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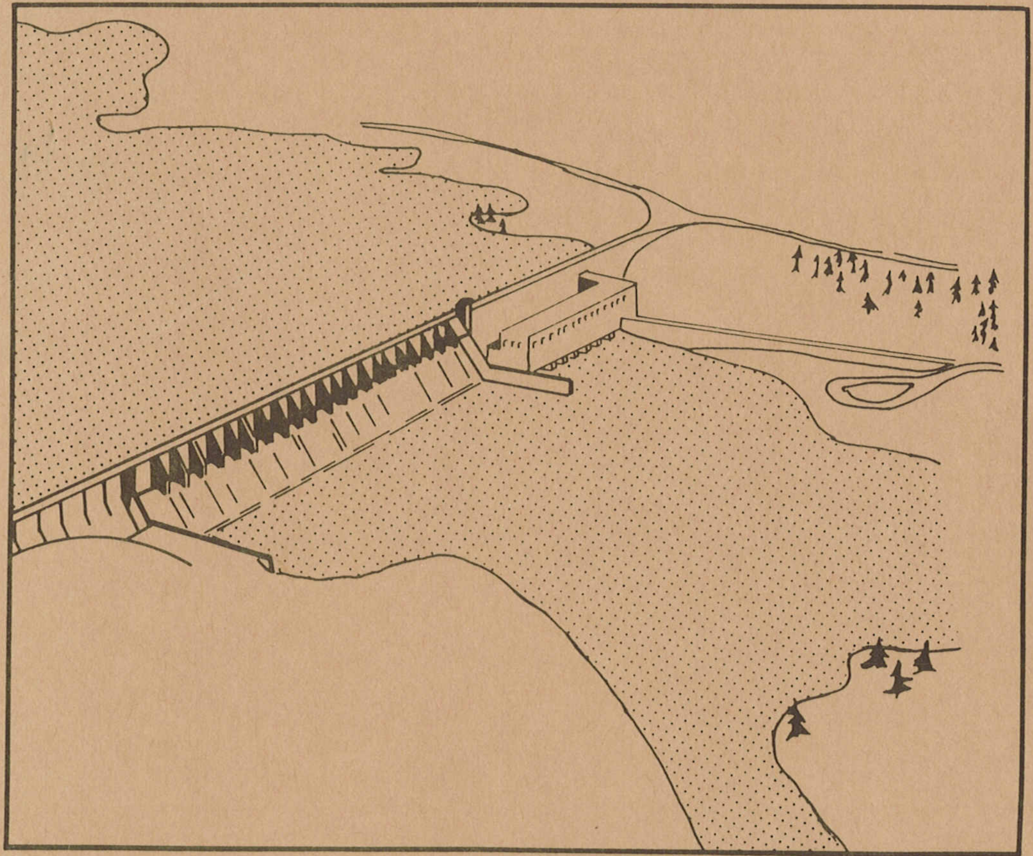

John H. Kerr Dam

ROANOKE RIVER WATER FLOW COMMITTEE REPORT FOR 1990

AUGUST 1991

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, NC 28516-9722

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ROANOKE RIVER WATER FLOW COMMITTEE REPORT FOR 1990

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

Sponsored by

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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 U.S. 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 purpose of this Flow Report is to document hydrological events and reservoir operations for 1990 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 two previous reports issued by the Flow Committee (Manooch and Rulifson 1989, Rulifson and Manooch 1990a) because it contains sections pertaining to geomorphology, water quality, recreational facilities of Kerr Reservoir, a listing of current and proposed studies of Roanoke/Albemarle natural resources, analysis of water flows for a 12-month period, sediment quality in the lower Basin, striped bass spawning activity with regard to reservoir discharge, and juvenile striped bass age, growth, and food habit analyses. In addition, discussions on floodplain ecology and forest resources are more detailed than in previous reports. Following are summaries of the major sections contained herein. Each summary is presented as a separate paragraph.

GEOMORPHOLOGY. The recent geologic history (past 18,000 years) of the lower Roanoke River and western Albemarle Sound system has been characterized by dramatic and continuous natural changes. These ongoing evolutionary processes involve major changes in the following: 1) restyling of the size and geometry of this complex drainage system; 2) shifts in chemical conditions and physical processes within the aquatic ecosystem; 3) fluctuations in the processes of erosion and sediment deposition; and 4) variations in the types of vegetation and organisms inhabiting these evolving ecosystems. The processes of change are still in progress as sea level continues to rise, causing Albemarle Sound to expand in size by eroding its sediment banks and flooding up the Roanoke River valley. Man's influence on and modifications to this drainage system during the past 300 years have added yet another major component of change to an already dynamic system. We are ever increasing our demands and effects upon this drainage system through our increased water withdrawals for industrial, municipal, and agricultural utilization; use as sewer for discharged industrial and municipal chemical, organic, and sediment wastes; and modification of adjacent lands for large-scale agriculture, silviculture, and urbanization. These and other impacts upon the lower Roanoke River and western Albemarle Sound continue to alter its water quality and to ensure us that these ecosystems are not the same today as they were yesterday, nor will they be the same tomorrow as they are today.

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 stream mileage of the Roanoke River Basin within North Carolina, it is estimated that 33% fully supports its uses, 46% partially supports, and 9% does not support its uses. The remaining 12% of stream mileage was not evaluated. In 1990, there were 41 facilities with NPDES permits operating within the lower Roanoke River Basin. Of these facilities, 10 were found to be in significant non-compliance with the conditions of their permits. Effluent from several facilities has failed acute or chronic aquatic toxicity tests. The Technical Support Branch of DEM is charged with assessing assimilative capacity of a stream (a stream's capacity to accept waste). 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 the 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.

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 harvesting.

KERR LAKE RECREATION. Extremes in water level of Kerr Reservoir affect recreational use of the seven recreation areas and two marinas managed by the North Carolina Division of Parks and Recreation. A water level of 300 feet above mean sea level (msl) enables maximum utilization of recreational areas and facilities. Some boat launching ramps become unsafe at lake levels between 290 and 297 feet msl. High water levels reduce or eliminate use of campsites, picnic areas, and access roads. For example, at 304 feet msl approximately 10% of access roads to campsites and day-use areas are inundated; 50% at 313 feet msl; and 90% at 319 feet msl. The most ideal lake levels for recreation range from 297 feet to 302 feet msl.

CHARACTERIZATION OF 12-MONTH RIVER FLOWS. Frequency analysis of the average daily flows downstream of Roanoke Rapids Dam revealed, not unexpectedly, substantial variation in the flow distribution during the year and substantial differences in pre- and postimpoundment flow distributions. These were expected since some months are wetter than others and because it was one of the objectives of the impoundment to mitigate extreme flows. Analysis of the relatively dry months (June-September) revealed a substantial number of days in which water flow is marginal at best (assuming that 2000 cfs is the minimum desirable flow, which is the lowest flow allowed under present agreements). Using the U.S. Army Corps of Engineers projected daily water use upstream of Kerr Reservoir, the percent reduction of instream flow at Roanoke Rapids gage would be 3.7%. However, at the minimums the change would be 15% at 2,000 cfs and 30% at 1,000 cfs. Because of this, substantial permitting of additional uses must result in releases from Power Pool storage or a change in reservoir management strategy.

STRIPED BASS JAI AND RIVER FLOWS. Abundance of juvenile striped bass in western Albemarle Sound is associated with Roanoke River water flows during the spring. The upper and lower flow boundaries recommended by the Committee were used to evaluate the impact of flow on the Juvenile Abundance Index (JAI), which has been recorded annually since 1955. It was postulated that as the number of days when Roanoke River water flows were within the springtime historical boundaries increased, juvenile striped bass abundance would also increase. Several models were developed to test this relationship and all revealed statistically significant correlations. The models did not identify high flow and low flow years. Most of the low JAI values were recorded when springtime flows in the Roanoke River were high.

GENERAL RIVER FLOW CONDITIONS, 1990. The flow record for the U.S. Geological Survey gage at Roanoke Rapids shows the first six months of 1990 to be the 13th wettest out of 79 years of record. For comparison, the first six months of 1989 ranked as the 29th wettest year. Flows during the period of April through mid-June 1990 were the 9th wettest on record. At the beginning of the flow augmentation period on 1 April, there was adequate storage available in Kerr Reservoir. The Reservoir level was approximately 303 feet msl. The large inflows into Kerr Reservoir caused the daily flows at Roanoke Rapids to exceed the trial flow regime 72.4% of the time. The daily flows were within the flow regime 26.3% of the time. For comparison, in 1989 the flows were within the regime 43% of the time. Flows were more stable in 1990 than in 1989.

MINIMUM RIVER FLOW REQUIREMENTS. The Federal Energy Regulatory Commission has established minimum water flow requirements for the lower Roanoke River. Upstream regulation has shifted the spring flood waters to later in the year. The impact on low flows caused by this regulation is an increase in the magnitude of minimum flows, but also an increase in the amount of time at low flows. On a daily and hourly basis, hydropower generation during peak use intervals causes extreme flow variability below the Roanoke Rapids Dam.

KERR RESERVIOR OPERATION, 1990. The Corps of Engineers attempted to operate Kerr Reservoir during 1990 in such a manner as to provide flows within the Committee's Negotiated Flow Regime. However, greater than normal rainfall and heavy inflows to the Reservoir forced deviations from the plan for most of the period.

HOURLY AND MEAN RIVER FLOWS, 1990. Only 23.5% of the hourly flows from 1 March - 30 June 1990 were within the historical Q_1-Q_3 boundaries identified by the Committee; about 32% of hourly flows were within the Negotiated Period boundaries from 1 April - 15 June. During the Negotiated Period, 57% of the days (43 of 76) had every hourly flow exceeding the recommended upper boundary. The overall trend in water flow during the spring of 1990 did not follow the historical pattern: flows increased in late May and June, when historically, they decrease.

TIME SERIES ANALYSIS, 1990 RIVER FLOW. Findings of the time series analysis for the year 1990 indicated that during the full recommended period (1 March to 30 June), the appropriate descriptive model of the flows was one which contained an autoregressive parameter at lag one and a moving average parameter at lag 21. That is, today's flow was best described by yesterday's flow and the random shock to the flow three weeks previous. This is a departure from the historical structure of the models, all of which have been totally autoregressive. For the shorter, Negotiated Period (1 April - 15 June), the time series model was not significantly different from a random walk model. The autoregression analysis showed that, as in the past, the flow still mimicked the demand for electricity. That is, over the period of a day, streamflow fell to a low point in the early morning, began to rise throughout the afternoon, and reached a peak in the early evening. This pattern was present in both the long and the short periods. Interestingly, the fluctuations were so much less pronounced during the Negotiated Period that much of the statistical significance disappeared.

STRIPED BASS AGE COMPOSITION AND SPORT HARVEST. Approximately 56,200 angler-hours of recreational fishing effort were directed specifically for striped bass in the lower Roanoke River during 1990. Most of the effort was concentrated near the spawning grounds and was greatest from 9 April - 6 May and continued until the season was closed on 9 May. Estimated harvest was 15,694 fish weighing 19,143 kg (42,204 lb). Approximately 52,400 striped bass were released in 1990. Numbers of caught and released fish combined were higher in 1990 than in 1988 or 1989, even though the fishing season was shorter in 1990. The overall success rate for striped bass harvest during 1990 was 0.16 fish and 0.19 kg per angler hour. More people from Halifax County, NC fished in the Roanoke River during the creel survey period than from any other county. Approximately one-third of the people who fish in the River during the spring do not live in a county adjacent to it. A total of 873 striped bass were aged in 1990. Males comprised 92% of the total and were mostly 3, 4, and 5 years old. Most females were 4-8 years old. About 4% of the females were less than 4 years old.

COMMERCIAL HARVEST OF STRIPED BASS. Commercial fishermen landed 100,830 pounds of striped bass valued at $101,002 in North Carolina during 1989 and 113,939 pounds valued at $159,630 during 1990. Historically, most of the fish have been caught in the Albemarle Sound area by set gill nets and pound nets. From 1980-1990, 67% to 96% of the striped bass landed by commercial gear in the State came from the Albemarle Sound area. Recent harvest estimates suggest that recreational and commercial interests may be harvesting approximately equal poundages from the Albemarle/Roanoke area. Seasons have been imposed on both harvest sectors, based on closely monitored quota allocations.

STRIPED BASS HARVEST REGULATIONS. The North Carolina resource management agencies have implemented a multitude of regulatory actions aimed at striped bass conservation from 1979 - 1991. In order to effectively manage the recreational harvest for Albemarle/ Roanoke striped bass, two distinct management areas were established effective 1 January 1991. In addition, annual harvest quotas were imposed on the recreational Albemarle/Roanoke striped bass fisheries.

STRIPED BASS EGG ABUNDANCE AND VIABILITY. Sampling for striped bass eggs was initiated on 16 April 1990 at Barnhill's Landing (River Mile 117). Eggs first appeared in samples on 24 April and were last collected on 12 June, for a 50-day spawning window. An estimated 964,791,625 eggs were spawned in the Roanoke River upstream of the sampling site. Two spawning peaks were observed: 7 May and 10 May. The estimated egg viability for the year was 58%. Spawning activity and egg viability were correlated with water temperature, which ranged from 14.0 to 23.5°C.

STRIPED BASS SPAWNING AND RESERVOIR DISCHARGE. Results of the egg studies by Rulifson conducted in 1988, 1989, and 1990 clearly illustrate the impact of water discharge from Roanoke Rapids Lake on striped bass spawning activity downstream. Spawning activity in the lower Roanoke River begins in the spring when water temperatures reach 18°C. Sudden releases of cooler water from upstream reservoirs cause ambient River water temperatures to decrease by several degrees on the striped bass spawning grounds. Spawning activity ceases if water temperatures drop below 18°C. This suggests that River flow conditions for uninterrupted spawning would include moderate and stable flows during April, May, and early June.

JUVENILE ABUNDANCE OF STRIPED BASS. The relative success of juvenile striped bass recruitment to the forming year class is monitored by the Juvenile Abundance Index (JAI). For the years 1978-1987, the JAI has averaged about 0.8 juvenile striped bass per trawl. The JAI for 1988 was 4.09 and the value for 1989 was 4.27. These were the highest values recorded since 1976, and represent the first time since 1975-1976 that two consecutive JAIs were greater than 4.0. The 1990 JAI of 1.41 was considerably less than the two previous years, but greater than the historically low levels. Comparisons between the western and eastern Albemarle Sound data suggest that Roanoke River flow affects juvenile production and distribution within the Albemarle Sound nursery area.

AGE AND GROWTH OF STRIPED BASS JUVENILES. Daily rings counted on otoliths removed from juvenile striped bass (n=101) were used to age the fish, determine growth up to 168 days, and to estimate the dates when spawning occurred for individual fish. Length conversion equations were also derived. The number of daily rings ranged from 43 to 168. Back-calculated spawning dates ranged from 30 March to 27 June, although most (68%) were spawned from 6 May through 26 May.

FOODS OF JUVENILE STRIPED BASS. The major food for young-of-year striped bass in Albemarle Sound in 1989 and 1990 was large zooplankton and invertebrates, with fish comprising a small proportion of total organisms consumed. No information on food abundance was collected, so it is difficult to ascertain whether juvenile striped bass were food limited.

ABUNDANCE AND FEEDING OF LARVAL STRIPED BASS. In 1990, approximately 98% of the 1,700 larvae present in samples were collected within the River, delta, and Batchelor Bay. Only 26 larvae were caught in western Albemarle Sound. This spatial distribution indicates dispersion and/or mortality. Two peaks in larval abundance were observed in 1990: one large peak representing 60% of the total from 11 May to 18 May, and a smaller peak (22.4%) on 24 May. Only 3.8% of the total were collected on the 12 sampling trips after 24 May. Few larvae were in feeding condition; of those, all but one were from western Albemarle Sound.

PHYTOPLANKTON. Chlorophyll *a* levels in the lower Roanoke-western Albemarle Sound have ranged generally between 1 and 10µg/L, with occasional higher values, in the 15-30 µg/L range. While these values are low in comparison to those measured during the summertime in higher salinity estuaries in the State (e.g., the Pamlico and Neuse River estuaries), they are comparable with data from the upper Pamlico River estuary and the lower Neuse River. Diatoms and green algae are the dominant taxa, together making up 80-90% of the total wet biomass. Relationships between Roanoke River flow and either chlorophyll *a* concentrations, algal biomass, or algal density are not immediately obvious.

ZOOPLANKTON. Sampling for zooplankton in 1990 was initiated on 18 April and was terminated on 17 June. A total of 25 stations in the River and western Albemarle Sound was established. Zooplankton was most abundant in the Cashie River area and was least abundant between Hamilton and just upstream of the Thoroughfare. The most abundant groups in the lower watershed were *Daphnia* and cyclopoid copepods. Dominant groups varied in the Sound from one area to another.

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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 (Fisheries/Wildlife)
Mr. Max Grimes, U.S. Army Corps of Engineers (Engineering/Hydrology)
Mr. Fred Harris, N.C. Wildlife Resources Commission (Fisheries)
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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/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)
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Dr. Stanley Riggs, East Carolina University (Geology)
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Dr. L.H. (Buddy) Zincone, Jr., East Carolina University (Modeling)

INTRODUCTION

The purpose of the Flow Report for 1990 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.

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 geomorphology, water resources, ecological resources, and age and growth of juvenile striped bass. The Committee is composed of 25 representatives of State and Federal agencies and State universities. [In addition, the Committee seeks outside expertise on areas of reservoir management, operation of dams for power production, and statistical analysis and interpretation.] A list of Committee members for 1990 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 U.S. 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. All of the work presented in the documents was endorsed by the Committee. The U.S. 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 north-eastern 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 U.S. 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.

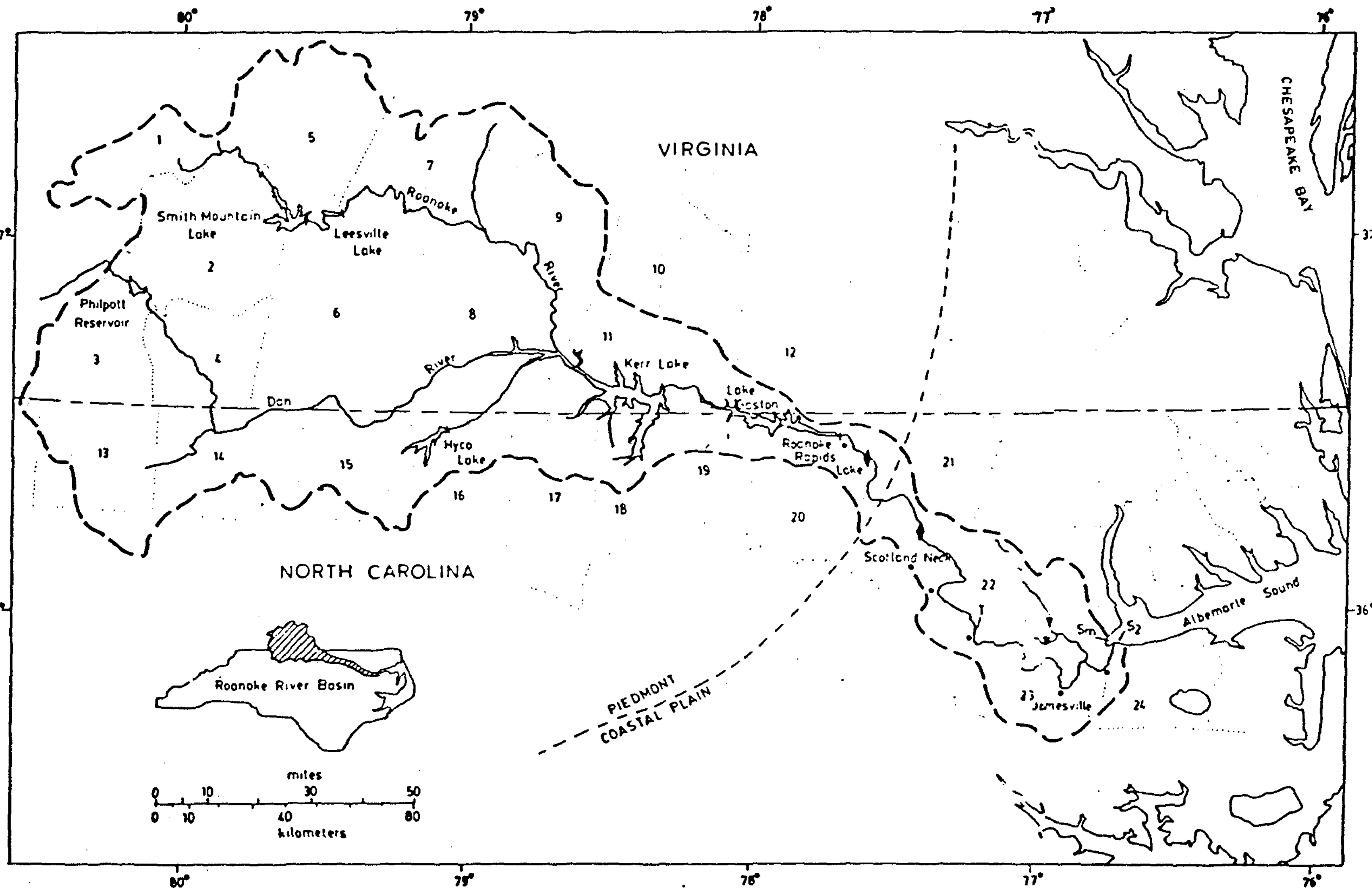


Figure 1. Drainage area of the Roanoke River Basin. Dashed line indicates approximate location of the Fall Line; diamonds= locations of USGS water quality and gaging stations; inverted triangle=USGS water quality station; T=upstream limit of tidal influence; S2=mean upstream intrusion limit of saltwater 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

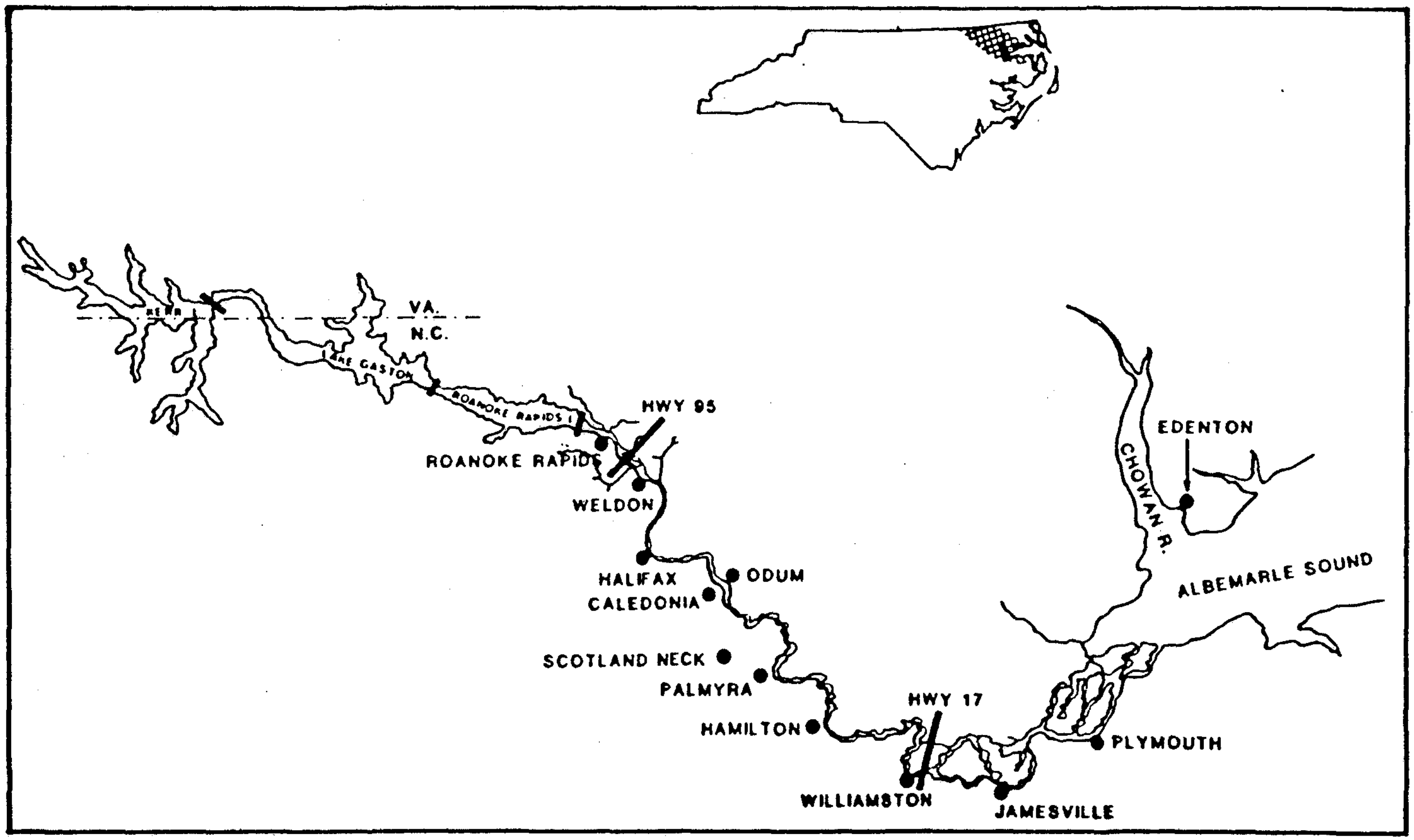


Figure 2. Lower Roanoke River watershed.

GEOMORPHOLOGY AND DEPOSITIONAL HISTORY OF THE LOWER ROANOKE RIVER AND INNER ALBEMARLE SOUND

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

Description of the Roanoke River Drainage Basin

Introduction

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 (Figure 1). 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, includes 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 small amounts of sediment and acidic blackwater 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 northern Chowan River. Between Cannon Ferry and Colerain, the Scarp crosses to the western shore of the Chowan River and forms the spectacular bluff shorelines that continue southward to 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 towards 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. Thus, 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 with a maximum of 15 to 20 feet above sea level along the base of the Scarp, with the low, flat surface sloping 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 universally 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 relative 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 with no direct water exchange with the Atlantic Ocean. The Sound ranges from totally fresh waters to slightly brackish waters, influenced by small lunar tides compounded with irregular, wind-driven tides. Sediments presently being deposited within the estuarine system are generally derived from four sources: 1) the dominant sediment component of inorganic clay that comes from the suspended sediment load in the Roanoke River during flood stages; 2) organic matter, an important secondary component (up to 20%) in some of the extensive mud deposits, derived from storm flushing and erosion of marsh and swamp forest shorelines that occur throughout the estuarine system; 3) most sand and some clay from erosion of Quaternary sediment units that form sediment bank shorelines and underlie the shallow platform flanks of most of the estuarine area; and 4) the outermost portion of Albemarle Sound with fine sands derived from the barrier islands by wind and storm overwash 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 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.

Geologic Framework of the Roanoke River Basin

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 (Riggs et al. in prep.). The Quaternary history continues today as discussed in subsequent sections of this report.

Figure 3 outlines the area that will be considered in the remainder of this report. It includes the lowermost portion of the lower Roanoke River and the inner (western) portion of Albemarle Sound and including the transition zone from river to estuarine environments.

Patterns of Sedimentation in the Lower River and Inner Sound

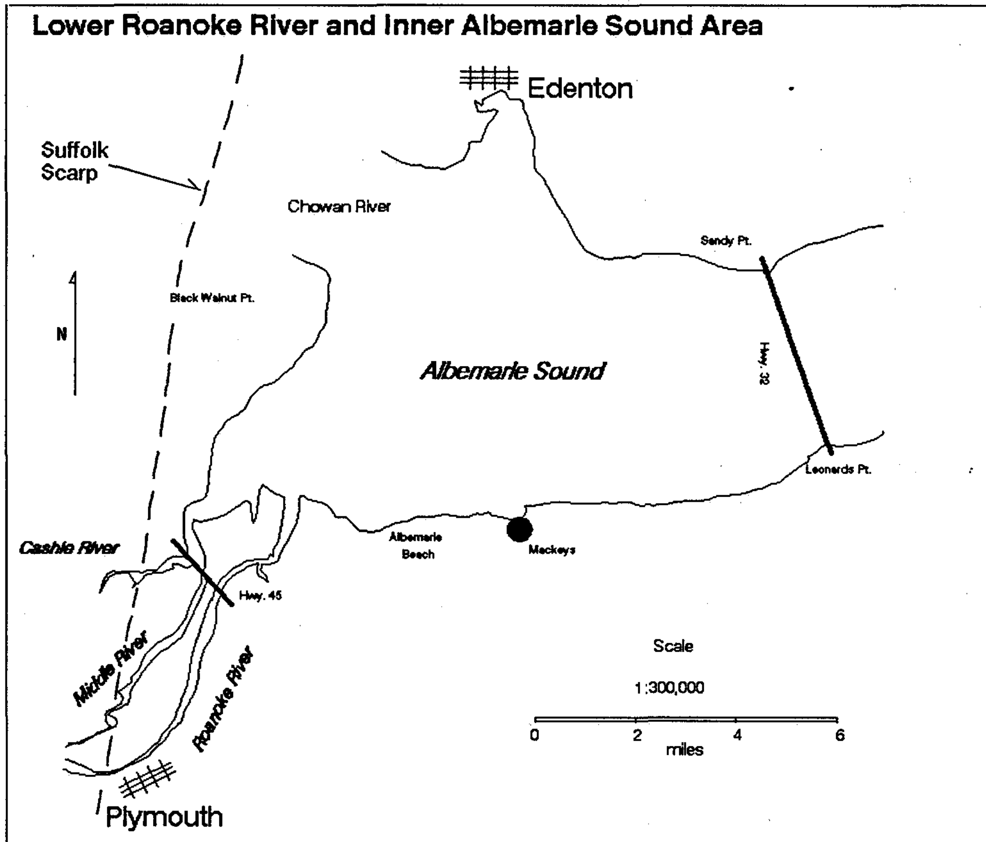
Subsurface Sediment Units

Six vibracores (up to 7 m in length), 53 surface samples, and two surface sample-bathymetric profiles (Figure 4) have been used to interpret the subsurface geology of the transition zone from the lower Roanoke River to the inner Albemarle Sound. Figure 5 shows the location of two geologic cross sections constructed through this transition zone. Three distinct sediment units have been recognized within the cores. These units are displayed in sections 1-1' and 2-2' (Figures 6 and 7, respectively). Each unit represents a very different depositional environment that has changed systematically through time.

The lowermost unit (unit 1) consists of basal medium to coarse sands that fine upward to fine sands, muds, and is locally capped by *in situ* peat deposits. The basal coarse to fine sands are interpreted to represent River channel lag sediments that were derived from the erosion of previous sediment units that constitute the channel banks. The upper muds and peats represent floodplain sediments deposited in broad low-energy environments with an abundance of local organic input. This gradational sediment sequence underlies the entire area and generally rises westward into the Roanoke River system. Carbon 14 dates place the beginning age for deposition of this unit at <5,000 years before present (Riggs et al. in prep.; Erlich 1980).

The middle unit (unit 2) is a highly interlaminated sequence of very fine, clean sands, and dark brown, organic-rich (>10 % organic matter) mud. Individual laminations range from <1mm to a few cm in thickness with up to hundreds of interlaminations. This unit is not present everywhere; it does not occur within either the Roanoke River or the River mouth, but becomes important within the estuary and thickens dramatically seaward to over 6 meters thick. The cyclical interlaminated structures are interpreted to represent normal inner estuarine deposition punctuated by storm events with a slightly irregular periodicity. The organic-rich muds represent the day to day estuarine depositional environments within the innermost and narrow portion of the flooded estuarine system. The irregular thicknesses and repetitive patterns of the very fine sand laminae suggest that they are due to short, high-energy episodes of active shoreline erosion, sediment transport, and deposition throughout the narrow inner estuarine environment. The very fine sand laminae tend to thin and fine in the seaward direction as the estuarine system becomes wider and deeper. The thinning and absence of this unit in the Roanoke River system suggest that these sediments are of an estuarine origin rather than a river origin.

The uppermost unit (unit 3 in cross-sectional profiles, Figures 6 and 7) consists of two parts that are directly related to location within the river-estuarine system: location along the



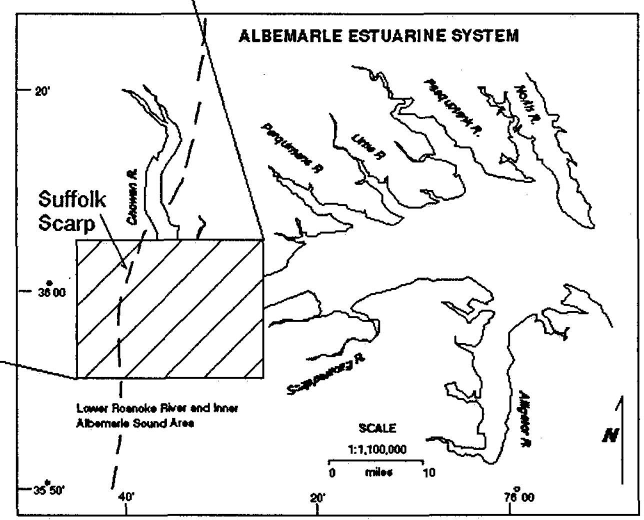


Figure 3. Lower Roanoke River and inner (western) Albemarle Sound.

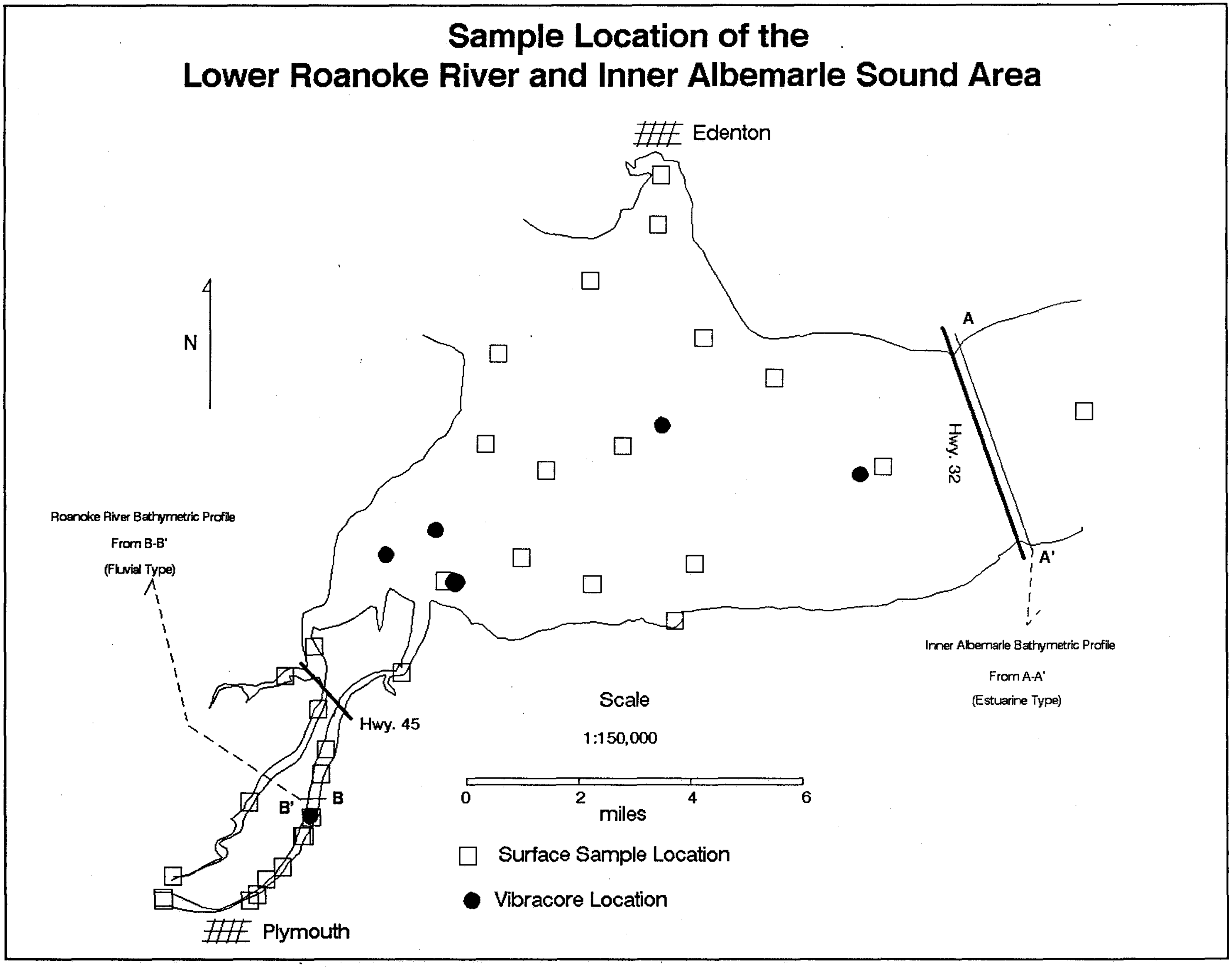


Figure 4. Location map of surface samples, vibracores, and bathymetric profiles.

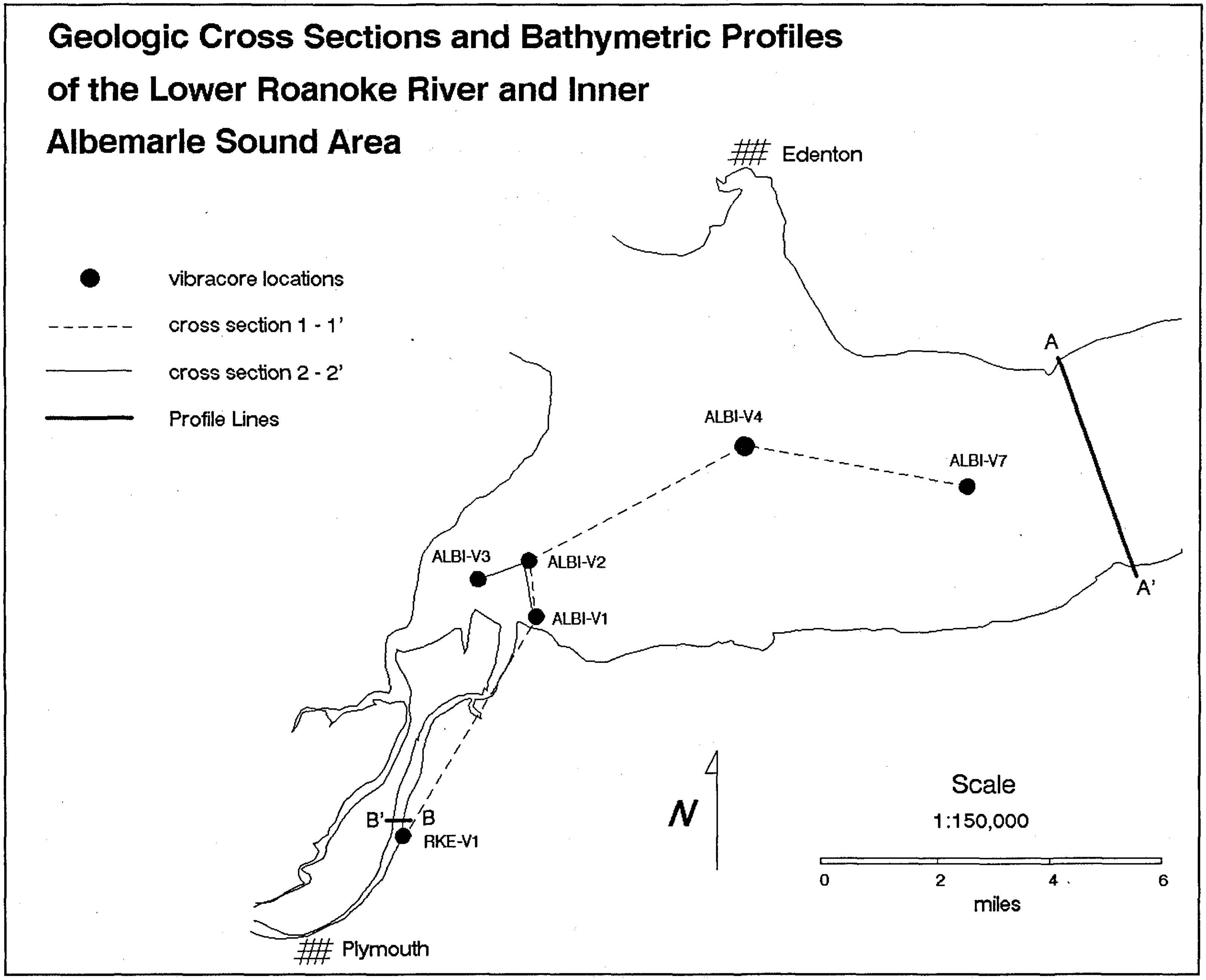


Figure 5. Locations of geologic cross-sections and bathymetric profiles

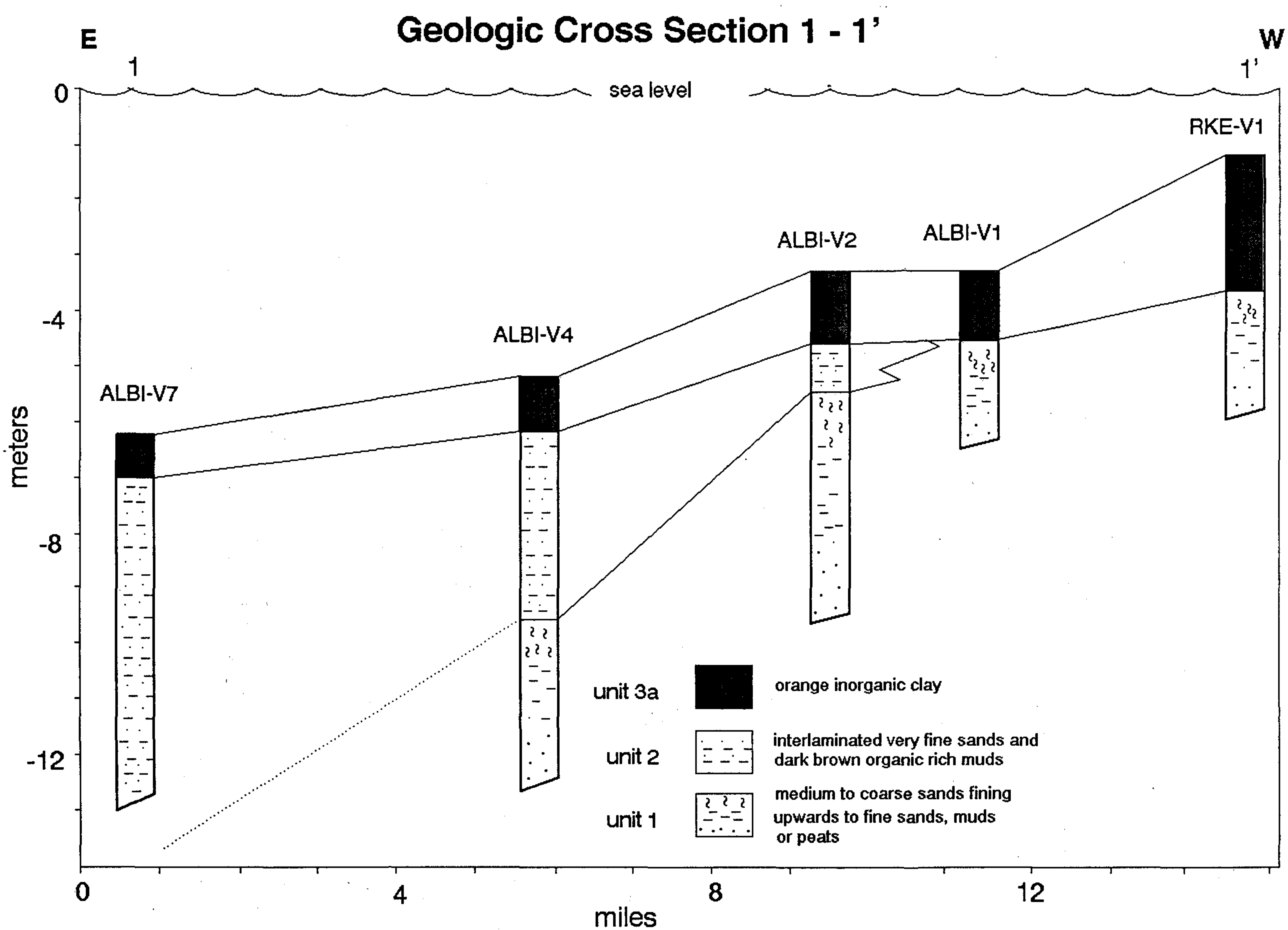


Figure 6. Geologic cross-section 1-1' showing the distribution of the three major subsurface sediment units. Location of section 1-1' is on Figure 5.

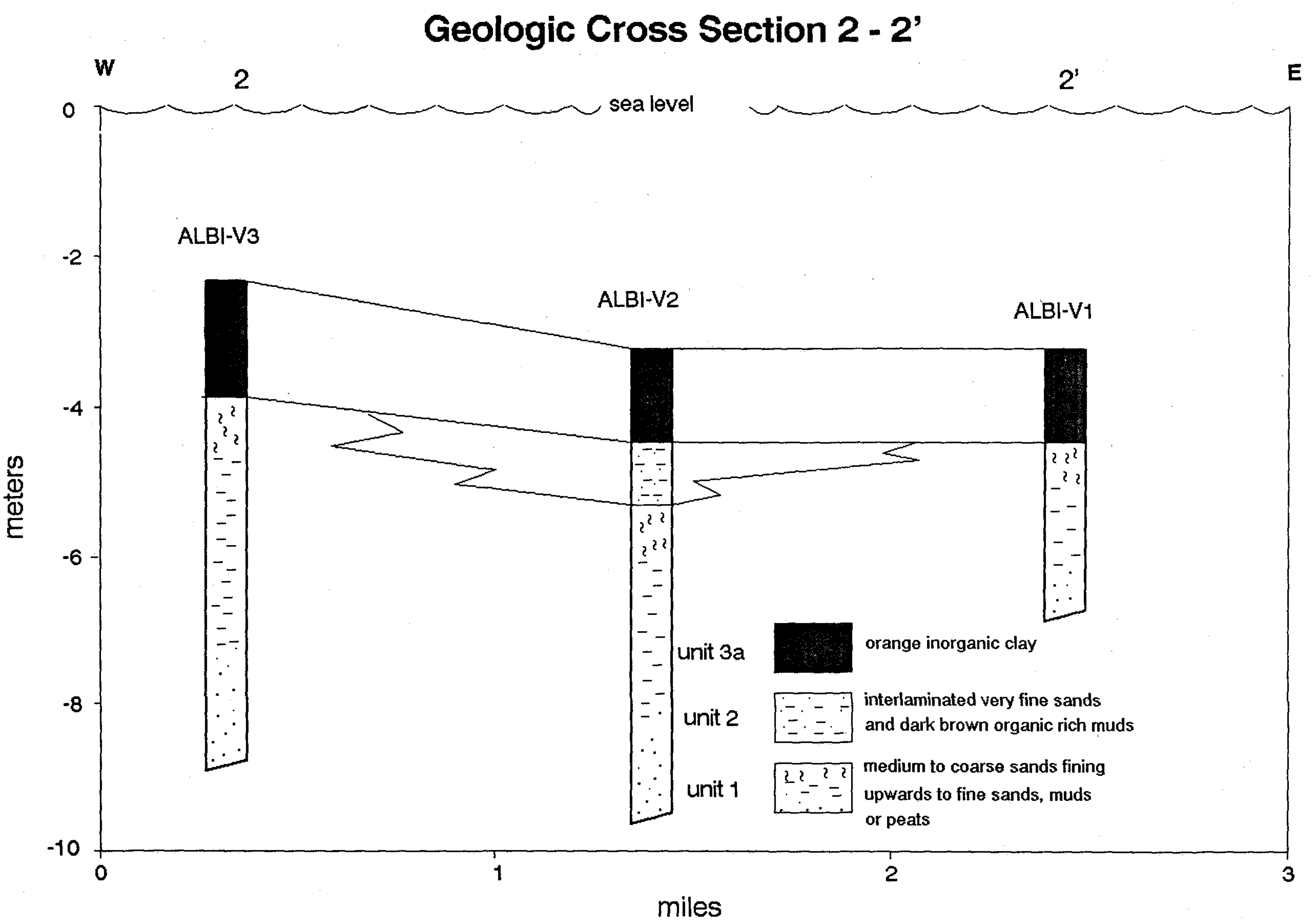


Figure 7. Geologic cross-section 2-2' showing the distribution of the three major subsurface sediment units. Location of section 2-2' is on Figure 5.

bathymetric profile, and the physical processes operating within different portions of the depositional system. This depositional unit generally constitutes the major portion of the modern surface sediment regime within the aquatic portion of both the river and estuarine systems. Unit 3a is an orange, inorganic clay that ranges from 1 to 3 m thick that fills the deeper, basinal portions of the estuary and the shallow channel flanks within the river environments. This unit is a very uniform clay mineral sediment with no sand laminae and minor organic matter (<5%). Unit 3a tends to thin eastward into the estuarine system and overlies all other units throughout this transition zone, suggesting that the clay mineral source is from upstream in the Roanoke River drainage basin.

Unit 3b consists of basically clean fine to medium quartz sands which only locally are coarse grained. The sands within this unit have quite different patterns of distribution depending upon their location within either the river or estuarine system, or the transitional zone in between these two systems. In the river system, sands occur within the channel, while in the estuarine system sands occur totally on the shallow perimeter platforms. Figures 8 and 9 are bathymetric profiles A-A' and B-B' across the estuary and river systems, respectively (see Figure 5 for profile location). Notice the inverse sediment distribution pattern that exists between the sand and mud (silt plus clay) components in these two systems. Unit 3c consists of organic and clay-based peat deposits that form within the extensive swamp forest wetlands which constitute a major environmental portion of the Roanoke River system. This environment and associated sediments extend eastward and terminate at the River mouth by the leading edge of estuarine drowning.

Modern Surface Sediments

The top of Unit 3 forms the modern surface sediments throughout the entire lower Roanoke River and inner Albemarle Sound area. The occurrence and distribution of the specific sediment subtypes (unit 3a = orange, inorganic clays; unit 3b = fine to medium quartz sands; and unit 3c = peats and clay-based peats) 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). Figure 10 shows the general distribution of the various sediment types that constitute the modern deposition of unit 3.

Surface sediment distribution within the lower Roanoke River (from Plymouth to the River mouth) consists of sand dominated channel deposits (unit 3b), mud dominated channel flanks (unit 3a), and peats in the adjacent swamp forests (unit 3c) (Figure 9). 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, a consequence of 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.

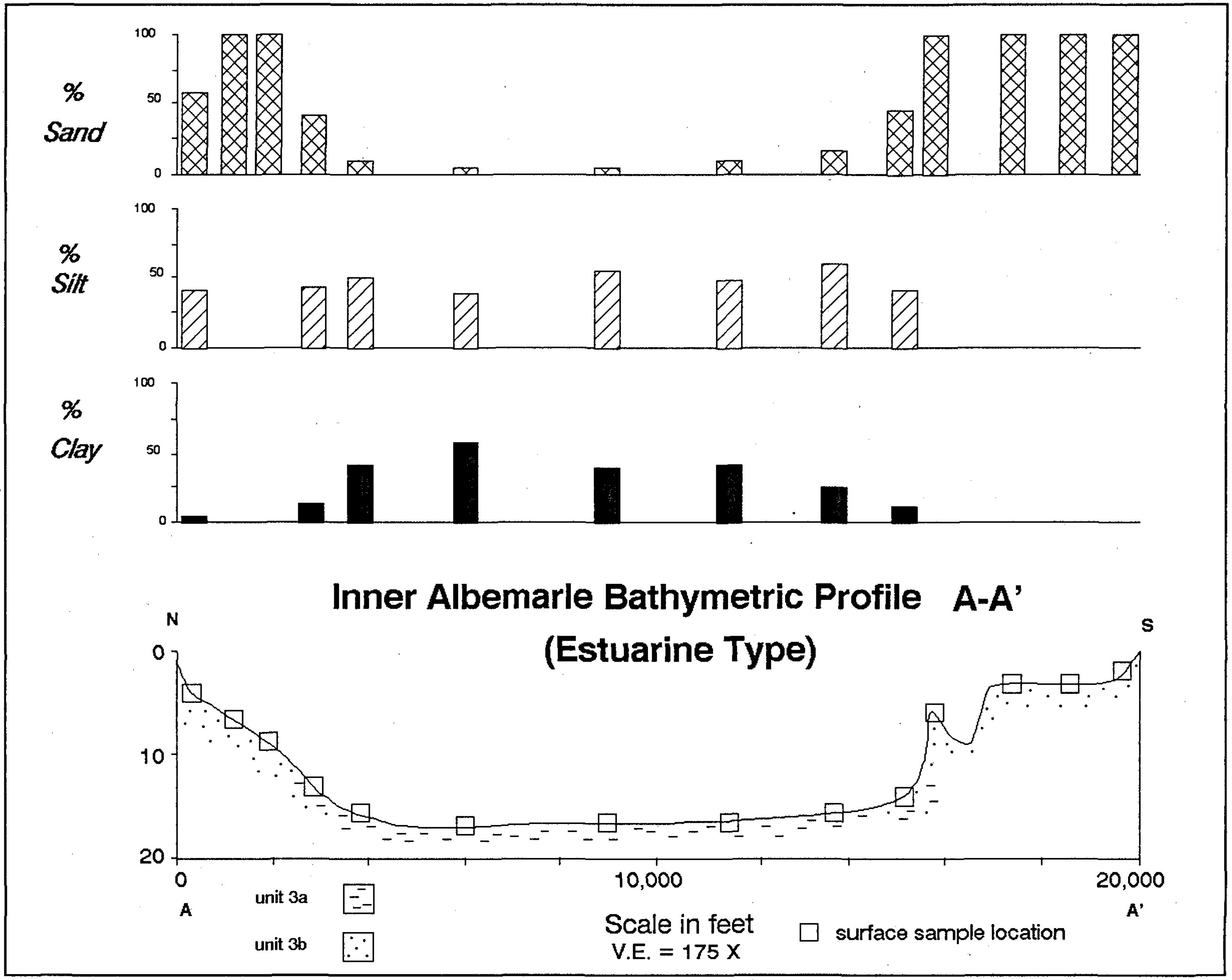


Figure 8. Bathymetric profile A-A' across inner (western) Albemarle Sound showing the distribution of the three major sediment components and their relationships to bottom morphology. Location of profile A-A' is on Figure 5.

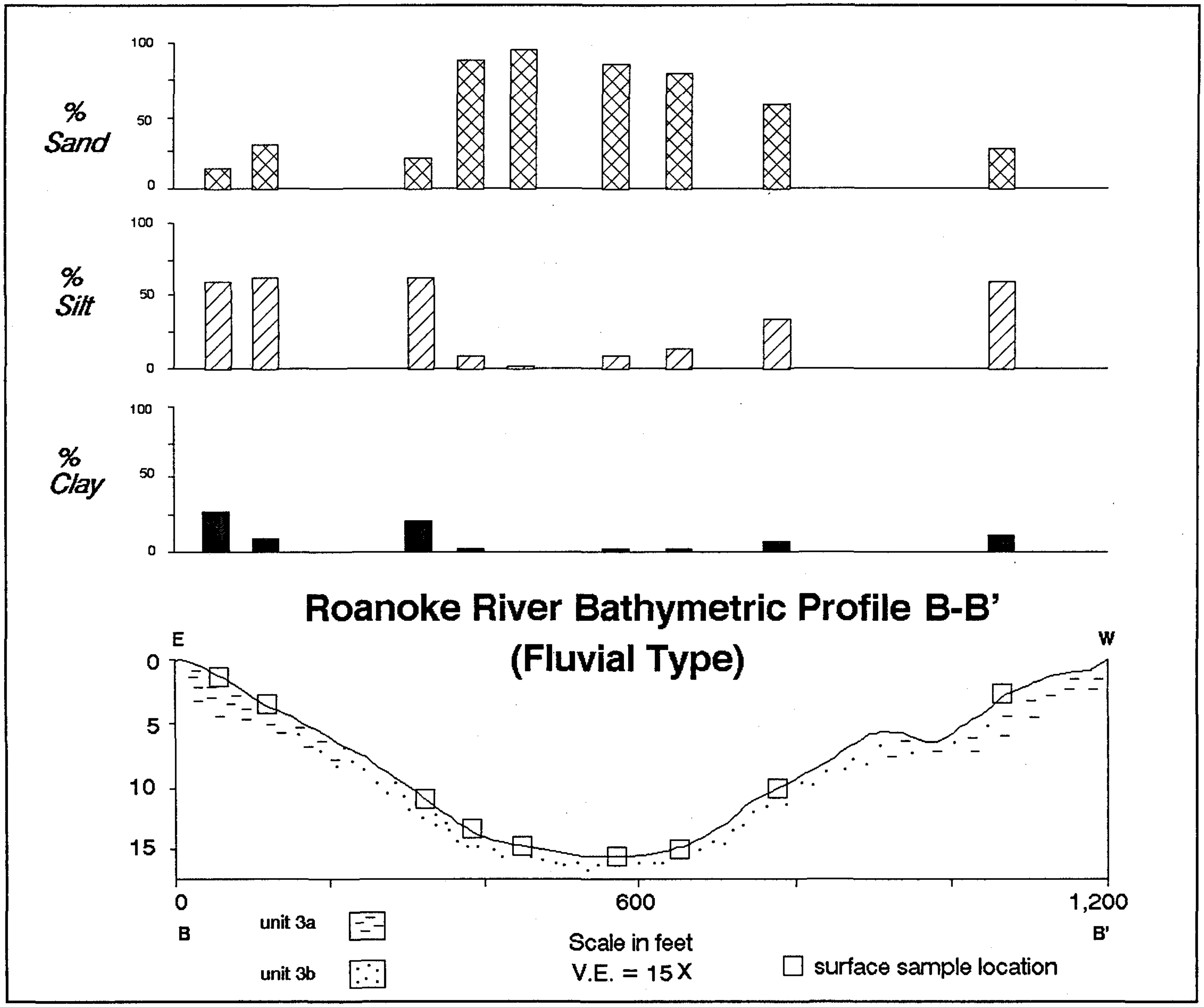


Figure 9. Bathymetric profile B-B' across the lower Roanoke River showing the distribution of the three major sediment components and their relationships to bottom morphology. Location of profile B-B' is on Figure 5.

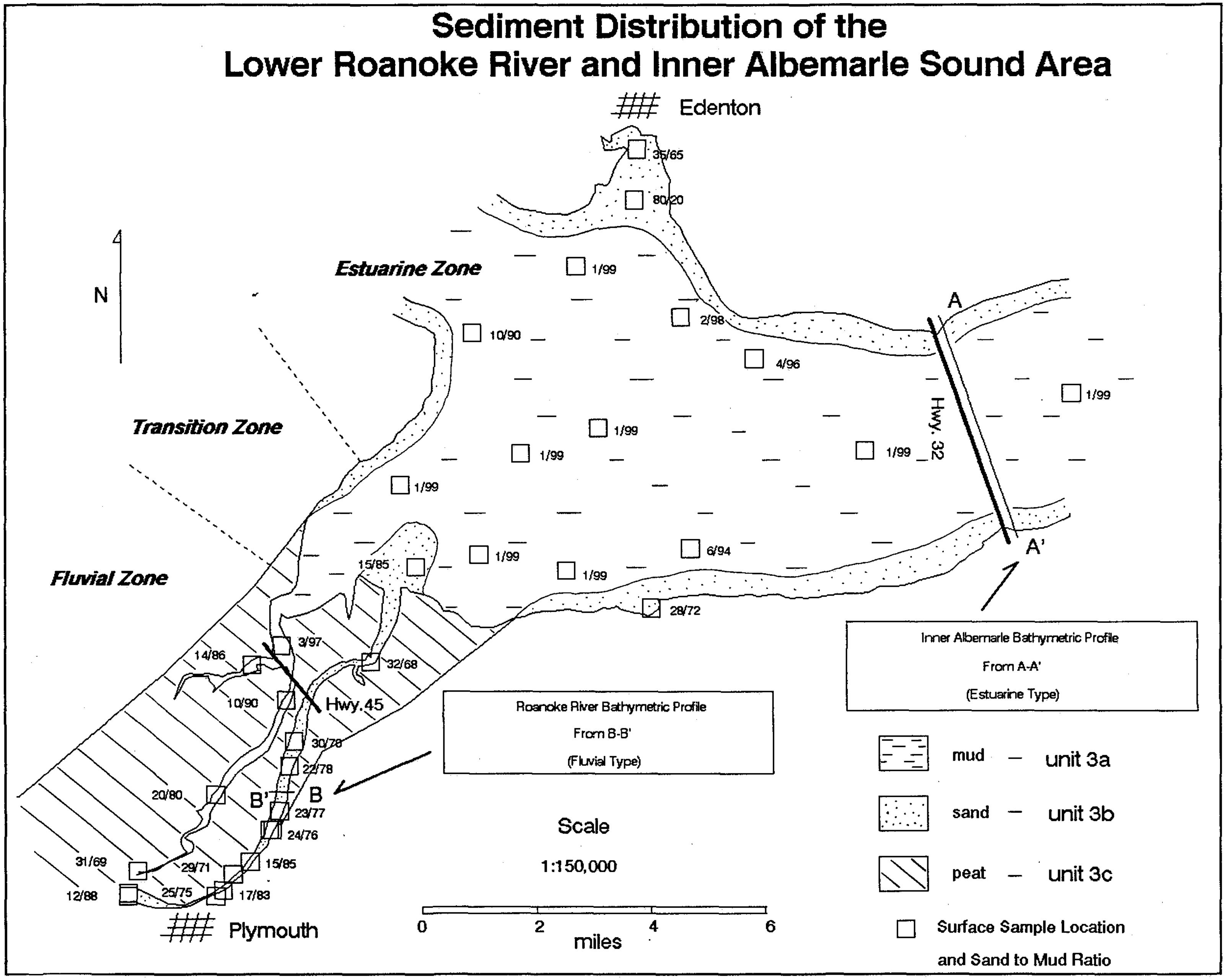


Figure 10. Map showing the distribution and composition of surface sediments within the various depositional zones of the lower Roanoke River and inner (western) Albemarle Sound.

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 accumulalation 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, 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 presents 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 (Figure 10), 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 to produce 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 these 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 orange, inorganic clays (unit 3a) with sand to mud ratios of 1:99 (Figures 6 and 10). 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 (Figures 8 and 10). These eroding sediment banks are the sole source for the thin, platform sands (unit 3b). 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.

Based upon the general patterns of sediment distribution and their changes through time, we can develop several very 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 dams and the resulting control of the water discharge (Figure 2), has had smaller but still important effects upon the resulting patterns of deposition. The effect of this has allowed the mud deposits to accumulate along the River channel flanks.

3. Rates of sedimentation within the inner Albemarle estuarine area are significantly higher than the slower, more normal 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. The recent change to a thick sequence of sediments with almost a total absence of included organic matter (<5%) around the mouth and up the Roanoke River, supports this conclusion.

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 layer of sands occurring on the shallow platform margins of Albemarle Sound is from the ongoing shoreline erosion of the adjacent Quaternary sediment banks.

Origin and Depositional History

Quaternary History

The morphology and confining sediment units of the drainage system, as well as the modern sediment and chemical character of the lower Roanoke River-Albemarle Sound water bodies are total products of the last one and two-thirds million years of geologic history, referred to as the Quaternary. During the Quaternary, massive ice sheets repeatedly formed in the polar regions and moved equator-wards across large portions of adjacent continents. In North America, the ice sheets moved southward to the Missouri and Ohio Rivers and extended across New York, New Jersey, and onto the New England continental shelf. Development of mile-thick ice sheets covering vast continental areas requires large volumes of water. Consequently, the periods of glaciation were accompanied by worldwide lowering of sea level (down to 125 meters below present sea level). Conversely, deglaciation brought about worldwide rise in sea level (up to 50 meters above present sea level). During the past several million years of history, the area now occupied by Albemarle Sound and the lower Roanoke River Basin has experienced repeated inundations by the sea and subsequent subaerial re-exposure as sea level oscillated in response to repeated polar glaciation-deglaciation.

Holocene Flooding Event

The Holocene represents the time since the last major period of glaciation (18,000 years ago) when the polar ice mass extended down to and was forming the features we now know as Cape Cod, MA and Long Island, NY. Riggs and Belknap (1988) described the scenario in North Carolina at this time as follows. Sea level was about 125 meters below the present level placing the ocean shoreline between 10 to 75 miles east of the present Outer Banks and beyond the edge of our present continental shelf. Cool and semiarid climatic conditions supported sparse vegetative cover with enough precipitation to maximize sediment erosion. The resulting sediment-choked, braided Roanoke River flowed across the sub-aerially exposed continental shelf and discharged coarse terrigenous sediments into the Roanoke Submarine Canyon. As climates moderated and glaciers receded, first boreal and then temperate vegetation developed along with extensive wetland pocosins (Whitehead 1981). Increased vegetative cover decreased the volume and size of River sediment regimes to predominantly a suspended load of silt and clay. The leading edge of the transgression flooded topographic lows, forming the present embayed estuarine system while the barrier islands migrated upward and landward across the continental shelf to their present location. Behind the barriers, old River channels were backfilled, first with a basal sequence of River gravel and coarse sand, followed by thick accumulations of organic-rich, estuarine mud and swamp forest peats.

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). Sea level rise is the basic cause, and storm wave energy is the force, of 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). The complex, broad, shallow aquatic environments of Albemarle Sound extending many miles into the Coastal Plain are the direct consequences of this process. 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 as demonstrated by Figures 11, 12, and 13. The maps in Figures 11 and 12 show the reconstructed shoreline position at between 6,000 to 8,000 and 4,000 to 5,000 years ago, respectively. Assuming transgression continues at the present rate, Figure 13 projects the position of the Albemarle Sound shoreline between 100 and 500 years into the future.

Depositional History

All three subsurface sediment units are interpreted to be Holocene in age and represent the depositional history of the river-estuarine transition zone during the past 5,000 years or less. Prior to the deposition of the basal unit 1 (>5,000 years before present), sea level was low and this entire region was a subaerial floodplain with multiple braided channels of the Roanoke River incised into it. The basal fining upward sequence of unit 1 is interpreted to represent the initial flooding process as sea level rose and began to inundate the braided channel complex of the Roanoke River floodplain, first in the eastern portion of section 1-1' (Figure 6) and systematically migrating westward through time. The initial flooding process caused systematic decreases in River gradients and processes causing the gradual backfill of broad, multiple channel systems with increasing development of broad, highly vegetated floodplains leading to broad depositional areas of mud and peat deposition and accumulation. Also, as sea level rose, the flooding process and resulting depositional environments migrated slowly westward and upslope through time.

Units 1 (River backfill deposits) and 2 (estuarine deposits) represent a contemporaneous couplet that migrated upward and landward in response to rising sea level and the general flooding process. Both of these units are interpreted to represent pre-man conditions within the Roanoke River drainage basin; deposition began about 5,000 years before present and continued up until about 300 years ago. The sediments in these units suggest that the Roanoke River discharge was not a mud sediment laden stream as all Piedmont streams are today, including the Roanoke River. Rather, the pre-man drainage basin would have been 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.

The orange, inorganic-rich clays of unit 3 are interpreted to be derived from erosion in the Piedmont Province reflecting the introduction of man into the Roanoke drainage basin. Time of large-scale land clearing for logging, farming, and urban construction that began in the early 18th century, opened the soil to major erosive forces that produced an extensive fine-grained sediment load. This increased sediment supply of inorganic clays delivered to the estuarine sys-

Figure 11. Map showing interpreted location of Albemarle Sound and the Roanoke River at approximately 6,000 to 8,000 years before present. Sea level was considerably lower due to the occurrence of much more extensive Quaternary continental ice masses of the last glacial episode. Figure is from Riggs et al. (1978).

Figure 12. Map showing the interpreted location of Albemarle Sound and the Roanoke River at approximately 4,000 to 5,000 years before present. Sea level is rising, causing the upward and landward migration of Albemarle Sound as it floods up the Roanoke River. This flooding is due to the continued decline of continental ice masses of the last glacial episode and the resulting rise in global sea level. Figure is from Riggs et al. (1978).

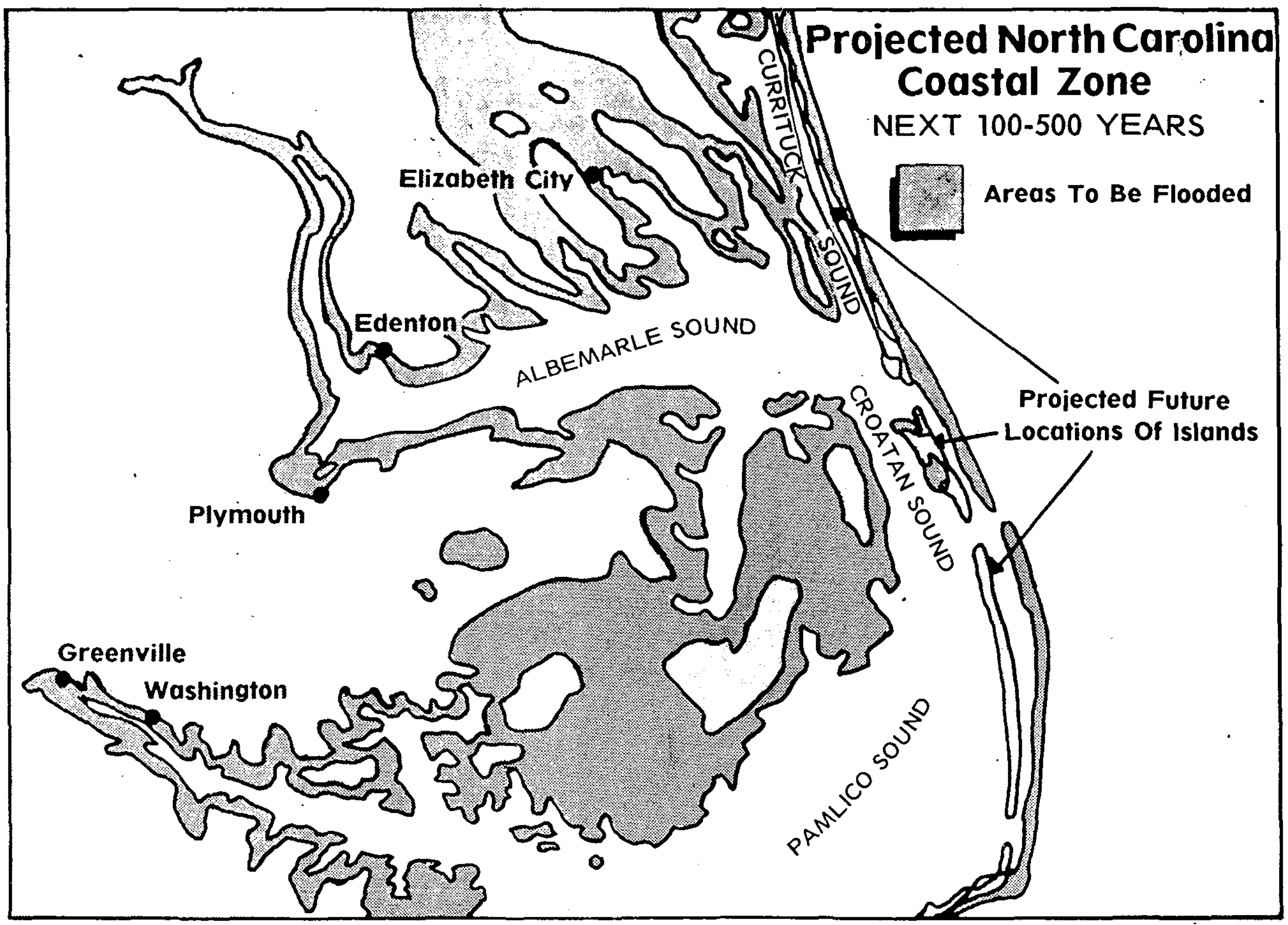


Figure 13. Map showing the interpreted location of Albemarle Sound and the Roanoke River at approximately 100 to 500 years in the future. The latter situation will occur in about 500 years if the present rate of rise in global sea level continues; however, if the "-greenhouse effect" is real and if the 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).

tem, rapidly overwhelmed the normal processes of sedimentation with a dramatic change in type, amount, and rate of sedimentation. This unit probably represents the past 300 years of deposition and mostly the past 125 years (since 1865). Sedimentation patterns changed quickly throughout the entire region as indicated by the minor gradational zone between the underlying units and the overlying unit 3. Sedimentation rates were probably at maximum levels during the period from about 1865 until the early 1950s when construction of the first of a series of dams on the Roanoke River was completed. Rates of deposition should have slowed during the past 30 years due to dam impoundments trapping more sediment and increased awareness, laws, and practices to decrease amounts of sediment pollution. However, the cumulative intensity of larger scale clearing practices downstream involving ever bigger equipment appears to have maintained the levels and rates of sedimentation. This is indicated by the nature of the modern surface sediments on the top of unit 3 (Figure 10).

WATER RESOURCES

Water Quality of the Lower Roanoke River Basin

Stephanie Spence Briggs

Introduction

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 (Tables 1-3). 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) (EHNR 1990).

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. These programs will be discussed later in this chapter.

The Roanoke River Basin encompasses 3,603 square miles in 17 counties located in the Piedmont and inner Coastal Plain regions of the State (Figure 14). 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 2,351 stream miles in North Carolina's portion of the Roanoke River Basin (EHNR 1990).

Use Support

Of the stream mileage of the Roanoke River Basin in North Carolina, it is estimated that 33% fully supports its uses, 46% partially supports, and 9% does not support its uses (Table 4). The remaining 12% was not evaluated.

Table 1. State of North Carolina water quality standards for bodies of fresh water (DEM). WS = water supply classes; trout = trout waters.

	Standards for all freshwater		More stringent standards to support additional uses	
Parameters	Aquatic life	Human health	WS classes	Trout
Arsenic (µg/L)	50			
Barium (mg/L)			1.0	
Benzene (µg/L)		71.4	1.19	
Beryllium (ng/L)		117	6.8	
Cadmium (µg/L)	2.0			0.4
Carbon tetrachloride (µg/L)		4.42	0.254	
Chloride (mg/L)	230 (AL)		250	
Chlorinated benzenes (µg/L)			488	
Chlorine, total residual (µg/L)	17 (AL)			17
Chlorophyll *a*, corrected (µg/L)	40 (N)			15 (N)
Chromium, total (µg/L)	50			
Coliform, total (MFTCC/100ml)			50 (N)(2)	
Coliform, fecal (MFTCC/100ml)		200 (N)		
Copper (µg/L)	7 (AL)			
Cyanide (µg/L)	5.0			
Dioxin (ng/L)		0.000014	0.000013	
Dissolved gases	(N)			6.0
Dissolved oxygen (mg/L)	5.0 (Sw)(1)			6.0
Fluoride (mg/L)	1.8			
Hardness, total (mg/L)			100	
Hexachlorobutadiene (µg/L)		49.7	0.445	
Iron (mg/L)	1.0 (AL)			
Lead (µg/L)	25 (N)			
Manganese (µg/L)			50 (WSII & III:200)	
MBAS (µg/L) (Methylene-Blue-Active Substances)	500			
Mercury (µg/L)	0.012			
Nickel (µg/L)	88		25	
Nitrate nitrogen (mg/L)			10	
Pesticides				
Aldrin (ng/L)	2.0	0.136	0.127	
Chlordane (ng/L)	4.0	0.588	0.575	
DDT (ng/L)	1.0	0.591	0.588	
Demeton (ng/L)	100			
Dieldrin (ng/L)	2.0	0.144	0.135	
Endosulfan (ng/L)	50			
Endrin (ng/L)	2.0			
Guthion (ng/L)	10			
Heptachlor (ng/L)	4.0	0.214	0.208	
Lindane (ng/L)	10			
Methoxychlor (ng/L)	30			
Mirex (ng/L)	1.0			
Parathion (ng/L)	13			
Toxaphene (ng/L)	0.2			

Table 1. (Continued)

Parameters	Standards for all freshwater: Aquatic life	Standards for all freshwater: Human health	More stringent standards to support additional uses: WS classes	More stringent standards to support additional uses: Trout
Pesticides (continued)				
2,4-D (μg/L)			100	
2-4,5-TP (Silvex) (μg/L)			10	
pH (units)	6.0-9.0 (Sw)			
Phenolic compounds (μg/L)		(N)	1.0 (N)	
Polychlorinated biphenyls (ng/L)	1.0			
Polynuclear aromatic hydrocarbons (ng/L)		31.1	2.8	
Radioactive substances		(N)		
Selenium (μg/L)	5			
Silver (μg/L)	0.06 (AL)			
Solids, total dissolved (mg/L)			500	
Solids, suspended	(N)			
Sulfates (mg/L)			250	
Temperature	(N)			
Tetrachloroethane (1,1,2,2) (μg/L)		10.8	0.172	
Tetrachloroethylene (μg/L)			0.8	
Toluene (μg/L)	11			0.36
Toxic Substances	(N)			
Trialkyltin (μg/L)	0.008			
Trichloroethylene (μg/L)		92.4	3.08	
Turbidity (NTU)	50,25 (N)			10 (N)
Vinyl chloride (μg/L)		525	2	
Zinc (μg/L)	50 (AL)			

Note:
- (N) See 28 .0211(b), (c), (d), or (e) for narrative description of limits.
- (AL) Values represent action levels as specified in .0211(b)(4).
- (Sw) Designated swamp waters may have a pH as low as 4.3 and dissolved oxygen less than 5.0 mg/L if due to natural conditions.
- (1) An instantaneous reading may be as low as 4.0 μg/L but the daily average must be 5.0 μg/L or more.
- (2) Applies only to unfiltered water supplies.
- WS Water supply (see Table 2 for WS levels: I-II).
- Trout Trout waters. Suitable for natural trout propagation and maintenance of stocked trout.

Table 2. State of North Carolina water quality standards for bodies of saltwater (DEM).

Parameters	Standards for all tidal saltwaters: Aquatic life	Standards for all tidal saltwaters: Human health	More stringent standards to support additional uses Class SA
Arsenic (µg/L)	50		
Benzene (µg/L)		71.4	
Beryllium (ng/L)		117	
Cadmium (µg/L)	5.0		
Carbon tetrachloride (µg/L)		4.42	
Chlorophyll *a* (µg/L)	40 (N)		
Chromium, total (µg/L)	20		
Coliform, fecal (MFTCC/100ml)		200 (N)	14 (N)
Copper (µg/L)	3 (AL)		
Cyanide (µg/L)	1.0		
Dioxin (ng/L)		0.000014	
Dissolved gases	(N)		
Dissolved oxygen (mg/L)	5.0 (1)		
Hexachlorobutadiene (µg/L)		49.7	
Lead (µg/L)	25 (N)		
Mercury (µg/L)	0.025		
Nickel (µg/L)	8.3		
Phenolic compounds		(N)	
Polychlorinated biphenyls (ng/L)	1.0	0.079	
Polynuclear aromatic hydrocarbons (ng/L)		31.1	
Pesticides			
Aldrin (ng/L)	3.0	0.136	
Chlordane (ng/L)	4.0	0.588	
DDT (ng/L)	1.0	0.591	
Demeton (ng/L)	100		
Dieldrin (ng/L)	2.0	0.144	
Endosulfan (ng/L)	9.0		
Endrin (ng/L)	2.0		
Guthion (ng/L)	10		
Heptachlor (ng/L)	4.0	0.214	
Lindane (ng/L)	4.0		
Methoxychlor (ng/L)	30		
Mirex (ng/L)	1.0		
Parathion (ng/L)	178		
Toxaphene (ng/L)	0.2		
pH (units)	6.8 - 8.5 (1)		
Radioactive substances		(N)	
Salinity	(N)		
Selenium (µg/L)	71		
Silver (µg/L)	0.1 (AL)		
Solids, suspended	(N)		
Temperature	(N)		
Tetrachloroethane (1,1,2,2) (µg/L)		10.8	
Toxic Substances	(N)		
Trialkyltin (µg/L)	0.002		
Trichloroethylene (µg/L)		92.4	

Table 2. (Continued)

Parameters	Standards for all tidal saltwaters: Aquatic life	Standards for all tidal saltwaters: Human health	More stringent standards to support additional uses Class SA
Turbidity (NTU)	25 (N)		
Vinyl chloride (μg/L)		525	
Zinc (μg/L)	86 (AL)		

Note: (N) See 28 .0211(b), (c), (d), or (e) for narrative description of limits.
(AL) Values represent action levels as specified in .0211(b)(4).
(1) Designated swamp waters may have a pH as low as 4.3 and dissolved oxygen less than 5.0 mg/L if due to natural conditions.
SA Shellfishing waters

Of the degraded stream mileage, approximately 51% is thought to be a result of agricultural nonpoint source runoff (Table 4). Sediment is thought to be the most widespread cause of this degradation (EHNR 1990).

Agriculture

In 1984, the General Assembly appropriated $2,165,000 to assist landowners from 16 counties within Nutrient Sensitive Waters (NSW) watersheds of the Chowan River, Falls Lake, and Jordan Lake in implementing agricultural best management practices (BMPs). This voluntary cost share program was expanded in July 1986 to include 17 coastal counties, thereby formally creating the N.C. Agriculture Cost Share Program (ACSP) for nonpoint source (NPS) pollution control. An additional 23 counties (Soil and Water Conservation Districts) were made eligible for the ACSP in 1987. These included all counties in the Roanoke River Basin except Vance, Warren, Halifax, and Martin counties. The ACSP was expanded statewide in 1989 and will make approximately $8 million available annually for paying 75% of the cost to implement BMPs and 50% of the cost to provide technical assistance to landowners (Harding, pers. comm.).

The local Soil and Water Conservation District Boards, under the administration of the N.C. Soil and Water Conservation Commission, 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 agricultural NPS Pollution Control Section of the N.C. Division of Soil and Water Conservation provides administrative and technical support to the Commission. The NPS Section 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. The N.C. Division of Environmental Management provides additional guidance in targeting watersheds through the 1985 Assessment of Surface

Table 3. Summary of water quality classifications and standards.

Primary classifications	Best usage	Numeric standards	Stormwater controls	Other requirements
Freshwater: Class C (standards apply to all freshwaters, unless preempted by more stringent standard for more protective classification)	Secondary recreation (including swimming on an unorganized or infrequent basis); fish and other aquatic life propagation and survival; agriculture and other uses, except for primary recreation, water supply or other food-related uses	See attached Table 1: Water quality standards for freshwater classes; standards listed under "standards for all freshwaters" column (aquatic life and human health sections) apply to Class C waters, unless preempted by more protective standard	Stormwater disposal rules apply in the 20 coastal counties as described in 15A NCAC 2H .1000	
Class B	Primary recreation (swimming on an organized or frequent basis) and all uses specified for Class C (and not water supply or other food-related uses)	Same as for Class C	Same as for Class C	Wastewater treatment reliability requirements (dual train design; backup power capability) may apply to protect swimming uses (15A NCAC 2H .0124)
WS-I Water supply (Note: Revised water supply classifications and standards were adopted December 1990. These will be effective in 1992.)	Water supplies in natural and uninhabited or predominantly undeveloped (not urbanized) watersheds	See Table 1 under "more stringent standards to support additional uses": WS classes heading; no point sources except existing swimming pool filter backwash discharges	Local land management program required by standards; technical requirements established by state guidelines (see other requirements	1 dwelling unit/2 acres or 6% built upon area throughout watershed (on average); built upon area may exceed 6% in rare instances, but must control 1-inch storm; no density greater than 35% recommended
WS-II Water supply	Water supplies in low to moderately developed watersheds	See Table 1 under "more stringent standards to support additional uses": WS classes heading; only domestic wastewater or non-process industrial discharges, such as cooling water. This classification may be used to protect critical portions of WS-III water supplies	Local land management program required by standards; technical requirements established by state guidelines (see other requirements)	1 dwelling unit/2 acres or 6% built upon area in critical area (on average); 1 unit/acre or 12% built upon area throughout remainder of watershed; with higher density, control 1/2-inch storm up to 30% built upon area; with 30-70%, control 1-inch storm
WS-III Water supply	Water supply segment (generally WS-I and WS-II apply to entire watersheds, not segments), in developed or urbanized areas	See Table 1 under "more stringent standards to support additional uses": WS classes heading; no categorical restrictions on point source discharges or development	No land management program required	

Table 3. (Continued)

Primary classifications	Best usage	Numeric standards	Stormwater controls	Other requirements
Saltwater: Class SC	Saltwaters protected for secondary recreation, aquatic life propagation and survival and other uses as described for Class C	See attached Table 2: Water quality standards for saltwater classes; standards listed under "standards for all tidal salt-waters" column (aquatic life and human health sections) apply to Class SC waters, unless pre-empted by more protective standard	Stormwater disposal rules (15A NCAC 2H .1000) apply to all waters in the 20 coastal counties; low density density option: 30% built upon area or 1/3 acre lots, or structural stormwater controls with higher density, as specified	
Class SB	Saltwaters protected for primary recreation and all Class SC uses (similar to Class B)	Same as Class SC except no floating solids, settleable solids or sludge deposits attributable to sewage, industrial or other wastes	Same as Class SC	Reliability requirements same as for Class B
Class SA	Shellfishing and all Class SC and SB uses	Same as for Class SC, except fecal coliform = 14 colonies per 100 ml of water; all other waters = 200/100 ml fecal	Same as for Class SC, except low density option = 25% built upon area	No domestic discharges and only nonprocess industrial discharges, such as seafood packing house or cooling water discharges

Supplemental Classifications are added to the primary classifications as appropriate (Examples include Class C-NSW, Class SA-ORW, Class B-Trout, etc.) and impose additional requirements.

Supplemental classifications	Best usage	Numeric standards	Stormwater controls	Other requirements
High Quality Waters (HQW) [categories: (1) waters rated as Excellent by DEM; (2) Primary Nursery Areas; (3) Native or Special Native Trout Waters; (4) Critical Habitat Areas; (5) WS-I WS-I and WS-II water supplies; (6) SA waters]	Waters with quality higher than the standards (EPA's Tier II waters; the minimum standards for Class C and SC define Tier I); see Standards and Stream Classifications Rules (15A NCAC 2B .0100) for detailed description [15A NCAC 2B .0101(e)(5)]	For new or expanded discharges, advanced treatment requirements are: BOD=5 mg/L; NH_3-N= 2 mg/L; DO=6 mg/L	1 acre lots or 12% built upon, or higher density with structural controls, using wet detention ponds; WS-I, WS-II, and 20 coastal exempt since coastal stormwater control requirements already apply	Other treatment requirements may apply, dependent upon type of discharge and receiving water (see pp. 1 and 2 of Section 200 Rules: 15A NCAC .0201(d) of Antidegradation Policy)

Table 3. (Continued)

Supplemental classifications	Best usage	Numeric standards	Stormwater controls	Other requirements
Outstanding Resource Waters (ORW)	Unique and special waters having exceptional water quality and being of exceptional state or national ecological or recreational significance; must meet other certain conditions and have 1 or more of 5 outstanding resource value criteria as described in Rule 2B .0216	Water quality must clearly maintain and protect uses, including outstanding resource values; management strategies must include at a minimum: no new or expanded discharges to freshwater ORWs some discharges may be allowed in coastal areas	Same as for High Quality Waters for Freshwater ORWs; for Saltwater ORWs, devel-activities within a 575 foot buffer must comply with the low density option of Stormwater Disposal Rules (generally, 25% built upon area around SA waters and 30% around other waters)	Other management strategy components as described in Rule .0216
Trout Waters (Tr)	Protected for natural trout propagation and survival of stocked trout; native and special native trout waters are also High Quality Waters (HQW)	More protective standards for cadmium, total residual chlorine, chlorophyll *a*, dissolved oxygen, turbidity, and toluene to protect these sensitive species (see Table 1 under "Trout" heading)		
Nutrient Sensitive Waters (NSW)	Waters needing additional nutrient management due to their being subject to excessive growth of microscopic or macroscopic vegetation	No increase of nutrients over background levels		Nutrient management strategies developed on a case-by-case basis
Swamp Waters (Sw)	Waters with low velocities and other characteristics different from other waterbodies (generally low pH, DO, high organic content)	pH as low as 4.3 and DO less than 5 mg/L allowed if due to natural conditions		

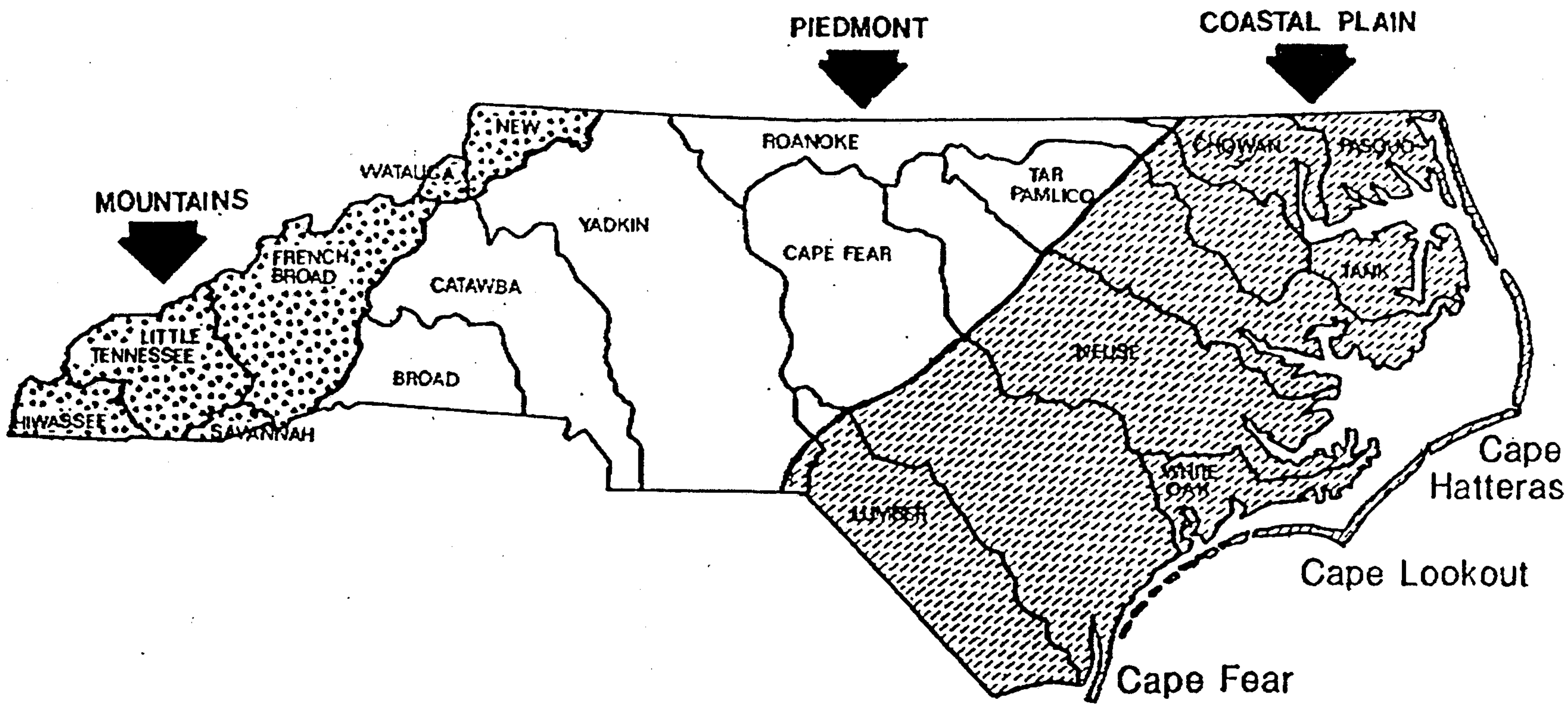


Figure 14. River basins and physiographic zones of North Carolina.

Water Quality in North Carolina, the Biennial 305(b) Report, and the 1989 Nonpoint Source Assessment Report. See Table 5 for a summary of ACSP activity within the Roanoke River Basin.

Other measures, in addition to the voluntary ACSP, have been taken to control agricultural pollutants. Some state and federal regulatory, or quasi-regulatory, control mechanisms include 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 concentrated animal feeding operations, and the Conservation Title of the Food Security Act of 1985.

Point Sources

In 1990, there were 41 facilities with NPDES discharge permits operating within the lower Roanoke River Basin (Table 6) (McCullen, pers. comm.). Of these facilities, 10 were found to be in significant noncompliance with the conditions of their permits. In addition, four others experienced difficulty during 1990 in meeting effluent toxicity limits (Ausley, pers. comm.).

Aquatic Toxicity

Caledonia Correctional Institute (Halifax County) is currently under a Special Order by Consent (SOC) that drops the effluent toxicity limit from May 1988 to March 1992. An administrative letter of January 1990 established a requirement of quarterly acute toxicity monitoring. This facility failed to report tests due in July and October 1990 following two failures of the acute toxicity test in 1990. The Raleigh Regional Office of DEM is preparing a Notice of Violation for failure to report.

Liberty Fabrics (Martin County) has consistently failed to meet limits on acute toxicity to fathead minnows. This facility has requested a consent order to address effluent toxicity problems.

Williamston Wastewater Treatment Plant (WWTP) failed acute toxicity tests in October and November 1990, but passed a test in December 1990. This brought it into compliance. The Washington Regional Office of DEM will continue to monitor its progress.

Windsor WWTP (Bertie County) failed chronic toxicity tests for five consecutive months from July through November 1990. This facility was sent a letter in July 1990 advising that chlorine levels should be assessed as a possible toxicant. The Washington Regional Office of DEM is drafting a Notice of Violation for failure to meet limits. This notice includes a request that the facility inform DEM as to what remedial actions will be taken. Possible sewer addition moratoria have also been discussed. Modifications in discharge location, as well as possible non-discharge options, have been considered.

Assimilative Capacity

The Technical Support Branch of DEM is charged with, among other things, assessing the assimilative capacity of a stream, or a stream's capacity to accept waste.

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

Table 4. Use support of the Roanoke River Basin in North Carolina.

Use Determination	Mileage	Percentage
Support, monitored	250.3	10
Support, evaluated	156.2	6
Support - threatened, monitored	36.6	2
Support - threatened, evaluated	342.5	15
Partial support, monitored	208.5	9
Partial support, evaluated	865.3	37
Nonsupport, monitored	70.5	3
Not evaluated	289.0	12
Total	2350.6	100 %
Major Sources of Degradation*		
Point	196.3	15
Major municipal	11.4	1
Major nonmunicipal	17.1	1
Minor municipal	7.3	1
Minor nonmunicipal	48.6	4
Schools	111.9	8
Nonpoint	1079.7	85
Agriculture	644.1	51
Urban runoff	55.2	4
Forestry	24.0	2
Mining	2.2	0
Disposal	21.5	2
Construction	322.0	25
Total	1,276.0	100 %
Major Causes of Degradation*		
Sediment	261.1	20
Fecal coliform	44.8	4
Dissolved oxygen	93.9	7
Aquatic toxicity	2.1	0
Metals	31.5	3
NH_3	43.2	3
Nutrients	35.1	3
Other	764.3	60
Total	1,276.0	100 %

* For partially and non-supporting streams only.

Table 5. North Carolina Agriculture Cost Share Program for the Roanoke River Basin, program years 1985-1991. BMP = Best Management Practices.

Program area	Number
Agreements	1,768
Acres	72,344
Acres erosion control	29,248
Tons saved of soil (from entering the waterway)	317,209
<u>Erosion Control BMPs</u>	
Sod-based rotation (acres)	5,605
Cropland conversion (acres)	4,669
Conservation tillage (acres)	11,283
Critical area planting (acres)	157
Stripcropping (acres)	3,077
Terraces/diversions (acres)	4,457
<u>Animal Waste Management</u>	
Systems (number)	53
Liquid waste application (gallons)	76,835,472
Poultry litter applied (tons)	43,988
Average of wastes applied (acres)	21,643
<u>Sediment Control BMPs</u>	
Grassed waterways (acres)	1,027
Field borders (acres)	928
Water control structures (number)	11
Stream protection systems (number)	6

of empirical equations and DEM procedures to establish model input parameter values. A modi fied 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 (Mangles, pers. comm.).

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.

Table 6. All NPDES permitted dischargers within the lower Roanoke River Basin in 1990.

Discharger and Permit Number	Receiving Stream and County	Type
Rich Square WWTP NC0025437	UT Bridgers Creek (Northampton)	Minor Nonmunicipal
N.C. Department of Corrections/ Odom Correctional Institute NC0027642	UT Roanoke River (Northampton)	Minor Nonmunicipal
Perdue, Inc. NC0028835	Roanoke River (Bertie)	Minor Nonmunicipal
Halifax WWTP NC0066192	Quankey Creek (Halifax)	Minor Nonmunicipal
Truckstops of America NC0029971	UT Arthurs Creek (Northampton)	Minor Nonmunicipal
N.C. Department of Corrections/ Halifax County Subsidiary #3315 NC0029734	Little Quankey Creek (Halifax)	Minor Nonmunicipal
Navnit Patel/Best Western NC0077356	Quankey Creek (Halifax)	Minor Nonmunicipal
Lee Operating Co. - Travel World NC0029262	Quankey Creek (Halifax)	Minor Nonmunicipal
Weldon WWTP NC0025721	Roanoke River (Halifax)	Minor Municipal
McIver Elementary School NC0038407	Deep Creek (Halifax)	Minor Nonmunicipal
William R. Davie Middle School NC0038385	Deep Creek (Halifax)	Minor Nonmunicipal
Bakers Elementary School NC0038636	UT Kehukee Swamp (Halifax)	Minor Nonmunicipal
Roanoke Rapids Sanitary Dist./ Roanoke Rapids WWTP NC0024201	Roanoke River (Halifax)	Major Municipal
Caledonia Prison Farm/ Correctional Institute NC0027626	UT Conoconnara Swamp (Halifax)	Minor Nonmunicipal
Northampton High School - West NC0049590	UT Occoneechee Creek (Northampton)	Minor Nonmunicipal

Table 6. (continued)

Discharger and Permit Number	Receiving Stream and County	Type
Panda-Rosemary Corporation NC0079014	UT Occoneechee Creek (Halifax)	Minor Nonmunicipal
VEPCO - Roanoke Rapids NC0056316	Roanoke River (Halifax)	Minor Nonmunicipal
Martin Marietta Aggregates/ Weldon Quarry NC0058041	UT Mush Island Gut (Halifax)	Minor Nonmunicipal
James C. Boone Residence NC0061077	UT Lily Pond Creek (Northampton)	Minor Nonmunicipal
VEPCO - Gaston Hydro Station NC0065323	Roanoke Rapids Lake (Halifax)	Minor Nonmunicipal
Roanoke Rapids Water Plant NC0069302	Roanoke River (Halifax)	Minor Nonmunicipal
Champion Papers NC0000752-001, 002, 003, 004	Roanoke River (Halifax)	Major Nonmunicipal
Williamston WWTP NC0020044	Roanoke River (Martin)	Major Municipal
Jamesville WWTP NC0035858	Roanoke River (Martin)	Minor Municipal
NC Department of Corrections/ Martin Subsidiary NC0027791	UT Dog Branch (Martin)	Minor Nonmunicipal
Hamilton WWTP NC0044776	Roanoke River (Martin)	Minor Municipal
West Point Pepperell/ Hamilton Plant NC0001961	Roanoke River (Martin)	Major Nonmunicipal
Weyerhaeuser Company/ Plymouth Plant NC0000680	Roanoke River (Martin)	Major Nonmunicipal
Liberty Fabrics, Inc. NC0023710	Roanoke River (Martin)	Minor Nonmunicipal
Plymouth WWTP NC0020028	Roanoke River (Washington)	Minor Municipal

Table 6. (continued)

Discharger and Permit Number	Receiving Stream and County	Type
Plymouth WTP NC0002313	Conaby Creek (Washington)	Minor Nonmunicipal
West Martin Elementary NC0002313	UT Conoho Creek (Washington)	Minor Nonmunicipal
United Organics NC0068187	Roanoke River (Martin)	Minor Nonmunicipal
Outer Banks Contractors, Inc. NC0074161	UT Conaby Creek (Washington)	Minor Nonmunicipal
Outer Banks Contractors/ Nicholson Sand Pit NC0077828	UT Conoho Creek (Martin)	Minor Nonmunicipal
Lewiston-Woodville Utilities NC0023116	Cashie River (Bertie)	Minor Municipal
Louisiana Pacific Corp. NC0047007	UT Cashie River (Bertie)	Minor Nonmunicipal
Askewville Elementary School NC0032409	UT White Oak Swamp (Bertie)	Minor Nonmunicipal
Bertie High School NC0032450	UT Cashie River (Bertie)	Minor Nonmunicipal
Windsor WWTP NC0026751	Broad Branch (Bertie)	Major Municipal
Ladd Furniture/ Lea Lumber and Plywood NC0075671	UT Cashie River (Bertie)	Minor Nonmunicipal

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. It is expected that, in the future, a level C analysis (i.e., using actual field data) will be developed which will better predict the assimilative capacity of the Roanoke River.

Finally, in the absence of a basin-wide management strategy, the Roanoke River assimilative capacity for other water quality parameters cannot be assessed at this time.

Ambient Monitoring

James Mulligan

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 the sampling frequency appear in Table 7. The locations are identified by station number in Figures 15 and 16. A sample of these data is found in Table 8, where average concentrations for each parameter are shown for every monitoring location for the period beginning January 1989 and continuing up to the present. Similar data exists for some parameters back to 1961.

This most recent data summary shows consistently good water quality with the noteworthy exception of dissolved oxygen. In the late spring, summer, and early fall the dissolved 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 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.

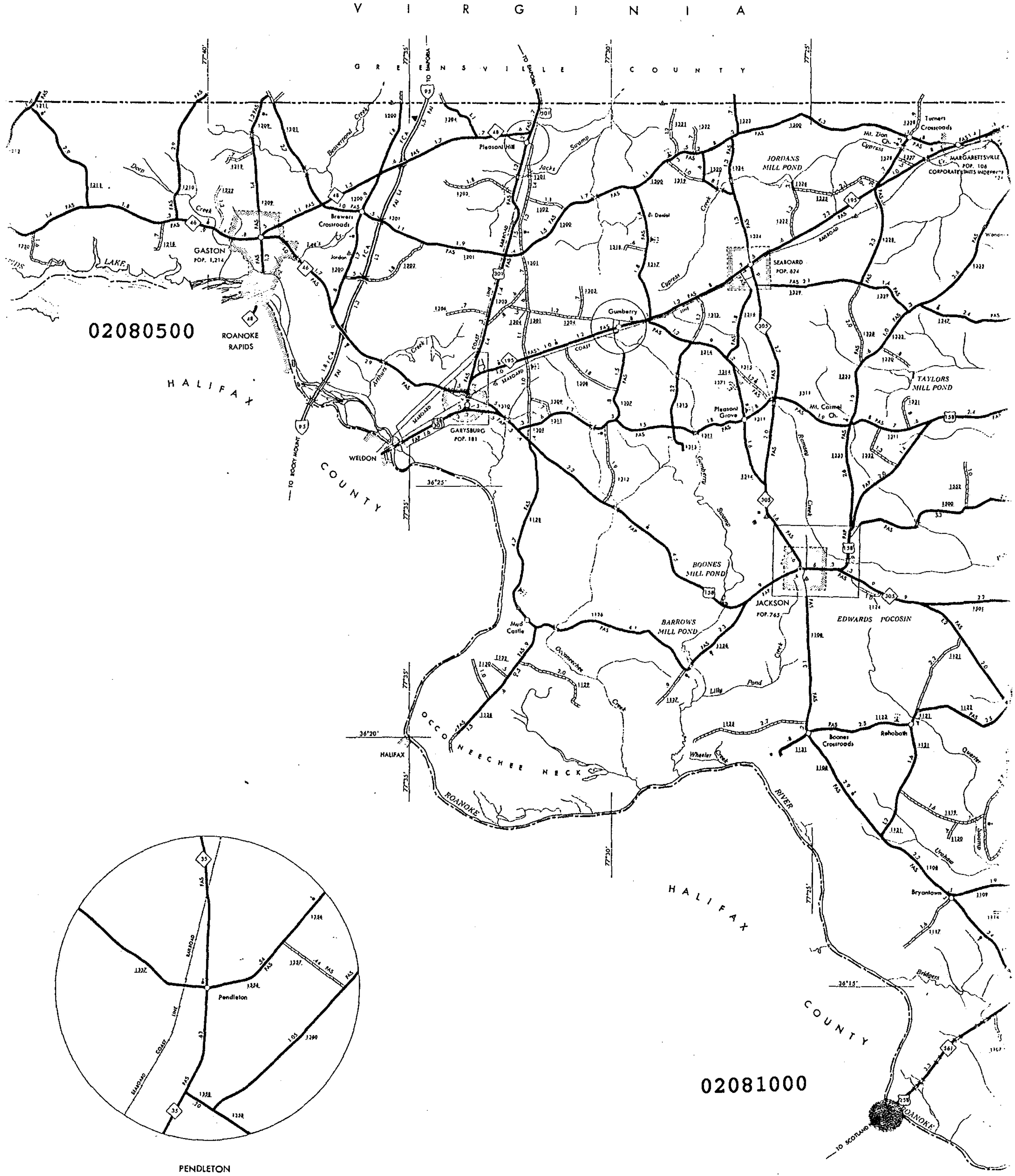


Figure 15. Sampling stations on Roanoke River used by the N.C. Division of Environmental Management (1).

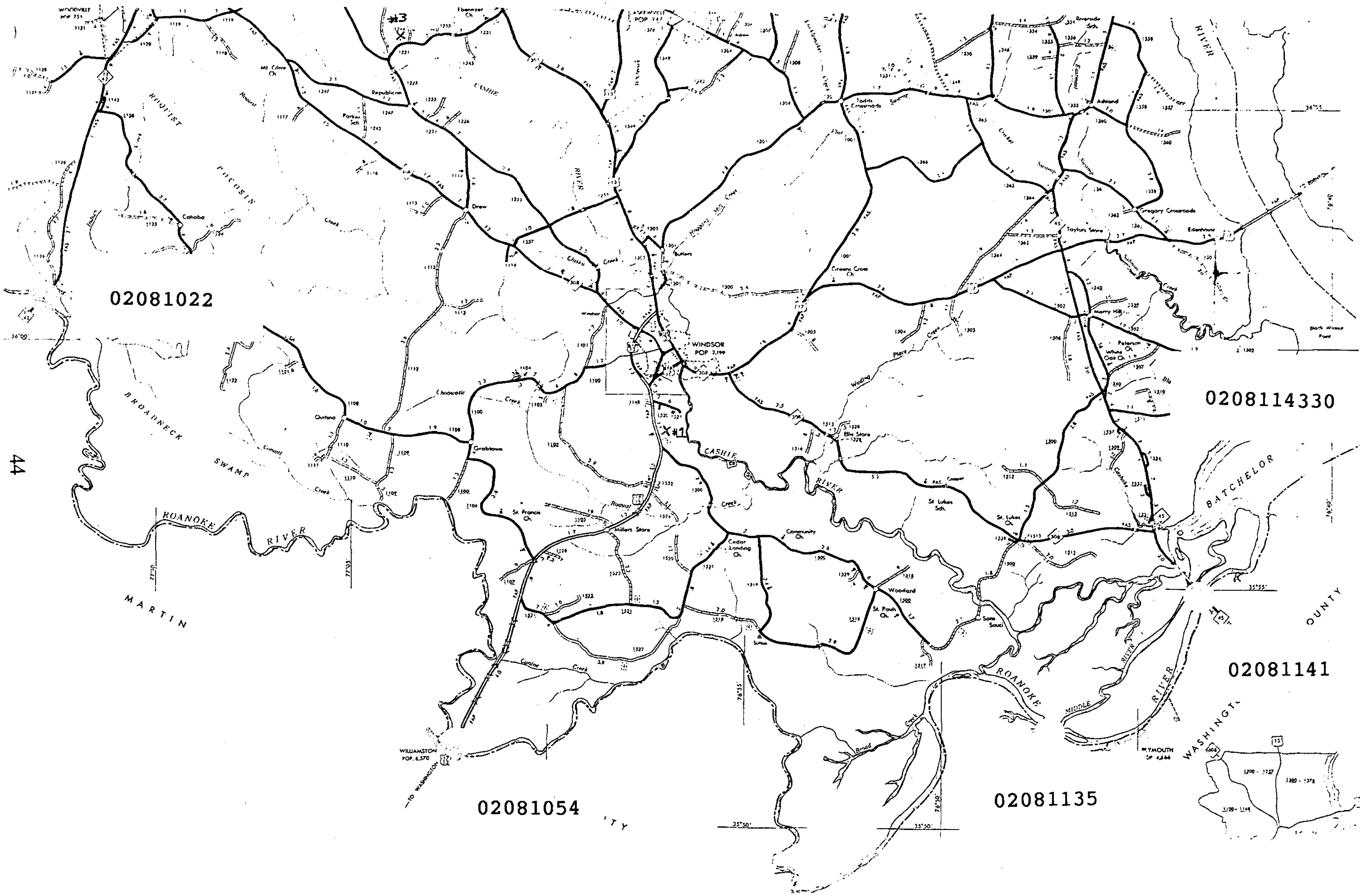


Figure 16. Sampling stations on Roanoke River used by the N.C. Division of Environmental Management (2).

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.).

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

Station Identification		Roanoke River Monitoring Data Summary Monitored Parameter (Average for January 1989 through 1990*)													
Location Description	Number	T	DO	pH	Alk	Cond	Cd	Cr	Cu	Pb	Ni	Zn	Hg	As	Al
At Roanoke Rapids	02080500	17.1	9.3	7.1	29.0	90.1	<2	<25	<3	<10	<15	<10	<0.2	<10	205.8
Near Scotland Neck	02081000	17.2	8.8	7.1	29.5	101.7	<2	<25	<3	<10	<15	<10	<0.2	<10	594.3
At NC 11 near Lewiston-Woodville	02081022	17.2	8.1	7.0	29.0	102.5	<2	<25	6.3	<10	<15	<10	<0.2	<10	-
At US 13-17 at Williamston	02081054	17.1	7.4	7.8	26.9	101.9	<2	<25	4.3	<10	<15	<10	<0.2	<10	-
1.3 miles above Welches Cr. near Plymouth	02081135	17.8	6.5	6.8	28.3	99.0	<2	<25	<3	<10	<15	<10	<0.2	<10	-
At NC 45 near Sans Souci	02081141	18.1	6.4	6.8	30.9	119.1	<2	<25	3.7	<10	<15	<10	<0.2	<10	-
Batchelor Bay (Albemarle Sound)	02081143	20.0	6.9	6.8	23.7	148.9	<2	<25	3.7	<10	<15	<10	<0.2	<10	-

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

T = temperature in degrees Centigrade; DO = dissolved oxygen in mg/L; pH = in standard units; Alk = alkalinity in mg/L; Cond = conductivity in micromhos; Cd = cadmium in µg/L; Cr = chromium in µg/L; Cu = copper in µg/L; Pb = lead in µg/L; Ni = nickel in µg/L, Zn = zinc in µg/L; Hg = mercury in µg/L; As = arsenic in µg/L; Al = aluminum in µg/L.

Table 8. (continued)

Station Identification		Monitored Parameter (Average for January 1989 through 1990*)															
Location Description	Number	BOD	Hd	Turb	Res	TSR	Tot P	PO_4	NO_2+ NO_3	NH_3	Org-N	TOC	Color	Chlor	Phe	Fec Col	Cl
At Roanoke Rapids	02080500	0.9	29.6	6.5	78.9	4.5	-	-	-	-	-	-	-	-	-	-	-
Near Scotland Neck	02081000	1.3	31.9	14.0	104.4	16.7	0.039	<0.01	0.25	<0.01	0.26	-	-	-	-	-	-
At NC 11 near Lewiston-Woodville	02081022	1.2	28.0	14.4	86.8	18.0	-	-	-	-	-	-	-	-	-	96	-
At US 13-17 at Williamston	02081054	1.2	27.8	12.6	90.0	17.0	0.058	0.012	0.22	0.04	0.27	-	-	-	-	-	-
1.3 miles above Welches Cr. near Plymouth	02081135	1.5	27.0	10.6	75.4	11.9	0.053	0.011	0.18	0.04	0.29	10.6	41	4.5	2.2	-	16
At NC 45 near Sans Souci	02081141	-	27.8	10.3	82.7	10.5	0.101	0.015	0.18	0.10	0.35	-	-	3.8	2.0	3	10.5
Batchelor Bay (Albemarle Sound)	02081143	-	-	8.2	76.7	7.9	0.058	0.014	0.17	0.07	0.33	-	-	4.0	3.0	11	10.8

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

BOD = 5-day biochemical oxygen demand in mg/L; Hd = hardness as mg/L of calcium carbonate; Turb = turbidity in FTU; RES = total residue in mg/L; TSR = total suspended residue in mg/L; Tot P = total phosphorus in mg/L; PO_4 = ortho; NO_2 + NO_3 = nitrite plus nitrate as mg/L of nitrogen; NH_3 = ammonia s mg/L of nitrogen; Org-N = total Kjeldahl nitrogen as mg/L of nitrogen; TOC = total organic carbon as mg/L of carbon; Color = color in standard units; Chlor = chlorophyll *a* in µg/L; Phe = pheophytin in µh/l; Fec Col = fecal coliforms in colonies per 100 ml; Cl = chlorides in mg/L.

ECOLOGICAL RESOURCES OF THE LOWER ROANOKE RIVER BASIN

Merrill Lynch

Introduction

The Roanoke River's headwaters are located in the Ridge and Valley Province of the Appalachian Mountains west of Roanoke, Virginia. It is the northernmost of the five major brownwater rivers draining the Atlantic slope of the southern Appalachian Mountains. The others are the Altamaha in Georgia, the Savannah in Georgia and South Carolina, and the Santee (Catawba) and Pee Dee (Yadkin) in the Carolinas.

The River flows in a general southeasterly direction almost 400 miles to its mouth at the western end of Albemarle Sound in North Carolina. The total area of the drainage basin is 9,666 square miles including about 3,506 square miles in North Carolina. The lower Roanoke River Basin is located below the "Fall Line" where the River drops out of the Piedmont Province and into the relatively flat, marine-deposited sediments of the Coastal Plain Province. North Carolina counties that border the River are Halifax, Northampton, Bertie, Martin, and Washington (Figure 1).

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.

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 9). 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). Most of the natural communities are represented by scattered old-growth forest remnants which contribute significantly to the floodplain's ecological diversity.

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 skullcap (*Scutellaria nervosa*), sessile-flowered trillium (*Trillium sessile*), a stinging nettle (*Urtica chamaedryoides*), and big shellbark hickory (*Carya laciniosa*).

Table 9. Natural communities of the lower Roanoke River Basin, North Carolina (Schafale and Weakley 1990).

Community type	Global Rank	NC Rank
*Mesic mixed hardwood forest, Coastal Plain subtype	G5T4	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	S4
*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

See Glossary for explanation of Global and NC rank codes; *floodplain natural communities

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 floodplain forests contain significant wildlife values. The Roanoke River floodplain is regarded as among the best wild turkey (*Meleagris gallapavo*) habitat 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) (see pages 72 and 74 of this document for additional waterfowl information).

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).

A summary of the Elements of Concern highlights the enormous biological significance of this area: two federally endangered animals (Table 10), 15 state-listed animals, 13 state-listed plants (Table 11), 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.

The North Carolina Plant Watch List (Table 12) 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. Watch Category 1 (W1) includes species with inadequate information about their distribution and rarity in North Carolina. These are generally species which have not been previously listed as rare in North Carolina, but which appear to be so, based on herbarium records and field experience of Natural Heritage Program staff, contractees, and cooperating scientists. All of the species on the Watch List from the lower Roanoke River Basin fall under this category.

Table 10. Rare and endangered animal species of the lower Roanoke River Basin, North Carolina (from LeGrand 1990). See Glossary for explanation of Status and Rank codes.

