60 days is currently provided by regulation for first offenders to permanently remove a discharge before being required to apply for a permit. However, with the passage of Senate Bill 386, animal operations where manmade pipes, ditches, or other conveyances have been constructed for the purpose of willfully discharging pollutants may be fined without a mandated grace period for the first offense effective 1 January 1992. A fine can also be assessed immediately for water quality standard violations. Civil and/or criminal penalties of up to $10,000 per day and/or imprisonment may be assessed for violations of water quality standards and illegal discharges. Fines for the willful discharge of pollutants shall not exceed $5,000 for the first offense unless water quality standards are violated.

The Soil, Plant Tissue, and Animal Waste Testing Program is administered by the Agronomic Division of the North Carolina Department of Agriculture. Water and wastewater from lagoons is also tested for irrigation and fertilizer use. These services provide farmers with information necessary to improve crop production efficiency, to manage the soil properly, and to protect environmental quality.

The Soil Survey Program in North Carolina is a cooperative effort between federal, state, and local governments. According to the SCS, in the Roanoke River Basin there are now 12 counties with published modern soil surveys.

State and local governments with the authority to plan and implement activities in multi-jurisdictional areas are assisted by the USDA-Soil Conservation Service through the Resource Conservation and Development Program (RC&D). Areas of assistance include flood prevention, sedimentation and erosion control, public water-based recreation, fish and wildlife development, agricultural water management, and the abatement of agricultural related pollution.

In North Carolina, there are seven RC&D program areas including: North Central Piedmont, New River Highlands, Southwestern North Carolina, Mountain Valleys, Mid-East, Albemarle, and Region H. Forty of the 100 counties in North Carolina are in RC&D areas.

The River Basin Surveys and Investigation Program is administered by the USDA-Soil Conservation Service to provide technical assistance in solving problems which involve erosion and sedimentation, flooding, floodplain management, and agricultural water management. Other priorities include protecting wetlands and floodplains and improving water quality. Erosion inventories have been completed in the Tar, Neuse, Haw, and Deep River Basins. In North Carolina, River Basin studies have formed the basis for strategies that support the Flood Prevention and Erosion Control Programs.

The purpose of the Watershed Protection and Flood Prevention Program is to provide technical and financial assistance in planning, designing, and installing improvement projects for protection and development of small watersheds. The Program is administered by the USDA-Soil Conservation Service in cooperation with the N.C. Division of Soil and Water Conservation, the State Soil and Water Conservation Commission, the U.S. Forest Service, Soil and Water Conservation Districts, and other project sponsors.

The emphasis of the Program over the past three decades has been to provide flood control. However, legislation has shifted emphasis of PL-566 land treatment projects so that a project proposal must demonstrate off-site water quality benefits in order to have any chance of funding. In the Roanoke River Basin, there are a number of land treatment projects underway with more in the planning stages.

There are several provisions authorized by the federal Food Security Act of 1985 (FSA) and re-authorized by the Food, Agriculture, Conservation, and Trade Act of 1990 (FACTA) which offer excellent opportunities for the abatement of agricultural nonpoint source pollution. The FSA and FACTA make the goals of the USDA farm and conservation programs more consistent by encouraging the reduction of soil erosion and production of surplus commodities and the retention of wetlands. At the same time, the provisions can serve as tools to remove from production those areas which critically degrade water quality by contributing to sedimentation. Important water quality-related provisions are known as the Conservation Reserve, Conservation Compliance, Sodbuster, Swampbuster, and Conservation Easement, Wetland Reserve, and Water Quality Incentive Program. These provisions are administered by the USDA.

Conservation Reserve Program

The Conservation Reserve Program (CRP) is administered by the USDA Agricultural Stabilization and Conservation Service (ASCS) and the USDA Soil Conservation Service. Other cooperating agencies include the N.C. Cooperative Extension Service, N.C. Division of Forest Resources, and local soil and water conservation districts. The CRP was established to encourage removing highly erodible land from crop production and to promote planting long-term permanent grasses and tree cover. The intention of the program is to protect the long-term ability of the United States to produce food and fiber by reducing soil erosion, improving water quality, and improving habitat for fish and wildlife. Additional objectives are to curb the production of surplus commodities and to provide farmers with income supports through rental payments over a 10-year contract period for land entered under the CRP.

Conservation Compliance

The Conservation Compliance provision of the FSA and FACTA discourages the production of crops on highly erodible cropland where the land is not carefully protected from erosion. Highly erodible land is defined as land where the potential erosion (erodibility index) is equal to eight times or greater than the rate at which th soil can maintain continued productivity. This rate is determined by the Soil Conservation Service.

Farmers had until 1 January 1990 to develop and begin applying a conservation plan on a highly erodible land. The plan must be operational by 1 January 1995. If a conservation plan is not developed and implemented, the farmer loses eligibility in price and income supports, crop insurance, Farmers Home Administration loans, Commodity Credit Corporation storage payments, farm storage facility loans, Conservation Reserve Program annual payments and other programs under which USDA makes commodity-related payments. In other words, Conservation Compliance is an economic disincentive, quasi-regulatory program.

Sodbuster

The Sodbuster provision of the FSA and FACTA is aimed at discouraging the conversion of highly erodible land for agricultural production. It applies to highly erodible land that was not planted in annually tilled crops during the period 1981-1985. As with the other provisions of the FSA, the Soil Conservation Service determines if a field is highly erodible. If highly erodible field is planted in an agricultural commodity without an approved conservation system, the landowner (or farmer) becomes ineligible for certain USDA program benefits.

Swampbuster

The purpose of Swampbuster is to discourage the conversion of wetlands to cropland use. Wetlands are defined as areas that have a predominance of hydric soils that are inundated or saturated by surface water or groundwater at a frequency or duration sufficient to support a prevalence of hydrophytic (water-loving) vegetation. It is the responsibility of the Soil Conservation Service to determine if an area is a wetland. Like the other provisions of the FSA and FACTA, a farmer will lose eligibility for certain USDA program benefits on all the land which is farmed if a wetland area is converted to cropland.

Conservation Easement

The Conservation Easement provision encourages producers whose Farmers Home Administration loans are in or near default to place their wetland, highly erodible land, and fragile land in conservation, recreation, or wildlife uses for periods of at least 50 years. The producer benefits by having the FHA loan partially canceled. The environment benefits by reducing the level of soil-disturbing activities and the threat of agricultural pollutants.

Wetland Reserve

FACTA established a voluntary program for farmers to grant the federal government a 30-year or perpetual easement to wetlands. Eligible land includes farmed or converted wetlands which could be restored to their highest wetland function and value. The goal is to enroll one million acres by the end of 1995.

Water Quality Incentive Program

FACTA established this cost sharing program to help farmers control pollution problems associated with agricultural activities. A producer could receive up to $3,500 in cost share assistance to implement approved BMPs. The goal is to enroll 10 million acres by 1995.

Point Sources

In order to properly determine the appropriate effluent limitations to be contained in permits for point sources of discharge, the river's capability to accept waste, assimilative capacity, must be determined. This is primarily a mathematical modeling effort performed by the Technical Support Branch of the Division of Environmental Management's Water Quality Section.

A level B model was developed in June 1986 by the Technical Support Branch to evaluate the impact of several discharges in the Roanoke River. A level B model incorporates the use of empirical equations and DEM procedures to establish model input parameter values. A modified version of the Streeter-Phelps coupled BOD/DO equation is used in the model to simulate impacts to dissolved oxygen in the watercourse from oxygen consuming waste.

The model includes the section of the River between the Champion International outfall and the Thoroughfare to the Cashie River. Below this point, the River becomes tidally influenced. The level B model for the Roanoke River cannot adequately model tidal mixing; therefore, the current model ends where the River becomes tidally influenced. The distance between the model beginning and end points is approximately 117 miles. There are 11 existing permitted dischargers on this section of the River.

In June 1987, the Roanoke River model was updated to reflect separation of BOD-ultimate into carbonaceous (CBOD) and nitrogenous (NBOD) components. In 1988, the

Roanoke River model was further updated during renewal of Champion International's NPDES permit.

The last revision of this model was performed in September 1990. The model predicted a minimum dissolved oxygen concentration of 4.47 mg/L below the Perdue Farms outfall. The Roanoke River model has consistently predicted that the CBOD capacity of the system is exhausted.

An analysis performed in July 1988 predicted Champion's discharge to be the major contributor to the dissolved oxygen deficit in the lower reaches of the Roanoke River. This area of the River is historically the area that has experienced the most severe water quality problems. Weyerhaeuser also operates a pulp and paper mill with a discharge to the Roanoke River. This discharge is located in the tidally influenced section of the Roanoke River.

Due to the empirical nature of the level B model, no actual stream data are used for model calibration. A level C analysis using actual field data (scheduled for collection in 1994) is expected to be completed by spring 1995, which will provide a much better prediction of Roanoke River assimilative capacity. This more sophisticated model will be the basis for a basinwide management plan which will be available in late 1995.

Point sources are permitted following analysis of the waste characteristics and river assimilative capacity. Water quality standards (and type of discharge-wide federally mandated control measures) along with the stream and waste character are modeled under extreme low flow conditions in order to assure maintenance of the assigned best use of the stream even with the discharge.

Thirty-six such permitted (NPDES) discharges are currently active in the portion of the Roanoke River Basin covered under this report. A listing of these dischargers indicating their location, type, permit number, and issue/expire dates is shown in Table 6. A general location map with each discharger identified by NPDES number is provided in Figure 12. A summary of point source compliance for 1991-1993 is shown in Appendix A. The dischargers are grouped by sub-basin listed by NPDES number and both permitted and actual flows for each period are given. Several facilities are operating under consent orders (Judicial Order by Consent, JOC or Special Order by Consent, SOC), which allows the dischargers to exceed permitted effluent limits for a specified period of time and so long as particular conditions are met, such as compliance with a construction schedule by which to achieve final effluent limitations. The summary indicates a very high degree of compliance weighted by flow at from 95.6 to 97.3%, depending on the year, while compliance is somewhat lower if judged on a per effluent parameter limited basis, which is from 78.2 to 79.2%, depending on the year. This is not a trend peculiar to the Roanoke Basin and generally indicates that the smaller dischargers (many are publicly owned, such as schools and prisons) are the ones with the most frequent compliance problems.

Water Quality Monitoring

Basic resource ambient monitoring is conducted by the Division of Environmental Management at seven locations in the river from the Roanoke Rapids Dam to the mouth at Batchelor Bay in Albemarle Sound. Monitoring station descriptions and identification numbers, parameters measured, and their sampling frequencies appear in Table 7. Figure 13 is a map with the sampling stations located by the position of the identification number. Data summaries for each station are shown for 1991 in Table 8, for 1992 in Table 9, for January through June 1993 in Table 10. Similar data for some parameters exists for these stations as far back as 1961.

The analysis of the most recent data finds consistently good water quality with the noteworthy exception of dissolved oxygen. In the late spring, summer, and early fall the dissolved

Table 6. NPDES point sources of discharge.

Facility permit number latitude/longitude	Receiving stream county issue date	Type sub-basin expiration date
Liberty Fabrics, Inc. NC0023710 35:48:43 / 76:53:05	Roanoke River Martin 92/07/10	Minor nonmunicipal 03-02-09 97/05/31
Jamesville, Town of - WWTP NC0035858 35:49:20 / 76:54:10	Roanoke River Martin 92/06/15	Minor municipal 03-02-09 97/05/31
DOC - Martin Co. Subsidiary NC 0027791 35:50:00 / 77:05:38	UT Dog Branch Martin 92/08/10	Minor nonmunicipal 03-02-09 97/05/31
United Organics Corporation NC0068187 35:51:25 / 77:02:37	UT Roanoke River Martin 93-02-26	Minor nonmunicipal 03-02-09 97/05/30
Williamston, Town of - WWTP NC0020044 35:51:26 / 77:01:51	Roanoke River Martin 92/08/21	Major municipal 03-02-09 97/05/31
Weyerhaeuser - Plymouth Facility NC0000680 35:51:57 / 76:46:59	Roanoke River Martin 93/07/26	Major nonmunicipal 03-02-09 97/05/31
Plymouth, Town of - WWTP NC0020028 35:53:38 / 76:43:47	Roanoke River Washington 92/06/15	Minor municipal 03-02-09 97/05/31
Plymouth, Town of - Water Tmt. Plant NC0002313 35:53:45 / 76:44:37	UT Conaby Creek Washington 93/02/26	Minor nonmunicipal 03-02-09 97/05/31
Outer Banks Construction - Nicholson Pt. NC00077828 35:54:12 / 77:05:05	UT Conoho Creek Washington 92/06/22	Minor nonmunicipal 03-02-09 97/05/31
West Point Pepperell - Hamilton Facility NC0001961 35:56:08 / 77:11:41	Roanoke River Martin 93/06/07	Minor nonmunicipal 03-02-09 97/05/31
Hamilton, Town of - WWTP NC0044776 35:56:15 / 77:11:49	Roanoke River Martin 93/07/26	Minor municipal 03-02-09 97/0531
Windsor, Town of - WWTP NC0026751 35:58:57 / 76:56:46	UT Cashie River Bertie 93/07/06	Major municipal 03-02-10 97/05/31

Table 6. (Continued)

Facility permit number latitude/longitude	Receiving stream county issue date	Type sub-basin expiration date
Ladd Furniture, Inc. - Lea Lumber NC0075671 36:02:25 / 76:57:22	UT Cashie River Bertie	Minor nonmunicipal 03-02-10
Bertie Co BOE - Bertie High School NC0032450 36:03:00 / 76:58:30	UT Cashie River Bertie 90/03/02	Minor nonmunicipal 03-02-10 97.05.31
Bertie Co BOE - Askewville Elem NC0032409 36:06:23 / 76:56:20	UT White Oak Swamp Bertie 92/05/20	Minor nonmunicipal 03-02-10 97/05/31
Evans Lumber Company, Inc. NC0047007 36:07:32 / 77:11:12	UT Cashie River Bertie 92/10/07	Minor nonmunicipal 03-02-10 97/05/31
Perdue Inc. - Lewiston Facility NC0028835 36:08:06 / 77:15:02	Roanoke River Bertie 92/09/25	Minor nonmunicipal 03-02-08 97/05/31
Lewiston-Woodville Utilities NC0023116 36:08:31 / 77:09:50	Cashie River Bertie 92/12/11	Minor municipal 03-02-10 97/05/31
Halifax Co BOE - Bakers Elem. NC0038636 36:08:53 / 77:22:47	UT Kehukee Swamp Halifax 92/07/09	Minor nonmunicipal 03-02-08 95/02/01
Rich Square WWTP, Town of NC0025437 36:15:32 / 77:18:05	Bridgers Creek Northampton 93/02/05	Minor municipal 03-02-08 97/05/31
DOC - Caledonia Correctional NC0027626 36:18:22 / 77:86:55	Roanoke River Halifax 92/08/28	Minor nonmunicipal 03-02-08 97/05/31
Halifax, Town of - New WWTP NC0066192 36:19:20 / 77:35:06	Quankey Creek Halifax 93/01/12	Minor municipal 03-02-08 97/05/31
DOC - Odom Correctional Inst. 3 NC0027642 36:19:30 / 77:26:29	Roanoke River Northampton	Minor nonmunicipal 03-02-08 97/05/31
DOC - Halifax Subsidiary NC0029734 36:20:41 / 77:36:46	Little Quankey Creek Halifax 92/07/10	Minor nonmunicipal 03-02-08 97/05/31

Table 6. (Continued)

Facility permit number latitude/longitude	Receiving stream county issue date	Type sub-basin expiration date
Halifax 66 Self Service NC0082856 36:22:01 / 77:40:12	UT Quankey Creek Halifax 93/05/07	Minor nonmunicipal 03-02-08 97/05/31
Boone Residence (James C.) NC0061077 36:22:02 / 77:25:02	UT Lilly Pond Creek Northampton 89/11/30	Minor nonmunicipal 03-02-08 94/11/30
Navnit Patel - Proposed Motel NC0077356 36:22:11 / 77:40:05	Quankey Creek Halifax 89/11/16	Minor nonmunicipal 03-02-08 94/10/31
Lee Operating Co. - Travel World NC0029262 36:22:14 / 77:39:50	Quankey Creek Halifax 93/03/02	Minor nonmunicipal 03-02-08 97/05/31
Martin Marietta - Weldon NC0058041 36:23:55 / 77:36:12	UT Roanoke River Halifax 89/10/01	Minor nonmunicipal 03-02-08 94/09/30
Weldon, Town of - WWTP NC0025721 36:25:25 / 77:34:38	Roanoke River Halifax 92/12/11	Major municipal 03-02-08 97/05/31
Roanoke Rapids Sanitary Dist. - WWTP NC0024201 36:26:14 / 77:36:38	Roanoke River Halifax 93/01/29	Major municipal 03-02-08 97/05/31
Halifax Co BOE - Wm. Davie Mid Sch NC0038385 36:26:38 / 77:44:35	UT Quankey Creek Halifax 92/12/11	Minor nonmunicipal 03-02-08 94/11/30
Panda-Rosemary, L.P. NC0079014 36:27:09 / 77:39:43	UT Chockoyotte Creek Halifax 92/02/07	Minor nonmunicipal 03-02-08 97/05/31
Champion Intl. - Roanoke Rapids Facil. NC0000752 36:28:19 / 77:38:14	Roanoke River Halifax	Major nonmunicipal 03-02-08 94/01/31
Roanoke Rapids Sanitary Dist. NC0069302 36:28:38 / 77:38:50	UT Roanoke River Halifax 87/08/03	Minor nonmunicipal 03-02-08 92/07/31
VEPCO - Roanoke Rapids Hydro Station NC0056316 36:28:45 / 77:40:21	Roanoke River Northampton	Minor nonmunicipal 03-02-08 93/08/31

Table 7. Description of monitoring stations used by the Division of Environmental Management on the Roanoke River.

Station Identification		Roanoke River Monitoring — Monitoring Parameter and Frequency																			
Location Description	Number	T	DO	pH	Alk	Cond	Met	Hg	As	Al	BOD	Hd	Turb	Res	TSR	Nut	TOC	Fec Col	Cl /Phe	Col	Sal
At Roanoke Rapids	02080500	M	M	M	M	M	Q	Q	Q	M	Q	M	M	M	M	-	-	-	-	-	-
Near Scotland Neck	0208100	M	M	M	M	M	Q	Q	Q	M	Q	M	Q	M	M	Q	-	-	-	-	-
At NC 11 near Lewiston-Woodville	02081022	M	M	M	M	M	Q	Q	-	-	Q	Q	Q	M	M	-	-	-	-	-	-
At US 13-17 at Williamston	02081054	M	M	M	M	M	Q	Q	Q	-	Q	Q	Q	M	M	M	-	-	-	-	-
1.3 miles above Welches Cr. near Plymouth	02081135	M	M	M	M	M	Q	Q	-	-	Q	Q	Q	Q	Q	M	M	M	M	-	-
At NC 45 near Sans Souci	02081141	M	M	M	M	M	Q	Q	Q	-	Q	Q	Q	Q	Q	M	-	-	M	-	-
Batchelor Bay (Albemarle Sound)	02081143	M	M	M	M	M	-	-	-	-	-	-	M	M	M	M	-	-	-	M	M

T = temperature; DO = dissolved oxygen; Alk = alkalinity; Acid = acidity; Cond = conductivity; Met = cadmium, chromium, copper, lead, nickel, and zinc; Hg = Mercury; As = arsenic; Al = aluminum; BOD = 5-day biochemical oxygen demand; Hd = hardness; Turb = turbidity; Res = total residue; TSR = total suspended residue; Nut = orthophosphate, total phosphorus, nitrite, nitrate, ammonia nitrogen, Kjeldahl nitrogen; TOC = total organic carbon; Fec Col=Fecal coliform; Chlor/Pheo = chlorophyll *a*/pheophytin; Sal = salinity; M = monthly; Q = quarterly (Jan., Apr., July, Oct.).

oxygen level drops below the swamp water standard of 4 mg/L for significant periods of time in the lower River. While some of these events do occur during low flow periods, the problem is not just flow related. In fact, these low levels are predicted by the 1990 assimilative capacity modeling calculations under a number of flow scenarios.

In addition to the ambient monitoring of basic water quality parameters and the benthic macroinvertebrate sampling that is incorporated in the use support data, some sampling of polychlorinated biphenyls (PCBs) in fish tissue has been carried out in the Roanoke River. A summary of the Division of Environmental Management's data for 1980 through 1989 is shown in Table 11. Forty samples were collected from five stations during this period. A total of 28 samples were collected for an evaluation of PCB levels in striped bass. Five of 26 (19%) fish samples and three of 14 (21%) roe samples contained detectable levels of PCB's. Detected levels in both fish and roe ranged from 0.4 to 0.77 parts per million. Other samples were below the laboratory detection level at the time of analysis. The Commonwealth of Virginia has developed a rather extensive monitoring plan to evaluate PCBs in fish in the upper (above the area of concern of this report) Roanoke River Basin (Willis 1993.)

Table 8. Roanoke River monitoring data summary of the Division of Environmental Management, 1991.

Roanoke River Monitoring Data Summary
Monitored Parameter Average for January 1991 through December 1991 *

Location Description	Number	T	DO	pH	Cond	Cd	Cr	Cu	Pb	Ni	Zn	Hg	As	Al
at Roanoke Rapids	02080500	21.1	7.1	7.1	93	<D	<D	<D	<D	<D	<D	<D	<D	216.2
near Scotland Neck	02081000	20.7	7.1	7.0	108.8	<D	<D	2.7	<D	<D	<D	<D	<D	637.8
near Lewiston-Woodville	02081022	19.2	7.7	7.1	102.6	<D	<D	3.0	<D	<D	<D	<D	<D	NS
at Williamston	02081054	18.9	7.1	6.9	105.8	<D	<D	3.2	<D	<D	<D	<D	<D	NS
near Plymouth	02081135	21.3	6.6	7.0	109.0	<D	<D	<D	<D	<D	<D	<D	NS	NS
near Sans Souci	02081141	21.7	5.9	7.0	143.1	<D	<D	<D	<D	<D	<D	<D	<D	NS
Batchelor Bay (Albemarle Sn)	0208114330	24.0	7.1	7.4	489.7	NS	NS	NS	NS	NS	NS	NS	NS	NS

* If less than half the data are above the detection limit, the average is reported as less the detection limit (< D); if more than half the data are above the detection limit the average includes the "less than" values at the detection limit.

T=Temperature in C°; DO=Dissolved Oxygen (mg/l); pH=pH (SU); Cond=Conductivity (µMhos); Cd=Cadmium (µg/l); Cr=Chromium (µg/l); Cu=Copper (µg/l); Pb=Lead (µg/l); Ni=Nickel (µg/l); Zn=Zinc (µg/l); Hg=Mercury (µg/l); As=Arsenic (µg/l); Al=Alumiunum(µg/l);

Table 8. (1991, continued)

Roanoke River Monitoring Data Summary
Monitored Parameter Average for January 1991 through December 1991 *

Number	BOD	Hd	Turb	Res	TSR	Tot P	PO_4	NOx	NH_3	TKN	TOC	Color	Chlor	Fec	Cl
02080500	0.93	31.0	5.0	81.5	5.0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02081000	0.87	38.0	8.1	119.8	13.8	0.03	<D	1.80	0.04	0.3	NS	NS	NS	NS	NS
02081022	1.13	28.5	15.0	101.0	23.1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02081054	1.23	27.5	18.5	96.4	16.8	0.06	0.01	0.25	0.05	0.31	NS	NS	NS	NS	NS
02081135	1.25	27.3	12.7	97.3	7.8	0.05	<D	0.22	0.06	0.3	<D	30.6	NS	2.78	1.44
02081141	1.45	28.0	14.0	132.7	6.0	0.07	0.02	0.21	0.15	0.42	NS	NS	NS	<D	1.44
0208114330	NS	NS	6.17	299.5	4.2	0.04	NS	<D	0.15	0.06	0.33	NS	NS	NS	NS

* If less than half the data are above the detection limit, the average is reported as less the detection limit (< D); if more than half the data are above the detection limit the average includes the "less than" values at the detection limit.

BOD=Biochemical Oxygen Demand (mg/l); Hd=Hardness (mg/l of calcium carbonate); Turb=Turbidity (FTU); Res=Total Residue (mg/l); TSR=Total Suspended Residue (mg/l); Tot P=Total Phosphorus (mg/l); PO_4=Ortho-Phosphate (mg/l); NOx=Nitrite plus Nitrate Nitrogen (mg/l); NH_3=Ammonia Nitrogen (mg/l); TKN=Total Kjeldahl Nitrogen (mg/l); TOC=Total Organic Carbon (mg/l); Color=Color (SU); Chlor=Chlorophyll *a* (µg/l); Fec=Fecal Coliforms (#/100ml); Cl=Chlorides (mg/l)

Table 9. Roanoke River Monitoring data summary of the Division of Environmental Management, 1992.

Roanoke River Monitoring Data Summary
Monitored Parameter Average for January 1992 through December 1992 *

Location Description	Number	T	DO	pH	Cond	Cd	Cr	Cu	Pb	Ni	Zn	Hg	As	Al
at Roanoke Rapids	02080500	18.2	9.1	7.0	107.0	<D	<D	<D	<D	<D	<D	<D	<D	285.6
near Scotland Neck	02081000	17.1	8.7	7.0	115.2	<D	<D	4.7	<D	<D	<D	<D	<D	462.5
near Lewiston-Woodville	02081022	17.7	8.1	7.0	120.2	<D	<D	3.3	<D	<D	<D	<D	<D	NS
at Williamston	02081054	17.1	7.8	6.9	130.4	<D	<D	3.5	<D	<D	<D	<D	<D	130
near Plymouth	02081135	17.3	7.6	6.9	118.7	<D	<D	<D	<D	<D	<D	<D	NS	NS
near Sans Souci	02081141	17.4	7.1	6.9	154.4	<D	<D	<D	<D	<D	<D	<D	<D	NS
Batchelor Bay (Albemarle Sn)	0208114330	19.7	8.0	7.1	351.6	NS	NS	NS	NS	NS	NS	NS	NS	NS

* If less than half the data are above the detection limit, the average is reported as less the detection limit (< D); if more than half the data are above the detection limit the average includes the "less than" values at the detection limit.

T=Temperature in C°; DO=Dissolved Oxygen (mg/l); pH=pH (SU); Cond=Conductivity (μMhos); Cd=Cadmium (μg/l); Cr=Chromium (μg/l); Cu=Copper (μg/l); Pb=Lead (μg/l); Ni=Nickel (μg/l); Zn=Zinc (μg/l); Hg=Mercury (μg/l); As=Arsenic (μg/l); Al=Alumiunum(μg/l);

Table 9. (1992, continued)

Roanoke River Monitoring Data Summary
Monitored Parameter Average for January 1992 through December 1992 *

Number	BOD	Hd	Turb	Res	TSR	Tot P	PO_4	NOx	NH_3	TKN	TOC	Color	Chlor	Fec	Cl
02080500	1.1	30.7	5.7	83.2	8.2	0.03	NS	0.08	0.05	0.3	NS	NS	NS	NS	NS
02081000	1.0	35.0	9.9	106.4	15.6	0.02	<D	0.66	0.03	0.3	NS	NS	NS	NS	NS
02081022	NS	29.5	14.5	119.5	25.2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02081054	NS	30.5	12.7	116.6	23.9	0.05	<D	0.20	0.05	0.3	NS	NS	NS	NS	NS
02081135	NS	29.0	11.1	98.2	9.5	0.05	<D	0.19	0.05	0.3	6.2	30.0	NS	2.45	1.8
02081141	NS	34.5	9.2	122.5	5.5	0.06	<D	0.17	0.11	0.4	NS	NS	NS	<D	1.8
0208114330	NS	NS	12.4	227.2	12.1	0.05	<D	0.16	0.07	0.3	NS	NS	NS	NS	NS

* If less than half the data are above the detection limit, the average is reported as less the detection limit (< D); if more than half the data are above the detection limit the average includes the "less than" values at the detection limit.

BOD=Biochemical Oxygen Demand (mg/l); Hd=Hardness (mg/l of calcium carbonate); Turb=Turbidity (FTU); Res=Total Residue (mg/l); TSR=Total Suspended Residue (mg/l); Tot P=Total Phosphorus (mg/l); PO_4=Ortho-Phosphate (mg/l); NOx=Nitrite plus Nitrate Nitrogen (mg/l); NH_3=Ammonia Nitrogen (mg/l); TKN=Total Kjeldahl Nitrogen (mg/l); TOC=Total Organic Carbon (mg/l); Color=Color (SU); Chlor=Chlorophyll *a* (µg/l); Fec=Fecal Coliforms (#/100ml); Cl=Chlorides (mg/l)

Table 10. Roanoke River Monitoring data summary of the Division of Environmental Management, 1993 (January to June).

Roanoke River Monitoring Data Summary
Monitored Parameter Average for January 1993 through June 1993 *

Location Description	Number	T	DO	pH	Cond	Cd	Cr	Cu	Pb	Ni	Zn	Hg	As	Al
at Roanoke Rapids	02080500	13.8	10.2	6.6	58.5	<D	<D	14.0	<D	15.0	<D	<D	<D	923.3
near Scotland Neck	02081000	13.1	10.0	6.5	62.5	<D	<D	6.0	<D	<D	<D	<D	<D	880.3
near Lewiston-Woodville	02081022	14.0	8.7	6.8	86.0	<D	<D	2.5	<D	<D	<D	<D	<D	1600
at Williamston	02081054	13.6	8.1	6.7	92.0	<D	<D	3.0	<D	<D	23.0	<D	<D	NS
near Plymouth	02081135	12.6	8.2	6.6	88.8	<D	<D	5.0	<D	<D	<D	<D	<D	1200
near Sans Souci	02081141	13.2	8.2	6.6	103.4	<D	<D	4.0	<D	<D	<D	<D	<D	940.0
Batchelor Bay (Albemarle Sn)	0208114330	17.0	8.0	6.8	98.2	NS	NS	NS	NS	NS	NS	NS	NS	NS

* If less than half the data are above the detection limit, the average is reported as less the detection limit (< D); if more than half the data are above the detection limit the average includes the "less than" values at the detection limit.

T=Temperature in C°; DO=Dissolved Oxygen (mg/l); pH=pH (SU); Cond=Conductivity (μMhos); Cd=Cadmium (μg/l); Cr=Chromium (μg/l); Cu=Copper (μg/l); Pb=Lead (μg/l); Ni=Nickel (μg/l); Zn=Zinc (μg/l); Hg=Mercury (μg/l); As=Arsenic (μg/l); Al=Alumiunum(μg/l);

Table 10. (1993, continued)

Roanoke River Monitoring Data Summary
Monitored Parameter Average for January 1993 through June 1993 *

Number	BOD	Hd	Turb	Res	TSR	Tot P	PO_4	NOx	NH_3	TKN	TOC	Color	Chlor	Fec	Cl
02080500	1.2	32.7	15.7	85.8	8.3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02081000	0.8	37.5	16.5	93.3	12.17	0.11	<D	0.26	0.04	0.25	NS	NS	NS	NS	NS
02081022	NS	29.0	20.0	91.8	20.5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02081054	NS	27.0	14.0	100.8	10.8	0.07	<D	0.23	0.05	0.35	NS	NS	NS	NS	NS
02081135	NS	27.0	14.5	94.0	16.0	0.06	<D	0.19	0.05	0.40	6.4	50.2	NS	2.6	1.7
02081141	NS	24.0	16.0	96.0	14.5	0.08	<D	0.18	0.08	0.44	NS	NS	NS	<D	<D
0208114330	NS	NS	18.2	104.2	9.5	0.08	<D	0.15	0.08	0.37	NS	NS	NS	NS	NS

* If less than half the data are above the detection limit, the average is reported as less the detection limit (< D); if more than half the data are above the detection limit the average includes the "less than" values at the detection limit.

BOD=Biochemical Oxygen Demand (mg/l); Hd=Hardness (mg/l of calcium carbonate); Turb=Turbidity (FTU); Res=Total Residue (mg/l); TSR=Total Suspended Residue (mg/l); Tot P=Total Phosphorus (mg/l); PO_4=Ortho-Phosphate (mg/l); NOx=Nitrite plus Nitrate Nitrogen (mg/l); NH_3=Ammonia Nitrogen (mg/l); TKN=Total Kjeldahl Nitrogen (mg/l); TOC=Total Organic Carbon (mg/l); Color=Color (SU); Chlor=Chlorophyll *a* (µg/l); Fec=Fecal Coliforms (#/100ml); Cl=Chlorides (mg/l)

Table 11. North Carolina Division of Environmental Management PCB data for fish collected from the Roanoke River at various locations.

Date Sampled	Description	Species	Weight (g)	Sample type	PCB (mg/kg)
6/3/80	Nutbush Creek at NC-VA Stateline NR Townsville	Gizzard Shad	114.2	Whole	< 0.40
6/3/80	Nutbush Creek at Nc-VA Stateline NR Townsville	Largemouth bass	241.0	Whole	< 0.40
6/3/80	Roanoke River at Scotland Neck (HWY 258)	Bowfin	969.8	Whole	< 0.40
6/3/80	Roanoke River at Scotland Neck (HWY 258)	White catfish	297.8	Whole	< 0.40
6/3/80	Roanoke River at Scotland Neck (HWY 258)	Gizzard shad	355.2	Whole	< 0.40
9/13/80	Roanoke River at NC-45 near Sans Souci	Channel catfish	501.4	Whole	< 0.40
9/22/80	Roanoke River at NC-45 near Sans Souci	White perch	80.4	Whole	< 0.40
4/23/81	Dan River at SR-1716 near Mayfield	Flat bullhead	28.4	Whole	< 0.40
4/23/81	Roanoke River at Weldon	Striped bass	5,000.0	Whole	< 0.40
4/23/81	Roanoke River at Weldon	Striped bass	6,100.0	Whole	< 0.40
4/23/81	Roanoke River at Weldon	Striped bass	5,000.0	Eggs	< 0.40
4/23/81	Roaonke River at Weldon	Striped bass	6,100.0	Eggs	< 0.40
4/27/81	Roanoke River at Weldon	Striped bass	6,500.0	Whole	< 0.40
4/27/81	Roanoke River at Weldon	Striped bass	6,200.0	Whole	< 0.40
4/27/81	Roanoke River at Weldon	Striped bass	8,000.0	Whole	0.49
4/27/81	Roanoke River at Weldon	Striped bass	8,300.0	Whole	0.45
4/27/81	Roanoke River at Weldon	Striped bass	4,900.0	Whole	< 0.40
4/27/81	Roanoke River at Weldon	Striped bass	6,500.0	Eggs	< 0.40
4/27/81	Roanoke River at Weldon	Striped bass	6,200.0	Eggs	0.47
4/27/81	Roanoke River at Weldon	Striped bass	8,000.0	Eggs	0.55
4/27/81	Roanoke River at Weldon	Striped bass	8,300.0	Eggs	< 0.40
4/27/81	Roanoke River at Weldon	Striped bass	4,900.0	Eggs	< 0.40
5/5/81	Roanoke River at Weldon	Striped bass	3,500.0	Eggs	< 0.40
5/5/81	Roanoke River at Weldon	Striped bass	6,500.0	Eggs	0.72
5/5/81	Roanoke River at Weldon	Striped bass	11,300.0	Eggs	< 0.40
5/5/81	Roanoke River at Weldon	Striped bass	5,900.0	Eggs	< 0.40
5/5/81	Roanoke River at Weldon	Striped bass	6,500.0	Whole	0.49
5/5/81	Roanoke River at Weldon	Striped bass	5,900.0	Whole	0.77
5/5/81	Roanoke River at Weldon	Striped bass	11,300.0	Whole	< 0.40

Table 11. (continued)

Date Sampled	Description	Species	Weight (g)	Sample type	PCB (mg/kg)
5/8/81	Roanoke River at Weldon	Striped bass	3,500.0	Whole	0.40
5/8/81	Roanoke River at Weldon	Striped bass	7,200.0	Whole	< 0.40
5/8/81	Roanoke River at Weldon	Striped bass	9,100.0	Whole	< 0.40
5/8/81	Roanoke River at Weldon	Striped bass	8,700.0	Whole	< 0.40
5/8/81	Roanoke River at Weldon	Striped bass	9,100.0	Eggs	< 0.40
5/8/81	Roanoke River at Weldon	Striped bass	7,200.0	Eggs	< 0.40
5/8/81	Roanoek River at Weldon	Striped bass	8,700.0	Eggs	< 0.40
9/22/81	Roanoke River at Scotland Neck (HWY258)	Carp	1,908.8	Whole	< 0.40
2/25/82	Nutbush Creek at NC-VA Stateline NR Townsville	Largemouth bass	922.8	Whole	< 0.40
2/25/82	Nutbush Creek at NC-VA Stateline NR Townsville	Gizzard shad	152.2	Whole	< 0.40
5/2/89	Roanoke River at Sans Souci	Brown bullhead	950.0	Whole	< 0.013

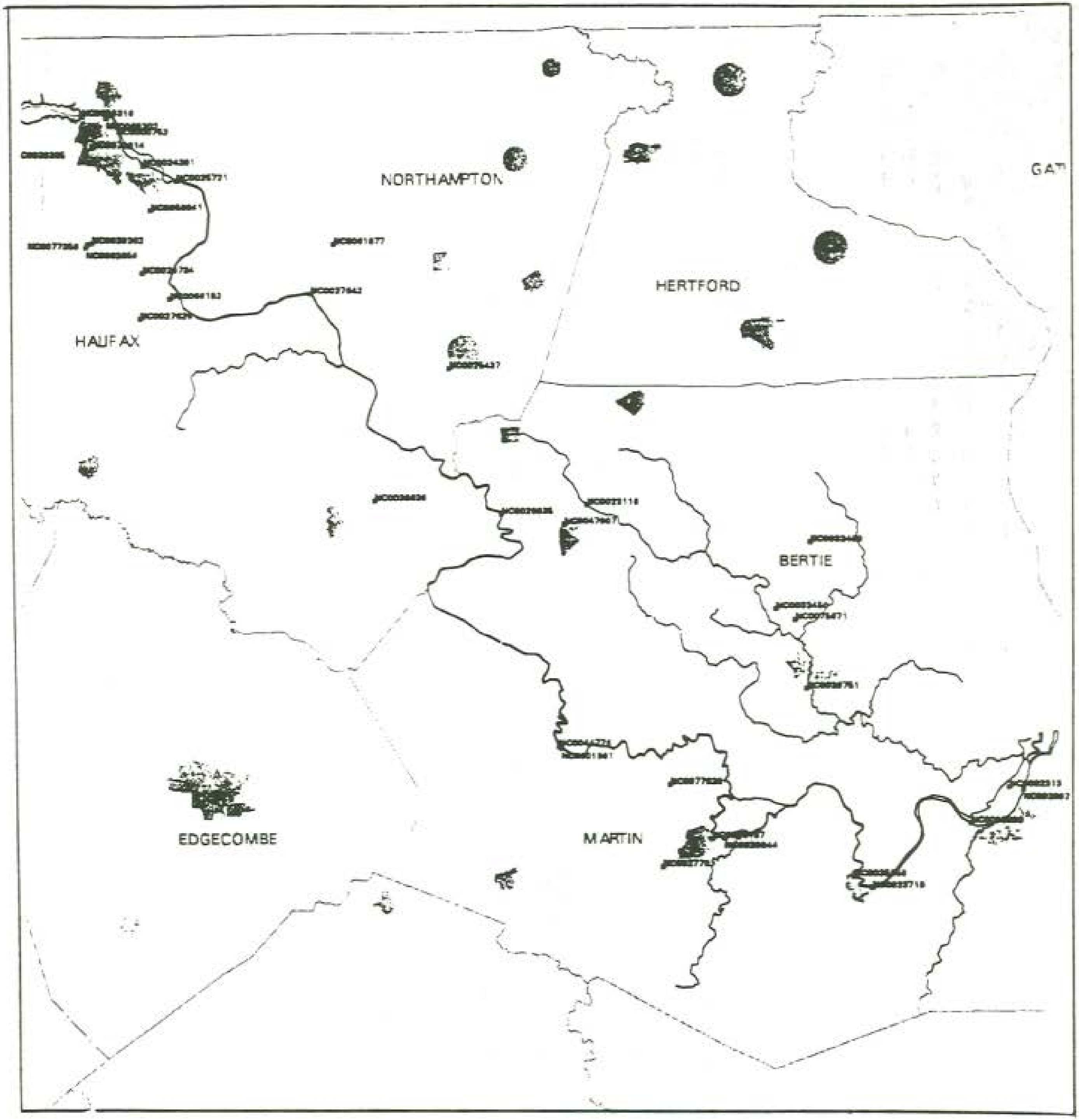

Figure 12. Lower Roanoke River basin wastewater discharge locations by NPDES number.

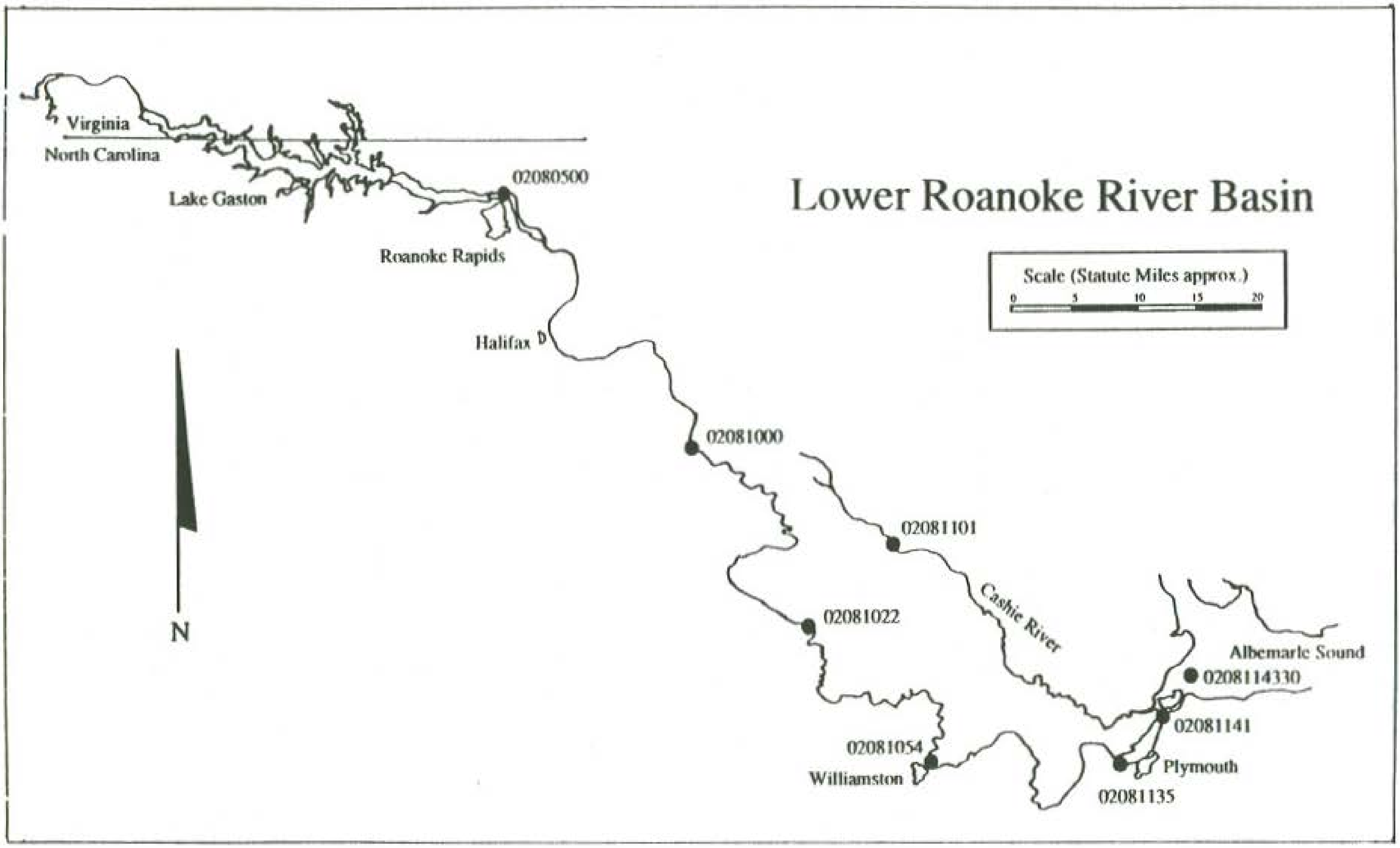

Figure 13. Ambient water quality sampling stations in the lower Roanoke River basin.

Wildlife Resources of the Lower Roanoke River Watershed

Wilson Laney, Dennis Luszcz, Scott Osborne, and Michael Seamster

Description of Floodplain Wildlife

The combination of hard and soft mast-producing trees and the availability of cover provides an ideal habitat for high mammal populations along the floodplain. The white-tailed deer is one of the most common mammals in the Roanoke River floodplain. It also is one of the most important species from a recreational standpoint in terms of providing hunting opportunity. This riverbottom area has traditionally maintained densities ranging from 50-80 deer per square mile (Osborne 1981). Surveys by biologists from the North Carolina Wildlife Resources Commission indicate that populations in the lower Roanoke have been at or above the carrying capacity of the habitat from the late 1950s to the present (USFWS 1988).

Deer use every habitat along and adjacent to the Roanoke, from the flats and ponds along the River channel to the oak ridges and farmlands adjacent to the bottoms. Principal spring and summer food items include green leaves and succulent sprouts of native hardwoods, numerous herbaceous plants, native grasses, and planted agricultural corps. Primary food items in fall and winter periods include oak mast, agricultural crop residues, honeysuckle, and greenbriar leaves. Soft mast is produced by numerous woody and herbaceous plants: e.g., blackgum, pokeweed, summer grapes, etc.

A remnant population of black bear is found along the lower River in one of the few remaining expanses of habitat for this species in this part of the State (USFWS 1981). The availability of food and large old trees for winter denning sites contribute to the quality of habitat (USFWS 1988).

Gray squirrels and marsh rabbits are abundant. The gray squirrel inhabits mature forests and likely reaches its greatest abundance in mature bottomland hardwood habitat. Periodic flooding restricts the movement of this species to the forest canopy. Food resources on the forest floor are unavailable during the duration of the flood. A positive aspect of floodplain habitat is that many of the hardwood species providing food and shelter for squirrels thrive under the regime of periodic flooding.

The range of the marsh rabbit is restricted to coastal marshes, river floodplains, and wetlands. This mammal thrives in bottomland cane thickets and cutovers. High water sometimes forces this species out of its normal habitat and into more crowded conditions, but they return when water levels recede. Mortality due to extensive and prolonged flooding occurs, but the high reproductive capacity of the species allows it to rebound quickly. Also, numerous furbearers are present including raccoon, mink, muskrat, otter, fox, bobcat, beaver, and opossum (Barick and Critcher 1975).

At least 214 species of birds, including 88 resident breeding species, are known to use the Roanoke River floodplain (Lynch and Crawford 1980). The area is believed to support the highest density of nesting birds, especially songbirds, anywhere in North Carolina (Harry LeGrand, North Carolina Natural Heritage Program, personal communication). The floodplain supports at least six active heron rookeries, containing great blue herons and great egrets. This is almost a third of the inland, non-estuarine heronries known in North Carolina and over 60% of all the inland nesting great blue herons (Lynch and Crawford 1980). The red-shouldered hawk and barred owl are characteristic raptor species found in the wooded swamps and bottomland hardwoods (USFWS 1988).

The woodcock is an important migratory gamebird which reaches peak populations in the State during late winter. A breeding population does occur in the State, but the extent of breeding in North Carolina is not known. The lower Roanoke bottomlands are important wintering areas for this species. The woodcock is a very mobile species and should benefit from periodic bottomland flooding which replenishes nutrients and concentrates earthworms, the woodcock's major food.

One of the largest populations of wild turkeys in North Carolina occurs along the Roanoke River in Bertie, Martin, Halifax, and Northampton counties. The Roanoke River floodplain in this area has long been regarded as having some of the best wild turkey habitat in the State. Densities exceed 15 birds per square mile in some areas. The ancient River ridges and terraces, supporting prime bottomland hardwood tree species, provide excellent food and cover for feeding and nesting turkeys (McClanahan 1979). The annual turkey harvest along the Roanoke River has increased steadily over the last 10 years, indicating that populations are strong and withstanding current hunting pressure (NCWRC unpublished data), although nesting success in recent years has suffered due to high water in the spring (USFWS 1988).

The eastern wild turkey is capable of surviving under a variety of habitat conditions. In general, however, habitat diversity seems to be one of the major factors controlling use of an area by turkeys and the presence or absence of scattered openings often determines whether turkey populations thrive. Isolation from human disturbance is also an important factor. Many populations seem to be associated with an abundant water supply. During the fall and winter, hardwood stands are the dominant habitat type used. During the spring and summer, turkeys primarily utilize open habitats. The Roanoke River floodplain is characterized by a rich herbaceous ground cover that is utilized as nesting and brooding habitat.

Bobwhite quail occur sporadically along the River (Barick and Critcher 1975). Also, seven bird species found here are listed as rare and of special concern in the State (Cooper et al. 1977). Most notable among these are disjunct populations of breeding cerulean warblers (Lynch 1981a) and Mississippi kites (Lynch 1981b). The federally-listed endangered bald eagle occurs as a transient along the River and has recently returned to nest near the mouth of the River after an absence of many years (USFWS, unpublished data).

At least 14 species of waterfowl utilize the Roanoke River floodplain regularly, with wood ducks, mallards, and black ducks the most abundant according to harvest data (USFWS 1983). Other frequently observed species include pintail, widgeon, gadwall, green-winged teal, blue-winged teal, ring-necked duck, hooded merganser, shoveler, bufflehead, Canada goose, and tundra swan. Over the 12-year period from 1973 to 1984, 24 species of waterfowl were recorded during the Roanoke Rapids Christmas Bird Count (Merrill Lynch, The Nature Conservancy, personal communication). Recent studies (USFWS 1988) have shown the importance of wooded wetlands to wintering waterfowl as a prime source of cover and food, meeting supplemental dietary needs prior to spring migration, mating, and nesting. Migratory mallards, black ducks, and some wood ducks utilize bottomland hardwoods and cypress-gum swamps in the fall, winter, and spring months. They often feed on the vegetable matter found in shallow water. For migration and pre-breeding activities they supplement this with the high-protein foods found in the wooded floodplain, including: acorns; beechnuts; the seeds of buttonbush, bald cypress, and tupelo gum; insects; and the abundant floodplain aquatic invertebrates, such as snails, crustaceans, and insects (Bellrose 1976). Wood ducks move into the area in the spring to nest in cavities in the standing timber along the Roanoke River (USFWS 1988).

Representative floodplain amphibians and reptiles include the southern leopard frog, green treefrog, southern dusky salamander, black rat snake, eastern cottonmouth, yellow-bellied turtle, snapping turtle, and five-lined skink (Maki et al. 1980). Tinkle (1959) found that narrow, long levees were indispensable for the egg laying of many amphibious snakes and reptiles.

Impacts of Flooding Events on Floodplain Wildlife

Prolonged flooding adversely affects habitats and the species utilizing these areas. Feeding, reproduction, and distribution are several life history aspects altered by flooding conditions. Also, major reductions in acreage of hardwood forests due to development have occurred in floodplains where water control has been altered to allow intensive agriculture, plantation forestry, or building.

The management regime of the John H. Kerr Reservoir periodically results in extended downstream flooding, usually during the spring of the year, which causes displacement of wild turkeys and a reduction in reproductive success and poult survival rates. Dramatic annual fluctuations in fall turkey populations have been associated with the severity of floods during the previous nesting and brood rearing seasons. A three-year research project completed in 1988 (Cobb 1990) conducted jointly by North Carolina State University and the North Carolina Wildlife Resources Commission determined the effects of flooding on the population dynamics and habitat utilization patterns of wild turkey on the Roanoke River. Results indicate that flooding influenced turkey nesting behavior. Drought conditions prevailed during the 1986 spring/ summer and 85% of the nesting took place in habitats usually inundated during floods. Approximately 65% of the brood range habitats would have been inundated if flooding had taken place. The next year, the River was at flood stage from 23 December 1986 until 22 June 1987. During that time, all radio-collared birds were displaced from their customary lowground habitats. No reproduction by radio-collared hens was documented in 1987, although two hens attempted to nest. The hen/poult ratio increased from 0.33 in 1986 to 7.06 in 1987, providing supporting evidence that a significant decrease in reproduction occurred. Flow conditions in 1988 during the nesting season were within the River bank, and reproductive rates reflected this favorable condition. These examples apparently show a cause-effect relationship between floodplain inundations patterns and turkey population dynamics and habitat use.

Populations of deer in the lower Roanoke watershed generally have exceeded capacity in most years; however, there have been situations in a number of years where the effects of prolonged discharges of water have been deleterious to populations in the floodplain. The timing and duration of flooding are important considerations in determining the impact on deer and most other species. Displacement of animals, lower physical condition levels, concentration of parasites and diseases, fawn mortality, and increased crop depredation have all been shown to occur in the River-bottom habitats where prolonged floodwaters exist. Flooding of short duration is not harmful to deer or their habitat. However, water level management that results in extended flooding during the spring or fall can adversely affect the number, condition, and survival of deer on the Roanoke River. It also can result in declines in harvest and hunter success in years following prolonged flood situations. This has been observed frequently by deer clubs who hunt in the floodplain of the Roanoke.

The small game species of the Roanoke floodplain, particularly the gray squirrel, marsh rabbit, and woodcock, are well equipped for life in a natural floodplain system. Maintenance of a flow regime closely resembling the flood frequency, extent, and duration of a natural river system will assure long-term well-being of small game on the lower Roanoke. Changes in managed water levels, which encourage increased human activity on the floodplain, present the greatest threat to small game population on the lower Roanoke (C. Manooch, personal communication).

The primary factor that controls the use of floodplain habitats by waterfowl is the degree to which they are flooded and, therefore, accessible. Some degree of flooding would be necessary on a year-round basis if optimum conditions were to be met for both waterfowl user groups (wintering versus breeding). However, fluctuations in duration and extent through time are necessary to ensure optimum conditions within the wetlands for the production of important waterfowl foods. Critical periods for the presence of water within forested wetlands can be defined as the periods November through March for wintering individuals and February through September for breeding individuals.

Migratory waterfowl that utilize forested wetland habitats within the lower Roanoke River Basin can be segmented into two seasonal components: a wintering population and a breeding population. A migratory, wintering population of at least 14 species use these wetlands during the winter months (USFWS 1983, 1988). Species which comprise this category include mallard, black duck, gadwall, pintail, green-winged teal, blue-winged teal, American wigeon, northern shoveler, wood duck, ring-necked duck, bufflehead, hooded merganser, Canada goose, and tundra swan. Data collected during Christmas bird counts of the Roanoke Rapids route reflect the presence of an additional 10 species, most of which are diving species more likely to frequent open water than forested wetland areas. These species are the snow goose, canvasback, greater scaup, lesser scaup, common goldeneye, oldsquaw, surf scoter, ruddy duck, common merganser, and redbreasted merganser (Lynch 1973 through 1982, 1984). Species that nest within the Roanoke River wetlands are present in late winter, spring, and summer. These species are primarily wood duck, but mallards, black ducks, and possibly hooded mergansers may breed in small numbers (Potter et al. 1980).

Abundance and Habitat Use of Overwintering Songbird and Woodpecker Communities Along the Roanoke River, North Carolina

Nanette S. Zeller and Jaime A. Collazo

Introduction

Habitat degradation and fragmentation, in both temperate and tropical zones, have been associated with population declines of neotropical migratory birds. Efforts are currently underway to identify factors affecting their populations and to formulate appropriate conservation strategies. While conservation needs of neotropical migrants have received adequate attention, little or no attention has been devoted to short-distance migrants and resident species overwintering in the United States.

Forested wetlands constitute 8% of the U.S. forested lands and 37% of all forests lost (Harris and Gosselink 1990). Loss and alteration of bottomland forests have occurred primarily as a result of clearing and drainage for crop production with other losses due to conversion to monoculture forests (Turner et al. 1981, Taylor et al. 1990). Information on winter avian communities associated with forested wetlands is scarce; however, available data suggest that these habitats support numerous species. Species presence is influenced by habitat structure and the distribution and availability of resources. The management of conservation areas in forested wetland systems, such as the Roanoke River floodplain, require that the importance of various habitat types to avian communities be determined, including those needed for overwintering avifauna. Moreover, appropriate baseline data are required to evaluate the potential effects of land and hydrological management practices.

This project focused on two research objectives: 1) to determine species composition and abundance of short-distance migrants (SDM) and resident species overwintering in the Roanoke River floodplain, and 2) to assess habitat use patterns of ten species selected on the basis of their abundance and migratory behavior (i.e., SDM, residents).

Methods

All data were collected from natural levee and swamp habitats, which comprise much of the Roanoke River floodplain. Three fixed radius (30 m) count stations were established at each of eight natural levee and seven swamp habitats. Count stations were separated by 150 m from other stations and habitats to ensure independence and avoid edge effects.

Count stations were visited once weekly from December 1992 through February 1993. Each visit lasted 15 minutes. The first 10 minutes were used to record all bird observations by sight or sound to obtain abundance data. Habitat-use data were collected after each count period to allow birds to resume behavioral activities in the presence of the observers. The recorded habitat-use data included type of behavior, time of day, location and canopy height, plant species, and diameter at breast height (dbh).

Habitat parameters were sampled once at each count station to describe vegetation structure (e.g., density, cover, etc.) and determine plant species availability. Habitat sampling methods were adopted from Martin and Geupel (in review) and James and Shugart (1970).

Results and Discussion

The information presented here is preliminary and additional analyses are planned. To date, a total of 28 bird species were recorded during the study. Twenty-one species were recorded in swamp habitats and 19 were recorded in levee habitats. The three most abundant species were Carolina wren (*Thryothorus ludovicianus*) (1.27/station), the Carolina chicadee (*Parus carolinensis*) (1.07), and the white-breasted nuthatch (*Sitta carolinensis*) (1.01) (Table 12). Of the behavioral activities noted during the study, foraging (50%) was the most prevalent followed by perching (e.g., resting) (33%). These activities were associated with cypress (*Taxodium disticum*), box elder (*Acer negundo*), and American elm (*Ulmus americana*) in greater proportion than expected based on their availability. When tree assemblages were classified by size class, avian behavioral activities were associated with trees ≥20 cm in greater proportion than expected. In levee habitats, variability in avian abundance levels was significantly explained by percent woody vegetation cover and tree density (20-50 cm dbh). Canopy height and tree density (20-50 cm dbh) significantly affected the variability in avian abundance in swamps.

Conclusion

Preliminary findings indicate that there is a consistent association between selected overwintering birds and large trees (≥20 cm), and that selected plant species provide important foraging and resting substrate. These findings have important management implications for overwintering avifauna given current land and hydrological management practices on the Roanoke River. Forest and habitat management practices should be designed to maintain a patchwork of tree stands of different size classes, thereby ensuring the availability of large trees. In terms of maintaining desired plant species composition as well as a viable community, Roanoke River basin hydrological management schemes should take into consideration the potential long-term effects on plant population processes such as regeneration, recruitment, and tree mortality rates.

The information summarized in this document is for the purpose of providing information about the North Carolina Cooperative Fish and Wildlife Research Unit's research activities. The reader is encouraged to contact the authors for additional information and a final copy of the project report and peer-reviewed papers.

Table 12. Overwintering songbird and woodpecker abundance (mean number/station) in the lower Roanoke River floodplain, December 1992-February 1993.

Species	Levee	Swamp	Overall
American goldfinch	0.179	0.101	0.127
American robin	0.244	0.214	0.190
Blue jay	0.143	0.012	0.075
Brown creeper	0.036	0.060	0.046
Brown thrasher	0.012	-	0.006
Carolina chickadee	1.393	0.798	1.066
Carolina wren	1.881	0.762	1.267
Cedar waxwing	0.155	0.042	0.099
Common flicker	1.042	0.964	0.931
Downy woodpecker	0.554	0.982	0.746
Eastern bluebird	0.036	0.131	0.074
Eastern phoebe	0.155	0.238	0.192
Fox sparrow	-	0.006	0.003
Gold-crowned kinglet	0.250	0.256	0.243
Hairy woodpecker	0.024	0.054	0.040
Hermit thrush	0.345	0.018	0.173
Mourning dove	0.095	0.042	0.066
Northern cardinal	0.440	0.036	0.233
Pileated woodpecker	0.405	0.208	0.302
Red-bellied woodpecker	0.899	0.982	0.915
Ruby-crowned kinglet	0.530	0.054	0.274
Rufous-sided towhee	0.048	-	0.024
Tufted titmouse	0.673	0.429	0.526
White-breasted nuthatch	0.464	1.583	1.012
Winter wren	0.321	0.274	0.279
White-throated sparrow	0.196	0.018	0.104
Yellow-bellied sapsucker	0.274	0.048	0.162
Yellow-rumped warbler	0.185	0.143	0.145

Aquatic Macroinvertebrate Ecology and Management Relative to Hydrology

Patrick Magee

Introduction

Aquatic macroinvertebrates are an important component of wetland systems because 1) they play an active role in detrital processing, and 2) they have a pivotal position in food/energy webs. Typically, wetland systems produce a large quantity of plant biomass that provides energy for much secondary production. The recycling of organic matter is a key nutrient and energy pathway in wetlands. Invertebrates fill several roles in detrital processing (Figure 14), but chiefly they consume microbial organisms, that colonize litter, and thus fragment litter into progressively smaller particles. The microbes (bacteria and fungi) are rich in nutrients, whereas detritus is largely comprised of nonpalatable materials such as cellulose. As litter decomposition proceeds, an abundance of aquatic invertebrates comprising a diverse community may result, depending on environmental factors such as substrate conditions and hydrology. The focus of this paper is on freshwater macroinvertebrate adaptations to forested wetland hydroregimes and on the effects of short-term hydrologies on invertebrate distribution and abundance. Hence, the bottom line is to develop strategies to manage invertebrate resources for waterbirds because invertebrates are key sources of energy, protein, and micronutrients needed by birds to successfully complete such life cycle events as molting, breeding, brood rearing, and migration.

Taxonomy

The term "invertebrate" is broad and comprehensive including 32 phyla in the animal kingdom (95%). The mollusks are represented by over 100,000 species, the annelids by 8,700 species and the arthropods by more than 850,000 species (Barnes 1980). The number of individuals alive at any one time is staggering (has been estimated at 10^{18}, a billion billion)! This vast number of organisms is characterized by a tremendous diversity in form and function, in fact, not a single trait is held in common among all the invertebrates (Barnes 1980). In this paper, most consideration is given to freshwater macroinvertebrates, and particularly to those found commonly in forested wetlands in the United States.

In forested wetlands, a large diversity of aquatic invertebrates are present, but the invertebrate communities are consistently dominated by a smaller number of taxa including several crustaceans (fairy shrimp, aquatic sowbugs, orb snails), oligochaetes (freshwater earthworms), and chironomids (larval midges) (Hubert and Krull 1973, White 1985, Batema 1987, Magee 1989).

In beaver impoundments -- without floating vegetation -- on the Roanoke River floodplain, qualitative sampling with a sweep net revealed an abundant fauna comprised of hemipterans (Nepidae and Notonectidae) and coleopterans (such as Gyrinidae and Noteridae). On similar sites with a dense covering of duckweed (*Lemna* and *Spirodella*) and water meal (Wolfia) few invertebrates were present.

Ecology

Freshwater macroinvertebrates in temporarily flooded wetlands, such as forested floodplains, live in an unpredictable environment that may be severe for part of the year. The truly aquatic macroinvertebrates find conditions favorable for growth and reproduction during flooding, but are faced with desiccation during dry periods. The long-term hydrology that characterizes these habitats has shaped many unique and curious morphological, physiological, and behavioral life history adaptations of wetland invertebrates.

In general, aquatic invertebrates have evolved mechanisms to avoid desiccation altogether (behavioral) or to survive desiccation during periods of drought (morphological and physiological). Many aquatic invertebrates suffer high mortality rates (type III survivorship) and are especially susceptible to death following drawdowns in wetlands. The few individuals that may survive the dry period often have explosive reproductive characteristics. For example, some mollusks (snails) are able to produce 40,000 young in a single effort. Further, hermaphrodytes are not uncommon, and these individuals have even greater potential for successful reproduction because they do not depend on the survival of a mate. Therefore, many aquatic invertebrates are able to quickly repopulate habitats when water returns after dry periods.

Another key adaptation is that invertebrates have rapid and flexible life cycles to take advantage of favorable environmental conditions in wetlands. Favorable conditions may only occur during a short window of flooding. Some midge species (insects in family Chironomidae) may have several generations per year (multivoltine) and thus the life cycle is completed in a very short time span (Pinder 1986). Insects undergo distinct metamorphoses from egg to immature forms to breeding adults. It is their highly variable form that allows insects to be adapted to dramatically different environmental conditions within a single site.

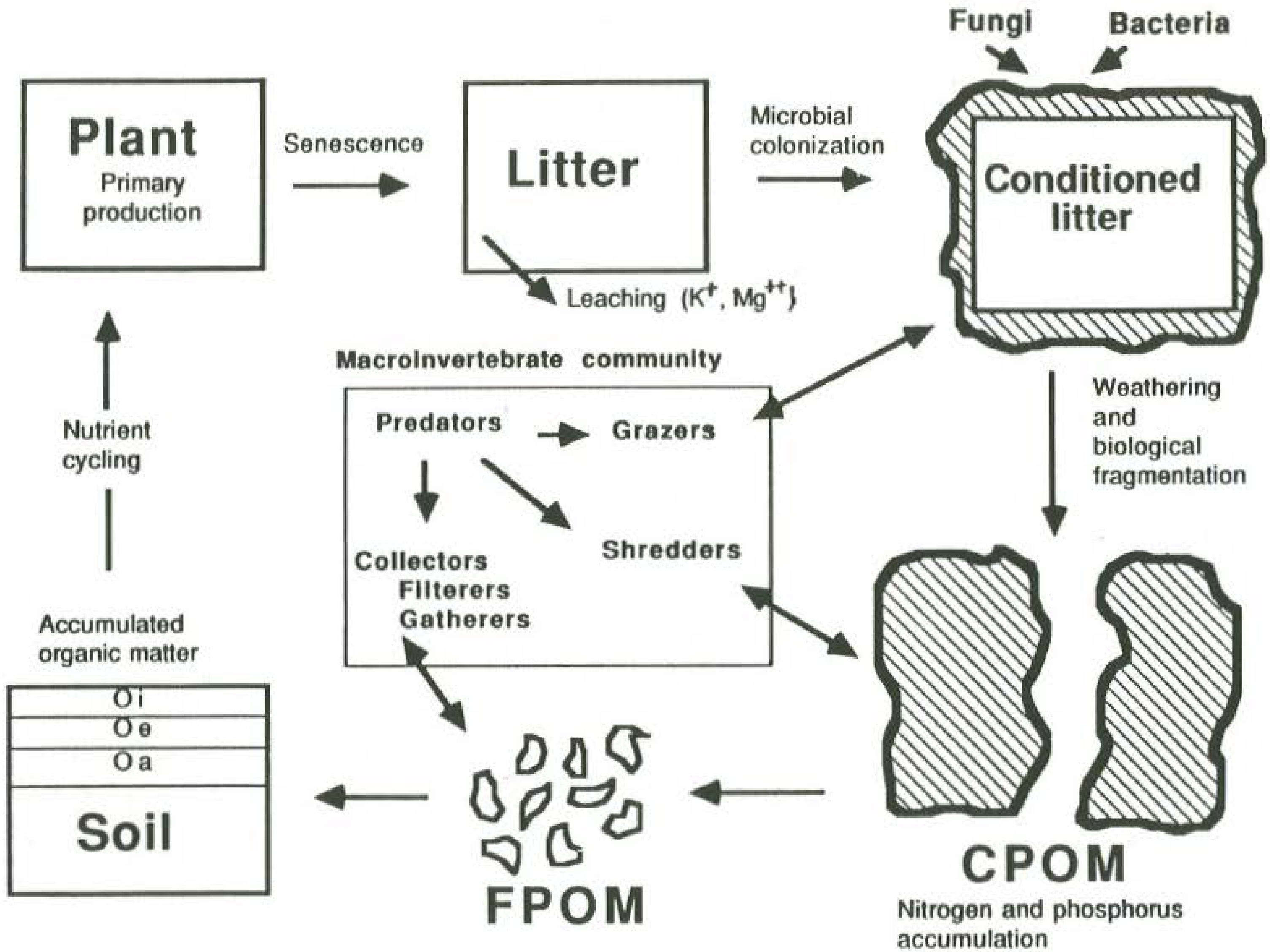

Figure 14. Litter decomposition is a complex, dynamic process in which detritus is slowly fragmented to fine organic matter and eventually to minerals. Detritus provides energy and nutrients which support microorganisms and macroinvertebrates. Taken from Magee (1993).

Invertebrates have developed many strategies to survive the dry period in temporarily flooded wetlands. For example, many insects lay their eggs in the moist drying mud; these eggs do not develop but remain viable for variable lengths of drought. Some organisms, such as fairy shrimp, lay eggs that will not develop unless they are dry and exposed to atmospheric oxygen and cold air temperatures in early winter (Wiggins et al. 1981). Similarly, some insect larvae are drought resistant and may enter a nondeveloping period in a burrow or case. Mollusks may remain viable in sealed shells. Typically, these life stages are called diapauses because the invertebrates are not developing but are simply in survival mode. Samples of dried substrate from a wetland basin have an invertebrate response when water is added (Pinder 1986). This phenomena, the invertebrate seed bank, can be likened to the seed bank of wetland plants.

Other invertebrates rely on behavioral mechanisms to negotiate drought periods. Many mollusks and crustaceans that dominate forested wetlands remain in a single basin throughout the year but have few morphological or physiological adaptations to deal with drought. Crayfish are abundant on the Roanoke River floodplain, as evidenced by many chimneys. These chimneys result when crayfish burrow to groundwater after surface water evaporates or seeps into the substrate. These burrows can be over 100 feet deep (Pennak 1978). Aquatic sowbugs (isopods) and freshwater shrimp (amphipods) are known to follow crayfish down their burrows or to seek moisture in buried litter layers. Similarly, fingernail clams move downward underneath tree bark. Highly mobile flying insects often migrate to permanent water.

Hydrological Effects on Invertebrates

Although the long-term hydrology of a site dictates invertebrate strategies, it is the short-term water regime that determines particular invertebrate responses on a site. The timing, rate, duration, and depth of flooding affect invertebrate distribution and abundance. Similarly, the timing and rate of drawdowns affect invertebrates. In general, the variable nature of floodplain hydrology dictates that invertebrates are adapted to a wide range of flooding conditions, but each taxa responds differentially depending on their life history characteristics. For example, fairy shrimp occur in vernal pools; those wetlands that are not flooded until winter. Fairy shrimp lay their eggs in a basin before it dries and the eggs lie dormant in the substrate throughout the dry summer and fall. The eggs eventually receive stimulus for development when air temperature drops in early winter. Further, the eggs must be exposed to atmospheric oxygen at this time (no flooding). After these conditions are met, and if flooding occurs, vernal wetlands throughout the United States often have an abundance of fairy shrimp. In contrast to fairy shrimp, some freshwater shrimp (amphipods) typically survive dry periods as adults or nondeveloping juveniles. These invertebrates have high mortality rates as the length of drought increases. Therefore, in wetlands that are flooded for longer durations than vernal pools, freshwater shrimp are more likely to be present.

In forested wetlands, bimodal peaks in invertebrate abundance are typical, but the peaks are usually dominated by different taxa. When leaf litter is flooded, many nutrients are released into the water column providing a rich soup that promotes invertebrate productivity. Further, the diverse litter structure comprised of the litter produced last year, the year before last, and the year before that has already been partly decomposed by microbes. This old litter is more palatable than the new litter produced during the current year. New litter is not available to invertebrates until microbial colonization occurs, but this process may take several weeks or months. Where old litter occurs, quality substrate for invertebrates is available almost instantaneously upon flooding (Cummins et al. 1989). In forested wetlands in Missouri, chironomids responded almost immediately when flooding occurred in a greentree reservoir (impounded forested wetland). Within 2 weeks of flooding, in early November, chironomids reached a peak abundance of 13,000 individuals/m^2 (Batema 1987).

In addition to a rapid, often dramatic, invertebrate response to flooding in forested wetlands, a second peak typically occurs in spring as water temperature increases and water depths decline. In the Mingo Swamp of southeastern Missouri, amphipods contributed to the spring invertebrate peak, but their highest density and biomass depended on duration and depth of flooding. In Greentree Reservoir, which was flooded in early October to a mean depth of 22 cm, the first immatures appeared in mid March. In low elevations of naturally flooded forests at Mingo, flooding did not occur until December and depths were about half those in Greentree Reservoir. The first immatures also were present in mid March. In contrast, at higher elevations in the naturally flooded forests, shallow flooding (4 cm) occurred in late February. The first immatures were present in early April at this site. Therefore, early deep flooding tended to retard amphipod reproduction. In the wetlands flooded only to 4 cm, amphipod metabolism was high and reproduction occurred relatively rapidly (40 days) (White 1982).

In southern deciduous forested wetlands of the United States, flooding typically occurs during the dormant season because rates of evapotranspiration are low and precipitation may be greater than during summer (although rainfall is variable). At the end of the growing season, bottomland hardwood forests are dry in many years, but as photosynthesis decreases and rainfall increases, the ground becomes saturated. Soon depressions in the floodplain begin to fill, creating small puddles. These puddles slowly increase in size until they join with other puddles. Eventually much of the floodplain is simultaneously flooded because of this backwater flooding. This type of hydrology still occurs on many river floodplains and should be emulated in artificial impoundments. Headwater flooding caused by major precipitation events and rising river levels has largely been negated because of construction of flood control dams and levees. The periodic major disturbance is important in invertebrate ecology. A key to invertebrate management at a local level under controlled conditions is to understand the long-term precipitation cycle and to determine a flooding schedule that will mimic the natural variations inherent in the cycle.

Natural hydrology of the Roanoke River and floodplain have been altered by the construction of three upriver dams. The historical seasonal pattern of river flows and floodplain inundation has changed (Rulifson and Manooch 1991, page 281), and the variability in flow has been minimized (Rulifson and Manooch 1991, pages 251-252). Mean flows tend to be higher than during the pre-impoundment period. These high flows, in excess of 10,000 cfs, occurred in nine years from 1973 to 1991, whereas high mean flows only occurred eight years from 1910 to 1950 (Rulifson and Manooch 1991, page 250).

Invertebrate Management

Although invertebrate management may be approached from several perspectives, I bias this discussion toward managing invertebrates for waterbirds. During their annual cycle, birds undergo several physiological events that require a protein source. For example, mallards that arrive on southern wintering grounds are in the middle of their prealternate molt and require protein for tissue replacement. Female mallards initiate the prebasic molt in early winter and typically acquire about half the protein needed for reproduction on the wintering grounds (Krapu 1981, Heitmeyer 1985). Mallards forage on invertebrates because animals have high protein content and a mix of amino acids. Forested invertebrates, such as freshwater shrimp and aquatic sowbugs, are particularly high quality protein sources because their amino acid composition closely matches that of waterfowl. Further, the macrocrustaceans, snails, and fingernail clams are relatively nonmobile and have high biomass, making them good targets for waterbird predators.

As alluded to above, invertebrates respond to flooding in pulses because newly flooded habitat is rich in nutrients and the input of water makes the environment favorable for aquatic organisms. Further, drawdowns often increase invertebrate densities by concentrating individuals into progressively smaller areas of flooded habitat. The key to invertebrate management for waterbirds is to make invertebrates available. Because invertebrates tend to peak and then drop off in abundance, it is important that the peaks occur when waterbirds are foraging for invertebrates. When wetland managers have control of local hydrology, they can time flooding events to migrations, breeding, brood rearing, or molt periods of target bird species. Drawdowns can also be timed to waterbird events. Typically, slow drawdowns are desirable because the invertebrate food base is made available over a longer time period and few invertebrates are left high and dry.

Water depth is important because deep water may negatively affect invertebrate metabolism and reproduction (low temperature). Secondly, most waterbirds forage in depths less than 25 cm (about a foot), and most shorebirds forage in depths less than 6 cm. On the Roanoke River floodplain, recent high mean flows during winter and spring (especially April through June) may retard or negate invertebrate production and keep these invertebrate resources beyond the foraging depth of most waterbirds.

High river flows may also impact invertebrates by flushing the substrate from the floodplain floor. An accumulation of litter over several years is important in developing a diverse and functional invertebrate fauna. Further, spring invertebrate productivity depends on warming water temperature; therefore, water should be at a relatively constant, shallow depth (approximately 30 cm or less) for several weeks or under very slow drawdown conditions. The rapidly fluctuating water depth associated with dam releases creates a harsh environment under which aquatic invertebrates do not cope well.

The ridge/swale topography that characterizes the Roanoke River floodplain inherently promotes a diverse flooding scenario. Low river flows in autumn and early winter (below flood stage) will promote slow puddling in the floodplain depressions and provide appropriate hydrological conditions for rapid invertebrate responses. In contrast, headwater flooding will cause rapid puddling throughout the floodplain. If flows are reduced after flooding, and water velocity and depth decline in the swales, then hydrological conditions are appropriate for slower invertebrate responses and spring peaks. Where water is shallow and a rich detrital substrate occurs, these peaks may occur when wintering waterfowl are undergoing molt and preparing for reproduction and migration. Many of these birds will forage primarily in flooded forests.

Historically, the Roanoke River floodplain was typically dry during late summer and fall. This slow drying, however, concentrates invertebrates during late spring and summer, providing excellent foraging habitat for breeding wood ducks. The topographical diversity within the Roanoke River floodplain allows for variable drying among swales and thus lengthens the period over which prime invertebrate foraging can occur. Furthermore, the deepest sloughs (that dry latest) become critical habitat for wading birds (great blue heron, great egret, little blue heron, etc.) feeding on small fish and large invertebrates such as crayfish.

The key to long-term invertebrate management is to mimic natural (pre-impoundment) hydrology by creating a dynamic flow regime. Particular sites within the floodplain will vary in flood timing, rate, duration, and depth within a year and among years. The vast Roanoke River floodplain under dynamic flooding will have prolonged foraging opportunities for waterbirds because the topographic/hydrologic interactions create hundreds of unique microwetlands. Some of these wetlands will undoubtedly have the right combination of variables to promote abundant invertebrate responses that are tuned to waterbird foraging needs.

Public Lands

Jerry Holloman, Merrill Lynch, and Wilson Laney

Any summary of public lands ownership in the lower Roanoke River Basin must recognize the considerable contributions and ownerships by private conservation organizations. Public agency efforts to protect the Roanoke River floodplain's natural resources have occurred in concert with, or been dependent upon, prior or ongoing private organizations' efforts. This section reviews the progression and status of the lower Roanoke basin floodplain public ownerships and also chronicles the efforts and ownerships of others, particularly The Nature Conservancy, North Carolina Chapter (Conservancy). Through the efforts of businesses, conservationists, government officials, and private landowners, the protection of the floodplain has been greatly enhanced.

Efforts to protect large tracts of relatively intact forested wetlands of the Roanoke River floodplain have been underway since at least the late seventies. Organizations and agencies involved in land acquisitions include the North Carolina Nature Conservancy, the North Carolina Wildlife Resources Commission (NCWRC), the North Carolina Natural Heritage Program, the North Carolina Wildlife Federation, the U.S. Fish and Wildlife Service (USFWS), Ducks Unlimited (DU), the Sierra Club, the Bertie County Board of Commissioners, and the North Carolina Department of Transportation (DOT).

The preservation of the Roanoke River floodplain has been a major priority of the Conservancy since it was founded in 1977. The Conservancy and the North Carolina Natural Heritage Program jointly identified key tracts of the Roanoke River bottomlands and swamps that contained old-growth timber stands and unique populations of fish and wildlife resources (Lynch and Crawford 1980, Lynch 1981d). The USFWS identified approximately 145,000 acres in the Roanoke River floodplain supporting significant fish and wildlife resources worthy of protection (USFWS 1981). The Conservancy's 1981 acquisition of Camassia Slopes in Northampton County became the vanguard of its efforts to protect the Roanoke floodplain. The Camassia Slopes, 176 acres, were donated to the Conservancy by the Union Camp Corporation.

For the next eight years the Conservancy and other conservation groups employed a variety of strategies in acquiring additional land on the Roanoke. In 1983, a landowner sold the Conservancy 4,881 acres of Great and Goodman Islands, located near the mouth of the river, which were subsequently resold to the NCWRC.

This collaboration between the two conservation organizations was the first of many elaborate multi-party acquisitions negotiated on the Roanoke. By 1985, the Conservancy had helped protect about 14,000 acres on the river, most of which would be included in the NCWRC's Roanoke River Wetlands/Game Lands. DU and DOT were also involved in the protection of this land.

In 1985 the UFSWS focused on the potential of the Roanoke River bottomlands for enhancement of waterfowl habitat (A Biological Proposal for Fish and Wildlife Service Acquisition, 1985). In House Report 99-86, Part 1, filed in May 1985 and in the Congressional Record of 14 October 1986, the U.S. Congress identified the Roanoke River as a national priority under the Emergency Wetlands Resources Act (16 U.S.C. 3901 et. seq.). The last large contiguous tracts of bottomland hardwoods, such as those of the Roanoke River in North Carolina and others, were cited as examples of areas that should receive consideration for funding. The North American Waterfowl Management Plan (Plan), a 1986 cooperative agreement between the United States and Canada, noted the significant declines in black duck populations over the previous 30 years. The Plan identified the need to protect 50,000 acres of black duck migration and wintering habitat along the United States' east coast, concerns about the loss of wood duck breeding and wintering habitat, and the need to maintain pre-breeding, migrating, and wintering habitat for mallards.

In 1987 the USFWS proposed the establishment of the Roanoke River National Wildlife Refuge (Refuge). The proposal proved to be controversial. Governor Martin succeeded in arranging a compromise which addressed the concerns of local governments of the counties in which the Refuge was to be located and in the process established a Joint Venture Partnership between the USFWS and the NCWRC. The 33,000-acre Refuge was approved on 10 August 1989. At the time the Refuge was being planned, the Conservancy was negotiating to acquire the 1,046-acre Devil's Gut Natural Area in Martin County.

On 9 August 1990, the Conservancy purchased 10,626 acres along the lower Roanoke River floodplain in Bertie and Martin Counties from the Georgia Pacific Corporation; 5,313 acres in Bertie County and 5,313 acres in Martin County. With these acquisitions the Conservancy had been instrumental in the purchase/protection of over 26,000 acres in the lower Roanoke basin. The Bertie and Martin County purchases were to become part of the Refuge and the NCWRC's Roanoke River Wetlands/Game Lands, respectively. The 2,912-acre Rainbow Tract, part of the Conservancy's August 1990 acquisitions, was purchased by the USFWS on 19 September 1990, and became the first unit of the Refuge. Under terms of the 1989 Agreement between the Joint Venture Partners, all former NCWRC lands in Bertie County (11,665 acres) were to be purchased by the USFWS to become part of the Refuge. These transfers/purchases began in 1992. The NCWRC received Roanoke floodplain replacement lands in Martin County. As of 30 September 1993, 28,617 acres of the Roanoke floodplain are owned by public and private conservation agencies included the following: Conservancy - 2,441; NCWRC - 14,801; and the USFWS - 11,375. Following current acquisition plan completion by the Joint Venture Partners, they and the Conservancy, will protect a total of 53,000 acres of the Roanoke floodplain (Figure 15).

The Georgia-Pacific acquisition provided a critical link between state game lands and federal refuge lands and established a continuous riparian forested wetland corridor over 40 miles in length. The corridor will provide unfragmented habitat for a large diverse community of fish and wildlife.

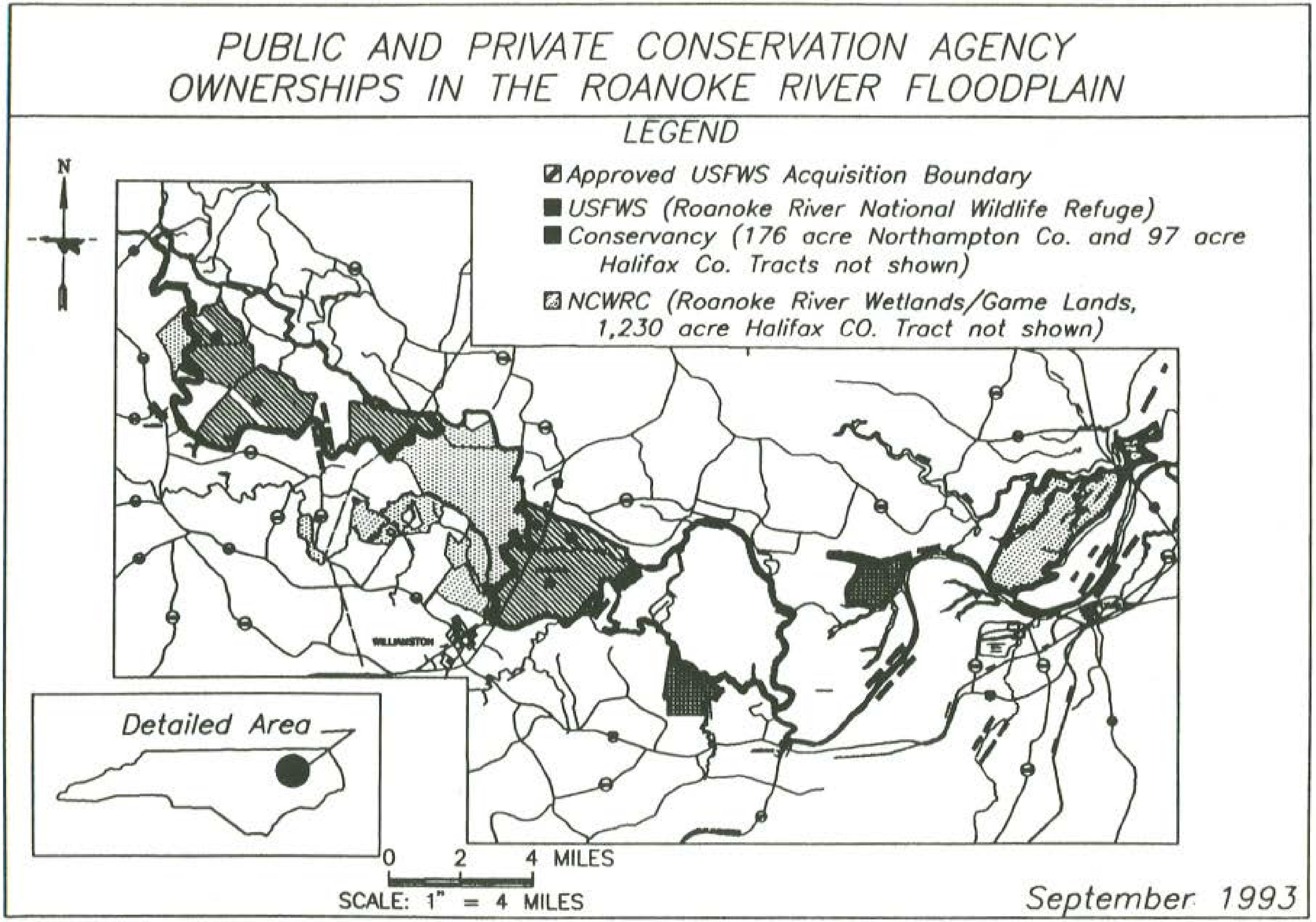

Figure 15. Public lands (USFWS and NCWRC) and the NC Nature Conservancy ownership in the Roanoke River floodplain.

CHRONOLOGICAL RECORD OF WATERSHED EVENTS

1912-1950	Natural, unaltered river flow (database 1912 to August 1950).
1940	Hurricane moves through North Carolina, instigating an investigation by U.S. Army Corps of Engineers to determine need for flood control in Roanoke River Basin.
1942	Study by U.S. Health Service, August-September, requested by U.S. Army Corps of Engineers, to evaluate minimum flows required to dilute pollution at river mile (RM) 128-137 for a power diversion canal. Report submitted in 1943 suggested minimum flows of 500 cfs to 2,500 cfs depending on month.
1944	Passage of Flood Control Act by Congress, which authorized construction of Buggs Island (Kerr Reservoir).
1945-1950	Period of rapid growth of lower Roanoke River industries and subsequent need for hydroelectric power generation.
1946	Construction of Buggs Island (Kerr Reservoir) began in February at RM 179.
	U.S. Fish and Wildlife Service report on fishery and wildlife resources and minimum flows for striped bass spawning (House Document 650, 78th Congress, 2nd Session). Minimum flows approved by Federal Power Commission=2,000 cfs (10.8-foot stage). Not to exceed 75 days from 15 March-15 June each year at the recommendation of the N.C. Department of Conservation and Development.
	U.S. Fish and Wildlife Service continues river studies.
	Minimum daily flows of 2,000 cfs and mean monthly flows of 6,000-9,000 cfs during April and May will not be detrimental to striped bass spawning. An emergency 3-days of 15,000 cfs during the last week of April may be required to start fish upriver.
1947	N.C. Wildlife Resources Commission created as separate agency.
1948	Virginia Electric & Power Company applied to Federal Power Commission for license regarding future construction and operation of power facility at RM 137 (to become Roanoke Rapids Reservoir).
1950	Natural river flows first altered by construction of Buggs Island (Kerr Reservoir) in August.
1951	Federal Power Commission issues license for construction of Roanoke Rapids Reservoir and sets minimum flow requirement of 2,500 cfs for navigation.
1952	Kerr Reservoir completed.
	First power is generated at Buggs Island in December. Report by U.S. Fish and Wildlife Service, Office of River Basins. If 2,000 cfs minimum flow is not adequate for striped bass spawning as determined by N.C. Wildlife Resources Commission, increased minimum flows will be required.

1953 Public hearing held at Weldon, NC on 28 January by U.S. Army Corps of Engineers and N.C. Wildlife Resources Commission: "minimum flows as required are too low." U.S. Army Corps of Engineers holds meeting with Federal and State conservation agencies to discuss Roanoke River flows and striped bass spawning. It was suggested at this meeting that there be four days of 12,000 cfs (18-foot stage) water at Weldon to attract fish and maintain 2,000 cfs for spawning.

First flood control measures implemented by Kerr Dam in spring of 1953.

N.C. Wildlife Resources Commission conducts experiments in the spring to determine rates of survival for striped bass fry using different sources of river water.

State and Federal conservation agencies and U.S. Army Corps of Engineers hold a conference. The N.C. Wildlife Resources Commission recommends a minimum of 2,300 cfs (11-foot stage) from late March-late May, and a minimum stage of 15 feet (8,350 cfs) at all times during striped bass spawning.

1954 Several agencies join together to study dissolved oxygen, passage of striped bass fry through the lower river and recreational fishing at Weldon.

1955 Roanoke Rapids Reservoir completed; gates were closed on 25 June and power generation started in July.

Laboratory studies proved conclusively that constant motion was a physiological necessity for development of striped bass eggs.

Dr. W.W. Hassler begins long-term studies on egg abundance, juvenile abundance, exploitation, and migration of striped bass in the Roanoke River/Albemarle Sound.

North Carolina Congressman Herbert C. Bonner called a meeting on 2 May at Weldon, NC for all Federal and State agencies, industries and private citizens interested in the Roanoke River. A Steering Committee was formed at this meeting.

1955-1958 Roanoke River Steering Committee holds meetings.

1956 Dr. Hassler and other scientists began study of Roanoke River striped bass.

1959 The Roanoke River Steering Committee issues its report, 30 June: "The Roanoke River carries more water, by far, than any other river in North Carolina. The annual flow through the State averages about 8,500 cfs. With the construction of the John H. Kerr flood control and hydroelectric project by the Federal Government, river flow was consistently altered. Following completion of the Roanoke Rapids Hydroelectric Project in 1955, further re-regulation of river flows were effected so that now the river flow pattern downstream is largely determined either by the stipulated schedule of minimum discharges from the Roanoke Rapids Dam or by the demands for peak power on the Virginia Electric and Power Company's distribution system.

The Roanoke River constitutes, by far, the most important spawning area for striped bass in North Carolina. Protection of the striped bass spawning in the Roanoke River should receive consideration equal to that given other primary uses of the water. The entire study area of the river -- including that section of the main stem at or below the industrial plants at Plymouth -- should contain water during the spawning season of such quantity as established for the maintenance of fish life.

The 13-foot water stage at Weldon is the minimum at which fishing boats may pass from Weldon to River Mile 133. It is recommended each year for the 75-day period, April 2 through June 15, for the two-fold purpose of providing access of both fish and fishing boats to the vicinity of River Mile 133."

The N.C. Wildlife Resources Commission restated its position taken in 1953 that four days of 25-foot stage peak at Weldon during late March should be maintained to attract fish upriver.

The Roanoke River Steering Committee adopted the following schedule of instantaneous minimum flows at their meeting of 29 October.

Instantaneous minimum river discharges, as measured at the U.S. Geological Survey gage on the US 301 Highway Bridge near Weldon, not less than: 2,000 cfs (10.8 feet) between 1 April and 25 April; 5,550 cfs (13 feet) between 26 April and 4 May; 8,950 cfs (15 feet) between 5 May and 20 May; and 5,550 cfs between 21 May and 15 June.

(This contradicted recommendations by others in that it did not provide adequate water in March-April to attract fish upriver).

The N.C. Wildlife Resources Commission, not satisfied by the Steering Committee findings and recommendations, issued a report by Fish and McCoy: "The N.C. Wildlife Resources Commission--the State agency now responsible for protection of the striped bass during their spawning activities--was not created until some time after the minimum flows of the Roanoke River below the John H. Kerr Dam had been established. Since the time of its inception, the Wildlife Resources Commission has vigorously contended that the Roanoke River minimum-flow schedule, as it pertains to striped bass, was woefully inadequate from a biological standpoint. The highest expectancy of survival for striped bass progeny would be provided at, or very close to, the average river condition which prevailed prior to the impoundment." Even the recommendations of this study conclude: "The foregoing recommendations are not advanced as providing optimum spawning conditions for the striped bass. They constitute what must be considered as *minimal* protection to the anadromous fishes of the Roanoke River."

1962 Gaston Reservoir first filled on 13-15 October, 1962.

1963 Lake Gaston is completed.

1970 Water shortage problems are projected for southeastern Virginia municipalities.

1971 Memorandum of Understanding (MOU) signed by representatives of Virginia Electric and Power Company, U.S. Army Engineer District, Wilmington, Corps of Engineers, and N.C. Wildlife Resources Commission, which identifies reserved storage space in Kerr Reservoir between 299.5 feet and 302 feet for augmentation flow for striped bass spawning; 13-foot water stage as minimum during spawning; and that either party may terminate the agreement, and a revised Memorandum of Understanding has been approved by the Federal Power Commission.

1972-1987 Period of possible damaging river water flows to the striped bass resource.

1980 U.S. Army Corps of Engineers holds public meetings in Weldon, NC on 10 December, and in Clarksville, VA on 11 December. Public concerns were heard pertaining to Roanoke River water flows on wildlife, fisheries, recreation, timber, agriculture and other river industries. Also opposition to transfer of water out of Roanoke River watershed in North Carolina.

1983 Dr. R.A. Rulifson, East Carolina University, began studies on striped bass larvae in lower river and in western Albemarle Sound. These studies are ongoing as are the studies of Dr. Hassler, NCSU, the N.C. Division of Marine Fisheries and the N.C. Wildlife Resources Commission. Problems with year class strength and water flows.

1984 U.S. Army Corps of Engineers, as directed by Congress, prepared a Water Supply Study for Hampton Roads, VA. The City of Virginia Beach, VA applied for and received a permit from the U.S. Army Corps of Engineers to withdraw 60 MGD (93 cfs) from Lake Gaston (Lake Gaston Pipeline Project).

1987 Judge W. Earl Britt, U.S. District Judge, Raleigh, NC, remanded the Corps, for further consideration on need of the Lake Gaston Pipeline project, and impacts on striped bass.

1988 U.S. Fish & Wildlife Service announces plans to establish a 30,000-acre National Wildlife Refuge in Halifax, Bertie, and Martin counties.

An *ad hoc* committee of representatives from State and Federal agencies and State universities was formed to develop a flow regime for the Roanoke River that would benefit striped bass and other downstream resources and users (Roanoke River Water Flow Committee).

The 100th Congress of the United States approved H.R. 4124, which under Section 5, established a three-year study of striped bass in Albemarle Sound and Roanoke River. Congress found that the stock has been declining for some time and that "the reasons for the decline are thought to include fishing; other human activities and environmental factors, such as unsuitable water flow before, during, and after critical spawning periods; degradation of water quality..."

The Virginia State Water Control Board publishes Planning Bulletin 339, "Roanoke Basin Water Supply Plan," which addresses total water demand, both existing and projected, and concludes that additional water withdrawals in the Virginia portion of the Basin will seriously limit the availability of water resources for future use in the lower Roanoke.

1989 Roanoke River Water Flow Committee publishes findings of initial "discovery process" and makes recommendations on flow conditions for March through June each year (Manooch and Rulifson 1989).

Judge W. Earl Britt, U.S. District Judge, Raleigh, NC, held a hearing on 30 October to hear arguments concerning the Lake Gaston Pipeline lawsuit (State of North Carolina versus Hudson).

The Roanoke River National Wildlife Refuge was approved by North Carolina Governor James G. Martin.

Department of the Army, Corps of Engineers, Norfolk District published an "intent to prepare a draft environmental impact statement (DEIS) for a proposed coal-fired generating plant to be constructed by Virginia Power Co. in either Cumberland, Greensville, or Mecklenburg Co, Virginia."

State park tourist attendance in NC reached an all time high in 1989. Kerr Lake State Recreation Area, located in Vance and Warren counties, received second highest use with about 925,000 visitors.

One of the richest deposits of titanium on the East Coast was identified in an area bordering Interstate 95 from Petersburg, VA to Bailey, NC. The titanium vein includes the Roanoke Rapids and Lake Gaston portion of the Roanoke watershed. The main environmental consideration is preventing muddy water from the mining process from entering the watershed.

1990 On 3 January 1990, an 18-month permitting process for proposed co-generation power facility at Jamesville in Martin County was initiated. The coal fired plant will withdraw approximately 80 cfs (about 52 MGD) from the Roanoke River and return heated effluent. Application later withdrawn.

On 2 February 1990, Judge W. Earl Britt, U.S. District Judge, Raleigh, NC, upholds decision of the U.S. Army Corps of Engineers to issue a permit to the City of Virginia Beach, VA, to construct a water intake structure and pipeline in Lake Gaston to extend to Suffolk, VA, and to enter into a water storage reallocation contract for Kerr Reservoir on behalf of the United States with the City of Virginia Beach.

On 1 March 1990, Judge W. Earl Britt, U.S. District Judge, Raleigh, NC, denied reconsideration by the State of North Carolina and the Roanoke River Basin Association of his 2 February ruling.

On 2 April 1990, the Roanoke River Basin Association filed notice of appeal with U.S. Court of Appeals for the Fourth Circuit, Richmond, VA, concerning Judge Britt's 2 February ruling.

On 3 April 1990, the State of North Carolina filed notice of appeal with U.S. Court of Appeals for the Fourth Circuit, Richmond, VA, concerning Judge Britt's 2 February ruling.

In April 1990, the Roanoke River Water Flow Committee publishes an update on findings and makes recommendations on flow conditions (expected flows, upper and lower flow boundaries, and hourly variations in flows) for April through June each year (Rulifson and Manooch 1990a).

On 10 December 1990, Judge Britt ruled that no pipeline project construction can take place until FERC (Federal Energy Regulatory Commission) considers amending the Virginia Power Co. license to allow for water withdrawal. The City of Virginia Beach immediately files for reconsideration.

1991 On 4 January 1991, Judge Britt upholds his 10 December decision to prohibit any construction of the Virginia pipeline until FERC considers amendments to the Virginia Power Co. license.

On 10 January 1991, the Town of Weldon applied for a Department of the Army permit (DA) to authorize the proposed construction of a raw water intake structure in the Roanoke River at Roanoke Rapids, Halifax County, NC directly below the existing pumping station at NC Highway 48. A portion of the additional water withdrawal will be sold to a co-generation facility planned for Weldon.

On 2 February 1991, The Roanoke River Water Flow Committee receives the Governor's Conservation Achievement Award as Water Conservationist of the Year for 1990.

On 7 February 1991, the Fourth Circuit Court will hear arguments concerning the appeal of Judge Britt's 2 February ruling.

March 1991, COE releases the final EA and FONSI for the Mecklenberg County general facility, which will result in net water use of 3.7 cfs from John H. Kerr Reservoir. Projected and existing water use upstream of Kerr was reported as approximately 300 cfs.

November 1991, NCSBSMB's report to Congress submitted to USDOI (FWS) and USDOC (NMFS) for agency review.

1992 May 1992, NCSBSMB report submitted to Congress.

On 13 June 1992, USDOC holds public meeting in Virginia Beach to receive comments on the proposed pipeline.

On 3 December 1992, USDOC rules that the Coastal Zone Management Act cannot be involved in interstate-interbasin transfer of Roanoke River waters.

1993 Spring-fall 1993, the largest striped bass spawn and Juvenile Abundance Index are recorded for the Roanoke/Albemarle system.

Fall 1993, the Roanoke River Water Flow Committee concludes its five-year study and makes its instream flow recommendations to the signatores of the 1971 Memorandum of Understanding (NC Wildlife Resources Commission, the Corps of Engineers, and Virginia Power Company). The recommendations call for a Q_1-Q_3 flow regime around median target flows for the period 1 April to 30 June each year, with the understanding that a 12-month flow regime may be recommended after further investigation.

July 1993, VEPCO had meetings with state and federal resource agencies about the Lake Gaston project relicensing process.

INITIAL (1988) RECOMMENDED AND NEGOTIATED FLOW REGIMES

As part of the ongoing activities of the Flow Committee, a Recommendations Subcommittee was formed in 1988 to examine various aspects of Roanoke River flow and report back to the full Committee with suggestions on how flows might be changed in the spring. Also, the Subcommittee was asked to keep in mind the understanding that control of low flows and high flows, as well as moderation of hydropower peaking activity at Roanoke Rapids Dam, was necessary.

The Subcommittee recommended that Roanoke River flow be controlled between the historical 25% and 75% quartiles of the daily median flows between 1 March and 30 June each year; that is, between the 25% low median flow value (Q_1) and 75% high flow value (Q_3). The rationale for choosing median rather than daily averages, and quartiles rather than other levels, was described in detail in the original report (Manooch and Rulifson 1989). The preimpoundment data (1912-1950) set of daily median values was used to develop these target values, which are presented in Table 13.

The original set of recommended flows from 1 March to 30 June was unacceptable to the U.S. Army Corps of Engineers because the time frame was not compatible with the guidelines mandated within the FERC license requirements agreed to by the Corps, Virginia Power, and the North Carolina Wildlife Resources Commission.

A second, "negotiated" set of target values was constructed that was acceptable to the Corps of Engineers, Wilmington District, and Virginia Power. The Negotiated Q_1-Q_3 Flow Regime involved a much shorter period of time than the original recommendations, but the time frame was now within the FERC license guidelines of 1 April to 15 June. The Negotiated Flow Regime values are presented in Table 14. In addition to recommending minimum, maximum, and target flows, the Subcommittee recommended that the hourly variation in flow should not exceed 1,500 cfs.

The origination of these recommendations was a statistical analysis of how the flow related to measures of striped bass spawning success. Additional information was provided by time series analysis of preimpoundment and postimpoundment flows, and generation of water surface profiles for specific reaches of the lower Roanoke River under various flow regimes using a water surface profile model developed by the Wilmington District Corps of Engineers. Details of these analyses, and presentation of the data sets used in the analyses, were presented in the initial report (Manooch and Rulifson 1989) and subsequently were published (Rulifson and Manooch 1990b; Zincone and Rulifson 1991).

Table 13. Roanoke River instream flow criteria (cfs) initially recommended by the Roanoke River Water Flow Committee (Manooch and Rulifson 1989). Q_1 = 25% low flow value; Q_3 = 75% high flow value.

Approximate dates	Median or target flow	Q_1	Q_3
1-7 Mar	8,577	6,127	11,175
8-14 Mar	9,799	7,543	16,029
15-21 Mar	9,090	6,973	14,429
22-28 Mar	8,930	6,626	14,300
29 Mar- 4 Apr	8,333	6,681	14,186
5-11 Apr	8,476	6,379	13,171
12-18 Apr	8,539	6,810	14,029
19-25 Apr	7,821	5,703	10,800
26 Apr-2 May	7,260	5,357	9,327
3-9 May	6,470	4,829	9,200
10-16 May	6,213	4,410	9,490
17-23 May	5,896	4,431	9,759
24-30 May	5,854	4,329	9,329
31 May-6 Jun	5,450	3,983 *	7,663
7-13 Jun	5,139	3,701 *	7,814
14-20 Jun	5,124	3,871 *	7,301
21-27 Jun	4,447	3,394 *	6,607
28 Jun-4 Jul	4,413	3,058 *	6,173

* 4,000 cfs minimum tentatively agreed to at the Roanoke River Water Flow Committee meeting on 3 May 1988 in Greenville, NC.

Table 14. Negotiated water flow regime (in cfs) for the Roanoke River below Roanoke Rapids Dam for the period 1 April to 15 June each year, which was accepted by the U.S. Army Corps of Engineers, Wilmington District and Virginia Power Company for a four-year (1989-1992) trial period (Manooch and Rulifson 1989).

Dates	Expected average daily flow	Lower limit	Upper limit
1-15 Apr	8,500	6,600	13,700
16-30 Apr	7,800	5,800	11,000
1-15 May	6,500	4,700	9,500
16-31 May	5,900	4,400	9,500
1-15 Jun	5,300	4,000	9,500

THE 1993 FLOW RECOMMENDATIONS OF THE COMMITTEE REGARDING THE STRIPED BASS SPAWNING WINDOW

In 1988, the Roanoke River Water Flow Committee (Committee) was formed to gather information on all resources of the lower Roanoke River watershed in North Carolina and recommend a flow regime that would be mutually beneficial to these resources and their down-stream users. The Recommendations Subcommittee of the Committee subsequently developed a recommended flow regime for an expanded (1 March through 30 June) striped bass spawning window. Discussions with the U.S. Army Corps of Engineers, Wilmington District (Corps), and Virginia Power resulted in a negotiated target flow regime covering 1 April through 15 June, which differs from that agreed to in the 1971 Memorandum of Understanding (MOU) between the Corps, Virginia Power, and the N.C. Wildlife Resources Commission (WRC). This regime, initiated informally in 1988 and formally from 1989 through 1993 through amending the 1971 MOU, is generally known as the "negotiated" or "experimental" flow regime. In the fall of 1993, the WRC indicated to the Corps that it would make a final recommendation regarding the use of this regime; the Committee opted to provide recommendations regarding that course of action.