Common name	Scientific name	NC status	US status	Global rank	NC rank
Mollusks					
Atlantic Pigtoe	*Fusconaia masoni*	T	-	G3	S1
Tidewater Mucket	*Leptodea ochracea*	SC	-	G4	S2
Crustaceans					
Chowan River Crayfish	*Orconectes virginiensis*	SC	-	G?	S?
Fishes					
Shortnose Sturgeon	*Acipenser brevirostrum*	E	LE	G3	S1
Birds					
Cooper's Hawk	*Accipiter cooperii*	SC	-	G4	S2
Anhinga	*Anhinga anhinga*	SR	-	G5	S2
Golden Eagle	*Aguila chrysaetos*	SR	-	G4	S1
Black Vulture	*Coragyps atratus*	SC	-	G5	S3
Cerulean Warbler	*Dendroica cerulea*	SR	-	G5	S3
Bald Eagle	*Haliaeetus leucocephalus*	E	LE	G3	S1
Mississippi Kite	*Ictinia mississippiensis*	SR	-	G5	S1
Warbling Vireo	*Vireo gilvus*	SR	-	G5	S2
Loggerhead Shrike	*Lanius ludovicianus*	SC	C2	G4	S2
Mammals					
Rafinesque's Big-eared Bat	*Plecotus rafinesquii*	SC	C2	G4	S3
Black Bear	*Ursus americanus*	SC[1]	-	G5	S3

[1]Status is unofficial, with no legal protection

Table 11. Rare and endangered plant species of the lower Roanoke River Basin, North Carolina (Weakley 1990). See Glossary for explanation of Status and Rank codes.

Common name	Scientific name	NC status	US status	Global rank	NC rank
Wild Hyacinth	*Camassia scilloides*	T	-	G4G5	S1
Big Shellbark Hickory	*Carya laciniosa*	SR	-	G5	S1
Multiflowered Mud-Plantain	*Heteranthera multiflora*	SR	-	GU	S1
Bog St. John's-wort	*Hypericum adpressum*	C	-	G2G3	SH
Riverbank Quillwort	*Isoetes riparia*	SR	-	G4	S1
Atlantic Isopyrum	*Isopyrum (Enemion) biternatum*	SR	-	G5	S2
Wild Ginseng	*Panax quinquefolius*	SR	-	G4	S4
Veined Skullcap	*Scutellaria nervosa*	SR	-	G5	S1
Magnolia Vine	*Schisandra glabra*	T	-	G4	S1
Reclining Bulrush	*Scirpus flaccidifolius*	C	C2	G1G2	S1
Virginia Least Trillium	*Trillium pusillum* var. *virginianum*	E	C2	G3T2	S1
Sessile-flowered Trillium	*Trillium sessile*	SR	-	G4G5	S1
Stinging Nettle	*Urtica chamaedryoides*	SR	-	G4G5	S1

Table 12. "Watch List" plants of the lower Roanoke River Basin, North Carolina (Weakley 1990).

Common name	Scientific name	Global rank	N.C. rank
Carolina Mosquito Fern	*Azolla caroliniana*	G5	S2
Longleaf Spikegrass	*Chasmanthium sessiliflorum*	G5	S2
Water Violet	*Hottonia inflata*	G3G4	S3
Green Violet	*Hybanthus concolor*	G5	S2S3
Catchfly Cutgrass	*Leersia lenticularis*	G5	S1?
Blackwater Turk's-cap Lily	*Lilium sp.1*	GU	S1
Wild Blue Phlox	*Phlox divaricata* ssp. *laphamii*	G5T?	S1
Wafer-ash	*Ptelea trifoliata*	G5	S2
Swamp Buttercup	*Ranunculus laxicaulis*	G5?	S1
A Heartleaf Skullcap	*Scutellaria ovata* ssp. *bracteata*	G5T?	S1
Northern Cup-plant	*Silphium perfoliatum* ssp. *perfoliatum*	G5T?	S1
Common Water-flaxseed	*Spirodela polyrrhiza*	G5	S2?
Smooth Hedge-nettle	*Stachys tenuifolia* var. *tenuifolia*	G4	S1
Three Birds Orchid	*Triphora trianthophora*	G4	S2?
Watermeal	*Wolffia brasiliensis*	G5	S2

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 blackswamps, 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.

Glossary: 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 factors(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, through it may be quite rare in parts of its range, especially at the periphery.

North Carolina Status - Animals

Endangered, Threatened, and Special Concern species of mammals, birds, reptiles, and amphibians have legally protected status in North Carolina (Wildlife Resources Commission). Lists of Mollusks for State protection were officially adopted June 1991. Lists for Fishes will be considered later in the year.

E Endangered. Any native or once-native species of wild animal whose continued existence as a viable component of the State's fauna is determined by the Wildlife Resources Commission to be in jeopardy or any species of wild animal determined to be an "endangered species" pursuant to the Federal Endangered Species Act.

T Threatened. Any native or once-native species of wild animal which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range, or one that is designated as a threatened species pursuant to the Federal Endangered Species Act.

SC Special Concern. Any species of wild animal native or once-native to North Carolina which is determined by the Wildlife Resources Commission to require monitoring but which may be taken under regulations adopted under the provisions of Article 25 (Chapter 113 of the General Statute).

SR Significantly Rare. Any other species which has not been determined as an Endangered, Threatened, or Special Concern species, but which exists in the State in small numbers and has been determined to need monitoring.

North Carolina Status - Plants

Endangered, Threatened, and Special Concern species have legally protected status in North Carolina (Plant Conservation Program, N.C. Department of Agriculture).

E Endangered. Any species of plant whose continued existence as a viable component of the State's flora is determined to be in jeopardy. Endangered species may not be removed from the wild except when a permit is obtained for research, propagation, or rescue which will enhance the survival of the species. Sale or distribution of wild-collected Endangered species is not permitted.

T Threatened. Any species of plant likely to become an endangered species within the foreseeable future. Regulations are the same as for Endangered species.

SC Special Concern. Any species of plant which requires population monitoring, but which may be collected and sold under specific regulations. Special Concern species which are not also listed as Endangered or Threatened may be collected from the wild and sold under specific regulations. Propagated material only of Special Concern species which are also listed as Endangered or Threatened may be traded or sold under specific regulations.

C Candidate. Any species for which there is not evidence of declining numbers or threats to the species in North Carolina, but which, because of small numbers of populations, rare habitat, or distribution, may become threatened in the future; or a species suspected of being endangered or threatened, but for which sufficient information is not currently available to support such a status classification. This category was formerly known as Primary Proposed (PP).

SR Significantly Rare. Any other species which has not been determined as an Endangered, Threatened, Special Concern, or Candidate species, but which has been determined to need monitoring. For most species in this category, actual biological status has not been determined, either because taxonomic validity is unresolved, or because the species is frequently overlooked in the field and could be more common than present data indicate, or because it is a peripheral species common in an adjacent state.

United States Status (as designated by the U.S. Fish and Wildlife Service)

E Endangered. A taxon that is threatened with extinction throughout all or a significant portion of its range.

T Threatened. A taxon that is likely to become endangered in the foreseeable future.

C1 Candidate 1. A taxon for which the Fish and Wildlife Service has on file enough substantial information to list as endangered or threatened. Listing is "warranted but precluded by other pending proposals of higher priority."

C2 Candidate 2. A taxon for which there is some evidence of vulnerability, but for which there are not enough data to support listing as endangered or threatened at this time. Listing is "warranted but precluded by other pending proposals of higher priority."

FOREST RESOURCES

Russ Lea

Introduction

The Roanoke River originates in the Blue Ridge mountains of Virginia, drains portions of the Piedmont and Coastal Plain of Virginia and North Carolina, and flows into the Albemarle Sound in the northeast portion of North Carolina. The Roanoke River Basin is bounded by the James and Chowan River basins on the north, by the New River Basin on the west, and by the Tar, Neuse, Cape Fear, and Pee Dee basins on the south. The Roanoke Basin is approximately 354 kilometers (220 miles) long and drains approximately 24,812 square kilometers (9,600 square miles), including nearly 6% of the land surface in North Carolina. The lower portion of the Basin has the largest intact bottomland forest ecosystem remaining in the Mid-Atlantic Region (Moody et al. 1985, N.C. Natural Heritage Program 1988, U.S. Army Corps of Engineers 1987) (refer to page 49 of this document for detailed information). Lynch (1981) has classified the Roanoke River floodplain into many community types which include extensive acreage in hardwood swamp forests, beaver ponds, oxbow lakes, and blackwater streams. The types of forests can be broadly defined as palustrine, forested, broad-/needle-leaved deciduous/needle-leaved evergreen, semi-permanently-, seasonally-, or temporarily-flooded wetlands derived from the U.S. Fish and Wildlife Service's Wetland and Deepwater Classification System (Cowardin et al. 1979). Palustrine forested wetland habitats included in the floodplain commonly include bottomland hardwoods, gum-cypress swamps, second terrace, river levee gallery forests, and others.

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 clearcut, drained, and converted to pine plantations.

Preimpoundment Conditions

Before impoundment, the mean annual discharge of the Roanoke River was influenced by prevailing weather patterns and runoff conditions in the tributary watersheds. High flows typically occurred during the winter and early spring, but extreme, extended floods were rare. The low-flow period in the early fall was infrequently interrupted by high discharges from heavy rainfall associated with coastal hurricanes. The forest vegetation types, prior to 1950, were a function of natural variances associated with the River's hydrological 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 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 (Bedinger 1981, Crow and MacDonald 1979, Fredricson 1979, Weller 1979, McKnight et al. 1981, Mitchell 1989, Mitsch and Gosselink 1986, Sather and Smith 1984). 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 (Larsen 1988, Leibowitz et al. 1988, Niering 1988, Sather and Smith 1984). 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.

Postimpoundment Conditions

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.

Forest Types

The floodplain forests of the Roanoke River Bottom are composed of generally recognized 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 community types can be found on the bottomlands (Cobb 1990).

Tupelo Gum/Bald Cypress Blackswamp

The tupelo gum (*Nyssa aquatica)* / bald cypress (*Taxodium distichum*) blackswamps 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.

Special Management Considerations

Asyncronous Flooding

The plant communities that inhabit the floodplain of the Roanoke River are well adapted to the stresses imposed by the hydroperiod under normal flooding fluctuations. Such communities have evolved along an elevational/soil gradient, and as such, their adaptations have become an integral part of the geological and chemical functioning of the ecosystem. Without the stabilizing forces of the vegetation to reduce water velocities and inhibit subsequent meander movement and floodplain scour, these physical alterations would likely occur at an accelerated rate.

Of the many factors that influence plant survival during flooded conditions, the timing, depth, and duration of flood waters are the most critical (Teskey and Hinckley 1977, Huffman and Forsythe 1981). According to Wharton et al. (1982), flooding characteristics are a function of regional precipitation and local weather patterns, watershed size and morphology, floodplain size, topographic variation, and drainage rates of floodplain soils.

The effects of flooding are most critical during the growing season, particularly during the period of leafout. Floods during the dormant season have relatively little effect on the physiology and survival of bottomland species, other than possible damage due to mechanical abrasion. Manooch and Rulifson (1989) analyzed postimpoundment flow data to 1988. Their findings suggest that for the period of November to March, the impoundment has produced significantly lower flows than preimpoundment conditions. High winter run-off is distributed through the spring, thereby decreasing the peaks of major flood events and prolonging the length of soil inundation or saturation into the growing season. Therefore, flood duration and frequency are higher than under preimpoundment conditions.

The consequences of altered hydroperiod in the Roanoke bottomlands can be assumed to have long-term effects on existing vegetation and on regeneration following harvesting. Floodwaters deep enough to inundate major portions of the stem lenticels during the growing season can cause reduced oxygen supply to the roots and toxic accumulation of the anaerobic respiratory products. The second effect of prolonged soil saturation is the reduced rate of oxygen diffusion to the roots with increasing length of waterlogging. Finally, seedlings submerged by the water column may undergo severe mortality through anoxia, mechanical damage, and siltation. In extreme cases,.there may be a regeneration failure because the coppice and seeds are inundated well into the growing season, and by the time drydown occurs, rank vegetation may occupy the site to the exclusion of bottomland hardwood regeneration. This latter instance was observed most markedly on the Roanoke River floodplain during the spring of 1987 flood.

Best Management Practices

Whenever silvicultural operations occur on bottomlands of the Roanoke River, a nonpoint pollution control strategy should be implemented through the use of Best Management Practices (BMPs). This strategy can be easily summarized by the implementation of four distinct steps that should follow an iterative process: (1) design/selection of appropriate BMPs, (2) application of practices by all operators and managers, (3) monitoring by responsible agencies with no conflict of interest, and (4) evaluation and refinement. In the above strategy, BMPs serve as landowner performance standards while state water quality standards function as an attainment standard.

Although states have a clear responsibility for the oversight of BMP selection and design, North Carolina has not extended this oversight to the project level. Additionally, the evaluation of monitoring results may need to be adjusted when considering water quality standards for wetlands in the bottomland hardwood habitat. We should not expect a landowner to have the expertise to conduct quantitative water quality monitoring; rather, landowners should be expected to ensure that all the appropriate BMPs have been applied according to published guidelines.

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.

Because of the aforementioned value of undisturbed vegetative zones in the bottomlands, the use of designated streamside management zones (SMZs) is probably the most important BMP that can be implemented to cleanse upslope inputs by natural means. The width of the SMZ (e.g., that portion of the bottomland subjected to special management considerations) necessary to achieve the desired protection of water quality and quantity has not been demonstrated by specific studies for all practices. Obviously, as the intensity of disturbance increases and/or the time of revegetation delayed, the width of the SMZ must become greater. Other conditions that must be factored into determination of optimal SMZ width are slope, depth to water table, vigor of the vegetation, nature of the hydraulic connectivity between the SMZ and the watercourse, degree of management within the SMZ, and other similar conditions (Nutter and Gaskin 1988). In summary, no scientific means are currently available for exact definition of the optimal SMZ width for a given watercourse. *[Editors' Note: See North Carolina DEM Water Quality Technical Report Number 91-02, which has a guideline table on slope, etc. on page 4].*

Summary

Along the Atlantic Coastal Plain, discharges of many major rivers are managed by dams or other water control structures. In floodplains of these rivers, water flow changes may exceed normal river stages or completely change the timing of hydrologic events. Flow regimes below dams are such that many forests are continuously flooded in the spring, causing widespread regeneration failures and stresses on the overstory communities (Sharitz and Lee 1985). In addition to changing the hydroperiod of forested wetland areas, dams can also influence downstream salinity and siltation patterns (Kjerfve 1979). One of the long-term results of the Roanoke River impoundments might be the conversion of coastal forests to marsh. Sedimentation is also a necessity to maintain the character of the bottomlands and the marsh communities where the Roanoke River meets Albemarle Sound. The starvation of sediments from downstream ecosystems can be dramatic when considering the net effects of subsidence and sea level rise (see Riggs et al., this report).

Forestry operations in the Roanoke floodplain forests involve road construction and maintenance, vegetation removal, and mechanical equipment operations. These operations occur infrequently and are extensive in nature, but during the operation, compliance with mandated BMPs is essential.

AGRICULTURE

Tom Ellis

Since the early days of North Carolina's colonization, the Roanoke River Valley's fertile soils have provided jobs and a strong economic base for the region. Cotton, tobacco, peanuts, corn, soybeans, wheat, and livestock have played a major role in providing income and allowing the rural nature of the counties to continue.

Flood waters from the Roanoke created the fertile soils. Sediment, nutrients, and organic material from throughout the upper watershed were deposited in the floodplain. This natural fertility was crucial for the establishment of a successful agricultural base; however, the severity of flooding created a conflict as the area became settled. Early attempts to control flood damages can still be seen in the old dikes and levees along the River. These were constructed by hand at a time when slave labor was available between harvest and planting seasons. The River provided the transportation route to the markets of the world.

The need for more efficient flood control came with the disastrous flood of 1940. The entire agricultural production of the lower valley was destroyed and an immense amount of property damage occurred. Congress then authorized, in 1944, the construction of the Buggs Island Reservoir for flood control and other purposes. The completion of Kerr Dam in 1952 was the first step for water management on the River and represents a major public policy and financial commitment to landowners, residents, and users of the Basin for protection from flooding.

Obtaining detailed financial information on damages and loss of production due to excessive moisture or delayed planting is not easily accomplished. Even a comparison of flood versus non-flood years for crop production on a county-specific basis is of limited value due to the large size of the affected counties and the many tens of thousands of acres of cropland outside of the floodplain. However, the impact on individuals who rely on farming in the floodplain for their livelihood can be severe.

The impact of flooding on agricultural production is relatively straightforward. Waters covering and/or saturating cropland during the spring prevents the planting of crops and the harvest of such winter cover crops as wheat, rye, and barley. Fall floods prevent harvest and destroy such standing crops as wheat, rye, and barley. Either event can turn an otherwise profitable crop year into a disaster. Further problems are faced when cattle or swine become stranded as flood waters inundate farm roads. Equipment is often left in standing water and the roads, buildings, and other facilities are damaged by the waters. Floodwaters also prevent adequate drainage of cropland on high grounds by filling ditches and drainage canals.

Flooding in 1975 caused much vocal concern of landowners in the Basin. Damages in Northampton County were estimated at $150,000 primarily due to the drowning of 400-500 acres of wheat and other small grains and the loss of several head of cattle. Martin County's damages were estimated at $500 to $1,000 per landowner, with two estimated at $15,000 and $30,000 respectively. Halifax County did not make an estimate but did record cropland and pasture land inundated with loss of crops and some cattle. Bertie County received the most extensive losses in 1975 -- damages totaling $1,000,000.

In 1975, the damage to public roads caused by flooding in Bertie ($7,521.88) and Martin ($500.00) counties totaled $8,028.88. An estimate of damages from the 1978 and 1979 floods was not available. However, a number of state roads including SR1502 and SR1505 (Martin County), SR1106 (Northampton), and SR1126, SR1127, SR1128, SR1129, and SR1130

(Bertie County) were inundated from 10 to 60 days. Damage to Bertie County public roads was $7,500 in 1987.

Flood damage to private farm and forestry roads is unknown. The only information on damages is from a 1980 survey of the 1978 and 1979 flooding. In 1978, flooding inundated 960 acres of cropland, 355 acres of pasture, and 22,481 acres of woodland. In 1979, 743 acres of cropland, 275 acres of pasture, and 23,714 acres of woodland were inundated. Bertie County reported 3,602 acres of farmland and 32,380 acres of woodland affected by flooding. Individuals reported continual replacement of farm roads to pasture areas. Another individual had to rebuild two roads. Eight miles of road were rebuilt at a cost of $3,000-$5,000. Another person reported that the sand topping washed from three miles of road, and $4,476.76 was expended on a forestry road which kept washing out. Information from landowners from the 1975 flooding also cited reduced access and road repairs as problems.

Farmers who have lived in the region for decades complain that both the frequency and duration of the flooding have changed. Present-day floods come more often and last longer. The historic spring "freshers" lasted less than a week, but the reservoir system now keeps water on the cropland for several weeks to several months in some years, thereby completely eliminating the potential for crop production in certain areas.

Irrigation of agricultural and other lands within the Roanoke watershed is a major concern because of its extensive use and the difficulty in quantifying. A study conducted by the USGS in 1983 (Treece 1990) examined water withdrawals in the Roanoke-Chowan subregion of North Carolina and Virginia. Irrigation water use included water applied to grow crops (including fertigation, chemigation, and frost-free protection), and maintenance of recreational lands (e.g., golf courses and parks).

In 1983, irrigation withdrawals in the subregion were estimated at 74 MGD, or 83,000 acre-feet per year. About 99% of all withdrawal was during the period April through September. Surface water constituted about 87% of irrigation water.

In 1983, about 81,000 acres of farmland were irrigated; 44,600 acres in North Carolina and 36,000 acres in Virginia. About 35 MGD (almost one-half) of irrigation withdrawals was used to irrigate 36,000 acres of tobacco (44% of total irrigated acreage). The irrigation rate was about one foot of water per acre during the year.

About one-fourth of the total withdrawals for irrigation occurred in Hertford County, NC, and Mecklenburg and Pittsylvania Counties, VA (Figure 17). Use of ground water for irrigation was greatest in Martin County, NC, and Mecklenburg County, VA (Treece 1990).

The face of agriculture in the Roanoke River Basin is changing. A combination of factors is altering the cropland acreage and crop selection in the watershed.

Cropland acreages across North Carolina and the Nation have decreased significantly in the past decade. Selection of crop species has changed due to many factors, including world trade.

In the lower Roanoke Basin counties, corn and soybeans were the staple crops since the mid-1960s. There were also cotton, peanuts, and tobacco grown. Within the River Basin itself, little tobacco was grown.

Cotton historically battled the boll weevil. This insect pest was hardy and expensive to control with pesticides. North Carolina addressed this pest through a biological control program of reducing cotton acreage, destroying habitat, and controlling the population through trapping by using scent baits near cotton fields.

The result has been the almost entire elimination of the boll weevil. This has resulted in a state-wide resurgence in cotton production. Although not documented on a basin/floodplain basis, the expansion of cotton acreage near the Roanoke River is an observable event.

Economically, cotton is of much greater value per acre than corn or soybeans. From a wildlife perspective, soybeans, and corn provide both seed and vegetation for deer and other important species. These crops also provide excellent habitat for insects which are utilized for food by many bird species. Cotton provides fewer benefits to wildlife.

This shift from grains to fiber production will result in less food in certain locations for certain wildlife species. It also indicates that flooding which would disrupt planting or destroy crops will be of greater economic harm to farmers in the Basin than in previous years.

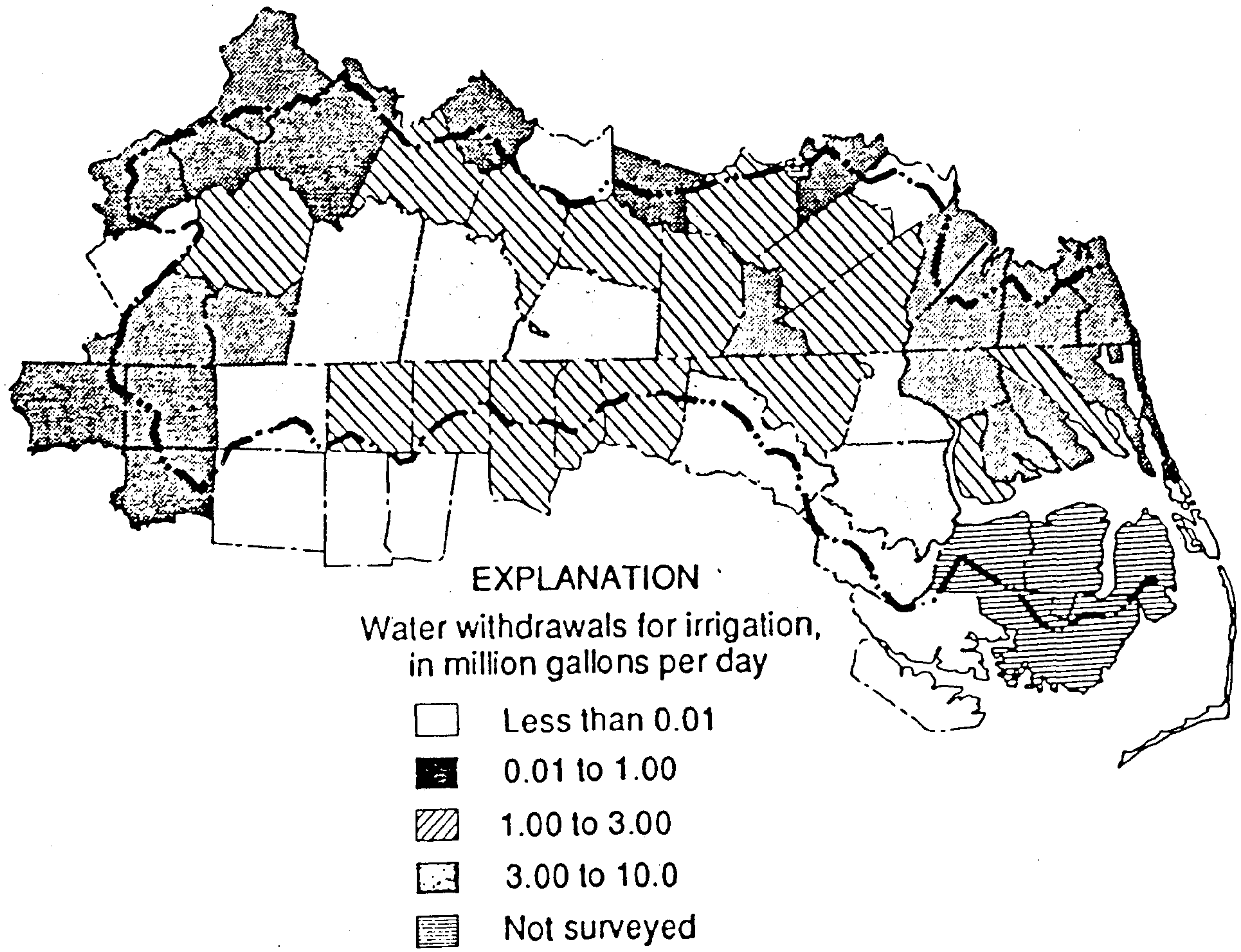


Figure 17. Water withdrawals for irrigation, in millions of gallons per day, within the Roanoke-Chowan subregion, 1983 (Treece 1990).

WILDLIFE RESOURCES

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

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 have revealed 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 utilize every habitat component 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 contributes 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. 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 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 utilize 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 both 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) (see page 51 for additional information).

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 1984) 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.

Prolonged flooding adversely affects habitats and the species utilizing these areas. Feeding, reproduction, and distribution are several life history aspects altered by flooding conditions.

Wild Turkey

The management regime of the John H. Kerr Reservoir periodically results in extended downstream flooding, usually during the spring of the year. This is suspected of causing 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) was conducted jointly by North Carolina State University and the North Carolina Wildlife Resources Commission to determine the effects of flooding on the population dynamics and habitat utilization patterns of wild turkey on the Roanoke River. Preliminary analyses of the data 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.

Deer

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 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.

Small Game

The primary small game species of the Roanoke floodplain are the gray squirrel, marsh rabbit, and woodcock. Each of these species is 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.

Waterfowl

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 utilizes 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).

The primary factor that controls the utilization of these 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 user groups. 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.

FISHERY RESOURCES

Pete Kornegay

The Roanoke River and its tributaries provide excellent habitat for a diverse assemblage of fish species, and their value to the ecosystem is well documented. Using a modification of Van Deusen's (1953) system for ecological classification of streams, Carnes (1965) and Fish (1968) categorized Roanoke River as a carp-catfish type stream. Conoho and Coniott Creeks were classified as redfin-warmouth streams.

The Roanoke River and the adjacent extensive areas of bottomland hardwood wetlands represent critical habitat for numerous anadromous species (Hassler et al. 1981, Johnson et al. 1981) which are important resources to both commercial and recreational fishermen (Rulifson et al. 1982). Blueback herring (*Alosa aestivalis*) and alewife (*Alosa pseudoharengus*) utilize tributaries of the Roanoke River and the inundated swamp forests as spawning habitat. Other anadromous species such as American shad (*Alosa sapidissima*), hickory shad (*Alosa mediocris*), and Atlantic sturgeon (*Acipenser oxyrhynchus*) also spawn in the Roanoke River. The upper reaches of the Roanoke River provide critical spawning habitat for the Roanoke River/Albemarle Sound striped bass (*Morone saxatilis*) population. The life cycle of this population is complex and spawning adults, eggs, larvae, and juveniles are all directly dependent upon specific water quality and quantity conditions to ensure successful progression to succeeding life cycle stages. Detailed information on these and other aspects of striped bass life history and management in the Roanoke River may be found in other sections of this document.

Other fish species which are recreationally important within the Roanoke River include largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), redbreast sunfish (*Lepomis auritus*), pumpkinseed (*Lepomis gibbosus*), black crappie (*Pomoxis nigromaculatus*), warmouth (*Lepomis gulosus*), flier (*Centrarchus macropterus*), redfin pickerel (*Esox americanus americanus*), chain pickerel (*Esox niger*), white perch (*Morone americana*), yellow perch (*Perca flavescens*), channel catfish (*Ictalurus punctatus*), and white catfish (*Ictalurus catus*). Yellow bullhead (*Ictalurus natalis*), brown bullhead (*Ictalurus nebulosus*), and carp (*Cyprinus carpio*) are caught incidentally while fishing for other species.

From 28 March 1988 through 19 June 1988, recreational fishermen on Roanoke River exerted 21,067 angler hours of fishing effort for largemouth bass and 112,000 angler hours for other fish species (Mullis 1989). During that period 4,338 (2,542 kg) largemouth bass and approximately 475,000 (133,000 kg) other fish species were harvested. During the period from 26 March 1989 through 9 May 1989, 15,305 angler hours were exerted for largemouth bass and 33,085 for other fish species. Approximately 1,079 (1,004 kg) largemouth bass and 42,707 (10,099 kg) other species were harvested (Kent Nelson, NCWRC, pers. comm.).

Bowfin (*Amia calva*), longnose gar (*Lepisosteus osseus*), American eel (*Anguilla rostrata*), tadpole madtom (*Noturus gyrinus*), margined madtom (*Noturus insignis*), creek chubsucker (*Erimyzon oblongus*), swampfish (*Chologaster cornuta*), pirate perch (*Aphredoderus sayanus*), mosquitofish (*Gambusia affinis*), golden shiner (*Notemigonus crysoleucas*), ironcolor shiner (*Notropis chalybaeus*), swamp darter (*Etheostoma fusiforme*), and tessellated darter (*Etheostoma olmstedi*) contribute to a high level of species diversity and provide forage for many of the game fish species. Shortnose sturgeon (*Acipenser brevirostrum*) once inhabited Roanoke River but are now believed to be extirpated (USFWS 1988).

RECREATIONAL FACILITIES OF JOHN H. KERR LAKE RESERVOIR

William Berry

The John H. Kerr Reservoir is located within the Roanoke River Basin on the Virginia and North Carolina border. The Reservoir was constructed by the U.S. Army Corps of Engineers for flood control, hydropower generation, downstream flow augmentation, and recreation. The 48,900-acre lake is easily accessible from Interstate 85 and is regionally noted for the fishing, sailing, motor boating, and the water skiing opportunities it supports. The Research Triangle Area of North Carolina, and Richmond, Virginia are within one and one-half hours' drive of the Reservoir. Extensive recreational facilities surround the Reservoir. The State of Virginia provides two state parks which include campgrounds, picnic areas, tennis courts, cabins, launching ramps, amphitheaters, and a swimming pool. The Corps of Engineers provides 13 areas (one park, eight recreation areas, two landings, one wayside, and one day-use area). The State of North Carolina provides seven recreation areas and two marinas that encompass over 2,600 acres. The parks facilities include 694 campsites, seven day-use areas, 14 boat ramps, 42 restrooms and shower facilities, 12 picnic shelters, six swimming beaches, and three community buildings (Figure 18).

The Effects of High and Low Water Levels on Recreation and Facilities

High and low water levels have effects on recreation and facilities at the seven recreation areas and two marinas managed by the North Carolina Division of Parks and Recreation. Virtually every spring and occasionally during the fall, Kerr Reservoir experiences a significant increase in the lake level. On the opposite side of flooding problems is the experience of drought conditions primarily during dry summers but also during the fall and winter months.

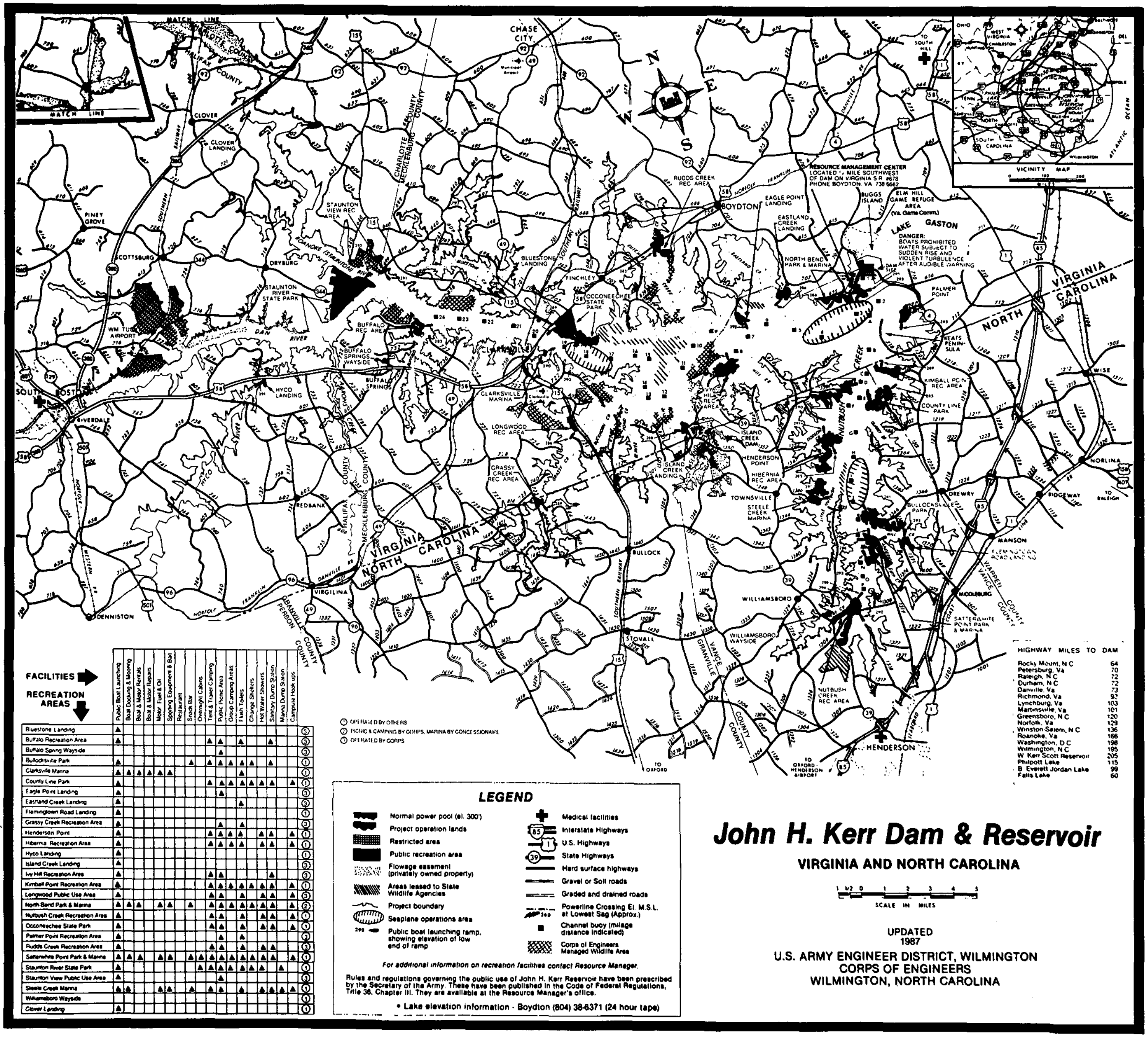
The normal lake level is 300 feet above mean sea level (msl), and at that level park users enjoy a quality recreation experience. However, as lake level fluctuates, the quality of experience decreases (Figure 19). At 304 feet, approximately 10% of access roads to campsites and day-use areas are inundated with water. At 309 feet, approximately 40% of access road to campsites and day-use areas are inundated with water. At 313 feet, main roads to approximately 50% of Kerr Reservoir State Recreation areas are inundated which, in effect, closes the entire area. All launching ramps become unusable. At 316 feet, main roads to approximately 70% of Kerr Reservoir State Recreation areas are inundated. Seventy percent of camping sites and day-use areas are underwater. Office and maintenance operations have to be altered considerably. At 319 feet, main roads to approximately 90% of Kerr Reservoir State Recreation areas are inundated. Twenty percent of restrooms, 70% of picnic shelters, and 40% of wells are underwater.

Low elevations listed in Table 13 reflect the end of each respective ramp. To safely launch a boat, approximately three feet of water is needed. Example: Bullocksville's low elevation is 294 feet. A water level of 297 feet is necessary to safely launch a typical (18-foot) boat.

Kerr Reservoir State Recreation Area is the most heavily visited park/recreation area within the N.C. Division of Parks and Recreation. When the lake level is extremely high, it significantly affects visitation and revenue. When the lake level is extremely low, it significantly affects safety in that sand bars and tree stumps expose themselves to unsuspecting boaters. Considering the number of individuals that frequent Kerr Reservoir annually, it is of paramount importance that the lake level be maintained as close as possible to 300 feet at all times during the year.

Table 13. Low reservoir elevations of boat launching ramps on Kerr Lake.

Facility	Number of ramps	Elevation (ft.) at end of ramp
Ramps		
Bullocksville	1	294
County Line	1	285
Henderson Point	3	290/290/290
Hibernia	2	285/291
Kimball Point	1	289
Nutbrush	2	290/288
Satterwhite Point	2	286/293
Marina areas		
Steel Creek	1	291
Satterwhite Point Marina	1	294



RECREATION AREAS	Public Boat Launching	Boat Docking & Mooring	Boat & Motor Rentals	Boat & Motor Repairs	Motor Fuel & Oil	Sporting Equipment & Bait	Restaurant	Snack Bar	Overnight Cabins	Tent & Trailer Camping	Public Picnic Area	Group Camping Areas	Flush Toilets	Change Shelters	Hot Water Showers	Sanitary Dump Station	Marina Dump Station	Campsite Hook ups	
Bluestone Landing	▲																		③
Buffalo Recreation Area	▲									▲	▲		▲			▲			③
Buffalo Spring Wayside											▲								③
Bullocksville Park	▲							▲		▲	▲	▲	▲	▲		▲			①
Clarksville Marina	▲	▲	▲	▲	▲	▲							▲						①
County Line Park	▲									▲	▲	▲	▲	▲	▲	▲		▲	①
Eagle Point Landing	▲										▲								③
Eastland Creek Landing	▲												▲						③
Flemingtown Road Landing	▲																		①
Grassy Creek Recreation Area	▲										▲		▲						③
Henderson Point	▲									▲	▲	▲	▲		▲	▲		▲	①
Hibernia Recreation Area	▲									▲	▲	▲	▲		▲	▲		▲	①
Hyco Landing	▲																		①
Island Creek Landing	▲																		③
Ivy Hill Recreation Area	▲									▲	▲					▲			③
Kimball Point Recreation Area	▲									▲	▲	▲	▲	▲	▲	▲		▲	①
Longwood Public Use Area	▲									▲	▲		▲		▲	▲		▲	③
North Bend Park & Marina	▲	▲	▲		▲	▲		▲		▲	▲	▲	▲	▲	▲	▲		▲	②
Nutbush Creek Recreation Area	▲									▲	▲		▲		▲	▲		▲	①
Occoneechee State Park	▲									▲	▲		▲		▲	▲		▲	①
Palmer Point Recreation Area	▲										▲		▲						③
Rudds Creek Recreation Area	▲									▲	▲		▲		▲	▲			③
Satterwhite Point Park & Marina	▲	▲	▲		▲	▲		▲	▲	▲	▲	▲	▲	▲	▲	▲		▲	①
Staunton River State Park	▲								▲	▲	▲	▲	▲	▲	▲		▲		①
Staunton View Public Use Area	▲										▲								③
Steele Creek Marina	▲	▲			▲	▲		▲		▲	▲		▲		▲	▲	▲	▲	①
Williamsboro Wayside																			①
Clover Landing	▲																		①

Figure 18. Facilities and recreation areas of John H. Kerr Dam and Reservoir.

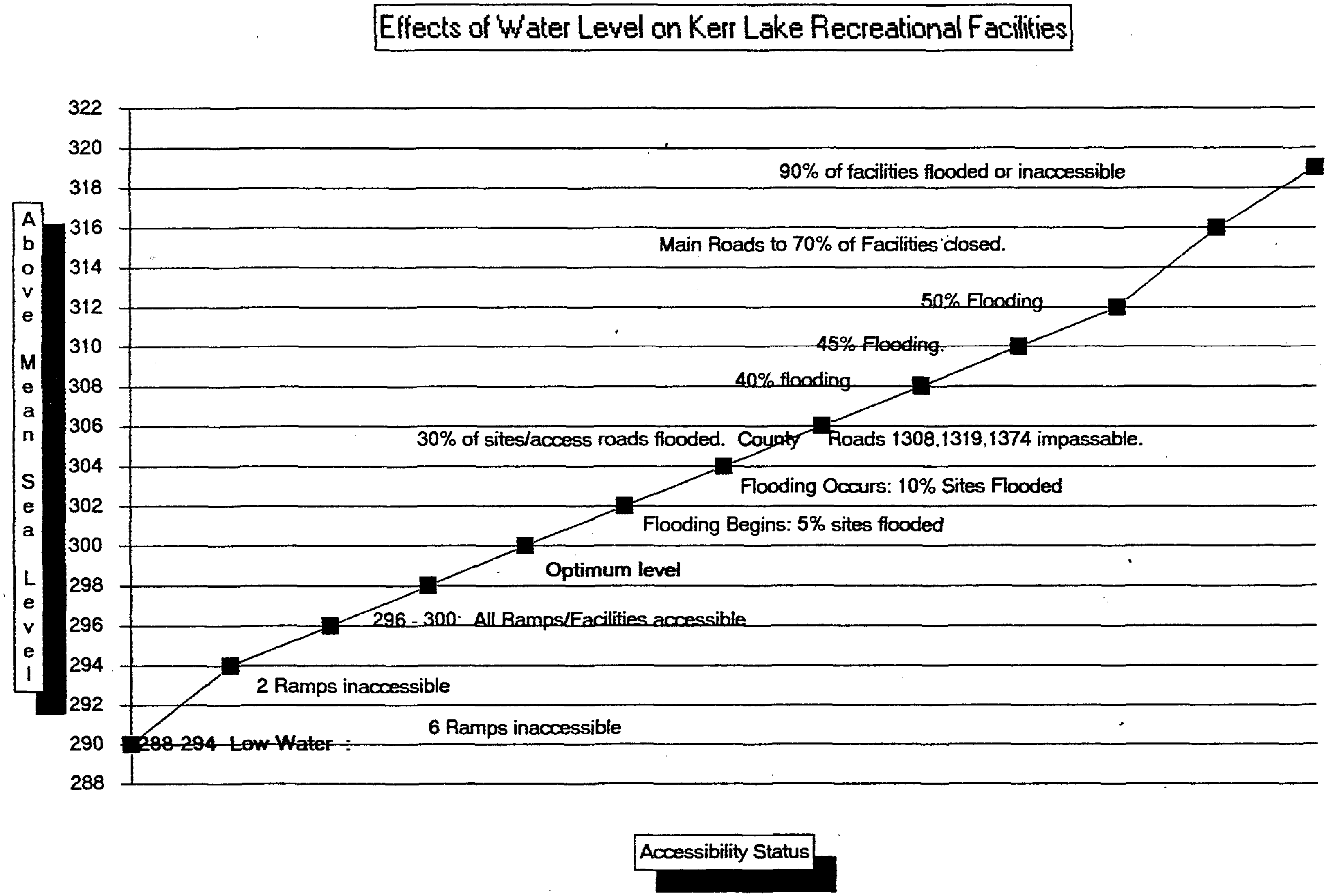


Figure 19. Effects of water level on Kerr Lake recreational facilities.

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.

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.

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.

CURRENT AND PROPOSED SCIENTIFIC STUDIES FOR ROANOKE/ALBEMARLE NATURAL RESOURCES

Project Title	Status	Agency/Investigator
Kerr Reservoir Striped Bass Spawning Flow Management Policy Investigation	Proposed	NCDWR/Fransen
Roanoke River Basin Consumptive Water Use Investigation	Current	NCDWR/Fransen
Determination of Tissue Concentrations and Potential Significance of Dioxins in Brood Stock Striped Bass	Proposed	USFWS/Fleming
Development of a Juvenile Abundance Index for White Perch and Other Key Species for Albemarle Sound, NC	Proposed	NCDMF (ECU)/Rulifson
Fishery Independent Gill Net Study for Albemarle Sound Striped Bass	Current	NCDMF/Henry
Maturation and Fecundity of Roanoke River/Albemarle Sound Striped Bass	Current	NCWRC (ECU)/Olsen and Rulifson
Existing Data, Striped Bass	Current	NMFS/Manooch
Water Flow Regulation Modeling	Current	USACOE/Grimes
Investigation of Flows in the Lower Roanoke River and Hydrodynamics of Albemarle Sound, NC	Current	USACOE (USGS)/Bales
Striped Bass Larvae and the Food Chain in Western Albemarle Sound, NC	Current	NCWRC (ECU)/Rulifson
Population Dynamics of Striped Bass in the Roanoke River and Albemarle Sound	Current	USFWS/Rago and Dorazio
Abundance and Viability of Striped Bass Eggs Spawned in the Roanoke River, NC in 1991	Current	NCWRC (ECU)/APES/Rulifson
Land and Water Use/Report Writer	Current	USFWS/Cole and Laney
Roanoke River Flow Time Series Analysis	Current	ECU/Zincone

Project Title	Status	Agency/Investigator
Age Composition and Sport Harvest of Striped Bass from the Roanoke River	Current	NCWRC/Nelson
Roanoke River Phytoplankton Species Composition and Biomass	Current	ECU/Stanley
Zooplankton Abundance in the Lower Roanoke River, Delta, and Western Albemarle Sound	Current	ECU/Rulifson
Food Habits of Juvenile Striped Bass in Albemarle Sound	Current	ECU/Rulifson
Age and Growth of Juvenile Striped Bass in Albemarle Sound	Current	NMFS/Isley
Delineation of Submerged Aquatic Vegetation in Currituck, Albemarle, and Western Pamlico Sounds	Proposed	NMFS/Ferguson
An Inventory and Protection Plan for Critical Natural Areas, Exemplary Wetlands/Endangered Species	Proposed	VA Conserv./Lipford and Smith
Effects of Trawling on Benthic Community Structure and Fish Production	Proposed	ECU/Ambrose and West
Error Analysis of Fishery Dynamics Models for the Albemarle Sound and Pamlico Sound Estuaries	Proposed	Versar/Jacobson
Shell Disease in Blue Crabs from the A/P Estuary	Proposed	NMFS/NCSE/Noga and Engel
Fishing Practices Mapping and Literature Review of Environmental Impacts	Proposed	RTI/NCDMF/Cunningham
Expanded Evaluation of Management and Resource Protection Programs Affecting the A/P Region	Proposed	RTI/Duffin
Land Use and Land Cover Change Detection Within the A/P Area Using Remote Sensing	Proposed	NCSU/CGIA/Khorram and Siderelis
GIS-Based Environmental Management Evaluation of Potential Water Quality Impacts of Land Use and Population Scenarios	Proposed	UNC/Godschalk and Walse

Project Title	Status	Agency/Investigator
Environmental Management Program for SE VA Portion of the A/P Watershed	Proposed	Hampton Rds PDC/Carlock
GIS: A Tool for Resource Management Modeling as Applied to the A/P Environment	Proposed	NCSU/Rice and Pittman
A Citizen's Water Quality Monitoring Program for the A/P Estuary	Current	ECU/Blinkoff
Identification of Ground-Water Recharge Areas Within the A/P Study Area/ Susceptibility to Pollution	Proposed	RTI/Liddle
Modeling and Visualization of the Circulation in the A/P System	Proposed	NCSU/Janowitz and Pittman
Baseline Water Quality Program	Proposed	NCDEHNR/Tedder
Continuous Monitoring of A/P Water Quality	Proposed	USGS/Bales
Histopathological Studies of Effects of Acid Waters and Aluminum on the Epidermis of Striped Bass Larvae	Current	ECU/Dorton
Genetic Heterogeneity of Roanoke/ Albemarle Striped Bass - Implications for Management	Proposed	ECU/Stellwag and Rulifson
Food and Feeding of Larval Fish Species in Roanoke River and Western Albemarle Sound	Current	EPA/APES/Rulifson
Water Quality of the Lower Roanoke River in 1991	Current	Weyerhaeuser/ECU, Herrmann and Rulifson

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 14.

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 15. 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). These articles are presented in Appendices D and E.

Table 14. 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 15. 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

CHARACTERIZATION OF ROANOKE RIVER FLOWS FOR 12-MONTH PERIOD

Roger A. Rulifson, Marsha E. Shepherd, and Charles S. Manooch III

One concern of the Flow Committee is that our focus on instream flow regulations for spring may be too narrow, and that a 12-month approach would more appropriate for a good watershed management plan. Moreover, a holistic watershed management approach would provide the information necessary to develop instream flow models which consider current and future water demands. These demands include pollution abatement and NPDES concerns, but also must include criteria for water withdrawal, consumptive use (e.g., electrical co-generation facilities), interbasin water transfer, reservoir release schedules, irrigation, and other uses. In addition, a holistic watershed management approach must have a mechanism for interstate watershed management for those situations in which watersheds cross state boundaries.

To initiate the first step in proposing such an approach, we characterized the instream flow of the lower Roanoke River downstream of Roanoke Rapids Reservoir using preimpoundment (1912-1950) and postimpoundment (1955-1990) data from the USGS gage located near Weldon, NC. In this comparison, we assumed that precipitation was not different between the preimpoundment and postimpoundment time segments. An examination of daily average (mean) flows smoothed by a seven-day running average indicate a seasonal pattern in instream flow (Figure 20). Natural, unregulated instream flows of the preimpoundment period typically fluctuated between about 10,000 cfs to just over 15,000 cfs during January through mid-April. During the period April through June, instream flows decreased steadily. Summer average flows were the lowest for the year, increasing gradually in late fall and into early winter (Figure 20.) Using median seven-day averages, the instream flow pattern for the preimpoundment period was similar, though less variable than that observed using daily mean values (Figure 21). The plot of median values resulted in average instream flow rates lower, in some cases several thousand cfs lower, than the plot of daily mean values.

The postimpoundment daily flow pattern deviates somewhat from the average preimpoundment instream flow rates but still exhibits a seasonal pattern. Using mean flow values (Figure 20), winter postimpoundment flows typically are lower than preimpoundment values, perhaps reflecting the storing of water within the reservoir system. Spring flows during the striped bass spawning season are greater than preimpoundment values. Summer reservoir releases tend to provide more stability in summer instream flow rates; fall postimpoundment River flows are typically higher than preimpoundment daily average flows (Figure 20). Again, a plot of smoothed daily median flows shows a similar trend, with the exception that average median postimpoundment values tend to exhibit greater variability, a trend opposite that of preimpoundment values (Figures 20 and 21).

To determine whether the postimpoundment instream flows differ significantly from preimpoundment values, we calculated the preimpoundment Q_1 and Q_3 values on a weekly basis for the entire 12-month period, then compared the values to those calculated for the postimpoundment period (Table 16). A t-test was used for each of 52 weeks to determine if postimpoundment values for the week were different from the historical flow record for Q_1 values, Q_3 values, the median flow, and mean flow. Table 17 shows the results of the t-test analysis; only those weeks with significant relationships are presented.

The daily flow patterns exhibited in the previous two figures can be explained by normal operation of the reservoir system upstream with no consideration given to basinwide precipitation. During the months of January, February, and March, the Q_3 boundary of historical flows (calculated on a weekly basis) is significantly higher for the preimpoundment period than for

Table 16. Roanoke River flow data, 1912-1950 and 1955-1990.

		Preimpoundment (1912-1950)									Postimpoundment (1955-1990)								
			Median		Q1		Q3		Mean			Median		Q1		Q3		Mean	
Week	Dates	N	mean	std	mean	std	mean	std	mean	std	N	mean	std	mean	std	mean	std	mean	std
1	01JAN-07JAN	39	11776	13203	7044	4742	18562	19186	12840	11576	36	9249	4702	5487	4961	11552	4647	8725	4450
2	08JAN-14JAN	39	10607	10083	7456	6343	16741	16976	11870	10653	36	10141	5346	6995	5661	11862	4654	9563	4883
3	15JAN-21JAN	39	9714	6575	7511	3921	16775	16671	11678	8525	36	10098	5771	7110	5250	12212	5446	9512	4874
4	22JAN-28JAN	39	9022	5254	6969	3198	15982	18649	10907	8858	36	9147	5429	6715	5593	10864	4798	8885	4953
5	29JAN-04FEB	39	9777	5154	7688	3978	15916	12371	11302	6201	36	10605	5755	7618	5948	12427	5473	10005	5306
6	05FEB-11FEB	39	10949	7183	8226	3993	16708	13790	12664	8170	36	10904	5336	7782	5600	13041	5291	10455	5139
7	12FEB-18FEB	39	12062	10066	8496	4201	18315	17642	13131	10015	36	10693	5673	7214	6081	12707	5363	10019	5246
8	19FEB-25FEB	39	10713	5504	8778	3953	15666	10724	11944	6569	36	9989	5934	7282	6212	13189	5356	10020	5202
9	26FEB-04MAR	39	10808	7613	8379	3940	15097	12552	11669	7783	36	11283	6488	7981	6470	13101	5984	10674	5989
10	05MAR-11MAR	39	13263	11699	8504	4011	19832	17937	14107	10251	36	11872	6843	8206	7131	13859	6387	11227	6360
11	12MAR-18MAR	39	12174	9540	8813	3806	18548	19052	13577	10453	36	10763	6729	7824	7209	12854	5782	10351	6262
12	19MAR-25MAR	39	11416	8016	8682	4087	19460	22172	13665	11424	36	10411	7299	8304	7922	12180	6789	10184	6962
13	26MAR-01APR	39	10913	7567	8693	4432	14436	9985	11629	7300	36	10772	8047	8868	8556	12782	7402	10709	7706
14	02APR-08APR	39	9992	5199	8074	3686	15417	10583	11662	6725	36	10554	8097	8463	8343	12573	7727	10540	7720
15	09APR-15APR	39	10907	7437	8314	4329	18433	13800	12677	7591	36	11289	9201	9356	8707	13074	8541	11282	8435
16	16APR-22APR	39	8914	3699	7459	2887	13719	8977	10530	5074	36	12741	9018	10069	8485	13983	8935	12217	8457
17	23APR-29APR	39	8687	5911	6579	2339	12375	13744	9402	6663	36	10278	7332	8216	7607	12424	8057	10314	7311
18	30APR-06MAY	39	7567	3660	6348	2201	10835	9059	8414	4885	36	11190	8199	9523	8018	12223	8082	11083	7834
19	07MAY-13MAY	39	6751	2654	5755	1886	10048	9154	7681	4226	36	11518	7634	10218	7727	12647	7608	11499	7576
20	14MAY-20MAY	39	7996	5908	6486	4710	12437	10968	9269	7418	36	10744	7507	9158	6864	11841	7681	10670	7062
21	21MAY-27MAY	39	7127	4789	5377	2388	10845	9620	8027	5419	36	9382	5993	8227	5893	10971	6901	9562	6196
22	28MAY-03JUN	39	6704	3296	5101	1851	9653	6161	7510	3810	36	8412	5508	6705	4657	10152	5897	8525	5058
23	04JUN-10JUN	39	6160	3290	4733	2033	9492	9706	6975	4336	36	8148	4934	6365	4889	10054	4836	8312	4584
24	11JUN-17JUN	39	5899	2843	4499	1659	8244	5458	6512	3366	36	7133	4979	4804	4421	9505	4600	7150	4346
25	18JUN-24JUN	39	5882	5827	4512	2563	8605	9606	6479	5624	36	6479	4340	4008	3740	8997	4658	6485	3691
26	25JUN-01JUL	39	5577	4157	4204	2287	7588	7338	5919	4328	36	6159	4971	4374	4042	7764	5421	6104	4364
27	02JUL-08JUL	39	5196	2640	3980	1529	7373	4360	5649	2805	36	5100	4838	4049	4439	6931	5156	5434	4536
28	09JUL-15JUL	39	5552	3493	4317	2213	8216	6569	6212	4102	36	4936	4136	3367	3150	7536	4292	5449	3574
29	16JUL-22JUL	39	7783	10040	4843	3214	11737	13527	8408	9017	36	6400	4856	4304	4273	7999	5007	6315	4343
30	23JUL-29JUL	39	7241	9404	4907	5033	10640	15182	7877	10026	36	5110	4127	3703	3783	6359	4244	5171	3886
31	30JUL-05AUG	39	5161	3005	3898	1862	7597	4781	5692	3149	36	5198	4521	3751	3913	6768	4539	5321	3960
32	06AUG-12AUG	39	5000	3256	3747	1786	7262	7125	5476	3897	36	5081	3450	3406	2313	6887	4301	5213	2983
33	13AUG-19AUG	39	7493	11550	4175	3269	13798	34685	8572	15754	35	5163	2706	3203	1575	7351	4228	5320	2467
34	20AUG-26AUG	39	5535	5052	3952	2600	13881	24485	8329	11546	35	6017	5889	4133	4932	8166	6051	6076	5180
35	27AUG-02SEP	39	5496	6413	3677	3407	7362	9098	5705	6307	35	5486	3966	3665	3340	7093	4498	5562	3605
36	03SEP-09SEP	39	5281	5522	3575	2641	8834	10296	6130	6041	35	4499	2649	3000	1528	6772	4140	4835	2459
37	10SEP-16SEP	39	3922	2804	3112	1968	5605	5440	4586	3860	35	5589	4418	4074	4152	7463	4412	5782	3970
38	17SEP-23SEP	39	6320	14518	3752	6106	11103	23965	7184	14079	35	5506	4411	3261	3293	7238	4776	5490	3688
39	24SEP-30SEP	39	3888	3055	3074	1836	7082	9368	5206	5549	35	5660	4635	3504	3477	7596	4884	5665	3950
40	01OCT-07OCT	39	7579	14719	3684	3795	12010	21003	7906	12888	35	5746	4683	3749	4179	7843	5623	5770	4531
41	08OCT-14OCT	39	4281	3325	3183	2042	6439	6862	4744	4082	35	5840	5623	4310	5607	7287	5745	5874	5445
42	15OCT-21OCT	39	3637	2394	3153	1719	6243	8031	4700	4080	35	5379	4755	3118	2853	7180	5592	5298	4052
43	22OCT-28OCT	39	4873	4604	3672	2545	8566	14228	6039	7601	35	6059	5143	3898	4145	7628	5490	5901	4501
44	29OCT-04NOV	39	4800	5957	3447	1845	6856	9076	5178	5128	35	5202	4823	3880	4593	7042	5056	5505	4531
45	05NOV-11NOV	39	4339	2965	3629	2118	6957	6954	5078	3752	35	6455	4956	4166	4918	8240	5039	6273	4552
46	12NOV-18NOV	39	4745	3633	3918	2902	6957	7010	5483	4522	35	6630	4494	4018	4983	8552	4949	6472	4490
47	19NOV-25NOV	39	5069	2651	4067	1915	8191	7125	5979	3769	35	6899	4428	4039	4091	8432	4248	6427	4013
48	26NOV-02DEC	39	5158	3454	4132	2433	9857	14641	6661	7094	35	6842	5495	4655	5710	9213	4772	6923	4926
49	03DEC-09DEC	39	7913	8881	5684	5273	13340	17321	9159	9973	35	7675	4492	4229	4331	9827	4459	7219	3906
50	10DEC-16DEC	39	6168	3770	5098	2744	8862	6796	6862	4399	35	7635	4376	5003	4388	9701	4410	7331	4076
51	17DEC-23DEC	39	6226	3585	4945	2338	8175	5561	6656	3888	35	8598	4775	5777	4845	10617	5010	8194	4509
52	24DEC-31DEC	39	8229	7832	5600	3244	11625	10904	8936	7228	35	7410	4975	4106	3962	10417	4628	7398	4119

Table 17. Results of a t-test comparing Roanoke River flows (on a weekly basis) for the preimpoundment (1912-1950) and postimpoundment (1955-1990) periods. Only weeks having one or more significant relationships are presented. NS = not significantly different.

		Q_1 Boundary		Q_3 Boundary		Median		Mean	
Week	Date	P>T	Flow	P>T	Flow	P>T	Flow	P>T	Flow
1	Jan 1-7	0.1688	NS	0.0323	Pre>Post	0.0446	Pre>Post	0.2680	NS
2	Jan 8-14	0.7416	NS	0.0913	Pre>Post	0.2275	NS	0.8010	NS
7	Feb 12-18	0.2959	NS	0.0648	Pre>Post	0.0938	Pre>Post	0.4666	NS
10	Mar 5-11	0.8265	NS	0.0570	Pre>Post	0.1454	NS	0.5284	NS
11	Mar 12-18	0.4663	NS	0.0818	Pre>Post	0.1069	NS	0.4591	NS
12	Mar 19-25	0.7985	NS	0.0569	Pre>Post	0.1130	NS	0.5727	NS
15	Apr 9-15	0.5202	NS	0.0456	Pre>Post	0.4533	NS	0.8435	NS
16	Apr 16-22	0.0866	Post>Pre	0.8988	NS	0.3042	NS	0.0222	Post>Pre
18	Apr 30-May 6	0.0269	Post>Pre	0.4876	NS	0.0849	Post>Pre	0.0186	Post>Pre
19	May 7-13	0.0017	Post>Pre	0.1875	NS	0.0101	Post>Pre	0.0009	Post>Pre
20	May 14-20	0.0558	Post>Pre	0.7850	NS	0.4057	NS	0.0811	Post>Pre
21	May 21-27	0.0096	Post>Pre	0.9481	NS	0.2564	NS	0.0750	NS
22	May 28-Jun 3	0.0597	Post>Pre	0.7215	NS	0.3273	NS	0.1124	NS
23	Jun 4-10	0.0693	Post>Pre	0.7494	NS	0.1981	NS	0.0462	Post>Pre
30	Jul 23-29	0.2483	NS	0.0979	Pre>Post	0.1243	NS	0.2036	NS
37	Sep 10-16	0.2176	NS	0.1136	NS	0.1932	NS	0.0609	Post>Pre
39	Sep 24-30	0.5164	NS	0.7650	NS	0.6808	NS	0.0599	Post>Pre
42	Oct 15-21	0.9507	NS	0.5589	NS	0.5294	NS	0.0563	Post>Pre
45	Nov 5-11	0.5533	NS	0.3713	NS	0.2200	NS	0.0322	Post>Pre
46	Nov 12-18	0.9178	NS	0.2586	NS	0.3493	NS	0.0500	Post>Pre
47	Nov 19-25	0.9706	NS	0.8586	NS	0.6220	NS	0.0380	Post>Pre
51	Dec 17-23	0.3601	NS	0.0520	Post>Pre	0.1195	NS	0.0175	Pre>Post
52	Dec 24-31	0.0789	Pre>Post	0.5304	NS	0.2593	NS	0.5893	NS

the postimpoundment period, reflecting water storage in the reservoir (Table 17). Beginning in mid-April, the Q_1 boundary for historical postimpoundment flows is significantly higher than that of preimpoundment, reflecting releases from the reservoir in context of spawning activity of striped bass, and the MOU agreement for additional water releases during the period. From July through December, weekly average flows of the postimpoundment period are significantly higher than for the preimpoundment period.

In summary, weekly estimates of Q_1, Q_3, median, and mean flows for the preimpoundment and postimpoundment periods reflect a significant change in River flow, although the seasonal patterns are similar. In a general sense, this means that on a weekly average more water is present in the lower River in the spring and fall due to reservoir releases. The Q_3 boundary is higher for the preimpoundment period, but the average flow rate was not. In a following section of this report, these trends are examined in closer detail.

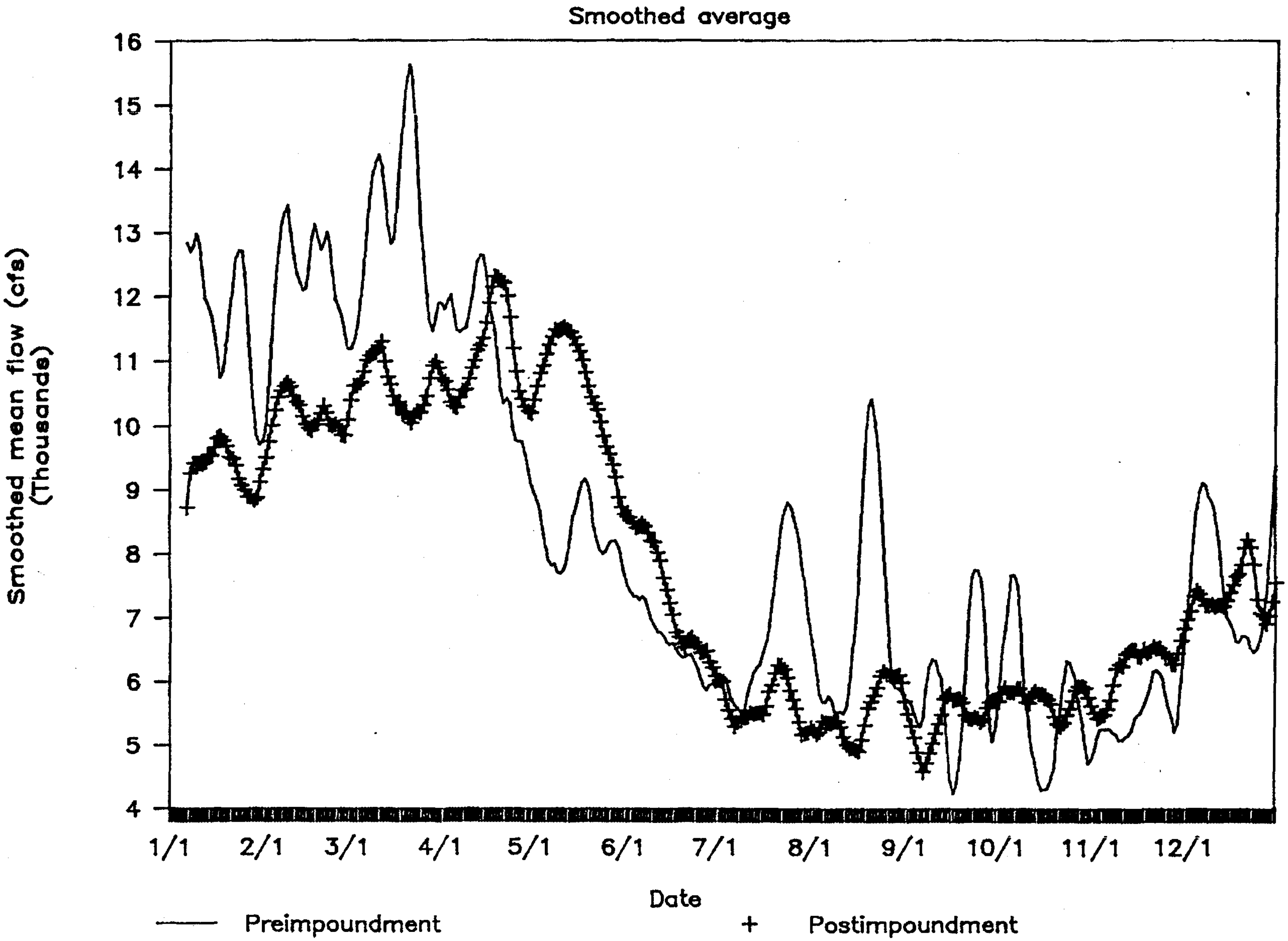


Figure 20. Roanoke River (mean) flow, 1912-1990.

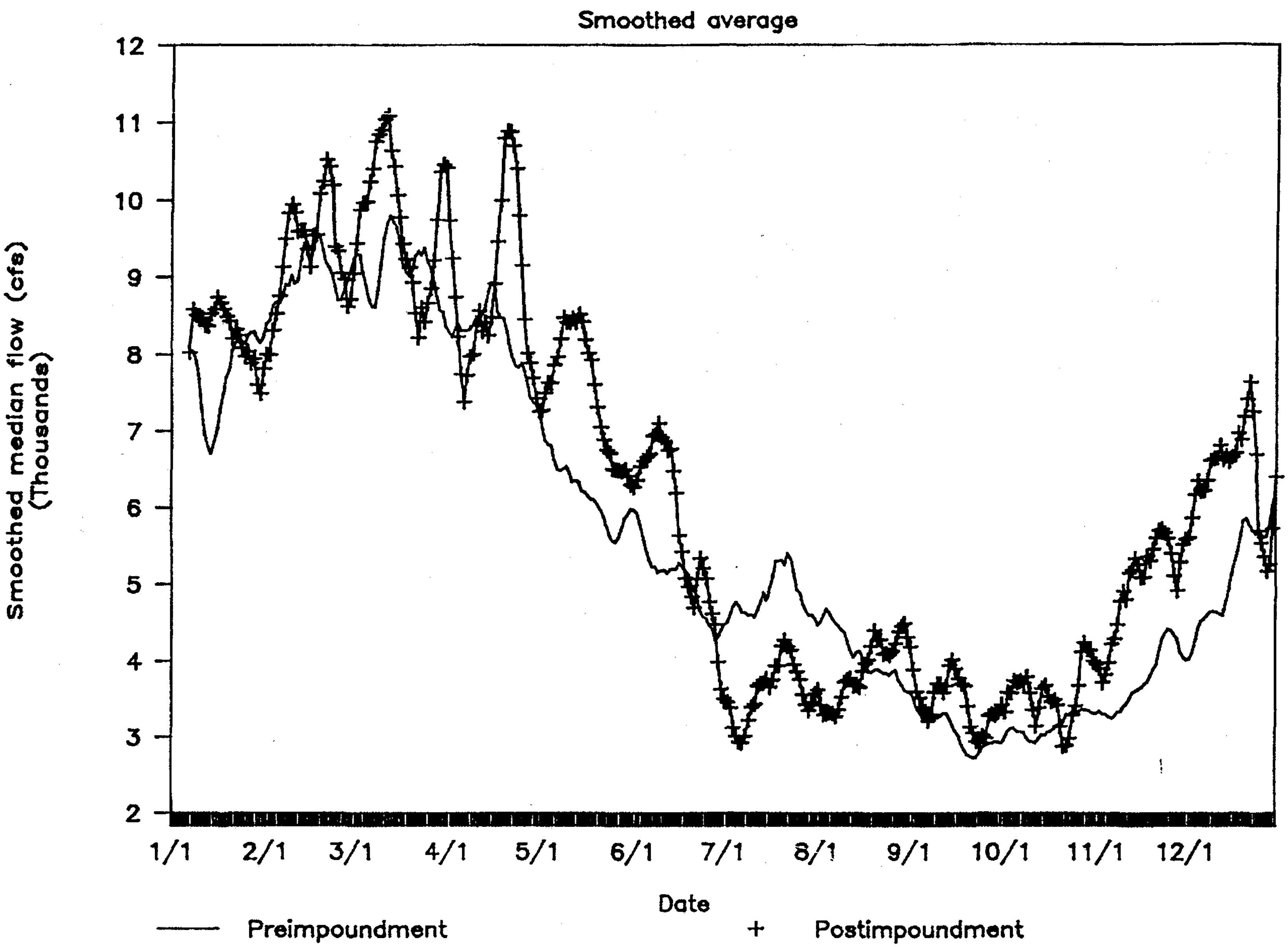


Figure 21. Roanoke River daily (median) flow, 1912-1990.

ANALYSIS OF ROANOKE RIVER FLOWS FOR 12-MONTH PERIOD

L.H. Zincone, Jr.

Frequency Analysis

Introduction

In previous reports, the various authors, including the present author, have concentrated on analyzing flows during the recommended period of March through June and the Negotiated Period, 1 April through 15 June. This section is an effort to describe the flows during the entire year, recognizing that it is the true charge of the Committee to examine all of the flows and their relationship to all of the resources. This section approaches the task in terms of frequency analysis. That is, the focus of this analysis will be on what percentage of days in each month had average daily flows in certain intervals. This is the best objective estimate of the probability that the flow on a given day will be in a certain range. For this analysis, preimpoundment is defined as 1912 through 1950 and postimpoundment is defined as 1955 to 1990. The years 1951 through 1954 are omitted since it was in these years when the majority of the dam construction occurred. The frequencies will be presented graphically and comments will be made on the figures. In addition to the comments, I will report on chi-square tests of independence. These tests, not surprisingly, lead to the conclusion that the frequency distributions of the flows are not independent of the pre- or postimpoundment status. This is understandable, since one of the major reasons for construction of the dams was flood control.

In accordance with the 1971 Memorandum of Understanding (MOU), the minimum agreed upon below-dam flow for the Roanoke River is monitored at the Weldon gage; at the present time all minimum flows throughout the year are allocated to NPDES permitted uses (see Water Quality section by Briggs). The minimum instantaneous flow required is only 1,000 cfs (depending on oxygen levels) for the period November-March, 1,500 cfs for April and October, and 2,000 cfs for the period May-September. There are exceptions for off-peak times (e.g., weekends). In this section, I use this flow as a standard to explore potential problems which might result from permitting additional upstream uses. Under current license requirements, only one scenario is possible under drought conditions. The minimum 2,000 cfs release downstream (monitored at the Weldon gage) must be maintained at the expense of lowering the Kerr Lake level (as per the 1971 MOU). If one assumes that the reservoir is currently operated efficiently, any additional upstream uses could result in a failure to meet the minimum flow requirements on any day when the flow would be less than 2000 cfs plus the additional upstream requirements. If all proposed and pending projects were approved, the projected water use would be the equivalent of about 332 cfs. Percent reduction in flows at Roanoke Rapids gage would be 3.7% at 8,106 cfs (Table 18) but at the minimum, the change would be 15% at 2,000 cfs, and 30% at 1,000 cfs. The import of this is that, by law, these flows must be maintained by utilizing Power Pool Storage, which will drop lake levels and affect wildlife and fisheries in the reservoir, economic development, and recreation.

[Editors' Note: The estimate for this analysis is reasonable in light of a recent Corps document (U.S. Army Corps of Engineers 1991) which presents the daily existing and projected future consumptive use of Roanoke River Basin waters upstream of Kerr Reservoir Dam (Table 15 of Corps report, Table 18 of this report). However, neither estimate considers irrigation or other consumptive uses downstream of Kerr Reservoir Dam.]

Table 18. Daily water use from Roanoke River Basin upstream of Kerr Reservoir Dam[a] (U.S. Army Corps of Engineers 1991). This table compiled for the proposed Mecklenburg Cogeneration Facility, Clarksville, Virginia (Mecklenburg Cogeneration Limited Partnership).

Facility	Water withdrawn (mgd)	Water returned[b] (mgd)	Net water use (mgd)	Reduction inflow at Roanoke inflow at Roanoke Rapids gage (cfs)	Percent reduction of average flows at Roanoke Rapids gage (8,106 cfs)
Existing Water Users					
Virginia facilities[c]	N/A	N/A	150.1[a]	(d)	(d)
North Carolina facilities[e]	N/A	N/A	39.0	(d)	(d)
Others					
Dan River Steam Station[f]	239.0[a]	232.9	6.1[a]	(d)	(d)
Belews Creek Steam Station[f]	1,160.0[a]	1,139.4	20.6[a]	(d)	(d)
Roxboro Generating Plant[f]	1,621.0[a]	1,588.7	32.3[a]	(d)	(d)
Mayo Generating Plant[f]	375.0[a]	367.3	7.7[a]	(d)	(d)
City of Virginia Beach[g]	60.0[a]	0.0	60.0[a]	93	1.15
Subtotal			315.8	93	1.15
Projected Future Water Users					
Mecklenburg Cogeneration Plant	3.1	0.8	2.3	4	0.05
Virginia facilities[c]	N/A	N/A	37.0[a]	57	0.70
North Carolina facilities[e]	N/A	N/A	54.0	84	1.04
Others					
Virginia Power[h]	25.2	2.1	23.1	36	0.44
Commonwealth Cogeneration Plant[h]	3.2[a]	0.8[a]	2.4[a]	4[a]	0.05
Ultrasystems Cogeneration Plant[h]	1.4[a]	0.2[a]	1.2[a]	2[a]	0.02
ODEC Cogeneration Plant (Clover)[i]	11.8[a]	0.8[a]	11.0[a]	17[a]	0.21
Multigrade Cogeneration Plant[i] (Hurt)	2.0[a]	0.3[a]	1.7[a]	3[a]	0.04
Subtotal			132.8	207	2.55
Grand Total			448.6	300	3.70

Sources: COE files; press announcements of proposed facilities; Virginia State Water Control Board, 1988; North Carolina Division of Water Resources, 1986; and estimates by MCLP.

Key for Table 18: MGD, million gallons per day; N/A, not available.

[a] Italicized values are fixed. All other values are estimates by MCLP.
[b] Estimated (nonitalicized) values assume that 25 percent of water withdrawn for thermal cooling will be returned to water source through effluent discharge.
[c] Estimates presented by Virginia State Water Control Board (1988, Table III-2). Existing is for 1990; future is for 2030.
[d] Existing condition, already reflected in average annual flow at Roanoke Rapids gage (8,106 cfs).
[e] Calculations based on estimates presented by North Carolina Division of Water Resources (1986, Table V-1). Value of 30.6 MGD reported for 1984 was projected to 1990 and 2030 using growth rate reflected in values shown in Table V-1 (Campbell 1991).
[f] Thermal-electric plant use from Table II-2 of Virginia State Water Control Board, 1988. Thermal-electric plant use was not included in Table V-1 of North Carolina Division of Water Resources, 1986. A second unit at Mayo plant forecast in this study has not been built.
[g] Released from Kerr Reservoir for withdrawal at intake at Lake Gaston. Water storage has been allocated; however, no withdrawals have been made.
[h] Draft worst-case projections provided by Virginia Power. These figures do not have environmental clearances and are subject to change.
[i] Minimum instream flow restrictions under Virginia Water Protection Act permit would apply to these users. Water use values from Virginia State Water Control Board permit applications.

Analysis by Month

Figures 22a through 33a show the percent of days when the average daily flow was in an interval centered upon the flow noted in the horizontal axis. Thus, the class interval denoted "1000" in Figure 22 shows that less than 1% of the preimpoundment January days had a flow of between 500 and 1499 cfs while approximately 8.5% of the postimpoundment January days had flows in that interval. On the other end of the spectrum, approximately 11.8% of the preimpoundment January days had flows at 20,000 cfs or above while less than 3% had such large flows during the postimpoundment period. It should be noted that anytime the frequency in a class interval was less than five, it was combined with one of its neighbors. This was necessary to perform the chi-square tests and was preserved in the figures. Hence, some of the zeros are really numbers which are less than five.

In order to make the differences in the flows clearer, Figures 22b through 33b show the difference in pre- and postimpoundment percentage frequencies for the 12 months. In these figures, the bars represent the difference between the percent of postimpoundment days and the percent of preimpoundment days in the class interval. A positive difference means that the percent of days increased when going from pre- to postimpoundment.

In analyzing the figures, especially the ones having the "b" suffix, two of the most noticeable characteristics are (1) the complementary relationship between the 19,000 and 20,000 cfs intervals in the months of January and February, and (2) the increase in the percent of days in the low class interval in all months except May and September. Comments on the individual months follow.

January - The two most prominent features of the difference in the distributions for January are the complementary reduction in days of 20,000 cfs or above and the increase in the days in the interval 19,000 cfs and the substantial increase in the percent of days in the 1000 cfs (500 to 1500 cfs) class interval. Moderate reductions occurred in the 4000 to 7000 cfs range (Figure 22).

February - The graph for February is similar to that for January in the upper two intervals. The largest increase in February is in the lowest range. Note that since the class interval 1000 is empty, there were less than five days in that range (Figure 23).

March - In March, the largest increase was in the lowest class interval followed by an increase of moderate size in the 19,000 cfs interval. These were offset by decreases in the 6000 to 11,000 range (Figure 24).

April - The increases in the largest and smallest class intervals suggest that the flow is less stable during postimpoundment (Figure 25).

May - The major changes in May occurred in the intervals from 4000 cfs to 6000 cfs. A large increase in the percent of days with a flow of 6000 cfs was offset by a similar decrease in the percent of days with flows of either 4000 cfs or 5000 cfs. Interestingly, a moderate increase in the percent of days in the 20,000 cfs interval occurred (Figure 26).

June - June represents a return to what might be called the "normal" pattern of changes, with the complementary changes in the upper two class intervals and a large increase in the 1000 cfs interval (Figure 27).

July - Similar to May except that there is a large increase in the lowest class interval offset by decreases in the 3000 to 5000 cfs classes (Figure 28).

August - The comments on July apply to August (Figure 29).

September - Shows large decreases in the 2000 to 4000 cfs class intervals and moderate increases in the 6000 to 10,000 cfs intervals (Figure 30).

October, November, and *December* - Show increases in the lowest interval and decreases in the next two or three intervals (Figures 31-33).

In summary, every month except September had an increase in the percentage of days in the lowest class interval and decrease in the percentage of days in the midrange of 3000 to 10,000 cfs. January and February had complementary changes in the two highest class intervals, with a substantial reduction in the percentage of days in the 20,000 cfs and above interval and a substantial increase in the percentage of days in the 19,000 cfs interval.

Table 19. Number and percent of days in all months on which the average daily flow was less than 2500 cfs.

Month	Preimpoundment		Postimpoundment	
	Number	Percent	Number	Percent
January	35/1209	2.9	155/1116	13.9
February	12/1102	1.1	125/1017	12.3
March	0/1209	0.0	206/1116	18.5
April	0/1170	0.0	195/1080	18.1
May	16/1209	1.3	56/1116	5.0
June	71/1170	6.1	250/1080	23.1
July	158/1209	13.1	393/1050	37.4
August	252/1209	20.8	346/1092	31.7
September	442/1170	37.8	393/1050	37.4
October	407/1209	33.7	433/1085	39.9
November	211/1170	18.0	296/1050	28.2
December	109/1209	9.0	229/1085	21.1

In order to focus on the percentage of potential "problem days," Table 19 shows the percentage of days each month in the pre- and postimpoundment periods for which the average daily flow was less than or equal to 2500 cfs. It is interesting that in every month other than September the percentage of days with flows less than or equal to 2500 cfs has increased in the postimpoundment period. In September, the percentages were essentially the same.

Chi-Square Analysis

Tables 20 through 31 present the results of the Chi-square tests of independence on the monthly frequency distributions of the daily flows. This test is based on the proposition that, if pre- and postimpoundment have no influence on the frequency distribution, the percent of days in the various class intervals should be approximately equal. Put another way, the frequencies would differ only randomly. The first column of the tables shows the midpoint of the flow class intervals. The second through fourth columns show the actual and expected flows and the computed Chi-square for the preimpoundment period. Columns five through seven give the same information for the postimpoundment period. The last column is the row sums; the last row shows the column sums. Finally, the computed Chi-square is shown at the bottom. Individual

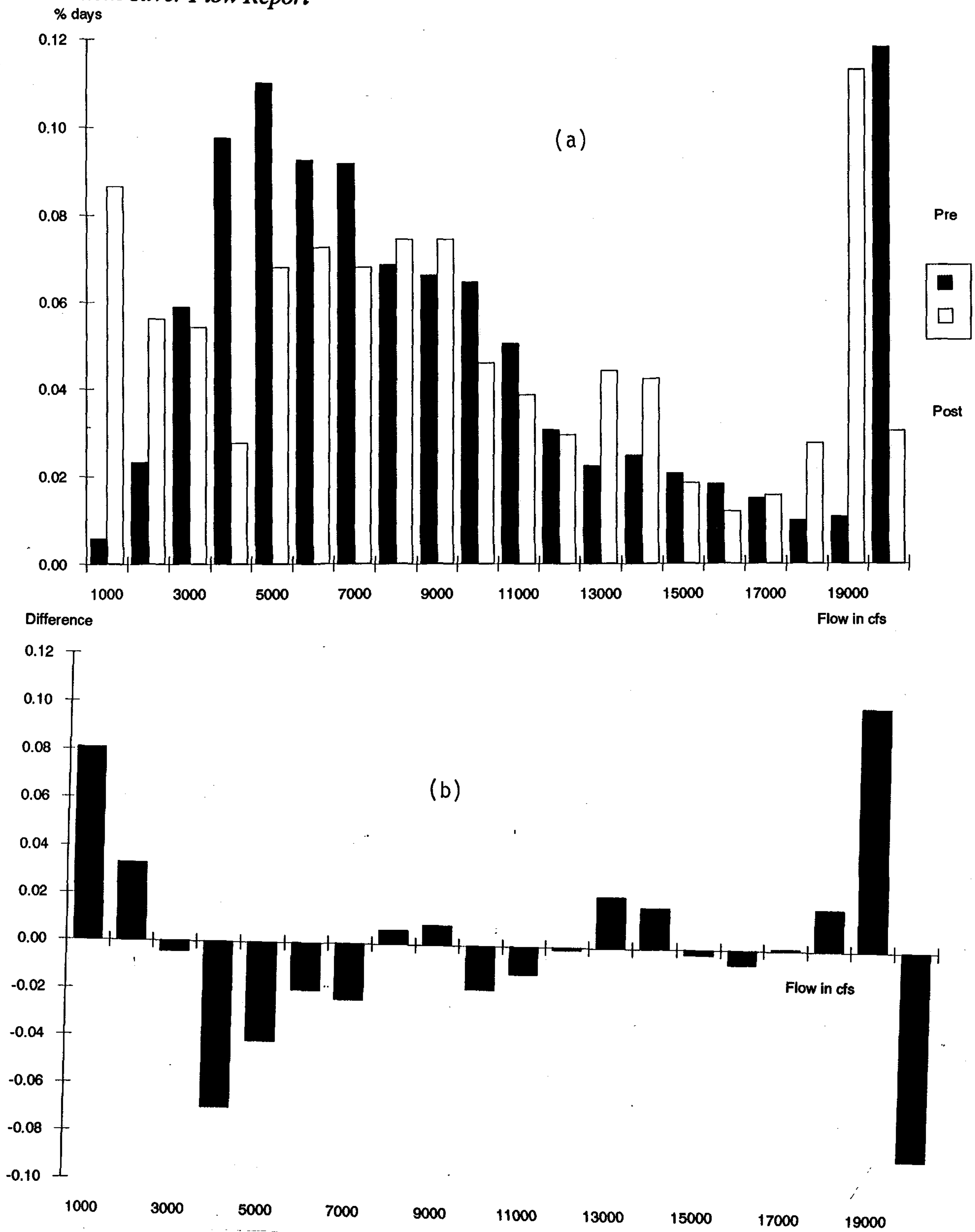


Figure 22. Preimpoundment and postimpoundment flow of the lower Roanoke River in January depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

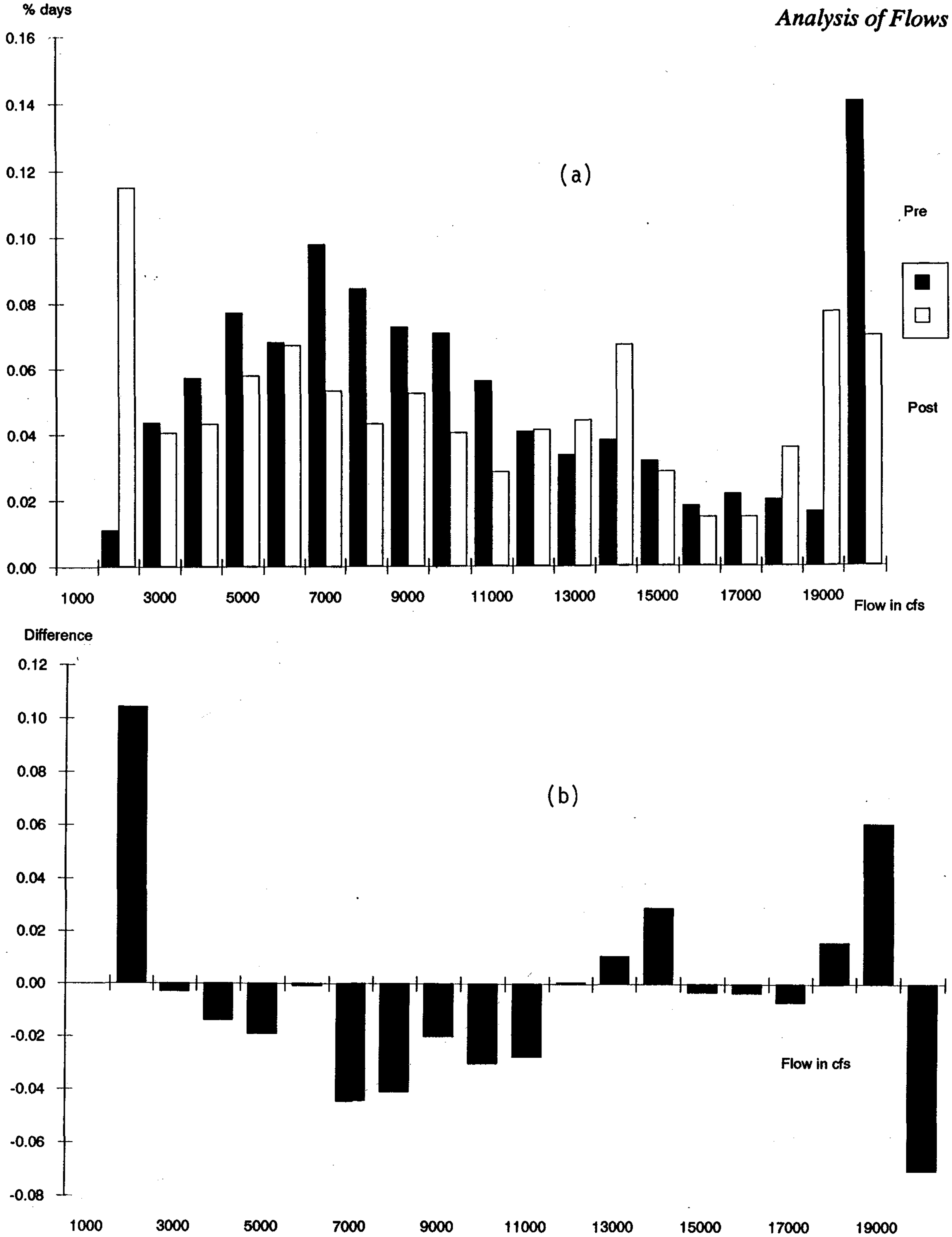


Figure 23. Preimpoundment and postimpoundment flow of the lower Roanoke River in February depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

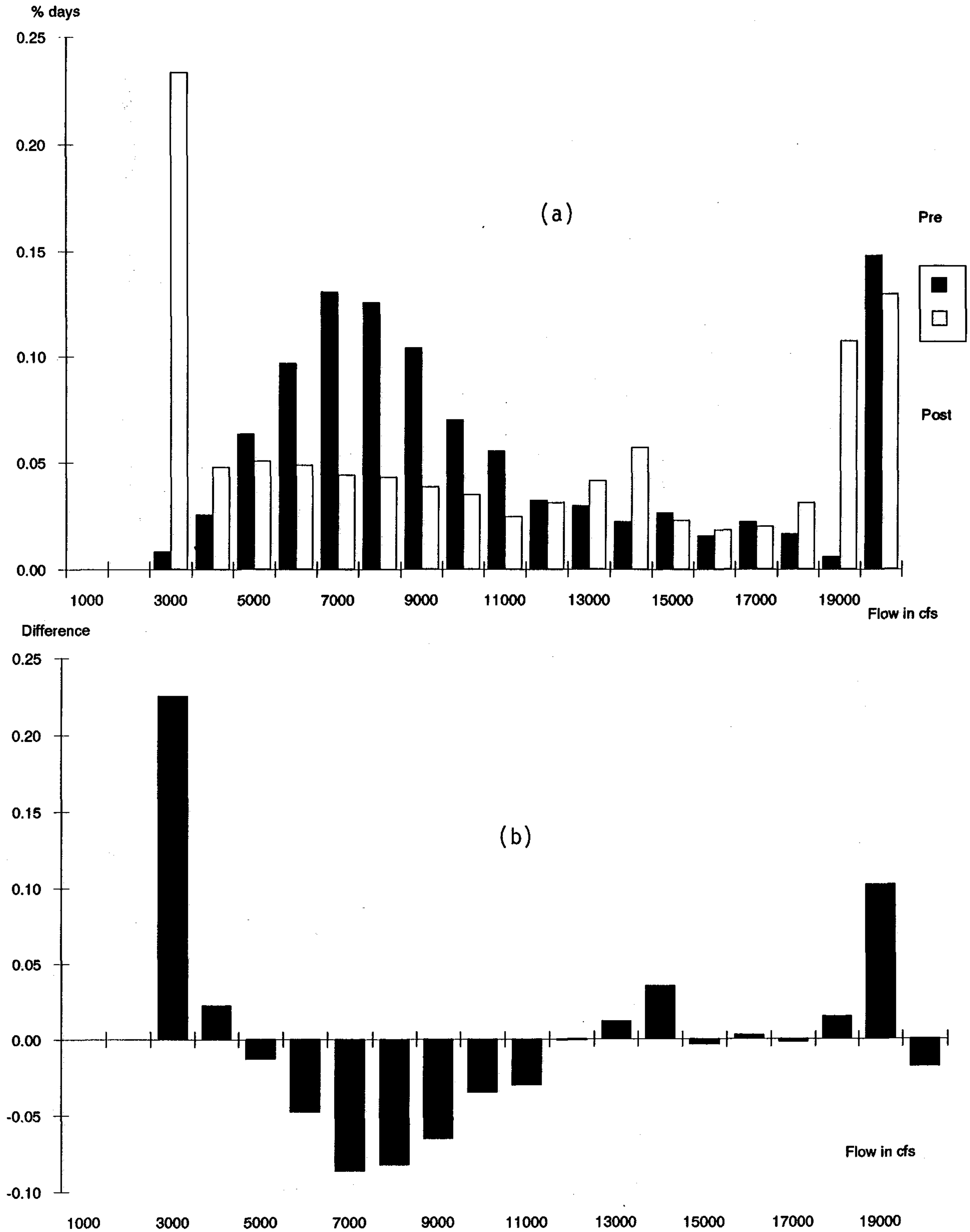


Figure 24. Preimpoundment and postimpoundment flow of the lower Roanoke River in March depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

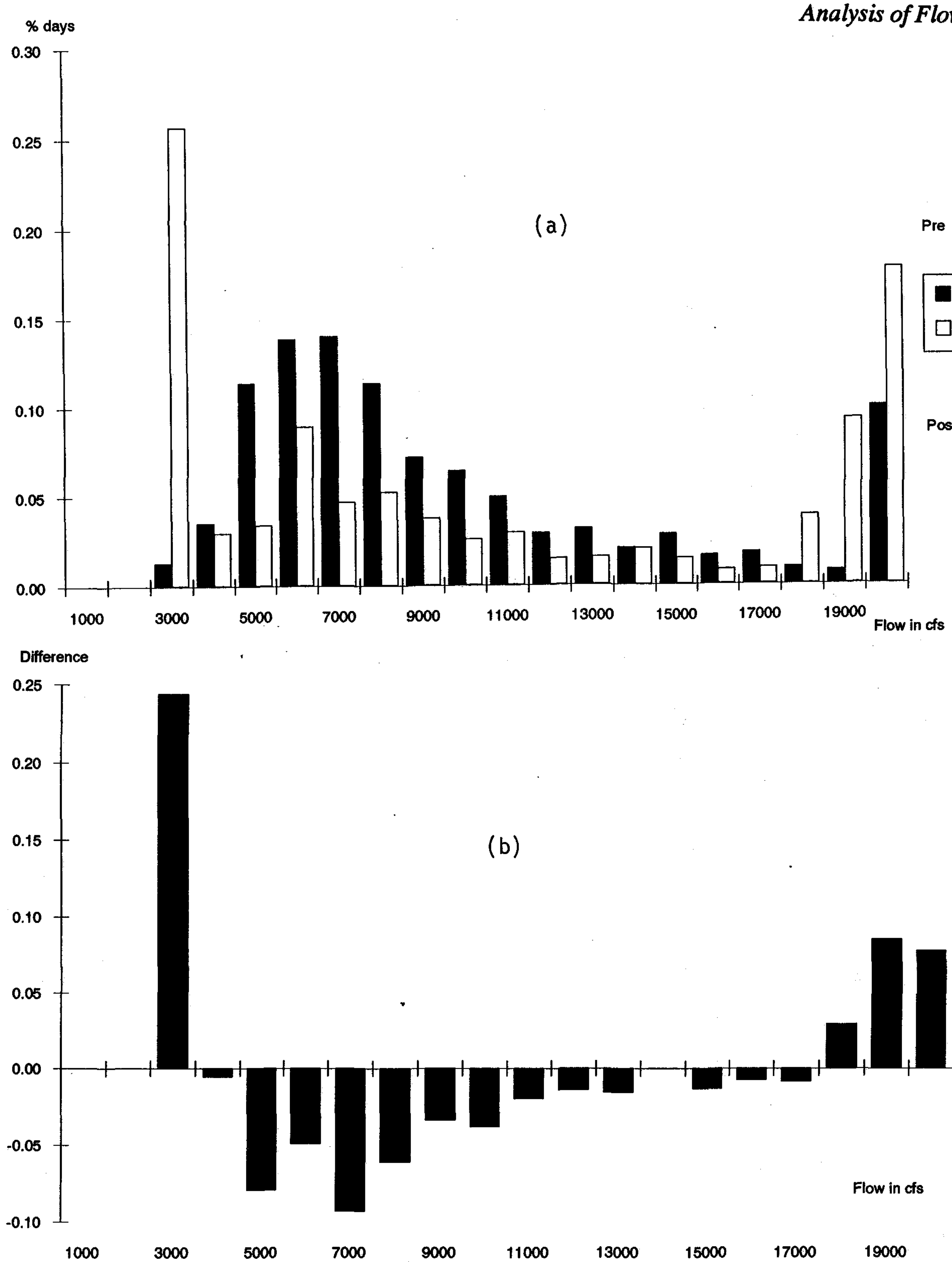


Figure 25. Preimpoundment and postimpoundment flow of the lower Roanoke River in April depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

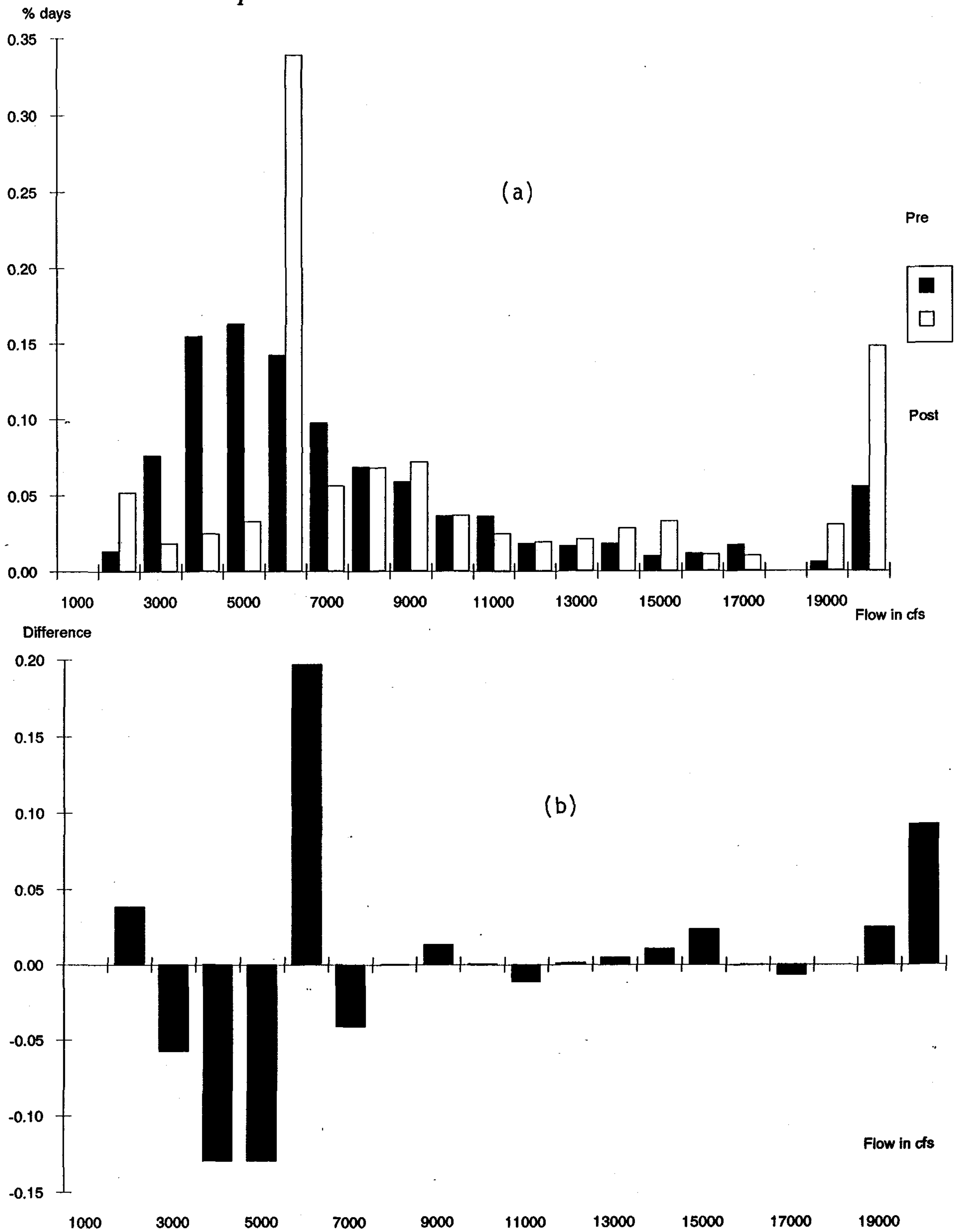


Figure 26. Preimpoundment and postimpoundment flow of the lower Roanoke River in May depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

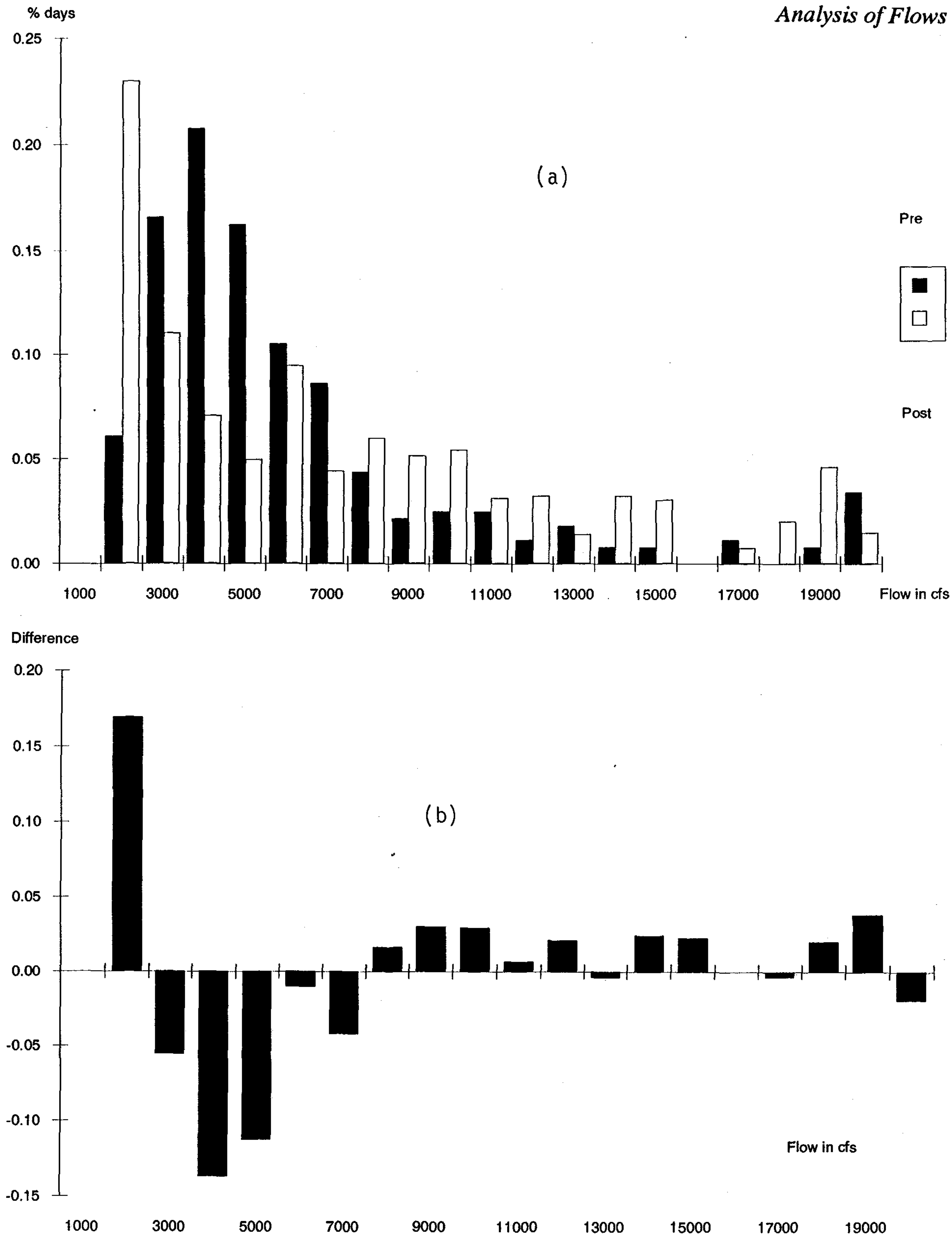


Figure 27. Preimpoundment and postimpoundment flow of the lower Roanoke River in June depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

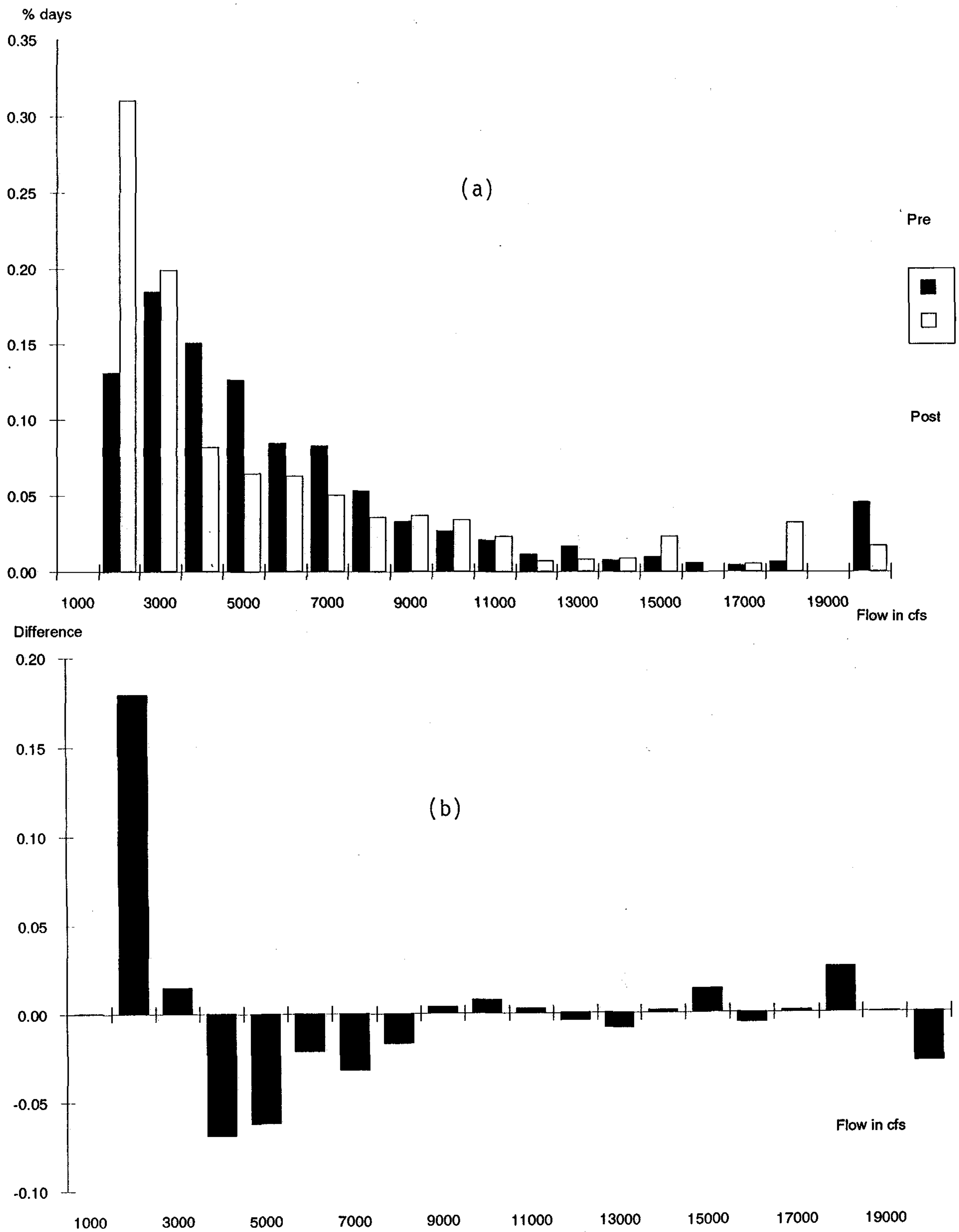


Figure 28. Preimpoundment and postimpoundment flow of the lower Roanoke River in July depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

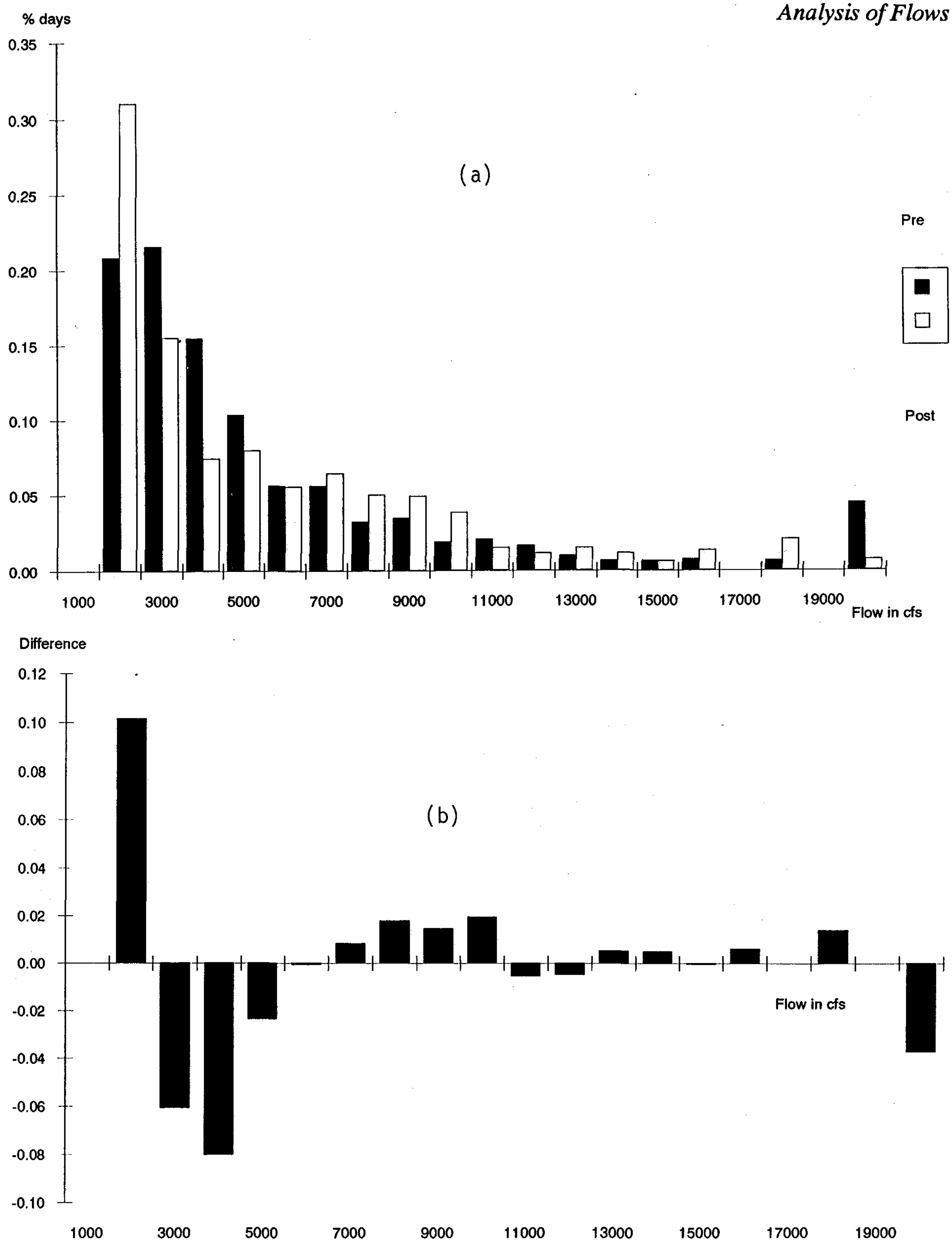


Figure 29. Preimpoundment and postimpoundment flow of the lower Roanoke River in August depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

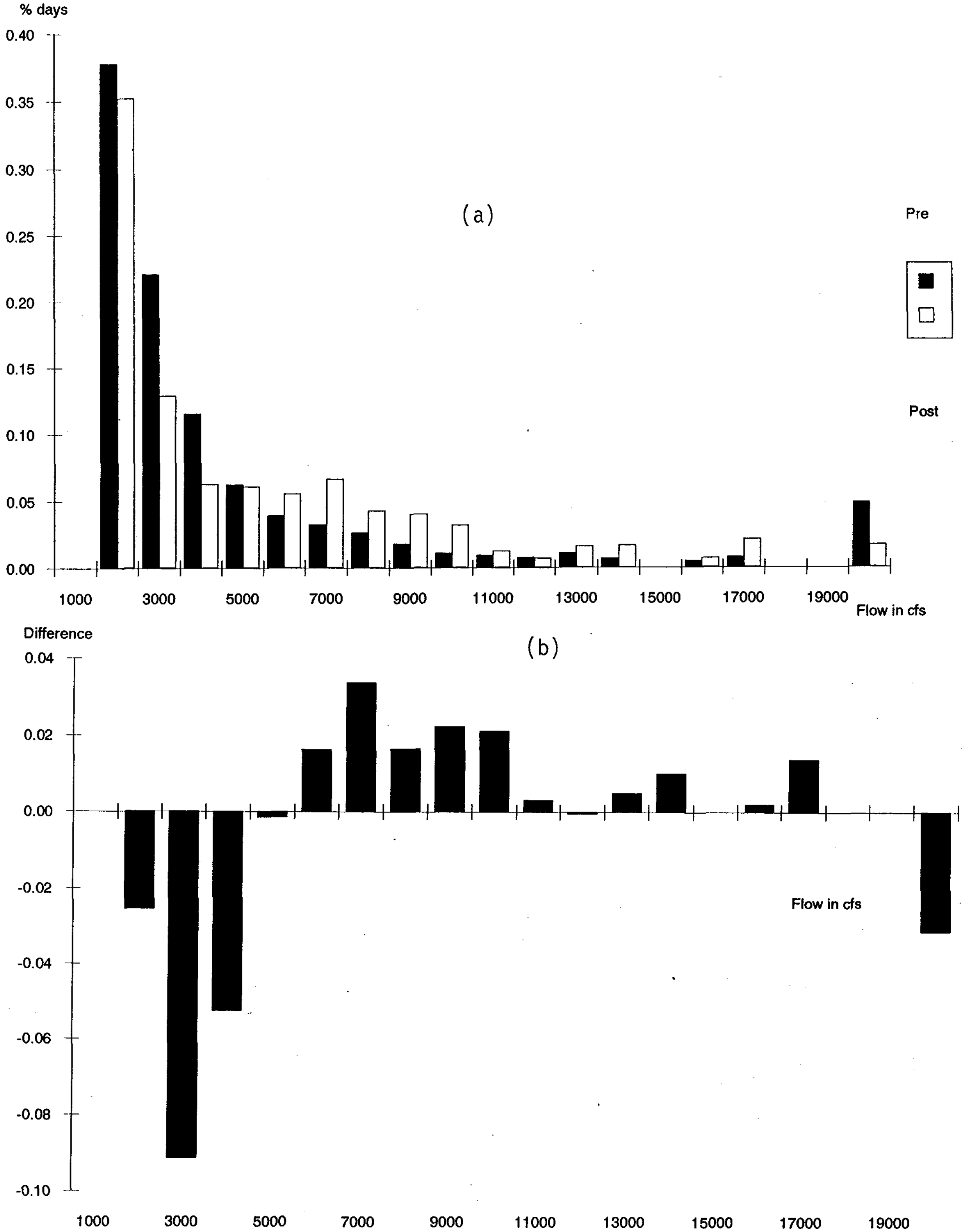


Figure 30. Preimpoundment and postimpoundment flow of the lower Roanoke River in September depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

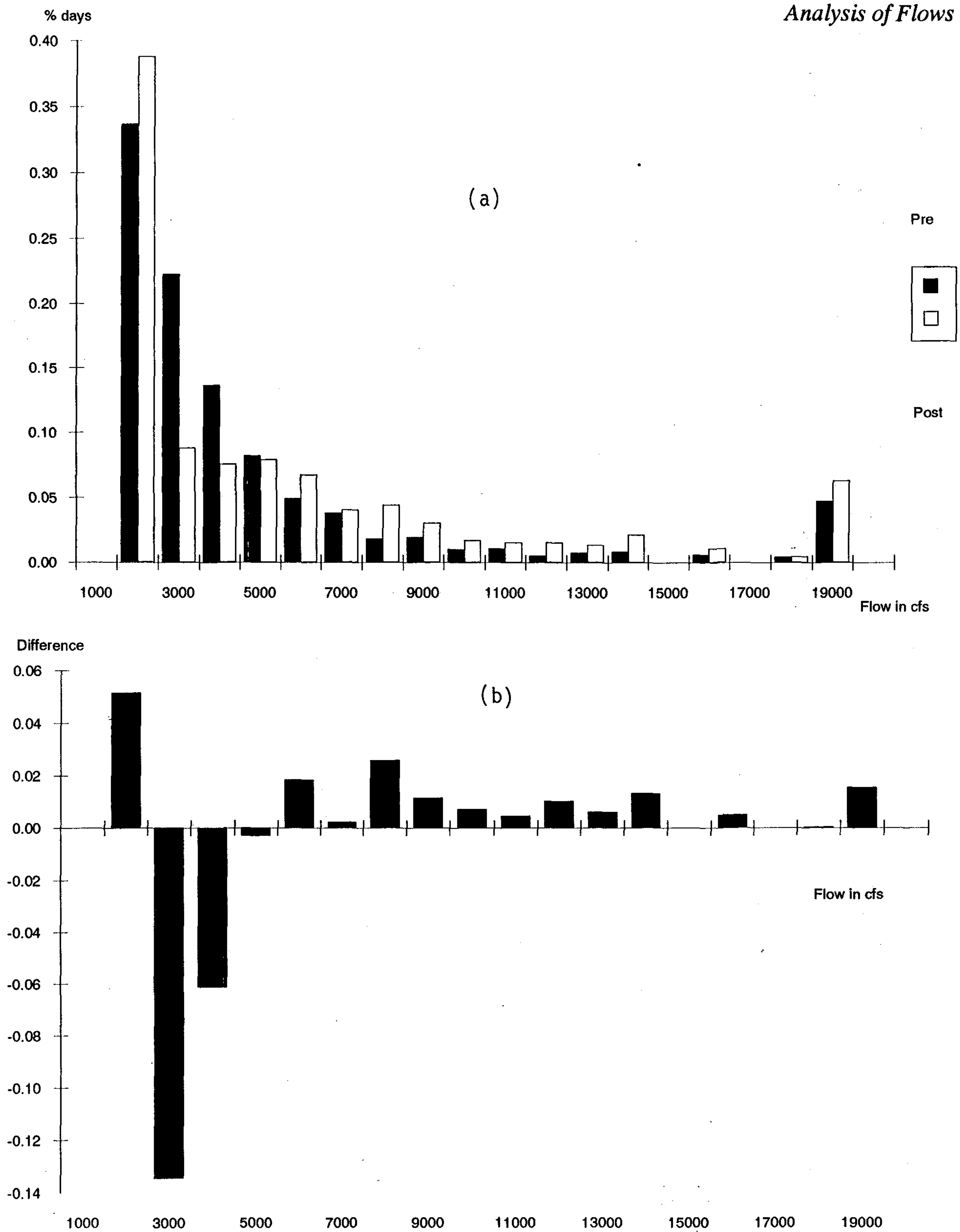


Figure 31. Preimpoundment and postimpoundment flow of the lower Roanoke River in October depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

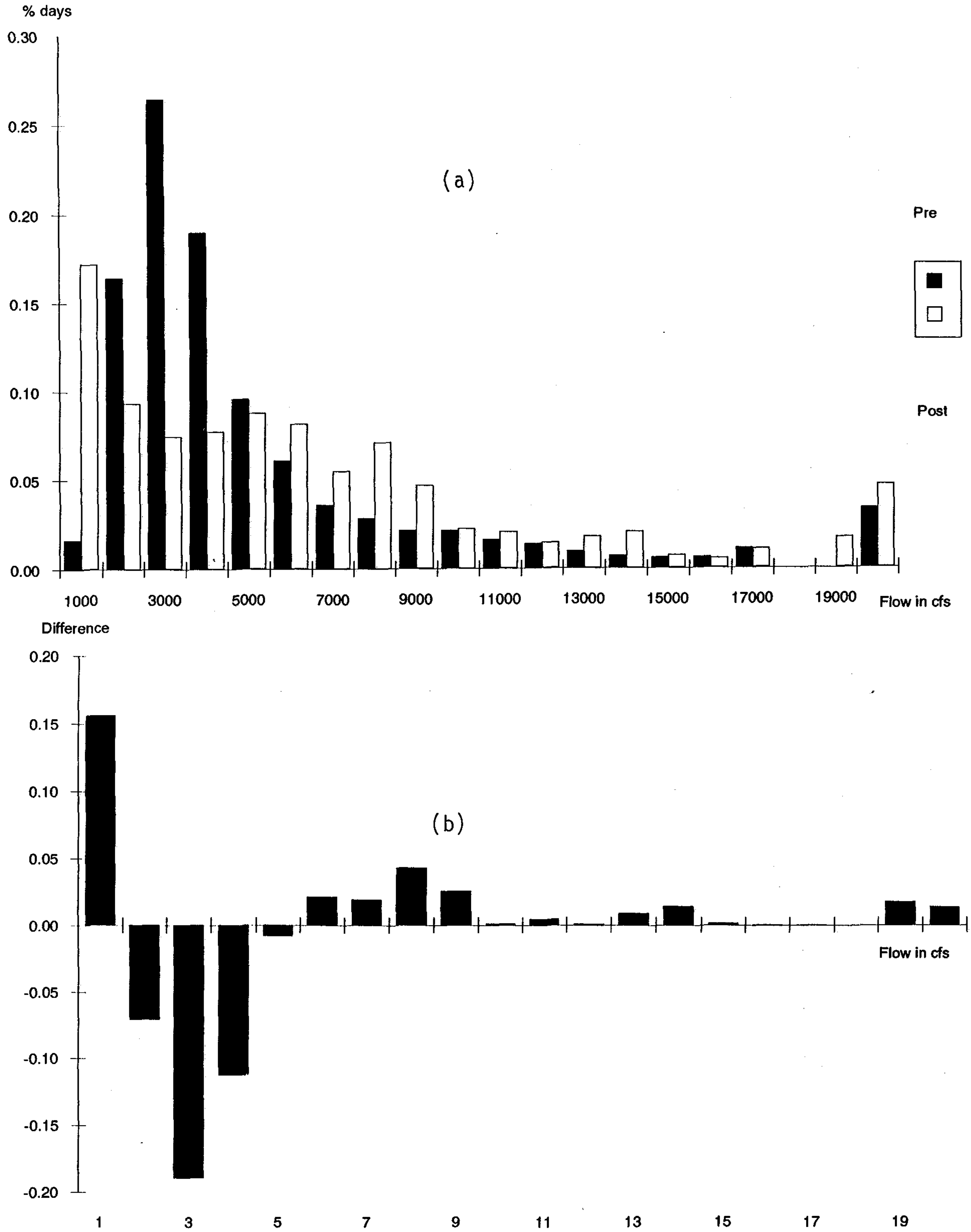


Figure 32. Preimpoundment and postimpoundment flow of the lower Roanoke River in November depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

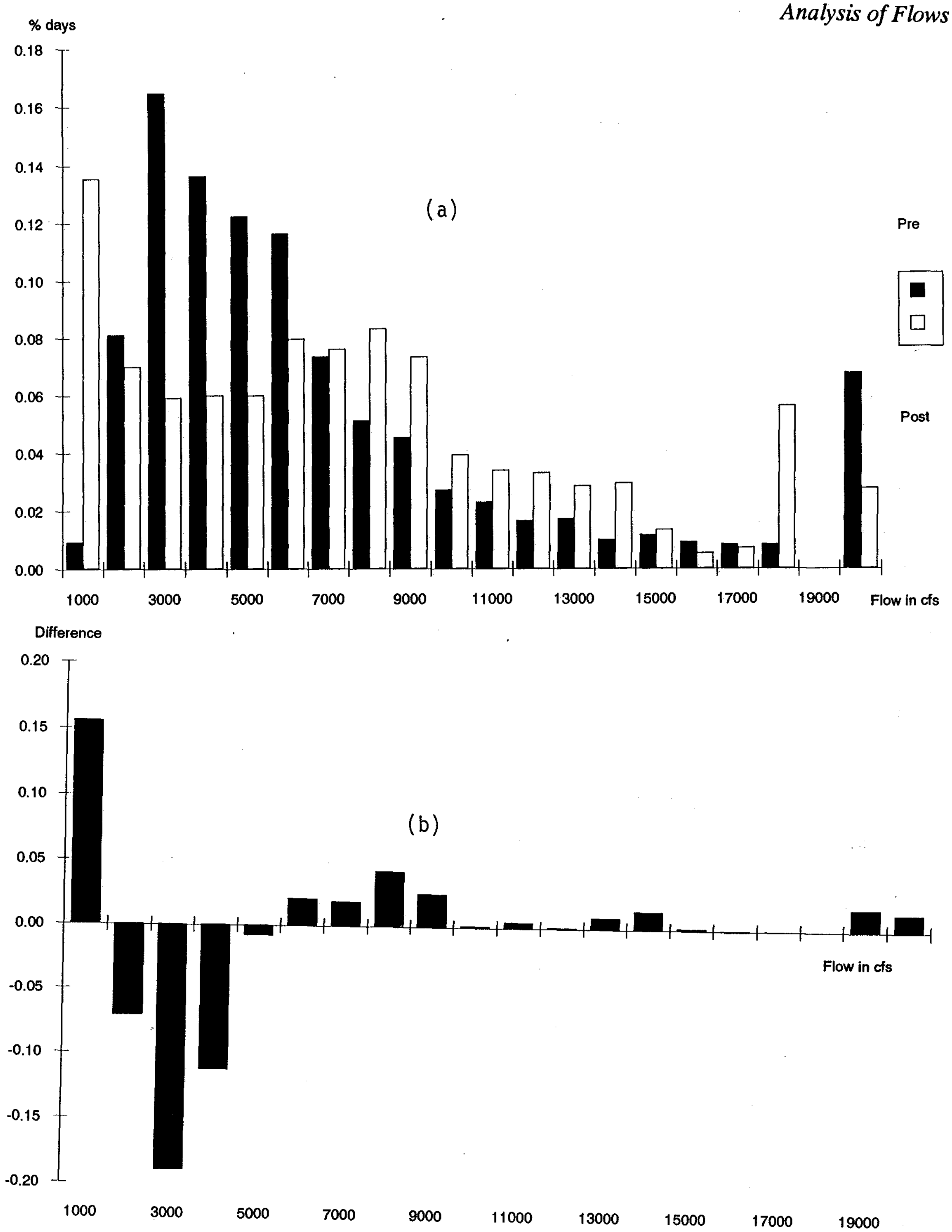


Figure 33. Preimpoundment and postimpoundment flow of the lower Roanoke River in December depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

Table 20. Chi-square analysis of flow classes for the lower Roanoke River for January.

Class Midpoint	Preimpoundment			Postimpoundment			Row sum
	Act.	expected	Chisq	Act.	expected	Chisq	
1,000	7	53	40.10	94	48	44.61	101
2,000	28	47	7.59	61	42	8.45	89
3,000	71	68	0.09	59	62	0.11	130
4,000	118	78	20.60	30	70	22.91	148
5,000	133	109	5.28	74	98	5.88	207
6,000	112	101	1.30	79	90	1.44	191
7,000	111	97	1.89	74	88	2.11	185
8,000	83	86	0.13	81	78	0.15	164
9,000	80	85	0.27	81	76	0.30	161
10,000	78	67	1.67	50	61	1.85	128
11,000	61	54	0.84	42	49	0.94	103
12,000	37	36	0.11	32	33	0.01	69
13,000	27	39	3.95	48	33	4.40	75
14,000	30	40	2.51	46	36	2.79	76
15,000	25	24	0.07	20	21	0.08	45
16,000	22	18	0.69	13	17	0.77	35
17,000	18	18	0.01	17	17	0.01	35
18,000	12	22	4.63	30	20	5.15	42
19,000	13	72	47.97	123	64	53.36	136
20,000	143	93	27.33	33	83	30.39	176
Sum	1,209	1,209	167	1,087	1,087	186	2,296
Chi square=		353					

Table 21. Chi-square analysis of flow classes for the lower Roanoke River for February.

Class Midpoint	Preimpoundment			Postimpoundment			Row sum
	Act.	expected	Chisq	Act.	expected	Chisq	
1,000	0	0		0	0		0
2,000	12	71	49.27	125	66	53.39	137
3,000	48	48	0.00	44	44	0.00	92
4,000	63	57	0.59	47	53	0.64	110
5,000	85	77	0.84	63	71	0.91	148
6,000	75	77	0.05	73	71	0.05	148
7,000	108	86	5.44	58	80	5.89	166
8,000	93	73	5.60	47	67	6.07	140
9,000	80	71	1.08	57	66	1.17	137
10,000	78	63	3.34	44	59	3.62	122
11,000	62	48	3.84	31	45	4.17	93
12,000	45	47	0.07	45	43	0.08	90
13,000	37	44	1.17	48	41	1.27	85
14,000	42	60	5.30	73	55	5.74	115
15,000	35	34	0.01	31	32	0.01	66
16,000	20	19	0.09	16	17	0.09	36
17,000	24	21	0.49	16	19	0.53	40
18,000	22	32	2.98	39	29	3.23	61
19,000	18	53	23.15	84	49	25.09	102
20,000	155	120	10.12	76	111	10.97	231
Sum	1,102	1,102	113	1,107	1,107	123	2,119
Chi square=		236					

Table 22. Chi-square analysis of flow classes for the lower Roanoke River for March.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	0	0.00		0	0		0
2,000	0	0.00		0	0		0
3,000	10	137.28	118.01	254	127	127.84	264
4,000	31	43.16	3.43	52	40	3.71	83
5,000	77	68.64	1.02	55	63	1.10	132
6,000	117	88.40	9.25	53	82	10.02	170
7,000	158	107.12	24.17	48	99	26.18	206
8,000	152	103.48	22.75	47	96	24.65	199
9,000	126	87.36	17.09	42	81	18.52	168
10,000	85	63.96	6.92	38	59	7.50	123
11,000	67	48.88	6.72	27	45	7.25	94
12,000	39	37.96	0.03	34	35	0.03	73
13,000	36	42.12	0.89	45	39	0.96	81
14,000	27	46.28	8.03	62	43	8.70	89
15,000	32	29.64	0.19	25	27	0.20	57
16,000	19	20.28	0.08	20	19	0.09	39
17,000	27	25.48	0.09	22	24	0.10	49
18,000	20	28.08	2.33	34	26	2.52	54
19,000	7	64.48	51.24	117	60	55.51	124
20,000	179	166.40	0.95	141	154	1.03	320
Sum	1,209	1,209	273.18	1,116	1,116	295.945	2,325
Chi square=		569					

Table 23. Chi-square analysis of flow classes for the lower Roanoke River for April.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	0	0		0	0		0
2,000	0	0		0	0		0
3,000	15	153	124.35	279	141	134.71	294
4,000	41	38	0.24	32	35	0.26	73
5,000	133	88	22.50	37	82	24.38	170
6,000	162	135	5.54	97	124	6.00	259
7,000	164	112	24.37	51	103	26.40	215
8,000	133	99	11.84	57	91	12.83	190
9,000	84	65	5.55	41	60	6.02	125
10,000	75	54	8.58	28	49	9.30	103
11,000	58	47	2.68	32	43	2.90	90
12,000	34	26	2.46	16	24	2.67	50
13,000	37	28	2.83	17	26	3.07	54
14,000	24	24	0.00	22	22	0.00	46
15,000	33	25	2.22	16	24	2.40	49
16,000	19	15	1.35	9	13	1.47	28
17,000	21	16	1.48	10	15	1.60	31
18,000	11	28	9.95	42	25	10.78	53
19,000	9	57	40.62	101	53	44.00	110
20,000	117	161	12.12	193	149	13.13	310
Sum	1,170	1,170	278.6983	1,080	1,080	301.9232	2,250
Chi square=		581					

Table 24. Chi-square analysis of flow classes for the lower Roanoke River for May.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	0	0		0	0		0
2,000	16	37	12.28	56	35	13.30	72
3,000	92	58	19.57	20	54	21.20	112
4,000	187	111	51.52	27	103	55.82	214
5,000	197	121	47.47	36	112	51.43	233
6,000	172	281	42.48	369	260	46.02	541
7,000	118	93	6.67	61	86	7.23	179
8,000	83	82	0.02	74	75	0.02	157
9,000	71	77	0.54	78	72	0.59	149
10,000	44	44	0.00	40	40	0.00	84
11,000	44	37	1.36	27	34	1.47	71
12,000	22	22	0.01	21	21	0.01	43
13,000	20	22	0.25	23	21	0.27	43
14,000	22	28	1.12	31	25	1.22	53
15,000	12	25	6.73	36	23	7.29	48
16,000	14	14	0.02	12	12	0.02	26
17,000	21	17	1.14	11	15	1.24	32
18,000	0	0		0	0		0
19,000	7	21	9.16	33	19	9.92	40
20,000	67	119	22.42	161	109	24.29	228
Sum	1,209	1,209	222.7641	1,116	1,116	241.3278	2,325
Chi square=		464					

Table 25. Chi-square analysis of flow classes for the lower Roanoke River for June.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	0	0		0	0		0
2,000	71	173	60.53	250	160	50.44	321
3,000	194	170	3.48	120	157	8.57	314
4,000	243	161	42.40	77	148	59.84	297
5,000	190	158	6.33	54	140	12.75	293
6,000	123	92	10.13	103	85	16.31	171
7,000	101	90	1.42	48	83	3.83	166
8,000	51	58	0.81	65	53	0.13	107
9,000	25	45	9.16	56	42	6.98	84
10,000	29	34	0.75	59	31	0.21	63
11,000	29	35	0.90	34	32	0.30	64
12,000	13	15	0.30	35	14	0.08	28
13,000	21	30	2.84	15	28	1.79	56
14,000	9	23	8.27	35	21	6.93	42
15,000	9	5	3.52	33	4	4.49	9
16,000							
17,000	13	19	1.85	8	17	1.18	35
18,000	0	27	27.02	22	25	25.17	50
19,000	9	14	1.51	50	12	1.00	25
20,000	40	22	15.63	16	20	19.95	40
Sum	1,170	1,170	197	1,080	1,080	220	2,165
Chi square=		417					

Table 26. Chi-square analysis of flow classes for the lower Roanoke River for July.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	0	0		0	0		0
2,000	158	262	41.33	346	242	45	504
3,000	223	231	0.30	222	214	0	445
4,000	182	142	11.29	91	131	12	273
5,000	153	117	11.08	72	108	12	225
6,000	102	89	1.76	70	83	2	172
7,000	100	81	4.39	56	75	5	156
8,000	64	54	1.82	40	50	2	104
9,000	40	42	0.11	41	39	0	81
10,000	32	36	0.53	38	34	1	70
11,000	25	27	0.09	26	24	0	51
12,000	14	11	0.57	8	11	1	22
13,000	20	15	1.61	9	14	2	29
14,000	9	10	0.08	10	9	0	19
15,000	12	20	3.05	26	18	3	38
16,000	7	4	3.10	0	3	3	7
17,000	5	6	0.09	6	5	0	11
18,000	8	23	9.68	36	21	10	44
19,000	0	0		0	0		0
20,000	55	38	7.09	19	36	8	74
Sum	1,209	1,209	98	1,116	1,116	106	2,325
Chi square=		204					

Table 27. Chi-square analysis of flow classes for the lower Roanoke River for August.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	0	0		0	0		0
2,000	252	314	12.31	346	284	14	598
3,000	261	228	4.77	173	206	5	434
4,000	187	142	14.36	83	128	16	270
5,000	125	112	1.40	89	102	2	214
6,000	68	68	0.00	62	62	0	130
7,000	68	74	0.42	72	66	0	140
8,000	39	50	2.39	56	45	3	95
9,000	42	51	1.58	55	46	2	97
10,000	23	35	3.93	43	31	4	66
11,000	25	22	0.39	17	20	0	42
12,000	20	17	0.41	13	16	0	33
13,000	12	15	0.69	17	14	1	29
14,000	8	11	0.83	13	10	1	21
15,000	8	8	0.00	7	7	0	15
16,000	9	13	1.03	15	11	1	24
17,000	0	0		0	0		0
18,000	8	16	4.22	23	15	5	31
19,000	0	0		0	0		0
20,000	54	33	14.09	8	29	16	62
Sum	1,209	1,209	63	1,092	1,092	70	2,301
Chi square=		132					

Table 28. Chi-square analysis of flow classes for the lower Roanoke River for September.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	0	0.00		0	0		0
2,000	442	440.07	0.01	393	395	0	835
3,000	258	211.86	10.05	144	190	11	402
4,000	135	108.04	6.73	70	97	7	205
5,000	73	74.31	0.02	68	67	0	141
6,000	46	56.92	2.09	62	51	2	108
7,000	38	59.03	7.49	74	53	8	112
8,000	31	41.64	2.72	48	37	3	79
9,000	21	34.78	5.46	45	31	6	66
10,000	13	25.82	6.37	36	23	7	49
11,000	11	13.18	0.36	14	12	0	25
12,000	9	8.96	0.00	8	8	0	17
13,000	13	16.34	0.68	18	15	1	31
14,000	8	14.23	2.73	19	13	3	27
15,000	0	0.00		0	0		0
16,000	6	7.38	0.26	8	7	0	14
17,000	9	17.39	4.05	24	16	5	33
18,000	0	0.00		0	0		0
19,000	0	0.00		0	0		0
20,000	57	40.05	7.17	19	36	8	76
Sum	1,170	1,170	56	1,050	1,050	63	2,220
Chi square=		119					

Table 29. Chi-square analysis of flow classes for the lower Roanoke River for October.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	0	0.00		0	0		0
2,000	442	440.07	0.01	393	395	0	835
3,000	258	211.86	10.05	144	190	11	402
4,000	135	108.04	6.73	70	97	7	205
5,000	73	74.31	0.02	68	67	0	141
6,000	46	56.92	2.09	62	51	2	108
7,000	38	59.03	7.49	74	53	8	112
8,000	31	41.64	2.72	48	37	3	79
9,000	21	34.78	5.46	45	31	6	66
10,000	13	25.82	6.37	36	23	7	49
11,000	11	13.18	0.36	14	12	0	25
12,000	9	8.96	0.00	8	8	0	17
13,000	13	16.34	0.68	18	15	1	31
14,000	8	14.23	2.73	19	13	3	27
15,000	0	0.00		0	0		0
16,000	6	7.38	0.26	8	7	0	14
17,000	9	17.39	4.05	24	16	5	33
18,000	0	0.00		0	0		0
19,000	0	0.00		0	0		0
20,000	57	40.05	7.17	19	36	8	76
Sum	1,170	1,170	56	1,050	1,050	63	2,220
Chi square=		119					

Table 30. Chi-square analysis of flow classes for the lower Roanoke River for November.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	19	111	76.45	192	100	85	211
2,000	192	156	8.31	104	140	9	296
3,000	309	207	50.76	83	185	57	392
4,000	222	162	21.94	86	146	24	308
5,000	112	111	0.02	98	99	0	210
6,000	71	85	2.42	91	77	3	162
7,000	42	54	2.78	61	49	3	103
8,000	33	59	11.48	79	53	13	112
9,000	25	41	5.98	52	36	7	77
10,000	25	26	0.07	25	24	0	50
11,000	19	22	0.44	23	20	0	42
12,000	16	17	0.04	16	15	0	32
13,000	11	16	1.74	20	15	2	31
14,000	8	16	4.26	23	15	5	31
15,000	7	8	0.10	8	7	0	15
16,000	7	7	0.00	6	6	0	13
17,000	13	13	0.00	12	12	0	25
18,000	0	0		0	0		0
19,000	0	10	10.01	19	9	11	19
20,000	39	48	1.67	52	43	2	91
Sum	1,170	1,170	198	1,050	1,050	221	2,220
Chi square=		420					

Table 31. Chi-square analysis of flow classes for the lower Roanoke River for December.

Class Midpoint	Preimpoundment Act.	Preimpoundment expected	Preimpoundment Chisq	Postimpoundment Act.	Postimpoundment expected	Postimpoundment Chisq	Row sum
1,000	11	85	64.80	151	77	72	162
2,000	98	93	0.30	78	83	0	176
3,000	199	140	25.21	66	125	28	265
4,000	165	122	14.93	67	110	17	232
5,000	148	113	10.62	67	102	12	215
6,000	141	121	3.23	89	109	4	230
7,000	89	92	0.08	85	82	0	174
8,000	62	82	4.75	93	73	5	155
9,000	55	72	4.10	82	65	5	137
10,000	33	41	1.42	44	36	2	77
11,000	28	35	1.32	38	31	1	66
12,000	20	30	3.36	37	27	7	57
13,000	21	28	1.72	32	25	2	53
14,000	12	24	5.79	33	21	6	45
15,000	14	15	0.11	15	14	0	29
16,000	11	9	0.46	6	8	1	17
17,000	10	9	0.03	8	9	0	18
18,000	10	38	21.07	63	35	23	73
19,000	0	0		0	0		0
20,000	82	60	8.46	31	53	9	113
Sum	1,209	1,209	172	1,085	1,085	191	2,294
Chi square=		363					

Chi-square statistics indicate, by their magnitude, how different the individual cells are. Note that if a cell contains less than five days, it must be combined with another cell to avoid excessive influence on the outcome of the test. When it was necessary to combine cells, cells closer to the lower end of the distribution were combined with that above them while cells closer to the higher end of the distribution were combined with those below them. Sparse cells occur most often at extreme values. Blank cells in the tables indicate where cells have been combined. The null hypothesis of the Chi-square test is that the distributions are independent. High values of Chi-square reject the null hypothesis.

Results of the Chi-square tests show that the distributions for all the months are not independent of preimpoundment or postimpoundment status. This, of course, is to be expected, since the very purpose of the dams, flood control, requires changing the flows of the River.

Analysis of June through September

The months June through September are critical to the question of flows for a number of reasons. First, these months are important to young-of-year striped bass habitat in Albemarle Sound -- extremely low flows may contribute to "habitat squeeze" by limiting areas of minimal D.O. and water temperature, respectively (Coutant and Benson 1990; C.C. Coutant, pers. comm.). Second, the problems of managing the reservoir become critical during these months since this is the peak of the recreational season above the dams and there is a certain importance to stabilizing the lake levels during these months. Finally, these months are important because, as will be shown later, they are dominated by days with low flows. It has been noted that permits might be granted which would use up the equivalent of approximately 332 cfs. Thus, in the situation in which all these permits were approved, the percentage of days where the flow is less than 2332 cfs would be the best estimate of the number of days on which the 2000 cfs minimum flow could not have been met under present management policies, and therefore releases from the Power Pool would be necessary. *[Editors' note: FERC requires that COE and Virginia Power Company must meet the 2000 cfs minimum]*. Let us examine more closely the percentage of days during the months of June through September falling close to these flows, with an appropriate margin for error.

Table 32 shows the percentages of the months June through September which had at least one day when the flow was below 2200 cfs or 2500 cfs. The preimpoundment percentages are given for comparison. It is clear that what is relevant to water allocation to different uses is the current situation. That situation is that at least 59% of the relevant months since 1955 have had at least

Table 32. Percentage of months with at least one day on which the average daily flow is less than or equal to 2200 cfs or 2500 cfs.

	Preimpoundment		Postimpoundment	
Month	% with < 2200	% with < 2500	% with < 2200	% with < 2500
June	16	32	70	94
July	43	56	59	94
August	66	66	59	94
September	82	79	64	97

one day in which the average daily flow has fallen below 2200 cfs and at least 94% of the months have had at least one day in which the flow has been below 2500 cfs. Returning to what was said above, at present all of the minimum permitted flow (2000 cfs) is currently allocated. If one considers 200 cfs a minimum cushion provided no further uses are permitted, then it is likely that 70% of all future Junes, 59% of all future July's and Augusts, and 64% of all future Septembers will have at least one day when there will not be enough flow to support the currently permitted uses and allow some margin for error. If permitted uses are allowed to increase, and there are many permits pending, the 2500 cfs percentage is perhaps the most relevant. If it is, then further permitting will result in substantially all the months having at least one day in which the 2000 cfs flow cannot be sustained. This means, by law, that additional water releases must be maintained by utilizing Power Pool Storage. If waters were released in a stable manner rather than saving water for several days to allow peaking, then this stable discharge would limit the power company's ability to contribute power during high electrical demand.

Table 33 shows the percentage of days in each class interval (columns 2 and 4) and the cumulative percentage percent of days less than or equal to the class interval (columns 3 and 5) for the preimpoundment and postimpoundment years, respectively, for the months of June through September. Note that the class interval width is 1500 cfs. Thus, the midpoint 2250 includes days on which flows were as low as 1500 and as high as 3000 cfs. The important number in this table is the 41.29% of the days when the average daily flow was less than or equal to 3000 cfs. That is the cumulative percentage for the 2250 cfs class interval. To identify potential problems of additional permitted uses, one must examine the distribution of these 41% of the days. If most of them are around 3000 cfs, there may be room to maneuver and allow some additional uses. If they are concentrated at the lower end, additional permitting will be more risky.

Table 33. Percentages and cumulative percentage of days for flow intervals

	Preimpoundment		Postimpoundment	
Class Midpoint	Percent	Cum. Percent	Percent	Cum. Percent
750	3.95	3.95	0.16	0.16
2250	25.75	29.70	41.12	41.29
3750	25.75	55.46	12.08	53.37
5250	14.93	70.33	10.03	63.39
6750	9.69	80.07	9.11	72.50
Above 6750	19.93	100.00	27.50	100.00

Figures 34(a) and 34(b) show the percent frequency and cumulative distribution of days for the months of June through September. Note that the overwhelming preponderance of the days in the four month period were concentrated in the lower two class intervals. As Table 33 shows, 41% of the postimpoundment days during the period were less than or equal to the 2250 class interval (3000 cfs). The change from the preimpoundment to the postimpoundment period is best illustrated in Figure 34(b). There it can be seen that the number of days in the 3750 class interval and the 5250 class interval has decreased while the number in the 2250 class interval has increased.

Table 34 shows the frequency distribution of the flow for days on which the average daily flow was less than or equal to 3000 cfs and Figures 35(a) and 35(b) present the data graphically. These days will be referred to as "low flow days." All of the detail is presented since this table represents the most critical of the days in the June through September period. In these

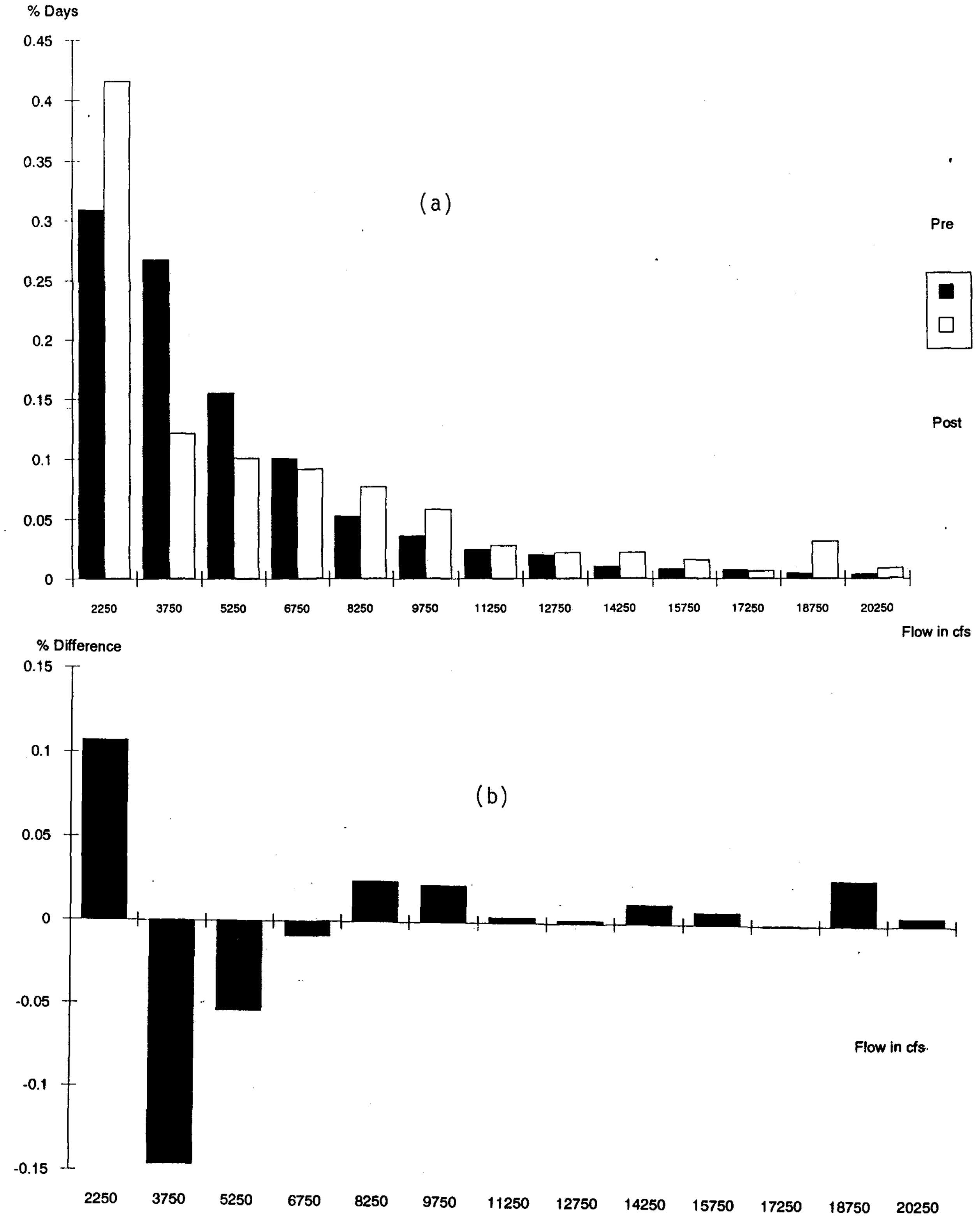


Figure 34. Preimpoundment and postimpoundment flow of the lower Roanoke River in June-September depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group. Percentages are in decimal format.

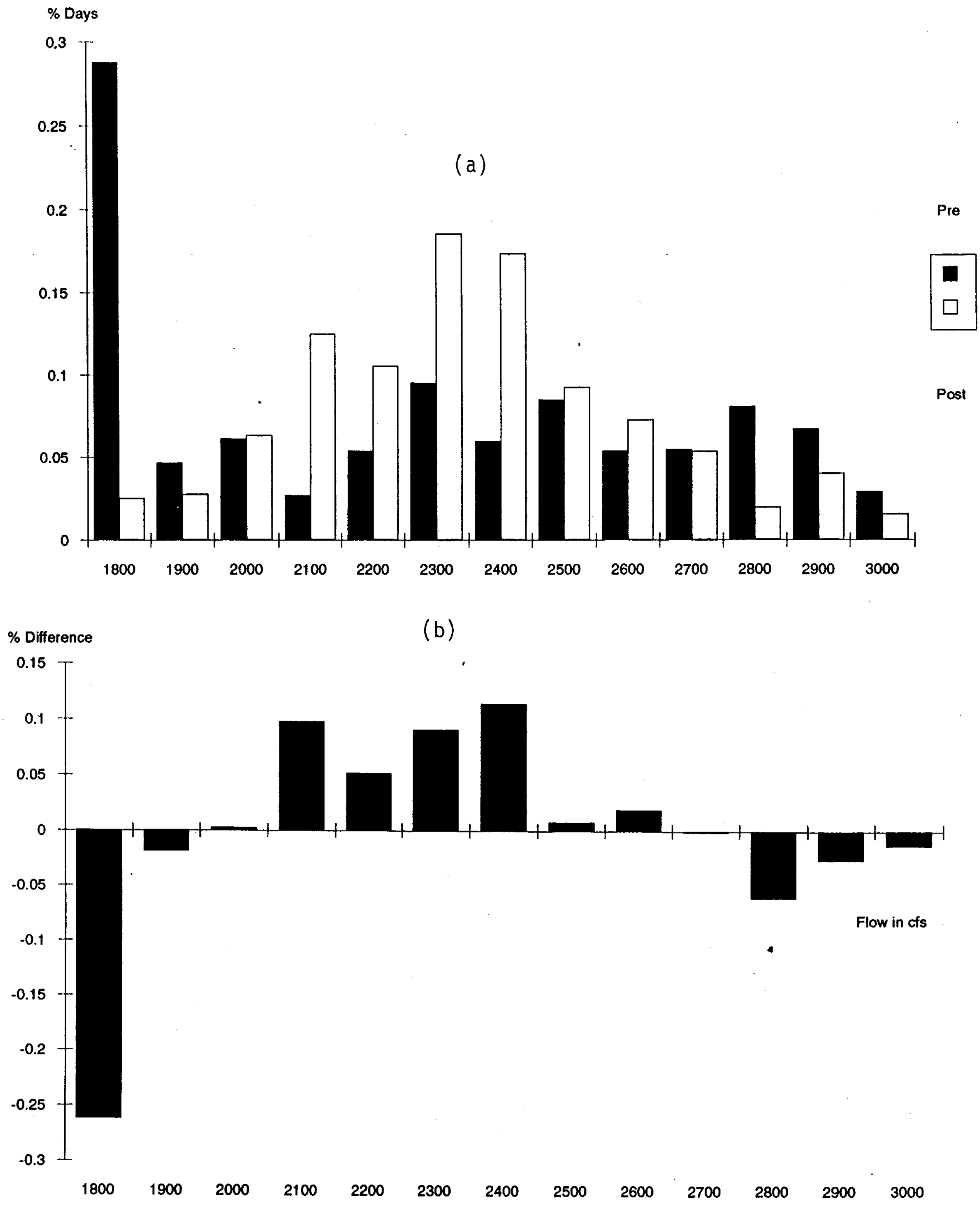


Figure 35. Preimpoundment and postimpoundment flow of the lower Roanoke River in June-September (% frequencies) depicting: (a) the percent frequency of flows within the range, and (b) the difference in percent frequencies between preimpoundment and postimpoundment for each flow group for flows less than or equal to 3000 cfs. Percentages are in decimal format.

exhibits, the midpoints of the class intervals are 1100 through 3000 and the class intervals themselves are 100 cfs wide except for the largest. Thus, the 1900 class interval represents flows from 1850 to 1950. The largest class interval is just those days in the 2950-3000 range since only days with flows less than or equal to 3000 cfs were counted. In Table 34, one additional column is introduced. The last column shows the cumulative postimpoundment percentage multiplied by 0.41; this calculation was made because only 41% of the postimpoundment days in these months had flows less than or equal to 3000. Thus, the final column represents the percentage of all postimpoundment days represented in the row. For example, 11.43% of the days with flows less than or equal to 3000 had flows less than or equal to 2000 cfs. But, since only 41% of the days had flows less than or equal to 3000 cfs, this represents only 4.68% (11.43 x 0.41) of the total postimpoundment days.

Important items to note from Table 34 are that 5.2% of the low flow (2.13% of the total) days had average flows of 1950 cfs or less and that 11.43% of the low flow days had flows of 2050 or less. The vast majority of these days occurred before the Memorandum Of Understanding was signed in 1971. Thus, since 1955, about 5% of the time during these months, the flow has not been sustained at the minimum. If one considers the effect of the pipeline and allows a minimum margin for error, the 2200 cfs class interval is relevant. During the postimpoundment period, approximately 13% of the days during the period have not had flows exceeding 2250 cfs. Thus, one could expect that, should the other uses be permitted and the reservoirs managed as they have been in the past, the 2000 cfs downstream flow would not be met approximately 13% of the time, meaning that additional water needed to make up the difference must come from Power Pool Storage.

Table 34. Percentage and cumulative percentages for preimpoundment and postimpoundment flows less than or equal to 3000 cfs.

	Preimpoundment		Postimpoundment		
Class Midpoint	Percent	Cum. Percent	Percent	Cum. Percent	Col. 5* X 0.41
1100	6.17	6.17	0.11	0.11	*
1200	2.76	8.93	0.11	0.23	*
1300	1.60	10.53	0.06	0.28	*
1400	2.32	12.85	0.00	0.28	*
1500	2.32	15.18	0.17	0.45	*
1600	4.36	19.54	0.11	0.57	*
1700	4.65	33.41	0.45	1.02	*
1800	4.58	28.76	1.47	2.49	1.02
1900	4.65	33.41	2.71	5.20	2.13
2000	6.10	39.51	6.22	11.43	4.68
2100	2.69	42.19	12.27	23.70	9.71
2200	5.37	47.57	10.35	34.05	13.96
2300	9.51	57.08	18.27	52.32	21.45
2400	5.95	63.04	17.08	69.40	28.45
2500	8.50	71.53	9.11	78.50	32.18
2600	5.37	76.91	7.13	85.63	35.38
2700	5.45	82.35	5.26	90.89	37.26
2800	8.06	90.41	3.62	94.51	38.74
2900	6.68	97.10	3.96	98.47	40.30
3000	2.90	100.00	1.53	100.00	41.00

Finally, when considering the possibility of many additional permitted uses, the 2500 cfs class interval becomes relevant. Since 1955, approximately 78.5% of the low flow days during the June-September period have seen a flow of less than or equal to 2550 cfs and 32% of the total days had flows below this amount. Thus, substantial additional permitting could result in a situation in which the reservoir would have to use Power Pool Storage to meet the minimum required downstream flow on 32% of the days in the four-month period.

Figures 35(a) and 35(b) show the percent frequencies and the differences, respectively. One should note here, as can be seen from Figure 35, that the effect of the dams when only the very low flow days are considered has so far been beneficial. In moving from the pre- to the postimpoundment period, the number of days in the lowest class interval has been substantially reduced and the days with flows in the 2100-2400 cfs range have been substantially increased.

Conclusion

The frequency analysis presented above indicates substantial variation in the flows during the 12 months of the year. This is not surprising since precipitation varies over the year and the Kerr Lake Rule Curve indicates that changes in the lake level and therefore the below-dam flow are necessary for flood control. Thus, the monthly frequency analysis and the Chi-Square analysis, which indicate substantial differences between pre- and postimpoundment flows, merely show that the dams are doing their jobs and give an indication of the extent and magnitude of their success in altering downstream flow.

When the analysis is confined to the relatively dry months of June through September, however, it has an implication for the additional water use permits which are presently being contemplated. What the analysis has shown is that there are a substantial number of days in the dry months when the present flow is marginal at best. Additional permitted usages may lead to undesirable changes in Kerr Lake levels and undesirable effects on the recreational uses of the lake if the minimum flow of 2000 cfs is to be preserved. Also, the ability of the power company to hold waters for peaking activity may be limited.

RIVER FLOW AND STRIPED BASS JAI

Roger A. Rulifson, James R. Waters, Robert J. Monroe, and Charles S. Manooch, III

Initial analyses by the Flow Committee in 1988 determined the relationship between the annual Juvenile Abundance Index (JAI) for striped bass and postimpoundment Roanoke River flow (1955-1987) as monitored by the USGS gage at Roanoke Rapids, North Carolina (Manooch and Rulifson 1989). A JAI value of 5 was selected by consensus of the original Recruitment Subcommittee as the cut-off between good and poor juvenile recruitment for the analyses.

Hassler et al. (1981) had concluded that abnormally high or low May River flows were detrimental to the formation of the year class, and the best JAI values were when May flows were moderately low to moderate (5,091-9,741 cfs). The Flow Committee analyzed the entire set of Hassler JAI values to confirm the relationship. Recruitment was best (JAI>5.0) for years in which River flows were low to moderate (5,000-11,000 cfs) and was poor (JAI<5.0) when flows were very low (3,900-8,100 cfs) or high (10,000 cfs or greater) during the spawning season. Additionally, the average flow pattern for good recruitment years (JAI>5.0) most closely resembled preimpoundment flow conditions. Details of the analyses were published in Rulifson and Manooch (1990a).

The average postimpoundment flow patterns for good year recruitment and poor year recruitment were modeled using a time series approach. Details of the analyses were published (Zincone and Rulifson 1991, see Appendix E). For this analysis, postimpoundment data included years from 1965 to 1986. Since it was the average seasonal flow patterns for the postconstruction period that were of interest, only River flow data after completion of Gaston Dam was used in the analysis. Seasonally, the full striped bass spawning window was used (1 march to 30 June) to include the prespawning, spawning, and postspawning periods. River flow data were subjected to time series analysis using the univariate Auto Regressive Integrated Moving Average (ARIMA) technique. The flow pattern in good recruitment years resembled a moderate plateau of discharge in March and early April, followed by a drop to a lower plateau (Figure 36). This pattern was similar to that determined for preimpoundment years (1912-1950, Figure 37). Instream flow in bad recruitment years remained higher throughout the four-month period and did not have the characteristic drop to the lower plateau (Figure 38).

Following the analyses described above, the Flow Committee recommended a River flow regime based on the preimpoundment flow patterns from 1 March to 30 June so that reservoir discharge would remain between the historical 25% and 75% quartiles of the daily flow (i.e., between the 25% low-flow value [Q_1] and 75% high flow value [Q_3] (Table 14). A modified flow regime from 1 April to 15 June was acceptable to the U.S. Army Corps of Engineers and Virginia Power Company because it did not require modification of the FERC license (Table 15).

This "Negotiated Flow Regime" was used in additional regression analyses to characterize patterns in postconstruction reservoir management. Briefly, the percentage of days during a season that reservoir discharge stayed within the historical (negotiated) Q_1-Q_3 bounds has decreased significantly over time, indicating that the manner in which the reservoir system is managed has changed throughout the years. Similarly, JAI values have declined with time, especially for the period 1978-1987, when the 10-year average was only 0.81. These analyses were presented in detail in the original report (Manooch and Rulifson 1989) and in the published article (Rulifson and Manooch 1990b, see Appendix D).

Additional analyses were performed to update and refine these earlier results. JAI and Q_1-Q_3 data sets for the period 1955-1990 were used in linear regression analyses to determine the

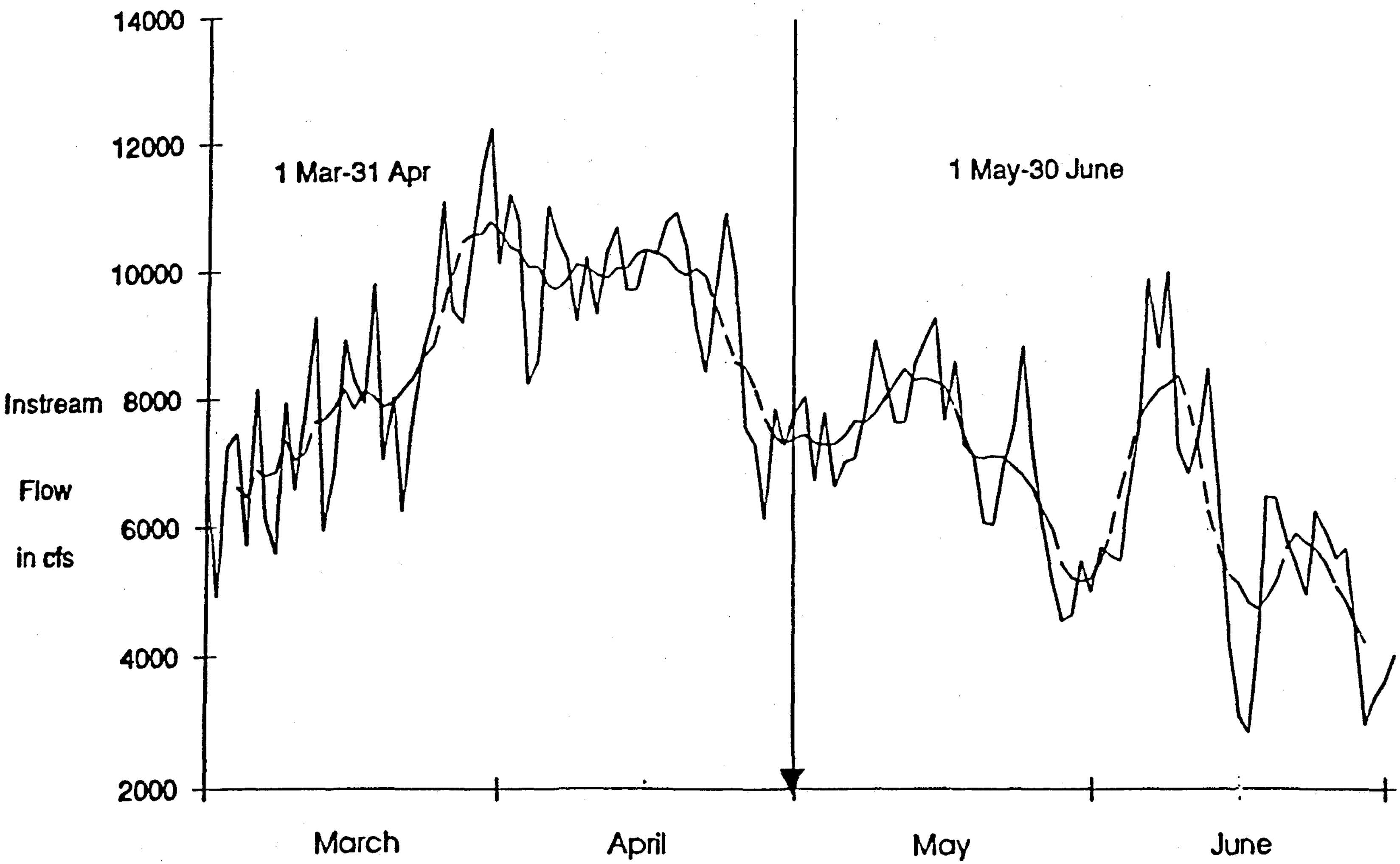


Figure 36. Roanoke River flow in postimpoundment years (1965-1986) exhibiting good striped bass recruitment (JAI>5.0). (Zincone and Rulifson 1991). The seven-day smoothed average is superimposed on a plot of trimmed means (see text).

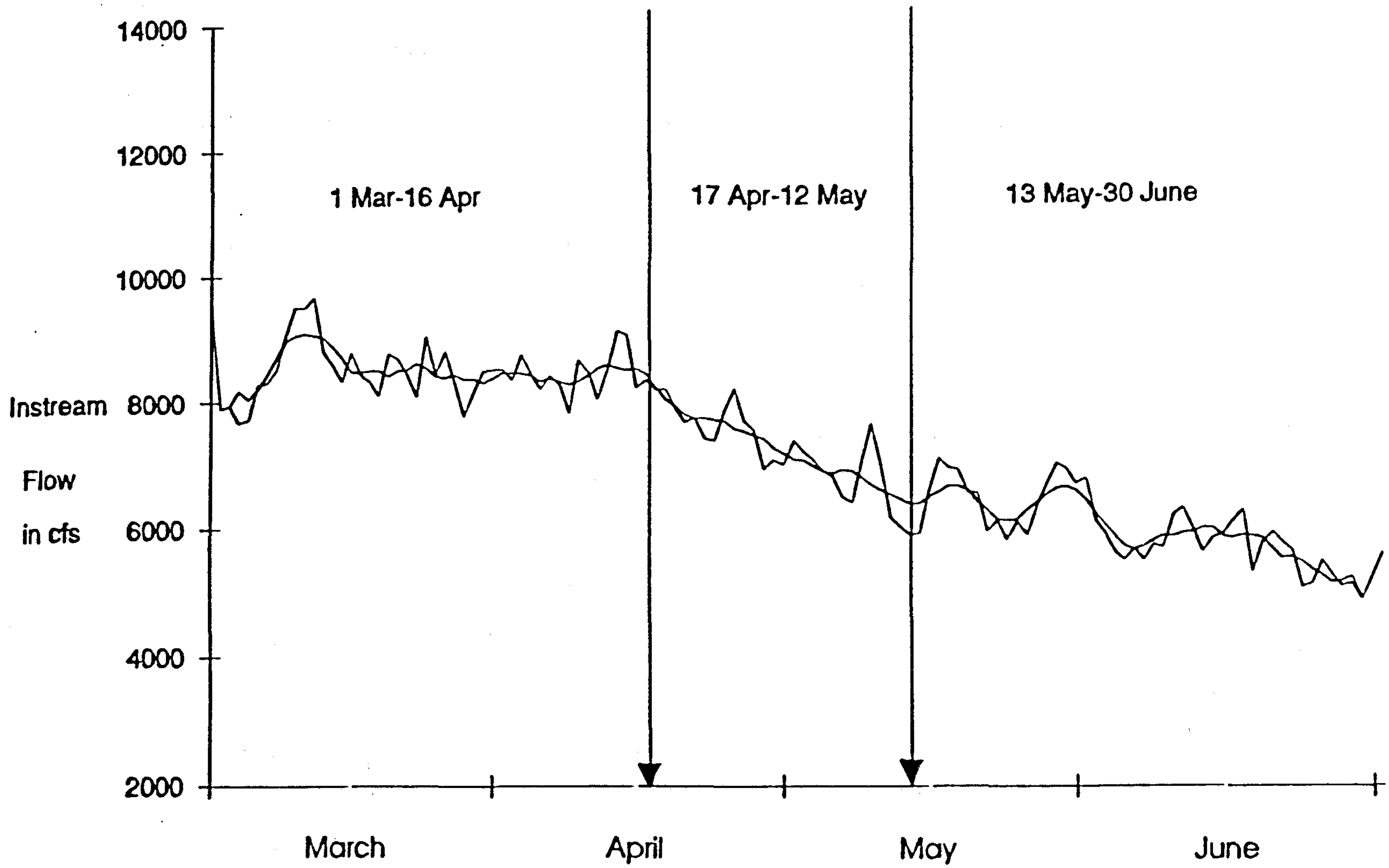


Figure 37. Time series analysis of preimpoundment flows (1912-1950) of the lower Roanoke River, NC (Zincone and Rulifson 1991). The seven-day smoothed average is superimposed on a plot of trimmed means (see text).

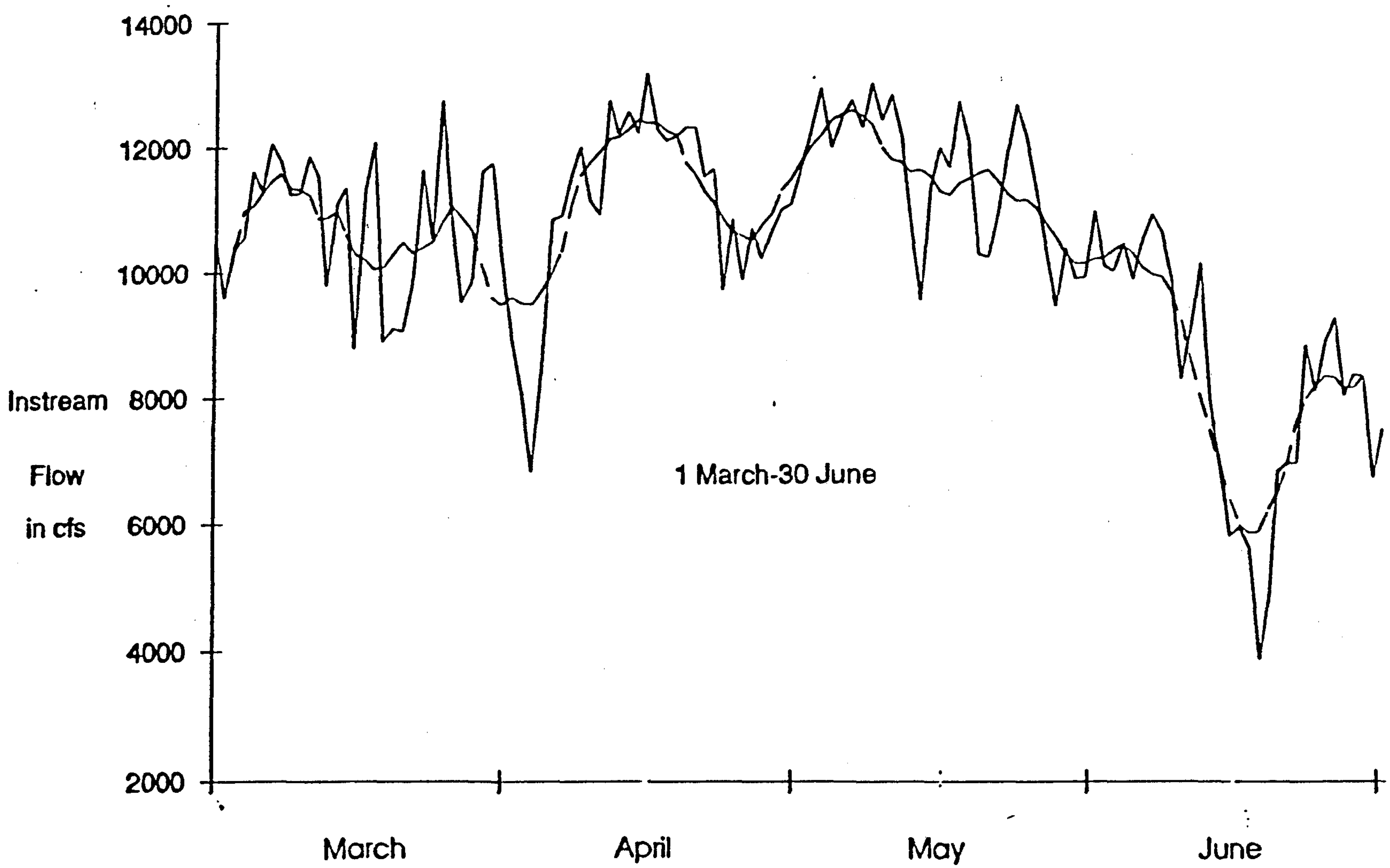


Figure 38. Roanoke River flow in postimpoundment years (1965-1986) exhibiting poor (JAI<5.0) striped bass recruitment (Zincone and Rulifson 1991). The seven-day smoothed average is superimposed on a plot of trimmed means (see text).

relationship between River flow and striped bass recruitment. River flow affects striped bass recruitment in California estuaries (Turner and Chadwick 1972, Stevens 1977), and white perch recruitment in portions of Chesapeake Bay (Summers et al. 1990). In our analysis, the JAI was estimated as a linear function of days within the Q_1-Q_3 bounds. The first analysis (full postimpoundment model) was performed on the original untransformed data set. A significant relationship between days within Q_1-Q_3 and JAI was established (df=1,34; F=9.977; P=0.0033; r^2=0.23, Table 35), but the residuals were not randomly distributed. The variance about the estimated regression increased with increases in both predicted JAI and observed days within Q_1-Q_3. In addition, there was an unusual pattern of negative residuals (i.e., the model overpredicted observed JAI) at the end of the time series.

To correct for this heterogeneity of variance, a second analysis was performed using data transformed to their natural logarithms. Again, a significant relationship between JAI and days within Q_1-Q_3 was established (df=1,34; F=28.891; P<0.0001; r^2=0.46, Table 35); however, the logarithmic model did not account for the unusual pattern of negative residuals at the end of the time series (Figure 39).

To accommodate the pattern of negative residuals, a third model was fitted which allowed for different intercepts and different slopes for the two periods 1955-1977, and 1978-1990 (Table 35). However, a direct test of parallelism in slopes was comfortably non-significant (P=0.66), meaning that the trend in both sets of data were similar, and that the differences could be corrected for by a different intercept. Thus, a fourth model with different intercepts only was fitted (Table 35), and a test of the difference between intercepts was highly significant (P=0.0004) (Figure 40). Residuals from this model were randomly distributed when plotted against LOGDAY values (Figure 41) and against years (Figure 42), thereby indicating that the model adequately describes the data.

The final equations for the fourth model (n=36, F=28.7, P>0.0001, R^2=0.63) were

1955-1977, LOGJAI = -3.4044 + 1.4657(LOGDAYS); and for

1978-1990, LOGJAI = -4.8706 + 1.4657(LOGDAYS).

In the logarithmic model the slope coefficient means that a 10% change in days within Q_1-Q_3 is associated with a 14.6% change in JAI. Further analyses of the influence of each observation on the predicted JAI and estimated slope coefficients suggested that years 1958 and 1986 were unusual years. Additional information is needed to determine why these years were unusual.

The model suggests that increasing the days within the Q_1-Q_3 bounds would result in an increase in juvenile abundance. Of course, this prediction applies only to the observed range of data. The need for two intercepts to describe the data indicates that some significant phenomenon occurred around 1977 to influence the striped bass spawning-river flow relationship.

Table 35. Results of ANOVA to determine the relationship between of Roanoke River flow (1955-1990) and the striped bass Juvenile Abundance Index (JAI). DAYSWIN = the number of days in which the instream flow measured at the USGS gage (Roanoke Rapids) was within the Q_1-Q_3 bounds. Standard errors appear in parenthesis below the estimated intercepts and slopes.

Independent Variable	Dependent Variable	Dummy Variable or Years	Estimated Intercept	Estimated Slope	Mean Square Error	DF	F	Prob>F	R^2
DAYSWIN	JAI	none	-1.3900 (2.3729)	0.2251 (0.0712)	30.2211	1,34	9.977	0.0033	0.23
LOGDAYS	LOGJAI	none	-5.7677 (1.2591)	2.0195 (0.3757)	1.3529	1,34	28.891	0.0001	0.46
LOGDAYS	LOGJAI	Dummy for 1955-77	-3.8974[a] (1.6078)	1.6078[a] (0.4712)	18.065	3,32	18.713	0.0001	0.64
LOGDAYS	JAI	Dummy for 1978-90	-0.4608[a] (2.2836)	-0.3111[a] (0.6971)					
LOGDAYS	LOGJAI	1955-77	-3.4044[a] (1.2068)	1.4657[a] (0.3430)	27.0014	2,33	28.666	0.0001	0.63
LOGDAYS	LOGJAI	Dummy for 1978-90	-1.4662[a] (0.3685)						

[a]Values reported are actually the difference in intercept and slope, respectively, between the 1955-1977 data and the 1978-1990 data.

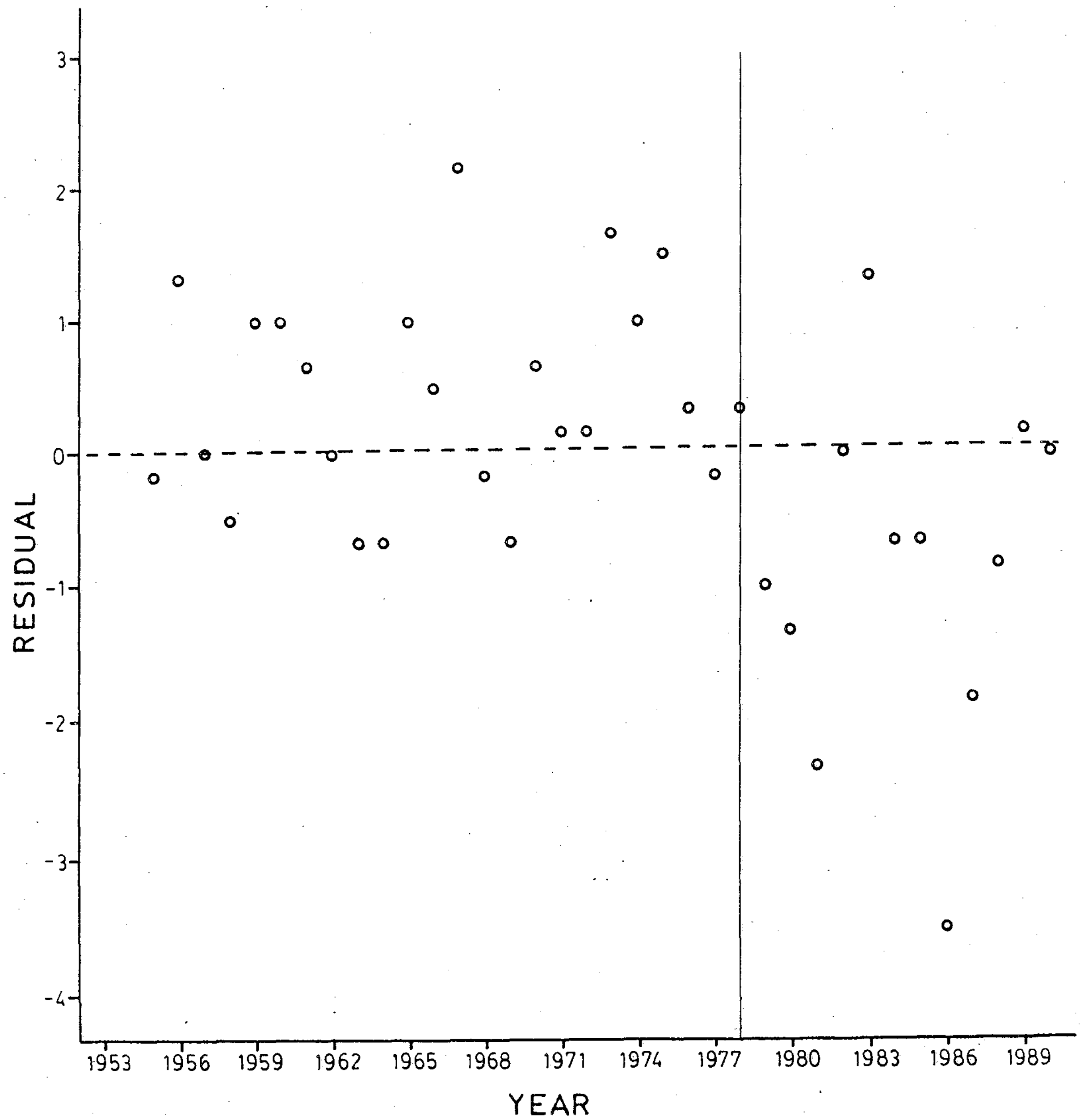


Figure 39. Plot of the residuals from the full model analysis (1955-1990) depicting the relationship of Roanoke River flow and striped bass recruitment in Albemarle Sound.

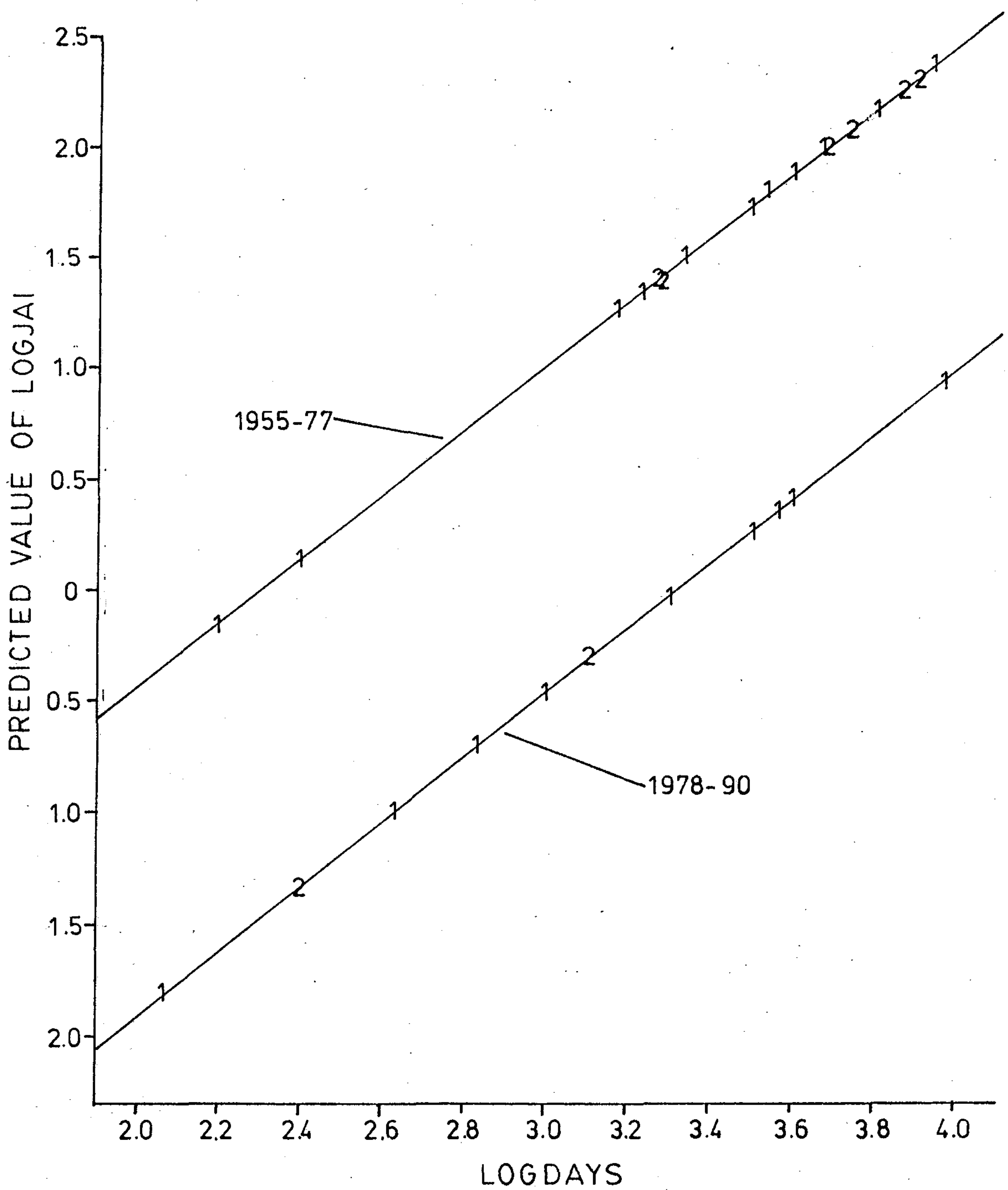


Figure 40. Full model (1955-1990) depicting the relationship between Roanoke River flow (days within Q_1-Q_3) and striped bass recruitment in Albemarle Sound.

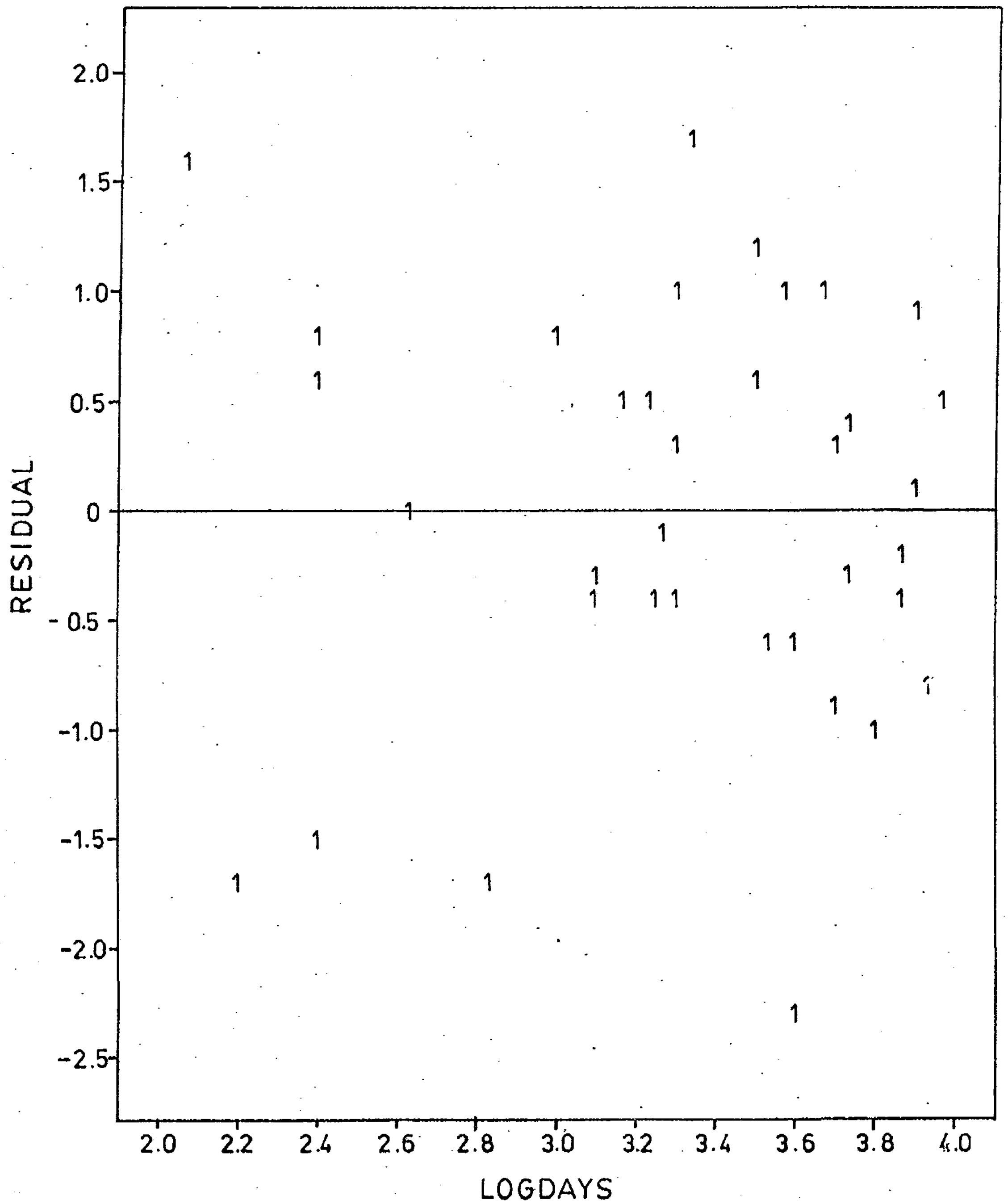


Figure 41. Plot of the natural log-transformed data analysis (1955-1990) showing the random distribution of the residuals against the logdays within Q_1-Q_3.

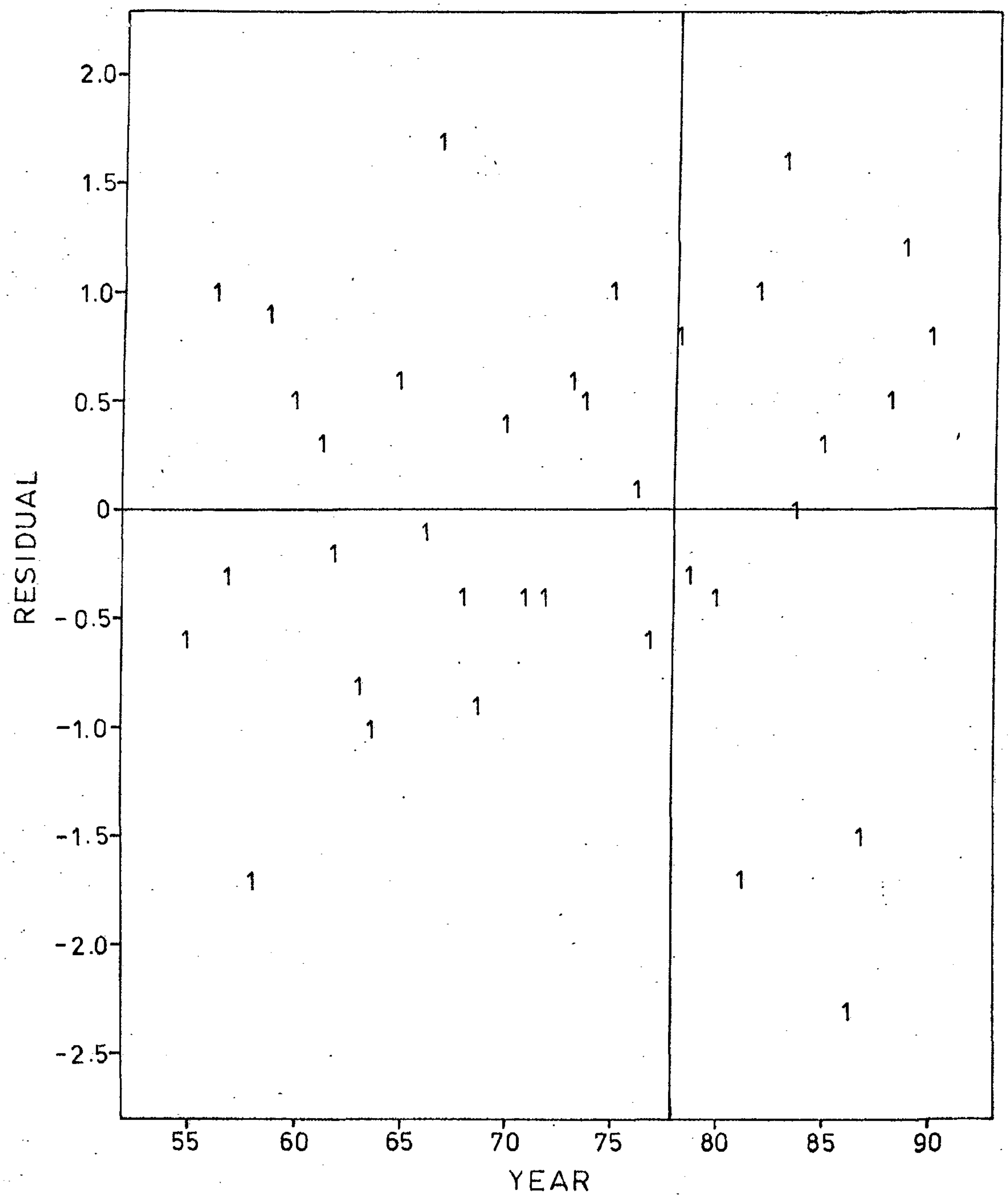


Figure 42. Plot of the natural log-transformed data analysis (1955-1990) showing the random distribution of the residuals against postimpoundment years.

HYDROLOGY FOR 1990

General Conditions

Tom Fransen

The flow records for the first six months of 1990 show stream flows to be above normal to moderately high. The flow record for the U.S. Geological Survey (USGS) gage at Roanoke Rapids shows the first six months to be the 13th wettest out of 79 years of record. For comparison, the first six months of 1989 ranked as the 29th wettest year. Flows during the period of April through mid-June were the 9th wettest on record. In 1989 for the same period, the flows were the 10th wettest on record.

During the first six months there were 10 storms that caused Kerr Reservoir inflows to exceed 90% of the historical inflow (Figure 43). The largest of these storms occurred at the end of May with a peak inflow of 54,328 cfs on 29 May. As a result of storing this flood event, Kerr Reservoir reached a peak elevation the first six months of 306.61 feet msl (Figure 44).

At the beginning of the flow augmentation period on 1 April, there was adequate storage available in Kerr Reservoir (Figure 44). The Reservoir level was approximately elevation 303 feet msl, about two feet above the Rule Curve. The large inflows into Kerr Reservoir caused the daily flows at Roanoke Rapids to exceed the flow regime 72.4% of time for the period 1 April-15 June, (Table 36, Figure 45); daily flows were within the flow regime 26.3% of the time. There was only one day, 1 April, that was below the flow regime. For comparison, in 1989 the flows were within the regime 43% of the time.

The flow stability, even with the high flows, was better in 1990 than 1989. In 1989 the hourly variation in flow exceeded 1,500 cfs 1.54% of the time (28 hours). However, in 1990 the hourly flow variation exceeded 1,500 cfs 1.10% of the time (20 hours). Figure 46 shows the absolute value of the hourly flow difference for April through mid-June.

Table 36. Bi-weekly summaries of daily flows of the Roanoke River at Roanoke Rapids, NC for 1990.

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 $> Q_3$	%Days $> Q_3$
01APR-15APR	015	6600.0	13700.0	1	6.7	2	13.3	12	80.0
16APR-30APR	015	5800.0	11000.0	0	0.0	10	66.7	5	33.3
01MAY-15MAY	015	4700.0	9500.0	0	0.0	8	53.3	7	46.7
16MAY-31MAY	016	4400.0	9500.0	0	0.0	0	0.0	16	100.0
01JUN-15JUN	015	4000.0	9500.0	0	0.0	0	0.0	15	100.0
01APR-15JUN	076			1	1.3	20	26.3	55	72.4

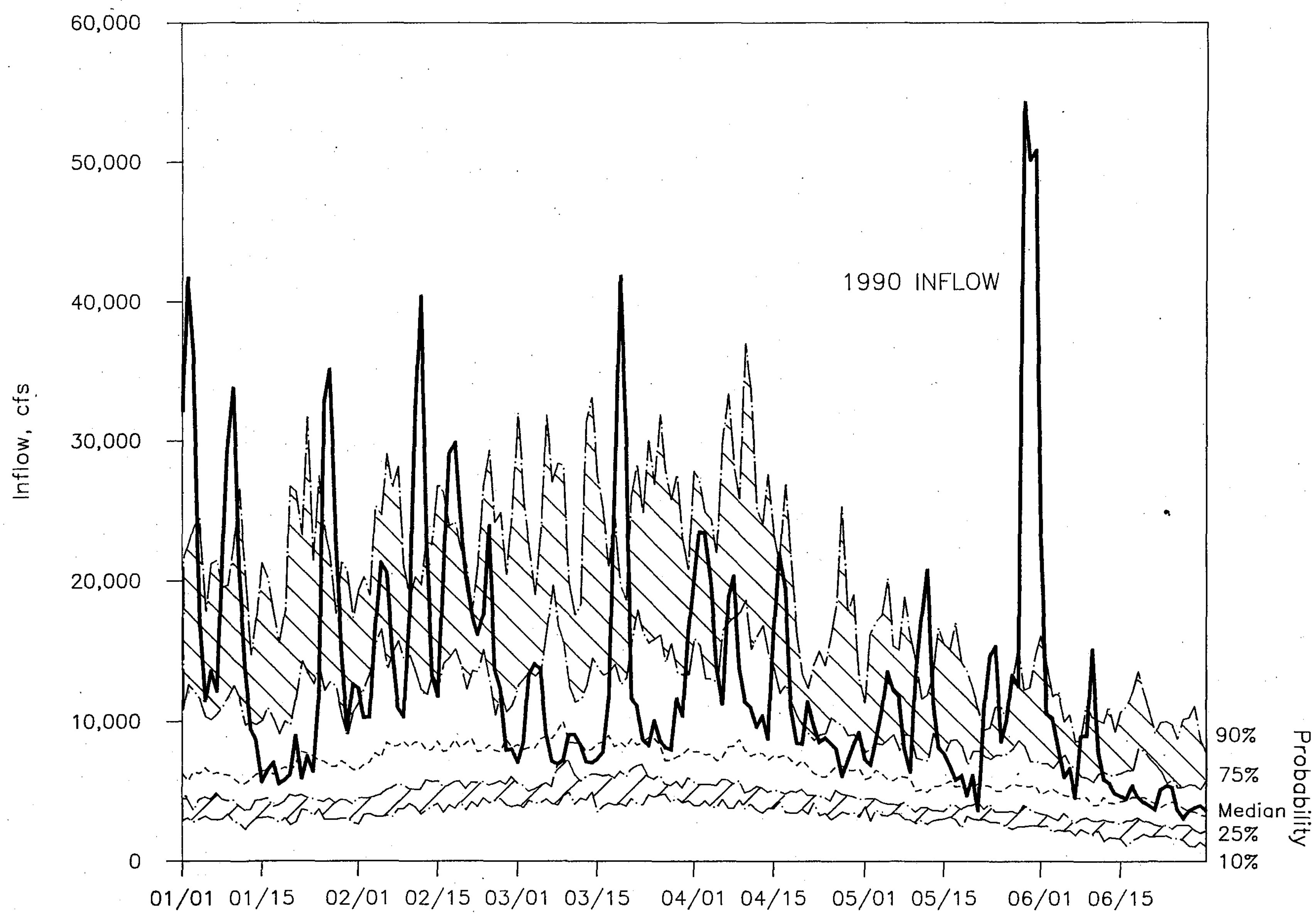


Figure 43. Kerr Reservoir Inflow for 1990 compared to the historical record.

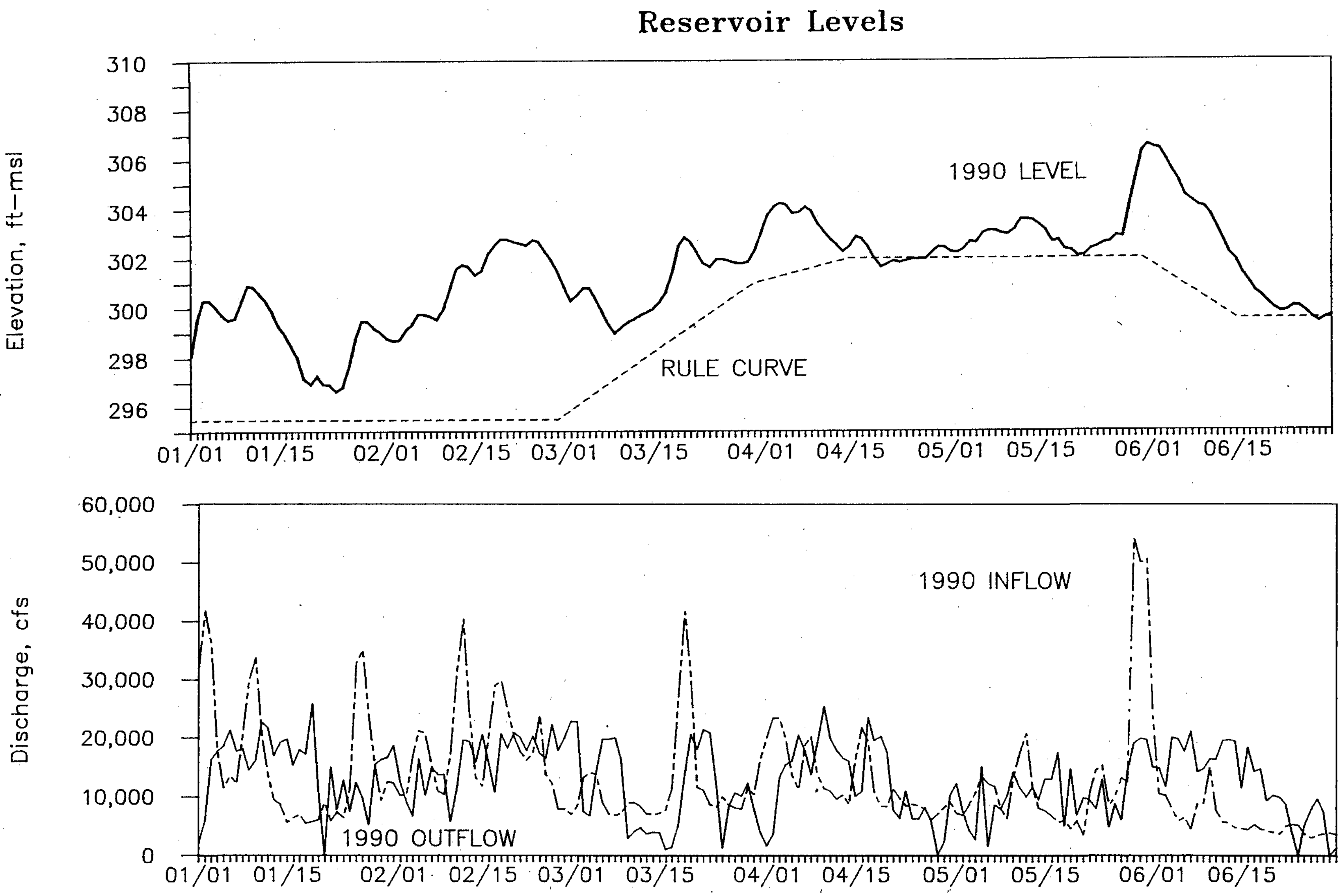


Figure 44. Kerr Reservoir levels; inflow and outflow (cfs) and elevation relative to the Rule Curve.

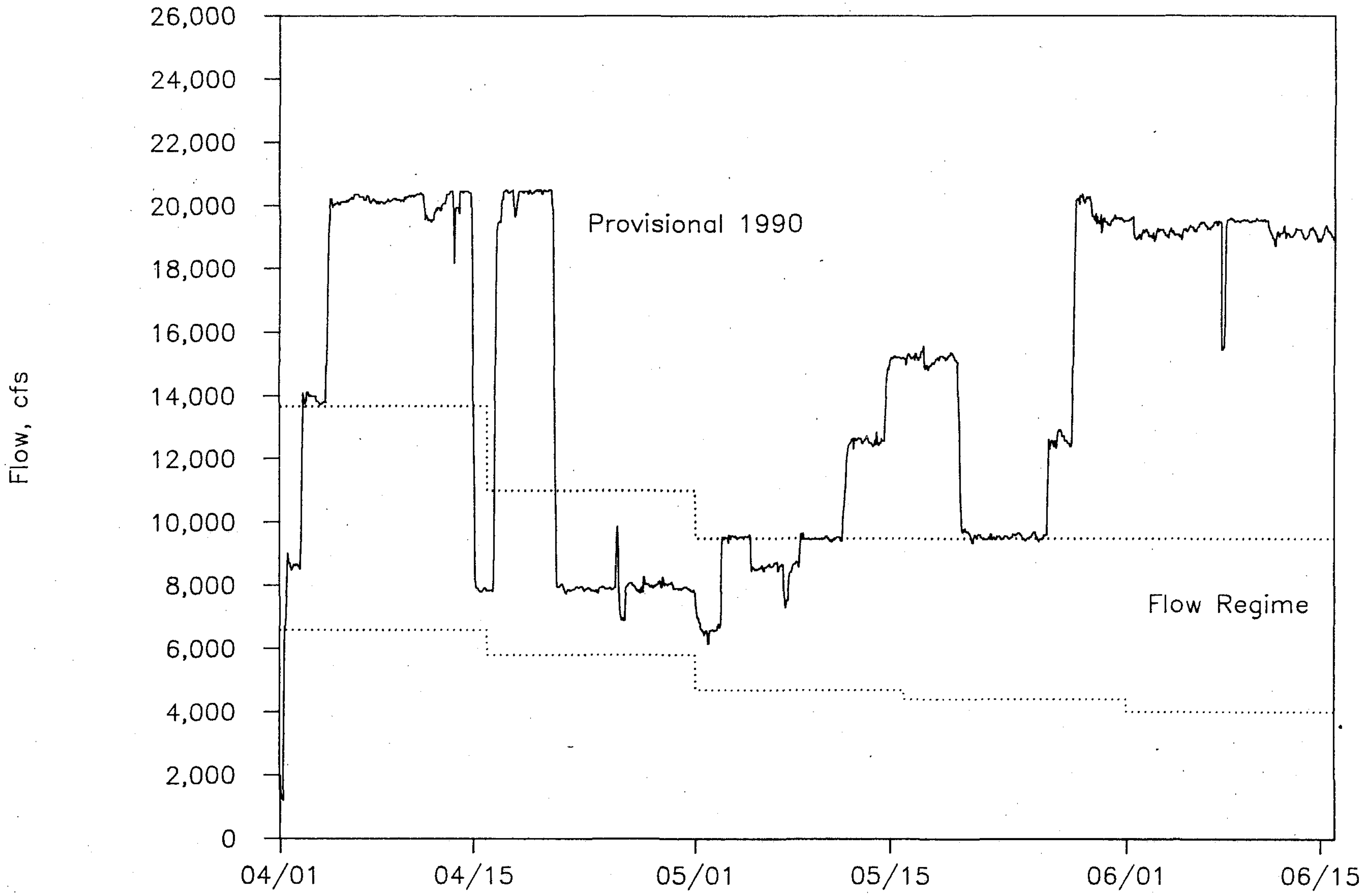


Figure 45. USGS hourly flow data (cfs) for Roanoke River at Roanoke Rapids, 1 April - 15 June, and the Q_1-Q_3 Negotiated Flow Regime.

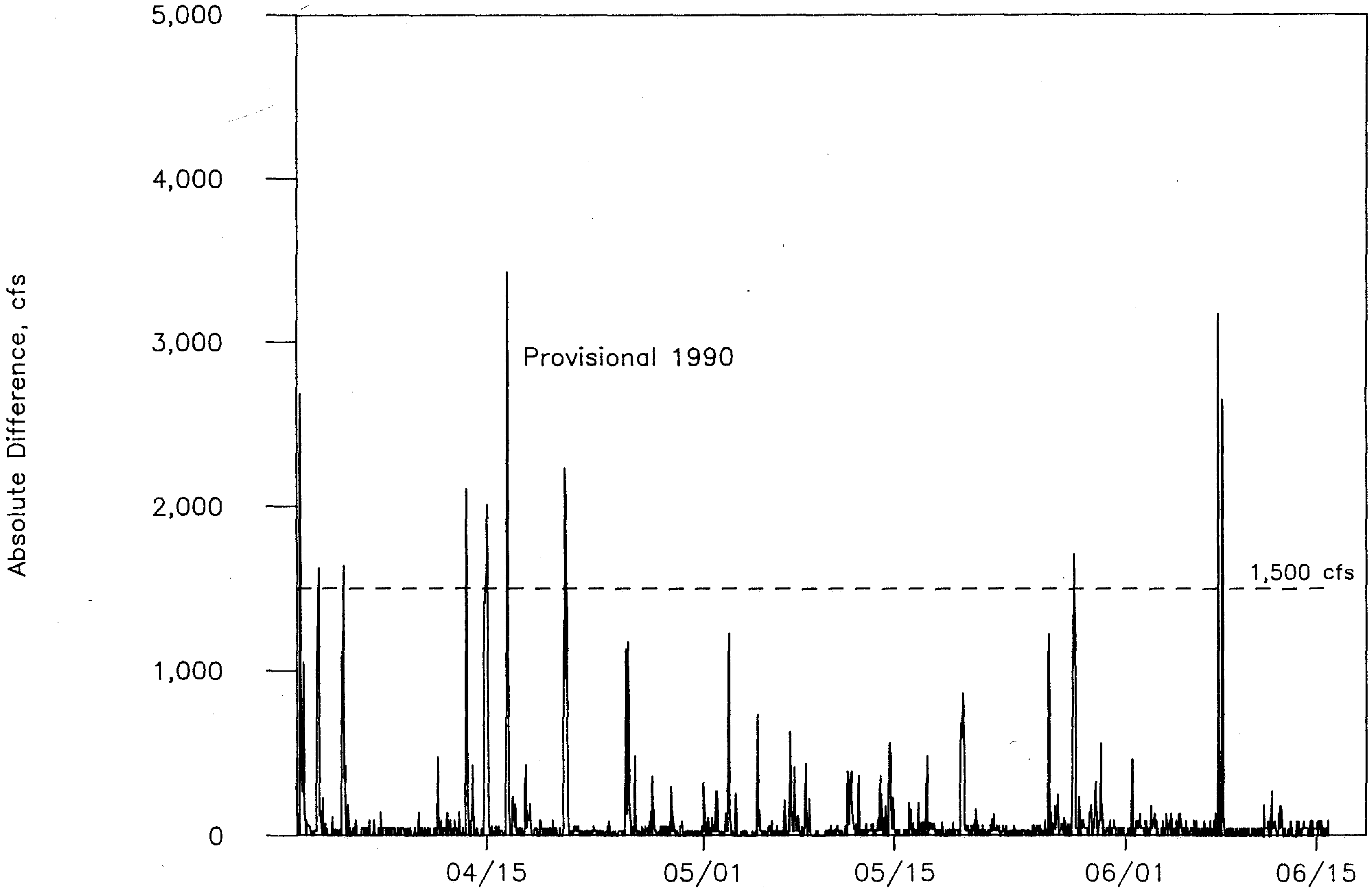


Figure 46. Absolute value of hourly differences in flow (cfs) of the Roanoke River downstream of Roanoke Rapids Dam.

Minimum Flow Requirements/Targets

Tom Fransen

The flows in the lower Roanoke River, below Roanoke Rapids Dam, are regulated by water release from Roanoke Rapids Reservoir. The Federal Energy Regulatory Commission (FERC) license for Gaston/Roanoke Rapids project requires a seasonal varying minimum release. Roanoke Rapids Dam was constructed by Virginia Electric and Power Company (VEPCO, now known as Virginia Power, a subsidiary of Dominion Resources). 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 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. Kerr Reservoir is an Army Corps of Engineers (COE) project. The COE has operational guidelines (Figure 47) for Kerr Reservoir that include target minimum flows. Table 37 summarizes the FERC required flows and the COE's target flows along with the Committee's flow regime.

To compare the impact of the reservoirs on low flows, the following time periods were used. For the preimpoundment or unregulated period, 1 January 1912 to 31 August 1950 was used. January 1912 begins the first fall calendar year of the USGS gage at Roanoke Rapids. In September of 1950, storage began in Kerr Reservoir. Therefore, the end of August 1950 was selected as the end of the pre-impoundment period.

The postimpoundment or regulated period is the period from 1 July 1955 to 30 September 1989. The period from September, 1950 through June, 1955 was not included because, during construction, low flow could occur due to construction and not hydrologic conditions or normal reservoir operations. Roanoke Rapids Lake begin operation 25 June 1955. The September 1989 data was the latest published data at the time the analysis was performed.

Figures 48 and 49 do not use the January 1912 to August 1950, and July 1955 to September 1989, time periods. An error in the figures was found too late to correct. The unregulated period used was 1 January 1912 to 31 December 1950. The regulated period is 1 January 1965 to 30 September 1989. The difference in dates cause the spring minimum flows to be higher for the regulated period.

The impact caused by the upstream regulation is to shift the spring flood waters to later in the year. Figure 48 demonstrates the shift by comparing the unregulated daily minimum flows with the regulated minimums at the Roanoke Rapids gage. As seen in Figure 48, the winter and spring flows (November - April) are reduced, followed by higher, more stable flows in the summer and fall (July - October).

The flow regulation causes an increase in the minimum flows. The unregulated daily minimum flow was 472 cfs (305 MGD) on 21 September 1932. The regulated 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. Figure 49, a low-flow frequency curve, shows the increase in time at lower flows. As seen in Figure 49, 25% of the time the unregulated flows are less than 3,440 cfs (2,224 MGD) and regulated flows are less than 2,440 cfs (1,577 MGD). Fifty percent of the time unregulated flows are less than 6,010 cfs (3,885 MGD) and regulated flows are less than 5,620 cfs (3,633 MGD).

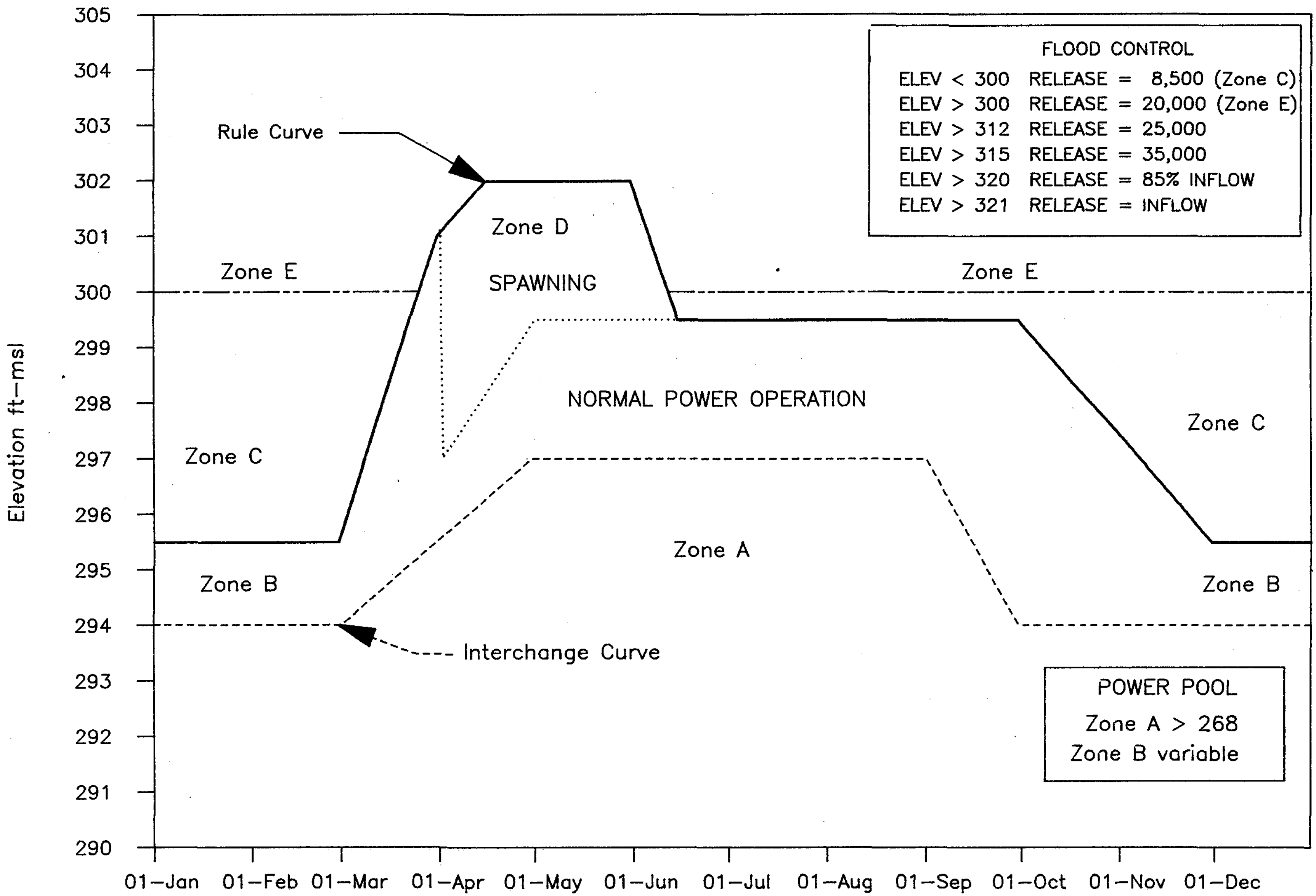


Figure 47. John H. Kerr Reservoir Rule Curves.

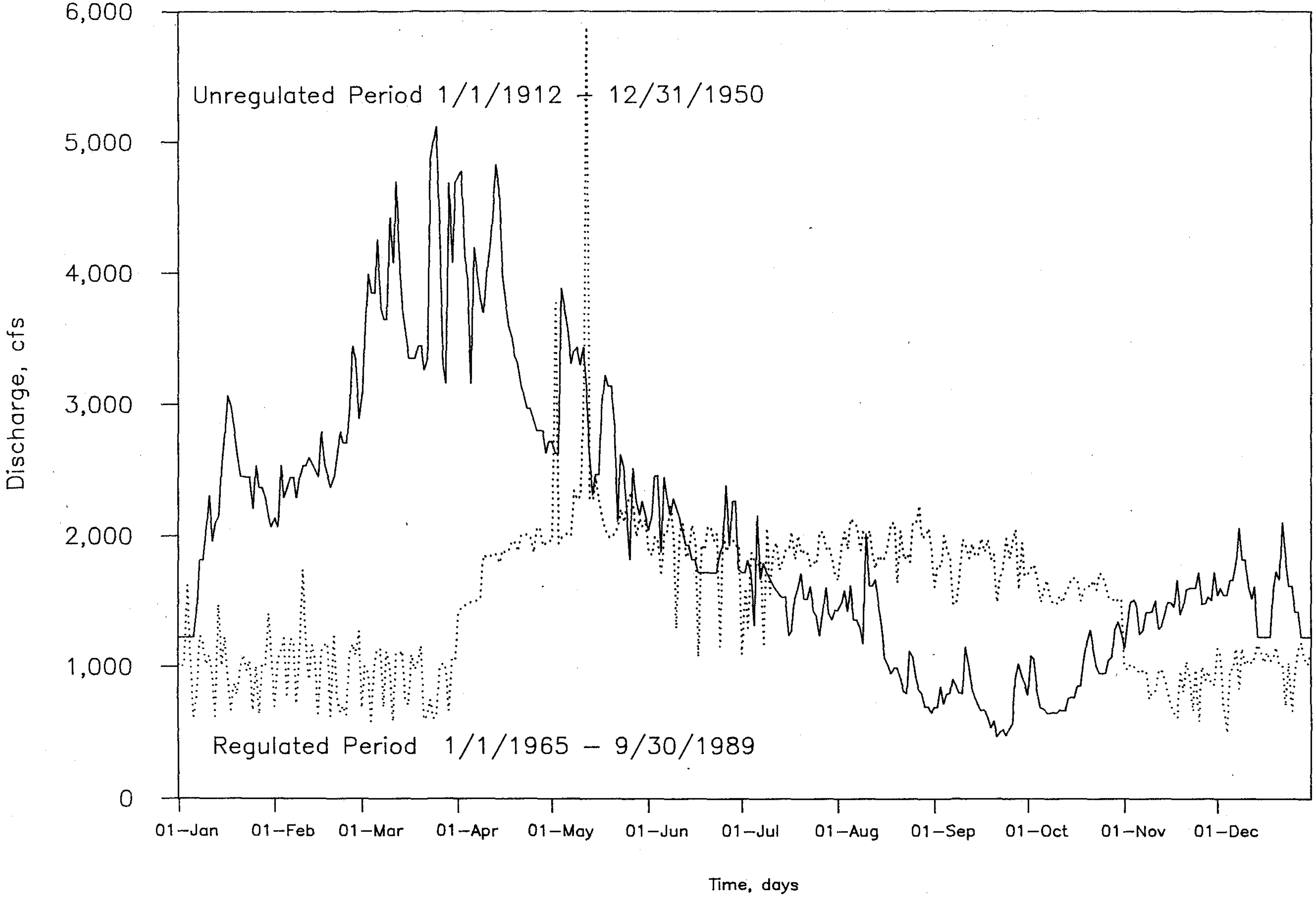


Figure 48. Comparison of daily minimum flows in Roanoke River at Roanoke Rapids. Key: solid = unregulated, dotted = regulated.

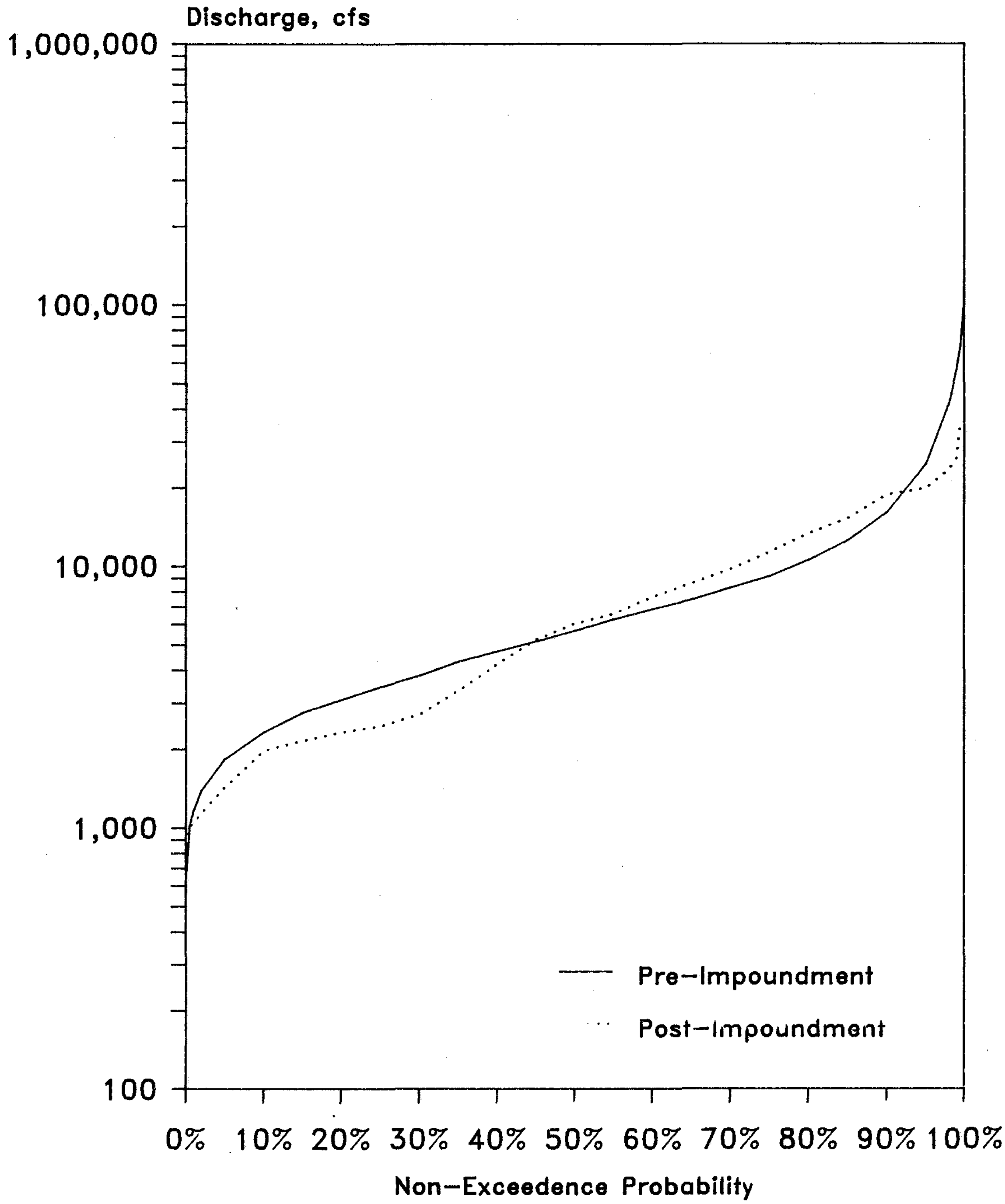


Figure 49. Preimpoundment and postimpoundment of Roanoke River at Roanoke Rapids.

Table 37. Roanoke River minimum flows. 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 not longer than 75 days.

	FERC Minimum Release Roanoke Rapids		Kerr Reservoir Target Releases		Roanoke River Flow Committee Lower Limit		Roanoke River Flow Committee Target Release	
	cfs	(MGD)	cfs	(MGD)	cfs	(MGD)	cfs	(MGD)
January	1,000	(646)	1,000	(646)				
February	1,000	(646)	1,000	(646)				
March	1,000	(646)	1,000	(646)				
April 1-15	1,500	(970)	2,000	(1,293)	6,600	(4,266)	8,500	(5,495)
April 16-30	1,500	(970)	5,700	(3,685)	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	(2,586)	5,300	(3,426)
June 16-30	2,000	(1,293)	2,000	(1,293)				
July	2,000	(1,293)	2,000	(1,293)				
August	2,000	(1,293)	2,000	(1,293)				
September	2,000	(1,293)	2,000	(1,293)				
October	1,500	(970)	1,500	(970)				
November	1,000	(646)	1,000	(646)				
December	1,000	(646)	1,000	(646)				

Another 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 37, the regulated flows will always exceed the 7Q10 as along 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.

Kerr Reservoir Operation

Max B. Grimes

To fully understand the basic operation of reservoir projects that are located above the fish spawning grounds, one should read page 17 of the 1988-1989 Report. The interim operation plan (the Negotiated Flow Regime) was again used in 1990 to make water releases for striped bass. The plan provided a step-down flow range from 1 April to 15 June which was designed to more closely represent pre-project conditions. At the beginning of the flow augmentation period on 1 April, storage was available in Kerr Reservoir up to elevation 302 feet msl. Greater than normal rainfall and heavy inflows to Kerr Reservoir forced deviations from the recommended plan during four periods of time, 4-14 April and 16-20 April (20,000 cfs operations), 11-20 May

(15,000 cfs operation), and 26 May-15 June (20,000 cfs operation). For the remainder of the fish flow days, releases were maintained to ensure that sufficient storage would be available for the entire flow period. Elevations at Kerr ranged from 301.6 to 306.7 feet during the period 1 April to 15 June. After the high flows in early April, an effort was made beginning on 20 April to release target-level flows thereafter, but additional rains in the first part of May made it necessary to go to upper-band releases which generally lasted through 11 May.

Hourly and Mean Flows

Charles S. Manooch, III and Marsha E. Shepherd

Roanoke River water flows were high during the spring of 1990 (Figure 50; Tables 38 and 39). Mean water flow for the period 1 March - 30 June was 12,909 cfs (Table 38) and was 14,283 cfs for the Negotiated Period, 1 April - 15 June (Table 39). By comparison, the mean flow for the Negotiated Period during the spring of 1988 was 5,669 cfs and was 13,712 cfs for 1989 (Rulifson and Manooch 1990a). Overall, only 20 days (26%) had mean daily flows that were within the upper and lower flow boundaries recommended by the Committee for the Negotiation Period (Table 36). This compares with 53 days (70%) for 1988 and 33 days (43%) during 1989 (Rulifson and Manooch 1990a; Table 31).

In terms of hourly data, only 23.5% of the hourly flows from 1 March - June 30 1990 were within the historical Q_1-Q_3 flow boundaries identified by the Committee, whereas 31.8% of hourly flows were within the Negotiated Period flow boundaries. Approximately 62% of the hourly flows exceeded the upper flow boundary for the entire period and 68% exceeded the upper boundary for the Negotiated Period (Tables 38 and 39). During the Negotiated Period, 57% of the days (43) had every hourly flow exceeding the recommended upper boundary (i.e., $\%>Q_3$).

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). Flow stability was evident in 1990 (Figure 51; Table 40) as it was during 1989 (see Table 7 in Rulifson and Manooch 1990a) as approximately 99% of the hourly variation was less than 1,500 cfs for both years.

The trend in water flow during the spring of 1990 was atypical of historical trends. Historically, flows have been relatively high during March and early April and then decrease during late April, May, and June. In 1990 flows were high during March and early April, decreased somewhat during late April and early May, but then increased during late May and June. This is a reversal of the preimpoundment (natural) trend.

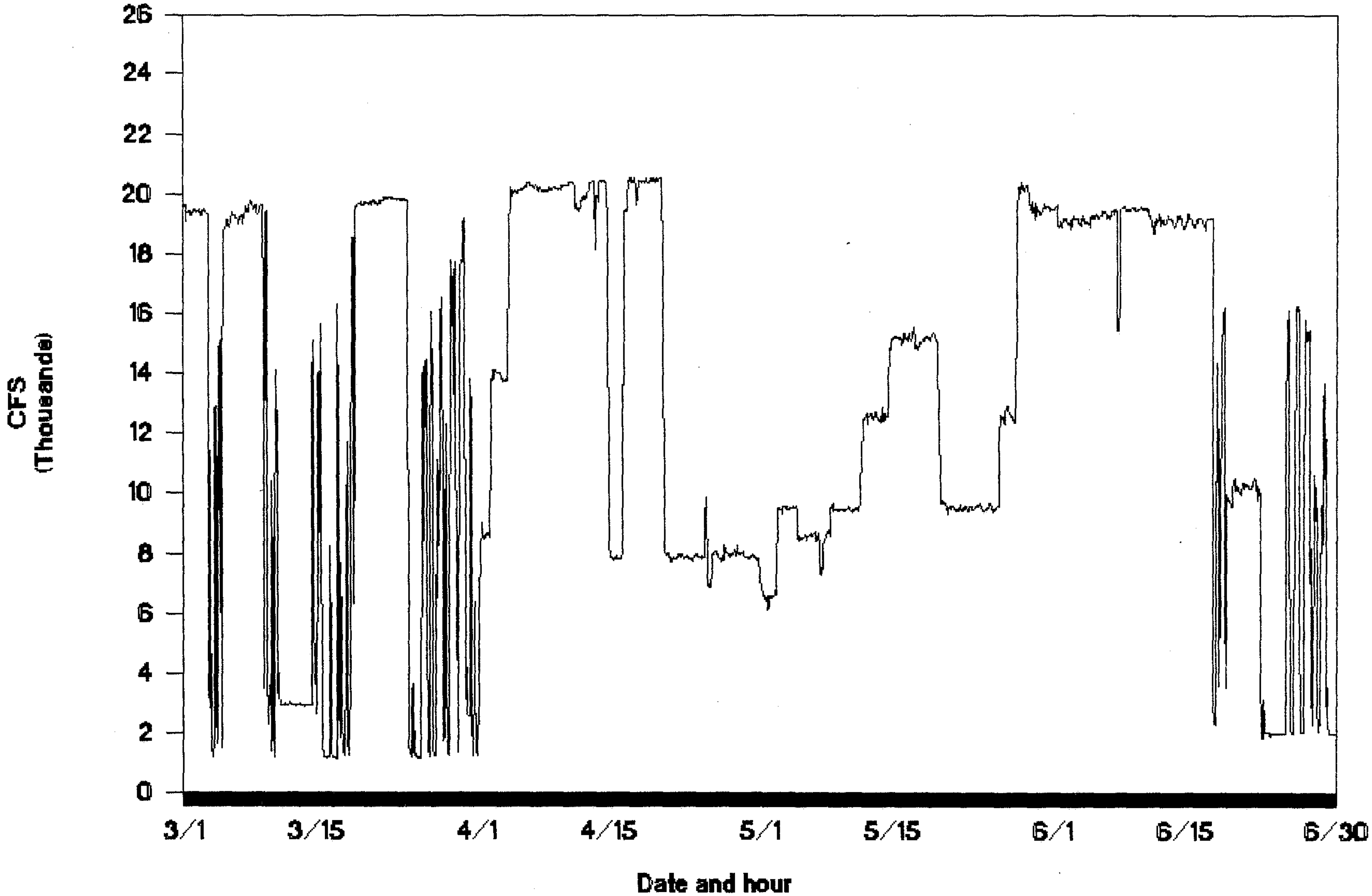


Figure 50. Hourly record of Roanoke River flows (cfs) downstream of the Roanoke Rapids Reservoir (USGS data), March through June 1990).