The Committee believes that natural resources of the lower Roanoke River basin and Albemarle Sound (which receives much of its freshwater inflow from the Roanoke) are best managed within the context of a flow regime that approximates as closely as possible a pre-impoundment hydrograph. No rigorous scientific analysis is required to support or document this ecologically defensible position. All of the natural resources of the lower basin, including fish, wildlife, and their supporting habitats, evolved in the context of a flow regime largely unaffected by human activities. Some of those resources have experienced impacts, including population declines, that are related to the extent by which the present regulated instream flow departs from a preimpoundment condition. Impacts on some species, such as those on wild turkeys resulting from unnaturally prolonged flooding, are well documented. Other impacts, such as declines in fishery resources, are less understood and are confounded by other variables. While further studies may enlighten managers as to exactly how natural resource populations respond to changes in the river flow patterns, these studies are not necessary for us to reduce natural resource disruption by returning the flow regime to a more natural pattern.

On 1 October 1993, the Committee Chairman (Merrill Lynch) detailed the recommendations of the Committee in a letter to the WRC (see Appendix). In the letter, the Committee emphasized that it was not advocating a return to a natural hydrograph which would allow discharges of the magnitude of the flood of record. The Committee recognized that flood control measures emplaced upon the system by human design largely preclude such events. However, the flow regime defined in the 1971 MOU has not adequately provided for fish and wildlife resources; it is these flows that must be altered to a more natural, but less variable, condition.

The experimental flow regime presently in place for the striped bass spawning window represents a step in the process of restoring a more natural flow pattern to the river. From that perspective, no additional analysis of its impact on natural resources is necessary. The Committee does note that the juvenile abundance index of striped bass, as measured in Albemarle Sound, has dramatically improved during 1988-1993 in comparison to the six prior years of 1982-1987. The striped bass juvenile abundance index mean value for 1982-1987 inclusive is 0.29, in contrast to the value for 1988-1993, which is 9.62. The latter mean was derived using a 1993 value of 44.54, the final 1993 index value. While no study has shown that the increase is entirely attributable to the experimental flow regime, it would appear that the revised flows, in concert with other management actions, have benefited striped bass recruitment.

The Committee recommended to the WRC that the present experimental flow regime be expanded by two weeks, to cover the dates 1 April through 30 June of each year. This extended flow regime would be continued for the next six years, 1994 through 2000, at which time the Federal Energy Regulatory Commission (FERC) license expires and other flow alternatives, as described below, may be recommended. The regime would continue as specified in the March 1989, Environmental Assessment and Finding of No Significant Impact for Modification to the Operation of John H. Kerr Dam and Reservoir, Virginia and North Carolina, by Amending the 1971 Memorandum of Understanding (MOU) for Reregulation of Augmentation Flows for Fish from John H. Kerr Dam and Reservoir Project, with the addition of the following flow targets:

Dates	Expected Average Daily Flow	Lower Limit	Upper Limit
16-30 June	5,300	4,000	9,500

The Committee asked that the Commission stress to the Corps that the target flows during the expanded spawning window be the average daily flow values, rather than the upper and lower limits. The Committee also continued to recommend that the hourly variation in flow not exceed 1,500 cfs.

The Committee further recommended to the WRC that it encourage the Corps and Virginia Power to consider a new annual flow regime for the Roanoke River based on pre-impoundment flows. Values in Table 15, derived from work performed by members of the Committee, should be used as a basis from which to begin analysis of the affect of the proposed annual regime on existing reservoir and hydropower operations. The Committee recognized that the WRC and other state and federal natural resource management agencies will be parties to ongoing discussions pertaining to the FERC relicensing of the Virginia Power hydropower facilities at Lake Gaston and Roanoke Rapids Reservoir. Since there is consensus in the natural resource management community that a natural (preimpoundment) hydrograph represents the best option for river management, and since preimpoundment flow data have already been analyzed to derive weekly flow values, nothing will be gained by delaying negotiations to allow for additional analysis. The Committee asked that the WRC stress to the Corps that the target flows during the year should be the average weekly flow values, rather than the upper and lower limits. The Committee also recommended that the hourly variation in flow not exceed 1,500 cfs.

The Committee and its Striped Bass Analysis Subcommittee will continue to vigorously pursue analysis of existing and future data on striped bass and other natural resources in an effort to understand the relationships between flows and natural resources, and to refine the annual flow pattern to produce a regime which is most compatible with natural resource management on the lower Roanoke River.

The Committee further recommended that the WRC, Corps, and Virginia Power employ an adaptive management approach to the regulation of flows on the Roanoke River. Simply stated, this means that as studies are performed which elucidate the relationships between flows and natural resource management, the flow regime may be altered in subsequent years to implement management strategies that are demonstrated to be better for fish and wildlife resource management. The Committee believes that it is unlikely, however, that any studies will contraindicate a more natural hydrograph.

Although the Committee believes that no further studies are necessary at this time to justify the recommended action, the Committee does recommend that studies be pursued on the Roanoke River with support from the Corps, Virginia Power, WRC, and other entities. Studies and/or actions which the Committee believes would be beneficial from a management perspective include: assessing the impact of future withdrawals; evaluating annual rainfall, temperature, and water quality patterns in relation to the historical hydrograph; integrating biological data with hydrographic data, at the smallest possible temporal scale; evaluating the response of juvenile abundance index to the experimental flow regime, using hourly flow data; evaluating the present Kerr Reservoir Guide Curve (formerly called Rule Curve) against the historical pre-impoundment hydrograph; comparing hourly flow patterns for pre- and postimpoundment flows; conducting multivariate analyses of appropriate environmental variables against recruitment as measured by the JAI or other appropriate stock parameters; and compiling hourly temperature and flow data from Roanoke Rapids in a database which is accessible to striped bass investigators and other researchers.

Table 15. Proposed annual flow regime for the Roanoke River below Roanoke Rapids Dam (derived from Table 16 of Rulifson et al. 1991). Discharge values are weekly means in cubic feet per second. Q_1 values are 25% low flow values; Q_3 values are 75% high flow values for the preimpoundment (1912-1950) period of record. Present minimum flows mandated under the existing license, target striped bass spawning flows under the 1971 Memorandum of Understanding, and target striped bass spawning flows under the present negotiated experimental flow regime are presented for purposes of comparison.

Week	Dates	Median discharge[1]	Q_1 Lower limit	Q_3 Upper limit	FERC minimum[2]	SB MOU[3]	SB Exp[4]
1	01-07 Jan	11,776	7,044	18,562	1,000		
2	08-14 Jan	10,607	7,456	16,741	1,000		
3	15-21 Jan	9,714	7,511	16,775	1,000		
4	22-28 Jan	9,022	6,969	15,982	1,000		
5	29 Jan-04 Feb	9,777	7,688	15,916	1,000		
6	05-11 Feb	10,949	8,226	16,708	1,000		
7	12-18 Feb	12,062	8,496	18,315	1,000		
8	19-25 Feb	10,713	8,778	15,666	1,000		
9	26 Feb-04 Mar	10,808	8,379	15,097	1,000		
10	05-11 Mar	13,263	8,504	19,832	1,000		
11	12-18 Mar	12,174	8,813	18,548	1,000		
12	19-25 Mar	11,416	8,682	19,460	1,000		
13	26 Mar-01 Apr	10,913	8,693	14,436	1,000-1,500		
14	02-08 Apr	9,992	8,074	15,417	1,500	2,000	8,500
15	09-15 Apr	10,907	8,314	18,433	1,500	2,000	8,500
16	16-22 Apr	8,914	7,459	13,719	1,500	5,700	7,800
17	23-29 Apr	8,687	6,579	12,375	1,500	5,700	7,800
18	30 Apr-06 May	7,567	6,348	10,835	1,500-2,000	5,700	6,500
19	07-13 May	6,751	5,755	10,048	2,000	5,700	5,900
20	14-20 May	7,996	6,486	12,437	2,000	5,700	5,900
21	21-27 May	7,127	5,377	10,845	2,000	5,700	5,900
22	28 May-03 Jun	6,704	5,101	9,653	2,000	5,700	5,300
23	04-10 Jun	6,160	4,733	9,492	2,000	5,700	5,300
24	11-17 Jun	5,899	4,499	8,244	2,000	5,700	5,300
25	18-24 Jun	5,882	4,512	8,605	2,000		
26	25 Jun-01 Jul	5,577	4,204	7,588	2,000		
27	02-08 Jul	5,196	3,980	7,373	2,000		
28	09-15 Jul	5,552	4,317	8,216	2,000		
29	16-22 Jul	7,783	4,843	11,737	2,000		
30	23-29 Jul	7,241	4,907	10,640	2,000		

Table 15. (continued)

Week	Dates	Median discharge[1]	Q_1 Lower limit	Q_3 Upper limit	FERC minimum[2]	SB MOU[3]	SB Exp[4]
31	30 Jul-05 Aug	5,161	3,898	7,597	2,000		
32	06-12 Aug	5,000	3,747	7,262	2,000		
33	13-19 Aug	7,493	4,175	13,798	2,000		
34	20-26 Aug	5,535	3,952	13,881	2,000		
35	27 Aug-02 Sep	5,496	3,677	7,362	2,000		
36	03-09 Sep	5,281	3,575	8,834	2,000		
37	10-16 Sep	3,922	3,112	5,605	2,000		
38	17-23 Sep	6,320	3,752	11,103	2,000		
39	24-30 Sep	3,888	3,074	7,082	2,000		
40	01-07 Oct	7,579	3,684	12,010	1,500		
41	08-14 Oct	4,281	3,183	6,439	1,500		
42	15-21 Oct	3,637	3,153	6,243	1,500		
43	22-28 Oct	4,873	3,672	8,566	1,500		
44	29 Oct-04 Nov	4,800	3,447	6,856	1,500-1,000		
45	05-11 Nov	4,339	3,629	6,957	1,000		
46	12-18 Nov	7,475	3,918	6,957	1,000		
47	19-25 Nov	5,069	4,067	8,191	1,000		
48	26 Nov-02 Dec	5,158	4,132	9,857	1,000		
49	03-09 Dec	7,913	5,684	13,340	1,000		
50	10-16 Dec	6,168	5,098	8,862	1,000		
51	17-23 Dec	6,226	4,945	8,175	1,000		
52	24-31 Dec	8,229	5,600	11,625	1,000		

[1] Median, Q_1 and Q_3 values are all mean weekly values derived from Table 16 of Rulifson et al. (1991).

[2] FERC minimum flow discharge values as mandated by the license for Lakes Gaston and Roanoke Rapids.

[3] Target flows provided by the Corps from Kerr Lake as agreed to in the 1971 Memorandum of Understanding between the Corps, N.C. Wildlife Resources Commission, and Virginia Power (target releases and dates are: April 1-15 -- 2,000; April 16-June 15 -- 5,700).

[4] Expected average daily flow during the time interval, based on the negotiated flow regime agreed to by the Corps, N.C. Wildlife Resources Commission, and Virginia Power (April 1-15 -- 8,500; April 16-30 -- 7,800; May 1-15 -- 6,500; May 16-31 -- 5,999; and June 1-15 -- 5,300).

HEAVY METAL CONTAMINANTS IN SEDIMENTS OF THE LOWER ROANOKE RIVER, LOWER CHOWAN RIVER, AND INNER ALBEMARLE SOUND, NORTH CAROLINA

Stanley R. Riggs, John T. Bray, J. Craig Hamilton, Charles R. Klingman, Robert A. Wyrick, and Dorothea v. Ames

Introduction

Increased human activity contributes ever increasing amounts of suspended sediment and chemical pollutants to the lower Roanoke and lower Chowan rivers and inner Albemarle Sound estuarine system, resulting in increased potential bioavailability of specific toxic elements. The 1989 population within the lower Roanoke River drainage basin (Figure 16) was 140,315 people. The lower basin had 17 NPDES waste water discharge permits with a total design flow of 109 million gallons of waste water per day. These permits include two large paper mill complexes that account for up to 84% of this waste water flow, several municipal waste water treatment plants, and several other smaller industrial operations. In addition to these figures for the lower Roanoke River drainage basin, the Chowan River drainage basin (Figure 16) also represents a significant, but poorly known contribution of waste water to the inner Albemarle Sound. Some point source facilities are permitted to discharge specific heavy metals; however, for most facilities the composition and concentration of heavy metal toxicants in their waste water discharge is either poorly known or totally unknown.

Discharge of apparently low concentrations of toxic heavy metals and other trace elements from various anthropogenic point and nonpoint sources into coastal waters leads to significant pollution problems within the North Carolina estuarine environments (Riggs et al. 1989, 1991a, 1993). High adsorption capacities of clay minerals and high chemical reactivity of organic matter, both major components of suspended and bottom sediments, continuously sequester trace elements discharged into the water column. The cumulative effect of large discharge volumes, even with low toxic metal concentrations over long time periods, leads to significant trace element enrichment in the associated bottom sediments. In addition, storms, biological processes, and man routinely resuspend the mud sediments into the water column. These processes continue to concentrate trace elements within the bottom sediments to levels that are orders of magnitude above acceptable water level concentrations. The toxic metals are then potentially available for further concentration and movement through the food chain by abundant filter and detritus feeding organisms living within these organic-rich mud environments. Thus, basin-wide assessment of heavy metal and other trace element pollution is prerequisite for future management plans and decisions concerning water quality improvement within our estuarine environments.

Description of the Roanoke River/Albemarle Sound Estuarine System

The Roanoke River/Albemarle Sound Drainage Basin

The entire Roanoke River drainage basin (Figure 16) encompasses approximately 9,666 square miles in 24 counties of North Carolina and Virginia in addition to another 8,694 square miles and 10 counties within the Albemarle Sound estuarine system. In terms of discussing the geologic setting, the Roanoke-Albemarle system can be divided into three distinctive parts: the upper Roanoke River, lower Roanoke River, and Albemarle Sound estuarine system (Copeland et al. 1983, Riggs et al. 1991b). The upper Roanoke River (above the Roanoke Rapids Dam) constitutes the major portion of the river drainage system (87%) and is located within the Piedmont province. The lower Roanoke River basin (below the Roanoke Rapids Dam to about 5

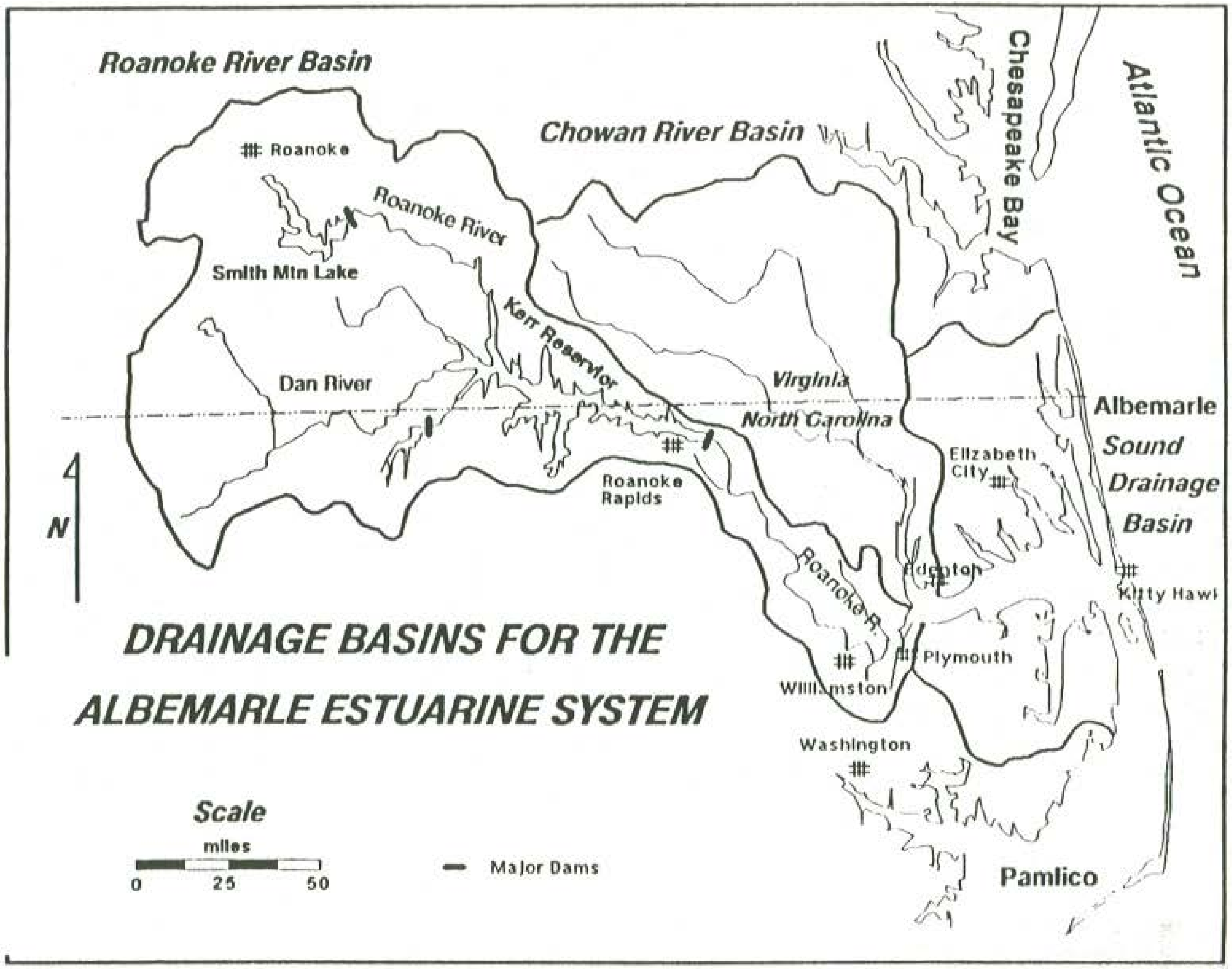

Figure 16. Map of the three major drainage basins supplying water, sediments, and contaminants to the Albemarle Sound estuarine system.

miles northeast of Plymouth) constitutes a much smaller portion of the river drainage basin (13%) and is totally within the Coastal Plain province. The Roanoke River drains into the western end of Albemarle Sound, an extensive complex of fresh to low-brackish water estuaries. The Albemarle Sound estuarine system contains approximately 900 square miles of water, includes seven major embayed lateral tributary estuaries and numerous small embayed lateral streams (Figure 17). These lateral streams drain the low, flat, swampy Coastal Plain and discharge relatively small amounts of sediment and acidic blackwater into the Sound.

Albemarle Sound is that portion of the Roanoke River drainage system which has been flooded by the present level of the sea (Copeland et al. 1983, Riggs et al. 1991b). Albemarle Sound is not directly connected to the ocean due to North Carolina's Outer Banks, a continuous barrier island without an ocean inlet in the Albemarle area (Figure 17). Since Albemarle Sound is dominated by large freshwater inflows with no direct water exchange with the Atlantic Ocean, the Sound is mostly fresh water with only minor amounts of low-brackish water. The Sound is dominated by irregular, wind-driven tides.

Sediments that are presently being deposited within the estuarine system are generally derived from four sources (Riggs et al., 1991b). 1) The dominant sediment component is inorganic clay that comes from the suspended sediment load in the Roanoke River during flood stages. 2) Organic matter is an important secondary component (up to 20%) in some of the extensive mud deposits; it is derived from storm flushing and erosion of marsh and swamp forest shorelines that occur throughout the estuarine system. 3) Most of the sand and some of the clay comes from erosion of Quaternary sediment units that form sediment bank shorelines and underlie the shallow platform flanks of most of the estuarine area. 4) The outermost portion of Albemarle Sound contains fine sands that are derived from the barrier islands by wind and storm overwash or have been transported into the estuary through former barrier island inlets.

Modern Surface Sediments

The modern surface sediments throughout the entire lower Roanoke River and inner Albemarle Sound area consist of four major sediment types (Pels 1967, Wells and Kim 1988, Wells 1989, Riggs et al. 1991b): 1) orange, inorganic clays, 2) organic-rich muds, 3) fine to medium quartz sands, and 4) peats and clayey peats. The occurrence and distribution of the specific sediment types are directly dependent upon the location and type of energy effecting the depositional system within the three different depositional environments (river system, estuarine system, or the transition zone between these two environments).

Surface sediment distribution within the lower Roanoke River (from Plymouth to the River mouth) consists of sand dominated channel deposits, mud dominated channel flanks, and peats in the adjacent swamp forests. The sands that do exist within the river system tend to be very fine to fine grained with slight increases to medium sand downstream from Plymouth. The river course through much of its lower extent occurs within the Holocene floodplain. However, at towns such as Williamston, Jamesville, and Plymouth, the river channel occurs on the south side of its floodplain where it has eroded into older Quaternary sediments that confine the floodplain. The presence of this highland is the reason these towns are located where they are. Consequently, sediment banks along the Plymouth shoreline present a local source for new and slightly coarser sand in the downstream portion of the river system as described by Erlich (1980).

Dramatic sediment changes occur within the transition zone from the Roanoke River system to the Albemarle estuarine system (Riggs et al. 1991b). Fine sands grade fairly abruptly into silty clays and to relatively pure clays within one mile seaward of the river mouth. A small lobe of fine sand extends from the mouth of the Roanoke River into Albemarle Sound, but is abruptly terminated or buried by subsequent deposition of estuarine muds. Within this transition zone, the floodplain swamp forest is being drowned and wave erosion is truncating the upper three to four

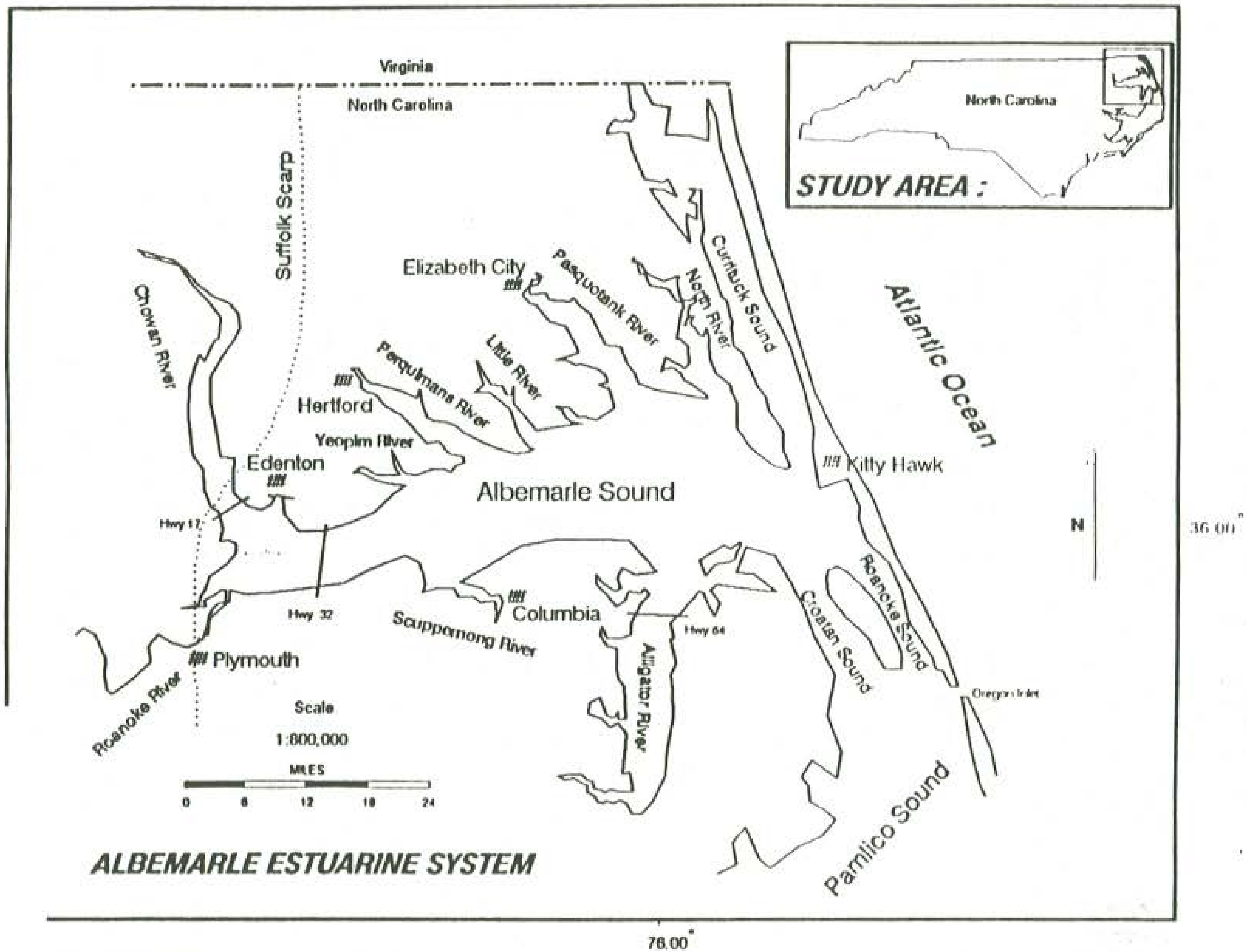

Figure 17. Location map of the Albemarle Sound estuarine system.

feet of modern peat deposits to produce a shallow, peat-floored platform that extends eastward to sediment banks at Albemarle Beach and northwestward along the entire western side of Bachelor Bay to sediment banks at Black Walnut Point. Wave erosion of these high, sediment bank shorelines on both the north and south sides supply new sands to the shallow platform areas along these shoreline areas.

Sediments within the central basin of the inner Albemarle estuarine system are dominated by clays with sand to mud ratios of 99:1 (Riggs et al. 1991b). Sand content only begins to significantly increase along the upward slope to the narrow, sand platform that occurs adjacent and parallel to the eroding sediment bank shorelines (Pels 1967, Wells and Kim 1988, Wells 1989). These eroding sediment banks are the sole source for the thin, platform sands (Riggs et al. 1991b). Bellis et al. (1975) found that these sediment bank shorelines were eroding at rates that ranged from lows of less than 1 foot per year to highs of 13 feet per year with an average of 2.5 feet per year depending upon bank composition, orientation and shape of the shoreline, and water depth and wind fetch. Within the shallower portions of the estuarine environments, the sediments are redistributed by periodic high-energy storms that winnow out the clays, erode and redistribute the shoreline sands.

Based upon the general patterns of sediment distribution and their changes through time, Riggs et al. (1991b) developed several preliminary conclusions for the inner estuarine environment around the mouth of the Roanoke River.

1. Habitation and development of North Carolina and Virginia by man, starting in the early 18th century and continuing to the present, has had the most significant impact with the largest change in sediment characteristics and resulting deposits of both the lower Roanoke River and inner Albemarle Sound. The effect of this was to significantly increase suspended sediment input resulting in rapid sedimentation of a major unit of inorganic Piedmont clay throughout the entire depositional area in the lower Roanoke and inner Albemarle regions.

2. Development of a series of dams during the 1950s and the resulting control of the water discharge has had important effects upon the resulting patterns of deposition. The dams significantly decreased the amount of Piedmont-derived suspended sediments as well as the rates of clay deposition in the downstream areas. In addition, organic-rich mud deposits began to accumulate along the River channel flanks and more normal estuarine organic-rich muds were again deposited within the inner Albemarle region.

3. Rates of sedimentation within the inner Albemarle estuarine area are still significantly higher than the slower rates that occur within the lateral tributaries and the middle estuarine area. These latter areas, as well as the deeper, pre-man estuarine sediments in the inner Albemarle area, are characterized by high concentrations (>10%) of organic matter.

4. The sands within the Roanoke River channel are basically relict with very minor amounts of modern sand being discharged into Albemarle Sound.

5. The sole source of the thin sand layer occurring on the shallow platform margins of Albemarle Sound is from the ongoing shoreline erosion of the adjacent Quaternary sediment banks.

Samples

This paper is a product of the research project entitled Heavy Metal Pollutants in Organic-Rich Muds of the Albemarle Sound Estuarine System. The research project is part of the Albemarle-Pamlico Estuarine Study for North Carolina and was funded by the U.S. Environmental Protection Agency and N.C. Department of Environment, Health, and Natural Resources.

The entire Albemarle estuarine system is addressed in a monograph by Riggs et al. (1993), but this section of the Flow Committee report only concerns the lower Roanoke River and inner Albemarle Sound estuarine system.

For the overall Albemarle study, a regional sampling grid was developed within the lower Roanoke River, Albemarle Sound, and associated tributary estuaries that included 178 short core (<0.5 m), 19 long core (<6 m), and many surface sample sites. The 197 core sites represented all possible geographic and geologic conditions, as well as major anthropogenic sources of pollutants throughout the Albemarle system. From these cores, 378 subsamples were processed and analyzed in the sediment and analytical laboratories for grain size, sediment composition, and chemical analyses for 22 major, minor, and trace elements that are quantitative and analytically reliable (Table 16). Figures 18 and 19 show the number and location of samples utilized in the discussion for the lower Roanoke River and inner Albemarle Sound in the present paper.

Data Analysis

All sediment and chemical data have been placed in the North Carolina GIS data base in Raleigh. All data were statistically analyzed and synthesized; these represent the basis for the following discussion and conclusions. Information on the analytical and statistical procedures were not included in this report due to space limitations. However, the procedures are described in detail elsewhere (Riggs et al. 1993).

Fifteen trace elements were utilized in this study (Table 16) and included the eight U.S. EPA "priority pollutant metals" plus seven other environmentally important trace elements. An estimate of background levels was determined for each of the 15 trace elements within the sediments of the Albemarle Sound estuarine system. This estimate was derived by the following procedure and results in a value hereafter referred to as the <u>Albemarle trimmed mean (ATM)</u>.

1. Mean concentrations and standard deviations were computed for each trace element in all surface samples within the Albemarle Sound estuarine system.

2. Those samples with values greater than two standard deviations from this original mean were then excluded. These 'outliers' were assumed to represent either anthropogenically contaminated sediments or depleted relict sediments and should not be incorporated into any process intended to derive a general background value.

3. Mean values were then calculated for these trimmed data sets resulting in the ATM for each element (Table 16).

4. The ATM for each element served as a reference point against which every sample, including the surface outliers excluded from the trimmed data set and samples from depth, were compared.

5. This comparison represented the <u>enrichment factor (EF)</u> for each element in each sample (EF is the ratio of actual concentration for the sample to the ATM). This provides a measure of either excess or depletion compared to an approximate 'background' level. It also provides a convenient and uniform method to graphically depict spatial distributions of concentrations of the elements.

6. The following definitions with respect to enrichment factors (EF) will be utilized in the remainder of this report:

   a. EF = 1 is equal to the ATM,
   b. EF < 1 is depleted relative to the ATM,

c. EF > 1 is enriched relative to the ATM,
d. EF between 1.5 X and 1.99 X the ATM is "slightly enriched,"
e. EF = 2 X the ATM or greater is "substantially enriched,"
f. MEF = maximum enrichment factor.

Results of the analytical data for the lower Roanoke River and inner Albemarle Sound regions are summarized in Tables 16 through 21.

Table 16. Albemarle trimmed mean (ATM) data for all surface samples that are less than two standard deviations from the mean total population. The standard deviation, coefficient of variation, and the minimum and maximum concentration values used in this calculation for 22 elements (in µg/g or ppm) in surface sediments of the Albemarle Sound estuarine system, are also included.

		Albemarle trimmed data				
Element	N	Trimmed mean µg/g	Coefficient of variation %	Standard deviation µg/g	Minimum value µg/g	Maximum value µg/g
Trace Elements						
As*	184	3.95	73.7	2.77	0.75	10.40
Cd	184	0.22	69.7	0.16	0.15	0.72
Cr	175	10.70	38.0	4.04	2.30	21.80
Co	175	6.67	44.9	3.00	1.78	13.20
Cu	175	10.80	53.7	5.80	2.03	33.30
Hg	149	0.14	88.1	0.12	0.02	0.63
Ni	175	4.28	36.1	1.54	0.67	7.31
Pb	175	21.70	62.0	13.50	3.62	69.30
Mn	175	329.00	100.7	331.00	30.40	1,227.00
Mo	183	0.29	31.8	0.09	0.25	0.60
P	175	401.00	52.1	209.00	92.10	1,109.00
Sn*	182	5.64	73.7	4.16	0.20	13.20
Ti	175	75.2	42.3	31.8	19.90	148.00
V	175	23.4	47.5	11.1	4.39	47.70
Zn	175	50.4	48.5	24.4	10.90	114.00
Major Elements						
Al	175	5,088.0	34.7	1,766.0	1,373.0	8,804.0
Ca	175	2,340.0	43.9	1,027.0	775.0	5,103.0
Fe	175	13,340.0	33.5	4,466.0	2,699.0	21,256.0
K	175	555.0	38.1	211.0	129.0	952.0
Mg	175	1,713.0	39.7	680.0	361.0	3,029.0
Na	175	609.0	69.2	421.0	51.0	1,633.0
Si	175	1,533.0	29.7	456.0	694.0	2,592.0

*Analyses have poor reproducibility, hence somewhat less reliability.

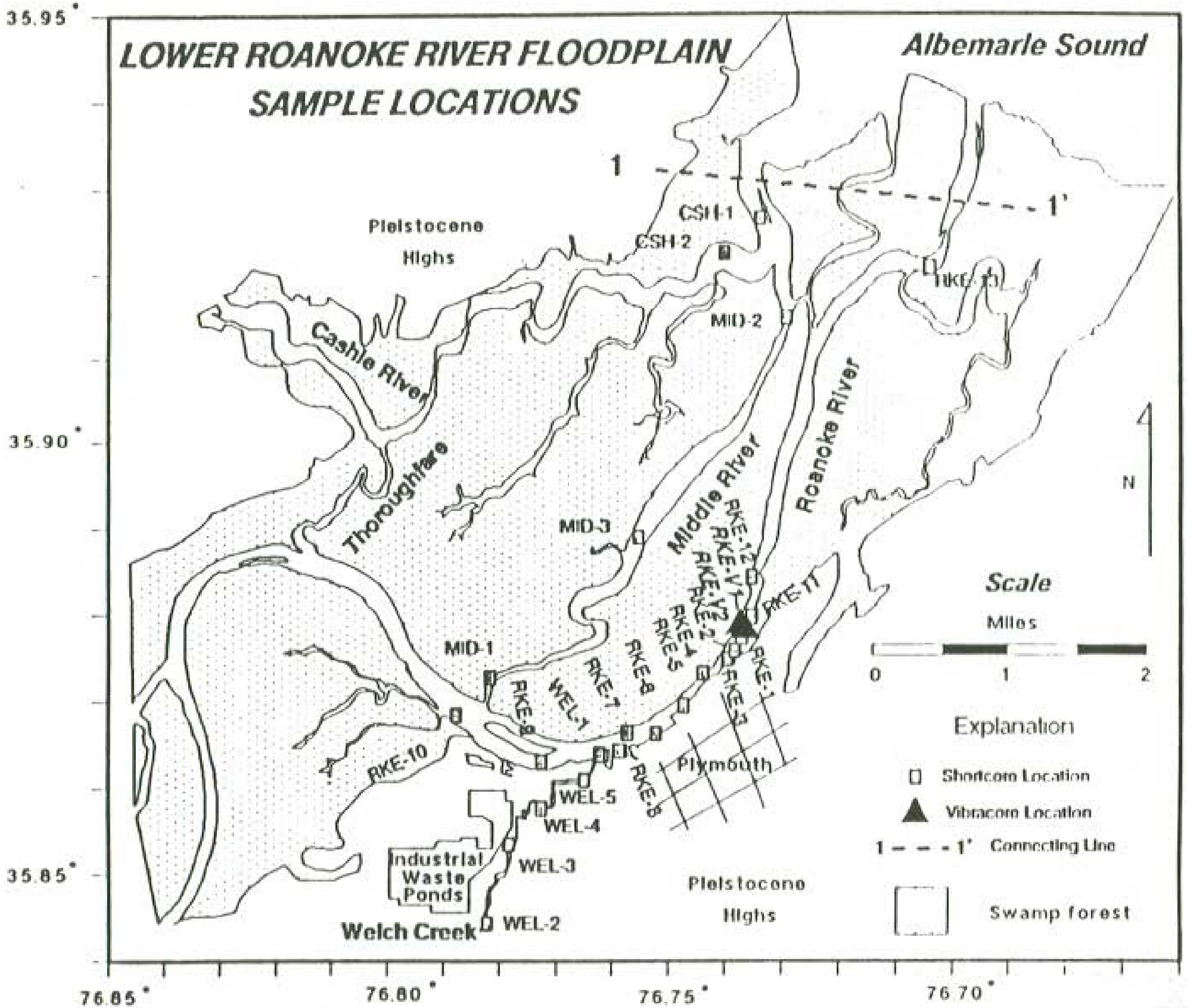

Figure 18. Sediment sample locations of the lower Roanoke River area.

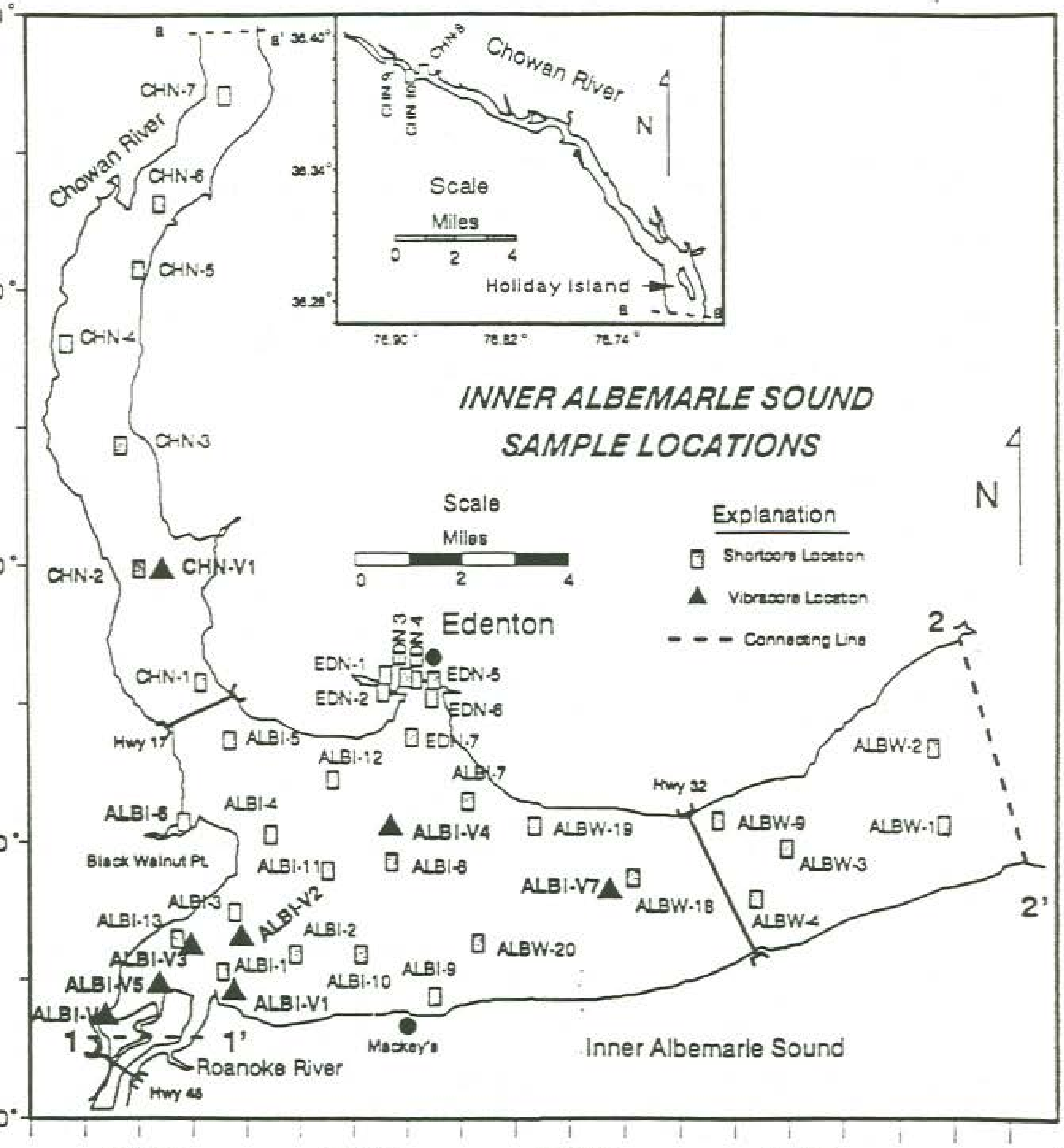

Figure 19. Sediment sample locations of the inner Albemarle Sound area.

Results and Discussion

Lower Roanoke River

One of the largest wood products facilities in the world is located on the banks of Welch Creek and the lower Roanoke River west of Plymouth. This industrial site has been operating since 1938 and today consists of 1200 acres, which includes 750 acres of industrial waste water treatment ponds (Figure 18). Originally, all industrial waste water from the facility was discharged directly into the Roanoke River. However, during the period between the early 1960s and 1988, all industrial waste water was discharged directly into Welch Creek (near WEL-4 in Figure 18). Beginning in 1968 all industrial waste water, except cooling water, was processed through a secondary treatment plant before being discharged into adjacent Creek waters. Since 1988, the 55 million gallons per day of noncooling, industrial waste water has been discharged directly into the Roanoke River through a diffuser pipe across the River bottom. This discharge pipe is located downstream of the plant site and slightly upstream of the mouth of Welch Creek.

In a site inspection report for North Carolina, Durway (1986) described three on-site areas where hazardous substances occur, or in the past have been generated or disposed of. There probably have been many different sources of numerous contaminants from this large and complex industrial facility over the years. It is not known to what extent any or all of these historic sites could continue to be impacting the adjacent waterways. These sites include the following:

1. A wood treatment plant has been operating since 1979 and produces a chromate copper arsenate sludge as a by-product material. This waste material is now stored in drums and removed from the site for disposal.

2. Considerable amounts of mercury were associated with various phases of the old chlorine plant that operated until 1968. Some waste mercury was volatilized, some was discharged directly into the River, and some was disposed of in the old on-site landfill.

3. An old landfill, situated on a 35 to 50 acre tract of low wetland, received much onsite chemical waste including mercury, until 1979 when it was sealed.

The main Roanoke River channel is the southern-most channel that flows past Plymouth (Figure 18). This channel receives up to 80 million gallons of waste water discharge per day (mgpd) directly from two large paper mills, up to 7 mgpd from various waste water treatment plants between Roanoke Rapids and Plymouth, and up to 3 mgpd from other small industrial dischargers. Most of this waste water is of unknown composition with respect to heavy metal concentrations.

Thirteen sites were sampled in the lower Roanoke River (Figure 18). Each mud-rich sample was obtained in shallow waters along the flanks of the main channel which is dominated by sand-rich sediments. In general, the lower Roanoke River has lower levels of trace element enrichment than Welch Creek. However, nine trace elements are substantially enriched and three elements are slightly enriched in multiple sample sites (Table 17). Three elements are enriched in all samples with maximum enrichment factors as follows: Mn = 4.8 X, Co = 2.5 X, and Ti = 2.3 X the ATM. Enrichment of these three elements is probably related to the geology of the drainage district and natural weathering processes rather than from anthropogenic sources. Four other elements are enriched at multiple sample sites with maximum enrichment factors as follows: Hg = 12.3 X, Cr = 4.0 X, As = 3.4 X, and Cu = 2.3 X the ATM. Mercury is substantially enriched (up to 12.3 X ATM) in two samples at one site (RKE-13) off the mouth of Canaby Creek, along with arsenic, cobalt, chromium, copper, manganese, tin, titanium, and zinc. Since all other Roanoke River samples, except RKE-9 near the present industrial site, have very low concentrations of mercury, it is assumed that there could be a major source of metal contamination up Canaby Creek. This creek should be sampled and analyzed for heavy metals.

Table 17. Concentrations of 15 trace elements for all surface samples and enrichment factors for all surface and deep samples collected in the lower Roanoke River. Depths of the deep samples range from 16 to 50 cm below the sediment surface for an average depth of 38 cm. Elements with underlined enrichment factors are substantially enriched (EF = or >2X ATM) relative to the Albemarle trimmed mean, whereas those in bold are slightly enriched (EF >1.5X to <2X ATM).

Trace elements	N	Concentrations (µg/g or ppm) surface samples mean	minimum	maximum	Enrichment factors deep samples mean (N=13)	maximum	surface samples mean (N=13)	maximum
Lower Roanoke River								
Mn	13	1,088.0	576.0	1,584.0	2.5	3.2	3.3	4.8
Ti	13	144.0	125.0	174.0	2.1	2.3	**1.9**	2.3
Hg	13	0.28	0.02	1.75	1.2	6.8	2.0	12.3
As *	13	7.6	0.9	12.9	1.4	2.5	2.0	3.4
Cr	13	16.4	11.4	39.3	**1.7**	4.0	**1.5**	3.7
Cu	13	15.9	12.3	21.9	**1.5**	2.3	**1.5**	2.0
Co	13	12.1	9.8	16.8	**1.5**	**1.7**	**1.8**	2.5
Zn	13	62.7	46.7	113.0	1.0	2.1	1.2	2.2
V	13	30.6	28.7	36.0	**1.5**	2.0	1.3	**1.5**
Sn *	13	6.8	5.3	8.7	1.1	**1.5**	1.2	**1.5**
Ni	13	3.9	3.0	4.9	0.9	**1.7**	0.9	1.1
P	13	432.0	147.0	683.0	0.7	1.0	1.1	**1.7**
Mo	13	0.25	0.25	0.25	0.9	0.9	0.9	0.9
Pb	13	15.3	13.6	19.5	0.7	1.0	0.7	0.9
Cd	13	0.16	0.15	0.31	0.7	0.7	0.7	1.4
Ca	13	2,122.0	1,405.	5,202.0	1.0	4.9	0.9	2.2
Al	13	5,393.	3,062.0	5,918.	1.1	1.3	1.1	1.2
Si	13	1,462.	1,334.0	1,500.	1.0	1.0	1.0	1.0
Na	13	61.8	39.0	110.	0.1	0.4	0.1	0.2

* analyses have poor reproducibility, hence somewhat low reliability.

Chromium and copper are slightly to substantially enriched (up to 4.0 X and 2.3 X ATM, respectively) in eight and 14 lower Roanoke River samples, respectively. All copper enrichment occurs downstream of the paper mill's new NPDES discharge site. Cobalt is substantially enriched in Welch Creek and is only slightly enriched in the Roanoke River in 21 of the 26 samples. Arsenic is not enriched in Welch Creek except for the surface sample at the mouth of the Creek; however, it is slightly to substantially enriched in 17 samples in the Roanoke River downstream of the paper mill discharge.

It appears that there are significant amounts of various trace elements within the sediments of the lower Roanoke River system. However, the general concentrations are lower than in Welch Creek and the distribution patterns of these trace elements are somewhat irregular. The

Roanoke River is dominated by rapidly fluctuating flow conditions and resulting processes of sedimentation that range from low energy during low flow conditions to high energy during high flow conditions. These environmental variations would cause major changes in processes of sediment deposition and erosion within the Roanoke River channel and could explain the erratic distribution patterns.

Welch Creek

The sediments within Welch Creek, a very small southern tributary to the Roanoke River (Figure 18), are substantially or slightly enriched in all 15 trace elements (Table 18). Thirteen of these trace elements are substantially enriched in multiple sample sites. Four elements have extremely high enrichments with maximum enrichment factors as follows: Cr = 156 X, Hg = 73 X, Ni = 20 X, and Cu = 9.4 X the ATM, respectively. Seven of the 10 samples analyzed in Welch Creek have Hg concentrations of 1 ppm or higher with some samples containing very high levels (3.3, 5.5, 9.6, and 10.3 ppm Hg). Lead and arsenic are only slightly enriched in multiple sample sites with maximum enrichment factors as follows: Pb = 1.6 X and As = 1.9 X the ATM.

Table 18. Concentrations of 15 trace elements for all surface samples and enrichment factors for all surface and deep samples collected in Welch Creek. Depths of the deep samples range from 16 to 50 cm below the sediment surface for an average depth of 38 cm. Elements with underlined enrichment factors are substantially enriched (EF = or >2X ATM) relative to the Albemarle trimmed mean, whereas those in bold are slightly enriched (EF >1.5X to <2X ATM).

Trace elements	N	Concentrations (µg/g or ppm) surface samples mean	minimum	maximum	Enrichment factors deep samples mean (N=5)	deep samples maximum (N=5)	surface samples mean (N=5)	surface samples maximum (N=5)
Welch Creek								
Cr	5	205.0	21.8	494.0	53.0	156.1	19.3	46.5
Hg	5	2.14	0.35	5.54	31.2	72.9	15.1	39.0
Ni	5	26.2	2.4	58.9	7.4	20.5	6.1	13.8
Cu	5	33.6	7.1	90.4	4.9	9.4	3.1	8.4
Zn	5	116.0	18.8	244.0	3.3	6.2	2.3	4.8
V	5	52.6	20.4	93.1	2.4	3.4	2.2	4.0
P	5	920.0	144.0	1,501.0	2.3	3.5	2.3	3.7
Cd	5	0.44	0.15	0.84	2.3	4.0	2.0	3.8
Sn *	5	11.4	2.8	22.0	**1.6**	2.9	2.0	3.9
Mo	5	0.46	0.25	1.29	1.3	2.0	**1.6**	4.5
Ti	5	89.1	27.3	152.0	**1.5**	2.4	1.2	2.0
Mn	5	500.0	85.4	945.0	**1.6**	3.1	**1.5**	2.9
Co	5	6.1	1.3	13.3	0.9	1.2	0.9	2.0
Pb	5	17.1	4.3	32.4	1.0	**1.6**	0.8	**1.5**
As *	5	2.8	0.9	7.1	0.5	1.4	0.7	**1.9**
Ca	5	44,339.	1,586.	186,079.	21.7	62.7	18.9	79.5
Al	5	15,060.	2,776.	29,688.	3.7	8.4	3.0	5.8
Si	5	2,630.	789.	5,196.	2.1	4.8	**1.7**	3.4
Na	5	594.	64.8	1,836.	**1.5**	3.2	1.0	3.0

* analyses have poor reproducibility, hence somewhat low reliability.

Four major elements (calcium, aluminum, silica, and sodium) are also substantially enriched in the Welch Creek sediments (Table 18) with maximum enrichment factors as follows: Ca = 79 X, Al = 8.4 X, Si = 4.8 X, and Na = 3.2 X the ATM. This is the only region where all four of these elements are enriched and are unquestionably related to the industrial discharge.

Five sites were sampled along the axis of Welch Creek (Figure 18). Two of these sites (WEL-2 and WEL-3) are above the former discharge point and have generally lower, but highly variable enrichment factors for most elements. This distribution probably reflects movement of discharged waters upstream during high-water flood conditions on the Roanoke River. The two middle sites (WEL-4 and WEL-5) are downstream of the former discharge point and have the highest levels of sediment enrichment of most elements. Concentrations generally remain high, but with a general decrease downstream to the mouth of the Creek (WEL-1). The deep sample at WEL-1 is substantially enriched in most elements; however, there is generally a major decrease in enrichment in most elements in the surface sample suggesting active deposition and dilution from the Roanoke River at this site during flood flow periods.

All elements except tin, molybdenum, manganese, and arsenic are significantly more enriched in the deeper, subsurface sediments than in the surface samples (Table 18). The four elements with increased enrichment in the surface samples are only slightly so. This vertical distribution pattern could result from several different factors. First, it may reflect the fact that the Welch Creek NPDES discharge site was abandoned in 1988 and changed to the Roanoke River. Second, it could result from ongoing discharge of groundwater through the subsurface and into the Creek on a slow and continuous basis from "leaky" on-land sites. Third, the actual distribution of each element could be a function of its chemistry and changes of bottom sediment and pore-water chemical conditions.

Middle and Cashie Rivers

Middle and Cashie Rivers are distributary channels of the lower Roanoke River that are situated north of the main channel (Figure 18). The Cashie River has its own tributary drainage; however, it is connected to the Roanoke River by the Thoroughfare Channel.

Chemical data for surface samples at three sites in the Middle River and two sites in the outermost Cashie River are summarized in Table 19. Manganese and titanium are enriched in all samples (up to 4.2 X and 1.9 X ATM, respectively), while arsenic and cobalt are enriched in eight and seven of the 10 samples (up to 2.8 X and 2.0 X ATM, respectively). Chromium and vanadium are variably enriched at both sites in the Cashie River (up to 1.7 X and 1.5 X ATM, respectively).

Lower Chowan River

The Chowan River represents a major drainage basin that flows south out of Virginia and discharges into the northwestern end of the inner Albemarle Sound (Figure 16). The lower Chowan River is an embayed estuary north to about Holiday Island where the River turns northwest (Figure 19). Northwest of Holiday Island, the River is a narrow, meandering, black-water river with extensive swamp forests along much of the shoreline. In this region, the River channel contains sand and is bordered by shallow perimeter platforms that consist of an eroding swamp-forest peat with scattered organic-rich mud accumulation. South of Holiday Island, the lower Chowan River is a wide, embayed estuary with mostly eroding sediment-bank shorelines. The bottom sediments consist of sand on shallow perimeter platforms and thick accumulations of organic-rich mud in the wide and deeper, flat-bottomed central basin.

Waste water from upstream industries, including a major paper mill located in Virginia, is probably the greatest potential source of trace elements in the lower Chowan River sediments.

Several small industries in North Carolina do have permitted NPDES discharges into the lower Chowan River with waste water discharges under two million gallons per day, including a major dye plant with a 1.5 mgpd permit. Samples at ten sites were obtained along the lower Chowan River (Figure 19). Seven sites (CHN-1 through CHN-7) are in the estuarine portion and three sites (CHN-8 through CHN-10) are in the riverine portion.

Table 19. Summary of mean and maximum enrichment factors for 15 trace elements in surface sediments from Middle River and Cashie River, two tributary channels of the lower Roanoke River. Elements with underlined enrichment factors are substantially enriched (EF = or >2X ATM) relative to the Albemarle trimmed mean, whereas those in bold print are slightly enriched (EF >1.5X to <2X ATM).

	Middle River surface samples N = 3		Cashie River surface samples N = 3	
Trace elements	Mean enrichment factor	Maximum enrichment factor	Mean enrichment factor	Maximum enrichment factor
Mn	3.7	4.2	2.8	3.9
As *	2.3	2.8	**1.6**	2.2
Co			**1.8**	2.0
Ti	**1.8**	**1.9**	**1.8**	**1.8**
Co	**1.5**	**1.7**		
Cr			**1.5**	**1.7**
V			1.4	**1.5**
Cr	1.2	1.4		
V	1.2	1.4		
Cu	1.2	1.4	1.4	1.4
P	0.9	1.2	1.0	1.4
Zn	1.0	1.1	1.2	1.2
Sn *	0.8	1.4	1.0	1.1
Mo	0.9	0.9	0.9	0.9
Ni	0.8	0.9	0.9	1.0
Pb	0.6	0.7	0.8	0.9
Cd	0.7	0.7	0.7	0.7
Hg	0.4	0.6	0.7	0.8

* analyses with poor reproducibility, hence somewhat less reliability.

Eleven of the 15 trace elements are substantially enriched in sediments of the lower Chowan River and two trace elements are slightly enriched (Table 20). Even though these 13 trace elements are enriched in multiple samples within the lower Chowan River sediments, their general concentrations are lower than in the lower Roanoke River. Also, the distribution patterns of these trace elements are somewhat irregular. Specific samples contain substantial enrichments of a few elements, but the samples are scattered and the enriched elements change from sample to sample.

Some of this irregularity may be due to the variability in concentration of chemically inert sands and silts relative to the chemically reactive clay and organic contents. The relative proportions of these sediment components vary considerably from sample to sample. For example, CHN-5 has no enriched elements in either of the samples, whereas the samples on either side of CHN-5, CHN-4 and CHN-6 (Figure 19), are relatively enriched in 12 and 11 trace elements, respectively. There is an apparent relationship between trace element enrichment and clay and organic content for these three samples. CHN-5 is adjacent to the flank of the estuarine basin and directly off an industrial discharge with sediments that are dominantly silty sand with little clay or organic matter, and consequently no enriched elements. In contrast, the two sites further into the estuarine basin have considerably higher concentrations of clay and organic matter and are substantially enriched in eight trace elements (As, Cd, Co, Mn, Ni, P, Sn, and Ti) and slightly enriched in three others (Hg, V, and Zn).

Table 20. Concentrations of 15 trace elements for all surface samples and enrichment factors for all surface and deep samples collected in the lower Chowan River. Depths of the deep samples range from 11 to 38 cm below the sediment surface for an average depth of 25 cm. Elements with underlined enrichment factors are substantially enriched (EF = or >2X ATM) relative to the Albemarle trimmed mean, whereas those in bold are slightly enriched (EF >1.5X to <2X ATM).

Trace elements	N	Concentrations (µg/g or ppm) surface samples mean	minimum	maximum	Enrichment factors deep samples mean (N=10)	maximum	surface samples mean (N=10)	maximum
Chowan River								
Mn	10	574.0	186.0	971.0	**1.6**	3.0	**1.7**	2.9
Co	10	11.4	3.8	19.0	1.2	2.6	**1.7**	2.8
Pb	10	23.7	7.0	68.0	0.6	2.0	1.1	3.1
As *	10	5.4	2.2	10.1	1.3	3.1	1.4	2.4
Ni	10	5.2	1.2	8.1	**1.5**	3.8	1.2	**1.9**
V	10	28.0	8.6	38.2	1.1	2.5	1.2	**1.6**
Sn *	10	7.6	2.2	11.2	1.2	**1.6**	1.3	2.0
Cd	10	0.3	0.2	0.7	0.7	1.4	1.4	3.1
Ti	10	48.1	16.5	87.2	1.2	2.4	0.6	1.2
Mo	10	0.25	0.25	0.25	1.3	2.4	0.9	0.9
P	10	402.0	225.0	809.0	0.6	1.1	1.0	2.0
Zn	10	56.8	26.5	92.3	0.6	**1.5**	1.1	**1.8**
Hg	10	0.11	0.02	0.21	0.3	1.1	0.8	**1.5**
Cu	10	9.4	4.5	13.8	0.8	1.3	0.9	1.3
Cr	10	7.7	2.4	11.9	0.8	1.2	0.7	1.1
Ca	10	2,689.0	1,162.0	4,522.	1.3	2.4	1.1	**1.9**
Al	10	4,196.0	1,373.0	6,332.	0.8	1.0	0.8	1.2
Si	10	1,275.0	785.0	1,470.	0.9	1.2	0.8	1.0
Na	10	83.4	32.8	164.	0.3	0.5	0.1	0.3

* analyses have poor reproducibility, hence somewhat low reliability.

Eleven elements are irregularly enriched in six samples collected around Tunis (CHN-8, CHN-9, and CHN-10) (Figure 19). Six elements are substantially enriched in five of the samples with maximum enrichment factors as follows: Pb = 3.1 X, Cd = 3.0 X, Co = 2.8 X, Mn = 2.5 X, Mo = 2.4 X, and As = 2.0 X the ATM. The other three elements are only slightly enriched in three of the samples with maximum enrichment factors as follows: Zn = 1.8 X, V = 1.6 X, and Ni = 1.6 X the ATM. The Tunis area has in the recent past had several major industries discharging into the lower Chowan River and including a fertilizer plant and aluminum plant, neither of which operates any longer. No substantial phosphorus enrichment was found in these samples.

Inner Albemarle Sound

Inner Albemarle Sound extends from the mouth of the lower Roanoke River with broad floodplain swampforests on the west northward to the embayed lower Chowan River estuary, and eastward to the western sides of the Yeopim River on the north and Bull Bay on the south (Figure 19). Inner Albemarle Sound is relatively narrow, about five miles wide, compared to the middle and outer portions further to the east, which are between 10 to 15 miles wide. Both the Roanoke and Chowan drainage basins (Figure 16) discharge directly into inner Albemarle Sound, which is an irregularly flooded, fresh water, drowned-river estuarine system. Figure 19 presents the locations of all sediment samples collected within the inner Albemarle Sound area and utilized for the following discussion.

Throughout the inner Albemarle region, the shorelines are dominated by high sediment banks with local areas of extensive swamp forests. The distribution of different shoreline types is directly dependent upon the complexity and location of the Suffolk Scarp (Figure 17). The Suffolk Scarp is a prominent physiographic feature on the North Carolina Coastal Plain; it is an old barrier island-estuarine complex left stranded during a prior sea-level highstand. This Pleistocene feature extends south from Suffolk, Virginia, forms the west side of the Dismal Swamp, crosses the lower Chowan and lower Roanoke rivers, and continues southward through Plymouth, North Carolina.

The northeastern and southwestern sides of the lower Chowan River estuary and the western portion of Albemarle Sound from Black Walnut Point and into Batchelor Bay are dominated by high sediment bank shorelines that are part of the upper morphologic terrace west of the Suffolk Scarp barrier island system. The northwestern and southeastern portions of the lower Chowan River and southwestern portion of Albemarle Sound are dominated by swamp forest shorelines that result from riverine floodplains with low elevations being flooded by the modern estuarine systems. All sediment bank shorelines within the inner Albemarle Sound area are dominated by erosion and backed by fringing upland forests and agricultural land. There are local areas that contain scattered individual homes along the shoreline.

Most trace element contaminants within the sediments in the inner Albemarle area probably have been derived from the substantial input of point and nonpoint anthropogenic waste into the upstream drainage of the Roanoke and Chowan rivers. The actual population of the counties that directly border this area (Bertie, Chowan, and Washington) is relatively small -- 48,383 people in 1980 (Tschetter, 1989) -- with only one small town (Edenton) and relatively few industries directly on the estuarine shoreline. As of May 1992 there were only about 27 associated NPDES permits with a design flow of about 2.04 mgd waste water discharge into waters within the inner Albemarle Sound area. Also, as of 1987 there were only four marinas that contained 160 boat slips in this portion of the study area (Tschetter 1989), which were totally in the Edenton area of Chowan County. Consequently, the inner Albemarle estuarine area reflects low direct levels of anthropogenic influence over broad portions of this area. However, substantial levels of elemental enrichment do occur in samples collected throughout the area.

Twenty-one sites were sampled within the inner Albemarle Sound area producing 42 sediment samples (Figure 19). Chemical data for these samples are summarized in Table 21. Nine of the 15 trace elements are substantially enriched in multiple samples with maximum enrichment factors as follows: Hg = 6.5 X, Mn = 5.6 X, As = 5.1 X, Cr = 3.2 X, Co = 2.6 X, V = 2.5 X, Ti = 2.5 X, P = 2.1 X, and Ni = 2.0 X the ATM. Four trace elements are slightly enriched within the mud sediments in this area with only 12 samples being slightly enriched in zinc (up to 1.8 X the ATM), six samples in copper (up to 1.7 X the ATM), three samples in cadmium (up to 1.9 X the ATM), and two samples in lead (up to 1.6 X the ATM). No samples are enriched in molybdenum or tin.

Most sample sites directly off the mouth of the Roanoke River (Figure 18) have generally low concentrations of the enriched elements. This is probably due to higher contents of chemically inert sand and silt from the Roanoke River in these samples. On the other hand, higher concentrations of trace elements occur in the richer mud sediments off the mouth of the lower Chowan River and extend southeast into the central and southern portion of inner Albemarle Sound. Concentrations of all elements decrease significantly toward the east and generally approach mean concentrations east of the Highway 32, Albemarle Sound bridge (Figure 19).

Table 21. Concentrations of 15 trace elements for all surface samples and enrichment factors for all surface and deep samples collected in the inner Albemarle Sound. Depths of the deep samples range from 13 to 51 cm below the sediment surface for an average depth of 38 cm. Elements with underlined enrichment factors are substantially enriched (EF = or >2X ATM) relative to the Albemarle trimmed mean, whereas those in bold are slightly enriched (EF >1.5X to <2X ATM).

Trace elements	N	Concentrations (μg/g or ppm) surface samples			Enrichment factors deep samples N=21		Enrichment factors surface samples N=21	
		mean	minimum	maximum	mean	maximum	mean	maximum
Inner Albemarle Sound								
Mn	21	919.0	175.0	1,271.0	2.1	5.6	2.8	3.9
Hg	21	0.3	0.07	0.68	0.9	6.5	2.1	4.8
As *	21	8.6	2.8	13.0	**1.6**	5.1	2.3	3.5
Co	21	11.3	5.9	17.2	1.4	2.1	**1.7**	2.6
Cr	21	16.9	8.0	25.8	1.3	3.2	**1.6**	2.4
V	21	41.1	15.8	51.9	**1.7**	2.5	**1.7**	2.2
Ti	21	95.5	35.6	163.0	**1.7**	2.5	1.3	2.2
Ni	21	5.1	2.3	8.4	1.0	**1.6**	1.2	2.0
P	21	466.0	248.0	828.0	0.6	1.3	1.2	2.1
Zn	21	70.4	41.5	87.6	0.7	**1.8**	1.4	**1.7**
Cu	21	13.2	7.7	17.0	1.2	**1.7**	1.2	**1.6**
Pb	21	23.3	7.9	35.0	0.7	1.4	1.1	**1.6**
Cd	21	0.19	0.15	0.42	0.7	0.7	0.9	**1.9**
Mo	21	0.25	0.25	0.25	0.9	0.9	0.9	0.9
Sn *	21	3.9	1.1	7.5	0.8	1.4	0.7	1.3
Ca	21	2,173.	1,312.0	3,333.	0.6	1.2	0.9	1.4
Al	21	6,226.	3,057.0	7,576.	1.2	**1.5**	1.2	**1.5**
Si	21	1,478.	1,229.0	1,699.	1.0	1.0	1.0	1.1
Na	21	474.	44.6	1,633.	0.9	2.3	0.8	2.7

* analyses have poor reproducibility, hence somewhat low reliability.

Conclusions

1. Due to the mineralogy and chemistry of organic-rich muds occurring within the North Carolina estuarine system, low concentrations of trace elements within the water column can be sequestered and concentrated within the sediments through time. These muds are continuously resuspended into the water column by bottom disturbing activities and allow for the continued interaction with water column chemicals. Most sequestered trace elements are loosely bound to fine-grained sediments and consequently are potentially available to filter- and bottom-feeding organisms living in these ecosystems.

2. All of the 15 trace elements analyzed in this study are substantially enriched within bottom sediments at one or more sites in the vicinity of known point source discharges within the lower Roanoke and lower Chowan rivers and inner Albemarle Sound areas. Maximum enrichment factors (MEF) for all samples analyzed in this region are as follows:
   Cr = 156.1 X, Hg = 72.9 X, Pb = 3.1 X, Ni = 20.5 X, Zn = 6.2 X,
   Cd = 4.0 X, Cu = 9.4 X, Mo = 4.5 X, Mn = 5.6 X, As = 5.1 X,
   V = 4.0 X, Sn = 3.9 X, P = 3.7 X, Ti = 2.5 X, and Co = 2.8 X the
   Albemarle trimmed mean or ATM.

3. Anthropogenic sources are largely responsible for trace element contamination within the lower Roanoke and lower Chowan rivers and inner Albemarle Sound estuarine sediments. NPDES permitted point source discharges appear to be the major contributors of enriched trace elements to bottom sediments. Nonpoint source discharges are also important, but are generally more diffuse and difficult to evaluate.

4. Based upon chemical quality of the bottom sediments of the lower Roanoke and lower Chowan rivers and inner Albemarle Sound estuarine system, <u>six contaminated areas of concern</u> have been identified. All of these areas have major levels of sediment pollution (20% or more of the analyses represent enriched trace elements relative to the ATM and include the following areas.

Region	Number of trace elements enriched	% analysis enriched
Welch Creek	14	55
Inner Albemarle	13	32
Lower Roanoke River	11	32
Middle River	7	30
Cashie River	7	30
Lower Chowan River	13	24

5. Industrial discharge associated with a large paper mill on the lower Roanoke River and Welch Creek, west of Plymouth, has apparently contributed the highest levels of trace elements to the Albemarle estuarine sediments.

   a. The most contaminated sediments are in Welch Creek, where 13 trace elements are substantially enriched as follows.
   (MEF: Cr = 156.1 X, Hg = 72.9 X, Ni = 20.5 X, Cu = 9.4 X, Zn = 6.2 X,
   Mo = 4.5 X, Cd = 4.0 X, V = 4.0 X, Sn = 3.9 X, P = 3.7 X, Mn = 3.1 X,
   Ti = 2.4 X, and Co = 2.0 X the ATM). Pb and As are slightly enriched within Welch Creek.

b. The lower Roanoke River is substantially enriched in nine trace elements and slightly enriched in three trace elements above the Albemarle trimmed mean, but the occurrence of contaminated sediments has an irregular distribution pattern. This is interpreted to be related to an irregular pattern of erosion in response to flooding events.

c. The inner Albemarle Sound is substantially enriched in nine trace elements and slightly enriched in four trace elements above the Albemarle trimmed mean. The highest level of enrichments for As and Ti (= 5.1 X and 2.5 X the Albemarle trimmed mean, respectively) occur in the inner Albemarle Sound.

d. The lower Chowan River is substantially enriched in 11 trace elements and slightly enriched in two trace elements above the Albemarle trimmed mean, but the occurrence of contaminated sediments has an irregular distribution pattern. The highest level of enrichments for Pb and Co (= 3.1 X and 2.8 X the Albemarle trimmed mean, respectively) occur in the lower Chowan River.

e. The Cashie and Middle rivers are the least contaminated areas with fewer enriched trace elements occurring at fewer sample sites; however, this is in part due to the small number of samples collected.

6. Based upon the present data base, the trace element contamination problem in Welch Creek appears to be relict and a result of former industrial discharge. It is not clear how much of the trace element contamination problem in the lower Roanoke River and inner Albemarle Sound is relict and due to historic processes and how much is a direct result of ongoing industrial and municipal discharge. Modern accumulation of metals is probably taking place in the surface sediments of both the lower Roanoke River and inner Albemarle Sound from ongoing NPDES permitted discharges; however, those enriched sediments within the River are probably ephemeral and end up being redeposited during periods of flood within inner Albemarle Sound, where they contribute to the overall low-grade, regional contamination.

HYDROLOGY, 1991-1993

General Conditions

Reid Campbell

1991

The flow records for the first six months of 1991 show stream flows to be above normal. The U.S. Geological Survey (USGS) gage at Roanoke Rapids showed the first six months to be the 22nd wettest out of 82 years of record (1912 to 1993) (Table 22). For comparison, the first six months of 1989 and 1990 ranked 31st and 14th respectively. Flows during the period of April through mid-June were the 18th wettest on record. In 1989 and 1990 for the same period, the flows were 11th and 10th wettest on record.

During the first six months there were six storms that caused Kerr Reservoir inflows to exceed 90% of the historical inflow (Figure 20). The largest of these storms occurred at the end of March with a peak inflow of 85,329 cfs on 31 March (Figure 21). As a result of storing these flood events, Kerr Reservoir reached a peak elevation of 308.85 feet msl for the first six months of 1991.

At the beginning of the flow augmentation period on 1 April, there was adequate storage available in Kerr Reservoir (Figure 22). The reservoir level reached 308.00 feet msl, about 6.93 feet above the Rule (Guide) Curve. The large inflows into Kerr Reservoir caused the daily flows at Roanoke Rapids to exceed the flow regime 100% of the time for the period 1 April through 15 April (Figures 23 and 24). From 1 April through 15 June, daily flows were within the flow regime 68% of the time, above the regime for 32% of the days, and no daily flow was below the regime lower limit (Table 23). In 1989, flows remained within the regime for 43% of the days. Conversely, in 1990, flows stayed inside the range for only 26% of the days.

Flow stability showed better results than in either 1989 or 1990. Hourly flow variation exceeded 1,500 cfs only eight hours or 0.44% of the time. In 1989 and 1990 the rate change was exceeded 1.54% and 1.10% of the time. The largest change per hour was an increase in flow of 8,585 cfs/hr on 15 June 1991 (Figure 25).

1992

Data for the first six months of 1992 show stream flows to be roughly in the lowest third of the record. The flow record for the gage at Roanoke Rapids shows the first six months to be the 54th wettest (or 29th driest) out of 83 years of record (1912 to 1993). However, flows during the period of April through mid-June were the 30th wettest on record (Table 22).

During the first six months there were four storms that caused Kerr Reservoir inflows to exceed 90% of the historical inflow (Figure 26). The largest of these storms occurred on 24 April, with a peak inflow of 69,457 cfs (Figure 27). As a result of storing these flood events, Kerr Reservoir reached a peak elevation of 306.04 feet msl, for the first six months of 1992 (Figure 28).

At the beginning of the flow augmentation period on 1 April, there was adequate storage available in Kerr Reservoir. The reservoir level reached 300.92 feet msl, only 0.15 below the Rule (Guide) Curve. The small inflows into Kerr Reservoir caused the daily flows at Roanoke Rapids to fall below the flow regime (Figures 29 and 30) level 53% of the hours (47% of days) for the period 1 April through 15 April (Table 24). From 1 April through 15 June, hourly flows were within the flow regime 45% of the hours (43% of the days), above the regime for 38% of were within the flow regime 45% of the hours (43% of the days), above the regime for 38% of the hours (39% of the days), and hourly flows were below the regime limit 17% of the time.

The flow stability was marginally worse in 1992 than in 1991. Hourly variation exceeded 1,500 cfs 0.55% of the time (10 hours). However, the greatest change was an increase of 4,519 cfs/hr on 10 June 1992 (Figure 31).

1993

The flow records for the first six months of 1993 show Roanoke River flows greatly above normal (Figure 32). The Roanoke Rapids USGS gage reported discharge between 1 January and 30 June to rank as the fourth wettest on record out of 83 years (Table 22). Between 1 April and 30 April 1993, flows were at the second highest level to occur during the gage accounting. By the last two weeks of the augmentation interval (1 June through 15 June) flows had dropped, but were still in the upper third of record for the bi-week period. Over the 1 April to 15 June span, flows ranked third wettest on record.

Several storms occurred between March and April that caused Kerr Reservoir inflows to exceed 90% of the historical inflow; twice they surpassed the 95th percentile (Figure 32). Maximum inflow reached 107,724 cfs on 6 March (Figure 33). As a result of these high flows on 30 March, Kerr Reservoir reached 316.57 ft msl, a peak elevation during the first six months of the year (Figure 34).

At the beginning of the Negotiated Period on 1 April, there was more than adequate storage available in Kerr Reservoir. The reservoir level was at approximately 316.13 feet msl, or 15.06 feet above the Guide Curve. The large inflows forced daily and hourly flows to exceed the flow regime (Figures 35 and 36) 100% of the hours between 1 April and 30 April, and 73% of the time during 1 May and 15 May (Table 25). Throughout the 1 April to 15 June window, flows exceeded the regime 54% of the time and met the limits 46% of it. For no interval, between 1 April and 15 June, were flows below the regime bottom bracket.

With the dramatically high flows, the flow stability degraded from 1991 and 1992. The hourly variation exceeded 1,500 cfs 14 times or 0.76% of the time (Figure 37). These rates were better than those occurring during 1989 and 1990. The greatest change was a drop of 3,958 cfs/hr on 28 April 1993.

Table 22. Rankings of mean flow for various periods during 1989, 1990, 1991, 1992, and 1993.

Period	Year	Wet rank	Dry rank	Mean, cfs
For the year	1989	9	73	10,746.74
	1990	12	70	10,494.77
	1991	44	38	7,800.99
	1992	54	28	7,291.34
	1993			(incomplete)
1/1 to 6/30	1989	31	52	11,092.49
	1990	14	69	13,930.72
	1991	22	61	12,271.71
	1992	54	29	8,835.55
	1993	4	79	17,076.24
4/1 to 6/15	1989	11	72	13,711.97
	1990	10	73	14,280.79
	1991	18	65	12,000.13
	1992	30	53	10,646.97
	1993	3	80	19,865.79
4/1 to 4/15	1989	34	49	11,878.00
	1990	19	64	17,146.67
	1991	12	71	20,073.33
	1992	65	18	6,154.67
	1993	2	81	35,026.67
4/16 to 4/30	1989	45	38	8,977.33
	1990	27	56	11,422.00
	1991	22	61	13,327.33
	1992	21	62	13,600.00
	1993	2	81	30,293.33
5/1 to 5/15	1989	8	75	18,871.33
	1990	28	55	9,974.00
	1991	33	50	9,380.67
	1992	15	68	11,954.67
	1993	11	72	16,720.00
5/16 to 5/31	1989	5	78	18,702.50
	1990	14	69	13,718.75
	1991	27	56	9,139.38
	1992	26	57	9,202.50
	1993	27	56	9,108.12
6/1 to 6/15	1989	19	64	9,798.00
	1990	1	82	19,180.00
	1991	28	55	8,270.67
	1992	7	76	12,419.33
	1993	25	58	8,898.00

Table 23. Bi-weekly summaries of daily flows of the Roanoke River at Roanoke Rapids, NC for 1991.

Dates	Total days	Q_1 cfs	Q_3 cfs	#Days $<Q_1$	%Days $<Q_1$	#Days Q_1-Q_3	%Days Q_1-Q_3	#Days $>Q_3$	%Day $>Q_3$
4/1 to 4/15	15	6,600	13,700	0	0.0	0	0.0	15	100.0
4/16 to 4/30	15	5,800	11,000	0	0.0	9	60.0	6	40.0
5/1 to 5/15	15	4,700	9,500	0	0.0	12	80.0	3	20.0
5/16 to 5/31	16	4,400	9,500	0	0.0	16	100.0	0	0.0
6/1 to 6/15	15	4,000	9,500	0	0.0	15	100.0	0	0.0
4/1 to 6/15	76			0	0.0	52	68.4	24	31.6

Table 24. Bi-weekly summaries of daily flows of the Roanoke River at Roanoke Rapids, NC for 1992.

Dates	Total days	Q_1 cfs	Q_3 cfs	#Days $<Q_1$	%Days $<Q_1$	#Days Q_1-Q_3	%Days Q_1-Q_3	#Days $>Q_3$	%Day $>Q_3$
4/1 to 4/15	15	6,600	13,700	7	46.7	8	53.3	0	0.0
4/16 to 4/30	15	5,800	11,000	6	40.0	0	0.0	9	60.0
5/1 to 5/15	15	4,700	9,500	0	0.0	10	66.7	5	33.3
5/16 to 5/31	16	4,400	9,500	0	0.0	8	50.0	8	50.0
6/1 to 6/15	15	4,000	9,500	0	0.0	7	46.7	8	53.3
4/1 to 6/15	76			13	17.1	33	43.4	30	39.5

Table 25. Bi-weekly summaries of daily flows of the Roanoke River at Roanoke Rapids, NC for 1993.

Dates	Total days	Q_1 cfs	Q_3 cfs	#Days $<Q_1$	%Days $<Q_1$	#Days Q_1-Q_3	%Days Q_1-Q_3	#Days $>Q_3$	%Day $>Q_3$
4/1 to 4/15	15	6,600	13,700	0	0.0	0	0.0	15	100.0
4/16 to 4/30	15	5,800	11,000	0	0.0	0	0.0	15	100.0
5/1 to 5/15	15	4,700	9,500	0	0.0	4	26.7	11	73.3
5/16 to 5/31	16	4,400	9,500	0	0.0	16	100.0	0	0.0
6/1 to 6/15	15	4,000	9,500	0	0.0	15	100.0	0	0.0
4/1 to 6/15	76			0	0.0	35	46.1	41	53.9

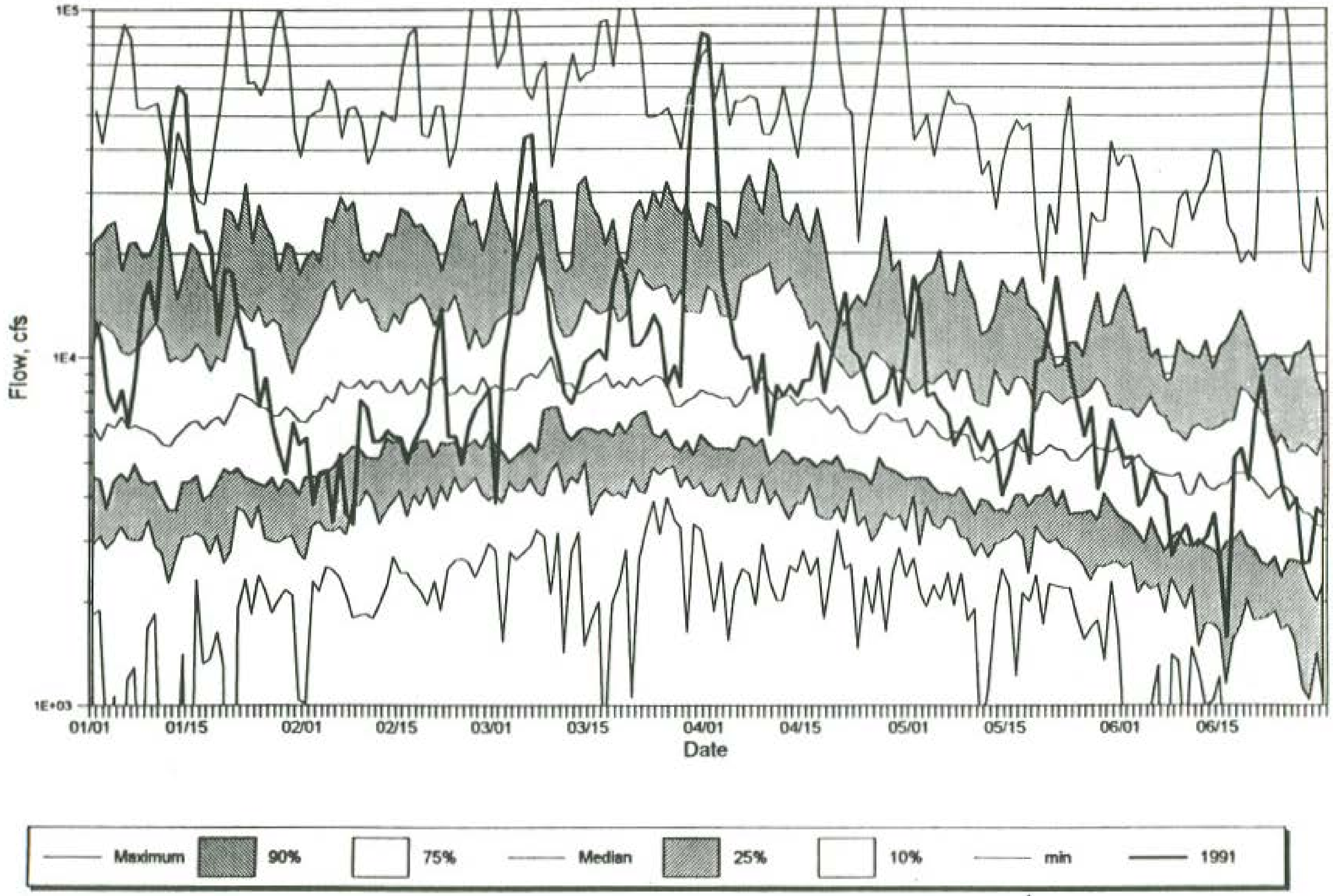

Figure 20. Kerr Reservoir inflow for 1991 compared to the historical record.

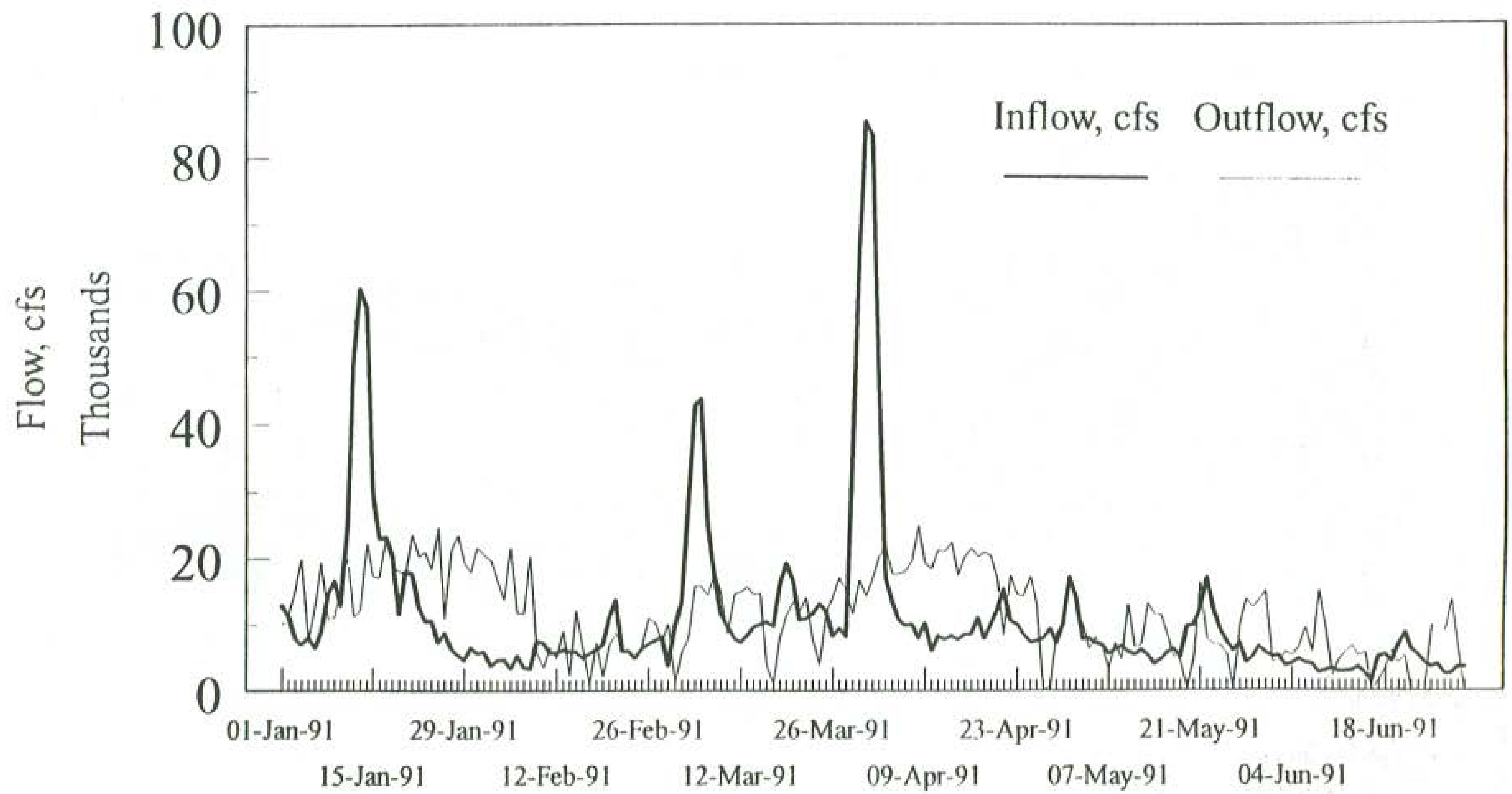

Figure 21. Kerr Lake inflow versus outflow, 1 January to 30 June 1991.

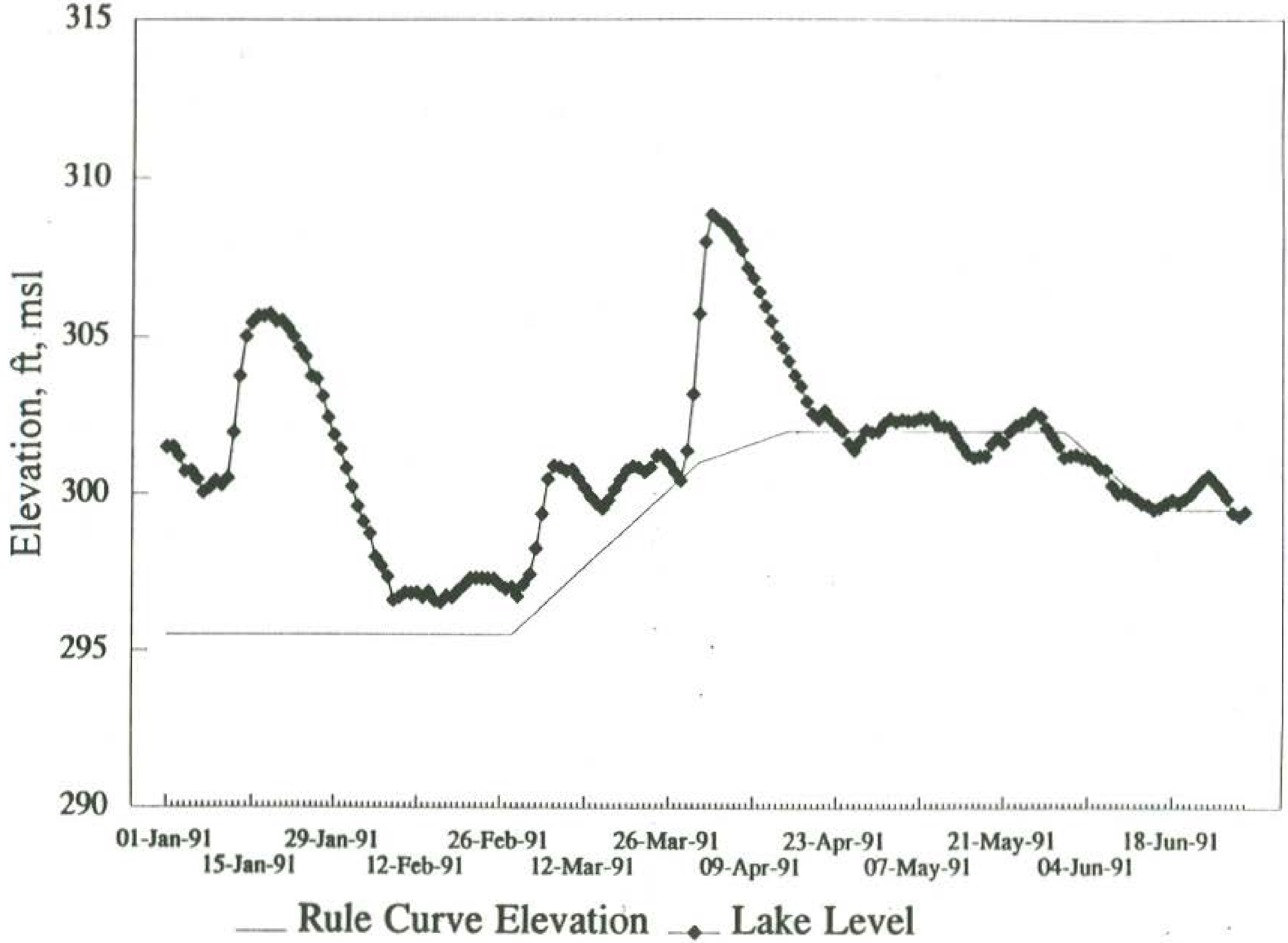

Figure 22. Kerr Lake Reservoir level, 1 January to 30 June 1991.

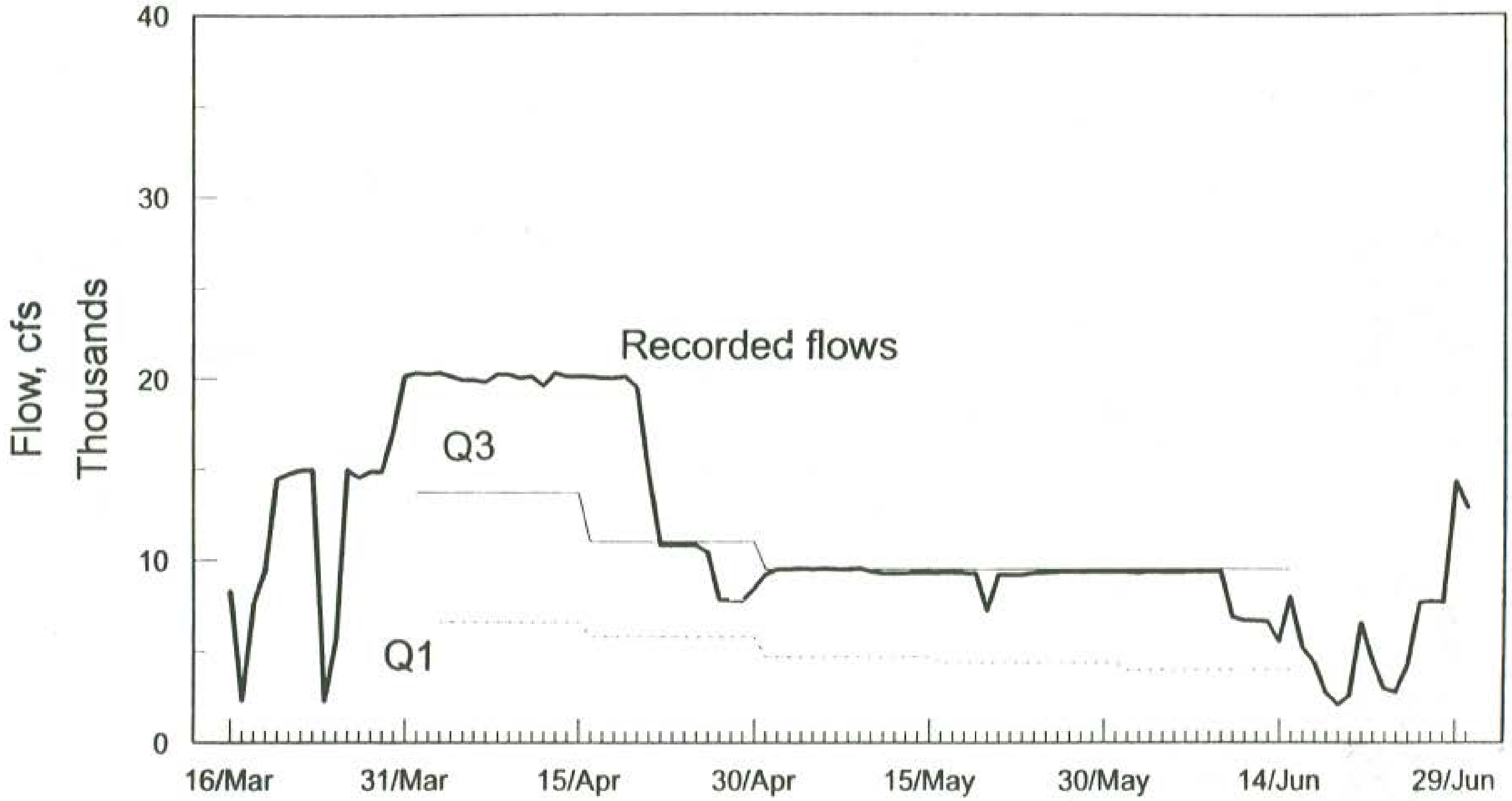

Figure 23. Daily flows of the Roanoke River at Roanoke Rapids, 16 March to 30 June 1991.

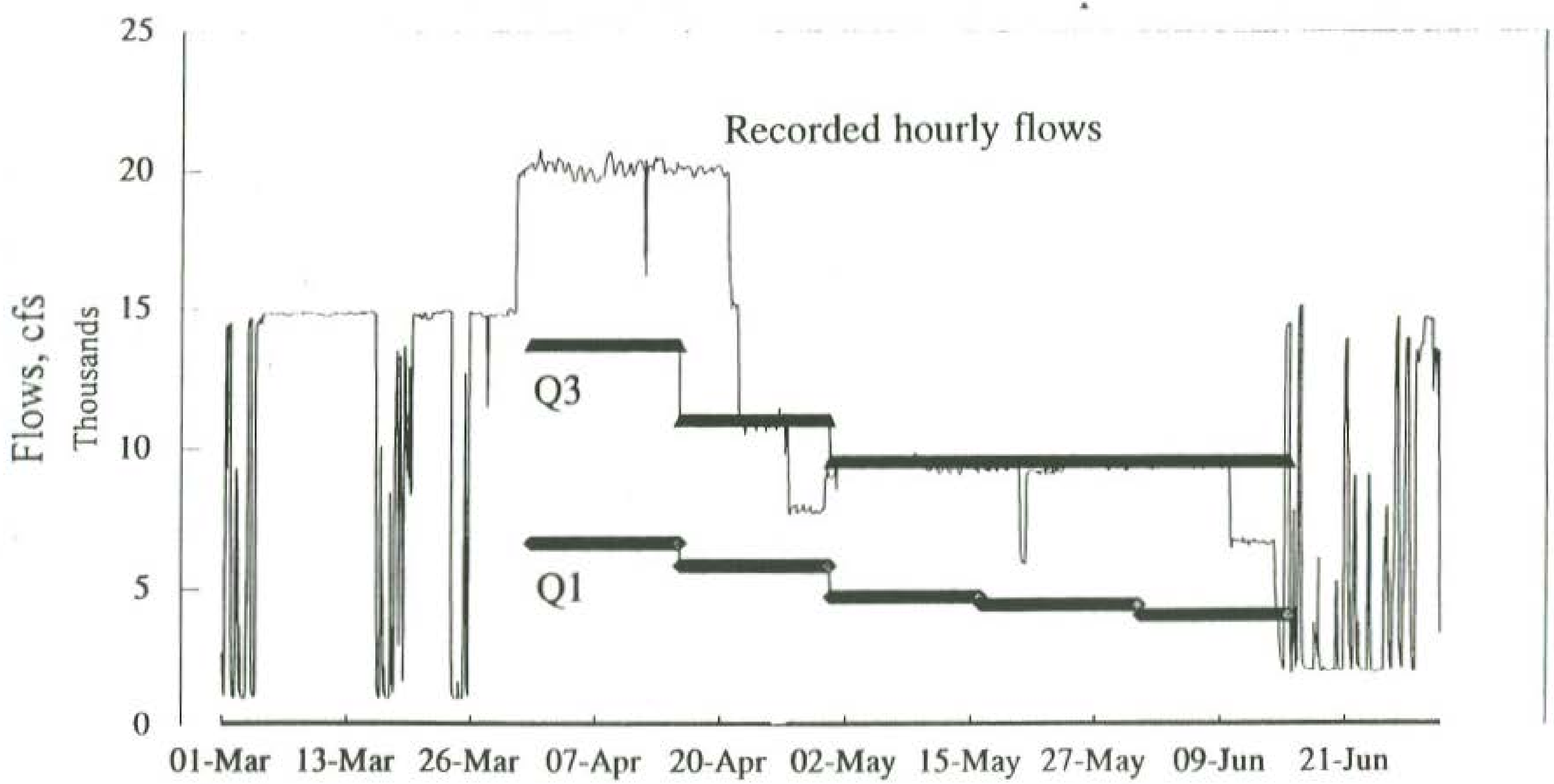

Figure 24. Hourly flows of the Roanoke River at Roanoke Rapids, 1 March to 30 June 1991.

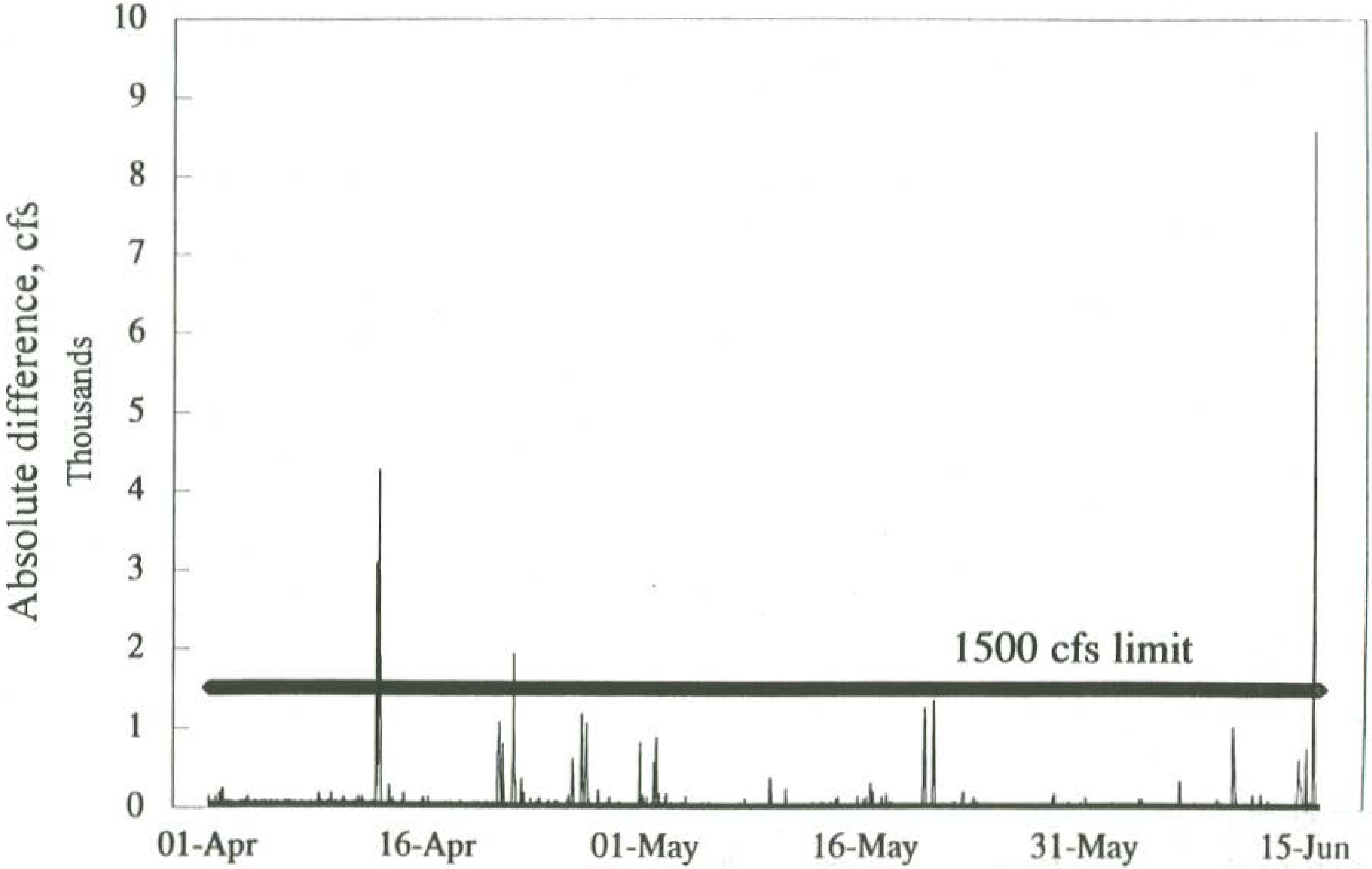

Figure 25. Absolute value of hourly differences in flow (cfs) of the Roanoke River downstream of Roanoke Rapids Dam, 1 April through 15 June 1991.

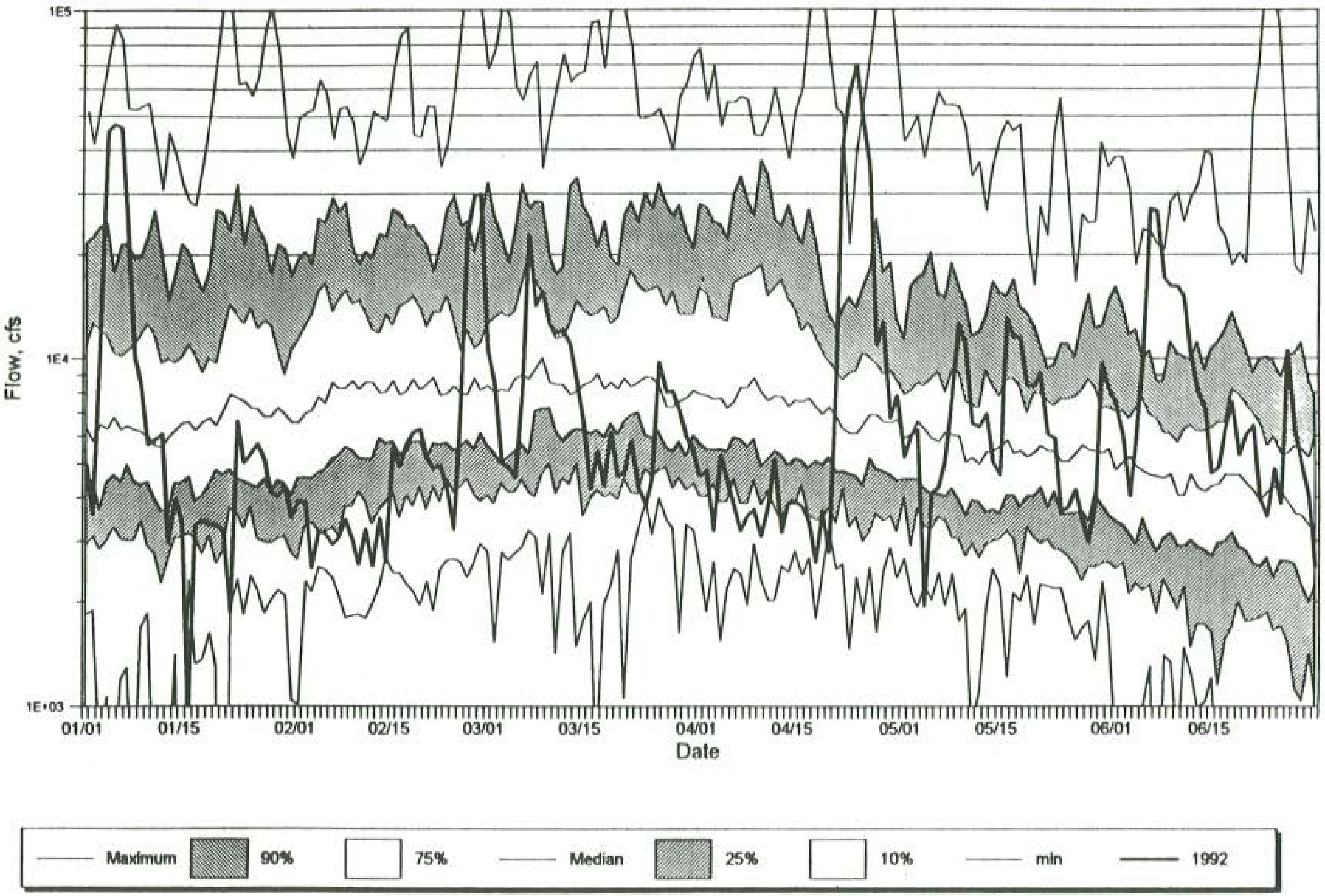

Figure 26. Kerr Reservoir inflow for 1992 compared to the historical record.