Table 38. Weekly summaries for 1990 hourly flows using Table 14 Q_1-Q_3 boundaries.

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	20	11.9	7	4.2	141	83.9	16,531	5,671	687
2	08 Mar-14 Mar	168	110	65.5	15	8.9	43	25.6	7,992	7,215	726
3	15 Mar-21 Mar	168	73	43.4	20	11.9	75	44.6	10,919	8,214	995
4	22 Mar-28 Mar	168	60	35.7	28	16.7	80	47.6	11,618	7,917	923
5	29 Mar-04 Apr	168	45	26.8	83	49.4	40	23.8	10,746	5,791	866
6	05 Apr-11 Apr	168	.	.	.	.	168	100.0	20,166	190	27
7	12 Apr-25 Apr	168	.	.	37	22.0	131	78.0	17,408	4,971	205
8	19 Apr-25 Apr	168	.	.	122	72.6	46	27.4	11,177	5,465	130
9	26 Apr-02 May	168	.	.	166	98.8	2	1.2	7,637	636	60
10	03 May-9 May	168	.	.	85	50.6	83	49.4	8,988	570	51
11	10 May-16 May	168	.	.	25	14.9	143	85.1	12,629	2,137	71
12	17 May-23 May	168	.	.	89	53.0	79	47.0	11,966	2,752	66
13	24 May-30 May	168	.	.	.	.	168	100.0	14,427	4,517	119
14	31 May-06 Jun	168	.	.	.	.	168	100.0	19,251	213	42
15	07 Jun-20 Jun	168	.	.	.	.	168	100.0	19,175	761	78
16	14 Jun-20 Jun	168	9	5.4	4	2.4	155	92.3	14,957	5,234	464
17	21 Jun-27 Jun	168	83	49.4	3	1.8	82	48.8	6,812	5,101	508
18	28 Jun-30 Jun	72	34	47.2	4	5.6	34	47.2	6,042	4,261	906
19	===========										
20	01 Mar-30 Jun	2,928	434	14.8	688	23.5	1806	61.7	12,909	6,367	367

Table 39. Weekly summaries for 1990 hourly flows using Table 17 median Q_1-Q_3 boundaries.

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	9	2.5	55	15.3	296	82.2	17,150	4,967	135
2	16 Apr-30 Apr	360	.	.	255	70.8	105	29.2	11,424	5,534	115
3	01 May-15 May	360	.	.	205	56.9	155	43.1	9,985	2,361	70
4	16 May-31 May	384	.	.	66	17.2	318	82.8	13,721	4,007	86
5	01 Jun-15 Jun	360	.	.	.	.	360	100.0	19,175	535	60
6	===========	.	.	.	.	.	.	.	.	.	.
7	01 Apr-15 Jun	1,824	9	0.5	581	38.1	1,234	67.6	14,283	5,205	93

Table 40. Weekly summaries of Roanoke River flow in 1990 based on absolute value of hourly variation; based on Negotiated Flow Regime.

Week	Dates	Total # hours	# hours <=1,500	% hours <=1,500	# hours >1,500	% hours >1,500
1	01 Apr-15 Apr	360	350	97.2	10	2.8
2	16 Apr-30 Apr	360	353	98.1	7	1.9
3	01 May-15 May	360	360	100.0	0	0.0
4	16 May-31 May	384	383	99.7	1	0.3
5	01 Jun-15 Jun	360	358	99.4	2	0.6
6	===========	. .	.	.	.	.
7	01 Apr-15 Jun	1,824	1,804	98.9	20	1.1

Table 17 = Negotiated values: used here for 1 April - 15 June.

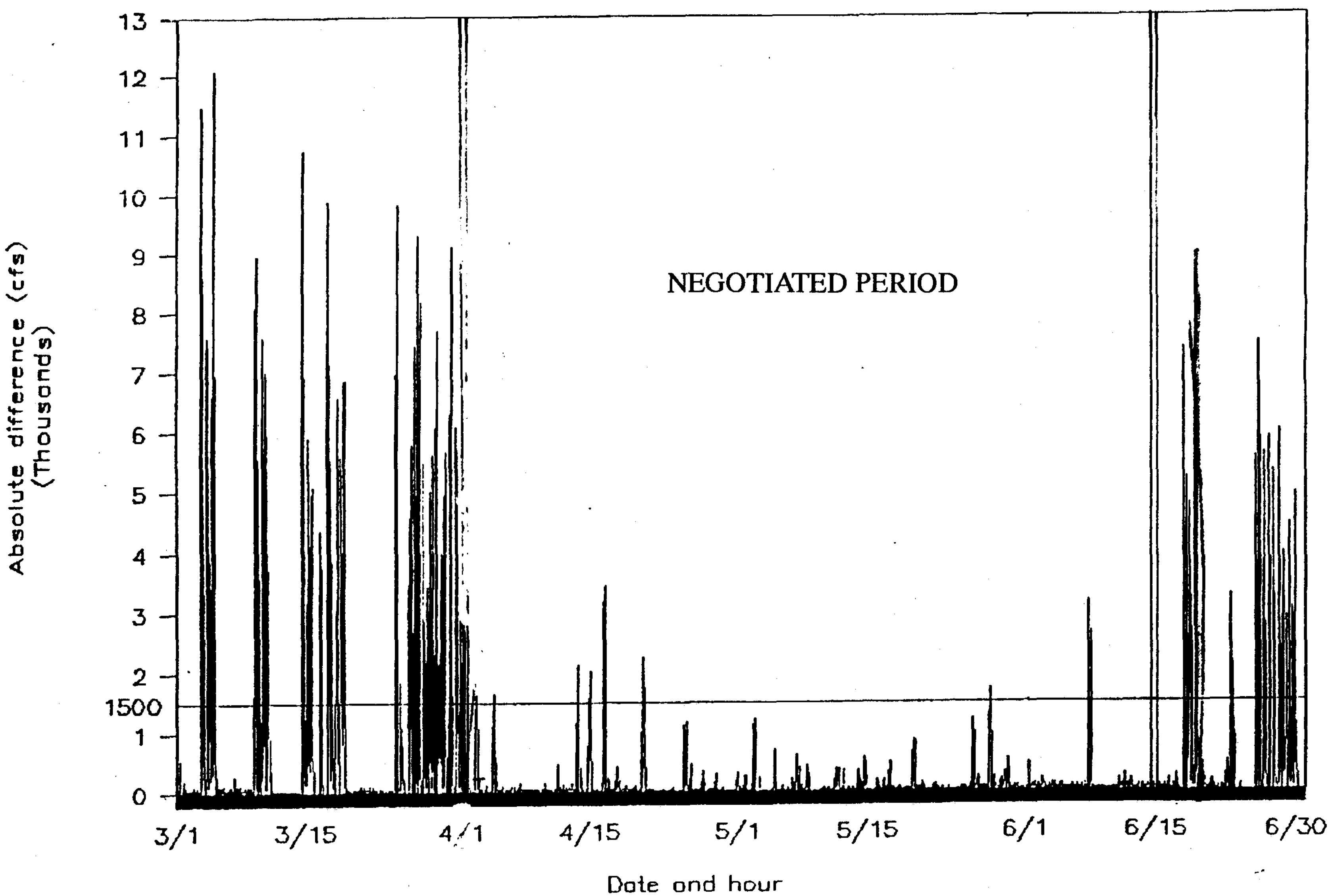


Figure 51. Roanoke River hourly difference for Negotiated Period.

Roanoke River Flow Time Series Analysis

L.H. Zincone, Jr.

Introduction

In order to be consistent with the 1990 report, this section will develop the autoregressive integrated moving average (ARIMA) models for the period March through June 1990 as well as that for the Negotiated Period 1 April to 15 June 1990. In the second section, the more structured autoregression models will be developed from data representing both the average daily flows and the hourly flows for each time period. The autoregression model for the daily flows includes months and days of the week as explanatory variables. The models built upon the hourly data include months, weekdays, and hours of the day as explanatory variables. As explained in the 1990 report, the autoregressive analysis with dummy variables is essentially the equivalent of analysis of variance (ANOVA) with one difference. Ordinary least squares ANOVA computes inefficient parameter estimates and biased standard errors since the model residuals are not free of autocorrelation. The autoregression procedure used in this analysis accounts for the residual autocorrelation and recomputes the model coefficients and standard errors so that they are efficient and unbiased, respectively. In most instances, the unbiased coefficients are substantially different from those estimated by ordinary least squares.

ARIMA Analysis

Table 41 shows the estimated coefficients of the ARIMA models for the entire period and the Negotiated Period for 1990. The value of each coefficient is shown along with the t-ratio. AR1 stands for an autoregressive term at lag 1. This indicates that flow in the current day is a function of the flow during the previous day or that the flow is relatively stable from one day to the next, other things equal. MA21 stands for a moving average term at lag 21. This means that flow today is a function of the random disturbance in the flow which occurred 21 days in the past. The Q statistic is the Ljung-Box Q and is not significantly different from zero if there is no autocorrelation present in the residuals of the model. That is, if the estimated model is an adequate representation of the process generating function of the data, the probability of a larger Q will be greater than 5%.

Table 41. Estimated coefficients and t values for ARIMA models of short and long period of analysis.

	1 March - 30 June		1 April - 15 June	
Variable	Value	t-ratio	Value	t-ratio
Constant	1975		155	
AR1	0.86	17.26	0.97	30.82
MA21	0.23	2.32		
Q	11.13		11.49	
P>Q	0.35		0.40	

The equations below show the model in expanded form.

(1) $$y_t = 0.86y_{t-1} + 0.23a_{t-21} + 1975 + a_t$$

(2) $$y_t = 0.97y_{t-1} + 155 + a_t$$

The variable y_t is average hourly flow at time *t* and a_{t-i} is random shock term at time *t-i*, *i*=0,1 or 21 as appropriate.

The 1989 report indicated that the model for the average bad recruitment year flow (JAI<5) was not significantly different from a random walk model. The 1990 JAI was less than five, so one would expect the estimated models to resemble the random walk model, or to be of the form

$$y_t = \Phi_1 y_{t-1} + a_t$$

where Φ_1 would not be significantly different from unity. However, model (1) differs from the random walk model in two ways. First, the AR1 coefficient (0.86) is significantly different from unity at the 5% level as well as significantly different from zero. Consequently, even though the flow changed slowly from day to day, as indicated by the positive AR1 coefficient, the effect represented by the AR1 term is that the flow today would be approximately 0.86 of the flow yesterday, all other things equal. Successive daily flows are positively related but the first differences are not random. Second, the model includes a moving average term at lag 21. That is, the flow at time *t* is associated with whatever random shock occurred 21 days prior to time *t*. There is no interpretation that we know of which would account for this pattern. The best interpretation is coincidence or that the true lag is seven, which is showing up at the harmonic value 21. Nevertheless, the relationship is present and serves to differentiate the model for the entire period from the random walk model.

When the model is estimated from the Negotiated Period data, the period in which the Corps and Virginia Power attempt to stay within the recommended Q_1-Q_3 limits, another story emerges. In this instance, the estimated model (2) is *not* significantly different from a random walk model. That is, the estimated coefficient 0.97 is not significantly different from unity. Since flow augmentation typically occurs during the Negotiated Period, finding the short period model to be a random walk is not particularly surprising.

In summary, the ARIMA models estimated during the two periods are different from one another, and the model estimated for the entire March-June time frame is not the random walk model, which we suggested in 1989 characterized the typical bad recruitment year. However, the model estimated during the Negotiated Period from 1 April to 15 June is, for all intents and purposes, a random walk model. Since all of the striped bass eggs spawned during 1990 were collected during the Negotiated Period, and since the flow during this time period is essentially a random walk, it is not surprising that the JAI was again well below five.

Autoregression Analysis

The model for the autoregression analysis of the daily data is of the form

$$y_t = a + \Sigma m_i M_i + \Sigma d_i D_i + \Sigma a_i e_{t-i} + e_t$$

where y_t is average daily flow on day *t*, M_i is a zero-one variable indicating three of the four months (March, April, and May) or two of the three months (April, May) in the particular data set, and D_i is a zero-one variable indicating six of the seven days of the week (all but Sunday).

The m_i and d_i are estimated regression coefficients and e_t is the model residual which is white noise. The e_{t-i} and the associated coefficients a_{t-i} represent the autoregressive scheme present in the residuals of ordinary least squares analysis of the data. As stated above, unless these effects are explicitly included in the model, the coefficients m_i and d_i will be inefficient and biased, respectively. As usual with zero-one dummy variables, a coefficient which is significantly different from zero indicates a situation where the flow in that particular month or on that particular day is significantly different from that of the base month or day. The base month for this analysis is June; the base day is Sunday.

The form of the autoregressive model for the hourly data is

$$y_t = a + \Sigma m_i M_i + \Sigma d_i D_i + \Sigma h_i H_i + \Sigma a_i e_{t-i} + e_t$$

where the definitions are the same as those given above and the H_i are the hours of the day and h_i the coefficients of the dummy variables representing the hours.

Table 42 shows the computed coefficients for the autoregression model estimated from the daily data for the entire March to June period. The first column shows the variable names. The remaining columns show the value of the coefficient, the coefficient's standard error and the t ratio associated with the particular statistic.

Table 42. Coefficients of the autoregression model for daily average data 1 March - 30 June 1990 (R^2=0.72).

Variable	Value	Std. Err.	t ratio	Prob > t
Intercept	9035	2837	3.19	0.00
MON	2071	797	2.60	0.01
TUES	3770	1033	3.65	0.00
WED	4434	1124	3.95	0.00
THURS	5133	1119	4.59	0.00
FRI	4721	1024	4.61	0.00
SAT	2395	812	2.95	0.00
MAR	-319	3721	-0.09	0.93
APR	2611	3431	0.76	0.45
MAY	-274	2901	-0.09	0.92
A(1)	-0.83	0.054	15.34	0.00

Table 43 shows the same information for the Negotiated Flow Period of 1 April to 15 June 1990.

For the entire period, the t values indicate that the coefficients for Monday through Saturday are significantly positive, indicating that flows on these days were significantly above the base day of Sunday. No monthly coefficients were significantly different from zero and there was significant autocorrelation at lag one in the least squares residuals. The model explained 72% of the variation in flows over that period.

For the shorter period, 81% of the variation was explained by the model. Again, no monthly coefficients were significant and the coefficients for Tuesday through Saturday were significantly positive. Thus, in both periods, average flows were higher on days other than

Table 43. Coefficients of autoregression model for daily average data for period 1 April - 15 June 1990 ($R^2 = 0.81$).

Variable	Value	Std. Err.	t ratio	Prob > t
Intercept	12576	2999	4.19	0.0001
MON	1105	710	1.56	0.1243
TUES	2490	932	2.67	0.0095
WED	2637	1020	2.59	0.0119
THURS	3019	1027	2.94	0.0045
FRI	2674	945	2.83	0.0062
SAT	1744	739	2.36	0.0212
APR	133	3173	0.04	0.9666
MAY	-1501	2508	-0.60	0.5515
A(1)	-0.89	0.06	-15.05	0.0001

Sunday than they were on Sunday. This is a typical pattern and most likely results from a greater demand for electricity during the week and a desire to stabilize lake levels on weekends. Differences between 1990 and the previous years include the facts that more weekday flows are significantly above Sunday's flow in 1990 than in the previous two years and that Saturday's flow was significantly above that of Sunday. Both of these results are probably related to the very high level of precipitation which occurred during the spring of 1990.

Figure 52 compares the patterns and the magnitudes of the daily coefficients shown in Tables 44 and 45. It is interesting to note that the fluctuations were not as extreme during the Negotiated Period as they were during the entire period, although the basic pattern was present. This indicates some success in mitigating the intraweek variability of the flows and hence the River and lake levels as a result of their efforts.

Table 44 shows the results of estimating the hourly autoregression model for the entire period. The model explains 97% of the total variation in hourly flows. None of the coefficients for the monthly variables is significantly different from zero. However, unlike the analysis of the data for 1988 and 1989, analysis of the 1990 hourly data from the entire period shows that the variables for the days Tuesday to Friday are significantly different from zero. One conclusion of the autoregression analysis of the 1988 and 1989 data was that the variation within the days was large enough to completely mask the variation among the days during those years. This evidently is not the case for the long period in 1990.

The most dramatic feature of the analysis of the hourly flows in the 1990 report was the persistent pattern of flows which mimicked the daily electricity demand. That pattern is a relatively low demand from midnight to early morning, followed by increasing demand until a peak is reached in the late afternoon or early evening. Demand then declines again throughout the night. The hourly coefficients estimated for the long period again show this pattern. Noting that the reference hour is 12:00 midnight to 1:00a.m., the hourly coefficients are significantly negative from 1:00a.m. to 4:00a.m., not significantly different from zero from 5:00a.m. to 5:00p.m. and then they are significantly positive. Thus, relative to midnight, the flow falls until about 3:00a.m., rises until early afternoon, and then declines.

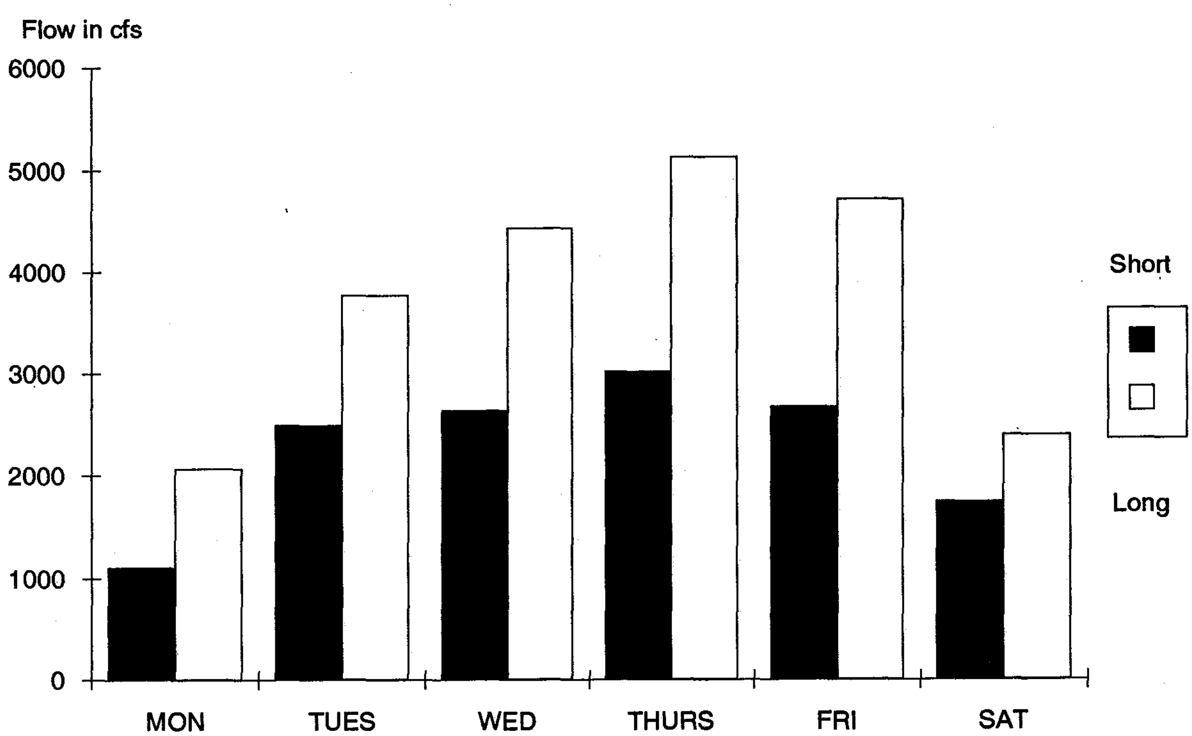


Figure 52. Daily coefficients from Negotiated Period (short) and the full regime (long) daily values.

Table 44. Estimated coefficients of the autoregressive model for hourly data, 1 March - 30 June 1990 (R^2=0.97).

Variable	Value	Std. Err.	t ratio	Prob > t
Intercept	11950	1899	6.29	0.00
MON	371	207	1.79	0.07
TUES	727	270	2.70	0.01
WED	895	294	3.05	0.00
THURS	922	294	3.14	0.00
FRI	775	267	2.90	0.00
SAT	190	212	0.90	0.37
MAR	-520	1537	-0.34	0.73
APR	593	1271	0.47	0.64
MAY	-112	920	-0.12	0.90
ONE	-248	110	-2.25	0.02
TWO	-493	186	-2.65	0.01
THREE	-601	240	-2.50	0.01
FOUR	-562	279	-2.01	0.04
FIVE	-394	309	-1.28	0.20
SIX	-96	331	-0.29	0.77
SEVEN	264	347	0.76	0.45
EIGHT	430	357	1.21	0.23
NINE	554	361	1.53	0.13
TEN	657	363	1.81	0.07
ELEVEN	673	363	1.85	0.06
TWELVE	434	363	1.20	0.23
THIRTEEN	353	363	0.97	0.33
FOURTEEN	321	363	0.88	0.38
FIFTEEN	331	362	0.92	0.36
SIXTEEN	490	357	1.38	0.17
SEVENTEEN	822	347	2.37	0.02
EIGHTEEN	931	331	2.81	0.01
NINETEEN	908	309	2.94	0.00
TWENTY	716	280	2.56	0.01
TWO-ONE	645	240	2.68	0.01
TWO-TWO	423	187	2.26	0.02
TWO-THREE	202	111	1.81	0.07
A(1)	-1.45	0.02	-79.05	0.00
A(2)	0.69	0.03	22.13	0.00
A(3)	-0.21	0.02	-8.82	0.00
A(4)	0.12	0.02	5.11	0.00
A(5)	-0.12	0.02	-5.31	0.00
A(6)	0.09	0.02	4.04	0.00
A(7)	-0.07	0.02	-4.21	0.00
A(8)	0.06	0.02	3.35	0.00
A(9)	-0.09	0.02	-4.04	0.00
A(10)	0.06	0.02	2.56	0.01
A(11)	-0.05	0.02	-2.83	0.00

Table 45. Estimated coefficients for autoregressive model of hourly data for Negotiated Period, 1 April to 15 June 1990 (R^2=0.99).

Variable	Value	Std. Err.	t ratio	Prob > t
Intercept	13564	2192	6.19	0.00
MON	34	48	0.71	0.48
TUES	31	63	0.49	0.63
WED	42	69	0.61	0.54
THURS	72	70	1.03	0.30
FRI	79	64	1.24	0.22
SAT	13	50	0.25	0.80
APR	181	254	0.72	0.47
MAY	-6	179	-0.03	0.97
ONE	-7	30	-0.22	0.82
TWO	-21	55	-0.38	0.71
THREE	-7	75	-0.09	0.93
FOUR	1	93	0.01	0.99
FIVE	20	108	0.19	0.85
SIX	54	120	0.45	0.66
SEVEN	119	130	0.91	0.36
EIGHT	169	139	1.22	0.22
NINE	173	145	1.19	0.23
TEN	170	149	1.14	0.25
ELEVEN	141	152	0.93	0.35
TWELVE	140	152	0.92	0.36
THIRTEEN	193	152	1.27	0.20
FOURTEEN	236	149	1.59	0.11
FIFTEEN	304	145	2.10	0.04
SIXTEEN	343	139	2.48	0.01
SEVENTEEN	328	130	2.52	0.01
EIGHTEEN	311	120	2.59	0.01
NINETEEN	271	108	2.52	0.01
TWENTY	224	93	2.41	0.02
TWO-ONE	178	75	2.36	0.02
TWO-TWO	96	55	1.75	0.08
TWO-THREE	36	31	1.19	0.24
A(1)	-1.72	0.02	-72.72	0.00
A(2)	0.78	0.04	17.45	0.00
A(3)	-0.06	0.03	-2.13	0.03
A(4)	0.02	0.02	1.34	0.18
A(5)	-0.02	0.01	-1.41	0.16

Table 45 shows the results of modeling the hourly data for the Negotiated Period. The percent of the variance explained was 99%. There were no daily or monthly coefficients which were significantly different from zero for the Negotiated Period. For the short period, the coefficients representing the hours of 3:00 p.m. to 9:00 p.m. were significantly positive.

Figure 53 compares the hourly coefficients from both periods. The coefficients are low relative to the midnight hour in the early morning and rise to a peak in the afternoon/evening hours. This reflects the typical daily cycle in electricity demand during the warm months. Briefly, that pattern is low demand from midnight until the early morning followed by increasing demand until late evening with a peak around 4:00 p.m. - 6:00 p.m. Thus, relative to the base midnight hour, flows would decline and then rise to a peak and then decline again. This is exactly the pattern observed in the coefficients from both the longer and the shorter period. Thus, in terms of overall pattern, the coefficients estimated from both periods are similar.

Two dissimilarities also exist, however. First, the coefficients for the short period are generally much smaller than those for the longer period (note that the short period coefficients are referred to the right-hand axis in Figure 53). Second, there are no significantly negative early morning coefficients during the short period. Thus, statistically speaking, from 12:00 midnight until 3:00 p.m., the flows in the short period remained constant. It is only from 3:00 p.m. to 9:00 p.m. that the flows were significantly above the midnight reference hour. For the entire period, the fluctuation in the flows went from 600 cfs below the midnight norm to 1,000 cfs above during the average 24-hour period. However, when the analysis is confined to the shorter period, the fluctuation is from 0 (equal to the midnight hour) to 350 cfs above that flow. Thus the average fluctuation when the entire period is considered is approximately 1,600 cfs daily; during the Negotiated Period it is only 350 cfs. This indicates a substantial reduction in daily fluctuation when compared to the March through June period.

Kerr Reservoir Operation in Hindsight

Max Grimes

The Corps of Engineers operated John H. Kerr Reservoir to meet the Negotiated Flow Regime and maintain Congressionally authorized project purposes to the maximum extent possible during the 1990 fish flow season. Abnormally high rainfall and inflow to Kerr Reservoir occurred during much of the spawning season (Figure 51). The average outflow from Roanoke Rapids Dam for the entire fish spawning season was 14,300 cfs. Daily releases from Roanoke Rapids Dam as computed by USGS (within $\pm$ 10 percent standard accuracy) were within the range of flows recommended in the negotiated plan 31 days out of a possible 76 days or 41% of the time. *[Editors' Note: Other Flow Committee members have calculated the percentage of days within Q_1 - Q_3 using absolute values as per the FERC policy of using only absolute values to stay within license requirements. Thus, the number of days within for 1990 was 20 of 76, or 26.1% (see Hydrology Section for 1990)].*

In summary, the 1990 fish season was probably too wet to be able to judge the effectiveness of the flow regime.

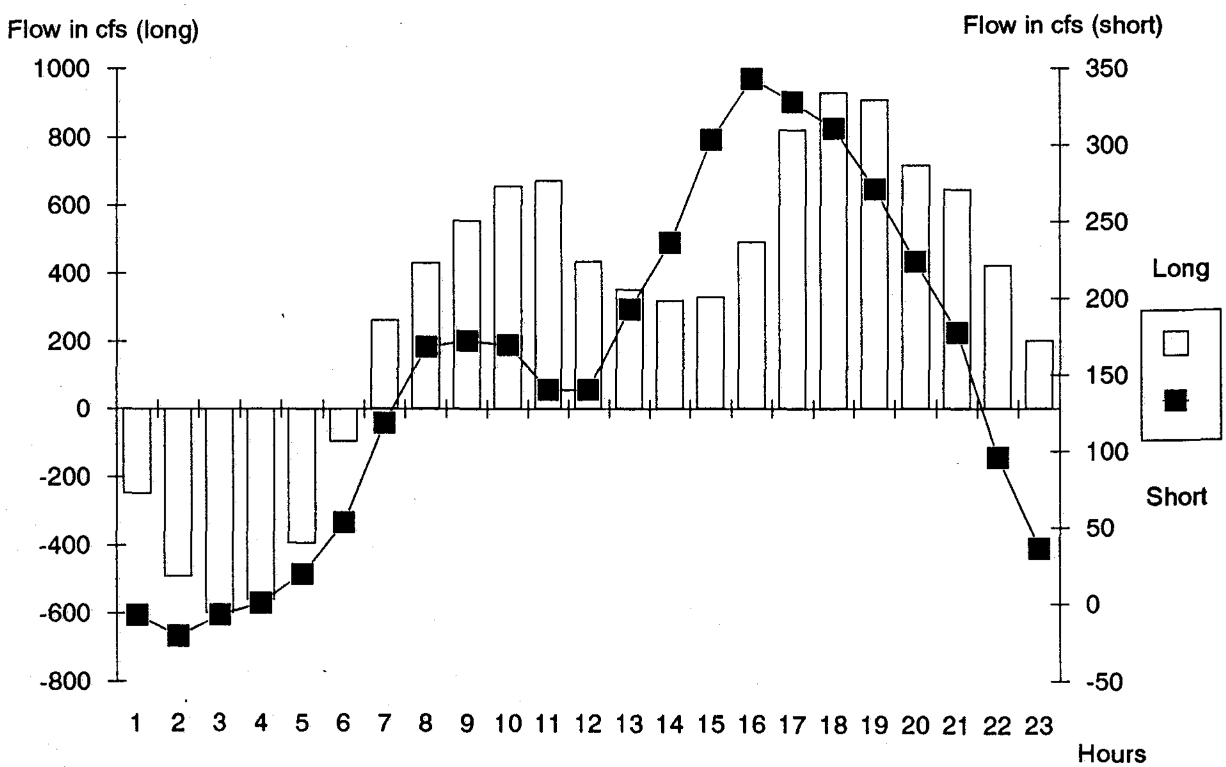


Figure 53. Hourly coefficients from the Negotiated Period (short) and the full regime (long).

WATER QUALITY, 1990

Robert M. Herrmann and Roger A. Rulifson

In 1990, water quality was monitored at several locations downstream of the Roanoke Rapids Dam similar to those sites used in 1988. The work was a cooperative effort by Weyerhaeuser Company and East Carolina University's Institute for Coastal and Marine Resources. The most upstream location was Barnhill's Landing (RM 117), which was the site for the 1990 striped bass egg production and viability study by Rulifson. In 1988, the water quality site was Pollock's Ferry (RM 105). Downstream sites within the Roanoke mainstem and delta were the same in 1988 and 1990; Station 6 in Middle River; Station 7 in the Roanoke just above Weyerhaeuser's diffuser pipe; Station 10 downstream of Plymouth near the Highway 45 bridge; and Station 8 in the Cashie River just upstream of the Highway 45 bridge (Figure 54). Following is a comparison of water quality data between years at these locations.

In 1988, River flows remained within the target range of the Flow Committee's recommendations through the end of May and exceeded the range in June. Maintaining River flow within this range should result in higher concentrations of metals and total suspended solids (TSS), except for parameters related to swamp flooding. Flooding of the swamp would increase some parameters such as color and total organic carbon (TOC).

In 1990, River flows in April were within the Flow Committee's target range, but in May the flows exceeded the target maximum. The higher flow should have resulted in lower concentrations of most environmental variables except those related to swampland flooding.

Pollock's Ferry/Barnhill's Landing, 1988 vs 1990

Average values for solids and turbidity were higher in 1988 when stream flow was lower and more stable. However, carbon was higher in 1990, presumably due to swamp input with higher runoff. Average values of nitrogen and phosphorus species except for NO2/NO3-N were higher in 1988 with less flow. Nitrate (and sulfate) were higher in 1990, perhaps due to atmospheric inputs rather than swamp inputs, which would have appeared as reduced forms of N and S. Nine metals were compared. The average concentrations of eight were higher in 1988, the year with more moderate and stable River flow. The average concentration for barium (Ba) was the same in both years (Table 46).

Plymouth Area Stations

Two stations showed consistent differences from each other, and from the other two stations, in both years: Station 10 (Highway 45 bridge) and Station 8 (Cashie River). Color, TKN, NH_3-N, SO_4, Ca, and Na were higher at Highway 45 due to the Plymouth mill wastewater discharge. The mill effluent is highly colored and contains $NaSO_4$ and calcium from the wood pulping process. Also, NH_3 is added to the treatment system to promote biological oxidation of the mill effluent. At the Cashie station, several water quality variables were affected by the swamps that border the stream for most of its length. Alkalinity, calcium, and SO_4 were lower, while carbon was higher (Table 46).

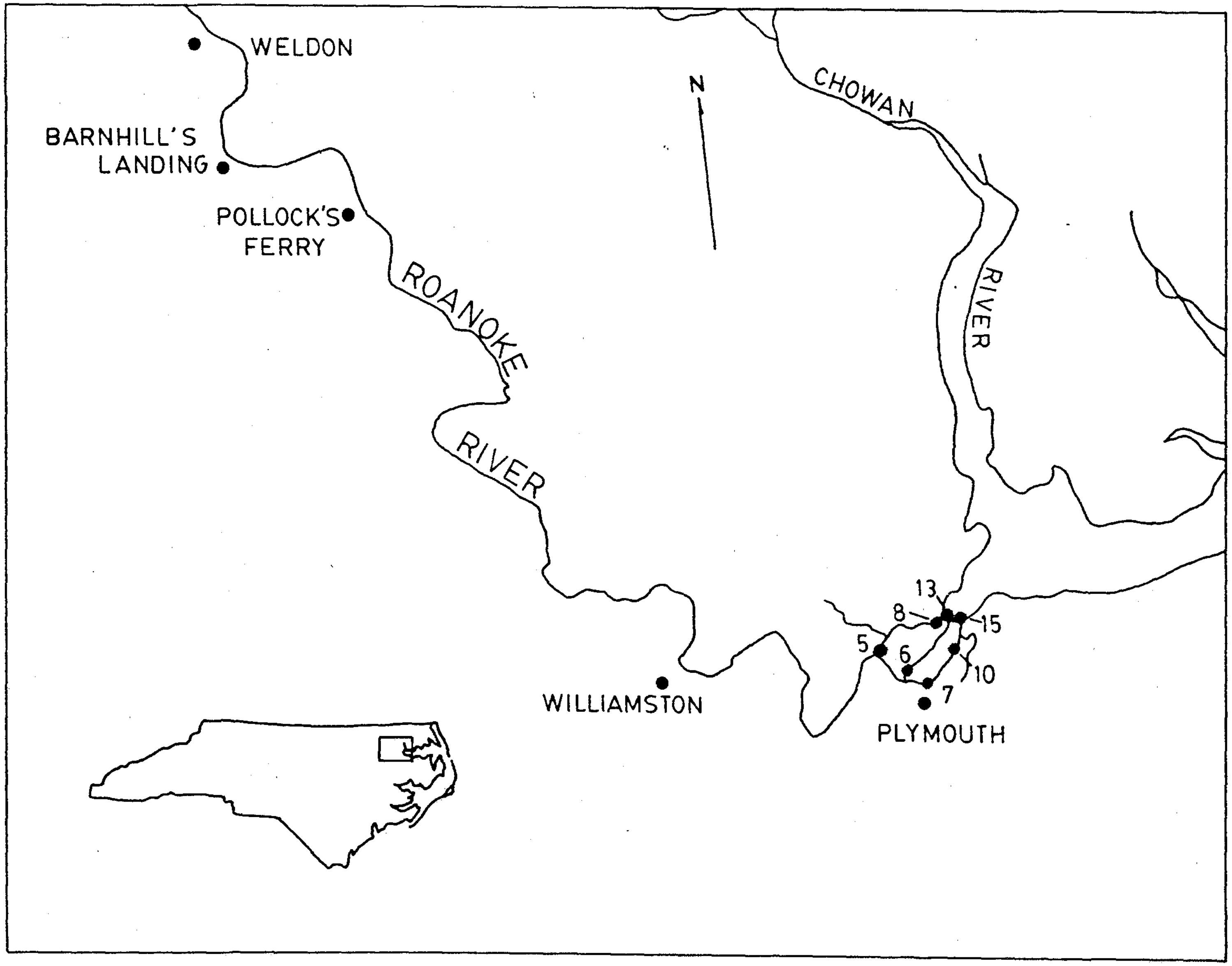


Figure 54. Lower Roanoke River and western Albemarle Sound depicting the sampling locations for water quality (this study).

Table 46. Scotland Neck and Plymouth area stations water quality comparisons.

Water quality parameter	1988 Comparisons Scotland Neck	1988 Comparisons Plymouth	1990 Comparisons Scotland Neck	1990 Comparisons Plymouth
pH	7.6	7.4		7.2
Alkalinity	27	25	26	27
Color	22	51.3	22	52
Turbidity	12.3	19.3	9.4	18.0
TSS	13.8	19.4	8.8	17.2
VSS	2.5	3.4	1.9	2.7
BOD	1.3	1.2	1.0	1.3
TOC	6	14	8	9
SOC	4	10	6	8
TKN	0.33	0.51	0.3	0.49
NH_3N	0.06	0.10	0.04	0.08
NO_2/NO_3N	0.15	0.18	0.2	0.21
TPO_4P	0.15	0.17	0.11	0.15
OPO_4P	0.05	0.07	0.06	0.07
SO_4	11.7	10.7	18.3	25.2
Al	0.49	0.77	0.35	0.54
Ba	0.02	0.03	0.02	0.03
Ca	6.68	6.62	5.97	5.80
Fe	0.62	1.27	0.48	1.13
K	2.23	2.36	2.02	2.12
Mg	2.79	2.74	2.71	2.70
Mn	0.05	0.09	0.04	0.08
Na	8.99	10.45	7.08	7.61
Zn	0.02	0.03	0.01	0.01

For solids-related parameters in the Plymouth area, both TSS and metals were higher in 1988, the lower flow year. During the higher flows in 1990, alkalinity, nitrate, and sulfate were higher than 1988 values.

Pollock's Ferry - Plymouth Area Comparisons

For both years, the average values of nearly all water quality parameters were higher in the Plymouth area compared to Pollock's Ferry, most notably TKN, NH_3N, and such metals as Al, Fe, K, and Na (Table 46). Calcium was an exception to the trend. Several of the higher average values observed at Plymouth were the result of traces of pulp mill effluent in waters sampled at Station 10: TKN, NH_3N, and Na. Other higher parameters such as color, Al, and Fe at the downstream stations may be from swamp drainage. Low average values for solids at the upstream station may be due to settling in the upstream reservoirs.

SEDIMENT QUALITY IN THE LOWER ROANOKE RIVER BASIN

Stanley R. Riggs and John T. Bray

Increased human activity contributes ever increasing amounts of suspended sediment and chemical pollutants to the Roanoke River and Albemarle Sound estuarine system, resulting in increased potential bioavailability of specific toxic elements. The 1989 population within the lower Roanoke River Basin alone was 140,315 people. Along with this are 17 NPDES waste water discharge permits within the lower River with a total design flow of 109 million gallons of waste water per day (see Table 6, page 39). 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. Some of these 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 critical trace elements from various anthropogenic point and nonpoint sources into coastal waters leads to significant pollution problems within North Carolina estuarine environments (Riggs et al. 1989; 1990). 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 critical 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. This basin-wide assessment of heavy metal and other critical trace element pollution is prerequisite for future management plans and decisions concerning water quality improvement within our estuarine environments.

Our US EPA/NC DEHNR funded study entitled "Heavy Metal Pollutants in Organic-Rich Muds of the Albemarle Sound Estuarine System" is part of the Albemarle-Pamlico Estuarine Study for North Carolina (Riggs et al. in prep.). A regional sampling grid was developed within the lower Roanoke River and entire Albemarle Sound estuarine area that included 178 short core (<0.5 meters), 19 long core (<6 meters), and 22 surface sample sites. These 219 sites represent all possible geographic and geologic conditions, as well as major anthropogenic sources of pollutants throughout the Albemarle system. From these cores, 378 subsamples have been completely processed and analyzed in the sediment and analytical laboratories for grain size, sediment composition, and chemical analyses for 30 major, minor, and trace elements. Results of both the sediment and chemical data are presently being statistically analyzed and synthesized. Consequently, only a few very preliminary conclusions can be presented at this point in time.

The Roanoke River and Welches Creek area west of Plymouth is the location of one of the largest wood products facilities in the world. This industrial site has been operating since 1938 and today consists of 1200 acres, 750 of which accommodates the industrial waste ponds with discharge of all waste water into Welches Creek, until recently. Waste water is now discharged directly into the Roanoke River through a diffuser pipe across the River bottom between the plant site and the mouth of Welches Creek. Durway (1986), in a site inspection report for North Carolina, described three on-site areas where hazardous substances are, or in the past have been generated or disposed of and include the following:

1. The wood treatment plant, operating since 1979, produces chromated copper arsenate sludge as a byproduct material at the rate of 2200 pounds per month. This material is stored in drums and removed from the site for disposal.

2. The old chlorine building, operated from 1958 to 1968, generated 11,000 pounds of spent graphite electrodes and marble cells as a result of chlorine production. This waste contains an estimated 57 pounds of mercury, all of which was disposed of in the old on-site landfill below.

3. The old landfill is situated on a 35- to 50-acre tract of low wetland and was used until 1979 when it was sealed.

The sediments within Welches Creek, a lateral tributary to the Roanoke, are significantly enriched in six elements (Cr, Hg, Ni, Cu, V, and Zn) at multiple sampling stations (Riggs et al. in prep). Chromium, mercury, and nickel enrichments are extremely high (from 10 to 100 times the background levels for all of Albemarle Sound). Four elements (Hg, Cr, As, and V) are also significantly enriched in a few samples within the Roanoke River itself, however at considerably lower concentrations (2 to 10 times the background levels) than in Welches Creek. Many sediment samples from the Roanoke River, Middle River, Cashie Creek, and Welches Creek have significantly enriched levels of manganese, titanium, and cobalt (from 2 to 10 times background). We are still in the process of evaluating these Roanoke River data, as well as the remaining data for all of Albemarle Sound estuarine system (Riggs et al. in prep.).

STRIPED BASS, 1990

Age Composition and Sport Harvest from the Roanoke River (1988-1990)

Kent L. Nelson

Methods

A non-uniform probability stratified access point creel survey was used to estimate sport fishing effort and harvest of striped bass (*Morone saxatilis*), largemouth bass (*Micropterus salmoides*), and other species from Roanoke River during the striped bass spawning season. The number of striped bass released by sport anglers also was estimated. The creel survey was designed by the N.C. State University Institute of Statistics and was conducted in 1988, 1989, and 1990.

The creel survey was conducted throughout the unimpounded reach of the Roanoke River from Roanoke Rapids Lake Dam downstream to the River's mouth at Albemarle Sound, comprising a surface area of approximately 3,016 ha (Fish 1968). The River was divided into 3 zones with the upper 2 zones (I and II) comprising the segment designated as inland waters (Figure 56). 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). The creel survey was conducted from 28 March - 19 June in 1988, 27 March - 18 June in 1989, and 26 March - 9 May in 1990. The harvest of striped bass was prohibited by regulation after 9 May in 1990 and harvest estimates were based only on 6.5 weeks, as compared to 12 weeks in 1988 and 1989. Creel survey design was based on 12 weeks divided into six two-week periods. The creel survey was stratified with respect to type of day, i.e., weekday or weekend (defined as all Fridays, Saturdays, Sundays, and Memorial Day), zone, and period. Probabilities of sampling the respective stratifications were assigned based on anticipated fishing effort.

Two [creel] clerks interviewed anglers returning from fishing trips at 16 selected boating access areas to provide data necessary to calculate catch per unit of effort. Probabilities of sampling (interviewing) at each respective access area were assigned based on its anticipated use by striped bass anglers relative to the others. Probabilities of sampling within each zone during each period were assigned based on migration patterns of spawning striped bass. Data collected from each fishing party interviewed included date and time of the interview, time fished, number in the party, catch of striped bass, largemouth bass and other species, and the county of residence of the anglers. All data were recorded on an interview form.

Total fishing effort was estimated from counts of empty boat trailers at boating access areas along the River. Counts were made on two weekdays and two weekend days per week. The end of the River at which the trailer counts began were selected randomly, and the times of day during which trailers were counted were selected based on probabilities of anticipated fishing activity. The trailer counts and relevant data were recorded on field sample sheets.

In 1989, procedures were modified slightly to improve accuracy of estimates for total fishing pressure. Trailer counts in 1989 were adjusted to eliminate non-sport fishermen, which included commercial fishermen, hunters, and recreational boaters. Data were adjusted based on the proportion of recreational fishermen observed by the creel clerk within each zone by period and kind of day. In addition, two minor access areas were deleted (one each in 1989 and 1990) and one was added in 1989.

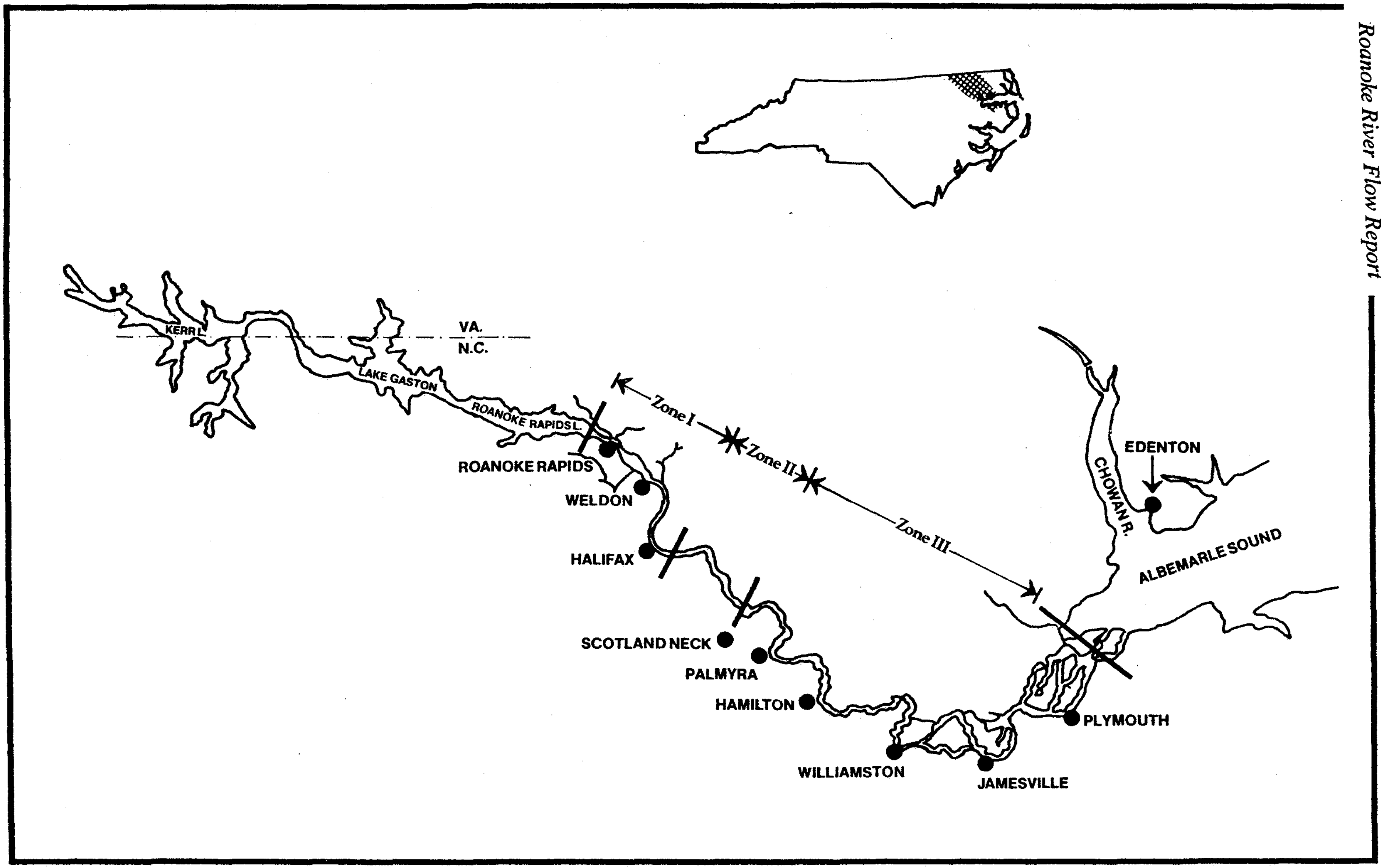


Figure 56. Roanoke River and vicinity depicting the three study zones for the striped bass creel survey in 1988-1990.

Total length (millimeters), weight (kilograms), and sex were recorded and a scale sample was collected from 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 Micro Design Model 995 microfiche reader, and ages were determined by counting annuli. A proportion of the scales did not have an annulus at the margin. One year was added to the age of these fish, based on a standardized 1 January birth date.

Estimates of fishing effort and catch of striped bass were compiled by the N.C. State University Institute of Statistics. The number of fish caught in each age class by sex and the average size were compared to previous data to evaluate changes in the age composition of the spawning striped bass population. Length-frequency distributions of male and female striped bass were compared for the three years with the Kruskal-Wallis test ($\alpha = 0.05$) and between years with the Dunn's multiple comparison procedure ($\alpha = 0.05$) (Hollander and Wolfe 1973).

Results

An estimated total of 234,621 (1988), 153,185 (1989), and 106,073 (1990) angler-hours of sport fishing effort were exerted by Roanoke River anglers *for all species* during the spring creel survey. Estimated effort and harvest were based on 12 weeks in 1988 and 1989 and 6.5 weeks in 1990. Most of the effort occurred in Zone III: 70% (1988), 66% (1989), and 59% (1990) (Figure 56). Nineteen percent (1988), 28% (1989), and 35% (1990) of the effort occurred in Zone I, while 11% (1988) and 6% (1989 and 1990) was found in Zone II.

Table 47. Fishing effort (angler-hours) exerted specifically for striped bass on the Roanoke River in spring 1988-1990 by zone and period (2-week intervals beginning March 28 (1988), 27 (1989), and 26 (1990)).

Zone or Period		Angler-hours					
		1988	%	1989	%	1990	%
Zone							
	I	40,151	40.16	36,542	78.47	32,976	58.71
	II	18,381	18.38	2,913	6.26	4,847	8.63
	III	41,449	41.46	7,110	15.27	18,346	32.66
Period							
	1	17,897	17.90	685	1.47	5,291	9.42
	2	18,850	18.85	13,208	28.36	26,008	46.30
	3	17,014	17.02	11,925	25.61	24,870 [a]	44.28
	4	38,498	38.51	11,694	25.11	-	
	5	5,833	5.83	4,795	10.30	-	
	6	1,889	1.89	4,259	9.15	-	
Total		99,981		46,566		56,169	

[a] Estimate based on 17 days

Approximately 100,000 (1988), 46,600 (1989), and 56,200 (1990) angler-hours of recreational fishing effort were directed *specifically for striped bass* (Table 47). Most of the striped bass effort in 1988 was exerted near the spawning grounds (Zone I) and the lower river (Zone III). In 1989 and 1990, however, most effort (78% and 59%) was concentrated in Zone I. Effort for striped bass peaked in 1988 during Period 4 (9-22 May), at and slightly after the peak of striped bass spawning activity. In 1989, greatest effort occurred in about equal proportions between 10 April - 21 May (Periods 2-4). In 1990, effort for striped bass was greatest during Period 2 and 3 (9 April - 6 May) and continued until the end of the season on 9 May.

Estimated harvest of striped bass from the Roanoke River (Figure 57; Table 48) was 16,657 fish in the spring of 1988, 8,753 in 1989, and 15,694 in 1990. Total weights harvested were estimated at 33,927 kg (74,796 lb) in 1988, 14,594 kg (32,174 lb) in 1989, and 19,143 kg (42,204 lb) in 1990 (Table 48; Figure 58). The number of fish harvested was highest in Zone I during all three years. Most of the estimated harvest by weight in 1988 occurred in Zone I (45%) and III (50%), while in 1989 and 1990 most weight was taken in Zone I (96 and 62%). About 9,000 striped bass were caught and released in both 1988 and 1989. In 1990, almost 52,400 stripers were estimated released. Numbers of caught and released, and kept fish combined was highest in Zone I: 65% (1988), 98% (1989), and 88% (1990).

Striped bass harvest and the number of striped bass released was highest during Period 4 in 1988 and period 3 in 1989 and 1990 (Figure 57). Estimated striper catch was higher during the periods prior to the spawning peak than after it. The catch fell to very low levels in late May and June in 1988 and 1989.

The overall success rate for striped bass harvest by sport fishermen was 0.08 fish and 0.15 kg per angler hour (1988), 0.06 fish and 0.10 kg per hour (1989), and 0.16 fish and 0.19 kg per hour (1990). Harvest rates were greatest in Zone I during the study with anglers harvesting 0.20 fish and 0.34 kg per hour (1988), 0.19 fish and 0.31 kg per hour (1989), and 0.33 fish and 0.35 kg per hour (1990). Striped bass were caught and released at the rate of 0.17 (1988), 0.19 (1989), and 1.31 (1990) fish per angler-hour in Zone I.

More people from Halifax County fished in the Roanoke River during the creel survey than from any other county (Figure 59). Relatively few of the fishing parties interviewed were residents of counties which border the downstream portion of Roanoke River. Approximately one-third of the people who fish in the Roanoke River in the spring do not live in a county adjacent to it.

A total of 908, 798, and 873 striped bass were aged in 1988, 1989, and 1990. Males comprised 77, 66, and 92% of the aged fish during the 3 years (Figure 60). Most of the males were 3, 4, and 5 years old while most of the females were between 4 - 8 years old. Few males over 8 years of age were caught and few females were over 9 years old. The youngest fish caught were 2 years old and were primarily males. About 4% of the females caught during the study were less than 4 years old (Figure 61).

Analyses indicated that the differences in male and female striped bass length-frequency distributions for the three years were significant ($P<0.05$). Significant differences were found between the distributions of females during 1988-1989 and 1988-1990 and males between all 3 years.

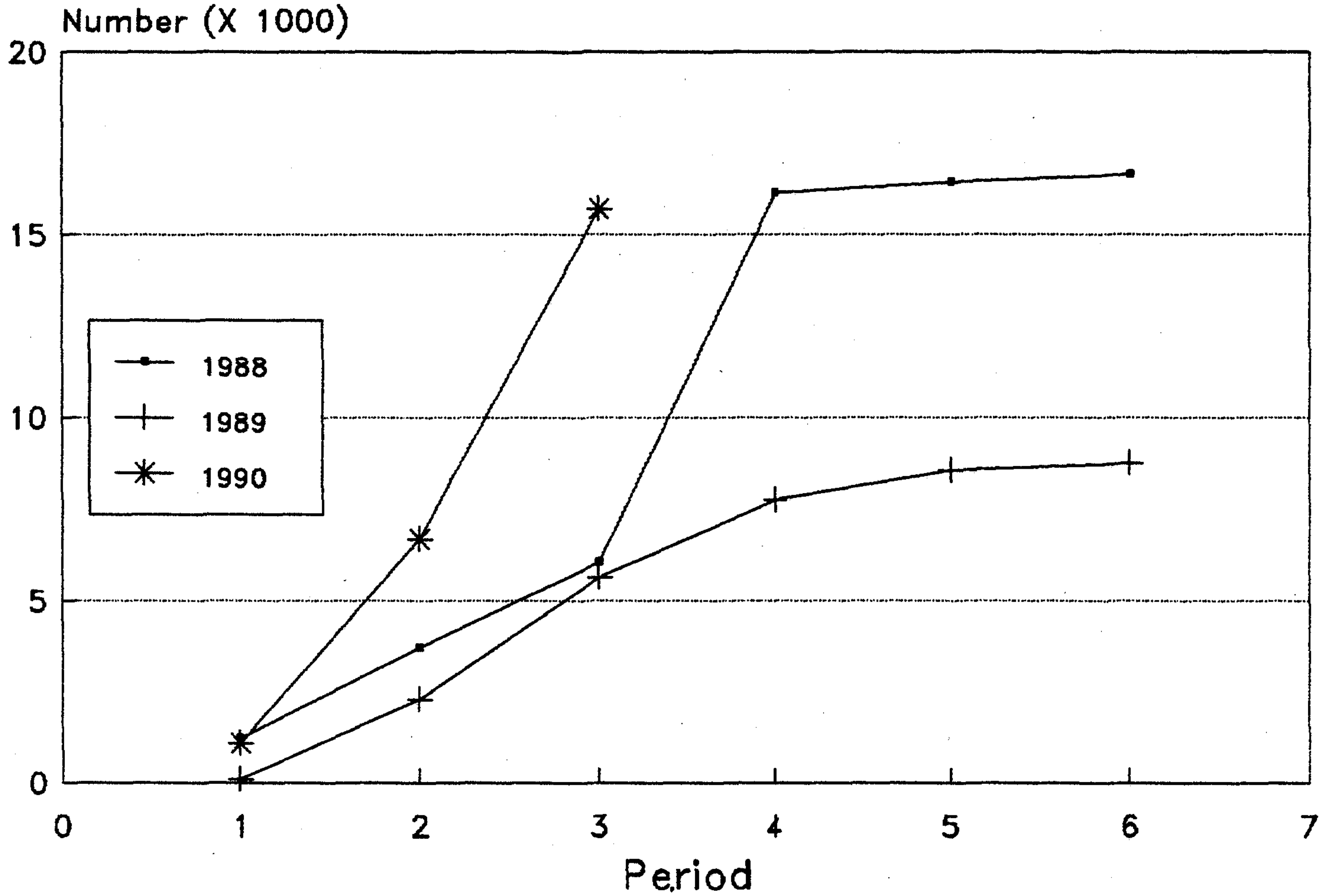


Figure 57. Estimated number of striped bass harvested from Roanoke River in spring 1988-1990 by period (2-week intervals, beginning March 28 (1988), 27 (1989), and 26 (1990)).

Table 48. Estimated catch of striped bass from Roanoke River in spring, 1988 - 1990 by zone. Standard errors are in parentheses.

	Harvested								
	Number			Weight(kg)			Number Released		
Zone	1988	1989	1990	1988	1989	1990	1988	1989	1990
I	8,827	8,473	11,407	15,355	14,085	11,867	7,682	8,590	48,475
	(2,660)	(2,404)	(3,553)	(4,542)	(3,938)	(3,557)	(3,242)	(2,282)	(20,552)
II	929	153	287	1,746	427	401	501	48	300
	(377)	(73)	(163)	(694)	(188)	(260)	(242)	(45)	(173)
III	6,901	127	3,999	16,826	82	6,875	715	28	3,597
	(6,987)	(59)	(2,892)	(17,465)	(34)	(5,221)	(612)	(30)	(2,913)
Total	16,657	8,753	15,694	33,927	14,594	19,143	8,898	8,666	52,372
	(9,736)	(2,355)	(4,829)	(21,861)	(3,891)	(6,890)	(4,040)	(2,312)	(23,441)

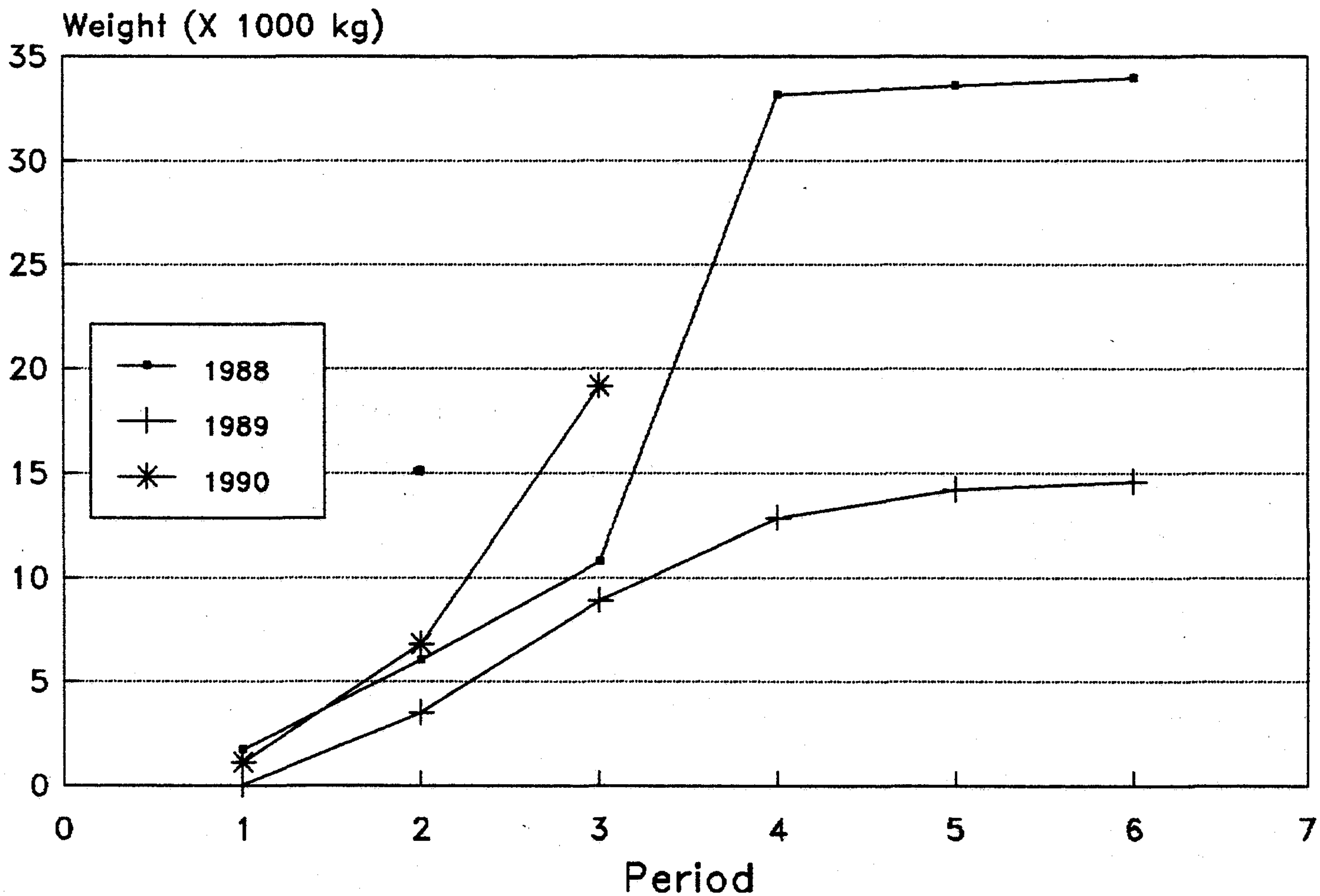


Figure 58. Estimated cumulative harvest (kg) of striped bass from Roanoke River in spring 1988-1990 by period (2-week intervals, beginning 28 March (1988), 27 (1989), and 26 (1990)).

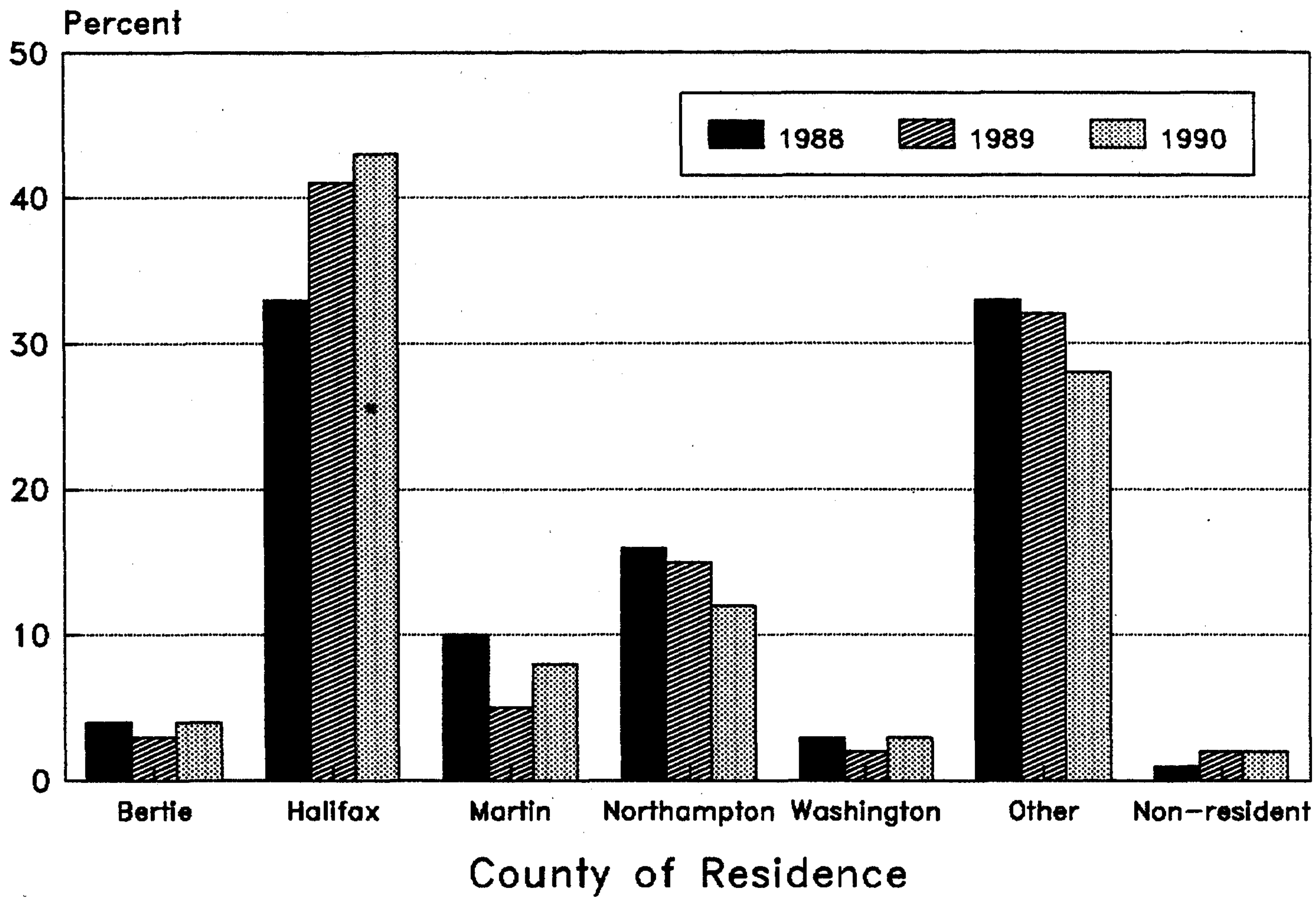


Figure 59. County residence composition (%) of anglers interviewed during the spring 1988-1990 Roanoke River creel survey.

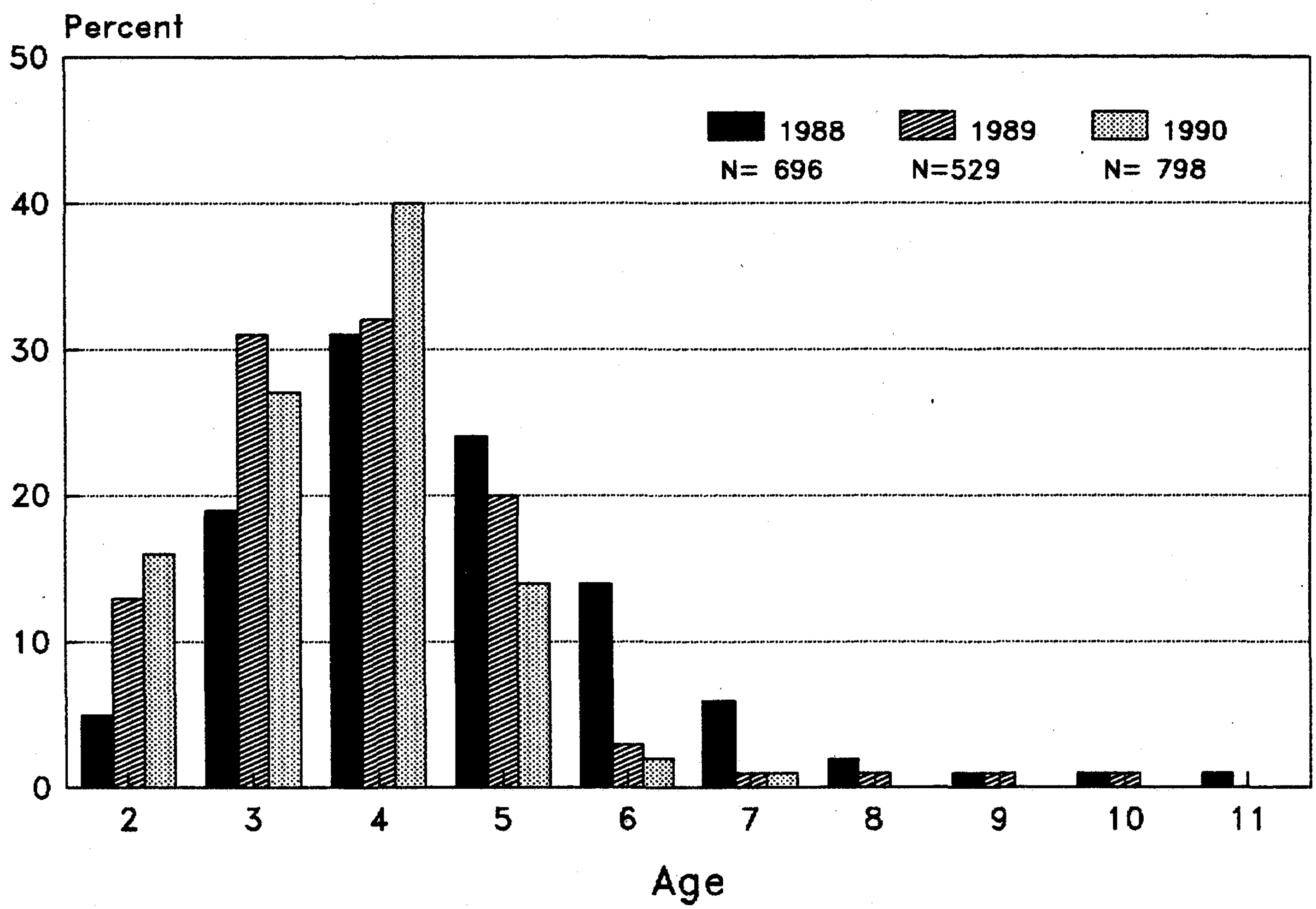


Figure 60. Percent by age of male striped bass harvested during spring 1988-1990 Roanoke River creel survey.

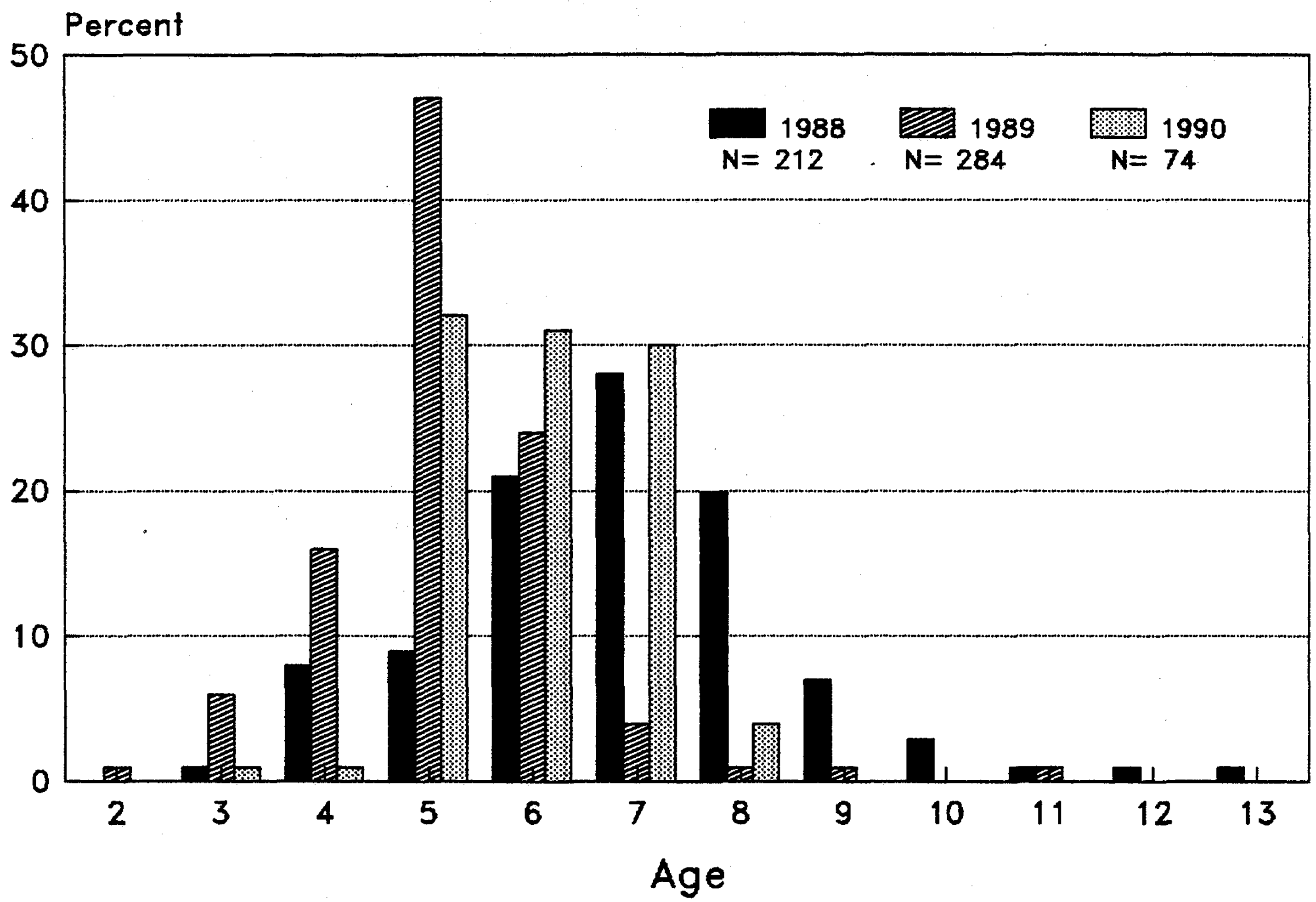


Figure 61. Percent by age of female striped bass harvested during spring 1988-1990 Roanoke River creel survey.

Discussion

An estimated 77.8 (1988), 50.8 (1989), and 35.2 (1990) angler-hours of sport fishing effort were exerted per hectare on the Roanoke River during the spring creel survey. In comparison, only 3.8 angler-hours of sport fishing effort were exerted per hectare per year on adjacent Albemarle Sound in the late 1970s (Mullis and Guier 1982). Albemarle Sound is an open water system with a relatively high proportion of area that is devoid of fish concentrating cover, while anadromous fishes are concentrated in the Roanoke River during their spawning migrations.

Approximately 119,000 angler-hours/year of effort were exerted specifically for striped bass on Albemarle Sound in the late 1970s (Mullis and Guier 1982). Effort during the spring of 1988 (approximately 100,000 angler-hours) approached this level, but declined in 1989 and 1990. Effort for striped bass was curtailed in 1990 due to season closure. Effort during the first three periods in 1990 was comparable to that found in 1988 (Table 47). The overall success rate for striped bass by sport fishermen in Albemarle Sound during the late 1970s averaged 0.018 fish per angler-hour, less than one-third of the rate at which stripers were caught from Roanoke River. Higher catch rates undoubtedly reflect increased vulnerability as fish are concentrated during the spawning run.

Hassler et al. (1981) estimated the sport harvest of striped bass from Roanoke River to be as high as 65,399 fish in 1971, but not less than 15,000 fish per year prior to 1981. However, the downward trend in harvest had been identified by 1981, and a series of restrictive regulation changes began that year. The regulation changes included the prohibition of special devices (e.g. bow nets) for catching striped bass in 1981, reduction of the daily creel limit from 25 to 8 fish in 1980 and further to three fish in 1985, and increasing the size limit from 305 mm (12 inches) to 406 mm (16 inches) in 1982. The estimated harvest ranged from about 4,000 to 7,000 fish from 1981 through 1984 (Hassler and Taylor 1984, 1986a). In 1985, the estimated harvest of 3,499 fish was the lowest on record (Hassler and Taylor 1986b), but a steady increase over the next two years brought the harvest to over 10,000 fish in 1987 (W.W. Hassler, N.C. State University, pers. comm.). Hassler's estimates and those from this study are not directly comparable because different methods of estimation were used. Estimated harvest of about 16,700 fish in 1988 and 15,700 in 1990 may not be significantly different from the mid 1980s harvest considering the standard errors (Table 48).

Estimates of the number of striped bass caught and released are not available for the period before restrictive regulations were imposed. It is assumed that most of the striped bass released were either under the legal size limit or in excess of the daily creel limit. This assumption is based on conversations with anglers during interviews and the lack of traditional voluntary catch and release practices in this fishery. The large increase in the number of released fish (52,000+) in 1990, as compared to about 9,000 in 1988 and 1989, was a result of the abundance of 2-3 year old males in the River. Harrell (1987) in a study of striped bass catch and release mortality found a total mortality of 16.4% for fish caught on bait (the preferred method on the Roanoke River) and held in ponds for two weeks. Mortality for controls captured by electrofishing was 10.4%. Mortality was 6.0% during October and February for fish caught on bait, and increased significantly for hooked and control fish at higher water temperatures in August. Hook and release mortality on the Roanoke River has not been evaluated, but obviously becomes more important as the number of released fish increases.

Mullis and Guier (1982) reported the Albemarle Sound commercial fishery was the largest harvester of striped bass from the system by a relatively large margin. In 1988, approximately 49,545 kg (109,000 lb) of striped bass were harvested by the commercial fishery in Albemarle Sound (L. Henry, N.C. Division of Marine Fisheries, pers. comm.). The almost 34,000 kg of striped bass harvested by River sport fishermen in 1988 was about 68% of the commercial harvest from the Sound.

In 1988, most of the striped bass harvest occurred in Zone I (53%) and Zone III (41%), while in 1989, 97% occurred in Zone I. In 1990, 62% of the harvest was in Zone I and 36% in Zone 2. The preponderance of those released in 1988 (86%), 1989 (99%), and 93% (1990) were caught in Zone I which encompassed the traditional spawning grounds. The midpoint of the striped bass spawning season generally occurs around 11-13 May each year (Hassler et al. 1981). During 1988 and 1989, the majority of striped bass harvested and released occurred between early April (Period 2) and the latter part of May (Period 4). During 1988, most of the striped bass catch (61%) and effort (38%) occurred between 9-22 May (Period 4). During 1990, more striped bass were harvested during Period 3 (23 April - 6 May).

Approximately half of the anglers interviewed were residents of counties that bordered the River in the vicinity of the traditional spawning area. However, about a third of the interviewed fishermen were not residents of counties that bordered any portion of the Roanoke River. This indicates that the striped bass fishery is not merely of local interest, and that anglers are drawn from considerable distances to participate in it.

Scofield (1931) concluded that the age of striped bass could be accurately determined in the first 8-10 years using scale analysis. However, Humphries and Kornegay (1985) reported the presence of false annuli and other checks made the use of scales for determining the age of Albemarle Sound-Roanoke River striped bass difficult and time consuming. They also evaluated several bony structures from striped bass in this population to determine their feasibility for use in age studies and concluded otoliths were easier to read than scales and provided similar age estimates. However, collection of otoliths is time consuming and requires mutilation of the fish, a procedure not well tolerated by fishermen in a hurry to return home. Therefore, scales were collected for ageing purposes from striped bass examined in the creel survey.

While ages could be assigned to most striped bass from which scales were collected, the difficulties in reading scales reported by Humphries and Kornegay (1985) likely led to reduced accuracy of the readings. A subsample of approximately 10% of the scales aged in 1988 were also read by the co-author (Kornegay) of the aforementioned report (Mullis 1989). Agreement on the ages assigned independently to the same scale samples by Kornegay and Mullis was only 44%. However most discrepancies were of only 1 year, and agreement of assigned ages plus or minus 1 year was 90%. The proportions of discrepancies that were 1 year higher or lower, respectively, than the ages assigned by this author were about equal (24% versus 21%). Therefore the ages assigned in this study were considered acceptable for use in determining the age composition of the striped bass sport harvest.

The mean lengths of striped bass caught by sport anglers from the Roanoke River in 1988 are somewhat smaller than those caught by a variety of sport and commercial gears in the mid 1960s and early 1980s when corrected for the discrepancies of fork length vs. total length (Table 49). Virtually all sources agree that the length of female striped bass at given ages is larger than that of males. The mean weight of striped bass caught by sport anglers during the survey (1.5 kg) approximates the 1.8 kg average weight of stripers collected in a Roanoke River fish kill in 1963 (Smith and Bayless 1963).

Significant differences in game fish population size structure between years are frequently observed (Van Horn et al. 1986). Changes in year class strength and growth rates can have a marked effect on size distributions. Other factors can also influence the angler catch composition of striped bass on the Roanoke River. Small males typically preceed larger males and then females on the spawning migration. When the season was curtailed in 1990, larger males and females were beginning to appear more frequently in the creel. This undoubtedly

Table 49. Comparison of mean lengths (mm) (fork lengths adjusted to total lengths) and percent composition of sex by age class of striped bass collected from Roanoke River.

Males

Age	1963-1965 Trent & Hassler (1968) %	Length	1981 Harriss et al.(1985) %	Length	1985 Winslow & Harriss (1986) %	Length	1987 Winslow & Henry (1988) %	Length	1988-1990 Present Study %	Length
1		1	292							
2	4	382	63	403	73	394	64	440	5-16	418
3	70	450	27	474	25	468	29	514	19-31	427
4	21	495	8	513	1	476	6	552	31-40	462
5	4	533					2	617	14-24	500
6	<1	585	1	634					2-14	554
7	1	628							1-6	605
8	<1	666							0-2	608
9	<1	855							0-<1	691
10									0-<1	706
11									0-<1	812
12										
13										

Females

Age	1963-1965 Trent & Hassler (1968) %	Length	1981 Harriss et al.(1985) %	Length	1985 Winslow & Harriss (1986) %	Length	1987 Winslow & Henry (1988) %	Length	1988-1990 Present Study %	Length
1										
2			2	402	28	394	25	425	0-1	443
3	7	492			42	492	15	539	1-6	532
4	53	543	25	620	6	555	40	586	1-8	553
5	24	574	31	631	19	637	14	654	9-47	557
6	7	636	22	665			1	718	21-31	587
7	6	688	7	681	5	762	3	817	4-30	626
8	4	709	6	724			1	842	1-20	656
9	2	762	5	802					0-7	666
10	2	780	2	839					0-3	710
11	1	804							0-1	828
12	1	1,011							0-<1	796
13	<1	948							0-<1	831

reduced the number of larger fish creeled. Females comprised 8% of the fish creeled in 1990 compared to 23 and 35% in 1988 and 1989. Adverse weather and flow conditions, which influence effort during the spring and fishermen culling their catch, can also bias catch composition. Length-frequency distributions and, therefore, age composition of striped bass in the sport harvest may not be representative of the composition of the spawning population.

A wider distribution of age classes of striped bass, particularly males, was examined during 1988-1990 than in previous studies (Table 49). The age composition of both males and females was shifted toward older fish in this study. The reason for this is not clear. Sampling gear used in the earlier studies may not have adequately sampled older, larger fish.

The age composition of female striped bass in the spawning population is more important than that of males. The percentage of spawning stock females age 8 and older is considered a criterion for restored stock status in the current draft of the Atlantic States Marine Fisheries Commission (ASMFC) Interstate Striped Bass Management Plan (Richkus and Perra 1989). The ASMFC believes that 10% of the striped bass spawning stock females should be age 8 and older. Approximately 13% (range: 2-31%) of the females caught in 1988-1990 were age 8 and older (Figure 61). In the early 1960s, Trent and Hassler (1968) estimated that only about 10% of the females collected from the Roanoke River in the spawning season were in those age categories. However, many of those fish were caught by gears, particularly gill nets, which are size selective, thus biasing estimates of age composition. In 1981, Harriss et al. (1985) found that 14% of the females were ages 8, 9, and 10, but, again, collection gear could have biased these results (Table 49). In 1985 and 1987, the proportion of age 8 and older females was negligible (Winslow and Harriss 1986, Winslow and Henry 1988). However, many of the fish examined in these studies, and all of them in 1985, were obtained from commercial fishermen from the lower Roanoke River. The commercial gears used to catch these fish may have been selective against larger and older fish.

The reduction in the number of female striped bass creeled in 1990 was likely a function of the large number of 2-3 year old males in the River and the closure of the fishery in early May. Management of the River fishery by harvest quotas should continue to protect females if large numbers of young fish are present in the spring and the quota is reached at or before the peak of the spawn. Additional protection of female striped bass was afforded in spring 1991 with a protective slot limit which prohibits the harvest of fish between 550 mm (22 inches) and 686 mm (27 inches). During 1988-1990, 69% of striped bass creeled within this size range were females which comprised 60% of the total number of females creeled.

Commercial and Recreational Landings of Striped Bass in Albemarle Sound, 1990

Lynn T. Henry

Commercial fishermen landed 100,830 pounds of striped bass valued at $101,002 in North Carolina during 1989, and 113,939 pounds valued at $159,630 during 1990 (Table 50). Historically, most of the fish have been caught in the Albemarle Sound area by set gill nets and pound nets. From 1980 to 1989, 67 to 96% of the striped bass landed by commercial gear in the State came from the Albemarle Sound area (Table 50). The remaining small percentages were caught in the Atlantic Ocean, and other riverine-estuarine systems, such as the Neuse-Pamlico.

A multitude of fishing regulations (refer to Table 52) 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 51. In recent years, most of the fish have been caught in November and December, and from January through April. Recreational fishermen have also 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 was also closed from May through December 1990 for the internal coastal waters, resulting in the first long-term closure of this fishery.

The recreational striped bass harvest in Albemarle Sound has not been evaluated since the NCWRC conducted a sport fishery survey during 1977-1980 (Mullis and Guier 1982). NCDMF is planning to re-implement an Albemarle Sound recreational creel survey during December 1990 to gain harvest information from this fishery. The study design will be similar to the earlier NCWRC survey. Information from the survey will be utilized for striped bass harvest quota (pounds) management.

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) from 1967 to 1973 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. Although the two commissions generally represent separate constituencies, they realize that management of the stock must be a shared responsibility. A management plan for the species is being developed by the State agencies (Note: see Table 52, and the section on updated striped bass conservation regulations, 1990-1991).

Both commissions and agencies face unique problems as the plan is moved forward. The Wildlife Resources Commission 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 Division of Marine Fisheries 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).

Table 50. Commercial harvest of striped bass in North Carolina 1980-90 (data from N.C. Division of Marine Fisheries).

	Statewide		Albemarle Sound area (including Roanoke R.)		Percent of total
Year	Pounds	Value	Pounds	Value	landings
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

Elimination of catches of other fishes would be an economic disaster to local fishermen and their families. The Division of Marine Fisheries is testing fyke nets as an alternative fishing technique (Henry 1989).

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. North Carolina is striving to adopt management options that complement the intent of the ASMFC coastwide management plan for striped bass.

Update on Regulations

Lynn T. Henry

Major regulatory actions implemented by the North Carolina resource management agencies from 1979 through early 1991 are presented in Table 52. 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.

Table 51. Commercial landings (pounds) of striped bass by month in the Albemarle Sound area (including Roanoke River), 1980-1990 (data from N.C. Division of Marine Fisheries).

Month	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
JAN		17,083	33,470	15,344	97,507	54,096	34,875	28,565	13,972	7,913	38,979
FEB		8,345	22,048	17,009	31,953	23,887	12,125	68,513	9,098	5,560	5,448
MAR		20,736	36,289	29,847	14,452	30,677	36,196	38,158	20,297	14,795	38,074
APR		27,324	50,884	27,689	28,547	38,965	0	56,074	9,807	8,701	21,256
MAY		18,675	23,007	21,167	12,718	24,289	0	0	0	0	0
JUN		15,772	8,878	1,970	10,995	0	0	0	0	0	0
JUL	12,098	11,437	7,457	1,089	6,187	0	0	0	0	0	0
AUG	13,214	13,149	8,007	850	0	0	0	0	0	0	0
SEP	25,948	41,745	9,594	5,800	0	0	0	0	0	0	0
OCT	82,977	76,860	13,269	69,026	93,499	0	0	0	0	0	0
NOV	94,622	64,359	5,964	23,294	129,425	27,662	48,447	26,554	43,955	60,092	0
DEC	33,295	17,299	9,137	75,657	50,357	70,095	41,043	11,007	11,662	0	0
Total		333,484	228,004	288,742	475,640	269,671	172,683	228,861	108,791	97,061	103,757

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 quota allocation. The annual recreational harvest quota 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 quota-based 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 harvest quota (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 quota 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 quota 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 are 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.

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 quota (pounds). The seasons were allowed due to an increase in the Atlantic migratory population, principally the Chesapeake stocks. Harvest seasons were also established during the fall 1990 and winter 1991 with very limited harvest.

Table 52. 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, 1979-1991). 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).
	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 has 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.).

Table 52. (Continued)

1984	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.).
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 of 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.).

Table 52. (Continued)

1986	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.).
	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 <u>closed</u> 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 <u>closed</u> 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 <u>opened</u> 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 <u>closed</u> 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 <u>closed</u> statewide 26 November (DMF/Nov.).
1990	<u>Commercial harvest in internal coastal waters</u>
	By proclamation striped bass commercial season <u>opened</u> statewide 1 January for internal coastal waters with gear restrictions and a 98,000-pound quota for 1990 to be managed on a monthly basis for the Albemarle Sound area (DMF/Jan.).

Table 52. (Continued)

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.).

By proclamation striped bass commercial season closed statewide 20 April 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 for hook-and-line harvest in internal coastal waters 1 January (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 quota allocation.

Table 52. (Continued)

	By proclamation striped bass commercial season in the N.C. Atlantic Ocean was <u>open</u> from 26 November - 23 December (Quota = 85,000 lbs) (DMF/Nov.).
	By proclamation striped bass recreational season in the N.C. Atlantic Ocean was <u>open</u> 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 <u>open</u> 19 November - 31 December (creel limit - 1 fish/day) (DMF/Feb.).
1991	<u>Commercial harvest in internal coastal waters</u>
	By proclamation striped bass commercial season was <u>opened</u> 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 is based on a 98,000-pound quota 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 (DMF/Jan.).
	By proclamation striped bass commercial season <u>opened</u> 7 January for internal coastal waters outside the Albemarle SCHMA (DMF/Jan.).
	By proclamation 8 January additional gill net restrictions were implemented during the <u>closed</u> striped bass season in the Albemarle SCHMA (DMF/Jan.).
	By proclamation striped bass season <u>opened</u> 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).
	<u>Recreational hook-and-line harvest in internal coastal waters and inland coastal waters (1991)</u>
	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 water 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 poundage quota 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.

Table 52. (Continued)

The Wildlife Resources Commission has management authority for hook-and-line harvest in the joint and inland waters of the <u>Roanoke River Recreational Harvest Management Area</u> (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 <u>Albemarle Sound Recreational Harvest Management Area</u> (Albemarle, Currituck, Roanoke, and Croatan Sound and their tributaries) (DMF/WRC).

*Note: The defined areas only apply to striped bass recreational hook-and-line harvest management.

By proclamation the striped bass season <u>opened</u> 1 January in the Albemarle Sound Recreational Harvest Management Area (Albemarle SRHMA) (DMF/Jan.).

By proclamation the striped bass season <u>opened</u> 1 January in the internal coastal waters statewide excluding the Albemarle SRHMA (DMF/Jan.).

By emergency rule the striped bass season <u>opened</u> 1 January in the inland coastal waters and in the Roanoke River Recreational Harvest Management Area (Roanoke RRHMA) (WRC/Jan.).

By proclamation the striped bass season <u>closed</u> 31 January in the Albemarle SRHMA to assess the harvest relative to quota management (DMF/Jan.).

By proclamation the striped bass season <u>opened</u> 7 February in the Albemarle SHRMA (DMF/Feb.).

<u>Atlantic Ocean (1991)</u>

By proclamation striped bass commercial season was open from 4-25 February with a 28-inch (TL) minimum size limit and daily landing restrictions for permitted harvesters.

By proclamation striped bass recreational season was opened from 19 January - 31 March with a 28-inch minimum size and a one fish/day creel limit.

Egg Abundance and Viability

Roger A. Rulifson

Sampling for striped bass eggs was initiated on 16 April 1990 at Barnhill's Landing (RM 117), the same site as was used in 1989 and the site of W.W. Hassler's egg collection efforts from 1975 through 1981. Field efforts were terminated on 15 June.

Eggs first appeared in samples on 24 April and were last observed in surface samples on 12 June, for a 50-day spawning window. The 1990 spawning season was quite different from the historical spawning record and from that observed in 1988 and 1989: continual spawning activity was observed throughout the 50-day period. In 1988, the 52-day spawning window had 27 consecutive spawning days; in 1989, the 55-day window had only 23 consecutive spawning days.

An estimated 964,791,625 eggs (S.D. = 32,193,436) were spawned in the Roanoke River upstream of Barnhill's Landing between 24 April and 12 June 1990. Two peaks in spawning activity were observed: 7 May (142,809,984 eggs or 14.8% of the total) and 10 May (193,313,468 or 20.04% of total). Over 50% of the total yearly egg production was completed by 10 May, and 80% was completed by 15 May. The estimated egg viability for the year was 58%.

The early morning hour samples contained the most eggs. About 42% of all eggs were collected at 0600 hours, and an additional 28% were caught at 0200 hours. About 12% of the eggs were observed from the 1000 hours sample; the remaining 17% were caught in the afternoon and evening. Most eggs were less than 10 hours old in stage of development, indicating that the major spawning activity probably occurred for several hours near or after dusk.

Spawning activity and egg viability were correlated with water temperature, which ranged from 14.0 to 23.5°C during the study. Nearly 96% of the eggs were spawned at water temperatures between 18.0 and 21.9°C. An additional 3.4% were caught at temperatures between 22.0 and 23.9°C, and less than 1% were caught between 16.0 and 17.9°C. Viability was only 15% at the lowest temperatures, but was 58% at all temperatures 18°C and higher.

Roanoke River waters were slightly basic for most of the study, ranging from 6.75 to 8.30. Most eggs (52%) were caught in waters with pH values of 7.50-7.74. An additional 36% were caught in waters ranging from 7.00-7.49. Less than 1% were collected in waters with pH values less than 7.00. No pattern in viability with pH was observed.

Levels of dissolved oxygen ranged from 6.0 to 9.4 mg/L during the study; most eggs (93%) were collected in waters with 7.0-8.9 mg/L oxygen.

Surface water velocities ranged from 56 cm/second to 125 cm/second at Barnhill's Landing; approximately 65% of all eggs were collected at velocities between 60.0 and 79.9 cm/second. An additional 26% were collected at velocities between 80.0 and 99.9 cm/second, and only 6.5% at surface water speeds of 100 to 119.9 cm/second. About 1.5% of the eggs were collected at water velocities less than 60 cm/second, which was also the group having the greatest viability (66%). Lowest egg viability (47%) was observed at highest water velocities.

Striped Bass Spawning Activity and Reservoir Discharge

Roger A. Rulifson

Results of the egg studies conducted in 1988, 1989, and 1990 clearly illustrate the impact of water discharge from the Roanoke Rapids Reservoir on spawning activity of striped bass downstream. Reservoir discharge can change the ambient water temperature on the spawning grounds, which then influences striped bass spawning activity. In all three years of the study, spawning was initiated when water temperatures reached 18°C.

In 1988, reservoir discharge was moderate ranging between 6,000 and 9,500 cfs during the spawning period. Early spawning was observed in mid-April when temperatures reached 18°C, but stopped when a cold rainfall lowered River water temperatures (Figure 62). On 9 May, River temperatures again rose above 18°C as a result of ambient air temperatures and solar heating; major spawning activity was observed.

In 1989, initially good River flow conditions allowed water temperatures to rise to 18°C by late April, and moderate spawning activity was observed. Spawning ceased one week later, however, when heavy rainfall above Kerr Reservoir forced the U.S. Army Corps of Engineers (Corps) to release 20,000 cfs of water through Kerr, Gaston, and Roanoke Rapids reservoirs. This prolonged and steady release of water caused water temperatures to drop below 18°C for several weeks before rising to 18°C in late May (Figure 63). Major spawning activity was delayed until the last week in May 1989.

In 1990, extraordinarily warm weather in late winter warmed reservoir waters earlier than usual. Spawning began in late April and was continuous through 13 June, when spawning ceased. Although release of reservoir waters varied considerably in magnitude during the 1990 spawning season, River temperatures never dipped below 18°C (Figure 64).

Differences in yearly spawning activity of striped bass in the lower Roanoke River can be attributed to fluctuating water temperatures, which is altered by reservoir discharge. These differences can be expressed as the total number of days of the spawning window, the number of consecutive spawning days within the window, and the rate at which spawning proceeds once major spawning activity is observed. The 52-day spawning window in 1988 started on 12 April and was completed by 2 June; only 27 days within the window were consecutive spawning days. In 1989, the spawning window started and ended later in the season but was expanded to 55 days, primarily due to the extensive freshwater input from the upper watershed (Table 53). In 1990, the spawning window was only 50 days, but all 50 days were used for spawning activity. The spawning window started on 24 April and ended on 12 June, but 50% of the estimated yearly egg production was completed by 10 May, more than five days earlier than in 1988 and over two weeks earlier than in 1989.

In summary, striped bass spawning activity in the lower Roanoke River begins in the spring when water temperatures reach 18°C. Sudden releases of cooler waters from upstream reservoirs cause ambient River water temperatures to decrease by several degrees on the striped bass spawning grounds. Spawning activity ceases if water temperatures drop below 18°C. Thus, the best River flow conditions for uninterrupted spawning activity would include moderate and stable flows during April, May and early June.

This phenomenon is not a recent development within the Roanoke River, but was not immediately apparent in the Hassler data base. The egg studies by Hassler and colleagues starting in 1959 were conducted to monitor the major portion of the spawning activity. Thus, any early spawning activity was not documented. Of the 21 years of egg study records available,

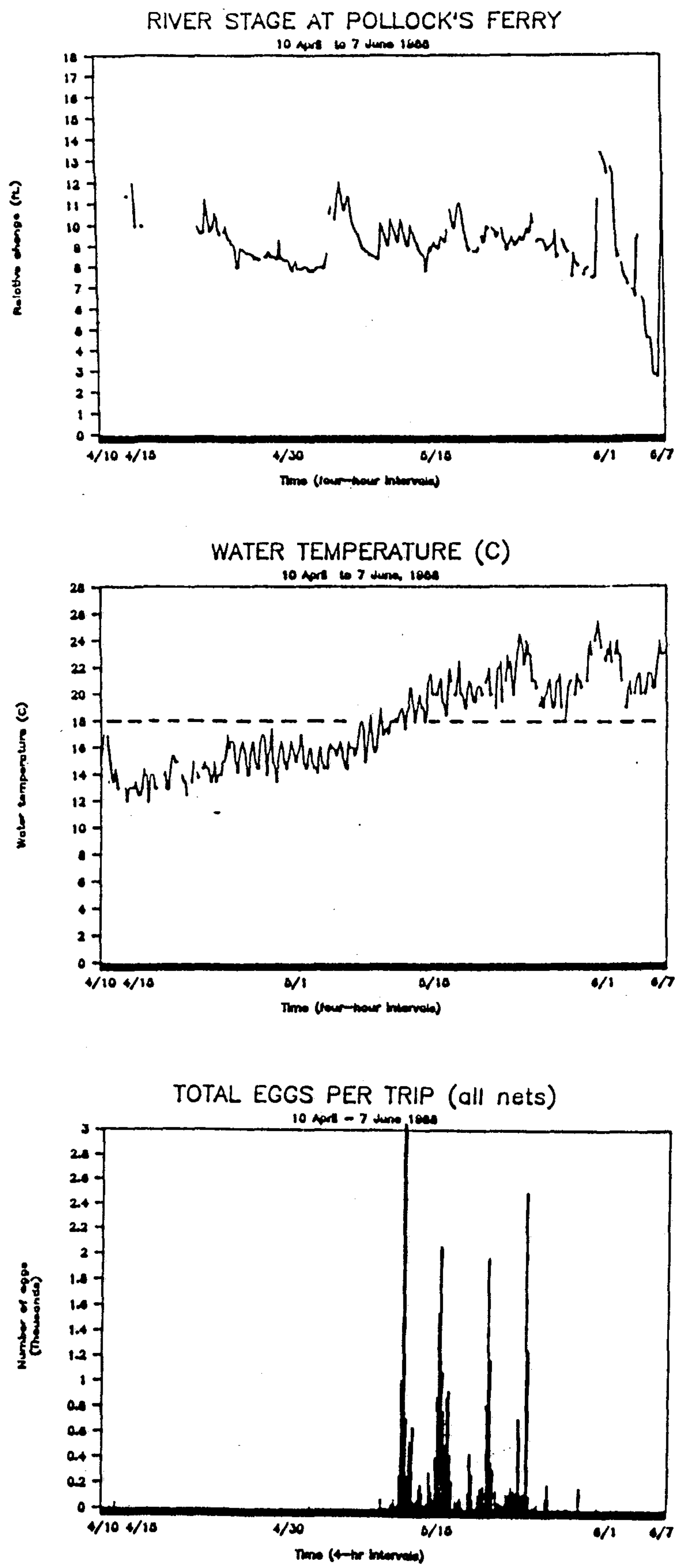


Figure 62. Spawning activity of striped bass (expressed as egg abundance) related to River stage and water temperature in the lower Roanoke River in 1988.

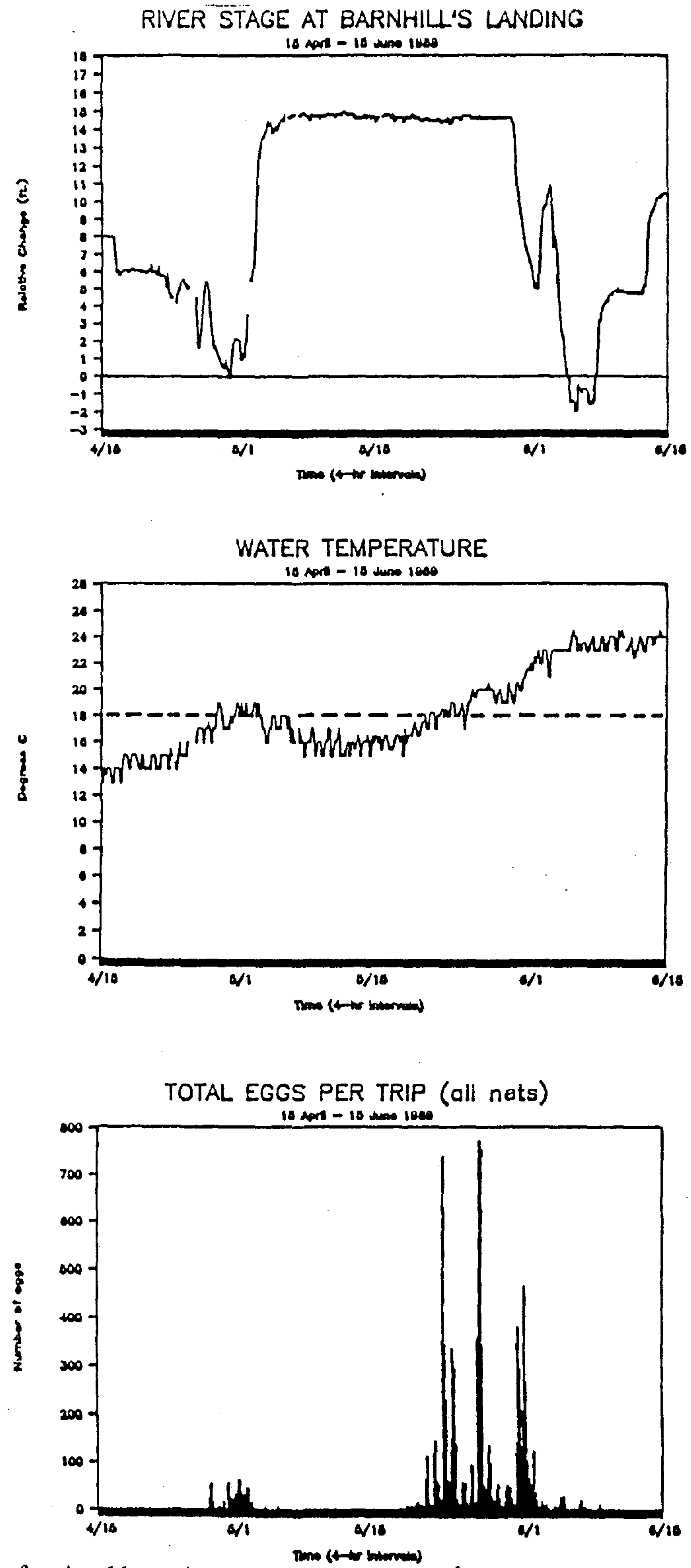


Figure 63. Spawning activity of striped bass (expressed as egg abundance) related to River stages and water temperature in the lower Roanoke River in 1989.

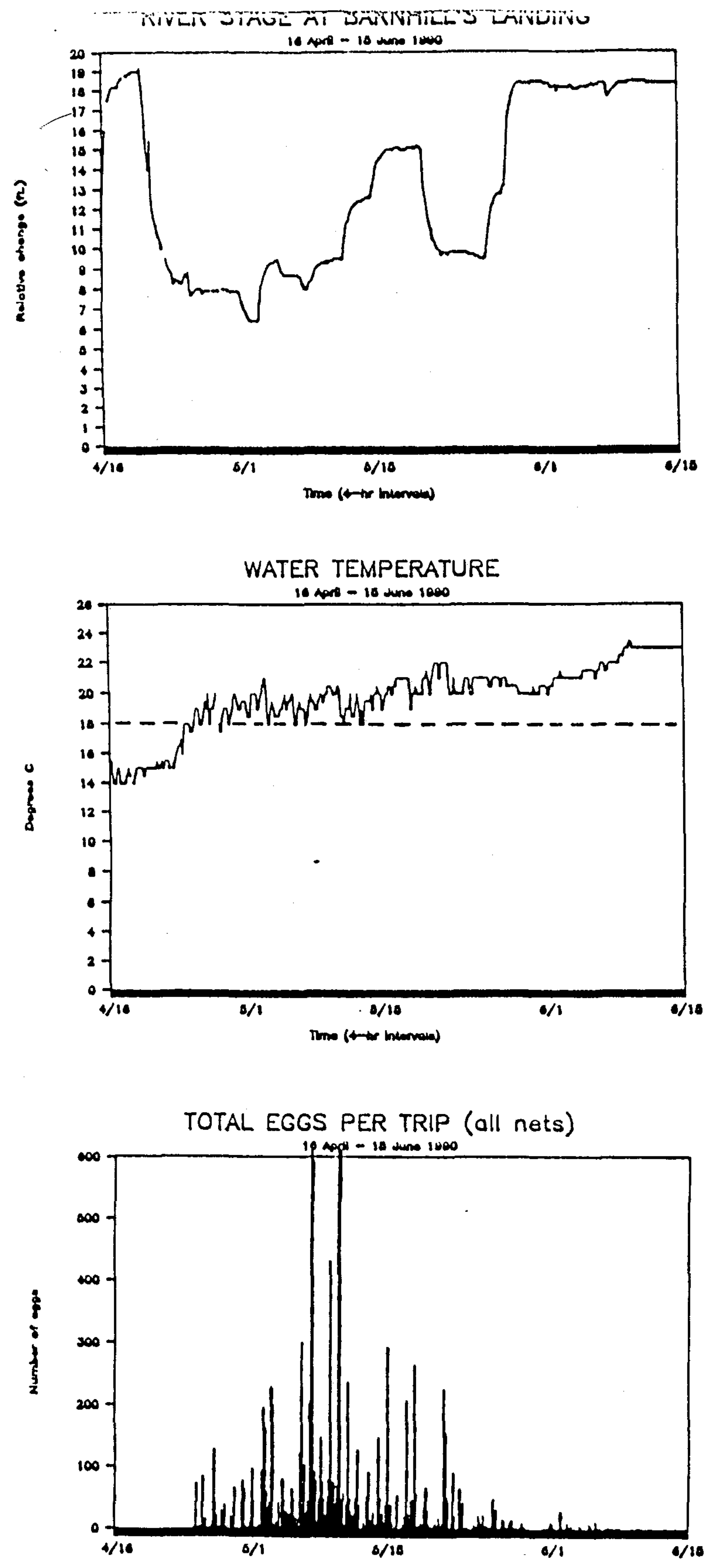


Figure 64. Spawning activity of striped bass (expressed as egg abundance) related to River stages and water temperature in the lower Roanoke River in 1990.

Table 53. Differences in yearly spawning activity of striped bass in the lower Roanoke River as related to water temperature and reservoir discharge.

Spawning Parameter	1988	1989	1990
First spawning date	12 Apr	16 Apr	24 Apr
Last spawning date	2 Jun	9 Jun	12 Jun
Total days in period	52	55	50
Greatest number of consecutive spawning days	27	23	50
Date at which egg production was:			
50% of yearly total	15 May	27 May	10 May
80% of yearly total	20 May	29 May	15 May
Estimated yearly egg production	2.08 billion	638 million	965 million
Estimated yearly egg viability	89%	42%	58%

only six years (1968, 1969, 1970, 1979, 1980, 1983) of these began with zero catches of striped bass eggs. Also, in only 11 of the 21 years available did the egg studies end with zero eggs collected (see Manooch and Rulifson 1989, Appendix Table B-8). Temperature records for these studies are not conducive for documenting the reservoir discharge-temperature-spawning activity relationship. The daily minimum and maximum water temperatures were recorded for 15 of the 21 years of data available (see Manooch and Rulifson 1989, Appendix Tables B-10 and B-11); no temperature data for individual sampling trips were reported. An interesting feature of the data is that the minimum water temperature did not always occur at night, but occurred at different times throughout the study, indicating that reservoir discharge was influencing water temperatures downstream at Hassler's sampling station. Graphical presentation of the Hassler data does show that major spawning activity occurred when water temperatures were above 18°C. Hassler data for years 1963, 1966, and 1968 are depicted in Figures 65, 66, and 67.

A similar phenomenon has been observed for striped bass spawning in the Santee-Cooper watershed. Jim Bulak (South Carolina Wildlife and Fisheries Resources, Columbia, pers.comm.) has documented cessation of striped bass spawning activity with coolwater reservoir discharge. The threshold temperature for spawning activity in the Congeree and Wateree Rivers is near 18°C, similar to the Roanoke.

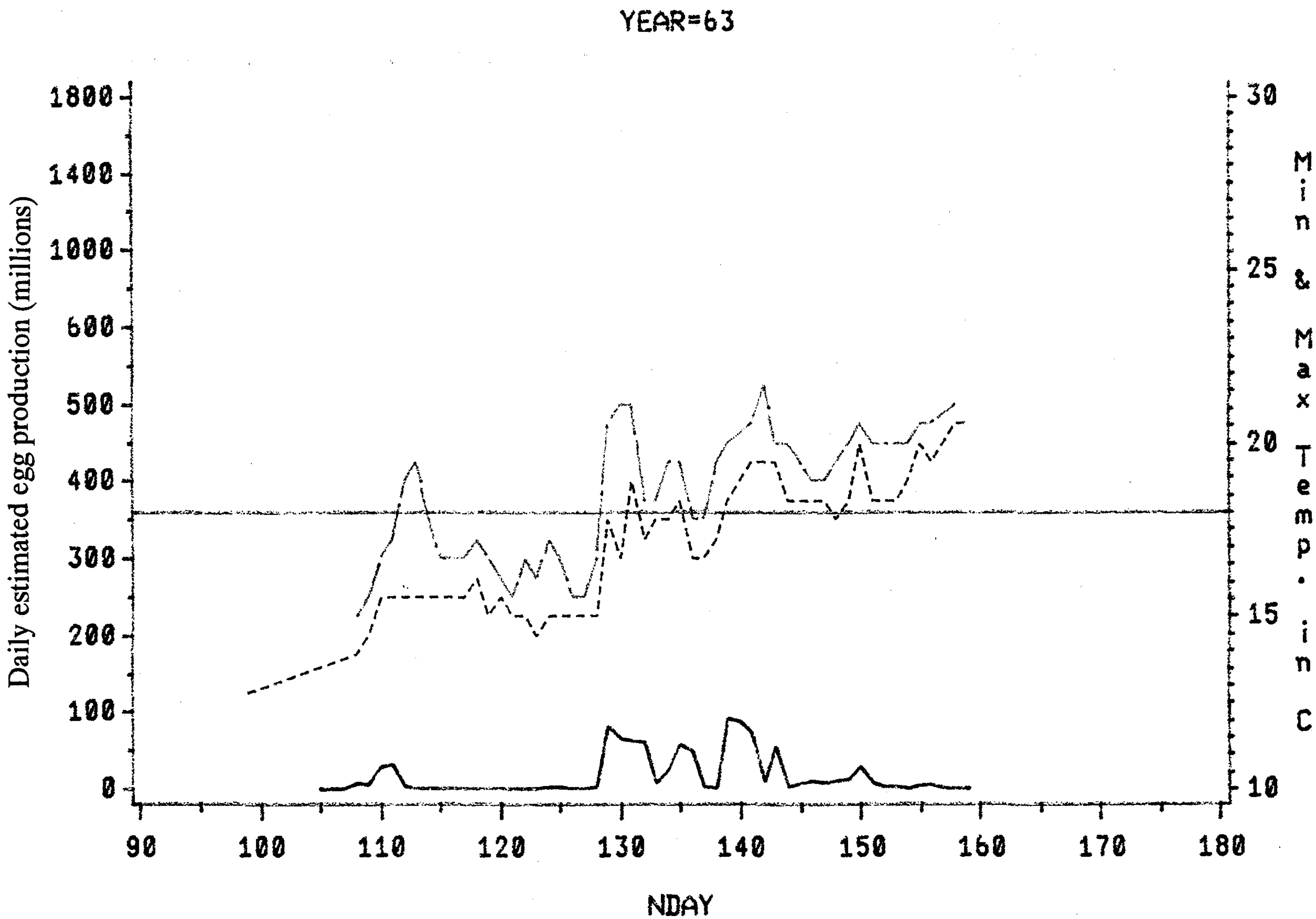


Figure 65. Striped bass spawning in the lower Roanoke River and associated maximum and minimum water temperature for 1963 (Hassler data).