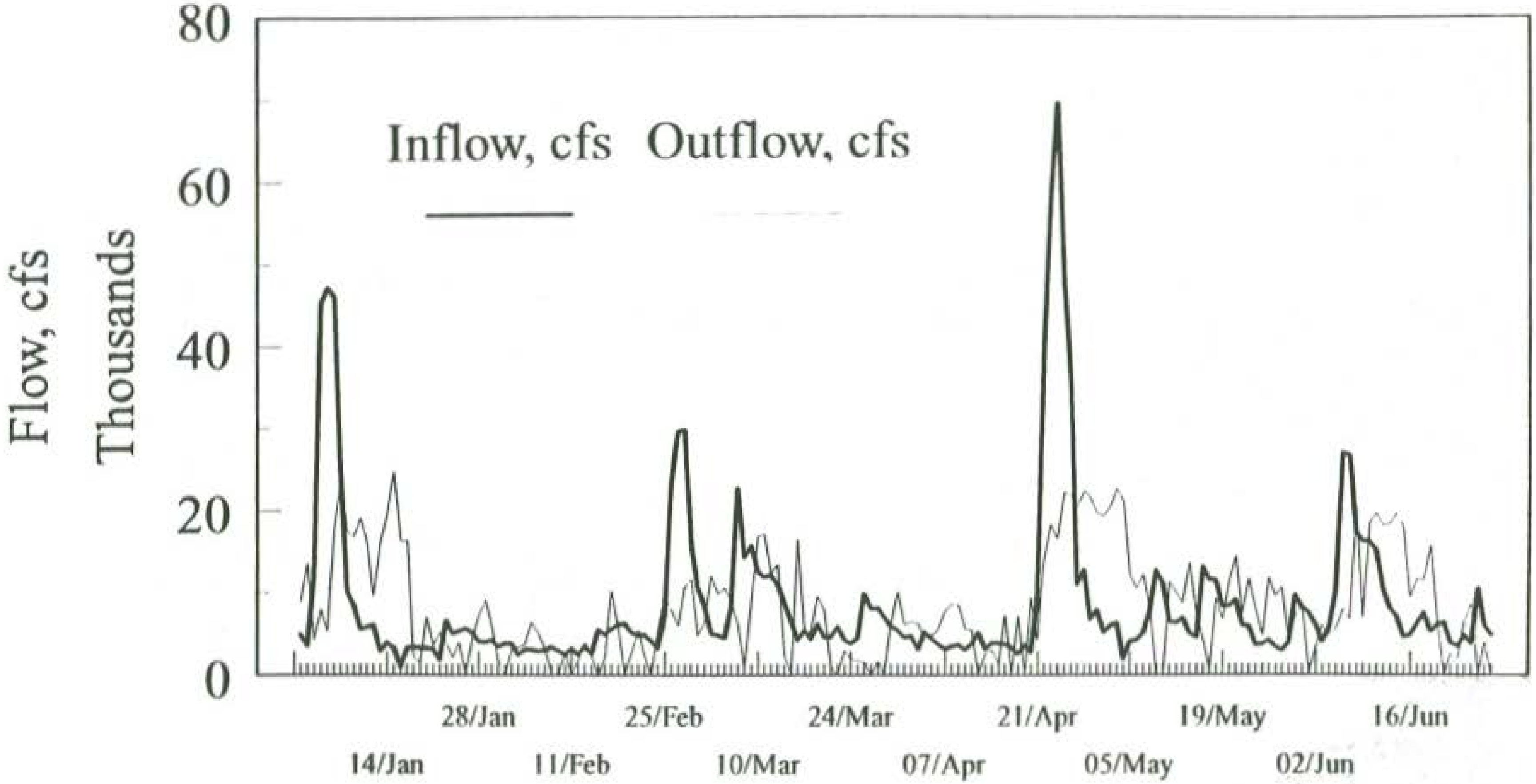

Figure 27. Kerr Lake inflow versus outflow, 1 January to 30 June 1992.

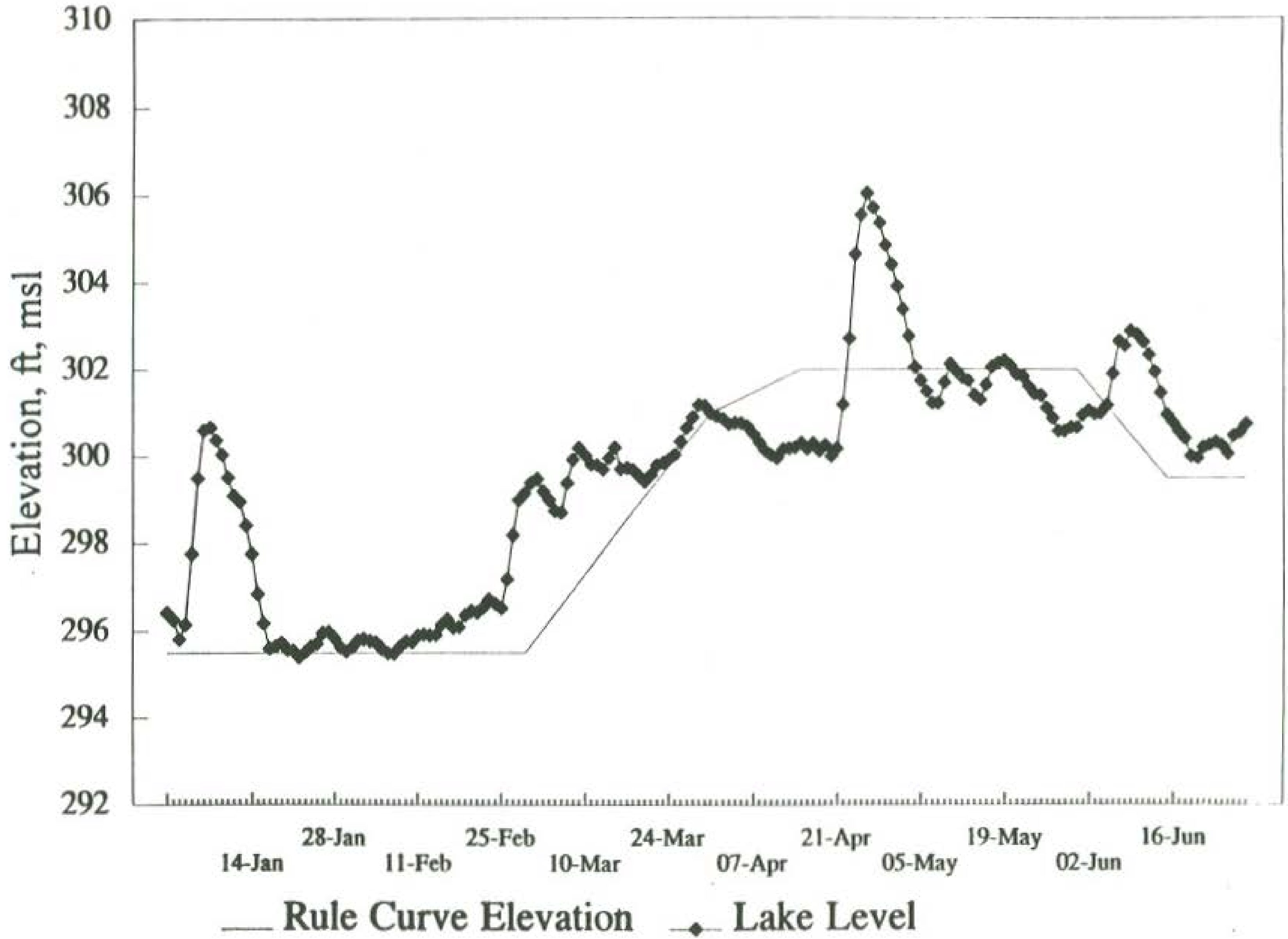

Figure 28. Kerr Lake Reservoir level, 1 January to 30 June 1992.

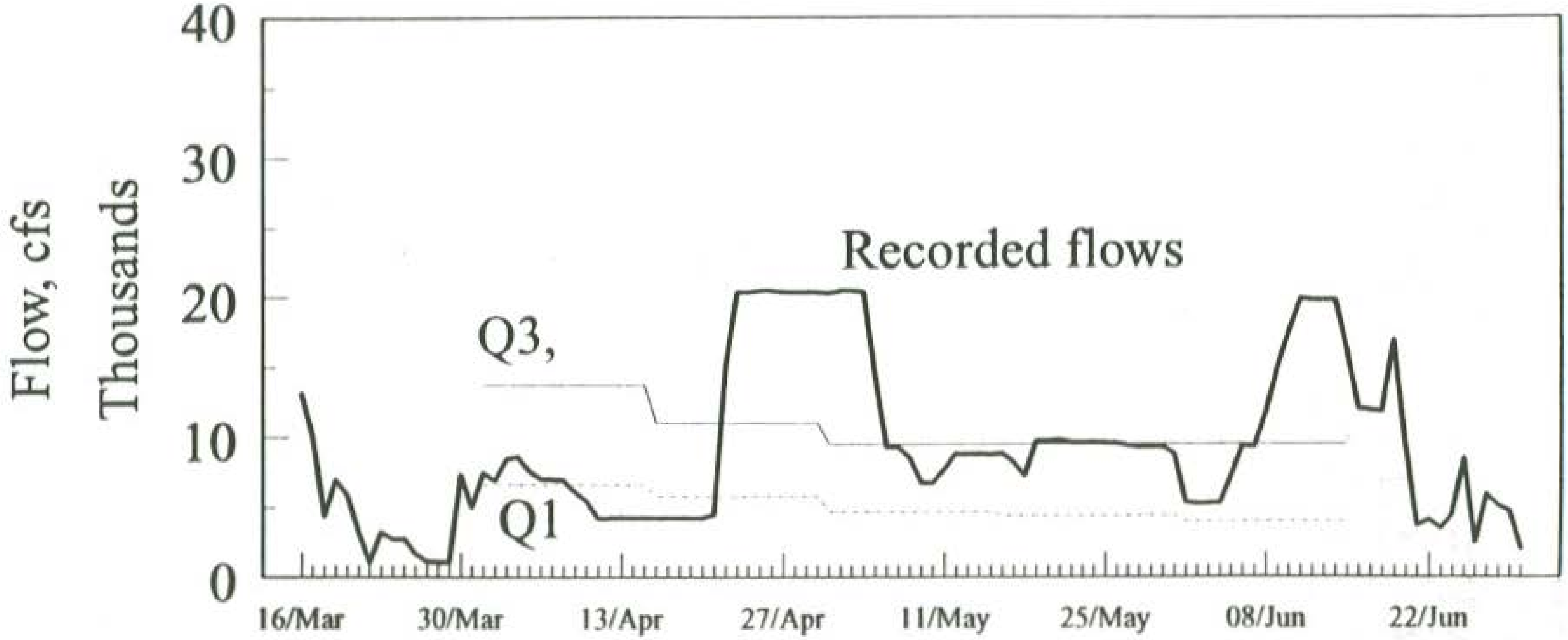

Figure 29. Daily flows of the Roanoke River at Roanoke Rapids, 16 March to 30 June 1992.

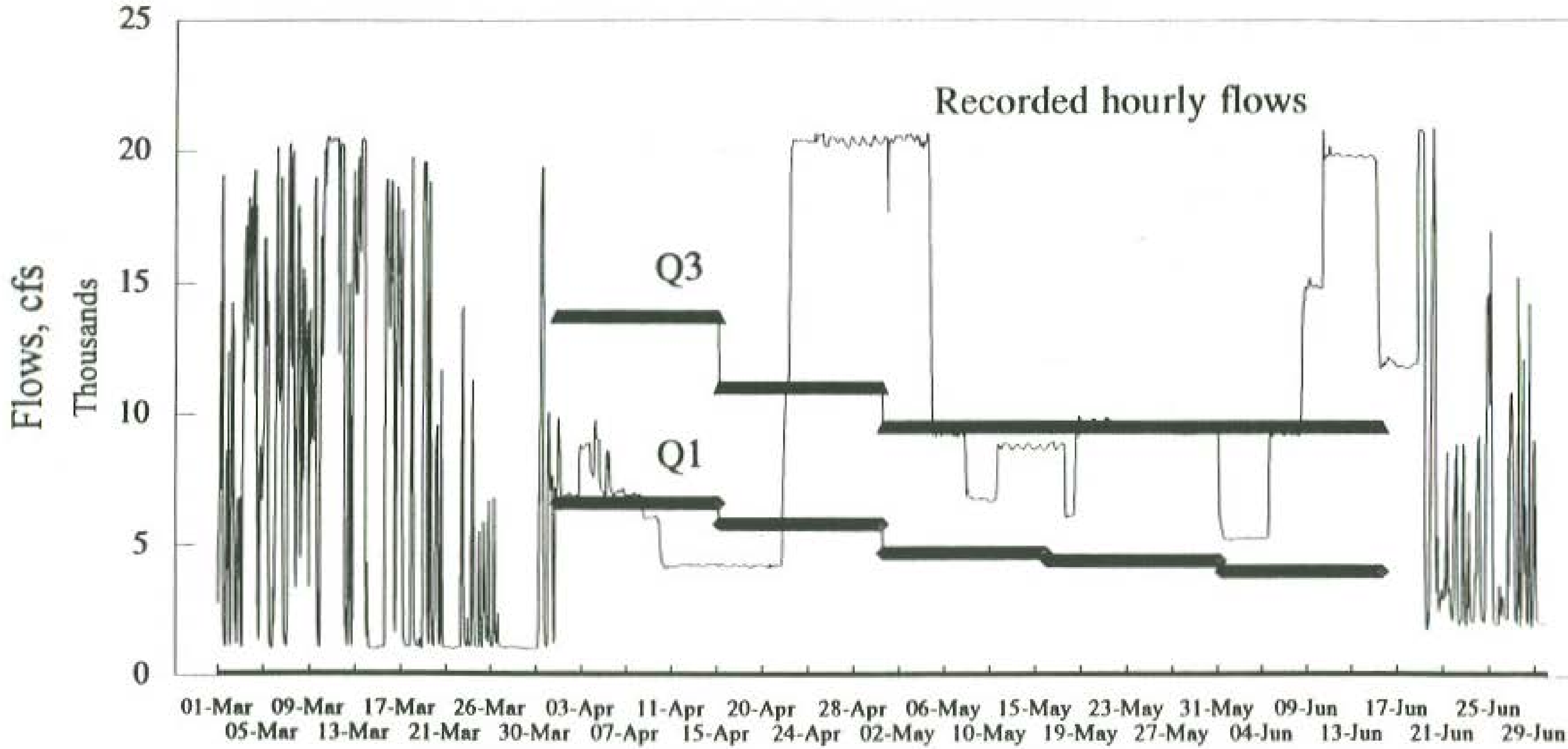

Figure 30. Hourly flows of the Roanoke River at Roanoke Rapids, 1 March to 30 June 1992.

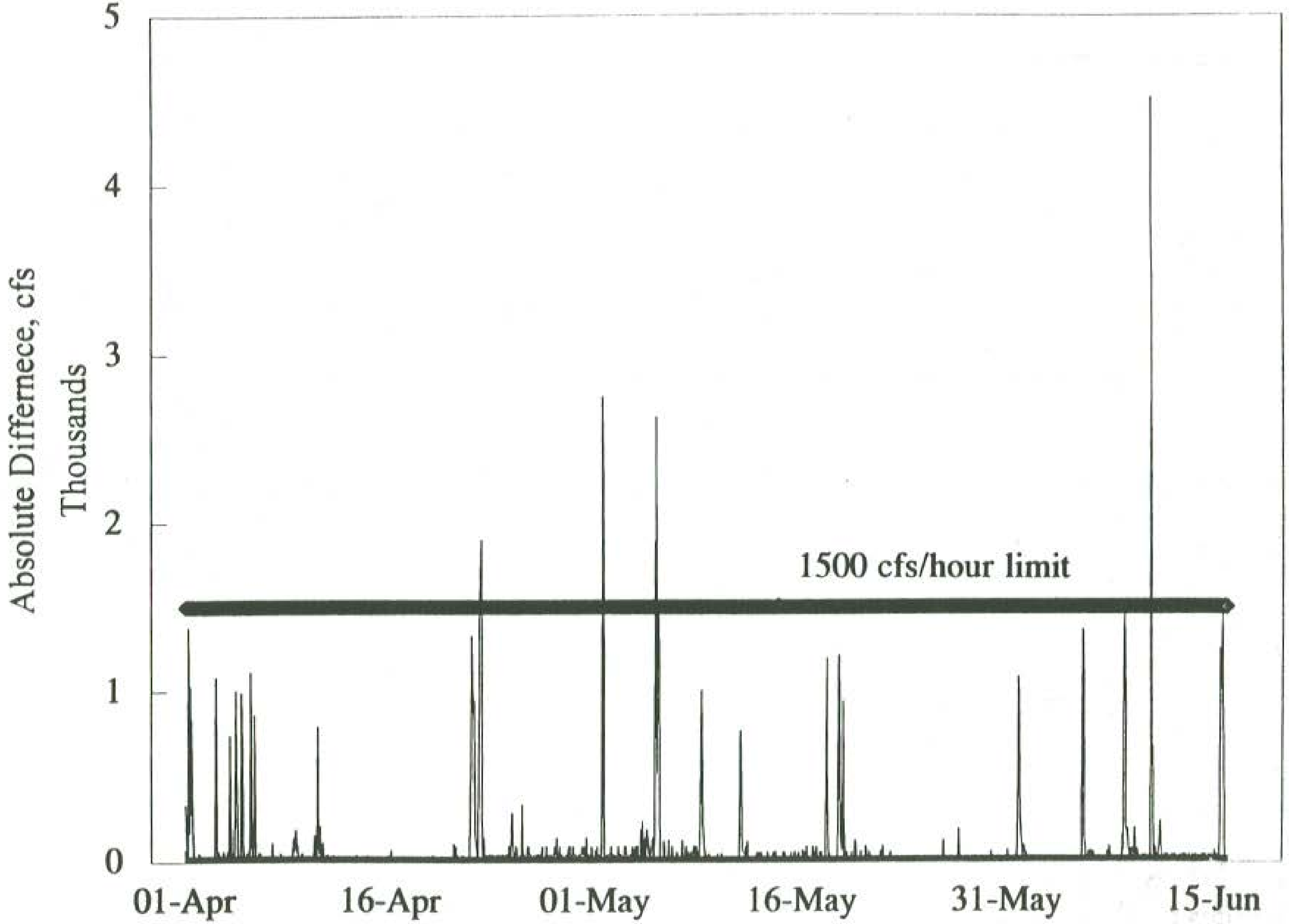

Figure 31. **Absolute value of hourly differences in flow (cfs) of the Roanoke River downstream of Roanoke Rapids Dam, 1 April through 15 June 1992.**

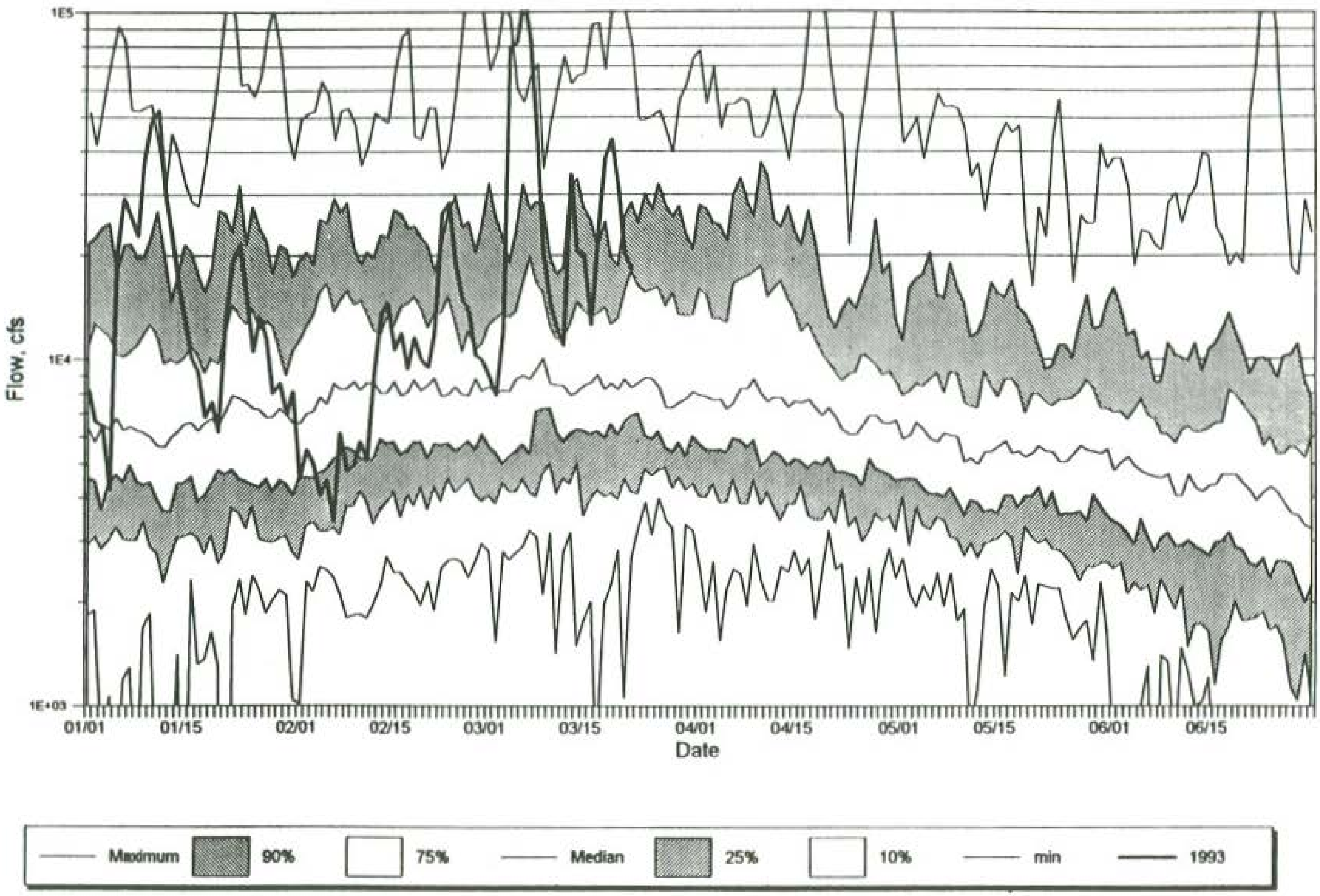

Figure 32. Kerr Reservoir inflow for 1993 compared to the historical record.

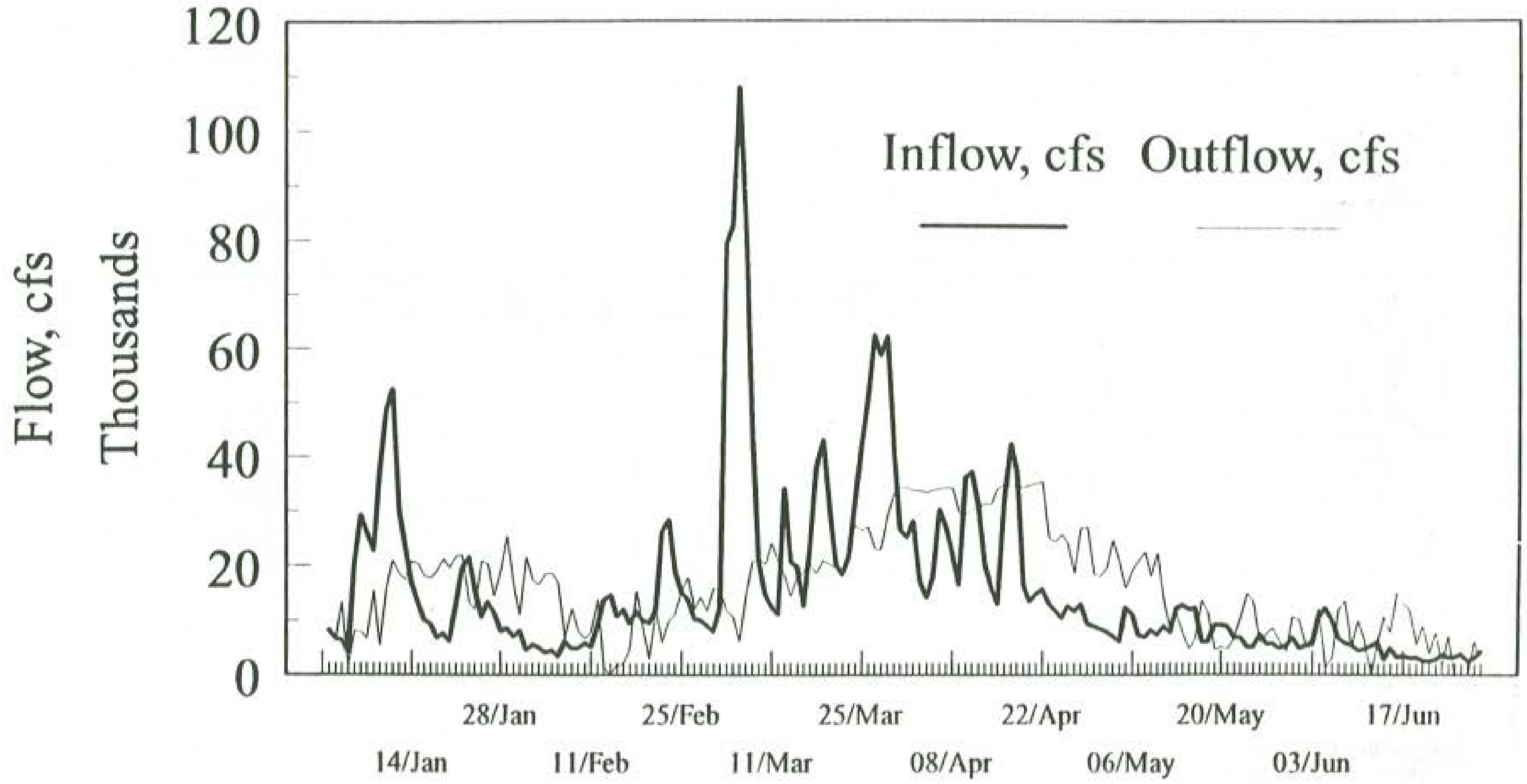

Figure 33. Kerr Lake inflow versus outflow, 1 January to 30 June 1993.

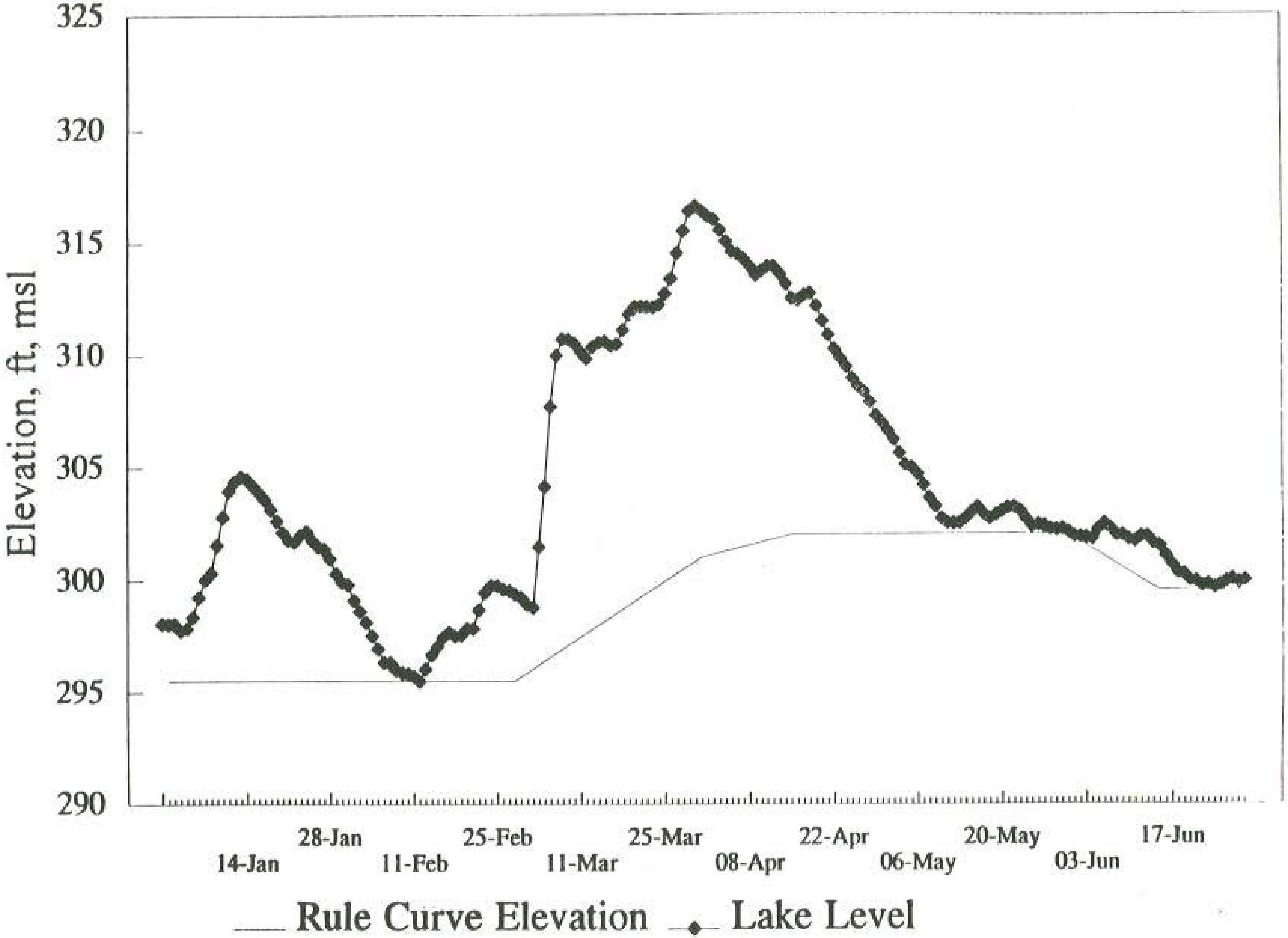

Figure 34. Kerr Lake Reservoir level, 1 January to 30 June 1993.

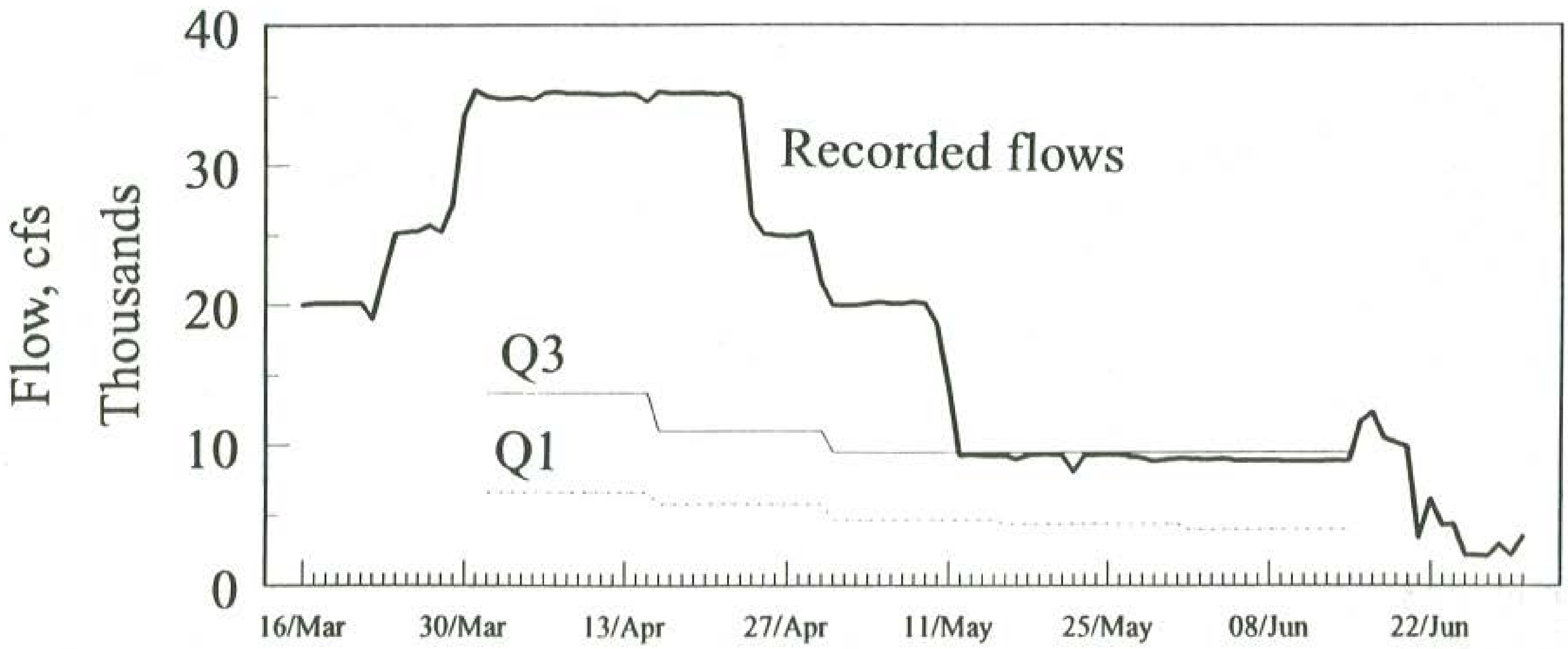

Figure 35. Daily flows of the Roanoke River at Roanoke Rapids, 16 March to 30 June 1993.

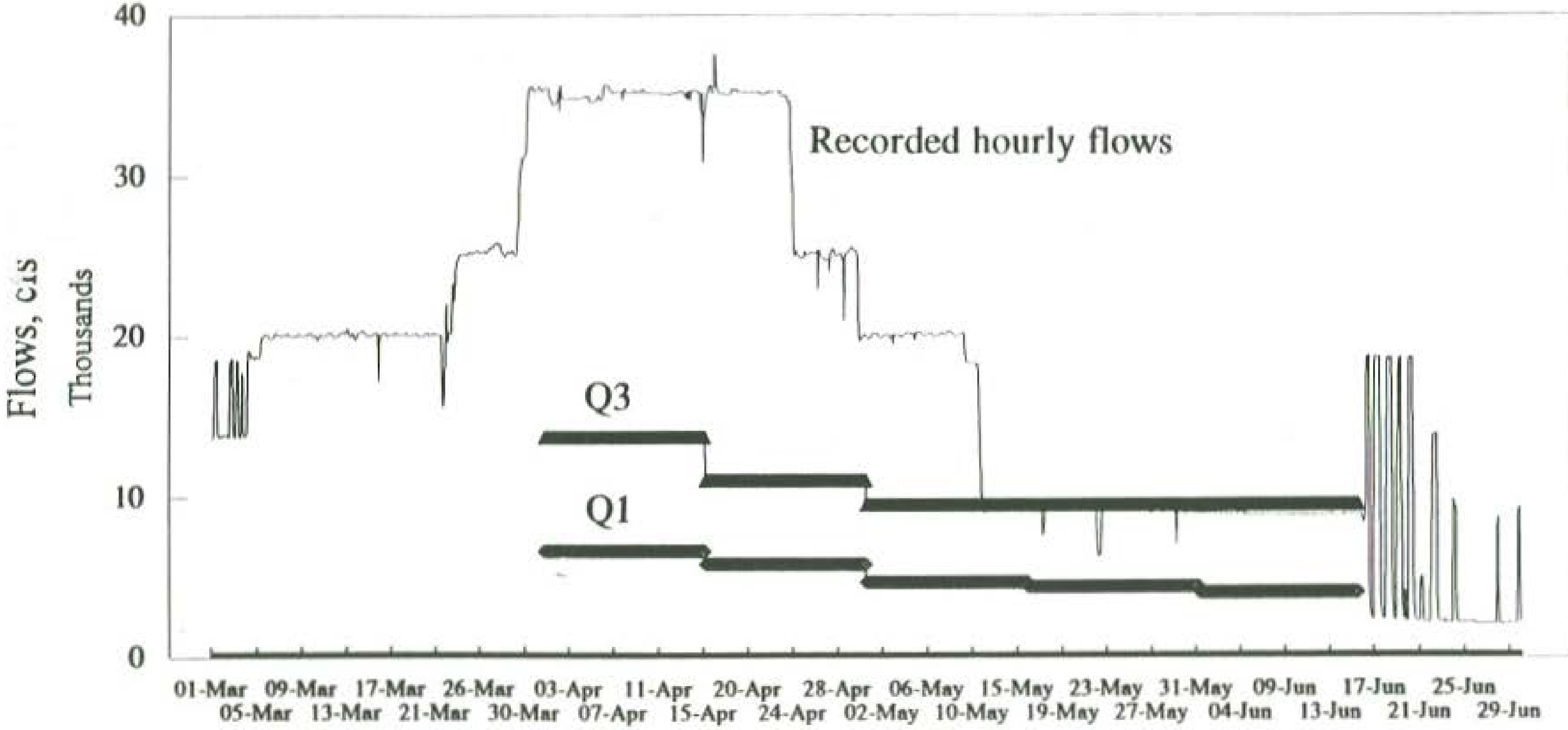

Figure 36. Hourly flows of the Roanoke River at Roanoke Rapids, 1 March to 30 June 1993.

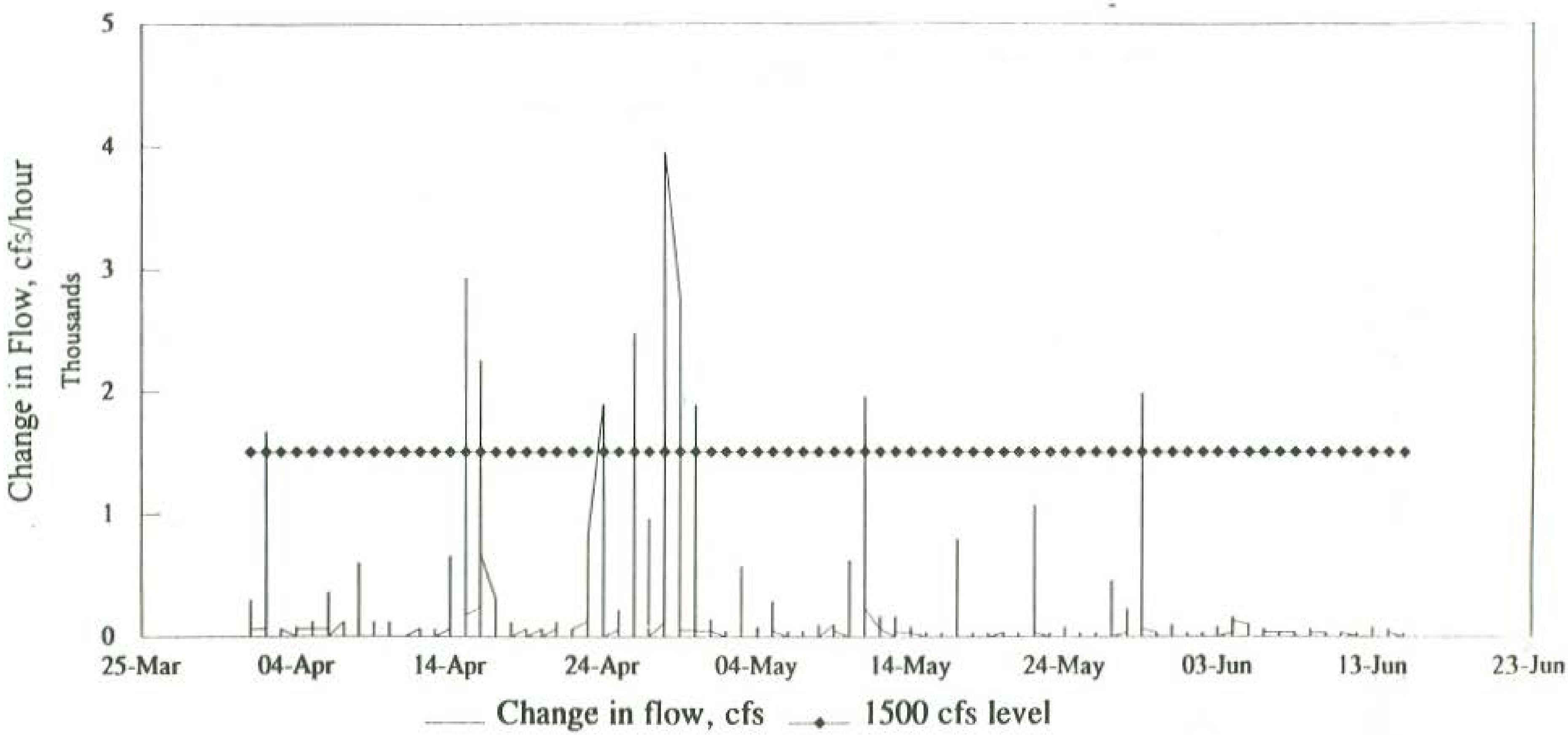

Figure 37. Absolute value of hourly differences in flow (cfs) of the Roanoke River downstream of Roanoke Rapids Dam, 1 April through 15 June 1993.

Kerr Reservoir Operation

Max Grimes

To fully understand the basic operation of Roanoke River reservoir projects that are located above the striped bass spawning grounds, one should read page 17 of the 1988-1989 report (Rulifson and Manooch 1990a). The interim operation plan (the Negotiated Flow Regime) has been used since 1988 as the instrument for water releases for striped bass. At the beginning of the flow augmentation period on 1 April, elevations in feet mean sea level (ft., msl) at John H. Kerr Reservoir, Gaston Lake, and Roanoke Rapids Lake during the past three years were:

	Kerr elevation (ft. msl) on 1 April		
Reservoir	1991	1992	1993
John H. Kerr Reservoir	305.7	301.0	316.4
Gaston Lake	200.0	200.0	200.3
Roanoke Rapids Lake	130.0	131.5	130.9

Periods of heavy rainfall prior to or in April during these past three years caused peak elevations at John Kerr Reservoir of 308.9 ft. msl on 3 April 1991 (Figure 38); 306.2 ft. msl on 26 April 1992 (Figure 39); and 316.6 ft. msl on 30 April 1993 (Figure 40). Discharges from the Roanoke Rapids Dam exceeded the upper flow target when flood control releases were made on the following dates in 1991, 1992, and 1993:

Flood control releases	Dates exceeding upper flow target		
(cfs)	1991	1992	1993
35,000	-	-	1-23 April
25,000	-	-	24-30 April
20,000	1-20 April	22 April - 5 May 10-15 June	30 April - 11 May -
15,000	21 April 15 June	8-9 June -	- -
Total no. of days	22	22	41

Results from operations during the 1991, 1992, and 1993 fish flow season using the Negotiated Flow Regime are shown in Table 26.

The average flow of the Roanoke River below Roanoke Rapids Dam at the Roanoke Rapids gage for the spawning window of 1 April - 15 June was 19,870 cfs in 1993, and 10,640 cfs and 12,100 cfs for the 1992 and 1991 spawning seasons, respectively.

It is estimated that the annual revenue loss to Virginia Power to operate Gaston and Roanoke Rapids projects for the benefit of fish spawning in 1991 alone was between 2 and 3 million dollars, not counting other losses such as being restricted to a 1,500 cfs flow differential per hour during the fish season (Note: The dollar amount was solely computed by the author and has not been authenticated by Virginia Power.) The preceding is presented to give Virginia Power credit for their cooperative efforts to enhance the striped bass population in the lower Roanoke River.

Table 26. Results of reservoir operations for 1991-1993 using the Negotiated Flow Regime (Corps calculations).

Fish flow dates	Upper flow target (cfs)	Lower flow target (cfs)	No. days above upper target (±10%)			No. days within upper & lower target (absolute)			No. days within upper & lower target of flows (±10%)		
			1991	1992	1993	1991	1992	1993	1991	1992	1993
01-15 April	13,700	6,600	15	0	15	0	7	0	0	8	0
16-30 April	11,000	5,800	5	8	15	9	0	0	9	0	0
01-15 May	9,500	4,700	0	4	10	5	10	3	15	10	4
16-31 May	9,500	4,400	0	0	0	14	6	16	16	16	16
01-15 June	9,500	4,000	1	7	0	12	7	15	14	7	15
Total			21	19	40	40	30	34	54	41	35
Percentage			28 %	25 %	53 %	53 %	39 %	45 %	71 %	54 %	46 %

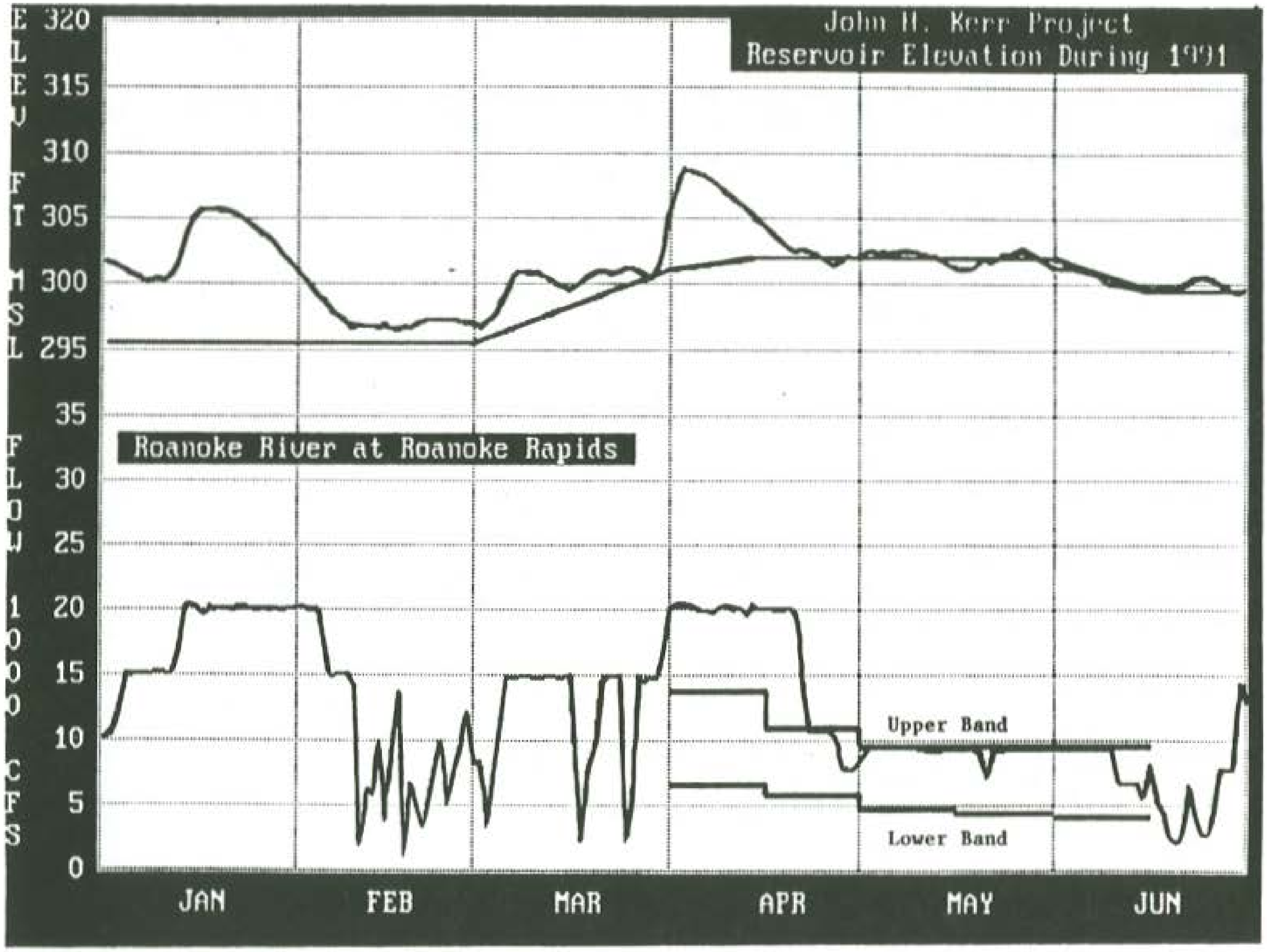

Figure 38. Elevation (ft, msl) of John H. Kerr Reservoir and instream flow (cfs x 1,000) of the Roanoke River downstream of Roanoke Rapids Dam, for the period January - June 1991.

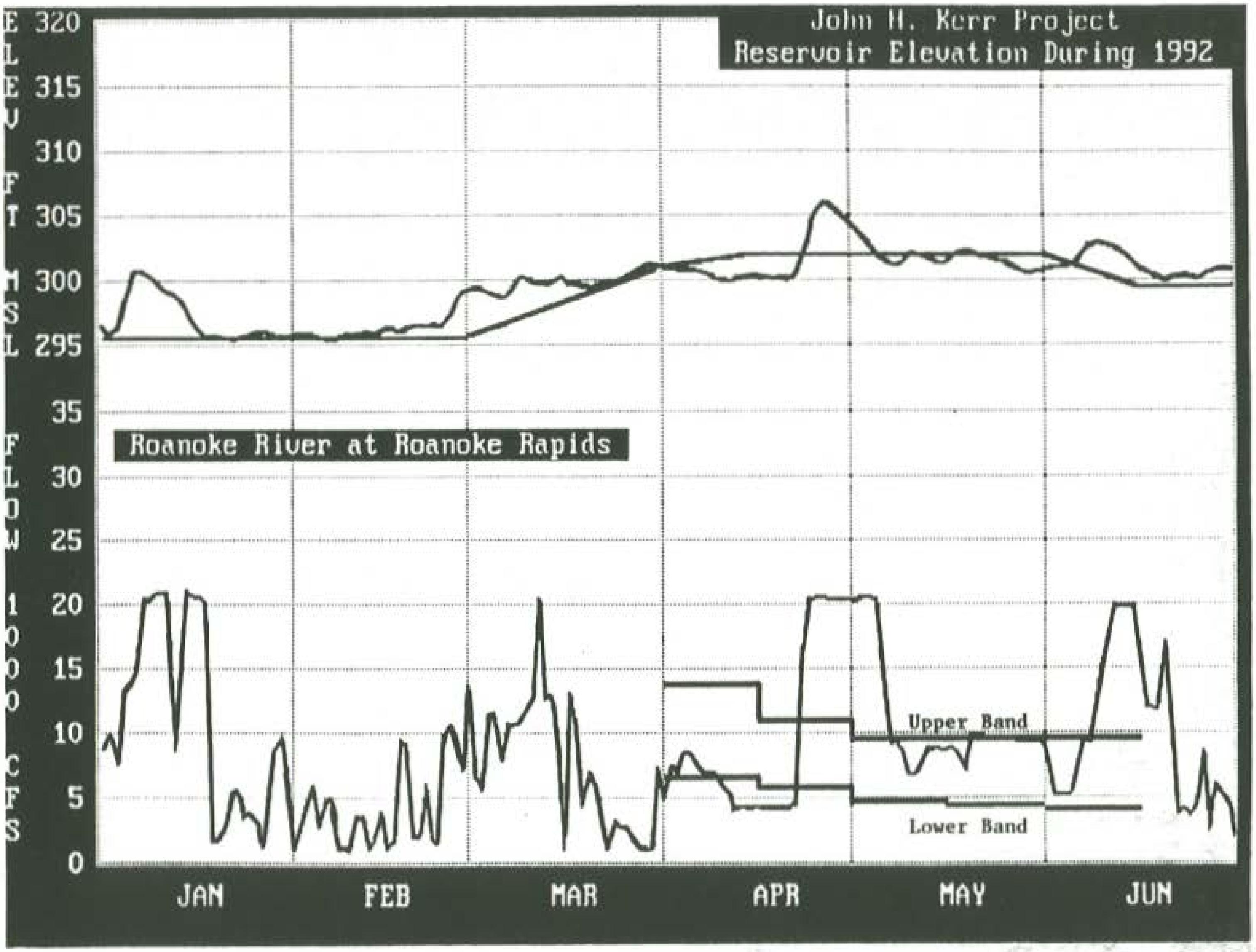

Figure 39. Elevation (ft, msl) of John H. Kerr Reservoir and instream flow (cfs x 1,000) of the Roanoke River downstream of Roanoke Rapids Dam, for the period January - June 1992.

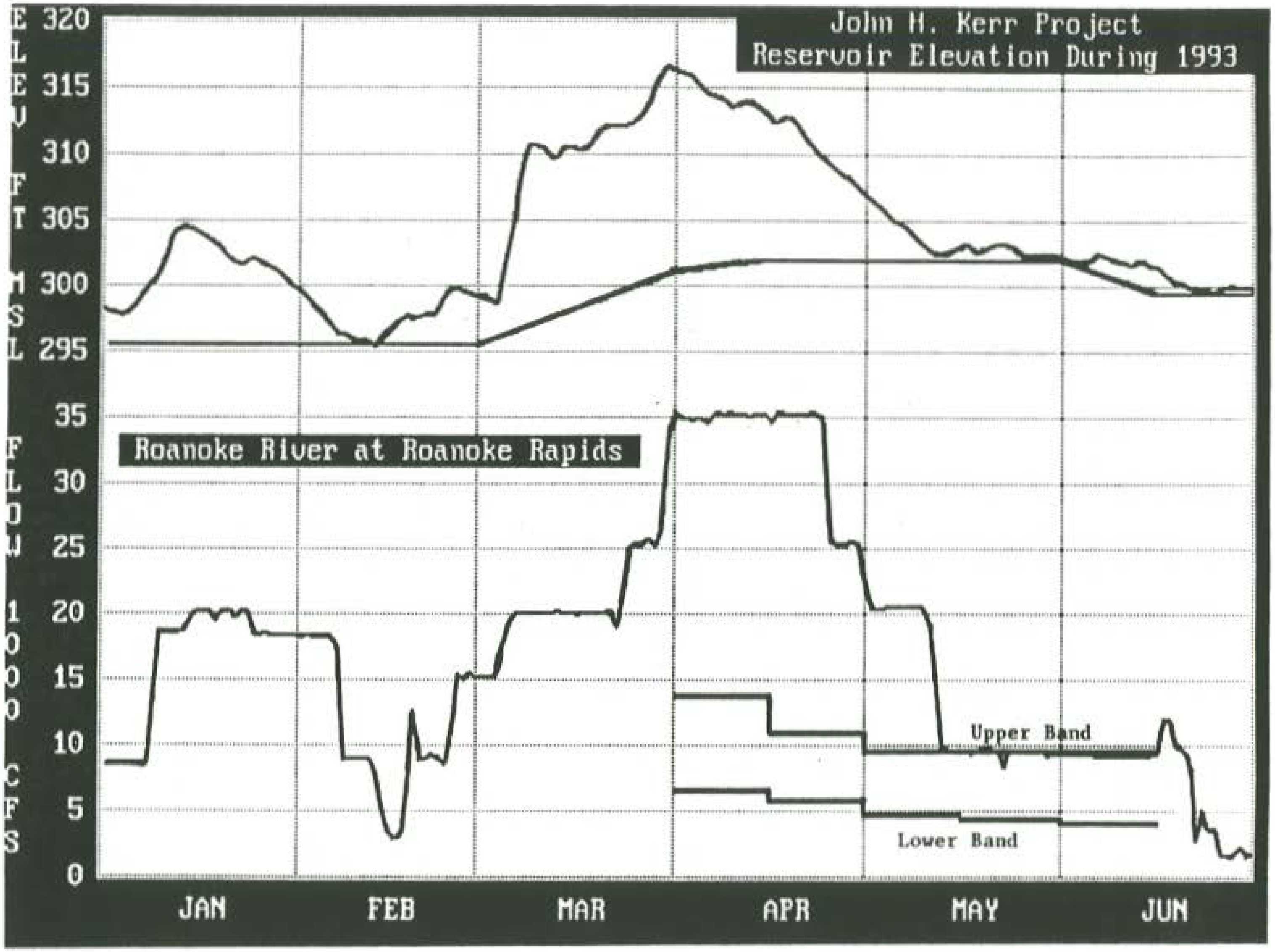

Figure 40. Elevation (ft, msl) of John H. Kerr Reservoir and instream flow (cfs x 1,000) of the Roanoke River downstream of Roanoke Rapids Dam, for the period January - June 1993.

Hourly and Mean Flows

Charles S. Manooch, III

1991

Roanoke River water flows were somewhat more moderate during the spring of 1991 (Figure 24; Tables 27 and 28) than they were during 1989 and 1990, but were much higher than during the spring of 1988 (Rulifson and Manooch 1990a; 1991). Mean water flow for the period 1 March - 30 June was 11,332 cfs (Table 27) and was 12,004 cfs for the Negotiated Period, 1 April - 15 June (Table 25). By comparison, the mean flows for the Negotiated Period during the springs of 1988, 1989, and 1990 were 5,669 cfs, 13,712 cfs, and 14,283 cfs, respectively (Rulifson and Manooch 1990a; 1991). Overall, 40 days (53%) had mean daily flows that were within the upper and lower flow boundaries recommended by the Committee for the Negotiated Period (Table 14). This compares with 53 days (70%) for 1988, 33 days (43%) during 1989, and 20 days (26%) for 1990.

In terms of hourly data, only 32% of the hourly flows from 1 March - 30 June 1991 were within the historical Q_1-Q_3 boundaries identified by the Committee (Table 27), whereas nearly 66% of hourly flows were within the Negotiated Period flow boundaries (Table 28). Approximately 56% of the hourly flows exceeded the upper flow boundary for the entire period, whereas only 33% exceeded the upper boundary for the Negotiated Period (Tables 27 and 28).

The Committee has recommended that water flows not change more than 1,500 cfs during any hour from 1 April - 15 June each year (Manooch and Rulifson 1989). Flows were relatively stable during 1991 (Figure 25; Tables 29 and 30) as they have been since the Committee expressed concern over drastically fluctuating water flows during the striped bass spawning season. Only 8 of 1,824 (0.4%) hours had water fluctuations that exceeded 1,500 cfs (Table 30).

The trend in water flow during the spring of 1991 appears to be more typical of historical springtime flows than those observed for 1989 and 1990. That is, flows were relatively high during early spring and generally trended downward during the striped bass spawning season. One area of concern, however, and one certainly anticipated during moderately high and moderately low flow years, is what happens when flows approximate the upper or lower flow boundaries for extended periods of time. That is exactly what occurred in 1991. From 1 May until 10 June (essentially 40 days), flows were very near the upper boundary, 9,500 cfs. It should be noted that the upper flow boundary of 9,500 cfs, which was negotiated with the Corps of Engineers and Virginia Power Co., was generally higher than the historical Q_3 (75% quartile) from late May until mid-June.

1992

Water flows were more moderate overall, yet more erratic on a weekly or biweekly basis during the spring of 1992 (Figure 29; Tables 31-32) than they were during 1991. Mean flow for the full period, 1 March - 30 June was 9,358 cfs (Table 31) and was 10,649 cfs for the Negotiated Period, 1 April - 15 June (Table 29). Overall, 30 days (39%) had mean daily flows that were within the flow boundaries recommended by the Committee for the Negotiated Period (Table 26).

Hourly data (Figure 30) revealed that only 32% of the hourly flows were within the Q_1 - Q_3 boundaries for the full period (Table 31), whereas approximately 45% of the hourly flows were within the flow boundaries for the abbreviated time period (Table 32).

Approximately 38% of the hourly flows exceeded the upper flow boundary for both the full and Negotiated periods. Over 30% of the hourly flows were less than the lower boundary for the full period compared with only 17% for the Negotiated Period (Tables 31-32).

Although mean flows were relatively erratic during 1992 based on weekly or biweekly intervals, hourly flows varied less than the recommended 1,500 cfs per hour 90% of the time from 1 March - 30 June (Table 33). This percentage is less than that recorded for 1991 and 1993.

The trend in water flow during the spring of 1992 appears to be less typical of springtime flows than those of 1991, or as discussed later, for 1993. Reference to Tables 31 and 32 mean flows reveals no consistent downward trend as is usually seen from April through June in the natural (pre-impoundment) flow pattern.

1993

Roanoke River early springtime flows were very high during 1993 (Figure 35; Tables 35-36). Mean flow from 1 March - 30 June was 18,568 cfs (Table 35), whereas the mean flow for the abbreviated period was somewhat higher, 19,863 cfs (Table 36). Overall, 34 days (45%) had mean daily flows that were within the upper and lower flow boundaries (Q_1 - Q_3) recommended by the Committee for the Negotiated Period (Table 26).

Only 16% of the hourly flows (Figure 36) were within the flow boundaries for the full period, compared with 46% for the Negotiated time interval. Approximately 76% of the hourly flows exceeded the upper boundary for the full period, whereas about 54% exceeded the boundary from 1 April - 15 June (Tables 35-36).

The recommended hourly variation in flow (less than 1,500 cfs) was observed 97% of the time from 1 March - 30 June (Table 37). Most of the 3% non-compliance was recorded from 14 June - 30 June, essentially outside of the Negotiated Period. Within the Negotiated Period the amount of time in which 1,500 cfs was exceeded was 0.8% (Table 38)..

Although flows were very high during the early spring of 1993, exceeding 30,000 cfs for four consecutive weeks in March and April (Tables 35-36), a general downward trend in the flow pattern was observed from early April through June. Flows were moderate from the middle of May through June.

Table 27. Weekly summaries for 1991 hourly flows using Table 13 Q_1-Q_3 boundaries, full period.

Week	Dates	Total # hours	# hours $<Q_1$	% hours $<Q_1$	# hours (Q_1-Q_3)	% hours (Q_1-Q_3)	# hours $>Q_3$	% hours $>Q_3$	Mean flow cfs	Std flow cfs	Mean abs hr diff
1	01 Mar-07 Mar	168	51	30.4	11	6.5	106	63.1	10,402	5,874	627
2	08 Mar-14 Mar	168	.	.	168	100.0	.	.	14,845	43	9
3	15 Mar-21 Mar	168	49	29.2	41	24.4	78	46.4	10,223	5,518	848
4	22 Mar-28 Mar	168	38	22.6	9	5.4	121	72.0	11,697	5,551	361
5	29 Mar-04 Apr	168	.	.	.	.	168	100.0	19,004	2,216	73
6	05 Apr-11 Apr	168	.	.	.	.	168	100.0	20,030	272	44
7	12 Apr-25 Apr	168	.	.	.	.	168	100.0	20,048	520	122
8	19 Apr-25 Apr	168	.	.	41	24.4	127	75.6	13,936	3,999	103
9	26 Apr-02 May	168	.	.	115	68.4	53	31.5	8,686	1,027	92
10	03 May-9 May	168	.	.	.	.	168	100.0	9,494	66	34
11	10 May-16 May	168	.	.	157	93.4	11	6.5	9,269	113	37
12	17 May-23 May	168	.	.	168	100.0	.	.	8,921	903	72
13	24 May-30 May	168	.	.	81	48.2	87	51.8	9,309	59	21
14	31 May-06 Jun	168	.	.	.	.	168	100.0	9,310	50	14
15	07 Jun-13 Jun	168	.	.	95	56.5	73	43.4	7,812	1,329	38
16	14 Jun-20 Jun	168	118	70.2	28	16.7	22	13.1	4,334	3,818	535
17	21 Jun-27 Jun	168	92	54.8	25	14.9	51	30.4	5,205	4,076	742
18	28 Jun-30 Jun	72	9	12.5	6	8.3	57	79.2	11,596	4,241	525
19	============	.	.	.	.	.	.	.	.	.	.
20	01 Mar-30 Jun	2,928	357	12.2	945	32.3	1,626	55.5	11,332	5,447	229

Table 28. Bi-weekly summaries for 1991 hourly flows using Table 13 Q_1 - Q_3 boundaries, Negotiated Period.

Week	Dates	Total # Hours	# Hours <Q_1	% Hours <Q_1	# Hours (Q_1-Q_3)	% Hours (Q_1-Q_3)	# Hours >Q_3	% Hours >Q_3	Mean Flow CFS	Std Flow CFS	Mean Abs Hr DIFF
1	01 Apr-07 Apr	360	.	.	.	.	360	100.0	20,090	417	87
2	16 Apr-30 Apr	360	.	.	213	59.2	147	40.8	13,324	5,011	83
3	01 May-15 May	360	.	.	278	77.2	82	22.8	9,381	165	43
4	16 May-31 May	384	.	.	381	99.2	3	0.8	9,139	629	44
5	01 Jun-15 Jun	360	18	5.0	328	91.1	14	3.9	8,278	2,071	72
6	===========	.	.	.	.	.	.	.	.	.	.
7	01 Apr-15 Jun	1,824	18	1.0	1,200	65.8	606	33.2	12,004	5,000	65

Table 29. Weekly summaries for 1991 based on absolute value of hourly variation, full period, Q_1-Q_3.

Week	Dates	Total # hours	# hours <=1,500	% hours <=1,500	# hours >1,500	% hours >1,500
1	01 Mar-07 Mar	167	146	87.4	21	12.6
2	08 Mar-14 Mar	168	168	100.0	0	0.0
3	15 Mar-21 Mar	168	135	80.4	33	19.6
4	22 Mar-28 Mar	168	157	93.5	11	6.5
5	29 Mar-04 Apr	168	167	99.4	1	0.6
6	05 Apr-11 Apr	168	168	100.0	0	0.0
7	12 Apr-18 Apr	168	163	97.0	5	3.0
8	19 Apr-25 Apr	168	167	99.4	1	0.6
9	26 Apr-02 May	168	168	100.0	0	0.0
10	03 May-09 May	168	168	100.0	0	0.0
11	10 May-16 May	168	168	100.0	0	0.0
12	17 May-23 May	168	168	100.0	0	0.0
13	24 May-30 May	168	168	100.0	0	0.0
14	31 May-06 Jun	168	168	100.0	0	0.0
15	07 Jun-13 Jun	168	168	100.0	0	0.0
16	14 Jun-20 Jun	168	150	89.3	18	10.7
17	21 Jun-27 Jun	168	135	80.4	33	19.6
18	28 Jun-30 Jun	72	66	91.7	6	8.3
19	===========	.	.	.	.	.
7	01 Mar-30 Jun	2,927	2,798	95.6	129	4.4

Table 30. Bi-weekly summaries for 1991 based on absolute value of hourly variation, Negotiated Period Q_1-Q_3.

Week	Dates	Total # hours	# hours <=1,500	% hours <=1,500	# hours >1,500	% hours >1,500
1	01 Apr-15 Apr	360	355	98.6	5	1.4
2	16 Apr-30 Apr	360	359	99.7	1	0.3
3	01 May-15 May	360	360	100.0	0	0.0
4	16 May-31 May	384	384	100.0	0	0.0
5	01 Jun-15 Jun	360	358	99.4	2	0.6
6	===========					
7	01 Apr-15 Jun	1,824	1,816	99.6	8	0.4

Table 31. Weekly summaries for 1992 hourly flows using Table 13 Q_1 - Q_3 boundaries, full period.

Week Dates	Total # hours	# hours <Q_1	% hours <Q_1	# hours (Q_1-Q_3)	% hours (Q_1-Q_3)	# hours >Q_3	% hours >Q_3	Mean flow cfs	Std flow cfs	Mean abs hr diff
01 Mar-07 Mar	168	64	38.10	32	19.05	72	42.86	9,161	6,142	2,116
08 Mar-14 Mar	168	47	27.98	47	27.98	74	44.05	12,904	7,068	1,759
15 Mar-21 Mar	168	110	65.48	23	13.69	35	20.83	6,361	6,789	1,499
22 Mar-28 Mar	168	160	95.24	8	4.76	0	0.00	1,950	2,174	573
29 Mar-04 Apr	168	49	29.17	113	67.26	6	3.57	6,393	3,934	461
05 Apr-11 Apr	168	72	42.86	96	57.14	0	0.00	6,283	1,149	62
12 Apr-18 Apr	168	168	100.00	0	0.00	0	0.00	4,227	33	8
19 Apr-25 Apr	168	69	41.07	6	3.57	93	55.36	12,800	7,710	122
26 Apr-02 May	168	0	0.00	0	0.00	168	100.00	20,403	247	65
03 May-09 May	168	0	0.00	56	33.33	112	66.67	12,686	5,667	123
10 May-16 May	168	0	0.00	168	100.00	0	0.00	8,335	830	37
17 May-23 May	168	0	0.00	141	83.93	27	16.07	9,110	1,154	69
24 May-30 May	168	0	0.00	76	45.24	92	54.76	9,416	150	13
31 May-06 Jun	168	0	0.00	114	67.86	54	32.14	6,613	1,855	60
07 Jun-13 Jun	168	0	0.00	0	0.00	168	100.00	16,157	4,220	99
14 Jun-20 Jun	168	10	5.95	4	2.38	154	91.67	13,957	4,957	467
21 Jun-27 Jun	168	96	57.14	33	19.64	39	23.21	4,656	3,368	903
28 Jun-30 Jun	72	47	65.28	11	15.28	14	19.44	3,939	3,147	1,351
01 Mar-30 Jun	2,298	892	30.46	928	31.69	1,108	37.84	9,358	6,279	517

Table 32. Bi-weekly summaries for 1992 hourly flows using Table 13 Q_1-Q_3 boundaries, Negotiated Period.

Week Dates	Total # hours	# hours $<Q_1$	% hours $<Q_1$	# hours (Q_1-Q_3)	% hours (Q_1-Q_3)	# hours $>Q_3$	% hours $>Q_3$	Mean flow cfs	Std flow cfs	Mean abs hr diff
01 Apr-15 Apr	360	170	47.22	190	52.78	0	0.00	6,149	1,613	69
16 Apr-30 Apr	360	141	39.17	7	1.94	212	58.89	13,615	7,814	70
01 May-15 May	360	0	0.00	249	69.17	111	30.83	11,945	5,532	92
16 May-31 May	384	0	0.00	188	48.96	197	51.30	9,199	852	47
01 Jun-15 Jun	360	0	0.00	179	49.72	181	50.28	12,435	6,042	88
01 Apr-15 Jun	1,824	311	17.05	813	44.52	701	38.43	10,649	5,753	73

Table 33. Weekly summaries for 1992 based on absolute value of hourly variation, full period, Q_1-Q_3.

Week Dates	Total # hours	# hours <=1,500	% hours <=1,500	# hours >1,500	% hours >1,500
01 May-07 Mar	167	93	55.69	74	44.31
08 Mar-14 Mar	168	108	64.29	60	35.71
15 Mar-21 Mar	168	119	70.83	49	29.17
22 Mar-28 Mar	168	147	87.50	21	12.50
29 Mar-04 Apr	168	156	92.86	12	7.14
05 Apr-11 Apr	168	168	100.0	0	0.00
12 Apr-18 Apr	168	168	100.0	0	0.00
19 Apr-25 Apr	168	165	98.21	3	1.79
26 Apr-02 May	168	166	98.81	2	1.19
03 May-09 May	168	165	98.21	3	1.79
10 May-16 May	168	168	100.00	0	0.00
17 May-23 May	168	168	100.0	0	0.00
24 May-30 May	168	168	100.00	0	0.00
31 May-06 Jun	168	168	100.00	0	0.00
07 Jun-13 Jun	168	166	98.81	2	1.19
14 Jun-20 Jun	168	154	91.67	14	8.33
21 Jun-27 Jun	168	127	75.60	41	24.40
28 Jun-30 Jun	72	55	76.39	17	23.61
01 Mar-30 Jun	2,927	2,629	89.82	298	10.18

Table 34. Bi-weekly summaries for 1992 based on absolute value of hourly variation, Negotiated Period Q_1-Q_3.

Week Dates	Total # hours	# hours <=1,500	% hours <=1,500	# hours >1,500	% hours >1,500
01 Apr-15 Apr	360	360	100.0	0	0.0
16 Apr-30 Apr	360	357	99.2	3	0.8
01 May-15 May	360	355	98.6	5	1.4
16 May-31 May	384	384	100.0	0	0.0
01 Jun-15 Jun	360	358	99.4	2	0.6
==========					
01 Apr-15 Jun	1,824	1,814	99.5	0.5	

Table 35. Weekly summaries for 1993 hourly flows using recommended Q_1-Q_3 boundaries.

Week	Dates	Total # hours	# hours $<Q_1$	% hours $<Q_1$	# hours $(Q_1\text{-}Q_3)$	% hours $(Q_1\text{-}Q_3)$	# hours $>Q_3$	% hours $>Q_3$	Mean flow cfs	Std flow cfs	Mean abs hr diff
01 Mar-07 Mar		168	0	0.00	0	0.00	72	42.86	17,514	736	285
08 Mar-14 Mar		168	0	0.00	0	0.00	168	100.00	20,108	38	31
15 Mar-21 Mar		168	0	0.00	0	0.00	168	100.00	20,102	281	54
22 Mar-28 Mar		168	0	0.00	0	0.00	168	100.00	23,972	407	152
29 Mar-04 Apr		168	0	0.00	0	0.00	168	100.00	33,696	286	117
05 Apr-11 Apr		168	0	0.00	0	0.00	168	100.00	35,138	78	35
12 Apr-18 Apr		168	0	0.00	0	0.00	168	100.00	35,120	368	135
19 Apr-25 Apr		168	0	0.00	0	0.00	168	100.00	32,408	256	91
26 Apr-02 May		168	0	0.00	0	0.00	168	100.00	23,085	484	155
03 May-09 May		168	0	0.00	0	0.00	168	100.00	20,119	67	35
10 May-16 May		168	0	0.00	28	16.67	140	83.33	11,287	243	84
17 May-23 May		168	0	0.00	166	98.81	2	1.19	9,079	190	63
24 May-30 May		168	0	0.00	162	96.43	6	3.57	9,134	200	45
31 May-06 Jun		168	0	0.00	95	56.55	73	43.45	8,961	30	18
07 Jun-13 Jun		168	0	0.00	0	0.00	168	100.00	8,856	16	11
14 Jun-20 Jun		168	0	0.00	0	0.00	168	100.00	10,341	2,053	930
21 Jun-27 Jun		168	80	47.62	21	12.50	67	39.88	3,487	1,005	313
28 Jun-30 Jun		72	64	88.89	1	1.39	7	9.72	2,827	943	394
01 Mar-30 Jun		2,928	144	4.92	473	16.15	2,215	75.65	18,568	671	156

Table 36. Bi-weekly summaries for 1993 hourly flows using Table 13 Q_1-Q_3 boundaries, Negotiated Period.

Week Dates	Total # hours	# hours $<Q_1$	% hours $<Q_1$	# hours (Q_1-Q_3)	% hours (Q_1-Q_3)	# hours $>Q_3$	% hours $>Q_3$	Mean flow cfs	Std flow cfs	Mean abs hr diff
01 Apr-15 Apr	360	0	0.00	0	0.00	360	100.00	35,031	411	77
16 Apr-30 Apr	360	0	0.00	0	0.00	360	100.00	30,280	5,385	134
01 May-15 May	360	0	0.00	98	27.22	262	72.78	16,712	4,847	58
16 May-31 May	384	0	0.00	383	99.74	1	0.26	9,109	482	49
01 Jun-15 Jun	360	0	0.00	360	100.00	0	0.00	8,899	75	14
01 Apr-15 Jun	1,824	0	0.00	841	46.11	983	53.89	19,863	11,283	66

Table 37. Weekly summaries for 1993 based on absolute value of hourly variation, full period Q_1-Q_3.

Week Dates	Total # hours	# hours <=1,500	% hours <=1,500	# hours >1,500	% hours >1,500
01 Mar-07 Mar	167	156	93.41	11	6.59
08 Mar-14 Mar	168	168	100.00	0	0.00
15 Mar-21 Mar	168	166	98.81	2	1.19
22 Mar-28 Mar	168	164	97.62	4	2.38
29 Mar-04 Apr	168	165	98.21	3	1.79
05 Apr-11 Apr	168	168	100.0	0	0.00
12 Apr-18 Apr	168	165	98.21	3	1.79
19 Apr-25 Apr	168	166	98.81	2	1.19
26 Apr-02 May	168	163	97.02	5	2.98
03 May-09 May	168	168	100.0	0	0.00
10 May-16 May	168	167	99.40	1	0.60
17 May-23 May	168	168	100.00	0	0.00
24 May-30 May	168	166	98.81	2	1.19
31 May-06 Jun	168	168	100.00	0	0.00
07 Jun-13 Jun	168	168	100.0	0	0.00
14 Jun-20 Jun	168	137	81.55	31	18.45
21 Jun-27 Jun	168	157	93.45	11	6.55
28 Jun-30 Jun	72	65	88.89	8	11.11
01 Mar-30 Jun	2,927	2,844	97.16	83	2.84

Table 38. Bi-weekly summaries for 1993 based on absolute value of hourly variation, Negotiated Period Q_1-Q_3.

Week Dates	Total # hours	# hours <=1,500	% hours <=1,500	# hours >1,500	% hours >1,500
01 Apr-15 Apr	360	357	99.2	3	0.8
16 Apr-30 Apr	360	352	97.8	8	2.2
01 May-15 May	360	359	99.7	1	0.3
16 May-31 May	384	382	99.5	2	0.5
01 Jun-15 Jun	360	360	100.0	0	0.0
==========					
01 Apr-15 Jun	1,824	1,810	99.2	14	0.8

Roanoke River Time Series Analysis for 1991

L.H. Zincone, Jr.

Introduction

Just as in the two most recent reports, this section will report on ARIMA and autoregression analysis of the flow in the spring of the reporting year, in this instance, 1991. In the interest of saving space, the reader is referred to the 1990 report for an explanation of the methodology. Briefly, ARIMA analysis relates flow to past values of flow and past value of the (actual-forecasted) flow. Autoregression analysis is similar to analysis of variance with date (for trend), months, days of the week, and (for hourly data) the hours of the day. These models describe what, if any, consistent pattern the flows followed. Models were estimated for both the entire spawning period (1 March to 30 June) and the Negotiated Period (1 April to 15 June). The entire spawning window will be referred to as the "entire period" or the "long period." The other will be called the "short period" or the "Negotiated Period."

ARIMA Analysis

Table 39 presents the results of the ARIMA analysis for both the short and long periods. The coefficient values, associated t values and level of differencing for the entire period are given in the left panel while those for the short period are shown in the right panel. A glance at a plot of the flow for 1991 will clearly show that the data did not fluctuate around a constant mean. From 1 March to 30 March, the average flow was 12,056 cfs (sd=4,429). The average flow from 31 March to 20 April was 20,042 cfs (sd=211). The flow then fell by almost half to an average flow of 11,400 cfs (sd=1,673) for the 21 April to 26 April period. Finally, from 27 April to 15 June, the average flow was 8,856 cfs (sd=977). Because of these fluctuations, we took the first difference of the data to attain stationarity in the mean.

Table 39. ARIMA coefficients and t values for ARIMA models for short and long period of analysis, 1991.

Variable	Value	t ratio	Value	t ratio
Differencing	1		1	
AR2	-0.246	-2.74		
AR8	0.235	2.58	RANDOM	WALK
Q	5.6		6.01	
P>Q	0.23		0.42	

The model for the entire 1991 spawning window contained autoregressive terms for lags 2 and 8. The AR2 coefficient is negative and the AR8 coefficient positive. This model yielded random residuals as shown by the value of Q and the probability of a larger Q (0.23). Despite the fact that only two parameters were necessary to randomize the model residuals, the interaction of the differencing and the lags of the two parameters yield the following expanded equation which describes the time path of the flows:

$$y_t = y_{t-1} - 0.246(y_{t-2} - y_{t-3}) + 0.235(y_{t-8} - y_{t-9})$$

where y represents flow and t indexes time. Hence, the major determinants of the flow on a given day t are the flow the day before, the flow two and three days before, and the flows 8 and 9 days before day t. It is difficult, if not impossible, to relate the pattern described here to any behavior related to power generation or anything else. It is my interpretation that the excessive rains during the early part of the years masked any flow pattern which might have been related to power generation or anything else.

Autoregression Analysis

Table 40 shows the results of the estimation of the autoregression model on the daily data for the entire spawning window. The first column shows the variable name, the second the estimated value of the coefficient, the third the standard error of the coefficient. The last two columns show the value of the t ratio and the approximate probability of observing a larger t value by chance. Thus, if the probability is less than or equal to 0.05, the coefficient is significantly different from zero at the five percent level.

Table 40. Coefficients of the model of daily data 1 March - 30 June 1991 (R^2=0.84).

Variable	B Value	Std. Error	T Ratio	Approx. Prob.
INTERCPT	882,449.607	526,882.327	1.675	0.0969
DATE	-76.2209	45.89055	-1.661	0.0997
MON	-24.4933	596.233	-0.041	0.9673
TUES	888.300	936.287	0.949	0.3449
WED	1,306.945	1,103.213	1.185	0.2388
THURS	1,231.439	1,096.091	1.123	0.2637
FRI	1,160.171	921.309	1.259	0.2107
SAT	1,036.296	577.654	1.794	0.0756
MAR	-1,828.192	4,022.492	-0.454	0.6504
APR	2,711.289	3,038.652	0.892	0.3743
MAY	470.759	1,923.930	0.245	0.8072
A(1)	-0.94743	0.09	-10.450	0.0001
A(2)	0.1643	0.0912	0.802	0.0743
A(8)	0.3054	0.099	-3.060	0.0028
A(9)	0.3486	0.101	3.429	0.0009

As in the other reports, the coefficient of the date measures linear trend, those of the days of the week measure whether the mean daily flow is significantly higher or lower than that of Sunday, the base day. The coefficients of the months measure whether the monthly average flow is significantly different from that of the base month, June. Finally, the autoregressive parameters are given. As can be seen from Table 40, none of the individual coefficients other than the autoregressive coefficients are significantly different from zero. The 84% of the variation which is explained by the model is explained entirely by the autoregressive terms.

Table 41 shows the coefficients of the autoregression model for the negotiated or short period from 1 April to 15 June. While there are some differences in the results between the periods, the overall pattern remains much the same. Flows on Mondays were significantly below those on Sundays and coefficient of the trend variable (DATE) is significantly negative. This is not surprising given how the average flow changed during the period. As in earlier reports, one would expect to find average flows on weekdays higher than those on weekends because of the need for peak power generation and the desire to stabilize the level of the lakes for recreational use on weekends. This is clearly not the case in 1991 and I would suggest these patterns did not appear because it was necessary to allow the water to drain from the lake, regardless of the need for power.

Table 41. Coefficients of the model of daily data 1 April - 15 June 1991 (R^2=0.97).

Variable	B Value	Std. Error	T Ratio	Approx. Prob.
INTERCPT	2,418,591.87	608,201.108	3.977	0.0002
DATE	-210.044	53.09659	-3.956	0.0002
MON	-613.374	224.240	-2.735	0.0081
TUES	-172.984	284.494	-0.608	0.5453
WED	2.309	314.447	0.007	0.9942
THURS	242.781	314.486	0.772	0.4430
FRI	281.606	292.171	0.964	0.3388
SAT	337.8244	224.052	1.508	0.1366
APR	-1,819.61	1,379.303	-1.319	0.1919
MAY	-917.493	978.022	-0.938	0.3518
A(1)	-0.964	0.040	-24.069	0.0001
A(14)	0.283	0.138	2.050	0.0446

Table 42 shows the results of the analysis of the hourly flow data for the entire period of 1991. Again, the pattern is atypical of what one would expect to observe when the dam controlling the flow was being used for peaking power. In earlier reports, we have observed hourly flows significantly below that of the base hour (midnight) until the early morning. Around breakfast and shower time, flows increased and then increased again toward an eventual peak in the late afternoon and early evening. None of these patterns are present in these data. There are no daily, monthly, or hourly coefficients (except that for 4:00am) which are significantly different from zero. The autoregressive pattern is quite complex and defies interpretation.

Table 43 shows the results of the autoregression analysis of the hourly data from the Negotiated Period. These results also show a significant downward trend which is caused by the fall in the average flow toward the last of April. In addition, the coefficients of hours 20 and 21 are significantly larger than zero, indicating that average flows at those times were higher than those of the midnight hour. Again, the pattern is not consistent with any previously observed behavior.

Conclusions

Results of the 1991 analyses are not consistent with those of earlier reports. One must, then, conclude that the extremely wet conditions of the early spring of 1991 resulted in so much water being stored that the outflow overwhelmed any pattern which might have been observed. What these results *are* consistent with, however, is the finding in the first report that bad spawning years are characterized by either very high or very low flows. Clearly, 1991 had atypically high flows and the resulting year class was the worst in recent memory.

Table 42. Coefficients of the model of hourly data 1 March - 30 June 1991 (R^2=0.98).

Variable	B Value	Std. Error	T Ratio	Approx. Prob.
INTERCPT	630,601.221	422,455.901	1.493	0.1356
DATE	-54.176	36.904	-1.468	0.1422
MON	-57.092	155.017	-0.368	0.7127
TUES	50.192	197.157	0.255	0.7991
WED	134.880	215.206	0.627	0.5309
THURS	93.056	213.557	0.436	0.6631
FRI	5.731	193.541	0.030	0.9764
SAT	5.752	147.446	0.039	0.9689
MAR	173.397	1,193.683	0.145	0.8845
APR	373.081	973.386	0.383	0.7015
MAY	107.526	684.161	0.157	0.8751
ONE	14.064	88.337	0.159	0.8735
TWO	-135.268	141.897	-0.953	0.3405
THREE	-278.921	181.692	-1.535	0.1249
FOUR	-410.390	211.829	-1.937	0.0528
FIVE	-450.788	238.075	-1.893	0.0584
SIX	-431.550	263.162	-1.640	0.1011
SEVEN	-297.373	284.520	-1.045	0.2960
EIGHT	-73.910	300.583	-0.246	0.8058
NINE	48.191	310.919	0.155	0.8768
TEN	114.178	317.273	0.360	0.7190
ELEVEN	110.384	321.107	0.344	0.7311
TWELVE	138.043	322.309	0.428	0.6685
THIRTEEN	366.908	320.924	1.143	0.2530
FOURTEEN	417.829	316.906	1.318	0.1875
FIFTEEN	436.619	310.364	1.407	0.1596
SIXTEEN	424.828	299.827	1.417	0.1566
SEVNTEEN	422.277	283.533	1.489	0.1365
EIGHTEEN	461.091	261.902	1.761	0.0784
NINETEEN	470.642	236.486	1.990	0.0467
TWENTY	577.867	209.809	2.754	0.0059
TWOONE	567.094	179.051	3.167	0.0016
TWOTWO	526.562	138.141	3.812	0.0001
TWOTHREE	191.504	81.56956	2.348	0.0190
A(1)	-1.404	0.01834146	-76.553	0.0001
A(2)	0.573	0.03047686	18.831	0.0001
A(3)	-0.144	0.0217811	-6.642	0.0001
A(6)	0.070	0.02194233	3.194	0.0014
A(7)	-0.020	0.03289287	-0.636	0.5249
A(8)	0.057	0.0332898	1.718	0.0858
A(9)	-0.127	0.02437108	-5.223	0.0001
A(11)	0.037	0.01599219	2.339	0.0194
A(13)	0.036	0.01373812	2.652	0.0080
A(16)	-0.056	0.01163589	-4.820	0.0001
A(19)	-0.071	0.02074904	-3.439	0.0006
A(20)	0.121	0.02280932	5.320	0.0001
A(22)	-0.085	0.01569803	-5.463	0.0001
A(24)	0.0236	0.01064526	2.220	0.0265

Table 43. Coefficients of the model of hourly data 1 April - 15 June 1991 (R^2=0.99).

Variable	B Value	Std. Error	T Ratio	Approx. Prob.
INTERCPT	1,695,752.58	679,803.87	2.494	0.0127
DATE	-146.964	59.38	-2.475	0.0134
MON	-129.304	75.64	-1.709	0.0875
TUES	-121.382	95.86	-1.266	0.2056
WED	-100.173	105.35	-0.951	0.3418
THURS	-66.289	105.33	-0.629	0.5292
FRI	-63.476	97.29	-0.652	0.5142
SAT	-10.383	75.59	-0.137	0.8908
ARP	-108.188	384.77	-0.281	0.7786
MAY	20.328	271.5	0.075	0.9403
ONE	86.594	66.2	1.308	0.1911
TWO	73.392	76.1	0.964	0.3350
THREE	48.717	83.1	0.586	0.5582
FOUR	11.138	89.9	0.124	0.9015
FIVE	-7.469	97.7	-0.076	0.9391
SIX	-13.251	104.855	-0.126	0.8994
SEVEN	-26.874	110.6	-0.243	0.8081
EIGHT	-36.029	115.53	-0.312	0.7552
NINE	-42.322	119.6	-0.354	0.7235
TEN	-42.754	122.73	-0.348	0.7276
ELEVEN	-91.481	124.87	-0.733	0.4639
TWELVE	-96.859	125.62	-0.771	0.4408
THIRTEEN	78.108	123.57	0.632	0.5274
FOURTEEN	115.360	120.07	0.961	0.3368
FIFTEEN	80.288	115.47	0.695	0.4870
SIXTEEN	114.994	109.82	1.047	0.2952
SEVNTEEN	173.174	103.19	1.678	0.0935
EIGHTEEN	180.690	95.40	1.894	0.0584
NINETEEN	168.491	85.90	1.961	0.0500
TWENTY	151.176	75.23	2.010	0.0446
TWOONE	139.281	64.94	2.144	0.0321
TWOTWO	85.873	53.20	1.614	0.1067
TWOTHREE	43.485	34.04	1.277	0.2016
A(1)	-1.278	0.02	-55.355	0.0001
A(2)	0.467	0.03	12.873	0.0001
A(3)	-0.281	0.02	-9.990	0.0001
A(5)	0.104	0.01	6.249	0.0001
A(11)	0.003	0.02	0.147	0.8834
A(12)	0.110	0.04	2.377	0.0175
A(13)	-0.141	0.06	-2.527	0.0116
A(14)	0.074	0.05	1.389	0.1651
A(15)	-0.068	0.04	-1.655	0.0982
A(17)	0.012	0.02	0.556	0.5780

Roanoke River Time Series Analysis for 1992

L.H. Zincone, Jr.

Introduction

The 1992 flow from the period of 1 March to 30 June can best be described as inconsistent in that during the middle of March (roughly 6-17) there was a large spike of high flows, reaching 20,000 cfs on at least one day. This was followed by a decline in the flows to the 1,000-3,000 cfs level from 17 to 28 March. At the beginning of the Negotiated Period from approximately 1 April to 22 April there was a period of flow which fluctuated around Q_1, with the flow during the earlier part of the period slightly above the lower Q_1 limit and that for the end of the period averaging approximately 28% below the Q_1 limit (9 April to 21 April). This period of low flow was followed by relatively high flows for the rest of the Negotiated Period. There were two times of extremely high flows separated by a time period where the flows fluctuated just at the upper Q_3 limit. The periods of high flows were from 22 April to 5 May 1992 and from 8 June to 19 June. During the first of these periods, daily flows averaged 19,600 cfs or approximately 88% higher than the recommended Q_3 limit for the period. During the second period of high flow, the flow was not as sustained at the 20,000 cfs level but nevertheless averaged approximately 17,000 cfs up to the end of the Negotiated Period on 15 June and approximately 16,000 if the days up to 19 June are counted (approximately 84% above Q_3 for the period as a whole). These flows were the results of major rain events in the watershed.

Table 44 shows two models which are adequate to describe the Negotiated Period. The difference between the two models is that the model shown in the first panel is additive while the other is multiplicative. The difference can be seen by comparing equations (1) and (2) below.

Table 44. Results of the 1992 ARIMA analysis showing the ARIMA coefficients and t values for models for the Negotiated Period.

Variable	Value	t Ratio	Lag
Differencing	1		
MU	66.19	0.34	0
AR1	0.37	3.79	1
AR13	-0.37	-3.56	13
Q	4.95		
P>Q	0.894		
MU	60.63	0.26	0
AR1	0.44	4.07	1
AR13	-0.42	-3.79	13
Q	5.08		
P>Q	0.886		

(1) $y_t = -0.63y_{t-1} + 0.37_{t-2} + 0.37(y_{t-13} - y_{t-14}) + 66.19$

(2) $y_t = 1.44y_{t-1} - 0.44y_{t-2} - 0.42(y_{t-13} - y_{t-14}) + 0.18(y_{t-14} - y_{t-15}) + 60.63$

While neither of these models could be called simple, the model represented in the first panel and in equation 1 does involve fewer interactions and, upon expansion, fewer terms. Thus, following the principle of Occam's razor would be the model of choice to describe the flows for the Negotiated Period. Just as in past years, one can conclude that the positive lag one correlation indicates that flows changed slowly from day to day. One is at a loss to explain the negative correlation at lag 13, but it is nevertheless statistically present in the 1992 data. No model is presented for the entire period since the data for the entire period are a random walk.

The existence of the two periods during which the flows depart substantially from the flows for the remainder of the period suggests that "intervention analysis" might yield additional insights into the flow process for 1992. Intervention analysis involves adding two zero-one (or dummy) variables to the model, one for each period of ultrahigh flow. Their values would be zero except during the specific period to which they referred. Thus, INT1 would take the value one from 22 April to 5 May and zero otherwise; the variable INT2 would be one from 8 June to 19 June for the analysis of the entire period, and from 8 June to 15 June for the Negotiated Period and zero otherwise. The effect of including these variables would be to account explicitly for the high flows and allow the remaining autoregressive or moving average coefficients to describe the flow net of these unusual events. An additional benefit would be that the coefficients of the intervention variables would statistically estimate the effect of the high precipitation which caused these events. Table 45 shows the model for the entire period when the intervention variables are included. Clearly, coefficients of the intervention variables would statistically estimate the effect of the high precipitation which caused these events. An additional benefit would be that the coefficients of the intervention variables would statistically estimate the effect of the high precipitation which caused these events. Table 45 shows the model for the entire period when the intervention variables are included. Clearly, coefficients of the intervention variables are statistically significant and the resulting model for the net flow is not the random walk found when the high periods were not specifically accounted for in the model. The negative AR1 coefficient indicates instability in successive daily flows. Generally, negative AR coefficients at short lags (e.g., 1) mean that if the flow were high yesterday it would tend to be low today and vice-versa. Negative AR2 and AR4 coefficients as well as very high values for the standard deviations of the flows also contribute to the notion of relative instability. Certainly, the presence of the two periods of high flows and the period of low flows described above contributed to the relatively high values of the standard deviations and to the presence of negative short lag correlation.

Table 45. Results of the 1992 ARIMA analysis showing the ARIMA coefficients and t values for ARIMA models for the entire period with intervention variables.

Variable	Value	t Ratio	Lag
Differencing	1		
Intercept	-33.76	-0.39	0
AR1	-0.39	-4.51	1
AR2	-0.27	-3.25	2
AR4	-0.17	-2.11	4
AR11	-0.30	-3.35	11
AR12	-0.34	-3.70	12
NUM1	10,222.60	7.44	0
NUM2	6,536.40	3.95	0
Q	5.23		
P>Q	0.631		

Table 46 shows the results of the ARIMA analysis for the Negotiated Period when the intervention variables are included. Interestingly, the models with and without the intervention variables are practically identical and the coefficient of the variable for the second intervention is not statistically different from zero. As for the coefficients and intercept term, they are all a little smaller in the model which includes the intervention variables. In general, as one can see, including the intervention variables in the model made essentially no change either in the structure or the significance of the AR terms. This is in contrast to the entire period, where inclusion of the intervention terms made a substantial difference in the structure of the model and the value of the parameters.

Table 46. Results of the ARIMA analysis for 1992 showing the ARIMA coefficients and t values for ARIMA models for the Negotiated Period with intervention variables.

Variable	Value	t Ratio	Lag
Differencing	1		
MU	56.53	0.32	0
AR1	0.31	2.60	1
AR13	-0.30	-2.27	13
INT1	4,361.10	4.46	0
INT2	1,410.20	1.02	0
Q	7.08		
P>Q	0.718		

Autoregression Analysis - Daily Data

Autoregression analysis of the daily average flow data without intervention yielded no information which could not be concluded from the ARIMA analysis. There were no statistically significant coefficients in the models for either period except for the autoregressive lags. Thus, for the flows in 1992, these analyses showed no indication of persistent trend, intermonthly differences in average flow, or a daily difference in flows. When the intervention variables were included, their coefficients were significantly different from zero. Still, no daily or monthly coefficients were statistically significant in the analysis for the entire period. However, for the Negotiated Period, the analysis revealed a positive trend and indicated that the flows for April and May were significantly higher than those from the period 1 June to 15 June. No daily coefficients were significantly different from zero. The results for the daily data analyses are summarized in Tables 47 and 48.

Autoregression Analysis - Hourly Data

Tables 49 and 50 summarize the results from the hourly data. Analysis of hourly data for the entire period again yielded the conclusion that there was no trend or daily pattern. However, hourly patterns similar to those found in analyses of earlier years were present when the analysis was performed both with and without the intervention variables. Flows during the 1 to 2 AM hour were significantly lower than those of the base 12-1 AM hour. Flows were significantly higher from 8 AM to 11 AM and from 5 until 10 PM. For the convenience of the reader, these rows in Table 48 have been boldfaced. Since analysis both with and without the intervention variables yield the same conclusions, this is strong evidence that the intradaily fluctuations actually occurred and were meaningful.

Table 47. Results of autoregression analysis for the entire period with intervention variables for 1992 (R^2 = 0.85).

Variable	B value	Std Error	t Ratio	Approx. prob.
Intercept	-92,089.60	518,000.00	-0.18	0.86
DATE	8.28	43.70	0.19	0.85
MON	372.91	755.00	0.49	0.62
TUES	106.93	1,080.00	0.10	0.92
WED	1,398.95	1,280.00	1.09	0.28
THURS	1,683.29	1,290.00	1.31	0.19
FRI	1,489.11	1,110.00	1.34	0.18
SAT	1,209.71	765.00	1.58	0.12
MAR	908.97	3,990.00	0.23	0.82
APR	-324.56	2,780.00	-0.12	0.91
MAY	2,249.96	1,650.00	1.47	0.14
INT1	10,632.59	1,270.00	8.37	0.00
INT2	7,244.05	1,660.00	4.37	0.00
A(1)	-0.58	0.08	-7.09	0.00
A(11)	0.28	0.08	3.47	0.00
A(13)	-0.25	0.09	-2.74	0.01
A(15)	0.29	0.08	3.58	0.00

Table 48. Results of autoregression analysis for the Negotiated Period with intervention variables for 1992 (R^2 = 0.95).

Variable	B value	Std Error	t Ratio	Approx. prob.
Intercept	1,571,295.16	450,000.00	-3.49	0.00
DATE	133.35	38.00	3.51	0.00
MON	-739.37	408.00	-1.81	0.07
TUES	-757.78	483.00	-1.57	0.12
WED	-51.07	500.00	-0.10	0.92
THURS	411.94	498.00	0.83	0.41
FRI	559.38	469.00	1.19	0.24
SAT	357.36	384.00	0.93	0.36
APR	5,521.32	2,150.00	2.57	0.01
MAY	3,594.74	1,320.00	2.72	0.01
INT1	10,181.49	954.00	10.68	0.00
INT2	6,122.59	1,380.00	4.43	0.00
A(1)	-0.62	0.10	-6.26	0.00
A(14)	0.32	0.11	3.01	0.00

Table 49. Comparison of autoregression coefficients for the entire period with and without intervention for 1992.

	Without intervention (R^2=0.95)			With intervention (R^2=0.95)		
Variable	B value	t Ratio	App prob	B value	t Ratio	App prob
Intercept	28,612.89	0.05	0.96	58,951.75	0.12	0.91
DATE	-1.64	-0.04	0.97	-4.22	-0.10	0.92
MON	-366.62	-1.27	0.21	-455.03	-1.54	0.12
TUES	-305.19	-0.82	0.41	-338.39	-0.90	0.37
WED	-189.23	-0.46	0.64	-196.45	-0.47	0.64
THURS	-318.56	-0.77	0.44	-319.03	-0.77	0.44
FRI	-451.28	-1.21	0.23	-454.78	-1.20	0.23
SAT	-108.67	-0.38	0.71	-77.07	-0.27	0.79
INT1				1,476.12	1.63	0.10
INT2				1,184.85	1.28	0.20
MAR	-1,375.15	-0.60	0.55	-1,399.80	-0.61	0.54
APR	-425.53	-0.23	0.82	-533.32	-0.29	0.77
MAY	-21.51	-0.02	0.99	-73.65	-0.06	0.95
ONE	**-321.25**	**-2.17**	**0.03**	**-319.20**	**-2.20**	**0.03**
TWO	-457.28	-1.95	0.05	-455.62	-1.97	0.05
THREE	-538.11	-1.82	0.07	-536.38	-1.83	0.07
FOUR	-532.23	-1.55	0.12	-530.35	-1.56	0.12
FIVE	-412.96	-1.09	0.28	-411.07	-1.10	0.27
SIX	-274.89	-0.68	0.50	-273.95	-0.69	0.49
SEVEN	514.90	1.23	0.22	515.51	1.25	0.21
EIGHT	**1,306.21**	**3.04**	**0.00**	**1,308.00**	**3.09**	**0.00**
NINE	**1,411.63**	**3.25**	**0.00**	**1,413.79**	**3.29**	**0.00**
TEN	**1,293.58**	**3.00**	**0.00**	**1,295.68**	**3.01**	**0.00**
ELEVEN	822.84	1.92	0.06	824.71	1.91	0.06
TWELVE	639.11	1.49	0.14	641.17	1.48	0.14
THIRTEEN	425.38	0.99	0.32	427.70	0.99	0.32
FOURTEEN	466.12	1.08	0.28	467.60	1.09	0.28
FIFTEEN	445.75	1.03	0.30	446.37	1.04	0.30
SIXTEEN	619.66	1.44	0.15	619.53	1.46	0.14
SEVENTEEN	**890.02**	**2.13**	**0.03**	**889.54**	**2.15**	**0.03**
EIGHTEEN	**937.74**	**2.33**	**0.02**	**937.84**	**2.36**	**0.02**
NINETEEN	**1,010.17**	**2.68**	**0.01**	**1,011.50**	**2.70**	**0.01**
TWENTY	**934.27**	**2.73**	**0.01**	**935.58**	**2.75**	**0.01**
TWOONE	**887.45**	**3.02**	**0.00**	**888.93**	**3.05**	**0.00**
TWOTWO	**541.52**	**2.35**	**0.02**	**543.95**	**2.38**	**0.02**
TWOTHREE	251.23	1.77	0.08	252.19	1.79	0.07
A(1)	-1.25	-67.64	0.00	-1.24	-67.57	0.00
A(2)	0.44	15.01	0.00	0.42	14.72	0.00
A(3)	-0.18	-6.20	0.00	-0.13	-5.95	0.00
A(4)	0.07	3.83	0.00			
A(5)				0.06	4.09	0.00
(7)				0.05	-3.93	0.00
A(10)	-0.03	-3.38	0.00			
A(14)	-0.05	-2.71	0.01	-0.07	-3.52	0.00
A(15)	0.13	4.55	0.00	0.13	4.63	0.00
A(16)	-0.08	-3.93	0.00	-0.08	-3.79	0.00
A(20)	0.08	4.23	0.00	0.08	4.19	0.0001
A(21)	-0.11	-6.51	0.00	-0.11	-6.50	0.0001

Note: Where autoregressive lags are different in the right hand column, it is so noted by the coefficient.

Analysis of the Negotiated Period, however, resulted in a completely different conclusion. During the Negotiated Period for 1992, **no coefficients were significanly different from zero except the autoregressive coefficients** which are supplied by the method on the basis of the highest influence on the dependent variable.

Table 50. Comparison of autoregression coefficients for the Negotiated Period with and without intervention for 1992.

	Without intervention (R^2=0.95)			With intervention (R^2=0.95)		
Variable	B value	t Ratio	App prob	B value	t Ratio	App prob
Intercept	-698,065.92	-0.71	0.4759	-800,486.06	-0.96	0.34
DATE	59.95	0.72	0.4694	68.61	0.97	0.33
MON	18.83	0.33	0.7449	-9.18	-0.12	0.90
TUES	20.48	0.28	0.7831	17.73	0.19	0.85
WED	53.25	0.66	0.5108	98.10	0.97	0.33
THURS	38.82	0.48	0.6288	87.57	0.88	0.38
FRI	38.12	0.53	0.5984	72.81	0.81	0.42
SAT	44.23	0.80	0.4262	79.31	1.15	0.25
INT1				264.86	1.52	0.13
INT2				-21.19	-0.08	0.93
APR	50.02	0.17	0.8648	-82.62	-0.23	0.82
MAY	-13.22	-0.06	0.9493	-44.69	-0.17	0.86
ONE	-45.95	-0.55	0.583	-55.47	-0.76	0.45
TWO	-27.16	-0.31	0.7579	-36.59	-0.49	0.62
THREE	-11.16	-0.12	0.9052	-19.73	-0.26	0.80
FOUR	4.18	0.04	0.9664	-3.11	-0.04	0.97
FIVE	19.12	0.18	0.8543	12.95	0.16	0.87
SIX	40.53	0.38	0.7077	35.19	0.44	0.66
SEVEN	46.59	0.42	0.6746	41.64	0.52	0.60
EIGHT	16.71	0.15	0.8823	11.78	0.15	0.88
NINE	-16.37	-0.14	0.8857	-21.50	-0.27	0.79
TEN	-66.70	-0.59	0.5587	-72.15	-0.90	0.37
ELEVEN	-83.61	-0.74	0.4616	-89.45	-1.12	0.26
TWELVE	-20.55	-0.18	0.8552	-26.79	-0.34	0.74
THIRTEEN	-24.77	-0.22	0.8234	-31.40	-0.41	0.69
FOURTEEN	44.41	0.41	0.6834	37.43	0.50	0.62
FIFTEEN	51.60	0.49	0.6266	44.27	0.61	0.54
SIXTEEN	57.71	0.57	0.5724	49.78	0.72	0.47
SEVENTEEN	58.10	0.60	0.5501	49.40	0.75	0.45
EIGHTEEN	37.91	0.42	0.6763	29.04	0.47	0.64
NINETEEN	22.47	0.27	0.7859	14.24	0.25	0.80
TWENTY	20.65	0.28	0.7763	13.85	0.27	0.79
TWOONE	21.45	0.36	0.7222	16.58	0.36	0.72
TWOTWO	2.80	0.06	0.9507	0.33	0.01	0.99
TWOTHREE	-14.36	-0.53	0.5931			
A(1)	-1.47	-62.33	0.0001	-14.96	-0.55	0.58
A(2)	0.39	9.48	0.0001			
A(3)	0.08	3.14	0.0017			
A(10)				-1.05	-234.74	0.00
A(12)	-0.01	-0.50	0.6208			
A(13)	-0.03	-0.71	0.4755			
A(14)	0.04	1.85	0.0652			

Note: Where autoregressive lags are different in the right hand column, it is so noted by the coefficient.

Conclusions

Overall, the flows for 1992 were unstable due to significant rain events during the period. The flows were within the recommended flow regime approximately 50% of the days during the Negotiated Period, albeit either close to the extremes. In terms of the models, the ARIMA models without the intervention variables were a random walk for the entire period and similar to the models for other years for the Negotiated Period. The model for the Negotiated Period had a positive AR1 parameter, indicating little day-to-day variation in the flows. There were major changes over short periods of time, but once the changes occurred, the flows were stable for several days/weeks after that.

When the intervention or dummy variables were included, thereby explicitly modeling the two periods of extremely high flows, the model for the entire period became very complicated, with negative AR1, AR2, and AR4 coefficients indicating short-term instability relative to the intervention periods. The coefficients of both intervention variables were significantly different from zero, as one would expect. On the other hand, the model for the Negotiated Period with interventions remained essentially the same, with a positive AR1 coefficient, a negative AR13 coefficient, and the first intervention coefficient significantly different from zero. Probably, the second intervention coefficient was not significantly different from zero because the entire intervention period was not included in the Negotiated Period.

The autoregressive models for the daily data revealed essentially nothing for the 1992 flows. Without the intervention variables, no coefficients were significant for either period. With the intervention terms, the intervention coefficients were significantly different from zero as were the coefficients for April and May. This is not surprising, given the pattern of flows in 1992.

Analysis of hourly flows, on the other hand, revealed that hourly flow patterns similar to those in other years were present in the data from the entire period whether the intervention variables were included in the model or not. However, they were not present in the models for the Negotiated Period. Thus, one would conclude that it is the data which is in the entire period but outside the Negotiated Period which gives rise to these daily patterns in 1992.

Roanoke River Time Series Analysis for 1993

L.H. Zincone, Jr.

Introduction

Examination of the flow data for 1993 shows that the most prominent feature of the March to June period was the extremely high flow plateaus occasioned by heavy spring rains. Specifically, there is:

A plateau at about 20,000 cfs from 6 March to 26 March;
An increase to an approximate 35,000 cfs plateau from 27 to 29 March;
A sustained 35,000 cfs plateau from 30 March to 23 April;
A drop to about 9,000 cfs from 24 April to 5 May;
A plateau at about 9,000 cfs until 15 June; and
A drop to a very low flow from 16 June to 30 June.

The magnitude of these flows is unusual when compared to the long sweep of flow history, but it should be noted that it is still the general pattern suggested in the analysis by Zincone and Rulifson (1991). That is, the flow still followed the pattern of an early spring flood followed by a decrease to a lower but steady flow.

Even though the magnitude of the 1993 flow is high relative to the majority of the years for which histories have been kept and certainly relative to flows since impoundment, they form the main feature of the 1993 flow. Consequently, one change has been made in the autoregressive model used to describe this year's flow. Specifically, previous analyses have used autoregressive models which contain a linear trend represented by the date. Since any trend in this data is clearly not linear, but rather an inverted U shape, the square of the date has been added to the autoregression models. Therefore, the autoregression models in the 1993 analysis are of the form:

$$FLOW = a + b_1DATE + b_2\ DATESQ + \ ciNTH_i + \ d_iDAY_i + \ e_1HOUR_i$$

for the models estimated from hourly data and the same without coefficients of hours for the daily data models.

ARIMA Analysis

For both the entire period and Negotiated Period, ARIMA models were random walks.

Autoregressive Analysis - Daily Data

Table 51 compares the autoregression models for the entire period and Negotiated Period for daily data. (In all tables describing the autoregressive analysis, lines with significant coefficients are boldfaced and where significant autoregressive lags differ between the entire and Negotiated Period, it is so noted in the body of the table.) For the entire, date, datesq, and the AR1 parameters are significantly different from zero.

Table 51. Comparison of models of daily data for the entire and Negotiated Period for 1993.

	Entire period (R^2=0.98)			Negotiated Period (R^2=0.98)		
Variable	B value	t Ratio	App prob	B value	t Ratio	App prob
Intercept	-5,733,325.23	-2.09	0.04	4,544,174.21	1.10	0.27
DATE	94,322.39	2.09	0.04	-74,543.11	-1.10	0.28
DATESQ	-3.88	-2.09	0.04	3.04	1.09	0.28
MON	-298.32	-0.90	0.37	163.52	0.45	0.66
TUES	244.46	0.57	0.57	144.24	0.30	0.77
WED	429.37	0.92	0.36	-27.13	-0.05	0.96
THURS	702.42	1.50	0.14	254.14	0.48	0.63
FRI	444.89	1.03	0.30	272.12	0.56	0.58
SAT	-38.33	-0.12	0.91	-337.53	-0.92	0.36
MAR	2,802.22	1.02	0.31			
APR	1,538.98	0.68	0.50	748.16	0.36	0.72
MAY	439.90	0.28	0.78	-322.54	-0.22	0.83
A(1)	-1.02	-28.65	0.00	-0.98	-19.58	0.00
A(7)	0.07	1.91	0.06	0.09	1.71	0.09

The positive coefficient for date and the negative coefficient from datesq are what one would expect for a quadratic trend which is shaped like an inverted U. No daily or monthly coefficients are significantly different from zero. For the Negotiated Period, there are no significant coefficients except for the AR1 coefficient.

Autoregressive Analysis - Hourly Data

Table 52 compares the coefficients of the models from hourly data for the entire and Negotiated Periods. For the entire period, the coefficients representing the hours beginning at 8, 9, 10, and 11 PM are significantly positive, indicating that flows at these hours were significantly higher than those of the benchmark midnight hour. In addition, many AR terms are significantly different from zero. During the Negotiated Period, the hourly coefficients representing the hours beginning at 2 AM to 9 AM are significantly positive as is the coefficient representing the 10 to 11 PM hour. Four AR terms are significantly different from zero in this model.

Conclusions

In the autoregressive analysis of the 1993 flows, significant monthly and daily coefficients in the models for daily data are conspicuous by their absence. Only in the daily model for the entire period are there significant coefficients which are not AR coefficients. Clearly, the inverted U trend compelled by the heavy spring floods are reflected in these coefficients. Daily and monthly coefficients contribute nothing to the understanding of daily data in 1993.

For hourly data, during the entire period, there were some statistically significant hourly variables. However, when one compares the coefficients of these variables with the average flow, even during the relatively low flow 9,000 cfs period, one concludes that even though the coefficients are statistically significant, they are not significant in any practical sense. That is, the hourly variation was so small when compared to the flow as a whole, they are of no practical significance.

Table 52. Comparison of hourly models for the entire period and Negotiated Period for 1993.

	Entire period (R^2=0.99)			Negotiated Period (R^2=0.99)		
Variable	B value	t Ratio	App prob	B value	t Ratio	App prob
Intercept	-88,739,059.30	-0.85	0.39	7,686,535.68	0.08	0.94
DATE	14,699.60	0.86	0.39	-856.18	-0.05	0.96
DATESQ	-0.61	-0.87	0.39	0.02	0.03	0.98
MON	-135.92	-1.14	0.25	9.36	0.14	0.89
TUES	-63.24	-0.41	0.68	15.28	0.17	0.87
WED	-26.35	-0.16	0.88	-6.75	-0.07	0.95
THURS	167.59	0.99	0.32	271.72	2.75	0.01
FRI	10.27	0.07	0.95	251.49	2.79	0.01
SAT	1.50	0.01	0.99	33.83	0.49	0.62
MAR	430.29	0.45	0.65			
APR	152.60	0.20	0.84	-152.48	-0.42	0.68
MAY	46.43	0.09	0.93	8.29	0.03	0.97
ONE	-44.45	-0.39	0.70	406.64	5.05	0.00
TWO	-170.98	-1.09	0.28	406.48	4.94	0.00
THREE	-266.85	-1.12	0.26	381.51	4.54	0.00
FOUR	-313.96	-1.29	0.20	345.42	4.01	0.00
FIVE	-350.89	-1.24	0.21	321.81	3.65	0.00
SIX	-375.92	-1.18	0.24	286.04	3.17	0.00
SEVEN	-337.47	-0.97	0.33	246.15	2.68	0.01
EIGHT	-330.69	-0.88	0.38	213.32	2.29	0.02
NINE	-325.57	-0.82	0.41	158.51	1.69	0.09
TEN	-260.70	0.64	0.53	125.71	1.34	0.18
ELEVEN	-152.69	-0.37	0.72	107.61	1.15	0.25
TWELVE	-58.94	-0.14	0.89	101.16	1.09	0.27
THIRTEEN	58.73	0.14	0.89	60.85	0.67	0.50
FOURTEEN	95.64	0.23	0.82	59.98	0.68	0.50
FIFTEEN	124.02	0.32	0.75	33.51	0.39	0.09
SIXTEEN	312.64	0.84	0.40	69.16	0.85	0.39
SEVENTEEN	461.39	1.34	0.18	57.98	0.76	0.45
EIGHTEEN	533.30	1.72	0.09	35.52	0.50	0.62
NINETEEN	535.03	1.95	0.05	8.81	0.14	0.89
TWENTY	497.42	2.14	0.03	-16.45	-0.29	0.77
TWOONE	428.74	2.30	0.02	46.06	0.94	0.35
TWOTWO	405.85	3.03	0.00	85.13	2.15	0.03
TWOTHREE	284.67	3.80	0.00	74.75	2.70	0.01
A(1)	-1.34	-77.54	0.00	-1.06	-115.27	0.00
A(2)	0.39	20.87	0.00			
A(6)				0.07	5.67	0.00
A(7)	0.06	2.89	0.00			
A(8)	-0.06	-2.78	0.01			
A(10)	0.16	6.47	0.00			
A(11)	-0.22	-7.26	0.00			
A(12)	0.11	5.59	0.00			
A(17)	-0.12	-6.41	0.00			
A(18)	0.09	4.28	0.00			
A(21)	-0.05	-0.005	0.00			

Kerr Reservoir Operation in Hindsight, 1991-1993

Max Grimes

In cooperation with state and federal fish and wildlife agencies, the Wilmington District Corps of Engineers continued to test the fish flow regime during 1 April through 15 June in the lower Roanoke River in an effort to enhance striped bass spawning. The Corps operated John H. Kerr Reservoir to meet downstream target flows during the Negotiated Flow Regime and maintain Congressionally authorized project purposes to the maximum extent possible during 1989 through 1993. In the past three years, high inflows prior to and during spawning season resulted in flood control releases above the upper band flow of 9,500 cfs. There were 40 days of the 76-day flow regime which were above the upper flow band in 1993 as compared to 19 days in 1992 and 21 days in 1991. There were 35 days or 46% of the time that flows (±10%) were within the upper and lower flow bands in 1993 as compared to 41 days or 54% in 1992 and 54 days or 71% in 1991. In spite of the high flows of early 1993, which were more than double the upper flow band for 40 days, preliminary reports indicate that the Juvenile Abundance Index (JAI) will be very high in 1993 (over 44) and was a very successful year for striped bass spawning. For the two previous years the JAI values were 0.86 and 2.60 in 1991 and 1992, respectively. The JAI in 1989 was 4.27, and 1.41 in 1990; therefore, from a JAI standpoint 1993 was the most successful fish spawning season during the five-year regime and 1991 was the worst. A "good year" JAI is considered to be 5.0 or more. Other factors (e.g., overfishing and pollution) have played a role in the decline in the striped bass population in the Roanoke/ Albemarle Sound watershed.

From a data collection standpoint, it was unfortunate that the entire five-year flow regime was relatively wet. Evaluating the Negotiated Flow Regime during drier times is needed.

Water Quality of the Lower Roanoke River, 1991-1993

Roger A. Rulifson

Methods

Water quality was measured in two different regions of the lower Roanoke River watershed. In late spring and early summer of 1991, several water quality parameters were monitored in the lower River, Delta, and western Albemarle Sound concurrent with a zooplankton and larval fish study (Rulifson et al. 1992a, 1992b), the results of which are summarized in other sections of this Flow Committee report. Water quality just downstream of the primary striped bass spawning grounds at RM 117 was measured during the springs of 1991 - 1993 concurrent with striped bass spawning studies (Rulifson 1993, Rulifson et al. 1993). In all studies, water temperature (°C) was measured *in situ* with a YSI oxygen meter (Model 58B) or with a Beckman electrodeless induction salinometer. Both meters were compared to and calibrated with a certified Fisher thermometer. Dissolved oxygen (mg/L) was measured with a YSI oxygen meter (Model 58B) *in situ*, which was calibrated to ambient conditions based on the manufacturer recommendations. The YSI meter was checked periodically by the Winkler method. *In situ* pH was determined with either a Corning PS15 pH meter or Fisher pH pen calibrated to a Fisher 7.0 pH solution.

Roanoke Delta and Western Sound, 1991

Water quality monitoring in the Roanoke River Delta was initiated on 1 March 1991. At that time, water temperatures were about 9°C (Figure 41). By 10 April, the average Delta temperature was 19°C reflecting the warmer than usual spring. Batchelor Bay and western Albemarle Sound temperatures were slightly lower than that observed in the Delta. River temperatures decreased in late April concurrent with a cold front and decreased reservoir discharge; however, Sound and Bay temperatures continued to increase. By mid-May the average water temperatures among the three areas remained similar through early June (Figure 41).

Dissolved oxygen levels in the Roanoke Delta and Batchelor Bay were above saturation in March (Figure 42). In early April, an oxygen sag to about 60% saturation was observed in the lower River and Delta, followed by a similar event in the Bay and western Sound in mid-April. Oxygen levels in the Bay and Sound were slightly higher than the lower River and Delta values through May and into early June (Figure 42).

Surface water pH remained at 7.0 or above for most of the study period. The exception was a sudden drop in lower River and Delta pH values at the end of April, perhaps the result of a precipitation event during 27-29 April. This pH decrease was not observed in Batchelor Bay (Figure 43).

Salinity was not observed in the study area until mid-May (Figure 44). The highest salinity value was 0.4 ppt recorded on 25 May along the south shore of the Sound near Mackey's Landing about 6.0 km east of the Roanoke River mouth.

The zooplankton and larval fish study was terminated in 1991, so no water quality information of this nature was available for 1992 and 1993 comparisons.

Upstream Water Quality, 1991-1993

1991 Conditions

In 1991 River water levels were high through March until the third week in April, when reservoir discharge was reduced (Figure 45). Heavy basinwide spring rains in March 1991 (3.4 inches above normal) resulted in high inflow to Kerr Reservoir, and the subsequent increased water releases downstream. Reduced inflow to Kerr Reservoir in early April allowed the Corps of Engineers to reduce flows downstream beginning on 20 April, 20 days after the Negotiated Flow Regime should have been implemented. The Corps was able to provide an appropriate water release schedule to allow Virginia Power Company to maintain water releases from Roanoke Rapids Reservoir within the Flow Committee guidelines beginning on 21 April. Water levels remained stable into mid-June with the exception of a slight flow reduction on 20 May. With the major decrease in reservoir discharge in April, instream flow velocities at Barnhill's Landing (RM 117) dropped from approximately 100-110 cm/second to 70-80 cm/second, where it remained for the rest of the study (Figure 45). Water temperatures ranged from 12.0 to 26.0°C during the study; however, most of these temperatures were quite warm throughout the spring period caused by the record-breaking hot weather prevailing at the time. Water temperatures upstream reached 18°C in late April following a cold front and reduction in reservoir discharge (Figure 46). Stable instream flows allowed water temperatures to increase as a function of ambient conditions to about 25-26°C by mid-June 1991. Dissolved oxygen levels at Barnhill's Landing in mid-April were higher (Figure 47) than those recorded in the lower River, Bay and Sound (Figure 42), but all locations had similar values by late May and early June. Surface water pH remained above 7.0 for most of the study (Figure 48).

1992 Conditions

In 1992, observed rainfall throughout the Roanoke basin for February (3.18 inches) and March (3.00 inches) was slightly below average. In April, basinwide rainfall (4.46 inches) was one inch greater than normal, while observed rainfall downstream of Kerr Reservoir (1.86 inches) was more than one inch less than normal (Table 53). A similar phenomenon was observed in May. In June, heavy rains throughout the watershed resulted in substantially higher rainfall basinwide (4.30 inches); downstream of Kerr Reservoir rainfall was more than two inches above normal (6.17 inches). Most of the June rainfall downstream occurred during the period 18-23 June. Seasonal changes in water releases at Roanoke Rapids Dams influenced surface water velocities and temperatures. Surface water velocities ranged from a high of 132 cm/second on 19 June to a low of 44 cm/second a mere two days later (Figure 49) corresponding to hydroelectric releases upstream (Figure 50). Relatively high instream flow conditions (seasonal mean = 89.2 cm/second) prevailed during the major period of striped bass spawning in 1992. Water temperatures remained cooler than usual throughout the 1992 study, ranging from 10.0°C to 23.0°C (mean = 18.9°C). Daily water temperatures averaged nearly 18°C from 18 April to 23 April, but decreased slightly until 14 May. Environmental data suggest that river temperature was stabilized by reservoir discharge while daily air temperatures exhibited typical diurnal variability (Figure 51). Dissolved oxygen levels in Roanoke River waters remained above 7.0 mg/L for most of the study. One exception was in mid-April when an oxygen decrease was recorded concurrent with a sudden increase in water release from Roanoke Rapids Dam (Figure 52). Surface water pH values were above 7.0 during the period (Figure 53).

1993 Conditions

In 1993, basinwide rainfall in March (8.37 inches) was considerably higher than normal (3.74 inches), causing extensive flooding throughout the watershed. This condition necessitated the opening of floodgates of the reservoir system on 29 March, allowing 35,000 cfs to spill downstream for an extended period. By mid-April, the extensive rains had passed but Roanoke

River flows downstream were still much higher than normal and water velocities exceeded 140 cm/second (Figure 54). May rainfall was slightly lower than normal (Table 53); floodwaters slowly receded to stabilize at the discharge rate of approximately 20,000 cfs by the second week in May (Figure 55). A sudden reduction in reservoir discharge on 11 May resulted in a drop of surface water velocities from over 100 cm/second to between 70 and 80 cm/second (Figure 54); tremendous striped bass spawning activity was initiated at this time. Several water quality parameters were influenced by this large reduction in flows. As reservoir discharges decreased from the maximum to about 20,000 cfs, the water temperatures reached or exceeded 18°C for brief periods during the day, for several days in a row the second week in May (Figure 56). The sudden reduction in reservoir discharge on 11 May resulted in water temperatures remaining above 18°C; major spawning activity occurred concurrently. Dissolved oxygen remained above 10 mg/L throughout April, but decreased suddenly to values less than 9 mg/L concurrent with the sudden decrease in reservoir discharge (Figure 57). Surface water pH values dipped below 7.0 only occasionally during the study (Figure 58).

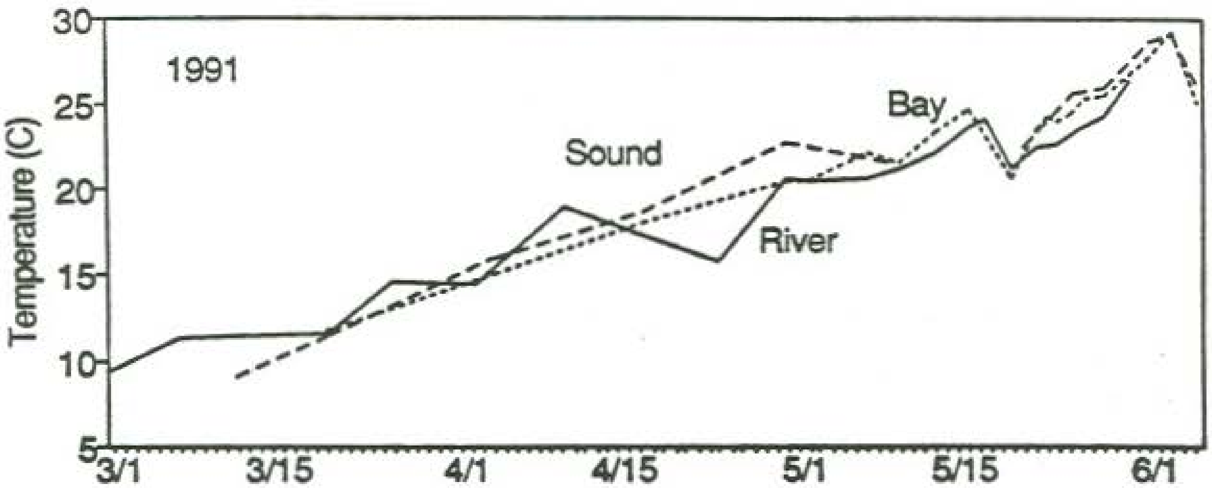

Figure 41. Average water temperature (°C), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1991.

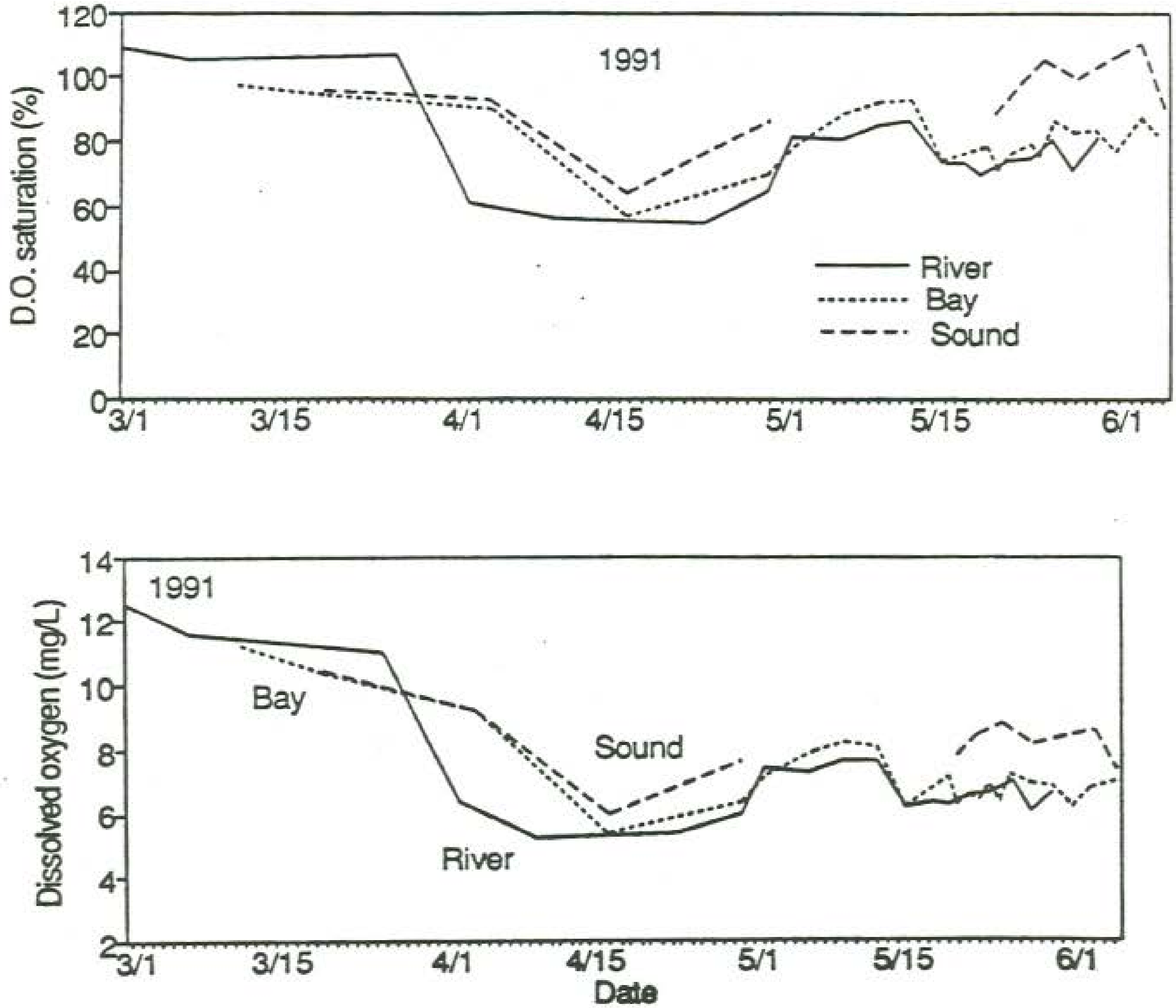

Figure 42. Average dissolved oxygen levels (mg/L) and percent saturation, by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1991.

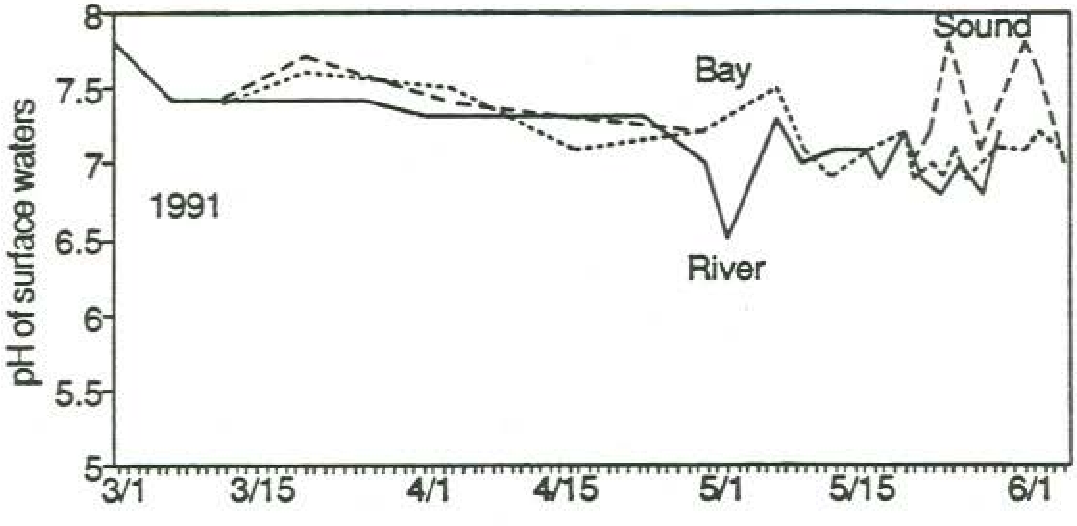

Figure 43. Average surface water pH, by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1991.

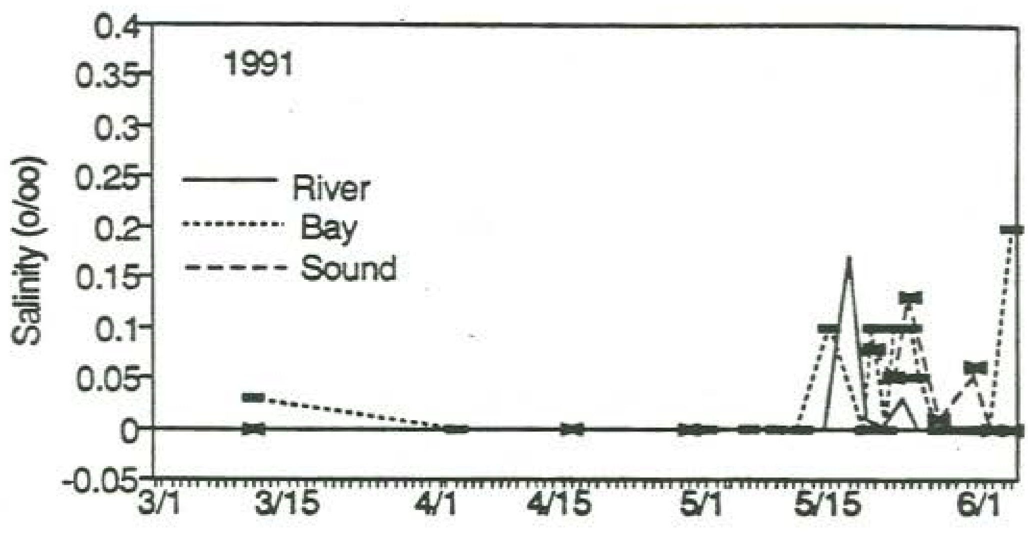

Figure 44. Average salinity (ppt), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1991.

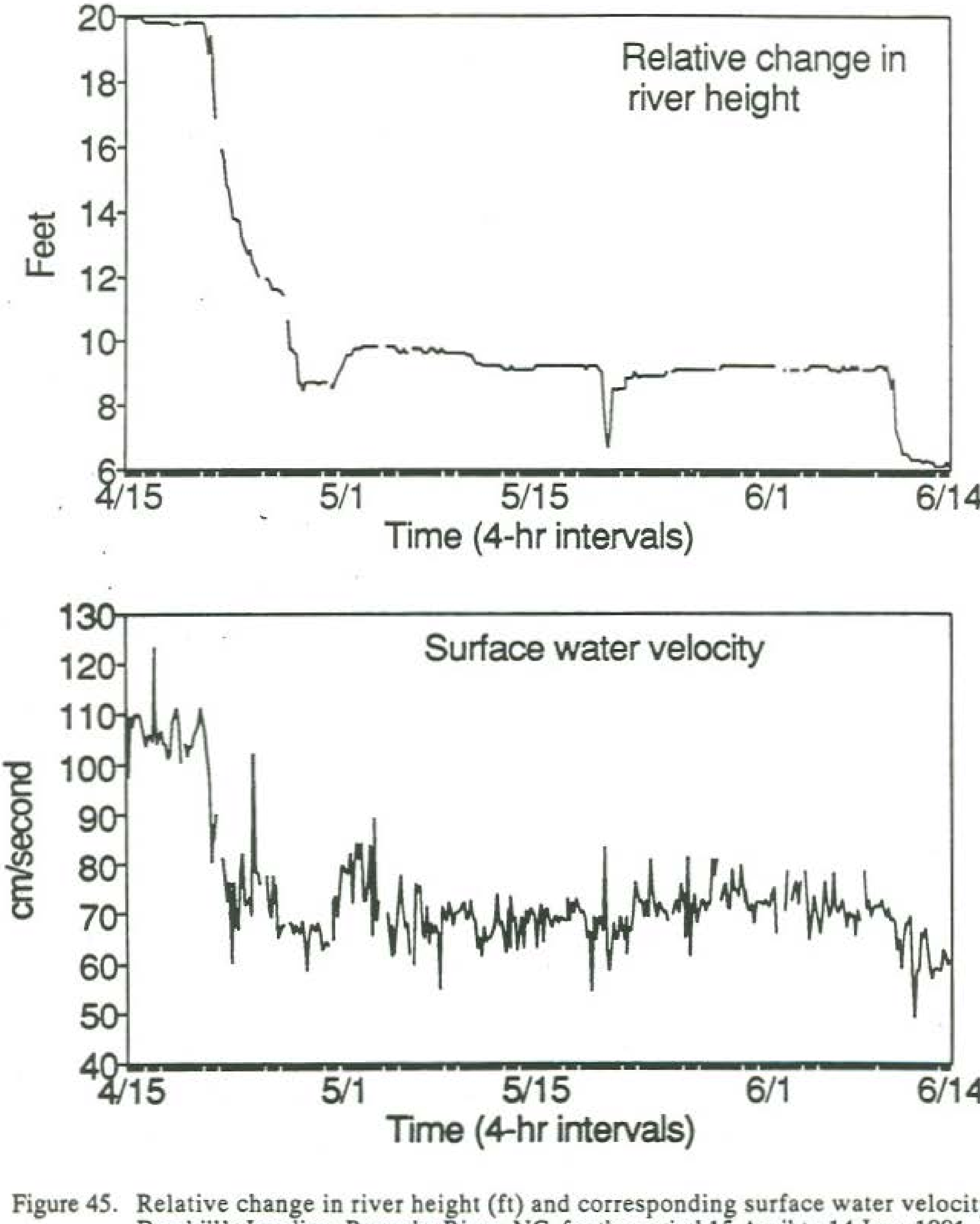

Figure 45. Relative change in river height (ft) and corresponding surface water velocity at Barnhill's Landing, Roanoke River, NC, for the period 15 April to 14 June 1991.

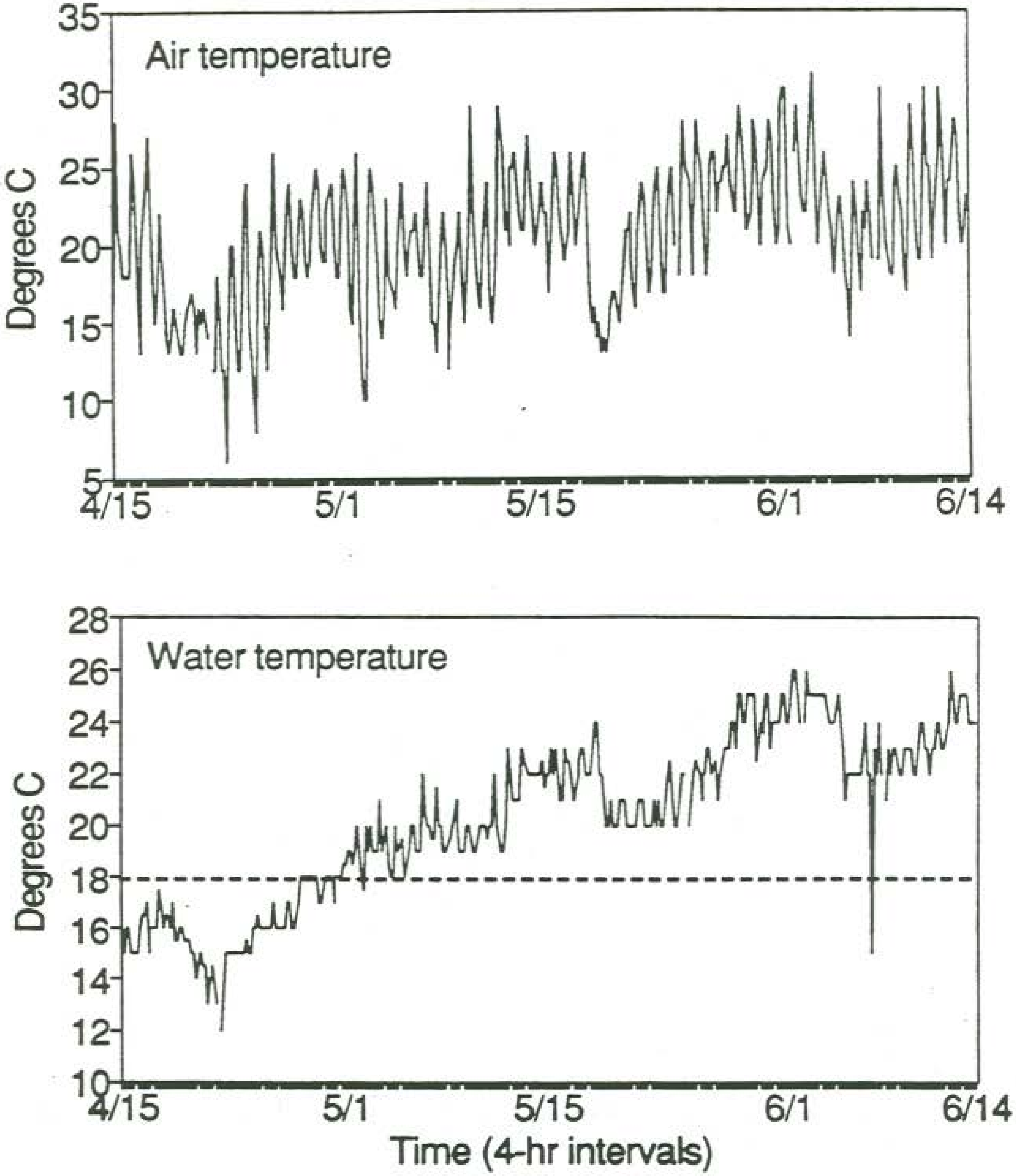

Figure 46. Air temperature and water temperature (°C) measured at Barnhill's Landing, NC, for the period 15 April to 14 June 1991.

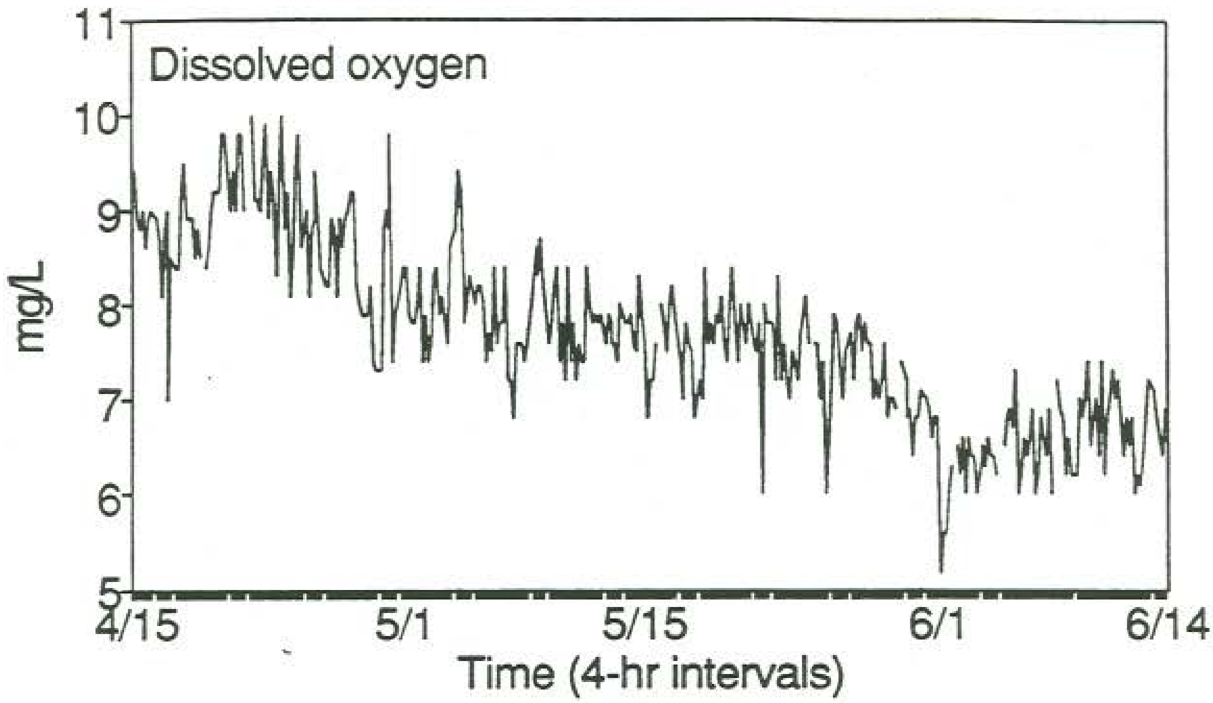

Figure 47. Changes in dissolved oxygen (mg/L) of Roanoke River waters at Barnhill's Landing, NC, for the period 15 April to 14 June 1991.

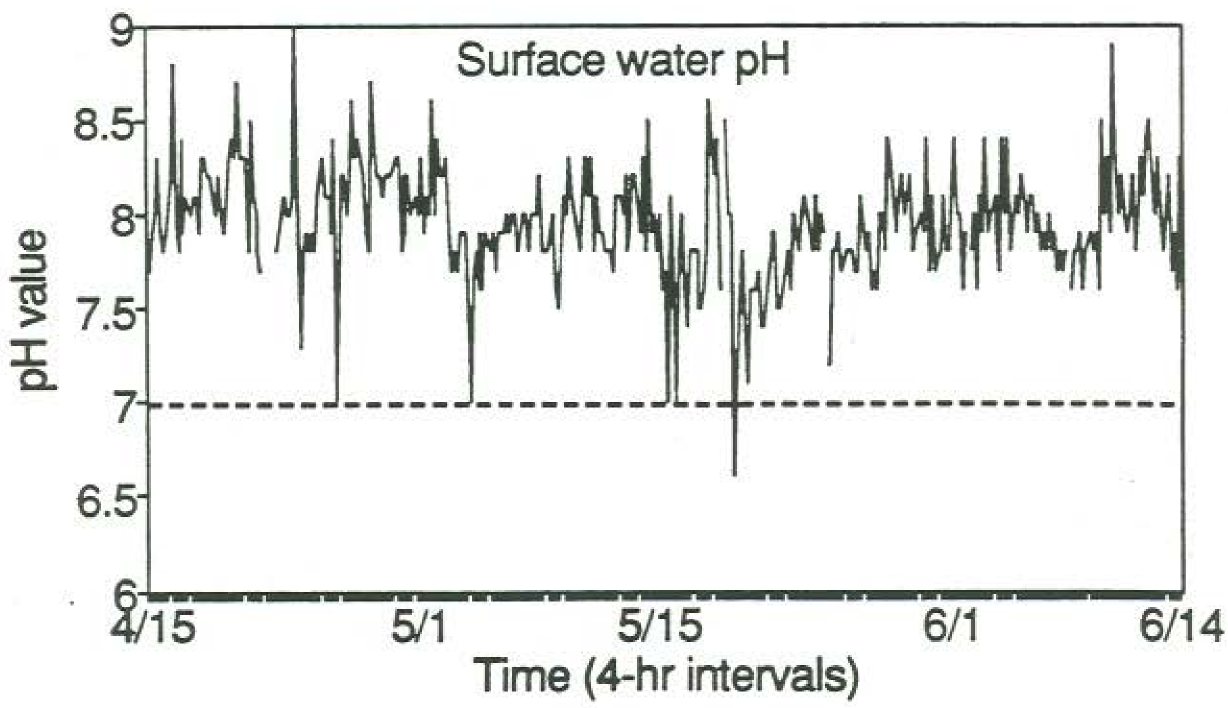

Figure 48. Changes in pH of Roanoke River surface waters at Barnhill's Landing, NC, for the period 15 April to 14 June 1991.

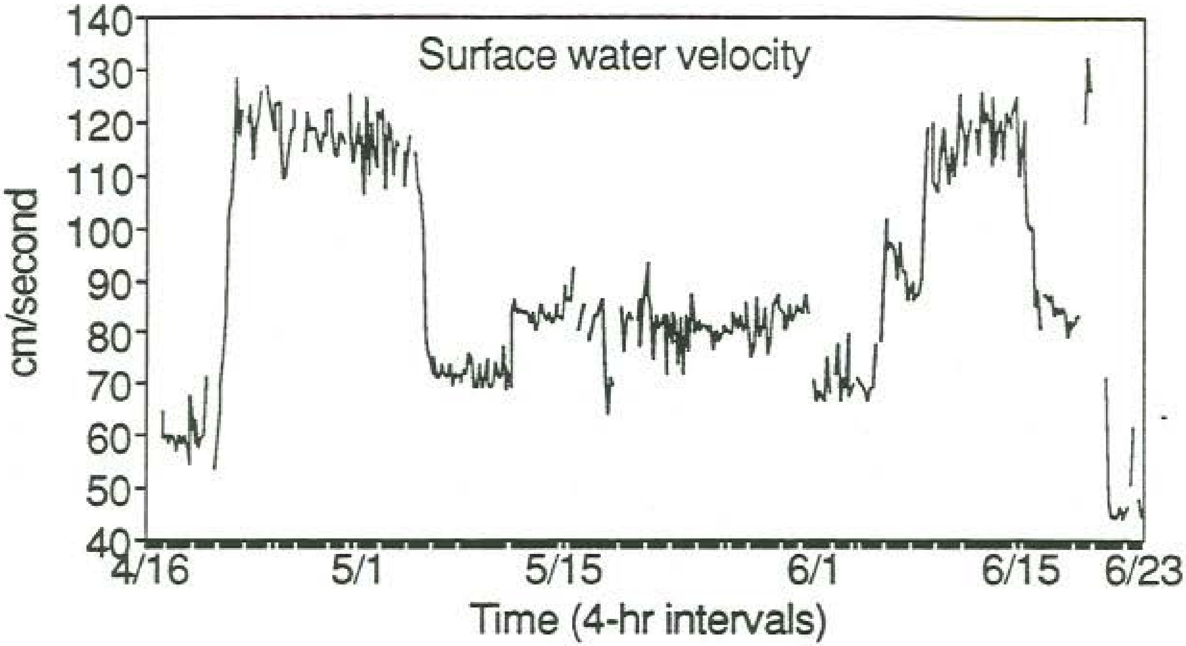

Figure 49. Surface water velocity (cm/second) measured at Barnhill's Landing, NC, for the period 16 April to 23 June 1992.

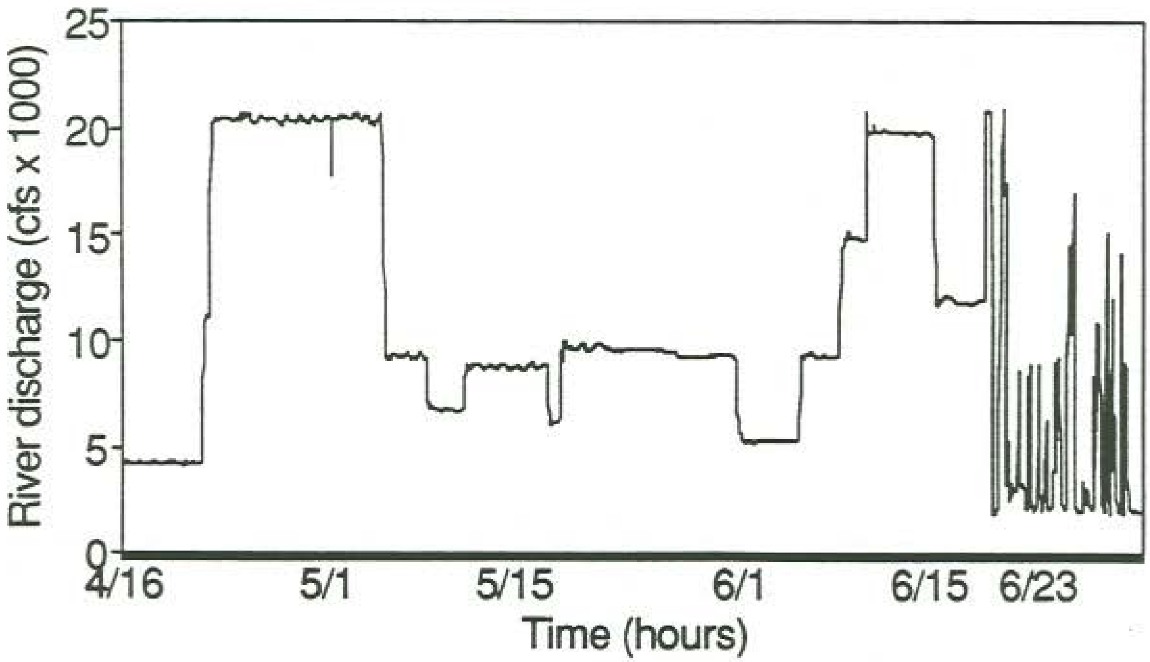

Figure 50. Hourly record of Roanoke River instream flow (cfs) downstream of the Roanoke Rapids Reservoir (USGS data), April-June 1992.

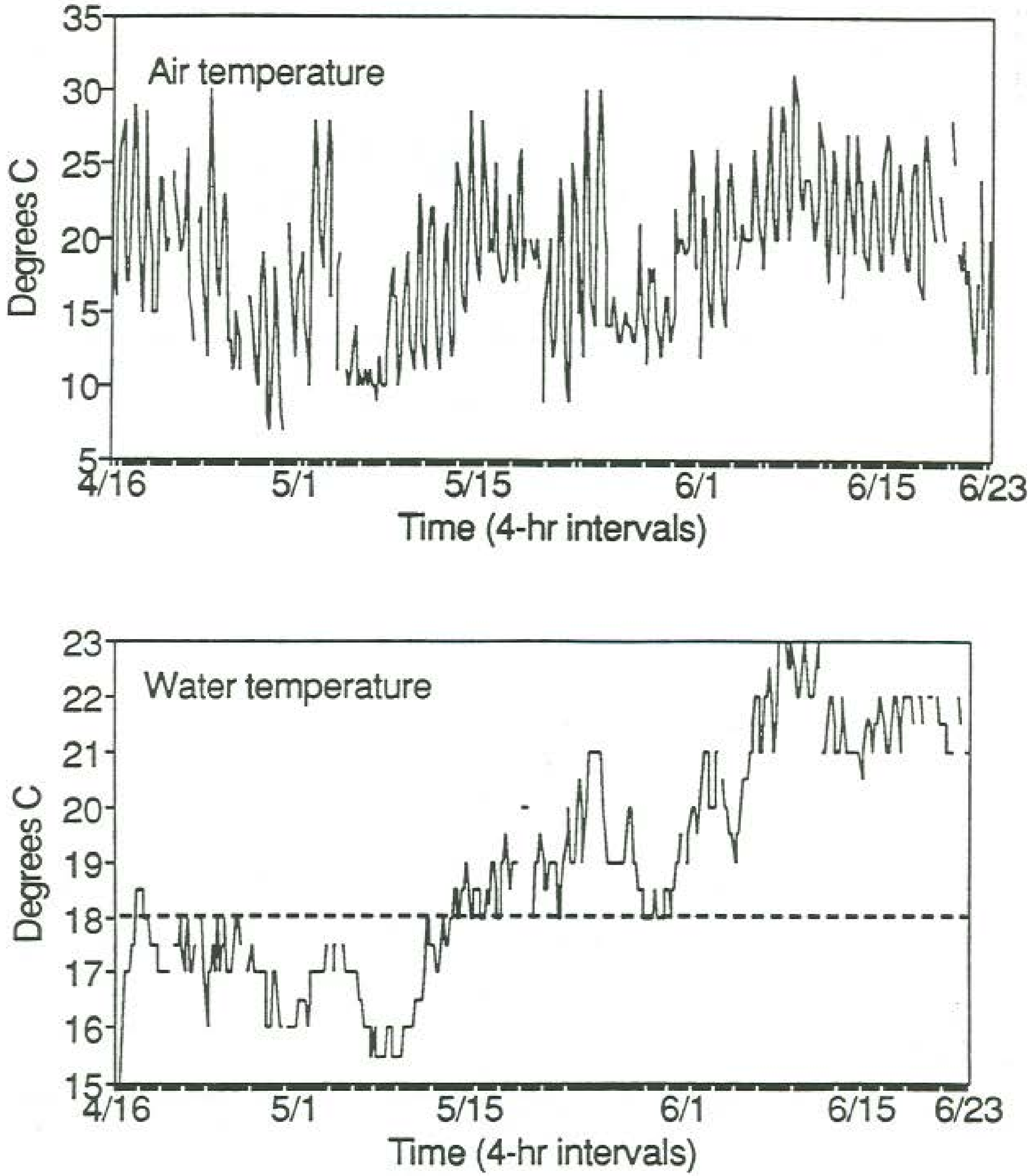

Figure 51. Air and water temperatures (°C) measured at Barnhill's Landing, NC, for the period 16 April to 23 June 1992.

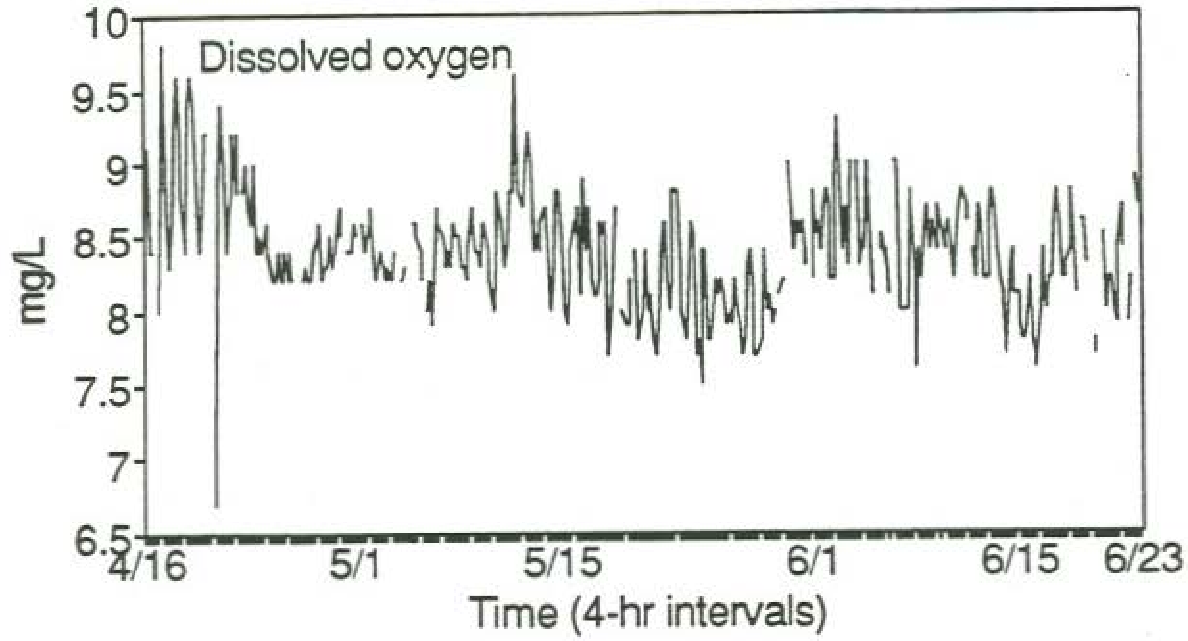

Figure 52. Changes in dissolved oxygen (mg/L) of Roanoke River waters at Barnhill's Landing, NC, for the period 16 April to 23 June 1992.

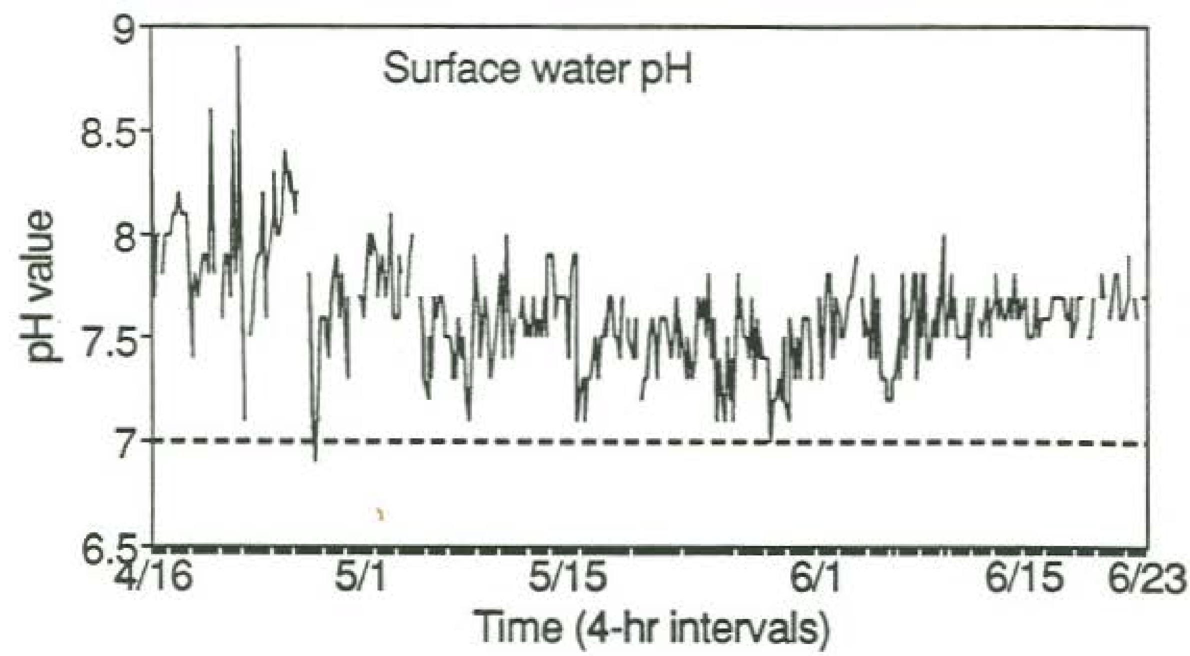

Figure 53. Changes in pH of Roanoke River surface waters at Barnhill's Landing, NC, for the period 16 April to 23 June 1992.

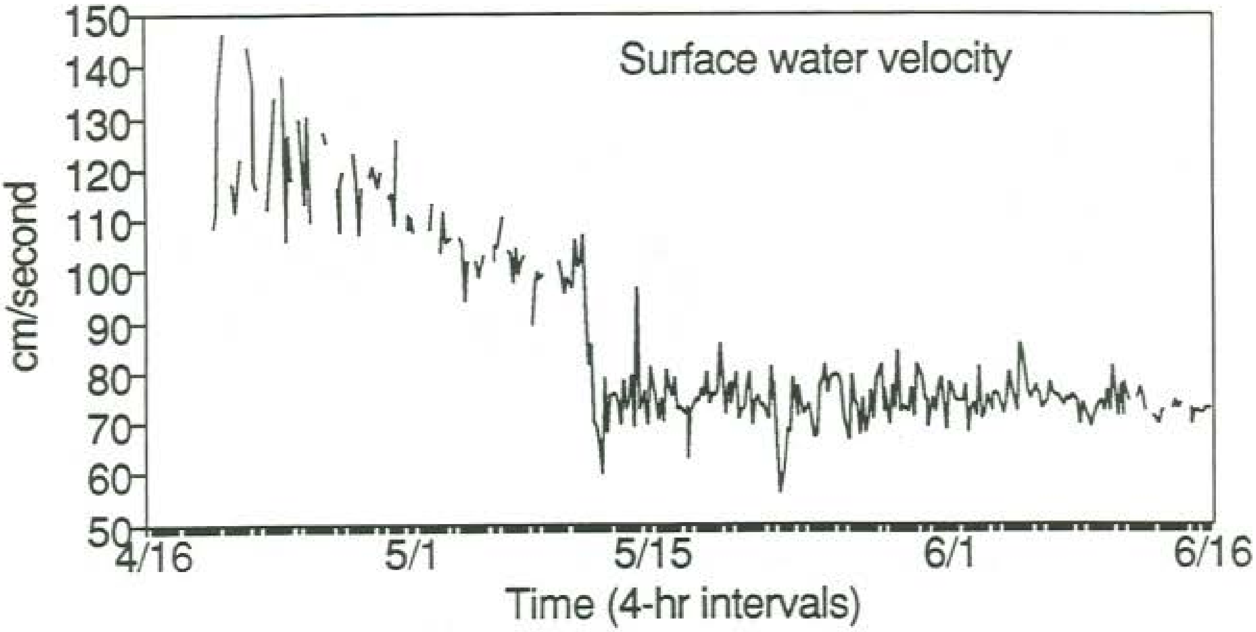

Figure 54. Surface water velocity (cm/second) measured at Barnhill's Landing, NC, for the period 16 April to 16 June 1993.

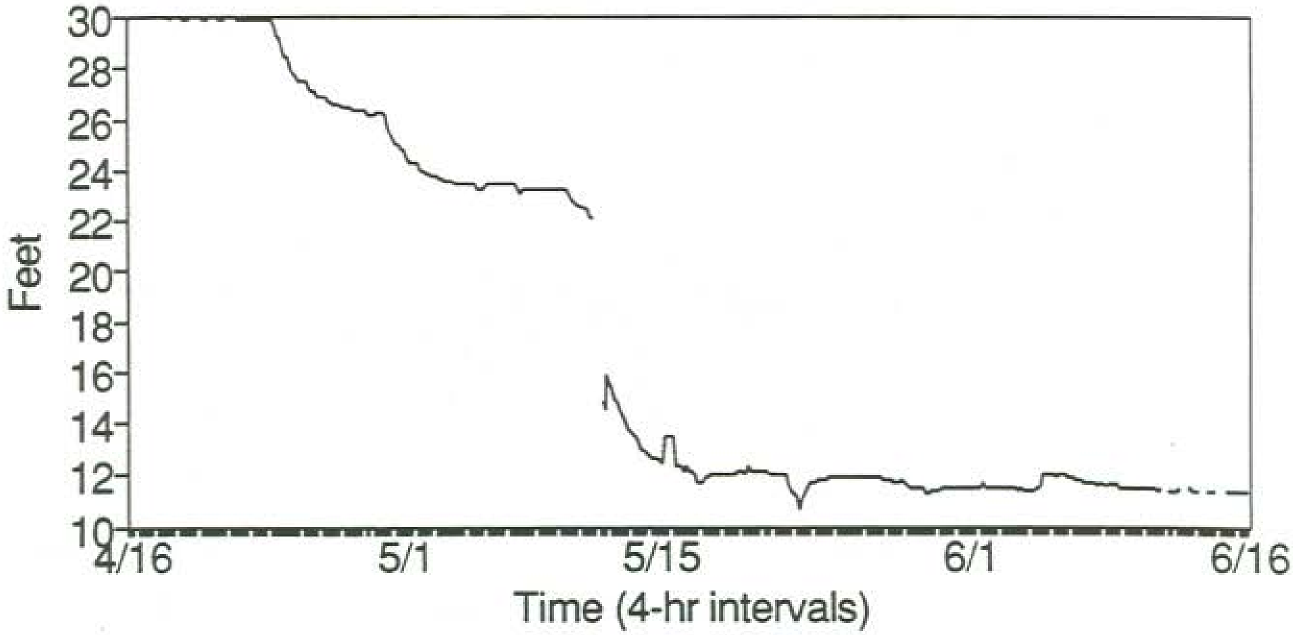

Figure 55. Relative change in Roanoke River height at Barnhill's Landing, 16 April to 16 June 1993.

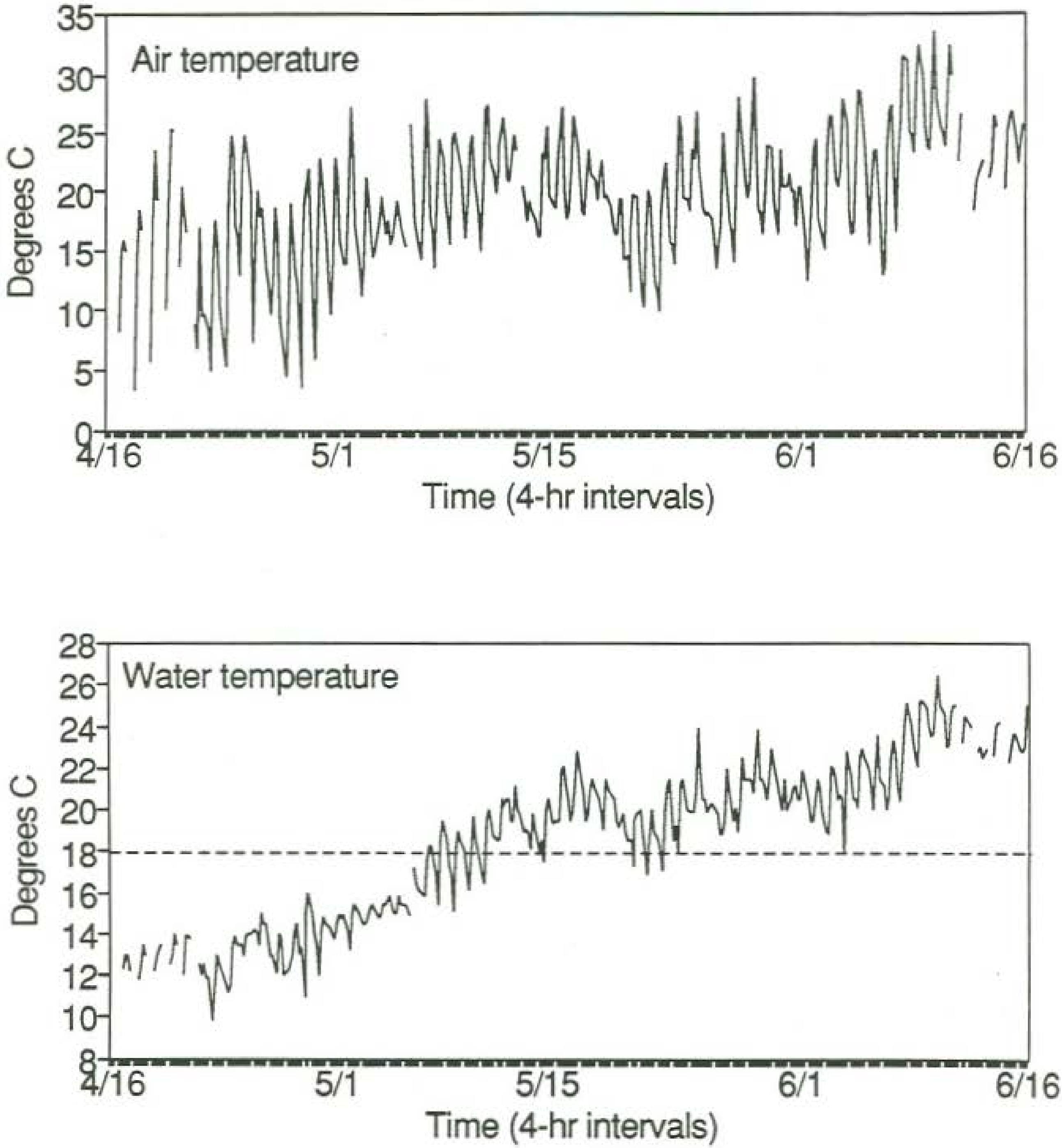

Figure 56. Air and water temperatures (°C) measured at Barnhill's Landing, NC, for the period 16 April to 16 June 1993.

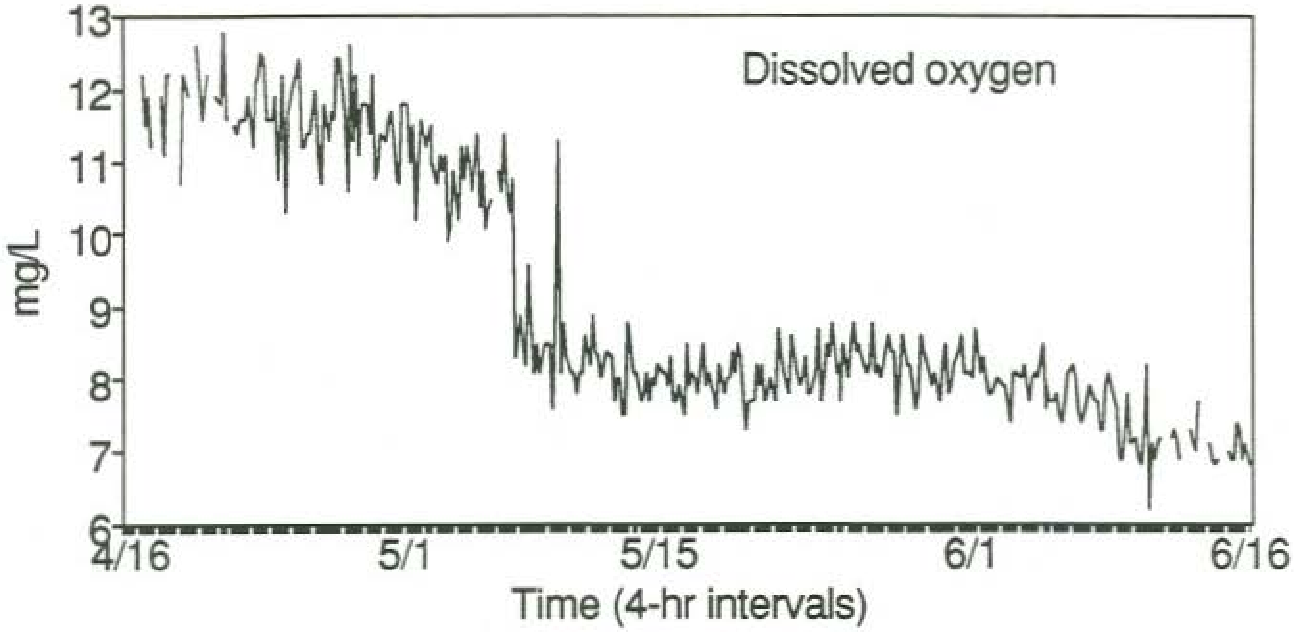

Figure 57. Changes in dissolved oxygen (mg/L) of Roanoke River waters at Barnhill's Landing, NC, for the period 16 April to 16 June 1993.

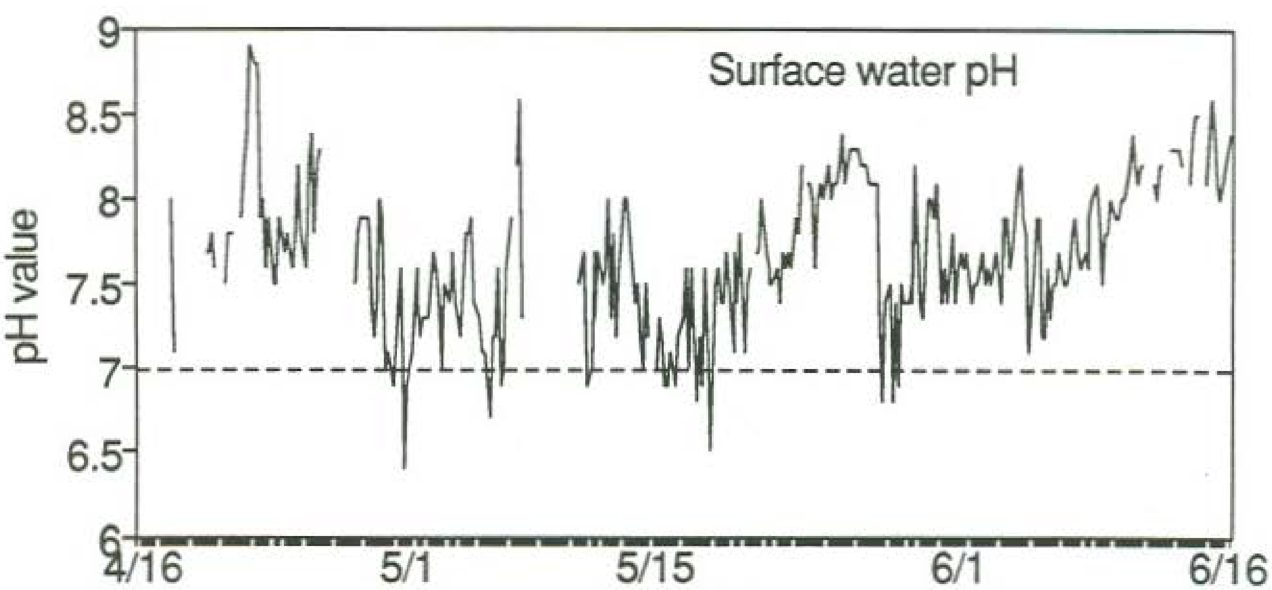

Figure 58. Changes in pH of Roanoke River surface waters at Barnhill's Landing, NC, for the period 16 April to 16 June 1993.

Table 53. Normal and observed rainfall (inches) for the Roanoke River basin downstream of Kerr Reservoir (RM 178.7), and basinwide, for April-June 1982-1993 (U.S. Army Corps of Engineers data).

	Below Kerr Dam						Basinwide					
	Normal			Observed			Normal			Observed		
Year	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun
1963	3.37	4.02	3.91	1.55	2.83	2.59						
1964	3.26	4.02	3.91	2.20	1.30	2.45						
1965	3.26	3.77	3.78	2.04	1.98	8.30						
1966	3.16	3.62	4.16	1.49	6.38	3.55						
1967	3.03	3.84	4.11	1.88	3.24	2.39						
1968	2.95	3.79	3.99	3.21	5.20	3.05						
1969	2.95	3.79	3.99	3.05	3.24	4.12						
1970	2.95	3.79	3.99	4.09	2.36	3.12						
1971	2.95	3.79	3.99	2.57	6.36	3.41						
1972	2.95	3.79	3.99	2.32	5.03	4.52						
1973	2.95	3.79	3.99	4.62	4.53	5.95						
1974	2.95	3.79	3.99	2.56	5.68	2.65						
1975	2.95	3.79	3.99	2.23	3.23	2.27						
1976	2.95	3.79	3.99	0.85	3.73	4.39						
1977	2.95	3.79	3.99	2.66	5.44	3.69						
1978	2.90	4.08	3.87	4.94	4.85	5.60						
1979	2.98	4.11	3.94	4.30	6.09	5.87						
1980	2.98	4.11	3.94	3.15	2.85	2.84						
1981	2.98	4.11	3.94	1.41	4.96	3.10						
1982	2.98	4.11	3.94	3.04	2.56	4.83						
1983	2.98	4.11	3.97	5.99[A]	3.99	2.48						
1984	2.98	4.11	3.97	4.59	6.83	2.49						
1985	3.13	4.19	3.88	1.13	3.03	3.32						
1986	3.13	4.19	3.88	1.40	1.98	0.32[B]						
1987	3.13	4.19	3.88	5.53	2.21	3.44						
1988	3.01	4.09	3.75	4.67	3.87	3.68						
1989	3.01	4.09	3.75	6.41	5.16	8.41	3.36	3.89	3.84	4.02	5.76	7.95
1990	3.22	4.06	3.87	3.37	5.83	2.34	3.40	3.87	3.83	3.51	7.55	1.76
1991	3.22	4.06	3.87	2.62	1.46	2.86	3.40	3.87	3.83	2.94	3.08	2.68
1992	3.22	4.06	3.87	1.86	3.11	6.17	3.40	3.87	3.83	4.46	4.51	4.30
1993	3.22	4.06	3.87		2.86	4.02	3.40	3.87	3.83		3.00	2.89

[A] Maximum observed April rainfall since 1952.
[B] Record low observed June rainfall.

STRIPED BASS, 1991-1993

Roanoke River Sport Fishery Creel Survey, Spring 1991-Spring 1993

Kent L. Nelson

Methods

A non-uniform probability stratified access point creel survey was used to estimate sport fishing effort, harvest, and catch rate of striped bass and other species from Roanoke River for three years: 1 January - 30 April 1991, 1 January and 19 April 1992, and 1 February and 6 June 1993. The number of striped bass released by sport anglers also was estimated. During 1993 the creel was extended beyond the period open to striped bass harvest (1 February - 25 April) to estimate catch-and-release fishing effort and numbers of striped bass released on the Roanoke River spawning grounds. The creel survey was designed by personnel from North Carolina State University, Institute of Statistics.

Spring 1991

The creel survey in 1991 was conducted throughout the unimpounded reach of the Roanoke River from the Roanoke Rapids Lake dam downstream to the River mouth at Albemarle Sound, comprising a surface area of approximately 3,016 ha (Fish 1968). The river was divided into three zones with the upper two zones (I and II) comprising the segment above the N.C. 258 bridge near Scotland Neck which is designated as inland waters. The lower zone (III) is designated as joint waters under the combined jurisdiction of the North Carolina Wildlife Resources Commission (WRC) and the North Carolina Division of Marine Fisheries (DMF). Creel design was based on two-week periods and was stratified with respect to type of day; i.e., weekday or weekend (defined as all Fridays, Saturdays, Sundays, and holidays), zone, and period. Between 1 January and 24 February, one half-day creel interview was scheduled for both weekdays and weekends for each zone per two-week period. Between 25 February and 7 April, two interviews were conducted on both weekdays and weekends in Zone I and II per period. In Zone III during this time, four interviews were scheduled for both weekdays and weekends. From 8-30 April, four interviews were conducted in Zone I and II, and two interviews conducted in Zone III for both weekdays and weekends. Two creel clerks interviewed anglers returning from fishing trips at boating access areas to provide data necessary to calculate catch per unit of effort. Probabilities of interviewing at each access area were based on its anticipated use by striped bass anglers. Data collected from each fishing party interviewed included date and time of the interview, hours fished, number of anglers in the party, catch and harvest of striped bass, largemouth bass and other species, and the county of residence of the anglers.

Total fishing effort was estimated from counts of empty boat trailers at boating access areas along the river. Counts were made on three weekdays and three weekend days per two-week period from 1 January to 24 February and on four weekdays and four weekend days per period from 25 February to 30 April. The end of the river where the trailer counts began was selected randomly, and the time of day during which trailers were counted was selected based on anticipated fishing activity. Counts were made in the morning, midday, or afternoon and probabilities for these periods were 0.3, 0.2, and 0.5 between 1 January and 7 April and were 0.3, 0.4, and 0.3 from 8-30 April. Trailer counts were adjusted to eliminate commercial fishermen, hunters, and recreational boaters. Data were adjusted based on the proportion of recreational fishermen interviewed by creel clerks within each zone by period and kind of day.

Total length in millimeters, weight in kilograms, and sex were recorded and a scale sample was collected from each striped bass harvested by interviewed anglers. Scales were removed from the left side of the fish below the lateral line near the end of the depressed pectoral fin. Scales were examined at 33x magnification on a microfiche reader and ages determined by counting annuli. Males between 400-524 mm were subsampled, with a minimum of 10 fish aged per 25-mm size group. The percentage of different age classes within the size groups was used to estimate the age distribution of all males sampled. Five females could not be aged and were assigned to the 1988 year class based on their length.

Estimates of fishing effort and catch of striped bass and other species were compiled by personnel from North Carolina State University, Institute of Statistics. Catch-per-unit-effort (CPUE = number fish/hour) was estimated for both harvested and released fish.

1992 and 1993 Surveys

The creel survey was conducted throughout the unimpounded reach of the Roanoke River from the Roanoke Rapids Lake dam downstream to the River mouth at Albemarle Sound. The river was divided into two zones with the upper zone (I) comprising the segment above the N.C. 258 bridge near Scotland Neck which is designated as inland waters. The lower zone (II) is designated as joint waters under the combined jurisdiction of the WRC and the DMF. Creel design was based on one-week periods and was stratified with respect to type of day, i.e. weekday or weekend (defined as all Fridays, Saturdays, Sundays, and holidays), zone, and period. One half of the interviews conducted during a period were on weekend days. Interviews were conducted during 1/3 of a day (early, middle or late) periods, based on the length of the day from one hour after sunrise to one hour after sunset. Equal probabilities were used to determine the interview time period, and the number of scheduled interviews were equally divided between zones in each period. Sampling effort was increased from two to four interviews per zone per week between late February and early March to reflect increased angler effort and harvest of striped bass.

Two creel clerks interviewed anglers returning from fishing trips at boating access areas to provide data necessary to calculate catch per unit of effort (CPUE = number and weight of fish per hour). Probabilities of interviewing at each access area were based on its anticipated use by striped bass anglers. Data collected from each fishing party interviewed included date and time of the interview, hours fished, number of anglers in the party, catch and harvest of striped bass, largemouth bass and other species, and the county of residence of the anglers.

Total fishing effort was estimated from counts of empty boat trailers at boating access areas along the river. As with the number of creel interviews scheduled, the frequency of pressure counts was increased from two to four per week between late February and early March. One-half of the counts were made on weekend days per period. The end of the river where the trailer counts began was selected randomly, with the day and time of the count synchronized with the creel interview schedule for Zone I. Counts were made during early, midday, or late periods, similar to the interview time periods, with periods having equal sampling probabilities. Trailer counts were adjusted to eliminate commercial fishermen, hunters, and recreational boaters. Data were adjusted based on the proportion of recreational fishermen interviewed by creel clerks within each zone by period and kind of day. Harvest was estimated as the product of mean catch rates and total fishing effort stratified by period, zone, and kind of day.

A sample of striped bass harvested by anglers was measured for total length in millimeters, weighted in kilograms, sex determined, and scale samples collected. Scales were removed from the left side of the fish below the lateral line near the end of the depressed pectoral fin. Scales were examined at 33x magnification on a microfiche reader and ages determined by counting annuli. Percent age composition for male striped bass was calculated based on subsamples during all years, while females were subsampled only in 1993. A minimum of 50 fish were aged per 25-mm size group for each sex. Males from 425-499 mm were subsampled in 1992 and males from 450-499 mm were sub-sampled in 1993. Females from 500-549 mm were sub-sampled in 1993. The proportions of each age group in each 25-mm size group were computed and then expanded to the total number of fish within each size group. One female could not be aged in 1992 and was assigned to the 1988 year class based on length. Mean length at capture was calculated from lengths of aged fish for each age group.

Estimates of fishing effort and catch of striped bass and other species were made using a computer program designed by personnel from North Carolina State University, Institute of Statistics on an IBM-compatible microcomputer. CPUE was estimated for both harvested and released striped bass.

Results

1991 Survey

The creel survey was conducted between 1 January and 30 April 1991. A total of 725 angler parties were interviewed during 69 half-day creel surveys. Striped bass harvest was prohibited by regulation on 1 May. An estimated total of 116,103 angler-hours (approximate standard error (ASE) = 10,637) of sport fishing effort were exerted by Roanoke River anglers for all species combined during the creel survey. Most of the effort (54%) occurred in Zone III, while 15% and 31% of the effort was in Zone I and Zone II.

Approximately 74,596 angler-hours of recreational fishing effort were directed specifically for striped bass (Table 54). Most of the effort for striped bass in 1991 (67%) was concentrated near the spawning grounds and occurred after 24 March. Effort for striped bass peaked between 22 and 30 April, just prior to closure of the striped bass season.

Estimated total weight of striped bass harvested from the Roanoke River was 32,893 kg (72,365 lbs). Estimated number of striped bass harvested was 26,934 fish. An estimated 98,148 striped bass were caught and released in 1991. Eighty-nine percent of the harvest of striped bass by number and 97% of the fish that were caught and released occurred in the upper river.

CPUE for harvested striped bass by sport fishermen on the Roanoke River was 0.344 fish per angler hour between 25 March and 30 April 1991. CPUE was highest in the upper river with anglers harvesting striped bass at the rate of 0.566 fish/angler-hour (ASE = 0.112) in Zone I and 0.494 fish/angler-hour (ASE = 0.118) in Zone II. CPUE for harvested striped bass in Zone II was 0.055 fish/angler-hour (ASE = 0.006). Striped bass were caught and released at the rate of 1.248 fish per angler-hour between 25 March and 30 April.

Males comprised 87% of 1,329 striped bass examined during 1991. Most of the males and females harvested were <525 mm. Ages were determined for 76 males and 179 females (Tables 55 and 56). Males and females ranged in age from 2-8 years. Most males and females were three years old (1988 year class), which comprised 86% of the total harvest.

Table 54. Striped bass recreational catch characteristics from Roanoke River, 1988 - 1991. (Standard errors are in parentheses).

	1988[a]	1989[b]	1990[c]	1991[d]
Number harvested	16,657 (9,736)	8,753 (2,355)	15,694 (4,829)	26,934 (6,945)
Weight harvested (kg)	33,927 (21,861)	14,594 (3,891)	19,143 (6,890)	32,893 (8,569)
Number released	8,898 (4,040)	8,666 (2,312)	52,372 (23,441)	98,148 (27,506)
CPUE[e]	0.075 (0.023)	0.058 (0.008)	0.163 (0.019)	0.344[f] (0.086)
Effort[g]	99,981 (30,481)	46,566 (11,128)	56,169 (18,117)	74,596 (10,047)

[a]28 March - 19 June
[b]27 March - 18 June
[c]26 March - 9 May
[d]1 Jan - 30 April
[e]No. harvested/hr.
[f]25 March - 30 April
[g]Angler-hrs.

Table 55. Age composition and mean length at capture of a subsample of male striped bass from the Roanoke River creel survey, 1 January to 30 April 1991.

				Total length (mm)		
Year class	Age	N aged	Estimated N (% Composition)	Mean	Min.	Max.
1989	2	11	122[a] (10.5)	413[b]	397[b]	427[b]
1988	3	37	997[a] (86.1)	468[b]	422[b]	517[b]
1987	4	10	21[a] (1.8)	528[b]	501[b]	555[b]
1986	5	8	8 (0.7)	555	531	580
1985	6	4	4 (0.3)	609	573	638
1984	7	5	5 (0.4)	652	611	697
1983	8	1	1 (0.1)	732	---	---

[a]based on subsample estimate
[b]based on lengths of male striped bass in subsample

Table 56. Age composition and mean length at capture of a subsample of female striped bass from the Roanoke River creel survey, 1 January to 30 April 1991.

Year class	Age	N aged	Estimated N (% Composition)	Total length (mm) Mean	Min.	Max.
1989	2	1	1 (0.5)	433	---	---
1988	3	156	161 (87.5)	487	440	538
1987	4	15	15 (8.2)	524	503	543
1986	5	3	3 (1.6)	595	565	620
1985	6	1	1 (0.5)	655	---	---
1984	7	2	2 (1.1)	784	755	813
1983	8	1	1 (0.5)	790	---	---

1992 and 1993 Surveys

A total of 583 angler parties comprised of 1,280 fishermen were interviewed during 92, 1/3-day creel surveys between 1 January and 19 April 1992. Between 1 February and 25 April 1993, 388 angler parties comprising 804 fishermen were interviewed during 80 creel surveys. To limit harvest in relation to the recreational poundage quota for the Roanoke River (29,400 lbs), harvest was prohibited by regulation effective on 20 April 1992 and 26 April 1993. Total sport fishing effort on the Roanoke River for all species was estimated at 75,505 and 82,106 angler-hours in 1992 and 1993 during the period open to striped bass harvest (Table 57). Most of the fishing occurred in Zone II, which comprised 64% of the total in 1992 and 80% in 1993.

An estimated 49,277 angler-hours of recreational fishing effort were directed specifically for striped bass in 1992 and 52,932 hours in 1993 during the period open to harvest (Table 57). Almost 8,000 hours of additional effort for striped bass occurred on the spawning grounds during the five-week period surveyed after season closure. Effort for striped bass in 1992 was about equally divided between zones, while in 1993, 75% of fishing for striped bass occurred in Zone II. Effort for striped bass peaked during the last two weeks of the season in both years.

Estimated total weight of striped bass harvested from the Roanoke River was 16,334 kg (35,935 lbs) in 1992 and 20,474 kg (45,146 lbs) in 1993. Most of the harvest by weight occurred in Zone I (74%) in 1992, while 73% of the harvest in 1993 was in Zone II. An estimated 13,372 and 14,325 striped bass were harvested in 1992 and 1993. The number of striped bass caught and released during the open season was estimated at 23,710 in 1992 and 10,566 in 1993. An additional 46,225 striped bass were caught and released on the spawning grounds after season closure in 1993.

CPUE for harvested striped bass by sport fishermen on the Roanoke River was 0.30 fish per angler hour between 30 March and 19 April 1992. CPUE was highest in the upper river with anglers harvesting striped bass at the rate of 0.47 fish per angler-hour in Zone I and 0.12 fish per angler-hour in Zone II. Between 29 March and 25 April 1993, CPUE for harvested striped bass was 0.30 fish per hour in Zone I and 0.21 fish per hour in Zone II, for a mean value of 0.23 fish per hour for the entire river. CPUE for striped bass that were caught and released declined from 0.53 fish per hour in 1992 to 0.16 fish per hour during 1993. CPUE for released striped bass was 6.14 fish per hour on the spawning grounds during the closed season in 1993.

Table 57. Recreational fishing effort and striped bass catch statistics from Roanoke River, 1992 - 1993. (Standard errors are in parentheses).

	Year		
	1992	1993	
	1/1-4/19[a]	2/1-4/25[a]	5/1-6/6[b]
Number harvested	13,372 (3,434)	14,325 (4,273)	
Weight harvested (kg)	16,334 (4,342)	20,474 (6,054)	
Number released	23,710 (6,401)	10,566 (3,278)	46,225 (15,395)
CPUE[c]	0.302[d] (0.050)	0.232[e] (0.058)	6.137[f] (0.802)
Effort[g] - striped bass	49,277 (9,809)	52,932 (9,723)	7,934 (1,279)
- all species	75,505 (12,460)	82,106 (9,500)	8,547 (1,403)

[a]Period open to harvest of striped bass, Zone I and II.
[b]Period closed to harvest of striped bass, Zone I only.
[c]Catch per unit effort: number of striped bass per hour.
[d]Number harvested per hour, 30 March - 19 April.
[e]Number harvested per hour, 29 March - 25 April.
[f]Number released per hour.
[g]Angler-hours.

Males comprised 87% of 796 striped bass examined during 1992 and 56% of 569 fish in 1993 (Tables 58 and 59). Ages were determined for 321 striped bass in 1992 and 338 in 1993. During the 2 years, males ranged from 2 to 5 years old and females ranged in age from 3 to 11. Most males were age 3 and 4, while most females were 4-year-olds during both years. The 1989 year class comprised 78 and 67% of the harvest in 1992 and 1993. The relative contribution of the 1988 year class declined from 20% in 1992 to 5% in 1993.

Table 58. Age composition and length and weight at capture for a subsample of striped bass from the Roanoke River creel survey, 1 January to 19 April 1992.

Year class	Age	N aged	Estimated N (% composition)	Total length (mm)[a] Mean	Min.	Max.	Mean weight (kg)[a]
Males							
1990	2	6	10[b] (1.4)	420	408	433	0.8
1989	3	149	603[b] (87.4)	448	403	509	1.0
1988	4	61	77[b] (11.2)	498	476	528	1.5
Females							
1989	3	18	18 (17.0)	488	435	558	1.3
1988	4	85	86[b] (81.1)	523	472	576	1.7
1987	5	1	1 (0.9)	556			2.2
1986	6	1	1 (0.9)	662			3.8

[a]Based on aged fish.
[b]Based on subsample estimate.

Table 59. Age composition and length and weight at capture for a subsample of striped bass from the Roanoke River creel survey, 1 February to 25 April 1993.

Year class	Age	N aged	Estimated N (% composition)	Total length (mm)[a] Mean	Min.	Max.	Mean weight (kg)[a]
Males							
1990	3	74	150[b] (47.5)	461	423	502	1.2
1989	4	85	151[b] (47.8)	492	445	533	1.4
1988	5	15	15 (4.7)	527	514	563	1.8
Females							
1990	3	5	5 (2.0)	473	454	483	1.2
1989	4	145	233[b] (92.1)	511	470	560	1.5
1988	5	13	14[b] (5.5)	559	525	620	2.1
1982	11	1	1 (0.4)	867			9.0

[a]Based on aged fish.
[b]Based on subsample estimate.

Assessment of Striped Bass Spawning Stock in Roanoke River

Kent L. Nelson

Since 1991, the North Carolina Wildlife Resources Commission has sampled striped bass on the spawning grounds near Weldon and Roanoke Rapids to determine the sex ratio and age composition of the spawning stock. The spawning stock has been comprised primarily of male fish, representing 83, 87, and 70% of the total number captured during the three years. Results indicated that a greater proportion of striped bass migrated to the spawning grounds at age 3 than at age 2, and that females did not migrate in equal proportions to males until at least age 4. This is likely an effect of differential maturation. Roanoke River striped bass males mature at 2 - 3 years old, whereas some females are mature at age 4 and all are mature by age 6 (Olsen and Rulifson 1992). Differential migration of striped bass as a function of age and sex is supported by spring gill net sampling in western Albemarle Sound during the spawning season (L. Henry, NCDMF, personal communication), a phenomenon documented by Hassler's work spanning 30 years.

During the three years, captured fish ranged from one to 10 years old; however, few fish older than age 5 were found during any year. The spawning stock has been dominated by the 1989 year class, which comprised 71, 78, and 64% of the fish captured from 1991 - 1993. The relative proportion of the 1988 year class has declined from 25% in 1991 to 12% (1992) and 4%(1993). The percentage of fish older than age 5 in the spawning stock has ranged from 1.5% in 1991 to 0.6% in 1993.

To examine changes in the relative abundance of striped bass captured by electrofishing between years, catch per unit effort (CPUE = number of fish per hour) data were analyzed. Results suggested that, by year class, striped bass are not present on the spawning grounds relative to their abundance in the population until at least age 4. CPUE comparisons between years have indicated a relative increase in number of females on the spawning grounds, comprised primarily of the 1988 and 1989 year classes. To evaluate the changes in the relative abundance of females between years on the spawning potential, a spawning index was developed based on age composition of females on the spawning grounds, mean fecundity and percent maturation at each age, and CPUE of females age 3 and older:

$$\text{Spawning index} = \left(\left(\sum_{i=3}^{k} (Ci)(Mi)(Fi)\right)(CPUE)\right) / 10^6$$

where C = percent of females at $age_{i(3-k)}$
M = percent of females mature at age_i
F = fecundity at age_i
$CPUE$ = catch per unit effort (n/hour) of females $\geq$ age 3

Percent maturation and fecundity at each age were based on Olsen and Rulifson (1992). Index values have increased markedly between 1991 and 1993 (Figure 59), mirroring increases observed in the estimates of striped bass egg production (Rulifson et al. 1993). Most of the increase in the 1993 spawning index can be attributed to 1989 year class females, which comprised 83% of the females captured on the spawning grounds.

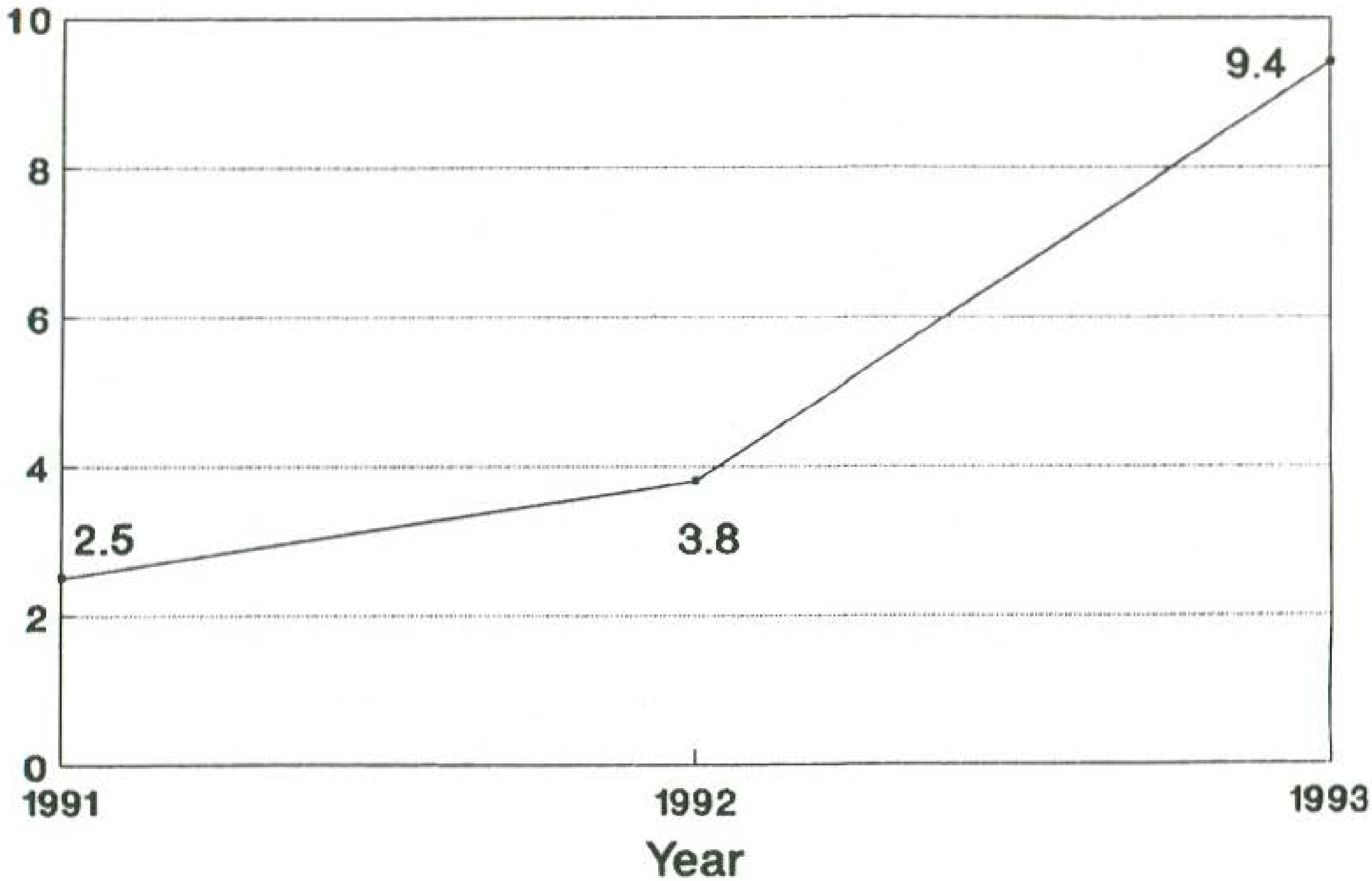

Figure 59. Spawning index, Roanoke River 1991-1993.

Commercial and Recreational Landings of Striped Bass in Albemarle Sound, 1991-1993

Lynn T. Henry

Commercial fishermen landed 161,009 pounds of striped bass valued at $204,434 in North Carolina during 1992, and 223,109 pounds valued at $285,085 during 1993 (Table 60). Historically, most of the fish have been caught in the Albemarle Sound area by set gill nets and pound nets. From 1980 to 1992, 63 to 96% of the striped bass landed by commercial gear in the State came from the Albemarle Sound area (Table 60). The remaining small percentages were caught in the Atlantic Ocean, and other riverine-estuarine systems, such as the Neuse, Pamlico, and Cape Fear. No commercial landings were reported from the Roanoke River from 1987 through 1993.

A multitude of fishing regulations (refer to Table 63) imposed by the NCWRC and NCDMF since the mid-1970s has complicated efforts to assess the striped bass resource in North Carolina. For instance, a once thriving commercial fishery, which had operated in the Roanoke River since colonial times, has been eliminated. In Albemarle Sound, commercial fishermen have seen restrictions placed on types and sizes of gear, fishing locations, minimum size limits, and closed seasons. The latter was imposed in 1984 and is clearly reflected in Table 61. In recent years, most of the fish have been caught from January through April. Recreational fishermen also have been restricted. Daily creel limits have been reduced from 25 fish to eight fish in 1980, and from eight fish to three fish in 1985. During the fall of 1989, NCDMF instituted the first recreational season closure on striped bass harvest for North Carolina's internal coastal waters in an effort to further protect the 1988 year class from excessive harvest. The recreational season also was closed from May through December 1990 for the internal coastal waters, resulting in the first long-term closure of this fishery.

The recreational harvest of Albemarle Sound striped bass has been evaluated sporadically. The first efforts to assess striped bass harvest were conducted by Hassler et al. (1981) from 1967 to 1973. Striped bass harvest was also estimated during 1977-1979 (Table 62) through a NCWRC sport fishery survey of Albemarle, Croatan, and Currituck Sound areas (Mullis and Grier 1982). A more recent harvest estimation, 1991-1993, was conducted by the NCDMF in an effort to manage an annual recreational striped bass harvest allocation of 29,400 pounds for the Albemarle Sound area. The NCDMF survey design was similar to the earlier NCWRC survey.

An estimated 43,835 vessel-hours (337,830 angler-hours) of directed recreational hook-and-line fishing effort was expended for striped bass during 1991 (Table 62). The majority of this effort (96%) occurred during the five-month (January-April and November) harvest season. Estimated striped bass recreational harvest totaled 14,869 fish, weighing 37,399 pounds (Henry and Phalen 1993). The estimated number of striped bass released during 1991 totaled 43,175 fish, with approximately 42% of the releases occurring during the closed striped bass season.

Age 3 fish of the 1988 year class (71%) dominated the 1991 recreational harvest followed by age 2 fish of the 1989 year class. These year classes correspond to the highest successive juvenile abundance indices since 1975-1976. The age structure of the Albemarle area recreational harvest was a direct function of the minimum size limits and the growth of the 1988 and 1989 year classes. Increasing the minimum size limits during 1990 and 1991 from 14 inches to 16 inches to 18 inches occurred concurrent with growth of the 1988 year class, forcing recreational fishermen to exert increased fishing pressure on this relatively abundant year class (Henry and Phalen 1992).

Albemarle Sound recreational fishermen directed an estimated 31,220 vessel-hours (198,976 angler-hours) for striped bass during 1992 (Table 62). The majority of the effort (81%) occurred during the five-month (January - April and November) harvest season. An estimated 10,542 striped bass, weighing 30,758 pounds were harvested. Estimated striped bass releases totaled 42,165 fish. Approximately 59% of the releases were during the closed striped bass season. Age 3 fish of the 1989 year class (73%) dominated the harvest followed by age 4 fish of the 1988 year class (25%).

Directed effort estimates for striped bass totaled 21,705 vessel-hours (161,070 angler-hours) during the January - June 1993 Albemarle Sound creel survey (Table 62). Approximately 94% of the directed effort for striped bass occurred during the open harvest season (1 February - 18 April). Recreational harvest estimates totaled 11,404 striped bass, weighing 36,049 pounds. The estimated number of striped bass released was 13,241 fish, with approximately 43% of the releases occurring during the closed harvest season. The majority (75%) of the striped bass harvested were age 4 fish of the 1989 year class. The 1990 year class (age 3) comprised approximately 15% of the catch. Eight percent of the harvest was from the 1988 year class (age 5).

Current and past harvest estimates, from the Albemarle Sound and Roanoke River recreational fisheries and recent commercial landing levels, suggest that commercial and recreational interests may be harvesting approximately equal poundage. Albemarle Sound recreational harvest estimates made by Hassler et al. (1981) and Mullis and Guier (1982) indicate that the best striped bass fishing occurs from October through April, with the greatest catches occurring during October and November.

Restrictions on fishing have been imposed because of the expressed public concern for the decline of striped bass in the State. Without the recently implemented commercial and recreational striped bass harvest management measures noted in Tables 62 and 63, the directed striped bass effort and harvest during 1991 through 1993 would have increased significantly due to the increased abundance of the 1988 and 1989 year classes.

The state agencies are working closely with the Atlantic States Marine Fisheries Commission (ASMFC), which is a board of representatives of the Atlantic coastal states chartered for the purpose of managing interjurisdictional fishery resources, including striped bass. Through this management plan, North Carolina is striving to adopt management options that complement the intent of the ASMFC coastwide management plan for striped bass. Although the two commissions (NCWRC and NCDMF) generally represent separate constituencies, they realize that management of the stock must be a shared responsibility. A statewide management plan for the species is being developed by the State agencies (Note: see the section on updated striped bass conservation regulations).

Both commissions and federal agencies face unique problems as the plan is moved forward. The NCWRC must evaluate the impacts of fishing on the spawning grounds, something that is not permitted in any other state on the east coast, and the NCDMF must manage controversial gill net and pound net commercial fisheries that operate in Albemarle Sound. These gear catch a variety of finfish, not just striped bass (i.e., white perch, yellow perch, white catfish, channel catfish, bullheads, shad, herring, flounder, and sciaenids). Elimination of catches of other fishes would be an economic disaster to local fishermen and their families. The NCDMF has tested the feasibility of fyke nets as an alternative to anchor gill nets in the Albemarle Sound area white perch fishery (Winslow and Henry 1992). Results of the study indicate that fyke nets would only be economically feasible during January through April, principally for yellow perch and to a lesser extent for white perch. The efficiency of the fyke nets in the white perch fishery could not be adequately evaluated due to the depressed status of the Albemarle Sound white perch stock.

Table 60. Commercial harvest of striped bass in North Carolina, 1980-1993 (data from N.C. Division of Marine Fisheries).

Year	Statewide		Albemarle Sound area (including Roanoke R.)		Percent of total landings
	Pounds	Value	Pounds	Value	
1980	472,503	435,479	376,510	318,054	79.7
1981	417,324	451,824	333,484	325,315	79.9
1982	338,310	531,470	228,004	316,222	67.4
1983	361,275	491,491	288,742	323,281	79.9
1984	512,896	452,002	475,640	381,378	92.7
1985	279,940	229,586	269,671	219,925	96.3
1986	188,992	189,859	172,683	171,220	91.4
1987	262,221	262,542	228,861	228,312	87.3
1988	115,915	116,776	108,791	109,364	93.9
1989	100,830	101,002	97,061	97,061	96.3
1990	113,939	159,630	103,757	145,905	91.1
1991	122,816	174,399	108,460	155,538	88.3
1992	161,009	204,434	100,549	134,384	62.5
1993*	223,109	285,085	83,735	105,084	37.5

* 91,236 pounds of the statewide landings were possibly illegally harvested from Albemarle Sound, transported, and sold in other areas.

Table 61. Commercial landings (pounds) of striped bass by month in the Albemarle Sound area (including Roanoke River), 1982-1993 (data from N.C. Division of Marine Fisheries).

Month	1982	1983	1984	1985	1986	1987*	1988*	1989*	1990*	1991*	1992*	1993*
JAN	33,470	15,344	97,507	54,096	34,875	28,565	13,972	7,913	38,979	32,618	32,300	0
FEB	22,048	17,009	31,953	23,887	12,125	68,513	9,098	5,560	5,448	13,298	24,791	46,554
MAR	36,289	29,847	14,452	30,677	36,196	38,158	20,297	14,795	38,074	39,455	25,217	31,860
APR	50,884	27,689	28,547	38,965	0	56,074	9,807	8,701	21,256	15,848	14,127	5,321
MAY	23,007	21,167	12,718	24,289	0	0	0	0	0	0	0	0
JUN	8,878	1,970	10,995	0	0	0	0	0	0	0	0	0
JUL	7,457	1,089	6,187	0	0	0	0	0	0	0	0	0
AUG	8,007	850	0	0	0	0	0	0	0	0	0	0
SEP	9,594	5,800	0	0	0	0	0	0	0	0	0	0
OCT	13,269	69,026	93,499	0	0	0	0	0	0	0	0	0
NOV	5,964	23,294	129,425	27,662	48,447	26,554	43,955	60,092	0	4,865	4,114	0
DEC	9,137	75,657	50,357	70,095	41,043	11,007	11,662	0	0	2,376	0	0
Total	228,004	288,742	475,640	269,671	172,683	228,861	108,791	97,061	103,757	108,460	100,549	83,735 **

*No reported commercial landings from the Roanoke River.

**An additional 91,236 pounds were possibly illegally harvested from Albemarle Sound, transported, and sold in other areas.