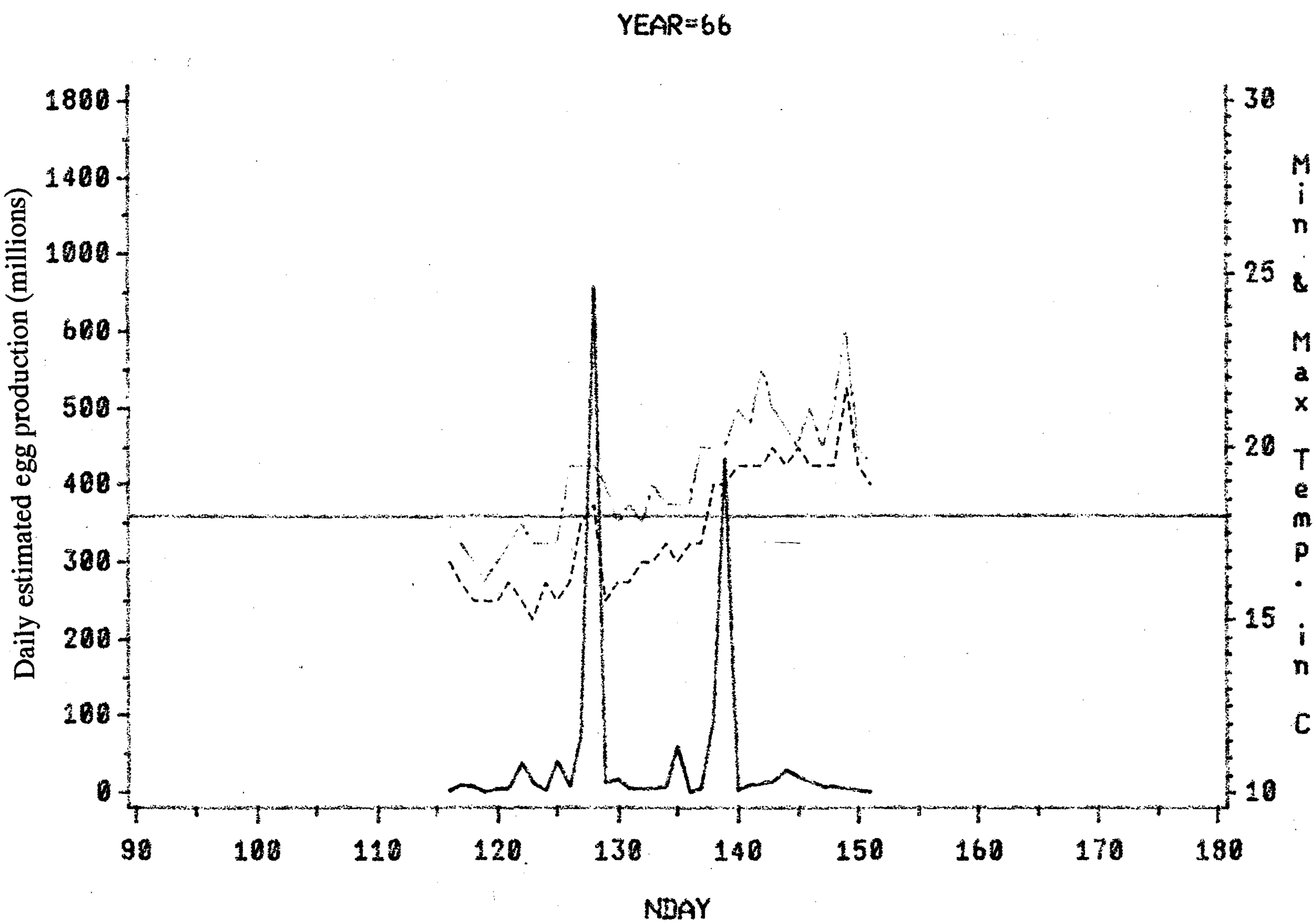


Figure 66. Striped bass spawning in the lower Roanoke River and associated maximum and minimum water temperature for 1966 (Hassler data).

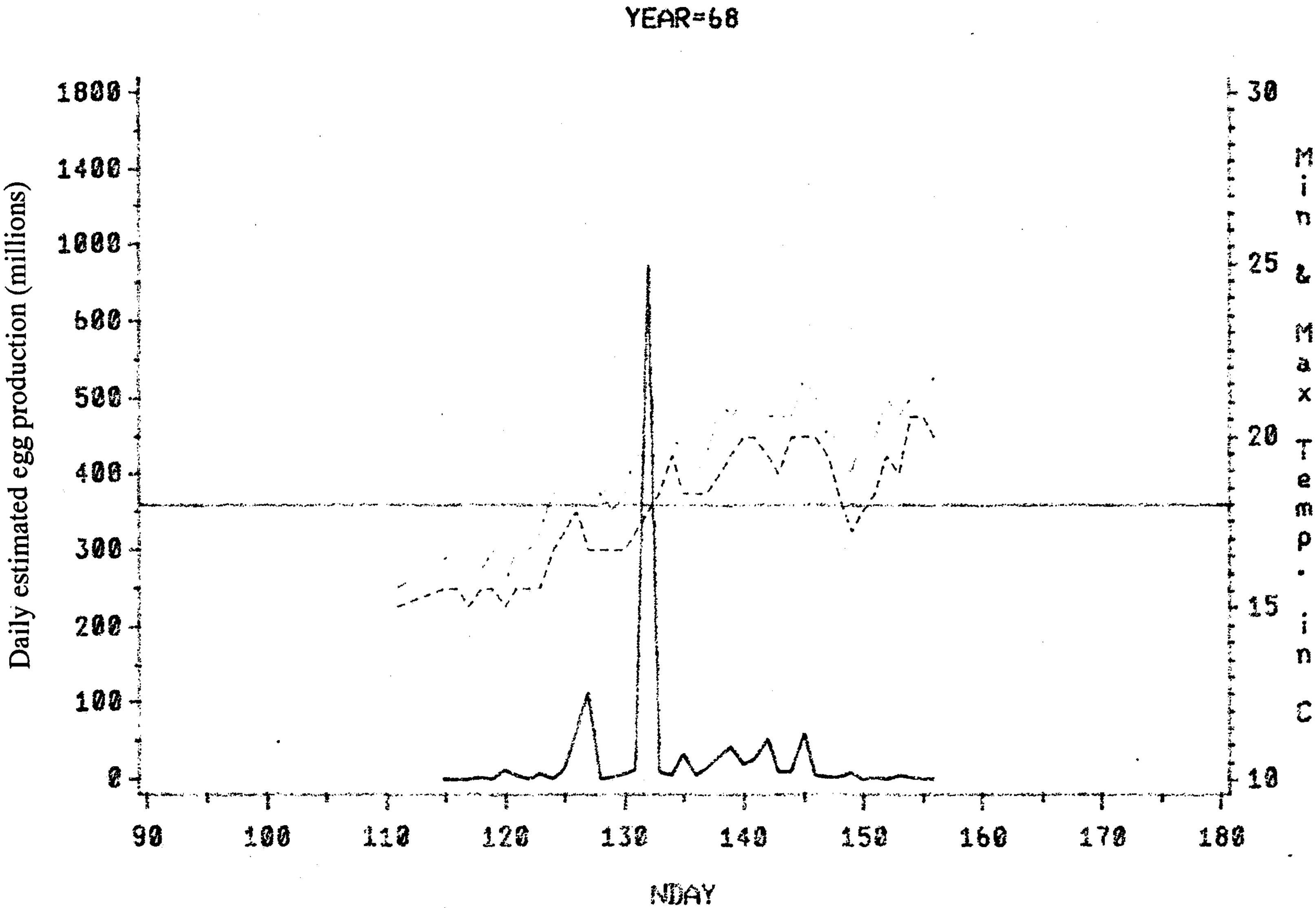


Figure 67. Striped bass spawning in the lower Roanoke River and associated maximum and minimum water temperature for 1968 (Hassler data).

Juvenile Abundance Index of Young-of-Year Striped Bass, 1988-1990

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 is conducted in the Albemarle Sound at approximately two-week intervals from July through October of each year and 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 54).

The sampling area is in western Albemarle Sound 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. Samples are 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 10 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. 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 through 1987, 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 55), the best value obtained since the summer and fall of 1976 (Table 54). 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, 1.17; 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 56), the highest value since 1976 (Table 54). 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, 7.36; 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 57). 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 54. Historical reproduction information on the Roanoke/Albemarle striped bass population (from Hassler and Taylor 1986[b], 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	0.61 [d]
1983	1,352,611,202	33.29	69,771	0.84	0.42 [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 [g]
1987[b]	1,382,496,006 [b]	42.87 [b]	91,738 [b]	0.06 [b]	0.30 [h]
1988	2,082,130,728 [c]	89.00 [c]			4.09 [i]
1989	637,919,162 [c]	41.80 [c]			4.27 [d]
1990	964,791,625 [c]	58.00 [c]			1.41 [d]

[a]Partial season data only.
[b]Hassler and Maraveyias (1988).
[c]Personal communication, R.A. Rulifson, East Carolina University, Greenville, NC.
[d]Personal communication, Lynn Henry, N.C. Division of Marine Fisheries, Elizabeth City, NC.
[e]Winslow et al. (1985).
[f]Winslow and Henry (1986).
[g]Winslow and Henry (1988).
[h]Winslow and Henry (1989).
[i]Henry and Winslow (1990).

Table 55. 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 56. 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 57. JAI catch matrix for seven stations in western Albemarle Sound, NC, 1988 and 1989.

1988				1989			
Date	Stations	Fish	JAI	Date	Stations	Fish	JAI
07/14	7	36	5.14	07/21	7	1	0.14
07/27	7	46	6.57				
Monthly	14	82	5.86	Monthly	7	1	0.14
08/09	7	19	2.71	08/08	7	7	1.00
08/23	7	28	4.00	08/16	7	37	5.29
				08/29	7	18	2.57
Monthly	14	47	3.21	Monthly	21	62	2.95
09/06	7	23	3.29	09/12	7	54	7.71
09/19	7	1	0.14	09/28	7	50	7.00
Monthly	14	24	1.71	Monthly	14	104	7.36
10/07	7	76	10.86	10/10	7	61	8.71
10/18	7	0	0.00	10/27	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 58) was considerably less than the two previous years, but greater than the historically low levels observed during the 10-year period, 1978-1987 (Table 54). 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 59) was: July, 2.79; August, 0.57; September, 0.64; and October, 1.64.

CPUE values for the eastern Sound stations (Figure 68) have been very low except during 1989, which was the first time significant numbers were captured since sampling began in 1984 (Figure 69). The drastic increase in 1989 eastern 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 eastern Sound juvenile information and Roanoke River flow data suggest that the density of juvenile striped bass in the eastern 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 eastern Sound CPUE and the 1989 western Sound JAI (Figure 70) 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 eastern Sound and gradually decreased towards the end of the season.

Table 58. 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 59. 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
Montlhy	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

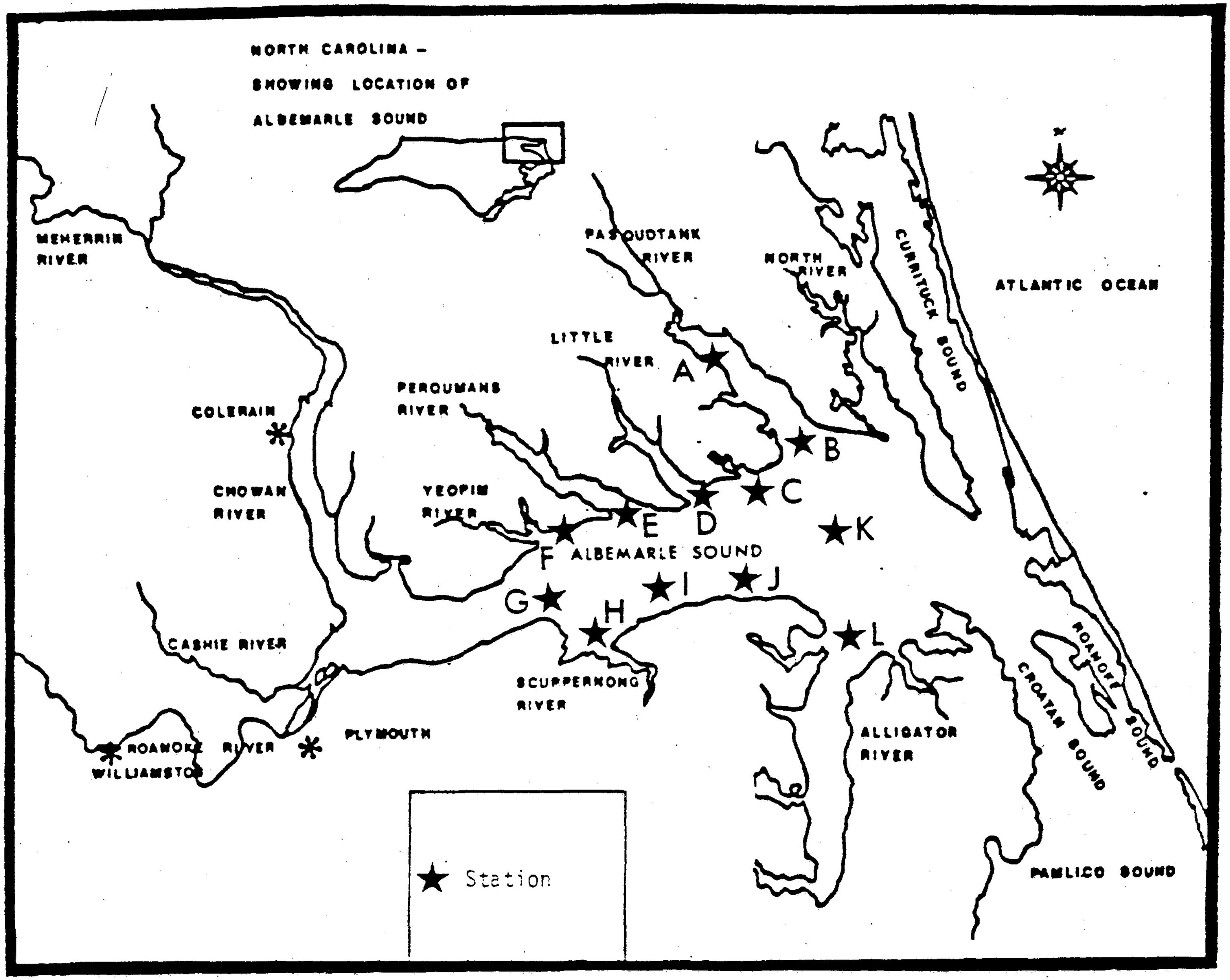
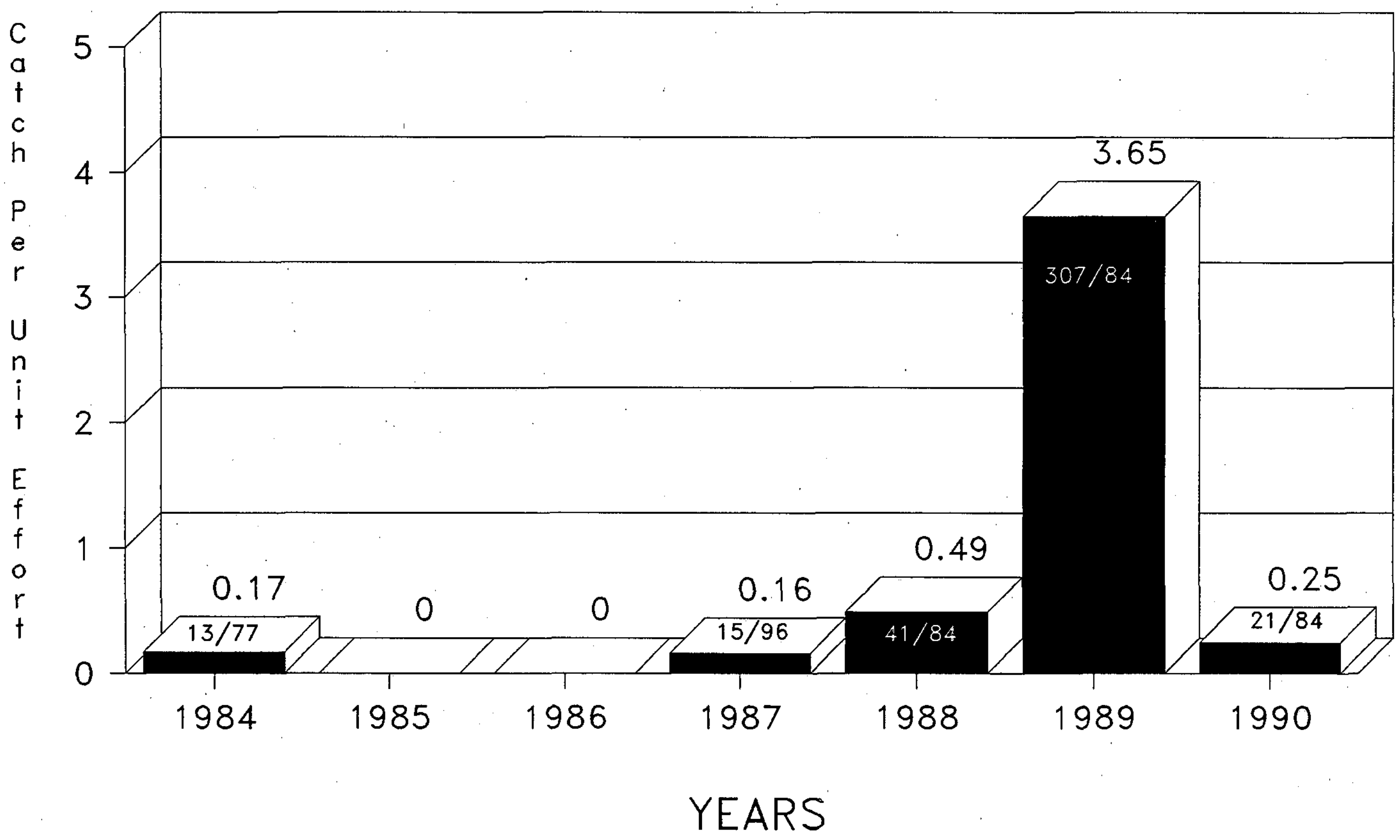


Figure 68. Station location for young-of-year striped bass sampling in central and eastern Albemarle Sound area, North Carolina.

The western Sound survey exhibited the opposite trend as the juveniles migrated back into the historical sampling area. Figure 70 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 eastern Sound nursery area and, therefore, juvenile production.

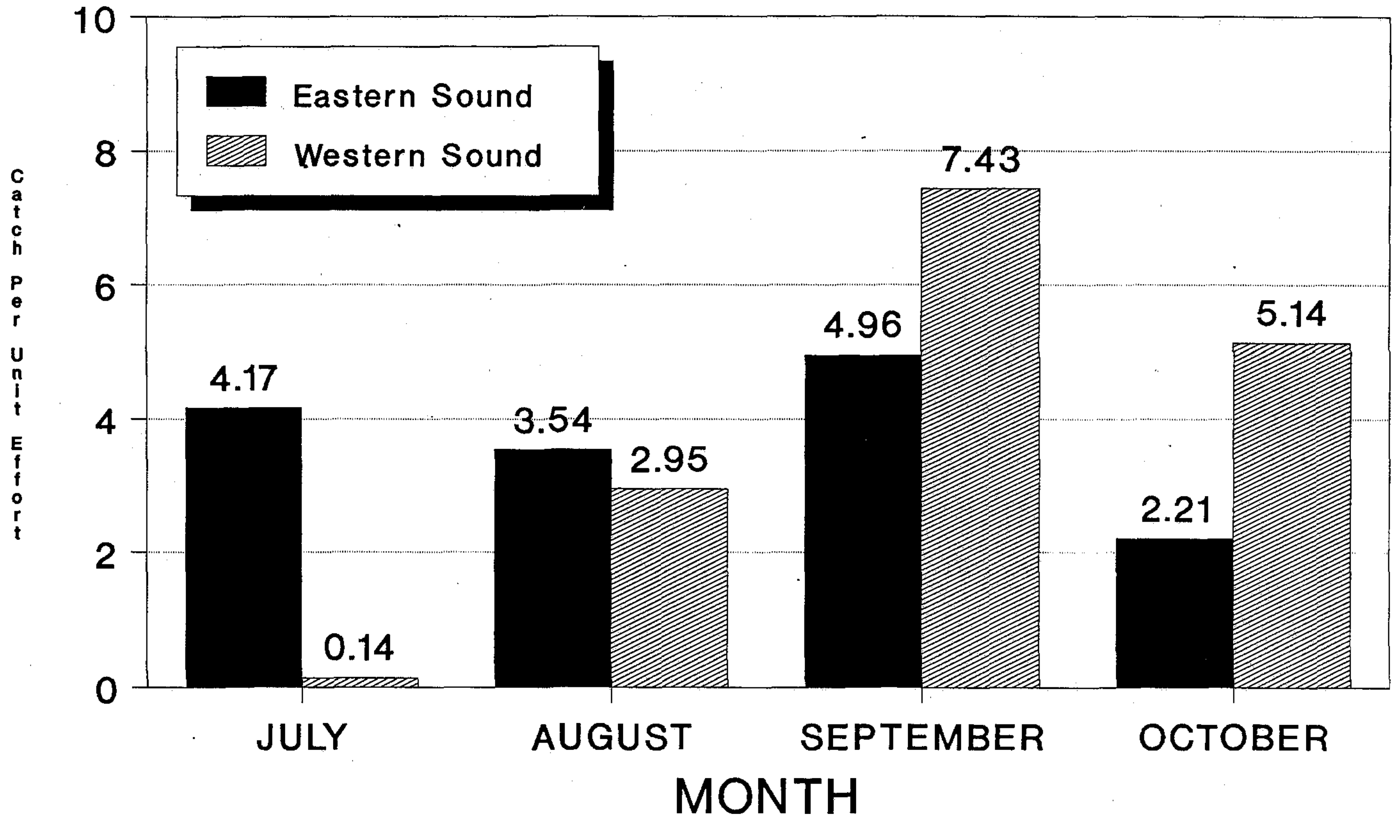
During 1990, the eastern Sound survey yielded very few juveniles, indicating continued poor production in this area. Roanoke River flows were relatively high throughout the season and not conducive to the establishment of a potentially productive nursery area in either the eastern or western Albemarle Sound.

A plausible shift in the historical striped bass nursery area due to poor water quality in the western Sound is not evident from the eastern Sound samples. Additional collections from the eastern 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.



(12 Stations sampled bi-weekly Jul-Oct)
Source:NC Div Marine Fisheries

Figure 69. Eastern Albemarle Sound striped bass juvenile catch/effort.



Source: NC DIV MARINE FISHERIES

Figure 70. Monthly CPUEs for 1989, western vs. eastern sound stations.

Age and Growth of Juvenile Striped Bass Determined by Counting Daily Growth Rings on Otoliths

J. Jeffrey Isley and Charles S. Manooch, III

Methods

Juvenile striped bass were collected from the Albemarle Sound during the summer and fall of 1990 as part of the N.C. Division of Marine Fisheries' Juvenile Abundance Index survey. Sampling stations are shown in Figure 71 and described in Table 60. Collection methods have been discussed in a previous section of this report (Juvenile Abundance Index by Lynn Henry). Fish were placed on ice, returned to the Elizabeth City Office, and were frozen until the otoliths could be removed in the laboratory.

Excised sagittal otoliths were stored dry in glass vials and were shipped to Panama City, Florida, for further study. Upon arrival, the whole otoliths were mounted on glass microscope slides with a small drop of thermoplastic cement. Otoliths were mounted with the proximal surface against the slide such that the concave surface faced away from the slide once embedded in the mounting medium. The sagittal plane of each otolith was ground by hand against a wet sheet of number 600 carborundum paper until the nucleus was exposed and daily rings were visible. Otoliths were not polished, instead, they were viewed through immersion oil at magnifications of 100-400X with transmitted polarized light. Otolith rings were counted only once by the author after it was determined 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.

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. A spawning date was determined by subtracting three days from the first-ring formation date for each fish.

All juveniles (n=101) were used to derive length conversion equations: TL to SL; SL to TL, and to derive a growth equation predicting the age in days of individual fish at a given length (TL mm).

Results

Otoliths from 105 fish were examined. Four 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 October and were not included in further analyses.

After plotting the lengths (SL and TL) and length (TL) and ages (daily rings) data, the linearity of the distributions was obvious. Therefore, linear regressions were used to describe the relationships.

Linear regressions were used to predict TL from SL and SL from TL:

$$TL = -0.8686 + 1.24478(SL);\ n = 101;\ r = 0.997, \text{ and}$$

$$SL = 1.132 + 0.7985(TL);\ n = 101;\ r = 0.997.$$

Age (daily rings) = 9.9286 + 0.9405(TL); n = 101; r = 0.919. Fish of the size range evaluated grew approximately 1 mm per day. A juvenile striped bass 50 mm TL was estimated to be 57 days old; a 100 mm fish, 104 days; a 130 mm fish, 132.2 days; and a fish measuring 160 mm TL was estimated to be 160.4 days old. The equations above should not be used to estimate the age of striped bass greater than 160 mm TL, or to convert length of fish larger than 160 mm TL.

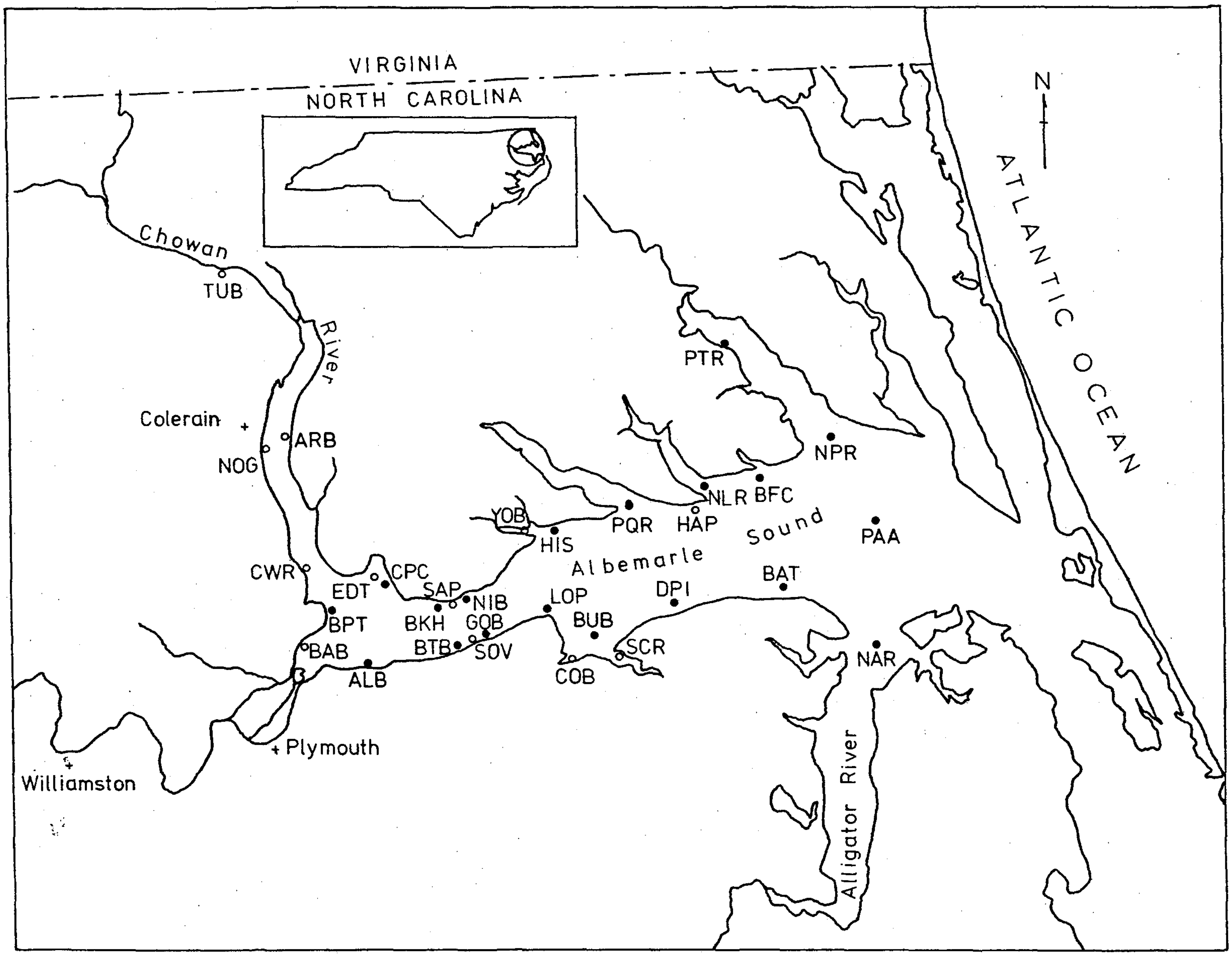


Figure 71. Sites used by the N.C. Division of Marine Fisheries to sample for young striped bass in Albemarle Sound, North Carolina, with trawl and seine. Site descriptions are presented in Table 60.

Table 60. Description of trawl and seine sampling stations used by the N.C. Division of Marine Fisheries. Asterisk (*) indicates fish captured at these sites.

Code	Seine or Trawl	Station	Description
ALB*	Trawl	Albemarle Beach	Southern shore of western Albemarle Sound
ARB	Seine	Arrowhead Beach	Eastern shore of Chowan River opposite Colerain
BAB*	Seine	Batchelor Bay	Near the mouth of Cashie River; western Albemarle Sound
BAT	Trawl	Bombing Target	South shore of central Albemarle Sound
BFC	Trawl	Big Flatty Creek	North shore; central Albemarle Sound
BKH*	Trawl	Brickhouse Point	North shore of western Albemarle Sound
BPT*	Trawl	Black Walnut Point	Western Albemarle Sound
BTB	Trawl	Bateman's Beach	Southern shore of western Albemarle Sound
BUB	Trawl	Bull's Bay	South shore; mouth of Scuppernong River
COB	Seine	Colonial Beach	South shore; mouth of Scuppernong River
CPC*	Trawl	Cape Colony	North shore of western Albemarle, near Edenton Bay
CWR*	Seine	Chowan River	Near Chowan River bridge; western Albemarle Sound
DPI*	Trawl	Dewey's Pier	Southern shore of central Albemarle Sound
EDT*	Seine	Edenton Bay	Mouth of Edenton Bay; north shore of western Albemarle Sound
GOB*	Trawl	George's Beach	Southern shore of western Albemarle Sound
HAP*	Seine	Harvey's Point	North shore of central Albemarle Sound
HIS*	Trawl	Holiday Island	Central Albemarle Sound, near the mouth of Yeopim River
LOP	Trawl	Laurel Point	South shore; central Albemarle Sound
NAR	Trawl	Alligator River	Eastern Albemarle Sound; mouth of Alligator River
NIB*	Trawl	Nixon's Beach	North shore of western Albemarle Sound
NLR	Trawl	Little River	North shore; mouth of Little River
NOG	Seine	Mount Gould	Near Colerain on Chowan River
NPR	Trawl	Pasquotank	Mouth of Pasquotank River; eastern Albemarle Sound
PAA	Trawl	Mid-sound	Mid-sound between Pasquotank and Alligator River
PQR*	Trawl	Perquimans River	North shore mouth of Perquimans River; central Albemarle Sound
PTR	Trawl	Pasquotank	Near Coast Guard Air Station
SAP	Seine	Sandy Point	North shore; western Albemarle Sound
SCR	Seine	Scuppernong River	Eastern shore of Scuppernong River
SOV*	Seine	Soundview	Southern shore of western Albemarle Sound near George's Beach
TUB	Seine	Tuscaroara Beach	Upper Chowan River
YOB*	Seine	Yeopim River	Near the mouth of Yeopim River north of Holiday Island

The number of daily rings on otoliths of the 101 juveniles ranged from 43 to 168 (Table 61). Back-calculated spawning dates ranged from 30 March to 27 June, although most (68%) were spawned from 6 May through 26 May (Table 62). Over 50% of the juveniles examined were spawned on days when Roanoke River water flows were considered favorable for survival (i.e., within the Committee's recommended boundaries). This is probably very significant since flows were favorable only 26% of the time from 1 April - 15 June. However, additional analyses are required before an evaluation can be made of the relationship of progeny survival and environmental parameters, such as water flow.

Table 61. Calculated spawning date as determined by counting daily rings on otoliths of juvenile striped bass collected during 1990 JAI survey.

Sample Number	Capture Date	Station	Rings	TL	Ring Date	Spawn Date
1-47	10/10/90	ALB	143	118	5/20	5/17
2-56	10/10/90	ALB	140	117	5/23	5/20
3-58	10/10/90	ALB	133	119	5/30	5/27
4-46	10/10/90	ALB	143	105	5/20	5/17
5-52	10/10/90	ALB	139	133	5/24	5/21
6-57	10/10/90	ALB	122	102	6/10	6/07
7-54	10/10/90	ALB	117	109	6/15	6/12
8-51	10/10/90	ALB	115	129	6/17	6/14
9-55	10/10/90	ALB	134	109	5/29	5/26
10-48	10/10/90	ALB	166	133	4/27	4/24
11-53	10/10/90	ALB	122	104	6/10	6/07
12-50	10/10/90	ALB	142	144	5/21	5/18
13-49	10/10/90	ALB	126	115	6/06	6/03
14-45	10/25/90	BTB	168	131	4/25	4/22
15-41	10/02/90	DPI	140	160	5/23	5/20
19-33	7/11/90	YOB	64	50	5/08	5/05
20-32	7/11/90	YOB	63	52	5/09	5/06
21-08	7/17/90	BKH	70	50	5/08	5/05
22-22	7/17/90	BKH	62	57	5/16	5/13
23-10	7/17/90	BKH	64	54	5/14	5/11
24-17	7/17/90	BKH	57	56	5/21	5/18
25-29	7/17/90	BKH	64	54	5/14	5/11
26-11	7/17/90	BKH	63	55	5/15	5/12
27-12	7/17/90	BKH	62	46	5/16	5/13
28-18	7/17/90	BKH	62	56	5/16	5/13
29-19	7/17/90	BKH	54	48	5/24	5/21
30-20	7/17/90	BKH	63	54	5/15	5/12
31-16	7/17/90	BKH	57	54	5/21	5/18
32-15	7/17/90	BKH	56	54	5/22	5/19
33-14	7/17/90	BKH	59	56	5/19	5/16
34-13	7/17/90	BKH	58	51	5/20	5/17
35-24	7/17/90	BKH	53	54	5/25	5/22
36-28	7/17/90	BKH	54	49	5/24	5/21
37-27	7/17/90	BKH	43	43	6/04	6/01
38-26	7/17/90	BKH	57	55	5/21	5/18
39-09	7/17/90	BKH	53	51	5/25	5/22
40-30	7/17/90	BKH	54	53	5/24	5/21
41-21	7/17/90	BKH	49	55	5/29	5/26
42-25	7/17/90	BKH	54	54	5/24	5/21
43-23	7/17/90	BKH	50	49	5/28	5/25
44-31	7/17/90	BKH	51	54	5/27	5/24
45-35	7/06/90	CWR	92	89	4/05	4/02
46-36	7/06/90	CWR	73	91	4/24	4/21
48-06	9/12/90	BKH	88	97	6/16	6/13
49-05	9/12/90	BKH	84	90	6/20	6/17
50-37	7/06/90	EDT	95	91	4/02	3/30
51-34	7/09/90	SOV	97	102	4/03	3/31
52-38	9/25/90	CPC	109	100	6/08	6/05
53-01	9/12/90	NIB	142	137	4/23	4/20
54-02	9/12/90	NIB	124	132	5/11	5/08
55-03	9/12/90	NIB	120	142	5/15	5/12

Table 61. (Continued)

Sample Number	Capture Date	Station	Rings	TL	Ring Date	Spawn Date
56-04	9/12/90	NIB	106	115	5/29	5/26
57-39	9/25/90	GOB	161	145	4/17	4/14
58-40	9/25/90	GOB	114	110	6/03	5/31
59-97	7/25/90	PTR	103	77	4/13	4/10
60-95	7/31/90	ALB	91	65	5/01	4/28
61-96	7/25/90	HIS	97	78	4/19	4/16
62-91	7/31/90	BKH	79	65	5/13	5/10
63-92	7/31/90	BKH	82	62	5/10	5/07
64-93	7/31/90	BKH	78	72	5/14	5/11
65-94	7/31/90	BKH	77	77	5/15	5/12
66-98	7/25/90	PQR	64	63	5/22	5/19
67-99	7/25/90	PQR	77	64	5/09	5/06
68-100	7/25/90	PQR	67	74	5/19	5/16
69-101	7/25/90	PQR	74	81	5/12	5/09
70-102	7/25/90	PQR	76	63	5/10	5/07
71-103	7/25/90	PQR	71	59	5/15	5/12
72-104	7/25/90	PQR	72	67	5/14	5/11
73-105	7/25/90	PQR	63	59	5/23	5/20
74-71	8/15/90	BKH	78	65	5/29	5/26
75-72	8/15/90	BKH	79	73	5/28	5/25
76-70	8/08/90	HAP	76	83	5/24	5/21
77-67	8/15/90	NIB	79	85	5/28	5/25
78-69	8/15/90	GOB	82	93	5/25	5/22
79-83	8/07/90	SOV	85	75	5/14	5/11
80-84	8/07/90	SOV	76	75	5/23	5/20
81-62	10/10/90	NIB	133	153	5/30	5/27
82-63	10/10/90	NIB	137	133	5/26	5/23
83-64	10/10/90	NIB	136	147	5/27	5/24
84-65	10/10/90	NIB	163	140	4/30	4/27
85-66	10/10/90	NIB	146	148	5/17	5/14
86-77	8/07/90	BAB	94	98	5/05	5/02
87-78	8/07/90	BAB	107	130	4/22	4/19
88-68	8/08/90	DPI	73	98	5/27	5/24
89-85	7/31/90	BTB	76	63	5/16	5/13
90-59	10/10/90	BTB	139	120	5/24	5/21
91-60	10/10/90	BKH	102	100	6/30	6/27
92-61	10/10/90	BKH	104	115	6/28	6/25
93-79	8/07/90	HIS	93	90	5/06	5/03
94-80	8/07/90	HIS	74	91	5/25	5/22
95-81	8/07/90	HIS	82	81	5/17	5/14
96-82	8/07/90	HIS	86	92	5/13	5/10
97-86	7/31/90	CPC	75	83	5/17	5/14
98-87	7/31/90	CPC	83	78	5/09	5/06
99-88	7/31/90	CPC	75	62	5/17	5/14
100-89	7/31/90	CPC	83	77	5/09	5/06
101-90	7/31/90	CPC	64	60	5/28	5/25
102-73	8/29/90	BKH	94	82	5/27	5/24
103-74	8/29/90	BKH	79	73	6/11	6/08
104-75	8/29/90	BKH	97	82	5/24	5/21
105-76	8/29/90	BKH	102	84	5/19	5/16

Table 62. Spawning date frequency distribution for juvenile striped bass aged by counting daily rings on otoliths.

Week Spawned	Number of Fish	Percent of Total
March 25-31	2	1.98
April 1-7	1	0.99
April 8-14	2	1.98
April 15-21	4	3.96
April 22-28	4	3.96
April 29-May 5	4	3.96
May 6-12	20	19.80
May 13-19	20	19.80
May 20-26	29	28.71
May 27-June 2	4	3.96
June 3-9	5	4.95
June 10-16	3	2.97
June 17-23	1	0.99
June 24-30	2	1.98
Total	101	99.99

Food Habit Analyses of Young-of-Year

Roger A. Rulifson and Drew Bass

Introduction

Two food habit studies on juvenile and adult striped bass have been conducted in the Roanoke/Albemarle system since closure of the Roanoke Rapids Dam in 1955, but prior to the crash of the population in 1978. Trent and Hassler (1968) reported that striped bass fed extensively on blueback herring and alewives in the River. Other fish prey were golden shiner (*Notemigonus crysoleucas*), other minnow species, and gizzard shad (*Dorosoma cepedianum*). Manooch (1973) conducted a seasonal food habit study on Albemarle striped bass. Fish, primarily clupeids, were found in 96.2% of all striped bass examined during the summer. In the fall, clupeids still dominated (64% occurrence), but engraulids (mainly bay anchovies) reached their maximum occurrence in the diet (37.7%). In winter months, invertebrates (primarily amphipods) occurred more frequently in the diet while the presence of forage fish decreased. In the spring, blue crab (*Callinectes sapidus*) was the major prey item found in striped bass collected from eastern Albemarle Sound. Manooch (1973) suggested that the lack of spiny-rayed fish species in the diet was due to the optimum size, schooling nature, and availability of young clupeids and anchovies.

Since the crash of the Roanoke striped bass population in 1978, no food habit studies of juvenile striped bass have been conducted. However, studies on larval striped bass in the Roanoke River in 1984 and 1985 indicated that concentrations of zooplankton, the primary food source, and larval striped bass exhibited a spatio-temporal mismatch in the spring (Rulifson et al. 1988). In 1984, larval striped bass were transported downstream too rapidly by high freshwater discharge and passed through the Roanoke River delta into western Albemarle Sound before first feeding was initiated. In 1985, reduced flow conditions resulted in early zooplankton development downstream but larvae were transported too slowly from upstream spawning areas; thus, first feeding was initiated upstream of the largest zooplankton concentrations.

In the 1980s, a general decline in river herring abundance in Albemarle Sound coincided with the decline in harvestable striped bass within the same area (Winslow 1989). The objective of our study was to examine the food habits of juvenile striped bass recruiting to the year class to ascertain whether food availability may be one factor contributing to poor recruitment.

Methods

In 1989 and 1990, young-of-year (YOY) striped bass were collected at various locations throughout Albemarle Sound by the North Carolina Division of Marine Fisheries during the juvenile trawl and beach seine surveys (Figure 72, Table 60)). In 1989, each fish was preserved in 10% formalin. In 1990, each fish was placed in a bag along with a label bearing the location and date of capture and placed on ice until it could be frozen. At the end of the fall sampling periods in both years, the specimens were transported to East Carolina University for examination. Each fish was measured (TL in mm); in 1990 fish also were weighed (g).

Stomach contents of each fish were examined by excising the digestive tract at the esophagus and anus, placing it on a gridded petri dish, and removing ingested items for enumeration and identification under lower power magnification. Partially digested fish were identified when possible by examining the remaining anatomical features. Otoliths from specimens collected in 1990 were removed to determine birth dates (see age and growth section by Isley and Manooch).

Results

In 1989, approximately 91% (136 of 149) of the striped bass examined contained prey. The two most important food items were zooplankton (copepods, cladocerans, gammarids) and mysid shrimp. Fish collected in July (n = 57) averaged 44 mm TL, ranging from 28 to 57 mm. Zooplankton was present in 62% of the stomachs, followed by 22% unidentified fish and 16% mysid shrimp. August fish (n = 36) averaged 68 mm TL, ranging in size from 57 to 86 mm. Food items present in stomachs were zooplankton (47%), mysid shrimp (36%) and fish (21%). In September, YOY striped bass averaged 82 mm TL, ranging from 70 to 110 mm. Nine of the 10 fish stomachs examined contained mysid shrimp; the remaining stomach contained fish. October fish (n = 37) relied primarily on mysid shrimp (72%) as a food source, but the diet included more fish (28%). Noteworthy is the fact that most YOY fish were concentrated in the eastern portion of Albemarle Sound early in the summer, but the concentration shifted to the western Sound during late summer and fall. Henry (1991, see section on the 1990 JAI) hypothesized that westward movement might coincide with greater concentrations of juvenile fish, especially herring and anchovy, in the western Sound later in the season.

In summary, fish were a minor constituent of prey items of juvenile striped bass in 1989. Most fish could not be identified, but were soft-rayed fishes and were most probably clupeids. In one instance, a striped bass collected in July from Edenton Bay had consumed a minnow. Zooplankton and mysid shrimp comprised the bulk of prey items for smaller juveniles in the summer, with small fishes entering the diet later in the season.

A total of 105 (101 juveniles; 4 yearlings) striped bass were collected and examined in 1990. Of the 52 fish caught in July, only 13% (7 fish) contained empty stomachs. The most abundant food item was zooplankton, which made up 75% of the total diet. The remaining 25% was mysid shrimp. July fish averaged 64 mm TL (43-130 mm) with a mean weight of 3.03 g. Mysid shrimp was the dominant prey for August fish (n=17), present in 70% of stomachs examined. Zooplankton was found in 26% of the stomachs, and only one stomach contained fish prey. August striped bass averaged 84 mm (65-98 mm) and 5.83 g in weight. Only nine fish were captured in September; all stomachs contained food. The primary food item was mysid shrimp, found in 88% of the stomachs. An additional 12% of the stomachs contained unidentified fish, most likely bay anchovy. September striped bass averaged 119 mm (90-145 mm) and 17.24 g. October sampling effort yielded the second highest number of juvenile striped bass in 1990; all 27 fish stomachs contained food. The primary food item shifted from mysid shrimp to bay anchovies, which were found in 70% of the stomachs. Mysid shrimp were found in 30% of all stomachs. September fish ranged in size from 100-283 mm, averaging 143.6 mm and 44.25 g.

Discussion

Adequate food availability at the larval stage of development can be one of the major factors contributing to successful recruitment to the year class (Doroshev 1970, Martin and Malloy 1981). Larvae of many fish species are omnivores, feeding primarily on mobile planktonic invertebrates. Striped bass larvae undergo an ontogenetic shift in diet as they grow, incorporating slightly larger aquatic invertebrates and small fishes (Shapovalov 1936, Ware 1971). Miller (1977) estimated that first-feeding striped bass larvae (5.7 to 6.3 mm TL) search between 0.185 and 0.250 liters of water per hour with a strike efficiency of only 2.0 to 2.6%. By 40 to 50 days post-hatch (22-35 mm TL), striped bass larvae feed readily on plankton and epibenthos including mysids and chironomid larvae (Doroshev 1970).

Food availability, both quantity and quality, may limit the success of a year class of striped bass throughout the year (Kernehan et al. 1981; Setzler-Hamilton et al. 1981; Martin et al.

1985). Juveniles and adults are opportunistic feeders; specific food types depend on the size of the predator to size of prey, habitat, and the season (Rulifson et al. 1982). Juveniles begin to school while foraging (Bowles 1976). Therefore, adequate food concentrations must be available for large schools of juvenile striped bass; food quality, such as prey size, must correlate with juvenile development. YOY striped bass will consume any food of the appropriate size 50 to 60 days post-hatch, but by 80-90 days (50-80 mm TL) juveniles prefer mysids, gammarids, and fish prey up to 20 mm long (Doroshev 1970).

Juvenile diets usually consist primarily of invertebrates, but older individuals become more piscivorous (Hildebrand and Schroeder 1928, Holland and Yelverton 1973, Manooch 1973, Hart 1973). Apparently, older striped bass will rely on invertebrates as the primary food source only under exceptional environmental conditions, such as the surf zone where fish would be more difficult to catch (Schaefer 1970) and the turbid waters of the upper Bay of Fundy in Atlantic Canada (Rulifson and McKenna 1987).

Conclusions

The major food source for young-of-year striped bass in Albemarle Sound in 1989 and 1990 was large zooplankton and invertebrates, with fish comprising a small proportion of total organisms consumed. No information on food abundance was collected, so it is difficult to ascertain whether juvenile striped bass were food limited. Considering that young-of-year striped bass shift diet preference to fish over zooplankton and invertebrates later in the season, we can assume that less than optimal forage fish species were present in western Albemarle Sound in 1989 and 1990.

Larval Striped Bass Abundance and Feeding in the Lower Roanoke River, Delta, and Western Albemarle Sound, 1990

Roger A. Rulifson, John E. Cooper, and Scott F. Wood

Methods

Ichthyoplankton samples were taken by N.C. Wildlife Resources Commission (WRC) personnel at Stations 1-5 (Figure 72) by towing a $0.5m^2$ square-mouth opening Tucker trawl (505u mesh) in an oblique manner for six minutes. Two tows were made at each station. Samples were collected from 1 May to 27 May 1990. East Carolina University (ECU) personnel sampled River Stations 6-13, 15, and 16 (and Station 5 after 27 May 1990) and all Sound stations (Figure 73) by towing paired, conical 0.5-m diameter nets (505u mesh) in an oblique manner for six minutes. Ichthyoplankton samples were preserved with 10% formalin containing Rose Bengal dye.

The sample schedule for each year depended on the level of spawning activity at Barnhill's Landing (RM 117), which is monitored by ECU personnel. In 1990, sampling in the lower River was initiated soon after spawning began at Barnhill's Landing (18 April). Sampling frequency started on a weekly basis at selected stations and increased to include all stations as the spawning level increased. Alternate sampling of River and Sound began after the peak of spawning was observed at Weldon (RM 130), upstream from Barnhill's Landing.

Larvae and small fish were removed from ichthyoplankton samples for identification and enumeration. *Morone* larvae were identified, 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 gut contents. Each prey item was identified to the lowest

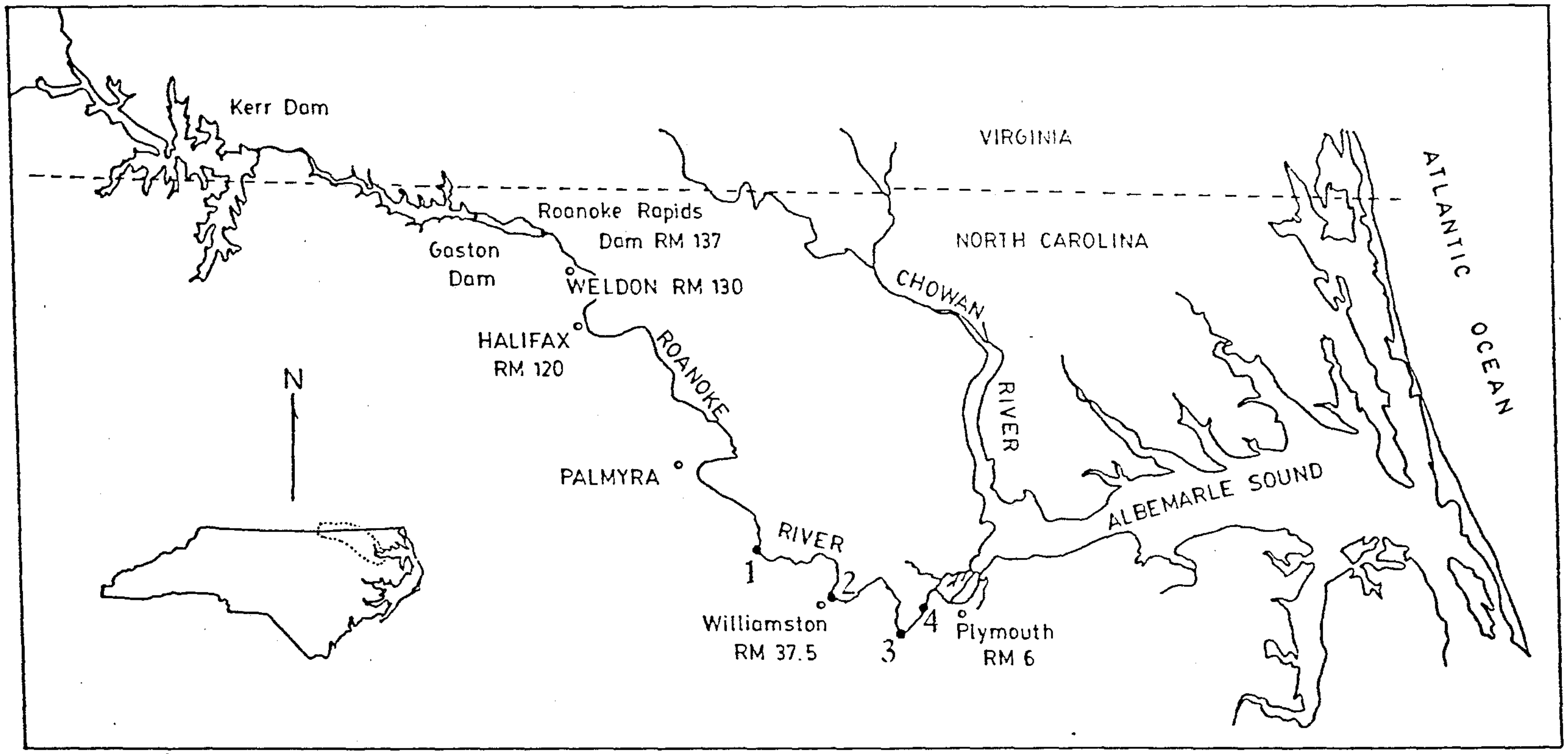


Figure 72. The lower Roanoke River watershed depicting Stations 1-4 used in sampling for phytoplankton, zooplankton, and ichthyoplankton in the spring by the N.C. Wildlife Resources Commission.

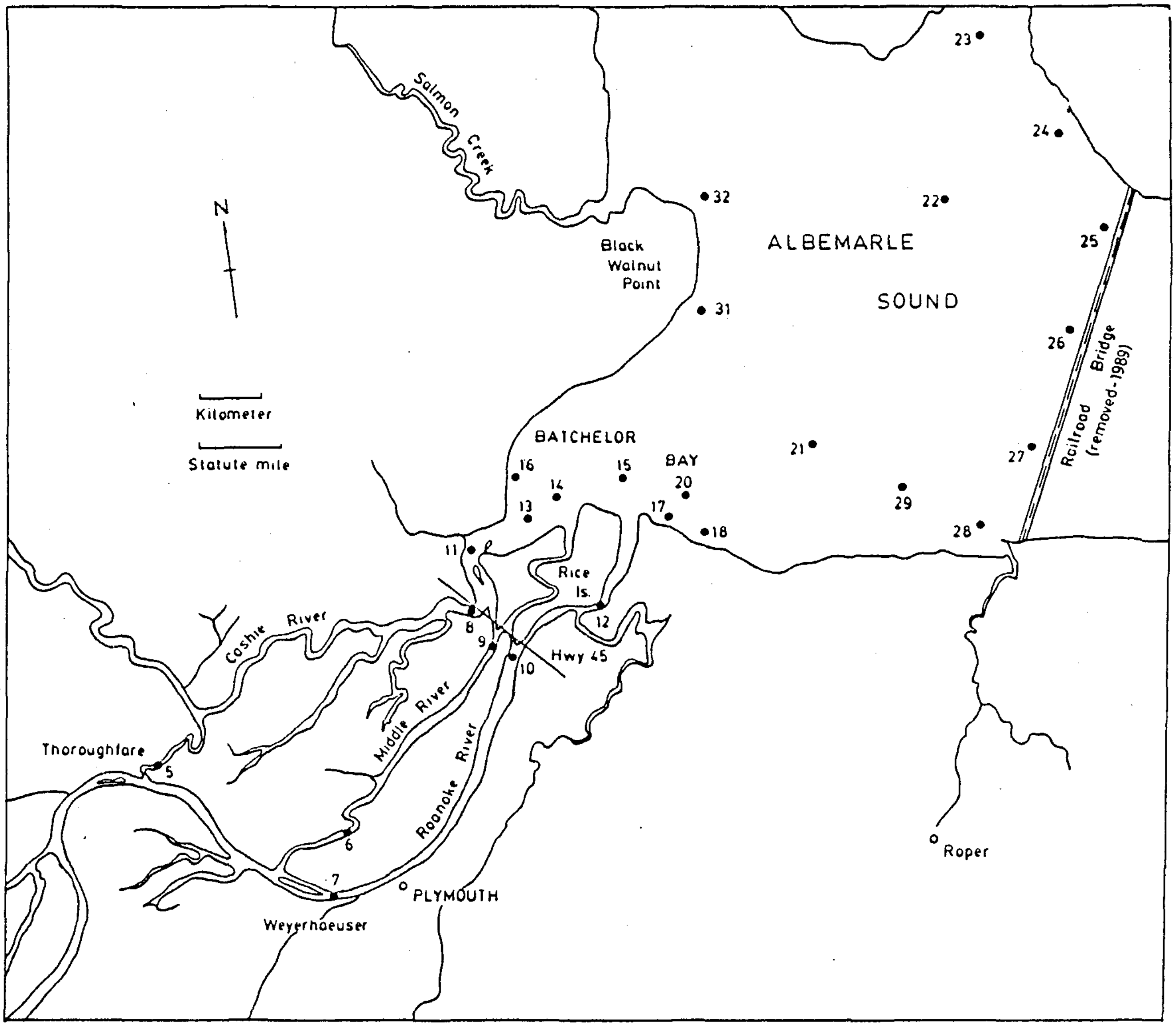


Figure 73. Fixed station array for sampling phytoplankton, zooplankton, and striped bass larvae for 1984-1990.

taxon practical (Gosner 1971, 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 each item and then dividing by the number of fish examined that contained prey.

Results and Discussion

Approximately 1,700 larvae were collected in 1990 at all 25 stations sampled in the lower River, delta, and western Albemarle Sound (Table 63). Approximately 98% of the larvae were collected at River stations and Batchelor Bay; only 26 larvae were caught in western Albemarle Sound. The spatial distribution indicates dispersion and/or mortality; highest larval numbers were collected in the River near Hamilton (Station 1), in the straight section of the main River upstream of the Thoroughfare (Station 4), and in the mainstem adjacent to Weyerhaeuser (Station 7). Also larvae were relatively more abundant at the beginning of Middle River (Station 6) and the companion downstream location (Station 9). Interestingly, few larvae were caught in the Roanoke main stem below Station 7 (Stations 10 and 12). Few larvae were collected in the Cashie River at Station 8, but greater numbers were collected downstream at Station 11 (Table 63). Stations 1, 4, 7, 6, 9, and 11 accounted for 77% of the total larval striped bass collected in 1990.

The total number of striped bass larvae collected in 1990 (1,701) was lower than in 1984 (2,829), 1985 (3,217), and 1986 (12,609).

Differences in catch among locations may be due in part to the River bottom configuration. Stations 2 and 3 are wider; the less directed current may allow larvae to disperse. Stations 4 and 7 are narrower, which confines the current and the larvae within a smaller area. Stations 6 and 9 are located upstream of 90° bends in the Middle River; larvae may tend to pool at the head of the bend.

Two peaks in abundance of larvae were observed in 1990: one large peak representing 60% of the total from 11 May to 18 May, and a smaller peak (22.4%) on 24 May. Twelve sampling trips after 24 May collected only 64 striped bass larvae (3.8% of the total).

Length frequency data indicated that larvae were larger at downstream stations and in Albemarle Sound compared to the most upstream stations sampled (Table 64). Most larvae were between 3.5 and 6.0 mm TL. The largest striped bass collected was 18.5 mm TL at Station 24 on 15 June 1990. A similar length frequency pattern was evident for the Roanoke River, Middle River, and Cashie River.

Feeding of Striped Bass Larvae

In 1990, first-feeding striped bass larvae were caught on 4 May but 75% of fish in feeding condition were found after 23 May, all in Albemarle Sound.

In 1990, few striped bass were collected in feeding condition (23 of approximately 1,700); all but one were found at stations in the western Sound. Samples from the historical nursery area (Black Walnut Point at Stations 31 and 32) had 32% of the total striped bass developed to the point of feeding. The majority (93%) of those collected were small ($\bar{x}$=6.1 mm) and four still contained yolk. One larger larvae (18.5 mm) was collected at Station 24 (Table 64). For those striped bass larvae capable of feeding, the feeding success was high: 71.5% had food in their guts at the time of capture. The major food items (95%) were *Bosmina* sp. and copepodite-stage copepods (Table 65). Those larvae identified as *Morone* sp. were larger ($\bar{x}$=11.2 mm) than *M. saxatilis* ($\bar{x}$=6.1) and were more successful: they captured more than three times as many prey organisms. *Morone* sp. fed exclusively on copepodite-stage copepods. There were too few larvae collected to make any observations on growth.

Table 63. Larval striped bass count data by date and station in the Roanoke River and Albemarle Sound in 1990.

	Station																									
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	18	20	21	22	23	24	26	28	31	32	All
04/25/90	.	.	.	.	.	.	.	.	.	.	.	.	2	.	1	.	.	.	.	.	.	.	.	.	.	3
04/27/90	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
05/01/90	2	1	.	.	.	.	.	.	.	1	2	.	5	.	4	.	.	.	.	.	.	.	.	.	.	17
05/04/90	44	3	.	6	2	.	1	1	2	1	.	3	4	1	1	.	.	.	.	.	.	.	.	.	.	69
05/07/90	29	1	1	7	1	2	3	.	.	2	4	.	8	9	7	.	.	.	.	.	.	.	.	.	.	74
05/11/90	144	20	5	24	4	13	4	2	25	.	48	1	22	.	.	.	.	.	.	.	.	.	.	.	.	312
05/13/90	64	15	4	56	6	32	124	1	67	9	1	12	5	9	8	.	.	.	.	.	.	.	.	.	.	413
05/15/90	124	2	9	6	1	1	3	.	19	.	5	.	.	3	2	.	.	.	.	.	.	.	.	.	.	175
05/18/90	26	4	6	5	.	7	2	.	9	3	44	2	10	2	2	.	.	.	.	.	.	.	.	.	.	122
05/21/90	14	.	1	3	1	4	1	2	15	.	8	13	.	.	.	.	.	.	.	.	.	.	.	.	.	62
05/23/90	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	5	.	7
05/24/90	7	12	5	8	1	117	79	.	63	63	14	4	7	.	1	.	.	.	.	.	.	.	.	.	.	381
05/26/90	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	5	7	.	.	.	.	1	.	.	15
05/27/90	12	5	1	4	.	5	2	.	1	.	2	.	.	3	.	.	.	.	.	.	.	.	.	.	.	5
05/29/90	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	3	1	5
05/30/90	.	.	.	.	.	.	1	.	.	.	.	.	1	2	.	.	.	.	.	.	.	.	.	.	.	4
06/04/90	.	.	.	.	.	3	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	4
06/15/90	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1
All 1990	466	63	32	119	16	184	220	6	201	81	128	36	64	33	26	2	5	7	1	0	1	0	1	8	1	1701

Table 64. Length frequency of striped bass larvae collected at all stations within the Roanoke/ Albemarle Sound system in 1990.

Station	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5+	All
1	4	74	18	1								97
2	0	2	2	33	11	2						50
3	0	0	1	18	9	1						29
4	0	0	1	17	40	42						100
5	0	0	0	1	8	7						16
6	0	0	1	20	63	65	1					150
7	0	0	0	20	76	68						164
8	0	0	0	0	1	3	1					5
9	0	0	1	6	51	83	4					145
10	0	0	0	3	15	51	2					71
11	0	0	0	12	29	33	1					75
12	0	0	0	4	8	20	2					34
13	0	0	0	5	14	15	2	0	1			37
15	0	0	0	0	4	18	3	2				27
16	0	0	0	1	5	17	2					25
18	0	0	0	0	0	2						2
20	0	0	0	0	1	4						5
21	0	0	0	1	2	1						4
22	0	0	0	0	0	0	1					1
23												0
24											(18.5)	1
26												0
28	0	0	0	0	0	1						1
31	0	0	0	0	3	4	1	1				9
32	0	0	0	0	0	0	1					1
All	4	76	24	142	340	437	21	3	1	0	1	1049

Table 65. Larval striped bass feeding in the Roanoke/Albemarle system in 1990. Status 1 = larvae with yolk and oil globule; status 2 = no yolk, may or may not have oil.

							Number of prey per fish						
Date	Station	N	Mean length	Minimum length	Maximum length	Percent with food	Bosmina	Copepodite	Copepod egg	Ostracod	Other cladocerans	Detritus	Other
Status=1													
900504	16	1	6.0	.	.	0	.	.	.	.	.	.	.
900523	31	2	5.8	5.5	6.0	0	.	.	.	.	.	.	.
900527	11	1	6.0	.	.	0	.	.	.	.	.	.	.
		4											
Status=2													
900507	13	1	5.5	.	.	0	.	.	.	.	.	.	.
900513	15	2	6.8	6.5	7.0	0	.	.	.	.	.	.	.
900513	16	3	6.2	6.0	6.5	67	0.5	0.5	0.0	0.0	0.0	0.0	0.0
900523	31	1	6.0	.	.	100	0.0	10.0	0.0	0.0	0.0	0.0	0.0
900526	18	2	6.0	6.0	6.0	100	0.5	0.0	0.0	0.0	1.0	0.0	0.0
900526	21	3	5.5	5.0	6.0	100	3.7	0.0	0.0	0.0	0.0	0.0	0.0
900526	28	1	6.0	.	.	100	2.0	0.0	0.0	0.0	0.0	0.0	0.0
900529	22	1	6.5	.	.	100	1.0	2.0	0.0	0.0	0.0	0.0	1.0
900529	31	3	6.5	6.0	7.0	67	1.0	3.5	0.0	0.0	0.0	0.0	0.0
900529	32	1	6.5	.	.	0	.	.	.	.	.	.	.
900615	24	1	18.5	.	.	100	0.0	125.0	0.0	0.0	4.0	0.0	0.0

PHYTOPLANKTON IN THE ROANOKE RIVER AND WESTERN ALBEMARLE SOUND: 1990

Donald W. Stanley

Methodology

Sampling for phytoplankton and chlorophyll *a* (a measure of phytoplankton biomass) has 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 and 1988). 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). The 1990 chlorophyll *a* data are given in Table 66, and sampling station locations are shown in Figures 72 and 73. Data for previous years can be found in the 1988-1989 Flow Committee Report (Rulifson and Manooch 1990a).

Results

Chlorophyll *a* levels in the lower Roanoke-western Albemarle Sound have ranged generally between 1 and 10 μg/L, with occasional higher values, in the 15-30 μg/L range. While these values are low in comparison to those measured during the summertime in higher salinity estuaries in the State (e.g., the Pamlico and Neuse River estuaries), they are comparable with data from the upper Pamlico River estuary, and the lower Tar River (Stanley 1988). The Roanoke sampling usually ends in late spring, but, based on extrapolation from year-round sampling results for the Tar-Pamlico, the Chowan (Stanley and Hobbie 1981), and other estuaries, chlorophyll *a* levels in the lower Roanoke and western Albemarle Sound probably are highest in the summer and early fall.

In every year since the Roanoke phytoplankton sampling began, species of diatoms and green algae have been the dominant taxa, together making up 80-90% of the total wet weight biomass. The wet weight biomass has generally ranged between 0.5 and 2.0 mg/L. Comparison of these numbers with those from other estuaries indicates that the Roanoke is not very different from these other, mostly low salinity, estuaries. As is the case in the Roanoke, many other systems have a phytoplankton community dominated by diatoms and green algae, both in terms of numbers of taxa, and percentage of total weight biomass.

Relationships between Roanoke River flow and either the chlorophyll *a* concentrations, algal biomass, or algal density are not immediately obvious from an examination of the data. However, we have noticed that most of the higher chlorophyll *a* concentrations at Station 1 seem to follow precipitation events by 3-5 days. This could be interpreted as an indication that algae-rich waters in floodplain swamps are being swept into the River during precipitation events. On the other hand, the 1984 data did suggest that unusually high River flow caused a washout of the phytoplankton that spring. Perhaps statistical tests, such as time-lagged regression analyses, can be made in the future which might elucidate some of the subtleties of the River flow-algae relationship.

Table 66. Chlorophyll a (µg/L) in the Roanoke River and western Albemarle Sound, 1990. Sampling station locations are shown in Figures 72 and 73.

Date	Station						
	1	4	8	15	26	31	Mean
18-Apr-90			3.68				3.68
27-Apr-90			5.29				5.29
01-May-90	4.33		1.44	1.12			2.30
04-May-90	4.17	3.04	1.12	1.00			2.33
07-May-90	7.69	3.36	1.60	1.00			3.41
11-May-90	8.65	6.25	2.40	1.00			4.58
13-May-90	7.37	6.09	2.08	1.00			4.14
15-May-90	6.89	4.81	3.48	1.00			4.05
18-May-90	4.17	3.36	2.40	1.00			2.73
21-May-90	4.65	2.56	2.08	5.08			3.59
23-May-90				1.00	1.00	1.00	1.00
24-May-90	3.36	2.72	2.24	1.00			2.33
26-May-90				1.00			1.00
27-May-90	3.84	2.08	1.76	1.00			2.17
29-May-90				1.00	1.00	1.00	1.00
02-Jun-90			2.24	1.00			1.62
04-Jun-90			2.72				2.72
06-Jun-90			2.72	1.00			1.86
08-Jun-90				1.92		4.17	1.92
10-Jun-90				1.00	7.05	1.00	1.00
13-Jun-90				1.00	1.92	3.68	1.00
15-Jun-90				1.28	2.56	1.60	1.28
17-Jun-90				1.00	4.49	4.65	1.00
Mean	5.51	3.81	2.48	1.27	3.00	2.44	

ZOOPLANKTON ABUNDANCE IN THE LOWER ROANOKE RIVER, DELTA, AND WESTERN ALBEMARLE SOUND, 1990.

Roger A. Rulifson, Scott F. Wood, and Marsha E. Shepherd

Sampling for zooplankton in the lower Roanoke River, delta, and western Albemarle Sound has been conducted since 1984 to gather information on the food chain available to support growth and development of larval fish species using the area as nursery habitat. Collection methods in 1990 were similar to previous years; these methods were described in detail in State reports (Rulifson et al. 1986 and 1988). A fixed station array (Figure 73) was used each year. Some stations were not sampled during certain years. Additional sites (Stations 1-4) upstream were sampled by the N.C. Wildlife Resources Commission (Figure 72).

Zooplankton samples were collected using nets constructed of 250-um nitex mesh material, with a 0.5-m diameter mouth opening and a 1:6 mouth-to-tail ratio. A flowmeter with slow speed propeller (General Oceanics model 2030) was mounted in the net frame to estimate the volume of water filtered. 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.

Zooplankton samples were processed using a standard subsample method. Each sample was diluted to 500 ml. A 5-ml subsample was removed from the sample, and all organisms were identified to the lowest practical taxon and enumerated. This procedure was repeated two more times. The average number of each taxonomic group was reported as number per cubic meter of water filtered.

Sampling in 1990 was initiated on 18 April and was terminated on 17 June. A total of 25 stations were sampled in 1990: 12 stations in the River and delta, three in Batchelor Bay, and 10 in the western Sound beyond Batchelor Bay (Figures 72 and 73).

In 1990, the average abundance of zooplankton was greatest in the Cashie River: Station 8 averaged $959/m^3$ and Station 11 downstream had $590/m^3$ (Table 67). Zooplankton concentrations were lowest in the Roanoke River between Hamilton (Station 1) and just upstream of the Thoroughfare (Station 4); average concentrations increased with distance downstream (Table 67).

The single largest concentration of zooplankton was at Station 8 on 7 May 1990 ($3824/m^3$), which was the result of a swarm of *Daphnia*. A similar high concentration of *Daphnia* was observed at Station 11 on the same date. On 4 May 1990, the second largest concentration ($2110/m^3$) of River zooplankton was observed, this time at Station 12 in the lower Roanoke River. Again, the abundance was the result of a swarm of *Daphnia*. For the study, the most abundant groups of zooplankters in the lower watershed were *Daphnia* (44.8%) and cyclopoid copepods (24.0%). Other important groups included ostracods (2.9%), *Bosmina* (2.8%), rotifers (2.4%), gammarids (1.6%), and "other" cladocerans, primarily *Sididae* and *Chydorinae* (12.0%).

Zooplankton concentrations in western Albemarle Sound were low in April but increased in June 1990 (Table 68). Average abundance was highest at Station 24 ($1128/m^3$), Station 22 ($971/m^3$), and Station 23 ($934/m^3$). The average abundance of zooplankton for western Albemarle Sound was greater than that of Batchelor Bay for nearly all sampling dates (Table 68).

Table 67. Average density (number/m^3) of zooplankton taxonomic groups in the lower Roanoke River and delta, 1990. Stations as in Figures 72 and 73.

YEAR=90 PERIOD=N	STATION												
TAXONOMIC GROUP	1	2	3	4	5	6	7	8	9	10	11	12	AVE.
Aeolosoma	1	0	0	0	1	1	0	0	0	1	1	0	1
Arachnids	0	1	1	1	0	1	0	3	0	0	0	0	1
Biting midge	.	.	.	0	1	0	.	0	0	.	1	0	0
Bivalve	0	1	.	.	0	0	.	.	.	.	.	.	0
Bivalve - larvae	.	.	.	.	.	.	.	0	0	1	.	.	0
Caddisfly larvae	0	1	1	0	0	0	0	0	0	0	1	0	0
Chironimid pupae	.	.	.	.	0	0	0	0	.	.	1	0	0
Chironomid adult	.	.	0	.	.	.	.	.	0	0	.	0	0
Chironomid larvae	.	1	1	2	1	1	1	2	2	2	5	1	2
Clad. - Bosmina	10	12	10	3	8	9	4	26	11	10	10	3	10
Clad. - Daphnia	20	60	94	128	126	185	161	393	126	120	213	213	153
Clad. - Leptodora	0	.	.	.	.	.	0	.	.	.	.	1	0
Cladoceran egg	.	1	.	.	0	.	0	2	0	0	0	1	1
Cladoceran juvenile	0	2	1	1	1	3	2	16	1	1	5	2	3
Cladocerans - other	7	10	49	46	49	40	28	112	26	27	91	18	42
Copepod - nauplius	1	.	.	.	.	.	.	.	.	0	.	.	0
Copepod - Calanoid	6	10	9	13	15	13	11	74	14	8	46	8	19
Copepod - Cyclopoid	20	40	42	55	67	96	68	230	59	47	140	118	82
Copepod - Harpactocoid	.	.	.	0	.	.	.	.	.	.	.	.	0
Copepod egg mass	.	.	.	.	0	0	0	2	.	0	3	.	1
Copepodids	1	0	.	0	.	0	0	4	1	1	2	1	1
Corixidae	.	.	.	.	0	.	.	.	.	.	.	.	0
Dero	.	.	0	1	0	0	.	.	0	0	.	.	0
Dragonfly nymphs	.	.	.	.	0	0	.	.	.	.	0	0	0
Dytiscidae larvae	.	.	.	.	.	.	0	.	.	0	.	.	0
Gammarid egg	.	.	.	.	.	.	.	0	0	.	0	.	0
Gammarids	.	0	0	2	3	5	2	10	13	1	21	5	6
Gyrinidae larvae	.	.	.	.	.	.	.	0	0	.	.	.	0
Hydra	6	6	2	0	1	2	1	0	1	2	.	0	2
Isopods	.	.	.	.	.	.	.	.	.	0	0	0	0
Mayfly nymphs	.	0	.	.	0	0	0	0	0	0	.	.	0
Mosquito larvae	.	0	.	0	0	.	.	.	0	.	.	.	0
Nematodes	.	.	.	.	.	0	.	.	.	0	.	.	0
Order Diptera	.	.	.	.	.	.	.	.	.	0	.	0	0
Order Odonata	.	.	.	.	.	.	.	.	.	0	.	.	0
Ostracods	1	3	6	5	5	13	6	44	5	4	20	5	10
Phantom midge larvae	.	0	1	1	0	0	1	6	0	0	3	3	2
Phantom midge pupae	.	.	0	.	0	0	0	1	0	.	0	0	0
Rotifer - colonial	.	.	0	0	1	1	1	0	0	1	0	1	1
Rotifer - single	2	12	2	3	5	3	1	28	2	1	25	8	8
Stylaria	.	.	0	0	0	2	1	3	1	0	4	1	1
Thysanoptera (thrip)	.	.	0	.	0	.	.	.	0	.	.	.	0
Unidentified	0	0	0	0	1	0	.	0	0	0	0	0	0
Total density (/m3)	75	160	220	262	289	377	291	959	264	230	590	391	342
Avg. volume sampled (m3)	19	19	20	21	21	23	22	22	24	23	21	23	21
(n) Dates sampled	10	10	10	9	10	13	13	15	15	16	14	14	149

Table 68. Average density (number/m^3) of zooplankton taxonomic groups in Batchelor Bay (Stations 13-15) and western Albemarle Sound, 1990. Stations as in Figure 73.

YEAR=90 PERIOD=N	STATION																
TAXONOMIC GROUP	13	14	15	16	17	18	20	21	22	23	24	26	28	31	32	AVE1	AVE2
Aeolosoma	0	.	.	0	.	.	0	.	.	.	.	.	.	0	.	0	0
Arachnids	1	.	0	0	.	2	0	1	1	.	0	1	1	1	2	0	1
Biting midge	0	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Bivalve	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	0
Bivalve - larvae	1	.	0	1	.	.	.	.	.	.	.	.	.	.	.	1	.
Caddisfly larvae	0	.	0	0	.	0	.	.	.	.	1	.	.	.	.	0	0
Chironimid pupae	0	.	0	0	.	0	0	.	.	.	.	.	.	6	.	0	2
Chironomid adult	.	.	0	0	.	0	.	.	.	0	.	.	1	.	.	0	0
Chironomid larvae	2	.	1	2	.	0	0	.	.	0	.	.	.	14	1	2	3
Clad. - Bosmina	18	.	8	13	.	9	6	2	14	4	10	11	4	7	6	13	7
Clad. - Daphnia	159	.	71	198	.	41	68	69	2	0	2	6	24	32	14	143	26
Clad. - Leptodora	.	.	.	0	.	2	2	6	156	85	61	86	28	76	74	0	58
Cladoceran egg	0	.	.	0	.	0	.	.	.	.	.	.	.	.	.	0	0
Cladoceran juvenile	5	.	1	3	.	.	1	.	0	0	0	.	0	.	0	3	0
Cladocerans - other	62	.	22	32	.	34	20	13	84	87	109	35	36	26	63	39	51
Collembola larvae	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Copepod - nauplius	.	.	0	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Copepod - Calanoid	45	.	14	58	.	22	15	14	24	11	8	6	8	12	12	39	13
Copepod - Cyclopoid	143	.	61	108	.	148	58	52	677	733	886	309	215	169	555	104	380
Copepod egg mass	0	.	0	2	.	1	0	.	.	.	.	.	.	.	.	1	1
Copepodids	1	.	1	2	.	.	.	0	.	.	.	.	.	.	.	1	0
Corixidae	.	.	.	.	.	0	0	.	.	.	.	.	.	.	.	.	0
Cumacean	.	.	.	.	.	.	.	.	.	0	.	.	.	.	.	.	0
Dragonfly nymphs	0	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.
Dytiscidae larvae	.	.	.	0	.	.	0	.	.	.	.	.	.	.	.	0	0
Gammarid egg	.	.	.	1	.	.	.	.	.	0	.	.	.	.	.	1	0
Gammarids	33	.	11	9	.	14	3	19	1	3	2	3	18	6	4	18	7
Gyrinidae larvae	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	0	.
Hydra	0	.	0	.	.	.	0	.	.	.	.	.	.	.	.	0	0
Isopods	.	.	0	.	.	.	0	0	0	1	1	1	1	.	1	0	1
Mayfly nymphs	.	.	0	0	.	.	.	0	1	1	39	.	.	.	0	0	8
Nematodes	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.	.	0
Order Diptera	.	.	.	.	.	.	.	1	.	.	.	.	0	.	.	.	1
Ostracods	9	.	3	5	.	1	2	1	1	0	2	1	1	1	1	5	1
Phantom midge larvae	2	.	1	2	.	1	0	.	8	7	6	1	1	0	4	1	3
Phantom midge pupae	0	.	0	0	.	.	.	.	0	0	.	.	.	.	.	0	0
Rotifer - colonial	0	.	0	.	.	.	0	.	.	.	.	.	.	.	.	0	0
Rotifer - single	4	.	1	4	.	0	1	1	0	.	.	.	0	.	.	3	0
Stylaria	2	.	2	1	.	0	0	.	.	.	.	.	.	.	.	2	0
Thysanoptera (thrip)	.	.	.	0	.	.	.	.	.	.	.	.	.	.	.	0	.
Unidentified	0	.	1	0	.	.	.	.	.	0	.	.	.	.	.	0	0
Total density (/m3)	489	.	199	442	.	277	178	180	971	934	1128	460	338	350	737	377	555
Avg. vol. sampled (m3)	24	.	23	24	.	25	25	23	27	25	24	24	23	24	25	24	24
(n) Dates sampled	14	.	18	13	.	7	6	6	6	6	6	5	6	7	7	45	62

The largest single concentration of zooplankton ($2351/m^3$) in western Albemarle Sound occurred at Station 24 on 10 June 1990 (Table 68). Cyclopoid copepods dominated the sample. In Batchelor Bay, the greatest single zooplankton ($1105/m^3$) was at Station 16, dominated by both *Daphnia* and cyclopoid copepods.

The dominant groups of zooplankton were different between Batchelor Bay and western Albemarle Sound. Overall, the most abundant zooplankters in Batchelor Bay were *Daphnia* (37.6%), cyclopoid copepods (27.8%), calanoid copepods (10.0%), and other cladocerans (10.4%). Gammarids (4.8%) and *Bosmina* (3.5%) also were important. In the western Sound, cyclopoid copepods were clearly dominant, representing 68.3% of all zooplankton (Table 68). *Leptodora*, a predatory cladoceran, comprised 10.3% of all zooplankton. Other important zooplankters included *Daphnia* (4.8%), calanoid copepods (2.4%), gammarids (1.3%), *Bosmina* (1.3%), and "other" cladocerans (9.1%).

WILDLIFE RESOURCES

Impacts on Wild Turkey

Michael H. Seamster

Periodic extended flooding of the Roanoke River Basin has been suspected of causing 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 recently completed three-year research project, conducted jointly by the North Carolina Wildlife Resources Commission (WRC) and North Carolina State University (Cobb 1990), on the effects of flooding on wild turkey populations verifies that there is a significant adverse effect of such flooding on wild turkey populations.

Personal communication from WRC personnel working in the area of the Roanoke River indicates that the water level fluctuated severely during 1990. As I understand it, the Roanoke River bottomland was flooded during the early part of the year (January - February), was flooded a second time from early May until early July, and again from early October until late November. Since the previously mentioned research project has been completed, the total impact of the 1990 River conditions cannot be specifically documented. However, data gathered during the recent three-year study allows several conclusions to be drawn on the impacts of this year's floods.

The most immediate effect of the 1990 floods was on wild turkey hunting. Since most of the lowground was flooded in early May while the wild turkey hunting season was in progress, hunting was certainly affected.

Undoubtedly, this year's floods adversely impacted wild turkey populations in the Roanoke River Basin. Obviously, during flooded conditions wild turkeys were displaced out of lowground habitats in which they would normally be found. Beyond displacement, reproduction was certainly affected. During 1986, when no floods occurred, 85% of the documented nesting took place in habitats that would be inundated during floods. Approximately 65% of the habitats utilized as brood range would have been inundated during flooding. These lowground habitats, where most of the wild turkey nesting and brood rearing takes place, were inundated from early May until early July.

Conclusions can be drawn from the effects similar floods have had in the past. In 1986, when no flooding occurred, an average of 3.03 poults per hen was recorded. In 1987, when flood conditions occurred throughout most of the spring and early summer, an average of only 0.14 poults per hen was recorded. One would surmise that the worst possible scenario would be for the River to flood after wild turkey egg laying and/or incubation has already begun. This appears to have been the case during 1990.

The most significant effect of this year's flood may be the fact that it so closely follows the 1987 and 1989 floods, making three of the last four years that reproduction has been affected. The use of population modeling techniques utilizing the data gathered during the three-year study indicates it takes four to five years for a wild turkey population to fully recover from the adverse effects on reproduction caused by flooding. Basically, an entire age class is lost from the population. The fact that this year's flood conditions closely follow the 1987 and 1989 floods greatly compounds the problem. The population had not fully recovered from the effects of these previous floods. Therefore, this year's flood conditions become even more damaging.

I am also concerned about the flooding during the October-November period. The most significant impact of the fall flooding on wild turkeys is the reduction of feeding areas containing hard mast. The availability of hard mast affects wild turkey condition and, subsequently, productivity the following spring.

In summary, flood conditions along the Roanoke River during 1990 undoubtedly affected reproduction for the third time in the last four years and will certainly affect the condition in which turkeys enter the 1991 breeding season. Therefore, I feel the 1990 flood conditions were obviously detrimental to the wild turkey population in the area.

Impacts on Deer

J. Scott Osborne

Information I obtained from Wildlife Resources Commission personnel who frequently work in the area of the Roanoke River indicates that a large portion of the River was at flood stage during the following periods: January through February; early May to the first of July; and early October to the end of November.

As I have mentioned in previous reports, the high water levels in the floodplain during the period of May to the middle of June correspond with the peak fawning period for white-tailed deer. The displacement of pregnant does just prior to fawning is most certainly detrimental to survival of fawns and has the potential for long-term displacement of resident deer of all ages and both sexes. Deer must disperse from the lowground to adjacent higher grounds and this often results in elevated depredations of recently planted row crops (e.g., soybeans, and peanuts).

The fall flooding again coincided with the deposition of acorns and other mast in mid to late September. This resulted in large areas being unavailable for foraging by deer (and wild turkeys) at a time when lipogenesis is needed to ensure that productivity, survival, and overall condition remain good through the winter and spring months.

The high water levels also resulted in the cancellation of several of our managed hunts during the early deer season. The inability of sportsmen to harvest deer and to obtain recreation was again a hindrance to successful management during the 1990 hunting season.

Although deer numbers remain high in the general area of the Roanoke River, I would have to conclude that water levels during 1990 were deleterious to the herds. Displacement of deer, lower condition levels, concentration of parasite and disease organisms, high fawn mortality, and increased crop depredation have all been shown to occur in riverbottom habitats where prolonged flood waters exist. Flow conditions along the Roanoke during 1990 were such that any or all of the above factors could have been enhanced because of the duration and intensity of flooding during the last year.

Impacts on Waterfowl

Dennis Luszcz

Flow regimes in the Roanoke River Basin can have a tremendous impact on waterfowl populations, both migrant and resident. The timing of flooding events and severity of floods effect habitat quality directly and habitat quality relates to numbers of birds present, their physical condition, and their productivity.

Winter flooding, December through March, makes the bottomlands available to ducks in the wintering period, and recharges permanent swamp basins for the summer which benefits local breeding populations, particularly wood ducks. Summer floods can be deleterious to fall and winter food resources, both from stressing and ultimately killing mast producing trees and from over-flooding of moist soil, seed producing herbaceous plants. Impacts on invertebrate populations, which are a major waterfowl food resource in swamps, may also be significant.

The spring flooding in 1990 extended well into June. Wood duck breeding appeared to benefit from the availability of water. It is not known what effect the high water during the post-hatching period had on brood survival, but good numbers of young wood ducks appeared to be available. Conditions were very dry in mid to late summer; however, a minimal amount of brood habitat appeared to remain.

The heavy flooding which occurred in early fall is of great concern in respect to over-wintering waterfowl populations. Early flooding undoubtedly reduced the amount of seeds of smartweed, wild millet, and similar plants which will be available. Flooding occurred before seed was formed in many species and the quality of seed already produced was probably impacted by the high water.

Prolonged flooding during the growing season is known to adversely impact growth, seed production, health, and even survival of mast producing species of hardwoods. During the last few years, summer flooding of the Roanoke Bottomlands has been frequent and prolonged. This flooding must be controlled if resources dependent on the hardwood forest are to remain productive.

Finally, flood waters receded at the very time (late November) when migrant waterfowl populations are expected to arrive. Only semi-permanent swamp basins continue to hold adequate surface water for wintering waterfowl.

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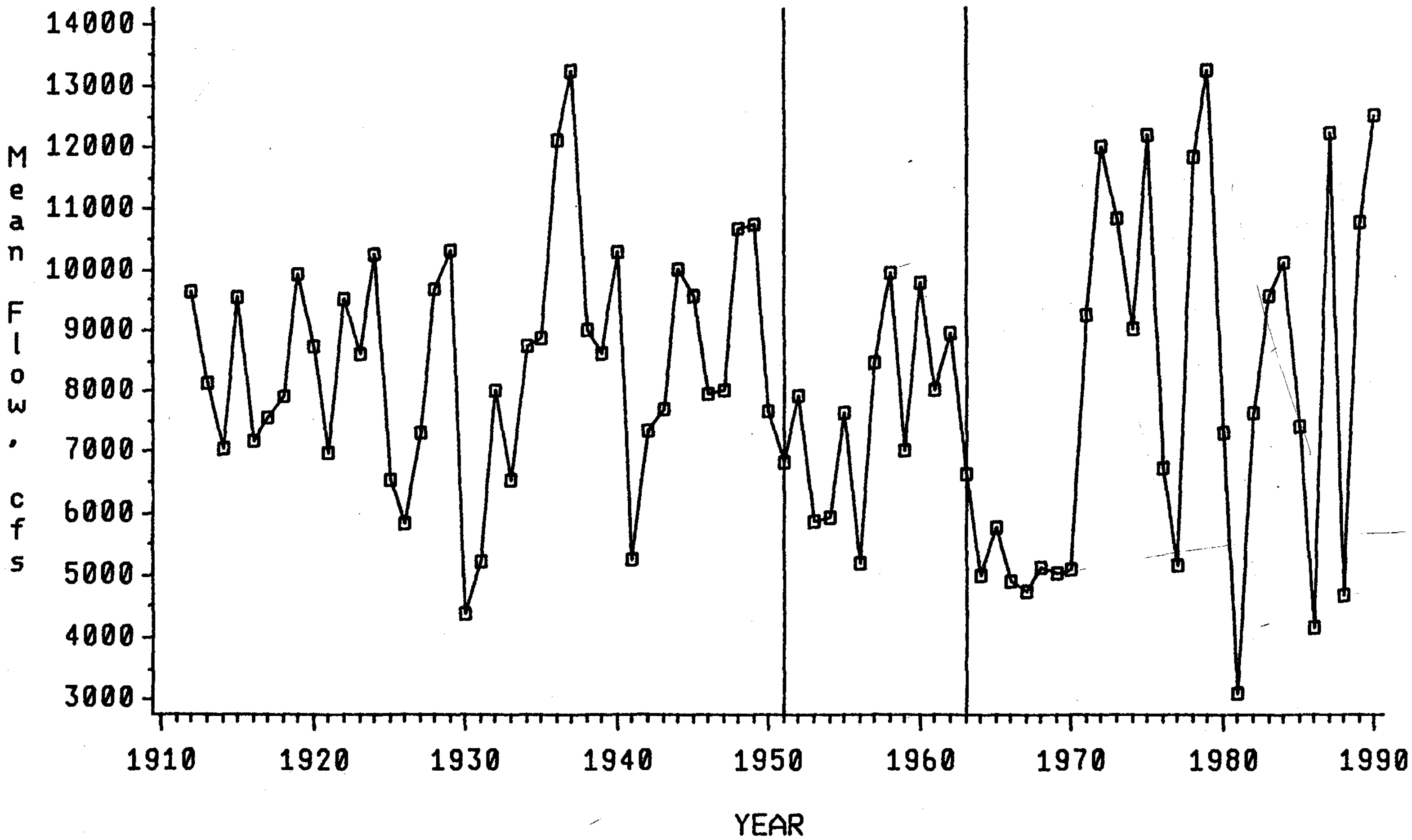
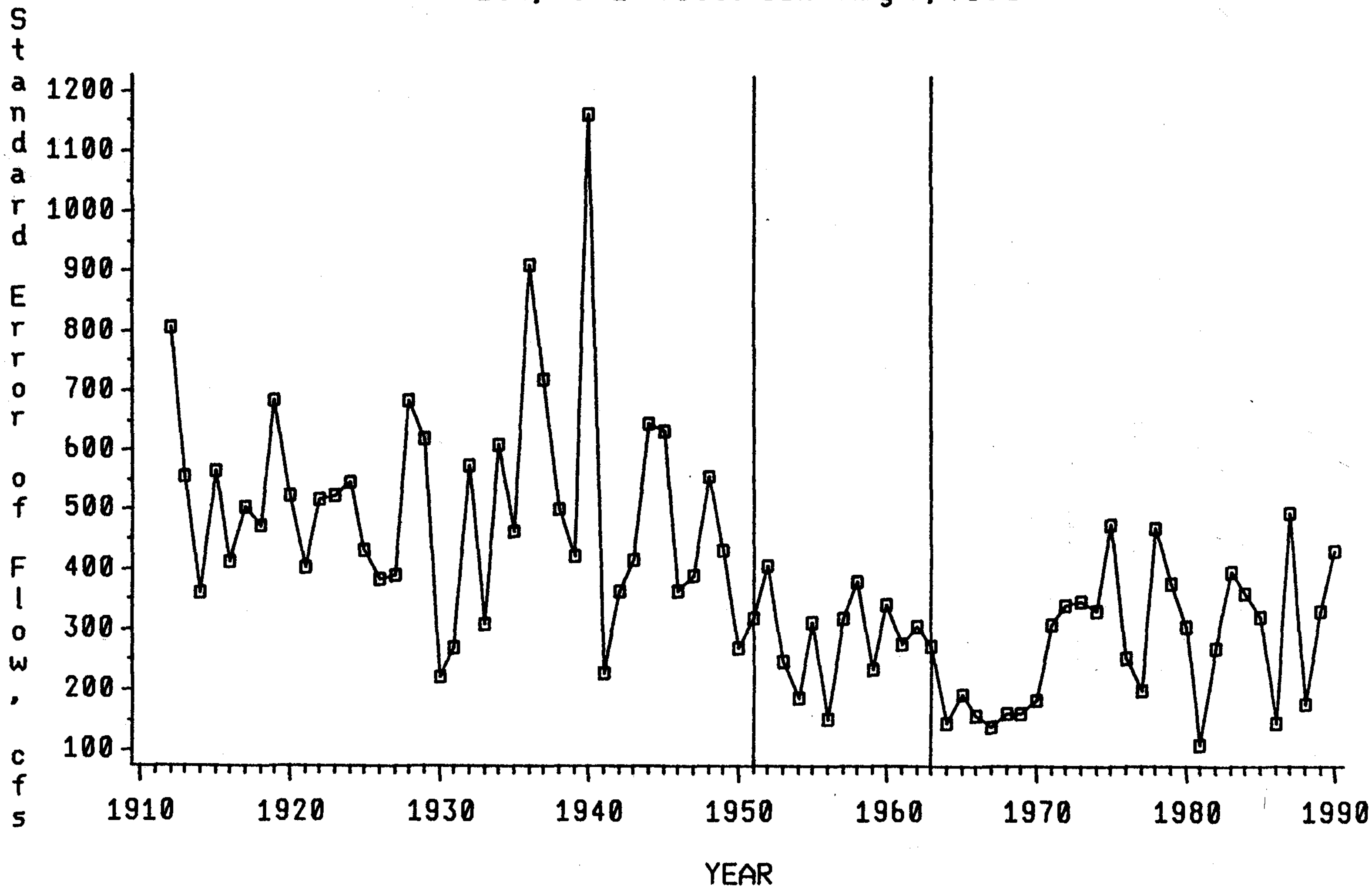
APPENDIX A-1.

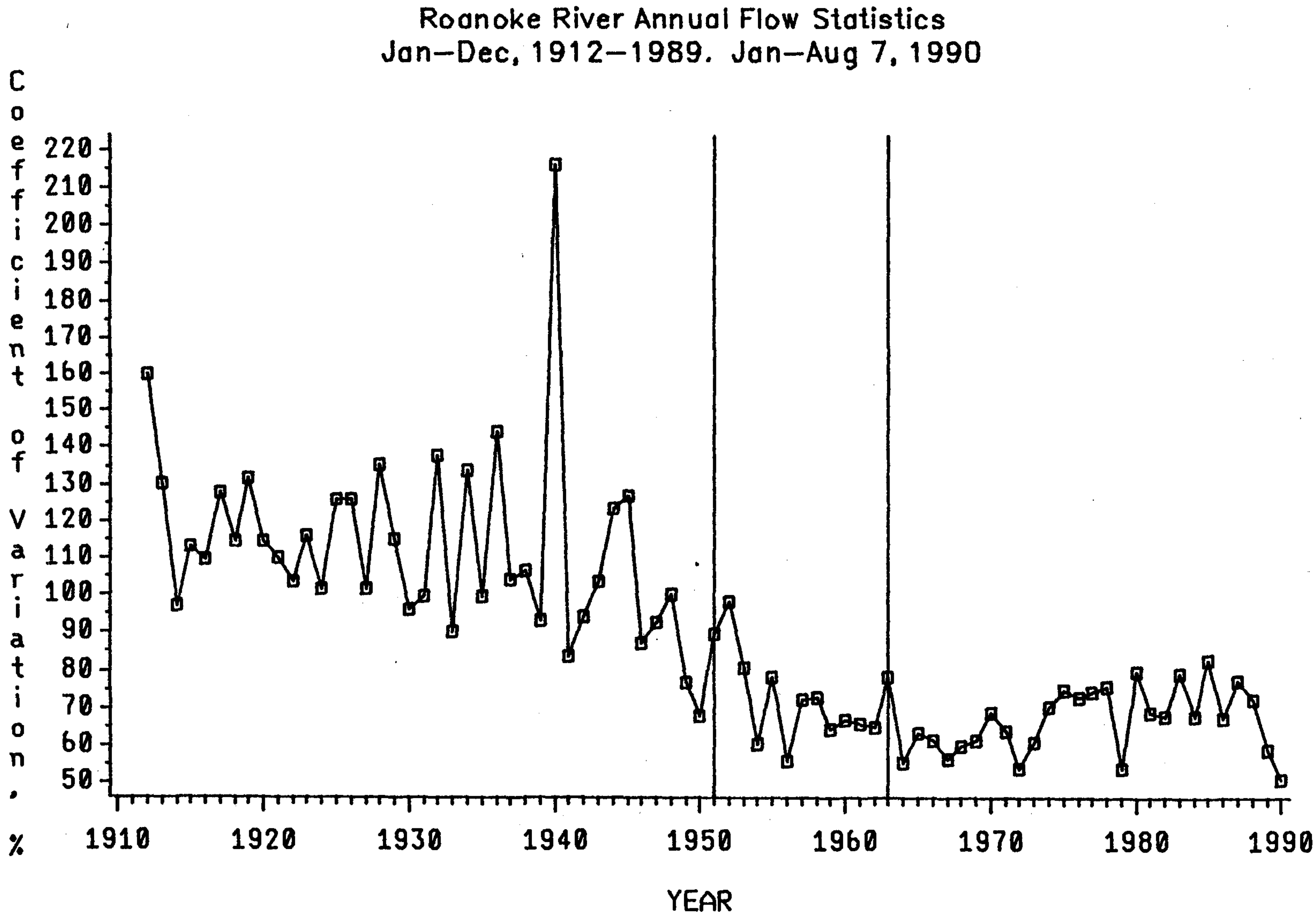
Roanoke River Annual Flow Statistics for 12 months, January through December 1912-1989, and January through August 7, 1990.

Roanoke River Annual Flow Statistics
Jan—Dec, 1912—1989. Jan—Aug 7, 1990



Roanoke River Annual Flow Statistics
Jan—Dec, 1912—1989. Jan—Aug 7, 1990




Roanoke River Annual Flow Statistics
Jan–Dec, 1912–1989. Jan–Aug 7, 1990
Coefficient of Variation, %
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
1910
1920
1930
1940
1950
1960
1970
1980
1990
YEAR

RR90PG06: ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990
ANNUAL DATA (JAN-DEC)

OBS	RANK MEAN FLOW	YEAR	MEAN FLOW CFS	RANK STDERR FLOW	YEAR	STDERR FLOW CFS	RANK CV %	YEAR	COEFF VAR %
1	1	1937	13230.6	1	1940	1161.51	1	1940	216.140
2	2	1979	13220.3	2	1936	912.22	2	1912	159.903
3	3	1990	12479.0	3	1912	806.04	3	1936	144.252
4	4	1987	12212.8	4	1937	719.83	4	1932	137.651
5	5	1975	12161.5	5	1919	685.08	5	1928	135.143
6	6	1936	12098.2	6	1928	683.16	6	1934	133.543
7	7	1972	11961.7	7	1944	645.67	7	1919	131.872
8	8	1978	11830.8	8	1945	633.05	8	1913	130.402
9	9	1973	10816.5	9	1929	619.46	9	1917	127.610
10	10	1989	10746.7	10	1934	611.16	10	1945	126.636
11	11	1949	10720.5	11	1932	574.97	11	1926	125.886
12	12	1948	10672.8	12	1915	563.99	12	1925	125.608
13	13	1929	10298.0	13	1948	557.10	13	1944	123.544
14	14	1940	10280.8	14	1913	554.30	14	1923	115.993
15	15	1924	10254.7	15	1924	545.74	15	1929	114.923
16	16	1984	10090.8	16	1920	524.16	16	1920	114.560
17	17	1944	9998.4	17	1923	522.24	17	1918	114.232
18	18	1919	9925.2	18	1922	515.96	18	1915	113.103
19	19	1958	9915.3	19	1917	505.22	19	1921	109.933
20	20	1960	9772.7	20	1938	501.55	20	1916	109.322
21	21	1928	9670.9	21	1987	493.96	21	1938	106.668
22	22	1912	9643.6	22	1975	475.68	22	1937	103.944
23	23	1945	9550.5	23	1918	473.27	23	1922	103.688
24	24	1983	9534.0	24	1978	470.33	24	1943	103.377
25	25	1915	9526.7	25	1935	461.49	25	1924	101.812
26	26	1922	9506.8	26	1990	430.86	26	1927	101.392
27	27	1971	9213.5	27	1949	430.80	27	1948	99.861
28	28	1974	9011.2	28	1925	429.63	28	1935	99.476
29	29	1938	8983.1	29	1939	419.85	29	1931	99.357
30	30	1962	8940.1	30	1943	415.90	30	1952	98.035
31	31	1935	8863.2	31	1916	409.99	31	1914	97.251
32	32	1920	8753.3	32	1952	405.16	32	1930	96.243
33	33	1934	8743.5	33	1921	401.05	33	1942	94.350
34	34	1939	8622.2	34	1983	395.61	34	1939	93.030
35	35	1923	8601.8	35	1947	388.45	35	1947	92.705
36	36	1957	8445.9	36	1927	387.65	36	1933	90.243
37	37	1913	8120.9	37	1926	383.79	37	1951	89.710
38	38	1947	8005.3	38	1958	378.03	38	1946	87.131
39	39	1961	7994.2	39	1979	375.40	39	1941	83.512
40	40	1932	7991.1	40	1946	362.36	40	1985	82.935
41	41	1946	7945.4	41	1942	361.73	41	1953	80.857
42	42	1918	7915.2	42	1984	359.22	42	1980	79.838
43	43	1952	7906.4	43	1914	359.03	43	1983	79.275
44	44	1943	7686.2	44	1973	346.52	44	1963	78.298
45	45	1950	7667.1	45	1960	341.83	45	1955	78.091
46	46	1955	7623.3	46	1972	339.29	46	1987	77.272
47	47	1982	7612.6	47	1974	332.54	47	1949	76.772
48	48	1917	7563.8	48	1989	332.42	48	1978	75.951
49	49	1985	7391.8	49	1985	320.88	49	1975	74.727
50	50	1942	7324.8	50	1957	319.74	50	1977	74.571
51	51	1980	7307.5	51	1951	319.58	51	1958	72.839

RR90PG06: ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990
ANNUAL DATA (JAN-DEC)

OBS	RANK MEAN FLOW	YEAR	MEAN FLOW CFS	RANK STDERR FLOW	YEAR	STDERR FLOW CFS	RANK CV %	YEAR	COEFF VAR %
52	52	1927	7304.25	52	1955	311.598	52	1976	72.6479
53	53	1916	7174.78	53	1971	309.383	53	1957	72.3259
54	54	1914	7053.07	54	1933	307.683	54	1988	72.3226
55	55	1959	7022.71	55	1980	304.956	55	1974	70.5038
56	56	1921	6969.67	56	1962	304.031	56	1970	68.8454
57	57	1951	6805.97	57	1961	276.674	57	1981	68.7901
58	58	1976	6714.67	58	1963	272.168	58	1984	68.1036
59	59	1963	6640.99	59	1950	271.906	59	1982	67.9269
60	60	1925	6534.60	60	1931	271.864	60	1950	67.7536
61	61	1933	6513.84	61	1982	270.663	61	1986	67.2981
62	62	1954	5909.78	62	1976	254.981	62	1960	66.9162
63	63	1953	5860.66	63	1953	248.037	63	1961	66.1214
64	64	1926	5824.62	64	1959	236.238	64	1962	64.9716
65	65	1965	5764.45	65	1941	229.088	65	1959	64.2676
66	66	1941	5240.85	66	1930	221.498	66	1971	64.1529
67	67	1931	5227.59	67	1977	200.879	67	1965	63.6373
68	68	1956	5176.14	68	1965	192.010	68	1969	61.5834
69	69	1977	5146.52	69	1954	186.766	69	1966	61.5280
70	70	1968	5117.47	70	1970	183.330	70	1973	61.2043
71	71	1970	5087.50	71	1988	176.467	71	1954	60.3771
72	72	1969	5031.84	72	1969	162.198	72	1968	60.0382
73	73	1964	4999.51	73	1968	160.599	73	1989	59.0954
74	74	1966	4893.73	74	1966	157.604	74	1967	56.3658
75	75	1967	4742.87	75	1956	151.725	75	1956	56.0780
76	76	1988	4667.99	76	1986	146.430	76	1964	55.7399
77	77	1930	4396.90	77	1964	145.664	77	1972	54.2639
78	78	1986	4156.94	78	1967	139.930	78	1979	54.2503
79	79	1981	3094.66	79	1981	111.427	79	1990	51.0946

APPENDIX A-2.

Roanoke River Annual Flow Statistics, Mean Flows by Quarter, January through December, 1912-1989, and January through August 7, 1990.

Roanoke River Annual Flow Statistics
Jan–Dec, 1912–1989. Jan– ~~Statistics~~ to August 7, 1990
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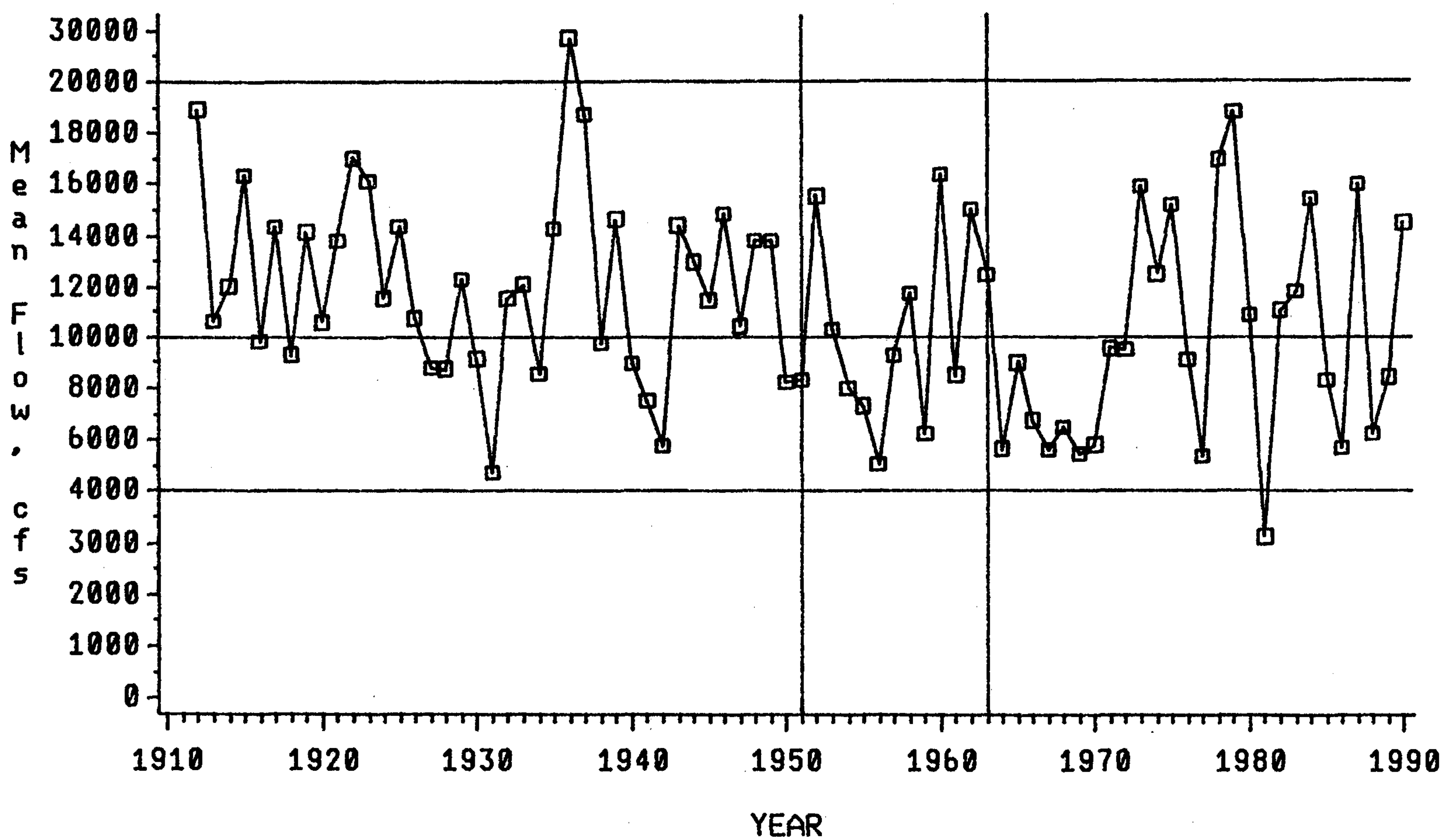

Roanoke River Annual Flow Statistics
Jan—Dec, 1912—1989. Jan— ~~Statistics~~ to August 7, 1990
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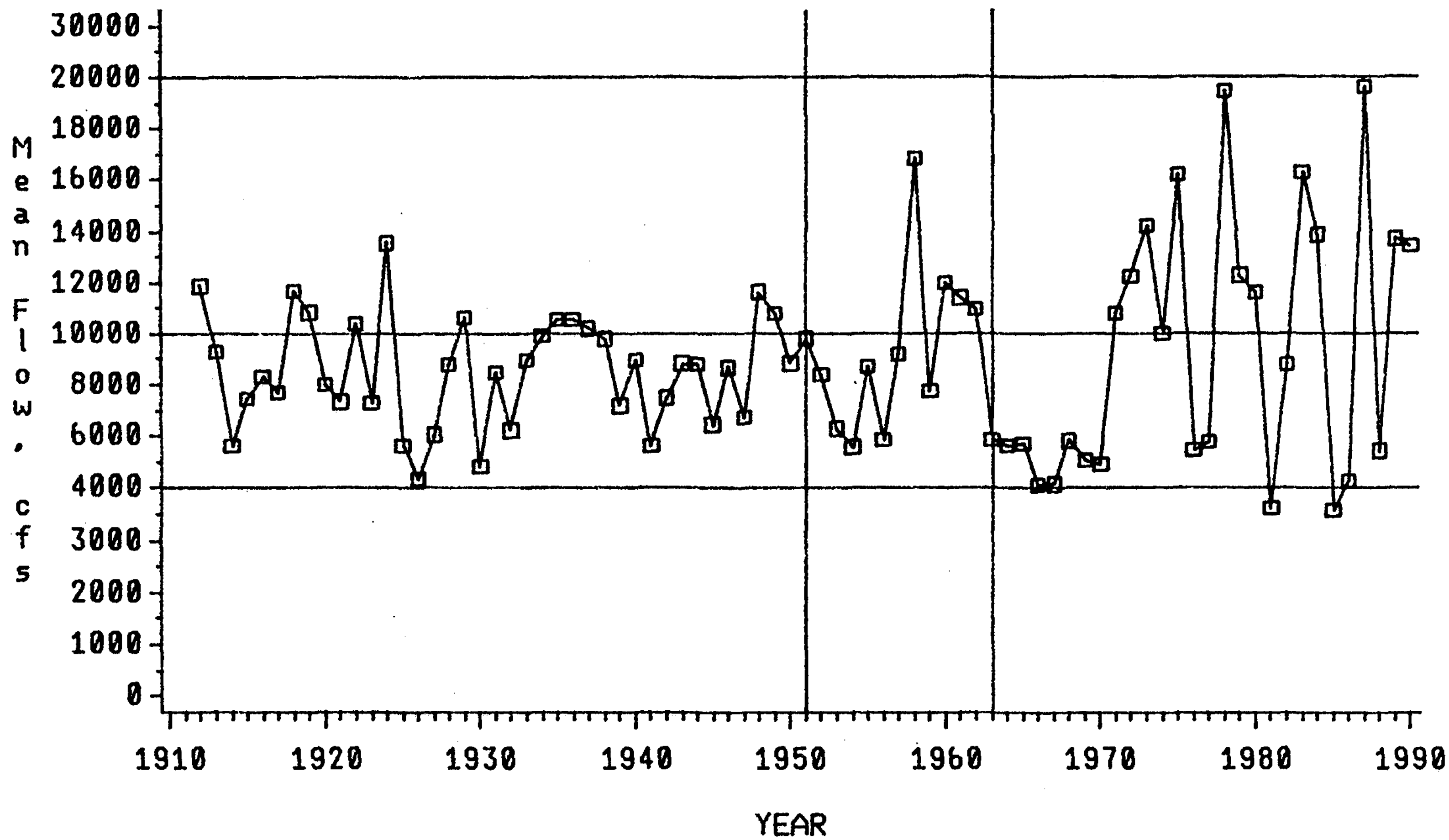

Roanoke River Annual Flow Statistics

Jan—Dec, 1912—1989. Jan— ~~Statistics~~ *to August 7, 1990*

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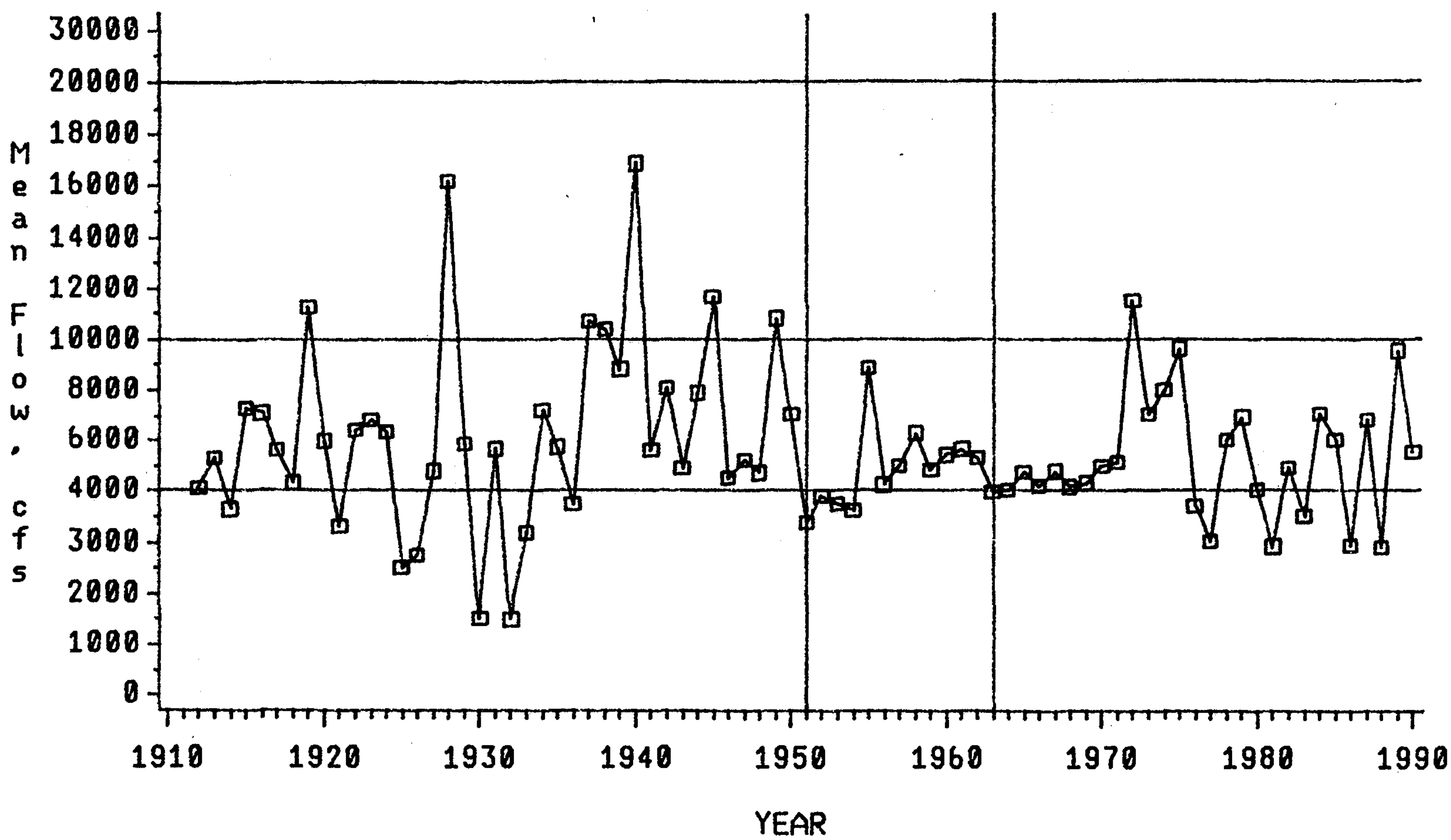

258

Roanoke River Annual Flow Statistics
Jan—Dec, 1912—1989. Jan— ~~Statistics~~ *to August 7, 1990*
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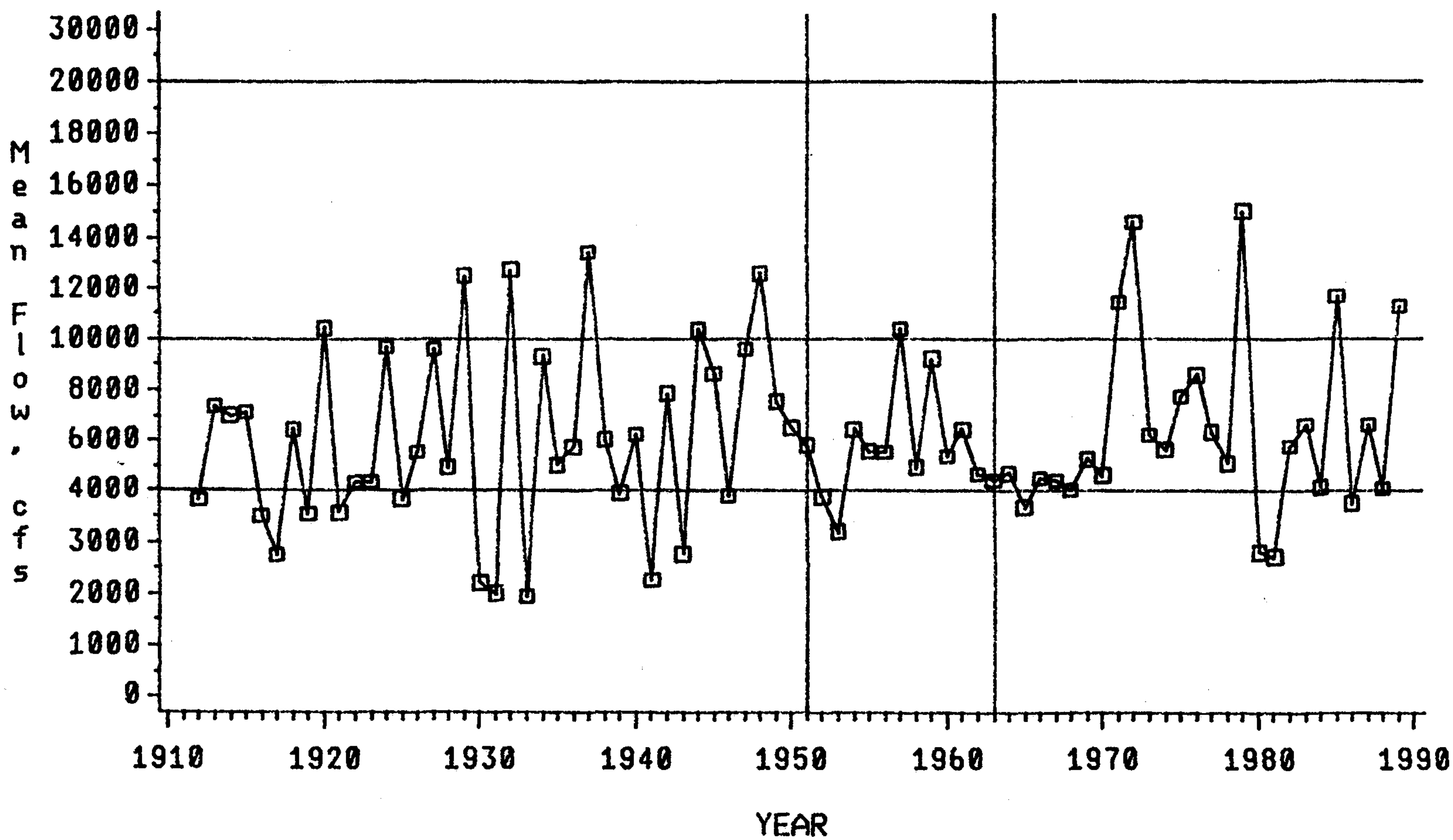

RR90PG06: ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990
RANKS BASED ON QUARTERLY MEAN FLOW

OBS	QT1RANK	QT1YEAR	QT1MEAN	QT2RANK	QT2YEAR	QT2MEAN	QT3RANK	QT3YEAR	QT3MEAN	QT4RANK	QT4YEAR	QT4MEAN
1	1	1936	28505.3	1	1987	19596.4	1	1940	16877.3	1	1979	15031.8
2	2	1912	18920.5	2	1978	19467.6	2	1928	16188.5	2	1972	14598.0
3	3	1979	18789.2	3	1958	16804.2	3	1945	11675.8	3	1937	13411.7
4	4	1937	18715.8	4	1983	16278.4	4	1972	11498.6	4	1932	12726.4
5	5	1922	17031.8	5	1975	16207.3	5	1919	11284.2	5	1948	12575.1
6	6	1978	16933.4	6	1973	14225.2	6	1949	10815.5	6	1929	12492.3
7	7	1960	16366.4	7	1984	13836.5	7	1937	10688.8	7	1985	11654.5
8	8	1915	16346.4	8	1989	13698.7	8	1938	10389.9	8	1971	11409.0
9	9	1923	16084.0	9	1924	13527.5	9	1975	9634.1	9	1989	11263.0
10	10	1987	15930.1	10	1990	13385.9	10	1989	9550.2	10	1920	10430.5
11	11	1973	15892.3	11	1979	12241.6	11	1955	8888.7	11	1957	10387.0
12	12	1952	15517.5	12	1972	12197.3	12	1939	8835.8	12	1944	10351.4
13	13	1984	15408.4	13	1960	11982.7	13	1942	8093.5	13	1924	9652.3
14	14	1975	15147.8	14	1912	11863.7	14	1974	7999.3	14	1947	9616.3
15	15	1962	14974.2	15	1918	11638.0	15	1944	7875.0	15	1927	9580.3
16	16	1946	14824.4	16	1948	11617.7	16	1915	7301.3	16	1934	9320.3
17	17	1939	14626.9	17	1980	11569.5	17	1934	7207.9	17	1959	9227.8
18	18	1990	14482.7	18	1961	11386.5	18	1916	7096.8	18	1945	8638.5
19	19	1943	14387.9	19	1962	10929.1	19	1984	7057.0	19	1976	8607.0
20	20	1917	14357.3	20	1919	10834.4	20	1950	7046.1	20	1942	7881.4
21	21	1925	14348.1	21	1949	10780.9	21	1973	7041.7	21	1975	7765.8
22	22	1935	14262.0	22	1971	10762.1	22	1979	6928.8	22	1949	7555.2
23	23	1919	14153.6	23	1929	10608.2	23	1987	6824.1	23	1913	7356.8
24	24	1921	13822.7	24	1935	10567.9	24	1923	6815.7	24	1915	7151.5
25	25	1948	13816.9	25	1936	10554.0	25	1922	6412.3	25	1914	6999.8
26	26	1949	13798.1	26	1922	10411.4	26	1924	6336.5	26	1987	6661.7
27	27	1944	12983.8	27	1937	10192.2	27	1958	6297.6	27	1983	6661.5
28	28	1974	12503.9	28	1974	9970.8	28	1978	6007.8	28	1950	6552.5
29	29	1963	12451.0	29	1934	9907.0	29	1985	6004.7	29	1961	6464.6
30	30	1929	12293.1	30	1951	9788.2	30	1920	5975.9	30	1954	6462.5
31	31	1933	12094.4	31	1938	9782.3	31	1929	5845.2	31	1918	6459.3
32	32	1914	12025.2	32	1913	9272.0	32	1935	5727.7	32	1977	6376.1
33	33	1983	11808.4	33	1957	9179.7	33	1931	5675.1	33	1940	6268.4
34	34	1958	11731.7	34	1933	8983.1	34	1961	5663.6	34	1973	6254.3
35	35	1924	11552.3	35	1940	8974.5	35	1917	5639.0	35	1938	6054.0
36	36	1932	11528.8	36	1950	8847.9	36	1941	5605.4	36	1951	5807.8
37	37	1945	11451.8	37	1943	8837.4	37	1990	5561.8	37	1982	5800.3
38	38	1982	11055.2	38	1944	8802.6	38	1960	5429.8	38	1936	5743.5
39	39	1980	10887.1	39	1928	8792.2	39	1962	5315.0	39	1974	5657.2
40	40	1926	10760.0	40	1982	8778.9	40	1913	5304.8	40	1955	5582.1
41	41	1913	10616.8	41	1955	8699.5	41	1947	5250.2	41	1956	5565.5
42	42	1920	10593.6	42	1946	8693.8	42	1971	5150.4	42	1926	5538.7
43	43	1947	10442.8	43	1931	8481.6	43	1970	5007.8	43	1960	5407.5
44	44	1953	10321.8	44	1952	8419.3	44	1957	4978.6	44	1969	5270.7
45	45	1916	9835.8	45	1916	8311.2	45	1943	4910.1	45	1978	5108.2
46	46	1938	9731.1	46	1920	8025.2	46	1982	4903.5	46	1935	5031.2
47	47	1971	9556.9	47	1959	7769.0	47	1959	4831.6	47	1958	4942.3
48	48	1972	9529.2	48	1917	7666.9	48	1927	4782.4	48	1928	4936.0
49	49	1918	9310.4	49	1942	7486.6	49	1967	4780.7	49	1964	4712.3
50	50	1957	9263.9	50	1915	7433.0	50	1965	4742.5	50	1962	4694.7
51	51	1930	9150.1	51	1921	7339.3	51	1948	4725.9	51	1970	4617.8
52	52	1976	9104.9	52	1923	7303.7	52	1946	4515.5	52	1966	4510.7
53	53	1965	9006.8	53	1939	7184.1	53	1918	4323.9	53	1967	4422.2

RR90PG06: ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990
RANKS BASED ON QUARTERLY MEAN FLOW

OBS	QT1RANK	QT1YEAR	QT1MEAN	QT2RANK	QT2YEAR	QT2MEAN	QT3RANK	QT3YEAR	QT3MEAN	QT4RANK	QT4YEAR	QT4MEAN
54	54	1940	8974.62	54.0	1947	6751.32	54	1969	4305.22	54	1963	4413.04
55	55	1927	8820.44	55.0	1945	6443.63	55	1956	4244.57	55	1923	4352.39
56	56	1928	8747.47	56.0	1953	6292.75	56	1966	4213.37	56	1922	4345.00
57	57	1934	8546.89	57.0	1932	6231.65	57	1968	4169.67	57	1984	4159.89
58	58	1961	8510.11	58.0	1927	6053.19	58	1912	4098.48	58	1988	4112.93
59	59	1989	8457.33	59.0	1956	5841.54	59	1980	4048.04	59	1968	4012.42
60	60	1951	8319.44	60.0	1963	5840.00	60	1964	4013.70	60	1939	3956.85
61	61	1985	8314.00	61.0	1968	5836.04	61	1963	3977.50	61	1946	3905.43
62	62	1950	8247.44	62.0	1977	5798.35	62	1952	3897.93	62	1952	3879.28
63	63	1954	8012.33	63.0	1965	5704.73	63	1936	3751.52	63	1925	3831.52
64	64	1941	7510.00	64.5	1914	5638.68	64	1953	3730.00	64	1912	3816.74
65	65	1955	7328.10	64.5	1941	5638.68	65	1976	3705.65	65	1986	3752.86
66	66	1966	6761.89	66.0	1964	5634.51	66	1914	3641.30	66	1965	3673.64
67	67	1968	6474.29	67.0	1925	5602.20	67	1954	3628.70	67	1921	3564.57
68	68	1988	6267.08	68.0	1954	5577.69	68	1983	3510.43	68	1919	3530.22
69	69	1959	6253.77	69.0	1976	5453.41	69	1951	3373.70	69	1916	3496.52
70	70	1970	5808.78	70.0	1988	5411.54	70	1921	3305.11	70	1953	3199.79
71	71	1942	5806.44	71.0	1969	5086.48	71	1933	3180.87	71	1980	2810.43
72	72	1986	5707.56	72.0	1970	4929.56	72	1977	3034.89	72	1943	2767.72
73	73	1964	5651.54	73.0	1930	4817.69	73	1986	2949.89	73	1917	2740.76
74	74	1967	5619.56	74.0	1926	4339.78	74	1981	2918.04	74	1981	2723.26
75	75	1969	5475.22	75.0	1986	4252.20	75	1988	2905.87	75	1941	2262.93
76	76	1977	5389.11	76.0	1967	4161.76	76	1926	2751.17	76	1930	2213.52
77	77	1956	5058.96	77.0	1966	4121.21	77	1925	2516.30	77	1931	2007.61
78	78	1931	4771.44	78.0	1981	3612.86	78	1930	1514.18	78	1933	1945.13
79	79	1981	3130.89	79.0	1985	3572.64	79	1932	1496.88	.	.	.