Table 62. Creel survey estimates for the recreational hook-and-line striped bass fishery in the Albemarle Sound area (excluding Roanoke River) during 1977-1979 (Mullis and Guier 1982) and 1991-1993 (Henry and Phalen 1993).

Year	Directed effort (vessel-hours)	Directed effort (angler-hours)	Number harvested	Weight harvested (lbs)	Number released
1977[a]	61,454	-	33,202	71,883	-
1978[a]	61,909	-	16,599	30,921	-
1979[a]	41,382	-	5,235	12,555	-
1991[b]	43,835	337,830	14,869	37,399	43,175
1992[c]	31,220	198,976	10,542	30,758	42,165
1993[d]	21,705	161,070	11,404	36,049	13,241

[a] Estimates are from an annual striped bass season with no daily creel limit and a 12-inch (TL) minimum size limit.

[b] Annual estimates with a five-month striped bass harvest season and a three-fish daily creel limit. Minimum size limit was 16 inches (TL) during January - April 1991 and 18 inches (TL) during November 1991.

[c] Annual estimates with a five-month striped season, a three-fish daily creel limit, and an 18-inch (TL) minimum size limit. One fish daily creel limit during November 1992.

[d] Estimates from six-month survey with a two and one-half month striped bass harvest season, a three-fish daily creel limit, and an 18-inch (TL) minimum size limit.

Update on Striped Bass Regulations

Lynn T. Henry

Major regulatory actions implemented by the North Carolina resource management agencies from 1979 through 1993 are presented in Table 63. Several regulations enacted during 1990 and 1991 resulted in significant harvest reductions and/or conservation of the recently expanding Roanoke-Albemarle striped bass stock, particularly the 1988 and 1989 year classes.

During October 1990, the N.C. Marine Fisheries Commission (MFC) and the N.C. Wildlife Resources Commission (WRC) adopted rules (effective January 1991) to divide the management responsibilities for recreational hook-and-line fishing in the Albemarle area coastal joint waters. The coastal joint waters affected by these rules included the Albemarle, Currituck, Roanoke, and Croatan sounds and their tributaries. In order to effectively manage the recreational harvest for Albemarle-Roanoke striped bass, two distinct management areas were established through the implementation of these new rules, thus allowing each commission to independently regulate that portion of the fishery over which they have authority. In the past both commissions had to agree on any proposed rule changes before implementing any action. This management system often led to delays and ineffective management.

The new management system grants each commission exclusive authority to open and close recreational striped bass harvest seasons and areas in their respective management area. The Wildlife Resources Commission has management authority for hook-and-line harvest in the joint and inland waters of the *Roanoke River Recreational Harvest Management Area* (Roanoke, Cashie, Middle, and Eastmost rivers and their tributaries). The Marine Fisheries Commission manages the hook-and-line harvest in the remaining internal coastal, joint, and inland fishing waters of the *Albemarle Sound Recreational Harvest Management Area* (Albemarle, Currituck, Roanoke, and Croatan sounds and their tributaries). Harvest management in the two areas is currently based upon an annual total allowable poundage allocation. The annual recreational harvest allocation is divided equally between the two management areas. Creel surveys to estimate landings are being conducted in both areas in order to effectively manage the harvest. In addition, each commission will develop a management plan consistent with the guidelines established in the Atlantic States Marine Fisheries Commission's Striped Bass Management Plan.

Subsequent to these rules the MFC and WRC entered into a memorandum of agreement to provide stewardship and continuity of management for the Albemarle-Roanoke striped bass restoration efforts. The memorandum established an annual total allowable harvest allocation (pounds) equal to 20% of the average harvest from the years 1972-1979. The memorandum further established a mechanism for future increase and/or decrease in the harvest allocation relative to the historical harvest by the commercial and recreational user groups. As restoration of the stocks progresses, commercial and recreational interests will share equally in that total allowable harvest allocation.

The N.C. Division of Marine Fisheries (DMF) continues to regulate the Albemarle Sound commercial striped bass fishery relative to an annual total allowable poundage allocation which was implemented in 1988. The recruitment of the relatively abundant 1988 and 1989 year classes into the 1990 and 1991 fisheries have led to additional restrictions, particularly on the existing multi-species gill net fisheries of the Albemarle Sound area. In order to reduce the harvest and wastage of striped bass, some gill net mesh sizes have been eliminated or restricted seasonally. During 1991, harvest permits were implemented for individual fishermen or operations which may land or sell striped bass from the Albemarle Sound management area. Permitted harvesters were required to maintain log books of their daily fishing activity. Daily landings limits, increased minimum size limits, and area gear restrictions were also implemented in 1991 and have continued through 1993.

During February 1990, the DMF established the first commercial and recreational Atlantic Ocean striped bass harvest seasons since 1984. A harvest moratorium was implemented in 1984 to protect the striped bass overwintering off North Carolina, in response to the coastwide declines in the Atlantic migratory stocks. The Atlantic Ocean striped bass fishery is currently managed under the guidelines of the Atlantic States Marine Fisheries Commission (ASMFC) Striped Bass Fishery Management Plan - Amendment 4. The plan requires a 28-inch (TL) minimum size limit in the ocean, reduced seasons and a maximum harvest allocation (pounds). The season was allowed due to an increase in the Atlantic migratory population, principally the Chesapeake stocks. Restricted striped bass harvest seasons in the Atlantic Ocean have continued through 1993.

Table 63. Regulations resulting in conservation and/or reduction in striped bass harvest for coastal North Carolina (principally in the Roanoke River-Albemarle Sound area, North Carolina, 1979-1993). DMF = North Carolina Division of Marine Fisheries; WRC = North Carolina Wildlife Resources Commission. Month = month in which regulation was passed.

Prior to 1979	Minimum size limit 12 inches (TL) for inland (WRC), internal coastal (DMF) and joint waters (WRC and DMF).
	No trawling in Albemarle and Croatan Sounds between 1 December and 31 March.
	Roanoke River drift gill nets attended at all times (DMF).
1979	Changed gill net mesh size from 3 1/4 to 3 1/2 inch in western Albemarle Sound and Chowan River, summer and fall (DMF/July).

Table 63. (Continued)

	Defined small mesh ("Mullet Nets" to be used only in the eastern Albemarle Sound (DMF/July)
1980	Creel limit reduced to eight fish per day in inland waters (WRC).
	Field possession limit reduced to one day's creel limit in inland waters (WRC).
	Eliminated set gill nets in Roanoke River for April-May and restricted mesh size of drift nets, resulting in sharply curtailed landings (Hassler 1984) (DMF/Oct.).
1981	Roanoke River bow netting eliminated on spawning striped bass (WRC).
	Possession of large dip nets prohibited in the inland waters of Roanoke River (WRC).
	Extended drift gill net regulations to mouth of Roanoke, Middle, Eastmost, and Cashie Rivers proper (DMF/Oct.).
1982	Minimum size limit of striped was increased to 16 inches (TL) in inland waters (WRC).
1983	Eliminated use of small mesh gill nets in Currituck Sound, increased minimum mesh to 3 1/2 inches (June-December) (DMF/Jan.).
	Roanoke River, reinstituted use of set gill nets in April-May of 3.0 inch and less. No more than one drift gill net may be used per boat (DMF/Jan. and Oct.).
	Eliminated use of 3 1/4-inch gill net (June-December) in all of Albemarle Sound and tributaries, increased minimum mesh to 3 1/2 inches (DMF/Oct.).
	Prohibited possession of striped bass on a vessel using a trawl in internal coastal waters (DMF/Jan.).
1984	First limited commercial season for striped bass October-May (DMF/Aug.).
	Minimum mesh 3 1/2-inch October-December (DMF/Aug.). Eliminated use of gill nets in Albemarle Sound and tributaries during June-September, except defined "Mullet Nets" (2 1/2-3.0-inch), floating, and within 300 yards of shore) (DMF/Aug.).
	First reduction in hook-and-line creel limit (eight fish/day) and increase in striped bass minimum size limit to 16 inches (TL) for internal joint and coastal waters (June-September) (DMF/Aug.).
	Unlawful to sell or offer for sale any striped bass from June-September (DMF/Aug.).
	First striped bass size limit for Atlantic Ocean (24 inches TL) (DMF/Aug.).
	Closure of Atlantic Ocean to the harvest of striped bass by proclamation (DMF/Aug.).

Table 63. (Continued)

1985	Year-round reduction in creel limit for inland waters to three fish/day (WRC).
	Sale of striped bass taken from inland waters of Roanoke River prohibited (N.C. General Assembly).
	Roanoke River, eliminated all gill nets June-September (DMF/Feb.).
	Reduction in striped bass commercial season (November-March). Unlawful to sell or possess striped bass taken from commercial gear except during the open season (DMF/Aug.).
	Revisions for summer gill net use (June-September), which allowed 5.0-inch and greater "Flounder Nets" and attendance at all times provisions for "Mullet Nets" in Albemarle Sound and tributaries (DMF/Aug.).
	Hook-and-line creel reduced to three fish/day in internal coastal and joint waters year-round. Hook-and-line-caught striped bass may not be sold (DMF/Aug.).
	Minimum size limit increased to 16 inches (TL) for joint waters (DMF/Aug.).
	Minimum size limit increased to 14 inches (TL) for internal coastal waters (DMF/Oct.).
1986	Minimum size limit increased to 16 inches (TL) for internal coastal waters (DMF/Oct.).
	Repealed 16-inch (TL) size limit and reverted back to the 14-inch (TL) minimum size limit for internal coastal waters (DMF/Nov.).
	Revisions to depth of water and net size for the fall gill net regulations (October-December) to allow for increased striped bass conservation without severely impacting the harvest of white perch and catfish (DMF/Nov.).
	Established proclamation authority to open or close a portion of the striped bass season (October and April) (DMF/Nov.).
	Aligned Currituck Sound net regulations with the Albemarle Sound regulations relative to striped bass conservation measures (DMF/Nov.).
	Eliminated the harvest and sale of striped bass from the spring Albemarle Sound gill net fishery and Roanoke River delta pound net fishery (DMF) (Effected by Aug. 1985 regulation).
1987	Eliminated all trawling in Albemarle Sound and tributaries year-round (DMF/Dec.).
	Closed a portion of western Albemarle Sound to gill netting (Batchelor Bay area) and restricted the spring pound net fishery in the Roanoke River delta by proclamation (DMF/Apr.).
1988	Striped bass size limit in Atlantic Ocean will correspond to the recommendation of the ASMFC interstate striped bass plan (DMF/Sept.).

Table 63. (Continued)

	Allow use of "mullet gill nets" in Currituck Sound between 2 1/2-3 1/4-inch, maximum of 400 yards, attended at all times (June-December) (DMF/Sept.).
	Closed a portion of western Albemarle Sound to gill netting (Batchelor Bay area) and eliminated harvest of striped bass from the Roanoke River delta pound net fishery by proclamation (DMF/Apr.).
1989	Established proclamation authority to specify season or seasons: (a) for hook-and-line and (b) for commercial fishing equipment between 1 October and 30 April. Proclamations may specify areas, quantity, size, and means/methods employed in harvest and require submission of statistical and biological data (DMF/Sept.).
	By proclamation closed a portion of western Albemarle Sound and Roanoke River delta to anchor gill netting (Batchelor Bay area) and restricted the harvest of striped bass taken in pound nets to fish not less than 18 or greater than 24 inches (TL). Striped bass season in internal coastal waters for commercial fishing closed 20 April (DMF/Apr.).
	By proclamation restricted the use of small mesh "mullet gill nets" in the Albemarle Sound and tributaries (DMF/June) (DMF/Sept.).
	By proclamation delayed the use of commercial gill nets of mesh sizes between 3.0-5.0 inches (Albemarle Sound and tributaries) from 1 October until 15 November, when the commercial striped bass season opened statewide. By proclamation required that "mullet gill nets" be attended at all times (DMF/Oct.).
	By proclamation striped season for commercial fishing equipment in internal coastal waters was closed statewide 22 November and gill net mesh sizes were restricted in Albemarle Sound (DMF/Nov.).
	By proclamation striped bass season for hook-and-line fishing in internal coastal waters was closed statewide 26 November (DMF/Nov.).
1990	Commercial harvest in internal coastal waters
	By proclamation striped bass commercial season opened statewide 1 January for internal coastal waters with gear restrictions and a 98,000-pound harvest allocation for 1990 to be managed on a monthly basis for the Albemarle Sound area (DMF/Jan.).
	By proclamation striped bass commercial season closed statewide 11 January with restrictions on gill net mesh sizes in Albemarle Sound (DMF/Jan.).
	By proclamation striped bass commercial season opened statewide 21 February with restrictions on gill net mesh sizes in Albemarle Sound (DMF/Feb.).
	By proclamation on 1 April closed a portion of western Albemarle Sound and Roanoke River delta to anchor gill netting (Batchelor Bay area) and prohibited the harvest of striped bass between 24 and 28 inches (TL), and less than 18 inches (TL) from pound nets (DMF/Mar.).

Table 63. (Continued)

By proclamation striped bass commercial season closed statewide 20 April for internal coastal waters with restrictions on gill net mesh sizes in Albemarle Sound (DMF/Apr.).

By proclamation delayed the use of commercial gill nets of mesh sizes between 3.0-5.0 inches (Albemarle Sound and tributaries) from 3 October until 7 January 1991 when the commercial striped bass season opened statewide. By proclamation required that "mullet gill nets" be attended at all times (DMF/Oct.).

Recreational hook-and-line harvest in internal coastal waters and inland coastal waters (1990)

By proclamation striped bass season opened statewide 1 January for hook-and-line harvest in internal coastal waters (DMF/Jan.).

By proclamation striped bass season closed statewide 24 April for hook-and-line harvest in internal coastal waters (excluding joint waters) (DMF/Apr.).

By collateral action through proclamation (DMF) and emergency rule (WRC) striped bass season closed 10 May for hook-and-line harvest in the joint waters of the Albemarle Sound area (DMF & WRC/May).

By emergency rule striped bass season closed 10 May for hook-and-line harvest in the inland waters of the Roanoke River (WRC/May).

By collateral action of the DMF and WRC, striped bass season closed statewide on 21 May for hook-and-line harvest in the coastal joint and inland waters not previously closed (DMF & WRC/May).

Atlantic Ocean (1990)

Established the first commercial and recreational hook-and-line harvest seasons since 1984. With ASFMC approval a 28-inch (TL) minimum size limit, gear, and daily landings restrictions were implemented. Individual harvest permits were required for fishermen or operations participating in the Atlantic Ocean commercial fishery (DMF/Feb.).

By proclamation striped bass commercial season in the N.C. Atlantic Ocean was open 12 February and 19-23 February with a 96,000-pound harvest allocation.

By proclamation striped bass commercial season in the N.C. Atlantic Ocean was open from 26 November - 23 December (Quota = 85,000 lbs) (DMF/Nov.).

By proclamation striped bass recreational season in the N.C. Atlantic Ocean was open 12 February - 18 March with a daily creel limit of one fish per person per day (DMF/Feb.).

By proclamation striped bass recreational season in the N.C. Atlantic Ocean was open 19 November - 31 December (creel limit - 1 fish/day) (DMF/Feb.).

Table 63. (Continued)

1991	Commercial harvest in internal coastal waters

By proclamation striped bass commercial season was opened 7-9 January for the internal waters of the Albemarle Sound Commercial Harvest Management Area (Albemarle SCHMA), which includes the Albemarle, Currituck, Roanoke, and Croatan Sounds and their tributaries. Striped bass commercial harvest for this area was based on a 98,000-pound harvest allocation for 1991 and managed on a monthly basis. Individual harvest permits were required for fishermen or operations participating in the Albemarle SCHMA fishery. Minimum size limit was 14 inches (TL) and 16 inches (TL) for the coastal and joint waters, respectively. Extensive gill net restrictions were implemented for permitted harvesters. Throughout 1991, harvest permittees were limited to a specific amount or yardage of gill nets less than five-inch stretched mesh. Gear and area restrictions varied seasonally (DMF/Jan.).

By proclamation striped bass commercial season opened 7 January for internal coastal waters outside the Albemarle SCHMA (DMF/Jan.).

By proclamation 8 January additional gill net restrictions were implemented during the closed striped bass season in the Albemarle SCHMA (DMF/Jan.).

By proclamation striped bass season opened 18 January in the Albemarle SCHMA with gear restrictions. Harvest permittees limited to three striped bass/day, minimum size 20 inches (TL).

By proclamation 13 February, Albemarle SCHMA harvest permittees limited to five striped bass/day, minimum size 18 inches (TL).

By proclamation 1 March, Albemarle SCHMA harvest permittees limited to 10 striped bass/day minimum size 18 inches (TL).

By proclamation 25 March, Albemarle SCHMA harvest permittees limited to 20 striped bass/day, minimum size 14 inches (TL) in internal coastal waters and 16 inches (TL) in joint waters. Closed a portion of western Albemarle Sound (Batchelor Bay) area) to anchor gill netting. Drift gill nets allowed in Roanoke, Eastmost, Middle, and Cashie Rivers with stationary gill nets being prohibited (DMF/March).

By proclamation 28 March, Albemarle SCHMA harvest permittees limited to 10 striped bass/day, minimum size 14 inches (TL) in internal coastal waters and 16 inches (TL) in joint waters (DMF/March).

By proclamation 6 April, Albemarle SCHMA harvest permittees limited to 5 striped bass/day, minimum size 18 inches (TL) (DMF/Apr.).

By proclamation 13 April, striped bass commercial season closed in the Albemarle SCHMA with gear restrictions on gill nets and area closures (DMF/Apr.).

By rule commercial striped bass season in internal coastal waters closed statewide on 30 April (DMF).

By proclamation 21 June, allowed three-inch stretched mesh gill nets throughout the Albemarle SCHMA. However, these small mesh nets must be attended at all times.

Table 63. (Continued)

By proclamation 3 September, Albemarle SCHMA allowed additional small mesh gill nets (3.0-3.5 inch stretched mesh) with area restrictions. Small mesh gill nets must be attended at all times (DMF/Sept.).

By proclamation 1 October, Albemarle SCHMA allowed unattended two and one-half and larger stretched mesh gill nets in the southern portions of Roanoke Sound and Croatan Sound (DMF/Oct.).

By proclamation 1 November, striped bass commercial season opened in the Albemarle SCHMA. Harvest permittees were limited to three striped bass/day, minimum size 18 inches (TL). Small mesh gill nets must be attended at all times with area restrictions (DMF/Nov.).

By proclamation 1 November, striped bass commercial season in internal coastal waters opened statewide, minimum size 18 inches (TL) (DMF/Nov.).

By rule effective 1 November the minimum size limit for striped bass harvested in internal coastal and joint waters increased to 18 inches (TL) (DMF).

By proclamation 8 November, Albemarle SCHMA allowed five and one-quarter inch and larger stretched mesh gill nets, consistent with the 18-inch (TL) minimum size limit for striped bass (i.e., this mesh size does not allow significant bycatch of striped bass less than 18 inches (TL)) (DMF/Nov.).

By proclamation 22 November Albemarle SCHMA allowed unattended small mesh gill nets (3.0-3.5 inch stretched mesh) in waters less than six feet in depth with restrictions (DMF/Nov.).

By proclamation 20 December striped bass commercial season closed in the Albemarle SCHMA with gear restrictions and area closures (DMF/Dec.).

Recreational hook-and-line harvest in internal coastal waters and inland coastal waters (1991)

Effective 1 January the Marine Fisheries Commission and the Wildlife Resources Commission adopted joint rules to manage the recreational hook-and-line harvest for the Albemarle-Roanoke striped bass stocks in the internal coastal waters designated as joint waters of the Albemarle, Currituck, Roanoke, and Croatan Sounds and their tributaries. Two distinct management areas were established through the implementation of these new rules. Harvest management in the two areas is based upon a harvest allocation of 29,400 pounds per year for each area, which corresponds to an 80% reduction in historical hook-and-line striped bass harvest. A 16-inch (TL) minimum size limit has been established for both management areas. A daily creel limit not to exceed three fish per person per day was established statewide for internal coastal, joint, and inland waters.

The Wildlife Resources Commission has management authority for hook-and-line harvest in the joint and inland waters of the Roanoke River Recreational Harvest Management Area (Roanoke, Cashie, Middle, and Eastmost Rivers and their tributaries). The Marine Fisheries Commission has management authority for hook-and-line harvest in the remaining internal coastal, joint, and inland fishing waters of the Albemarle Sound Recreational Harvest Management Area (Albemarle, Currituck, Roanoke, and Croatan Sounds and their tributaries) (DMF/WRC).

Table 63. (Continued)

*Note: The defined areas only apply to striped bass recreational hook-and-line harvest management.

By proclamation the striped bass season opened 1 January in the Albemarle Sound Recreational Harvest Management Area (Albemarle SRHMA) (DMF/Jan.).

By proclamation the striped bass season opened 1 January in the internal coastal waters statewide excluding the Albemarle SRHMA (DMF/Jan.).

By emergency rule the striped bass season opened 1 January in the inland and joint coastal waters and in the Roanoke River Recreational Harvest Management Area (Roanoke RRHMA) (WRC/Jan.).

By proclamation the striped bass season closed 31 January in the Albemarle SRHMA to assess the harvest relative to quota management (DMF/Jan.).

By proclamation the striped bass season opened 7 February in the Albemarle SRHMA (DMF/Feb.).

By proclamation the striped bass season closed 1 May in the Albemarle SRHMA (DMF/May).

By emergency rule the striped bass season closed 1 May in the inland and joint coastal waters of the Roanoke RRHMA (WRC/May).

By N.C. General Statute 113-292 (effective 23 May 1991) the NCWRC was granted proclamation authority to open and close striped bass harvest seasons for the Roanoke RRHMA.

By proclamation the striped bass season opened 1 November in the Albemarle SRHMA with a daily creel limit of three fish, minimum size 18 inches (TL) (DMF/Nov.).

By proclamation the striped bass season closed 30 November in the Albemarle SRHMA (DMF/Nov.).

By proclamation the striped bass season opened 1 November in all internal coastal and joint waters statewide, except for the Albemarle SRHMA and Roanoke RRHMA, with a daily creel limit of three fish (DMF/Nov.).

Creel Limit Regulations (1991)

By rule effective 1 July in the Roanoke RRHMA the following seasonal daily creel and size limits were established during the open striped bass harvest season in this management area (WRC/July).

1 January - 31 March: Inland waters - 1 fish daily creel, 18-inch minimum size limit; joint waters - 3 fish daily creel, 18-inch minimum size limit.

1 April - 31 May: Inland waters - 3 fish daily creel, 16-inch minimum size limit and *no* fish between 22-27 inches may be retained from U.S. Hwy 258 to Roanoke Rapids Dam; joint waters - 3 fish daily creel, 18-inch minimum size limit.

Table 63. (Continued)

	1 June - 31 December: Inland waters - 1 fish daily creel, 18-inch minimum size limit; joint waters - 3 fish daily creel, 18-inch minimum size limit.
	By rule effective 1 July a daily creel limit of one fish per person per day, 18 inches (TL) minimum size was established year round for the inland coastal waters of the Tar, Neuse, and Cape Fear Rivers (WRC/July).
	By joint rule effective 1 November the minimum size limit for striped bass harvested in joint waters increased to 18 inches (TL) (WRC, DMF/Nov.).
	By rule effective 1 November the minimum size limit for striped bass harvested in internal coastal waters increased to 18 inches (TL) (DMF).
	<u>Atlantic Ocean Commercial and Recreational Harvest (1991)</u>
	By proclamation striped bass commercial season was <u>opened</u> from 4-25 February with a 28-inch (TL) minimum size limit and daily landing restrictions for permitted harvesters (DMF/Feb.).
	By proclamation striped bass recreational season was <u>opened</u> from 19 January - 31 March with a 28-inch minimum size and a one fish/day creel limit (DMF/Jan.).
	By proclamation striped bass commercial season was <u>opened</u> from 1-31 December with a 28-inch (TL) minimum size limit. Harvest permittees were issued a specific allocation of harvest bands based on the number of permittees and the annual 1992 harvest allocation of 96,000 pounds. Harvest bands were required on all striped bass taken in this fishery (DMF/Dec.).
	By proclamation striped bass recreational season was <u>opened</u> from 1-31 December with a 28-inch minimum size and a one fish daily creel limit (DMF/Dec.).
1992	<u>Commercial harvest in internal coastal waters</u>
	Throughout 1992, Albemarle SCHMA (excluding Croatan and Roanoke Sounds) harvest permittees were limited to a specific yardage of gill nets with a stretched mesh less than five and one-quarter inches. Gear and area restrictions varied seasonally. Stationary gill nets were prohibited in the Roanoke, Eastmost, Middle, and Cashie Rivers.
	A statewide 18-inch minimum size limit was established (effective 1 November 1991) for striped bass harvested in internal coastal and joint waters (DMF/Nov.).
	By proclamation striped bass commercial season <u>opened</u> 11 January in the Albemarle SCHMA. Harvest permittees limited to ten striped bass/day (DMF/Jan.).
	By proclamation 3 February, Albemarle SCHMA harvest permittees limited to five striped bass/day (DMF/Feb.).
	By proclamation 19 march, Albemarle SCHMA harvest permittees limited to three striped bass/day. Drift gill nets allowed in Roanoke, Eastmost, Middle, and Cashie Rivers (DMF/Mar.).

Table 63. (Continued)

By proclamation 16 April, striped bass commercial season closed in the Albemarle SCHMA (DMF/Apr.).

By proclamation 21 April, striped bass commercial season for internal coastal and joint waters closed statewide (DMF/Apr.).

By proclamation 3 July, small mesh gill nets in the Albemarle SCHMA must be attended at all times (DMF/June).

By proclamation 21 October, small mesh gill nets in the Albemarle SCHMA must be attended between sunrise and sunset (DMF/Oct.).

By proclamation 23 October, striped bass commercial season opened statewide for internal coastal and joint waters, except in the Albemarle SCHMA (DMF/Oct.).

By proclamation 9 November, striped bass commercial season opened in the Albemarle SCHMA with an effective closure date of 20 November. Harvest permittees limited to three striped bass/day (DMF/Oct.).

By proclamation 23 November, allowed unattended small mesh gill nets in the Albemarle SCHMA (DMF/Nov.).

Recreational hook-and-line harvest in internal coastal, joint, and inland coastal waters (1992)

By proclamation the striped bass season opened 1 January in the Roanoke RRHMA (WRC/Jam.).

By proclamation the striped bass season opened 1 January in the Albemarle SRHMA (DMF/Jan.).

By proclamation the striped bass season closed 20 April in the Roanoke RRHMA (WRC/Apr.).

By proclamation the striped bass season closed 1 May in the Albemarle SRHMA (DMF/Apr.).

By proclamation the striped bass season opened 1 November in the Albemarle SRHMA (DMF/Nov.).

By proclamation the striped bass season closed 30 November in the Albemarle SRHMA (DMF/Nov.).

Atlantic Ocean commercial and recreational harvest (1992)

By proclamation striped bass commercial season was opened from 1 January - 29 February with a 28-inch (TL) minimum size limit. Harvest permittees were issued a specific allocation of harvest bands based on the number of permittees and the annual 1992 harvest allocation of 96,000 pounds. Harvest bands were required on all striped bass taken in this fishery (DMF/Dec.).

Table 63. (Continued)

	By proclamation striped bass recreational harvest was <u>open</u> from 1 January - 31 March with a 28-inch (TL) minimum size and a one-fish daily creel limit (DMF/Dec.).
	By proclamation striped bass recreational harvest season <u>opened</u> 1 December with a 28-inch (TL) minimum size and a one-fish daily creel limit (DMF/Nov.).
	By proclamation striped bass commercial season <u>opened</u> 15 December with a 28-inch (TL) minimum size limit. Harvest bands were required on all striped bass harvested by permittees in this fishery (DMF/Dec.). Harvest during December was included in the 1993 annual harvest allocation of 96,000 pounds.
1993	<u>Commercial harvest in internal coastal waters</u>
	Throughout 1993, Albemarle SCHMA (excluding Croatan and Roanoke sounds) harvest permittees were limited to a specific yardage of gill nets with a stretched mesh less than five and one-quarter inches. Gear and area restrictions for gill nets varied seasonally. Stationary gill nets were prohibited in the Roanoke, Eastmost, Middle, and Cashie rivers.
	By proclamation 17 January, striped bass commercial season <u>closed</u> statewide for internal coastal and joint waters (DMF/Jan.).
	By proclamation 18 January, drift gill nets allowed in Roanoke, Eastmost, Middle, and Cashie rivers (DMF/Jan.).
	By proclamation 1 February, striped bass commercial season <u>opened</u> in the Albemarle SCHMA. Harvest permittees limited to five striped bass/day. Prohibited the harvest of striped bass from commercial gear in the Roanoke, Eastmost, Middle, and Cashie rivers (DMF/Jan.).
	By proclamation 1 February, striped bass commercial season <u>opened</u> statewide for internal coastal and joint waters, excluding the Albemarle SCHMA (DMF/Jan.).
	By proclamation 1 March, Albemarle SCHMA harvest permittees limited to three striped bass/day (DMF/Feb.).
	By proclamation 5 April, striped bass commercial season <u>closed</u> in the Albemarle SCHMA (DMF/Apr.).
	By proclamation 5 April, striped bass commercial season <u>closed</u> statewide for internal coastal and joint waters, excluding the Albemarle SCHMA (DMF/Apr.).
	By proclamation 17 May, gill nets prohibited in the Mackey's Creek - Batchelor Bay area of western Albemarle Sound, Roanoke, Eastmost, Middle, and Cashie rivers. Excluding the prohibited area, gill nets in the western Albemarle Sound from Chowan River to the NC Power Transfer Line must be attended at all times.
	By proclamation 2 August, small mesh gill nets in the Albemarle SCHMA must be attended at all times, excluding Croatan and Roanoke sounds (DMF/July).

Table 63. (Continued)

By proclamation 6 October, prohibited small mesh gill nets in water depths greater than 6 feet in the Albemarle SCHMA, excluding Croatan and Roanoke sounds (DMF/Oct.).
Recreational hook-and-line harvest in internal coastal, joint, and inland coastal waters (1993)
By proclamation the striped bass season opened 1 February in the Roanoke RRHMA (WRC/Jan.).
By proclamation the striped bass season opened 1 February in the Albemarle SRHMA (DMF/Jan.).
By proclamation the striped bass season closed 18 April in the Albemarle SRHMA (DMF/Mar.).
By proclamation the striped bass season closed 25 April in the Roanoke RRHMA (WRC/Apr.).
Atlantic Ocean commercial and recreational harvest (1993)
By proclamation the striped bass recreational harvest season closed 31 March (DMF/Nov.).
By proclamation the striped bass commercial harvest season closed 31 March (DMF/Mar.).

Abundance and Viability of Striped Bass Eggs Spawned in the Roanoke River, 1991-1993

Roger A. Rulifson

Spawning, 1991

Striped bass spawning activity in the Roanoke River was monitored every four hours by sampling the water column for striped bass eggs just downstream of the primary spawning grounds. The sampling location was Barnhill's Landing at River Mile (RM) 117, the location used in previous studies from 1975-1981, and 1989-1990 (Figure 60). Sampling was initiated on 15 April 1991 and was terminated on 14 June, for a total of 1,348 samples. Several samples were lost or were not taken due to severe weather. Details of the methodology and results were presented in Rulifson (1992, 1993).

Eggs first appeared in samples on 17 April and were last observed in surface samples on 12 June for a 57-day spawning window. Consecutive spawning was observed for 41 of the 57 days. Greatest spawning activity occurred in the second week in May (Table 64).

An estimated 1.837 billion eggs (± 301 million) were spawned upstream of Barnhill's Landing in 1991. The 1991 estimate is the fifth largest observed since 1959, and the second largest value obtained at Barnhill's Landing (Table 65). Three peak spawning periods were

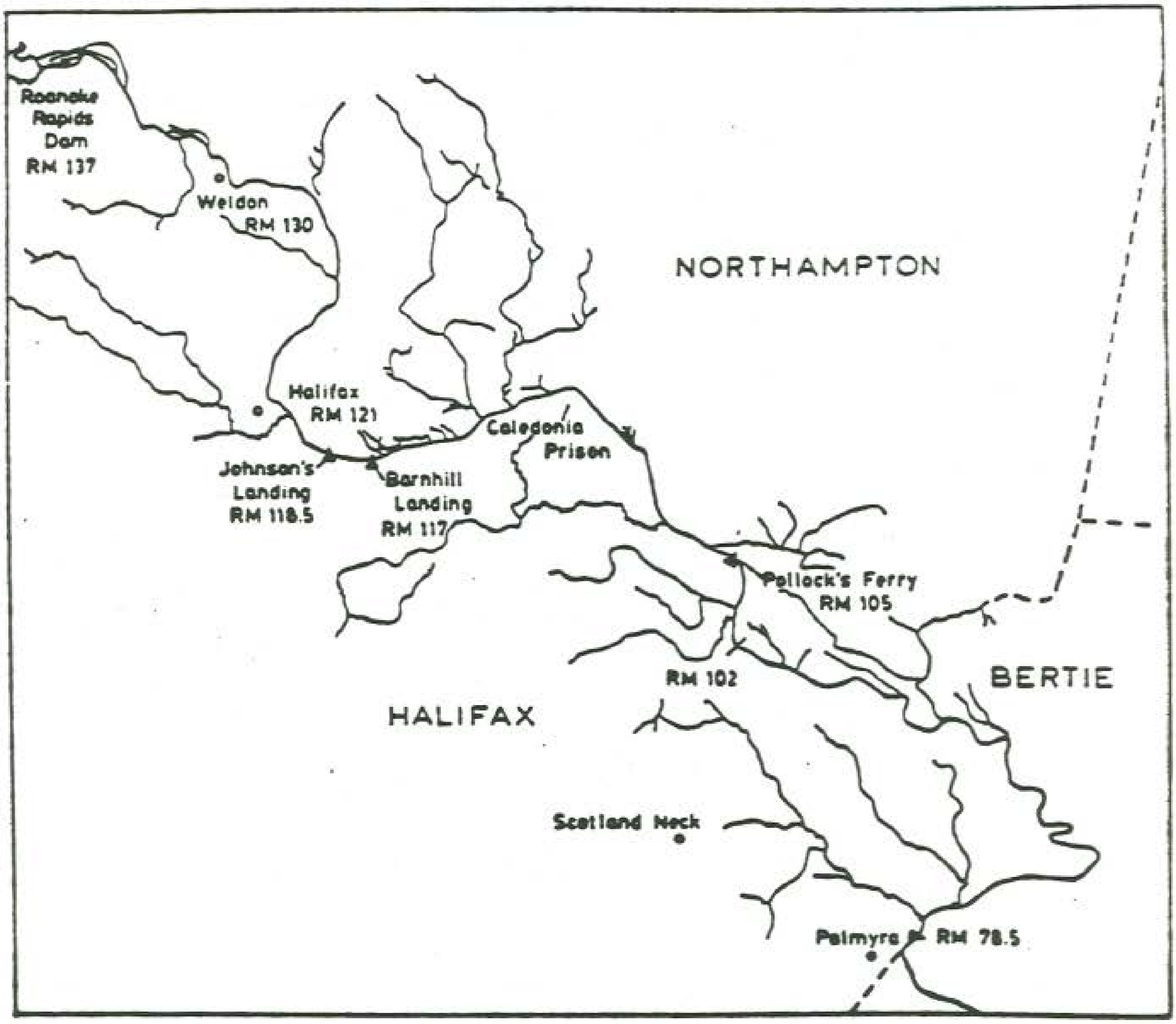

Figure 60. Roanoke River watershed downstream of Roanoke Rapids Reservoir showing the historical sampling stations for striped bass eggs: Palmyra (1959-1960), Halifax (1961-1974), Barnhill's Landing (1975-1981, 1989-1993), Johnson's Landing (1982-1987), and Pollock's Ferry (1988).

observed in 1991: 8-9 May (20% of total production), 11-12 May (17%), and 14 May (19%). Egg production for the year was 50% complete by 13 May, 75% complete by 15 May, and 90% complete by 25 May. The estimated egg viability for the year was 55%. Most (62%) of the viable eggs were less than 10 hours old (measured rate of development at 17°C). The remainder (38%) were 10 to 18 hours old; less than 0.1% were 30+ hours old (Table 66).

Most spawning activity occurred at night, though some "rock fights" were observed during the day. About 67% of all egg were collected between 0200 and 1000 hours, with an additional 23% at 1800 and 2200 hours. Fewest eggs were collected at mid day (1400 hours, 9.5%).

Striped bass spawning activity was related to water temperature. Most eggs (about 94%) were collected at water temperatures 18°-23.9°C. Less than 2% were collected at water temperatures less than 18°C, and an additional 4.5% were caught at temperatures of 24.0-25.9°C. No pattern of egg viability with water temperature was evident.

Other environmental parameters were correlated with egg abundance. Surface water velocities ranged from 49-113 cm/second during the study; most eggs (92%) were collected in the range 60.0-79.9 cm/second. About 3.8% of the eggs were collected at surface water velocities less than 60 cm/second, and a similar number were caught at water velocities 80 cm/second or more. Surface water pH was high throughout the study. Most eggs (85%) were collected at pH values of 7.75 or greater; 33% were collected at pH values above 8.0. Less than 1% of the eggs were caught at the lowest pH observed (6.5-6.74). Dissolved oxygen levels were adequate for most of the study; most eggs (95%) were caught in waters of 7.0-8.9 mg/L dissolved oxygen. Less than 1% were collected at 5.0-5.9 mg/L, the minimum oxygen values recorded (Table 66).

Spawning, 1992

The 1992 egg study was conducted in the same manner and location as those from 1989-1991. Results were presented in detail elsewhere (Rulifson et al. 1993). Egg sampling was conducted every four hours from 16 April to 23 June, for a total of 1,441 samples. Several of the samples were subsampled due to the tremendous number of eggs collected during the peak spawn period. Also, moderate spawning was still observed on the last day of sampling. For these two reasons, the 1992 egg production estimates were lower than the estimate using all possible samples and all days of spawning.

The spawning window was more than 68 days in 1992, with at least 45 days of continuous spawning activity (Table 66). Eggs first appeared in surface samples on 17 April and were still present in moderate numbers on 23 June. Local fishermen reported "rock fights" upstream of Barnhill's Landing through June after the termination of egg sampling. Examination of young-of-year otoliths collected on the nursery grounds indicated that spawning activity continued into July 1992 (refer to the section by Rulifson, Isely, and Manooch).

The estimated number of eggs spawned in 1992 was 9.65±0.49 billion from a total of 56,674 eggs collected in surface nets. This estimate was low as explained above; however, the 1992 estimate was the highest ever recorded since the initiation of studies in 1959 (Table 65). Four peak spawning periods were observed in 1992: 15 May (10%), 19-20 May (47%), 25-26 May (11%), and 1-3 June (9%). Considering only those dates sampled, 50% of the eggs were collected by 20 May, 75% by 26 May, and 90% by 6 June (Table 66). The estimated egg viability for 1992 was 46.4%. About 64% of the eggs drifting past Barnhill's Landing were less than 10 hours old, and 36% were 10-18 hours into development.

Table 64. Spawning activity of adult striped bass, expressed as percent of total estimated egg production, in the lower Roanoke River, North Carolina, 1988-1992 (Rulifson annual reports) and 1993 (unpublished data subject to revision).

Date		1988	1989	1990	1991	1992	1993
Apr	15	0.02			0.00		0.0
	16	0.00	0.02	0.00	0.00	0.0	0.0
	17	0.00	0.00	0.00	0.02	0.0	0.0
	18	0.00	0.00	0.00	0.00	0.0	0.0
	19	0.01	0.00	0.00	0.00	0.1	0.0
	20	0.01	0.00	0.00	0.00	0.3	0.0
	21	0.00	0.00	0.00	0.00	0.0	< 0.1
	22	0.00	0.00	0.00	0.00	0.0	0.0
	23	0.02	0.00	0.00	0.03	0.0	0.0
	24	0.00	0.00	0.02	0.05	0.0	0.0
	25	0.00	0.00	1.23	0.17	0.0	0.0
	26	0.02	0.00	0.43	0.01	0.0	0.0
	27	0.00	0.00	1.10	0.00	0.0	0.0
	28	0.00	0.31	0.54	0.21	0.0	0.0
	29	0.00	0.14	0.56	0.48	0.0	< 0.1
	30	0.01	0.83	1.05	0.26	0.0	0.0
May	1	0.00	1.17	0.94	0.27	0.0	0.0
	2	0.06	1.14	3.00	2.30	0.0	< 0.1
	3	0.00	0.00	4.21	0.91	0.0	0.0
	4	0.00	0.17	1.58	0.14	0.0	0.0
	5	0.01	0.07	1.42	0.77	0.1	0.0
	6	0.00	0.00	4.83	2.21	0.0	0.0
	7	0.01	0.00	14.80	1.54	0.0	< 0.1
	8	0.01	0.00	3.24	13.73	0.0	< 0.1
	9	0.21	0.00	7.10	6.44	0.0	< 0.1
	10	0.58	0.00	20.04	1.44	0.0	< 0.1
	11	31.67	0.07	3.05	5.82	0.1	< 0.1
	12	6.68	0.00	1.84	11.03	1.3	< 0.1
	13	1.65	0.00	1.71	4.97	1.0	61.2
	14	1.64	0.00	2.31	18.77	2.3	3.0
	15	14.91	0.02	5.04	3.23	10.4	0.1
	16	6.92	0.00	1.00	3.20	1.1	0.3
	17	0.88	0.00	3.30	2.74	0.0	14.8
	18	2.28	0.10	3.52	3.98	0.2	6.2
	19	1.41	0.41	1.54	1.87	7.5	0.3
	20	12.58	0.87	0.40	0.35	39.6	1.0
	21	0.88	1.99	3.55	0.69	0.1	0.3
	22	1.76	4.39	1.57	1.08	0.1	0.5
	23	4.04	15.18	0.48	0.66	0.2	4.7
	24	9.82	11.83	0.24	1.53	1.3	2.9
	25	0.27	1.93	0.28	1.38	7.7	1.9
	26	0.84	8.38	0.75	2.23	3.5	1.5
	27	0.04	25.32	0.58	1.33	0.1	0.2
	28	0.12	4.18	0.35	1.04	0.3	0.2

Table 64. (Continued)

Date	1988	1989	1990	1991	1992	1993
29	0.37	1.87	0.07	0.88	0.3	0.4
30	0.01	1.68	0.00	0.77	0.2	0.2
31	0.07	11.82	0.10	0.39	0.1	0.1
Jun 1	0.09	4.32	0.44	0.34	1.5	< 0.1
2	0.02	0.81	0.60	0.22	6.4	< 0.1
3	0.00	0.13	0.15	0.11	1.5	0.1
4	0.00	0.26	0.10	0.17	0.4	< 0.1
5	0.00	0.16	0.43	0.03	0.6	< 0.1
6	0.00	0.16	0.13	0.06	1.1	< 0.1
7	0.00	0.11	0.07	0.07	2.3	< 0.1
8		0.11	0.00	0.00	1.7	< 0.1
9		0.06	0.10	0.01	1.1	< 0.1
10		0.00	0.07	0.03	0.4	< 0.1
11		0.00	0.07	0.02	0.4	< 0.1
12		0.00	0.10	0.04	0.5	0.0
13		0.00	0.00	0.00	0.3	0.0
14		0.00	0.00	0.00	0.5	0.0
15			0.00	0.00	0.6	0.0
16					0.8	0.0
17					0.5	0.0
18					0.6	0.0
19					0.5	0.0
20					0.0	0.0
21					0.4	0.0
22					0.1	0.0
23					0.0	0.0

Most of the eggs were collected from 2200 through 1000 the next morning, indicating that most spawning activity occurred at night.

Spawning activity was related to water temperature. Major spawning occurred when water temperatures reached 18°C. Over 90% of the eggs were collected at water temperatures from 18-21.9°C. Only 5% of the eggs were collected at 22°C or higher due to the prevailing moderate water temperatures throughout June. These moderate temperatures may have been responsible for the prolonged and extensive spawning activity throughout June.

Other environmental factors were correlated with egg abundance and egg viability. The variability in egg viability observed at Barnhill's Landing in 1992 was partially explained (46%, linear model) by an inverse relationship with water velocity and a positive relationship with water temperature. Most eggs were collected in waters of pH values 7-8 (99%), dissolved oxygen levels of 7-10 mg/L (99%), and water velocities of 60-100 cm/second (92%).

Spawning, 1993

Results of the 1993 egg study are preliminary and subject to revision. However, the overall trends in spawning activity are summarized for this report.

The 1993 study was initiated on 16 April and was terminated on 16 June. Eggs first appeared in surface samples on 21 April and last appeared on 11 June, for a 52-day spawning window. Spawning activity was continuous for 36 days in 1993.

Based on the number of eggs collected in 1993, the spawning run of adults must have been one of the largest ever documented. A total of 102,649 eggs were collected in surface samples for a total egg production estimate of 23.9 billion eggs, the largest value ever recorded (Table 65). Over 64% of the egg production was on 13-14 May, a time of decreasing reservoir discharge. The relative change in river height dropped 8 feet in 24 hours on 11-12 May; major spawning occurred upstream the evening of 12 May. A second peak was observed on 17-18 May (21%) and a third peak occurred on 23-24 May (8%). Spawning was over 50% completed by 13 May, 75% completed by 17 May, and 90% completed by 23 May.

The relationship of egg production to water quality was similar to other years. Water temperatures exceeded 18°C by the time reservoir discharge was reduced. Even so, over 95% of the eggs were collected at temperature 18-21.9°C (Table 66). Surface water pH was above 7.0 for most of the egg collection periods, but some eggs were collected in waters as low as 6.5. Nearly all eggs were collected in water of 7-8.9 mg/L of dissolved oxygen, and moderate surface water velocities of 60-79.9 cm/second.

Table 65. Estimated number of striped bass eggs spawned in the Roanoke River, NC, and the corresponding egg viability, 1959-1987 (Hassler reports), 1988-1993 (Rulifson reports), and 1993 (unpublished data subject to revision).

Year	Sampling period	Estimated number of eggs	Egg viability (%)	Site of egg collection
1959		300,000,000 [a]	92.88	Palmyra (RM 78.5)
1960	23 Apr-8 Jun	740,000,000	92.88	Palmyra
1961		2,065,232,519	79.74	Halifax (RM 121)
1962		1,088,076,294	86.22	Halifax
1963	18 Apr-8 Jun	918,652,436	79.94	Halifax
1964	24 Apr-27 May	1,285,351,276	95.77	Halifax
1965	21 Apr-28 May	823,522,540	95.91	Halifax
1966	26 Apr-31 May	1,821,385,754	94.51	Halifax
1967	21 Apr-11 Jun	1,333,312,869	96.20	Halifax
1968	24 Apr-4 Jun	1,483,102,338	86.20	Halifax
1969	27 Apr-6 Jun	3,229,715,526	89.86	Halifax
1970	30 Apr-1 Jun	1,464,841,490	89.23	Halifax
1971		2,833,119,620	80.81	Halifax
1972	2 May-28 May	4,932,000,707	90.51	Halifax
1973	29 Apr-3 Jun	1,501,498,887	87.21	Halifax
1974	1 May-2 Jun	2,163,239,468	87.31	Halifax
1975	7 May-2 Jun	2,193,008,096	55.69	Barnhill's (RM 117)
1976	1 May-30 May	1,496,768,659	50.73	Barnhill's Landing
1977	29 Apr-31 May	1,775,957,318	52.72	Barnhill's Landing
1978		1,691,227,585	37.72	Barnhill's Landing
1979	10 May-11 Jun	1,613,382,382	43.62	Barnhill's Landing
1980	1 May-1 Jun	870,322,832	43.39	Barnhill's Landing
1981	29 Apr-29 May	344,364,065	73.70	Barnhill's Landing
1982	3 May-2 Jun	1,698,888,853	71.93	Johnson's (RM 118)
1983	6 May-12 Jun	1,352,611,202	33.29	Johnson's Landing
1984	9 May-9 Jun	703,879,559	22.73	Johnson's Landing
1985	23 Apr-23 May	600,562,645	72.21	Johnson's Landing
1986		2,279,071,483	51.10	Johnson's Landing
1987		1,382,496,006	42.87	Johnson's Landing
1988	10 Apr-7 Jun	2,082,130,728	89.00	Pollock's Ferry (RM 105)
1989	16 Apr-15 Jun	637,919,162	41.80	Barnhill's Landing
1990	16 Apr-15 Jun	964,791,625	58.00	Barnhill's Landing
1991	15 Apr-14 Jun	1,837,208,211	55.36	Barnhill's Landing
	15 Apr-14 Jun	2,068,304,334	69.51	Jacob's Landing (RM 102)
1992	16 Apr-23 Jun	9,655,219,935 [b]	46.37	Barnhill's Landing
1993	16 Apr-16 Jun	23,900,000,000	49.1	Barnhill's Landing

[a] partial season data only
[b] underestimate caused by subsampling and termination of sampling prior to cessation of spawning activity
[c] preliminary estimates subject to revision

Table 66. Summary of striped bass spawning activity in the Roanoke River observed at Barnhill's Landing (RM 117), 1989-1993. Results of the 1992 study are preliminary and subject to revision.

Activity	1989	1990	1991	1992	1993
Number of samples examined:					
surface	688	698	692	751	
bottom	678	696	690	740	
total	1,366	1,394	1,382	1,441	
Number of eggs collected:					
surface	4,722	5,309	10,467	56,674 *	102,649
bottom	5,107	6,630	11,641	40,718 *	61,138
total	9,829	11,939	22,108	97,392 *	163,787
Hassler egg production estimate:					
surface	0.638 billion	0.965 billion	1.837 billion	9.655 billion*	23.9 billion
bottom	0.720 billion	1.261 billion	2.052 billion	7.004 billion*	--
average of combined samples	0.677 billion	1.114 billion	1.944 billion	8.653 billion*	--
Egg viability estimate:	41.8%	58.5%	55.4%	46.4%	49.1%
Date of first egg:	16 Apr	24 Apr	17 Apr	17 Apr	21 Apr
Date of last egg:	9 Jun	12 Jun	12 Jun	after 23 Jun	11 Jun
Days within spawning window:	55	50	57	more than 68	52
Number of days of continuous spawning:	23	50	41	more than 45	36
Major spawning activity and percent of total eggs collected:					
first peak	23-24 May (27%)	2-3 May (7%)	8-9 May (20%)	15 May (10%)	13-14 May (64%)
second peak	26-27 May (33%)	7 May (15%)	11-12 May (17%)	19-20 May (47%)	17-18 May (21%)
third peak	31 May-1 Jun (26%)	10 May (20%)	14 May (19%)	25-26 May (11%)	23-29 May (8%)
fourth peak				1-3 Jun (9%)	

Table 66. (Continued)

Activity	1989	1990	1991	1992	1993
Date at which egg production was:					
50% complete	26 May	10 May	13 May	20 May*	13 May
75% complete	27 May	14 May	15 May	26 May*	17 May
90% complete	31 May	20 May	25 May	6 Jun*	23 May
Percent of all staged viable eggs (17° C criteria):					
less than 10 hours	77	71	62	64	--
10 to 18 hours	5	29	38	36	--
20 to 28 hours	19	<1	<1	<1	--
30 hours and older	<1	<1	0	<1	--
newly-hatched larvae	0	0	0		
Percent of all eggs collected at water temperature (°C):					
12-13.9	0	0	0	0	<1
14-15.9	<1	0	<1	<1	<1
16-17.9	3	<1	2	5	4
18-19.9	40	48	22	56	38
20-21.9	48	48	36	34	57
22-23.9	8	3	36	5	<1
24-25.9	<1	0	5	0	<1
26 +	0	0	<1	0	0
Percent of all eggs collected at surface water pH:					
5.50-5.74	0	0	0	0	0
6.00-6.24	0	0	0	0	0
6.25-6.49	0	0	0	0	0
6.50-6.74	<1	0	<1	0	<1
6.75-6.99	1	1	0	0	4
7.00-7.24	1	12	2	22	11
7.25-7.49	3	24	<1	30	2
7.50-7.74	6	52	12	32	26
7.75-7.99	38	6	52	15	8
8.0 +	47	3	33	<1	48
not recorded	3	1	<1	<1	<1

Table 66. (Continued)

Activity	1989	1990	1991	1992	1993
Percent of all eggs collected at surface dissolved oxygen (mg/L):					
5-5.9	0	0	<1	0	0
6-6.9	0	3	3	0	<1
7-7.9	28	47	68	20	61
8-8.9	72	46	28	73	39
9-9.9	<1	3	<1	6	<1
10-10.9	0	0	0	0	<1
11-11.9	0	0	0	0	<1
not recorded	<1	<1	<1	<1	0
Percent of all eggs collected at surface water velocity (cm/second):					
40-59.9	7	2	4	3	<1
60-79.9	22	66	92	28	99
80-99.9	9	26	4	64	1
100-119.9	58	7	<1	2	<1
120-139.9	5	0	0	<1	<1
140+	0	0	0	0	<1
not recorded	<1	0	0	3	<1
Percent of all eggs collected at time:					
0200	18	28	23	11	--
0600	28	42	21	32	--
1000	22	12	24	27	--
1400	11	6	9	11	--
1800	6	4	13	7	--
2200	15	7	10	12	--

* Indicates a low estimate caused by several missed samples during peak spawning activity, and termination of sampling efforts while spawning was still in progress.

Juvenile Abundance Index of Young-of-Year Striped Bass, 1988-1993

Lynn T. Henry and Stephen D. Taylor

The relative success of juvenile striped bass recruitment to the forming year class is monitored by the Juvenile Abundance Index (JAI), which is simply the number of young striped bass captured per unit of effort. Although the use of this type of index is common in most states with striped bass stocks, the methodology used to determine the JAI is unique to each state. The JAI for North Carolina pre-dates those of other states who designed their indices after that of North Carolina. The JAI for the Roanoke-Albemarle stock was initiated in 1955 by Dr. W.W. Hassler; estimation methods for the JAI have remained essentially unchanged since that time. Hassler's studies provide an uninterrupted data base through 1987 (Table 67).

The sampling area is in western Albemarle Sound (Figure 60) extending eastward approximately 12 miles. Seven permanent sampling stations were established in 1955 and are currently used: Station 1, Black Walnut Point; Station 2, east of Edenton Bay; Station 3, north shore side between the (now demolished) Norfolk and Southern Railway bridge and the NC32 highway bridge; Station 4, northeast side of NC32 bridge; Station 5, southeast side of NC32 bridge; Station 6, south shore between the bridges; and Station 7, Albemarle Beach. Samples were collected early in the sampling season by trawl with 6.35-mm stretched mesh. Later samples were taken with a cod end of 12.7-mm stretched mesh. Samples were taken every two weeks starting in July and ending in October for a maximum of 56 samples for the season. Each trawl is for a period of 15 minutes at a speed of approximately 2.75 miles per hour. Trawling depth ranges between six and ten feet. Young striped bass are counted and measured (fork length). Numbers (JAI) are expressed as the average number of juvenile striped bass caught per unit of effort (15-minute tow).

In 1982, the North Carolina Division of Marine Fisheries (DMF) initiated a JAI survey using the same methods and stations as the Hassler (NCSU) studies (Table 67). The only change to the study involved mesh size. The DMF study, which has replaced Hassler's efforts, used the 12.7-mm stretched mesh cod end exclusively from 1984 to present, a 6.35-mm cod end in 1983, and a combination of 6.35-, 12.7-, and 25.4-mm stretched mesh cod ends in 1982.

The DMF JAI for 1988 was 4.09 fish per trawl (Table 68), the best value obtained since the summer and fall of 1976 (Table 67). The relatively high value for 1988 substantiated the feelings of many Committee members that the Roanoke-Albemarle stock of striped bass was not depressed beyond recovery. The monthly JAI values for 1988 were: July, 5.86; August, 3.36; September, 1.71; and October, 5.43. A JAI of 10.86 was recorded on 7 October, by far the highest daily value obtained since the early 1970s.

The JAI for 1989 was 4.27 (Table 69), the highest value since 1976 (Table 67). The indices for 1988 and 1989 represent the first time that two consecutive JAIs were greater than 4.00 since 1975-76. The monthly JAIs for 1989 were: July, 0.14; August, 2.95; September, 7.43; and October, 5.14. The trends in catch per unit effort between the two years are different. In 1988, juvenile striped bass were recruited (captured) by the gear much earlier in the season than in 1989 (Table 70). The delayed recruitment into the historical western Albemarle nursery area during 1989 may have been the result of displacement of the young fish to more easterly sections of the Sound by the high stable flows from the Roanoke River and/or the late peak spawning activity (late May to mid-June).

Table 67. Historical reproduction information on the Roanoke/Albemarle striped bass population (from Hassler and Taylor 1986, except as otherwise noted).

Year	Number of eggs spawned	% egg viability	Number of fish in spawning migration	Juvenile abundance index	
				NCSU	NCDMF
1955				3.27	
1956			239,489	19.14	
1957			173,289	5.71	
1958			251,280	0.15	
1959	300,000,000 [a]		448,292	23.86	
1960	740,000,000	92.88	418,062	5.93	
1961	2,065,232,519	79.74	310,135	10.33	
1962	1,088,076,294	86.22	148,260	7.86	
1963	918,652,436	79.94	157,246	4.80	
1964	1,285,351,276	95.77	251,906	3.14	
1965	823,522,540	95.91	310,003	10.08	
1966	1,821,385,754	94.51	277,397	3.48	
1967	1,333,312,869	96.20	174,286	23.39	
1968	1,483,102,338	86.20	317,474	6.59	
1969	3,229,715,526	89.86	200,259	2.99	
1970	1,464,841,490	89.23	421,571	12.45	
1971	2,833,119,620	80.81	441,823	2.86	
1972	4,932,000,707	90.51	507,145	2.52	
1973	1,501,498,887	87.21	402,593	1.95	
1974	2,163,239,468	87.31	433,213	5.52	
1975	2,193,008,096	55.69	377,024	10.80	
1976	1,496,768,659	50.73	277,630	10.52	
1977	1,775,957,318	52.72	347,584	3.63	
1978	1,691,227,585	37.72	354,152	0.59	
1979	1,613,382,382	43.62	313,736	0.55	
1980	870,322,832	43.39	100,192	0.46	
1981	344,364,065	73.70	34,032	0.09	
1982	1,698,888,853	71.93	70,650	3.80	0.58 [d]
1983	1,352,611,202	33.29	69,771	0.84	0.44 [e]
1984	703,879,559	22.73	59,890	0.36	0.00 [e]
1985[b]	600,562,645 [b]	72.21 [b]	32,937 [b]	1.24 [b]	0.32 [f]
1986[b]	2,279,071,483 [b]	51.10 [b]	61,656 [b]	0.14 [b]	0.11 [f]
1987[b]	1,382,496,006 [b]	42.87 [b]	91,738 [b]	0.06 [b]	0.30 [f]
1988	2,082,130,728 [c]	89.00 [c]			4.09 [f]
1989	637,919,162 [c]	41.80 [c]			4.27 [f]
1990	964,791,625 [c]	58.00 [c]			1.41 [g]
1991	1,837,207,211 [c]	55.36 [c]			0.86 [h]
1992	9,655,219,935 [c]	46.37 [c]			2.57 [i]
1993	23,900,000,000 [j]	49.10 [j]			44.54 [i]

[a]Partial season data only.
[b]Hassler and Maraveyias (1988).
[c]Rulifson et al. (1993).
[d]Personal communication, Lynn Henry, NC DMF, Elizabeth City, NC.
[e]Winslow et al. (1985).
[f]Henry et al. (1991).
[g]Taylor et al. (1992).
[h]Taylor and Hardy (1993a).
[i]Taylor and Hardy (1993b).
[j]Rulifson, unpub. data subject to revision.

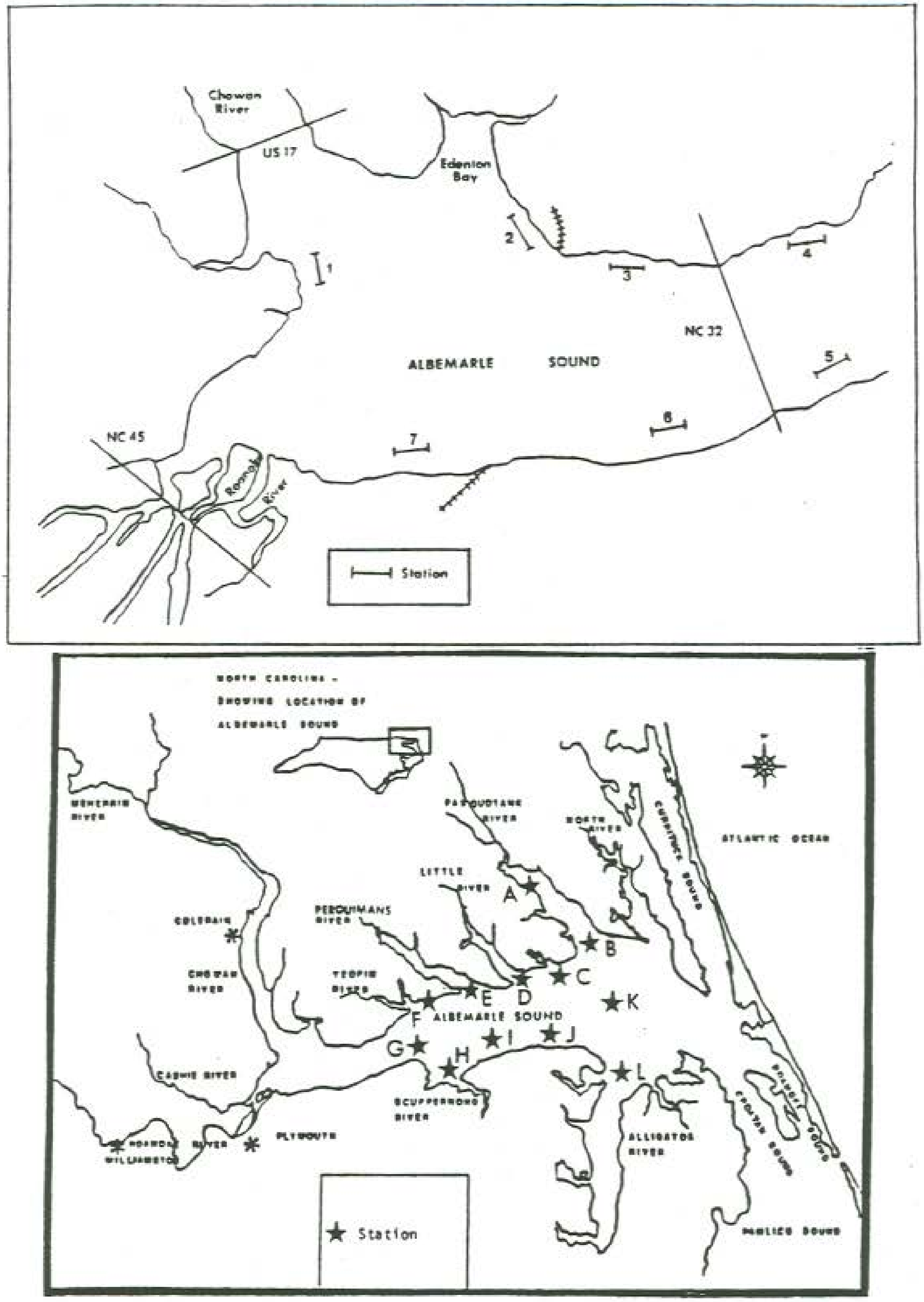

Figure 61. Station locations for young-of-year striped bass sampling in both the western (top) and central (bottom) Albemarle Sound areas, North Carolina.

Table 68. Number of young-of-year striped bass captured by semi-balloon trawl in western Albemarle Sound, NC, by station, July-October, 1988. The Juvenile Abundance Index of 4.09 is calculated by the total samples (56) divided into the total number of striped bass captured (229).

	Station Number							
Date	1	2	3	4	5	6	7	Total
14 Jul 88	2	0	2	17	9	5	1	36
27 Jul 88	16	0	0	29	1	0	0	46
9 Aug 88	0	0	1	9	0	1	8	19
23 Aug 88	2	0	0	4	21	1	0	28
6 Sep 88	4	1	0	4	8	1	5	23
19 Sep 88	0	1	0	0	0	0	0	1
7 Oct 88	1	20	2	0	0	53	0	76
18 Oct 88	0	0	0	0	0	0	0	0
Total	25	22	5	63	39	61	14	229

Table 69. Number of young-of-year striped bass captured by semi-balloon trawl in western Albemarle Sound, NC, by station, July-October, 1989. The Juvenile Abundance Index of 4.27 is calculated by the total samples (56) divided into the total number of striped bass captured (239).

	Station Number							
Date	1	2	3	4	5	6	7	Total
21 Jul 89	0	0	0	0	0	0	1	1
8 Aug 89	0	0	6	1	0	0	0	7
16 Aug 89	0	0	10	27	0	0	0	37
29 Aug 89	0	1	3	0	14	0	0	18
12 Sep 89	0	1	15	4	11	13	10	54
28 Sep 89 (3 Oct 89)	1	0	5	6	3	15	20	50
10 Oct 89	1	4	13	14	22	7	0	61
27 Oct 89	1	0	9	0	1	0	0	11
Total	3	6	61	52	51	35	31	239

Table 70. JAI catch matrix for seven stations in western Albemarle Sound, NC, 1988 and 1989.

1988				1989			
Date	Stations	Fish	JAI	Date	Stations	Fish	JAI
14 Jul	7	36	5.14	21 Jul	7	1	0.14
27 Jul	7	46	6.57				
Monthly	14	82	5.86	Monthly	7	1	0.14
09 Aug	7	19	2.71	08 Aug	7	7	1.00
23 Aug	7	28	4.00	16 Aug	7	37	5.29
				29 Aug	7	18	2.57
Monthly	14	47	3.36	Monthly	21	62	2.95
06 Aug	7	23	3.29	12 Sep	7	54	7.71
19 Aug	7	1	0.14	28 Sep	7	50	7.00
Monthly	14	24	1.71	Monthly	14	104	7.43
07 Oct	7	76	10.86	10 Oct	7	61	8.71
18 Oct	7	0	0.00	27 Oct	7	11	1.57
Monthly	14	76	5.43	Monthly	14	72	5.14
Total	56	229	4.09	Total	56	239	4.27

The increased JAI (1988 and 1989) has been attributed to both the beneficial effects of water flow modification from the Roanoke River reservoir system and favorable water quality conditions. Harvest limitations implemented by the NC resource management agencies during the mid-1980s may also be reflected in the increased JAI (ASMFC 1990).

The 1990 JAI of 1.41 (Table 71) was considerably less than the two previous years, but greater than the historically low levels observed during the 10-year period, 1978-1987 (Table 67). This relatively low JAI could have been initial larval displacement caused by high and unstable flows (late May and June) from the Roanoke River and extensive blue-green algal blooms in the western Albemarle Sound and Chowan River. The monthly JAI for 1990 (Table 72) was: July, 2.79; August, 0.57; September, 0.64; and October, 1.64.

The 1991 JAI of 0.86 (Table 73) is the lowest since 1987. Considering the favorable water quality conditions of the Roanoke River and western Albemarle Sound area, along with the high to moderate outflows from the Roanoke reservoir system, a higher JAI would have been expected. The monthly JAI for 1990 (Table 74) was: July, 1.50; August, 1.43; September, 0.43; and October, 0.07.

The 1991 flows followed the seasonal pattern as recognized in the Recruitment Subcommittee's optimum flow regime for increased or good reproduction. However, the magnitude of the flows were considerably higher than those flows termed optimum by this same committee. The March and April flows were outside the Negotiated Flow Regime (established by the Flow Committee), and during May and June were near the 75% quartile (or upper level) of the flow regime. Based on the low juvenile abundance, it does not appear that these higher flows were conducive to favorable reproduction and survival.

Table 71. Number of young-of-year striped bass captured by semi-balloon trawl in western Albemarle Sound, NC, by station, July-October, 1990. The Juvenile Abundance Index of 1.41 is calculated by the total samples (56) divided into the total number of striped bass captured (79).

	Station Number							
Date	1	2	3	4	5	6	7	Total
17 Jul 90	0	2	26	0	0	0	0	28
31 Jul 90	0	5	4	0	0	1	1	11
15 Aug 90	0	0	2	1	1	0	0	4
29 Aug 90	0	0	4	0	0	0	0	4
12 Sep 90	0	0	2	4	0	0	0	6
26 Sep 90	0	1	0	0	2	0	0	3
10 Oct 90	0	0	2	6	0	1	13	22
25 Oct 90	0	0	0	0	0	1	0	1
Total	0	8	40	11	3	3	14	79

Table 72. JAI catch matrix for seven stations in western Albemarle Sound, NC, 1990.

Date	Stations	Fish	JAI
17 Jul 90	7	28	4.0
31 Jul 90	7	11	1.57
Monthly	14	39	2.79
15 Aug 90	7	4	0.57
29 Aug 90	7	4	0.57
Monthly	14	8	0.57
12 Sep 90	7	6	0.86
26 Sep 90	7	3	0.43
Monthly	14	9	0.64
10 Oct 90	7	22	3.14
25 Oct 90	7	1	0.14
Monthly	14	23	1.64
Total	56	79	1.41

Table 73. Number of young-of-year striped bass captured by semi-balloon trawl in western Albemarle Sound, NC, by station, July-October, 1991. The Juvenile Abundance Index of 0.86 is calculated by the total samples (56) divided into the total number of striped bass captured (48).

	Station Number							
Date	1	2	3	4	5	6	7	Total
16 Jul 91	1	0	8	7	0	0	0	16
30 Jul 91	0	0	0	0	0	0	4	4
15 Aug 91	0	2	1	4	0	0	1	8
27 Aug 91	0	5	1	0	1	2	3	12
10 Sep 91	0	0	1	3	0	0	0	4
26 Sep 91	2	0	0	0	0	0	0	2
08 Oct 91	0	0	0	0	0	0	0	0
22 Oct 91	0	0	1	0	0	0	0	1
Total	3	7	12	14	1	2	9	48

Table 74. JAI catch matrix for seven stations in western Albemarle Sound, NC, 1991.

Date	Stations	Fish	JAI
16 Jul 91	7	16	2.29
30 Jul 91	7	5	0.71
Monthly	14	21	1.50
15 Aug 91	7	8	1.14
27 Aug 91	7	12	1.71
Monthly	14	20	1.43
10 Sep 91	7	4	0.57
26 Sep 91	7	2	0.29
Monthly	14	6	0.43
08 Oct 91	7	0	0
22 Oct 91	7	1	0.14
Monthly	14	1	0.07
Total	56	48	0.86

The 1992 JAI of 2.57 (Table 75) was the highest since 1989. Estimated striped bass egg production in the Roanoke River was at a record high level; however, an expected high level of juvenile survival was not realized. During May when the majority of the egg production occurred, Raonoke River flows were within the Negotiated Flow Regime. High flows, particularly late in the flow augmentation period, may have hampered juvenile survival. The monthly JAI for 1992 (Table 76) was: July, 2.71; August, 5.07; September, 2.14; and October, 0.36.

The 1993 JAI of 44.54 (Table 77) was the highest recorded level since the inception of the survey in 1955. In only two other years -- 1959 and 1967 -- has the JAI exceeded 20 (Table

Table 75. Number of young-of-year striped bass captured by semi-balloon trawl in western Albemarle Sound, NC, by station, July-October 1992. The Juvenile Abundance Index of 2.57 is calculated by the total samples (56) divided into the total number of striped bass captured (144).

	Station Number							
Date	1	2	3	4	5	6	7	Total
15 Jul 92	2	3	0	1	1	0	0	7
28 Jul 92	0	15	10	6	0	0	0	31
10 Aug 92	0	45	0	6	0	1	0	52
27 Aug 92	1	3	6	8	0	0	1	19
08 Sep 92	0	0	24	0	0	0	0	24
22 Sep 92	0	0	2	0	3	1	0	6
08 Oct 92	0	0	0	1	0	0	1	2
22 Oct 92	0	0	0	0	1	1	1	3
Total	3	66	42	22	5	3	3	144

Table 76. JAI catch matrix for seven stations in western Albemarle Sound, NC, 1992.

Date	Stations	Fish	JAI
15 Jul 92	7	7	1.00
28 Jul 92	7	31	4.43
Monthly	14	38	2.71
10 Aug 92	7	52	7.43
27 Aug 92	7	19	2.71
Monthly	14	71	5.07
08 Sep 92	7	24	3.43
22 Sep 92	7	6	0.86
Monthly	14	30	2.14
08 Oct 92	7	2	0.29
22 Oct 92	7	3	0.43
Monthly	14	5	0.36
Total	56	144	2.57

Table 77. Number of young-of-year striped bass captured by semi-balloon trawl in western Albemarle Sound, NC, by station, July-October, 1993. The Juvenile Abundance Index of 44.54 is calculated by the total samples (56) divided into the total number of striped bass captured (2,494).

	Station Number							
Date	1	2	3	4	5	6	7	Total
13 Jul 93	1	0	244	15	37	8	136	441
27 Jul 93	60	15	6	30	19	38	471	639
11 Aug 93	20	18	83	5	2	43	17	188
23 Aug 93	28	4	38	102	0	11	4	187
07 Sep 93	13	27	51	60	2	23	7	183
23 Sep 93	13	14	65	278	2	27	6	405
05 Oct 93	1	49	84	148	7	11	1	301
19 Oct 93	3	16	16	24	6	19	66	150
Total	139	143	587	662	75	180	708	2,494

Table 78. JAI catch matrix for seven stations in western Albemarle Sound, NC, 1993.

Date	Stations	Fish	JAI
13 Jul 93	7	441	63.00
27 Jul 93	7	639	91.29
Monthly	14	1,080	77.14
11 Aug 93	7	188	26.86
23 Aug 93	7	187	26.71
Monthly	14	375	26.79
07 Sep 93	7	183	26.14
23 Sep 93	7	405	57.86
Monthly	14	588	42.00
05 Oct 93	7	301	43.00
19 Oct 93	7	150	21.43
Monthly	14	451	32.21
Total	56	2,494	44.54

67). The potential for good juvenile production did not appear favorable during March due to the high rainfall and high Roanoke River flows that threatened the entire spawning season. Although very high, flows during early 1993 resembled the seasonal pattern recognized by the Recruitment Subcommittee as being favorable for increased reproduction (i.e., higher flow levels early in the spring followed by a decrease in flow rate), but the magnitude of flow was considerably higher than those flows deemed favorable by the Committee. Throughout March and April flows were outside the Negotiated Flow Regime. River flows remained stable except for a significant decrease which occurred in May. During mid-May, river flow levels dropped over several days to the upper boundary of the Negotiated Flow Regime. River flow continued at this upper boundary from 12 May through the end of the flow augmentation period (15 June), and then trended downward throughout the remainder of June. Based on the high level of juvenile abundance, it appears that these early, very high flows followed by more moderate flows, were very conducive to reproduction and survival.

During 1993, estimated striped bass egg production achieved another record level, approximately 2.5 times greater than the previous record observed in 1992 (Table 65). This increase in egg production has been attributed to the abundance of the 1988 and 1989 year classes on the spawning grounds. The monthly JAI values for 1993 (Table 78) were: July, 77.14; August, 26.79; September, 42.0; and October, 32.21. The phenomenal 1993 JAI has been attributed to stable Roanoke River flows, favorable water quality conditions, striped bass harvest limitations, and Mother Nature.

CPUE values for the central Sound stations have been very low except during 1989, which was the first time significant numbers were captured since sampling began in 1984 (Figure 62). The drastic increase in 1989 central Sound CPUE may have been positively influenced by the high and stable Roanoke River spring flow and its effect on the Albemarle Sound nursery area. Analysis of the western and central Sound juvenile information and Roanoke River flow data suggests that the density of juvenile striped bass in the central Sound survey area is related to River flow and water quality conditions. Flow into the Albemarle Sound, principally from the Roanoke River, appears to affect the striped bass nursery area location and distribution of larvae within the Sound. Monthly comparisons between the 1989 central Sound CPUE and the 1989 western Sound JAI (Figure 63) further support the high flow and larval displacement hypothesis as an explanation for delayed recruitment observed during the 1989 western Sound JAI survey. Juvenile abundance was high and levels peaked early in the sampling season for the central Sound and gradually decreased towards the end of the season.

The 1989 western Sound survey exhibited the opposite trend as the juveniles migrated back into the historical sampling area. Figure 63 clearly shows this pattern, starting in July, with a low 0.14 JAI, increasing in August to 2.95. In September the JAI peaked with a 7.43 and then decreased in October to a 5.14 JAI. One explanation is that the juveniles may have followed a potential food source, the bay anchovy (*Anchoa mitchilli*), as they returned to the western Albemarle survey area. Another possibility may be an emigration of later-spawned juveniles from the Roanoke River delta into the western Sound, thus increasing juvenile abundance in the western survey area later in the season. It appears that the 1989 early spring (March and early April) flooding and the high, stable May flows from the Roanoke River had a positive impact on the central Sound nursery area and, therefore, juvenile production.

During 1990, the central Sound survey yielded very few juveniles (CPUE 0.25, Figure 62), indicating continued poor production in this area. Roanoke River flows were relatively high throughout the season and not conducive to the establishment of a potentially productive nursery area in either the eastern or western Albemarle Sound.

The 1991 catch per unit effort for the eastern Sound survey was a low 0.12 (Figure 62). This CPUE value substantiates the continued poor production in this area.

The central Sound survey produced a CPUE of 0.43 (Figure 62) during 1992. This survey continued to yield few juveniles compared to the western Sound survey.

The 1993 central Sound survey produced the highest CPUE (12.4) since DMF started these central Sound trawls in 1984 (Figure 62). The only other year in which a large number of juveniles were captured in this area was 1989. Analysis of the western and central Sound juvenile information (Figure 64) and Roanoke River flow data suggest that the density of striped bass in the central Sound survey area is related, as in 1989, to River flow and water quality conditions. Flow into the Albemarle Sound, principally from the Roanoke River, affects the striped bass nursery area location and distribution of larvae within the Sound on a yearly basis. However, during 1993 the drastic increase in abundance of juveniles observed in the central Sound was potentially a function of the phenomenal juvenile recruitment observed in the Albemarle Sound nursery area.

A plausible shift in the historical striped bass nursery area due to poor water quality in the western Sound is not evident from the central Sound samples. Additional collections from the central Sound will provide a basis for future evaluations relative to historical juvenile abundance and the impacts of flow and water quality on juvenile distribution within the Albemarle Sound system.

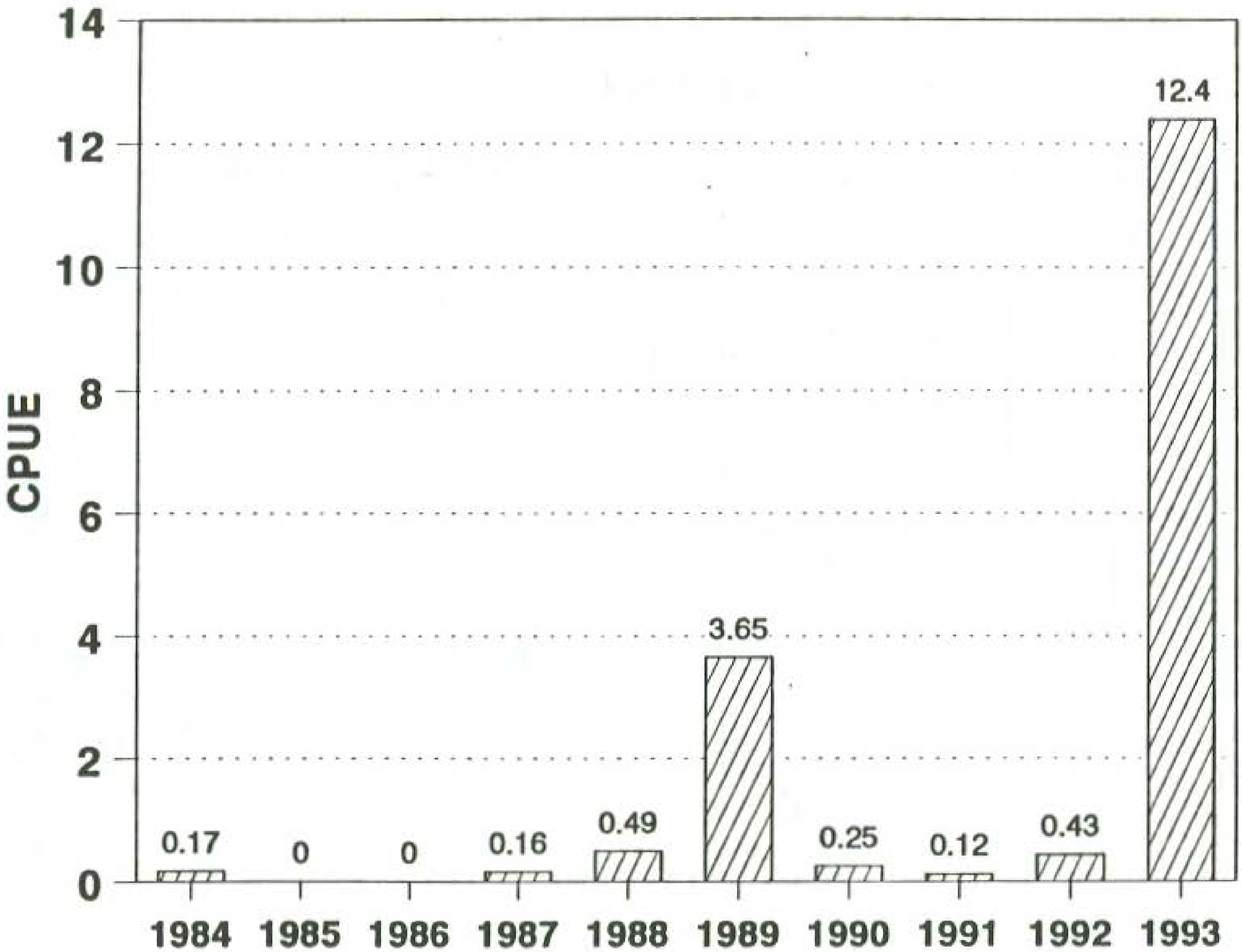

Figure 62. Central Albemarle Sound striped bass juvenile catch-per-unit-effort values from 1984-1993.

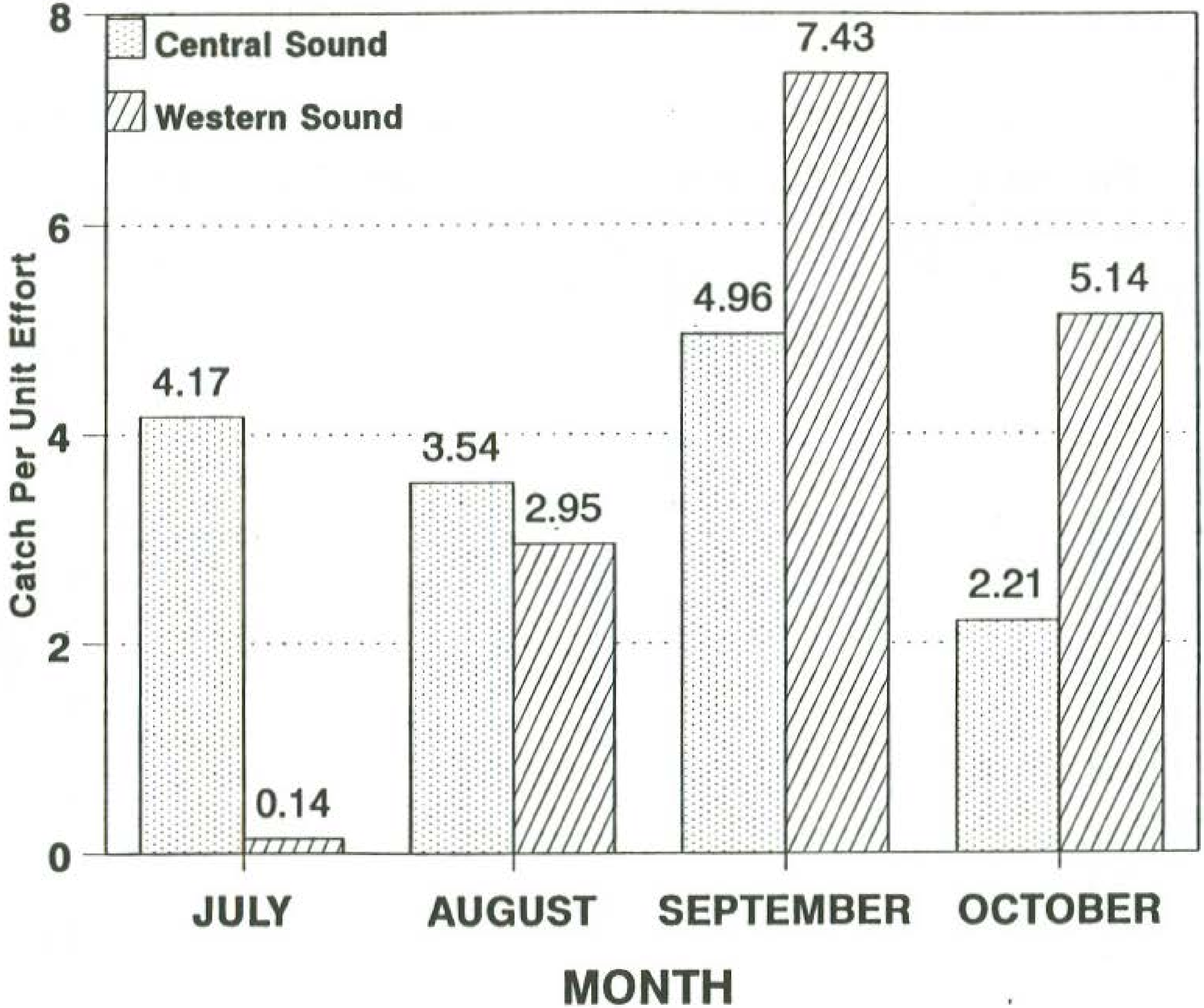

Figure 63. Monthly CPUEs for 1989 central vs. western Albemarle Sound stations.

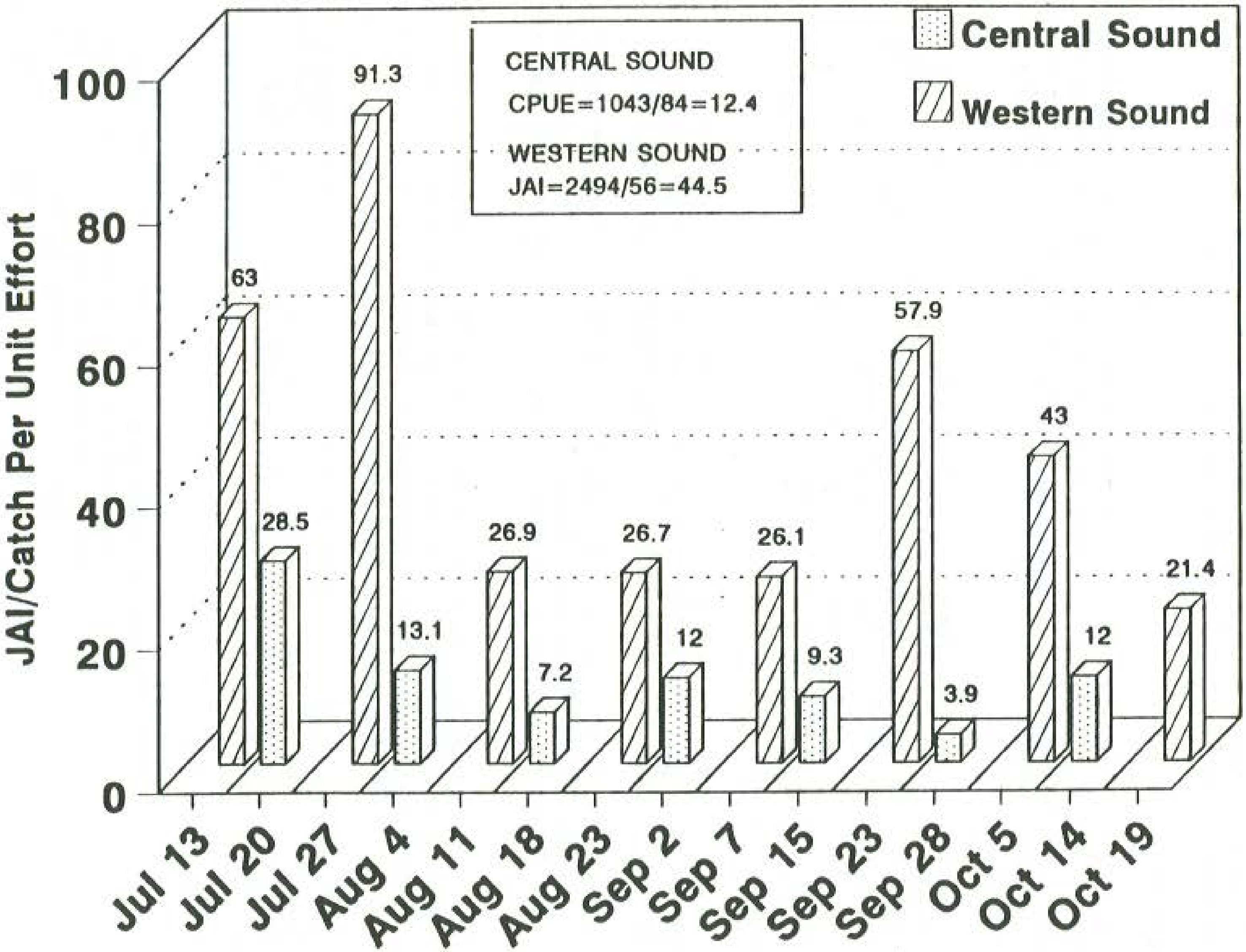

Figure 64. Juvenile striped bass CPUEs for 1993, central vs. western Albemarle Sound stations.

Age, Growth, and Survival of Juvenile Striped Bass Determined by Counting Daily Growth Rings on Otoliths, 1990-1992

Roger A. Rulifson, J. Jeffery Isely and Charles S. Manooch, III

When Roanoke/Albemarle striped bass studies were initiated in the mid-1950s, no technique was available to document the exact date of spawning for an individual fish. The recent development of reading the daily growth rings of otoliths now provides the ability to pinpoint the spawning dates of young-of-year (YOY) fish. Results of a three-year study (1990-1992) were detailed elsewhere (Rulifson et al. 1993) but are summarized for this report.

Young-of-Year Collection

YOY striped bass were collected by the DMF at various locations in Albemarle Sound in four separate studies: the western Albemarle Sound trawl survey (Hassler trawls), the central and eastern Albemarle Sound trawl survey, the alosid beach seine survey, and the exploratory beach seine survey. Figure 65 depicts the location of each sampling site; a verbal description of the sites is presented in Table 77.

The western Sound trawl survey was initiated by Hassler in 1955 to estimate relative year class strength, a technique still used by DMF to produce the annual Juvenile Abundance Index (JAI). Refer to the previous section by Henry and Taylor for a detailed description of the collection methods. Briefly, DMF personnel sample seven permanent stations in western Albemarle Sound on a bi-weekly schedule from July through October each year, producing a total of 56 samples. A standard trawl is towed for 15 minutes at a speed of approximately 2.75 miles per hour in waters 6-10 feet deep. The JAI is expressed as the mean number of young striped bass caught per 15-minute tow.

The central and eastern Sound trawl survey is similar to the western Sound trawl survey in sample design and gear. Twelve fixed stations are sampled bi-weekly July through October to determine a relative abundance index (CPUE) of juvenile striped bass per 10-minute tow.

The alosid beach seine survey is used primarily for juvenile shad and river herring assessment but collected YOY striped bass are enumerated. Eleven fixed stations are sampled monthly June through November each year with a 18.5-m bag seine containing a 6.4-mm ace mesh bag. One seine haul is one unit of effort.

The exploratory beach seine survey is primarily for YOY striped bass and is conducted in a manner similar to the alosid beach seine survey. In past years, a number of locations were sampled to determine habitat utilization by juvenile striped bass. This survey became a fixed-station survey in 1993 to provide a relative abundance index.

In each survey, all YOY striped bass from a particular station were enumerated, bagged and labeled by station and date, then frozen for transport to the laboratory. Each fish was numbered individually, measured (FL and TL), and weighed (0.01 g). The head was surgically removed to obtain the otoliths for age analysis.

Aging YOY Striped Bass

The age of each YOY striped bass was assigned by counting the number of rings appearing on the sagittal otolith. Each otolith was mounted with the proximal side affixed to a glass microscope slide with a small drop of thermoplastic cement such that the concave surface faced away from the slide. The sagittal plane of each otolith was polished by hand against a wet sheet of number 600 carborundum paper until the nucleus was exposed and the rings became visible.

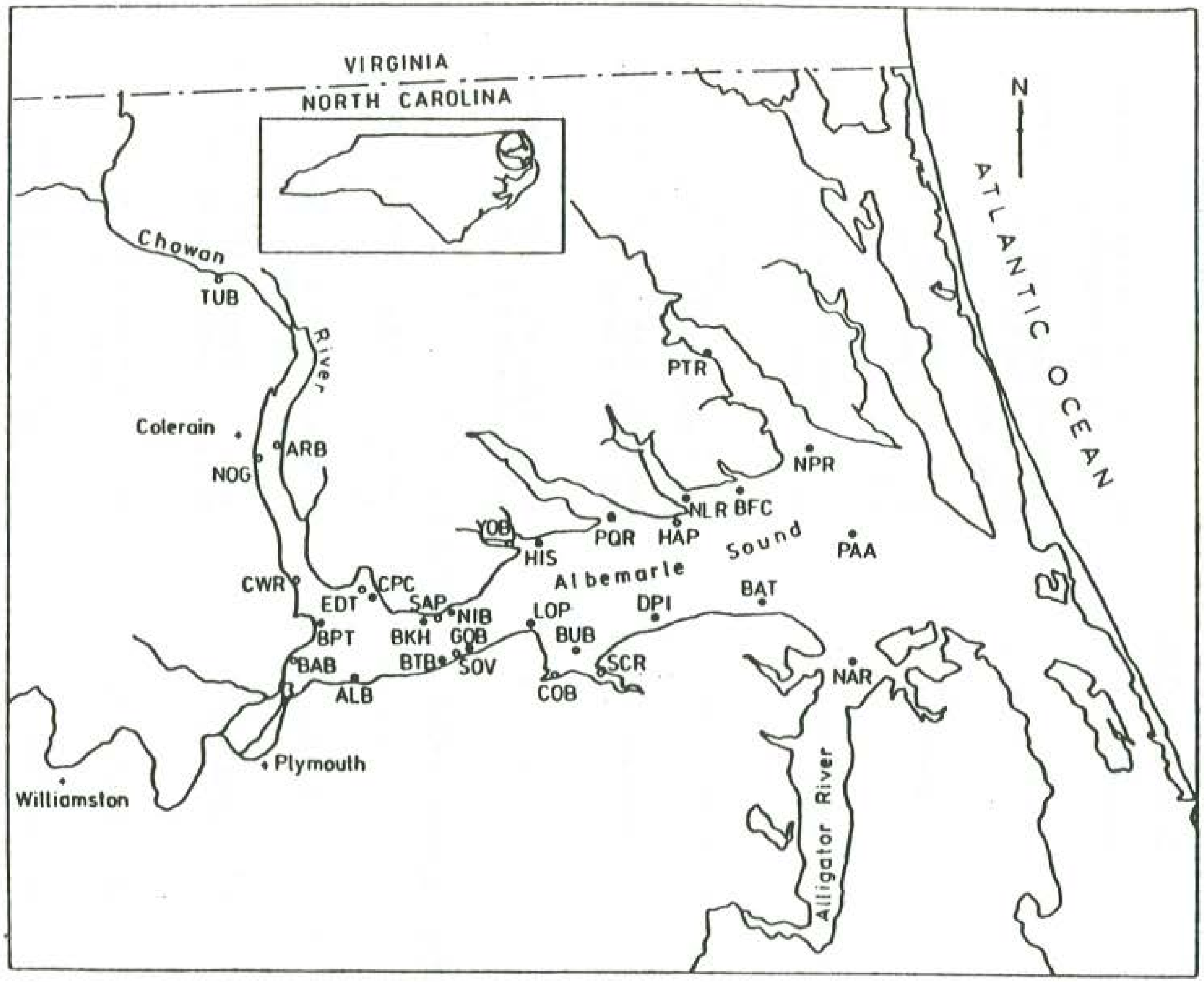

Figure 65. Sampling stations of the NC Division of Marine Fisheries used for the western Sound (Hassler) trawl survey (JAI), the central and eastern trawl survey (EST), the alosid beach seine survey (ALO), and the exploratory beach seine survey (EXP). Written descriptions of each station presented in Table 79.

Table 79. Description of trawl and beach seine sampling stations in Albemarle Sound used by the N.C. Division of Marine Fisheries. See Figure 65 for locations.

Code	DMF station number	Station name	Description
Hassler trawls for YOY striped bass (JAI)			
BPT	139	Black Walnut Point	Hassler station #1; western Alb. Sound south of Chowan River bridge
CPC	153	Cape Colony	Hassler station #2; north shore of western Alb. Sound near Edenton Bay; west of NC power lines
BKH	149	Brickhouse Point	Hassler station #3; north shore of western Alb. Sound between power lines and Hwy 32 bridge
NIB	137	Nixon's Beach	Hassler station #4; north shore of western Alb. Sound east of Hwy 32 bridge (east of Sandy Pt.)
GOB	150	George's Beach	Hassler station #5; south shore of western Alb. Sound east of Hwy 32 bridge
BTB	151	Bateman's Beach	Hassler station #6; south shore of western Alb. Sound between power lines and Hwy 32 bridge
ALB	152	Albemarle Beach	Hassler station #7; south shore of western Alb. Sound west of NC power lines
Central and Eastern Sound trawl survey (EST) for striped bass			
NLR	28	Little River	mouth of Little River; north shore of eastern Alb. Sound
BFC	134	off Big Flatty Creek	north shore of central Alb. Sound off-shore from Frog Island Seafood
LOP	142	Laurel Point	south shore of central Alb. Sound west of Bull Bay off light (inshore of light tower)
HIS	160	off Holiday Island	north shore of central Alb. Sound east of Yeopim River mouth
BUB	143	Bull Bay	south shore of central Alb. Sound off west side of Scuppernong River mouth
DPI	144	off Dewey's Pier	south shore of central Alb. Sound west of Ship Pt. (near shore)

Table 79. Continued.

Code	DMF station number	Station name	Description
Central and Eastern Sound trawl survey (EST) for striped bass (continued)			
PAA	154	Mid-sound	Middle of eastern Alb. Sound between Pasquotank and Alligator rivers mouths
BAT	155	off Barge (bombing) target	south shore of central Alb. Sound west of Ship Pt. (offshore)
NAR	156	Alligator River	western side of Alligator River mouth; south shore of eastern Alb. Sound
HAP	157	Harvey Point	north shore of central Alb. Sound in the mouth of Perquimans River
NPR		Pasquotank River (mouth)	mouth of Pasquotank River on north shore of eastern Alb. Sound
PTR	159	Pasquotank River - Coast Guard Air Station	in Pasquotank River near the Coast Guard Air Station; north shore of eastern Alb. Sound
Juvenile alosid beach seine survey (ALO)			
CWR	46S	Chowan River Bridge	directly south of Chowan River bridge; north shore of western Alb. Sound
NOG	47S	Sheep's Landing Rd. (Mount Gould)	west side of Chowan River below Colerain
TUB	48S	Tuscaroara Beach	western shore of Chowan River below Winton
ARB	56S	Arrowhead Beach	eastern shore of Chowan River at Arrowhead State Park
BAB	128S	Batchelor Bay	western Alb. Sound between Cashie River mouth and Black Walnut Creek
SOV	130S	Soundview	south shore of western Alb. Sound just east of Hwy 32 bridge
SAP	127S	Sandy Point	north shore of western Alb. Sound just east of Hwy 32 bridge
HAP	126S	Harvey Point	west of Perquimans River, north shore of central Alb. Sound

Table 79. Continued.

Code	DMF station number	Station name	Description
Juvenile alosid beach seine survey (ALO) (continued)			
SCR	84S	Scuppernong River	eastern shore of Scuppernong River, south shore of central Alb. Sound
COB	85S	Colonial Beach	mouth of Scuppernong River, south shore of central Alb. Sound (Bull Bay)
YOB	39S	Yeopim River	near mouth of Yeopim River north of Holiday Island, north shore of central Alb. Sound
Exploratory beach seine survey (EXP) for striped bass			
	128S	Batchelor Bay	west shore of western Alb. Sound between Terrapin Pt. and Avoca Farm
	46S	Chowan River Bridge	same as Alosid seines
		Country Club Drive: Swim Beach	north shore of central Alb. Sound, east of Edenton Bay, Cape Colony, and the old Bayliner plant
	139S	Black Walnut Point	Point below mouth of Salmon Creek, north of Black Walnut Creek
BAF	162S	Batchelor Bay @ Avoca Farm	north side of Batchelor Bay along south shore of Black Walnut Creek
	152S	Albemarle Beach	south side of western Alb. Sound east of Swan Bay and west of Mackey's Creek
WOM	129S	West of Mackey's Creek	south shore of western Alb. Sound west of NC power lines
		Bateman's Beach seine	
	153S	Albemarle Sound at Cape Colony	north shore of western Alb. Sound west of NC power lines
EDT	49S	Edenton Bay	east side of Edenton Bay mouth, north shore of western Alb. Sound
OBP	163S	Albemarle Sound off Old Bayliner Plant	north shore of western Alb. Sound near the Union Camp pier and east of the power lines off Horniblow Pt.

Otoliths were examined using immersion oil at magnifications of 100-400x with transmitted polarized light (Figure 66). Otolith rings were counted only once, since experience indicated that repeated counts resulted in a range of less than five rings from minimum to maximum counts through the range of ages represented in the total sample (Isely and Manooch 1991).

Spawning dates were estimated by assuming that each ring on the otolith represented one day of life (Secor and Dean 1989; Secor et al. 1989, 1990; Kline 1990). A first-ring formation date was calculated for each fish by subtracting the number of rings counted from the date when the fish was collected. The spawning date was determined by subtracting three days from the first-ring formation of the otolith.

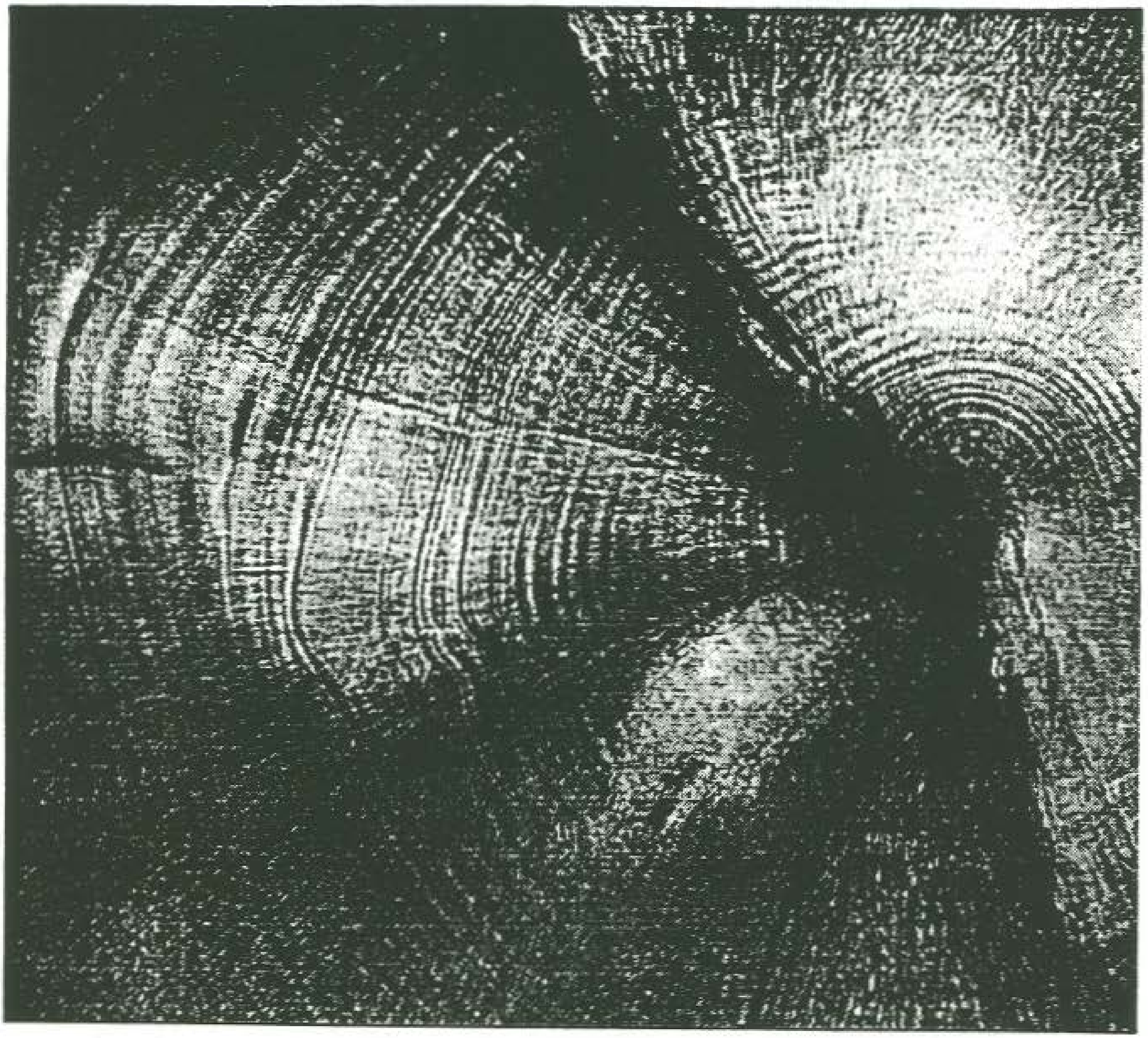

Figure 66. Digitized microphotograph of a young-of-year striped bass sagittal otolith depicting the rings used to backcalculate the spawn date.