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APPENDIX A-3.

Roanoke River Annual Flow Statistics, Standard Error of Flows by Quarter, January through December, 1912-1989, and January through August 7, 1990.

Roanoke River Annual Flow Statistics
Jan–Dec, 1912–1989. Jan– ~~Statistics~~ to August 7, 1990
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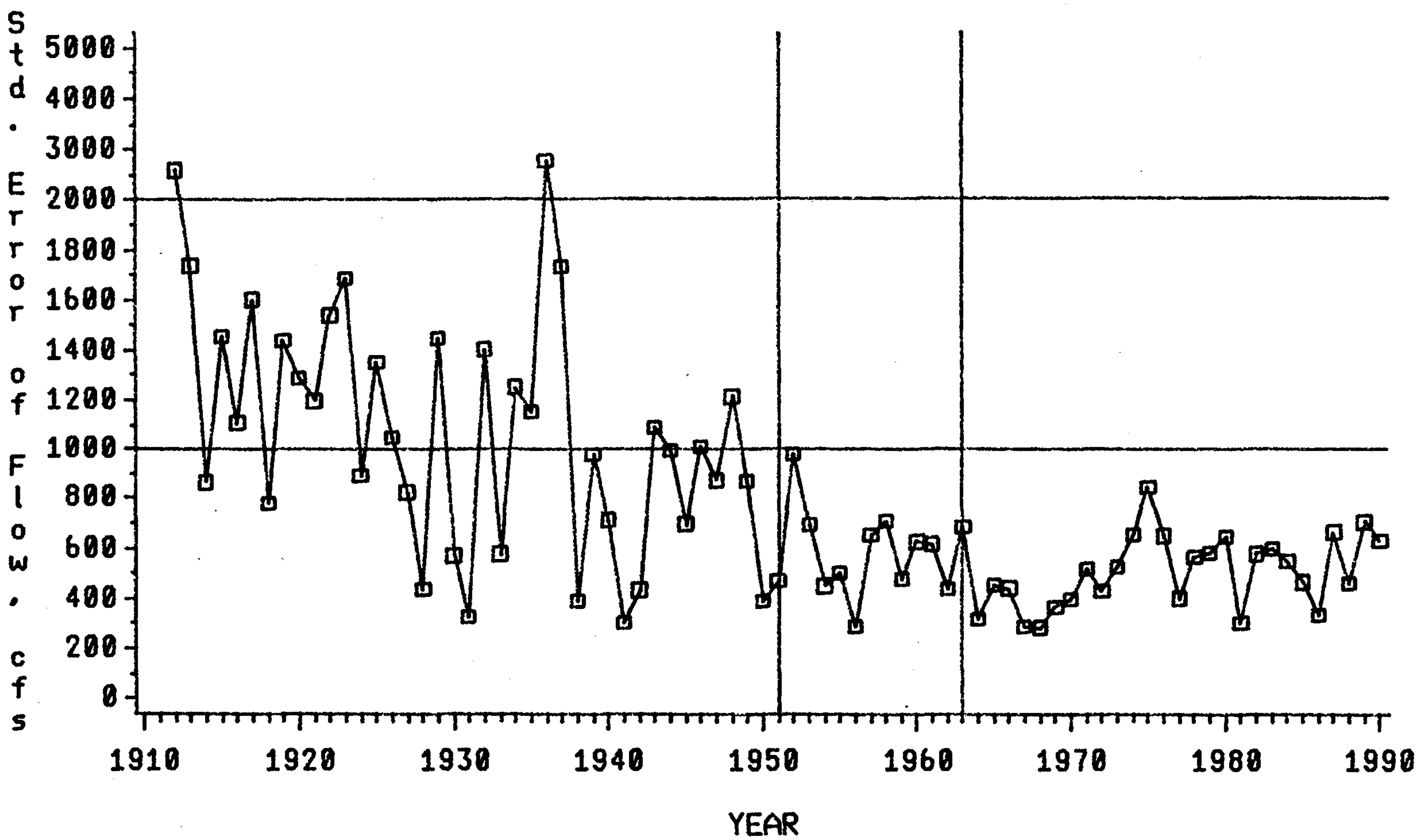
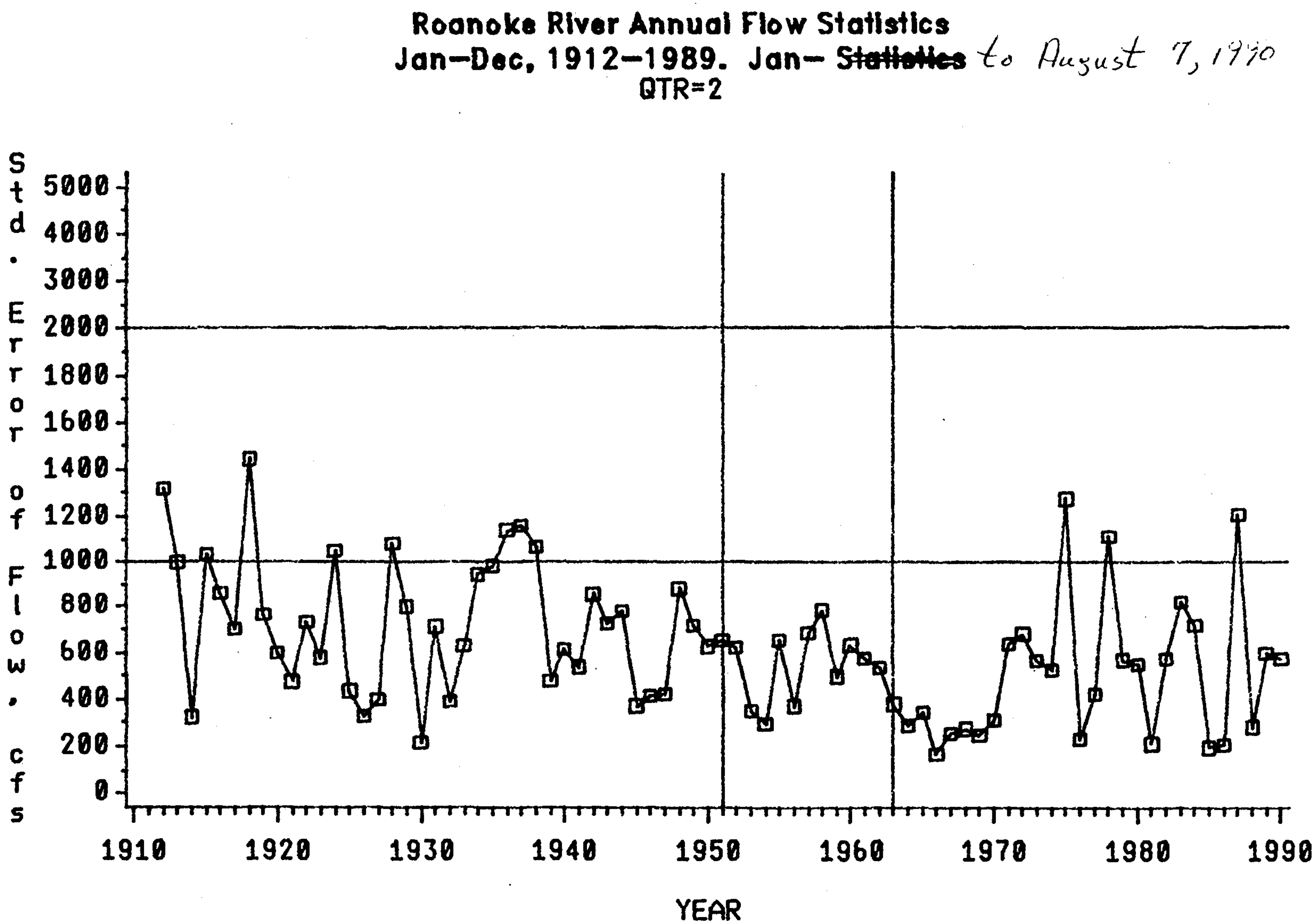
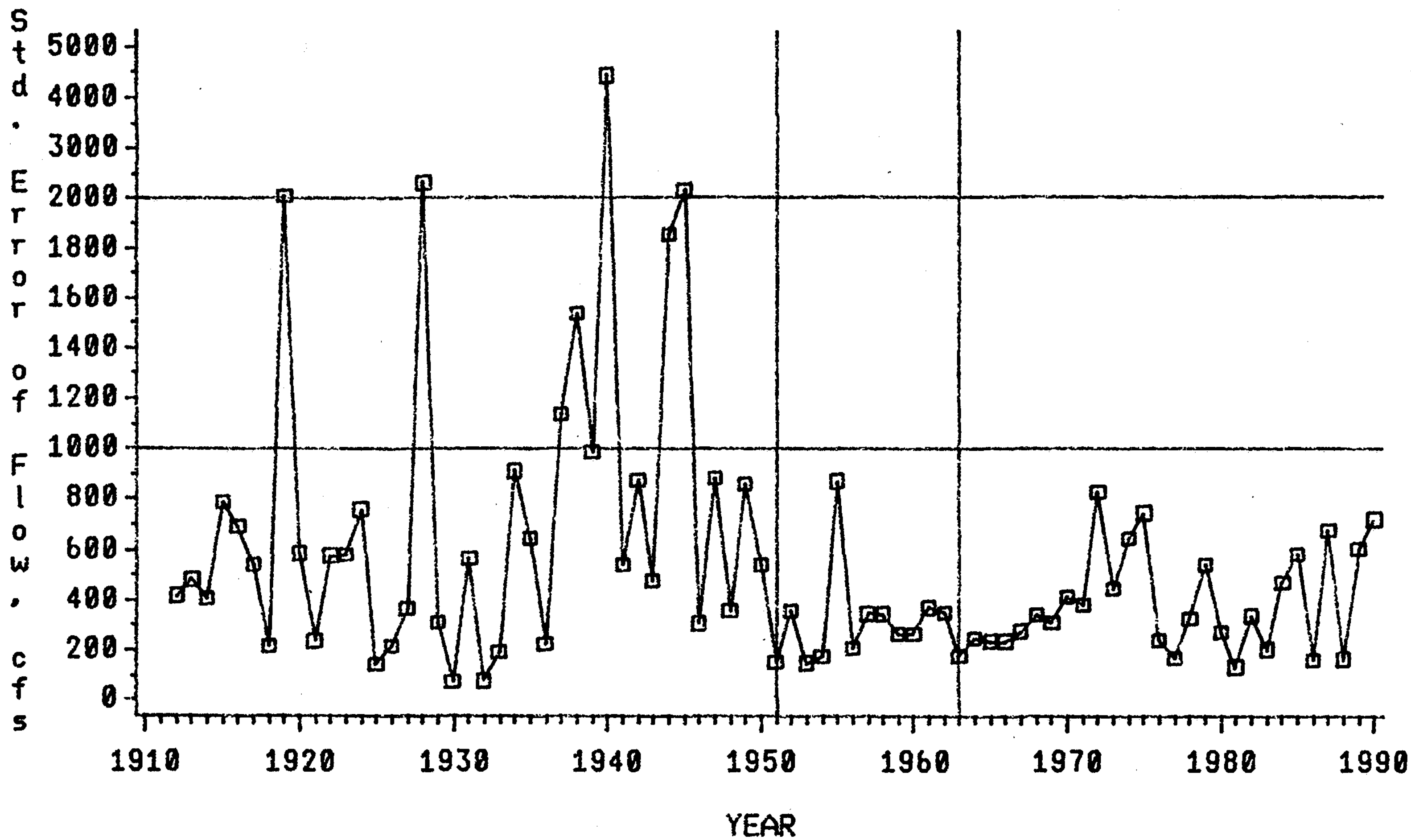




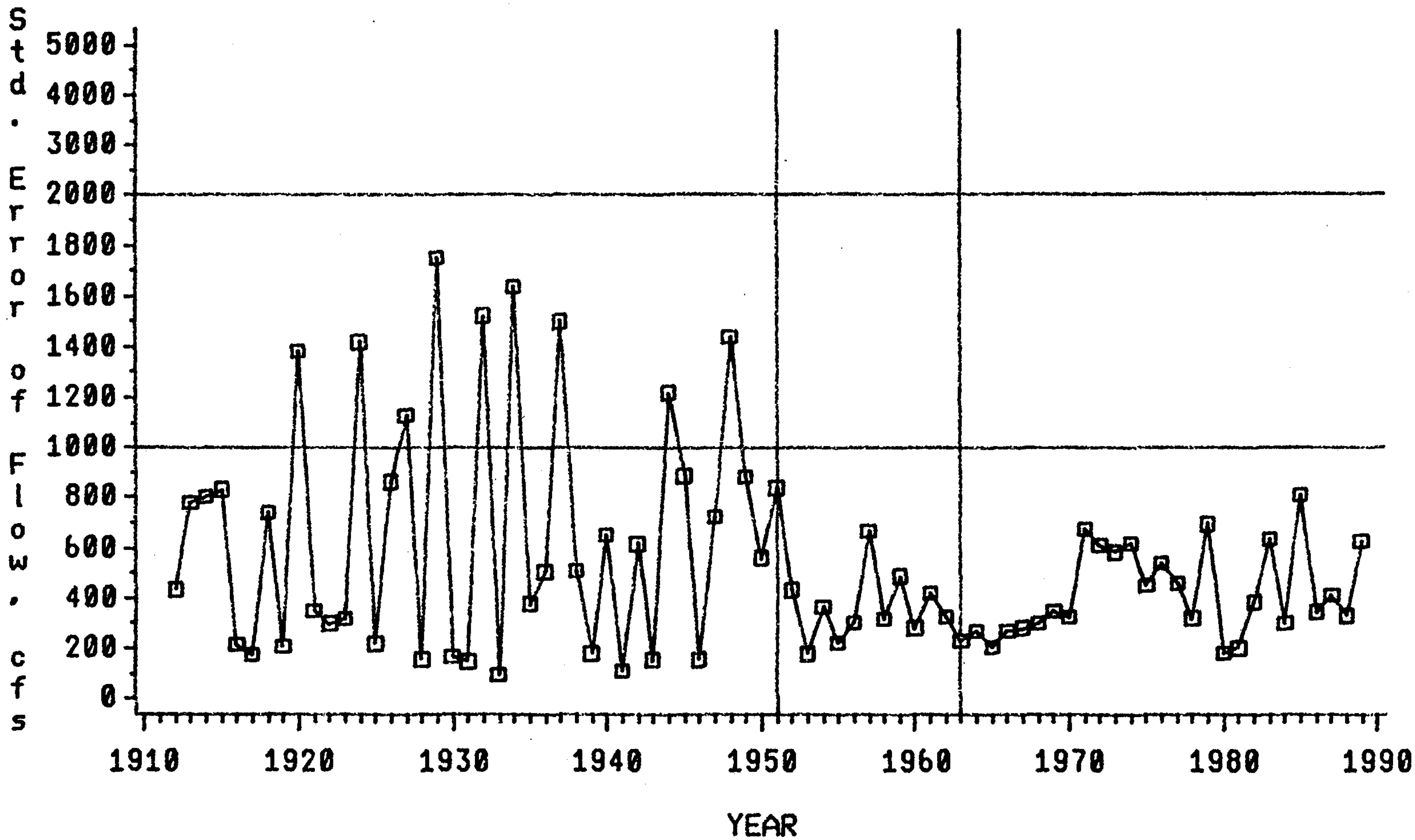
Roanoke River Annual Flow Statistics
Jan—Dec, 1912—1989. Jan— ~~Statistics~~ to August 7, 1990
QTR=2
Std. Error of Flow, cfs
5000
4000
3000
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
YEAR

265

Roanoke River Annual Flow Statistics
Jan-Dec, 1912-1989. Jan- ~~Statistics~~ to August 7, 1990
QTR=3



Roanoke River Annual Flow Statistics
Jan–Dec, 1912–1989. Jan– ~~Statistics~~ August 7, 1990
QTR=4



267

RR90PG06: ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990
RANKS BASED ON QUARTERLY STANDARD ERROR FLOW

OBS	QT1RANK	QT1YEAR	QT1SE	QT2RANK	QT2YEAR	QT2SE	QT3RANK	QT3YEAR	QT3SE	QT4RANK	QT4YEAR	QT4SE
1	1	1936	2776.10	1	1918	1444.18	1	1940	4421.07	1	1929	1748.38
2	2	1912	2596.80	2	1912	1321.07	2	1928	2315.90	2	1934	1638.67
3	3	1913	1735.93	3	1975	1277.01	3	1945	2184.35	3	1932	1521.66
4	4	1937	1731.36	4	1987	1206.65	4	1919	2045.11	4	1937	1499.94
5	5	1923	1683.74	5	1937	1162.10	5	1944	1853.88	5	1948	1441.15
6	6	1917	1601.46	6	1936	1139.77	6	1938	1533.47	6	1924	1419.19
7	7	1922	1538.16	7	1978	1112.52	7	1937	1135.30	7	1920	1381.35
8	8	1915	1456.76	8	1928	1079.51	8	1939	987.82	8	1944	1220.07
9	9	1929	1445.05	9	1938	1063.87	9	1934	910.88	9	1927	1131.09
10	10	1919	1439.41	10	1924	1048.82	10	1947	882.12	10	1945	888.18
11	11	1932	1402.23	11	1915	1032.81	11	1942	873.18	11	1949	881.79
12	12	1925	1353.34	12	1913	998.46	12	1955	870.48	12	1926	862.94
13	13	1920	1289.23	13	1935	981.40	13	1949	857.02	13	1951	839.62
14	14	1934	1250.76	14	1934	943.70	14	1972	828.09	14	1915	830.81
15	15	1948	1214.09	15	1948	879.96	15	1915	787.20	15	1985	812.04
16	16	1921	1197.64	16	1916	856.77	16	1924	759.80	16	1914	804.92
17	17	1935	1151.21	17	1942	856.13	17	1975	742.75	17	1913	781.08
18	18	1916	1107.89	18	1983	817.05	18	1990	719.48	18	1918	741.70
19	19	1943	1088.22	19	1929	798.84	19	1916	690.70	19	1947	722.79
20	20	1926	1047.88	20	1958	783.49	20	1987	674.54	20	1979	697.44
21	21	1946	1008.46	21	1944	780.11	21	1935	642.48	21	1971	678.64
22	22	1944	994.76	22	1919	762.50	22	1974	642.43	22	1957	668.64
23	23	1952	979.77	23	1922	732.41	23	1989	602.93	23	1940	653.86
24	24	1939	978.52	24	1943	721.85	24	1920	584.11	24	1983	638.04
25	25	1924	891.48	25	1949	718.01	25	1985	583.29	25	1989	630.42
26	26	1947	871.49	26	1984	715.84	26	1923	579.00	26	1974	622.69
27	27	1949	865.54	27	1931	712.08	27	1922	575.94	27	1942	618.33
28	28	1914	863.88	28	1917	702.12	28	1931	564.66	28	1972	612.61
29	29	1975	842.72	29	1957	685.05	29	1941	541.99	29	1973	585.73
30	30	1927	822.84	30	1972	679.42	30	1950	541.64	30	1950	560.43
31	31	1918	778.74	31	1951	653.54	31	1979	541.25	31	1976	542.78
32	32	1940	712.18	32	1955	650.68	32	1917	539.71	32	1938	507.71
33	33	1958	708.78	33	1971	634.63	33	1913	482.07	33	1936	506.04
34	34	1989	705.29	34	1960	631.78	34	1943	479.87	34	1959	489.62
35	35	1945	696.15	35	1933	628.03	35	1984	471.21	35	1977	460.04
36	36	1953	691.21	36	1950	626.12	36	1973	443.71	36	1975	456.22
37	37	1963	684.52	37	1952	620.42	37	1912	417.60	37	1952	435.18
38	38	1987	663.65	38	1940	611.24	38	1970	416.58	38	1912	434.29
39	39	1957	653.34	39	1920	598.50	39	1914	408.59	39	1961	420.69
40	40	1974	651.48	40	1989	595.58	40	1971	384.45	40	1987	415.36
41	41	1976	650.09	41	1923	576.07	41	1961	371.84	41	1982	387.73
42	42	1980	644.21	42	1990	574.16	42	1927	364.40	42	1935	377.56
43	43	1990	630.15	43	1961	574.11	43	1948	361.10	43	1954	366.51
44	44	1960	625.58	44	1982	572.00	44	1952	356.37	44	1969	353.08
45	45	1961	616.60	45	1979	568.94	45	1962	350.35	45	1921	350.83
46	46	1983	598.38	46	1973	566.89	46	1957	348.17	46	1986	346.82
47	47	1979	583.35	47	1980	547.90	47	1958	345.47	47	1988	332.32
48	48	1982	577.29	48	1941	536.35	48	1968	344.03	48	1962	329.11
49	49	1933	575.74	49	1962	532.17	49	1982	338.21	49	1970	326.91
50	50	1930	569.89	50	1974	527.68	50	1978	324.65	50	1978	321.73
51	51	1978	567.15	51	1959	497.06	51	1929	309.93	51	1923	319.92
52	52	1984	550.84	52	1939	477.19	52	1969	308.98	52	1958	316.91
53	53	1973	523.92	53	1921	473.97	53	1946	308.52	53	1956	304.71

RR90PG06: ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990
RANKS BASED ON QUARTERLY STANDARD ERROR FLOW

OBS	QT1RANK	QT1YEAR	QT1SE	QT2RANK	QT2YEAR	QT2SE	QT3RANK	QT3YEAR	QT3SE	QT4RANK	QT4YEAR	QT4SE
54	54	1971	516.180	54	1925	433.342	54	1967	274.403	54	1968	304.473
55	55	1955	501.756	55	1977	423.492	55	1980	272.729	55	1984	302.128
56	56	1959	476.346	56	1947	422.339	56	1960	262.376	56	1922	298.174
57	57	1951	472.090	57	1946	413.982	57	1959	261.792	57	1967	283.061
58	58	1985	466.062	58	1927	399.601	58	1964	248.700	58	1960	282.834
59	59	1988	463.813	59	1932	392.424	59	1976	240.612	59	1964	273.024
60	60	1965	455.641	60	1963	377.349	60	1921	236.502	60	1966	271.717
61	61	1954	450.130	61	1956	370.342	61	1966	235.591	61	1963	233.188
62	62	1966	441.750	62	1945	369.158	62	1965	235.159	62	1955	226.128
63	63	1928	438.713	63	1953	351.394	63	1936	225.838	63	1925	220.681
64	64	1962	436.025	64	1965	344.209	64	1918	217.366	64	1916	215.832
65	65	1942	433.484	65	1926	328.557	65	1926	214.883	65	1919	209.143
66	66	1972	429.676	66	1914	321.759	66	1956	206.661	66	1965	206.575
67	67	1977	401.775	67	1970	309.029	67	1983	203.808	67	1981	204.281
68	68	1970	397.518	68	1954	293.594	68	1933	193.405	68	1980	184.973
69	69	1938	391.361	69	1964	287.688	69	1954	178.272	69	1939	181.595
70	70	1950	390.190	70	1988	282.139	70	1963	176.626	70	1953	181.160
71	71	1969	366.326	71	1968	274.257	71	1977	167.286	71	1917	175.251
72	72	1986	336.700	72	1967	255.042	72	1988	163.820	72	1930	168.921
73	73	1931	326.732	73	1969	248.467	73	1986	162.071	73	1928	156.774
74	74	1964	320.716	74	1976	233.317	74	1951	151.887	74	1946	156.430
75	75	1941	304.920	75	1930	216.221	75	1953	148.118	75	1943	155.702
76	76	1981	304.566	76	1981	212.934	76	1925	144.833	76	1931	149.785
77	77	1956	288.529	77	1986	205.975	77	1981	131.951	77	1941	112.921
78	78	1967	286.622	78	1985	197.102	78	1932	77.462	78	1933	97.149
79	79	1968	282.374	79	1966	167.484	79	1930	71.232	.	.	.

APPENDIX A-4.

Roanoke River Annual Flow Statistics, Coefficient of Variation in Flows by Quarter, January through December, 1912-1989, and January through August 7, 1990.

Roanoke River Annual Flow Statistics
Jan–Dec, 1912–1989. Jan– ~~Statistics~~ to August 7, 1990
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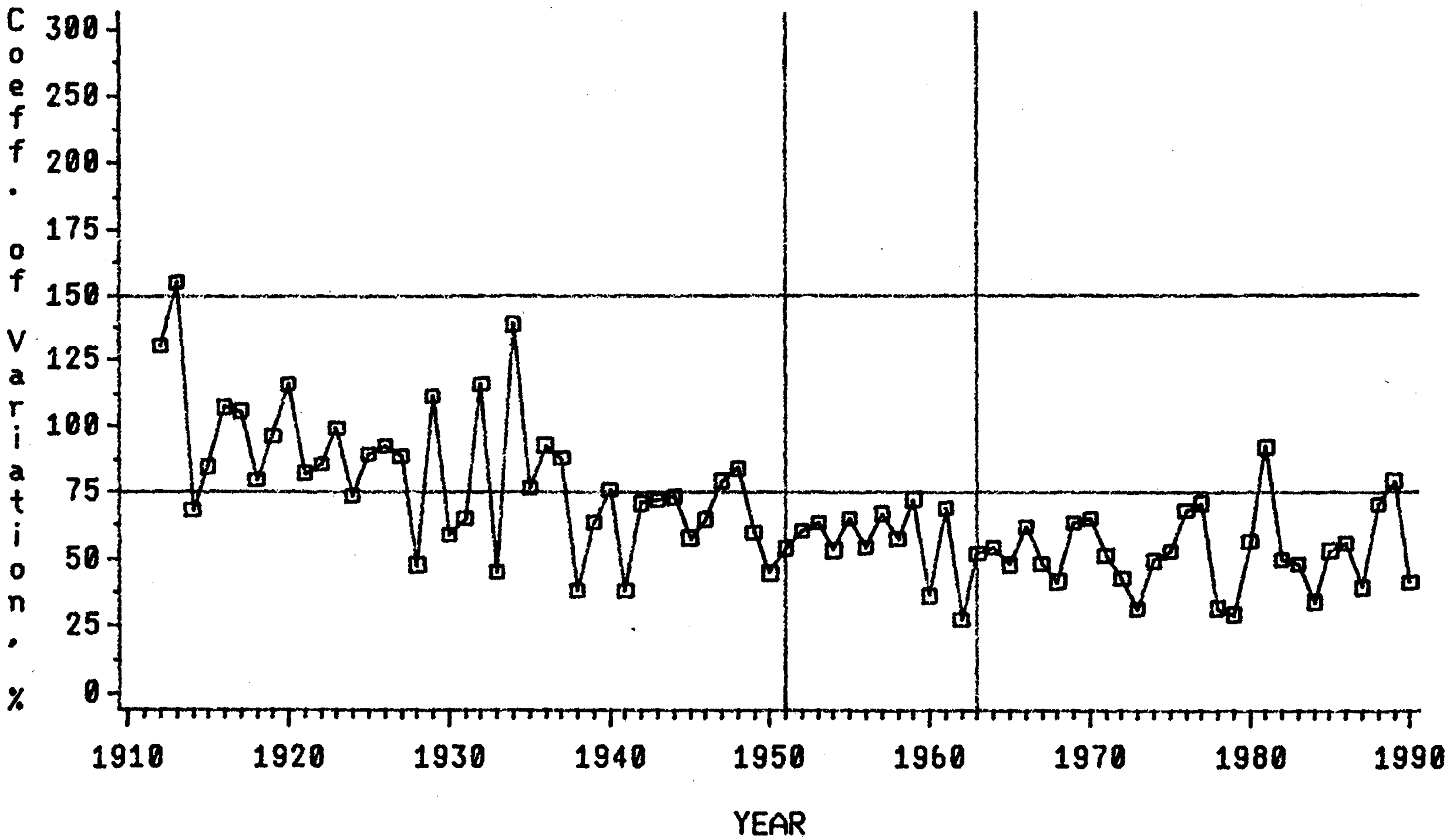

Roanoke River Annual Flow Statistics
Jan—Dec, 1912—1989. Jan— ~~Statistics~~ to August 7, 1990
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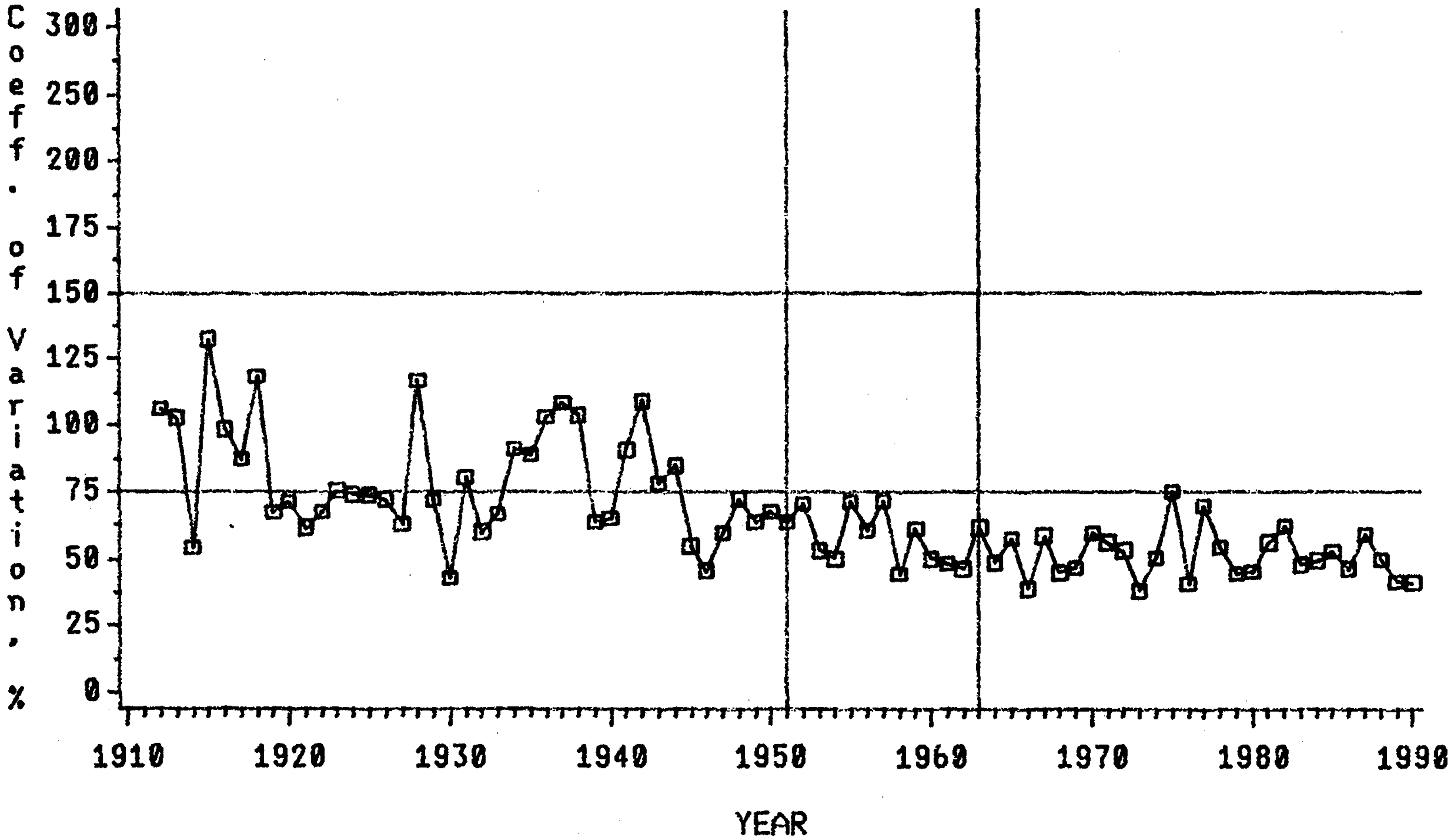
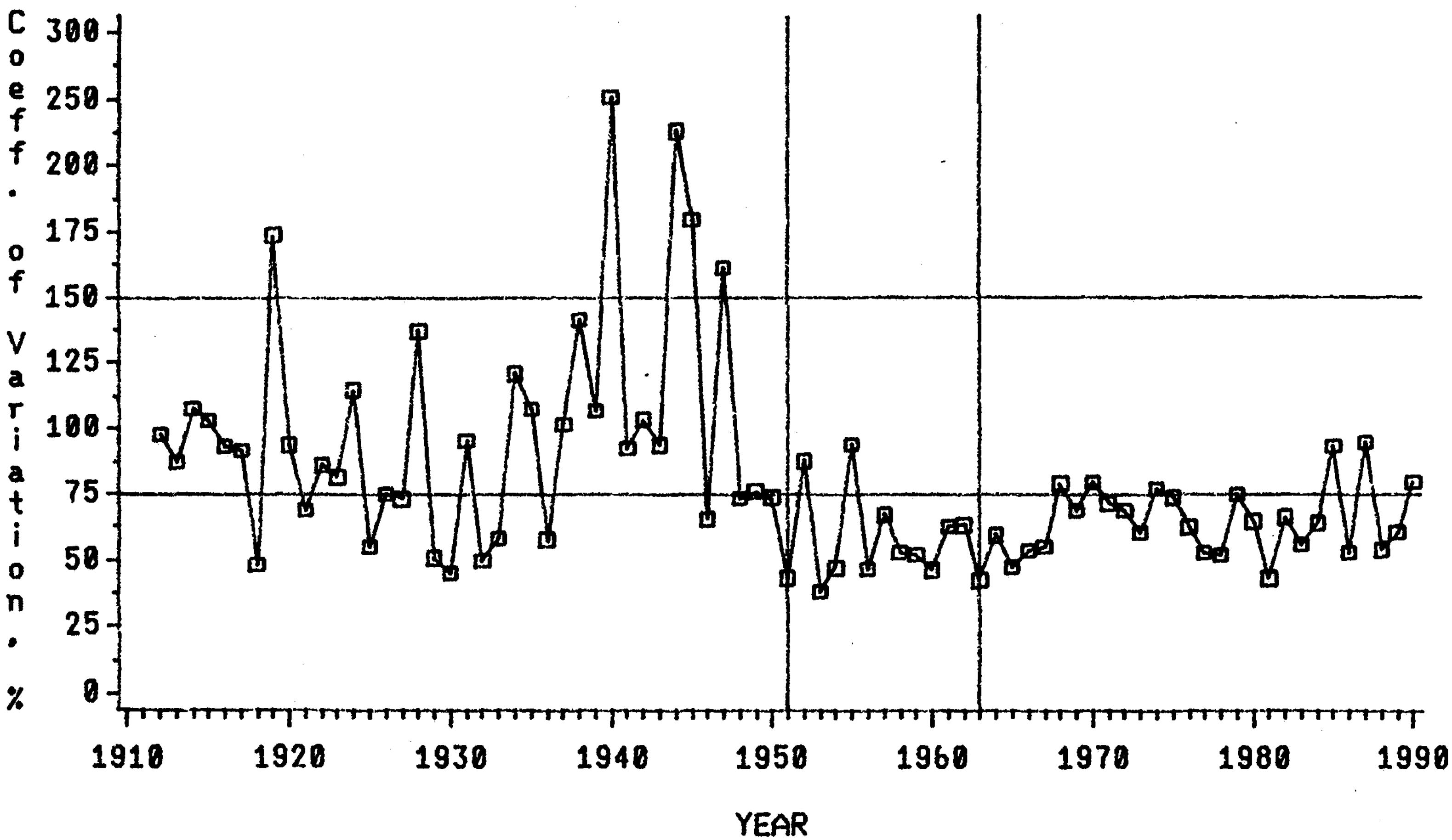
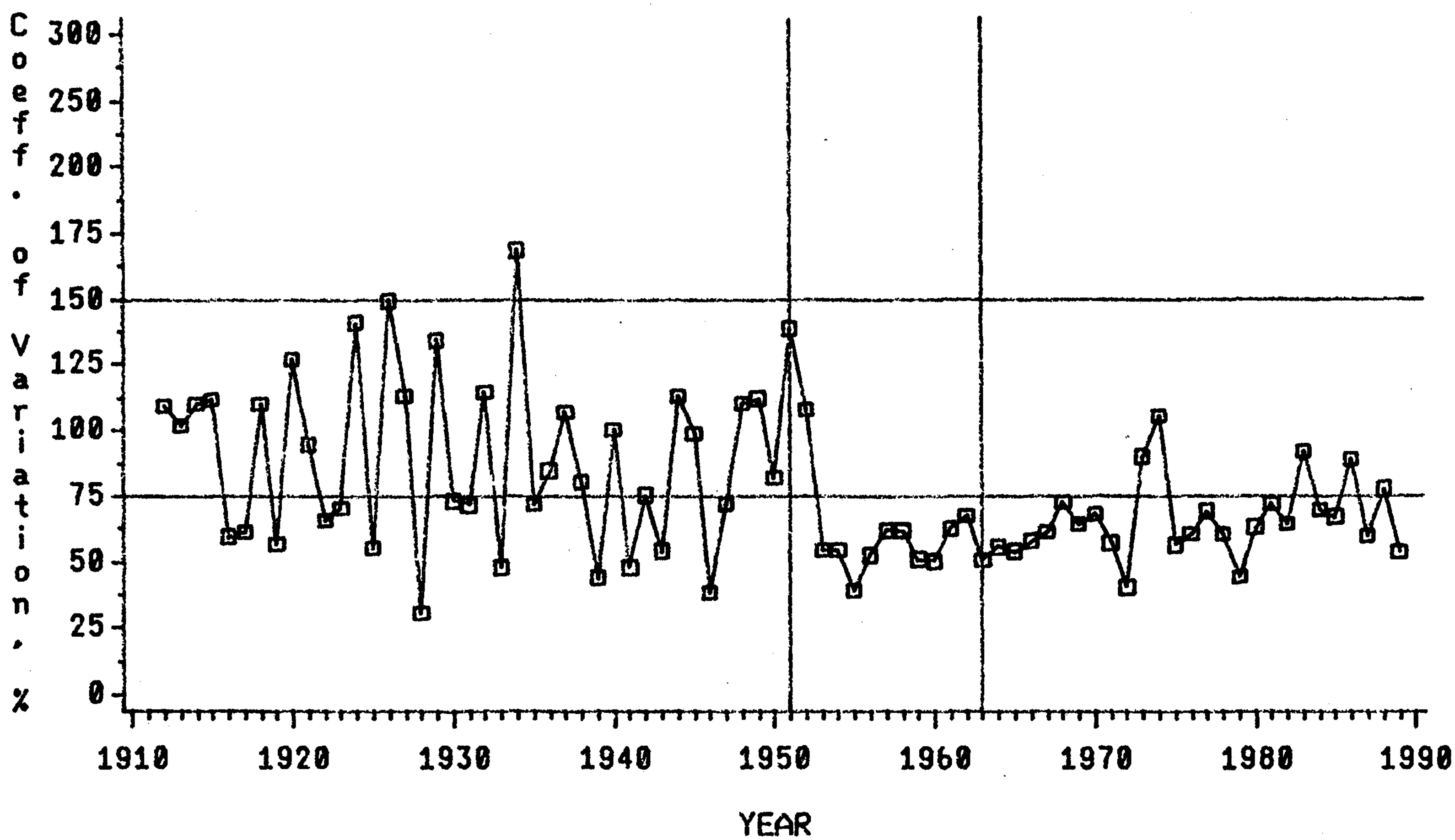


Roanoke River Annual Flow Statistics
Jan—Dec, 1912—1989. Jan— ~~Statistics~~ to August 7, 1990
QTR=3



Roanoke River Annual Flow Statistics
Jan—Dec, 1912—1989. Jan— ~~Statistics~~ to August 7, 1990
QTR=4



RR90PG06: ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990
RANKS BASED ON QUARTERLY COEFFICIENT OF VARIATION (%)

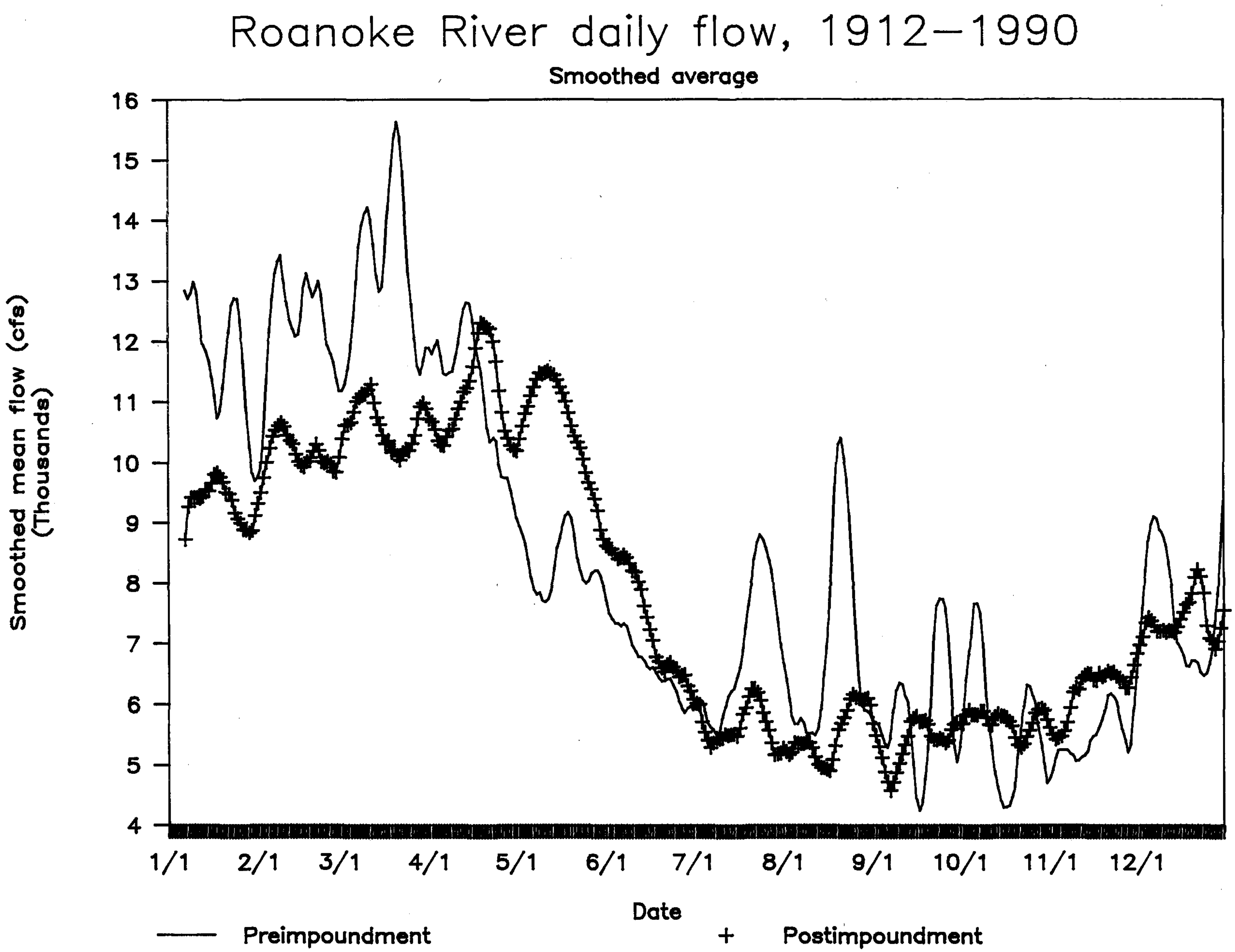
OBS	QT1RANK	QT1YEAR	QT1CV	QT2RANK	QT2YEAR	QT2CV	QT3RANK	QT3YEAR	QT3CV	QT4RANK	QT4YEAR	QT4CV
1	1	1913	155.118	1	1915	132.550	1	1940	251.257	1	1934	168.638
2	2	1934	138.831	2	1918	118.375	2	1944	225.801	2	1926	149.441
3	3	1912	130.926	3	1928	117.125	3	1945	179.445	3	1924	141.028
4	4	1920	116.093	4	1942	109.087	4	1919	173.836	4	1951	138.664
5	5	1932	116.026	5	1937	108.767	5	1947	161.156	5	1929	134.242
6	6	1929	111.517	6	1912	106.225	6	1938	141.566	6	1920	127.026
7	7	1916	107.450	7	1938	103.746	7	1928	137.217	7	1932	114.685
8	8	1917	105.819	8	1936	103.021	8	1934	121.212	8	1927	113.243
9	9	1923	99.312	9	1913	102.726	9	1924	115.012	9	1944	113.052
10	10	1919	96.480	10	1916	98.337	10	1914	107.629	10	1949	111.947
11	11	1936	92.903	11	1934	90.868	11	1935	107.590	11	1915	111.428
12	12	1926	92.389	12	1941	90.738	12	1939	107.232	12	1914	110.296
13	13	1981	92.286	13	1935	88.588	13	1942	103.482	13	1918	110.137
14	14	1925	89.481	14	1917	87.360	14	1915	103.413	14	1948	109.924
15	15	1927	88.501	15	1944	84.541	15	1937	101.876	15	1912	109.138
16	16	1937	87.761	16	1931	80.089	16	1912	97.732	16	1952	107.600
17	17	1922	85.677	17	1943	77.919	17	1931	95.434	17	1937	107.271
18	18	1915	84.544	18	1923	75.240	18	1987	94.810	18	1974	105.576
19	19	1948	83.822	19	1975	75.163	19	1955	93.932	19	1913	101.835
20	20	1921	82.197	20	1924	73.962	20	1920	93.754	20	1940	100.052
21	21	1918	79.349	21	1925	73.789	21	1943	93.741	21	1945	98.618
22	22	1947	79.171	22	1948	72.254	22	1916	93.351	22	1921	94.404
23	23	1989	79.115	23	1926	72.221	23	1985	93.173	23	1983	91.868
24	24	1935	76.577	24	1929	71.835	24	1941	92.742	24	1973	89.828
25	25	1940	75.700	25	1955	71.350	25	1917	91.801	25	1986	88.641
26	26	1924	73.615	26	1957	71.190	26	1952	87.692	26	1936	84.509
27	27	1944	73.086	27	1920	71.142	27	1913	87.164	27	1950	82.036
28	28	1959	72.261	28	1952	70.295	28	1922	86.151	28	1938	80.439
29	29	1943	71.753	29	1977	69.672	29	1923	81.482	29	1988	77.499
30	30	1942	70.825	30	1950	67.505	30	1970	79.788	30	1942	75.251
31	31	1977	70.727	31	1919	67.136	31	1990	79.742	31	1930	73.197
32	32	1988	70.599	32	1922	67.107	32	1968	79.138	32	1968	72.784
33	33	1961	68.737	33	1933	66.692	33	1974	77.031	33	1947	72.094
34	34	1914	68.152	34	1940	64.971	34	1949	76.004	34	1935	71.980
35	35	1976	68.111	35	1951	63.693	35	1979	74.926	35	1981	71.950
36	36	1957	66.907	36	1949	63.533	36	1926	74.917	36	1931	71.562
37	37	1931	64.963	37	1939	63.364	37	1975	73.948	37	1923	70.503
38	38	1955	64.957	38	1927	62.974	38	1950	73.732	38	1984	69.663
39	39	1970	64.922	39	1982	62.156	39	1948	73.288	39	1977	69.205
40	40	1946	64.536	40	1963	61.638	40	1927	73.085	40	1970	67.902
41	41	1953	63.530	41	1921	61.605	41	1971	71.597	41	1962	67.239
42	42	1969	63.473	42	1959	61.033	42	1972	69.076	42	1985	66.831
43	43	1939	63.466	43	1956	60.478	43	1969	68.839	43	1922	65.822
44	44	1966	61.977	44	1932	60.072	44	1921	68.635	44	1969	64.254
45	45	1952	60.231	45	1970	59.802	45	1957	67.078	45	1982	64.117
46	46	1949	59.510	46	1947	59.675	46	1982	66.156	46	1980	63.129
47	47	1930	59.086	47	1987	58.739	47	1946	65.533	47	1961	62.419
48	48	1945	57.670	48	1967	58.459	48	1980	64.622	48	1957	61.744
49	49	1958	57.316	49	1965	57.558	49	1984	64.046	49	1958	61.504
50	50	1980	56.446	50	1971	56.253	50	1962	63.226	50	1967	61.395
51	51	1986	55.965	51	1981	56.223	51	1961	62.974	51	1917	61.331
52	52	1956	54.406	52	1945	54.652	52	1976	62.280	52	1976	60.488
53	53	1964	54.134	53	1978	54.515	53	1989	60.554	53	1978	60.412

RR90PG06: ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990
RANKS BASED ON QUARTERLY COEFFICIENT OF VARIATION (%)

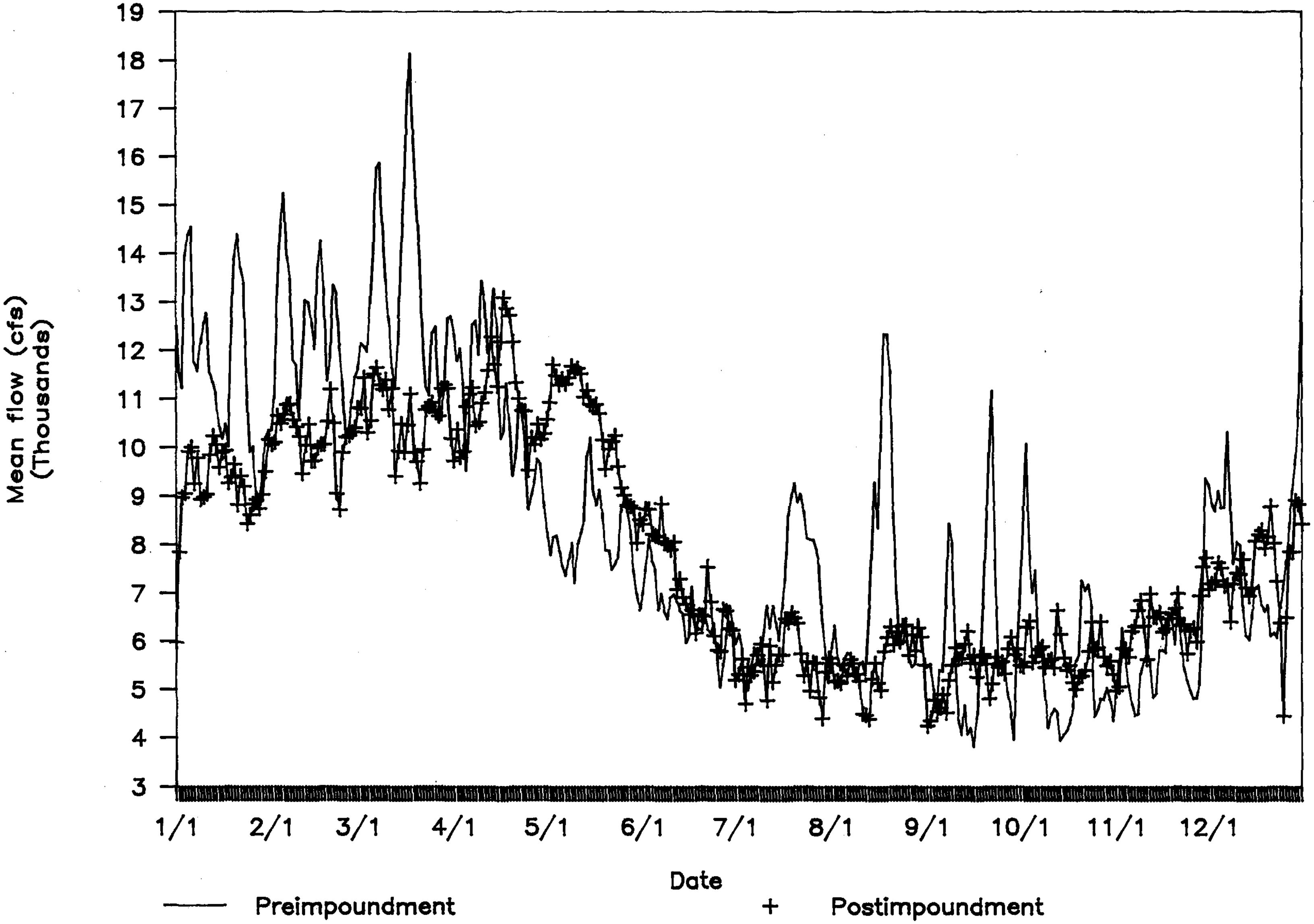
OBS	QT1RANK	QT1YEAR	QT1CV	QT2RANK	QT2YEAR	QT2CV	QT3RANK	QT3YEAR	QT3CV	QT4RANK	QT4YEAR	QT4CV
54	54	1951	53.8334	54	1914	54.4344	54	1973	60.4390	54	1987	59.8054
55	55	1954	53.2967	55	1953	53.2691	55	1964	59.4327	55	1916	59.2071
56	56	1985	53.1809	56	1972	53.1368	56	1933	58.3197	56	1966	57.7790
57	57	1975	52.7781	57	1985	52.6287	57	1936	57.7409	57	1971	57.0542
58	58	1963	52.1562	58	1974	50.4852	58	1983	55.6871	58	1919	56.8245
59	59	1971	51.2397	59	1960	50.2959	59	1925	55.2076	59	1975	56.3490
60	60	1982	49.5387	60	1954	50.2127	60	1967	55.0548	60	1964	55.5729
61	61	1974	49.4281	61	1988	49.7352	61	1988	54.0736	61	1925	55.2442
62	62	1967	48.3870	62	1984	49.3528	62	1966	53.6318	62	1954	54.3982
63	63	1983	48.0731	63	1964	48.7065	63	1977	52.8701	63	1953	54.3042
64	64	1965	47.9926	64	1961	48.0978	64	1986	52.6977	64	1943	53.9592
65	65	1928	47.8431	65	1983	47.8807	65	1958	52.6169	65	1965	53.9356
66	66	1933	45.1611	66	1969	46.5984	66	1959	51.9704	66	1989	53.6866
67	67	1950	44.8826	67	1962	46.4500	67	1978	51.8306	67	1956	52.5149
68	68	1972	43.0134	68	1986	46.2085	68	1929	50.8575	68	1959	50.8925
69	69	1968	41.6058	69	1946	45.4246	69	1932	49.6360	69	1963	50.6829
70	70	1990	41.2778	70	1980	45.1761	70	1918	48.2178	70	1960	50.1678
71	71	1987	39.5221	71	1968	44.8291	71	1965	47.5606	71	1933	47.9055
72	72	1941	38.5183	72	1958	44.4774	72	1954	47.1224	72	1941	47.8624
73	73	1938	38.1537	73	1979	44.3348	73	1956	46.7003	73	1979	44.5028
74	74	1960	36.4628	74	1930	42.8134	74	1960	46.3484	74	1939	44.0198
75	75	1984	34.1030	75	1989	41.4748	75	1930	45.1223	75	1972	40.2515
76	76	1978	31.7744	76	1990	40.9171	76	1981	43.3725	76	1955	38.8556
77	77	1973	31.2752	77	1976	40.8130	77	1951	43.1825	77	1946	38.4188
78	78	1979	29.4537	78	1966	38.7676	78	1963	42.5931	78	1928	30.4646
79	79	1962	27.6241	79	1973	38.0153	79	1953	38.0885	.	.	.

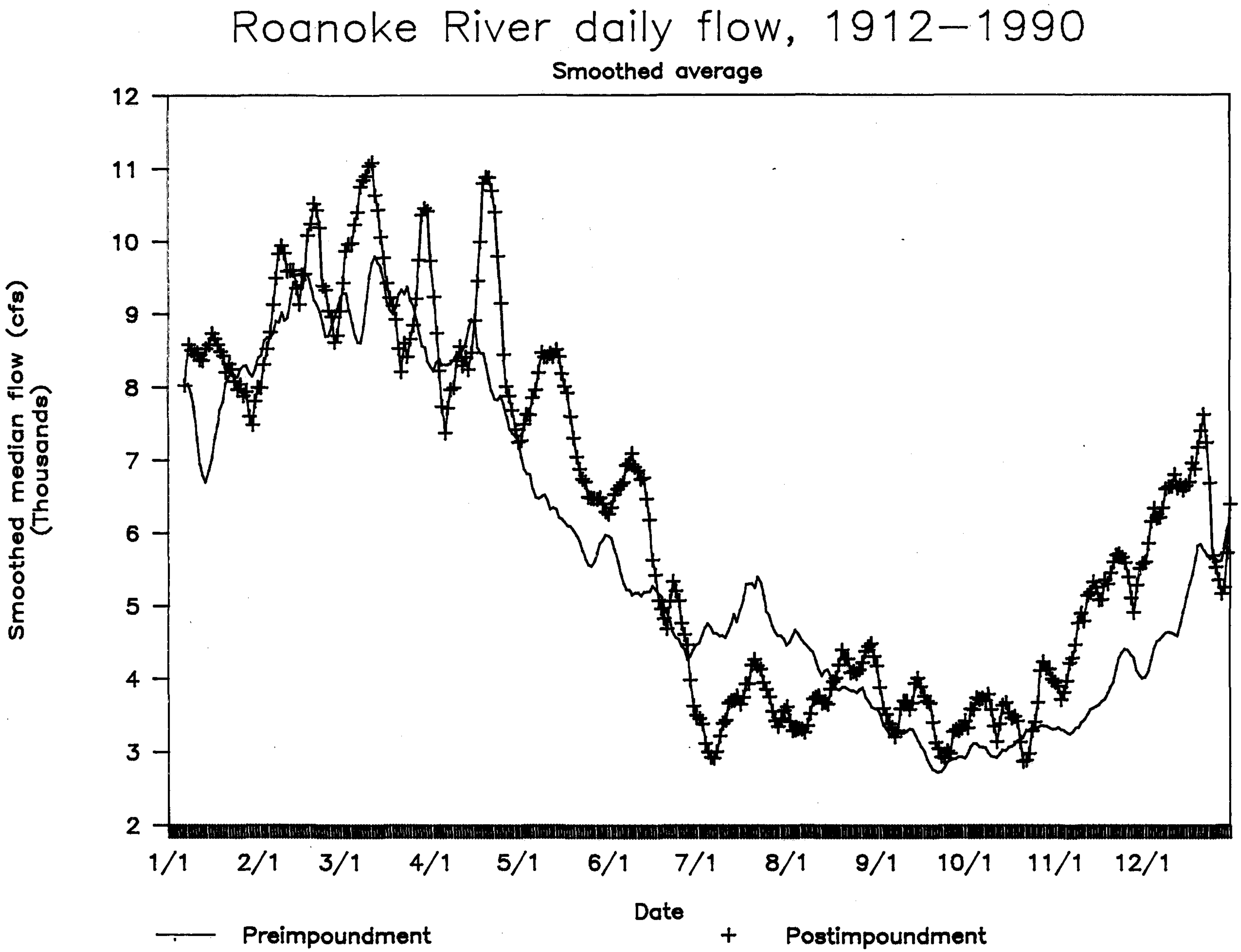
APPENDIX A-5.

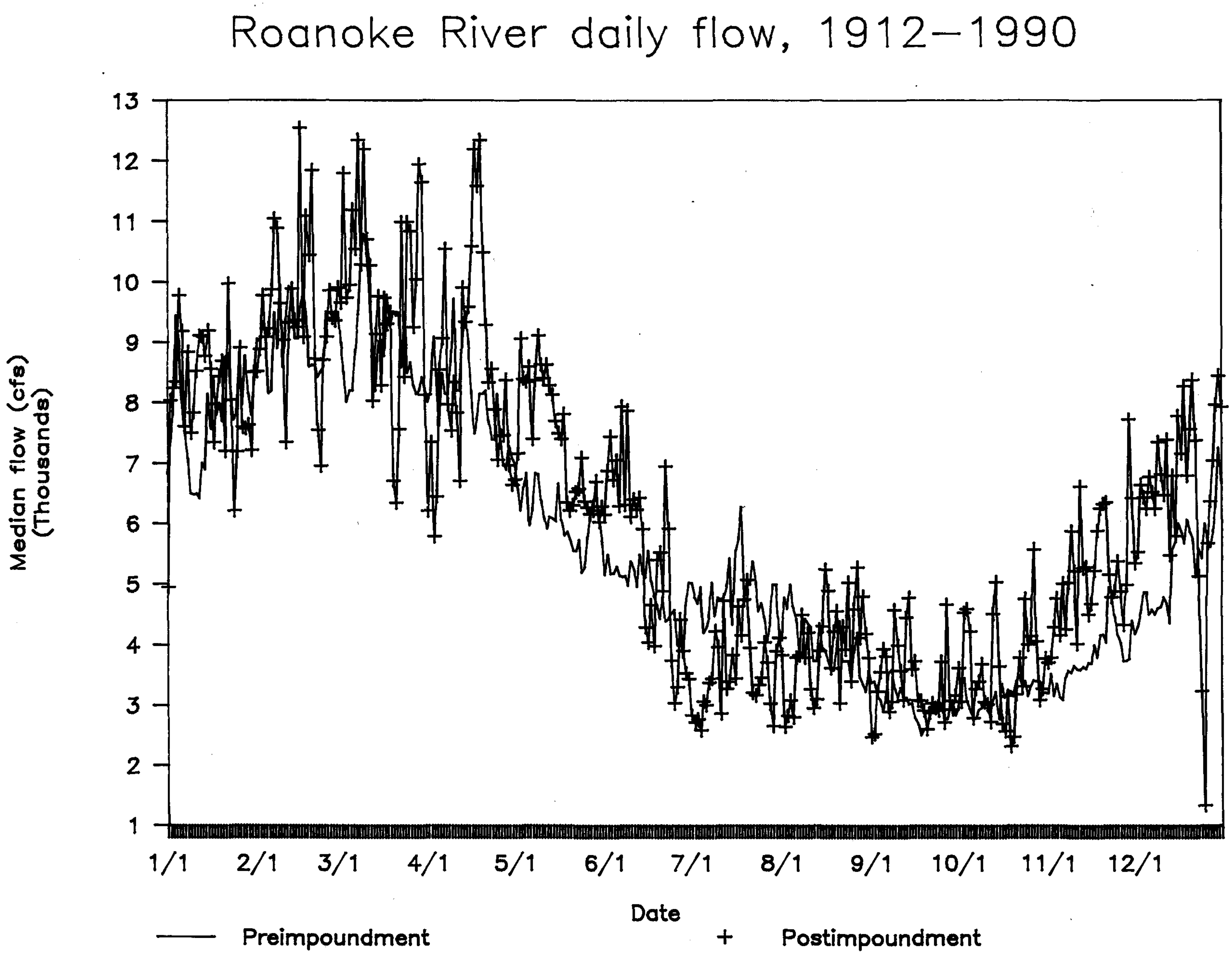
Plots of Roanoke River Daily Flows for 12 Months (1912-1989, and Jan-Aug 7, 1990).


Roanoke River daily flow, 1912–1990
Smoothed average
Smoothed mean flow (cfs)
(Thousands)
16
15
14
13
12
11
10
9
8
7
6
5
4
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
Date
Preimpoundment
+
Postimpoundment

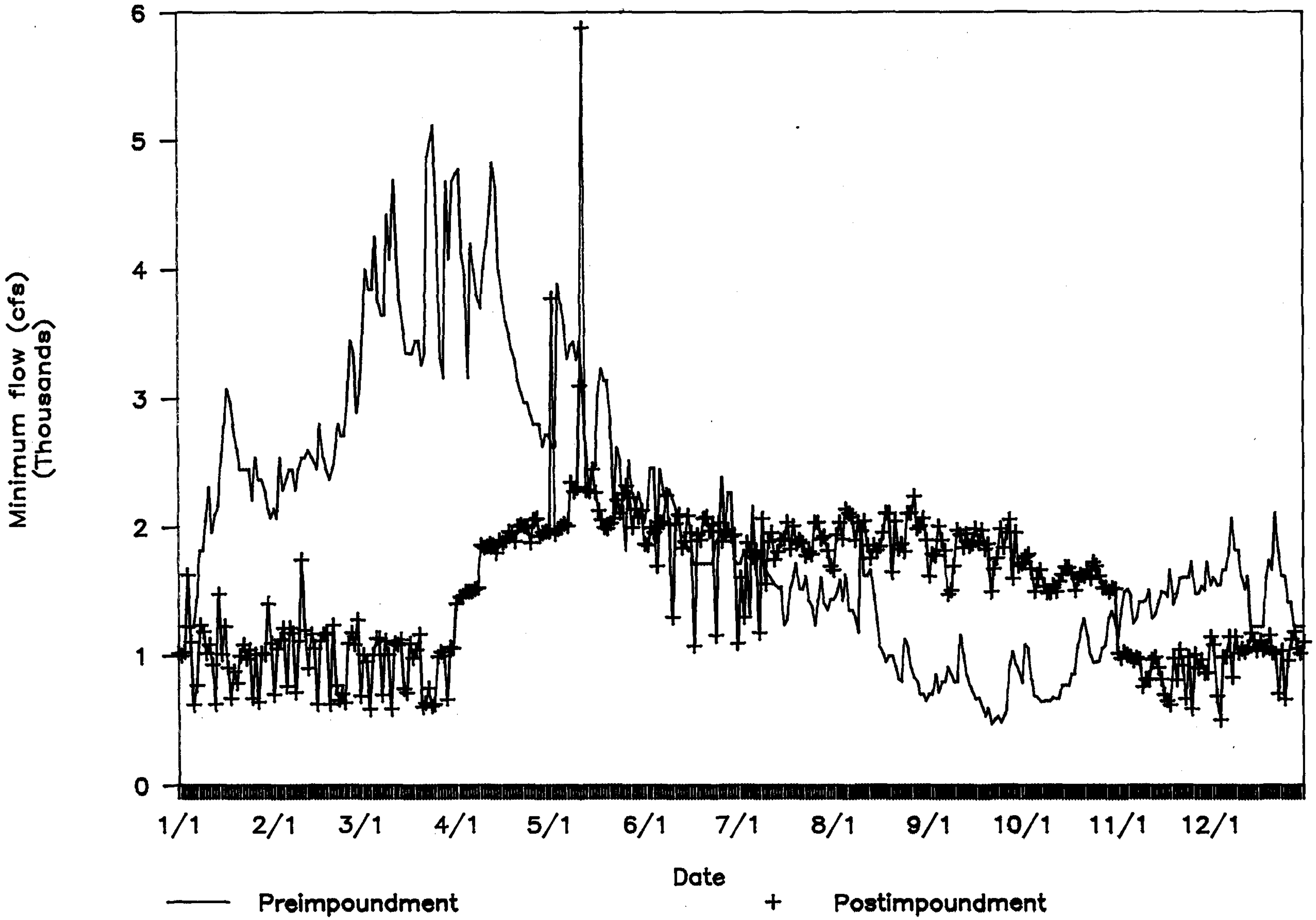
Roanoke River daily flow, 1912–1990

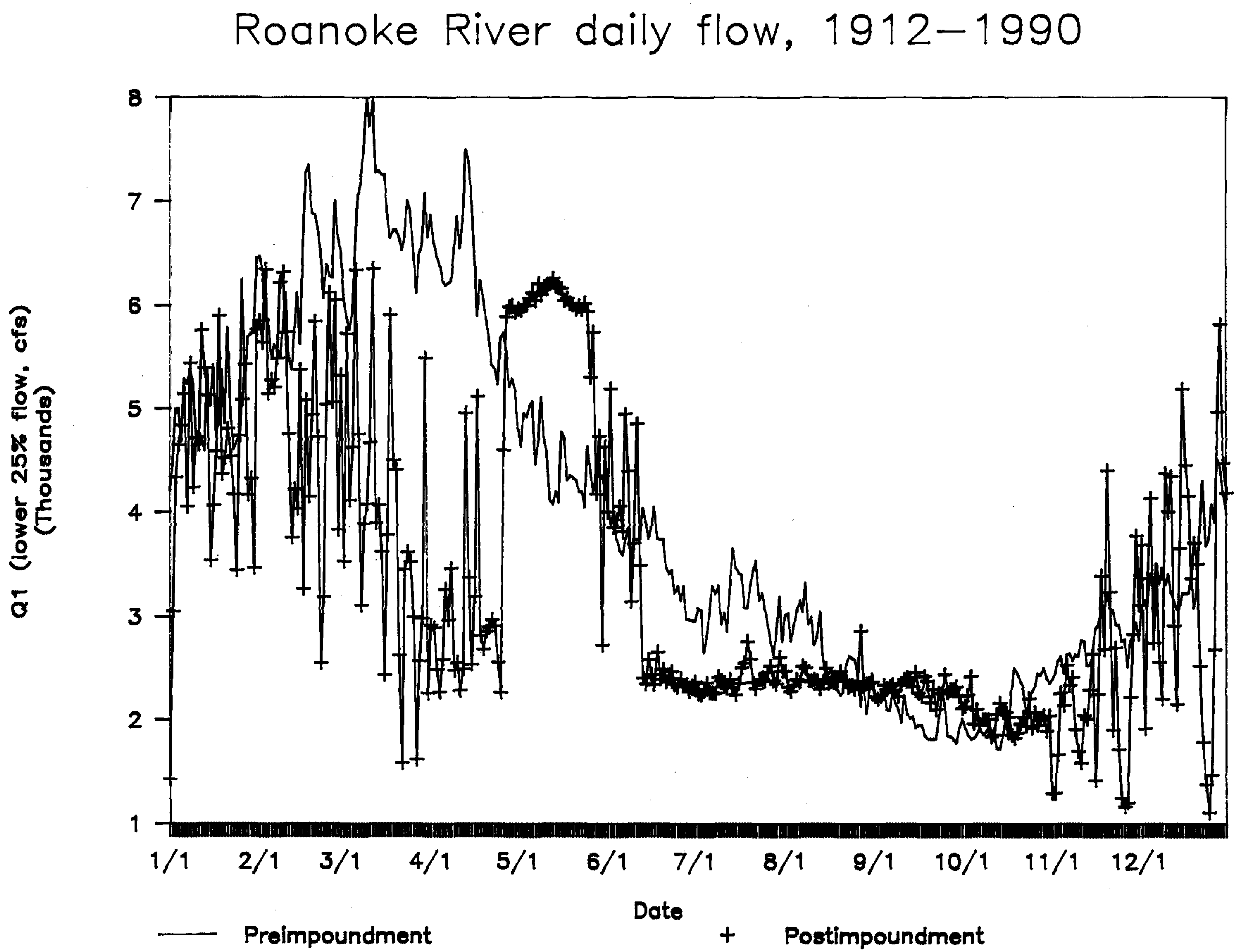



Roanoke River daily flow, 1912–1990
Smoothed average
Smoothed median flow (cfs)
(Thousands)
12
11
10
9
8
7
6
5
4
3
2
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
Date
Preimpoundment
+ Postimpoundment


Roanoke River daily flow, 1912–1990
Median flow (cfs)
(Thousands)
13
12
11
10
9
8
7
6
5
4
3
2
1
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
Date
Preimpoundment
+ Postimpoundment

Roanoke River daily flow, 1912–1990





Roanoke River daily flow, 1912–1990
Q1 (lower 25% flow, cfs)
(Thousands)
8
7
6
5
4
3
2
1
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
Date
Preimpoundment
+ Postimpoundment

1

APPENDIX A-6.

Percentage of Days in the Year (1912-1989, and Jan-Aug 7, 1990) that Roanoke River Flows were Within Specific Discharge Criteria (0-20,000 cfs).

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

	FLOW (IN THOUSANDS)																											
	0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
12	.	.	19	5.2	76	20.8	53	14.5	63	17.2	32	8.7	40	10.9	21	5.7	8	2.2	9	2.5	7	1.9	.	.	38	10.4	366	100
13	.	.	5	1.4	39	10.7	86	23.6	87	23.8	47	12.9	40	11.0	11	3.0	13	3.6	5	1.4	6	1.6	4	1.1	22	6.0	365	100
14	.	.	52	14.2	74	20.3	33	9.0	42	11.5	41	11.2	49	13.4	32	8.8	11	3.0	8	2.2	4	1.1	2	0.5	17	4.7	365	100
15	.	.	4	1.1	43	11.8	65	17.8	79	21.6	37	10.1	46	12.6	21	5.8	11	3.0	15	4.1	8	2.2	1	0.3	35	9.6	365	100
16	.	.	16	4.4	67	18.3	59	16.1	62	16.9	61	16.7	50	13.7	18	4.9	4	1.1	8	2.2	2	0.5	3	0.8	16	4.4	366	100
17	.	.	44	12.1	49	13.4	71	19.5	55	15.1	35	9.6	46	12.6	21	5.8	4	1.1	13	3.6	2	0.5	2	0.5	23	6.3	365	100
18	.	.	29	7.9	52	14.2	55	15.1	72	19.7	47	12.9	37	10.1	24	6.6	6	1.6	8	2.2	6	1.6	5	1.4	24	6.6	365	100
19	.	.	26	7.1	47	12.9	39	10.7	41	11.2	79	21.6	41	11.2	28	7.7	7	1.9	11	3.0	7	1.9	4	1.1	35	9.6	365	100
20	.	.	19	5.2	52	14.2	41	11.2	74	20.2	51	13.9	43	11.7	29	7.9	11	3.0	8	2.2	10	2.7	1	0.3	27	7.4	366	100
21	.	.	47	12.9	55	15.1	49	13.4	65	17.8	43	11.8	47	12.9	23	6.3	7	1.9	6	1.6	3	0.8	3	0.8	17	4.7	365	100
22	.	.	3	0.8	49	13.4	53	14.5	72	19.7	47	12.9	36	9.9	19	5.2	26	7.1	12	3.3	11	3.0	2	0.5	35	9.6	365	100
23	.	.	.	.	38	10.4	67	18.4	91	24.9	52	14.2	30	8.2	20	5.5	13	3.6	14	3.8	13	3.6	4	1.1	23	6.3	365	100
24	.	.	.	.	17	4.6	23	6.3	98	26.8	67	18.3	44	12.0	34	9.3	24	6.6	12	3.3	4	1.1	10	2.7	33	9.0	366	100
25	.	.	52	14.2	60	16.4	65	17.8	70	19.2	40	11.0	22	6.0	22	6.0	6	1.6	3	0.8	5	1.4	2	0.5	18	4.9	365	100
26	2	0.5	89	24.4	62	17.0	48	13.2	57	15.6	42	11.5	23	6.3	10	2.7	5	1.4	7	1.9	3	0.8	3	0.8	14	3.8	365	100
27	.	.	8	2.2	42	11.5	78	21.4	99	27.1	47	12.9	29	7.9	9	2.5	17	4.7	4	1.1	7	1.9	3	0.8	22	6.0	365	100
28	.	.	1	0.3	14	3.8	40	10.9	129	35.2	70	19.1	38	10.4	23	6.3	12	3.3	1	0.3	5	1.4	4	1.1	29	7.9	366	100
29	.	.	.	.	1	0.3	36	9.9	87	23.8	92	25.2	53	14.5	31	8.5	18	4.9	9	2.5	6	1.6	4	1.1	28	7.7	365	100
30	32	8.8	91	24.9	52	14.2	41	11.2	60	16.4	48	13.2	17	4.7	8	2.2	4	1.1	3	0.8	4	1.1	1	0.3	4	1.1	365	100
31	.	.	84	23.0	58	15.9	64	17.5	75	20.5	26	7.1	11	3.0	13	3.6	9	2.5	4	1.1	5	1.4	6	1.6	10	2.7	365	100
32	30	8.2	49	13.4	39	10.7	29	7.9	71	19.4	51	13.9	23	6.3	19	5.2	8	2.2	9	2.5	7	1.9	5	1.4	26	7.1	366	100
33	2	0.5	85	23.3	66	18.1	26	7.1	25	6.8	47	12.9	40	11.0	21	5.8	13	3.6	4	1.1	13	3.6	7	1.9	16	4.4	365	100

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

	FLOW (IN THOUSANDS)																											
	0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
34	.	.	1	0.3	103	28.2	52	14.2	67	18.4	31	8.5	28	7.7	23	6.3	12	3.3	10	2.7	3	0.8	4	1.1	31	8.5	365	100
35	.	.	.	.	61	16.7	41	11.2	61	16.7	69	18.9	50	13.7	19	5.2	9	2.5	15	4.1	4	1.1	7	1.9	29	7.9	365	100
36	.	.	11	3.0	59	16.1	67	18.3	53	14.5	30	8.2	28	7.7	28	7.7	14	3.8	13	3.6	9	2.5	1	0.3	53	14.5	366	100
37	.	.	.	.	.	.	10	2.7	64	17.5	102	27.9	57	15.6	26	7.1	26	7.1	13	3.6	10	2.7	5	1.4	52	14.2	365	100
38	.	.	.	.	31	8.5	45	12.3	79	21.6	85	23.3	43	11.8	20	5.5	15	4.1	7	1.9	16	4.4	2	0.5	22	6.0	365	100
39	.	.	.	.	47	12.9	55	15.1	80	21.9	55	15.1	37	10.1	17	4.7	19	5.2	9	2.5	12	3.3	7	1.9	27	7.4	365	100
40	.	.	.	.	8	2.2	69	18.9	121	33.1	60	16.4	33	9.0	14	3.8	17	4.6	6	1.6	5	1.4	7	1.9	26	7.1	366	100
41	.	.	72	19.7	68	18.6	34	9.3	83	22.7	47	12.9	22	6.0	14	3.8	8	2.2	6	1.6	3	0.8	2	0.5	6	1.6	365	100
42	.	.	1	0.3	35	9.6	71	19.5	118	32.3	56	15.3	27	7.4	17	4.7	10	2.7	3	0.8	2	0.5	3	0.8	22	6.0	365	100
43	.	.	24	6.6	96	26.3	22	6.0	49	13.4	72	19.7	30	8.2	13	3.6	10	2.7	13	3.6	3	0.8	10	2.7	23	6.3	365	100
44	.	.	22	6.0	28	7.7	39	10.7	106	29.0	43	11.7	22	6.0	19	5.2	15	4.1	17	4.6	10	2.7	5	1.4	40	10.9	366	100
45	.	.	.	.	23	6.3	49	13.4	112	30.7	60	16.4	30	8.2	22	6.0	15	4.1	11	3.0	7	1.9	6	1.6	30	8.2	365	100
46	.	.	3	0.8	51	14.0	70	19.2	62	17.0	47	12.9	34	9.3	40	11.0	20	5.5	10	2.7	5	1.4	7	1.9	16	4.4	365	100
47	.	.	2	0.5	49	13.4	34	9.3	121	33.2	55	15.1	25	6.8	19	5.2	16	4.4	9	2.5	6	1.6	6	1.6	23	6.3	365	100
48	.	.	.	.	24	6.6	43	11.7	79	21.6	49	13.4	41	11.2	32	8.7	20	5.5	21	5.7	10	2.7	10	2.7	37	10.1	366	100
49	.	.	.	.	.	.	5	1.4	103	28.2	61	16.7	72	19.7	27	7.4	31	8.5	11	3.0	9	2.5	7	1.9	39	10.7	365	100
50	.	.	.	.	1	0.3	46	12.6	139	38.1	72	19.7	44	12.1	16	4.4	14	3.8	6	1.6	8	2.2	3	0.8	16	4.4	365	100
51	.	.	41	11.2	49	13.4	32	8.8	95	26.0	64	17.5	27	7.4	14	3.8	10	2.7	7	1.9	4	1.1	3	0.8	19	5.2	365	100
52	9	2.5	49	13.4	45	12.3	38	10.4	59	16.1	50	13.7	31	8.5	15	4.1	13	3.6	11	3.0	3	0.8	8	2.2	35	9.6	366	100
53	1	0.3	43	11.8	59	16.2	41	11.2	90	24.7	62	17.0	27	7.4	12	3.3	14	3.8	2	0.5	.	.	1	0.3	13	3.6	365	100
54	1	0.3	43	11.8	42	11.5	59	16.2	57	15.6	66	18.1	37	10.1	39	10.7	9	2.5	11	3.0	1	0.3	.	.	.	.	365	100
55	3	0.8	21	5.8	31	8.5	20	5.5	87	23.8	76	20.8	64	17.5	18	4.9	19	5.2	7	1.9	4	1.1	.	.	15	4.1	365	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

	FLOW (IN THOUSANDS)																										ALL	
	0		1		2		3		4		6		8		10		12		14		16		18		20			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
56	13	3.6	29	7.9	52	14.2	33	9.0	121	33.1	64	17.5	33	9.0	11	3.0	3	0.8	6	1.6	.	.	1	0.3	.	.	366	100
57	10	2.7	26	7.1	41	11.2	18	4.9	59	16.2	59	16.2	49	13.4	14	3.8	19	5.2	6	1.6	17	4.7	36	9.9	11	3.0	365	100
58	8	2.2	28	7.7	26	7.1	20	5.5	58	15.9	52	14.2	37	10.1	17	4.7	12	3.3	21	5.8	7	1.9	49	13.4	30	8.2	365	100
59	13	3.6	9	2.5	61	16.7	25	6.8	61	16.7	70	19.2	62	17.0	16	4.4	10	2.7	14	3.8	5	1.4	19	5.2	.	.	365	100
60	1	0.3	14	3.8	31	8.5	24	6.6	61	16.7	57	15.6	45	12.3	18	4.9	11	3.0	28	7.7	11	3.0	27	7.4	38	10.4	366	100
61	.	.	20	5.5	48	13.2	18	4.9	71	19.5	68	18.6	42	11.5	16	4.4	18	4.9	15	4.1	11	3.0	38	10.4	.	.	365	100
62	.	.	30	8.2	50	13.7	15	4.1	45	12.3	40	11.0	58	15.9	8	2.2	27	7.4	22	6.0	16	4.4	54	14.8	.	.	365	100
63	3	0.8	21	5.8	75	20.5	37	10.1	94	25.8	57	15.6	16	4.4	6	1.6	7	1.9	8	2.2	6	1.6	35	9.6	.	.	365	100
64	.	.	38	10.4	85	23.2	38	10.4	63	17.2	77	21.0	48	13.1	15	4.1	2	0.5	.	.	.	.	.	.	.	.	366	100
65	2	0.5	29	7.9	83	22.7	35	9.6	63	17.3	63	17.3	50	13.7	5	1.4	26	7.1	6	1.6	1	0.3	2	0.5	.	.	365	100
66	2	0.5	31	8.5	81	22.2	76	20.8	58	15.9	66	18.1	31	8.5	4	1.1	1	0.3	15	4.1	.	.	.	.	.	.	365	100
67	4	1.1	52	14.2	86	23.6	34	9.3	55	15.1	74	20.3	53	14.5	7	1.9	.	.	.	.	.	.	.	.	.	.	365	100
68	5	1.4	45	12.3	87	23.8	32	8.7	66	18.0	51	13.9	58	15.8	14	3.8	6	1.6	2	0.5	.	.	.	.	.	.	366	100
69	6	1.6	36	9.9	100	27.4	28	7.7	71	19.5	65	17.8	27	7.4	16	4.4	16	4.4	.	.	.	.	.	.	.	.	365	100
70	3	0.8	76	20.8	76	20.8	14	3.8	79	21.6	34	9.3	41	11.2	23	6.3	15	4.1	4	1.1	.	.	.	.	.	.	365	100
71	5	1.4	52	14.2	22	6.0	13	3.6	32	8.8	48	13.2	36	9.9	43	11.8	40	11.0	19	5.2	.	.	53	14.5	2	0.5	365	100
72	2	0.5	22	6.0	26	7.1	11	3.0	16	4.4	37	10.1	33	9.0	35	9.6	32	8.7	30	8.2	22	6.0	81	22.1	19	5.2	366	100
73	1	0.3	27	7.4	44	12.1	12	3.3	27	7.4	27	7.4	41	11.2	29	7.9	29	7.9	18	4.9	9	2.5	101	27.7	.	.	365	100
74	1	0.3	66	18.1	50	13.7	8	2.2	24	6.6	22	6.0	25	6.8	36	9.9	33	9.0	34	9.3	27	7.4	37	10.1	2	0.5	365	100
75	.	.	20	5.5	52	14.2	4	1.1	22	6.0	43	11.8	32	8.8	25	6.8	46	12.6	18	4.9	5	1.4	61	16.7	37	10.1	365	100
76	.	.	24	6.6	105	28.7	21	5.7	37	10.1	60	16.4	39	10.7	23	6.3	23	6.3	8	2.2	4	1.1	22	6.0	.	.	366	100
77	.	.	43	11.8	138	37.8	20	5.5	35	9.6	49	13.4	24	6.6	25	6.8	23	6.3	4	1.1	2	0.5	2	0.5	.	.	365	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

FLOW (IN THOUSANDS)

YR	0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
78	.	.	27	7.4	42	11.5	16	4.4	36	9.9	31	8.5	50	13.7	19	5.2	14	3.8	4	1.1	6	1.6	70	19.2	50	13.7	365	100
79	.	.	7	1.9	37	10.1	7	1.9	23	6.3	42	11.5	18	4.9	22	6.0	28	7.7	23	6.3	18	4.9	102	27.9	38	10.4	365	100
80	.	.	50	13.7	94	25.7	14	3.8	30	8.2	37	10.1	38	10.4	19	5.2	27	7.4	5	1.4	11	3.0	41	11.2	.	.	366	100
81	.	.	93	25.5	165	45.2	32	8.8	37	10.1	22	6.0	9	2.5	3	0.8	3	0.8	1	0.3	.	.	.	.	.	.	365	100
82	.	.	17	4.7	86	23.6	26	7.1	35	9.6	53	14.5	41	11.2	26	7.1	25	6.8	15	4.1	26	7.1	15	4.1	.	.	365	100
83	.	.	19	5.2	91	24.9	29	7.9	32	8.8	27	7.4	20	5.5	14	3.8	20	5.5	17	4.7	16	4.4	34	9.3	46	12.6	365	100
84	.	.	29	7.9	56	15.3	19	5.2	28	7.7	41	11.2	31	8.5	18	4.9	27	7.4	17	4.6	16	4.4	21	5.7	63	17.2	366	100
85	.	.	16	4.4	121	33.2	26	7.1	38	10.4	44	12.1	20	5.5	10	2.7	27	7.4	9	2.5	8	2.2	23	6.3	23	6.3	365	100
86	11	3.0	42	11.5	143	39.2	25	6.8	57	15.6	48	13.2	21	5.8	11	3.0	5	1.4	2	0.5	.	.	.	.	.	.	365	100
87	1	0.3	15	4.1	66	18.1	15	4.1	22	6.0	25	6.8	43	11.8	21	5.8	29	7.9	11	3.0	6	1.6	37	10.1	74	20.3	365	100
88	1	0.3	66	18.0	111	30.3	19	5.2	52	14.2	61	16.7	24	6.6	15	4.1	12	3.3	4	1.1	.	.	1	0.3	.	.	366	100
89	.	.	30	8.2	21	5.8	22	6.0	36	9.9	29	7.9	47	12.9	23	6.3	21	5.8	49	13.4	15	4.1	21	5.8	51	14.0	365	100
90	.	.	5	2.3	19	8.7	7	3.2	12	5.5	22	10.0	26	11.9	14	6.4	10	4.6	17	7.8	8	3.7	67	30.6	12	5.5	219	100

APPENDIX A-7.

Percentage of Days in Quarter 1 (Jan-Mar, 1912-1990) that Roanoke River Flows were Within Specific Discharge Criteria (0-20,000 cfs).

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 1

	FLOW (IN THOUSANDS)																										ALL	
	0		1		2		3		4		6		8		10		12		14		16		18		20			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
12	.	.	.	.	.	.	2	2.2	22	24.2	8	8.8	15	16.5	7	7.7	3	3.3	5	5.5	4	4.4	.	.	25	27.5	91	100
13	.	.	.	.	.	.	20	22.2	25	27.8	17	18.9	9	10.0	4	4.4	3	3.3	2	2.2	1	1.1	1	1.1	8	8.9	90	100
14	.	.	.	.	.	.	.	.	10	11.1	14	15.6	25	27.8	17	18.9	9	10.0	3	3.3	3	3.3	.	.	9	10.0	90	100
15	.	.	.	.	.	.	.	.	4	4.4	11	12.2	28	31.1	10	11.1	6	6.7	10	11.1	2	2.2	.	.	19	21.1	90	100
16	.	.	.	.	.	.	3	3.3	21	23.1	28	30.8	25	27.5	5	5.5	1	1.1	1	1.1	1	1.1	1	1.1	5	5.5	91	100
17	.	.	.	.	.	.	4	4.4	14	15.6	12	13.3	23	25.6	11	12.2	2	2.2	8	8.9	1	1.1	.	.	15	16.7	90	100
18	.	.	9	10.0	3	3.3	.	.	18	20.0	20	22.2	15	16.7	8	8.9	2	2.2	4	4.4	.	.	5	5.6	6	6.7	90	100
19	.	.	.	.	.	.	.	.	6	6.7	27	30.0	20	22.2	9	10.0	1	1.1	3	3.3	5	5.6	2	2.2	17	18.9	90	100
20	.	.	7	7.7	3	3.3	7	7.7	15	16.5	21	23.1	12	13.2	8	8.8	3	3.3	2	2.2	4	4.4	.	.	9	9.9	91	100
21	.	.	.	.	.	.	.	.	1	1.1	18	20.0	30	33.3	14	15.6	5	5.6	5	5.6	2	2.2	1	1.1	14	15.6	90	100
22	.	.	.	.	6	6.7	5	5.6	10	11.1	5	5.6	5	5.6	9	10.0	14	15.6	6	6.7	5	5.6	.	.	25	27.8	90	100
23	.	.	.	.	.	.	.	.	12	13.3	11	12.2	11	12.2	11	12.2	7	7.8	10	11.1	9	10.0	4	4.4	15	16.7	90	100
24	.	.	.	.	.	.	.	.	11	12.1	21	23.1	22	24.2	10	11.0	10	11.0	2	2.2	1	1.1	5	5.5	9	9.9	91	100
25	.	.	.	.	.	.	.	.	2	2.2	26	28.9	16	17.8	16	17.8	5	5.6	3	3.3	4	4.4	2	2.2	16	17.8	90	100
26	.	.	.	.	1	1.1	1	1.1	23	25.6	26	28.9	16	17.8	4	4.4	2	2.2	4	4.4	1	1.1	3	3.3	9	10.0	90	100
27	.	.	.	.	.	.	1	1.1	42	46.7	15	16.7	12	13.3	2	2.2	8	8.9	1	1.1	2	2.2	1	1.1	6	6.7	90	100
28	.	.	.	.	.	.	.	.	16	17.6	35	38.5	20	22.0	8	8.8	5	5.5	.	.	2	2.2	2	2.2	3	3.3	91	100
29	.	.	.	.	.	.	2	2.2	34	37.8	11	12.2	14	15.6	6	6.7	5	5.6	4	4.4	1	1.1	1	1.1	12	13.3	90	100
30	.	.	.	.	.	.	.	.	22	24.4	34	37.8	13	14.4	7	7.8	2	2.2	3	3.3	4	4.4	1	1.1	4	4.4	90	100
31	.	.	.	.	17	18.9	35	38.9	25	27.8	4	4.4	1	1.1	4	4.4	2	2.2	.	.	.	.	2	2.2	.	.	90	100
32	.	.	.	.	.	.	9	9.9	28	30.8	19	20.9	8	8.8	8	8.8	2	2.2	3	3.3	2	2.2	1	1.1	11	12.1	91	100
33	.	.	.	.	.	.	.	.	.	.	22	24.4	22	24.4	10	11.1	10	11.1	2	2.2	12	13.3	3	3.3	9	10.0	90	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 1

	FLOW (IN THOUSANDS)																															
	0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
34	.	.	.	.	38	42.2	16	17.8	7	7.8	3	3.3	4	4.4	6	6.7	3	3.3	1	1.1	.	.	2	2.2	10	11.1	90	100
35	.	.	.	.	.	.	.	.	.	.	19	21.1	27	30.0	11	12.2	6	6.7	9	10.0	1	1.1	3	3.3	14	15.6	90	100
36	.	.	.	.	.	.	2	2.2	.	.	1	1.1	9	9.9	17	18.7	9	9.9	8	8.8	5	5.5	1	1.1	39	42.9	91	100
37	.	.	.	.	.	.	.	.	.	.	11	12.2	25	27.8	11	12.2	7	7.8	6	6.7	5	5.6	3	3.3	22	24.4	90	100
38	.	.	.	.	.	.	.	.	.	.	38	42.2	26	28.9	12	13.3	4	4.4	1	1.1	4	4.4	1	1.1	4	4.4	90	100
39	.	.	.	.	.	.	.	.	6	6.7	18	20.0	14	15.6	7	7.8	8	8.9	6	6.7	6	6.7	7	7.8	18	20.0	90	100
40	.	.	.	.	7	7.7	9	9.9	23	25.3	19	20.9	9	9.9	4	4.4	5	5.5	3	3.3	1	1.1	1	1.1	10	11.0	91	100
41	.	.	.	.	.	.	.	.	35	38.9	25	27.8	14	15.6	9	10.0	3	3.3	2	2.2	1	1.1	1	1.1	.	.	90	100
42	.	.	1	1.1	7	7.8	24	26.7	34	37.8	12	13.3	4	4.4	3	3.3	.	.	1	1.1	.	.	2	2.2	2	2.2	90	100
43	.	.	.	.	.	.	.	.	6	6.7	23	25.6	15	16.7	5	5.6	5	5.6	9	10.0	2	2.2	9	10.0	16	17.8	90	100
44	.	.	.	.	1	1.1	16	17.6	14	15.4	3	3.3	6	6.6	10	11.0	6	6.6	9	9.9	4	4.4	4	4.4	18	19.8	91	100
45	.	.	.	.	.	.	.	.	17	18.9	21	23.3	12	13.3	9	10.0	6	6.7	7	7.8	4	4.4	5	5.6	9	10.0	90	100
46	.	.	.	.	.	.	.	.	.	.	9	10.0	16	17.8	27	30.0	11	12.2	8	8.9	2	2.2	2	2.2	15	16.7	90	100
47	.	.	.	.	.	.	.	.	33	36.7	20	22.2	9	10.0	5	5.6	4	4.4	4	4.4	3	3.3	2	2.2	10	11.1	90	100
48	.	.	.	.	.	.	.	.	19	20.9	9	9.9	11	12.1	13	14.3	7	7.7	7	7.7	7	7.7	3	3.3	15	16.5	91	100
49	.	.	.	.	.	.	.	.	.	.	10	11.1	26	28.9	10	11.1	20	22.2	6	6.7	5	5.6	2	2.2	11	12.2	90	100
50	.	.	.	.	.	.	.	.	31	34.4	20	22.2	27	30.0	1	1.1	3	3.3	2	2.2	3	3.3	2	2.2	1	1.1	90	100
51	.	.	.	.	.	.	.	.	31	34.4	30	33.3	9	10.0	7	7.8	4	4.4	1	1.1	2	2.2	2	2.2	4	4.4	90	100
52	.	.	.	.	.	.	.	.	6	6.6	17	18.7	12	13.2	10	11.0	8	8.8	5	5.5	2	2.2	5	5.5	26	28.6	91	100
53	.	.	2	2.2	3	3.3	1	1.1	7	7.8	32	35.6	16	17.8	9	10.0	5	5.6	1	1.1	.	.	1	1.1	13	14.4	90	100
54	.	.	7	7.8	5	5.6	10	11.1	7	7.8	24	26.7	6	6.7	10	11.1	9	10.0	11	12.2	1	1.1	.	.	.	.	90	100
55	1	1.1	11	12.2	7	7.8	.	.	29	32.2	7	7.8	13	14.4	5	5.6	7	7.8	5	5.6	3	3.3	.	.	2	2.2	90	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 1

	FLOW (IN THOUSANDS)																											
	0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																												
56	7	7.7	5	5.5	5	5.5	10	11.0	36	39.6	22	24.2	3	3.3	.	.	1	1.1	2	2.2	.	.	.	.	.	.	91	100
57	7	7.8	8	8.9	3	3.3	2	2.2	12	13.3	13	14.4	11	12.2	3	3.3	8	8.9	2	2.2	5	5.6	14	15.6	2	2.2	90	100
58	4	4.4	5	5.6	5	5.6	4	4.4	10	11.1	4	4.4	2	2.2	7	7.8	7	7.8	11	12.2	4	4.4	27	30.0	.	.	90	100
59	13	14.4	8	8.9	8	8.9	7	7.8	8	8.9	13	14.4	18	20.0	7	7.8	4	4.4	.	.	.	.	4	4.4	.	.	90	100
60	.	.	1	1.1	1	1.1	1	1.1	4	4.4	3	3.3	3	3.3	4	4.4	9	9.9	13	14.3	11	12.1	20	22.0	21	23.1	91	100
61	.	.	13	14.4	5	5.6	6	6.7	11	12.2	18	20.0	6	6.7	2	2.2	9	10.0	5	5.6	4	4.4	11	12.2	.	.	90	100
62	.	.	1	1.1	2	2.2	.	.	3	3.3	1	1.1	2	2.2	4	4.4	20	22.2	12	13.3	9	10.0	36	40.0	.	.	90	100
63	3	3.3	5	5.6	3	3.3	3	3.3	5	5.6	7	7.8	9	10.0	4	4.4	7	7.8	7	7.8	6	6.7	31	34.4	.	.	90	100
64	.	.	18	19.8	8	8.8	4	4.4	13	14.3	22	24.2	20	22.0	6	6.6	.	.	.	.	.	.	.	.	.	.	91	100
65	.	.	7	7.8	5	5.6	2	2.2	3	3.3	20	22.2	22	24.4	3	3.3	20	22.2	5	5.6	1	1.1	2	2.2	.	.	90	100
66	.	.	11	12.2	4	4.4	10	11.1	18	20.0	16	17.8	13	14.4	2	2.2	1	1.1	15	16.7	.	.	.	.	.	.	90	100
67	.	.	13	14.4	9	10.0	6	6.7	15	16.7	25	27.8	22	24.4	.	.	.	.	.	.	.	.	.	.	.	.	90	100
68	.	.	9	9.9	2	2.2	5	5.5	20	22.0	23	25.3	24	26.4	8	8.8	.	.	.	.	.	.	.	.	.	.	91	100
69	.	.	19	21.1	10	11.1	9	10.0	16	17.8	16	17.8	8	8.9	7	7.8	5	5.6	.	.	.	.	.	.	.	.	90	100
70	.	.	22	24.4	4	4.4	6	6.7	19	21.1	11	12.2	16	17.8	5	5.6	5	5.6	2	2.2	.	.	.	.	.	.	90	100
71	1	1.1	5	5.6	5	5.6	3	3.3	11	12.2	9	10.0	10	11.1	15	16.7	19	21.1	5	5.6	.	.	7	7.8	.	.	90	100
72	2	2.2	2	2.2	4	4.4	2	2.2	5	5.5	16	17.6	16	17.6	19	20.9	12	13.2	10	11.0	.	.	3	3.3	.	.	91	100
73	.	.	2	2.2	.	.	1	1.1	3	3.3	2	2.2	4	4.4	4	4.4	12	13.3	8	8.9	1	1.1	53	58.9	.	.	90	100
74	1	1.1	5	5.6	5	5.6	.	.	7	7.8	3	3.3	9	10.0	9	10.0	12	13.3	4	4.4	14	15.6	19	21.1	2	2.2	90	100
75	.	.	6	6.7	2	2.2	1	1.1	3	3.3	7	7.8	3	3.3	4	4.4	17	18.9	5	5.6	2	2.2	28	31.1	12	13.3	90	100
76	.	.	17	18.7	4	4.4	6	6.6	10	11.0	5	5.5	8	8.8	10	11.0	12	13.2	2	2.2	.	.	17	18.7	.	.	91	100
77	.	.	21	23.3	12	13.3	9	10.0	15	16.7	10	11.1	7	7.8	13	14.4	1	1.1	1	1.1	1	1.1	.	.	.	.	90	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 1

	FLOW (IN THOUSANDS)																											ALL	
	0		1		2		3		4		6		8		10		12		14		16		18		20			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
78	.	.	2	2.2	.	.	2	2.2	3	3.3	1	1.1	5	5.6	1	1.1	7	7.8	3	3.3	2	2.2	45	50.0	19	21.1	90	100
79	.	.	2	2.2	.	.	1	1.1	1	1.1	1	1.1	2	2.2	3	3.3	2	2.2	4	4.4	13	14.4	36	40.0	25	27.8	90	100
80	.	.	10	11.0	4	4.4	2	2.2	6	6.6	6	6.6	15	16.5	9	9.9	12	13.2	2	2.2	7	7.7	18	19.8	.	.	91	100
81	.	.	45	50.0	18	20.0	5	5.6	11	12.2	3	3.3	4	4.4	1	1.1	2	2.2	1	1.1	.	.	.	.	.	.	90	100
82	.	.	6	6.7	4	4.4	2	2.2	10	11.1	7	7.8	7	7.8	5	5.6	16	17.8	10	11.1	23	25.6	.	.	.	.	90	100
83	.	.	3	3.3	1	1.1	7	7.8	8	8.9	8	8.9	9	10.0	6	6.7	15	16.7	7	7.8	8	8.9	10	11.1	8	8.9	90	100
84	.	.	1	1.1	1	1.1	1	1.1	4	4.4	7	7.7	3	3.3	2	2.2	9	9.9	13	14.3	10	11.0	12	13.2	28	30.8	91	100
85	.	.	8	8.9	3	3.3	8	8.9	13	14.4	12	13.3	12	13.3	8	8.9	17	18.9	7	7.8	2	2.2	.	.	.	.	90	100
86	.	.	13	14.4	6	6.7	10	11.1	23	25.6	17	18.9	13	14.4	6	6.7	.	.	2	2.2	.	.	.	.	.	.	90	100
87	.	.	1	1.1	3	3.3	.	.	5	5.6	4	4.4	4	4.4	4	4.4	15	16.7	5	5.6	5	5.6	25	27.8	19	21.1	90	100
88	1	1.1	25	27.5	3	3.3	4	4.4	13	14.3	13	14.3	9	9.9	11	12.1	9	9.9	2	2.2	.	.	1	1.1	.	.	91	100
89	.	.	25	27.8	4	4.4	8	8.9	3	3.3	7	7.8	11	12.2	2	2.2	9	10.0	4	4.4	5	5.6	4	4.4	8	8.9	90	100
90	.	.	4	4.4	2	2.2	2	2.2	4	4.4	5	5.6	5	5.6	7	7.8	4	4.4	6	6.7	7	7.8	44	48.9	.	.	90	100

APPENDIX A-8.

Percentage of Days in Quarter 2 (Apr-Jun, 1912-1990) that Roanoke River Flows were Within Specific Discharge Criteria (0-20,000 cfs).

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 2

	FLOW (IN THOUSANDS)																									
	1		2		3		4		6		8		10		12		14		16		18		20		ALL	
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
12	.	.	.	.	1	1.1	21	23.1	17	18.7	23	25.3	10	11.0	4	4.4	4	4.4	2	2.2	.	.	9	9.9	91	100
13	.	.	.	.	16	17.6	29	31.9	15	16.5	12	13.2	3	3.3	4	4.4	3	3.3	1	1.1	1	1.1	7	7.7	91	100
14	4	4.4	17	18.7	19	20.9	14	15.4	15	16.5	13	14.3	7	7.7	.	.	1	1.1	1	1.1	.	.	.	.	91	100
15	1	1.1	6	6.6	15	16.5	42	46.2	9	9.9	8	8.8	4	4.4	2	2.2	.	.	1	1.1	.	.	3	3.3	91	100
16	.	.	2	2.2	23	25.3	23	25.3	13	14.3	11	12.1	6	6.6	3	3.3	2	2.2	1	1.1	1	1.1	6	6.6	91	100
17	1	1.1	3	3.3	23	25.3	19	20.9	17	18.7	14	15.4	5	5.5	.	.	3	3.3	1	1.1	1	1.1	4	4.4	91	100
18	1	1.1	5	5.5	13	14.3	21	23.1	12	13.2	8	8.8	9	9.9	4	4.4	2	2.2	4	4.4	.	.	12	13.2	91	100
19	.	.	.	.	4	4.4	11	12.1	26	28.6	16	17.6	12	13.2	4	4.4	6	6.6	2	2.2	2	2.2	8	8.8	91	100
20	.	.	2	2.2	14	15.4	25	27.5	15	16.5	15	16.5	7	7.7	3	3.3	4	4.4	1	1.1	1	1.1	4	4.4	91	100
21	.	.	1	1.1	13	14.3	32	35.2	19	20.9	12	13.2	7	7.7	1	1.1	1	1.1	1	1.1	2	2.2	2	2.2	91	100
22	.	.	.	.	.	.	21	23.1	20	22.0	17	18.7	7	7.7	9	9.9	5	5.5	6	6.6	1	1.1	5	5.5	91	100
23	.	.	1	1.1	16	17.6	32	35.2	21	23.1	6	6.6	6	6.6	3	3.3	1	1.1	2	2.2	.	.	3	3.3	91	100
24	.	.	.	.	.	.	8	8.8	21	23.1	11	12.1	12	13.2	11	12.1	8	8.8	2	2.2	4	4.4	14	15.4	91	100
25	.	.	10	11.0	17	18.7	46	50.5	9	9.9	3	3.3	3	3.3	.	.	.	.	1	1.1	.	.	2	2.2	91	100
26	12	13.2	24	26.4	21	23.1	18	19.8	8	8.8	2	2.2	2	2.2	1	1.1	1	1.1	2	2.2	.	.	.	.	91	100
27	.	.	3	3.3	37	40.7	18	19.8	12	13.2	10	11.0	2	2.2	3	3.3	1	1.1	3	3.3	1	1.1	1	1.1	91	100
28	.	.	.	.	18	19.8	31	34.1	19	20.9	7	7.7	5	5.5	2	2.2	.	.	2	2.2	.	.	7	7.7	91	100
29	.	.	.	.	.	.	12	13.2	28	30.8	21	23.1	11	12.1	6	6.6	3	3.3	2	2.2	1	1.1	7	7.7	91	100
30	.	.	9	9.9	31	34.1	35	38.5	11	12.1	2	2.2	1	1.1	2	2.2	.	.	.	.	.	.	.	.	91	100
31	.	.	9	9.9	11	12.1	30	33.0	10	11.0	5	5.5	6	6.6	3	3.3	3	3.3	4	4.4	3	3.3	7	7.7	91	100
32	.	.	15	16.5	14	15.4	26	28.6	17	18.7	6	6.6	4	4.4	3	3.3	3	3.3	2	2.2	.	.	1	1.1	91	100
33	.	.	9	9.9	6	6.6	15	16.5	19	20.9	15	16.5	10	11.0	3	3.3	2	2.2	1	1.1	4	4.4	7	7.7	91	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 2

	FLOW (IN THOUSANDS)																									
	1		2		3		4		6		8		10		12		14		16		18		20		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
34	.	.	2	2.2	15	16.5	21	23.1	10	11.0	13	14.3	6	6.6	6	6.6	7	7.7	3	3.3	1	1.1	7	7.7	91	100
35	.	.	2	2.2	4	4.4	20	22.0	30	33.0	9	9.9	5	5.5	3	3.3	3	3.3	2	2.2	2	2.2	11	12.1	91	100
36	.	.	.	.	15	16.5	25	27.5	17	18.7	10	11.0	5	5.5	2	2.2	3	3.3	2	2.2	.	.	12	13.2	91	100
37	.	.	.	.	.	.	27	29.7	32	35.2	13	14.3	4	4.4	4	4.4	3	3.3	.	.	1	1.1	7	7.7	91	100
38	.	.	.	.	3	3.3	37	40.7	25	27.5	5	5.5	3	3.3	4	4.4	1	1.1	4	4.4	1	1.1	8	8.8	91	100
39	.	.	2	2.2	5	5.5	40	44.0	20	22.0	11	12.1	3	3.3	5	5.5	1	1.1	2	2.2	.	.	2	2.2	91	100
40	.	.	.	.	2	2.2	30	33.0	24	26.4	11	12.1	4	4.4	8	8.8	1	1.1	4	4.4	3	3.3	4	4.4	91	100
41	.	.	23	25.3	17	18.7	28	30.8	11	12.1	4	4.4	2	2.2	2	2.2	1	1.1	.	.	.	.	3	3.3	91	100
42	.	.	15	16.5	13	14.3	30	33.0	15	16.5	5	5.5	4	4.4	1	1.1	.	.	.	.	.	.	8	8.8	91	100
43	.	.	.	.	2	2.2	23	25.3	37	40.7	12	13.2	5	5.5	4	4.4	2	2.2	1	1.1	1	1.1	4	4.4	91	100
44	.	.	5	5.5	11	12.1	29	31.9	13	14.3	10	11.0	7	7.7	2	2.2	4	4.4	2	2.2	1	1.1	7	7.7	91	100
45	.	.	5	5.5	7	7.7	50	54.9	13	14.3	2	2.2	4	4.4	4	4.4	3	3.3	2	2.2	.	.	1	1.1	91	100
46	.	.	.	.	3	3.3	22	24.2	27	29.7	13	14.3	10	11.0	7	7.7	1	1.1	3	3.3	4	4.4	1	1.1	91	100
47	.	.	5	5.5	11	12.1	36	39.6	17	18.7	8	8.8	7	7.7	2	2.2	2	2.2	.	.	1	1.1	2	2.2	91	100
48	.	.	.	.	.	.	9	9.9	28	30.8	15	16.5	10	11.0	9	9.9	7	7.7	1	1.1	3	3.3	9	9.9	91	100
49	.	.	.	.	.	.	22	24.2	10	11.0	25	27.5	11	12.1	5	5.5	4	4.4	3	3.3	1	1.1	10	11.0	91	100
50	.	.	.	.	.	.	36	39.6	24	26.4	7	7.7	8	8.8	5	5.5	1	1.1	3	3.3	.	.	7	7.7	91	100
51	.	.	.	.	5	5.5	22	24.2	21	23.1	16	17.6	6	6.6	4	4.4	5	5.5	2	2.2	1	1.1	9	9.9	91	100
52	.	.	.	.	11	12.1	19	20.9	27	29.7	19	20.9	4	4.4	2	2.2	1	1.1	.	.	1	1.1	7	7.7	91	100
53	.	.	16	17.6	11	12.1	20	22.0	20	22.0	11	12.1	3	3.3	9	9.9	1	1.1	.	.	.	.	.	.	91	100
54	6	6.6	13	14.3	18	19.8	9	9.9	27	29.7	11	12.1	7	7.7	.	.	.	.	.	.	.	.	.	.	91	100
55	4	4.4	9	9.9	4	4.4	6	6.6	26	28.6	20	22.0	8	8.8	7	7.7	1	1.1	1	1.1	.	.	5	5.5	91	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 2

	FLOW (IN THOUSANDS)																								ALL	
	1		2		3		4		6		8		10		12		14		16		18		20			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
56	3	3.3	19	20.9	8	8.8	29	31.9	9	9.9	13	14.3	3	3.3	2	2.2	4	4.4	.	.	1	1.1	.	.	91	100
57	.	.	10	11.0	5	5.5	18	19.8	13	14.3	23	25.3	5	5.5	3	3.3	.	.	3	3.3	6	6.6	5	5.5	91	100
58	1	1.1	1	1.1	1	1.1	6	6.6	6	6.6	7	7.7	7	7.7	3	3.3	5	5.5	3	3.3	21	23.1	30	33.0	91	100
59	.	.	12	13.2	6	6.6	19	20.9	22	24.2	14	15.4	4	4.4	.	.	5	5.5	1	1.1	8	8.8	.	.	91	100
60	.	.	5	5.5	2	2.2	7	7.7	15	16.5	13	14.3	9	9.9	2	2.2	14	15.4	.	.	7	7.7	17	18.7	91	100
61	.	.	6	6.6	.	.	8	8.8	11	12.1	24	26.4	7	7.7	4	4.4	2	2.2	6	6.6	23	25.3	.	.	91	100
62	1	1.1	1	1.1	1	1.1	17	18.7	12	13.2	19	20.9	3	3.3	5	5.5	9	9.9	6	6.6	17	18.7	.	.	91	100
63	.	.	23	25.3	1	1.1	39	42.9	20	22.0	2	2.2	1	1.1	.	.	1	1.1	.	.	4	4.4	.	.	91	100
64	.	.	23	25.3	7	7.7	9	9.9	35	38.5	10	11.0	5	5.5	2	2.2	.	.	.	.	.	.	.	.	91	100
65	1	1.1	31	34.1	4	4.4	11	12.1	20	22.0	16	17.6	1	1.1	6	6.6	1	1.1	.	.	.	.	.	.	91	100
66	3	3.3	21	23.1	37	40.7	9	9.9	20	22.0	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	91	100
67	14	15.4	35	38.5	4	4.4	7	7.7	24	26.4	6	6.6	1	1.1	.	.	.	.	.	.	.	.	.	.	91	100
68	6	6.6	16	17.6	3	3.3	31	34.1	13	14.3	18	19.8	4	4.4	.	.	.	.	.	.	.	.	.	.	91	100
69	2	2.2	28	30.8	3	3.3	26	28.6	20	22.0	10	11.0	2	2.2	.	.	.	.	.	.	.	.	.	.	91	100
70	16	17.6	16	17.6	2	2.2	40	44.0	5	5.5	4	4.4	4	4.4	4	4.4	.	.	.	.	.	.	.	.	91	100
71	8	8.8	1	1.1	3	3.3	12	13.2	13	14.3	10	11.0	9	9.9	6	6.6	7	7.7	.	.	22	24.2	.	.	91	100
72	6	6.6	4	4.4	2	2.2	3	3.3	15	16.5	6	6.6	8	8.8	8	8.8	9	9.9	3	3.3	22	24.2	5	5.5	91	100
73	.	.	2	2.2	.	.	5	5.5	7	7.7	12	13.2	8	8.8	8	8.8	7	7.7	1	1.1	41	45.1	.	.	91	100
74	9	9.9	5	5.5	2	2.2	6	6.6	12	13.2	8	8.8	13	14.3	5	5.5	22	24.2	9	9.9	.	.	.	.	91	100
75	.	.	8	8.8	1	1.1	1	1.1	24	26.4	4	4.4	7	7.7	8	8.8	9	9.9	1	1.1	3	3.3	25	27.5	91	100
76	.	.	25	27.5	5	5.5	10	11.0	37	40.7	14	15.4	.	.	.	.	.	.	.	.	.	.	.	.	91	100
77	.	.	38	41.8	3	3.3	3	3.3	27	29.7	5	5.5	5	5.5	6	6.6	2	2.2	.	.	2	2.2	.	.	91	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 2

	FLOW (IN THOUSANDS)																									
	1		2		3		4		6		8		10		12		14		16		18		20		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
78	.	.	7	7.7	2	2.2	1	1.1	2	2.2	9	9.9	5	5.5	4	4.4	1	1.1	4	4.4	25	27.5	31	34.1	91	100
79	.	.	4	4.4	.	.	2	2.2	25	27.5	6	6.6	6	6.6	11	12.1	7	7.7	1	1.1	29	31.9	.	.	91	100
80	.	.	5	5.5	3	3.3	2	2.2	16	17.6	13	14.3	8	8.8	14	15.4	3	3.3	4	4.4	23	25.3	.	.	91	100
81	.	.	54	59.3	12	13.2	9	9.9	11	12.1	3	3.3	2	2.2	.	.	.	.	.	.	.	.	.	.	91	100
82	.	.	19	20.9	1	1.1	6	6.6	26	28.6	7	7.7	8	8.8	4	4.4	4	4.4	1	1.1	15	16.5	.	.	91	100
83	.	.	9	9.9	2	2.2	2	2.2	5	5.5	6	6.6	4	4.4	2	2.2	6	6.6	1	1.1	16	17.6	38	41.8	91	100
84	.	.	12	13.2	1	1.1	1	1.1	8	8.8	8	8.8	5	5.5	9	9.9	2	2.2	1	1.1	9	9.9	35	38.5	91	100
85	1	1.1	57	62.6	6	6.6	6	6.6	18	19.8	3	3.3	.	.	.	.	.	.	.	.	.	.	.	.	91	100
86	.	.	42	46.2	7	7.7	22	24.2	16	17.6	2	2.2	2	2.2	.	.	.	.	.	.	.	.	.	.	91	100
87	.	.	6	6.6	2	2.2	4	4.4	6	6.6	9	9.9	5	5.5	5	5.5	1	1.1	.	.	9	9.9	44	48.4	91	100
88	7	7.7	20	22.0	4	4.4	18	19.8	34	37.4	4	4.4	2	2.2	1	1.1	1	1.1	.	.	.	.	.	.	91	100
89	.	.	1	1.1	1	1.1	8	8.8	7	7.7	15	16.5	9	9.9	1	1.1	12	13.2	5	5.5	2	2.2	30	33.0	91	100
90	.	.	3	3.3	.	.	2	2.2	13	14.3	19	20.9	7	7.7	5	5.5	6	6.6	1	1.1	23	25.3	12	13.2	91	100

APPENDIX A-9.

Percentage of Days in Quarter 3 (Jul-Sep, 1912-1989, and Jul-Aug 7, 1990) that Roanoke River Flows were Within Specific Discharge Criteria (0-20,000 cfs).

QUARTER 3

	FLOW (IN THOUSANDS)																											
	0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
12	.	.	16	17.4	34	37.0	18	19.6	10	10.9	5	5.4	2	2.2	3	3.3	1	1.1	.	.	1	1.1	.	.	2	2.2	92	100
13	.	.	2	2.2	26	28.3	25	27.2	17	18.5	4	4.3	10	10.9	3	3.3	2	2.2	.	.	.	.	1	1.1	2	2.2	92	100
14	.	.	35	38.0	23	25.0	10	10.9	13	14.1	7	7.6	1	1.1	.	.	.	.	1	1.1	.	.	.	.	2	2.2	92	100
15	.	.	.	.	26	28.3	20	21.7	15	16.3	8	8.7	4	4.3	5	5.4	2	2.2	2	2.2	2	2.2	.	.	8	8.7	92	100
16	.	.	7	7.6	22	23.9	12	13.0	9	9.8	13	14.1	13	14.1	6	6.5	.	.	4	4.3	.	.	1	1.1	5	5.4	92	100
17	.	.	12	13.0	16	17.4	22	23.9	17	18.5	5	5.4	7	7.6	4	4.3	2	2.2	2	2.2	.	.	1	1.1	4	4.3	92	100
18	.	.	4	4.3	21	22.8	30	32.6	20	21.7	10	10.9	6	6.5	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
19	.	.	10	10.9	19	20.7	10	10.9	12	13.0	17	18.5	5	5.4	6	6.5	1	1.1	2	2.2	.	.	.	.	10	10.9	92	100
20	.	.	6	6.5	16	17.4	16	17.4	24	26.1	13	14.1	6	6.5	6	6.5	2	2.2	.	.	1	1.1	.	.	2	2.2	92	100
21	.	.	25	27.2	33	35.9	12	13.0	11	12.0	4	4.3	5	5.4	2	2.2	.	.	.	.	.	.	.	.	.	.	92	100
22	.	.	.	.	16	17.4	15	16.3	26	28.3	18	19.6	6	6.5	3	3.3	3	3.3	.	.	.	.	1	1.1	4	4.3	92	100
23	.	.	.	.	16	17.4	16	17.4	20	21.7	16	17.4	11	12.0	2	2.2	3	3.3	2	2.2	2	2.2	.	.	4	4.3	92	100
24	.	.	.	.	17	18.5	21	22.8	28	30.4	11	12.0	4	4.3	4	4.3	1	1.1	2	2.2	1	1.1	.	.	3	3.3	92	100
25	.	.	40	43.5	31	33.7	14	15.2	3	3.3	2	2.2	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	92	100
26	2	2.2	40	43.5	27	29.3	12	13.0	4	4.3	3	3.3	2	2.2	1	1.1	.	.	1	1.1	.	.	.	.	.	.	92	100
27	.	.	4	4.3	24	26.1	24	26.1	22	23.9	8	8.7	4	4.3	1	1.1	2	2.2	2	2.2	.	.	.	.	1	1.1	92	100
28	.	.	1	1.1	14	15.2	13	14.1	9	9.8	10	10.9	10	10.9	8	8.7	4	4.3	1	1.1	1	1.1	2	2.2	19	20.7	92	100
29	.	.	.	.	1	1.1	31	33.7	24	26.1	21	22.8	6	6.5	3	3.3	4	4.3	1	1.1	.	.	1	1.1	.	.	92	100
30	13	14.1	61	66.3	15	16.3	1	1.1	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100
31	.	.	17	18.5	15	16.3	14	15.2	19	20.7	11	12.0	4	4.3	2	2.2	4	4.3	1	1.1	1	1.1	1	1.1	3	3.3	92	100
32	30	32.6	39	42.4	20	21.7	3	3.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100
33	1	1.1	22	23.9	35	38.0	16	17.4	10	10.9	4	4.3	3	3.3	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 3

	FLOW (IN THOUSANDS)																										ALL	
	0		1		2		3		4		6		8		10		12		14		16		18		20			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
34	.	.	1	1.1	31	33.7	12	13.0	20	21.7	5	5.4	7	7.6	6	6.5	1	1.1	2	2.2	.	.	.	.	7	7.6	92	100
35	.	.	.	.	25	27.2	24	26.1	20	21.7	10	10.9	7	7.6	1	1.1	.	.	.	.	1	1.1	1	1.1	3	3.3	92	100
36	.	.	11	12.0	27	29.3	25	27.2	20	21.7	5	5.4	3	3.3	.	.	.	.	.	.	1	1.1	.	.	.	.	92	100
37	.	.	.	.	.	.	10	10.9	33	35.9	17	18.5	6	6.5	4	4.3	6	6.5	1	1.1	2	2.2	1	1.1	12	13.0	92	100
38	.	.	.	.	5	5.4	24	26.1	20	21.7	15	16.3	6	6.5	2	2.2	5	5.4	3	3.3	5	5.4	.	.	7	7.6	92	100
39	.	.	.	.	19	20.7	13	14.1	14	15.2	11	12.0	11	12.0	6	6.5	5	5.4	2	2.2	4	4.3	.	.	7	7.6	92	100
40	.	.	.	.	.	.	23	25.0	30	32.6	13	14.1	7	7.6	5	5.4	3	3.3	2	2.2	.	.	1	1.1	8	8.7	92	100
41	.	.	19	20.7	22	23.9	10	10.9	14	15.2	8	8.7	4	4.3	3	3.3	3	3.3	3	3.3	2	2.2	1	1.1	3	3.3	92	100
42	.	.	.	.	13	14.1	21	22.8	22	23.9	9	9.8	7	7.6	5	5.4	5	5.4	1	1.1	2	2.2	.	.	7	7.6	92	100
43	.	.	6	6.5	32	34.8	18	19.6	18	19.6	8	8.7	2	2.2	2	2.2	1	1.1	2	2.2	.	.	.	.	3	3.3	92	100
44	.	.	22	23.9	22	23.9	11	12.0	16	17.4	10	10.9	2	2.2	.	.	2	2.2	2	2.2	.	.	.	.	5	5.4	92	100
45	.	.	.	.	18	19.6	18	19.6	18	19.6	10	10.9	9	9.8	4	4.3	3	3.3	.	.	1	1.1	.	.	11	12.0	92	100
46	.	.	3	3.3	32	34.8	19	20.7	23	25.0	7	7.6	2	2.2	2	2.2	2	2.2	1	1.1	.	.	1	1.1	.	.	92	100
47	.	.	2	2.2	41	44.6	18	19.6	20	21.7	4	4.3	2	2.2	.	.	1	1.1	1	1.1	.	.	.	.	3	3.3	92	100
48	.	.	.	.	24	26.1	24	26.1	31	33.7	6	6.5	4	4.3	.	.	.	.	.	.	.	.	2	2.2	1	1.1	92	100
49	.	.	.	.	.	.	1	1.1	27	29.3	20	21.7	15	16.3	6	6.5	5	5.4	.	.	1	1.1	3	3.3	14	15.2	92	100
50	.	.	.	.	1	1.1	25	27.2	22	23.9	22	23.9	6	6.5	5	5.4	5	5.4	2	2.2	1	1.1	1	1.1	2	2.2	92	100
51	.	.	17	18.5	29	31.5	15	16.3	24	26.1	7	7.6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100
52	.	.	28	30.4	27	29.3	12	13.0	15	16.3	2	2.2	.	.	1	1.1	1	1.1	5	5.4	1	1.1	.	.	.	.	92	100
53	.	.	15	16.3	12	13.0	21	22.8	42	45.7	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100
54	.	.	16	17.4	19	20.7	23	25.0	24	26.1	9	9.8	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	92	100
55	.	.	4	4.3	9	9.8	3	3.3	26	28.3	15	16.3	16	17.4	5	5.4	5	5.4	1	1.1	.	.	.	.	8	8.7	92	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 3

	FLOW (IN THOUSANDS)																											ALL	
	0		1		2		3		4		6		8		10		12		14		16		18		20			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
56	.	.	10	10.9	22	23.9	10	10.9	35	38.0	11	12.0	2	2.2	2	2.2	.	.	.	.	.	.	.	.	.	.	92	100
57	.	.	9	9.8	26	28.3	10	10.9	19	20.7	17	18.5	3	3.3	2	2.2	3	3.3	2	2.2	1	1.1	.	.	.	.	92	100
58	.	.	7	7.6	14	15.2	8	8.7	11	12.0	23	25.0	21	22.8	3	3.3	1	1.1	4	4.3	.	.	.	.	.	.	92	100
59	.	.	.	.	35	38.0	6	6.5	20	21.7	19	20.7	10	10.9	1	1.1	1	1.1	.	.	.	.	.	.	.	.	92	100
60	.	.	.	.	18	19.6	15	16.3	25	27.2	18	19.6	14	15.2	1	1.1	.	.	1	1.1	.	.	.	.	.	.	92	100
61	.	.	3	3.3	25	27.2	6	6.5	20	21.7	23	25.0	7	7.6	2	2.2	1	1.1	4	4.3	.	.	1	1.1	.	.	92	100
62	.	.	1	1.1	28	30.4	12	13.0	18	19.6	19	20.7	8	8.7	1	1.1	2	2.2	1	1.1	1	1.1	1	1.1	.	.	92	100
63	.	.	.	.	35	38.0	25	27.2	19	20.7	10	10.9	3	3.3	.	.	.	.	.	.	.	.	.	.	.	.	92	100
64	.	.	.	.	46	50.0	19	20.7	13	14.1	5	5.4	5	5.4	4	4.3	.	.	.	.	.	.	.	.	.	.	92	100
65	.	.	.	.	29	31.5	17	18.5	23	25.0	11	12.0	11	12.0	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
66	.	.	.	.	42	45.7	19	20.7	8	8.7	15	16.3	7	7.6	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
67	.	.	5	5.4	30	32.6	14	15.2	14	15.2	11	12.0	14	15.2	4	4.3	.	.	.	.	.	.	.	.	.	.	92	100
68	.	.	.	.	58	63.0	10	10.9	6	6.5	6	6.5	5	5.4	.	.	5	5.4	2	2.2	.	.	.	.	.	.	92	100
69	.	.	5	5.4	49	53.3	4	4.3	12	13.0	11	12.0	5	5.4	2	2.2	4	4.3	.	.	.	.	.	.	.	.	92	100
70	.	.	11	12.0	43	46.7	2	2.2	5	5.4	5	5.4	12	13.0	6	6.5	6	6.5	2	2.2	.	.	.	.	.	.	92	100
71	.	.	33	35.9	10	10.9	6	6.5	3	3.3	21	22.8	9	9.8	4	4.3	2	2.2	4	4.3	.	.	.	.	.	.	92	100
72	.	.	12	13.0	12	13.0	4	4.3	5	5.4	4	4.3	8	8.7	5	5.4	2	2.2	1	1.1	12	13.0	13	14.1	14	15.2	92	100
73	.	.	7	7.6	19	20.7	5	5.4	11	12.0	9	9.8	19	20.7	11	12.0	7	7.6	.	.	4	4.3	.	.	.	.	92	100
74	.	.	2	2.2	35	38.0	5	5.4	4	4.3	5	5.4	6	6.5	7	7.6	11	12.0	3	3.3	2	2.2	12	13.0	.	.	92	100
75	.	.	.	.	37	40.2	2	2.2	4	4.3	2	2.2	2	2.2	5	5.4	11	12.0	.	.	2	2.2	27	29.3	.	.	92	100
76	.	.	.	.	64	69.6	5	5.4	8	8.7	6	6.5	8	8.7	.	.	1	1.1	.	.	.	.	.	.	.	.	92	100
77	.	.	.	.	76	82.6	3	3.3	6	6.5	5	5.4	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	92	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 3

	FLOW (IN THOUSANDS)																											
	0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																												
78	.	.	.	.	28	30.4	6	6.5	14	15.2	12	13.0	21	22.8	10	10.9	1	1.1	.	.	.	.	.	.	.	.	92	100
79	.	.	.	.	31	33.7	5	5.4	16	17.4	12	13.0	7	7.6	5	5.4	6	6.5	2	2.2	.	.	8	8.7	.	.	92	100
80	.	.	.	.	58	63.0	4	4.3	11	12.0	8	8.7	8	8.7	2	2.2	1	1.1	.	.	.	.	.	.	.	.	92	100
81	.	.	.	.	74	80.4	7	7.6	7	7.6	3	3.3	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	92	100
82	.	.	.	.	46	50.0	9	9.8	10	10.9	4	4.3	15	16.3	6	6.5	1	1.1	1	1.1	.	.	.	.	.	.	92	100
83	.	.	.	.	55	59.8	12	13.0	13	14.1	9	9.8	1	1.1	2	2.2	.	.	.	.	.	.	.	.	.	.	92	100
84	.	.	.	.	25	27.2	9	9.8	7	7.6	16	17.4	13	14.1	7	7.6	8	8.7	2	2.2	5	5.4	.	.	.	.	92	100
85	.	.	.	.	44	47.8	7	7.6	14	15.2	9	9.8	1	1.1	1	1.1	1	1.1	1	1.1	6	6.5	8	8.7	.	.	92	100
86	.	.	.	.	76	82.6	5	5.4	4	4.3	5	5.4	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
87	.	.	1	1.1	48	52.2	2	2.2	7	7.6	7	7.6	6	6.5	2	2.2	1	1.1	3	3.3	1	1.1	3	3.3	11	12.0	92	100
88	.	.	.	.	73	79.3	5	5.4	7	7.6	5	5.4	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	92	100
89	.	.	.	.	12	13.0	8	8.7	15	16.3	9	9.8	9	9.8	5	5.4	2	2.2	21	22.8	3	3.3	3	3.3	5	5.4	92	100
90	.	.	1	2.6	14	36.8	5	13.2	6	15.8	4	10.5	2	5.3	.	.	1	2.6	5	13.2	.	.	.	.	.	.	38	100

APPENDIX A-10.

Percentage of Days in Quarter 4 (Oct-Dec, 1912-1989) that Roanoke River Flows were Within Specific Discharge Criteria (0-20,000 cfs).

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 4

	FLOW (IN THOUSANDS)																											
	0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																												
12	.	.	3	3.3	42	45.7	32	34.8	10	10.9	2	2.2	.	.	1	1.1	.	.	.	.	.	.	.	.	2	2.2	92	100
13	.	.	3	3.3	13	14.1	25	27.2	16	17.4	11	12.0	9	9.8	1	1.1	4	4.3	.	.	4	4.3	1	1.1	5	5.4	92	100
14	.	.	13	14.1	34	37.0	4	4.3	5	5.4	5	5.4	10	10.9	8	8.7	2	2.2	3	3.3	.	.	2	2.2	6	6.5	92	100
15	.	.	3	3.3	11	12.0	30	32.6	18	19.6	9	9.8	6	6.5	2	2.2	1	1.1	3	3.3	3	3.3	1	1.1	5	5.4	92	100
16	.	.	9	9.8	43	46.7	21	22.8	9	9.8	7	7.6	1	1.1	1	1.1	.	.	1	1.1	.	.	.	.	.	.	92	100
17	.	.	31	33.7	30	32.6	22	23.9	5	5.4	1	1.1	2	2.2	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
18	.	.	15	16.3	23	25.0	12	13.0	13	14.1	5	5.4	8	8.7	6	6.5	.	.	2	2.2	2	2.2	.	.	6	6.5	92	100
19	.	.	16	17.4	28	30.4	25	27.2	12	13.0	9	9.8	.	.	1	1.1	1	1.1	.	.	.	.	.	.	.	.	92	100
20	.	.	6	6.5	31	33.7	4	4.3	10	10.9	2	2.2	10	10.9	8	8.7	3	3.3	2	2.2	4	4.3	.	.	12	13.0	92	100
21	.	.	22	23.9	21	22.8	24	26.1	21	22.8	2	2.2	.	.	.	.	1	1.1	.	.	.	.	.	.	1	1.1	92	100
22	.	.	3	3.3	27	29.3	33	35.9	15	16.3	4	4.3	8	8.7	.	.	.	.	1	1.1	.	.	.	.	1	1.1	92	100
23	.	.	.	.	21	22.8	35	38.0	27	29.3	4	4.3	2	2.2	1	1.1	.	.	1	1.1	.	.	.	.	1	1.1	92	100
24	.	.	.	.	.	.	2	2.2	51	55.4	14	15.2	7	7.6	8	8.7	2	2.2	.	.	.	.	1	1.1	7	7.6	92	100
25	.	.	12	13.0	19	20.7	34	37.0	19	20.7	3	3.3	1	1.1	3	3.3	1	1.1	.	.	.	.	.	.	.	.	92	100
26	.	.	37	40.2	10	10.9	14	15.2	12	13.0	5	5.4	3	3.3	3	3.3	2	2.2	1	1.1	.	.	.	.	5	5.4	92	100
27	.	.	4	4.3	15	16.3	16	17.4	17	18.5	12	13.0	3	3.3	4	4.3	4	4.3	.	.	2	2.2	1	1.1	14	15.2	92	100
28	.	.	.	.	.	.	9	9.8	73	79.3	6	6.5	1	1.1	2	2.2	1	1.1	.	.	.	.	.	.	.	.	92	100
29	.	.	.	.	.	.	3	3.3	17	18.5	32	34.8	12	13.0	11	12.0	3	3.3	1	1.1	3	3.3	1	1.1	9	9.8	92	100
30	19	20.7	30	32.6	28	30.4	9	9.8	1	1.1	3	3.3	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	92	100
31	.	.	67	72.8	17	18.5	4	4.3	1	1.1	1	1.1	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
32	.	.	10	10.9	4	4.3	3	3.3	17	18.5	15	16.3	9	9.8	7	7.6	3	3.3	3	3.3	3	3.3	4	4.3	14	15.2	92	100
33	1	1.1	63	68.5	22	23.9	4	4.3	.	.	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100

(CONTINUED)

QUARTER 4

	FLOW (IN THOUSANDS)																											
	0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																												
34	.	.	.	.	32	34.8	9	9.8	19	20.7	13	14.1	4	4.3	5	5.4	2	2.2	.	.	.	.	1	1.1	7	7.6	92	100
35	.	.	.	.	34	37.0	13	14.1	21	22.8	10	10.9	7	7.6	2	2.2	.	.	3	3.3	.	.	1	1.1	1	1.1	92	100
36	.	.	.	.	32	34.8	25	27.2	8	8.7	7	7.6	6	6.5	6	6.5	3	3.3	2	2.2	1	1.1	.	.	2	2.2	92	100
37	.	.	.	.	.	.	.	.	4	4.3	42	45.7	13	14.1	7	7.6	9	9.8	3	3.3	3	3.3	.	.	11	12.0	92	100
38	.	.	.	.	26	28.3	18	19.6	22	23.9	7	7.6	6	6.5	3	3.3	2	2.2	2	2.2	3	3.3	.	.	3	3.3	92	100
39	.	.	.	.	26	28.3	37	40.2	20	21.7	6	6.5	1	1.1	1	1.1	1	1.1	.	.	.	.	.	.	.	.	92	100
40	.	.	.	.	1	1.1	35	38.0	38	41.3	4	4.3	6	6.5	1	1.1	1	1.1	.	.	.	.	2	2.2	4	4.3	92	100
41	.	.	53	57.6	23	25.0	7	7.6	6	6.5	3	3.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100
42	.	.	.	.	.	.	13	14.1	32	34.8	20	21.7	11	12.0	5	5.4	4	4.3	1	1.1	.	.	1	1.1	5	5.4	92	100
43	.	.	18	19.6	64	69.6	2	2.2	2	2.2	4	4.3	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
44	.	.	.	.	.	.	1	1.1	47	51.1	17	18.5	4	4.3	2	2.2	5	5.4	2	2.2	4	4.3	.	.	10	10.9	92	100
45	.	.	.	.	.	.	24	26.1	27	29.3	16	17.4	7	7.6	5	5.4	2	2.2	1	1.1	.	.	1	1.1	9	9.8	92	100
46	.	.	.	.	19	20.7	48	52.2	17	18.5	4	4.3	3	3.3	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
47	.	.	.	.	3	3.3	5	5.4	32	34.8	14	15.2	6	6.5	7	7.6	9	9.8	2	2.2	3	3.3	3	3.3	8	8.7	92	100
48	.	.	.	.	.	.	19	20.7	20	21.7	6	6.5	11	12.0	9	9.8	4	4.3	7	7.6	2	2.2	2	2.2	12	13.0	92	100
49	.	.	.	.	.	.	4	4.3	54	58.7	21	22.8	6	6.5	.	.	1	1.1	1	1.1	.	.	1	1.1	4	4.3	92	100
50	.	.	.	.	.	.	21	22.8	50	54.3	6	6.5	4	4.3	2	2.2	1	1.1	1	1.1	1	1.1	.	.	6	6.5	92	100
51	.	.	24	26.1	20	21.7	12	13.0	18	19.6	6	6.5	2	2.2	1	1.1	2	2.2	1	1.1	.	.	.	.	6	6.5	92	100
52	9	9.8	21	22.8	18	19.6	15	16.3	19	20.7	4	4.3	.	.	.	.	2	2.2	.	.	.	.	2	2.2	2	2.2	92	100
53	1	1.1	26	28.3	28	30.4	8	8.7	21	22.8	8	8.7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100
54	1	1.1	14	15.2	5	5.4	8	8.7	17	18.5	6	6.5	19	20.7	22	23.9	.	.	.	.	.	.	.	.	.	.	92	100
55	2	2.2	2	2.2	6	6.5	13	14.1	26	28.3	28	30.4	15	16.3	.	.	.	.	.	.	.	.	.	.	.	.	92	100

(CONTINUED)

ROANOKE RIVER FLOW REPORT 1990
STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 4

	FLOW (IN THOUSANDS) 0		1		2		3		4		6		8		10		12		14		16		18		20		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																														
56	6	6.5	11	12.0	6	6.5	5	5.4	21	22.8	22	23.9	15	16.3	6	6.5	.	.	.	.	.	.	.	.	.	.	92	100
57	3	3.3	9	9.8	2	2.2	1	1.1	10	10.9	16	17.4	12	13.0	4	4.3	5	5.4	2	2.2	8	8.7	16	17.4	4	4.3	92	100
58	4	4.3	15	16.3	6	6.5	7	7.6	31	33.7	19	20.7	7	7.6	.	.	1	1.1	1	1.1	.	.	1	1.1	.	.	92	100
59	.	.	1	1.1	6	6.5	6	6.5	14	15.2	16	17.4	20	21.7	4	4.3	5	5.4	9	9.8	4	4.3	7	7.6	.	.	92	100
60	1	1.1	13	14.1	7	7.6	6	6.5	25	27.2	21	22.8	15	16.3	4	4.3	.	.	.	.	.	.	.	.	.	.	92	100
61	.	.	4	4.3	12	13.0	6	6.5	32	34.8	16	17.4	5	5.4	5	5.4	4	4.3	4	4.3	1	1.1	3	3.3	.	.	92	100
62	.	.	27	29.3	19	20.7	2	2.2	7	7.6	8	8.7	29	31.5	.	.	.	.	.	.	.	.	.	.	.	.	92	100
63	.	.	16	17.4	14	15.2	8	8.7	31	33.7	20	21.7	2	2.2	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
64	.	.	20	21.7	8	8.7	8	8.7	28	30.4	15	16.3	13	14.1	.	.	.	.	.	.	.	.	.	.	.	.	92	100
65	2	2.2	21	22.8	18	19.6	12	13.0	26	28.3	12	13.0	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	92	100
66	2	2.2	17	18.5	14	15.2	10	10.9	23	25.0	15	16.3	10	10.9	1	1.1	.	.	.	.	.	.	.	.	.	.	92	100
67	4	4.3	20	21.7	12	13.0	10	10.9	19	20.7	14	15.2	11	12.0	2	2.2	.	.	.	.	.	.	.	.	.	.	92	100
68	5	5.4	30	32.6	11	12.0	14	15.2	9	9.8	9	9.8	11	12.0	2	2.2	1	1.1	.	.	.	.	.	.	.	.	92	100
69	6	6.5	10	10.9	13	14.1	12	13.0	17	18.5	18	19.6	4	4.3	5	5.4	7	7.6	.	.	.	.	.	.	.	.	92	100
70	3	3.3	27	29.3	13	14.1	4	4.3	15	16.3	13	14.1	9	9.8	8	8.7	.	.	.	.	.	.	.	.	.	.	92	100
71	4	4.3	6	6.5	6	6.5	1	1.1	6	6.5	5	5.4	7	7.6	15	16.3	13	14.1	3	3.3	.	.	24	26.1	2	2.2	92	100
72	.	.	2	2.2	6	6.5	3	3.3	3	3.3	2	2.2	3	3.3	3	3.3	10	10.9	10	10.9	7	7.6	43	46.7	.	.	92	100
73	1	1.1	18	19.6	23	25.0	6	6.5	8	8.7	9	9.8	6	6.5	6	6.5	2	2.2	3	3.3	3	3.3	7	7.6	.	.	92	100
74	.	.	50	54.3	5	5.4	1	1.1	7	7.6	2	2.2	2	2.2	7	7.6	5	5.4	5	5.4	2	2.2	6	6.5	.	.	92	100
75	.	.	14	15.2	5	5.4	.	.	14	15.2	10	10.9	23	25.0	9	9.8	10	10.9	4	4.3	.	.	3	3.3	.	.	92	100
76	.	.	7	7.6	12	13.0	5	5.4	9	9.8	12	13.0	9	9.8	13	14.1	10	10.9	6	6.5	4	4.3	5	5.4	.	.	92	100
77	.	.	22	23.9	12	13.0	5	5.4	11	12.0	7	7.6	10	10.9	7	7.6	16	17.4	1	1.1	1	1.1	.	.	.	.	92	100

(CONTINUED)

STATISTICAL SUMMARIES BASED ON DAILY FLOW DATA, 1912-1990

QUARTER 4

	FLOW (IN THOUSANDS)																										ALL	
	0		1		2		3		4		6		8		10		12		14		16		18		20			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																												
78	.	.	25	27.2	7	7.6	6	6.5	18	19.6	16	17.4	15	16.3	3	3.3	2	2.2	.	.	.	.	.	.	.	.	92	100
79	.	.	5	5.4	2	2.2	1	1.1	4	4.3	4	4.3	3	3.3	8	8.7	9	9.8	10	10.9	4	4.3	29	31.5	13	14.1	92	100
80	.	.	40	43.5	27	29.3	5	5.4	11	12.0	7	7.6	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	92	100
81	.	.	48	52.2	19	20.7	8	8.7	10	10.9	5	5.4	1	1.1	.	.	1	1.1	.	.	.	.	.	.	.	.	92	100
82	.	.	11	12.0	17	18.5	14	15.2	9	9.8	16	17.4	12	13.0	7	7.6	4	4.3	.	.	2	2.2	.	.	.	.	92	100
83	.	.	16	17.4	26	28.3	8	8.7	9	9.8	5	5.4	4	4.3	2	2.2	3	3.3	4	4.3	7	7.6	8	8.7	.	.	92	100
84	.	.	28	30.4	18	19.6	8	8.7	16	17.4	10	10.9	7	7.6	4	4.3	1	1.1	.	.	.	.	.	.	.	.	92	100
85	.	.	7	7.6	17	18.5	5	5.4	5	5.4	5	5.4	4	4.3	1	1.1	9	9.8	1	1.1	.	.	15	16.3	23	25.0	92	100
86	11	12.0	29	31.5	19	20.7	3	3.3	8	8.7	10	10.9	5	5.4	2	2.2	5	5.4	.	.	.	.	.	.	.	.	92	100
87	1	1.1	13	14.1	9	9.8	11	12.0	6	6.5	8	8.7	24	26.1	10	10.9	8	8.7	2	2.2	.	.	.	.	.	.	92	100
88	.	.	34	37.0	15	16.3	6	6.5	14	15.2	9	9.8	9	9.8	2	2.2	2	2.2	1	1.1	.	.	.	.	.	.	92	100
89	.	.	5	5.4	4	4.3	5	5.4	10	10.9	6	6.5	12	13.0	7	7.6	9	9.8	12	13.0	2	2.2	12	13.0	8	8.7	92	100

APPENDIX A-11.

Percentage of Days Over 12 Months (1912-1989, and Jan-Aug 7, 1990) that Roanoke River Flows were Less Than 2000 cfs, Between 2000 and 3100 cfs, and Greater than 3100 cfs.

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
12	29	7.9	11	3.0	6	1.6	4	1.1	9	2.5	.	.	13	3.6	9	2.5	.	.	14	3.8	13	3.6	258	70.5	366	100
13	9	2.5	5	1.4	.	.	7	1.9	6	1.6	.	.	5	1.4	7	1.9	.	.	5	1.4	10	2.7	311	85.2	365	100
14	60	16.4	11	3.0	.	.	15	4.1	14	3.8	.	.	10	2.7	7	1.9	.	.	9	2.5	4	1.1	235	64.4	365	100
15	8	2.2	5	1.4	.	.	6	1.6	5	1.4	1	0.3	10	2.7	7	1.9	1	0.3	4	1.1	9	2.5	309	84.7	365	100
16	19	5.2	2	0.5	9	2.5	.	.	10	2.7	5	1.4	24	6.6	.	.	13	3.6	1	0.3	9	2.5	274	74.9	366	100
17	53	14.5	1	0.3	18	4.9	2	0.5	7	1.9	2	0.5	4	1.1	6	1.6	.	.	.	.	20	5.5	252	69.0	365	100
18	36	9.9	5	1.4	10	2.7	.	.	11	3.0	.	.	.	.	19	5.2	.	.	.	.	12	3.3	272	74.5	365	100
19	34	9.3	8	2.2	7	1.9	.	.	12	3.3	.	.	.	.	12	3.3	.	.	.	.	14	3.8	278	76.2	365	100
20	30	8.2	4	1.1	12	3.3	.	.	2	0.5	8	2.2	.	.	15	4.1	.	.	.	.	14	3.8	281	76.8	366	100
21	61	16.7	.	.	9	2.5	1	0.3	2	0.5	7	1.9	6	1.6	6	1.6	.	.	10	2.7	9	2.5	254	69.6	365	100
22	4	1.1	2	0.5	5	1.4	1	0.3	5	1.4	1	0.3	6	1.6	9	2.5	.	.	19	5.2	15	4.1	298	81.6	365	100
23	.	.	.	.	.	.	2	0.5	.	.	8	2.2	10	2.7	10	2.7	8	2.2	.	.	10	2.7	317	86.8	365	100
24	.	.	3	0.8	5	1.4	1	0.3	.	.	1	0.3	3	0.8	.	.	4	1.1	.	.	4	1.1	345	94.3	366	100
25	56	15.3	3	0.8	6	1.6	3	0.8	7	1.9	9	2.5	6	1.6	10	2.7	2	0.5	10	2.7	14	3.8	239	65.5	365	100
26	98	26.8	5	1.4	13	3.6	1	0.3	8	2.2	11	3.0	5	1.4	7	1.9	3	0.8	2	0.5	7	1.9	205	56.2	365	100
27	9	2.5	1	0.3	3	0.8	8	2.2	.	.	3	0.8	11	3.0	5	1.4	10	2.7	.	.	14	3.8	301	82.5	365	100
28	3	0.8	.	.	3	0.8	1	0.3	.	.	2	0.5	3	0.8	1	0.3	2	0.5	.	.	3	0.8	348	95.1	366	100
29	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	0.3	.	.	3	0.8	361	98.9	365	100
30	132	36.2	3	0.8	8	2.2	6	1.6	1	0.3	3	0.8	4	1.1	6	1.6	5	1.4	7	1.9	3	0.8	187	51.2	365	100
31	87	23.8	3	0.8	8	2.2	5	1.4	7	1.9	4	1.1	2	0.5	8	2.2	8	2.2	10	2.7	7	1.9	216	59.2	365	100
32	86	23.5	1	0.3	10	2.7	2	0.5	5	1.4	5	1.4	1	0.3	2	0.5	4	1.1	2	0.5	1	0.3	247	67.5	366	100
33	94	25.8	3	0.8	16	4.4	9	2.5	5	1.4	2	0.5	4	1.1	7	1.9	8	2.2	5	1.4	1	0.3	211	57.8	365	100

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

	FLOW (CFS)																									
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
34	6	1.6	5	1.4	5	1.4	15	4.1	15	4.1	15	4.1	12	3.3	10	2.7	8	2.2	13	3.6	8	2.2	253	69.3	365	100
35	.	.	4	1.1	10	2.7	11	3.0	10	2.7	3	0.8	3	0.8	10	2.7	4	1.1	6	1.6	9	2.5	295	80.8	365	100
36	16	4.4	7	1.9	.	.	5	1.4	1	0.3	2	0.5	7	1.9	6	1.6	13	3.6	13	3.6	9	2.5	287	78.4	366	100
37	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	365	100	365	100
38	.	.	.	.	.	.	.	.	.	.	2	0.5	6	1.6	8	2.2	5	1.4	10	2.7	3	0.8	331	90.7	365	100
39	.	.	.	.	.	.	1	0.3	1	0.3	14	3.8	5	1.4	8	2.2	6	1.6	12	3.3	9	2.5	309	84.7	365	100
40	.	.	.	.	1	0.3	.	.	.	.	.	.	2	0.5	.	.	1	0.3	4	1.1	2	0.5	356	97.3	366	100
41	81	22.2	5	1.4	3	0.8	8	2.2	7	1.9	5	1.4	10	2.7	6	1.6	10	2.7	5	1.4	4	1.1	221	60.5	365	100
42	2	0.5	1	0.3	.	.	3	0.8	2	0.5	2	0.5	7	1.9	5	1.4	6	1.6	8	2.2	3	0.8	326	89.3	365	100
43	31	8.5	13	3.6	5	1.4	6	1.6	15	4.1	25	6.8	8	2.2	4	1.1	5	1.4	8	2.2	3	0.8	242	66.3	365	100
44	26	7.1	3	0.8	4	1.1	2	0.5	.	.	4	1.1	2	0.5	1	0.3	3	0.8	5	1.4	5	1.4	311	85.0	366	100
45	.	.	.	.	2	0.5	2	0.5	1	0.3	3	0.8	3	0.8	1	0.3	4	1.1	7	1.9	2	0.5	340	93.2	365	100
46	6	1.6	5	1.4	1	0.3	2	0.5	7	1.9	8	2.2	6	1.6	6	1.6	5	1.4	8	2.2	17	4.7	294	80.5	365	100
47	5	1.4	6	1.6	5	1.4	8	2.2	3	0.8	3	0.8	7	1.9	3	0.8	4	1.1	7	1.9	6	1.6	308	84.4	365	100
48	.	.	.	.	1	0.3	6	1.6	1	0.3	2	0.5	5	1.4	3	0.8	4	1.1	2	0.5	2	0.5	340	92.9	366	100
49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	365	100	365	100
50	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	0.3	.	.	4	1.1	360	98.6	365	100
51	46	12.6	12	3.3	5	1.4	3	0.8	2	0.5	4	1.1	.	.	9	2.5	4	1.1	5	1.4	1	0.3	274	75.1	365	100
52	70	19.1	6	1.6	6	1.6	3	0.8	7	1.9	3	0.8	1	0.3	1	0.3	6	1.6	.	.	3	0.8	260	71.0	366	100
53	51	14.0	8	2.2	4	1.1	5	1.4	10	2.7	8	2.2	4	1.1	6	1.6	3	0.8	4	1.1	3	0.8	259	71.0	365	100
54	51	14.0	8	2.2	2	0.5	3	0.8	5	1.4	3	0.8	2	0.5	5	1.4	2	0.5	5	1.4	7	1.9	272	74.5	365	100
55	29	7.9	1	0.3	2	0.5	4	1.1	6	1.6	3	0.8	2	0.5	3	0.8	4	1.1	1	0.3	3	0.8	307	84.1	365	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
56	43	11.7	9	2.5	6	1.6	2	0.5	12	3.3	4	1.1	2	0.5	1	0.3	9	2.5	6	1.6	2	0.5	270	73.8	366	100
57	43	11.8	12	3.3	1	0.3	4	1.1	5	1.4	3	0.8	1	0.3	6	1.6	1	0.3	1	0.3	3	0.8	285	78.1	365	100
58	46	12.6	7	1.9	4	1.1	.	.	.	.	1	0.3	.	.	1	0.3	.	.	3	0.8	.	.	303	83.0	365	100
59	27	7.4	12	3.3	12	3.3	7	1.9	5	1.4	6	1.6	2	0.5	4	1.1	1	0.3	7	1.9	2	0.5	280	76.7	365	100
60	22	6.0	12	3.3	4	1.1	2	0.5	.	.	2	0.5	2	0.5	1	0.3	.	.	1	0.3	2	0.5	318	86.9	366	100
61	39	10.7	6	1.6	4	1.1	4	1.1	3	0.8	1	0.3	5	1.4	2	0.5	2	0.5	2	0.5	4	1.1	293	80.3	365	100
62	35	9.6	13	3.6	6	1.6	15	4.1	4	1.1	2	0.5	2	0.5	.	.	.	.	3	0.8	1	0.3	284	77.8	365	100
63	33	9.0	15	4.1	5	1.4	7	1.9	7	1.9	5	1.4	6	1.6	5	1.4	5	1.4	11	3.0	5	1.4	261	71.5	365	100
64	44	12.0	12	3.3	11	3.0	3	0.8	15	4.1	10	2.7	11	3.0	7	1.9	8	2.2	2	0.5	6	1.6	237	64.8	366	100
65	35	9.6	6	1.6	9	2.5	7	1.9	15	4.1	15	4.1	5	1.4	9	2.5	8	2.2	5	1.4	11	3.0	240	65.8	365	100
66	47	12.9	5	1.4	7	1.9	11	3.0	5	1.4	9	2.5	10	2.7	8	2.2	4	1.1	8	2.2	10	2.7	241	66.0	365	100
67	74	20.3	6	1.6	4	1.1	5	1.4	11	3.0	13	3.6	8	2.2	9	2.5	6	1.6	6	1.6	2	0.5	221	60.5	365	100
68	63	17.2	10	2.7	18	4.9	11	3.0	9	2.5	7	1.9	7	1.9	4	1.1	5	1.4	3	0.8	3	0.8	226	61.7	366	100
69	56	15.3	16	4.4	16	4.4	8	2.2	13	3.6	11	3.0	6	1.6	7	1.9	4	1.1	5	1.4	1	0.3	222	60.8	365	100
70	107	29.3	18	4.9	13	3.6	6	1.6	2	0.5	3	0.8	2	0.5	.	.	.	.	4	1.1	1	0.3	209	57.3	365	100
71	61	16.7	6	1.6	1	0.3	2	0.5	1	0.3	2	0.5	.	.	2	0.5	2	0.5	2	0.5	2	0.5	284	77.8	365	100
72	31	8.5	2	0.5	5	1.4	1	0.3	3	0.8	1	0.3	1	0.3	2	0.5	3	0.8	1	0.3	.	.	316	86.3	366	100
73	43	11.8	14	3.8	3	0.8	3	0.8	2	0.5	3	0.8	2	0.5	.	.	2	0.5	.	.	2	0.5	291	79.7	365	100
74	71	19.5	3	0.8	14	3.8	13	3.6	2	0.5	6	1.6	4	1.1	2	0.5	1	0.3	1	0.3	1	0.3	247	67.7	365	100
75	20	5.5	1	0.3	1	0.3	32	8.8	11	3.0	2	0.5	3	0.8	.	.	1	0.3	1	0.3	1	0.3	292	80.0	365	100
76	27	7.4	.	.	4	1.1	30	8.2	40	10.9	10	2.7	7	1.9	3	0.8	2	0.5	6	1.6	2	0.5	235	64.2	366	100
77	45	12.3	6	1.6	16	4.4	73	20.0	20	5.5	6	1.6	4	1.1	3	0.8	4	1.1	4	1.1	3	0.8	181	49.6	365	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
78	29	7.9	1	0.3	2	0.5	19	5.2	11	3.0	2	0.5	.	.	2	0.5	3	0.8	.	.	.	.	296	81.1	365	100
79	7	1.9	.	.	13	3.6	11	3.0	5	1.4	6	1.6	1	0.3	.	.	1	0.3	.	.	.	.	321	87.9	365	100
80	55	15.0	6	1.6	9	2.5	32	8.7	21	5.7	8	2.2	5	1.4	.	.	4	1.1	4	1.1	3	0.8	219	59.8	366	100
81	95	26.0	5	1.4	44	12.1	40	11.0	26	7.1	14	3.8	14	3.8	12	3.3	2	0.5	6	1.6	4	1.1	103	28.2	365	100
82	20	5.5	4	1.1	9	2.5	33	9.0	13	3.6	9	2.5	4	1.1	4	1.1	5	1.4	2	0.5	1	0.3	261	71.5	365	100
83	41	11.2	30	8.2	11	3.0	4	1.1	6	1.6	5	1.4	4	1.1	2	0.5	5	1.4	2	0.5	2	0.5	253	69.3	365	100
84	47	12.8	12	3.3	2	0.5	4	1.1	3	0.8	4	1.1	6	1.6	3	0.8	3	0.8	1	0.3	3	0.8	278	76.0	366	100
85	35	9.6	28	7.7	19	5.2	11	3.0	10	2.7	24	6.6	5	1.4	1	0.3	2	0.5	2	0.5	2	0.5	226	61.9	365	100
86	67	18.4	22	6.0	26	7.1	15	4.1	10	2.7	13	3.6	16	4.4	17	4.7	2	0.5	8	2.2	2	0.5	167	45.8	365	100
87	24	6.6	11	3.0	11	3.0	8	2.2	7	1.9	8	2.2	6	1.6	3	0.8	3	0.8	1	0.3	5	1.4	278	76.2	365	100
88	95	26.0	23	6.3	21	5.7	18	4.9	3	0.8	5	1.4	3	0.8	2	0.5	3	0.8	5	1.4	3	0.8	185	50.5	366	100
89	31	8.5	2	0.5	3	0.8	2	0.5	3	0.8	3	0.8	1	0.3	2	0.5	3	0.8	1	0.3	2	0.5	312	85.5	365	100
90	8	3.7	2	0.9	3	1.4	1	0.5	1	0.5	4	1.8	1	0.5	2	0.9	.	.	2	0.9	2	0.9	193	88.1	219	100

APPENDIX A-12.

Percentage of Days for Quarter 1 (Jan-Mar, 1912-1990) that Roanoke River Flows were Less Than 2000 cfs, Between 2000 and 3100 cfs, and Greater than 3100 cfs.

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000)   (3100 MEANS >=3100)

QTR 1

	FLOW (CFS)																						ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
12	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
18	10	11.1	.	.	.	.	.	.	1	1.1	.	.	.	.	1	1.1	.	.	.	.	.	.	78	86.7	90	100
19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
20	7	7.7	.	.	1	1.1	.	.	.	.	.	.	.	.	2	2.2	.	.	.	.	2	2.2	79	86.8	91	100
21	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
22	.	.	.	.	.	.	1	1.1	.	.	.	.	1	1.1	.	.	.	.	4	4.4	3	3.3	81	90.0	90	100
23	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
24	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
25	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
26	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	.	.	.	.	.	.	1	1.1	88	97.8	90	100
27	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
28	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
29	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
30	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
31	.	.	.	.	2	2.2	1	1.1	3	3.3	3	3.3	1	1.1	.	.	4	4.4	3	3.3	5	5.6	68	75.6	90	100
32	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 1

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
--																										
33	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
34	2	2.2	2	2.2	1	1.1	3	3.3	8	8.9	4	4.4	7	7.8	4	4.4	4	4.4	3	3.3	3	3.3	49	54.4	90	100
35	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
36	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
37	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
38	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
39	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
40	.	.	.	.	1	1.1	.	.	.	.	.	.	2	2.2	.	.	1	1.1	3	3.3	1	1.1	83	91.2	91	100
41	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
42	2	2.2	1	1.1	.	.	1	1.1	.	.	1	1.1	.	.	1	1.1	.	.	2	2.2	1	1.1	81	90.0	90	100
43	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
44	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	2	2.2	88	96.7	91	100
45	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
46	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
47	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
48	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
50	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
51	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	100	90	100
52	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
53	3	3.3	1	1.1	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	.	.	.	.	85	94.4	90	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 1

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
54	7	7.8	.	.	.	.	.	.	2	2.2	2	2.2	.	.	.	:	.	.	1	1.1	.	.	78	86.7	90	100
55	15	16.7	1	1.1	.	.	.	.	1	1.1	1	1.1	.	.	.	.	1	1.1	.	.	.	.	71	78.9	90	100
56	12	13.2	1	1.1	.	.	1	1.1	1	1.1	1	1.1	.	.	.	.	1	1.1	.	.	.	.	74	81.3	91	100
57	15	16.7	1	1.1	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	.	.	.	.	72	80.0	90	100
58	11	12.2	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	76	84.4	90	100
59	21	23.3	1	1.1	1	1.1	.	.	.	.	2	2.2	.	.	.	.	.	.	4	4.4	.	.	61	67.8	90	100
60	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	89	97.8	91	100
61	13	14.4	.	.	2	2.2	.	.	.	.	.	.	.	.	1	1.1	1	1.1	1	1.1	2	2.2	70	77.8	90	100
62	1	1.1	1	1.1	.	.	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	87	96.7	90	100
63	8	8.9	.	.	.	.	.	.	1	1.1	1	1.1	.	.	.	.	1	1.1	.	.	.	.	79	87.8	90	100
64	20	22.0	.	.	.	.	.	.	.	.	2	2.2	1	1.1	.	.	2	2.2	1	1.1	.	.	65	71.4	91	100
65	7	7.8	2	2.2	.	.	.	.	1	1.1	2	2.2	.	.	.	.	.	.	.	.	1	1.1	77	85.6	90	100
66	11	12.2	1	1.1	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	2	2.2	73	81.1	90	100
67	14	15.6	.	.	1	1.1	1	1.1	2	2.2	1	1.1	.	.	1	1.1	.	.	2	2.2	1	1.1	67	74.4	90	100
68	9	9.9	.	.	.	.	.	.	1	1.1	.	.	.	.	.	.	1	1.1	.	.	.	.	80	87.9	91	100
69	21	23.3	2	2.2	1	1.1	.	.	.	.	4	4.4	.	.	.	.	.	.	1	1.1	1	1.1	60	66.7	90	100
70	22	24.4	.	.	2	2.2	1	1.1	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	64	71.1	90	100
71	6	6.7	1	1.1	.	.	.	.	.	.	1	1.1	.	.	1	1.1	1	1.1	1	1.1	.	.	79	87.8	90	100
72	4	4.4	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	2	2.2	1	1.1	.	.	83	91.2	91	100
73	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	88	97.8	90	100
74	6	6.7	.	.	.	.	2	2.2	.	.	2	2.2	1	1.1	.	.	.	.	.	.	.	.	79	87.8	90	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 1

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
75	6	6.7	.	.	.	.	1	1.1	.	.	.	.	.	.	.	.	1	1.1	.	.	.	.	82	91.1	90	100
76	20	22.0	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	.	.	.	.	70	76.9	91	100
77	21	23.3	3	3.3	1	1.1	2	2.2	1	1.1	1	1.1	1	1.1	.	.	1	1.1	2	2.2	1	1.1	56	62.2	90	100
78	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	88	97.8	90	100
79	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	88	97.8	90	100
80	10	11.0	.	.	1	1.1	.	.	2	2.2	1	1.1	.	.	.	.	.	.	.	.	.	.	77	84.6	91	100
81	46	51.1	4	4.4	3	3.3	.	.	2	2.2	.	.	.	.	6	6.7	.	.	2	2.2	.	.	27	30.0	90	100
82	7	7.8	2	2.2	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	80	88.9	90	100
83	3	3.3	.	.	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	86	95.6	90	100
84	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	.	.	89	97.8	91	100
85	8	8.9	.	.	.	.	.	.	2	2.2	.	.	.	.	.	.	.	.	1	1.1	.	.	79	87.8	90	100
86	15	16.7	1	1.1	.	.	1	1.1	.	.	.	.	1	1.1	.	.	.	.	1	1.1	1	1.1	70	77.8	90	100
87	1	1.1	.	.	2	2.2	.	.	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	86	95.6	90	100
88	26	28.6	.	.	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	61	67.0	91	100
89	25	27.8	.	.	.	.	.	.	1	1.1	1	1.1	1	1.1	.	.	1	1.1	.	.	.	.	61	67.8	90	100
90	4	4.4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2.2	.	.	84	93.3	90	100

APPENDIX A-13.

Percentage of Days for Quarter 2 (Apr-Jun, 1912-1990) that Roanoke River Flows were Less Than 2000 cfs, Between 2000 and 3100 cfs, and Greater than 3100 cfs.

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 2

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
12	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
14	5	5.5	3	3.3	.	.	2	2.2	4	4.4	.	.	2	2.2	1	1.1	.	.	4	4.4	2	2.2	68	74.7	91	100
15	1	1.1	.	.	.	.	1	1.1	1	1.1	.	.	2	2.2	1	1.1	.	.	1	1.1	.	.	84	92.3	91	100
16	.	.	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	2	2.2	87	95.6	91	100
17	1	1.1	1	1.1	.	.	1	1.1	.	.	1	1.1	.	.	.	.	.	.	.	.	1	1.1	86	94.5	91	100
18	1	1.1	2	2.2	.	.	.	.	1	1.1	.	.	.	.	2	2.2	.	.	.	.	4	4.4	81	89.0	91	100
19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
20	.	.	.	.	.	.	.	.	1	1.1	.	.	.	.	1	1.1	.	.	.	.	3	3.3	86	94.5	91	100
21	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	90	98.9	91	100
22	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
23	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	.	.	90	98.9	91	100
24	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
25	.	.	.	.	1	1.1	2	2.2	.	.	3	3.3	1	1.1	1	1.1	2	2.2	.	.	1	1.1	80	87.9	91	100
26	14	15.4	3	3.3	8	8.8	.	.	4	4.4	4	4.4	2	2.2	1	1.1	.	.	.	.	2	2.2	53	58.2	91	100
27	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	2	2.2	.	.	.	.	2	2.2	86	94.5	91	100
28	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	90	98.9	91	100
29	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
30	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	2	2.2	3	3.3	3	3.3	1	1.1	81	89.0	91	100
31	.	.	.	.	1	1.1	.	.	2	2.2	.	.	1	1.1	2	2.2	2	2.2	1	1.1	1	1.1	81	89.0	91	100
32	.	.	1	1.1	5	5.5	1	1.1	3	3.3	1	1.1	1	1.1	1	1.1	1	1.1	1	1.1	.	.	76	83.5	91	100

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 2

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
33	.	.	.	.	4	4.4	.	.	.	.	.	.	2	2.2	2	2.2	1	1.1	.	.	.	.	82	90.1	91	100
34	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	1	1.1	88	96.7	91	100
35	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	2	2.2	87	95.6	91	100
36	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
37	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
38	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
39	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	.	.	89	97.8	91	100
40	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
41	.	.	3	3.3	.	.	3	3.3	3	3.3	3	3.3	3	3.3	3	3.3	3	3.3	2	2.2	1	1.1	67	73.6	91	100
42	.	.	.	.	.	.	1	1.1	2	2.2	.	.	4	4.4	2	2.2	4	4.4	2	2.2	1	1.1	75	82.4	91	100
43	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
44	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	.	.	.	.	3	3.3	1	1.1	85	93.4	91	100
45	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	2	2.2	1	1.1	.	.	86	94.5	91	100
46	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
47	.	.	.	.	.	.	.	.	.	.	.	.	2	2.2	1	1.1	2	2.2	.	.	1	1.1	85	93.4	91	100
48	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
50	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
51	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
52	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	91	100	91	100
53	1	1.1	.	.	3	3.3	3	3.3	3	3.3	4	4.4	1	1.1	1	1.1	.	.	.	.	.	.	75	82.4	91	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 2

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
54	8	8.8	1	1.1	1	1.1	1	1.1	2	2.2	1	1.1	.	.	3	3.3	.	.	2	2.2	2	2.2	70	76.9	91	100
55	6	6.6	.	.	.	.	1	1.1	1	1.1	1	1.1	.	.	3	3.3	1	1.1	.	.	.	.	78	85.7	91	100
56	4	4.4	2	2.2	2	2.2	.	.	7	7.7	2	2.2	.	.	.	.	4	4.4	1	1.1	1	1.1	68	74.7	91	100
57	3	3.3	5	5.5	.	.	1	1.1	.	.	.	.	.	.	1	1.1	.	.	.	.	2	2.2	79	86.8	91	100
58	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	89	97.8	91	100
59	3	3.3	2	2.2	3	3.3	.	.	.	.	3	3.3	.	.	.	.	1	1.1	.	.	1	1.1	78	85.7	91	100
60	1	1.1	2	2.2	.	.	.	.	.	.	.	.	1	1.1	.	.	.	.	1	1.1	.	.	86	94.5	91	100
61	3	3.3	.	.	.	.	1	1.1	.	.	.	.	1	1.1	.	.	.	.	1	1.1	.	.	85	93.4	91	100
62	1	1.1	.	.	.	.	.	.	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	89	97.8	91	100
63	6	6.6	6	6.6	1	1.1	4	4.4	3	3.3	.	.	2	2.2	.	.	.	.	1	1.1	.	.	68	74.7	91	100
64	3	3.3	8	8.8	6	6.6	.	.	4	4.4	.	.	.	.	2	2.2	.	.	.	.	1	1.1	67	73.6	91	100
65	1	1.1	4	4.4	4	4.4	5	5.5	8	8.8	6	6.6	2	2.2	2	2.2	.	.	.	.	1	1.1	58	63.7	91	100
66	12	13.2	.	.	.	.	4	4.4	.	.	1	1.1	3	3.3	3	3.3	.	.	1	1.1	3	3.3	64	70.3	91	100
67	30	33.0	3	3.3	1	1.1	.	.	5	5.5	2	2.2	4	4.4	2	2.2	1	1.1	1	1.1	.	.	42	46.2	91	100
68	9	9.9	1	1.1	4	4.4	2	2.2	1	1.1	.	.	2	2.2	1	1.1	2	2.2	.	.	.	.	69	75.8	91	100
69	11	12.1	2	2.2	2	2.2	3	3.3	2	2.2	2	2.2	2	2.2	4	4.4	2	2.2	.	.	.	.	61	67.0	91	100
70	21	23.1	2	2.2	4	4.4	2	2.2	2	2.2	.	.	1	1.1	.	.	.	.	.	.	.	.	59	64.8	91	100
71	9	9.9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	81	89.0	91	100
72	8	8.8	.	.	2	2.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	81	89.0	91	100
73	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	89	97.8	91	100
74	11	12.1	1	1.1	1	1.1	.	.	.	.	.	.	1	1.1	.	.	.	.	.	.	.	.	77	84.6	91	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000)   (3100 MEANS >=3100)

QTR 2

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
75	.	.	.	.	.	.	6	6.6	1	1.1	.	.	1	1.1	.	.	.	.	.	.	.	.	83	91.2	91	100
76	.	.	.	.	2	2.2	10	11.0	5	5.5	1	1.1	2	2.2	2	2.2	1	1.1	2	2.2	.	.	66	72.5	91	100
77	.	.	.	.	10	11.0	24	26.4	1	1.1	2	2.2	.	.	.	.	1	1.1	.	.	2	2.2	51	56.0	91	100
78	.	.	.	.	.	.	3	3.3	2	2.2	1	1.1	.	.	.	.	1	1.1	.	.	.	.	84	92.3	91	100
79	.	.	.	.	1	1.1	1	1.1	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	87	95.6	91	100
80	.	.	.	.	3	3.3	.	.	.	.	1	1.1	.	.	.	.	.	.	1	1.1	1	1.1	85	93.4	91	100
81	.	.	.	.	29	31.9	4	4.4	5	5.5	6	6.6	7	7.7	2	2.2	1	1.1	.	.	3	3.3	34	37.4	91	100
82	.	.	1	1.1	6	6.6	10	11.0	.	.	1	1.1	.	.	1	1.1	.	.	.	.	.	.	72	79.1	91	100
83	3	3.3	1	1.1	1	1.1	.	.	3	3.3	.	.	.	.	.	.	1	1.1	.	.	.	.	82	90.1	91	100
84	6	6.6	4	4.4	1	1.1	.	.	.	.	.	.	1	1.1	.	.	.	.	.	.	.	.	79	86.8	91	100
85	16	17.6	8	8.8	6	6.6	3	3.3	5	5.5	17	18.7	1	1.1	.	.	1	1.1	1	1.1	.	.	33	36.3	91	100
86	.	.	4	4.4	5	5.5	6	6.6	4	4.4	10	11.0	4	4.4	7	7.7	1	1.1	1	1.1	.	.	49	53.8	91	100
87	.	.	1	1.1	1	1.1	1	1.1	1	1.1	.	.	.	.	.	.	1	1.1	1	1.1	1	1.1	84	92.3	91	100
88	13	14.3	1	1.1	3	3.3	4	4.4	1	1.1	2	2.2	1	1.1	2	2.2	.	.	.	.	.	.	64	70.3	91	100
89	.	.	.	.	.	.	1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	89	97.8	91	100
90	1	1.1	1	1.1	.	.	.	.	.	.	1	1.1	.	.	.	.	.	.	.	.	.	.	88	96.7	91	100

APPENDIX A-14.

Percentage of Days for Quarter 3 (Jul-Sep, 1912-1989, and Jul-Aug 7, 1990) that Roanoke River Flows were Less Than 2000 cfs, Between 2000 and 3100 cfs, and Greater than 3100 cfs.

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 3

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
12	24	26.1	8	8.7	6	6.5	.	.	6	6.5	.	.	3	3.3	.	.	.	.	3	3.3	1	1.1	41	44.6	92	100
13	4	4.3	3	3.3	.	.	6	6.5	5	5.4	.	.	4	4.3	4	4.3	.	.	2	2.2	7	7.6	57	62.0	92	100
14	40	43.5	2	2.2	.	.	4	4.3	4	4.3	.	.	4	4.3	2	2.2	.	.	2	2.2	1	1.1	33	35.9	92	100
15	1	1.1	4	4.3	.	.	3	3.3	4	4.3	.	.	5	5.4	6	6.5	.	.	3	3.3	5	5.4	61	66.3	92	100
16	8	8.7	.	.	2	2.2	.	.	2	2.2	2	2.2	8	8.7	.	.	7	7.6	.	.	1	1.1	62	67.4	92	100
17	18	19.6	.	.	4	4.3	1	1.1	.	.	1	1.1	4	4.3	.	.	.	.	.	.	7	7.6	57	62.0	92	100
18	4	4.3	2	2.2	6	6.5	.	.	5	5.4	.	.	.	.	8	8.7	.	.	.	.	6	6.5	61	66.3	92	100
19	15	16.3	.	.	6	6.5	.	.	4	4.3	.	.	.	.	4	4.3	.	.	.	.	4	4.3	59	64.1	92	100
20	8	8.7	4	4.3	3	3.3	.	.	1	1.1	.	.	.	.	6	6.5	.	.	.	.	6	6.5	64	69.6	92	100
21	36	39.1	.	.	6	6.5	1	1.1	.	.	6	6.5	3	3.3	4	4.3	.	.	2	2.2	1	1.1	33	35.9	92	100
22	.	.	1	1.1	4	4.3	.	.	5	5.4	.	.	1	1.1	3	3.3	.	.	2	2.2	3	3.3	73	79.3	92	100
23	.	.	.	.	.	.	2	2.2	.	.	3	3.3	4	4.3	2	2.2	5	5.4	.	.	4	4.3	72	78.3	92	100
24	.	.	3	3.3	5	5.4	1	1.1	.	.	1	1.1	3	3.3	.	.	4	4.3	.	.	4	4.3	71	77.2	92	100
25	43	46.7	1	1.1	4	4.3	.	.	5	5.4	5	5.4	5	5.4	2	2.2	.	.	6	6.5	4	4.3	17	18.5	92	100
26	46	50.0	2	2.2	5	5.4	1	1.1	3	3.3	4	4.3	2	2.2	5	5.4	.	.	1	1.1	2	2.2	21	22.8	92	100
27	5	5.4	1	1.1	3	3.3	6	6.5	.	.	2	2.2	3	3.3	2	2.2	6	6.5	.	.	8	8.7	56	60.9	92	100
28	3	3.3	.	.	3	3.3	1	1.1	.	.	2	2.2	3	3.3	1	1.1	2	2.2	.	.	2	2.2	75	81.5	92	100
29	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	3	3.3	88	95.7	92	100
30	78	84.8	.	.	3	3.3	2	2.2	.	.	.	.	2	2.2	2	2.2	1	1.1	1	1.1	.	.	3	3.3	92	100
31	19	20.7	3	3.3	4	4.3	1	1.1	1	1.1	.	.	.	.	2	2.2	1	1.1	1	1.1	1	1.1	59	64.1	92	100
32	73	79.3	.	.	5	5.4	1	1.1	2	2.2	4	4.3	.	.	1	1.1	2	2.2	1	1.1	1	1.1	2	2.2	92	100

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000)   (3100 MEANS >=3100)

QTR 3

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
33	25	27.2	.	.	7	7.6	5	5.4	4	4.3	2	2.2	1	1.1	4	4.3	5	5.4	5	5.4	.	.	34	37.0	92	100
34	4	4.3	2	2.2	4	4.3	6	6.5	3	3.3	2	2.2	1	1.1	2	2.2	3	3.3	5	5.4	3	3.3	57	62.0	92	100
35	.	.	1	1.1	3	3.3	4	4.3	3	3.3	2	2.2	2	2.2	6	6.5	2	2.2	2	2.2	6	6.5	61	66.3	92	100
36	16	17.4	6	6.5	.	.	5	5.4	1	1.1	1	1.1	4	4.3	.	.	5	5.4	.	.	6	6.5	48	52.2	92	100
37	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
38	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	1	1.1	2	2.2	3	3.3	84	91.3	92	100
39	.	.	.	.	.	.	1	1.1	1	1.1	6	6.5	.	.	5	5.4	3	3.3	3	3.3	1	1.1	72	78.3	92	100
40	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
41	21	22.8	1	1.1	1	1.1	2	2.2	2	2.2	2	2.2	3	3.3	1	1.1	5	5.4	3	3.3	2	2.2	49	53.3	92	100
42	.	.	.	.	.	.	1	1.1	.	.	1	1.1	3	3.3	2	2.2	2	2.2	4	4.3	1	1.1	78	84.8	92	100
43	9	9.8	7	7.6	3	3.3	3	3.3	3	3.3	1	1.1	3	3.3	2	2.2	2	2.2	5	5.4	3	3.3	51	55.4	92	100
44	26	28.3	3	3.3	4	4.3	2	2.2	.	.	3	3.3	1	1.1	1	1.1	3	3.3	1	1.1	2	2.2	46	50.0	92	100
45	.	.	.	.	2	2.2	2	2.2	1	1.1	3	3.3	2	2.2	.	.	2	2.2	6	6.5	2	2.2	72	78.3	92	100
46	6	6.5	5	5.4	1	1.1	1	1.1	5	5.4	7	7.6	5	5.4	2	2.2	1	1.1	2	2.2	3	3.3	54	58.7	92	100
47	5	5.4	6	6.5	5	5.4	8	8.7	3	3.3	3	3.3	4	4.3	1	1.1	2	2.2	6	6.5	3	3.3	46	50.0	92	100
48	.	.	.	.	1	1.1	6	6.5	1	1.1	2	2.2	5	5.4	3	3.3	4	4.3	2	2.2	2	2.2	66	71.7	92	100
49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
50	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	4	4.3	87	94.6	92	100
51	21	22.8	7	7.6	3	3.3	3	3.3	1	1.1	4	4.3	.	.	5	5.4	2	2.2	.	.	.	.	46	50.0	92	100
52	34	37.0	5	5.4	1	1.1	2	2.2	5	5.4	3	3.3	1	1.1	.	.	4	4.3	.	.	1	1.1	36	39.1	92	100
53	18	19.6	7	7.6	.	.	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	1	1.1	64	69.6	92	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 3

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
54	21	22.8	6	6.5	1	1.1	.	.	1	1.1	.	.	2	2.2	1	1.1	2	2.2	1	1.1	3	3.3	54	58.7	92	100
55	4	4.3	.	.	2	2.2	.	.	4	4.3	.	.	1	1.1	.	.	1	1.1	1	1.1	1	1.1	78	84.8	92	100
56	10	10.9	5	5.4	3	3.3	1	1.1	3	3.3	.	.	2	2.2	.	.	4	4.3	4	4.3	1	1.1	59	64.1	92	100
57	13	14.1	6	6.5	1	1.1	2	2.2	5	5.4	3	3.3	.	.	4	4.3	.	.	1	1.1	1	1.1	56	60.9	92	100
58	14	15.2	4	4.3	1	1.1	.	.	.	.	1	1.1	.	.	.	.	.	.	1	1.1	.	.	71	77.2	92	100
59	.	.	9	9.8	6	6.5	7	7.6	5	5.4	.	.	2	2.2	4	4.3	.	.	2	2.2	1	1.1	56	60.9	92	100
60	3	3.3	8	8.7	4	4.3	.	.	.	.	1	1.1	1	1.1	1	1.1	.	.	.	.	2	2.2	72	78.3	92	100
61	15	16.3	4	4.3	1	1.1	3	3.3	1	1.1	1	1.1	2	2.2	.	.	1	1.1	.	.	1	1.1	63	68.5	92	100
62	4	4.3	8	8.7	3	3.3	9	9.8	3	3.3	.	.	1	1.1	.	.	.	.	1	1.1	1	1.1	62	67.4	92	100
63	3	3.3	3	3.3	.	.	2	2.2	3	3.3	4	4.3	4	4.3	4	4.3	3	3.3	9	9.8	5	5.4	52	56.5	92	100
64	.	.	2	2.2	4	4.3	2	2.2	11	12.0	8	8.7	10	10.9	3	3.3	5	5.4	1	1.1	5	5.4	41	44.6	92	100
65	.	.	.	.	2	2.2	.	.	1	1.1	7	7.6	2	2.2	5	5.4	8	8.7	4	4.3	6	6.5	57	62.0	92	100
66	2	2.2	1	1.1	3	3.3	7	7.6	5	5.4	7	7.6	7	7.6	3	3.3	3	3.3	4	4.3	5	5.4	45	48.9	92	100
67	5	5.4	2	2.2	1	1.1	3	3.3	4	4.3	8	8.7	2	2.2	4	4.3	4	4.3	2	2.2	1	1.1	56	60.9	92	100
68	9	9.8	6	6.5	12	13.0	9	9.8	4	4.3	6	6.5	5	5.4	2	2.2	2	2.2	3	3.3	1	1.1	33	35.9	92	100
69	7	7.6	9	9.8	10	10.9	5	5.4	10	10.9	4	4.3	3	3.3	2	2.2	2	2.2	2	2.2	.	.	38	41.3	92	100
70	30	32.6	12	13.0	7	7.6	2	2.2	.	.	2	2.2	.	.	.	.	.	.	1	1.1	.	.	38	41.3	92	100
71	36	39.1	2	2.2	1	1.1	1	1.1	1	1.1	.	.	.	.	.	.	1	1.1	1	1.1	1	1.1	48	52.2	92	100
72	17	18.5	1	1.1	3	3.3	1	1.1	.	.	.	.	.	.	2	2.2	.	.	.	.	.	.	68	73.9	92	100
73	10	10.9	7	7.6	2	2.2	3	3.3	1	1.1	2	2.2	1	1.1	.	.	.	.	.	.	1	1.1	65	70.7	92	100
74	4	4.3	2	2.2	13	14.1	9	9.8	1	1.1	4	4.3	1	1.1	1	1.1	1	1.1	1	1.1	1	1.1	54	58.7	92	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 3

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
75	.	.	.	.	.	.	24	26.1	9	9.8	1	1.1	2	2.2	.	.	.	.	1	1.1	1	1.1	54	58.7	92	100
76	.	.	.	.	.	.	17	18.5	30	32.6	9	9.8	5	5.4	.	.	.	.	3	3.3	1	1.1	27	29.3	92	100
77	.	.	.	.	4	4.3	46	50.0	16	17.4	2	2.2	3	3.3	2	2.2	2	2.2	1	1.1	.	.	16	17.4	92	100
78	.	.	.	.	2	2.2	16	17.4	8	8.7	1	1.1	.	.	1	1.1	.	.	.	.	.	.	64	69.6	92	100
79	.	.	.	.	12	13.0	9	9.8	4	4.3	4	4.3	1	1.1	.	.	1	1.1	.	.	.	.	61	66.3	92	100
80	.	.	.	.	4	4.3	31	33.7	16	17.4	2	2.2	2	2.2	.	.	1	1.1	2	2.2	1	1.1	33	35.9	92	100
81	.	.	.	.	9	9.8	34	37.0	16	17.4	5	5.4	6	6.5	1	1.1	1	1.1	2	2.2	1	1.1	17	18.5	92	100
82	.	.	.	.	1	1.1	18	19.6	11	12.0	6	6.5	3	3.3	2	2.2	4	4.3	1	1.1	.	.	46	50.0	92	100
83	11	12.0	24	26.1	5	5.4	2	2.2	1	1.1	3	3.3	3	3.3	1	1.1	3	3.3	2	2.2	1	1.1	36	39.1	92	100
84	8	8.7	6	6.5	.	.	1	1.1	2	2.2	2	2.2	2	2.2	2	2.2	1	1.1	1	1.1	1	1.1	66	71.7	92	100
85	3	3.3	18	19.6	9	9.8	5	5.4	1	1.1	5	5.4	1	1.1	1	1.1	1	1.1	.	.	1	1.1	47	51.1	92	100
86	8	8.7	10	10.9	19	20.7	8	8.7	6	6.5	2	2.2	9	9.8	8	8.7	1	1.1	5	5.4	1	1.1	15	16.3	92	100
87	7	7.6	9	9.8	8	8.7	5	5.4	4	4.3	6	6.5	6	6.5	3	3.3	1	1.1	.	.	1	1.1	42	45.7	92	100
88	19	20.7	18	19.6	16	17.4	12	13.0	2	2.2	1	1.1	1	1.1	.	.	3	3.3	1	1.1	1	1.1	18	19.6	92	100
89	1	1.1	2	2.2	3	3.3	.	.	2	2.2	1	1.1	.	.	1	1.1	2	2.2	.	.	.	.	80	87.0	92	100
90	3	7.9	1	2.6	3	7.9	1	2.6	1	2.6	3	7.9	1	2.6	2	5.3	.	.	.	.	2	5.3	21	55.3	38	100

APPENDIX A-15.

Percentage of Days for Quarter 4 (Oct-Dec, 1912-1989) that Roanoke River Flows were Less Than 2000 cfs, Between 2000 and 3100 cfs, and Greater than 3100 cfs.

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000)   (3100 MEANS >=3100)

QTR 4

	FLOW (CFS)																									
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100		ALL	
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
12	5	5.4	3	3.3	.	.	4	4.3	3	3.3	.	.	10	10.9	9	9.8	.	.	11	12.0	12	13.0	35	38.0	92	100
13	5	5.4	2	2.2	.	.	1	1.1	1	1.1	.	.	1	1.1	3	3.3	.	.	3	3.3	3	3.3	73	79.3	92	100
14	15	16.3	6	6.5	.	.	9	9.8	6	6.5	.	.	4	4.3	4	4.3	.	.	3	3.3	1	1.1	44	47.8	92	100
15	6	6.5	1	1.1	.	.	2	2.2	.	.	1	1.1	3	3.3	.	.	1	1.1	.	.	4	4.3	74	80.4	92	100
16	11	12.0	1	1.1	7	7.6	.	.	8	8.7	3	3.3	16	17.4	.	.	5	5.4	1	1.1	6	6.5	34	37.0	92	100
17	34	37.0	.	.	14	15.2	.	.	7	7.6	.	.	.	.	6	6.5	.	.	.	.	12	13.0	19	20.7	92	100
18	21	22.8	1	1.1	4	4.3	.	.	4	4.3	.	.	.	.	8	8.7	.	.	.	.	2	2.2	52	56.5	92	100
19	19	20.7	8	8.7	1	1.1	.	.	8	8.7	.	.	.	.	8	8.7	.	.	.	.	10	10.9	38	41.3	92	100
20	15	16.3	.	.	8	8.7	.	.	.	.	8	8.7	.	.	6	6.5	.	.	.	.	3	3.3	52	56.5	92	100
21	25	27.2	.	.	3	3.3	.	.	2	2.2	1	1.1	3	3.3	2	2.2	.	.	7	7.6	8	8.7	41	44.6	92	100
22	4	4.3	1	1.1	1	1.1	.	.	.	.	1	1.1	4	4.3	6	6.5	.	.	13	14.1	9	9.8	53	57.6	92	100
23	.	.	.	.	.	.	.	.	.	.	5	5.4	6	6.5	8	8.7	2	2.2	.	.	6	6.5	65	70.7	92	100
24	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
25	13	14.1	2	2.2	1	1.1	1	1.1	2	2.2	1	1.1	.	.	7	7.6	.	.	4	4.3	9	9.8	52	56.5	92	100
26	38	41.3	.	.	.	.	.	.	1	1.1	2	2.2	1	1.1	1	1.1	3	3.3	1	1.1	2	2.2	43	46.7	92	100
27	4	4.3	.	.	.	.	2	2.2	.	.	.	.	8	8.7	1	1.1	4	4.3	.	.	4	4.3	69	75.0	92	100
28	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
29	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
30	54	58.7	3	3.3	5	5.4	4	4.3	1	1.1	3	3.3	1	1.1	2	2.2	1	1.1	3	3.3	2	2.2	13	14.1	92	100
31	68	73.9	.	.	1	1.1	3	3.3	1	1.1	1	1.1	.	.	4	4.3	1	1.1	5	5.4	.	.	8	8.7	92	100
32	13	14.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	.	.	.	.	78	84.8	92	100

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 4

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
33	69	75.0	3	3.3	5	5.4	4	4.3	1	1.1	.	.	1	1.1	1	1.1	2	2.2	.	.	1	1.1	5	5.4	92	100
34	.	.	1	1.1	.	.	6	6.5	4	4.3	9	9.8	4	4.3	4	4.3	.	.	4	4.3	1	1.1	59	64.1	92	100
35	.	.	3	3.3	7	7.6	7	7.6	7	7.6	1	1.1	1	1.1	4	4.3	1	1.1	3	3.3	1	1.1	57	62.0	92	100
36	.	.	1	1.1	.	.	.	.	.	.	1	1.1	3	3.3	6	6.5	8	8.7	13	14.1	3	3.3	57	62.0	92	100
37	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
38	.	.	.	.	.	.	.	.	.	.	2	2.2	5	5.4	7	7.6	4	4.3	8	8.7	.	.	66	71.7	92	100
39	.	.	.	.	.	.	.	.	.	.	8	8.7	5	5.4	3	3.3	2	2.2	8	8.7	8	8.7	58	63.0	92	100
40	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	90	97.8	92	100
41	60	65.2	1	1.1	2	2.2	3	3.3	2	2.2	.	.	4	4.3	2	2.2	2	2.2	.	.	1	1.1	15	16.3	92	100
42	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
43	22	23.9	6	6.5	2	2.2	3	3.3	12	13.0	24	26.1	5	5.4	2	2.2	3	3.3	3	3.3	.	.	10	10.9	92	100
44	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
45	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
46	.	.	.	.	.	.	1	1.1	2	2.2	1	1.1	1	1.1	4	4.3	4	4.3	6	6.5	14	15.2	59	64.1	92	100
47	.	.	.	.	.	.	.	.	.	.	.	.	1	1.1	1	1.1	.	.	1	1.1	2	2.2	87	94.6	92	100
48	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
49	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
50	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	92	100	92	100
51	25	27.2	5	5.4	2	2.2	.	.	1	1.1	.	.	.	.	4	4.3	2	2.2	5	5.4	1	1.1	47	51.1	92	100
52	36	39.1	1	1.1	5	5.4	1	1.1	2	2.2	.	.	.	.	1	1.1	2	2.2	.	.	2	2.2	42	45.7	92	100
53	29	31.5	.	.	1	1.1	1	1.1	6	6.5	4	4.3	3	3.3	4	4.3	3	3.3	4	4.3	2	2.2	35	38.0	92	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 4

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
YR	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
54	15	16.3	1	1.1	.	.	2	2.2	.	.	.	.	.	.	1	1.1	.	.	1	1.1	2	2.2	70	76.1	92	100
55	4	4.3	.	.	.	.	3	3.3	.	.	1	1.1	1	1.1	.	.	1	1.1	.	.	2	2.2	80	87.0	92	100
56	17	18.5	1	1.1	1	1.1	.	.	1	1.1	1	1.1	.	.	1	1.1	.	.	1	1.1	.	.	69	75.0	92	100
57	12	13.0	.	.	.	.	1	1.1	.	.	.	.	1	1.1	.	.	.	.	.	.	.	.	78	84.8	92	100
58	20	21.7	1	1.1	2	2.2	.	.	.	.	.	.	.	.	1	1.1	.	.	1	1.1	.	.	67	72.8	92	100
59	3	3.3	.	.	2	2.2	.	.	.	.	1	1.1	.	.	.	.	.	.	1	1.1	.	.	85	92.4	92	100
60	17	18.5	1	1.1	.	.	2	2.2	.	.	1	1.1	.	.	.	.	.	.	.	.	.	.	71	77.2	92	100
61	8	8.7	2	2.2	1	1.1	.	.	2	2.2	.	.	2	2.2	1	1.1	.	.	.	.	1	1.1	75	81.5	92	100
62	29	31.5	4	4.3	3	3.3	5	5.4	.	.	2	2.2	1	1.1	.	.	.	.	2	2.2	.	.	46	50.0	92	100
63	16	17.4	6	6.5	4	4.3	1	1.1	.	.	.	.	.	.	1	1.1	1	1.1	1	1.1	.	.	62	67.4	92	100
64	21	22.8	2	2.2	1	1.1	1	1.1	.	.	.	.	.	.	2	2.2	1	1.1	.	.	.	.	64	69.6	92	100
65	27	29.3	.	.	3	3.3	2	2.2	5	5.4	.	.	1	1.1	2	2.2	.	.	1	1.1	3	3.3	48	52.2	92	100
66	22	23.9	3	3.3	2	2.2	.	.	.	.	1	1.1	.	.	2	2.2	1	1.1	2	2.2	.	.	59	64.1	92	100
67	25	27.2	1	1.1	1	1.1	1	1.1	.	.	2	2.2	2	2.2	2	2.2	1	1.1	1	1.1	.	.	56	60.9	92	100
68	36	39.1	3	3.3	2	2.2	.	.	3	3.3	1	1.1	.	.	1	1.1	.	.	.	.	2	2.2	44	47.8	92	100
69	17	18.5	3	3.3	3	3.3	.	.	1	1.1	1	1.1	1	1.1	1	1.1	.	.	2	2.2	.	.	63	68.5	92	100
70	34	37.0	4	4.3	.	.	1	1.1	.	.	1	1.1	1	1.1	.	.	.	.	2	2.2	1	1.1	48	52.2	92	100
71	10	10.9	3	3.3	.	.	1	1.1	.	.	1	1.1	.	.	1	1.1	.	.	.	.	.	.	76	82.6	92	100
72	2	2.2	1	1.1	.	.	.	.	3	3.3	1	1.1	.	.	.	.	1	1.1	.	.	.	.	84	91.3	92	100
73	30	32.6	6	6.5	1	1.1	.	.	1	1.1	1	1.1	1	1.1	.	.	2	2.2	.	.	1	1.1	49	53.3	92	100
74	50	54.3	.	.	.	.	2	2.2	1	1.1	.	.	1	1.1	1	1.1	.	.	.	.	.	.	37	40.2	92	100

(CONTINUED)

RR90PG13: ROANOKE RIVER FLOW REPORT 1990
LOW FLOW CONDITIONS BY YEAR
(2000 MEANS <=2000) (3100 MEANS >=3100)

QTR 4

	FLOW (CFS)																								ALL	
	2000		2100		2200		2300		2400		2500		2600		2700		2800		2900		3000		3100			
	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN	N	PCTN
YR																										
75	14	15.2	1	1.1	1	1.1	1	1.1	1	1.1	1	1.1	.	.	.	.	.	.	.	.	.	.	73	79.3	92	100
76	7	7.6	.	.	2	2.2	3	3.3	5	5.4	.	.	.	.	.	.	1	1.1	1	1.1	1	1.1	72	78.3	92	100
77	24	26.1	3	3.3	1	1.1	1	1.1	2	2.2	1	1.1	.	.	1	1.1	.	.	1	1.1	.	.	58	63.0	92	100
78	27	29.3	1	1.1	.	.	.	.	1	1.1	.	.	.	.	1	1.1	2	2.2	.	.	.	.	60	65.2	92	100
79	5	5.4	.	.	.	.	1	1.1	.	.	1	1.1	.	.	.	.	.	.	.	.	.	.	85	92.4	92	100
80	45	48.9	6	6.5	1	1.1	1	1.1	3	3.3	4	4.3	3	3.3	.	.	3	3.3	1	1.1	1	1.1	24	26.1	92	100
81	49	53.3	1	1.1	3	3.3	2	2.2	3	3.3	3	3.3	1	1.1	3	3.3	.	.	2	2.2	.	.	25	27.2	92	100
82	13	14.1	1	1.1	1	1.1	5	5.4	2	2.2	2	2.2	1	1.1	1	1.1	1	1.1	1	1.1	1	1.1	63	68.5	92	100
83	24	26.1	5	5.4	4	4.3	2	2.2	2	2.2	2	2.2	1	1.1	1	1.1	1	1.1	.	.	1	1.1	49	53.3	92	100
84	32	34.8	2	2.2	1	1.1	3	3.3	1	1.1	2	2.2	3	3.3	1	1.1	1	1.1	.	.	2	2.2	44	47.8	92	100
85	8	8.7	2	2.2	4	4.3	3	3.3	2	2.2	2	2.2	3	3.3	.	.	.	.	.	.	1	1.1	67	72.8	92	100
86	44	47.8	7	7.6	2	2.2	.	.	.	.	1	1.1	2	2.2	2	2.2	.	.	1	1.1	.	.	33	35.9	92	100
87	16	17.4	1	1.1	.	.	2	2.2	1	1.1	2	2.2	.	.	.	.	1	1.1	.	.	3	3.3	66	71.7	92	100
88	37	40.2	4	4.3	1	1.1	1	1.1	.	.	2	2.2	1	1.1	.	.	.	.	3	3.3	1	1.1	42	45.7	92	100
89	5	5.4	.	.	.	.	1	1.1	.	.	1	1.1	.	.	1	1.1	.	.	1	1.1	1	1.1	82	89.1	92	100

APPENDIX B.

Water Quality for the Lower Roanoke River Including Barnhill's Landing and Four Roanoke Delta Stations for the Period April-June, 1990.

ROANOKE RIVER WATER QUALITY, APRIL-JUNE 1990. ELEMENT CONCENTRATIONS (MG/L)

Week No.	Al		Ba		Ca		Fe		K		Mg		Mn		Na		Zn	
	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
17	0.37	0.35	0.022	0.025	5.91	5.86	0.61	0.89	1.59	2.02	2.72	2.68	0.028	0.047	7.43	7.09	0.021	0.011
18	0.33	0.46	0.021	0.028	6.05	5.94	0.50	1.32	2.20	2.15	2.70	2.69	0.030	0.086	7.29	8.66	0.009	0.009
19	0.18	0.45	0.019	0.026	5.62	5.23	0.28	1.24	1.54	1.53	2.46	2.44	0.028	0.086	7.09	7.19	0.012	0.006
20	0.38	0.42	0.024	0.026	6.60	6.11	0.40	0.80	3.72	3.18	3.03	2.91	0.045	0.081	8.15	9.10	0.009	0.009
21	0.33	0.42	0.023	0.024	6.19	5.89	0.48	0.81	2.09	1.93	2.94	2.90	0.044	0.065	7.58	8.29	0.010	0.009
22	0.55	0.64	0.027	0.028	6.01	5.52	0.72	1.16	2.38	2.32	2.68	2.57	0.063	0.073	6.32	7.06	<0.010	<0.010
23	0.35	0.98	0.019	0.032	5.18	5.46	0.37	1.93	1.81	2.36	2.33	2.52	0.043	0.129	5.99	6.88	0.009	0.009
24	0.32	0.59	0.022	0.030	6.23	6.02	0.46	1.11	0.83	1.06	2.83	2.78	0.056	0.086	6.78	7.27	0.012	0.013
25	--	0.57	--	0.030	--	6.31	--	0.98	--	2.53	--	2.88	--	0.071	--	7.69	--	0.040
Avg.	0.35	0.54	0.022	0.028	5.97	5.82	0.48	1.14	2.02	2.12	2.71	2.71	0.042	0.080	7.08	7.69	0.011	0.013

Elements

d:/rbh90/elmconc.wk3

BARNHILL LANDING WATER QUALITY AVERAGES (MG/L UNLESS SPECIFIED)

Week No.	No. Obs.	Alk.	pH	Turb. NTU	Color APHA	BOD5	TSS	VSS	TKN	NH3N	NO3N	TPO4P	OPO4P	SO4	TOC	SOC
17	7	27	7.5	10	22	1.2	8.5	1.2	0.34	0.05	0.27	0.19	0.07	18.6	5	4
18	5	26	7.5	9	38	1.2	9.4	2.0	0.42	0.94	0.24	0.17	0.10	16.8	11	10
19	1*	29	7.5	8	42	1.2	6.0	2.2	0.26	0.01	0.21	0.10	0.07	17.4	23	12
20	7	26	7.4	8	16	1.1	9.5	2.2	0.44	0.06	0.22	0.08	0.04	17.6	5	5
21	7	26	7.3	9	16	1.0	9.2	1.9	0.42	0.02	0.23	0.16	0.07	16.2	4	4
22	1*	23	7.4	15	18	0.6	9.5	1.6	0.18	0.02	(1.57)	0.13	0.08	21.2	6	7
23	6	26	7.4	8	11	1.2	8.6	1.6	0.31	0.01	0.17	0.04	0.03	23.1	3	4
24	6	27	7.3	8	11	0.7	9.8	1.8	0.34	0.03	0.17	0.04	0.03	17.0	7	4
Avg.		26	7.4	9	22	1.0	8.8	1.8	0.34	0.03	0.22	0.11	0.06	18.5	8	6

* time composite/sample

1990 MIDDLE RIVER (STATION 6) WATER QUALITY AVERAGES (MG/L UNLESS SPECIFIED)

Week No.	No. Obs.	Alk.	pH	Turb. NTU	Color APHA	BOD5	TSS	VSS	TKN	NH3N	NO3N	TPO4P	OPO4P	SO4	TOC	SOC
17	1*	30	7.3	10	38	1.3	9.3	1.6	0.33	0.07	0.14	0.24	0.03	19.5	6	8
18	1	28	7.3	18	60	2.5	16.0	2.9	0.64	0.02	0.22	0.21	0.11	24.8	15	10
19	1	29	7.3	22	90	---	18.5	3.2	0.45	0.10	0.27	0.22	0.06	29.2	15	20
20	1	30	7.2	24	26	1.3	24.5	3.7	0.57	0.06	(1.19)	0.16	0.10	30.1	5	5
21	1	27	7.3	14	43	1.1	12.8	2.1	0.75	0.05	0.26	0.15	0.08	26.9	4	5
22	1	23	7.3	26	41	1.0	21.7	2.5	0.61	0.07	0.27	0.20	0.06	24.8	6	5
23	1	28	7.4	46	31	1.4	65.8	9.0	0.46	0.04	0.15	0.10	0.07	27.4	8	5
24	1	27	7.0	21	25	0.4	23.1	3.1	0.35	0.08	0.16	0.06	0.03	29.7	6	6
25	1	26	7.0	15	47	1.2	13.6	2.2	0.18	0.06	0.14	0.05	0.04	28.3	3	3
Avg.		28	7.2	22	45	1.3	22.7	3.4	0.48	0.06	0.20	0.15	0.06	26.7	8	7

* depth composited sample

PLYMOUTH (STATION 7) WATER QUALITY AVERAGES (MG/L UNLESS SPECIFIED)

Week No.	No. Obs.	Alk.	pH	Turb. NTU	Color APHA	BOD5	TSS	VSS	TKN	NH3N	NO3N	TPO4P	OPO4P	SO4	TOC	SOC
17	1*	29	7.2	10	42	1.5	9.3	1.1	0.31	0.04	0.14	0.15	0.02	20.2	8	7
18	3	29	7.3	15	106	1.1	12.3	2.5	0.53	0.13	0.22	0.26	0.14	16.0	13	13
19	1*	26	7.2	26	91	---	24.2	3.3	0.59	0.08	0.25	0.15	0.12	29.7	16	11
20	1*	25	7.3	21	26	1.1	21.2	3.2	0.26	0.04	0.21	0.16	0.09	31.8	5	4
21	1*	31	7.2	13	33	1.0	10.6	0.8	0.25	0.05	0.20	0.14	0.08	26.0	5	4
22	1*	23	7.3	23	35	0.7	17.1	2.4	0.46	0.07	0.17	0.16	0.11	29.5	6	5
23	1*	25	7.3	21	31	1.3	25.3	3.3	0.54	0.05	0.17	0.08	0.05	23.8	6	6
24	1*	28	7.0	23	22	1.0	25.7	3.1	0.35	0.05	0.17	0.07	0.04	29.9	14	4
25	3	27	7.0	17	49	1.3	17.8	3.1	0.28	0.06	0.15	0.06	0.05	28.5	3	3
Avg.		27	7.2	19	48	1.1	18.2	2.5	0.40	0.06	0.19	0.14	0.08	25.8	8	6

* depth composite sample

CASHIE RIVER (STATION 8) WATER QUALITY AVERAGES (MG/L, UNLESS SPECIFIED)

Week No.	No. Obs.	Alk.	pH	Turb. NTU	Color APHA	BOD5	TSS	VSS	TKN	NH3N	NO3N	TPO4P	OPO4P	SO4	TOC	SOC
17	1*	26	7.3	7	39	1.70	4.9	0.9	(0.64)	0.04	0.42	0.12	0.05	15.7	12	17
18	1*	27	7.2	9	80	0.95	4.7	0.9	0.44	0.17	0.19	0.15	0.11	13.8	11	9
19	1*	25	7.2	13	136	---	10.9	2.5	0.22	0.11	0.18	0.56	0.06	13.2	15	19
20	1*	26	7.3	11	45	1.05	8.8	2.1	0.48	0.04	0.18	0.09	0.06	14.7	11	7
21	1*	28	7.3	12	36	1.05	7.6	1.5	0.40	0.06	0.43	0.13	0.09	27.2	5	5
22	1*	25	7.2	13	60	0.75	9.6	1.6	0.50	0.08	0.20	0.17	0.12	15.4	9	8
23	1*	22	7.2	24	41	1.55	26.0	4.9	(1.56)	0.05	0.20	0.08	0.05	16.9	7	7
24	1*	26	7.0	13	27	0.80	9.4	1.8	0.18	0.05	0.16	0.06	0.04	23.0	5	5
25	1*	25	7.1	10	54	1.45	7.4	2.1	0.46	0.04	0.15	0.05	0.04	21.3	5	7
Avg.		26	7.2	12	58	1.20	9.9	2.0	0.42	0.07	0.23	0.16	0.07	17.9	9	9

* depth composited sample

HIGHWAY 45 (STATION 10) WATER QUALITY AVERAGES (MG/1 UNLESS SPECIFIED)

Week No.	No. Obs.	Alk.	pH	Turb. NTU	Color APHA	BOD5	TSS	VSS	TKN	NH3N	NO3N	TPO4P	OPO4P	SO4	TOC	SOC
17	1*	28	7.4	11	46	1.5	10.5	2.5	0.58	0.13	(1.19)	0.20	0.03	21.6	6	11
18	3	27	7.2	18	89	1.9	14.7	2.7	0.83	0.24	(0.23)	0.20	0.15	34.0	12	15
19	1*	29	7.2	22	118	---	18.4	1.9	0.33	0.22	0.28	0.14	0.12	33.6	16	18
20	1*	29	7.3	15	38	1.7	11.8	2.9	(1.07)	0.16	(1.56)	0.11	0.06	36.2	7	6
21	1*	31	7.2	15	45	1.9	12.5	2.3	0.83	0.12	0.22	0.14	0.08	31.7	---	7
22	1*	25	7.3	20	45	0.9	13.2	2.2	0.79	0.10	0.29	0.21	0.11	17.6	7	6
23	1*	26	7.2	33	46	1.0	40.0	5.3	0.69	0.09	0.18	0.10	0.06	31.0	9	8
24	1*	27	7.0	20	28	1.2	23.7	3.6	0.52	0.12	0.18	0.07	0.04	35.9	6	5
25	3	26	7.0	17	53	1.4	16.0	2.9	0.53	0.05	0.15	0.08	0.05	31.6	5	6
Avg.		28	7.2	19	56	1.4	17.9	2.9	0.64	0.14	0.22	0.14	0.08	30.4	9	9

* depth composite sample

APPENDIX C.

Pertinent Correspondence of the Roanoke River Water Flow Committee.

PERTINENT CORRESPONDENCE

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Southeast Fisheries Center
Beaufort Laboratory
Beaufort, N.C. 28516-9722

March 9, 1990

Mr. Charles R. Fullwood
Executive Director
N.C. Wildlife Resources Commission
512 N. Salisbury St.
Raleigh, N.C. 27611

Dear Charles,

As you are aware the Roanoke River Water Flow Committee has been evaluating water flows in the Roanoke River and the impact of a revised spring 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 Colonel Paul Woodbury, US Army Corps of Engineers, Wilmington District, of the Committee's recommendations and your support of them in your letter dated February 21. At its meeting in Greenville, NC yesterday, the Committee agreed 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 boundaries, expected ("target") flows, and allowable hourly variation in flows. This information is covered in the attached materials. We also ask that the Commission stress the importance of the expected flows. The Corps should attempt not only to stay within the upper and lower boundaries, but also meet the expected rates when possible.

I understand that there has been a change of command in the Corps Wilmington District. Lt. Colonel Thomas C. Suermann has replaced Colonel Woodbury. Also, members of the Flow Committee asked that Fred Harris, Mike Gantt (U.S. Fish and Wildlife Service), John Norris (N.C. Div. Water Resources), and George McCabe (Virginia Power Co.) be included on your list of names to receive copies.

The Committee appreciates the service provided by you and members of your staff as we strive together to manage the natural resources in the lower Roanoke River Basin.

Sincerely,

Charles S. Manooch, III
Co-Chairman
Roanoke River Water Flow
Committee

Enclosures
As Stated

cc: 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 27611, 919-733-3391
Charles R. Fullwood, Executive Director

March 20, 1990

Lt. Colonel Thomas C. Suermann
U.S. Army Corps of Engineers
P. O. Box 1890
Wilmington, NC 28401

Dear Colonel Suermann:

Last year 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 established last year be continued this year with the inclusion of target flows and allowable hourly variations in flows. Our recommended flow regime for 1990 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

CRF/lr

cc: Mike Gantt, U.S. Fish & 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

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Southeast Fisheries Center
Beaufort Laboratory
Beaufort, N.C. 28516-9722

April 26, 1990

Mr. Max Grimes
U.S. Army Corps of Engineers
Wilmington District
P.O. Box 1890
Wilmington, NC 28402-1890

Dear Max,

Roger Rulifson telephoned me yesterday to inform me that striped bass had started to spawn on the Roanoke River. This was good news and reflects the Corps and Virginia Power Company efforts to provide the target (or expected) water flows during this time of the year as recommended by the Roanoke River Water Flow Committee, and expressed by Mr. Charles Fullwood in his letter to Lt. Colonel Thomas Suermann on March 20, 1990.

It was not surprising to note that initial spawning occurred soon after the water flow rate was decreased from approximately 20,000 cfs to 7,900 between April 20-21. The latter flow rate is very close to the target flow, and underscores the importance of favorable water flow and water temperature on the spawning behavior of striped bass. If these water conditions are maintained, they should prove conducive not only to spawning, but also the survival of eggs and larvae as they are transported downstream.

I believe that we should all be encouraged by the fact that the resource will respond in a positive manner when we work together. We appreciate the efforts of the Corps of Engineers and Virginia Power Company in obtaining this goal.

Sincerely,

Charles S. Manooch, III
Co-Chairman
Roanoke River Water Flow Committee

cc: George McCabe, Virginia Power Co.
Roger Rulifson, East Carolina University

DEPARTMENT OF THE ARMY
WILMINGTON DISTRICT, CORPS OF ENGINEERS
P.O. BOX 1890
WILMINGTON, NORTH CAROLINA 28402-1890

IN REPLY REFER TO April 30, 1990

Dr. Charles S. Manooch, III
U.S. Department of Commerce, NOAA
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, North Carolina 28516

Dear Chuck:

I appreciate your concerns for flow conditions in the lower Roanoke River as expressed in your letter of April 15, 1990. Let me try to ease your concerns by presenting another side of the issue as follows.

We also watched, with anticipation and concern, the storm system in mid-March that produced heavy rainfall and subsequent major flooding in Alabama and Georgia. However, anticipated precipitation forecasts from the National Weather Service predicted only one to two inches of rainfall would occur over the Roanoke River Basin from the same weather system. In actuality, the majority of the rainfall occurred on Saturday night, March 17, when an average rainfall of 1.2 inches fell. The reservoir level adjusted for power storage at John H. Kerr was below the bottom of the flood control pool elevation of 300 feet m.s.l. before this storm system came through.

You suggested in your letter that the releases into the lower Roanoke River were too low by citing hourly minimums of 1,210, 1,190, 1,180, and 1,260 c.f.s. for March 15-18. If you had cited the hourly maximums for the same period, March 15-18, you would have found them to be 16,450, 8,200, 16,160, and 18,300 c.f.s. which presents a different picture. The daily flow during those 4 days averaged over 4,200 c.f.s. I have a feeling that you are using hindsight to its fullest extent. Remember the adage, "Hindsight is 20/20, but foresight is blind". Granted the outflows on those 4 days could have been higher, but two of those days were weekend days when power demand is at its lowest.

We do not predraw reservoirs in anticipation of forecasted rainfall. Experience has taught us that reservoir operation based upon a rainfall forecast is highly subjective to error and reservoir storage may be lost if the rainfall does not materialize as forecasted. Furthermore, while we may be in a wet period at a given time, the trend could take a complete turnaround to a dry period as history has proven. The 1980's had some complete turnarounds from dry to wet and vice versa.

Your expressed belief that the Wilmington District operates John H. Kerr Reservoir project with the "underlying fear that insufficient waters will be available for striped bass spawning for the full 76-day period each spring" would be a true statement if the words "each spring" were replaced with "during dry periods". In March, no one knows whether or not the 76-day period will be wet or dry. The question needs to be answered as to whether too much water or too little water is better for fish spawning. Even assuming a perfect reservoir operation, the number of 20,000-c.f.s. flow days would have been reduced only 2 days from 27 days to 25 days during March and April of this year. These 2 days are equivalent to over 9 days of fish-flow days in mid-May.

In your letter, you contradict yourself by the statement on page one, "watershed rainfall accumulation was about normal for the year" while page two of your letter states, "during normal-wet years." Both statements reference rainfall occurring so far this year.

I trust that during future flow committee meetings, we can all come to a better understanding of reservoir operations, needs, and solutions for the betterment of all interests.

Sincerely,

Max B. Grimes

Max B. Grimes
U.S. Army Corps of Engineers
Member, Roanoke River Flow
Committee

Copies Furnished:

Mr. Richard Hamilton
N.C. Wildlife Resources Commission
Post Office Box 2919
Raleigh, North Carolina 27602

✓Dr. Roger Rulifson
Institute For Coastal and Marine Resources
East Carolina University
Greenville, North Carolina 27858-4353

Mr. George McCabe
Virginia Power Company
Post Office Box 26666
Richmond, Virginia 23261

1

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Southeast Fisheries Center
Beaufort Laboratory
Beaufort, N.C. 28516-9722

May 9, 1990

MEMORANDUM FOR: Roanoke River Water Flow Committee and Interested Parties

FROM: Charles S. Manooch, III
Committee Co-Chairman

SUBJECT: Committee Report

Please find enclosed a copy of "Roanoke River Water Flow Committee Report for 1988 and 1989", NOAA Technical Memorandum, NMFS-SEFC - 256. You will note that this document has an Errata sheet placed before page 36, and a Clarification Statement before page 19. Contents of these two pages will be incorporated into the text for all subsequent printings of the document.

Enclosure
As Stated

EAST CAROLINA UNIVERSITY

GREENVILLE, NORTH CAROLINA 27858-4353

INSTITUTE FOR COASTAL
AND MARINE RESOURCES

(919) 757-6779

June 18, 1990

MEMORANDUM TO: Roanoke River Water Flow Committee members

FROM: R.A. Rulifson RAR and C.S. Manooch, III

SUBJECT: Suggested revisions in Committee membership

At our last meeting in March 1990, we were directed by the Committee to solicit individuals or agencies for Committee membership that would provide expertise in additional areas such as forestry, floodplain ecology, and above-dam parks and recreation.

As we reviewed our current list of members, it became obvious that we could use additional expertise in areas of water quality and floodplain geology. If these positions are filled, we are concerned that the Committee will become too large, which in turn may affect the efficiency and timeliness in fulfilling the Committee's purpose and objectives unless some present members are excused from the Committee.

Enclosed is a list of current Committee members and proposed new areas of expertise. Please review this list. We ask your approval of these five new areas of expertise, and the individuals listed that have indicated their willingness to actively participate in Committee business. Also, several current members have mentioned feeling overcommitted and have not been able to participate as expected. If you feel that you fit into this category and would like to excuse yourself from Committee participation, please let us know as soon as possible.

We would like to have a Committee meeting in September to discuss river flow conditions, water quality, spawning success of striped bass, etc. in 1990. It would be helpful if you could compile information on your particular expertise prior to the meeting. Please consider possible dates. The first week or last week in September look promising at the moment.

On another matter, the first Committee report is in its fourth printing, and the second Committee report will soon go for a second printing. If you have identified significant errors in the second report, please bring it to our attention soon so that we can incorporate the changes in the next printing.

RRWFC MEMBERS, POTENTIAL MEMBERS, AND EXPERTISE

As of 6/90

National Marine Fisheries Service:

Charles S. Manooch, III - striped bass biology
Larry Hardy - NMFS habitat assessment leader

U.S. Fish and Wildlife Service:

Willard Cole - Coordinator of State anadromous fish management plan
L.K. Mike Gantt - regional office supervisor
R. Wilson Laney - fishery biologist

U.S. Army Corps of Engineers:

Max Grimes - Kerr Reservoir operation, watershed management

Virginia Power Co.:

George McCabe - Daily operations at Gaston and Roanoke Rapids dams

N.C. Wildlife Resources Commission:

Fred Harris - Chief, Inland Fisheries
Pete Kornegay - striped bass biologist, district biologist
Kent Nelson - regional research coordinator; striped bass biologist

N.C. Division of Marine Fisheries:

Bill Hogarth - Director; striped bass biologist
Harrel Johnson - regional supervisor; striped bass biologist
Sara Winslow - striped bass biologist
Lynn Henry - striped bass biologist
Bob Monroe - statistical consultant

N.C. Division of Water Resources:

Tom Fransen - hydrologist

N.C. Department of Agriculture:

Tom Ellis - liason for environmental affairs

East Carolina University:

Roger Rulifson - striped bass biologist
Buddy Zincone - forecast modeling
Marsha Shepherd - statistical and computer consultant

Independents:

Bill Hassler - striped bass biologist
T.L. Quay - floodplain ecology

Proposed areas of expertise and candidates:

Water Quality - N.C. Division of Environmental Managment

Forestry -

Above-Dam Parks and Recreation -

Frank Boteler. Chief, Planning and Assessment

Floodplain Ecology -

Merrill Lynch (N.C. Nature Conservancy, see the original report for prior contributions)

Geologist -

Stan Riggs, East Carolina University

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, N.C. 28516-9722

September 7, 1990

MEMORANDUM FOR: Roanoke River Water Flow Committee

FROM: Charles S. Manooch, III and Roger A. Rulifson, Co-Chairmen

SUBJECT: Committee Meeting

The Committee will meet at 10:00 a.m. on Thursday, October 4, 1990 at the East Carolina University, Institute for Coastal and Marine Resources, Greenville, NC. We should adjourn before 5:00 p.m. on the 4th.