Calculating Relative Survival

Relative survival rates of egg cohorts spawned in the Roanoke River each day (see section by Rulifson on egg abundance and viability) were compared to the number of YOY Albemarle fish from each spawning date (YOY cohorts) to determine if differential survival occurred, thus indicating higher than expected success of one particular cohort. The egg data set was the daily egg production estimate adjusted by the daily egg viability estimate. The juvenile data set used was only those fish collected by trawls; i.e., the Hassler (JAI) and central-eastern (EST) trawl surveys. Juveniles were enumerated by estimated spawn date; the resultant number was adjusted to reflect daily mortality. This was accomplished by first subtracting the estimated spawning date from the collection date to determine the fish age (in days). Second, the number of fish in the YOY daily cohort (N_0) was weighted (N_t) by determining the length of time "at large" from a standard 60-day period assuming a daily instantaneous mortality rate (Z) of 0.01. The weighting formula was

$$N_t = N_0 e^{-(60-Age)Z}.$$

Detailed information of the methods, results, and assumptions used in interpreting the data is in Rulifson et al. (1993).

The 1990 Year Class

Otoliths from 58 fish were examined. Two of the fish were judged to have more than 365 rings, and thus were not considered to be juveniles. These yearling striped bass were captured in the western Albemarle Sound during August and were not included in further analyses. The remainder were used to derive length conversion equations: TL to FL, FL to TL, and to derive a growth equation predicting the age in days of individual fish at a given length (TL mm). Data distribution was linear; therefore, linear regressions were used to describe the relationships:

$$TL = 1.0484(FL) - 0.8871; n = 56; r = 0.999$$

$$FL = 0.9521(FL) - 0.7312; n = 56; r = 0.999$$

$$Age\ (daily\ rings) = 0.7307(TL) + 14.1033; n = 56; r = 0.8809.$$

Fish of the size range evaluated grew approximately 1 mm per day. A juvenile striped bass 50 mm TL was estimated to be 51 days old; a 70-mm fish, 65 days; a 100-mm fish, 87 days. The equations above should not be used to estimate the age of striped bass greater than 112 mm TL, or to convert length of fish larger than 112 mm TL.

A 91-day spawning window and rather weak JAI value describe the 1990 year class. The western trawl survey indicted that the 1990 year class was a rather weak year class with a JAI value of 1.41 fish per trawl (Table 67). Examination of 91 otoliths from fish collected by all surveys indicated that YOY striped bass recruited to the 1990 year class were spawned as early as 28 March and as late as 27 June, for a 91-day spawning window (Table 80).

Results of the 1990 egg study and 1990 otolith study identified differences in the estimated spawning window for 1990. Spawning activity documented by field observations of egg deposition indicated that spawning began on 24 April and was completed by 12 June, for a 50-day spawning window. Using all trawl survey data only (as a single gear type), spawning was estimated to have started at least by 10 April (the first spawn date of any YOY fish caught by any gear) and ended as early as 27 June (the latest spawned fish documented by any gear).

Comparison of the egg study and trawl study results indicated a non-uniform rate of mortality during the season, with the highest rate occurring during peak spawning activity (Figure 67). A uniform mortality rate of each daily cohort should have produced similar images of egg production and resultant YOY fish collected from Albemarle Sound. However, the data show that over 75% of the YOY recruited in 1990 were spawned after the peak spawn on 10 May; about 13% of all YOY fish examined came from eggs spawned after 1 June.

For the most part, the overall poor recruitment of daily YOY cohorts to the 1990 year class was greatest on dates during which the Roanoke River discharge ranged between 8,000 and 15,000 cfs. Most eggs were spawned within the same range of flows.

The 1991 Year Class

An 80-day spawning window and weak JAI characterized the 1991 year class. The western trawl survey indicated that the 1991 year class was weaker than the 1990 year class, with a JAI value of 0.86 fish per trawl (Table 67). Interestingly, the estimated number of eggs spawned in 1991 was double that of 1990, with an estimated viability of 3% less than 1990. Results from reading the otoliths of 50 fish collected by trawl indicated that YOY recruited to the 1991 year class were spawned as early as 4 May and as late as 6 July (63 days). Field observations of spawning activity documented a 17 April starting date and 12 June ending date for a 57-day spawning window. Combined, these two data sets indicate an 80-day spawning window (Table 80).

Again, a comparison of egg study and trawl study results demonstrated a high mortality rate during peak spawning (Figure 68). Peak spawning in 1991 occurred on 14 May at which time recruitment should have been about 70% completed. On the same date, recruitment indicated by surviving YOY fish was only 17% complete; fully 83% of juvenile recruitment came from eggs spawned after the peak of spawning activity and 41% came from eggs spawned after 1 June.

Most juvenile recruitment of the weak 1991 year class was from spawning dates during which the River discharge was stable at about 9,000 cfs (Figure 68). However, fish recruitment also was evident from dates of reduced river flow when few eggs were spawned.

The 1992 Year Class

The 1992 year class was the strongest of the three-year study, but the annual JAI of 2.57 was lower than that observed in 1988 and 1989 even though egg production estimates were the highest ever recorded since measurements were started in 1959 (Table 67).

Striped bass successfully recruited to the 1992 year class from eggs spawned as early as 20 April and as late as 25 July (96 days). These results, combined with the field observations, indicated a 99-day spawning window. A total of 231 YOY fish from trawls and seines were aged. The 1992 year was the first in which the exploratory beach seine survey was used to sample fixed stations in a consistent manner. Results suggest that YOY fish less than one month in age probably are not susceptible to beach seine capture.

Table 80. Comparisons of striped bass spawning activity in the Roanoke River documented by field observations of the egg study, and by backcalculating spawn dates of juveniles (using otoliths) collected by the NCDMF (Hassler) trawl survey (JAI), the central and eastern trawl survey (EST), the alosid beach seine survey (ALO), and the exploratory beach seine survey (EXP).

			Trawl surveys		Beach seine surveys		
Year	Activity	Egg study	JAI	EST	ALO	EXP	All data
1990	start spawning:	24 April	15 April	10 April	28 March	30 March	28 March
	end spawning:	12 June	27 June	25 May	20 May	-	27 June
	days in spawning window:	50	73	45	53	-	91
	recruitment 50% complete:	10 May	18 May				
	recruitment 90% complete:	19 May	7 June				
1991	start spawning:	17 April	11 May	4 May	-	-	17 April
	end spawning:	12 June	6 July	8 June	-	-	6 July
	days in spawning window:	57	56	35	-	-	80
	recruitment 50% complete:	13 May	28 May				
	recruitment 90% complete:	25 May	20 June				
1992	start spawning:	17 April	17 May	19 May	-	20 April	17 April
	end spawning:	>23 June	25 July	23 June	-	8 June	25 July
	days in spawning window:	>67	69	35	-	49	99
	recruitment 50% complete:	20 May	13 May				
	recruitment 90% complete:	7 June	>30 June				

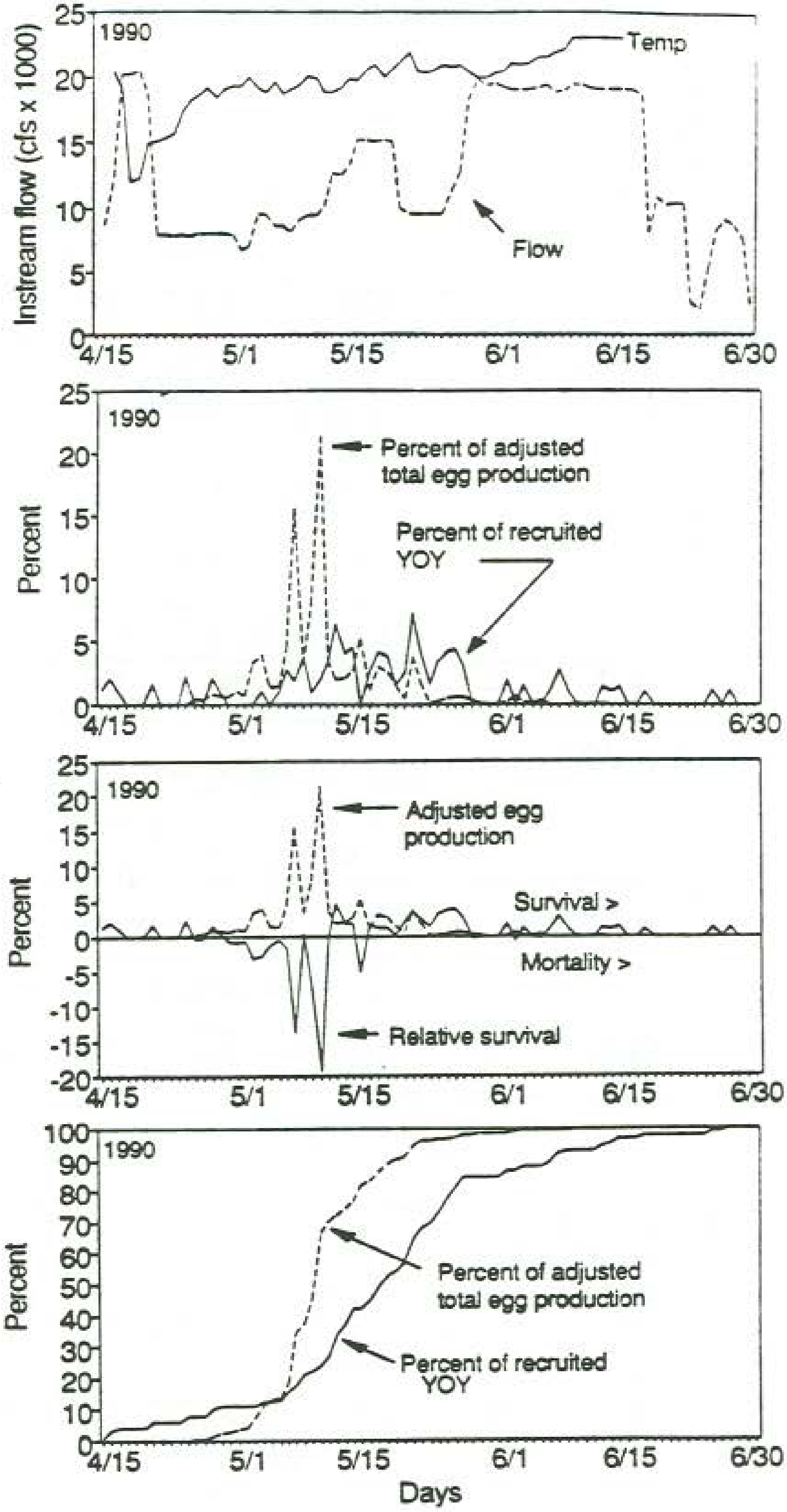

Figure 67. Water temperature (°C) and flow (cfs) of the Roanoke River, daily adjusted egg production and spawn dates of surviving YOY striped bass collected in trawls, YOY daily cohort survival relative to egg production, and predicted spawning window based on egg production and spawn dates of recruited YOY fish in 1990.

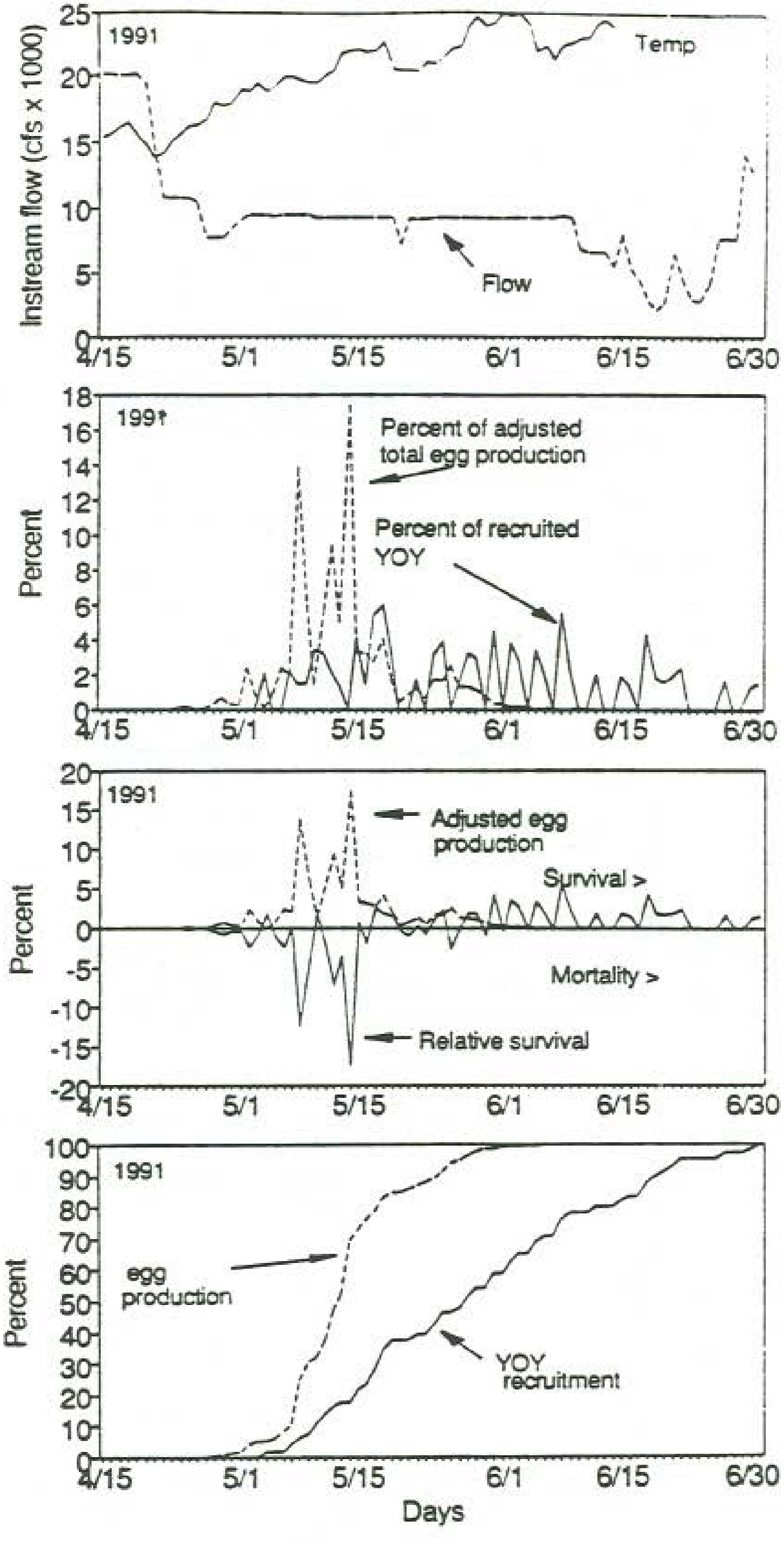

Figure 68. Water temperature (°C) and flow (cfs) of the Roanoke River, daily adjusted egg production and spawn dates of surviving YOY striped bass collected in trawls, YOY daily cohort survival relative to egg production, and predicted spawning window based on egg production and spawn dates of recruited YOY fish in 1991.

Comparisons of the egg study and trawl survey data sets depict extremely poor survival of the YOY cohort from the peak spawning period and good survival from eggs spawned through June and into July (Figure 69). Prior to this study, July spawning of striped bass had never been documented in the Roanoke River. However, this unique event did occur: field observations at Barnhill's Landing documented moderate and continuous spawning activity on 23 June, after which no egg sampling was conducted. However, local fishermen observed rock fights in the River through the last week in June. The moderate water temperatures most likely contributed to the prolonged spawning period. Peak spawn occurred on 20 May, at which time 60% of the annual egg production was completed. Otolith data indicated that only 2.4% of the recruited YOY fish came from this tremendous amount of eggs. By 1 June, only 77% of the egg production was completed and only 17% of the recruited YOY fish had been spawned. Juvenile recruitment in 1992 was only 50% complete by 13 June and 82% compete by 30 June.

Most eggs were spawned during moderate flow periods of 5,000 and 10,000 cfs, yet successful recruitment of the daily cohorts was poor for all levels of River discharge (Figure 69).

Conclusions and Management Implications

Striped bass spawning in the lower Roanoke River can be manipulated by water releases from Roanoke Rapids Reservoir upstream; however, the factors involved in success or failure of any YOY cohort to recruit to the forming year class is unclear. The spawning window is longer (80-100 days) than is currently considered (76 days) by Virginia Power, the Corps, and the WRC for management purposes. Three years of data indicate that spawning activity late in the season accounts for over half of the successfully recruited YOY striped bass in Albemarle Sound. This implies that YOY recruitment may be from a few surviving eggs spawned throughout the season, with late season progeny accounting for a greater proportion of the forming year class than was believed previously. The YOY cohorts in greater abundance may have been spawned during optimal environmental conditions, or may be from older females, or both. Since what constitutes "optimal conditions" is not known, the Roanoke River flow should be managed to mimic historical river flows as much as possible over the longest period of time possible (1 April to 30 June). Moderate flows result in the highest juvenile abundance indices in Albemarle Sound (Hassler et al. 1981, Rulifson and Manooch 1990b). This management action should include providing adequate downstream water temperatures from warming too quickly and to continue the moderate releases after the peak spawn, since spawning continues through June. Moderate flow regime guidelines as recommended by the Flow Committee, and implemented by the Corps and Virginia Power during the Flow Regime Study Period (1988-1993), should continue to be used.

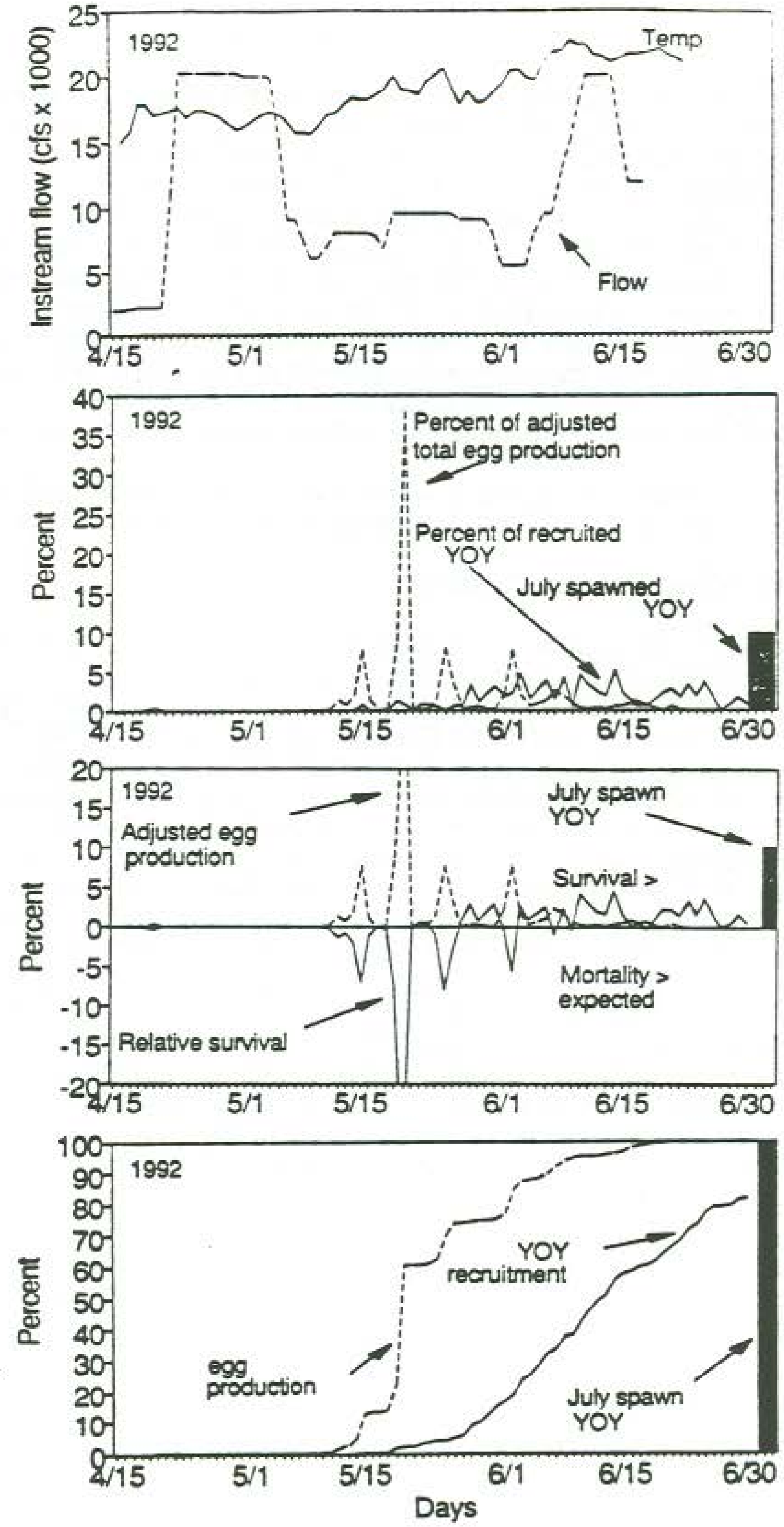

Figure 69. Water temperature (°C) and flow (cfs) of the Roanoke River, daily adjusted egg production and spawn dates of surviving YOY striped bass collected in trawls, YOY daily cohort survival relative to egg production, and predicted spawning window based on egg production and spawn dates of recruited YOY fish in 1992.

Food Habits of Juvenile Striped Bass in Albemarle Sound, NC, 1991

John E. Cooper and Scott F. Wood

Introduction

Food habit studies of juvenile striped bass have become more important in assessing possible causes of the decline of the Roanoke/Albemarle population. Previous studies have shown that larger juvenile and sub-adult striped bass (125-304 mm TL; Manooch 1973) preyed primarily on clupeid fish; smaller bass (44-110 mm TL; Rulifson and Bass 1991) preyed on zooplankton and mysid shrimp. The objective of the present study was to compare the food habits of juvenile striped bass to the findings of previous studies.

Methods

From July through October 1991, young-of-year striped bass were collected by trawl and beach seine at various locations in Albemarle Sound as part of the annual juvenile assessment program conducted by the NC Division of Marine Fisheries (Figure 70, Table 79). Fish from each station were placed in labeled bags and kept on ice until they could be frozen. Frozen fish were measured (total length in mm), weighed (g), and the entire digestive tract was removed and preserved in 10% buffered formalin. Otoliths were removed to estimate hatching dates.

Stomach contents of each fish were examined by excising the stomach from the remainder of the tract, then washing the stomach contents into a petri dish. Organisms were identified to the lowest practical taxon. The results are presented as the percentage of total fish in which the various taxa occurred. Collection stations were grouped into western Sound and eastern Sound locations determined by an arbitrary line drawn from Drummond Point to just west of Laurel Point (Figure 70).

Results and Discussion

A total of 58 fish were collected and of these, 56 (mean TL=54.1 mm) were collected in June, July, August, and early September. The remaining two fish (mean TL=315 mm) were taken in late September and were treated separately.

Mysid shrimp (*Mysidopsis bigelowi*) composed 57% of the diet of striped bass in 1991, similar to that found in 1989 and 1990. Copepods and other fish were second and equally abundant, found in 17.9% of the fish stomachs. Contents in 25% of the stomachs could not be identified. The remainder of the stomach contents is given in Table 81. Nearly 11% of the fish stomachs examined contained no food.

Fish represented a minor component of the diet in 1991. A similar trend was found in 1989 and 1990 (Rulifson and Bass 1991). Manooch (1973) found that small fish, primarily clupeids, were the dominant prey of juvenile and sub-adult (125-304 mm TL) striped bass. In the present study, only two fish were collected in this size range and the stomachs of both contained only fish.

There was a shift in food preference by month. In June, the primary prey taxa were mysid shrimp, copepods, and gammarids; in July the dominant prey taxon was mysid shrimp followed by chironomids and *Argulus*. In August, the percentage of mysid shrimp declined while fish and copepods increased dramatically (Table 81). These results are similar to that found in 1989 and 1990 although the apparent shift in diet occurred one month later in those years (Rulifson and Bass 1991). The fish examined by Manooch (1973) were generally larger than those examined in this study or in Rulifson and Bass (1991) and did not show this shift in diet: presumably it had passed prior to the fish being collected.

In 1991, nearly 70% of the striped bass stomachs examined came from fish collected in the western Sound. The mean total length of fish from west and east were not significantly different (T test; P = 0.53; west 66.1 mm, n = 39 ; east 62.4 mm, n = 17). More than 15% of the western fish stomachs did not contain food while none of the eastern fish stomachs were empty. A higher percentage of unidentifiable material was found in eastern fish stomachs than western fish stomachs. The stomachs of the two larger fish collected in late September contained only fish and were collected in the western sound. A higher percentage of the western fish stomachs contained mysid shrimp, copepods, and chironomids than did eastern fish stomachs (Table 81). Manooch (1973) found that the invertebrates *Gammarus* and palaemonid shrimp were consumed at a higher frequency in the west and *Callinectes* and penaeid shrimp prey were higher in the east. The distinction between west and east in Manooch (1973) differed considerably from that used in the present study and the relatively low abundance of juvenile striped bass in the east (as used by Manooch) in this study would prevent any comparisons.

The relationship of log weight to log length is shown in Figure 71. This equation has an r^2 of 0.99 and shows a similar relationship to that found by Trent (1962) for young-of-year striped bass in Albemarle Sound. The mean lengths of striped bass by month in 1991 were similar to the mean lengths found in 1989 and smaller than those found in 1990. Mean lengths in 1990 were about 20% larger than those in 1989 (Rulifson and Bass 1991) or 1991.

Summary

Juvenile striped bass consumed a greater percentage of mysid shrimp in 1989 through 1991 than any other prey taxa. Invertebrates in general were more prevalent in the diet than were fish but it would be expected that fish would become increasingly more important as striped bass length increased. More fish were examined from the western Sound than the eastern Sound, particularly as the season progressed from summer to fall and this may reflect a westward movement of juvenile striped bass (Henry et al. 1991). There is a similarity between the log-weight to loglength relationships of the present study and that of Trent (1962). There is insufficient evidence to determine any change in the benthic or epibenthic fauna that would be reflected in the diet of juvenile striped bass. Determination of food availability, particularly invertebrate fauna, at the time of juvenile fish collection would indicate if the juvenile fish were limited by food.

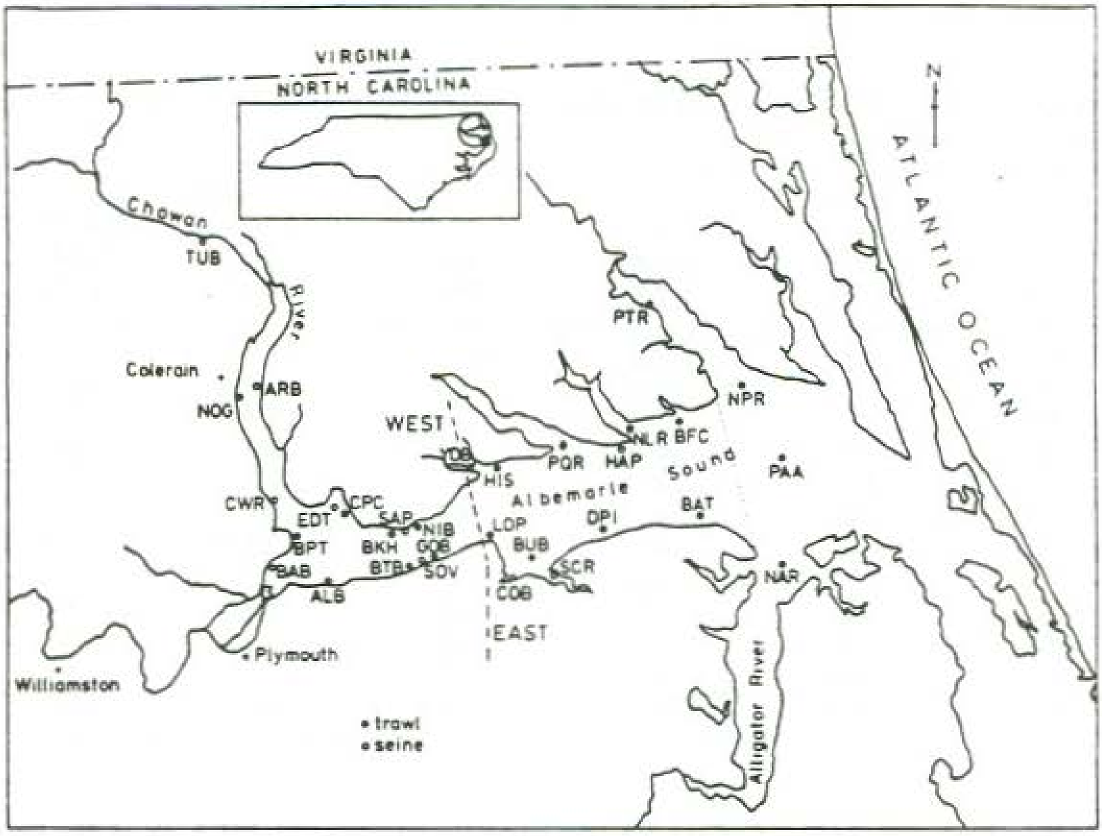

Figure 70. Trawl and seine stations used by the NCDMF for annual juvenile abundance surveys. Dashed line indicates separation of sampling locations into western and eastern sites.

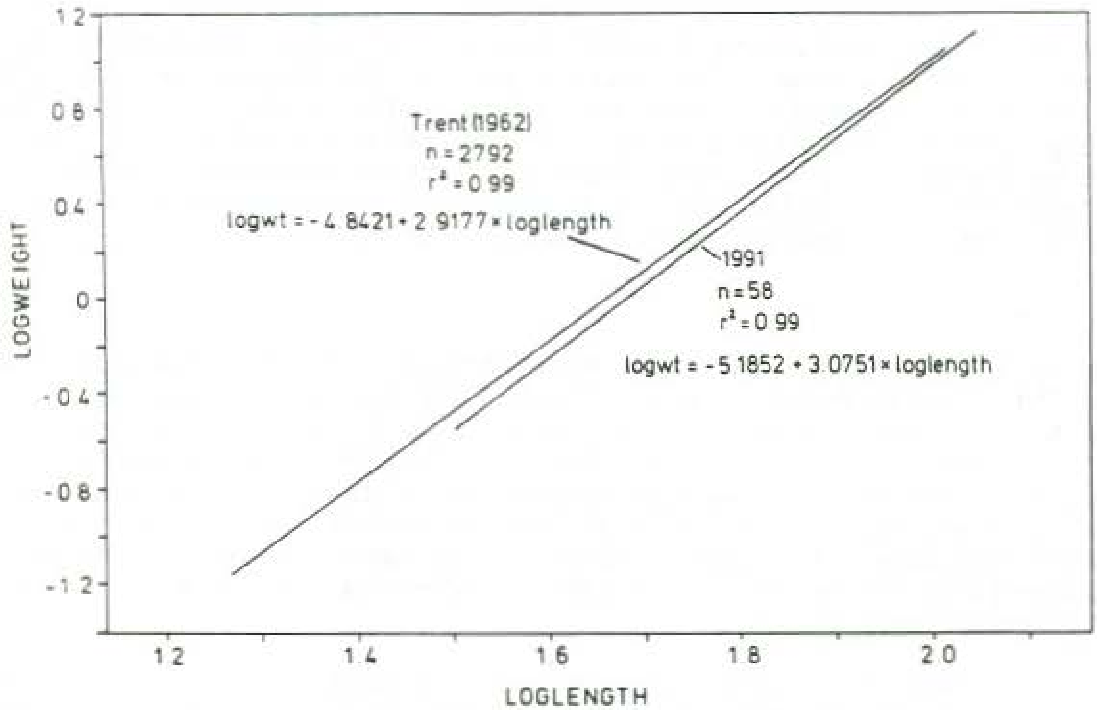

Figure 71. Relationship of log weight to log length for juvenile striped bass in 1991 and from Trent (1962) derived from means of 18 size class groups.

Table 81. Percent occurrence of prey taxa in striped bass stomachs from western and eastern Albemarle Sound, NC, in 1991.

	Month				Station sites	
Prey	June (6)	July (25)	August (25)	Total (56)	West (39)	East (17)
mysid	16.7	68.0	56.0	57.1	61.5	47.8
unid.	83.3	24.0	12.0	25.0	10.3	64.7
fish	0	4.0	36.0	17.9	15.4	17.6
copepods	16.7	0	36.0	17.9	23.1	5.9
chironomids	0	12.0	12.0	10.7	12.8	0
Argulus	0	8.0	4.0	5.4	0	17.6
gammarids	16.7	0	4.0	3.6	2.6	5.9
Cyathura	0	0	4.0	1.8	2.6	0
mayfly nymph	0	4.0	0	1.8	2.6	0
diptera	0	4.0	0	1.8	2.6	0
no food	0	8.0	16.0	10.7	15.4	0
Mean TL	42.8	56.0	79.9	54.1	66.1	62.4

Larval Striped Bass Abundance in the Lower Roanoke River, Delta, and Western Albemarle Sound, 1990-1991

Roger A. Rulifson, John E. Cooper, and Scott F. Wood

In the spring of 1991, ichthyoplankton and zooplankton samples were collected in the lower Roanoke watershed and western Albemarle Sound to examine the abundance and relative distribution of striped bass larvae and potential food sources. The sampling was part of a long-term study designed to investigate whether poor food availability (quantity and quality) may be one limiting factor to recruitment of young-of-year striped bass to the forming year class. Results of the zooplankton portion of the study were summarized in another section of this report. Details of the methods and results of the entire study were presented in Rulifson et al. (1992a, 1992b); the striped bass information is summarized in this section.

Methods

Ichthyoplankton samples were collected by personnel of the North Carolina Wildlife Resources Commission (WRC) at Stations 1-5 (Figure 72) by towing a 0.5^2 square-mouth opening Tucker trawl (505 µm mesh) in an oblique manner for six minutes. Two tows were made at each station. Samples were collected from 7 May to 26 May 1991. East Carolina University (ECU) personnel collected ichthyoplankton samples at River Stations 6-12 and Batchelor Bay Stations 13-15 from 2 May to 30 May 1991, and selected western Sound stations until 5 June. ECU samples were taken by towing paired, conical 0.5-m diameter nets (505 µm mesh) in an oblique manner for six minutes. All ichthyoplankton samples were preserved with 10% buffered formalin containing Rose Bengal dye.

Fish larvae were removed from samples for identification and enumeration. *Morone* larvae were measured (mm TL) and stage of development noted using Mansueti (1964), Lippson and Moran (1974), and Olney et al. (1983). *Morone* in feeding condition were examined for stomach contents. Each prey item was identified to the lowest practical taxon (Gosner 1971,

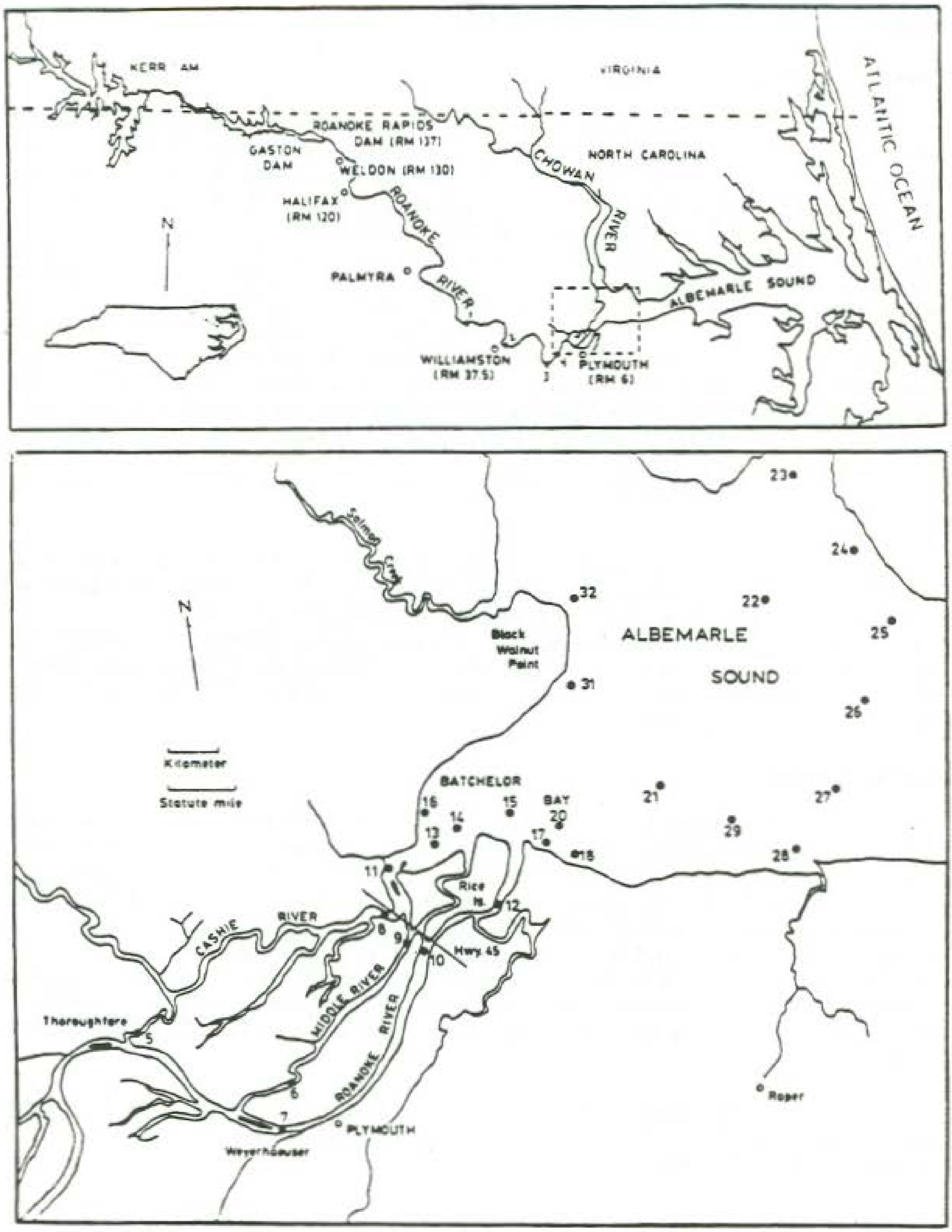

Figure 72. Map depicting the locations of larval striped bass sampling sites used in 1990 and 1991. Not all stations were sampled each trip.

Pennak 1979, Merritt and Cummins 1984), and counted. The average number of each prey item ingested per fish was calculated by counting the total number of each item and then dividing by the number of fish examined that contained prey. *Morone* larval abundance was expressed as the number per 100 cubic meters of water filtered.

Larval Abundance

The 1991 pattern of larval abundance downstream was much higher, but of shorter duration, than that observed in 1990 (Figure 73). In 1991, larval striped bass were present in the first samples collected on 24 April at selected stations in the lower Roanoke River. An average of 1 larvae/100m^3 was found in the Cashie River at Station 8 (just upstream of the Hwy. 45 bridge), indicating minor but successful spawning in mid-April. A similar larval abundance was observed at the mouth of the Roanoke River at Station 12 (Figure 74) on 2 May (Table 82). By 7 May, larval abundance of 4/100m^3 was observed at Williamston (Station 2). At this time, it appears that larval striped bass were being transported through Middle River: abundance was 4/100m^3 at Station 6 and 1/100m^3 at Station 9. Three days later on 10 May, larval abundance at upstream locations was over 200/100m^3, and increased downstream over a several day period. This pattern is interesting in that peak spawning activity upstream occurred on 8-9 May (20% of total egg production) and 11-14 May (41%). Downstream larval transport is depicted in Figure 74. Note that in 1991 larval densities were highest in Middle River, indicating that the major larval transport was through this segment of the Roanoke Delta at a stable reservoir discharge of about 10,000 cfs. Average larval abundance in the River and Delta was greatest on 18 May (127/100m^3).

In Batchelor Bay, larval abundance was of a fairly short duration with peak abundance of 330/m^3 occurring several days after peak abundance in the River (Table 83). Larvae were concentrated on the extreme western shoreline of Batchelor Bay (Stations 13 and 16). Only 9/100m^3 were observed offshore of the Roanoke River mouth (Station 15). Outside of Batchelor Bay, highest average concentrations (18/100m^3) were located along the southern shore at Station 20 (Figure 74). As expected, larvae in the Sound were slightly larger than those collected from the lower River, Delta, and Bay.

Larval Feeding

Larval striped bass feeding was only slightly more successful in 1991 than that observed in 1990 (Table 84). Larval feeding in the River was first observed on 18 May and in the Bay and Sound by 21 May (Table 85). Only 3% of the 921 River larvae capable of feeding contained food in guts, but the diet was quite varied. Prey consumed were *Bosmina* (36%), small bivalves (25%), other cladocerans (11%), copepodid copepods (8%), detritus (6%), copepod nauplii (4%), biting midge and chironomid larvae and pupae (4%), and ostracods (2%). In the Bay, only 2% of the 771 larvae capable of feeding had ingested prey: copepod adults (33%), *Bosmina* (19%), copepodid copepods (14%), bivalves (14%), and ostracods (5%). In the Sound, 47% of the 194 larvae capable of feeding had consumed prey, primarily copepodids (58%) and copepod adults (39%) (Table 84).

The length frequency distribution for 1991 indicates that larvae capable of feeding were slightly larger than the general population for the River, Bay, and Sound, but the rate of feeding success was not a function of fish length.

Table 82. Density (number/100 m^3) of striped bass larvae in the lower Roanoke River (Stations 1-12), North Carolina, 1990-1991. Period (P) N-night samples.

Date	P	Station 1	2	3	4	5	6	7	8	9	10	11	12	Ave.
04/18/90	N	.	.	.	.	.	.	.	0	0	0	.	.	0
04/27/90	N	.	.	.	.	.	.	.	0	0	2	.	.	1
05/01/90	N	2	1	0	.	.	.	.	.	.	1	2	0	1
05/04/90	N	10	4	0	6	2	0	1	1	3	1	0	4	3
05/07/90	N	29	1	1	7	1	2	3	0	0	2	4	0	4
05/11/90	N	162	24	6	26	4	16	5	2	29	0	54	1	27
05/13/90	N	0	14	7	59	6	41	141	3	74	11	1	14	31
05/15/90	N	0	2	8	6	1	1	4	0	22	0	6	0	4
05/18/90	N	0	3	6	5	0	8	2	0	10	4	53	2	8
05/21/90	N	0	0	1	3	1	4	1	2	17	0	9	19	5
05/24/90	N	8	10	6	8	1	144	96	0	78	71	15	5	37
05/27/90	N	0	6	0	4	0	6	2	0	1	0	2	0	2
05/30/90	N	.	.	.	.	0	0	1	0	0	0	0	0	0
06/02/90	N	.	.	.	.	.	0	0	0	0	0	0	0	0
06/04/90	N	.	.	.	.	.	4	0	0	0	0	0	1	1
06/06/90	N	.	.	.	.	.	0	0	0	0	0	0	0	0
Ave. Density		21	7	3	14	2	17	20	1	16	6	11	3	10
Ave. Volume		47	45	44	48	48	41	42	43	43	42	43	44	44
n (efforts)		10	10	10	9	10	13	13	15	15	16	14	14	149
04/24/91	N	.	.	.	.	.	.	.	1	0	0	.	.	0
05/02/91	N	.	.	.	.	.	0	0	0	0	0	0	1	0
05/07/91	N	0	4	0	0	0	4	0	0	1	0	0	0	1
05/10/91	N	212	54	17	20	9	16	3	0	4	1	0	2	28
05/13/91	N	250	52	8	31	13	17	1	2	21	3	16	6	35
05/16/91	N	148	253	101	120	31	31	22	11	82	29	43	93	81
05/18/91	N	21	34	64	87	201	630	48	39	120	118	26	136	127
05/20/91	N	59	35	24	72	0	93	6	22	473	5	86	3	73
05/22/91	N	25	13	12	105	64	335	80	20	151	41	69	49	80
05/24/91	N	15	9	1	26	11	14	2	18	57	5	15	5	15
05/26/91	N	19	9	7	15	1	35	17	5	18	12	29	8	15
05/30/91	N	.	.	.	.	.	158	49	7	74	45	18	58	59
Ave. Density		83	52	26	53	37	121	21	11	84	22	27	33	47
Ave. Volume		46	47	44	45	47	47	46	930	46	47	49	46	120
n (efforts)		9	9	9	9	9	11	11	12	12	12	11	11	125

Table 83. Density (number/100 m^3) of striped bass larvae in Batchelor Bay (Stations 13-16) and western Albemarle Sound (Stations 17-32), North Carolina, 1990-1991. Period (P) N=night samples.

		Station																
Date	P	13	14	15	16	17	18	20	21	22	23	24	26	28	31	32	Ave1	Ave2
04/25/90	N	2	.	0	1	.	0	.	.	.	.	.	.	.	.	.	1	0
05/01/90	N	7	.	2	4	.	.	.	.	.	.	.	.	.	.	.	4	.
05/04/90	N	4	.	1	1	.	.	.	.	.	.	.	.	.	.	.	2	.
05/07/90	N	10	.	10	8	.	.	.	.	.	.	.	.	.	.	.	9	.
05/11/90	N	23	.	0	0	.	.	.	.	.	.	.	.	.	.	.	8	.
05/13/90	N	5	.	9	11	.	.	.	.	.	.	.	.	.	.	.	8	.
05/15/90	N	0	.	3	3	.	.	.	.	.	.	.	.	.	.	.	2	.
05/18/90	N	12	.	2	2	.	.	.	.	.	.	.	.	.	.	.	6	.
05/23/90	N	.	.	2	.	.	0	0	0	0	0	0	0	0	6	0	2	1
05/24/90	N	7	.	0	1	.	.	.	.	.	.	.	.	.	.	.	3	.
05/26/90	N	.	.	0	.	.	2	4	8	.	.	.	.	1	.	.	0	4
05/27/90	N	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	3	.
05/29/90	N	.	.	.	.	.	.	.	.	1	0	.	.	.	5	1	.	2
05/30/90	N	1	.	2	0	.	.	.	.	.	.	.	.	.	.	.	1	.
06/02/90	N	0	.	0	0	.	.	.	.	.	.	.	.	.	.	.	0	.
06/06/90	N	0	.	0	0	.	.	.	.	.	.	.	.	.	.	.	0	.
06/08/90	N	.	.	.	.	.	.	.	.	.	.	.	.	.	0	0	.	0
06/10/90	N	.	.	0	.	.	0	0	0	0	0	0	0	0	0	0	0	0
06/13/90	N	.	.	0	.	.	0	0	0	0	0	0	0	0	0	0	0	0
06/15/90	N	.	.	.	.	.	.	.	.	.	0	1	.	.	.	.	.	1
06/17/90	N	.	.	0	.	.	0	0	0	0	0	0	0	0	.	0	0	0
Ave. Density		6	.	2	3	.	0	1	2	0	0	0	0	0	2	0	4	1
Ave. Volume		46	.	48	48	.	48	48	49	46	46	46	46	47	46	46	47	47
n (efforts)		12	0	18	12	0	6	5	5	5	6	5	4	5	5	6	42	52
04/17/91	N	0	.	0	0	.	0	.	.	.	.	.	.	.	.	.	0	0
04/30/91	N	0	.	0	0	.	0	.	.	.	.	.	.	.	.	.	0	0
05/02/91	N	0	.	0	0	.	.	.	.	.	.	.	.	.	.	.	0	.
05/07/91	N	1	.	0	0	.	.	.	.	.	.	.	.	.	.	.	0	.
05/10/91	N	0	.	0	2	.	.	.	.	.	.	.	.	.	.	.	1	.

Table 83. Continued

Date	P	Station																
		13	14	15	16	17	18	20	21	22	23	24	26	28	31	32	Ave1	Ave2
05/13/91	N	22	.	6	41	.	.	.	.	.	.	.	.	.	.	.	23	.
05/16/91	N	30	.	69	14	.	.	.	.	.	.	.	.	.	.	.	38	.
05/20/91	N	675	.	9	306	.	.	.	.	.	.	.	.	.	.	.	330	.
05/21/91	N	.	.	68	.	.	7	33	21	18	1	35	0	0	2	0	68	12
05/22/91	N	101	.	11	8	.	.	.	.	.	.	.	.	.	.	.	40	.
05/23/91	N	.	.	0	.	.	0	1	2	4	0	1	7	1	2	11	0	3
05/24/91	N	17	.	2	12	.	.	.	.	.	.	.	.	.	.	.	10	.
05/25/91	N	.	.	5	.	.	0	44	1	0	0	0	0	0	0	1	5	5
05/26/91	N	0	.	5	2	.	.	.	.	.	.	.	.	.	.	.	2	.
05/30/91	N	1	.	1	0	.	.	.	.	.	.	.	.	.	.	.	1	.
06/01/91	N	.	.	0	.	.	1	22	0	.	.	.	.	.	0	0	0	5
06/03/91	N	.	.	1	.	.	0	9	3	.	.	.	.	.	.	.	1	4
06/05/91	N	.	.	.	.	.	.	.	.	0	0	0	1	0	0	.	.	0
Ave. Density		71	.	10	32	.	1	18	5	4	0	7	2	0	2	3	38	4
Ave. Volume		55	.	47	48	.	46	45	42	45	46	46	46	45	46	45	50	45
n (efforts)	12	0	18	12	0	8	6	6	5	5		5	6					
need last line																		

Table 84. Relative contribution (% by enumeration) of prey consumed by larval striped bass in the lower Roanoke River (Stations 1-12), Batchelor Bay (Stations 13-16) and western Albemarle Sound (Stations 17-32), North Carolina, 1984-1991 (Rulifson et al. 1992b). Period (.) = not observed in striped bass stomachs.

	River		Bay		Sound	
Taxonomic group	1990	1991	1990	1991	1990	1991
Clad. - Bosmina	.	36.17	50	19.05	10.12	0.85
Copepodids	.	8.51	50	14.29	85.71	58.36
Copepoda-egg mass	.	.	.	.	.	.
Ostracoda	.	2.13	.	4.76	.	.
Clad.-other (Daphnia)	.	10.64	.	.	3.57	0.28
Detritus	.	6.38	.	.	.	.
Unidentified	.	2.13	.	14.29	.	0.28
Copepoda-nauplius	.	4.26	.	.	.	.
b.midge&chir.lar/pup.	.	4.26	.	.	.	.
Rotifer-single&colonial	.	.	.	.	0.60	0.85
Clad.-unid. egg	.	.	.	.	.	.
Bivalvia-larvae	.	.	.	.	.	.
Eph.-mayfly nymphs	.	.	.	.	.	.
Nematoda	.	.	.	.	.	.
Amphipoda - Gammarids	.	.	.	.	.	.
Arachnida	.	.	.	.	.	.
Hymenoptera-diving wasp	.	.	.	.	.	.
Oligochaetes	.	.	.	.	.	.
Bivalvia	.	25.53	.	14.29	.	.
Tubellaria	.	.	.	.	.	.
Spongillaflylarv.,adults	.	.	.	.	.	.
Bryozoans	.	.	.	.	.	.
Fish	.	.	.	.	.	.
Diptera adults	.	.	.	.	.	.
Copepod adults	.	.	.	33.33	.	39.38
Total prey items	0	47	2	21	168	353
Total fish examined	1	921	7	771	15	194
Total fish with food (%)	0	3	29	2	73	47

Table 85. Date at which feeding by striped bass larvae was first observed in the lower Roanoke River (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound, North Carolina, 1984-1991 (Rulifson et al. 1992b). Asterisk (*) indicates date of first sample.

	Stage 1 larvae (yolk and oil)		Stage 2 larvae (oil only)		Unidentified *Morone* larvae	
	1990	1991	1990	1991	1990	1991
Sta. 1						
Sta. 2						
Sta. 3						
Sta. 4						
Sta. 5						
Sta. 6				May 18		
Sta. 7						
Sta. 8				May 18		
Sta. 9				May 18		
Sta. 10						
Sta. 11				May 18		
Sta. 12				May 18		
Sta. 13				May 20		
Sta. 14						
Sta. 15				May 25		
Sta. 16			May 13			
Sta. 17						
Sta. 18			May 26	May 28		
Sta. 20				May 25		May 25
Sta. 21			May 26	May 21		May 25
Sta. 22			May 29	May 21	May 23	May 21*
Sta. 23				May 21		May 23
Sta. 24			Jun 15	May 21		May 23
Sta. 26				May 23	Jun 13	May 25
Sta. 28			May 26			May 28
Sta. 31			May 23*	May 21	Jun 13	May 23
Sta. 32				May 23		May 23

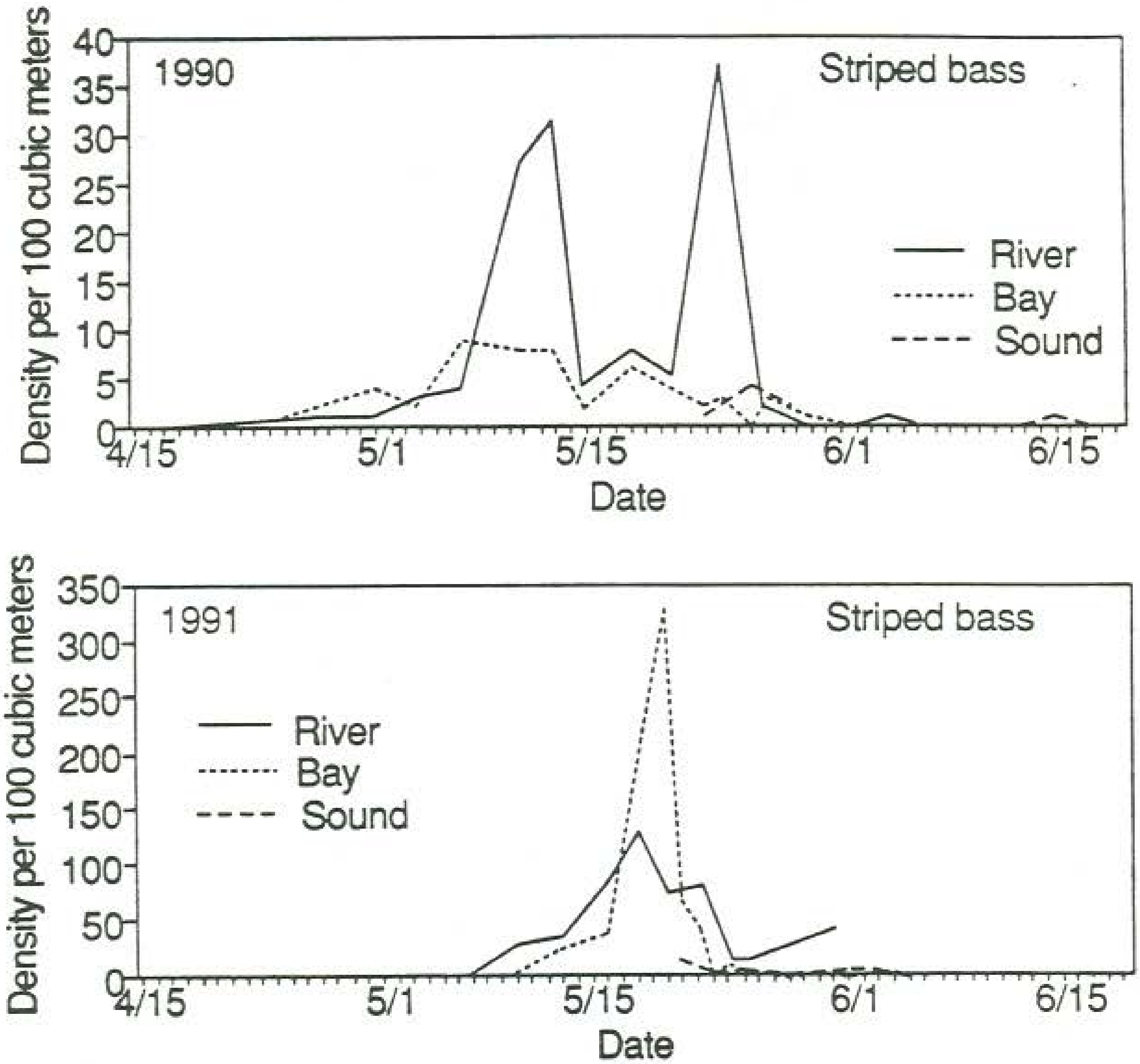

Figure 73. Average larval striped bass density (number/100 m^3), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1990 and 1991.

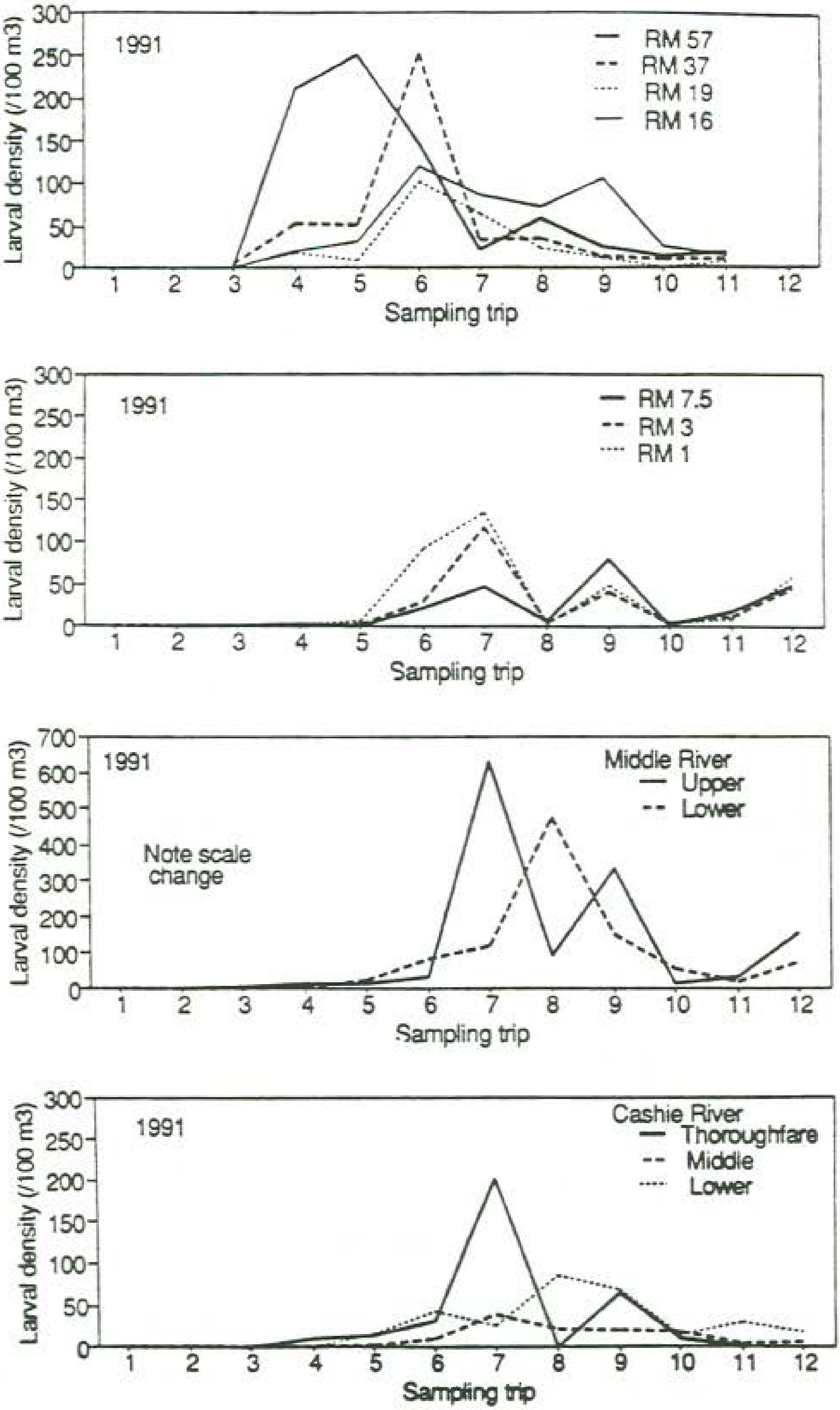

Figure 74. Temporal and spatial changes in the 1991 densities of larval striped bass (#/100 m^3) in the lower Roanoke River from River Mile 16-57 (upper panel) and Delta; lower River, RM 1-7.5; Middle River; and Cashie River including Thoroughfare. Refer to Figure 72 for station positions.

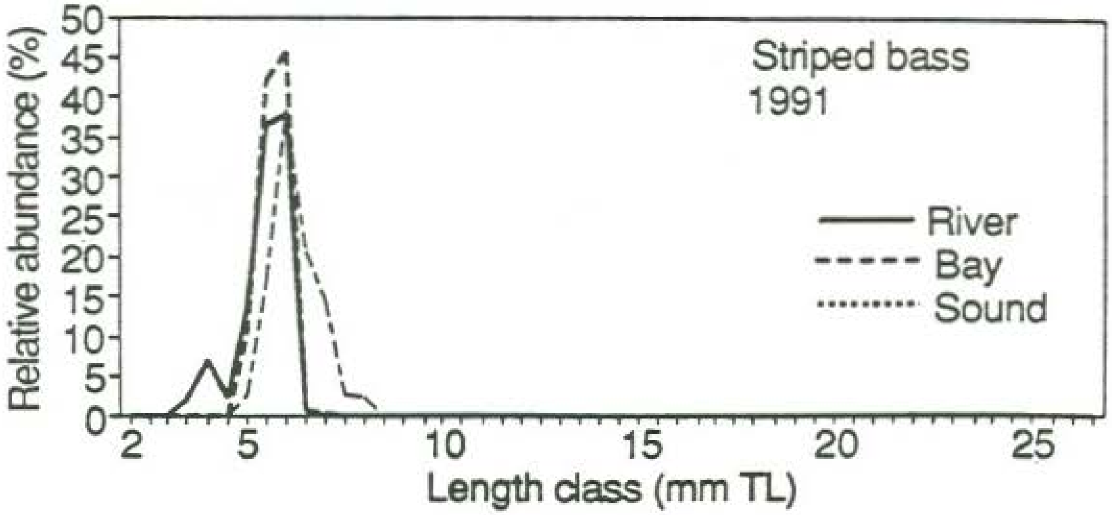

Figure 75. Relative abundance (%) of striped bass larvae, by 0.5-mm TL size class, collected from the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1991.

RELATIVE ABUNDANCE OF SPECIES OTHER THAN STRIPED BASS IN WESTERN ALBEMARLE SOUND TRAWLING SURVEYS, 1982-1993

Lynn T. Henry and Charles S. Manooch, III

We have witnessed a remarkable increase in the striped bass Juvenile Abundance Index since 1987. In fact, the 1993 value of 44.54 fish per trawl is the highest ever recorded for the species in this system, and is 148 times greater than that recorded in 1987 (0.30). Also, the six-year mean for 1988-1993 (9.62) is approximately 33 times the six-year mean for 1982-1987 (0.29) as documented by NC Division of Marine Fisheries personnel. It would appear that revised Roanoke River water flows, in concert with other management actions, have benefited striped bass recruitment.

A major consideration is how other fish species have responded during this same period of time as measured by the annual trawling survey. To evaluate this, we selected 10 species: white perch (*Morone americana*), blueback herring (*Alosa aestivalis*), alewife (*A. pseudoharengus*), American shad (*A. sapidissima*), Atlantic menhaden (*Brevoortia tyrannus*), bay anchovy (*Anchoa mitchilli*), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*), channel catfish (*Ictalurus punctatus*), and white catfish (*I. catus*), and have plotted annual catch rates (number of fish/trawl) for each species, 1982-1993 (Figures 76-85). Except for catfishes, only the young-of-year (YOY) of each species were evaluated. It must be noted that some of these species are more susceptible to the bottom trawl gear than are others. One would hope that as striped bass recruitment, as measured by annual CPUE, improved, that recruitment for other species of fish would increase, or at least remain stable. However, it is impossible at this time to identify any single factor such as water flow, water quality, or fishing regulations, that may have influenced any specific CPUE value, or may have resulted in a trend over time for any of the following species. Overall, an average of 41.46 fish were collected per trawl for the years 1982-1987 compared with 144.15 for 1988-1993 (Tables 86 and 87). Bay anchovies accounted for most of the increase in catch. If this species is excluded from the calculations, the difference is reduced to only four fish per trawl. Of the 10 species evaluated, six had higher CPUE values for 1988-1993 compared with the earlier time segment. White perch, blueback herring, Atlantic menhaden, spot, Atlantic croaker, and bay anchovy were more abundant (Table 86). It would appear that the revised flow regime has not had a significant impact on the recruitment of these selected species as indicated by annual trawling surveys. Unlike the striped bass, however, the selected species are not restricted to spawning in the Roanoke River. Spot, Atlantic croaker, and Atlantic menhaden spawn outside of the system, and the other species spawn in the Albemarle Sound or its many tributaries.

White Perch, YOY

The decline in harvest of Roanoke-Albemarle white perch during the 1980s has caused much concern among fisheries scientists and managers. The species is valued as both a sport and commercial fish and supports major fisheries in the Albemarle Sound and the Roanoke River. The State of North Carolina should sponsor extensive biological studies of this species in order to prevent a further decline in the stock and to begin the process of restoration. Fortunately, an improvement in recruitment has been recorded recently, in 1989 and 1993 (Figure 76). In fact, white perch, blueback herring, and striped bass, the major anadromous spawners of the Roanoke River, all had relatively good year classes in 1993.

Blueback Herring, YOY

Blueback herring are anadromous, early spawners that utilize the main channel and floodplain of the Roanoke River to reproduce. Unlike striped bass, blueback herring also spawn in the many rivers and creeks tributary to the Albemarle Sound. Although the bottom trawl is certainly not considered the best gear to measure relative abundance for this species, young-of-year blueback herring are frequently caught in the trawls. Recruitment, which had declined during the mid-late 1980s, seems to have improved, particularly in 1990, 1991, and 1993 (Figure 77).

Alewife, YOY

Alewife and blueback herring are known collectively as "river herring." Alewife, due to an earlier spring spawning season, are locally referred to as "forerunner herring." Juveniles of the species are somewhat of an enigma because whereas adults are abundant in the system during the March and April spawning season, juveniles are seldom collected in the Albemarle Sound. A comparison of blueback herring and alewife juvenile abundance may be made by reviewing Figures 77 and 78. Some of this discrepancy in numbers may be due to species identification in some years. Unfortunately, recruitment has continued to decline since 1982. Unlike blueback herring, there have been only minor improvements in year class from 1982-1993 (Figure 78).

American Shad, YOY

Once abundant enough to support a large Federal fish hatchery on the Roanoke River at Weldon, NC, in the late 1800s, the American shad stocks are now considered stressed in the Roanoke-Albemarle system. The plight of the species in North Carolina is not unlike that experienced by other populations all along the East Coast of the United States, but whereas other stocks are being restored or have recovered, American shad inhabiting the Roanoke River and Albemarle Sound are in trouble. The species has not been studied in the Roanoke River since the turn of the Century. As would be expected, juveniles are very rare in trawl samples (Figure 79). There is no difference in abundance of the species for the periods 1982-1987 and 1988-1993 (Table 86).

Atlantic Menhaden, YOY

The Atlantic menhaden is one of four species evaluated, which typically spawns in high salinity waters. In fact, three of the four (Atlantic menhaden, Atlantic croaker, and spot) all spawn in the open ocean during the fall, winter, and early spring. The Atlantic menhaden is a commercial species that is also highly regarded as food for many of the predatory fishes caught by recreational anglers. Atlantic menhaden are the preferred food of adult striped bass in the Albemarle Sound (Manooch 1973). Since 1987, recruitment of menhaden has generally improved, especially in 1988 (Figure 80).

Bay Anchovy

The bay anchovy is a schooling species of marine fish that can tolerate a wide range in salinity -- fresh water to hypersaline. It is found in a variety of habitats including lower rivers, bays, and coastal waters, and spawns during the spring and summer. The species has no recreational or commercial fisheries value other than as food for predatory fishes such as striped bass. Numbers of bay anchovy collected by trawl have expanded greatly since 1989 (Figure 81).

The number of individuals collected by trawl are estimated since this species is apparently quite abundant. Many, because of their small size, undoubtedly slip through the meshes of the net.

Spot, YOY

This species spawns in the ocean in late fall and winter, and the young utilize estuaries as nursery grounds. Relative abundance of juveniles in the western Albemarle Sound appears to be related to fresh water inflow. The species may be more abundant in dry years, those with low instream flow, when salinities in the western Sound may be slightly higher. An evaluation of this possibility should include all years for which relative abundance and flow data are available. Obvious annual peaks in year class were recorded in 1985, 1986, 1988, 1990, and 1992 (Figure 82).

Atlantic Croaker, YOY

Atlantic croaker and spot are closely related and have very similar life cycles. As expected, relative abundance of the two species is almost identical with the obvious exception of 1990 (Figures 83 and 82) when fewer Atlantic croaker were encountered. Abundance of both species was particularly high in 1985, 1986, and 1988.

Channel Catfish

Ictalurids, both channel and white catfishes, support large commercial and recreational fisheries throughout Albemarle Sound and its tributaries. More catfishes are landed commercially in the region than any other species of fish except river herring, and anglers catch the species throughout the year. Not many catfish are sampled by the trawls, and the numbers plotted reflect captured adults as well as juveniles. Relative abundance of channel catfish has continued to decline since 1985 (Figure 84).

White Catfish

Like channel catfish, white catfish were rarely sampled by the annual trawl surveys (Figure 85). Highest catch rates were recorded in 1985 and 1986. Infrequent sampling of this species, and most of the others selected, and very high standard deviations (Table 86), make statistical testing of the data unnecessary.

Table 86. Mean catch per trawl of 10 finfish species other than striped bass collected in western Albemarle Sound by NC Division of Marine Fisheries personnel, 1982-1987 and 1988-1993.

Species	1982-1987 Mean	1982-1987 S.D.	1988-1993 Mean	1988-1993 S.D.
White perch YOY	0.53	0.93	0.58	0.83
Blueback herring YOY	13.42	13.70	14.35	16.49
Alewife YOY	0.92	1.02	0.29	0.37
American shad YOY	0.07	0.07	0.05	0.04
Atlantic menhaden YOY	0.18	0.17	0.88	1.05
Spot YOY	6.29	8.54	8.45	9.49
Atlantic croaker YOY	5.75	8.94	7.36	13.30
Bay anchovy	13.21	9.91	111.90	97.80
Channel catfish	0.64	0.50	0.10	0.07
White catfish	0.45	0.41	0.19	0.19
Total CPUE	41.46		144.15	

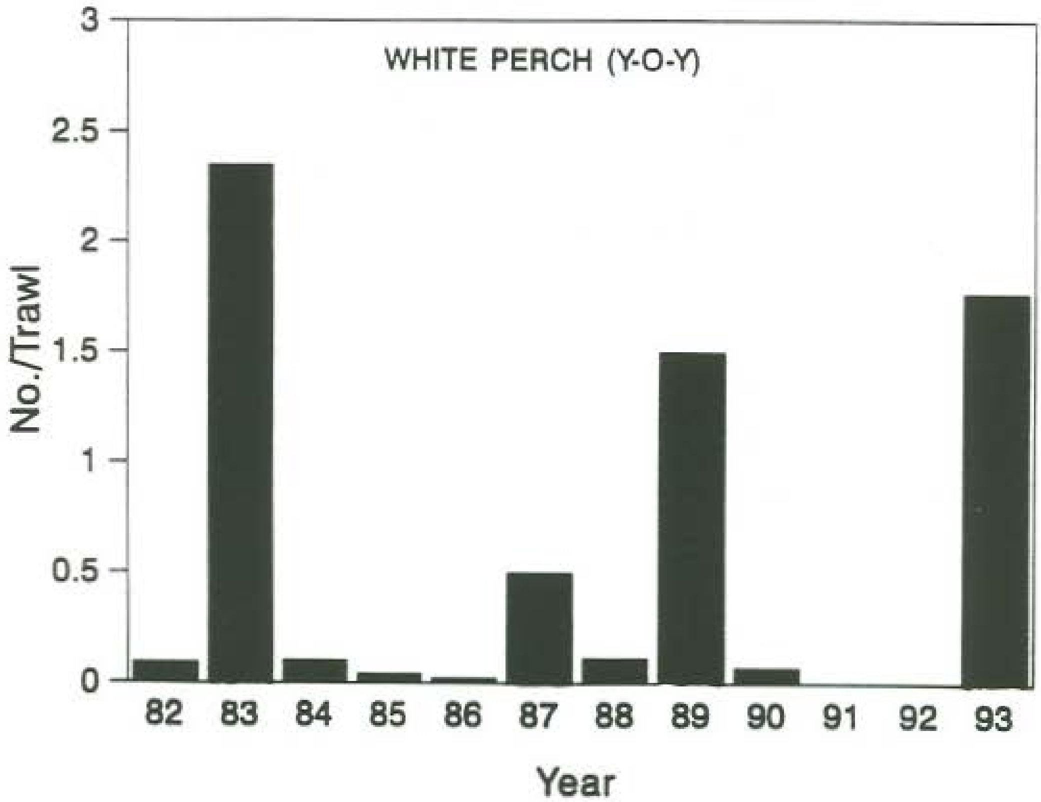

Figure 76. Relative abundance of young-of-year white perch in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

Table 87. Catch per unit effort (number of fish/trawl) of selected finfish species collected in western Albemarle Sound by N.C. Division of Marine Fisheries personnel, 1982-1993. Number of samples appears under each year.

Species	1982 71	1983 97	1984 49	1985 56	1986 63	1987 63	1988 56	1989 56	1990 56	1991 56	1992 56	1993 56
White perch YOY	0.10	2.40	0.10	0.04	0.02	0.50	0.11	1.50	0.07	0.00	0.00	1.77
Blueback herring YOY	38.90	14.00	3.80	0.21	8.90	14.70	1.90	0.16	27.60	17.25	0.05	39.13
Alewife YOY	2.30	0.50	2.10	0.02	0.60	0.02	1.00	0.09	0.39	0.09	0.11	0.05
American shad YOY	0.00	0.06	0.14	0.00	0.03	0.17	0.00	0.07	0.11	0.02	0.02	0.07
Atlantic menhaden YOY	0.23	0.01	0.45	0.11	0.25	0.03	2.98	0.89	0.20	0.50	0.30	0.43
Spot YOY	1.65	0.51	0.08	14.36	19.79	1.37	25.63	0.23	9.29	2.18	11.20	2.14
Atlantic croaker YOY	0.38	0.67	0.24	11.61	21.51	0.10	34.27	2.54	0.41	0.38	5.20	1.36
Bay anchovy YOY	10.07	3.52	11.90	3.45	23.51	26.78	9.52	17.21	71.77	152.84	264.00	156.07
Channel catfish	0.14	0.74	0.41	1.57	0.63	0.33	0.23	0.13	0.05	0.04	0.07	0.07
White catfish	0.01	0.30	0.16	1.05	0.83	0.32	0.21	0.32	0.48	0.02	0.04	0.05

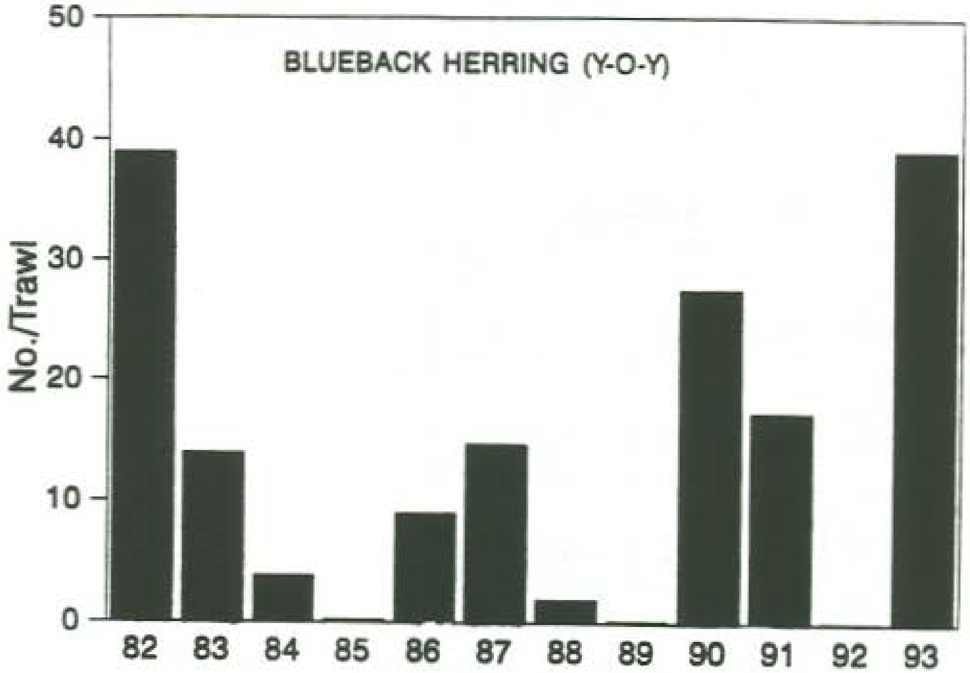

Figure 77. Relative abundance of young-of-year blueback herring in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

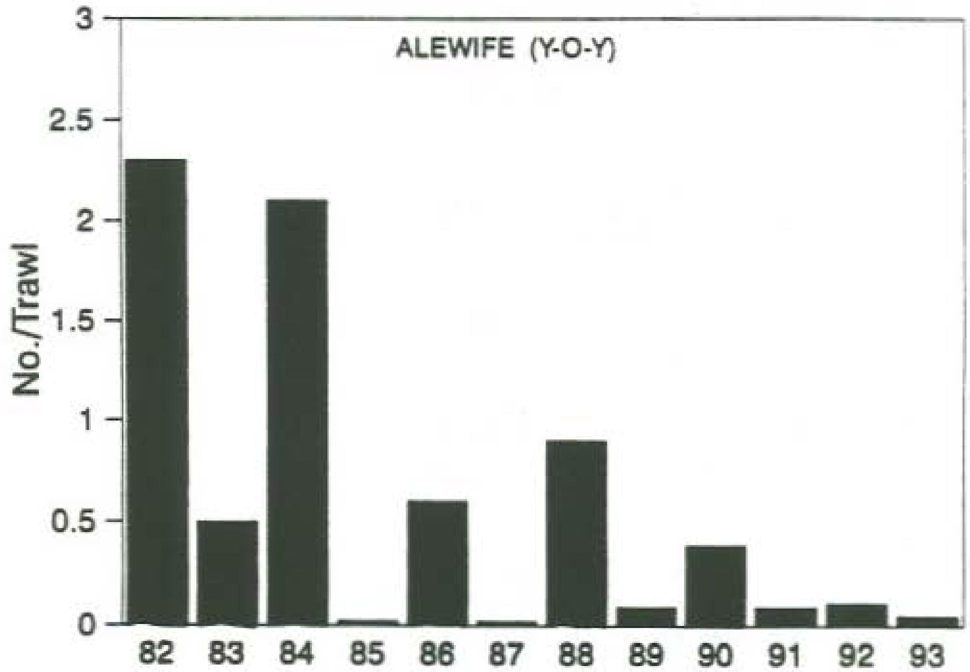

Figure 78. Relative abundance of young-of-year alewife in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

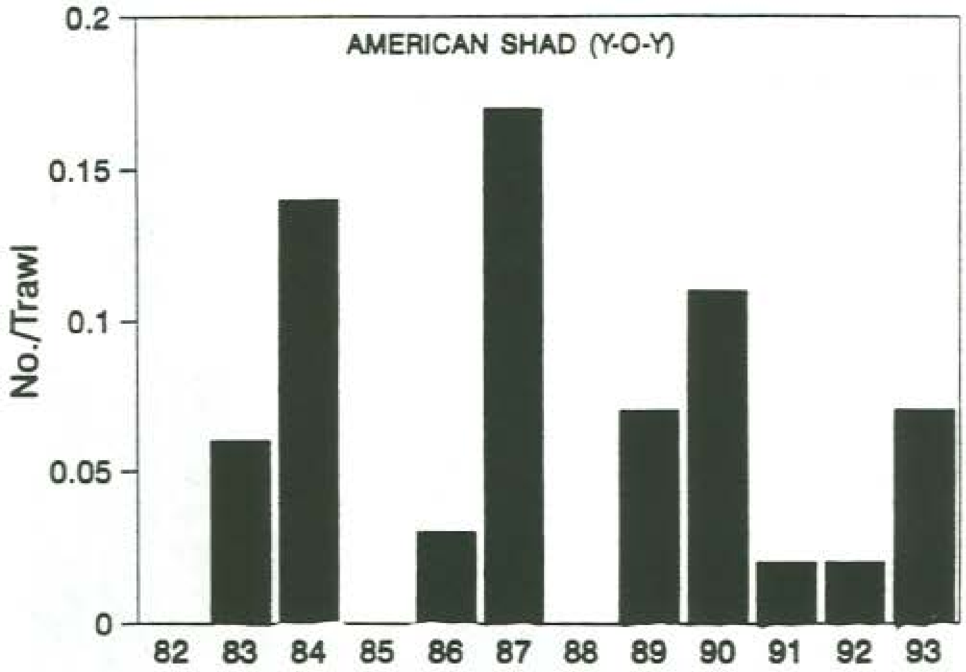

Figure 79. Relative abundance of young-of-year American shad in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

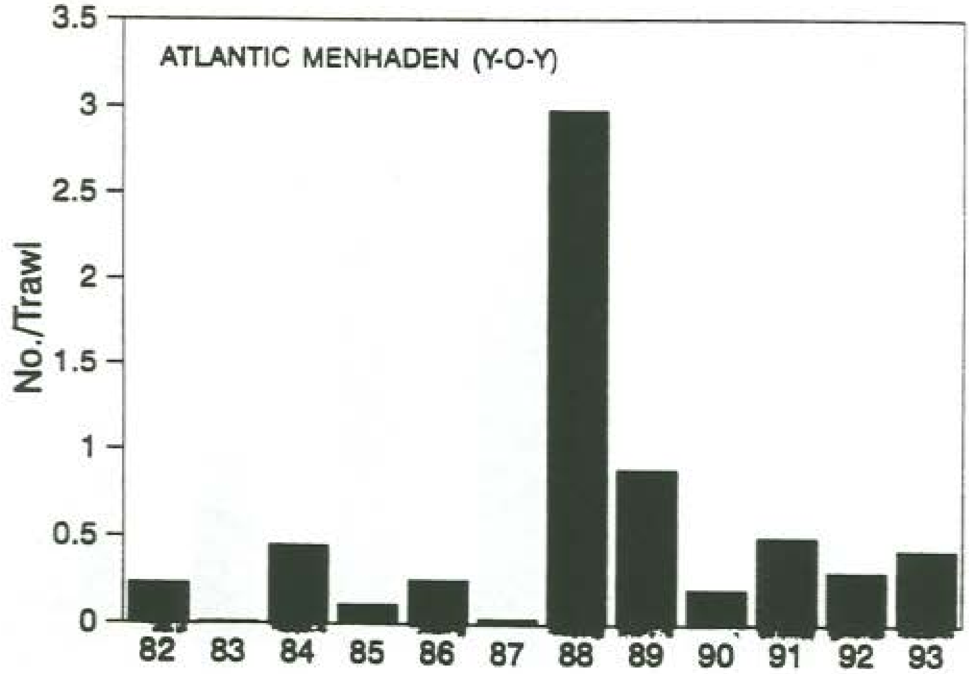

Figure 80. Relative abundance of young-of-year Atlantic menhaden in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

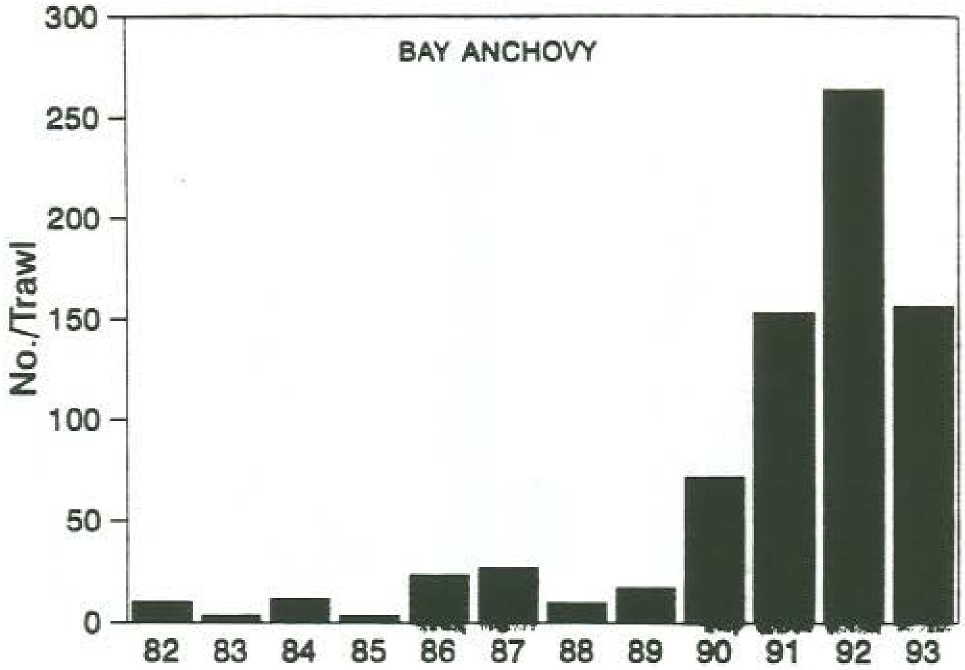

Figure 81. Relative abundance of bay anchovy in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

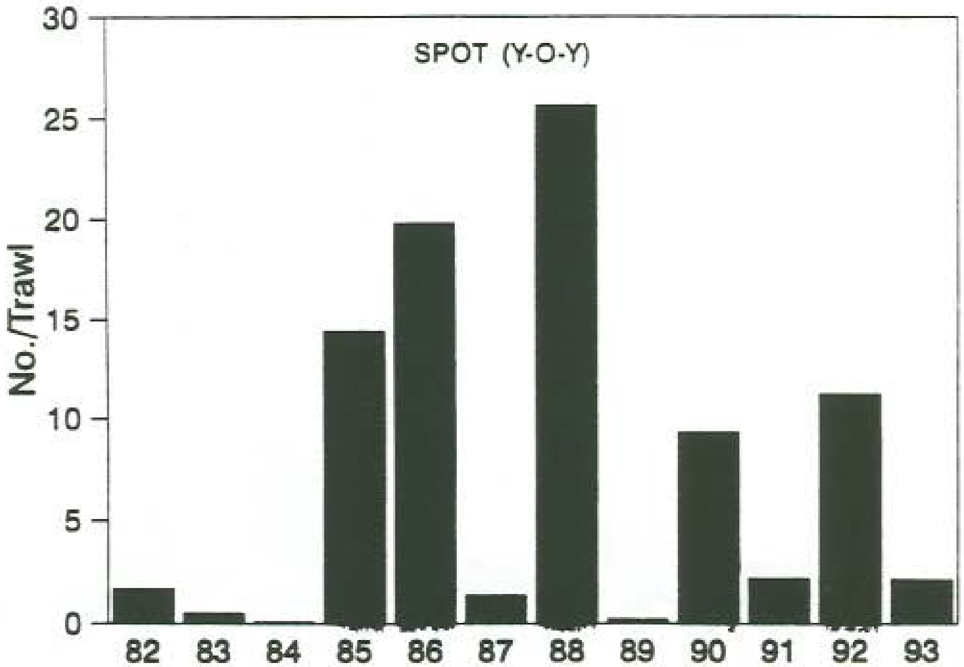

Figure 82. Relative abundance of young-of-year spot in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

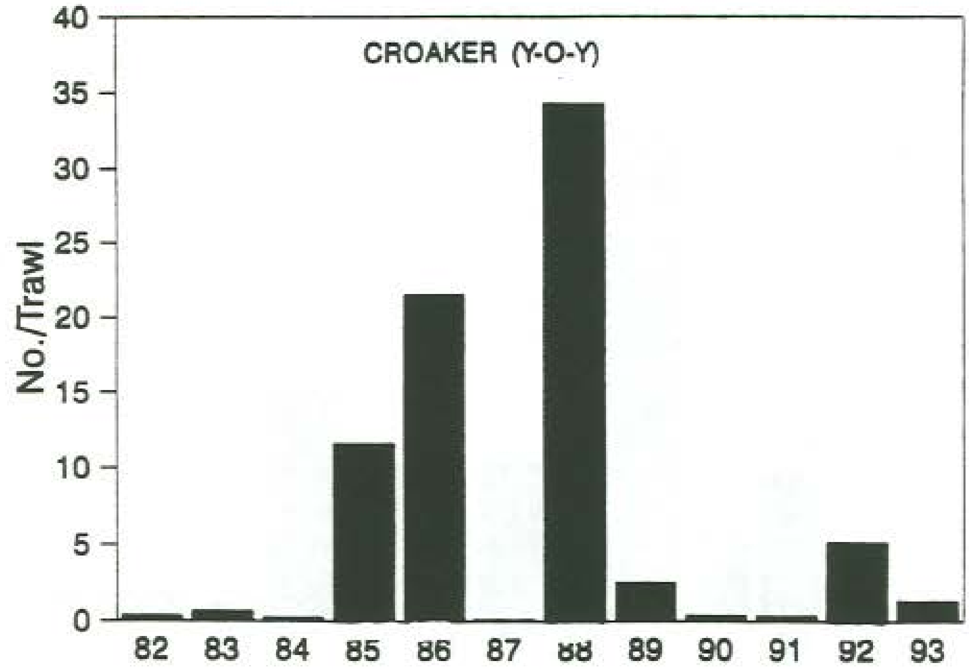

Figure 83. Relative abundance of young-of-year croaker in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

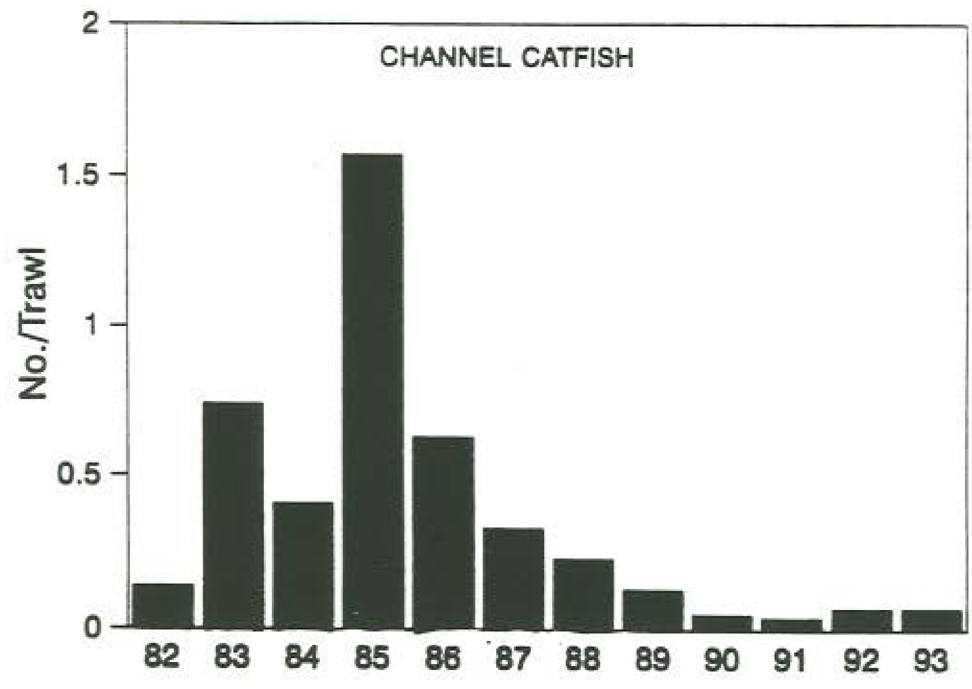

Figure 84. Relative abundance of channel catfish in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

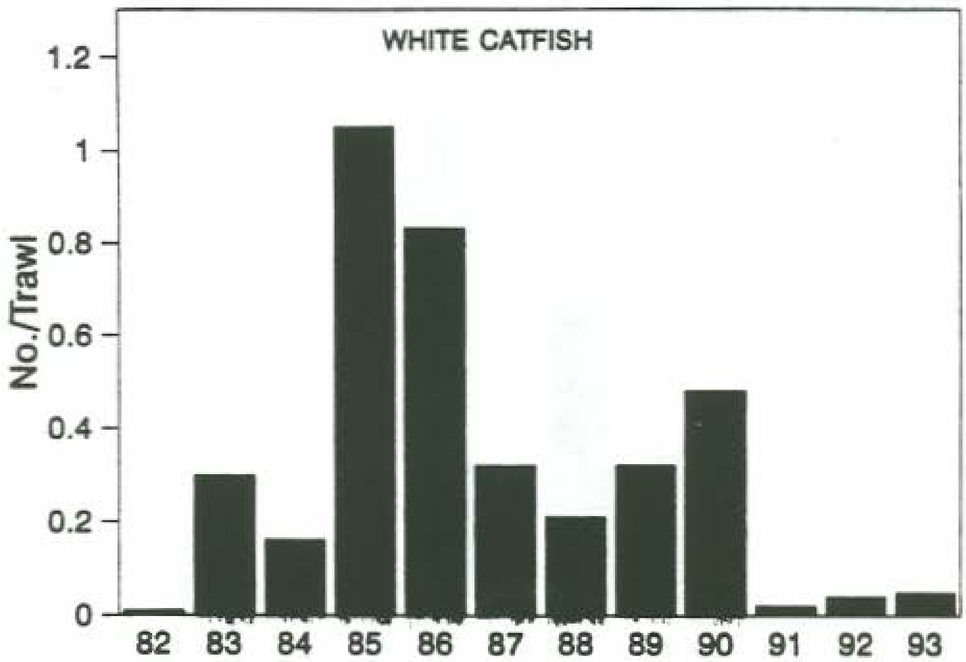

Figure 85. Relative abundance of white catfish in the standard trawl survey conducted each year in western Albemarle Sound, NC, 1982-1993.

CHLOROPHYLL *a* AND PHYTOPLANKTON IN THE ROANOKE RIVER AND WESTERN ALBEMARLE SOUND, 1991

Donald W. Stanley

Sampling for chlorophyll *a* (a measure of phytoplankton biomass) and phytoplankton have been conducted in the lower Roanoke River and western Albemarle Sound during each spring since 1984. Collection methods were similar in all years and are described in detail in Rulifson et al. (1986, 1988, 1992a, 1992b). Analyses for chlorophyll *a* were performed by the standard acetone extraction method (Strickland and Parsons 1972) and reported as micrograms per liter of water (µg/L). Phytoplankton cell densities were determined using the membrane filtration method (APHA 1975). The preserved algae were concentrated by filtering the sample through a 0.45-µm pore size membrane filter. Concentrated algae were counted using an inverted microscope and reported as number of individuals per liter. These counts were converted to volume (cubic microns) by estimating the volume of an average individual of each species with geometric formulae. The total volume of algae per liter was converted to weight by assuming a specific gravity of unity. Sampling locations are shown in Figure 72. Data for previous years were reported in earlier Flow Committee reports (Rulifson and Manooch 1990a, 1991).

Chlorophyll *a*

In general, spring 1991 chlorophyll *a* values were higher in the lower Roanoke River and western Sound than in Batchelor Bay. Individual concentrations ranged from less than 0.1 to over 12 µg/L, but were mostly between 2 and 6 µg/L. Average River values were within the 4.0-6.2 µg/L range, while average Bay values were 1.0-2.0 µg/L. Increases up to 10.0 µg/L were observed in all three water bodies in late May into June (Figure 86). These results are similar to those of previous years; historically, chlorophyll *a* values are generally less than 10 µg/L in the lower Roanoke, Delta, and western Sound at this time of year (Rulifson et al. 1992a).

Phytoplankton

A total of 154 phytoplankton species have been identified in the study area. The phytoplankton group with the highest diversity is the Bacillariophyceae (diatoms, 77 species), followed by the Chlorophyceae (green algae, 42 species). In addition, there are a few representatives of other groups each year: Chrysophyceae (9 species), Dinophyceae (dinoflagellates, 9 species), Euglenophyceae (euglenophytes, 5 species), and Cyanophyceae (blue-greens, 2 species). In addition, there are species that could not be identified and so are placed in the 'Unknown' category.

In 1991, as in previous years, only a few of the taxa listed above were common. Only five cell types appeared in more than 10% of the samples. Diatoms and green algae dominated the list. Common diatom genera included *Cyclotella* sp., *Melosira granulata*, *Synedra* sp., *Navicula* sp., *Coscinodiscus* sp., and *Fragilaria* sp. Common green algae genera included *Schizogonium murale* and *Zygnema* sp.

Phytoplankton cell densities ranged widely in 1991, from less than 100 cells/ml to almost 3,000 cells/ml in a few samples, but values in the range 500-1,000 were most common. Average River algal densities were highest early in the sampling period, and tended to decline later (Figure 87). Average Batchelor Bay densities showed less of a temporal pattern, and overall were lower than those in the River.

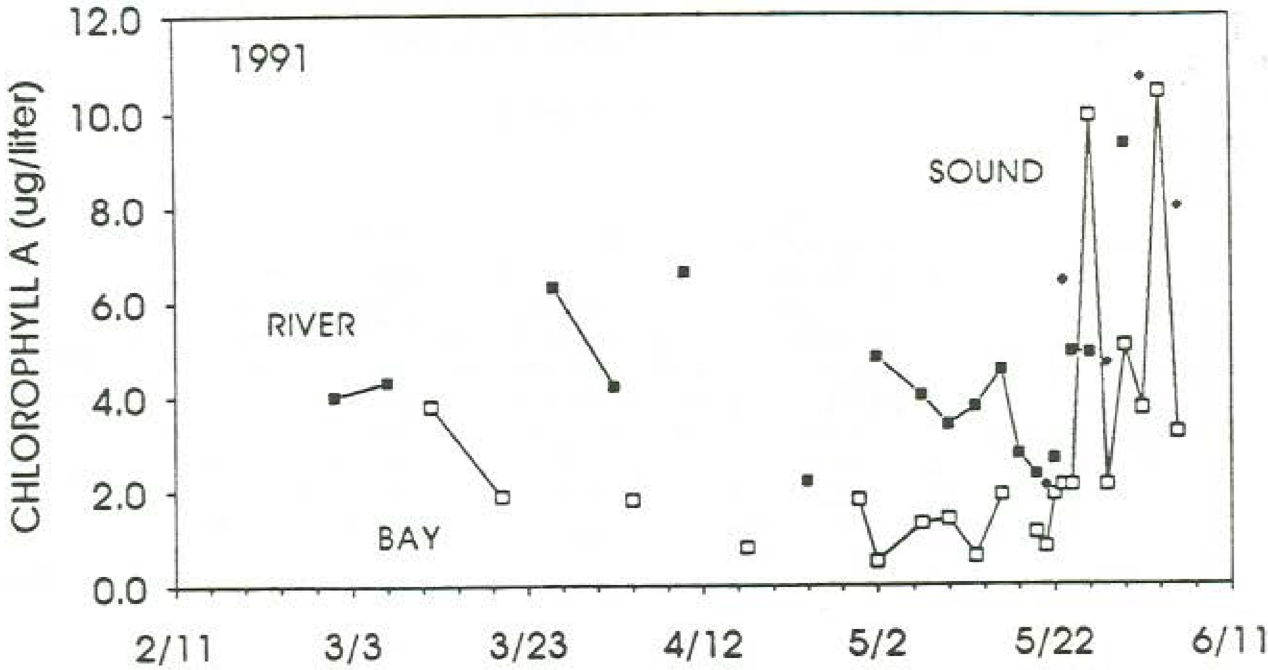

Figure 86. Average values of chlorophyll *a* (μg/L), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1991.

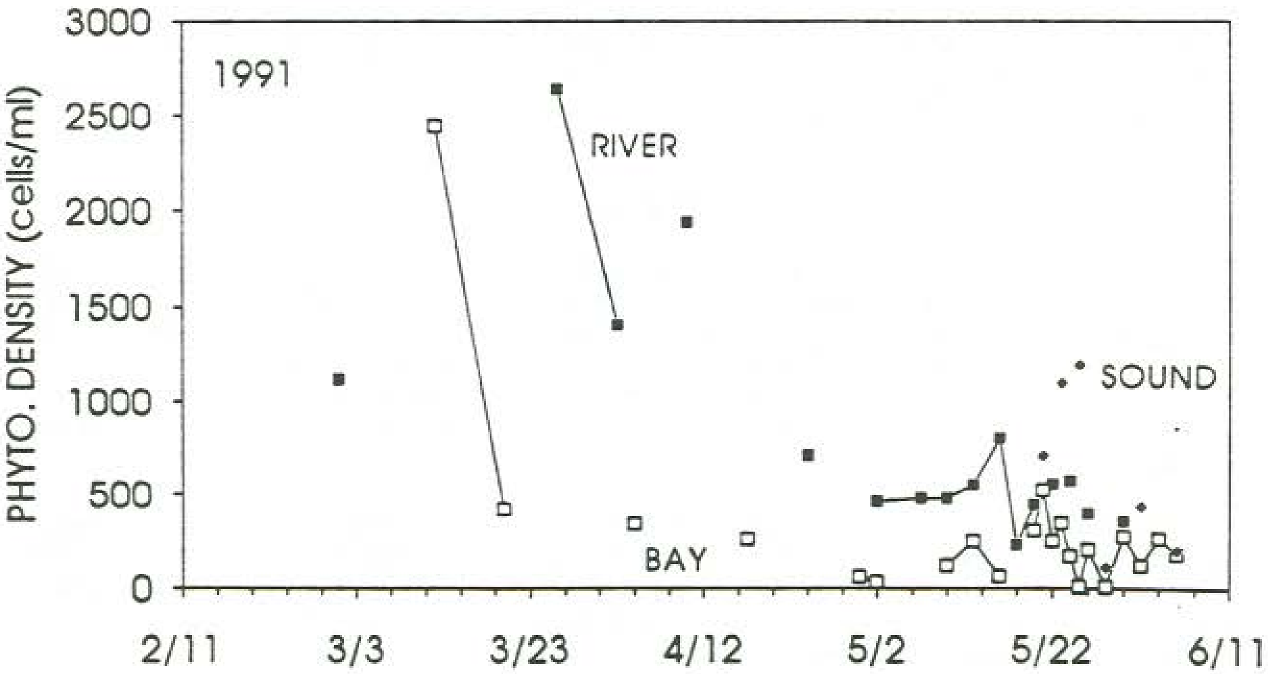

Figure 87. Average phytoplankton density (cells/ml), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1991.

Phytoplankton biomass (µg wet weight/L) also was highly variable, but some trends were evident (Figure 88). For most samples the biomass fell between 50 and 300 µg/L. Algal biomass was usually higher in the River than in the Sound or Bay, a pattern supported by the chlorophyll *a* and cell density results. Unusually high biomass values (greater than 1,000 µg/L) were measured in a few samples, and were the result of either very high densities of average-sized cells, or relatively low densities of very large phytoplankters.

Phytoplankton biomass values for 1991 were similar to those reported for 1990, both of which were lower than those reported during the low flow years of 1985 and 1986 (Rulifson et al. 1992a). There is good evidence that this difference was caused by differences in River flow. This inverse relationship between instream flow and phytoplankton biomass appears to be common in riverine ecosystems. Christian et al. (1986) reported that phytoplankton biomass in the lower Neuse River was a function of river flow. Laboratory growth studies and mathematical modeling demonstrated that high river flows retarded algal growth by a combination of light limitation (i.e., high turbidity) and short residence time in the river (i.e., rapid water velocity). Consequently, algae-poor runoff water from upriver is swept through the lower river and into the estuary so quickly that the algal populations do not have time to build up. Conversely, lower flows result in less turbidity and less light limitation along with longer residence times in the river. This inverse river flow-algal biomass relationship has been demonstrated for other systems, including the Potomac River estuary (Christian et al. 1986).

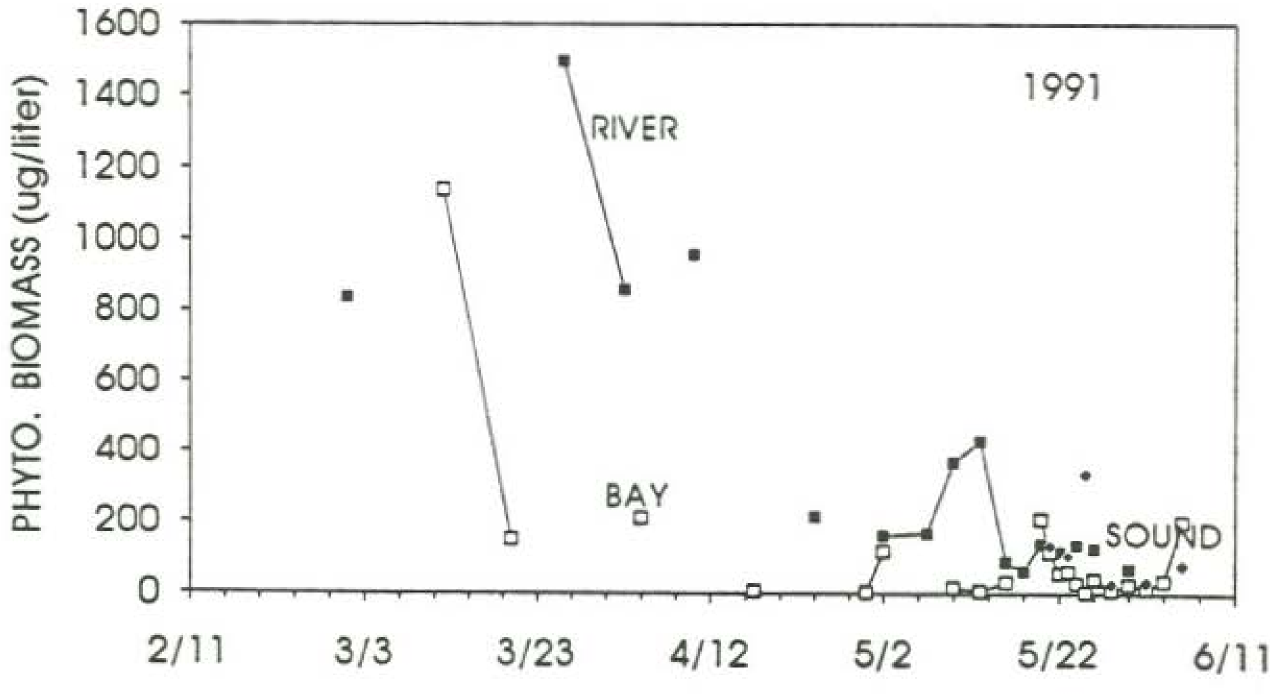

Figure 88. Average phytoplankton biomass (µg/L), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1991.

ZOOPLANKTON ABUNDANCE IN THE LOWER ROANOKE RIVER, DELTA, AND WESTERN ALBEMARLE SOUND, 1991

Roger A. Rulifson, Scott F. Wood, and John E. Cooper

Sampling for zooplankton in the lower Roanoke River, Delta, and western Albemarle Sound has been conducted since 1984 to gather information about the food chain available to support growth and development of larval fish species using the area as a nursery habitat. Collection methods in 1991 were similar to those in past years (Rulifson et al. 1992a). A fixed station array (Figure 72) was used each year. Some stations were not sampled each year. Additional sites upstream (Stations 1-4) were sampled by personnel of the North Carolina Wildlife Resources Commission (Figure 72).

Zooplankton samples were collected using nets constructed of 250-μm mesh nitex material, with a 0.5-m diameter mouth opening and a 1:6 mouth-to-length ratio. Volume filtered was estimated by a flowmeter with slow speed propeller mounted in the net frame. Samples of two-minute duration were taken against the current at River stations, and against the wind or current in the Sound, whichever was strongest. Zooplankton were preserved in 10% buffered formalin containing Rose Bengal stain. Zooplankton abundance was estimated by subsampling, identifying the organisms to the lowest taxon practical, and reporting the average number of each taxon as number per cubic meter of water filtered.

Sampling in 1991 was initiated 1 March and was terminated 5 June. A total of 25 sites was sampled in 1991: 12 stations in the River and Delta, three in Batchelor Bay, and 10 in western Albemarle Sound beyond Batchelor Bay.

In 1991, the average zooplankton abundance was highest in mid-April followed by a second peak in late May. River zooplankton was more abundant in April than densities observed for Batchelor Bay and the western Sound (Figure 89).

Zooplankton was concentrated at several locations within the study area during the spring 1991 study. Within the River and Delta, the highest average densities were observed in the Cashie River: Station 11 (Cashie River mouth) with $576/m^3$, and Station 8 with $462/m^3$. Concentrations were lowest in the upper portions of the Roanoke River sampling area (Hamilton through Jamesville). In western Albemarle Sound, 1991 zooplankton abundance was highest along the north shore of western Albemarle Sound in the Edenton Bay area (Stations 22-24); densities averaged between 600 and 742 $zooplankton/m^3$.

Dominant zooplankton taxa differed among the three water bodies. Cladocerans dominated River zooplankton, representing about 35% of the community. Dominant cladoceran taxa were *Daphnia* (13%) and *Bosmina* (8%). Copepods were the other dominant group . Cyclopoid copepods represented 28% of the zooplankton community. Calanoid copepods contributed an additional 7%. Rotifers (19.6%), primarily single rotifers (18.5%), were important to the riverine zooplankton (Table 88).

Batchelor Bay is a region of transition for the zooplankton community. In 1991, copepods dominated the Batchelor Bay zooplankton community representing 42.4% of the total. Again, cyclopoid copepods were the major group (31.6%), followed by calanoid copepods (9.9%). Cladocerans represented 40.2% of the Bay zooplankton community; however, *Bosmina* were dominant (16.9%) followed by *Daphnia* (11.2%). Rotifer abundance was lower in the Bay: single rotifers (7.9%) and colonial rotifers (1.1%) comprised 9% of the zooplankton. Gammarid amphipods represented about 3% of all Bay zooplankton in 1991 (Table 88).

Western Albemarle Sound zooplankton was dominated by cyclopoid copepods (82.2%), with calanoid copepods as a minor contributor (2.2%). Cladocerans were the other major organisms in the western Sound, but represented only 13.4% of the community. Western Sound cladocerans were primarily *Leptodora* (2.7%), a large predatory species, and *Bosmina* (2.5%). *Daphnia* comprised only 1% of the Sound zooplankton community (Table 88).

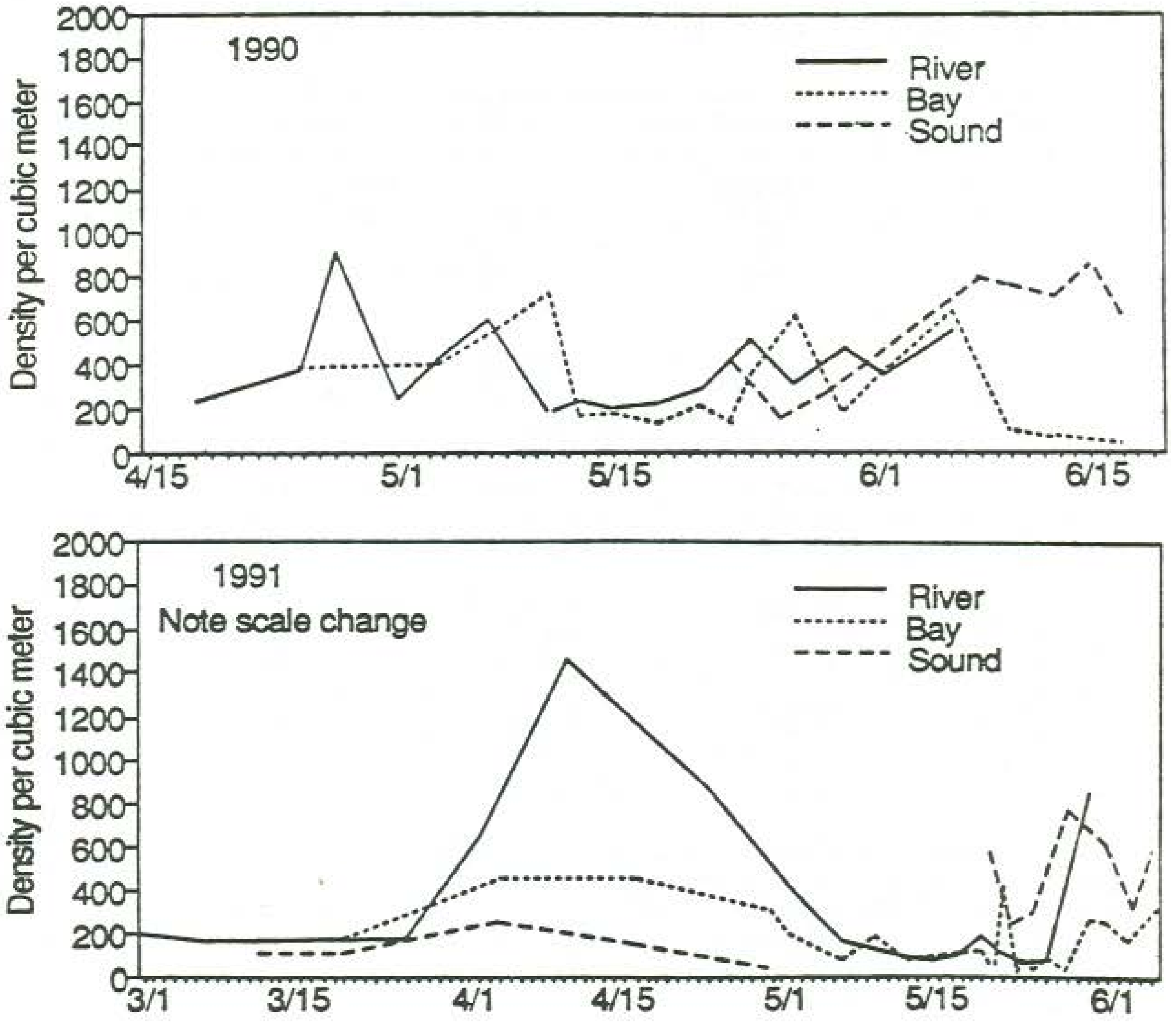

Figure 89. Average zooplankton density (number/ml), by sampling date, of the lower Roanoke River and delta (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32) in the spring of 1990 and 1991.

Table 88. Relative contribution (% using density) of each taxonomic group to the spring zooplankton community of the lower Roanoke River (Stations 1-12), Batchelor Bay (Stations 13-16), and western Albemarle Sound (Stations 17-32), North Carolina, 1990-1991 (Rulifson et al. 1992b). Period (.)=not observed in samples.

	River		Bay		Sound	
Taxonomic group	1990	1991	1990	1991	1990	1991
Amphipoda-gammarid egg	0.0	0.0	0.1	0.0	0.0	.
Amphipoda - Gammaridae	1.6	0.7	4.8	2.7	1.3	0.3
Arachnida	0.2	0.3	0.1	0.3	0.2	0.1
Bivalvia	0.0	0.0	.	.	0.0	0.0
Bivalvia-larvae	0.0	0.3	0.2	0.1	.	0.0
Caddisfly adult	.	.	.	.	.	.
Caddisfly larvae	0.1	0.1	0.1	0.1	0.0	.
Clad. - Bosmina	2.8	7.8	3.5	16.9	1.3	2.5
Clad. - Daphnia	44.8	12.8	37.6	11.2	4.8	1.0
Clad. - Leptodora	0.0	0.0	0.0	0.2	10.3	2.7
Cladocera - other	12.0	11.2	10.4	9.9	9.1	7.1
Clad.-unid. egg	0.1	1.6	0.1	1.0	0.0	0.0
Clad.-unid. juvenile	0.9	1.2	0.8	1.0	0.0	0.1
Coleopt.-Dytiscidae larvae	0.0	0.0	0.0	.	0.0	.
Coleopt.-Gyrinidae adult	.	.	.	.	.	.
Coleopt.-Gyrinidae larvae	0.0	.	0.0	.	.	.
Coleopt.-Peltodytes larvae	.	.	.	.	.	.
Coleoptera	.	0.0	.	0.0	.	.
Coleoptera-Elmidae	.	0.0	.	.	.	.
Collembola larvae	.	0.0	0.0	.	.	.
Copepoda-egg mass	0.1	0.5	0.2	0.7	0.0	0.1
Copepoda-nauplius	0.0	0.1	0.0	0.0	.	.
Copepoda-Argulus sp.	.	.	.	.	.	0.0
Copepoda-Calanoida	5.6	6.8	10.0	9.9	2.4	2.2
Copepoda-Cyclopoida	24.0	28.4	27.8	31.6	68.3	82.2
Copepoda-Harpacticoida	0.0	0.0	.	0.0	.	0.0
Copepodids	0.3	0.2	0.3	0.2	0.0	0.0
Cumacea	.	.	.	.	0.0	.
Decapoda - shrimp larvae	.	.	.	.	.	.
Dipt.-biting midge larvae	0.0	0.0	0.0	0.0	.	0.0
Dipt.-biting midge pupae	0.0	0.0	.	.	.	.
Dipt.-chironomid adult	0.0	0.0	0.1	0.0	0.0	0.0
Dipt.-chironomid larvae	0.4	0.6	0.4	0.7	0.3	0.0
Dipt.-chironomid pupae	0.0	0.0	0.0	0.0	0.1	0.0
Dipt.-mosquito adult	.	.	.	.	.	.
Dipt.-mosquito larvae	0.0	0.0	.	.	.	.
Dipt.-mosquito pupae	.	.	.	.	.	.
Dipt.-phantom midge adult	.	.	.	.	.	.
Dipt.-phantom midge larvae	0.4	0.9	0.3	0.6	0.5	0.7
Dipt.-phantom midge pupae	0.0	0.1	0.1	0.0	0.0	0.1
Dipt.-Dixidae adult	.	.	.	.	.	.
Diptera	0.0	0.0	.	0.0	0.0	0.0

Table 88. Continued

	River		Bay		Sound	
Taxonomic group	1990	1991	1990	1991	1990	1991
Eph.-mayfly adults	.	.	.	.	.	.
Eph.-mayfly nymphs	0.0	0.0	0.0	0.0	0.7	0.0
Gastropoda-snail	.	.	.	.	.	.
Gastropoda - egg	.	.	.	.	.	.
Hemiptera	.	0.0	.	.	0.0	.
Hemiptera-Belostomatidae	.	.	.	.	.	.
Hemiptera-Corixidae	0.0	0.0	0.0	.	0.0	.
Hemiptera-Gerridae	.	.	.	.	.	.
Hirudinea	.	.	.	.	.	.
Hydra	0.4	0.8	0.0	.	0.0	.
Hydra - medusa	.	.	.	.	.	.
Hymenoptera-ant	.	0.0	.	.	.	0.0
Hymenoptera-diving wasp	.	0.0	.	.	.	0.0
Isopoda	0.0	.	0.0	0.0	0.1	0.0
Megalopt.-alderfly larvae	.	0.0	.	.	.	.
Mysidacea - Mysis shrimp	.	.	.	.	.	0.0
Mysidacea - Mysis zoea	.	.	.	.	.	.
Nematoda	0.0	0.0	.	0.0	0.0	0.0
Odonata	0.0	0.0	0.0	0.0	.	.
Oligo.-Aeolosoma	0.2	0.4	0.0	0.2	0.0	.
Oligo.-Dero	0.0	0.1	.	.	.	.
Oligo.-Stylaria	0.3	0.3	0.5	0.3	0.0	0.0
Ostracoda	2.9	4.6	1.5	.	0.2	0.1
Plecoptera adult	.	.	.	.	.	.
Plecoptera nymph	.	.	.	.	.	.
Polychaeta	.	.	.	.	.	.
Rotifer - colonial	0.1	1.1	.	.	.	.
Rotifer - single	2.3	18.5	0.0	1.1	0.0	0.1
Spongillafly adult	.	.	0.7	7.9	0.0	0.4
Spongillafly larvae	.	.	.	0.0	.	.
Tanaid	.	.	.	.	.	.
Tardigrada	.	0.0	.	.	.	.
Thysanoptera (thrip)	0.0	0.1	0.0	0.0	.	0.0
Tubellaria	.	0.0	.	0.0	.	.
Unidentified	0.1	0.1	.	0.1	0.0	0.0
Total average density (/m^3)	342	196	337	208	555	482
(n) Total samples	149	140	45	52	62	63

SUSCEPTIBILITY OF LARVAL FISHES TO ENTRAINMENT BY WATER WITHDRAWAL PIPES BASED ON BODY DIMENSIONS

Roger A. Rulifson

In recent years there has been an increased demand for water from the lower Roanoke River. Water withdrawal pipes for municipalities, electrical co-generation facilities, industry, and agricultural crop irrigation may adversely affect the food chain and early life stages of many resident and anadromous fish species.

In 1991, state agencies began review of a CAMA permit for a co-generation facility proposed for Lewiston, North Carolina. Concern was raised about the possibility of entraining the eggs and larvae of striped bass through a water withdrawal pipe having a wedge-wire screen diameter of 2 mm. The study described herein was undertaken to address these concerns as well as provide information for future water withdrawal projects.

Methods

Larval fish of seven taxa common to the lower Roanoke River were analyzed for body dimensions. Taxa included striped bass (*Morone saxatilis*), *Morone* species, common carp (*Cyprinus carpio*), herrings (Clupeidae), *Notropis* species, suckers (*Catostomus* species), and pirate perch (*Aphrododerus sayanus*). Specimens were collected from the Roanoke River as part of a larval fish study (Rulifson et al. 1992a, 1992b) in the spring of 1991 and preserved in 5% buffered formalin. Each specimen was measured by ocular micrometer under a dissecting microscope for total length and widest body dimension (nearest 0.1 mm). Linear regression was used to determine the relationship between body length and width.

Results and Discussion

The theoretical entrainable size assumes that organisms, in this case fish larvae, will orient against the water current as it passes through the wedge-wire screen; the larva will therefore pass through the screen as a function of its maximum body width. The maximum entrainable size is reached when the body width of the fish is equal to the mesh dimension of the screen; all fish less than this maximum value are of entrainable size.

The theoretical minimum impingeable size (being retained on the screen rather than passing though it) should be equal to a fish length slightly longer than the mesh dimension of the screen. However, fish larvae are very flexible at this life stage and will probably fold in half from force of the water to pass through the screen. In either case the trauma to the fragile larvae will likely result in mortality. Therefore, for purposes of discussion the theoretical minimum impingeable size will be equal to the theoretical maximum entrainable size.

Results indicate that fish larvae of both resident and anadromous species are of entrainable size through a 2-mm wedge-wire screen. Table 89 provides the results of the total length-body width regressions. Individual fish of the taxon and the regression line relative to the 2-mm mesh dimension are plotted in Figure 90 through Figure 96.

Since the young of these fish species are common to the lower Roanoke River, the siting of the intake for the water withdrawal pipe is critical. Fish larvae are feeble swimmers. Placement of the intake in a portion of the river where fish larvae congregate (e.g., inside of a curve) may greatly increase susceptibility of fish larvae to entrainment. Another important factor is the velocity profile of the water being withdrawn. Low flow velocities (by increasing pipe diameter) will reduce the susceptibility of fish larvae to entrainment.

Table 89. Results of linear regressions to determine the relationship of body width to body length of seven larval fish taxa.

Species	n	Constant	Constant stderr	x coeff.	Coeff. stderr	r^2
Clupeidae	33	-0.408	0.344	0.151	0.008	0.913
Carp	26	-0.749	0.190	0.233	0.018	0.873
Morone sp.	12	0.311	0.182	0.156	0.024	0.813
Striped bass	38	-0.328	0.126	0.204	0.010	0.921
Notropis sp.	38	0.124	0.266	0.126	0.007	0.902
Pirate perch	21	-0.031	0.242	0.227	0.029	0.766
Sucker sp.	16	-1.783	0.244	0.233	0.037	0.736

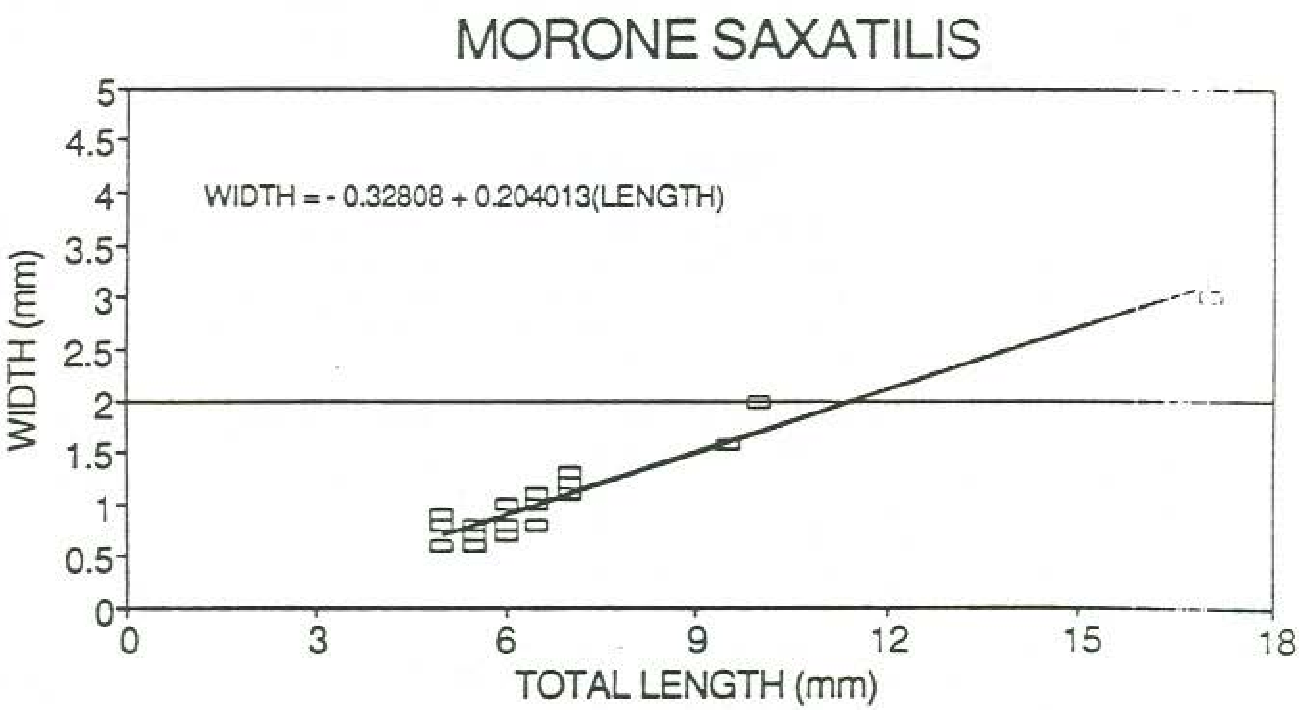

Figure 90. The relationship of body width to body length (TL) of striped bass larvae, and the theoretical length at which the larva shifts in susceptibility from entrainment to impingement on a 2-mm wedge-wire intake screen.

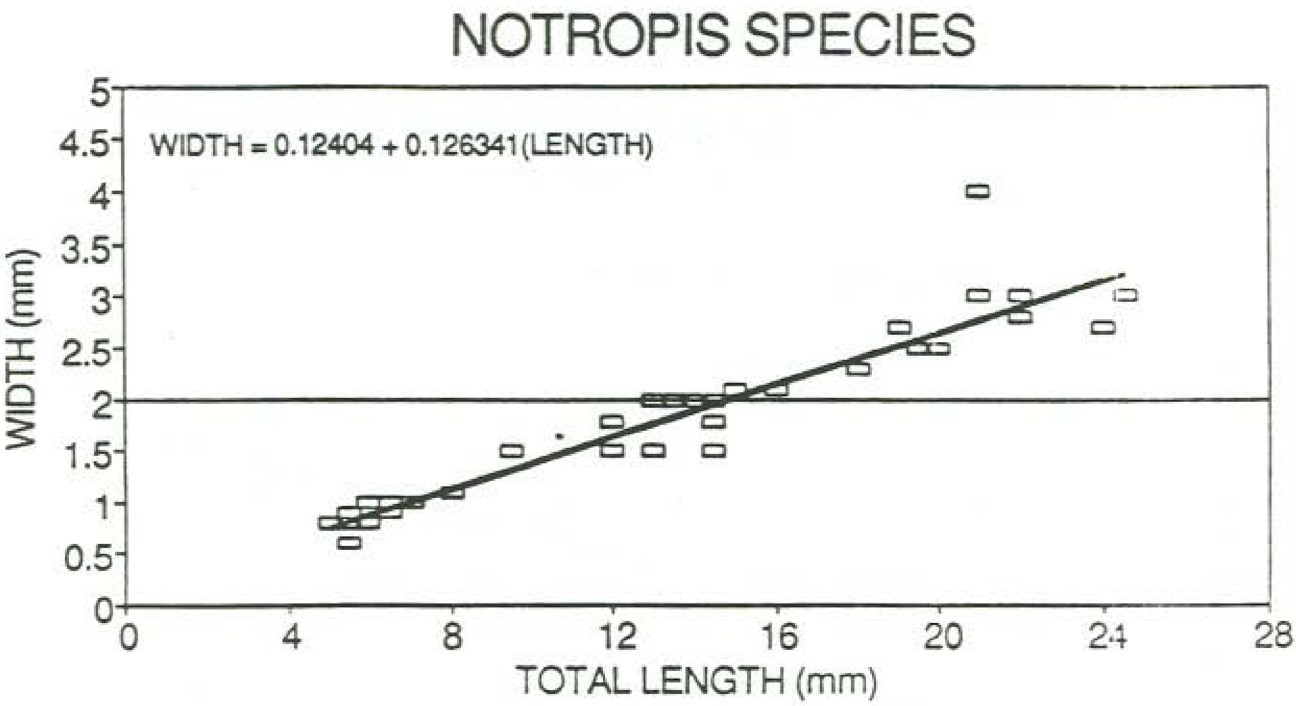

Figure 91. The relationship of body width to body length (TL) of *Notropis* larvae, and the theoretical length at which the larva shifts in susceptibility from entrainment to impingement on a 2-mm wedge-wire intake screen.

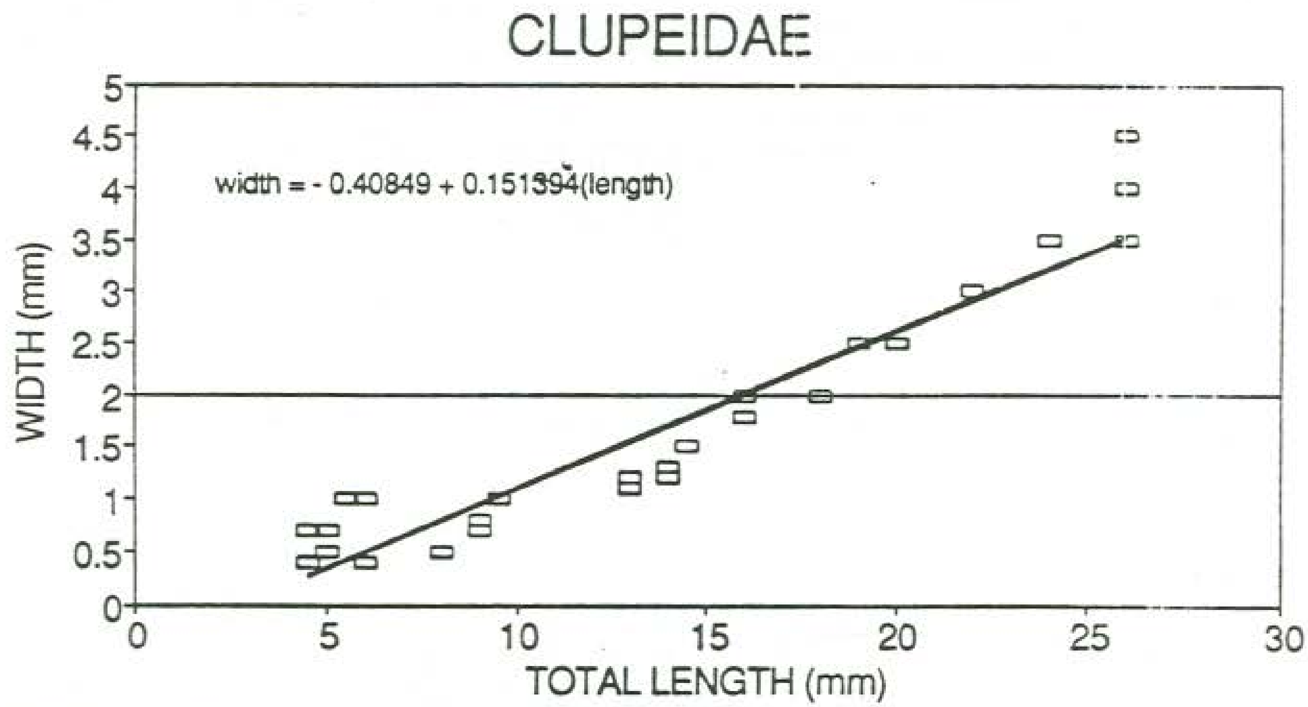

Figure 92. The relationship of body width to body length (TL) of *Clupeidae* larvae, and the theoretical length at which the larva shifts in susceptibility from entrainment to impingement on a 2-mm wedge-wire intake screen.

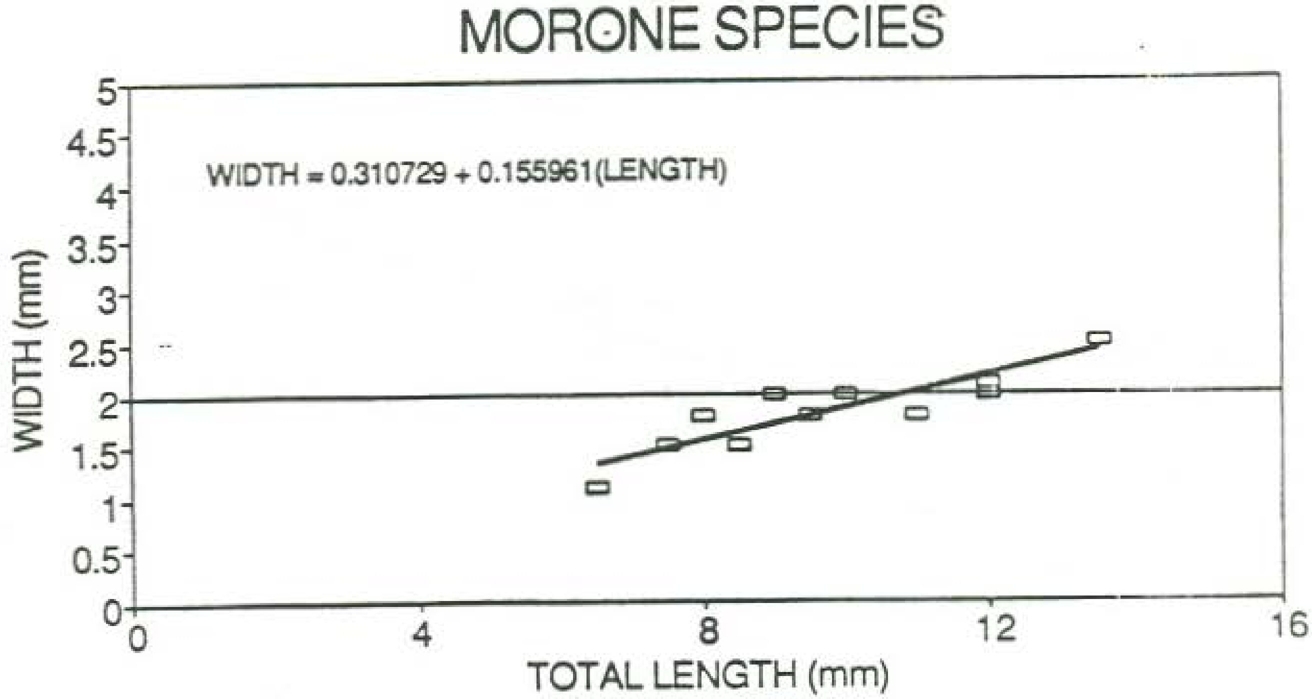

Figure 93. The relationship of body width to body length (TL) of *Morone* larvae, and the theoretical length at which the larva shifts in susceptibility from entrainment to impingement on a 2-mm wedge-wire intake screen.

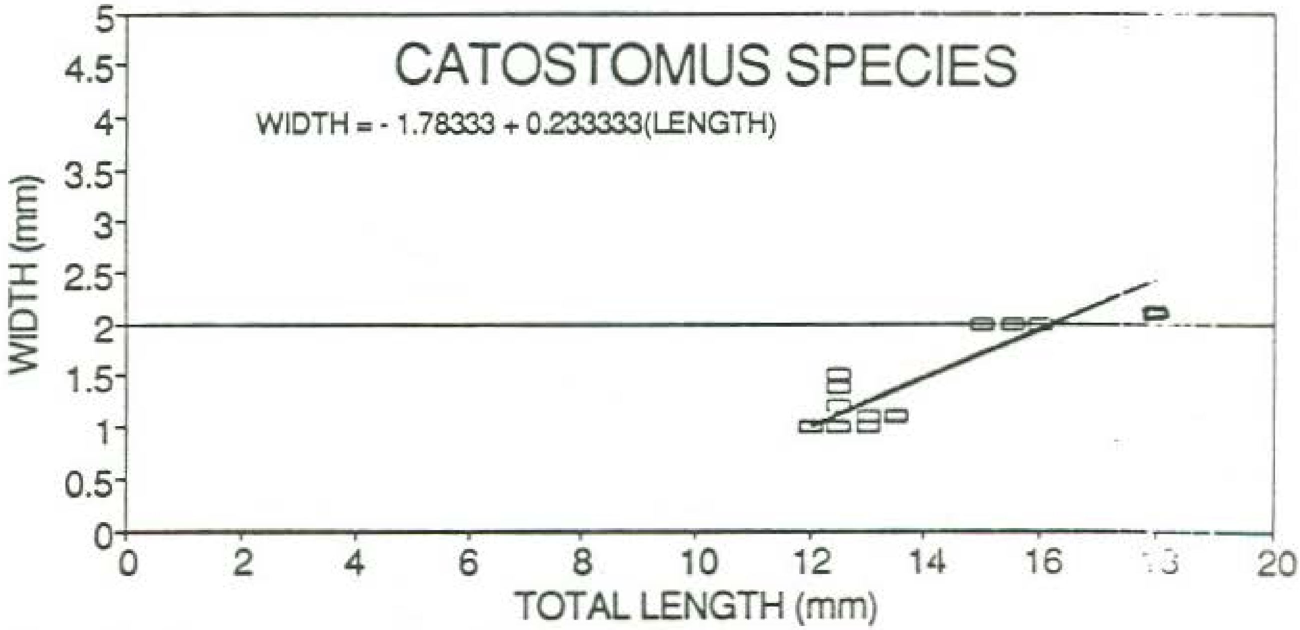

Figure 94. The relationship of body width to body length (TL) of *Catostomus* larvae, and the theoretical length at which the larva shifts in susceptibility from entrainment to impingement on a 2-mm wedge-wire intake screen.

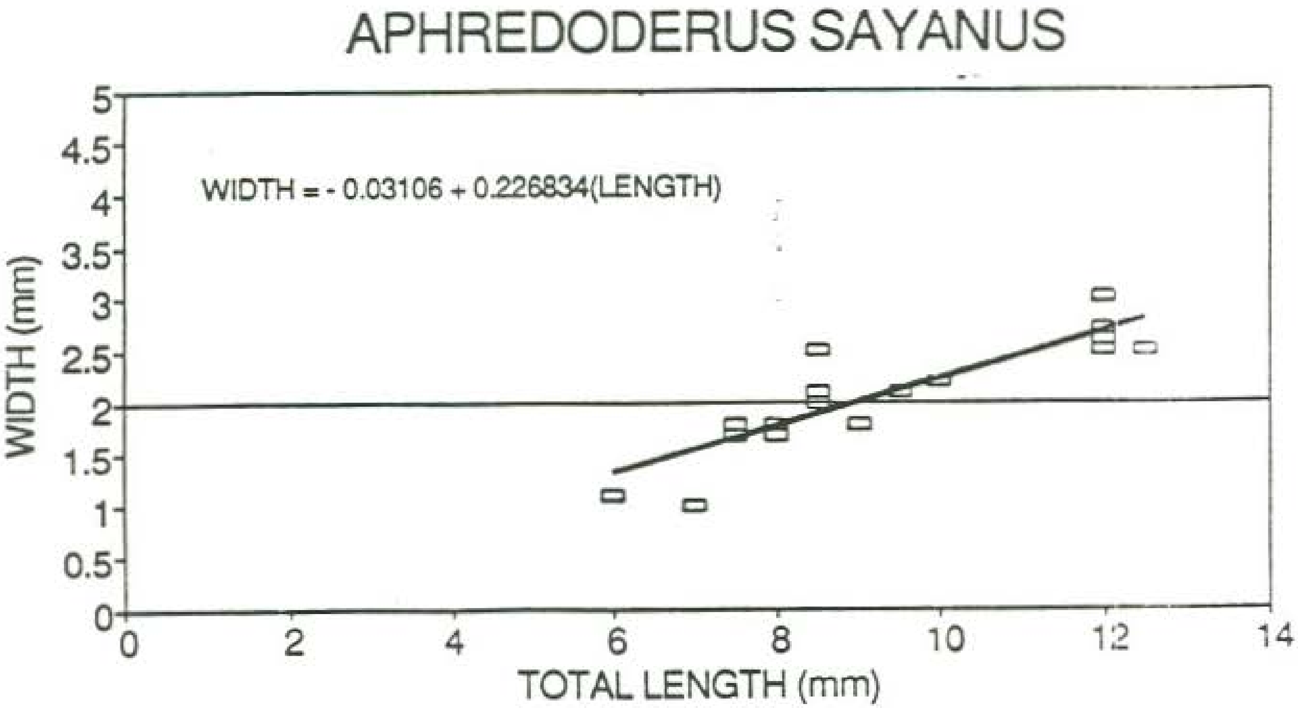

Figure 95. The relationship of body width to body length (TL) of *Aphredoderus* larvae, and the theoretical length at which the larva shifts in susceptibility from entrainment to impingement on a 2-mm wedge-wire intake screen.

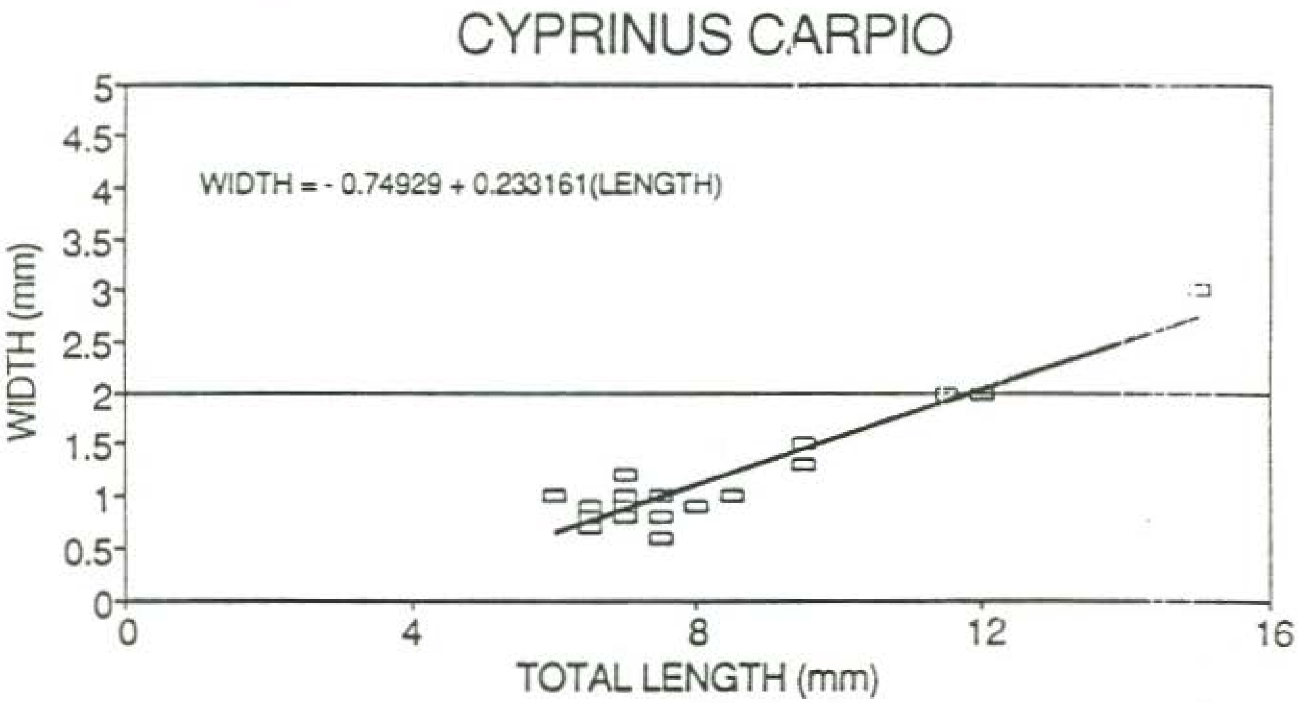

Figure 96. The relationship of body width to body length (TL) of *Cyprinus* larvae, and the theoretical length at which the larva shifts in susceptibility from entrainment to impingement on a 2-mm wedge-wire intake screen.

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APPENDIX A.

North Carolina Division of Environmental Management Water Quality Criteria

Table A-1. Use support totals of rivers and streams by river basin (1989-1991).

River Basin	Use Support Totals					
	Total Stream Miles	Fully Supporting	Support-Threatened	Partially Supporting	Not Supporting	Not Evaluated
Broad	1450	638	527	253	11	21
Cape Fear	6282	2131	2067	1211	331	542
Catawba	3083	1197	936	636	163	151
Chowan	782	48	184	345	176	29
French Broad	4113	1765	939	1050	70	289
Hiwassee	986	261	563	92	0	70
Little Tennessee	2696	1614	681	364	15	22
Lumber	2294	702	1055	271	79	187
Neuse	3293	735	1341	812	165	240
New *	830	409	284	101	15	21
Pasquotank	464	101	11	230	77	45
Roanoke	2414	359	470	1129	168	288
Savannah	209	123	74	7	0	5
Tar - Pamlico	2346	420	978	602	162	184
Watauga	283	148	60	52	8	15
White Oak	277	101	44	132	0	0
Yadkin - Pee Dee	5855	2172	1619	1320	256	488
Totals	37657	12924	11833	8607	1696	2597
Percentage		34	31	23	5	7

Note: In Tables A-1 to A-5, the column totals may vary slightly due to rounding.

Table A-2. Use support totals of rivers and streams by river basin on a monitored or evaluated basis (1989-1991).

	Use Support									
	Total	Fully Supporting		Support-Threatened		Partially Supporting		Not Supporting		Not
River Basin	Stream Miles	Monitored	Evaluated	Monitored	Evaluated	Monitored	Evaluated	Monitored	Evaluated	Evaluated
Broad	1450	108	530	121	406	102	151	5	6	21
Cape Fear	6282	580	1551	343	1724	336	875	193	138	542
Catawba	3083	436	761	175	761	191	445	110	53	151
Chowan	782	13	35	0	184	140	205	29	147	29
French Broad	4113	459	1306	124	815	176	874	41	29	289
Hiwassee	986	96	165	3	560	22	70	0	0	70
Little Tennessee	2696	489	1125	72	609	106	258	2	13	22
Lumber	2294	240	462	162	893	39	232	50	29	187
Neuse	3293	366	369	386	955	432	380	97	68	240
New	830	203	206	94	190	38	63	10	5	21
Pasquotank	464	11	90	0	11	33	197	15	62	45
Roanoke	2414	217	142	44	426	171	958	8	160	288
Savannah	209	47	76	23	51	3	4	0	0	5
Tar - Pamlico	2346	162	258	67	911	114	488	19	143	184
Watauga	283	52	96	17	43	0	52	5	3	15
White Oak	277	35	66	0	44	19	113	0	0	0
Yadkin - Pee Dee	5855	728	1444	336	1283	293	1027	80	176	488
Totals	37657	4242	8682	1967	9866	2215	6392	664	1032	2597
Percentage		11	23	5	26	6	17	2	3	7

Table A-3. Classification or use support for rivers and streams by river basin (1989-1991).

	Use Support and Classification															Total Miles		
	Not Evaluated			Not Supporting			Partially Supporting			Fully Supporting			Support Threatened			Total Miles		
River Basin	B	C	WS	B	C	WS	B	C	WS	B	C	WS	B	C	WS	B	C	WS
Broad	0	21	0	0	11	0	0	238	15	13	449	176	1	295	232	15	1014	422
Cape Fear	34	460	48	3	265	62	14	966	231	78	1663	391	40	1625	402	169	4978	1134
Catawba	1	131	19	0	154	9	5	519	112	143	663	391	5	793	138	153	2259	669
Chowan	0	29	0	6	170	0	60	286	0	23	25	0	16	168	0	104	678	0
French Broad	38	225	26	15	50	5	17	939	94	81	1279	405	18	727	194	169	3219	723
Hiwassee	9	53	8	0	0	0	0	92	0	11	241	9	3	547	13	22	933	30
Little Tennessee	5	8	9	0	14	1	11	320	33	122	1357	134	77	514	90	215	2213	266
Lumber	12	175	0	0	79	0	9	263	0	33	502	166	53	882	120	108	1901	286
Neuse	1	201	38	6	153	7	17	736	58	8	432	295	48	1000	294	80	2522	692
New	0	21	0	0	15	0	0	99	2	25	339	45	0	267	17	25	741	63
Pasquotank	0	45	0	0	77	0	0	204	26	6	95	0	0	11	0	6	432	26
Roanoke	43	217	28	1	163	4	47	1006	76	28	220	111	25	417	27	144	2024	247
Savannah	2	3	0	0	0	0	0	7	0	27	95	1	7	65	1	36	170	2
Tar - Pamlico	0	125	59	0	129	33	10	498	94	30	272	119	29	750	199	69	1774	503
Watauga	0	15	0	0	8	0	0	52	0	36	106	6	2	58	0	38	239	6
White Oak	0	0	0	0	0	0	0	132	0	0	101	0	0	44	0	0	276	0
Yadkin - Pee Dee	27	275	186	0	218	38	9	818	493	134	1553	484	17	1243	359	187	4107	1560
Totals	171	2004	421	30	1506	159	200	7174	1233	800	9390	2731	340	9406	2085	1540	29479	6628
Percentage	0	5	1	0	4	0	1	10	3	2	25	7	1	25	6	4	69	18

Table A-4. Major sources of use impairment of rivers and streams by river basin (1989-1991).

	Major Sources										
River Basin	Total Nonpoint	Total Point	Agricultural Runoff	Forestry	Construction	Urban Runoff	Mining	Land Disposal	Hydromod	Unknown	Other
Broad	224	34	171	20	86	18	4	26	30	38	25
Cape Fear	1263	232	691	86	219	371	41	90	41	167	46
Catawba	692	156	385	24	165	138	23	86	0	67	25
Chowan	470	106	342	0	0	0	0	0	4	130	0
French Broad	856	53	642	17	70	111	4	24	15	132	6
Hiwassee	85	0	164	3	27	0	19	0	0	23	0
Little Tennessee	271	3	158	9	26	0	11	0	0	91	0
Lumber	263	34	180	0	0	58	0	0	42	44	0
Neuse	518	107	339	39	126	143	0	14	47	0	51
New	108	9	85	7	23	28	11	0	0	0	22
Pasquotank	294	16	251	0	17	12	0	43	58	31	0
Roanoke	1028	186	714	54	29	68	7	60	19	215	19
Savannah	6	0	0	0	0	0	0	0	0	4	0
Tar - Pamlico	634	102	534	20	8	44	0	30	71	56	20
Watauga	49	5	49	0	46	1	5	46	0	0	3
White Oak	113	0	46	0	13	11	0	0	0	0	0
Yadkin - Pee Dee	1290	196	1027	34	202	349	65	57	26	69	1
Totals	8164	1240	5777	313	1058	1352	189	477	354	1066	219
% Total Miles	22	3	15	1	3	4	1	1	1	3	1
%PS and NS Miles	79	12	56	3	10	13	2	5	3	10	2

Table A-5. Major causes of use impairment of rivers and streams by river basin (1989-1991).

	Major Causes														
River Basin	BOD	TSS	NH3	Fecal	Sediment	Low DO	Toxicants	Nutrients	Dioxin	pH	Turbidity	Temp	Metals	Low Flow	Chl-A
Broad	0	0	0	15	138	0	15	0	0	0	3	0	3	0	0
Cape Fear	77	0	6	117	665	25	119	97	0	54	86	8	66	0	0
Catawba	83	0	0	60	417	9	35	47	0	0	46	0	67	0	0
Chowan	8	0	21	0	198	97	0	29	51	0	28	0	0	0	0
French Broad	5	0	0	84	325	4	5	0	38	2	39	9	71	2	0
Hiwassee	0	0	0	0	25	19	0	0	0	0	0	0	0	0	0
Little Tennessee	0	0	0	5	116	0	0	0	0	0	0	0	13	0	0
Lumber	28	0	0	9	107	26	19	9	0	0	0	0	0	0	0
Neuse	39	0	7	65	300	150	25	39	0	21	32	0	48	0	0
New	0	0	0	1	42	0	0	0	0	3	0	18	3	0	0
Pasquotank	0	0	0	0	0	31	0	4	0	0	12	0	0	0	0
Roanoke	87	0	0	101	347	57	148	162	37	0	8	0	12	0	0
Savannah	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Tar - Pamlico	73	0	20	24	442	41	42	32	0	0	14	0	34	0	0
Watauga	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0
White Oak	0	11	0	0	31	19	0	0	0	0	0	0	0	0	8
Yadkin - Pee Dee	63	0	0	175	759	29	127	100	0	4	45	0	6	0	0
Totals	461	11	54	656	3941	507	535	518	126	84	312	35	324	2	8
% Total Miles	1	0	0	2	10	1	1	1	0	0	1	0	1	0	0
% PS and NS Miles	4	0	1	6	38	5	5	5	1	1	3	0	3	0	0

Table A-6. Roanoke River basin freshwater segments (1989-1991).

Station Number	Station Location	Classification	Index Number	Miles	1989-91 Chemical Rating	1987 (Biological Rating)	1988	1989	1990	1991	Problem Parameters (Overall Rating)	Use Support	Source
02068500	Dan River near Francisco, NC	C Tr	22-(1)	91.7	NS		Good		Excellent		Temp, Turb	S	NP
02071000	Dan River near Wentworth, Big Ck. to Mill Br.	WS-III	22-(8)	57.2	PS	Excellent		Good			Hg,Turb	S	P
	Cascade Creek at SR 1212/Moore Springs near SR 1001, St	B	22-12c	3.7					Good/Good			S	
	Above Swimming Lake, Stokes Co.	B	22-12-1	1.6					Good	Good		S	
	Indian Creek below hiking trail, Stokes Co.	WS-III	22-13a	0.1					Good			S	
	Indian Creek at SR 1001, Stokes Co.	WS-III	22-13b	1.5					Good			S	
	Indian Creek at NC 135, Stokes Co.	WS-III	22-13c	1.5					Good			S	
02070500	Mayo River near Price, SR-1358	WS-III	22-30-(1)a	0.8	ST	Excellent		Excellent				S	P
	Mayo River at NC 770, Rockingham Co.	WS-III	22-30-(1)b	8.3		Excellent		Good-Fair				ST	
	Mayo River at US 220, Rockingham Co.	WS-III	22-30-(1)c	3.9		Excellent		Good-Fair				ST	
	Mayo River at NC 135, Rockingham Co.	WS-III	22-30-(1)d	3.6		Excellent		Good				S	
02074218	Dan River near Mayfield, SR-1761	C	22-(39)a	13.5	ST	Good				Good		S	
02075198	Dan River at Milton, NC-VA State Line	C	22-(39)b	6.4	PS						Turb	PS	
02074000	Smith River at Eden	WS-III	22-40-(1)	3.6	ST		Good		Good			S	
	NC/VA State Line, Caswell Co.	C	22-56-(6)	23.3		Good			Good		Fecal, Tox	S	NP,P
02077303	Hyco River near McGhees Mill, below Bay Dam	C	22-58-(9.5)	22.8	PS						Selenium	PS	NP
02077200	Hyco Creek near Leasburg, U.S. Hwy 158	C	22-58-1	16.5	PS	Good-Fair					Hg	ST	NP
02077348	Marlowe Creek near Woodsdale	C	22-58-12-6-(1)	2.7	S							S	
02077631	Mayo Creek near Allenville, SR-1547	C	22-58-15a	4.0	ST							ST	NP
02077670	Mayo Creek near Bethel Hill	C	22-58-15b	14.7	ST							ST	
02079101	Grassy Creek near Cornwall, SR-1436	C	23-2-(1)	16.5	ST						DO	ST	
	Little Island Creek at SR1342, Vance Co.	C	23-4-3	9.3					Good-Fair		Fecal, BOD, Tox	ST	
02079264	Nutbrush Creek near Henderson at NC 39, Vance Co.	C	23-8-(1)a	2.0				Good-Fair				ST	NP
	Anderson Creek at I-85, Vance Co.	WS-III&B	23-8-6-(1)	7.0					Fair			PS	NP,P
	Anderson Creek at I-85, Vance Co.	WS-III&B	23-8-6-(1)a	0.0					Poor			NS	
02079717	Smith Creek, source to NC/VA Line	C	23-10	11.6	ST			Fair				PS	NP
02080500	Roanoke River at Roanoke Rapids, NC Hwy. 48	WS-III	23-(25)	1.6	S						Sed	S	
02081022	Roanoke River near Lewiston, NC Hwy. 11	C	23-(26)c	56.7	S						Sed	S	
02081054	Roanoke River at Williamston, U.S. Hwys. 13/17	C	23-(26)d	16.6	S						Dioxin	PS	NP

Table A-7. Examples of nonpoint source programs.

PROGRAM	MANAGEMENT AGENCIES		
	LOCAL	STATE	FEDERAL
AGRICULTURE			
Agriculture Cost Share Program	SWCD	SWCC, DSW	
N.C. Pesticide Law of 1971		NCDA	
Pesticide Disposal Program		NCDA	
Animal Waste Management	SWCD	DEM, DSW, CES	SCS
Laboratory Testing Services		NCDA	
Watershed Protection (PL-566)			SCS
1985 and 1990 Farm Bills			USDA
- Conservation Reserve Program			
- Conservation Compliance			
- Sodbuster			
- Swampbuster			
- Conservation Easement			
- Wetland Reserve			
- Water Quality Incentive Program			

Abbreviations: SWCD, Soil and Water Conservation Districts; SWCC, Soil and Water Conservation Commission; DSW, Division of Soil and Water; NCDA, N.C. Department of Agriculture; DEM, Division of Environmental management; CES, Cooperative Extension Service; SCS, Soil Conservation Service; USDA, U.S. Department of Agriculture.

Table A-8. BMP log summary report -- Roanoke basin -- program year 1991 (North Carolina Cost Share Program, Soil and Water Conservation Districts).

Acres	7,109.50
Acres Erosion Control	961.54
Tons Saved	34,845.00
Erosion/Nutrient Control BMP's	Acres
Sod-Based Rotation	268.71
Cropland Conversion	278.93
Conservation Tillage	88.72
Critical Area Planting	19.08
Stripcropping	306.08
Terraces/Diversions (ft.)	29,670.00
Animal Waste Management	
Structures (#)	4
Composters (#)	1
Solid Set Systems (#)	0
Hydrants (#)	0
Liquid Waste Application (gallons)	1,535,250
Poultry Litter Applied (tons)	6,660.00
Acres Applied	1,835.00
Stream Protection Systems (#)	12
Livestock Exclusion (ft.)	6,682.00
Sediment/Nutrient Control BMP's	
Grassed Waterways	156.47
Field Borders/Filter Strips	143.14
Water Control Structures (#)	0
Grade Stabilization Structures (#)	0
Agri-Chemical Handling Facility (#)	0

Table A-9. BMP log summary report -- Roanoke basin -- program year 1992 (North Carolina Cost Share Program, Soil and Water Conservation Districts).

Acres	9,705.60
Acres Erosion Control	1,417.45
Tons Saved	55,308.00
Erosion/Nutrient Control BMP's	
Sod-Based Rotation	377.18
Cropland Conversion	378.21
Conservation Tillage	261.40
Critical Area Planting	28.18
Stripcropping	374.48
Terraces/Diversions (ft.)	114,969.00
Animal Waste Management	
Structures (#)	11
Composters (#)	0
Solid Set Systems (#)	1
Hydrants (#)	
Liquid Waste Application (gallons)	5,093.350
Poultry Litter Applied (tons)	5,693.20
Acres Applied	836.00
Stream Protection Systems (#)	16
Livestock Exclusion (ft.)	29,843.00
Sediment/Nutrient Control BMP's	
Grassed Waterways	184.04
Field Borders/Filter Strips	204.70
Water Control Structures (#)	3
Grade Stabilization Structures (#)	1
Agri-Chemical Handling Facility (#)	0

Table A-10. BMP log summary report -- Roanoke basin – program year 1993 (North Carolina Cost Share Program, Soil and Water Conservation Districts). Information is for a partial year.

Acres	7,035.30
Acres Erosion Control	1,015.43
Tons Saved	28,644.00
Erosion/Nutrient Control BMP's	
Sod-Based Rotation	151.78
Cropland Conversion	343.27
Conservation Tillage	29.50
Critical Area Planting	17.45
Stripcropping	473.43
Terraces/Diversions (ft.)	115,557.00
Animal Waste Management	
Structures (#)	5
Composters (#)	1
Solid Set Systems (#)	2
Hydrants (#)	0
Liquid Waste Application (gallons)	2,757,500.00
Poultry Litter Applied (tons)	6,485.00
Acres Applied	1,720.00
Stream Protection Systems (#)	10
Livestock Exclusion (ft.)	12,187.00
Sediment/Nutrient Control BMP's	
Grassed Waterways	166.60
Field Borders/Filter Strips	189.99
Water Control Structures (#)	1
Grade Stabilization Structures (#)	0
Agri-Chemical Handling Facility (#)	0

Table A-11. Point source compliance summary (Roanoke River basin (030208-030210)), permitted and actual flow data from 1991 to 1993. Number of violations in parentheses.

			1993		1992		1991	
Permit #	Facility	Pipe	Perm. limit	Actual flow	Perm. limit	Actual flow	Perm. limit	Actual flow
NC0000752	CHAMPION INTERNATIONAL-WWTP	001	28.0000	17.1230	28.0000	18.3431	28.0000	17.2725
NC0000752	CHAMPION INTERNATIONAL-WWTP	002	.0000	.0000	.0000	.0000	.0000	.0000
NC0000752	CHAMPION INTERNATIONAL-WWTP	003	.0000	.0000	.0000	.0000	.0000	.0000
NC0000752	CHAMPION INTERNATIONAL-WWTP	004	.0000	.0100	.0000	.0100	.0000	.0100
NC0025437 (24201)	ROANOKE RAPIDS SANITARY DISTRICT	001	8.3400	6.0110	.0000	6.1541	.0000	5.9107
NC0025437	RICH SQUARE WWTP, TOWN OF	001	.1500	.0729	.3000	.0748	.3000	.0490
NC0025721	WELDON WWTP, TOWN OF	001	.6000	.3398	.6000	.3028	.6000	.2044
NC0027626	DOC-CALENDONIA CORRECTIONAL	001	.8000	.4630	.8000	.4048	.8000	.2396
NC0027642	DOC-ODOM CORRECTIONAL INST.3	001	.0750	.0695 (2)	.0750	.2068 (4)	.0750	.1950 (8)
NC0028835	PERDUE INC.-LEWISTON PLT	001	3.0000	2.3636	3.0000	2.1838	3.0000	2.2653
NC0029262	LEE OPERATING CO.-TRAVEL WORLD	001	.0100	.0041	.0100	.0041	.0100	.0030
NC0029734	DOC.-HALIFAX SUBSIDIARY	001	.0180	.0108	.0180	.0145 (2)	.0180	.0162 (3)
NC0038385	HALIFAX CO SCH-WM. DAVIE MID	001	.0120	.0022	.0120	.0021	.0120	.0036
NC0038407	HALIFAX CO SCH-MCIVER ELEM.	001	.0055	.0017	.0055	.0019	.0055	.0022
NC0038636	HALIFAX CO SCH-BAKERS ELEM.	001	.0073	.0012	.0073	.0008	.0073	.0018
NC0056316	VEPCO/ROANOKE RAPIDS HYDRO ST.	001	.0000	.3314	.0000	.9283	.0000	1.3554
NC0066192	HALIFAX NEW WWTP	001	.0750	.0297	.0750	.0325	.0750	.0180
NC0079014	PANDA-ROSEMARY,L.P.	001	.0000	.0078	.0000	.0068	.0000	.0077
Subbasin 08	Total		41.0928	26.8417	32.9028	28.6712	32.9028	27.5544
	Average		2.2829	1.4912	1.8279	1.5928	1.8279	1.5308
	% compliance (flow monitoring data)			97.75		96.00		93.29
	Flow violations			2		6		11
	% compliance (all parameters)			73.81		70.83		68.40
NC000680	WEYERHAEUSER, PLYMOUTH	001	55.0000	45.8122	55.0000	46.8975	55.0000	46.7161
NC000680	WEYERHAEUSER, PLYMOUTH	002	.0000	52.1073	.0000	48.2599	.0000	48.8817
NC000680	WEYERHAEUSER, PLYMOUTH	004	.0000	.0000	.0000	.0000	.0000	.0000
NC000680	WEYERHAEUSER, PLYMOUTH	005	.0000	.0019	.0000	.0153	.0000	.0068
NC0001961	WEST POINT PEPPERELL,HAMILTON	001	1.5000	1.2889	1.5000	1.1823	1.5000	1.1372
NC0020028	PLYMOUTH WWTP, TOWN OF	001	.8000	.5294 (1)	.8000	.4282	.8000	.3851
NC0020044	WILLIAMSTON WWTP, TOWN OF	001	2.0000	1.6091 (3)	2.0000	1.1613	2.0000	1.0546
NC0023710	LIBERTY FABRICS, INC.	001	.4500	.2371	.4500	.3268	.4500	.1997
NC0027791	DOC-MARTIN CO. SUBSIDIARY	001	.0180	.0105	.0180	.0133 (1)	.0180	.0780 (1)
NC0035858	JAMESVILLE WWTP, TOWN OF	001	.1500	.0762	.1500	.0707	.1500	.0712
NC0044776	HAMILTON WWTP, TOWN OF	001	.0800	.0444	.0800	.0389	.0800	.0398
NC0077628	OUTER BANKS CONTR-NICHOLSON PT	001	.0000	.0000	.0000	.1160	.0000	.0950
Subbasin 09	Total		59.9980	101.7170	59.9980	98.5102	59.9980	98.6650
	Average		4.9998	8.4764	4.9998	~~8.2221~~ 8.2072	4.9998	8.2221
	% compliance (flow monitoring data)			93.10		98.03		98.97
	Flow violations			4		1		1
	% compliance (all parameters)			88.41		93.18		93.13

Table A-11. Continued.

Permit #	Facility	Pipe	1993 Perm. limit	1993 Actual flow	1992 Perm. limit	1992 Actual flow	1991 Perm. limit	1991 Actual flow
NC0023116	LEWISTON WOODVILLE UTILITIES	001	.1500	.0967	.1500	.0626	.1500	.0573 (1)
NC0026751	WINDSOR WWTP, TOWN OF	001	1.1500	.5448	1.1500	.4230	1.1500	.3119
NC0032409	BERTIE CO SCH-ASKEWVILLE ELEM.	001	.0025	.0014	.0025	.0017 (1)	.0025	.0012
NC0032450	BERTIE CO SCH-BERTIE HIGH SCHOOL	001	.0200	.0115	.0200	.0114	.0200	.0115
NC0047007	EVANS LUMBER COMPANY, INC.	001	.0000	.0000	.0000	.0000	.0000	.0000
Subbasin 10	Total		1.3225	.6244	1.3225	.4989	1.3225	.3819
	Average		.2645	.1249	.2645	.0998	.2645	.0764
	% compliance (flow monitoring data)			95.83		97.73		97.62
	Flow violations			1		1		1
	% compliance (all parameters)			74.29		78.57		80.00
All subbasins	Final totals		102.4133	129.1831	94.2233	127.6803	94.2233	126.6013
	Final averages		7.5473	10.0925	7.0923	9.9018	7.0923	9.8293
	Total % compliance (flow)			96.11		97.28		95.55
	Total flow violations			7		8		13
	Total % compliance (all parameters)			78.26		79.21		~~78.18~~ 78.16

APPENDIX B.

1971 Memorandum of Understanding

MEMORANDUM OF UNDERSTANDING

BETWEEN

VIRGINIA ELECTRIC AND POWER COMPANY

AND

U. S. ARMY ENGINEER DISTRICT, WILMINGTON, CORPS OF ENGINEERS

AND

NORTH CAROLINA WILDLIFE RESOURCES COMMISSION

FOR

REREGULATION OF AUGMENTATION FLOWS FOR FISH FROM JOHN H. KERR RESERVOIR

SECTION 1 - PURPOSE

SECTION 2 - DESCRIPTION

SECTION 3 - REGULATION PLAN

MEMORANDUM OF UNDERSTANDING

REREGULATION OF AUGMENTATION FLOWS FOR FISH FROM JOHN H. KERR RESERVOIR

SECTION 1 - PURPOSE

1.1 The purpose of this Memorandum of Understanding is to establish a plan for the reregulation of additional water discharged from John H. Kerr Reservoir for the protection of the striped bass in the lower Roanoke River. Article 32 of Federal Power Commission license for the construction and operation of Gaston and Roanoke Rapids Reservoirs (Project No. 2009) states:

> "The Licensee shall be responsible for reregulating additional water discharge from John H. Kerr Reservoir either specifically for the protection of the striped bass fishery during the migration and spawning period, or specifically for stream sanitation purposes, in accordance with an agreement or agreements to be entered into by the Licensee and the affected State and Federal agencies subject to the approval of the Commission."

1.2 The licensee is Virginia Electric and Power Company; the State agency involved is the North Carolina Wildlife Resources Commission; and the Federal agency is the U. S. Army Corps of Engineers, operators of John H. Kerr Reservoir.

SECTION 2 - DESCRIPTION

2.1 General. John H. Kerr, Gaston, and Roanoke Rapids Reservoirs are tandem reservoirs located on the Roanoke River in Virginia and North Carolina. From the headwaters of Kerr to Roanoke Rapids

Dam with Gaston in between, a continuous chain of reservoirs is formed.

2.2 John H. Kerr Reservoir. Kerr project is a multiple-purpose project operated for flood control, power generation, fish and wildlife protection, water-quality control, recreation, and other purposes. The dam is located on the Roanoke River, about 20 miles downstream from Clarksville, Virginia, and at river-mile 179 above the mouth. It is a concrete gravity dam having a maximum height of 144 feet, 22 spillway tainter gates, and 9 generating units rated at 206,000 kilowatts total capacity. Storage space is reserved in the reservoir between elevations 299.5 feet and 302 feet to provide water for augmentation of flows during the striped bass spawning season. This space will be utilized each year when there is inflow in excess of minimum energy requirements prior to and during the striped bass spawning season.

2.3 Gaston and Roanoke Rapids Reservoirs. Both Gaston and Roanoke Rapids projects are licensed power projects located about 34 and 42 river-miles, respectively, downstream from Kerr Dam. Gaston has 3 feet of flood control storage space between elevations 200 feet and 203 feet for replacement of valley storage lost by the construction of the reservoir. Roanoke Rapids has no flood control space. Gaston Dam is a concrete and earthfill structure with a maximum height of 105 feet. The project is equipped with 11 radial spillway gates and the powerplant consists of four 44,480-kilowatt units. Roanoke Rapids Dam is a concrete gravity structure with a maximum height of 72 feet. The spillway has 24 radial gates and the powerplant has four 25,020-kilowatt units. The Roanoke Rapids tailrace is 8,000 feet long, 80 feet wide, and has an average depth of 45 feet. It was excavated from bedrock.

SECTION 3 - REGULATION PLAN

3.1 General. In the spring of the year, striped bass ascend the Roanoke River for the purpose of spawning in the vicinity of Weldon, North Carolina. A minimum river stage of 13 feet is required at Weldon for successful spawning. Minimum discharge from Roanoke Rapids Reservoir is not sufficient to maintain the 13-foot stage. Consequently, supplemental or augmentation water must be released from Kerr Reservoir. The reregulation of this augmentation water through Gaston and Roanoke Rapids Reservoirs is the subject of this memorandum.

3.2 Basic release. Virginia Electric and Power Company will release from Roanoke Rapids Reservoir a basic minimum instantaneous discharge of 2,000 cubic feet per second for the period requested by the North Carolina Wildlife Resources Commission, to begin as early as April 1, but not later than April 15, and to continue for at least 60 days, but not longer than 75 days in any one year.

3.3 Augmentation release. The minimum release of 2,000 cubic feet per second from Roanoke Rapids will be supplemented by augmentation water from John H. Kerr Reservoir sufficient to maintain a minimum stage of 13 feet on the river gage at Weldon, North Carolina. The Corps will determine the normal energy from Kerr, and then, taking into account Kerr powerplant efficiencies, water leakages from Kerr Dam, and local inflows, will determine the amount of augmentation water necessar to maintain the 13-foot minimum stage at Weldon. Vepco will release such water through energy schedules, and reregulate Kerr Reservoir discharges in such a manner as to maintain the 13-foot minimum stage at Weldon. Should the declared augmentation water prove to be insufficient to maintain the 13-foot minimum stage, the Corps will increase the augmentation declaration sufficiently to counter the deficiencies.

3.4 Unless otherwise requested by the North Carolina Wildlife Resources Commission, augmentation flows from Roanoke Rapids Reservoir will begin at 8 a.m. on 26 April and will continue throughout the fish spawning season, but not later than 15 June of each year, provided storage for augmentation flows is available in Kerr Reservoir. It is recognized by all parties that some minor adjustment of the starting date may be necessary to conform with variations in water temperatures and other factors that affect the migration and spawning pattern of the fish. Augmentation flows will be released from Kerr as on-peak energy during weekdays, and Gaston and Roanoke Rapids will reregulate it to provide a minimum river stage of 13 feet for the full week. Vepco may store a portion of the augmentation water in Gaston Reservoir between elevations 200 and 201 for release on the weekend.

3.5 It is therefore agreed by the parties listed below that the foregoing Memorandum of Understanding shall prevail until such time as either party requests a termination of the agreement, and a revised Memorandum of Understanding has been approved by the Federal Power Commission.

VIRGINIA ELECTRIC AND POWER COMPANY

[signature]

E. B. CRUTCHFIELD
Senior Vice President
Virginia Electric and Power Company
Richmond, Virginia

Date 18 Oct. 1971

UNITED STATES OF AMERICA

[signature]

ALBERT C. COSTANZO
Colonel, Corps of Engineers
District Engineer, Wilmington

Date 30 April 1971

STATE OF NORTH CAROLINA

[signature]

CLYDE P. PATTON, Executive Director
N. C. Wildlife Resources Commission
Raleigh, North Carolina

Date Sept 9 1971

APPENDIX C.

Pertinent Correspondence

Pertinent Correspondence

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Memo from Mr. J. Merrill Lynch to RRWFC, 9/3/93 365

Memo from Dr. R.W. Laney to Striped Bass Analysis Subcommittee, 9/14/93 366

Memo from Mr. J. Merrill Lynch to RRWFC, 10/1/93 379

DEPARTMENT OF THE ARMY
Wilmington District, Corps of Engineers
Post Office Box 1890
Wilmington, North Carolina 28402-1890

CESAW-PD-E-91-NC/VA-0007 June 19, 1991

PUBLIC NOTICE

EXECUTIVE ORDER 11990 - PROTECTION OF WETLANDS
JOHN H. KERR DAM & RESERVOIR, VIRGINIA
PHILPOTT LAKE, VIRGINIA
FALLS LAKE, NORTH CAROLINA
B. EVERETT JORDAN DAM & LAKE, NORTH CAROLINA
W. KERR SCOTT RESERVOIR, NORTH CAROLINA

TO WHOM IT MAY CONCERN:

THE WILMINGTON DISTRICT CORPS OF ENGINEERS, Wilmington, North Carolina, is hereby issuing the following general Executive Order 11990 public notice for established silviculture activities for each of the five reservoir projects. The reservoir projects are: John H. Kerr Dam and Reservoir, Virginia; Philpott Lake, Virginia; Falls Lake, North Carolina; B. Everett Jordan Dam and Lake, North Carolina; and W. Kerr Scott Reservoir, North Carolina. Hereafter, these projects located in Virginia and in North Carolina will be referred to as the five projects. Ongoing or established silviculture activities which require the discharge of dredged or fill material into waters of the United States do not require Section 404 of the Clean Water Act (33 U.S.C. 1344) permits, in accordance with 33 U.S.C. Section 1344(f)(1)(A), provided the discharge is not incidental to any activity having as its purpose bringing an area into a use to which it was not previously subject, where the flow or circulation of waters or wetlands may be impaired, or the reach of waters or wetlands reduced. Corps of Engineer Regulations, found at 33 CFR Section 323.4(a) state, that in order to fall under this exemption, the silviculture activities must be part of an established (i.e., ongoing) silviculture operation and must be in accordance with definitions found at 33 CFR Section 323.4(a)(1)(iii). In addition to exempting normal silviculture activities (such as plowing, seeding, cultivating, minor drainage, and harvesting for the production of food, fiber, and forest products) from permit requirements, the Clean Water Act also exempts discharges for the purpose of construction or maintenance of forest roads pursuant to 33 U.S.C. Section 1344(f)(1)(E), where such roads are constructed and maintained in accordance with best management practices (BMPs) to assure that flow and circulation patterns and chemical and biological characteristics of waters of the United States are not impaired, that the reach of the waters of the United States is not reduced, and that any adverse effect on the aquatic environment will be otherwise minimized. These BMPs are found in 33 CFR Section 323.4(a)(6)(i-xv).

Executive Order 11990, issued on May 24, 1977, is entitled "Protection of Wetlands." This Executive Order was issued by the President of the United States of America in furtherance of the National Environmental Policy Act of 1969, as amended (42 U.S.C. 4321, et seq.), in order to avoid to the greatest extent possible the long and short term adverse impacts associated with the destruction or modification of wetlands and to avoid direct or indirect support of new construction in wetlands wherever there is a practicable alternative.

Normal silviculture activities may be exempt from permit requirements pursuant to Section 404 of the Clean Water Act (33 U.S.C. 1344), but not exempt from the general requirements of Section 1 of Executive Order 11990.

The purpose of this general Executive Order 11990 public notice is to authorize any new construction associated with normal silviculture activities on the five projects in the Wilmington District. Normal silviculture activities are defined in 33 CFR Section 323.4 and include plowing, seeding, cultivating, minor drainage, and harvesting for the production of forest products. Construction or maintenance of forest roads are also included in this section. Wherever an established (i.e., ongoing) silviculture operation is taking place on the five projects, this general Executive Order 11990 public notice authorizes those activities found in 33 CFR Section 323.4. Before any forestry roads are constructed, the BMPs found in 33 CFR Section 323.4(a)(6)(i-xv) will be followed.

This general Executive Order 11990 public notice does not obviate the need to obtain authorizations associated with: (1) rivers named in Section 3 of the Wild and Scenic Rivers Act (15 U.S.C. 1273), those proposed for inclusion as provided by Section 4 and 5 of the Act, and wild, scenic, and recreational rivers established by State and local entities; (2) historic, cultural, or archeological sites listed in or eligible for inclusion in the National Register of Historic Places as defined in the National Historic Preservation Act of 1966 and its codified regulations and in the National Historic Preservation Amendment Act of 1980; (3) sites included in or determined eligible for listing in the National Registry of Natural Landmarks; (4) endangered or threatened species or habitat of such species as determined by the Secretaries of the U.S. Department of Interior or Commerce and conserved in accordance with the Endangered Species Act (16 U.S.C. 1531); and (5) other State and Federal requirements. In addition, any new activity must conform with Section 1 of Executive Order 11990, which states: "Each agency shall provide leadership and shall take action to minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands in carrying out the agency's responsibilities."

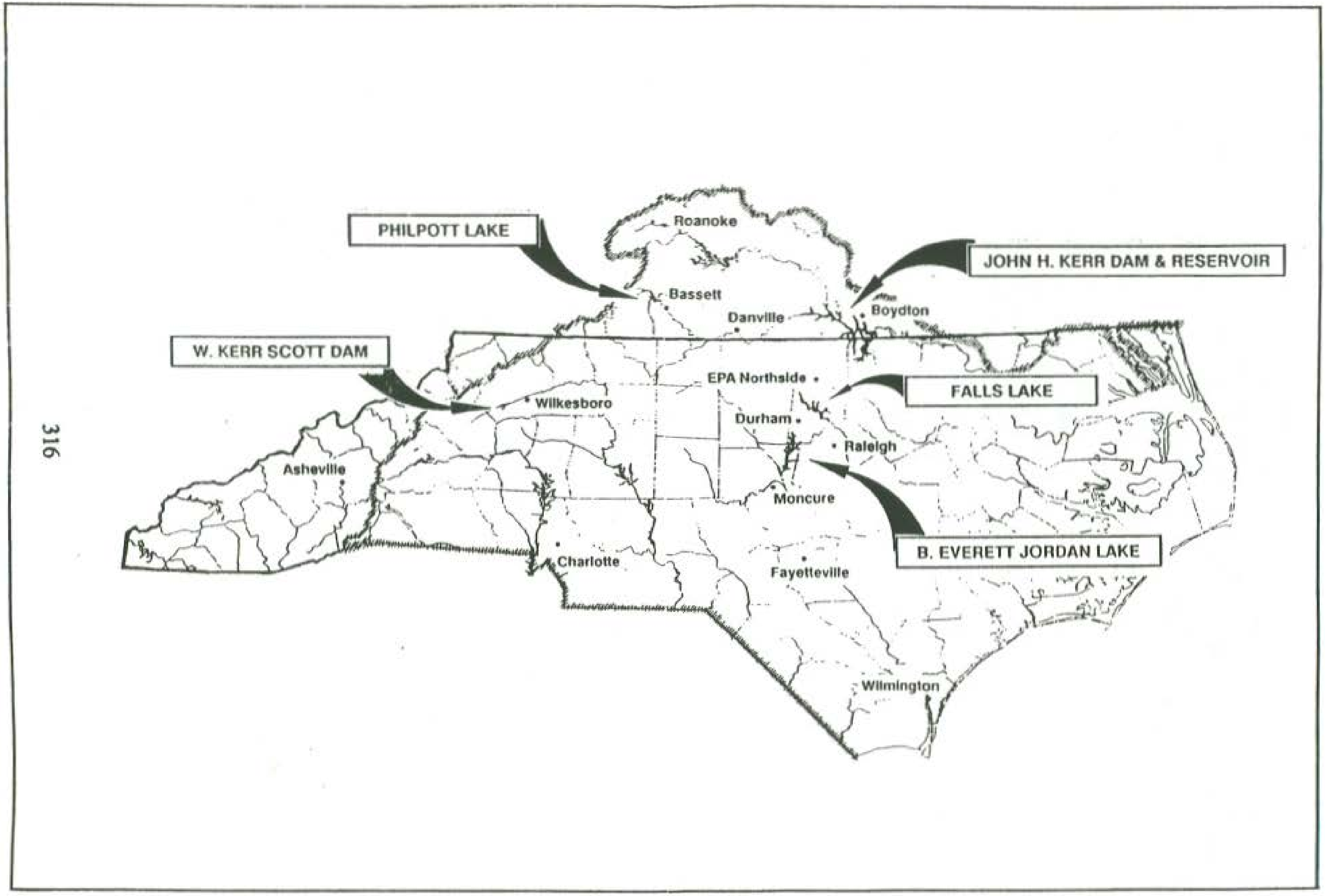
The proposed action has been evaluated and judged to be in compliance with Executive Order 11990, Protection of Wetlands, dated May 24, 1977. The proposed action includes all practicable measures to minimize harm to wetlands which may result from such use.

Anyone wishing to comment on the proposed work may do so by writing to Mr. Hugh Heine, Environmental Resources Branch, Wilmington District, Corps of Engineers, Post Office Box 1890, Wilmington, North Carolina 28402-1890 or by telephone (919) 251-4070 or FTS 232-4070. All written comments should refer to the date, number, and title of this public notice and should be received on or before July 19, 1991.

Jason C Hauck
FOR Thomas C. Suermann
Lieutenant Colonel,
Corps of Engineers
District Engineer

Attachment

Jason C. Hauck
Major, Corps of Engineers
Acting District Engineer


PHILPOTT LAKE
Roanoke
JOHN H. KERR DAM & RESERVOIR
Bassett
Danville
Boydton
W. KERR SCOTT DAM
EPA Northside
FALLS LAKE
Wilkesboro
Durham
Raleigh
Asheville
Moncure
B. EVERETT JORDAN LAKE
Charlotte
Fayetteville
Wilmington

Received 15 Oct 91 S Fed EX
FAT Received 11 Oct 91 S

City of Virginia Beach

PUBLIC UTILITIES DEPARTMENT
WATER RESOURCES DIVISION
(804) 427-8035

MUNICIPAL CENTER
VIRGINIA BEACH, VIRGINIA 23456-9002

October 11, 1991

Mr. John T. Brown, Chairman
NC Striped Bass Study Management Board
US Fish and Wildlife Service
75 Spring Street, S.W.
Atlanta, GA 30303

RECEIVED
OCT 23 19
ICMR/ECU

Dear Mr. Brown:

This letter is for your consideration with respect to the latest draft of the North Carolina Striped Bass Study report which has been circulated for comment.

At page 31, the draft Board references a regression analysis developed by the Roanoke River Flow Committee in its latest Flow Committee Report (hereinafter referred to as the 1991 FCR). The analysis is a pair of linear regressions using log-log transformed data of the number of days in the Flow Committee's negotiated regime and the JAI. The purpose of this letter is to demonstrate that with the single exception of 1981 (the driest spring in an 80 year period of record) the correlation developed in the FCR is driven by the number of days with flows above the negotiated regime.

Before I present my analysis, I will again state my objection to the NC Striped Bass Study Board incorporating or adopting any work product of the Roanoke River Flow Committee without having that work product independently verified by qualified and unbiased experts. The City and its consultants have identified major problems, to say the least, with the Flow Committee's work. Few, if any, of those problems have been factually or scientifically addressed. As I have previously indicated, the NMFS convened a panel of 3 independent scientists from NOAA and NMFS, two of which were on your Scientific Review Committee. The conclusions of that three scientist panel contradicted virtually every conclusion and premise set forth by the Roanoke River Flow Committee except for the conclusions concerning high flows. The scientific panel also concluded that the single greatest problem with the collapse of the striped bass fishery was over-fishing and that the stock would be unlikely to recover unless fishing mortality was properly managed. I have included as an attachment to this letter, a summary of the panel's major findings and conclusions with respect to flows and striped bass.

With respect to the regression analysis which was incorporated into the draft Board report before anyone had been given the opportunity to review and comment on the analysis, I have the following to offer:

This analysis has been revised and changed so many times that it is impossible to know which analysis, if any, is correct. The changes in the analysis have not been minor refinements or adjustments, they have been drastic and radical overhauls. Most of the changes appear to be quick fixes to address criticisms and/or attempts to find any mathematical manipulation, regardless of its theoretical basis or merit, which will fit the data. The analysis continues to be performed in a vacuum ignoring the fact that other variables have almost certainly accounted for much of the variability in JAI. A short list of these other variables would include water quality, overfishing, number and age distribution of fish (particularly females) participating in the spawn, temperature and other meteorological conditions, and other environmental factors. The analysis continues to combine the NCSU and NCDMF JAI indices even though the indices are not comparable. Of the six years that both indices are available, there are only two years in which the JAI was not essentially equal to zero. Those two years had statistically different results.

Previously, I have provided you evidence demonstrating that the Flow Committee's purported relationship depends upon the number of days above the negotiated regime. By plotting days within the negotiated regime without regard to whether they are wet or dry years, the Flow Committee obscures the fact that the correlation is almost entirely the result of high flows. The Flow Committee's latest regression analysis is based upon log-log transformations of both the JAI and the number of days in the negotiated regime. Therefore, I have prepared XY plots using the same log-log transformations that the Flow Committee used. As described below, the log-log analysis is even more dependant upon days above the negotiated regime than its untransformed predecessors were.

Figure 1 is a plot of the natural log of the days in the negotiated regime versus the natural log of the JAI for the period 1955 to 1977 with flood years identified. It is obvious from Figure 1 that the entire relationship is dependent upon two years (1958 and 1973). These two years were among the wettest springs on record and had a great number of days above the negotiated regime (67 and 62 days, respectively, out of 76). It is obvious from Figure 1 that if the two flood years are deleted, the relationship is virtually random.

Figure 2 is a plot of the natural log of the days within the negotiated regime versus the natural log of the JAI for the period 1978 through 1990 with flood years identified. It is obvious from Figure 2 that the correlation is driven by seven data points in the lower, left-hand quadrant of the graph. Six of those data points (1978, 1979, 1980, 1983, 1984, and 1987) are flood years in which there were 50 days or more of flows above the negotiated regime, out of 76 days. Only one of the seven years is a dry period; that was 1981 which is the single driest spring, by a very wide margin, in an eighty year period of record. Without those seven data points, no relationship exits.

Figure 3 is a plot of the natural log of the days within the negotiated flow regime versus the natural log of the JAI for the period 1955-1990 with flood years identified. Once again, the entire correlation depends upon nine data points in the lower left hand quadrant (two from 1955-1977 and seven from 1978-1990). Eight of the nine data points are flood years in which there were 50 days or more of flows above the negotiated flow regime, out of 76 days. The ninth data point is 1981.

Figure 4 is a plot of the natural log of the days within the negotiated flow regime versus the natural log of the JAI for the period 1978-1990 excluding the flood years and 1981. Also, an estimate for 1991 has been plotted. Obviously, without the flood years and 1981, it is impossible to observe a relationship between the number of days within the flow regime and the JAI. It is also worth noting that if the NCDMF index is used for all the years in which it is available, the scatter becomes even more random.

Finally, Figure 5 is a plot of the natural log of the days within the negotiated flow regime versus the natural log of the JAI for the entire period of record 1955-1990 excluding the flood years and 1981. An estimate for 1991 has also been plotted. Once again, without the contribution of the flooding and the single driest spring in an eighty year period, there is no relationship.

The only effect of the log-log transformation has been to accentuate the fact that the relationship is dominated by the number of days above the Flow Committee's negotiated regime. Since the Flow Committee's upper limit is approximately 10,000 cfs during most of the actual spawning period, the Flow Committee has done little more than to recast, in a different format, Hassler's decade-old observation that flows above 10,000 cfs during the spawning season are associated with poor JAI's. Both the FCR and the draft Board report include brief statements suggesting that high flows were more responsible for the relationship than low flows. However, as this analysis points out, those statements do not go far enough to accurately describe the situation.

I respectfully request that you review this information and discuss it with Bill Cole and Wilson Laney. To the extent that the Board report refers to the Flow Committee's regression analysis, it should properly document that with the exception of 1981, the entire analysis is dependent upon days above the Flow Committee's negotiated regime, not days below.

Sincerely,

J. M. Leahy

Thomas M. Leahy, III, P.E.
Water Resources Engineer

TML/smm

Attachments

pc: Bill Cole
Wilson Laney

FINDINGS OF INDEPENDENT SCIENTIFIC TEAM FROM NMFS/NOAA

1. "It appears that low-to-moderate flows in the Roanoke River are conducive to establishment of successful striped bass year classes, although such conditions are not sufficient to predict year-class strength. Years of high flow are associated with year-class failures. During the post-impoundment years, median flows generally have been lower than pre-impoundment flows, albeit more variable on a short time scale. Thus, if flow itself is the cause of poor survival of striped bass early life stages, it is not clear to us that post-impoundment flows have contributed to poorer survival conditions."

2. "The Roanoke-Albemarle population of striped bass is currently badly depleted. In our view, the predominant agent leading to this depletion has been fishing mortality, and the stock is unlikely to recover unless fishing mortality is reduced."

3. "It is not certain that the moderate flow levels that are associated with good JAIs during post-impoundment years were also associated with relatively good JAIs during the pre-impoundment years, because no JAI's are available for the earlier period. Median river flows since 1980 have ranged from low to high, but all JAI's since 1980 were low. The approximately equal JAI values for 1988 and 1989, although low by historical standards, were the highest in more than a decade. However, the flow regimes in 1988 and 1989 contrasted greatly and it is not possible to attribute the modest recruitment levels to flow characteristics."

Source: October 22 and 30, 1990 Memos from Dr. John Boreman of NOAA, Dr. Phillip Goodyear of NMFS, and Dr. Edward Houde of the Chesapeake Biological Laboratory to Dr. Andrew J. Kemmerer of the NMFS.

LOGDAYS VS LOGJAI 1955-1977

WITH FLOOD YEARS IDENTIFIED

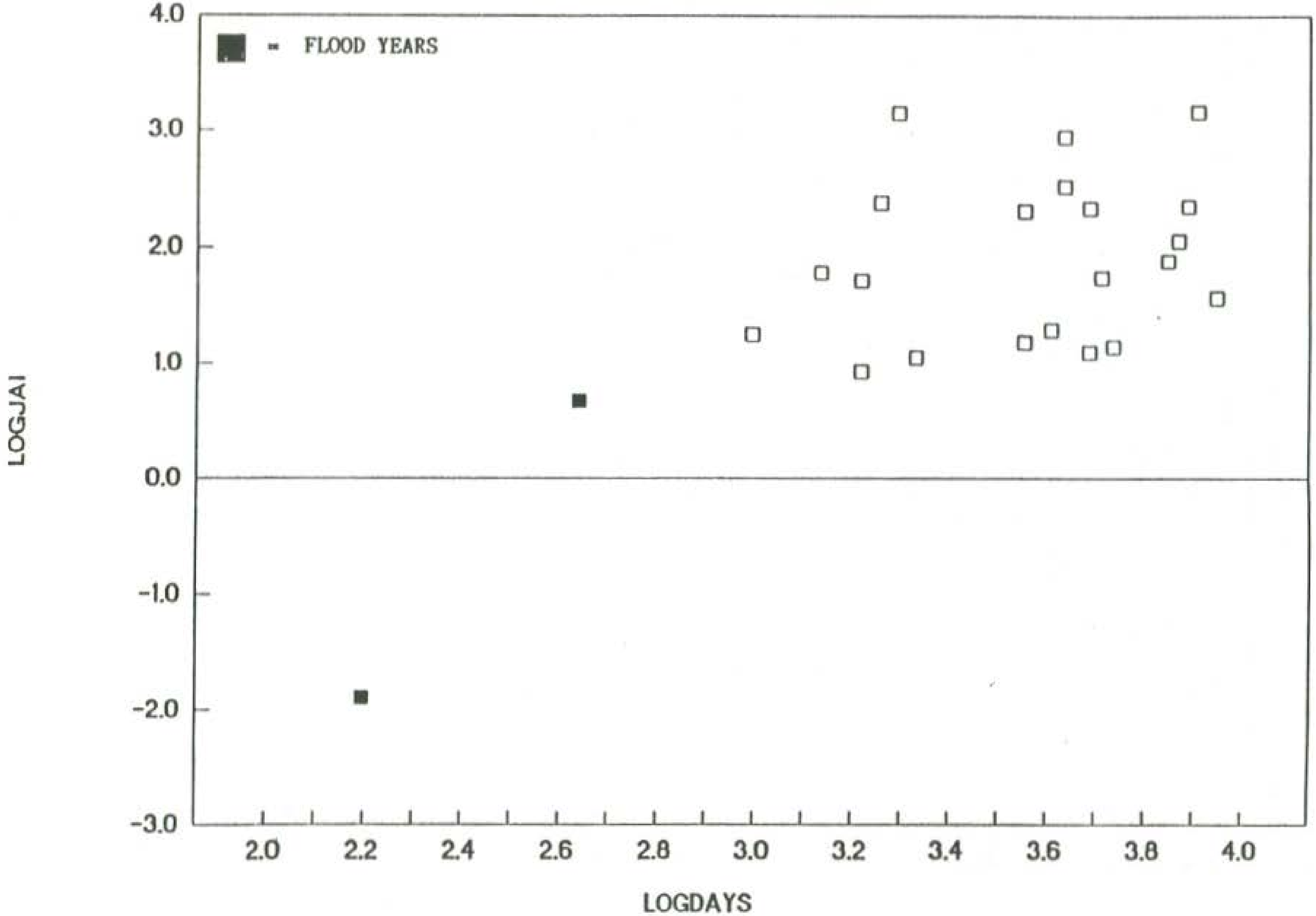


FIGURE 1

LOGDAYS VS LOGJAI 1978-1990

WITH FLOOD YEARS IDENTIFIED

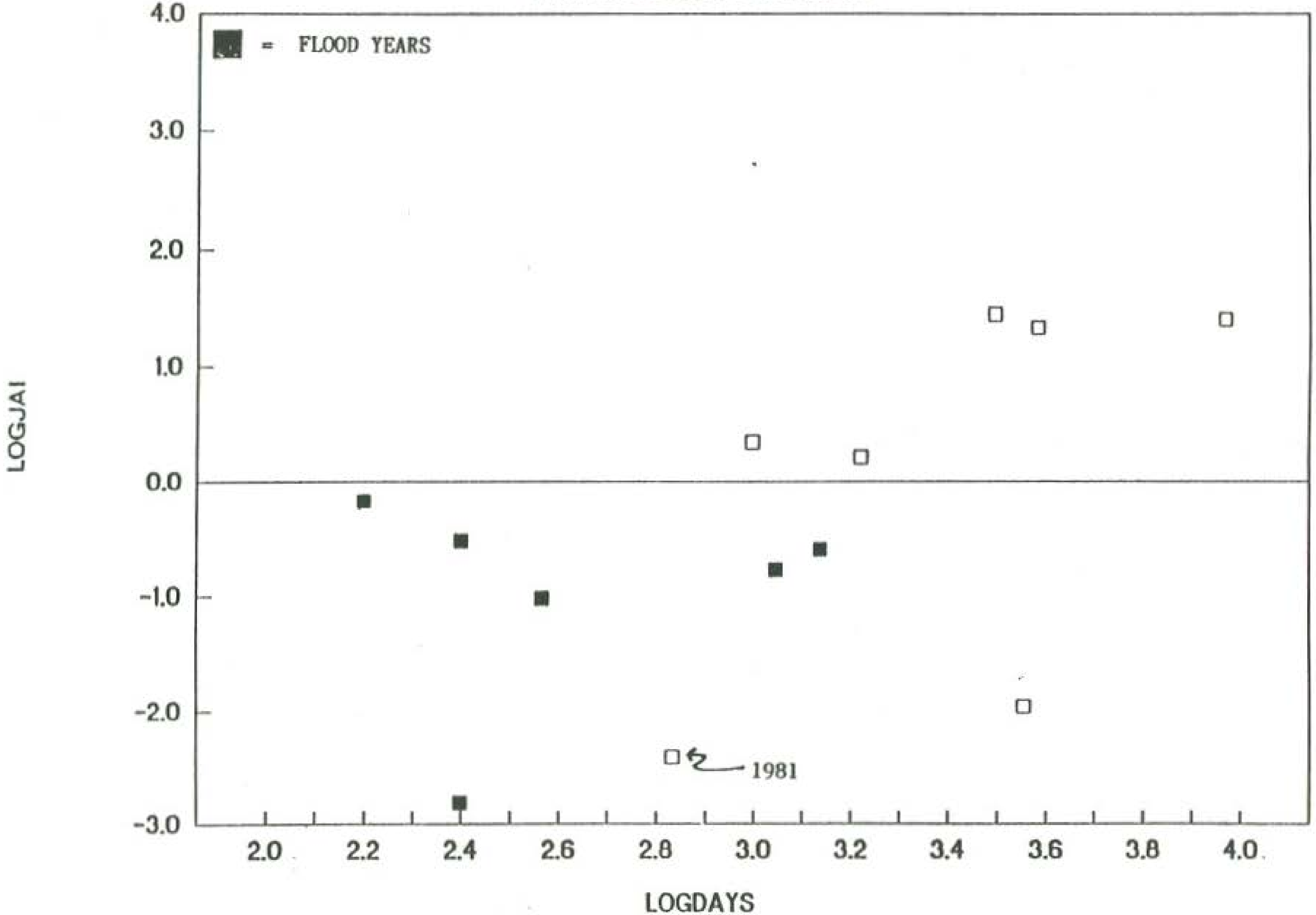


FIGURE 2

LOGDAYS VS LOGJAI 1955-1990

WITH FLOOD YEARS IDENTIFIED

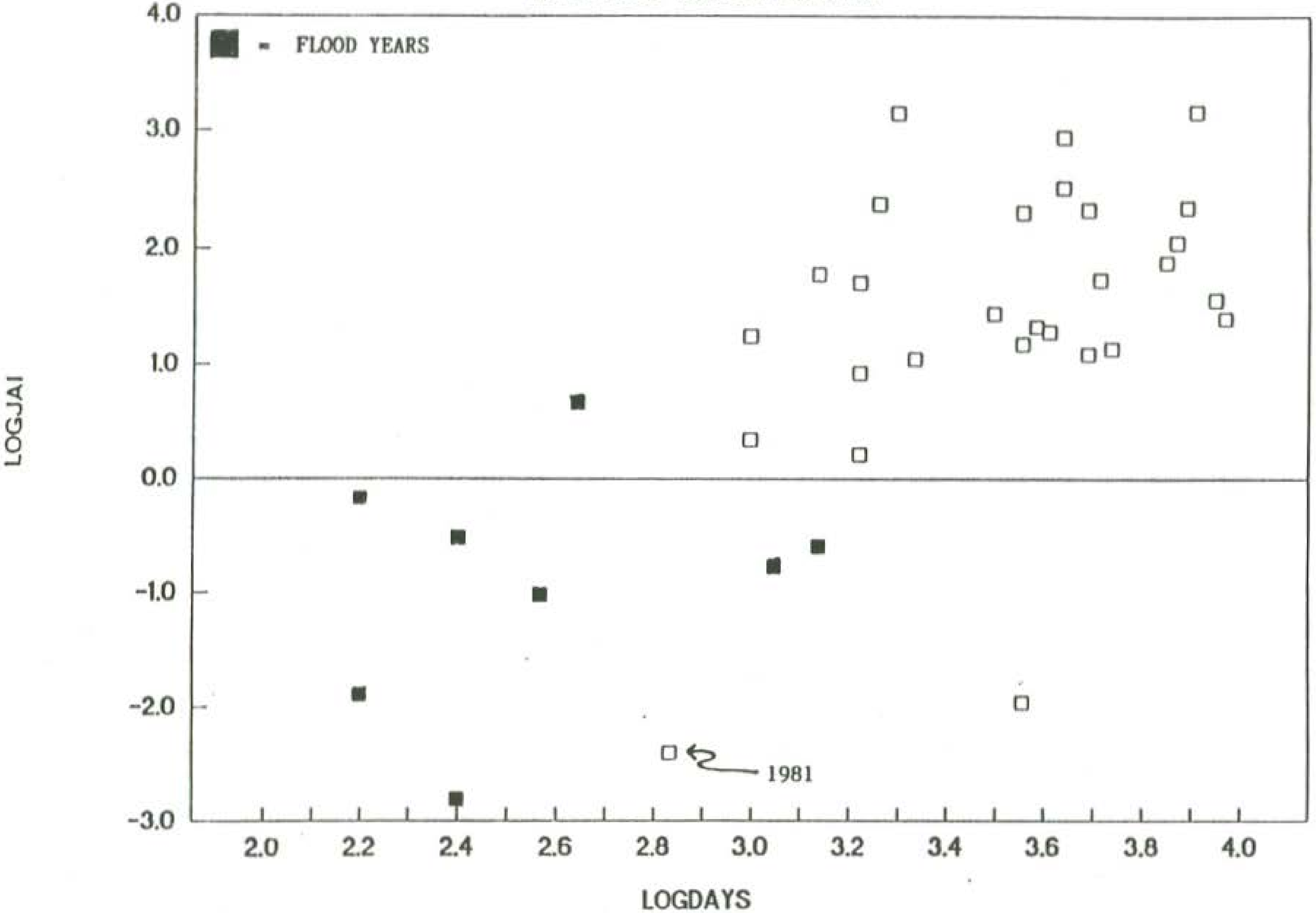


FIGURE 3

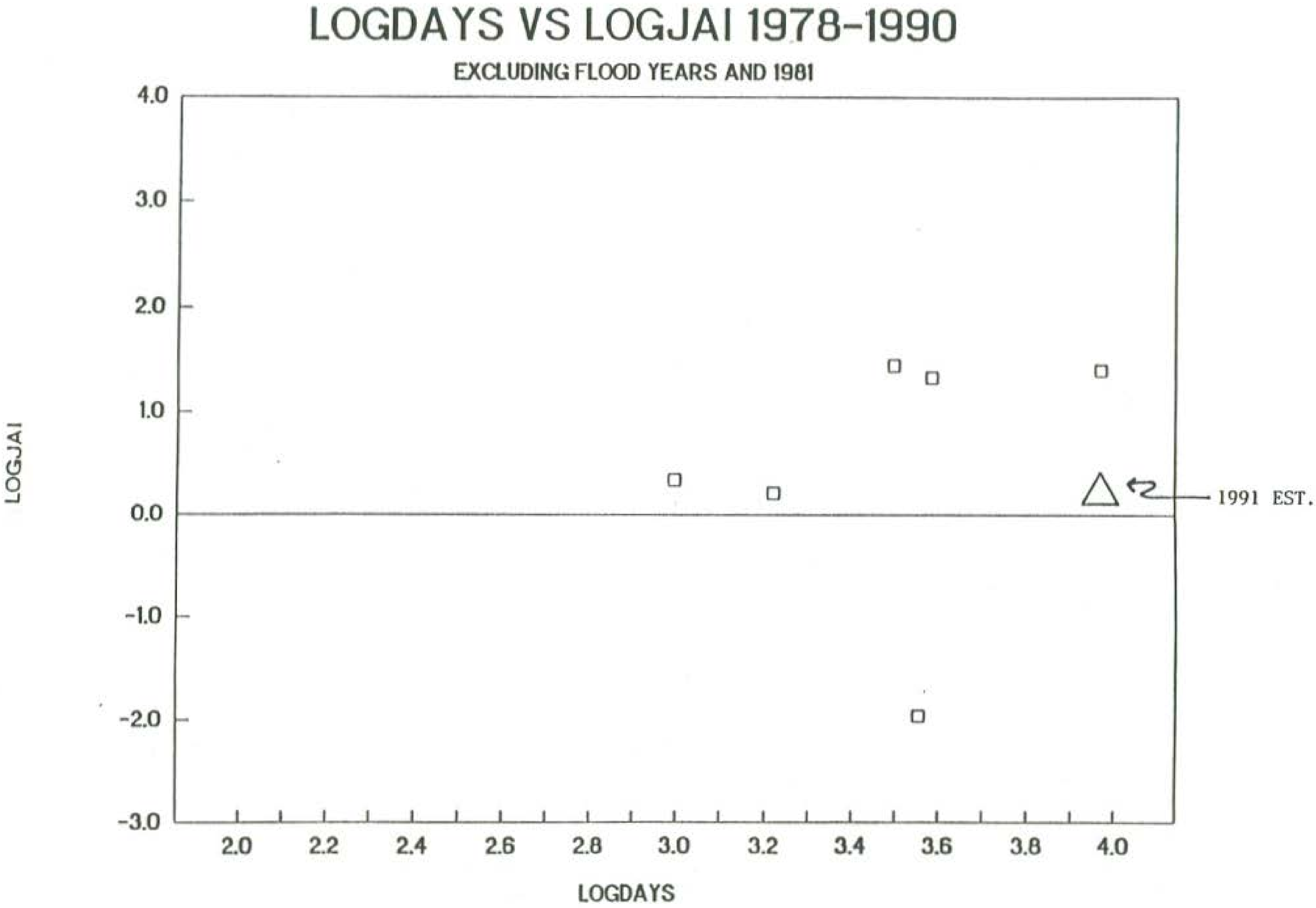

LOGDAYS VS LOGJAI 1978-1990
EXCLUDING FLOOD YEARS AND 1981
LOGJAI
LOGDAYS
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
1991 EST.

FIGURE 4

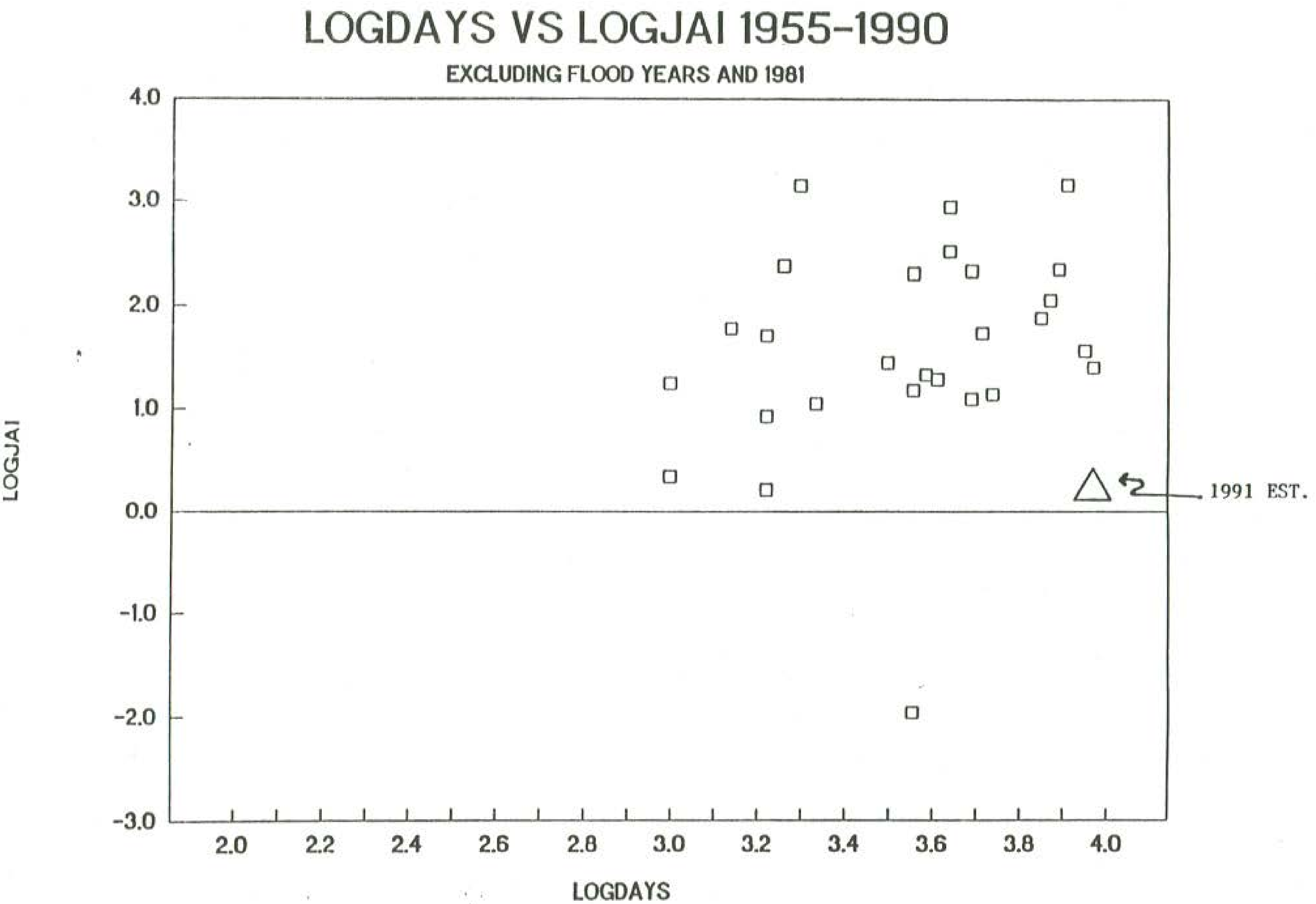
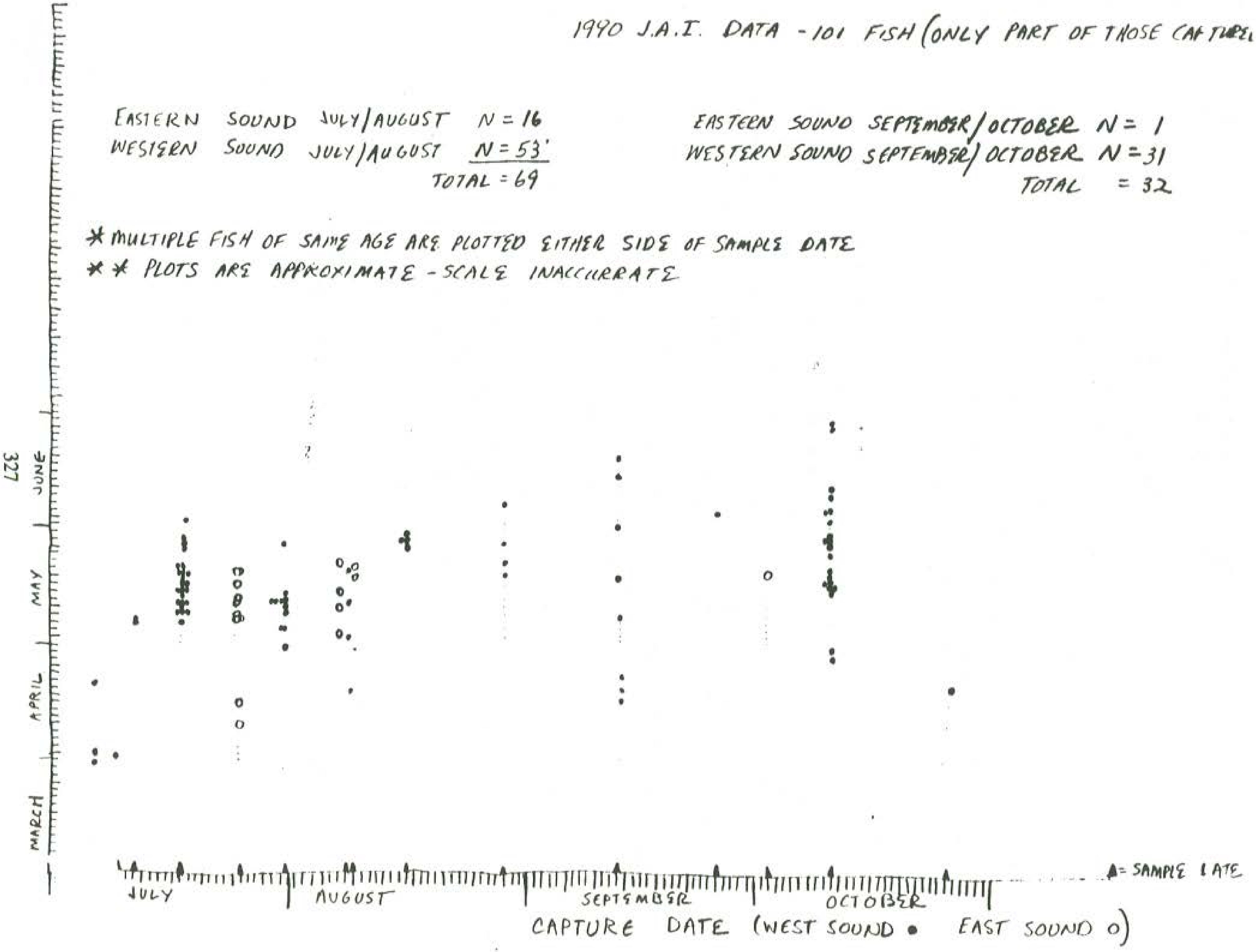

LOGDAYS VS LOGJAI 1955-1990
EXCLUDING FLOOD YEARS AND 1981
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
LOGJAI
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
LOGDAYS
1991 EST.

FIGURE 5


1990 J.A.I. DATA - 101 FISH (ONLY PART OF THOSE CAPTURE
EASTERN SOUND JULY/AUGUST N = 16
WESTERN SOUND JULY/AUGUST N = 53
TOTAL = 69
EASTERN SOUND SEPTEMBER/OCTOBER N = 1
WESTERN SOUND SEPTEMBER/OCTOBER N = 31
TOTAL = 32
* MULTIPLE FISH OF SAME AGE ARE PLOTTED EITHER SIDE OF SAMPLE DATE
** PLOTS ARE APPROXIMATE - SCALE INACCURRATE
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
▲ = SAMPLE DATE
CAPTURE DATE (WEST SOUND • EAST SOUND o)

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

RAPIFAX 10-23-91

Southeast Fisheries Science Center
Beaufort Laboratory
101 Pivers Island
Beaufort, NC 28516-9722

October 23, 1991

Dr. Roger Rulifson
Institute for Coastal & Marine Resources
East Carolina University
Greenville, NC 27858-4353

Dear Roger,

Enclosed is a copy of a letter from Thomas Leahy, City of Virginia Beach, to John Brown, Chairman of the NC Striped Bass Study Management Board, that discusses a regression analysis developed in the latest report of the Roanoke River Flow Committee. John has asked me to coordinate a reply to this letter for him. Therefore, as Chairman of the Roanoke River Flow Committee, I am submitting this letter to you with a request for a response by appropriate committee members. Because of the need to finalize the Striped Bass Report in the near future, I would like to receive a response by November 1, 1991. This will allow your response to be considered in the final revision of the report.

I apologize for the short response time, but the decision to request this review was made yesterday. Please call if you have questions.

Sincerely,

Dr. Ford A Cross
Laboratory Director

Enclosure
As Stated

cc: Mr. John Brown (Ltr only)
U.S. Fish and Wildlife Service
75 Spring Street, S.W.
Atlanta, GA 30303

RECEIVED
OCT 23 1991
ICMR/ECU

Roanoke River Water Flow Committee
Institute for Coastal and Marine Resources
East Carolina University
Greenville, NC 27858-4353

30 October 1991

Dr. Ford A. Cross
Laboratory Director
Southeast Fisheries Science Center
Beaufort Laboratory
101 Pivers Island
Beaufort, NC 28516-9722

Re: Letter from City of Va. Beach to Mr. John Brown (USWFS) dated October 11, 1991

Dear Dr. Cross:

As requested in your letter dated October 23, 1991, this letter addresses concerns raised to Mr. John Brown, Chair of the N.C. Striped Bass Study Management Board, by the City of Virginia Beach regarding linear regression analysis of Roanoke River flows and the resultant Juvenile Abundance Index (JAI) for young striped bass in western Albemarle Sound. The analysis appeared in the latest Roanoke River Water Flow Committee (RRWFC) Report for 1990 (Rulifson and Manooch, eds., 1991, p. 31).

I find the City's letter to Mr. Brown (10/11/91) significant in that the City acknowledges, for the record, the relationship between river flow and the annual JAI. Up to this point, documents produced by the City do not admit to such a relationship.

The linear regression analysis was performed by Dr. Robert J. Monroe, Professor Emeritus, Department of Statistics, North Carolina State University; and Dr. James R. Waters, Industry Economist, NOAA/NMFS, Southeast Fisheries Center, Beaufort. Each was provided a set of data with the annual JAI value and corresponding number of days in which Roanoke River discharge, monitored at the USGS gage at Roanoke Rapids, was within the Q_1-Q_3 bounds criteria established by the RRWFC. Both statisticians identified several years of outlier data, and both individuals cautioned against eliminating any data from the analysis because of the City's criticisms in the past about "arbitrarily" excluding data. Therefore, the resulting (published) linear regression has a lower r^2 value than a linear regression excluding these data. Both statisticians derived similar linear equations using similar techniques. I trust their abilities implicitly. To summarize, our analysis uses the appropriate standard statistical techniques on all available data; the r^2 value of 0.63 means that 63% of the variability in the log annual JAI can be explained by the log number of days within the negotiated flow regime. The remaining 37% is probably comprised of numerous unknown or unquantified factors, perhaps including the ones mentioned by the City (i.e., "... water quality, overfishing, number and age distribution of fish (particularly females) participating in the spawn, temperature and other meteorological conditions, and other environmental factors").

In the remainder of the letter, the City attempts to discredit our analysis by inserting and deleting data, and presenting groups of analyses to confuse the reader. Their observation that values outside the Q_1-Q_3 bounds are usually high flow rather than low flow is valid. However, the few low flow years present in the data set contribute to the overall linear regression and increase, not decrease, the resulting r^2. Whether this relationship will hold true under a number of low flow years remains to be seen; however, for the few years of data available, each has resulted in water quality problems and the inability of adult striped bass to make it to the spawning grounds. Other City criticisms of previous RRWFC reports, and proper use of the Hassler (NCSU) and NCDMF JAI data sets, were addressed in the appendix of the 1990 flow report.

Please do not hesitate to contact me if additional information is needed.

Sincerely,

Roger A. Rulifson
RRWFC Co-Chairman

cc: C.S. Manooch, III
RRWFC Co-Chairman

November 18, 1991

MEMORANDUM FOR: Roanoke River Water ~~Flow~~ Committee

FROM: RAR Roger A. Rulifson and Charles S. Manooch, III, Co-Chairmen

SUBJECT: Fall 1991 Meeting

The fall 1991 meeting of the RRWFC has been scheduled for December 5 at East Carolina University, Institute for Coastal and Marine Resources. The meeting will convene at 0930; ECU parking passes will be available upon arrival. Those Committee members unable to attend should send a representative if possible.

An agenda and first draft of the 1991 report outline are enclosed. Note that the Committee will be selecting a new Chairperson(s) at this meeting. Please give thought about who should provide future leadership for this group (i.e., come with names of nominees that are willing to undertake this task). The incumbents are offering to continue serving as Editors of the annual reports if it is the desire of the Committee and new leadership.

Enclosures as stated

Committee members for 1991:

W. Berry, S. Briggs, W. Cole, T. Ellis, T. Fransen, L.K. Gantt, M. Grimes, F. Harris, W.W. Hassler, L. Henry, H. Johnson, P. Kornegay, R.W. Laney, R. Lea, M. Lynch, C.S. Manooch, III, G. McCabe, R. Monroe, J. Mulligan, K. Nelson, T. Quay, R.A. Rulifson, S. Riggs, M. Shepherd, L.H. Zincone, Jr.

ROANOKE RIVER WATER FLOW COMMITTEE

Fall 1991 Meeting

East Carolina University, Institute for Coastal and Marine Resources
Thursday, December 5, 1991   0930 hours

AGENDA

Welcome and Announcements

Governor's Award Recognition for 1990

Changes in Membership

1990 Report and Circulation

Other Publications, Reports, Meetings

Conditions During 1991 Season

Selection of New Chairperson(s)

Future Goals and Emphasis (toward final report and recommendations)

Report for 1991 and Writing Assignments

Other Business

Adjourn

ROANOKE RIVER WATER FLOW COMMITTEE REPORT FOR 1991

Tentative outline (November 14, 1991)

Executive Summary - editors and committee

Table of Contents - editors

List of Tables - editors

List of Figures - editors

RRWFC Representatives for 1991 - editors

Introduction - editors

Watershed Description
- Geomorphology - editors
- Floodplain Ecology - natural communities - editors
- * Hydrology - 12 month, minimum flow, Kerr Reservoir operations - editors; Bales
- Water Quality - DEM, editors
- * Human Population Trends - Holman, editors
- Wildlife and Fishery Resources - editors
- * Public Lands - Holloman, Lynch, NCWRC

Chronological Record of Watershed Events - committee, editors

Recommended and Negotiated Flow Regimes - editors

Trends in Water Flow for 12-Month Period - editors

* Analysis of Reservoir Construction Years (1950-1963) - Zincone and Monroe

* Quality Habitat Conditions: Potential for Habitat Squeeze in the Roanoke River and Albemarle Sound - Coutant, Kornegay, Bales

* Recent Analyses of Contaminated Sediments from the Roanoke/Albemarle - Riggs

* Fishery Resource Trends Using Juvenile Abundance Survey Data - Henry

Hydrology, 1991
- * General Conditions - Fransen
- * Kerr Reservoir Operation - Grimes
- * Hourly and Mean Flows - Manooch and Shepherd
- * Roanoke River Time Series Analysis - Zincone
- * Kerr Reservoir Operation in Hindsight - Grimes

* Water Quality, 1991 - DEM, Herrmann, Rulifson, Bales

Tentative outline for 1991 report (continued)

Striped Bass, 1991
* Age Composition and Sport Harvest from the Roanoke River - Nelson
* Commercial and Recreational Landings from Albemarle Sound - Henry
* Update on Regulations - Henry
* Egg Abundance and Viability - Rulifson
* Juvenile Abundance Index - Henry and Taylor
* River Flow and Striped Bass JAI - Rulifson, Waters, Monroe, Manooch
* Age and Growth of Juvenile Striped Bass - Isley and Manooch
* Food Habits of Young-of-Year - Rulifson and Wood
* Larval Striped Bass Abundance, Lower River, Delta, and Western Albemarle Sound - Rulifson, Cooper, and Wood

* Phytoplankton in the Roanoke River and Western Albemarle Sound - Stanley

* Zooplankton Abundance in the Lower Roanoke River, Delta, and Western Albemarle Sound - Rulifson, Wood, and Shepherd

* Wildlife Resources - Seamster, Osborne, Luszcz

* Acknowledgments - authors, editors

* Literature Cited - authors, committee, editors

* Appendices - committee, editors

* = new information

editors = compile previous information and/or write new information

committee = information contributed from committee members

United States Department of the Interior
FISH AND WILDLIFE SERVICE

November 21, 1991

Dr. Charles M. Manooch, III
Co-Chairman
Roanoke River Water Flow Committee
National Marine Fisheries Service
Pivers Island
Beaufort, NC 28516

Dear Dr. Manooch;

Please be advised that I am appointing Dr. Wilson Laney as my designee to serve as a member of the committee representing the U.S. Fish and Wildlife Service's South Atlantic Fisheries Coordination Office. Wilson will serve in my behalf. I will continue to attend committee meetings and participate to the extent that other duties allow.

I have enjoyed participating as a member of the Committee and anticipate continued involvement as we conclude and evaluate the four-year trial for the experimental flow regime on the Roanoke River.

Sincerely yours,

W.W. Cole, Jr.
S. Atlantic Fisheries Coordinator

WL\cs

CC: Dr. Roger Rulifson, Co-Chairman, ECU Greenville, NC
Jerry Holloman, Roanoke River NWR, FWS, Windsor, NC
Mike Gantt, Fish and Wildlife Enhancement, FWS, Raleigh, NC
John Brown, ARD, Fisheries/Federal Aid, FWS, Atlanta, GA
Atten: Leslie N. Bartels

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Beaufort Laboratory
101 Pivers Island Road
Beaufort, NC 28516-9722

March 5, 1992

Mr. Charles R. Fullwood
Executive Director
N.C. Wildlife Resources Commission
512 N. Salisbury St.
Raleigh, NC 27611

Dear Charles,

As you are aware the Roanoke River Water Flow Committee has been evaluating water flows in the lower Roanoke River and the impacts of a revised springtime water flow regime on striped bass and other downstream resources. A copy of the Committee's recommended guidelines and a table of suggested flows are attached.

Last year you informed Lt. Colonel Thomas C. Suermann, US Army Corps of Engineers, Wilmington District, of the Committee's recommendations and your support of them in your letter dated March 20. The Committee has again expressed its desire that a similar letter this year would enhance the implementation of the Committee's guidelines. We respectfully request that you identify the spring flow regime by dates, lower and upper flow boundaries, expected ("target") flows, and hourly variation in flows. We also ask that the Commission stress the importance of the expected flows. Last spring the Corps worked diligently to stay within the upper flow boundary, however, flows may have been too high during the later stages (mid-May through June 9) of the spawning season to assist in the formation of a good year class of striped bass. Therefore, the Corps should be encouraged to not only attempt to provide flows within the upper and lower flow boundaries, but also meet the expected flows when possible.

I believe that there has been a change of command in the Corps' Wilmington District. Colonel W. Scott Tulloch has replaced Lt. Colonel Suermann. Also, Committee members asked that Fred Harris (N.C. Wildlife Resources Commission), Mike Gantt (U.S. Fish and Wildlife Service), John Norris (N.C. Division of Water Resources), Bill Hogarth (N.C. Division of Marine Fisheries), and George McCabe (Virginia Power Co.) be included on your list of names to receive copies.

The Committee appreciates the leadership and service provided by you and your staff as we strive together to manage the natural resources in the lower Roanoke River Basin.

Sincerely,

Charles S. Manooch, III

Enclosures
As Stated

cc: Ford A Cross
Roger A. Rulifson

COMMITTEE RECOMMENDATIONS

Recommended flows presented in Table 17 were agreed upon by members of the Recommendation Subcommittee after consultation with Mr. Max Grimes, US Army Corps of Engineers, Wilmington District and Mr. J.D. Mitchell, Virginia Power Company. Pre-impoundment USGS data for the years 1912-1950 were used to develop the recommended flows for the dates indicated.

Upper and Lower Flow Limits

At no time must flows (cfs) be greater than or less than those specified for the dates indicated. As an example, for May 1-15 the maximum, or upper flow limit is 9500 cfs, and the minimum, or lower flow limit is 4700 cfs. Flows must be within these values at all times during the indicated dates.

The Subcommittee recognizes the certainty of extremely wet (flood) and extremely dry (drought) years. Under these extreme conditions, where the US Army Corps of Engineers has very little control over watershed events, we merely expect the Corps to attempt to meet the flow regime as well as possible. However, the Subcommittee remains concerned that the flow regime does not adequately address low flow augmentation for striped bass during dry years, when the Kerr Reservoir level is below 299.5', nor any flood storage in Kerr above elevation 302' during wet, nondisastrous flood (20,000 cfs) periods. In other words, where does the priority status of the anadromous striped bass resource rank when flood control, hydropower, and above dam recreational interests are considered? Additional Committee discussion and action on this concern are needed.

It should be noted that the recommended flow regime is not consistent with the current Memorandum of Understanding between the North Carolina Wildlife Resources Commission, US Army Corps of Engineers, and Virginia Power Company. Specifically, minimum allowable flows recommended for 1 May - 15 June are lower than those in the 1971 Memorandum. However, the timeframe of 1 April - 15 June is consistent with the FERC license requirement and Memorandum of Understanding.

Variation of Flow

A maximum variation rate of 1500 cfs per hour is recommended. Flows may be increased or decreased as long as they do not fall outside the proposed upper and lower units for the dates indicated. The Subcommittee underscores the importance of moderate, sustained flows during the actual spawning period(s). Therefore, as little variation as possible in flow during this period of time is preferred.

Friendly Amendments to Negotiated, Recommended Flow Regime

1. The Ad Hoc Committee shall compile and issue a formal report of its findings and recommendations in Federal FY 1989, preferably by Spring 1989 (this document).

2. A standing committee on Roanoke River Water Flows should be formed. The committee should meet at least annually and issue a progress report. It is recommended that the standing committee compile and issue a formal report at approximately five year intervals.

   The negotiated, recommended flow regime as adopted by the Ad Hoc Committee shall be evaluated over a four-year period. During the evaluation period, the following shall be studied and shall be subject to change:

   a. Flow augmentation period (i.e. dates).
   b. Upper and lower flow limits.
   c. Hourly variation in flow.
   d. Impacts on other resources and users.

3. The Ad Hoc Committee recommends that the Memorandum of Understanding (MOU) between the U.S. Army Corps of Engineers, Virginia Power Company, and North Carolina Wildlife Resources Commission be re-examined to incorporate the recommendations of the Ad Hoc Committee. The MOU should also be re-examined at the conclusion of the trial/evaluation period discussed above. We recommend that the N.C. Division of Marine Fisheries participate in these discussions.

4. Anadromous striped bass shall receive "high" priority status, at least equal to other resources and uses/users in the Roanoke River Basin.

5. At the conclusion of the four-year trial period, if the recommended or amended flow regime has proved to be beneficial to striped bass and in consideration with other resources and users, then the Rule Curve and FERC license should be re-examined to ensure a regularly maintained, new, recommended flow regime for the Roanoke River.

Additional Comments

If meaningful flow regime changes are to be accomplished, then the Corps may have to modify the operating rules of Kerr both in the flood and in normal power operation zones. These modifications may take the form of adjustments to the Rule Curve or to operations policy on such things as rates of drawdown in early spring (to retain storage for spring flows) or in hydropower operations during critical periods of spawning runs.

Table 17. Negotiated (Q_1-Q_3) water flow regime (in cfs) for the Roanoke River below Roanoke Rapids dam for the period 1 April to 15 June each year.

Dates	Expected Average Daily Flow	Lower Limit	Upper Limit
April 1-15	8,500	6,600	13,700
April 16-30	7,800	5,800	11,000
May 1-15	6,500	4,700	9,500
May 16-31	5,900	4,400	9,500
June 1-15	5,300	4,000	9,500

North Carolina Wildlife Resources Commission

512 N. Salisbury Street, Raleigh, North Carolina 27604-1188, 919-733-3391
Charles R. Fullwood, Executive Director

March 16, 1992

Colonel W. Scott Tulloch
U. S. Army Corps of Engineers
P. O. Box 1890
Wilmington, NC 28401

Dear Colonel Tulloch:

In 1989 the 1971 Memorandum of Understanding for maintenance of spawning flows for striped bass in Roanoke River was amended to reflect the recommendations of the Roanoke River Flow Committee. We request that the amended flow regime be continued this year. Our recommended flow regime for 1992, including target flows and hourly variations, is as follows:

Dates	Flow Range	Target Flow	Max. Hourly Variation
April 1-15	6,600-13,700 cfs	8,500 cfs	1,500 cfs
April 16-30	5,800-11,000 cfs	7,800 cfs	1,500 cfs
May 1-15	4,700- 9,500 cfs	6,500 cfs	1,500 cfs
May 16-31	4,400- 9,500 cfs	5,900 cfs	1,500 cfs
June 1-15	4,000- 9,500 cfs	5,300 cfs	1,500 cfs

We strongly encourage the maintenance of flows in the river that closely approximate the target values. These flows represent our best estimates of optimum flows for striped bass spawning and subsequent survival of striped bass larvae.

We appreciate your assistance in restoring the Roanoke River/Albemarle Sound striped bass population.

Sincerely,

Charles R. Fullwood

Charles R. Fullwood
Executive Director

CRF/lr

cc: Mike Gantt, U.S. Fish and Wildlife Service
John Morris, Division of Water Resources
George McCabe, Virginia Power Company
Charles Manooch, Roanoke River Flow Committee
Roger Rulifson, Roanoke River Flow Committee
William T. Hogarth, Division of Marine Fisheries

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Beaufort Laboratory
101 Pivers Island Road
Beaufort, NC 28516-9722

April 21, 1992

Mr. Charles R. Fullwood
Executive Director
N.C. Wildlife Resources Commission
512 N. Salisbury St.
Raleigh, NC 27611

Dear Charles,

I received a copy of your March 16 letter to Colonel W. Scott Tulloch, US Army Corps of Engineers, Wilmington District, in which you requested the maintenance of springtime spawning flows for striped bass in the Roanoke River. For the first eight days in April the Corps provided flows which were within the Commission's recommended upper and lower flow boundaries. However, for the past 12 days the flows have been lower than requested. Provisional data provided by the USGS reveal average daily flows of 6,060; 651; 4,158; 4,205; 4,231; 4,210; 4,247; 4,212; 4,203; 4,208; 4,208; and 4,208 cfs, respectively, for April 9-20. You will recall that the recommended minimum flow for April 1-15 is 6,600 cfs, and for April 16-30 is 5,800 cfs.

Striped bass spawning has already occurred. Major spawning was documented on April 20, and some spawning occurred at least as early as April 17. It is imperative that proper flows be provided during the remainder of the spawning season and for the establishment and maintenance of the nursery habitat. Flows lower than what are now being experienced would be expected to be detrimental for these purposes.

Sincerely,

Charles S. Manooch, III

cc: Ford A Cross
Roger A. Rulifson

"The Forest Management Experts"

Timberlands Unlimited, Inc.

Box 650, Windsor, N.C. 27983

May 11, 1992

COL Walter S. Tullock
District Engineer
Wilmington US Army Engineer District
P. O. Box 1890
Wilmington, NC 28401-1890

COPY

Dear COL Tullock:

Again, we see our Roanoke River Basin severely flooded in late April and May, after experiencing extremely low water conditions in early April. In the last few days, I witnessed an unusual sight - seven, mature hen turkeys feeding together at the edge of a Roanoke River flooded field in Bertie County. In the way of explanation, normally these birds would have had nothing to do with each other during this time period, because each should have been incubating her eggs on a nest. These magnificent birds nest at or close to waters' edge in early to mid-April. It is very apparent to me that almost all of the turkey nests have been destroyed along the entire Roanoke River Basin this year because of flooding after nest establishment.

The damage to wildlife within the Roanoke Basin is not limited to turkeys. Many furbearing animals, ducks (except wood ducks), and numerous other species of wildlife nest or den at or near water level throughout the Basin. When March and early April water levels are extremely low as they were in 1992, all of these creatures are extremely vulnerable to flooding. When water in the Roanoke is already high during this period the risk or vulnerability decreases dramatically.

Striped Bass spawning also corresponds with this period. Even though I know very little about the massive amounts of research that has been collected and analyzed concerning the Striped Bass, I do know that stream flow and water temperature are critical to egg development. Contacts with fish biologists indicate that the recent water surge has significantly disrupted and destroyed much of the spawning process.

The mysterious part of this entire problem is that it makes no sense. I realize that water must be released from the lake when rains come, but must it be so erratic? Also, I realize that discharges cannot be based on weather predictions. I do know, however, that weather results are documented, and there must be massive seasonal data on volumes of water coming

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David L. Jennette
President Timberlands Manager

into the lake system from upstream rainfall. I know that recently I watched the TV reports on the water level of Kerr Lake rise from 300 to 306 feet prior to the Corps releasing flood waters. The following is some collected research on Roanoke River water levels at Williamston and Kerr Lake during the period in question:

Water Levels at
Roanoke River Bridge and
Kerr Lake

Date	Roanoke River Levels*	Kerr Lake Levels **
17 Apr 92	4.69	300.19
18 Apr 92	4.95	300.3
19 Apr 92	4.93	300.2
20 Apr 92	4.98	300.3
21 Apr 92	5.02	300.0
22 Apr 92	5.31	300.6
23 Apr 92	7.12	301.8
24 Apr 92	8.78	303.6
25 Apr 92	9.12	305.3
26 Apr 92	9.38	306.1
27 Apr 92	----	306.1
28 Apr 92	10.10	305.8
29 Apr 92	10.41	305.3
30 Apr 92	10.68	304.9
1 May 92	10.83	304.4
2 May 92	10.96	304.0
3 May 92	11.05	303.3
4 May 92	11.11	302.7
5 May 92	11.14	302.0
6 May 92	11.16	301.6

(* Data collected from US Geological Survey/Raleigh. To adjust for mean sea level, subtract 2.85 feet.)
(** Data collected from Corps of Engineers/Wilmington.)
(In summary, Kerr Lake experienced a rise of 6 feet in 5 days, while the Roanoke experienced a 6.5 foot rise over 20 days.)

I am not a protectionist/environmentalist, but I am a conservationist who believes the wise use and protection of our resources. It does not seem rational or logical that the Corps entirely supports that the only priority in Roanoke river water management is the recreational lake levels. I believe that the following quote is very applicable in this particular abuse of our heritage in the Roanoke River Basin:

> "Like winds and sunsets, wild things are taken for granted until PROGRESS begins to do away with them. Now we face the question of whether a still higher 'standard of living' is worth its cost in things natural, wild and free."
>
> (Author Unknown)

Understand that I am not being critical of the lake/dam system or the professionalism of the Corps, but I am experiencing rage at the system and the Corp's total lack of concern for important things in their idiotic policy for water management on the Roanoke.

I have been a part of the Army Corps of Engineers for a number of years on the combat side. I retired in July of 1990 as the Commanding General of the 30th Engineering Brigade (TA). My association with the Corps has always been very close with Ft. Leonardwood and Vicksburg. Concurrent with my military career, I have remained a professional management forester dedicated to conservation ideals. Currently, I serve as a commissioner on the NC Coastal Resources Commission.

COL Tullock, the intent of this letter is to make you aware of great discontent in the Corps' policy and practice of water management in the Roanoke River Basin. The recent establishment of the Roanoke River National Wildlife Refuge will fuel additional furor for your policies. The Roanoke River Basin is a pristine area that deserves everything that our heritage demands -- respect, concern and consideration. I simply do not understand why recreational lake levels during this critical spring period take total priority over the well-being and livelihood of all the creatures in almost 150,000 acres of the Roanoke River Basin. Please consider the remarks and concerns expressed here as a suggestion to begin the necessary research and communications to change. I will be available to discuss these matters with you at your convenience.

Respectfully submitted:

TIMBERLANDS UNLIMITED, INC.

David L. Jennette
Timberlands Manager

cc: Senator Jesse Helms
Senator Terry Sanford
Governor James Martin
NC Wildlife Resources Commission
NC Coastal Resources Commission
NC Dept. of Marine Fisheries
US Fish and Wildlife Service
Bertie County Manager
Martin County Manager
NC Wildlife Federation
The Nature Conservancy

EAST
CAROLINA
UNIVERSITY

Institute for Coastal and Marine Resources
Mamie Jenkins Building

919-757-6779

June 9, 1992

Mr. Max Grimes
U.S. Army Corps of Engineers
Wilmington District
P.O. Box 1890
Wilmington, NC 28402-1890

Dear Max:

Thank you for the telephone call of 6/9/92 informing me that you must increase the Roanoke River flows to 15,000 cfs because of the two weather fronts in our region. As we discussed, large numbers of striped bass are still in the Weldon area and downstream past Halifax and Barnhill's Landing. Spawning continues daily with no sign of stopping. These increased flows downstream may keep river waters cooler and perhaps prolong the spawning period even more.

As you noted in our conversation last Friday, the spawning season got off to a rough start with not enough water in the watershed to maintain the Negotiated Flow Regime target flows set up by the Roanoke River Water Flow Committee. WRC personnel informed me that they had to agree, on two separate occasions (week of April 6 and week of April 12) to reduced flows in order to maintain adequate flows later in the spawning season. Perhaps a Rule Curve more flexible than is now possible would help in situations like that which occurred this spring.

Thanks again for the notification and for checking into the watershed precipitation data for me.

Sincerely,

Roger A. Rulifson

RogerA. Rulifson
Associate Scientist - ICMR
Associate Professor - Biology

cc: Kent Nelson, WRC

Greenville,
North Carolina
27858-4353

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STATE OF NORTH CAROLINA
OFFICE OF THE GOVERNOR
RALEIGH 27603-8001

JAMES G. MARTIN
GOVERNOR

December 17, 1992

Dr. Charles S. Manooch, III
National Marine Fisheries Service
101 Pivers Island Road
Beaufort, North Carolina 28516-9277

Dear Chuck:

On behalf of the citizens of North Carolina, I wish to thank you for the time you have dedicated to matters pertaining to the conservation and wise use of natural resources in the state during my Administration. I appreciate your serving on my Blue Ribbon Panel for Environmental Indicators, and particularly for sharing your knowledge of the resources. Your efforts in this area have been instrumental in assuring that the management strategies for striped bass, as developed by State and Federal conservation agencies, are working.

Your work, and the work of those serving on the Roanoke River Water Flow Committee, have made it clear that the habitat for striped bass, in terms of water quality and water quantity, must be protected if regulations on fishing are to be effective.

Unfortunately, there are times when management decisions are based on avoiding controversy or resistance. In the past, fishermen have been blamed for a problem for which they are only partially responsible. Those who share a stewardship role for the environment or habitat in which the striped bass resides must also be held accountable for the stock decline, and must become actively involved in its restoration.

Through your endeavors, and those of your colleagues, this process has begun. I hope that you will continue to use your knowledge, experience, concern, and expertise to serve the resources and citizens of our State.

Sincerely,

Jim Martin

James G. Martin

JGM:ngb .

DEPARTMENT OF THE ARMY
WILMINGTON DISTRICT, CORPS OF ENGINEERS
P.O. BOX 1890
WILMINGTON, NORTH CAROLINA 28402-1890

IN REPLY REFER TO

March 12, 1993

Planning Division

Dear Sir or Madam:

This letter is to provide notification of a proposed 1-year extension of the 4-year trial period of augmentation flows for fish from John H. Kerr Reservoir, as described in the Environmental Assessment and Finding of No Significant Impact for Modification to the Operation of John H. Kerr Dam and Reservoir, Virginia and North Carolina, by Amending the 1971 Memorandum of Understanding (MOU) for Reregulation of Augmentation Flows for Fish from John H. Kerr Dam and Reservoir Project, dated March 1989. The proposed 4-year trial period ended after the 1992 striped bass spawning season.

This extension will be made in response to a request from the North Carolina Wildlife Resources Commission (NCWRC) by letter dated November 24, 1992. The NCWRC plans to evaluate the results of the amended flow regime this year. The proposed 1-year extension of the trial flow regime would not affect the findings described in the aforementioned Environmental Assessment and Finding of No Significant Impact, and no further documentation in accordance with the National Environmental Policy Act of 1969, as amended, is proposed prior to its implementation.

If you have any questions concerning this matter, please contact Mr. Charles Wilson, Environmental Resources Branch, at (919) 251-4746.

Sincerely,

Walter S. Tulloch
Colonel, Corps of Engineers
District Engineer

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Beaufort Laboratory
101 Pivers Island Road
Beaufort, NC 28516-9722

March 25, 1993

Dr. Roger A. Rulifson
East Carolina University
Institute for Coastal and Marine Resources
Greenville, NC 27858-4353

Dear Roger,

The spring of 1993 is off to a very wet start in the Roanoke River watershed. As you know I have been receiving provisional hourly flow data for the lower Roanoke River for station number 02080500 located at Roanoke Rapids, North Carolina. Enclosed please find a graph, which reveals daily mean flows for the period March 1 - March 24, 1993. I have also received hourly data through 0700 hours today and all values exceed 25,000 cfs. The Kerr Reservoir lake level is approximately 312 feet above mean sea level, and rains and melting ice and snow in the extreme western portion of the watershed indicate that water flows into the Reservoir will be very high for the near future. It is doubtful that the U.S. Army Corps of Engineers (Corps) will be able to evacuate Reservoir water rapidly enough to restore the lake level to 302 feet above mean sea level and maintain the desired Roanoke River flows by the start of the experimental flow period, which begins on April 1.

This spring to date reminds me of the springs of 1975 and 1978. For both of those springs, mean daily flows were relatively high. However, during 1975, the highest flows occurred in March and April and then subsided during May and for most of June. The juvenile abundance index for striped bass that year was 10.80. During the spring of 1978, flows were high in March, subsided somewhat during April, were very high during May (exceeding 33,000 cfs for 23 consecutive days), and remained relatively high during June. The juvenile abundance index for striped that year was only 0.59. It would be interesting to see how 1993 compares.

The 1993 striped bass spawning season is one that merits study. The moderately successful 1988 and 1989 striped bass year classes are now 4-5 years old, and if adequate numbers have survived, should provide the opportunity for a good spawning season. Unfortunately, I understand that the striped bass egg study (i.e. spawning study), which you have conducted for the past five years, will not be funded this year. If this is true, scientists will not be able to document spawning conditions, egg production, or egg viability. Also, even though they may be able to back-calculate the spawning date for surviving juveniles, they will be unable to adjust data to account for the impacts of egg production and egg viability. I feel that due to a lack of funding, scientists and managers will be restricted when they attempt to describe the 1993 striped bass spawning season. This is especially sad since the Corps has kindly agreed to extend the experimental flow regime to include 1993 at the request of the North Carolina Wildlife Resources Commission (attachment).

Sincerely,

Charles S. Manooch, III

cc: Charles Fullwood, NCWRC
Bill Hogarth, NCDMF
Joe Hightower, NCSU Coop. Unit

Author's Note

The previous paper on analyzing time signatures is reprinted with permission from the *Proceedings of the Southeast Chapter of Decision Sciences Institute* which held its annual meeting in February, 1993. It is written as a tutorial on the Diggle method for my collegues at the meeting. Nevertheless, the results shown in Table 2 bear on the controversy surrounding Zincone and Rulifson. There has been some criticism concerning the modeling of the data averaged over the dates in the different periods. While our reply to that critique has been published and will not be repeated here, one should note that the results shown in Table 2 show that the good and bad recruitment years have statistically different time signatures. In this section, what is averaged are the **periodograms** not the data and therefore, this analysis is not subject to the criticism leveled at the original article.

ANALYZING TIME SIGNATURES: AN EXAMPLE AND CASE STUDY

L. H. Zincone, Jr., East Carolina University, Decision Sciences Dept., Greenville, NC 27858-4353, 919-757-6970

ABSTRACT

This paper presents a method for statisitcally analyzing cyclical differences in multiple time series data sets. It is applied to a simulated example and a real world problem.

INTRODUCTION

The inclusion of the time dimension in statistical analysis introduces a number of considerations not present when dealing with data which are not time-ordered. Cross section data is typically compared by using typical measures of central tendency and dispersion as well as correlation if the data are ordered pairs. Time series data can, of course, be compared along the same dimensions, but it also has another dimension. This dimension is its cyclical nature, how it moves through time, or its "time signature". This time signature can vary from white noise to complicated overlapping cycles. Moreover, time signatures resulting from different causes can be different. For example, it is likely that the seismograph resulting from stampeding elephants would be different from that generated by an earthquake. The method explained in this paper summarizes and applies a method to differentiate those time signatures.

Figure 1 shows two examples of data with different time signatures. The solid line represents simulated short term autocorrelated data while the line with the boxes represents simulated data with 12 period seasonality. While the difference in these two data sets is obvious from the plot (and will be obvious from the graph of the periodogram of the spectrum), that is not always true. This paper outlines a method described by Diggle to determine whether there are significant differences in the spectra of data series and apply it to a real problem.

In 1807, Joseph Fourier showed that any time series can be transformed into the sum of sine and cosine terms of different frequencies. Thus, in order to assess the time signature of a data set, one could fit a series of regressions with sines and cosines of various frequencies as independent variables and examine the model sums of squares to determine the "periodicity" of a data series. An easier way to do the same thing is to examine the spectrum of the data at various frequencies by calculating a "periodogram" at the Fourier frequencies. The ordinate of the periodogram at a particular frequency or period is the explained sum of squares for a regression of the dependent variable on a sine and cosine term at that particular frequency. [1] The periodogram ordinate is a function of the spectral density at that frequency. [4] Thus, the graph of the periodogram yields a "picture" of the time signature of the data set.

Often, it is necessary or desirable to compare the time signatures of different data sets. The brief description of spectral analysis given above suggests that comparison of the spectra of the two stationary series is an appropriate way to do so. However, spectra calculated from sample data is, of course, affected by sampling error. The periodogram is an estimate of the true spectrum and in order to make meaningful statements, comparative or otherwise, about the spectrum, one must know its sampling distribution.

Diggle [2] has shown that the periodogram ordinates are approximately χ^2 distributed and suggests the following method for testing hypotheses concerning the spectra of two replicated series. Suppose a company has two groups of products, group A and group B and it is interested in whether the time signatures of the sales are the same. Regard the sales data for each product in a particular class as a replication. One would then do the following:

1. Calculate the periodogram for each product in each group
2. Average the periodogram ordinates at each frequency within each group
3. Form the ratio of the larger to the smaller average periodogram at each frequency
4. Compare the ratio to the value of the F statistic for $2r_i$ degrees of freedom in the numerator and denominator where $i=1,2$ is the number of groups and r_i is the number of replications in each group i.

At each frequency where the F statistic exceeds the critical F at the particular level of significance chosen for the hypothesis test, the spectra would be significantly different. Clearly, if two spectra were not significantly different at any frequency, they would be statistically identical and the time signatures would be the same. Otherwise, they are not.

The purpose of this paper is to demonstrate the technique outlined above on simulated data and on a meaningful data. I do this since the real example represents a situation I have been struggling to analyze for some time. I offer the paper in the hope that technique will be helpful to others who seek to distinguish between the time signatures of two or more groups of data.

ANALYSIS OF SIMULATED DATA

In order to illustrate the concepts outlined above, ten replications of an autocorrelated series and ten replications of a seasonal series were generated. Both series were stationary in the mean (i.e., there was no trend in the data). Obviously, there was, however, a systematic difference in the seasonal means. It was assumed that the data represented monthly product sales. Thus, the seasonal period for the seasonal data is 12.

Equations for the simulated data are:

$$(1\text{-}0.9B)x_t = a_t \qquad (1)$$

for the autocorrelated series and

$$(1\text{-}0.9B^{12})x_t = a_t \qquad (2)$$

for the seasonal series. In these equations, x represents the data, B is the backshift operator, i.e., $Bx = x_{t-1}$, and a_t is a white noise term.

Figure 2 shows a comparison of the partial periodograms for the two series. The solid line represents the simulated autocorrelated series and the dotted line the seasonal series. Table 1 shows periods of the sine/cosine functions in the first column, the ordinate for the autocorrelated series in the second column, the ordinate for the seasonal series in the third column and, finally, the computed F statistic in the fourth column.

TABLE 1: PARTIAL AVERAGE PERIODOGRAMS OF SIMULATED SERIES

Period	AC Series	Seas.Series	F
128	15.424	0.41602	37.075
64	11.6707	0.08924	130.774
42.667	9.4837	0.0664	142.822
32	2.4235	0.1803	13.442
25.6	4.6193	0.10058	45.929
21.333	2.3524	0.15624	15.056
18.286	1.7199	0.14854	11.579
16	0.593	0.24784	2.393
14.222	1.2285	0.72003	1.706
12.8	0.5725	2.09854	3.666
11.636	1.1017	7.93592	7.203
10.667	1.0631	0.57454	1.85
9.846	0.5023	0.35777	1.404
9.143	0.6772	0.1773	3.819
8.533	0.3052	0.08639	3.533
8	0.5972	0.12629	4.729
7.529	0.3637	0.09665	3.763
7.111	0.2756	0.07324	3.763
6.737	0.466	0.25532	1.825

For 20 and 20 degrees of freedom, the significant 5 percent F is 2.12.

Figure 2 shows the differences in the spectra of the two series quite clearly.

Specifically, as is typical of series that have short-term autocorrelations, the ordinates for the longer periods (sine/cosine waves with the smallest frequencies) explain most of the cyclical movement in the autocorrelated series. Indeed, the sine/cosine waves for the first three periods would explain approximately 60 percent of the total variation in the series while all of the frequencies listed in the table would explain approximately 90 percent of the autocorrelated series. On the other hand, the greatest amount of variation is explained by a sine/cosine wave sum with a period of 11.64 months for the seasonal series. This period represents the closest Fourier frequency to the actual 12 month cycle simulated in the data. The periods of other sine/cosine waves which would explain relatively large portions of the variance in the seasonal series are harmonics (approximately exact factors of) 12 or frequencies close to these harmonics. They are:

Period	Percent Explained
12.8 and 11.63	0.15
6.09 and 5.8	0.15
4, 3, and 2.4	0.33
Total	0.63

Thus, approximately 60 percent of the variance represented by the periodogram would be explained by sine/cosine models representing the seasonal period and its harmonics.

Examination of Table 1 shows that the ordinates are significantly different at almost every period. In fact, the only periods at which the ordinates are not different are 14.22, 10.66, 9.84, and 6.73. Of course, this is a contrived example and one would expect large differences, especially after examining Figure 2.

ANALYSIS OF WATER FLOW

The analysis in this section focuses on a problem relating the time signature of water flow in the Roanoke River NC to the success (or lack thereof) of the spawning season for striped bass or rockfish. The main question which has been addressed in several papers, reports, and journal articles relate to whether there is a systematic difference in the water flow immediately below the downstream dam in an impoundment during successful and unsuccessful spawning years. [6, 7, 9, 8] A brief history of the Roanoke River impoundments indicates that the river flowed freely up until 1951 when construction on the first dam was begun. During the period 1951 to 1964, six dams were built. The last one was closed during 1964 and the flow has been regulated by these dams ever since. Previous research has indicated that seven years between 1965 and 1986 (1965, 1967, 1968, 1970, and 1974-76) could be considered years in which the rockfish spawn was successful (or as the biologists would say, were good recruitment years). The years 1966, 1969,1971-73, and 1977-86 were determined to be bad recruitment years. The issue in question is whether the time signatures were different during the two types of years.

Figure 3 shows the average periodograms for the good and bad recruitment years. That for the good years is the solid line; that for the bad years is the line with the little boxes. Cursory examination of the figure will not yield an obvious difference. Both periodograms are dominated by the seven day period and its harmonic the 3.5 day period. In some places the spectra are almost identical. In others, it is not. Clearly, "eyeballing" the periodogram will not be sufficient to conclude there are differences in them.

TABLE 2: PARTIAL AVERAGE PERIODOGRAM FOR WATER FLOW DATA, GOOD AND BAD RECRUITMENT YEARS

Period	GoodAv	BadAv	F	Crit. F
6.095	32565163	9225074	3.53	2.01
8.533	2635670	8499169	3.22	2.25
5.818	33271100	10444372	3.19	2.01
4.571	6355734	17437824	2.74	2.25
14.222	7228749	2948052	2.45	2.01
3.048	31094313	12899722	2.41	2.01
5.12	45846177	19461243	2.36	2.01
10.667	13932399	6024798	2.31	2.01
2.909	31726405	14864208	2.13	2.01
6.4	14226078	29970149	2.11	2.25
32	2692385	5585088	2.07	2.25

Table 2 shows the partial average periodogram for the good and bad recruitment years sorted by F value. All of the periods in which the ordinates were significantly different are shown in the table. Again, it can be seen from the contents of the table that there are several frequencies at which the spectra were statistically different. Thus, one can conclude that the time signatures of the flows in the good and bad recruitment years were different but similar. Both were dominated by the seven and 3.5 day frequencies and interestingly, the ordinates at these key frequencies were not significantly different. However, they were different in several periods close to 7 (6.09, 8.53) and the harmonic of seven, 14.22.

SUMMARY AND CONCLUSION

This paper outlined a method of distinguishing statistically between two spectra, applied it to simulated data and applied it to real data. Spectral analysis is something which is more popular among hard scientists and engineers than among those of us who analyze business data. Many use it as part of their portfolio of preliminary analysis techniques. However, use of the method outlined in this paper gives the analyst a tool which can be used to compare the time signature of two different replicated data sets. Such analysis could be undertaken to determine if the data's path through time had changed as a result of the passage of years or the occurrence of something external to the system, such as changing strategies for releasing water or different water release conditions. In a business context, one could examine the effect of advertising campaigns, locations, or a variety of other conditions to determine the similarity or dissimilarity of the time signature of data sets.

BIBLIOGRAPHY

[1] Brocklebank, J.C and David A Dickey. 1986. *The SAS System for Forecasting Time Series*, Cary, NC SAS Institute.

[2] Diggle, Peter, 1990. *Time Series, A Biostatistical Introduction*, Oxford Science Publications, Clarendon Press, Oxford.

[3] Kendall, Sir Maurice and J. Keith Ord, 1990. *Time Series* third edition. London, Edward Arnold.

[4] Makridakis, Spyros and Steven C. Wheelwright. 1975. *Interactive Forecasting Volume II Appendices*, Hewlett Packard Co., Santa Clara, California.

[5] Manooch, Charles III and R. A. Rulifson (eds.). 1989. *Roanoke River Water Flow Committee Report: A Recommended Water flow Regime for the Roanoke River, North Carolina, to Benefit Anadromous Striped Bass and Other Below-Dam Resources and Users*. NOAA Technical Memorandum NMFS-SEFC-216.

[6] Rulifson, R.A. and Charles Manooch III 1990a. Recruitment of Juvenile Striped Bass in the Roanoke River, North Carolina, as Related to Reservoir Discharge, *North American Journal of Fisheries Management* 10: 397-407

[7] Rulifson, R. A. and Charles Manooch III (eds.) 1990b. *Roanoke River Water Flow Committee Report for 1988 and 1989*. NOAA Technical Memorandum NMF-SEFC-256.

[8] Zincone, L.H.. 1990. Fish, Fecundity, and Forecasting: How Time Series (May Have) Helped my Rockfishing. *Proceedings of the Southeast Region of the Decision Sciences Institute*, pp. 86-88.

[9] Zincone, L.H. and Roger A. Rulifson. 1991. Instream Flow and Striped Bass Recruitment in the Lower Roanoke River, North Carolina *Rivers* 2:126-137.

Figures available upon request.

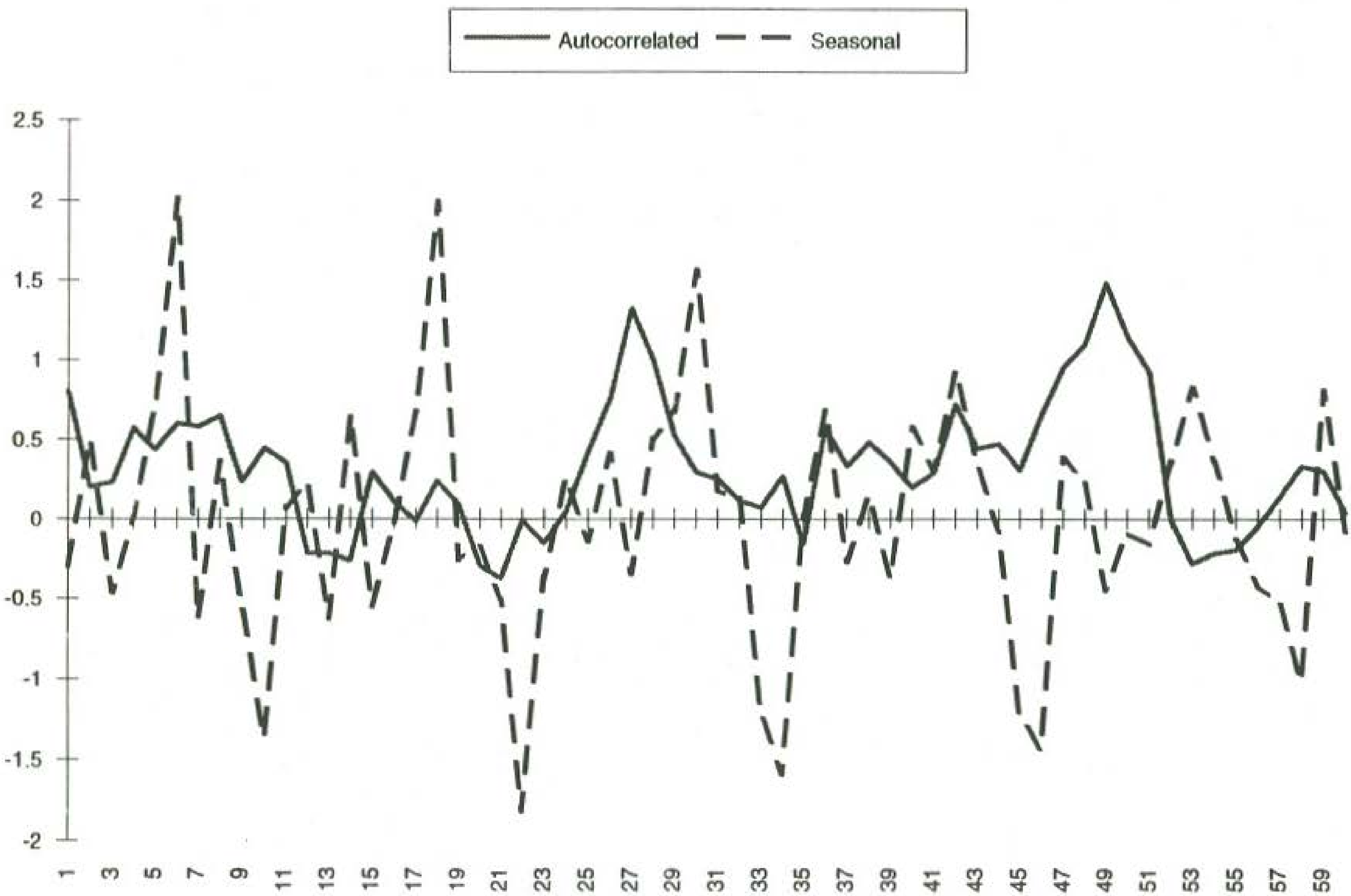

Figure 1. Plot of simulated data.

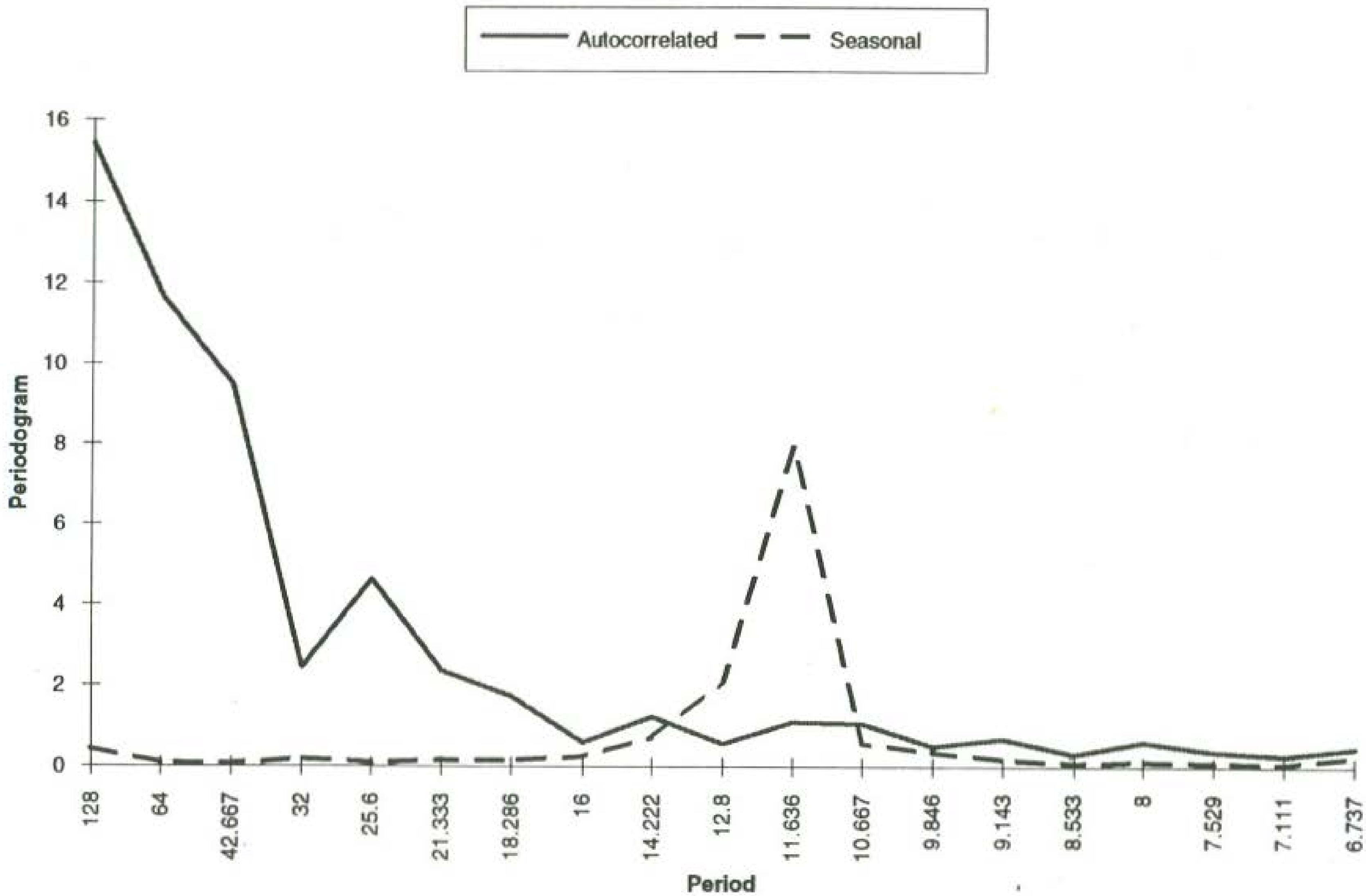

Figure 2. Periodgram of simulated data.

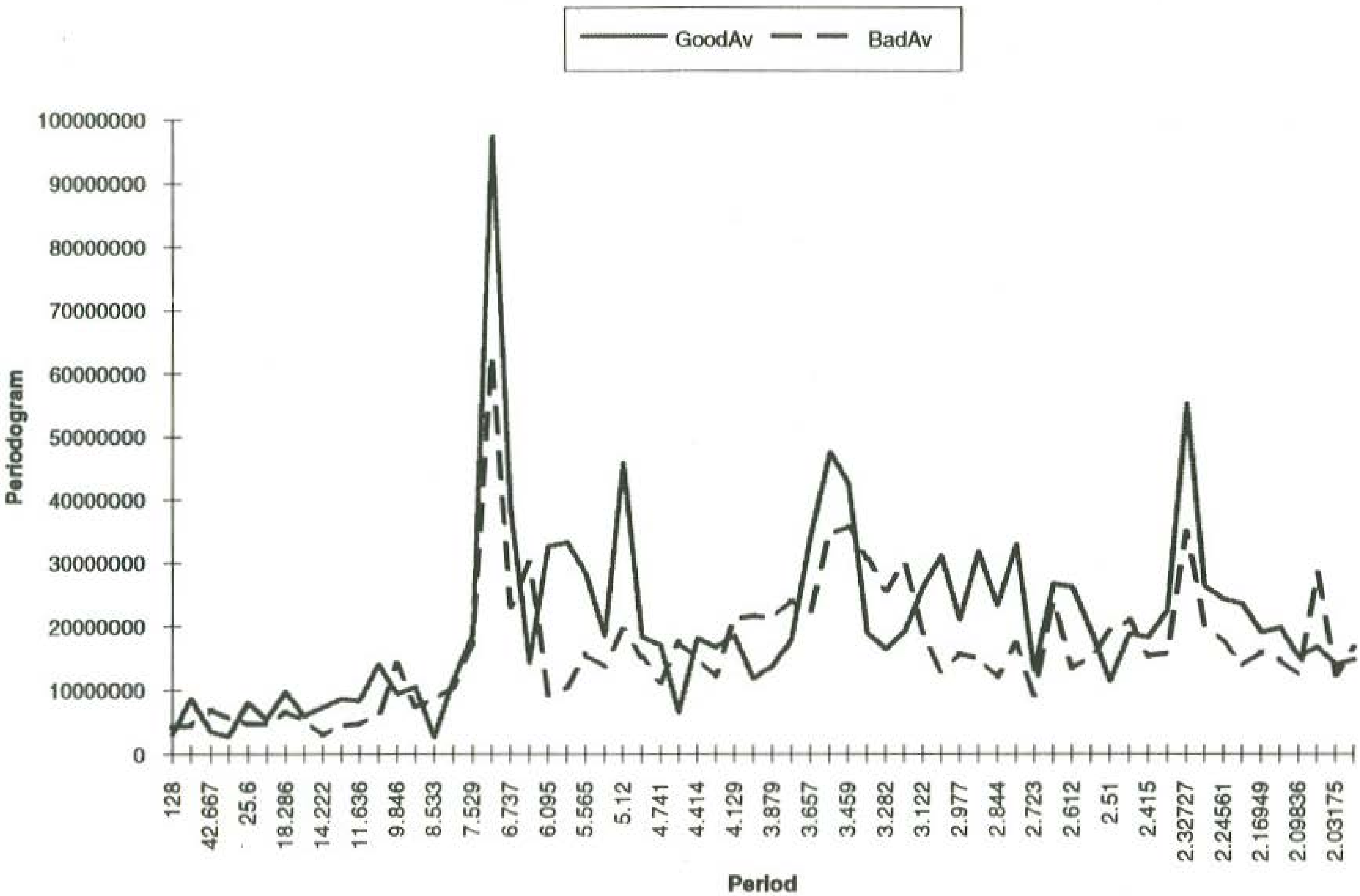

Figure 3. Periodogram of flows from good and bad recruitment years.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Beaufort Laboratory
101 Pivers Island Road
Beaufort, NC 28516-9722

June 16, 1993

MEMORANDUM FOR: Distribution

FROM: Charles S. Manooch, III

SUBJECT: Roanoke River Water Flow Graphs

Please find enclosed a graph of Roanoke River water flows recorded at Station 02080500, Roanoke Rapids, for the period June 1 - June 15, 1993. This graph, the last you will receive for this year, and those previously sent to you, were prepared as a courtesy by Jennifer Potts, a member of the Beaufort Laboratory Reef Fish Team. If you would like to receive a complete color set of graphs for the entire season (March, April, and May) please call me at 919-728-8716.

Enclosure
As Stated

Distribution:

B. Hogarth, NCDMF
R. Hamilton, NCWRC
R. Rulifson, ECU
T. Ellis, NCDA
C. Wilson, USACOE
B. Cole, USFWS
W. Laney, USFWS
J. Hightower, NCSU
L. Henry, NCDMF
S. Taylor, NCDMF
K. Nelson, NCWRC

NORTH CAROLINA
NATURE CONSERVANCY

TO: 1991 Roanoke River Flow Committee Members

FROM: J. Merrill Lynch

SUBJECT: 1991 Roanoke River Flow Committee Meeting - Wednesday, 11 August 1993

DATE: 4 August 1993

Since many of you will be in Williamston attending the Roanoke River Wildlife Management Workshop, 10-12 August, I have decided to have a meeting of the Flow Committee at 7:30 p.m., Wednesday, 11 August at the Holiday Inn, Hwy 17 bypass, Williamston, NC to discuss committee business. The meeting will be held in one of the conference rooms in the restuarant located adjacent to the registration desk at the front of the motel building.

I apologize for the late notice of the meeting but hope that most of you will be able to attend. There are two main agenda items that I would like to have the group discuss.

First, we need to review and discuss the Roanoke River Water Flow Committee Report for 1991, a draft copy of which was sent to committee members in June. We are still missing sections from committee members who committed to provide information.

Second, we need to discuss the future of the committee. Where do we go from here? I would appreciate each member thinking about this and come prepared to discuss the future role and purpose of the committee. Comments, ideas, suggestions, etc. would be most appreciated in writing if you will not be able to attend the 11 August meeting.

If anyone has any questions or other comments concerning this meeting please call me at 919-967-7007. I look forward to seeing you in Williamston next Wednesday evening.

SUITE 223 CARR MILL MALL CARRBORO, NORTH CAROLINA 27510 919-967-7007

United States Department of the Interior

FISH AND WILDLIFE SERVICE

South Atlantic Fisheries Coordination Office
P.O. Box 33683
Raleigh, North Carolina 27636-3683
Telephone: 919-515-5019
Faxform: 919-515-4454

August 18, 1993

MEMORANDUM

Reply: Chairman, Striped Bass Analysis Subcommittee, Roanoke River Water Flow Committee

Subject: Meeting to Discuss Analysis of Experimental Flow Regime

To: Subcommittee Members:
Tom Fransen, DWR, NCDEHNR, Raleigh, NC
Max Grimes, USACOE, Wilmington, NC
Harrell Johnson, DMF, NCDEHNR, Elizabeth City, NC
Chuck Manooch, SEFC, NMFS, Beaufort, NC
Kent Nelson, DBIF, NCWRC, Greenville, NC
Roger Rulifson, ICMR, ECU, Greenville, NC
Marsha Shepherd, CIS, ECU, Greenville, NC
Buddy Zincone, School of Business, ECU, Greenville, NC

Please accept my apologies for getting this out so late in the week; however, I have tried to reach most of you by telephone. Our meeting to discuss approaches for analyzing the effect of the experimental flow regime on the Roanoke River upon striped bass youny-of-year recruitment is scheduled for Friday, August 20th. The meeting will be held in Room 145, Everette Building, on the campus of Pitt Community College in Greenville, NC. Pitt Community College is located on NC 11 south of Greenville, off the US 264 southern by-pass. Follow the signs.

The draft agenda for the meeting is as follows:

10:00 - Call to Order, Discussion of Agenda
10:05 - Approach to Analysis (time period to include, variables, etc.)
12:00 - Lunch
1:15 - Options for Conducting Analysis (volunteers are welcomed)
2:00 - Schedule for Conducting Analysis
2:30 - Adjourn

Attached for your information and use is a draft list of the Subcommittee Members as formulated at the August 11, 1993, Roanoke River Water Flow Committee meeting held in Williamston, NC. Please advise me of any corrections to the list.

If you are unable to attend the meeting, please advise me by telephone and provide either verbal or written input prior to Friday.

Call if you have questions.

Attachment(s)
WL: Filename: RRWFCSBA.001
cc: Chairman, Roanoke River Water Flow Committee, Carrboro, NC
District 1 Fishery Biologist, DBIF, NCWRC, Camden, NC
Supervisory Biologist, DMF, NCDEHNR, Elizabeth City, NC
General Biologist (Campbell), ES, FWS, Raleigh, NC
Dr. Bob Monroe, Statistics, NCSU, Raleigh, NC

STRIPED BASS ANALYSIS SUBCOMMITTEE
Draft Membership List

Tom Fransen/Reid Campbell
Division of Water Resources
NC Department of Environment, Health and Natural Resources
P.O. Box 27687
Raleigh, NC 27611-7687
Telephone: 919-733-4064
Faxform: 919-733-3558

Max Grimes/Terry Brown
U.S. Army Corps of Engineers-Wilmington District
Engineering Division-Hydrology and Hydraulics Branch
P.O. Box 1890
Wilmington, NC 28402-1890
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Faxform: 919-251-4002

Harrell Johnson
Division of Marine Fisheries
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Telephone: 1-800-338-7805
Faxform: 919-264-3723

Wilson Laney (Chairman)
South Atlantic Fisheries Coordination Office
U.S. Fish and Wildlife Service
P.O. Box 33683
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Chuck Manooch
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National Marine Fisheries Service
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Kent Nelson
Division of Boating and Inland Fisheries
NC Wildlife Resources Commission
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Floodplain area called one of Last Great Places

WORKSHOP PROMOTES UNDERSTANDING OF ROANOKE RIVER ECOSYSTEM

North Carolina's lower Roanoke River floodplain has the largest and least disturbed bottomland forest remaining in the Mid-Atlantic region of the United States. According to the U.S. Fish and Wildlife Service (USFWS), the Roanoke River floodplain is one of the most important wetland habitats in North Carolina, and its large riparian forest is a critical haven for waterfowl and neotropical migratory birds. Moreover, the river is crucial to striped bass propagation.

The USFWS, the N.C. Wildlife Resources Commission, and N.C. Chapter of The Nature Conservancy have a total of 28,699 acres on the lower Roanoke River under conservation ownership (Roanoke River National Wildlife Refuge, Roanoke River Wetlands, and Roanoke River Nature Preserves). The organizations are attempting to determine what management measures will best conserve the areas for wildlife habitat.

To gain a better understanding of the Roanoke River ecosystem, the three organizations sponsored a three-day workshop for scientists and resource managers in August. The workshop, hosted by Bertie County, was held in Windsor and featured a large number of technical presentations on general ecology, wildlife needs, wetlands, and hydrology of the river ecosystem.

David Harrison, water resources consultant to The Nature Conservancy, called the Roanoke River floodplain area one of the "Last Great Places." He said that the Conservancy's Last Great Places campaign promotes conservation on a landscape scale — that is, a scale at which biological communities interact— for the long-term. Harrison and other speakers repeatedly made the point that wildlife conservation cannot be accomplished incrementally or species-by-species but must focus on ecosystems.

Dr. Stanley Riggs of East Carolina University traced the geologic history of the Roanoke River Basin and described the effects on the river of large-scale forest clearing in the 18th century; construction upstream of Gaston, Kerr, and Roanoke Rapids dams in the decades of the 1950s and 1960s; and currently increasing wastewater discharges into the river. Riggs emphasized that the lower Roanoke is a changing system and that it must be managed as such.

Brian Richter of The Nature Conservancy discussed the historic and altered flooding regimes of the river. He pointed out that before the dams were constructed, there was a great deal of "spikeyness" in the flood regime but that now there is less variation. As a result, he said, some areas of the floodplain are now staying flooded for longer periods, and other areas formerly flooded are no longer on the floodplain. The altered flood regime is changing the pattern of recruitment in forested areas, he said, but the change in species will not be evident until older trees begin to be replaced.

David Cobb, of the Florida Game and Fresh Water Fish Commission, described how flooding at the wrong time of year can destroy nesting area for the wild turkey and predicted that continuous late spring flooding of the Roanoke floodplain would have serious impacts on wild turkey populations.

Other speakers addressed the effect of flooding on the food supply for waterfowl and the effects of water releases on spawning behavior of striped bass.

Several researchers from N.C. State University described their projects focusing on habitat fragmentation and its effects on wildlife populations. Graduate student Shawn Fraver described his research showing that when forest habitat is fragmented by clearing, vegetation changes — such as dense understory growth and invasion of exotics — begin at the edge and can extend significant distances into the forest. In very small forest fragments (1 hectare), more than 90 percent of the area can experience vegetation changes. Vegetation changes affect habitat suitability, and could have the effect of attracting some species — such as crows — that displace other species, such as neotropical migratory birds.

Following two days of technical presentations, the scientists and resource managers formed workgroups to develop management and research recommendations. Workgroups addressed the topics of Ecosystem Processes, Floodplain Fisheries, Nongame Wildlife, Game Wildlife Species, User Groups/Land Uses of the River Basin, and Landscape/Ecosystem Planning.

Abstracts of the presentations as well as the results of the workgroup deliberations will be available in workshop proceedings soon to be published. For information about the proceedings, contact the U.S. Fish and Wildlife Service in Raleigh (919/856-4520).

EXTENSION HIRES AREA ENVIRONMENTAL AGENT

Craven F. Hudson, North Carolina's first Area Specialized Environmental Management Agent, will be at work in Orange, Durham and Chatham counties October 1. The position was created by and is funded by Durham County and the N.C. State University Cooperative Extension Service.

According to Hudson, he will provide information to local government, farmers and other about how to comply with environmental regulations; conduct public policy education; establish educational programs for youth and college students; and facilitate network building among groups concerned with environmental issues in the three-county area.

Hudson was previously 4H/Forestry Extension Agent in Pamlico County.

TO: 1991 Roanoke River Flow Committee Members

FROM: J. Merrill Lynch, Chairman

SUBJECT: Roanoke River Flow Committee Meeting, September 16, 1993

DATE: 3 September 1993

The next meeting of the full committee will be held on Thursday, September 16, 1993 at the Health Sciences Building at Pitt Community College located on NC Hwy 11 south of Greenville. Meeting time is 10:00 am.

Directions to the meeting place: Going south on Hwy 11 from Greenville, Pitt Community College is located on the right (west) side of the road about 3 miles south of the junction with US Hwy 264 bypass (just before reaching the town of Winterville). The Health Sciences Building is the last building on your right on the campus. Follow the signs.

Items for discussion:

We will discuss the draft recommendations of the Striped Bass Analysis Subcommittee chaired by Wilson Laney. We will also discuss the combined 1991-1992-1993 RRWFC draft report. Those of you who were asked to submit papers for this report should send them to Dr. Roger Rulifson at East Carolina University ASAP.

Finally, we will discuss the future direction and makeup of this committee. Where do we go from here?

I look forward to seeing all of you at the meeting.

FAX TRANSMITTAL SHEET

DATE: Sept. 14, 1993

FROM: Assistant Coordinator
South Atlantic Fisheries Coordination Office
U.S. Fish and Wildlife Service
P.O. Box 33683
Raleigh, NC 27636-3683
Office: 919-515-5019
Faxform: 919-515-4454

TO: STRIPED BASS ANALYSIS SUBCOMMITTEE, ROANOKE RIVER WATER FLOW COMMITTEE

NUMBER OF PAGES TRANSMITTED INCLUDING THIS ONE: 13

MESSAGES: FINAL AND FINAL DRAFT MATERIALS FOR THURSDAY'S MEETING

TO: FRANSEN/CAMPBELL - NC DWR
GRIMES/BROWN/PINER - COE
TAYLOR/WINSLOW/JOHNSON/HENRY - NC DMF
MANOOCH - NMFS
RULIFSON - ECU
SHEPHERD - ECU
ZINCONE - ECU
MERRILL LYNCH - NCNC

United States Department of the Interior

FISH AND WILDLIFE SERVICE

South Atlantic Fisheries Coordination Office
P.O. Box 33683
Raleigh, North Carolina 27636-3683
Telephone: 919-515-5019
Faxform: 919-515-4454

September 14, 1993

MEMORANDUM

Reply: Chairman, Striped Bass Analysis Subcommittee, Roanoke River Water Flow Committee, Raleigh, NC

Subject: Final Minutes, Final Draft Proposed Recommendations to Full Committee

To: Subcommittee Members:
Tom Fransen (Reid Campbell), DWR, NCDEHNR, Raleigh, NC
Max Grimes (Alan Piner), USACOE, Wilmington, NC
Harrell Johnson (Steve Taylor), DMF, NCDEHNR, Elizabeth City, NC
Chuck Manooch, SEFC, NMFS, Beaufort, NC
Kent Nelson (Pete Kornegay), DBIF, NCWRC, Greenville, NC
Roger Rulifson, ICMR, ECU, Greenville, NC
Marsha Shepherd, CIS, ECU, Greenville, NC
Buddy Zincone, School of Business, ECU, Greenville, NC
Chairman, Roanoke River Water Flow Committee, Carrboro, NC

Attached for your use and information are the approved minutes of the Striped Bass Analysis Subcommittee meeting which was held August 20, 1993, in Greenville, NC, and a list of Subcommittee members. Also attached is a proposed final draft letter for transmittal from the Chairman of the Roanoke River Water Flow Committee to the Executive Director of the N.C. Wildlife Resources Commission, the Colonel of the Wilmington District, U.S. Army Corps of Engineers, and Virginia Power.

The final draft letter was developed by the Striped Bass Analysis Subcommittee after deliberations during the August 20th meeting and subsequent deliberations and vote by telephone on September 14th. Members of the Subcommittee voted for draft Option C to be included in the final draft letter which we have developed for your signature. Several members did indicate that they would be willing to recommend Option B if the N.C. Wildlife Resources Commission was uncomfortable recommending Option C. The actual vote was: 5-Option C, 1-Option B and 1-Option A (with modification to change spawning window to April 15-June 15). I have modified the text of the final draft letter to recommend Option C.

I am unable to attend the Committee meeting on September 16th due to a prior commitment. In my absence, I have asked Dr. Roger Rulifson to present these materials to the Committee at the September 16 Greenville meeting for action.

Should the Committee decide at the September 16th meeting to modify the proposed draft letter, I will work with the Chairman to prepare the text, should he wish, since I have all the options on my computer.

If you have any questions, please call.

Attachment(s)
WL:wl Filename: RRWFCSBA.003

cc: District 1 Fishery Biologist, DBIF, NCWRC, Camden, NC
Supervisory Biologist, DMF, NCDEHNR, Elizabeth City, NC
General Biologist (Campbell), ES, FWS, Raleigh, NC
Dr. Bob Monroe, Statistics, NCSU, Raleigh, NC
Coordinator, SAFCO, FWS, Morehead City, NC
Supervisor, ES, FWS, Raleigh, NC

ATTACHMENT 1
[September 14, 1993]

STRIPED BASS ANALYSIS SUBCOMMITTEE
Membership List*

Tom Fransen/Reid Campbell
Division of Water Resources
NC Department of Environment, Health and Natural Resources
P.O. Box 27687
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Max Grimes/Terry Brown/Alan Piner
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Engineering Division-Hydrology and Hydraulics Branch
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Steve Taylor/Sara Winslow/Harrell Johnson
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NC Department of Environment, Health and Natural Resources
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Faxform: 919-264-3723

Wilson Laney (Chairman)/Bill Cole
South Atlantic Fisheries Coordination Office
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Chuck Manooch
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National Marine Fisheries Service
Pivers Island
Beaufort, NC 28516
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Marsha Shepherd
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Buddy Zincone
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* For voting purposes, each agency or institution represented on the Subcommittee is allowed only one vote.

ATTACHMENT 2
[September 14, 1993]

ROANOKE RIVER WATER FLOW COMMITTEE
MINUTES--STRIPED BASS ANALYSIS SUBCOMMITTEE MEETING
Pitt Community College, Greenville, NC, August 20, 1993

The meeting convened at 10:00 am in Room 145, Everette Building, Pitt Community College campus in Greenville, NC. Individuals present for the meeting were: John Copeland (N.C. Wildlife Resources Commission, Division of Boating and Inland Fisheries--hereafter WRC/DBIF); Pete Kornegay (WRC/DBIF); Wilson Laney (U.S. Fish and Wildlife Service, Fishery Resources--hereafter FWS/FR), Chairman; Kent Nelson (WRC/DBIF); Allen Piner, U.S. Army Corps of Engineers, Wilmington District, Engineering Division, Hydrology and Hydraulics Branch (hereafter Corps); Roger Rulifson, East Carolina University, Institute for Coastal and Marine Resources (ECU/ICMR); Marsha Shepherd, East Carolina University, Computer and Information Systems (ECU/CIS); and Steve Taylor, N.C. Department of Environment, Health and Natural Resources, Division of Marine Fisheries (NCDEHNR/DMF).

Handouts (attached to the file copy of the minutes) were provided to the members. Steve Taylor provided graphs of the weekly catch-per-unit-effort (CPUE) for western and central Albemarle Sound juvenile abundance stations, and a summary of individual station data for "Hassler" stations from 1982-1992. Roger Rulifson provided selected pages (16-18, 20, 34-35, 39, 41-42, 46, 48, 52, and 127) from a recent report which analyzes egg production and subsequent juvenile recruitment for 1990-1992 (Rulifson, R.A., C.S. Manooch, III, and J.J. Isley. 1993. Striped bass egg abundance and viability in the Roanoke River, North Carolina, and young-of-year survivorship, for 1992. Completion Report for Project F-50, Segment 1, to the N.C. Division of Marine Fisheries, Morehead City, NC).

The merits of two possible strategies were discussed. One strategy is to request that the agencies (Corps, Virginia Power, WRC) defer making any decision on flows during the striped bass spawning window until the Subcommittee has completed an analysis. The other strategy which the Subcommittee could consider would be to recommend that the Committee send a letter to the Corps, Virginia Power and WRC which requested continuation of the present experimental flow regime through the year 2000. This would allow time for the Subcommittee, or any other interested parties, to conduct rigorous analyses of the impact of the experimental flow regime upon the Albemarle Sound-Roanoke River striped bass stock (AR stock), while still meeting the WRC commitment to provide a recommendation to the Corps by the end of the calendar year. Any desired revisions to the experimental flow regime could be recommended at a later date to the agencies, or recommended to the Federal Energy Regulatory Commission during the relicensing process for Lakes Gaston and Roanoke Rapids. The Subcommittee could also include a recommendation for expanding the present spawning window by two weeks, through June 30. The Subcommittee indicated that the second strategy was preferred.

A discussion of what the recommendation of the Subcommittee should be ensued. Allen indicated that the Corps supported continuation of the present experimental flow regime; however, he noted that Virginia Power would experience a 2-3 million dollar loss per year by not peaking during the spawning window. The Corps' concerns with regard to the experimental regime are: 1) having enough water during dry years; possible impacts to the reservoir striped bass fishery through entrainment of Kerr Reservoir fish; and hydropower loss due to cessation of peaking. Allen indicated that the Corps would prefer to retain the present 75-day spawning window, and that expanding the window would create management problems because the present Guide Curve (formerly Rule Curve) had no provisions for retaining sufficient water to provide the necessary flows.

Steve Taylor noted that DMF has two concerns. DMF would like to see an analysis performed which assesses the impact of hourly changes on flow on spawning activity, and would like to see the spawning window expanded to include portions of March.

Roger reviewed the analyses presented in his handout which document the need for expanding the present spawning window. Egg sampling on the river clearly indicates that striped bass are spawning both before and after the presently designated window. He explained that data collected from daily growth rings in the otoliths of juveniles collected from Albemarle Sound documents that the distribution of egg production and subsequent recruits is skewed. This means that the recruits which survive to form a given year class are not necessarily coming from the period when the majority of eggs are produced. Indeed, in 1992, an estimated 20 percent of the recruits were produced from eggs spawned after June 30th. Marsha Shepherd noted that the Hassler egg data also indicate early spawning. Steve reiterated the DMF preference to expand the spawning window into March. Roger indicated that the Subcommittee should recommend that the spawning window be designated as April 1 through June 30.

The Subcommittee digressed to discuss the possibility of recommending an annual flow regime to the Corps. Pete asked what would happen after the life span of Kerr Dam had expired. Allen indicated that the facility would likely be refurbished and that operations would continue. Roger noted that flow releases from Kerr appeared to be less than those from Falls of the Neuse and B. Everette Jordan and that water levels in those reservoirs appeared to decline more during the summer than the level at Kerr. Allen responded that the other two reservoirs tend to reach lower levels because the Corps must meet downstream minimum flow targets for those two systems which mandate relatively higher minimum flow releases. Roger noted that Kerr releases this summer were being held to the minimum required, and that dissolved oxygen values in the lower river were low, around 4 parts per million. Kent stated that flow patterns in Albemarle Sound influenced the lower river to such an extent that effluent from point source discharges were held within the river. Roger stated his concern that present summer flows were not adequate for maintaining water quality, despite that fact that present minimum flow releases have eliminated historical flows as low as 700 cfs. Allen pointed out that the 1971 Memorandum of Understanding is tied to the FERC license and only addressed the spawning window, and suggested that any further discussion be restricted to that issue.

The Subcommittee discussed possible options for revising or altering the present spawning window to provide for easier implementation and/or to maximize efficient use of the available water. Several members noted that we had not had a dry year during the evaluation period for the present experimental flow regime, therefore the capabilities of the Corps to meet the regime under dry flow conditions had not really been tested. We discussed the possibility of developing a matrix using water temperature, flow and possibly other parameters, which would provide for shifting the spawning window earlier or later in an attempt to optimize spawning conditions. Allen indicated that the Corps would prefer to delay provision of spawning flows until April 15 and terminate them June 15.

[The Subcommittee adjourned temporarily for lunch from 12:00 to 1:00]

The Subcommittee outlined the content of the draft letter to be sent to the WRC from the Committee as follows: 1) the best flow regime for the system is the preimpoundment hydrograph; 2) the present experimental regime, which is based on the preimpoundment hydrograph, has had no adverse effect and possibly a beneficial one; 3) at a minimum, recommend extending the experimental flow regime for six more years, through 2000, while in the interim working through the relicensing process to develop an appropriate annual regime; 4) indicate that changes are needed in the experimental regime to a) expand the striped bass spawning window and b) develop an appropriate annual hydrograph which addresses management needs for all species (i.e. take an adaptive management approach which involves undertaking the necessary analyses to further refine the experimental flow regime or develop a operations matrix as discussed above); and 5) recommend needed analyses which should be conducted. Roger indicated that our recommendation should encourage the Corps to use the historical median values as targets, rather than the upper or lower bound. It was also noted that the present limitation of flow increase to 1500 cfs per hour should be maintained as part of the recommendation.

Analyses which were deemed needed in the immediate future included: impact of future withdrawals; evaluation of annual rainfall, temperature and water quality patterns in relation to the historical hydrograph; integration of biological data with hydrographic data, at the smallest possible scale; evaluation of the response of juvenile abundance index to the experimental flow regime, using hourly flow data; evaluate the present Guide Curve against the historical preimpoundment hydrograph; evaluate the construction years' hydrograph against the preimpoundment years to see whether they should be included with those data (Dr. Zincone apparently plans to do this analysis); compare hourly flow patterns for pre- and postimpoundment flows; conduct multivariate analyses of appropriate environmental variables against recruitment as measured by the JAI or other appropriate stock parameters; and compile hourly temperature and flow data from Roanoke Rapids in a database which is accessible to striped bass and other researchers.

The Chairman agreed to be responsible for preparing a draft letter and transmitting it to the Subcommittee members for review and revision.

The meeting adjourned at approximately 2:30 (?).

ATTACHMENT 3
[September 14, 1993]

DRAFT LETTER TO BE SENT FROM CHAIRMAN OF COMMITTEE TO CORPS, VIRGINIA POWER AND WRC

Chairman, Roanoke River Water Flow Committee
Suite D-12
Carr Mill
Carrboro, North Carolina 27510

September , 1993

Mr. Charles Fullwood, Executive Director
N.C. Wildlife Resources Commission
Archdale Building
512 N. Salisbury Street
Raleigh, North Carolina 27604-1188

Dear Mr. Fullwood:

In 1988, the Roanoke River Water Flow Committee (Committee) was formed to gather information on all resources of the lower Roanoke River watershed in North Carolina and recommend a flow regime that would be mutually beneficial to these resources and their downstream users. The Recommendations Subcommittee of the Committee subsequently developed a recommended flow regime for an expanded (March 1 through June 30) striped bass spawning window. Discussions with the U.S. Army Corps of Engineers, Wilmington District (Corps) and Virginia Power resulted in a negotiated target flow regime covering April 1 through June 15 which differs from that agreed to in the 1971 Memorandum of Understanding (MOU) between the Corps, Virginia Power and the N.C. Wildlife Resources Commission (WRC). This regime, initiated informally in 1988 and formally from 1989 through 1993 through amending the 1971 MOU, is generally known as the "experimental" flow regime. Since the WRC has indicated to the Corps that it will make a final recommendation regarding the continued use of this regime prior to the end of 1993, the Committee is providing recommendations to you at this time regarding what course of action the WRC should take.

The Committee is of the opinion that natural resources of the lower Roanoke River Basin, and Albemarle Sound which receives much of its freshwater inflow from the Roanoke, are best managed within the context of a flow regime which approximates as closely as possible the preimpoundment hydrograph. No rigorous scientific analysis is required to support or document this common sense conclusion. All of the natural resources of the lower basin, including fish, wildlife and their supporting habitats, evolved in the context of a hydrograph which was largely unaffected by human activities. Some of those resources have experienced impacts, including population declines, which are related to the extent by which the present regulated hydrograph departs from the preimpoundment condition. Impacts on some species, such as those on wild turkeys resulting from unnaturally prolonged flooding, are well documented. Others, such as declines in fishery resources, are less clear and are confounded by other variables. While further studies may enlighten managers as to exactly how natural resource populations respond to changes in the river hydrograph, these studies are not necessary for us to begin to minimize the risk of natural resource disruption through returning the hydrograph to a more natural pattern.

The Committee emphasizes that it is <u>not</u> advocating a return to a natural hydrograph which would allow discharges of the magnitude of the flood of record We recognize that constraints emplaced upon the system by human design preclude such events. However, we also believe that the initially-negotiated regulated flow regime did not adequately provide for fish and wildlife resources and that those flows must and can be altered to a more natural, but less variable, condition.

The experimental flow regime presently in place for the striped bass spawning window represents a step in the process of restoring a more natural hydrograph to the river. From that perspective, no additional analysis of its impact on natural resources is necessary. The Committee does note that the juvenile abundance index of striped bass, as measured in Albemarle Sound, has dramatically improved during 1988-1993 in comparison to the six prior years of 1982-1987. The striped bass juvenile abundance index mean value for 1982-1987 inclusive is 0.29, in contrast to the value for 1988-1993, which is 7.08. The latter mean was derived using a 1993 value of 29.25, current as of September 14. The final 1993 index value will likely be higher. While no study has shown that the increase is entirely attributable to the experimental flow regime, it would appear that the revised flows, in concert with other management actions, have benefitted striped bass recruitment.

The Roanoke River Water Flow Committee therefore recommends to the N.C. Wildlife Resources Commission that the Commission undertake to negotiate with the Corps and Virginia Power to implement a new annual flow regime for the Roanoke River. Values in the attached Table 1, derived from work performed by members of the Committee's Striped Bass Analysis Subcommittee, should serve as a basis from which to begin negotiation. The Committee recognizes that the Commission and other state and federal natural resource management agencies will be parties to ongoing discussions pertaining to Federal Energy Regulatory Commission relicensing of the Virginia Power hydropower facilities at Lake Gaston and Roanoke Rapids Reservoir. However, since there is consensus in the natural resource management community that the natural (preimpoundment) hydrograph represents the best option for river management, and since preimpoundment flow data have already been analyzed to derive weekly flow values, nothing will be gained by delaying negotiations to allow for additional analysis. The Committee recommends that the Commission stress to the Corps that the target flows during the year should be the average weekly flow values, rather than the upper and lower limits. The Committee also continues to recommend that the hourly variation in flow not exceed 1,500 cubic feet per second.

The Committee and its Striped Bass Analysis Subcommittee will continue to vigorously pursue analysis of existing and future data on striped bass and other natural resources in an effort to understand the relationships between flows and natural resources, and to refine the annual flow regime to produce a regime which is most compatible with natural resource management on the lower Roanoke River.

The Committee further recommends that the WRC, Corps and Virginia employ an adaptive management approach to the regulation of flows on the Roanoke River. Simply stated, this means that as studies are performed which elucidate the relationships between flows and natural resource management, the flow regime may be altered in subsequent years to implement management strategies which are demonstrated to be better for fish and wildlife resource management. We believe that it is unlikely, however, that any studies will contraindicate a more natural hydrograph.

Although we believe that no further studies are necessary at this time to justify the action we have recommended, the Committee does recommend that studies be pursued on the Roanoke River with support from the Corps, Virginia Power, WRC and other entities. Studies and/or actions which we believe would be beneficial from a management perspective include: assess the impact of future withdrawals; evaluate annual rainfall, temperature and water quality patterns in relation to the historical hydrograph; integrate biological data with hydrographic data, at the smallest possible temporal scale; evaluate the response of juvenile abundance index to the experimental flow regime, using hourly flow data; evaluate the present Kerr Reservoir Guide Curve against the historical preimpoundment hydrograph; evaluate the construction years' hydrograph against the preimpoundment years to see whether they should be included with those data (Dr.

Zincone apparently plans to do this analysis); compare hourly flow patterns for pre- and -postimpoundment flows; conduct multivariate analyses of appropriate environmental variables against recruitment as measured by the JAI or other appropriate stock parameters; and compile hourly temperature and flow data from Roanoke Rapids in a database which is accessible to striped bass and other researchers.

By copy of this letter to the Corps and Virginia Power, we request that they work with the WRC to negotiate a flow regime which addresses the Committee's concerns.

We appreciate the opportunity to provide these recommendations to you. Should you have any questions, the Committee and its Subcommittees stand ready to provide assistance.

Sincerely,

J. Merrill Lynch, Chairman
for the Roanoke River Water Flow Committee

cc: Colonel George L. Cajigal, U.S. Army Corps of Engineers, Wilmington, NC
Kenneth E. Baker, Virginia Power, Glen Allen, VA

Table 1. Proposed annual flow regime for the Roanoke River below Roanoke Rapids Dam (derived from Table 16 of Rulifson et al. 1991). Discharge values are weekly means in cubic feet per second. Q_1 values are 25% low flow values; Q_3 values are 75% high flow values for the preimpoundment (1912-1950) period of record. Present minimum flows mandated under the existing license, target striped bass spawning flows under the 1971 Memorandum of Understanding, and target striped bass spawning flows under the present negotiated experimental flow regime are presented for purposes of comparison.

Week	Dates	Median Discharge[1]	Q_1 Lower Limit	Q_3 Upper Limit	FERC Minimum[2]	SB MOU[3]	SB Exp[4]
1	01-07 Jan	11,776	7,044	18,562	1,000		
2	08-14 Jan	10,607	7,456	16,741	1,000		
3	15-21 Jan	9,714	7,511	16,775	1,000		
4	22-28 Jan	9,022	6,969	15,982	1,000		
5	29 Jan-04 Feb	9,777	7,688	15,916	1,000		
6	05-11 Feb	10,949	8,226	16,708	1,000		
7	12-18 Feb	12,062	8,496	18,315	1,000		
8	19-25 Feb	10,713	8,778	15,666	1,000		
9	26 Feb-04 Mar	10,808	8,379	15,097	1,000		
10	05-11 Mar	13,263	8,504	19,832	1,000		
11	12-18 Mar	12,174	8,813	18,548	1,000		
12	19-25 Mar	11,416	8,682	19,460	1,000		
13	26 Mar-01 Apr	10,913	8,693	14,436	1,000-1,500		
14	02-08 Apr	9,992	8,074	15,417	1,500	2,000	8,500
15	09-15 Apr	10,907	8,314	18,433	1,500	2,000	8,500
16	16-22 Apr	8,914	7,459	13,719	1,500	5,700	7,800
17	23-29 Apr	8,687	6,579	12,375	1,500	5,700	7,800
18	30 Apr-06 May	7,567	6,348	10,835	1,500-2,000	5,700	6,500
19	07-13 May	6,751	5,755	10,048	2,000	5,700	5,900
20	14-20 May	7,996	6,486	12,437	2,000	5,700	5,900
21	21-27 May	7,127	5,377	10,845	2,000	5,700	5,900
22	28 May-03 Jun	6,704	5,101	9,653	2,000	5,700	5,300
23	04-10 Jun	6,160	4,733	9,492	2,000	5,700	5,300
24	11-17 Jun	5,899	4,499	8,244	2,000	5,700	5,300
25	18-24 Jun	5,882	4,512	8,605	2,000		
26	25 Jun-01 Jul	5,577	4,204	7,588	2,000		
27	02-08 Jul	5,196	3,980	7,373	2,000		
28	09-15 Jul	5,552	4,317	8,216	2,000		
29	16-22 Jul	7,783	4,843	11,737	2,000		
30	23-29 Jul	7,241	4,907	10,640	2,000		
31	30 Jul-05 Aug	5,161	3,898	7,597	2,000		
32	06-12 Aug	5,000	3,747	7,262	2,000		

Table 1. Continued.

Week	Dates	Median Discharge	Q_1 Lower Limit	Q_3 Upper Limit	FERC Minimum	SB MOU	SB Exp
33	13-19 Aug	7,493	4,175	13,798	2,000		
34	20-26 Aug	5,535	3,952	13,881	2,000		
35	27 Aug-02 Sep	5,496	3,677	7,362	2,000		
36	03-09 Sep	5,281	3,575	8,834	2,000		
37	10-16 Sep	3,922	3,112	5,605	2,000		
38	17-23 Sep	6,320	3,752	11,103	2,000		
39	24-30 Sep	3,888	3,074	7,082	2,000		
40	01-07 Oct	7,579	3,684	12,010	1,500		
41	08-14 Oct	4,281	3,183	6,439	1,500		
42	15-21 Oct	3,637	3,153	6,243	1,500		
43	22-28 Oct	4,873	3,672	8,566	1,500		
44	29 Oct-04 Nov	4,800	3,447	6,856	1,500-1,000		
45	05-11 Nov	4,339	3,629	6,957	1,000		
46	12-18 Nov	4,745	3,918	6,957	1,000		
47	19-25 Nov	5,069	4,067	8,191	1,000		
48	26 Nov-02 Dec	5,158	4,132	9,857	1,000		
49	03-09 Dec	7,913	5,684	13,340	1,000		
50	10-16 Dec	6,168	5,098	8,862	1,000		
51	17-23 Dec	6,226	4,945	8,175	1,000		
52	24-31 Dec	8,229	5,600	11,625	1,000		

[1] Median, Q_1, and Q_3 values are all mean weekly values derived from Table 16 of Rulifson et al. (1991).

[2] FERC minimum flow discharge values as mandated by the license for Lakes Gaston and Roanoke Rapids.

[3] Target flows provided by the Corps from Kerr Lake as agreed to in the 1971 Memorandum of Understanding between the Corps, N.C. Wildlife Resources Commission, and Virginia Power (target releases and dates are: April 1-15--2,000; April 16-June 15--5,700).

[4] Expected average daily flow during the time interval, based on the negotiated flow regime agreed to by the Corps, N.C. Wildlife Resources Commission and Virginia Power (April 1-15--8,500; April 16-30--7,800; May 1-15--6,500; May 16-31--5,900; and June 1-15--5,300) .

NORTH CAROLINA
NATURE CONSERVANCY

MEMORANDUM

To: Roanoke River Flow Committee Members

From: J. Merrill Lynch, Chairman

Subject: Final letter from Committee to N.C. Wildlife Resources Commission

Attached is the final signed letter from the Chairman of the Roanoke River Water Flow Committee to the Executive Director of the N.C. Wildlife Resources Commission, containing the recommendations of the Committee concerning flow regimes on the Roanoke River.

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Chairman, Roanoke River Water Flow Committee
Suite D-12
Carr Mill
Carrboro, North Carolina 27510

October 1, 1993

Mr. Charles Fullwood, Executive Director
N.C. Wildlife Resources Commission
Archdale Building
512 N. Salisbury Street
Raleigh, North Carolina 27604-1188

Dear Mr. Fullwood:

In 1988, the Roanoke River Water Flow Committee (Committee) was formed to gather information on all resources of the lower Roanoke River watershed in North Carolina and recommend a flow regime that would be mutually beneficial to these resources and their downstream users. The Recommendations Subcommittee of the Committee subsequently developed a recommended flow regime for an expanded (March 1 through June 30) striped bass spawning window. Discussions with the U.S. Army Corps of Engineers, Wilmington District (Corps) and Virginia Power resulted in a negotiated target flow regime covering April 1 through June 15 which differs from that agreed to in the 1971 Memorandum of Understanding (MOU) between the Corps, Virginia Power and the N.C. Wildlife Resources Commission (WRC). This regime, initiated informally in 1988 and formally from 1989 through 1993 through amending the 1971 MOU, is generally known as the "negotiated" or "experimental" flow regime. Since the WRC has indicated to the Corps that it will make a final recommendation regarding the continued use of this regime prior to the end of 1993, the Committee is providing recommendations to you at this time regarding what course of action the WRC should take.

The Committee is of the opinion that natural resources of the lower Roanoke River Basin, and Albemarle Sound which receives much of its freshwater inflow from the Roanoke, are best managed within the context of a flow regime which approximates as closely as possible a preimpoundment hydrograph. No rigorous scientific analysis is required to support or document this ecologically defensible position. All of the natural resources of the lower basin, including fish, wildlife and their supporting habitats, evolved in the context of a flow regime which was largely unaffected by human activities. Some of those resources have experienced impacts, including population declines, that are related to the extent by which the present regulated instream flow departs from a preimpoundment condition. Impacts on some species, such as those on wild turkeys resulting from unnaturally prolonged flooding, are well documented. Other impacts, such as declines in fishery resources, are less understood and are confounded by other variables. While further studies may enlighten managers as to exactly how natural resource populations respond to changes in the river flow patterns, these studies are not necessary for us to begin to minimize the risk of natural resource disruption by returning the flow regime to a more natural pattern.

The Committee emphasizes that it is <u>not</u> advocating a return to a natural hydrograph which would allow discharges of the magnitude of the flood of record. We recognize that flood control measures emplaced upon the system by human design largely preclude such events. However, we believe that the flow regime defined in the 1971 MOU did not adequately provide for fish and wildlife resources and that those flows must and can be altered to a more natural, but less variable, condition.

The experimental flow regime presently in place for the striped bass spawning window represents a step in the process of restoring a more natural flow pattern to the river. From that perspective, no additional analysis of its impact on natural resources is necessary. The Committee does note that the juvenile abundance index of striped bass, as measured in Albemarle Sound, has dramatically improved during 1988-1993 in comparison to the six prior years of 1982-1987. The striped bass juvenile abundance index mean value for 1982-1987 inclusive is 0.29, in contrast to the value for 1988-1993, which is 8.28. The latter mean was derived using a 1993 value of 36.48, current as of September 23. The final 1993 index value will likely be higher. While no study has shown that the increase is entirely attributable to the experimental flow regime, it would appear that the revised flows, in concert with other management actions, have benefitted striped bass recruitment.

The Roanoke River Water Flow Committee recommends to the N.C. Wildlife Resources Commission that the present experimental flow regime be expanded by two weeks, to cover the dates April 1 through June 30 of each year. This extended flow regime would be continued for the next six years, 1994 through 2000, at which time the FERC license expires and other flow alternatives, as described below, may be implemented. The regime would continue as specified in the March, 1989, Environmental Assessment and Finding of No Significant Impact for Modification to the Operation of John H. Kerr Dam and Reservoir, Virginia and North Carolina, by Amending the 1971 Memorandum of Understanding (MOU) for Reregulation of Augmentation Flows for Fish from John H. Kerr Dam and Reservoir Project, with the addition of the following flow targets:

Dates	Expected Average Daily Flow	Lower Limit	Upper Limit
June 16-30	5,300	4,000	9,500

The Committee recommends that the Commission stress to the Corps that the target flows during the expanded spawning window should be the average daily flow values, rather than the upper and lower limits. The Committee also continues to recommend that the hourly variation in flow not exceed 1,500 cubic feet per second.

The Roanoke River Water Flow Committee further recommends to the N.C. Wildlife Resources Commission that the Commission encourage the Corps and Virginia Power to consider a new annual flow regime for the Roanoke River. Values in the attached Table 1, derived from work performed by members of the Committee, should serve as a basis from which to begin analysis of the affect of the proposed annual regime on existing reservoir and hydropower operations. The Committee recognizes that the Commission and other state and federal natural resource management agencies will be parties to ongoing discussions pertaining to Federal Energy Regulatory Commission relicensing of the Virginia Power hydropower facilities at Lake Gaston and Roanoke Rapids Reservoir. Since there is consensus in the natural resource management community that a natural (preimpoundment) hydrograph represents the best option for river management, and since preimpoundment flow data have already been analyzed to derive weekly flow values, nothing will be gained by delaying negotiations to allow for additional analysis. The Committee recommends that the Commission stress to the Corps that the target flows during the year should be the average weekly flow values, rather than the upper and lower limits. The Committee also continues to recommend that the hourly variation in flow not exceed 1,500 cubic feet per second.

The Committee and its Striped Bass Analysis Subcommittee will continue to vigorously pursue analysis of existing and future data on striped bass and other natural resources in an effort to understand the relationships between flows and natural resources, and to refine the annual flow pattern to produce a regime which is most compatible with natural resource management on the lower Roanoke River.

The Committee further recommends that the WRC, Corps and Virginia Power employ an adaptive management approach to the regulation of flows on the Roanoke River.

Simply stated, this means that as studies are performed which elucidate the relationships between flows and natural resource management, the flow regime may be altered in subsequent years to implement management strategies which are demonstrated to be better for fish and wildlife resource management. We believe that it is unlikely, however, that any studies will contraindicate a more natural hydrograph.

Although we believe that no further studies are necessary at this time to justify the action we have recommended, the Committee does recommend that studies be pursued on the Roanoke River with support from the Corps, Virginia Power, WRC and other entities. Studies and/or actions which we believe would be beneficial from a management perspective include: assess the impact of future withdrawals; evaluate annual rainfall, temperature and water quality patterns in relation to the historical hydrograph; integrate biological data with hydrographic data, at the smallest possible temporal scale; evaluate the response of juvenile abundance index to the experimental flow regime, using hourly flow data; evaluate the present Kerr Reservoir Guide Curve (formerly called Rule Curve) against the historical preimpoundment hydrograph; compare hourly flow patterns for pre- and -postimpoundment flows; conduct multivariate analyses of appropriate environmental variables against recruitment as measured by the JAI or other appropriate stock parameters; and compile hourly temperature and flow data from Roanoke Rapids in a database which is accessible to striped bass investigators and other researchers.

By copy of this letter to the Corps and Virginia Power, we request that they work with the WRC to negotiate a flow regime which addresses the Committee's concerns.

We appreciate the opportunity to provide these recommendations to you. Should you have any questions, the Committee and its Subcommittees stand ready to provide assistance.

Sincerely,

J. Merrill Lynch, Chairman
for the Roanoke River Water Flow Committee

Attachment
cc: Colonel George L. Cajigal, U.S. Army Corps of Engineers, Wilmington, NC
Kenneth E. Baker, Virginia Power, Glen Allen, VA
Roanoke River Water Flow Committee members

Table 1. Proposed annual flow regime for the Roanoke River below Roanoke Rapids Dam (derived from Table 16 of Rulifson et al. 1991). Discharge values are weekly means in cubic feet per second. Q_1 values are 25% low flow values; Q_3 values are 75% high flow values for the preimpoundment (1912-1950) period of record. Present minimum flows mandated under the existing license, target striped bass spawning flows under the 1971 Memorandum of Understanding, and target striped bass spawning flows under the present negotiated experimental flow regime are presented for purposes of comparison.

Week	Dates	Median Discharge[1]	Q_1 Lower Limit	Q_3 Upper Limit	FERC Minimum[2]	SB MOU[3]	SB Exp[4]
1	01-07 Jan	11,776	7,044	18,562	1,000		
2	08-14 Jan	10,607	7,456	16,741	1,000		
3	15-21 Jan	9,714	7,511	16,775	1,000		
4	22-28 Jan	9,022	6,969	15,982	1,000		
5	29 Jan-04 Feb	9,777	7,688	15,916	1,000		
6	05-11 Feb	10,949	8,226	16,708	1,000		
7	12-18 Feb	12,062	8,496	18,315	1,000		
8	19-25 Feb	10,713	8,778	15,666	1,000		
9	26 Feb-04 Mar	10,808	8,379	15,097	1,000		
10	05-11 Mar	13,263	8,504	19,832	1,000		
11	12-18 Mar	12,174	8,813	18,548	1,000		
12	19-25 Mar	11,416	8,682	19,460	1,000		
13	26 Mar-01 Apr	10,913	8,693	14,436	1,000-1,500		
14	02-08 Apr	9,992	8,074	15,417	1,500	2,000	8,500
15	09-15 Apr	10,907	8,314	18,433	1,500	2,000	8,500
16	16-22 Apr	8,914	7,459	13,719	1,500	5,700	7,800
17	23-29 Apr	8,687	6,579	12,375	1,500	5,700	7,800
18	30 Apr-06 May	7,567	6,348	10,835	1,500-2,000	5,700	6,500
19	07-13 May	6,751	5,755	10,048	2,000	5,700	5,900
20	14-20 May	7,996	6,486	12,437	2,000	5,700	5,900
21	21-27 May	7,127	5,377	10,845	2,000	5,700	5,900
22	28 May-03 Jun	6,704	5,101	9,653	2,000	5,700	5,300
23	04-10 Jun	6,160	4,733	9,492	2,000	5,700	5,300
24	11-17 Jun	5,899	4,499	8,244	2,000	5,700	5,300
25	18-24 Jun	5,882	4,512	8,605	2,000		
26	25 Jun-01 Jul	5,577	4,204	7,588	2,000		
27	02-08 Jul	5,196	3,980	7,373	2,000		
28	09-15 Jul	5,552	4,317	8,216	2,000		
29	16-22 Jul	7,783	4,843	11,737	2,000		
30	23-29 Jul	7,241	4,907	10,640	2,000		
31	30 Jul-05 Aug	5,161	3,898	7,597	2,000		
32	06-12 Aug	5,000	3,747	7,262	2,000		

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