The objectives of the meeting are to review water flow conditions and results of field studies during 1990, discuss new initiatives, and to make assignments for our next report, which should be printed in the spring of 1991. Please come prepared to discuss these topics. Several new members have joined the Committee and we hope they will be able to meet with us in Greenville.

An agenda may be developed over the next couple of weeks. If so, you will receive a copy prior to the meeting. A map of the campus is enclosed for your convenience.

Enclosure
As Stated

File

ROANOKE RIVER WATER FLOW COMMITTEE MEETING

East Carolina University, ICMR, Greenville, NC

October 4, 1990 - 10:00 am

AGENDA

Welcome

Recognition of New Members and Guests

Summary Statement of Committee Purpose and Direction

1990 Conditions and Studies:

- Publications and Meetings
- Water Flow Conditions
- Water Quality
- Fisheries
- Striped Bass Eggs
- Striped Bass Larvae
- Striped Bass JAI
- Wildlife Resources and Habitats
- Agriculture
- Forest Resources
- Other

New Topics and Initiatives:

- Time Series Modeling of Flows for All Seasons
- Other

Report:

- Format
- New Emphasis
  - (more forest, agriculture, wildlife, other fish species)
- Assignments and Deadlines
- Proper Response to Previous Reports

Old Business

New Business .

Adjourn

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, N.C. 28516-9722

November 9, 1990

MEMORANDUM FOR: Roanoke River Water Flow Committee

FROM: C. S. Manooch, III and R. A. Rulifson

SUBJECT: 1990 Flow Committee Report Assignments

At our meeting on 4 October 1990 at ECU in Greenville, assignments were made for our 1990 report. This memo is to bring everyone up to date on progress of the report, and to serve as a reminder for assignments.

We (Manooch and Rulifson) will again serve as editors for the 1990 report. As agreed upon by the Committee, each section of the report will bear the names of the individual authors. Enclosed is an updated version of the outline and the authors responsible for each section.

Deadline for submission of your rough draft is 1 January 1991. However, we would greatly appreciate receiving materials earlier. Please submit materials on floppy disk if possible, as well as a hard copy to RULIFSON, ICMR, EAST CAROLINA UNIVERSITY, GREENVILLE, NC 27858. Your section will be edited and incorporated into a rough draft of the report, which will be circulated prior to our next meeting in February or March.

Enclosure
As Stated

State of North Carolina
Department of Agriculture
Raleigh

JAMES A. GRAHAM
COMMISSIONER

November 29, 1990

Mrs. Harry Wilfong
North Carolina Wildlife Federation
Post Office Box 10626
Raleigh, North Carolina 27605

Dear Mrs. Wilfong:

I would like to take this opportunity to recommend the Roanoke River Water Flows Committee for consideration in the North Carolina Wildlife Federation Awards Program.

This multiagency effort has been an outstanding example of cooperation and concern about the natural resources, productive lands and citizenry of the Roanoke River Valley. Our state can be proud of the dedication of the committee members who have pulled this work together without worrying about budgetary constraints. The concern for farmland protection from flooding was as important to the considerations as were striped bass spawning and turkey nesting. Recognition of this effort would be in the best interest of furthering cooperative approaches to complex resource issues by our agencies.

Thank you for your consideration.

With all good wishes.

Cordially,

Jim Graham

James A. Graham
Commissioner

JAG:mk

bcc: ✓Dr. Charles Manooch, III

EARTH DAY EVERY DAY™

NORTH CAROLINA WILDLIFE FEDERATION

P.O. Box 10626
RALEIGH, NORTH CAROLINA 27605-0626
(919) 833-1923

January 3, 1991

Dr. Roger A. Rulifson
Roanoke River Water Flow Committee
East Carolina University
Institute for Coastal & Marine Resources
Greenville, N.C. 27858

Dear Dr. Rulifson:

The North Carolina Wildlife Federation congratulates the Roanoke River Water Flow Committee on being chosen to receive the Water Conservationist of the Year award in our 1990 Governor's Conservation Achievement Awards Program.

This prestigious award, sponsored by the North Carolina Wildlife Federation, National Wildlife Federation and Sears, will be presented at our twenty-ninth Annual Governor's Award Banquet at 6:30 p.m. on Saturday, February 2, 1991 at the Sheraton Imperial Convention Center just off I-40 at Page Road in Research Triangle Park.

We hope that you and a companion can attend this banquet as our guests to receive an engraved statuette signifying your organization's accomplishments.

Please use the enclosed form and envelope to let us know if you'll be able to attend in person, and if you'll be bringing a companion.

Best wishes and, again, congratulations on winning this important award.

Sincerely,

M F Corcoran

Michael F. Corcoran
Executive Vice President

MFC/ad
enclosure

cc: Lynn T. Henry
Charles S. Manooch
William H. Queen
James A. Graham

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, N.C. 28516-9722

January 25, 1991

Dr. Roger A. Rulifson
Institute of Coastal & Marine Resources
East Carolina University
Greenville, NC 27858

Dear Dr. Rulifson:

I am pleased to announce that the Roanoke River Water Flow Committee has been selected to receive the prestigious Governor's Award for Water Conservationist of the Year for 1990. You should feel proud to be a member of this Committee and know that your role has contributed to this recent official recognition. Roger Rulifson, Co-Chairman of the Committee, will go to Raleigh on February 2 to receive the award from Governor Martin on behalf of the Committee. If you would like to attend the ceremony, please call Roger (919-757-6220) for specific information.

Materials for our 1990 report are being received, edited and collated. We would like to have the report printed this spring (probably April). Before that time you will receive a draft copy to review and will be invited to attend a meeting to discuss the report and conditions and initiatives for 1991.

Some members who have promised to submit materials for our 1990 report have not yet done so. If you are one of these please fulfill your obligation as soon as possible. We would like to distribute the draft by mid-February. An outline of the report with assignments is enclosed for your information.

Sincerely,

Charles S. Manooch, III
Co-Chairman Roanoke River
Water Flow Committee

Enclosures
As Stated

EAST
CAROLINA
UNIVERSITY

Institute for Coastal and Marine Resources
Mamie Jenkins Building

919-757-6779

12 April 1991

Mr. Max Grimes
U.S. Army Corps of Engineers
Wilmington District
P.O. Box 1890
Wilmington, NC 28402-1890

Dear Max:

The purpose of this letter is to request from your office the best predictions on the water release schedule from Kerr Reservoir for the remainder of April and all of May. This request is made to you as a member of the Roanoke River Water Flow Committee (RRWFC), and manager of the Roanoke River water resource. As we prepare for our 1991 spring field season on the Roanoke River, I have been keeping daily track of the Kerr Reservoir elevation, and have been dismayed by the fact that Kerr was over 307 feet for several days. The lower Roanoke River has been full and raging since 1 April, presumably with a discharge at Roanoke Rapids Dam of 20,000 cfs or slightly more, with no relief in sight.

Results of our egg studies clearly show that reservoir discharge influences river temperature, which in turn controls spawning activity. Yesterday (11 April), I took my two egg study field crews to Scotland Neck for orientation in field procedures, and we caught one striped bass egg on our first sample. We have received reports for some time that fishermen at Weldon have been catching striped bass; enforcement officers noted that a group of striped bass were just above the Scotland Neck bridge last week. Water temperatures were 16°C at Scotland Neck, and were 18-19°C downstream at Plymouth two nights ago.

These high and stable flows of warmer water will set the stage for early, possibly major, spawning activity. Therefore, any drastic or sudden changes to the lower Roanoke River instream flow could substantially influence pattern, and success, of the 1991 spring spawning season.

In addition to your best predictions for April and May, I also request that I be kept informed of any changes in reservoir releases for the safety of my field crews downstream. Thank you.

Sincerely,

Roger A. Rulifson

Roger A. Rulifson
Associate Scientist - ICMR
Co-Chair - RRWFC

cc: Dr. C.S. Manooch, III, Co-chair RRWFC
Mr. Charles Fullwood, Director NCWRC
Mr. Fred Harris, Chief of Inland Fisheries, NCWRC
Dr. William T. Hogarth, Director, NCDMF
Mr. John Brown, Chair, N.C. Striped Bass Study Mgmt. Board
Mr. George McCabe, Virginia Power Company

Greenville,
North Carolina
27858-4353

DEPARTMENT OF THE ARMY
WILMINGTON DISTRICT, CORPS OF ENGINEERS
P.O. BOX 1890
WILMINGTON, NORTH CAROLINA 28402-1890

April 24, 1991

IN REPLY REFER TO

Reservoir Regulation Section

Dr. Roger A. Rulifson
Institute for Coastal and Marine Resources
Mamie Jenkins Building
East Carolina State University
Greenville, North Carolina 27858-4353

Dear Roger:

In response to your letter of April 12, 1991, enclosed are plots showing predicted water levels in John H. Kerr Reservoir and flows in the Roanoke River at the Roanoke Rapids stream gage for April 1 to June 15, 1991. Fish flows should be available for the remainder of the fish flow season even if no precipitation were to occur for the remainder of the striped bass spawning season.

Rainfall was about 90 percent above normal during the month of March with resulting inflows to Kerr dam being 50 percent above normal. The weather patterns responsible for these above-average inflow amounts continued into April and have made it difficult to conform to the fish flow regime.

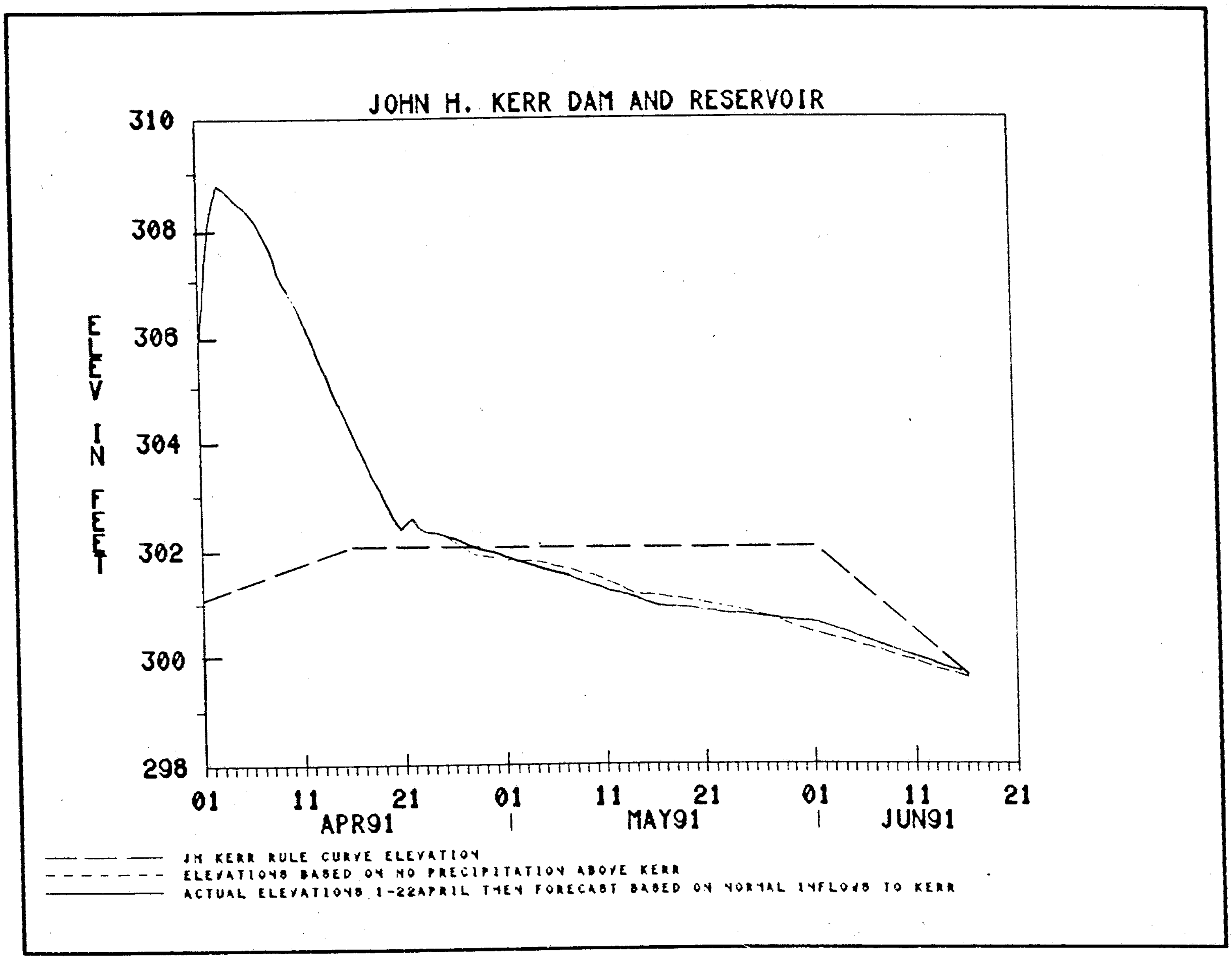
I apologize for the delay in getting back to you, but rainfall kept changing our operating schedule. Per your request, I have instructed my staff to inform you of any major changes in the outflows from the Roanoke Rapids project.

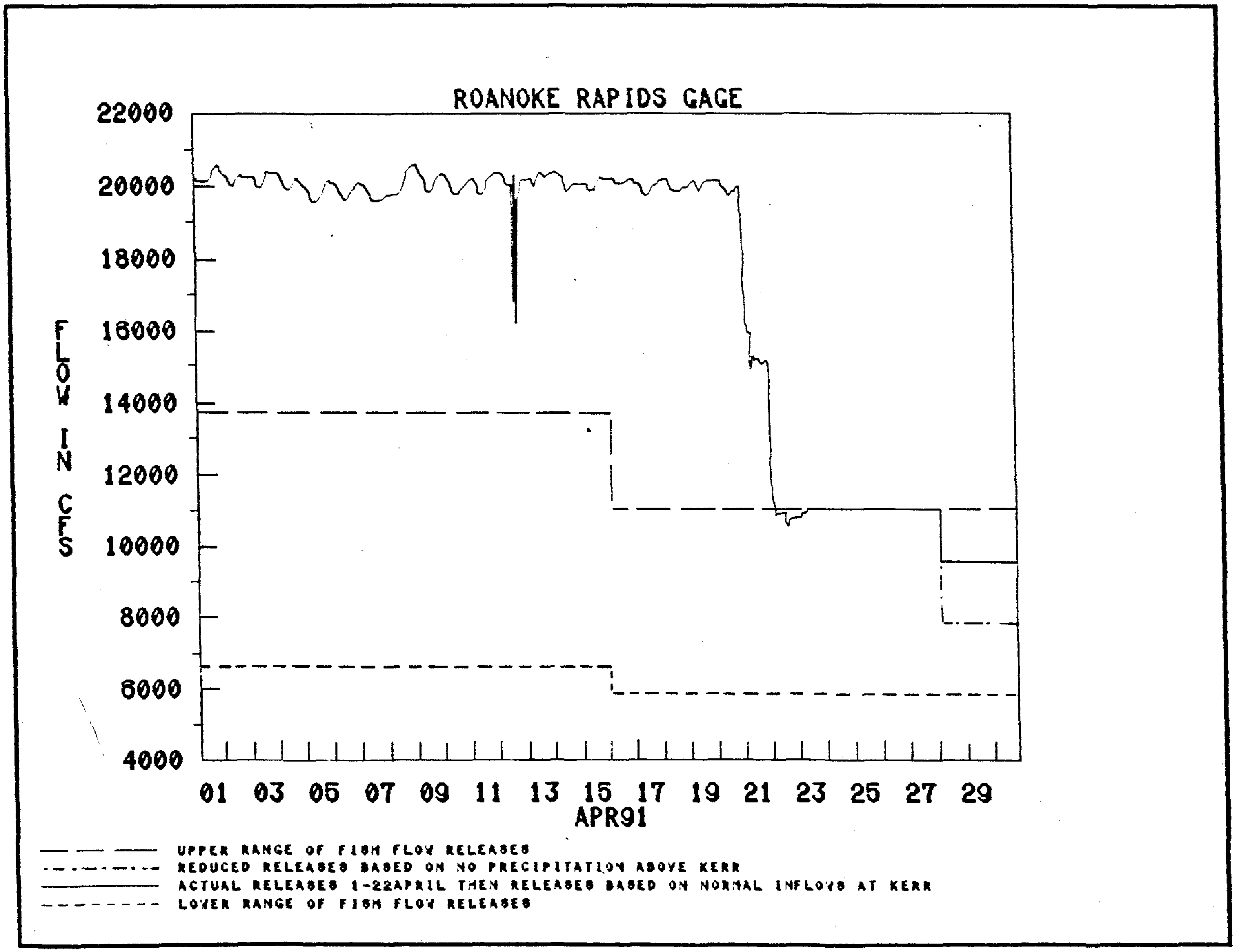
Sincerely,

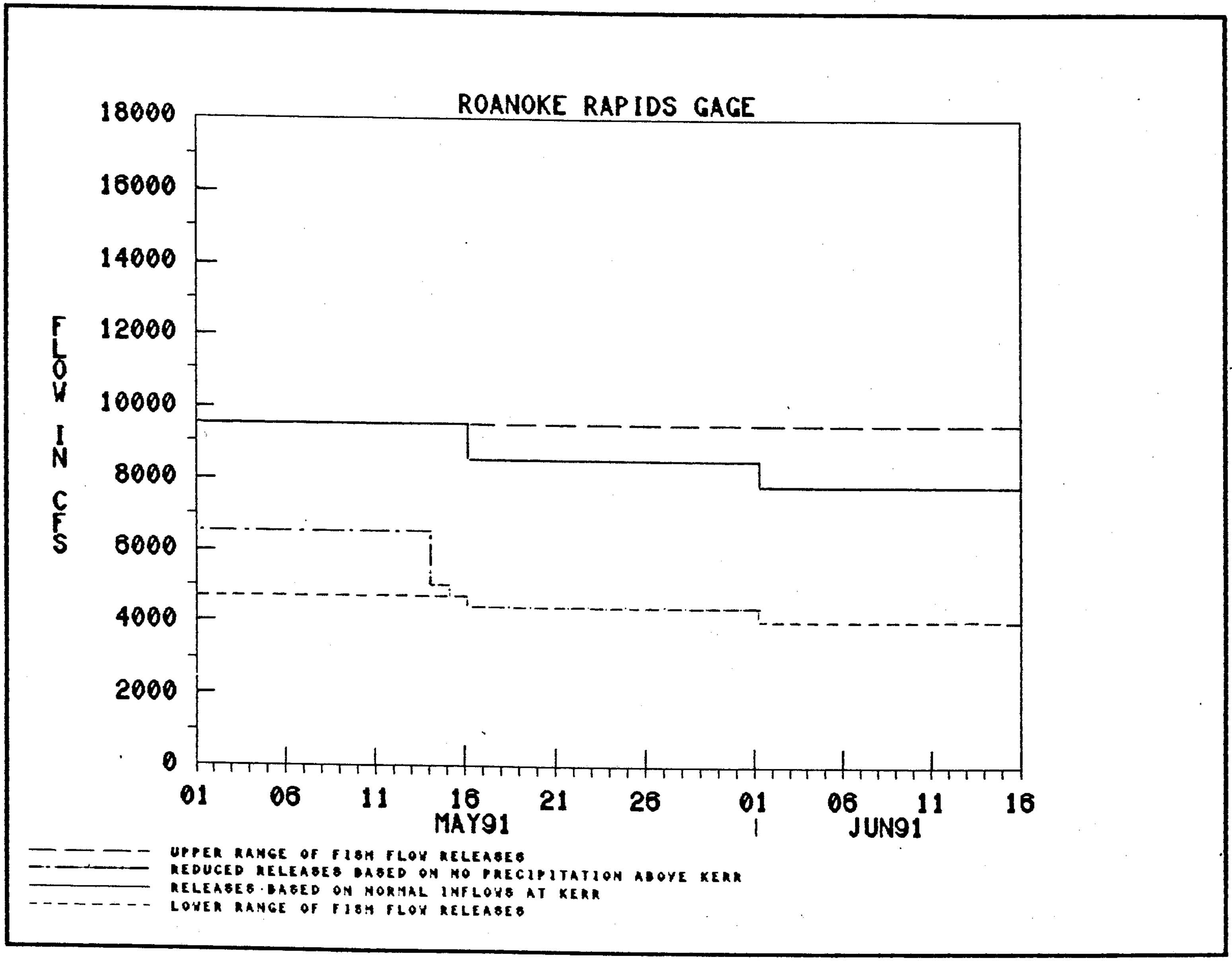
Max B. Grimes

Max B. Grimes, Chief
Hydrology & Hydraulics Branch

Enclosures


JOHN H. KERR DAM AND RESERVOIR
ELEV IN FEET
310
308
306
304
302
300
298
01
11
21
APR91
01
11
21
MAY91
01
11
21
JUN91
JH KERR RULE CURVE ELEVATION
ELEVATIONS BASED ON NO PRECIPITATION ABOVE KERR
ACTUAL ELEVATIONS 1-22APRIL THEN FORECAST BASED ON NORMAL INFLOWS TO KERR


ROANOKE RAPIDS GAGE
FLOW IN CFS
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
01 03 05 07 09 11 13 15 17 19 21 23 25 27 29
APR91
UPPER RANGE OF FISH FLOW RELEASES
REDUCED RELEASES BASED ON NO PRECIPITATION ABOVE KERR
ACTUAL RELEASES 1-22APRIL THEN RELEASES BASED ON NORMAL INFLOWS AT KERR
LOWER RANGE OF FISH FLOW RELEASES


ROANOKE RAPIDS GAGE
FLOW IN CFS
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
01
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11
16
21
26
01
06
11
16
MAY91
JUN91
UPPER RANGE OF FISH FLOW RELEASES
REDUCED RELEASES BASED ON NO PRECIPITATION ABOVE KERR
RELEASES BASED ON NORMAL INFLOWS AT KERR
LOWER RANGE OF FISH FLOW RELEASES

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Fisheries Science Center
Beaufort Laboratory
Beaufort, N.C. 28516-9722

May 3, 1991

MEMORANDUM FOR: Roanoke River Water Flow Committee

FROM: Charles S. Manooch, III and Roger A. Rulifson, Co-Chairmen

SUBJECT: Draft Copy of Committee's Report for 1990

Enclosed please find a very rough draft copy of subject report. We would like to give you several assignments pertaining to this draft. First, read the report in its entirety and note any errors. Second, concentrate on your, or your agency's section(s), read it very carefully , and make corrections as needed. Third, if you have written a section(s), please provide us a brief (three-five sentences) summary. You may do this by simply underlining pertinent sentences, or by rewriting. We will use these to draft an Executive Summary. Please make your comments directly on the draft and return them to Roger Rulifson, ECU, ICMR, Greenville, NC 27858-4353 by May 20.

After we have received your comments and have made corrections, we will schedule a Committee meeting. The meeting will probably be held in Beaufort in early June. We will try to send you a revised copy including the appendices before the meeting.

Enclosure
As Stated

City of Virginia Beach

PUBLIC UTILITIES DEPARTMENT
WATER RESOURCES DIVISION
(804) 427-8035

MUNICIPAL CENTER
VIRGINIA BEACH, VIRGINIA 23456-9002

May 9, 1991

Dr. Roger A. Rulifson
Charles S. Manooch
Editors
Roanoke River Flow Committee

Gentlemen:

This letter transmits a number of documents and comments which address certain aspects of your 1989 and 1990 Flow Committee Reports.

With respect to the 1989 Flow Committee Report, three documents are enclosed:

1. "A Technical Response to the March 1989 Roanoke River Flow Committee Report" dated April 24, 1991 which I prepared. This report identifies serious factual, methodological, and scientific reasoning errors in the 1989 report. Please note that I provided a draft of this response to Dr. Rulifson and other members of the Flow Committee and provided a detailed presentation of the response at a January 24, 1991 meeting of the North Carolina Striped Bass Study Management Board. At that time, I solicited any input, facts, or evidence which anyone wished to share with me, before finalizing the response. No one responded and Dr.
1. Rulifson advised Ms. Rita Sweet, of my staff, that no response would be forthcoming.

The response to the 1989 Flow Committee Report deals mostly with the factual, methodological, and scientific process errors which were made by the Flow Committee. With some exceptions which are noted in the response, I did not recreate the Flow Committee's analyses to check the validity of the individual calculations or the data presented. In other words, I assumed what that was <u>claimed</u> to have been done is what was <u>actually</u> done. However, subsequent to the printing of the Technical Response to the 1989 Flow Committee Report, I learned that my assumption was wrong. I have discovered that the data, calculations, and results of the
2. time series analysis, which is the entire basis for the

conclusion that pre-impoundment flows are similar to post-impoundment good JAI years, are seriously misrepresented in the report. (This discovery is in addition to the other serious flaws concerning the time series analysis described in my technical response).

Attached to this letter is a copy of Dr. Zincone's April 7, 1988 "Time Series Analysis of River Flow" in which he purports to establish that pre-impoundment flows "are similar" to a select group of post-impoundment good JAI years. A comparison of Dr. Zincone's memo with the time series analysis contained in the 1989 Flow Committee Report demonstrates that the graphs and models are number-for-number and point-for-point identical. Obviously Dr. Zincone's analysis is the same analysis which has been presented in the 1989 Flow Committee Report. The Flow Committee Report clearly states that Dr. Zincone's analysis of pre-impoundment flows is based on the 1912-1950 time period. However, Dr. Zincone's April 7, 1988 analysis predates, by almost three weeks, a memo from Dr. Manooch which indicates that data for the 1912-1929 period (which the Committee did not have until it was provided by Virginia Beach) was not loaded into your computers until sometime after April 25, 1988.

Although the Flow Committee did not have access to the 1912-1929 data at the time Dr. Zincone prepared his analysis, it did have the 1930-1950 data. This led me to speculate that the analysis of pre-impoundment flows in the Flow Committee Report was actually based on the 1930-1950 period instead of the 1912-1950
3. period. To test this theory, I have recreated Dr. Zincone's analysis of pre-impoundment flows and have proved conclusively that the time series analysis of pre-impoundment flows represented in the Flow Committee Report as being based on the <u>1912</u>-1950 period is actually based on the <u>1930</u>-1950 period. The hydrologic conditions for 1912-1950 were not the same as 1930-1950, therefore, the analysis cannot properly be used to substantiate a flow regime based on the 1912-1950 time frame.

The misrepresentation of the time periods is not the only error I discovered when I recreated Dr. Zincone's analysis. In his analysis of the 1930-1950 pre-impoundment data, Dr. Zincone states that "the average [was] taken after eliminating the top and bottom ten percent of the flows." Until I recreated his
4. analysis, I had assumed that what Dr. Zincone did was to eliminate the top and bottom ten percent of the observations from each daily set of flows being averaged. For example, to calculate a mean for March 1, the smallest 10% and largest 10% of all March 1 values would be disregarded and the mean would be calculated on all March 1 values <u>between</u> the 10th and 90th percentiles. This procedure would be performed individually on each daily set of flows (i.e., all March 1st's, all March 2nd's,

all March 3rd's . . .). This is referred to as a "trimmed mean"
5. and it is a valid statistical manipulation for eliminating extreme values.

However, I have discovered that what Dr. Zincone did was to trim the lowest 10% and highest 10% of flows from the entire, combined set of daily flows from January 1, 1930 through December 31, 1950 (7670 daily flows over the 21-year period). Because spring is a high flow period of the year, very few low flows and a great many high flows were eliminated from the March 1 through June 30 time period. Of the 2562 daily flows used in the analysis of pre-impoundment flows (21 years times 122 days; March 1-June 30 for the years 1930-1950), only 18 low flows were deleted (less than 1%) while 291 high flows were deleted (11%). Furthermore, the deletions were not evenly or equally distributed. The number of observations which were deleted from the individual daily data sets ranged from zero to 7 (out of a total of 21 observations per data set). As a result, the means used in Dr. Zincone's analysis of the 1930-1950 pre-impoundment data were, on the average, about 1000 cfs lower than if traditional 10% trimmed means had been calculated and about 2000 cfs lower than if means using all the data values had been calculated. Therefore, what Dr. Zincone did was to greatly bias the 1930-1950 pre-impoundment means towards low-to-moderate flows. There is no theoretical or logical justification for trimming the flows in such an arbitrary manner. In any event, the Committee concluded that the resulting pre-impoundment flow path model was similar to a select group of good JAI years. Since the data was heavily biased toward low-to-moderate flows, all that can actually be concluded from the time series analysis is that low-to-moderate flows are associated with the mean time path of some good JAI years.

Aside from the serious questions raised about the manner in which the time series analysis was prepared and presented, I am sure you both realize that the only analysis in the 1989 Flow Committee Report which purports to demonstrate that the 1912-1950 pre-impoundment flows were similar to flows during the selected post-impoundment good JAI years is the time series analysis. Obviously, no valid conclusions can be drawn concerning the 1912-1950 pre-impoundment period because it was not analyzed. Furthermore, since the 1930-1950 data was heavily biased toward low-to-moderate flows, the time series analysis cannot even be claimed to represent "pre-impoundment" conditions for the 1930-1950 period. Therefore, there is no basis for the recommended or negotiated regimes or the conclusions in the Flow Committee Report.

2. The second document enclosed is "Review of the 1989 and 1990 Roanoke River Water Flow Committee Reports" dated April 1991 and prepared by W. Richkus and P. Jacobson of Versar, Inc. This is a

more abbreviated critique of the 1989 and 1990 Flow Committee reports. Versar's conclusions also seriously question the objectivity and validity of the Flow Committee's analyses.

6. 3. Letter reports dated October 22 and 30, 1990 from Dr. John Boreman, Dr. Phillip Goodyear, and Dr. Edward Houde concerning flows in the Roanoke River, striped bass reproduction, fishing mortality, and the Lake Gaston project. This team of experts from <u>outside</u> North Carolina was assembled at the request of Dr. William W. Fox, Director of the National Marine Fisheries Service (NMFS), in response to complaints by Virginia Beach that comments with respect to the Lake Gaston project originating from <u>inside</u> North Carolina were not factually based. The following are direct quotes from the two letter reports:

> 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.
>
> . . . 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 poor survival conditions.
>
> 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.
>
> . . . the flow regimes in 1988 and 1989 contrasted greatly and it is not possible to attribute the modest recruitment levels to flow characteristics.
>
> In our opinion, it is unlikely that the [Virginia Beach] project will significantly affect the flow regime in the Roanoke system during the 76-day spawning period and thus will not be detrimental to spawning or early life survival of striped bass during that time.

Also included with the letter reports is a November 13, 1990 response from Dr. Rulifson to the letter reports and a March 29, 1991 response, which I prepared, addressing the letter reports and Dr. Rulifson's response. They are self-explanatory.

With specific reference to the 1990 report, I am unable to comprehend the Committee's continued insistence on claiming that flows in the 1988 spawning season were provided pursuant to the negotiated flow regime (1990 Flow Committee Report at 19). On at least three occasions, the Corps has informed you, in writing, that flows for the 1988 season were provided pursuant to the 1971
7. Memorandum of Understanding (MOU). Furthermore, the Corps specifically advised you that it would not implement the new flow regime until such time as it had conducted an environmental assessment (EA) of the consequences of such an action (1989 Flow Committee Report at 181). The Corps prepared an EA for a four year trial of the negotiated regime (1989-1992) in March 1989, long after the 1988 spawning season was concluded.

The Flow Committee Report states that at the April 12, 1988 Flow Committee meeting in Beaufort, N.C., the Corps and Virginia Power agreed to implement "flows in accordance with the flow guidelines under discussion at the time, but which had not been formally
8. adopted." (1990 Flow Committee Report at 207). However, as previously indicated, Dr. Manooch's April 25, 1988 memo to the Flow Committee makes it very clear that the 1912-1929 pre-impoundment data had not yet been entered into the computer and the 1912-1950 pre-impoundment flow regime had not yet been calculated. The record is also clear that the recommended flow regime was not presented or discussed with the Corps, Virginia Power, or anyone else until the May 3, 1988 Flow Committee meeting, several weeks after spawning augmentation flows had begun. The Corps and Virginia Power could not have agreed on April 12, 1988 to implement a flow regime which they had never seen and which had not yet been calculated.

The Flow Committee Report also cites a March 6, 1989 letter from Virginia Power as substantiation for the claim that flows in 1988 were provided pursuant to the new flow regime. That letter refers only to Virginia Power's attempt to limit hydropower (hourly) fluctuations during the 1988 season. It is not related to the daily quantity of flow which was released from Roanoke Rapids Dam. I believe that you are both aware that releases from the Roanoke Rapids Dam "are driven by releases at Kerr Reservoir" (1989 Flow Committee Report at 23). If releases at Kerr Dam (which are controlled by the Corps) during the 1988 spawning season were made pursuant to the 1971 MOU, then obviously, so were releases at Roanoke Rapids Dam. One needs only to look at the flow data for 1988 (1990 Flow Committee Report at 23) to see that the minimum flow during the augmentation period was a constant 6000 cfs, which is the minimum release required by the 1971 MOU.

I note that the Flow Committee issued a "clarification statement" stating that Mr. Max Grimes "belie[ves]" that flows for the 1988 season were made pursuant to the 1971 MOU. Mr. Grimes is the manager of the Hydraulics and Hydrology branch of the Wilmington District Corps of Engineers. As such, he is <u>directly</u> responsible for programing and ordering the releases from Kerr Reservoir. The following is a direct quote from an April 18, 1990 memo from Max Grimes to Dr. Rulifson:

> As I have stated many times at meetings, etc., the operation of reservoir projects in the 1988 fish season was conducted under the old flow regime. Flows for the new flow regime were not established until after the 1988 season was past.

Finally, I believe that this debate can be ended by a quote from a report which Dr. Rulifson wrote <u>following</u> the 1988 spawning season:

> At the <u>present time</u>, the manner in which waters are released from Roanoke Rapids Dam is governed by a tri-party agreement involving the U.S. Army Corps of Engineers, Virginia Power, and the North Carolina Wildlife Resources Commission [i.e., the 1971 MOU].
>
> Water discharged from Roanoke Rapids Reservoir during spawning activity remained at a base of approximately 6,000 cfs (augmentation flow required by the <u>cooperative agreement</u>). . .

(Rulifson, R.A., "Abundance and Viability of Striped Bass Eggs Spawned in the Roanoke River, North Carolina, in 1988" October 1989, emphasis added). It is one thing to argue that 1988 had a large number of days with flow in the negotiated regime. It is another matter entirely to argue that flows were released pursuant to the negotiated regime or some yet to be adopted version of it. The former is accurate, the latter is not.

It is understandable that the Flow Committee does not wish to acknowledge that flows during the 1988 season were released pursuant to the 1971 MOU regime. The spring of 1988 (March, April, May and June) had the <u>5th lowest average flow in a 78-year period of record</u>. The fact that a relatively good JAI occurred in a very dry year pursuant to the 1971 MOU regime certainly argues against the theory that the 1971 MOU regime needed to be changed (at least with respect to the minimums). Given that the entire analysis which purports to establish the basis for the recommended and negotiated regimes is defective, it may be prudent to return to the 1971 MOU regime, at least with respect to minimum flows, during the spawning period.

The 1990 Flow Committee Report clearly acknowledges that flows in the 1988 and 1989 seasons were very different. As stated above, 1988 was the 5th driest spring in the 78-year period of record (1912-1989), placing it in the 6th percentile. 1989 was the 10th wettest spring on record which puts it in the 88th percentile. 9. Flows in 1988 were low, variable, and a large number of days were in the negotiated regime. Flows in 1989 were high, stable, and a low number of days were in the regime. It is difficult, if not impossible, to imagine any two years that could be much more different. Yet the juvenile abundance index for both years was virtually identical. This is not the only time such a situation has occurred. There are quite a few instances of good spawning years in which the flow patterns have been vastly different (e.g., 1975 and 1976). There are also many instances where years which had very similar flow patterns had very different juvenile abundance indices (e.g., 1970 and 1977).

Setting aside the serious factual and other problems surrounding the time series analysis in the 1989 Report and the manner in which it was prepared and presented, the time series analysis in the 1990 report still needs a theoretical justification as did its 1989 counterpart. Proper scientific research is not a matter of loading data into a statistical package to generate meaningless correlations and post-hoc rationalizations. "Kitchen sink empiricism" will not hold up to unbiased and objective scientific scrutiny. The time series analyses in both reports have been conducted by researchers with <u>no</u> hydrologic or engineering expertise in water resources, and no theoretical basis has been established for the analyses. They are not consistent with any standard method used to assess hydrologic patterns in river systems, regulated or unregulated. One fact which suggests that the time series analyses are irrelevant is that the model for the 1989 spawning season (a <u>good</u> JAI year) was very similar, and in some respects "substantially identical," to the model which was determined for the <u>bad</u> JAI years in the 1989 report.

The exercise in which the Corps was asked to prepare hypothetical scenarios for water releases from the Roanoke Rapids Dam assuming it had been in possession of <u>a priori</u> knowledge about inflows to Kerr Reservoir is an analysis which demonstrates the obvious. It goes without saying, that if the Corps had known in advance of the extremely high Kerr Reservoir inflows which would occur during the spring of 1989, it could have taken actions to improve upon the operation of the system. If the Corps had known, in advance, that 1988 was going to be extremely dry, it could have implemented actions (much different from those in 1989) which would have enhanced management of the reservoir in 1988. However, the Corps has no such knowledge and neither does anyone else. The proper method for developing operational rules and regulations for Kerr Dam is to model conditions over the entire period of record and formulate rules and regulations which produce the best conditions, overall, considering dry, normal and wet years, and their respective frequencies of occurrence. While aiming for the target flows in 1989 might have increased the number of days in the regime for that year, the same action might have resulted in fewer days in the regime in other years.

The Committee's "hypothetical guide" to operational rules at Kerr Reservoir was prepared by an employee of the North Carolina Division of Water Resources. It was not based on computer modeling or an analysis of how such a guide would have affected the entire 78-year period, and the Corps was not consulted concerning the impact of the hypothetical guide on the other resources and interests which depend upon Kerr Reservoir releases. Furthermore, the recommendations were made without any evidence to justify a need to make such changes. There is not in existence today a factual basis to support the Flow Committee's recommended changes in the flow regime, much less changes in the Kerr Reservoir rule curve. Without a scientifically rigorous and statistically defensible analysis, it is unlikely that any such proposed changes will make it through a NEPA review.

The 1990 Flow Committee Report clearly establishes that all areas of water resources (water quality, floodplain conditions, agricultural activities and timber interests) were significantly better in 1988 than they were in 1989. The fact that 1988 was the 5th driest spring in almost eight decades more than adequately indicates that the Kerr Reservoir system is capable of meeting downstream water resource needs during very dry years. In fact, with respect to the number of days in the negotiated regime, Virginia Beach's modeling shows that it is very rare that dry flow years will pose a significant problem in meeting the negotiated regime. As the 1989 and 1990 spawning season demonstrate, high flows are far more likely to be the reason for days being outside the negotiated flow regime.

I have limited my comments on the 1990 report because it depends upon and builds upon the results of the 1989 report. The 1989 report is so seriously flawed, that it would not be a productive use of limited resources to conduct an in-depth analysis of the 1990 report given that it is built on such a faulty foundation.

4

To the extent that the 1990 report adopts conclusions, findings, facts, methodologies, or data from the 1989 report which are flawed, then those aspects of the 1990 report will also be flawed.

In closing, I must re-emphasize that I did not recreate all the Flow Committee's statistics and analyses. However, those that I did check were wrong. There is no rational way that either Flow Committee Report can be used to justify <u>any</u> conclusions, findings, or recommendations concerning striped bass or any other resource in the Roanoke River. The reports are a disservice to the National Marine Fisheries Service and a liability to the striped bass because they will undoubtedly mislead future researchers. They should be formally retracted and withdrawn from publication.

If you have any facts, evidence, or reliable documentation to respond to my review of the Flow Committee Reports, I will be happy to evaluate it.

Sincerely,

Thomas M. Leahy III

Thomas M. Leahy, III, P.E.
Project Engineer

TML/smm

EAST CAROLINA UNIVERSITY

Institute for Coastal and Marine Resources
Mamie Jenkins Building

919-757-6779

10 May 1991

Mr. Thomas M. Leahy, III, P.E.
Project Engineer
City of Virginia Beach
Department of Public Utilities
Municipal Center
Virginia Beach, VA 23456-9002

Dear Mr. Leahy:

Thank you for your letter of 9 May 1991 and accompanying documents addressing the Roanoke River Water Flow Committee reports for 1989 and 1990. Dr. Manooch and I have discussed your letter by telephone. We appreciate your constructive criticisms about certain aspects of both reports. We also appreciate the amount of time it must have taken to review these reports in such detail. Several of your points are well-taken and we are in the process of updating and revising information for the 1991 report. Other points will be taken under advisement and will require more effort to address.

Sincerely,

Roger A. Rulifson

Roger A. Rulifson
Co-Chair, Roanoke River Water Flow Committee

Greenville,
North Carolina
27858-4353

City of Virginia Beach

PUBLIC UTILITIES DEPARTMENT
WATER RESOURCES DIVISION
(804) 427-8035

MUNICIPAL CENTER
VIRGINIA BEACH, VIRGINIA 23456-9002

May 23, 1991

Dr. Roger A. Rulifson, Co-Chair
Roanoke River Water Flow Committee
Institute for Coastal and Marine Resources
Mamie Jenkins Building
East Carolina University
Greenville, North Carolina 27858-4353

Dear Dr. Rulifson:

I received your letter of May 10, 1991 indicating that you intend to respond to my Technical Evaluation of the Roanoke River Water Flow Committee Reports for 1989 and 1990. You may recall that I provided you a draft of the evaluation in January. Although you indicated then that you would not be responding, I am glad to see that you have changed your mind. I will be happy to review any data, evidence, or other facts and documentation which you have to offer in the way of a response or rebuttal.

As I indicated in the evaluation, I did not list all the concerns which were identified in the Flow Committee Reports, only the most significant and serious ones. Since you now apparently intend to respond to the evaluation, I thought it best to advise you of an additional discovery which I have made with respect to the time series analysis. Page 96 of the 1989 Flow Committee Report indicates that the "*good post-impoundment years were 1965, 1967, 1970, 1975, and 1976. All other JAI years were defined as bad.*" My analysis indicates that this is not correct. It would appear that <u>seven</u> years, not five, were used to determine the mean time path of the "*good [JAI] post-impoundment years.*" Therefore, neither the good JAI years nor the bad JAI years are correctly represented in the 1989 Flow Committee Report.

What this means is that three completely different sets of "*good*" and "*bad*" JAI years were used for the recruitment subcommittee analysis, the time series analysis, and the t-test/F-test analysis. There is no explanation which I can think of for such inconsistent treatment of the data, and these analyses can not be claimed to be supportive of each other because all three analyses used different sub-sets of the data.

These problems, of course, are in addition to the other concerns already noted in the analysis.

I will continue my review of your analyses and calculations and if I find any other areas of concern, I will let you know.

Sincerely,

Thomas M. Leahy III

Thomas M. Leahy, III, P.E.
Water Resources Engineer

cc John Brown
Bill Cole

Roanoke River Water Flow Committee
Institute for Coastal and Marine Resources
East Carolina University
Greenville, NC 27858

10 July 1991

Mr. John T. Brown
Chairman,
N.C. Striped Bass Study Management Board
U.S. Fish and Wildlife Service
Richard B. Russell Federal Building
75 Spring Street, S.W.
Atlanta, GA 30303

Dear Mr. Brown:

Recently, several Management Board events have transpired in which the Roanoke River Water Flow Committee was mentioned or targeted as the topic of interest. As Co-chairman of the Flow Committee, I feel it my responsibility to address these events and register my concerns.

The first issue involves the transmittal of Flow Committee correspondence to Management Board members and principal investigators. I believe that this practice is totally inappropriate, and I respectfully request that this practice stop immediately. As Flow Committee Co-Chairman, I will not transmit Board documents and correspondence to Flow Committee members unless asked to do so by you, as Chairman.

The second issue is the manner in which the Board's "Principal Investigator's meeting" was conducted on 8-9 July 1991. The agenda for this meeting contained several presentations by groups not identified by the Board as "principal investigators". I saw a draft agenda for the meeting before it was distributed, and voiced my objection at that time that VERSAR and the City of Virginia Beach would present rebuttal and perceived damaging evidence concerning the work of the Roanoke River Water Flow Committee. I believed that a Board principal investigator's meeting was not an appropriate forum for that type of presentation. Also, since the Board has a desire to distance itself from Flow Committee activities, there was no reason for the Board to allow this type of presentation. However, my objections were dismissed, and the presentations were allowed. The protocol for the meeting was such that only Board members were allowed to ask questions. No one in attendance except Dr. Manooch (the other Flow Committee Co-Chair), Dr. Zincone (ECU), and me knew the appropriate responses to VERSAR and the City's presentations, but we could not respond because none of us are Board members. Again, I believe that this whole situation was totally inappropriate, and I respectfully request that the Board either address only the issues directly related to their activities, or develop an appropriate forum that allows fair and appropriate exchange of information from all groups.

The Roanoke River Water Flow Committee is an all-volunteer group of professionals interested only in conserving and protecting what natural resources remain in the Roanoke Basin, and using them wisely. From our inception in 1988, we have excluded all private and public interest groups and resisted the external pressures to specifically address interbasin transfer, municipal and industrial uses, and federal refuge lands. As long as I remain Co-Chair of the Roanoke River Water Flow Committee, this will be our policy.

Sincerely,

Roger A. Rulifson

Roger A. Rulifson
Co-Chair, RRWFC

cc: N.C. Striped Bass Study Management Board
Roanoke River Water Flow Committee

United States Department of the Interior
FISH AND WILDLIFE SERVICE
75 SPRING STREET, S.W.
ATLANTA, GEORGIA
30303

TAKE PRIDE IN AMERICA

July 17, 1991

Dr. Roger A. Rulifson, Co-Chairman
Roanoke River Water Flow Committee
Institute for Coastal and Marine Resources
East Carolina University
Greenville, North Carolina 27858

Dear Dr. Rulifson:

This acknowledges receipt of your July 10, 1991, letter expressing concerns about several recent events involving the North Carolina Striped Bass Study Management Board.

While I have not yet had the opportunity to discuss your concerns with other Board members, I do believe that the Board had already set in motion at its July 8-9, 1991, meeting in Raleigh, North Carolina, actions which I am sure you will find at least partially address these issues. The Board requested that I invite you, on behalf of the Flow Committee, to make a presentation at our next meeting. Please consider this letter as that invitation. The presentation would, as with those made on July 8-9, be a 20-minute uninterrupted presentation of the Flow Committee's technical findings, followed by a 15-minute question period by Board members. We also would like for you to provide the most up-to-date documents for the Board's use in preparing its report.

The next Board meeting is scheduled for July 30, 1991, in Morehead City, North Carolina, at the Hampton Inn. I have scheduled your presentation for 1:30 p.m. If you desire to have other Flow Committee members present to address specific questions, please let me know. If you have any further questions or desire additional clarification, please feel free to contact me at the above address or 404/331-3576. The Board looks forward to your presentation on July 30th.

I will respond to the other concerns you expressed in your letter after I have had the opportunity to discuss them with other Board members.

Sincerely yours,

John T. Brown

John T. Brown, Chairman
North Carolina Striped Bass Study
Management Board

cc:
Board Members

E A S T
CAROLINA
UNIVERSITY

Institute for Coastal and Marine Resources
Mamie Jenkins Building

919-757-6779

29 July 1991

Dr. Ford A. Cross
Laboratory Director
NOAA/NMFS
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, NC 28516

Re: Release of draft Roanoke River Water Flow Committee Report for 1990

Dear Dr. Cross:

The purpose of this letter is to object to the premature release of a draft document entitled "Roanoke River Water Flow Committee Report for 1990", of which I am the senior editor.

As editor, it is my responsibility to ensure that the various authors have ample opportunity to examine and respond to comments generated by our internal peer review process before the manuscript is disseminated for public consumption. The manuscript is still in draft form. The comment period ends Wednesday, July 31, 1991, and additional time will be required to incorporate comments into the manuscript once they are received. The result of your request for a July 30 release of a document undergoing revision is that information subsequently may be revised prior to publication.

This procedure is highly irregular, and again I must protest this course of events. The Managing Editor of the American Fisheries Society, an international society which publishes at least four well-respected fisheries journals and numerous books, is in total agreement with my position and has encouraged me to respond negatively to your request. Since you have indicated that such a response is not possible, I herewith present the editor's copy with revisions made to date. In addition, there are several sections of the report that the authors do not want released pending further revision. These sections have been removed from your copy.

Sincerely,

Roger A. Rulifson

Roger A. Rulifson
Co-Chair, Roanoke River Water Flow Committee
Co-Editor, 1990 Flow Committee Report

Greenville,
North Carolina
27858-4353

Roanoke River Water Flow Committee
Institute for Coastal and Marine Resources
East Carolina University
Greenville, NC 27858

13 August 1991

Mr. John T. Brown
Chairman,
N.C. Striped Bass Study Management Board
U.S. Fish and Wildlife Service
75 Spring Street, S.W.
Atlanta, GA 30303

Dear Mr. Brown:

On behalf of the Roanoke River Water Flow Committee, I want to thank you for the opportunity to address the Striped Bass Study Management Board and describe for you our perspective concerning the preservation and conservation of the natural resources remaining in the Roanoke River watershed. I hope that the information presented at your Board meeting will be helpful in assembling and interpreting the extensive amount of information on this resource.

Also, thank you for providing a complementary copy of the City of Virginia Beach's letter to you of 29 July 1991, which offers their views of our 1991 report. It is unfortunate that the 30 authors of the report did not have the opportunity to revise their sections (after our internal review) prior to making the document public. Although the letter was sent to you rather than the Flow Committee, we have taken the opportunity to consider the comments made by the City, and have revised the document where possible.

Sincerely,

Roger A. Rulifson

Roger A. Rulifson
Co-Chair, Roanoke River Water Flow Committee

Roanoke River Water Flow Committee
Institute for Coastal and Marine Resources
East Carolina University
Greenville, NC 27858-4353

August 23, 1991

Mr. Thomas M. Leahy, III, P.E.
Water Resources Engineer
Public Utilities Department
Water Resources Division
City of Virginia Beach
Municipal Center
Virginia Beach, VA 23456-9002

Dear Mr. Leahy:

The purpose of this letter is to provide comment to your two letters, dated May 9 and May 23, 1991, written to the Co-Chairs of the Roanoke River Water Flow Committee concerning your review of the first Flow Committee report (Manooch and Rulifson, eds. 1989). On several occasions in the past, your office provided comments on the analyses and information presented in Flow Committee reports. We indicated that concise reviews of our work would be published in the appendix of the next available Flow Committee report. A draft document entitled, "A Technical Response to the March 1989 Roanoke River Flow Committee Report" prepared by you was received by the Co-Chairs on January 24, 1991 at the meeting of the North Carolina Striped Bass Study Management Board. We did not feel compelled to respond to this document at the time because it was a draft version of a document. Subsequently, you provided a final version of the document dated April 24, 1991. This document was substantial in size (98 pages of text, tables, and attachments) and did not fit the criteria given you for document submission. Since April 24, 1991, we have received two letters from you (5/9/1991; 5/23/1991), which address more concisely the relevant issues of the Flow Report. These letters will be published in the appendix of the 1991 Flow Report along with our response to your concerns.

Before providing detailed itemized comments to the letters, we would like to address the two subject areas of your concern: 1) the time series analysis performed by Dr. Zincone in the original report; and 2) the events leading up to the flow conditions for 1988. We would like to note at this point that several of the analyses conducted by various authors of the first flow report have been published in the peer-review literature, and are enclosed for your information. Also, we have produced a second flow report (Rulifson and Manooch, eds. 1990), which you have chosen not to address in detail because of your concerns about the first document. Many of your initial concerns about exactly how analyses were performed, and the dates and data used, we believe have been addressed or revised in these peer-reviewed publications.

TIME SERIES ANALYSIS. The time series analysis by Dr. Zincone represents only one aspect of a number of activities and initial analyses conducted by the Flow Committee in early 1988, immediately prior to that year's spawning season. As you know, we divided the Committee into working subgroups, based on member expertise, to identify and investigate various aspects of river flows and associated information about watershed natural resources. Thus, dates used for various analyses by subgroups did not necessarily correspond because, in any investigation set up to discover cause and effect relationships, much of the initial time and effort is devoted to trying new ideas and revising analyses to incorporate other information. Dr. Zincone's analyses may not agree exactly with dates used in other analyses, but he performed the analyses as requested at the time by other Flow Committee subgroups, and we presented the information in the document knowing that not all dates were exactly the same for all analyses. Dr. Zincone has informed us that, to the best of his knowledge and his documentation, the last analysis on preimpoundment years and which appeared in the first Flow report, was of preimpoundment data from 1912 to 1950; however, the data set was trimmed incorrectly as addressed below. Earlier modeling efforts were performed on the 1930-1950 data set. The year 1965 was selected for beginning the postimpoundment years for time series modeling because, at the time, it was believed that the first full calendar year after closing Gaston Dam was 1965. Subsequently, we now understand that Gaston Reservoir was first filled on October 13-15, 1962, and so the first full calendar year for modeling efforts should have been 1963, not 1965. The 1955-1963 period will be investigated further to determine the exact period of time not influenced by project construction.

One aspect of Dr. Zincone's analysis brought to our attention by you is much appreciated, and that aspect concerns the way in which the preimpoundment data set (1912-1950) was trimmed to reduce variability prior to analysis. Dr. Zincone received a data set for analysis in which the preimpoundment data (1912-1950) were trimmed in a manner inconsistent with the intent of the analysis, as you suspected. The postimpoundment data were not trimmed. The analysis has been redone, with the result that the preimpoundment streamflow pattern actually fits the pattern of postimpoundment "good JAI years" (more than five juvenile striped bass per trawl) more closely than the original analysis. None of the other analyses in the first flow report used trimmed data, so results of other analyses are not changed. Additional detailed comments on this aspect are presented later in this document.

In your letter of May 23, 1991, you refer to a possible problem concerning the number of "good postimpoundment years" used in the analysis for the 1989 report. Apparently, a typographical error has caused this confusion. Please note that the enclosed peer-reviewed publication (Zincone and Rulifson 1991) correctly lists the seven "good postimpoundment years". One discrepancy does appear in the peer-reviewed article, which is the years used in the postimpoundment data set. The article says that Dr. Zincone used the period 1965-1986. The manuscript should have stated the dates as 1965-1987, which are the dates Dr. Zincone says were used in the analysis for the manuscript. An early draft of the manuscript had the dates correct, but sometime in the editorial process after submitting it for publication, the dates were edited inappropriately. Please note that "Table 2" of the manuscript has the correct number of observations for "good" postimpoundment years (n=7) and "bad" postimpoundment years (n=16).

RIVER CONDITIONS IN 1988. It appears that your second area of concern is the sequence of events in 1988 and the resultant flow pattern of the Roanoke River below Roanoke Rapids Dam. The written record is incomplete on this matter, and herein we present what the Flow Committee believes is the correct sequence of events.

On March 8-9, 1988, the Flow Committee held its first meeting in Greenville, NC, at which time procedures, data availability, etc. were discussed. At that time, attendees were divided into groups defined by expertise and/or interests to initiate the process of understanding all aspects of the natural resources, and of defining user groups and natural resources in the lower watershed, and their relationships to river flow. One of the working subgroups was the Recruitment Subcommittee comprised of W. Cole, M. Clemmons, L. Henry, and S. Winslow. This subgroup examined the juvenile abundance index and hydrologic conditions for possible relationships. At this time, most Flow Committee members were unsure about the extent of the USGS database, but assumed that it consisted of years 1930-1950. Late in this work session, the Full Committee was informed by personnel of the N.C. Division of Water Resources and City of Virginia Beach that a more extensive data base dating back to 1912 existed.

On March 11, 1988, Rita Sweet of your office transmitted a memo to Dr. Rulifson, which contained floppy computer disks of the USGS Roanoke River flows from 1/1/12 to 7/31/87. Concurrently, the N.C. Division of Water Resources also sent a computer-ready copy of the same data base. These were entered into the ECU mainframe computer in March of 1988, and were compared for discrepancies.

On March 30, 1988, the Recruitment Subcommittee sent out a memo to attendees of the March 8-9 Flow Committee meeting, which detailed its "optimum or neo-optimum flow" recommendations. Included in the recommendations were river flow values of mean, maximum, minimum, median, Q1, Q3, P5, and P95 of postimpoundment years having a JAI value of greater than five fish per trawl.

On April 12, 1988, A Flow Committee meeting was held at Beaufort, NC. Specific objectives for the meeting included endorsing a flow regime and specification on allowable water fluctuation. At the beginning of the meeting, Max Grimes informed the group that at 0800 hours, the Corps began flow augmentation releases of 5,700 cfs. This release was for a two-week period only, unless additional precipitation occurred in the upper watershed. Field biologists noted that these flows were essential since striped bass spawning activity had been observed.

A Recommendations Subcommittee was formed at the April 12, 1988 meeting to develop a water flow regime and present it to the Full Committee for evaluation. The Recommendations Subcommittee was comprised of the following individuals (agency in parentheses): M. Clemmons (NCWRC), W. Cole (USFWS), D. Crawford (NCDWR), T. Ellis (NCDA), L. Henry (NCDMF), C. Manooch (NMFS), R. Monroe (NCDMF), T. Mullis (NCWRC), R. Rulifson (ECU), and L. Zincone (ECU). Also, the following Flow Committee Advisors were participants in the Subcommittee: M. Grimes (COE), J. Mitchell (Virginia Power Co.), and M. Shepherd (ECU).

The Recommendations Subcommittee used the draft recommended flow regime submitted by the Recruitment Subcommittee based on years in which river flows were 5,000-11,000 cfs that had a JAI value greater than 5.0 (i.e., "Group 1"). This "Flow Regime" encompassed the dates of 1 March to 30 June within the approximately 18-week period. The Recruitment Subcommittee recommended that, if flows were regulated on a weekly basis, then the median flows of Group 1 could be used. If monthly regulation was the only option, then the flow regime should be: March, 8000 $\pm$ 1000 cfs; April, 11000 $\pm$ 4000 cfs; May, 7500$\pm$ 1000 cfs; and June, 5000 $\pm$ 1000 cfs (First Flow Report, p. 96). At the same time that the Recruitment Subcommittee was working on an "optimum flow" recommendation, Dr. Zincone was characterizing preimpoundment and postimpoundment flows using a time series approach. His work, using data from 1912-1950, indicated that the postimpoundment good JAI years had a flow pattern similar, but not identical, to the preimpoundment period. Dr. Zincone's work supported the findings of the Recruitment Subcommittee, but the conclusion was that of using a preimpoundment criterion rather than an "optimum flow" approach.

On April 22, 1988, Dr. Rulifson sent to the Recommendation Subcommittee a memo listing tasks to be completed prior to the meeting. Task #4 was to enter the USGS data from 1912-1930 into the ECU computer, and indicated that this indeed had been accomplished and work to recharacterize preimpoundment flows was progressing (Dr. Zincone's work). Dr. Manooch sent a similar memo on April 25, 1988 listing tasks to be accomplished; however, he did not know that preimpoundment recharacterization was in progress.

On May 3, 1988, the Recommendations Subcommittee met in Greenville, NC, to discuss the recommendations of the Recruitment Subcommittee. The Subcommittee adjourned to a computer lab in ECU's General Classroom Building, where additional modeling was conducted. At that time, Jack Mitchell of Virginia Power was asked if the utility could operate within the release schedules that we were considering, and he indicated that Virginia Power could limit their discharges to our recommendations, but that he had to work within the volume of water given to him by Max Grimes each week. Max was then asked if he could deliver flows that would allow Virginia Power to stay within the guidelines that we were discussing at that moment. Max indicated that it might be possible to stay within wanted stable flows for the remainder of spring 1988. After some discussion, the Subcommittee asked that Mr. Mitchell not exceed the Q_3 boundaries developed on that day (May 3). In addition, the Subcommittee asked that the rate of flow change be 1000 cfs over a 12-hour period. Mr. Mitchell stated that such fine tuning from the operators may not be possible, but that he would work with us on this point. Also, Mr. Mitchell pointed out that this trial period for spring 1988 could be a test for operators to refine their control of water through the turbines; computerization to optimize flows for up to five sets of criteria (e.g., dissolved oxygen, power production) was still several years away. At the end of the meeting on May 3, 1988, the Subcommittee left with a verbal understanding that an attempt would be made to control water releases within the draft guidelines for the remainder of the striped bass spawning season if possible. Fortuitously, the amount of inflow to Kerr Reservoir was conducive to powerplant operation that paralleled what would later become the "Negotiated Flow Regime." We note here that at no time had we asked either the Corps of Engineers or Virginia Power Company to violate the 1971 Memorandum of Understanding, which would still be in effect during this pilot effort.

On May 6, 1988, Lynn Henry circulated a memo to the Recommendations Subcommittee which provided copies of computer-generated information from the May 3 meeting.

On May 27, 1988, Dr. Manooch advised Dr. Ford Cross, NMFS-Beaufort Laboratory Director, by memo of the progress made by the Flow Committee, pointing out the cooperation of the Corps and its willingness to ensure that this year's [1988] water flows more closely resembled what occurred prior to impoundment.

On May 31, 1988, Dr. Manooch sent a memo to the Recommendations Subcommittee announcing the June 23 meeting and asking for further review of the 1912-1950 data base discussed on May 3, and any additional recommendations.

On June 23, 1988, the Recommendations Subcommittee reconvened in Beaufort, NC, to discuss the outcome of the spring efforts, and to formally adopt a flow regime for recommendation to the full Flow Committee. At this meeting, Mr. Grimes produced a numeric table containing a flow regime that he believed could be acceptable from a managerial perspective. After lengthy discussion, the Subcommittee constructed a Negotiated Flow Regime, similar to that presented by Mr. Grimes, that was acceptable to Mr. Grimes, representing the U.S. Army Corps of Engineers, Wilmington District, and Mr. Mitchell representing Virginia Power Company. This negotiated period was shortened so as to keep the recommendations within the FERC license agreement. Furthermore, the Subcommittee recommended that short-term variation in flow should not exceed 1500 cfs per hour.

On August 11, 1988, the full Flow Committee held a meeting in Raleigh, North Carolina, at which time the Negotiated Flow Regime was formally adopted unanimously. The Negotiated Flow Regime was to be implemented for a four-year trial period after which a final report would be written to describe the findings and provide recommendations for a flow regime to benefit all resources, not just striped bass. During the four-year period, yearly reports would be written describing the springtime conditions, and to present additional information about the watershed and its resources as they became available.

Following are comments addressing specific concerns of your letter dated May 9, 1991. Numbered items refer to points enumerated by us on your letter (see attached).

1. Reasons for our no response to a draft document given above.

2. Dr. Zincone's time series analysis was addressed above.

3. According to Dr. Zincone, the full preimpoundment period for 1912-1950 data set was used in the analysis by Dr. Zincone. See attached publication by Zincone and Rulifson (1991).

4. Data set values were trimmed incorrectly as you state. See attached unpublished manuscript by Dr. Zincone.

5. Point noted that "trimmed means" is an appropriate statistical manipulation for eliminating extreme values.

6. Dr. W.W. Fox of the National Marine Fisheries Service did indeed request that independent professionals be assembled to assess the NMFS position relative to the Lake Gaston project. We note that the group did not recommend that NMFS change its position relative to the Lake Gaston project, and the agency has not changed its position.

7. The issue of the correct sequence of events that transpired in the spring of 1988 has been addressed in detail above.

8. As stated above, 1988 releases were under the 1971 MOU but also incorporated verbal agreement among Recommendations Subcommittee participants that attempts would be made to control flows within the Q_3 and hourly flow guidelines under discussion at the time.

9. Both quantity and quality (duration, stability, and timing) of river flow is important to ensure proper development and hatching of anadromous fish eggs. In 1988, as you point out, the watershed was quite dry during the early part of the season. Enhanced flows during the early spring period may have resulted in a better JAI than was recorded due to a number of factors including attractant flows for adults and nutrient input for development of the food base. In 1989, the timing of flows was quite different than observed for 1988. Extremely high, unstable flows were recorded in March. The decrease in flows in early April was quite sudden, followed by a second high flow sequence in mid-April. Reservoir discharge was abruptly decreased to the mid-range of flows as the Corps attempted to put reservoir releases within the Q1-Q3 criterion. Ambient water temperatures below the spawning grounds fluctuated with these changing flow conditions, thus stopping spawning activity. Additional large volumes of freshwater input resulted in high stable flows discharged from the dam from early May to near the end of May. These flows were quite stable because they were released at the maximum capacity of Roanoke Rapids Dam (about 20,000 cfs). This stability allowed water temperatures to increase gradually; striped bass spawning occurred very late in the season (Memorial Day weekend) and into June.

We believe that these comments, along with the accompanying publications and file manuscript, have addressed your concerns regarding the Flow Committee's analysis and reports of each year's events.

Sincerely,

Roger A. Rulifson
Co-Chair, RRWFC

Charles S. Manooch, III
Co-Chair, RRWFC

enclosures as stated

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APPENDIX D.

Rulifson, R.A. and C.S. Manooch, III. 1990. 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.

North American Journal of Fisheries Management 10:397–407, 1990

Recruitment of Juvenile Striped Bass in the Roanoke River, North Carolina, as Related to Reservoir Discharge

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Abstract.—A multiagency committee was established to examine potential effects of reservoir management and hydroelectric power activities in the lower Roanoke River, North Carolina, on downstream resources and their users. Striped bass *Morone saxatilis* was selected as a key species because of the extensive long-term data base on spawning activity and nursery utilization established in the late 1950s. Specifically, the juvenile abundance index (JAI) values for young-of-year striped bass in Albemarle Sound (1955–1987) were compared to preimpoundment (1912–1950) and postimpoundment (1955–1987) flows of the Roanoke River during the spawning season (1 March–30 June). Recruitment was best (JAI > 5.0) for years in which river flows were low to moderate (5,000–11,000 ft^3/s) and was poor (JAI < 5.0) when flows were very low (3,900–8,100 ft^3/s) or high (10,000 ft^3/s or greater) during spawning season. Additionally, the average flow pattern for good recruitment years (JAI > 5.0) most closely resembled preimpoundment flow conditions. Preimpoundment flow patterns were used to develop a recommended flow regime for the lower river (1 March–30 June) to maintain reservoir discharge between the historical 25% and 75% quartiles of the daily flow (i.e., between the 25% low-flow value [Q1] and 75% high-flow value [Q3]). A modified (negotiated) flow regime (1 April–15 June) accepted by the U.S. Army Corps of Engineers and a public utility was used in regression analyses to characterize patterns in postconstruction reservoir management. Briefly, the number of days during a season that reservoir discharge stayed within the historical (negotiated) Q1–Q3 bounds has decreased significantly over time, indicating that the manner in which the reservoir system is managed has changed throughout the years. Similarly, JAI values have declined with time, especially for the period 1977–1987, when the 10-year average was only 0.81. The JAI values were divided into four categories (<1, 1.0–4.9, 5.0–9.9, and ≥10); analyses indicated that the years of lowest JAI values were also those with the fewest days in which river flow was within the Q1–Q3 bounds. Striped bass egg viability showed similarly declining trends: for the period 1960–1969, viability was 90% and flows stayed within the Q1–Q3 bounds over 50% of the days; during and after 1978, mean egg viability was less than 50% and days within the Q1–Q3 bounds averaged 27%. The committee's recommendations for a controlled flow regime resembling preimpoundment conditions were accepted by the U.S. Army Corps of Engineers and the public utility for 4 years (beginning in 1989), during which studies will be conducted to monitor the outcome. The flow regime allows the new set of conditions to operate within the guidelines of the original license from the Federal Energy Regulatory Commission.

Several striped bass *Morone saxatilis* populations in the USA have been affected by changes in streamflow characteristics caused by construction and operation of hydroelectric generation facilities and water diversion projects (e.g., Santee and Cooper Rivers in South Carolina, Sacramento–San Joaquin system in California). In some cases, access to historical spawning grounds has been restricted or blocked. Examples in North Carolina include the Roanoke, Tar, Neuse, and Cape Fear rivers (Rulifson et al. 1982). The Roanoke–Albemarle population is considered to be the southernmost stock along the U.S. eastern seaboard that exhibits anadromy and contributes a modest number of individuals to the Atlantic coastal migration (Boreman and Lewis 1987).

Of those striped bass populations exhibiting anadromy, the Roanoke–Albemarle stock is unusual in that the adults migrate more than 130 mi upstream beyond tidal influence to spawn. Before 1950, flows in the Roanoke watershed were unregulated; since that time, six impoundments within Virginia and North Carolina regulate downstream flows for flood control, hydroelectric power generation, and recreation. The most downstream of these reservoirs is Roanoke Rapids Lake (Figure 1), which was completed in 1955 at river mile (RM) 137 (distance upstream from the river

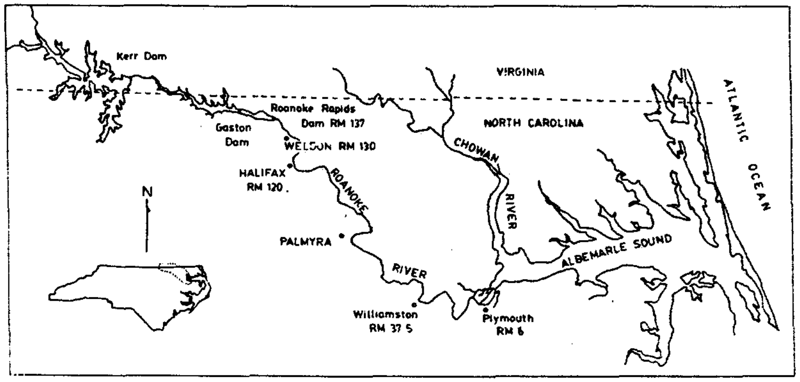

FIGURE 1.—Lower Roanoke River watershed.

mouth). Passage of striped bass to the upstream spawning grounds was blocked (McCoy 1959). Spawning now occurs from late April through early June from approximately RM 78 to RM 137, but is concentrated at the fall line (RM 130) near Weldon, North Carolina (Hassler et al. 1981).

The location and timing of striped bass spawning activity in the Roanoke River is influenced by river flow and by water temperature; discharges from the reservoir control river flow and cause water temperatures to drop (Rulifson, unpublished data). Hassler et al. (1981) suggested, after 30 years of monitoring, that best recruitment occurs in years possessing low to moderate (5,091–9,741 ft³/s) river flows during the striped bass spawning season.

Minimum-flow criteria during the spawning season were outlined within the guidelines of the original Federal Power Commission license, which was signed in 1971 by three agencies: U.S. Army Corps of Engineers, North Carolina Wildlife Resources Commission, and Virginia Power Company. The memorandum of understanding for the license allows some flexibility for water release; it required a minimum release of 2,000 ft³/s during the spawning season, with sufficient additional water release from the John H. Kerr Reservoir to maintain a minimum of 13 ft at the Weldon river gage. The spawning season was characterized as a 60–75-d period between late April and early June, with the window established each year by the North Carolina Wildlife Resources Commission. However, the minimum instantaneous instream flow required is only 1,000 ft³/s (depending on oxygen levels) for the prespawning period (November–March), 1,500 ft³/s for April and October, and 2,000 ft³/s for the postspawning period (May–September), with exceptions for off-peak times (e.g., on weekends). At any given time, the rate of water release from the reservoir can be doubled or halved over a 1-h period. Guidelines for maximum river flow were not established in the license.

Harvest of Roanoke–Albemarle striped bass began to decline precipitously in the late 1970s, followed by reductions in egg viability and recruitment of juveniles to the forming year-classes (Hassler et al. 1981). In 1988, the Roanoke River Water Flow Committee (Roanoke Committee) was formed to investigate the potential effects of reservoir discharge on downstream resources and users. Striped bass was used as a key species. A comprehensive report detailing the hydrological and ecological information was published by the Roanoke Committee (Manooch and Rulifson 1989). The objective of the study described herein was to evaluate the relationship between reservoir discharge and striped bass recruitment in the Roanoke–Albemarle system; these results are a condensed version of those presented in the original report.

Methods

Juvenile abundance index.—The relative success of juvenile striped bass recruitment to the forming year-class was monitored and reported as a juvenile abundance index (JAI). The Roanoke–Albemarle JAI was initiated in 1955 by W. W. Hassler (North Carolina State University, personal communication; Hassler and Taylor 1986) and was continued through 1987 (Table 1). Estimation methods for the JAI remained essentially unchanged during that time. The sampling area was in western Albemarle Sound and extended eastward about 12 mi. Seven permanent sampling stations were established (Figure 2).

TABLE 1.—Historical reproduction information on the Roanoke–Albemarle striped bass population. Data are from Hassler and Taylor (1986) except as otherwise noted; NCSU = North Carolina State University; NCDMF = North Carolina Department of Marine Fisheries.

Year	Number of eggs spawned	Percent egg viability	Juvenile abundance index NCSU	Juvenile abundance index NCDMF
1955			3.27	
1956			19.14	
1957			5.71	
1958			0.15	
1959	300,000,000[a]		23.86	
1960	740,000,000	92.88	5.93	
1961	2,065,232,519	79.74	10.33	
1962	1,088,076,294	86.22	7.86	
1963	918,652,436	79.94	4.80	
1964	1,285,351,276	95.77	3.14	
1965	823,522,540	95.91	10.08	
1966	1,821,385,754	94.51	3.48	
1967	1,333,312,869	96.20	23.39	
1968	1,483,102,338	86.20	6.59	
1969	3,229,715,526	89.86	2.99	
1970	1,464,841,490	89.23	12.45	
1971	2,833,119,620	80.81	2.86	
1972	4,932,000,707	90.51	2.52	
1973	1,501,498,887	87.21	1.95	
1974	2,163,239,468	87.31	5.52	
1975	2,193,008,096	55.69	10.80	
1976	1,496,768,659	50.73	10.52	
1977	1,775,957,318	52.72	3.63	
1978	1,691,227,585	37.72	0.59	
1979	1,613,382,382	43.62	0.55	
1980	870,322,832	43.39	0.46	
1981	344,364,065	73.70	0.09	
1982	1,698,888,853	71.93	3.80	0.61[b]
1983	1,352,611,202	33.29	0.84	0.42[b]
1984	703,879,559	22.73	0.36	0.00[b]
1985[c]	600,562,645	72.21	1.24[c]	0.32[d]
1986[c]	2,279,071,483	51.10	0.14[c]	0.11[e]
1987[c]	1,382,496,006[c]	42.87[c]	0.06[c]	0.30[b]
1988	2,082,147,979[f]	89.00[f]		4.09[b]

[a] Partial season data only.
[b] L. Henry, personal communication, NCDMF.
[c] W. W. Hassler, personal communication, NCSU.
[d] S. E. Winslow and L. T. Henry, unpublished (1986), NCDMF.
[e] Winslow and Henry, unpublished (1988).
[f] Rulifson, unpublished data.

Samples were collected early in the sampling season by a 17.4 ft balloon trawl with a ¼-in stretched-mesh cod end. Samples later in the season were taken with a cod end of ½-in stretched mesh. Samples were taken every 2 weeks, starting in July and ending in October. Each trawl was of 15-min duration at a towing speed of about 2.75 mi/h. Trawling depth ranged between 6 and 10 ft. The annual JAI was expressed as the average number of age-0 striped bass per unit of effort (15-min tow).

In 1982, the North Carolina Division of Marine Fisheries (DMF) initiated their own JAI survey by using the same methods and stations used by Hassler. The DMF survey is the only information available after 1987. Statistical comparisons of the overlapping data sets were used to validate similarities in trends of the two indices (Phalen 1988). For our analyses, we chose Hassler's historical data base for all years available and used the DMF value for 1988 (Table 1).

Egg production and viability.—Striped bass egg production and viability were determined by Hassler (personal communication; Hassler and Taylor 1986) from 1960 to 1987 according to techniques and procedures developed by McCoy (1959) and Cheek (1961). McCoy concluded that 10-in-diameter nets were more efficient than 3-ft nets, and that tows of 5 min were more efficient than 10- or 15-min tows. Cheek determined that sampling variance was lowest with 3-h intervals between tows. Briefly, the estimated number of eggs spawned daily was calculated by obtaining a mean number of eggs counted in eight replicate samples taken over 24 h and then extrapolating that mean for the average cross section of the river for that day. Viability was determined by visual inspection of each egg to determine status of the yolk, perivitelline space, oil globule, and embryo development. Details of the methodology were described by Hassler et al. (1981).

From 1960 through 1987, annual sampling for striped bass egg production was conducted at several locations downstream from the spawning grounds based on initial studies conducted during 1956–1958 to identify the principal spawning grounds. Samples were taken at RM 78.5 in 1959 and 1960, at RM 121 from 1961 to 1974, at RM 117 from 1975 to 1981, and at RM 118.5 from 1982 through 1987.

River flow data.—Discharge from the Roanoke Rapids Reservoir is monitored every 15 min by the U.S. Geological Survey (USGS) water gage 02080500 on the Roanoke River at Roanoke Rapids, North Carolina, which is located 2.8 mi downstream from the Roanoke Rapids Dam and 133.6 mi upstream from the river mouth at Albemarle

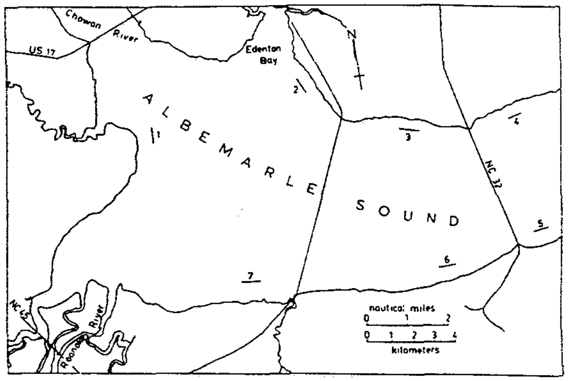

FIGURE 2.—Sampling area and seven station locations for annual surveys to obtain the striped bass juvenile abundance index for western Albemarle Sound, North Carolina.

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Sound. River flow records from this gage, presented as daily averages in cubic feet per second, are available for 1911 to the current year from the USGS. Maximum discharge for the period of record was 261,000 ft³/s on 18 August 1940 as a result of an August hurricane, whereas the minimum recorded discharge was 250 ft³/s on 16 December 1955. The average annual discharge for the period of record was about 8,500 ft³/s (Giese et al. 1979).

Preimpoundment years were considered to be 1912 through Water Year 1950. After the completion of Roanoke Rapids Dam in June 1955, flows were completely regulated downstream from RM 137. Therefore, postimpoundment years were considered to be 1955 through Water Year 1987. Preimpoundment data were used to characterize the natural flows of the lower river before 1951 (Manooch and Rulifson 1989).

Results

JAI and River Flow

Hassler et al. (1981) had concluded that river flows during May in the low to moderate range (5,091–9,741 ft³/s) were favorable for striped bass recruitment, whereas high May flows were detrimental to formation of good to strong year-classes. To test this hypothesis, we plotted each JAI value (Table 1) against the average river flow for May for years 1955 through 1986 (Figure 3). A JAI value of 5.0 was close to the median JAI for all years and therefore was chosen as the cut-off between good and poor recruitment.

Four general groupings were apparent based on ranges of May river flows and JAI values. Group 1 (N = 13) was characterized by relatively low to moderate flows (5,000–11,000 ft³/s) with a JAI greater than 5.0. Group 2 represented years (N = 9) in which the JAI was less than 5.0 and May

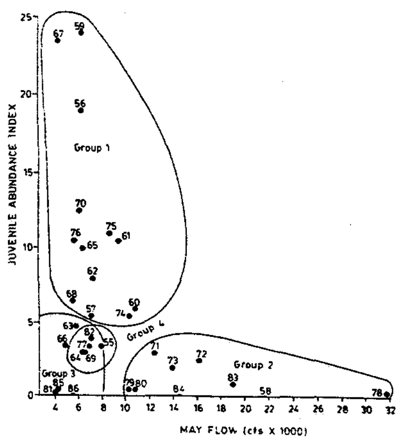

FIGURE 3.—The relationship of lower Roanoke River May flows to the striped bass juvenile abundance index (JAI) depicting several distinct year-groups: Group 1 = optimal flows, JAI > 5; Group 2 = high flows, JAI < 5; Group 3 = low flows, JAI < 5; Group 4 = low to moderate flows, JAI < 5. Flow is given in thousands of cubic feet per second (cfs).

river flows were ~~1,000~~ 10,000 ft³/s or greater. Group 3 represented years (N = 10) that also had JAI values less than 5.0 but in which May flows were very low (3,900–8,100 ft³/s). A fourth group of years (N = 5) was identified as a subset of Group 3; Group 4 was characterized by moderate flows (6,400–8,100 ft³/s) and a JAI of less than 5.0 (Figure 3). However, this approach did not consider the prespawning (March–early April) and postspawning (June) periods.

To determine river flows characteristic of the entire period of spawning activity (1 March–30 June), the mean and median flows for each group were plotted and compared (Figure 4). River flows for Group 1 were moderate (8,000–10,000 ft³/s) in March, followed by a peak flow period in April, and a return to moderation in May continuing into June. This pattern is similar to the preimpoundment flow patterns of the Roanoke River determined from time-series analysis (Manooch and Rulifson 1989). Group 2 reflected a seasonal pattern of high flows above 10,000 ft³/s until the first of June (Figure 4). Group 3 differed from Group 1 in that river flows were low throughout the period, which implies that high flows in March or early April are important to striped bass recruitment. Group 4 had river flows during May within

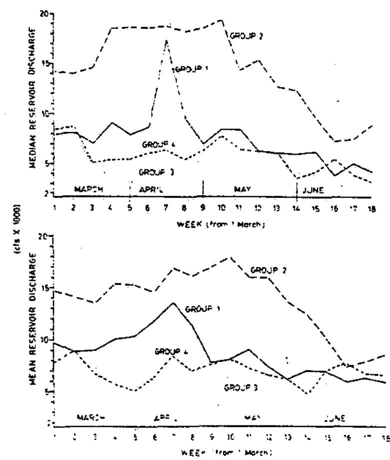

FIGURE 4.—Mean and median weekly flows of the lower Roanoke River for Group 1 (optimum flow, JAI > 5), Group 2 (high flows, JAI < 5), Group 3 (low flows, JAI < 5), and Group 4 (moderate flows, JAI < 5). Flow is given in thousands of cubic feet per second (cfs).

TABLE 2.—Negotiated (Q1–Q3) water flow regime (ft³/s) for the Roanoke River below Roanoke Rapids Dam for 1 April–15 June each year.

Dates	Expected average daily flow	Lower limit (Q1)[a]	Upper limit (Q3)[b]
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

[a] Q1 = historical 25% quartile of daily flow.
[b] Q3 = historical 75% quartile of daily flow.

the optimal range of Group 1, but without the subsequent good year-classes. The primary difference between Group 1 and Group 4 was that the late March–early April flows of Group 4 were lower than what appeared to be optimum. This suggests that a strong Roanoke River flow in early April, followed by low to moderate flows during May, contributes to strong year-class formation of Albemarle striped bass.

Based upon the initial JAI analyses described above and time-series analyses of preimpoundment and postimpoundment flows, a recommended flow regime starting 1 March and ending 30 June was established by the Roanoke Committee (see Manooch and Rulifson 1989). A similar but shorter flow regime (designated the negotiated flow regime) was accepted by the U.S. Army Corps of Engineers and Virginia Power Company (Table 2). Briefly, the recommendation was to control river flows between the historical (preimpoundment) 25% low-flow value (Q1) and the 75% high-flow

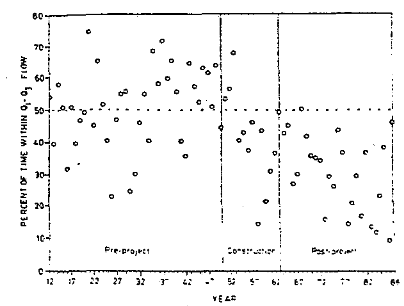

FIGURE 5.—Percent of the time that Roanoke River flows were within the Q1–Q3 bounds for 1912–1988. Q1 and Q3 are historical 25 and 75% quartiles of daily flow, respectively.

TABLE 3.—Results of regression analysis (SAS 1985) on the relationship of striped bass egg viability (EGGV) and juvenile abundance index (JAI) to year and percent of flow days within the negotiated Q1–Q3 bounds (PDAYS).[a]

Dependent variable	Independent variable	df	F	P	r^2
PDAYS	Year	1, 35	16.558	0.0003	0.32
EGGV	Year	1, 26	35.591	0.0001	0.58
	PDAYS	1, 26	6.854	0.0145	0.21
JAI	Year	1, 31	10.610	0.0027	0.26
	PDAYS	1, 31	10.657	0.0027	0.26

[a] Q1 = historical 25% quartile of daily flow; Q3 = historical 75% quartile of daily flow.

value (Q3) of the average daily flows between 1 April and 15 June each year.

The negotiated flow regime criteria were used to plot historical trends of preimpoundment and postimpoundment flows to look for change in flow patterns over time. As expected by definition, preimpoundment flows stayed within the Q1–Q3 range about 50% of the time (Figure 5). For postimpoundment years, flow patterns showed a definite trend away from the expected 50% variation. The number of days that flows remained within the negotiated Q1–Q3 bounds (PDAYS, for the period 1 April–15 June) was negatively correlated (N = 36; P = 0.003; r^2 = 0.32) with increasing number of years postconstruction (Table 3, Figure 6).

Subsequently, analysis of variance (SAS 1985) was used to determine if the percent of flows within the negotiated Q1–Q3 bounds varied by decade or part of a decade. The year-class (YRCLASS) designations were 1951–1959, 1960–1969, 1970–1977, and 1978–1987. The 1970s were divided into two portions because 1977 was the last in a series of years of reasonably good JAI values (Table 1). The variable PDAYS was significantly related (N = 37, P = 0.0021, r^2 = 0.36) to YRCLASS; the average percentage of days in which river flow was within the negotiated Q1–Q3 bounds was significantly less after 1977 than for the period before 1970, but was not significantly different from that during 1970–1977 (Table 4).

These analyses confirm a significant change in the flow regime postimpoundment, particularly since 1977. The frequency with which flows of the Roanoke River were within the negotiated (Q1–Q3 bounds decreased over the years.

To determine how the negotiated flow regime criteria were related to historical JAI records, several statistical analyses of all available data were conducted. Based on a similar YRCLASS designation for data grouping, a general postimpoundment decline in the JAI was apparent (N = 32, P = 0.0027, r^2 = 0.26; Table 3). The average JAI from 1955 to 1959 was 10.43, dropping to about 7.0 during the 1960s and 1970s (Table 5, Figure 7). After 1977, the 10-year average JAI dropped drastically to 0.81 fish per trawl (Table 5, Figure

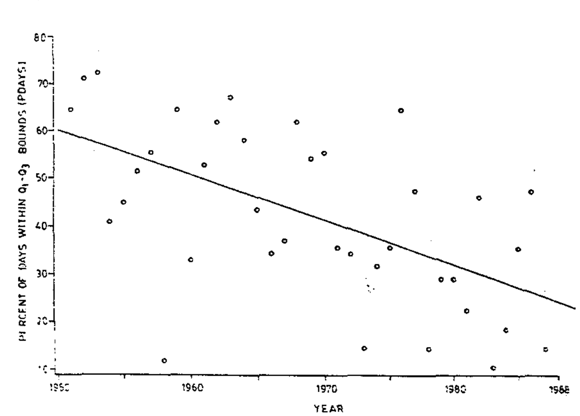

FIGURE 6.—The relationship of the percent of days that Roanoke River flows were within the negotiated Q1–Q3 bounds (PDAYS) to year after initial reservoir construction. Q1 and Q3 are historical 25 and 75% quartiles of daily flow, respectively.

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TABLE 4.—Results of analysis of variance (SAS 1985) among decades postimpoundment (YRCLASS) for the percent of flow days within the negotiated Q1–Q3 bounds (PDAYS),[a] striped bass egg viability (EGGCLASS), and striped bass juvenile abundance index (JAICLASS). Means along a row followed by the same letter are not significantly different (P > 0.05; Duncan's multiple-range test).

Variable	Mean for YRCLASS[b] 1	2	3	4	N	df	F	P
PDAYS	52.9 z	50.5 z	39.8 yz	26.7 y	37	3, 33	6.07	0.0021
EGGCLASS[c]		0.0 z	0.4 y	1.0 x	28	2, 25	33.93	0.0001
JAICLASS[d,e]	2.8 z	2.9 z	2.9 z	1.1 y	33	3, 29	9.84	0.0001

[a] Q1 and Q3 = historical 25 and 75% quartiles of daily flow, respectively.
[b] YRCLASS: 1 = 1951–1959; 2 = 1960–1969; 3 = 1970–1977; 4 = 1978–1987.
[c] EGGCLASS: 0 = viability of at least 75%; 1 = viability below 75%.
[d] JAICLASS: 1 = less than 1.0; 2 = 1.0–4.99; 3 = 5.0–9.99; 4 = 10 or greater.
[e] Only data for 1955–1959 are included in the analysis of JAICLASS for YRCLASS 1.

7). This general trend matched the general decline in percent of flow days within the Q1–Q3 bounds (Tables 3 and 4, Figure 8). Also significant was the decrease in JAI and corresponding decrease in percent of flow days within Q1–Q3 bounds (N = 32, P = 0.0027, r^2 = 0.26). The data were reexamined by subdividing the JAI values into four categories: <1.0, 1.00–4.99, 5.00–9.99, and ≥10.0. In general, the lowest JAI values corresponded to the lowest percent of flow days within the negotiated Q1–Q3 bounds (Table 6). The JAI for the period from 1978 to 1987 was significantly lower than those for the other postimpoundment periods (Table 4).

Egg Viability and River Flow

Egg viability estimates (Table 1) have also exhibited a declining trend since data collection was initiated in 1960. A regression analysis on egg viability indicated a significant negative correlation between viability and year (N = 27, P = 0.0001, r^2 = 0.58; Table 3). During the period 1960–1969, the average egg viability was about 90%, which corresponded with over 50% of the days during spawning that had flows within the Q1–Q3 bounds (Table 5). From 1970 to 1977, average egg viability dropped to about 74%. Beginning in 1978, mean egg viability was less than 50%, and the percent of days within the Q1–Q3 bounds averaged about 27%.

To determine the relationship between negotiated flow criteria and postimpoundment egg viability, the viability estimates were stratified into values less than 75% (poor survival) and values 75% or greater (good survival). Subsequently, we examined the mean percentage of flow days within the negotiated Q1–Q3 bounds and the mean percentage of viable eggs by viability class. In years of relatively good egg survival, the percent of flow days within Q1–Q3 bounds averaged 45%; in poor survival years, the percent of flow days within Q1–Q3 was only about 32% (Table 7). A t-test indicated a significantly higher average percent of flow days within the Q1–Q3 bounds for the 75% or greater egg viability class.

No relationships between egg production and other variables used in the analyses described above were evident.

Discussion

Factors dictating the formation of a successful or dominant year-class of striped bass in the Roanoke River watershed are not completely understood. However, we believe that one major factor

TABLE 5.—Mean percent of days that Roanoke River flow was within the negotiated Q1–Q3 flow criterion, by period, and mean values of the juvenile abundance index (JAI) and percent egg viability.

Period	Number of years	Percent of days within Q1–Q3[a] Mean	SD	JAI Mean	SD	Percent egg viability Mean	SD
1951–1959	9	52.92	17.90	10.43[b]	9.33		
1960–1969	10	50.53	12.09	7.86	5.76	89.67	6.16
1970–1977	8	39.80	14.50	6.28	4.01	74.28	16.70
1978–1987	10	26.71	12.40	0.81	1.05	49.25	16.85

[a] Q1 and Q3 = historical 25 and 75% quartiles of daily flow, respectively.
[b] Based on 5 years of data for this period.

TABLE 6.—Mean percent of days that Roanoke River was within the negotiated Q1–Q3 flow criterion for years within each category of striped bass juvenile abundance index (JAI).

JAI category	Years	Percent of days within Q1–Q3[a] Mean	SD	JAI Mean	SD
<1.00	1958, 1978, 1979, 1980, 1981, 1983, 1984, 1985, 1986, 1987	23.29	11.26	0.33	0.26
1.00–4.99	1955, 1963, 1964, 1966, 1969, 1971, 1972, 1973, 1977, 1982	43.82	14.34	3.24	0.73
5.00–9.99	1957, 1960, 1962, 1968, 1974	48.68	13.65	6.32	0.85
≥10.00	1956, 1959, 1961, 1965, 1967, 1970, 1975, 1976	50.49	10.48	15.07	5.66

[a] Q1 and Q3 = historical 25 and 75% quartiles of daily flow, respectively.

influencing recruitment of striped bass juveniles is river flow. Hassler et al. (1981) reached a similar conclusion for the Roanoke River.

The influence of water flow on the formation of a successful year-class of striped bass is not unique to the Roanoke River. Studies involving this species in the Sacramento–San Joaquin system, California, indicate that different rates of water discharge can have either beneficial or detrimental effects on juvenile striped bass abundance (Turner and Chadwick 1972; Stevens 1977; Stevens et al. 1985). Annual distribution and abundance of young striped bass were measured from 1959 to 1970 in the estuary, and annual abundance of juveniles in late summer was closely related to water flow in June–July ($r = 0.89$; Turner and Chadwick 1972). As with the Roanoke River, the Sacramento and San Joaquin rivers have extremely variable flows that are controlled by an extensive series of reservoirs throughout the watershed. Survival of young striped bass increases rapidly as mean June–July outflows increase from 2,000 to 10,000 ft^3/s (Turner and Chadwick 1972). Stevens (1977) not only reaffirmed the results of Turner and Chadwick's (1972) study, but also referred to water flow conditions in Chesapeake Bay as being correlated to juvenile striped bass abundance. According to Stevens, the Maryland Department of Natural Resources found that the mean catch of juveniles per seine haul in the Potomac River was highly correlated with the mean April–May river flow ($r = 0.865$ for 1961–1971).

Watershed hydrology affects all facets of the complex life history of Roanoke striped bass. Long-term research in the Roanoke River suggests that river flow directly influences (1) seasonal timing and location of spawning (Hassler et al. 1981); (2) daily or hourly patterns in spawning activity (Rulifson, unpublished data); (3) egg transport downstream (Kornegay 1981; Kornegay and Mullis 1984; Rulifson et al. 1988); (4) larval transport and feeding (Rulifson et al. 1988); (5) location of primary nursery grounds in Albemarle Sound (S. E. Winslow and L. T. Henry, DMF, unpublished data); and (6) concentration and distribution of zooplankton (Rulifson et al. 1988).

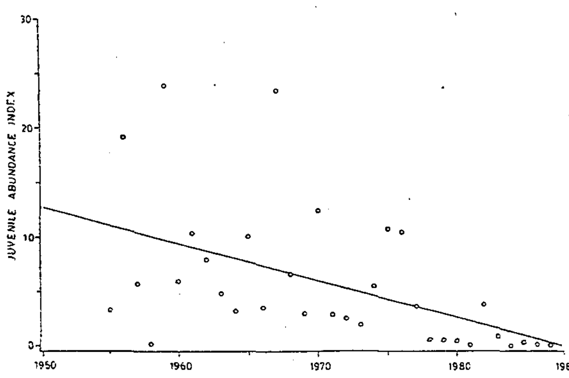

FIGURE 7.—The relationship of the striped bass juvenile abundance index to years postimpoundment (1955–1987).

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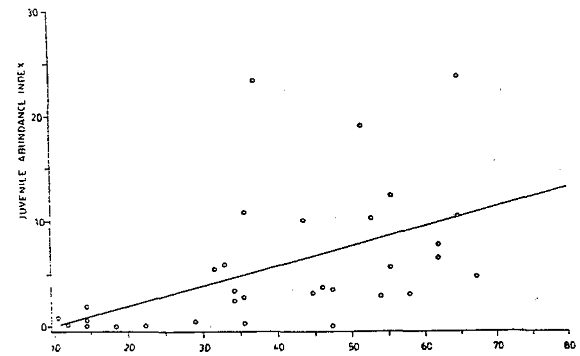

FIGURE 8.—The relationship of the juvenile abundance index to the percentage of days that Roanoke River flows were within the negotiated Q1–Q3 bounds (PDAYS). Q1 and Q3 are historical 25 and 75% quartiles of daily flow, respectively.

Studies in the Sacramento–San Joaquin system have also demonstrated that water flows affect striped bass in various ways. Young striped bass were farther upstream during years of high salinity and low outflow than in years of low salinity and high outflow (Turner and Chadwick 1972). Also, the amount of outflow partially determined the time of striped bass spawning by affecting water temperature, particularly in the Sacramento River above the delta. Turner and Chadwick (1972) hypothesized that food availability, reflecting some combination of effects of striped bass distribution, detritus–nutrient input, and spawning time was the most probable mechanism influencing the flow–survival relationship. Stevens et al. (1985) believed that phytoplankton development had been suppressed by the use of the major delta channels as conduits to carry increasing amounts of water to diversions in the south delta.

There is also evidence that water flow affects the abundance of adult striped bass. Stevens (1977) found that the mean June–July delta flow accounted for 63% of the variation in catch per angler-day at Suisan Bay, California.

Flooding events of the lower Roanoke River below the reservoirs are controlled for the most part by the manner in which water is released from the reservoirs during hydroelectric plant operation rather than by nature. Natural flooding events in the Roanoke River before construction of the reservoirs tended to be of larger magnitude but of shorter duration than postconstruction flooding events. The overall result of reservoir management is moderation of the floodwaters, essentially through controlling rising waters so that flooded areas are restricted primarily to the floodplain. The excess freshwater input to the watershed upstream is held by the reservoirs and released over

TABLE 7.—Mean percent of days that Roanoke River flow was within the negotiated Q1–Q3[a] bounds (PDAYS) and striped bass juvenile abundance index (JAI) within years with poor (<75.0%) and good (75.0–100.0%) egg viability. Means for PDAYS and JAI were significantly different between egg viability classes ($P \le 0.05$; t-test).

Percent of viable eggs	Number of years	PDAYS Mean	SD	JAI Mean	SD	Egg viability Mean	SD
<75.0	13	31.88	15.49	2.45	3.71	50.13	14.90
75.0–100.0	15	45.09	14.58	6.93	5.38	88.78	5.45

[a] Q1 and Q3 = historical 25 and 75% quartiles of daily flow, respectively.

prolonged periods, thus extending the flooding event downstream. This phenomenon is evident in the USGS flow record, particularly since 1977, and was significant in our analyses.

We conclude that the best young-of-year recruitment to the forming year-class occurs when Roanoke River flows are moderate (5,000–11,000 ft^3/s), which falls within the moderate range of river flow values discussed by Turner and Chadwick (1972) for the Sacramento–San Joaquin system. This conclusion reaffirms the results of analyses by Hassler et al. (1981), who stated that the best JAI values occurred in years of relatively low to moderate flow (5,092–9,741 ft^3/s). Also of importance is the number of days in sequence that river flows remain moderate (i.e., within the historical Q1–Q3 bounds); we will investigate this aspect over the next several years.

Because the Roanoke–Albemarle striped bass population evolved and thrived under natural, unregulated conditions before reservoir construction, the Roanoke River Water Flow Committee believes that making the river flows consistent with preimpoundment flows will likely improve production of striped bass. Indeed, this was believed to be the case in 1988, when river flow conditions followed the historical Q1–Q3 bounds over 60% of the days and resulted in the highest egg viability (89%) since 1972 and the largest JAI value (4.09) since 1976 (Table 1).

The Committee's recommendations for a controlled flow regime resembling preimpoundment conditions (Table 2) were accepted by the U.S. Army Corps of Engineers (Wilmington District) and Virginia Power Company for 4 years (1989–1992). Although the duration of the flow regime is much shorter than desired, the revised plan allows the new set of conditions to operate within the guidelines of the original license from the Federal Energy Regulatory Commission. In addition to the target flows, and upper and lower limits (Table 2), the Committee underscored the importance of moderate, sustained flows during the actual spawning period. Sustained flow refers to minimal flow variation (as much as physically possible) within hours as opposed to days; therefore, a maximum rate of change in flow of 1,500 ft^3/s per hour was recommended.

Acknowledgments

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APPENDIX E.

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Instream Flow and Striped Bass Recruitment in the Lower Roanoke River, North Carolina

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ABSTRACT: Hydroelectric generation by upstream facilities has changed the springtime instream flow patterns of the lower Roanoke River in North Carolina, which contains the primary spawning grounds of a large population of striped bass (*Morone saxatilis*). The continued inability of striped bass to form a dominant year class led to an examination of the potential effects of reservoir discharge on the species. Postimpoundment instream flow data (1965–1986) from U.S. Geological Survey records were subset into two categories based on values of annual striped bass juvenile abundance index (JAI) in the Albemarle Sound: good recruitment years (JAI > 5.0) and bad recruitment years (JAI < 5.0). Seasonally, only data from 1 March to 30 June (full striped bass spawning window) were used in modeling. Data were subjected to time series analysis using the univariate autoregressive integrated moving average technique. The flow pattern in good recruitment years resembled a moderate plateau of discharge in March and early April, followed by a drop to a lower plateau. This pattern was similar to that determined for preimpoundment years (1912–1950). Instream flows in bad recruitment years remained higher throughout the 4-month period and did not have the characteristic drop to the lower plateau. Changes in the water release schedule of upstream hydroelectric facilities during the striped bass spawning season were recommended and accepted by the U.S. Army Corps of Engineers and the public utility for a 4-year trial period.

KEY WORDS: Impoundments, instream flow, recruitment, Roanoke River, striped bass, time series analysis.

INTRODUCTION

Impounding coastal rivers of the United States for hydroelectric generation, improved navigation, and water diversion projects has caused a number of problems for anadromous fish species, particularly as this practice restricts or blocks access to historical spawning grounds. In southeastern coastal states, more than one-third of the rivers containing anadromous species have spawning problems because of dams and impoundments; nearly half (46%) of the impounded rivers have inadequate fishways, and more than one-third (38%) have poor water release schedules during spawning seasons (Rulifson et al. 1982a). Many of these dams are approaching the

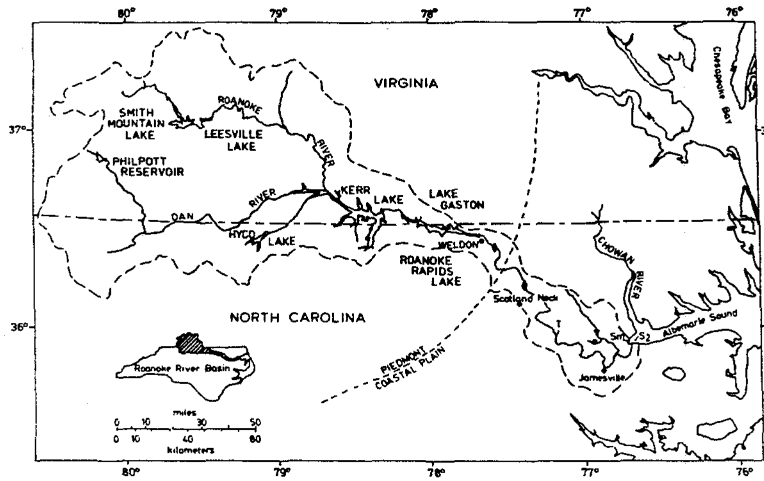

FIGURE 1. *The Roanoke River watershed. Dashed line = approximate location of fall line; diamonds = locations of USGS water quality and gaging stations; inverted triangle = USGS water quality station; T = upstream limit of tidal influence; S2 = mean upstream intrusion limit of saltwater front (200 mg/L chloride); Sm = maximum upstream intrusion of saltwater front (Giese et al. 1979).*

end of their Federal Energy Regulatory Commission (FERC) licenses and must undergo environmental assessments before new licenses are issued.

In North Carolina, the Roanoke River is one of five rivers containing anadromous fish species that have problems related to dams and impoundments. Natural streamflows were altered in 1952 with the completion of the John H. Kerr Reservoir built for flood control at river mile (RM) 179 (Figure 1). Apparently, closure of the dam resulted in landlocking anadromous striped bass (*Morone saxatilis*), which spawn at several locations in tributary rivers upstream. Construction of the most downstream facility (Roanoke Rapids Dam) at RM 137 in 1955 blocked access to the remaining historical spawning grounds (McCoy 1959). Gaston Dam, positioned between Kerr Reservoir and Roanoke Rapids, was completed in 1963. Of the six impoundments on the watershed, Kerr Reservoir is the most important to the lower river and Albemarle Sound because of its storage capacity and direct influence on the operation of the two hydroelectric dams downstream. Regulation of flow by the reservoir system virtually precludes saltwater intrusion into the lower Roanoke River except in cases of extreme drought or unusual wind-tide conditions (Giese et al. 1979).

Historically, the Roanoke River/Albemarle Sound system supported the largest striped bass population south of Chesapeake Bay and annually contributed approximately 93% of the striped bass landings in North Carolina (Rulifson et al. 1982b). The Roanoke population is an important contributor to the anadromous stock of the east coast of the United States, ranking third behind Chesapeake Bay and the Hudson River (USDOI and USDOC 1987). In the late 1970's, the Roanoke population suffered a precipitous decline in numbers of harvestable adults, followed by 11 years of poor egg viability downstream of the spawning grounds and thus poor recruitment of juveniles (Manooch and Rulifson 1989).

Concern about water release from these reservoirs to meet instream flow needs for wastewater dilution and protection of the striped bass resource resulted in the formation of the Steering Committee for Roanoke River Studies in 1955. Results and recommendations of the studies were published (Fish 1959). Minimum flow criteria

for the April-June spawning period were established in the original Federal Power Commission license; a Memorandum of Understanding (MOU) was signed in 1971 by three agencies: U.S. Army Corps of Engineers (Corps), North Carolina Wildlife Resources Commission, and Virginia Power Company (Manooch and Rulifson 1989). The MOU allows some flexibility in water releases; however, during the spawning season a minimum flow of 2,000 cfs is required along with enough additional water release from Kerr Reservoir to maintain a 13-ft level at the Weldon river gage downstream (near the spawning grounds). At any given time, the reservoir operators can double or halve the water discharge over a 1-hour period. The MOU did not stipulate guidelines for maximum river flows.

The continued inability of Roanoke striped bass to form a dominant year class, and concerns about increasing water use by municipalities, industry, and agriculture, resulted in the formation in 1988 of the Roanoke River Water Flow Committee (Flow Committee). The objective of the Flow Committee was to investigate the potential effects of reservoir discharge on downstream resources and users; striped bass was a key resource species because of the extensive data base available. Extensive hydrological and ecological information (Manooch and Rulifson 1989; Rulifson and Manooch 1990a) were compiled in two Flow Committee reports. The relationship between reservoir discharge and juvenile striped bass recruitment in the Roanoke/Albemarle system was evaluated in a subsequent publication (Rulifson and Manooch 1990b).

Recommendations for rates of reservoir discharge during the striped bass spawning period were produced by the Flow Committee and accepted by the Corps and Virginia Power Company for a 4-year trial period. These recommendations were based on examination of preimpoundment data from 1912 to 1950, assuming that the average preimpoundment flows resulted in moderate to good striped bass recruitment (Hassler et al. 1981; Rulifson and Manooch 1990b). During the process of developing flow recommendations, the central question involved aspects of what flow patterns resulted in good striped bass recruitment or in bad or reduced recruitment, because no data on juvenile striped bass recruitment were available for preimpoundment years.

The purpose of the study described herein was three-fold: (1) to describe the patterns of average river flows in postimpoundment years for good and bad recruitment years of juvenile striped bass; (2) to compare these flow patterns to the average preimpoundment flow pattern; and (3) to relate these patterns to available biological information. It was these comparisons that established the similarity in average river flow patterns between the postimpoundment good recruitment years and that of the preimpoundment years, thereby constituting the justification for basing the recommended flow regime of the Flow Committee on preimpoundment median flows. Results presented here are a condensed version of those presented in the original report. Slight revisions in the data set since the initial analysis have caused some changes in the numerical representation, but results and conclusions remain the same.

METHODS

Description of the Watershed

The Roanoke River in Virginia and North Carolina drains an area of 9,666 mi^2 (Moody et al. 1985) with headwaters in the Blue Ridge Mountains of central Virginia, flowing east-southeast into northcentral North Carolina, where it empties into Albemarle Sound in the northeastern part of the state (Figure 1). Major tributaries are the Dan, Mayo, Smith, and Hyco rivers. The main stem of the Roanoke is formed by the confluence of the Dan and Staunton rivers approximately 200 mi above the river mouth. Between RM 150 and RM 128, the Roanoke crosses the fall line between the Piedmont Plateau and the broad and flat Coastal Plain. The watershed downstream of the last dam is an extensive floodplain, considered to be the largest and least disturbed bottomland hardwood forest ecosystem remaining in the mid-Atlantic region (Manooch and Rulifson 1989).

Average daily flow of the Roanoke River is about 8,500 cfs, representing about 87% of the freshwater input to the coastal watershed (Giese et al. 1979). Six major dams regulate downstream flows; total water volume held by the reservoirs is 4,372,000 acre-feet or 1,420,000 million gallons (MG) (Moody et al. 1985). Flows were natural and unregulated until August 1950, when construction activities of the Philpott project in Virginia and the Kerr project downstream first affected flow records at the U.S. Geological Survey (USGS) gage at Roanoke Rapids, North Carolina. Permanent regulation of river flow downstream of RM 137 occurred with the closure of the gates at the Roanoke Rapids project on 25 June 1955 (Fish 1959).

Data Sources, Definitions, and Adjustments

River Flow. Water flow (cfs) was measured at USGS gage 0208050, located 2.8 mi downstream from the Roanoke Rapids Dam. Original data were collected every 15 minutes; the data set used for our analyses included the daily averages from 1912 to 1986 published in USGS annual reports. Preimpoundment refers to the period 1912–1950; postimpoundment is the period 1955–1986. We only used data beginning in 1965 for postimpoundment analyses, as it was the first year after all reservoir construction was completed. The period from 1 March to 30 June was used in the analysis because it encompasses striped bass prespawning, spawning, and postspawning activities. The data set is extremely variable from year to year. To eliminate extreme flow values, the highest 10% and lowest 10% of values were deleted, and the analysis was performed on the trimmed daily average flows. In other words, the data for 1 March in the analysis of preimpoundment data represent the trimmed average values for all 1 March flows for the preimpoundment period. Averages determined by the same method were obtained for good striped bass recruitment years and for bad recruitment years. Each year represents a replication of the time series, an approach that is appropriate for repeated measure analysis (Wong and Miller 1990). This method does not completely preserve the flow relationships of individual years, but that preservation is not necessary because we are interested in average seasonal patterns in streamflow during the spawning season.

Juvenile Abundance Index. The juvenile abundance index (JAI) reflects the relative success in juvenile recruitment for the developing year class of striped bass. The JAI for Roanoke/Albemarle striped bass was established in 1955 by W. W. Hassler (personal communication), and the methods have remained essentially unchanged since that time (Hassler et al. 1981). Briefly, standard (semiballoon) trawls were used biweekly from July through October at seven fixed stations in western Albemarle Sound, for a maximum of 56 samples per year. Numbers were expressed as the average number of juvenile striped bass per unit of effort (15-minute tow). Rulifson and Manooch (1990b) provide a detailed description.

Juvenile abundance index values were used to divide the postimpoundment river flow data into good recruitment years and bad recruitment years. A JAI value of 5.0 was selected as the division between good and bad recruitment based on statistical analyses of the JAI trends since 1955 as reported by Manooch and Rulifson (1989) and Rulifson and Manooch (1990b). We used only JAI values beginning in 1965, the year following the beginning of commercial hydroelectric generation by the Gaston Dam facility (Table 1). Good recruitment years were 1965, 1967, 1968, 1970, and 1974–1976. The bad recruitment years were 1966, 1969, 1971–1973, and 1977–1986.

Time Series Analysis. Because of its ability to handle many different patterns, the univariate autoregressive integrated moving average (ARIMA) approach was used to model the average flow (Box and Jenkins 1976). This technique is used routinely in assessing trends in fisheries data (Van Winkle et al. 1979; Saila et al. 1980; Mendelssohn 1981; Jensen 1985, Jeffries et al. 1989). Surveys of the use of time series analysis, especially multivariate time series analysis, in the investigation of water flows are

summarized in Yevjevich and Harmancioglu (1985) and Hipel (1985).

Let y_t be the adjusted average flow series with the observations taken at equally spaced intervals $t = 1, 2, \ldots n$. Then the general form of the ARIMA-type model is

$$y_t = \Sigma\, \Phi_i y_{t-i} + \Sigma\, \Theta_i a_{t-i} + a_t$$

where Φ_i and Θ_i are estimated autoregressive and moving average parameters, respectively; a_{t-i} is a past error term, indicating the carryover of random shocks from one time period to the next; and a_t is a random error term that is independently and identically distributed with a zero mean and constant variance (Kendall and Ord 1990). This is commonly referred to as "white noise" (Granger and Newbold 1986). In order to estimate ARIMA models, it is necessary that the series y_t be stationary; that is, the joint density function of y_t, y_{t-i} for all i depends only on the relative locations of the observations (Kendall and Ord 1990). Practically, the stationarity condition requires that y_t have a constant mean (no long-term trend) and variance. If these conditions do not hold, the data must be transformed so that they do hold. The typical method of eliminating trend is to take one or more differences $\Delta^i y_t$ where

$$\Delta^1 y_t = (y_t - y_{t-1}) \ldots$$
$$\Delta^2 y_t = (\Delta^1 y_t - \Delta^1 y_{t-1}) \ldots \text{etc.}$$

In our analysis, all flow data had a homogeneous variance, but, for the preimpoundment period of 17 April to 12 May, a trend was present and was removed by taking the first difference.

Analysis of the data from the postimpoundment good recruitment years indicated that, in order to estimate an appropriate model, the segments 1 March to 30 April and 1 May to 30 June had to be analyzed separately. Likewise, it was necessary to estimate three different models for the preimpoundment data. The preimpoundment segments were 1 March to 16 April, 17 April to 12 May, and 13 May to 30 June. Only one model was required for the bad recruitment year data.

TABLE 1

The Hassler juvenile abundance index for Roanoke/Albemarle striped bass for the postimpoundment period (1965–1986) (after Rulifson and Manooch 1990b).

Year	JAI
1965	10.08
1966	3.48
1967	23.39
1968	6.59
1969	2.99
1970	12.45
1971	2.86
1972	2.52
1973	1.95
1974	5.52
1975	10.80
1976	10.52
1977	3.63
1978	0.59
1979	0.55
1980	0.46
1981	0.09
1982	3.80
1983	0.84
1984	0.36
1985	1.24
1986	0.14

Building ARIMA models of stationary time series involves: (1) identifying model structures that are consistent with the auto- and partial autocorrelation functions, (2) estimating the appropriate Φ_i and Θ_i, and (3) testing the coefficients for significance with the usual *t*-test. If the coefficients are significantly different from zero, the residual autocorrelation function is examined for any remaining pattern. If the *Q* statistic for the residual autocorrelation function is not significantly different from zero, usually at the 5% level, the residuals are white noise and the model is an acceptable representation of the stochastic process driving the time series. If *Q* is significant, the model is reformulated, reestimated, and rechecked. In other words, both the *Q* statistic and the *t*-ratios indicate that a model is appropriate.

RESULTS AND DISCUSSION

Postimpoundment Years

Depending on the data set, either one or several models were necessary to adequately characterize springtime Roanoke River flow patterns. Flow data comprising the postimpoundment good recruitment years were divided into two segments: 1 March to 30 April, and 1 May to 30 June (Table 2, Figure 2). Data analysis of the flow records for bad juvenile recruitment indicated that only one model was required (Tables 2 and 3, Figure 3). Immediately apparent is that the average instream flow in years of bad juvenile recruitment remains higher throughout the 4-month period and does not taper off to the lower plateau as shown in years of good recruitment (Figure 2). We argue below that tapering off to the lower plateau during the spawning period is critical to the survival of larval fish.

The expanded time series model for segment 1 of river flow in good recruitment years indicates that the average daily flow in time t is related to that at time $t-1$, $t-6$, and $t-7$ (Table 2). In other words, today's average river flow is a function of yesterday's, that of 6 days ago, and 7 days ago. Similarly, for segment 2 of river flow in good recruitment years, the average flow at time t is related to that at time $t-3$ and $t-4$. The expanded model for river flow in years of bad recruitment indicates that flow at time t is a function of the flow at $t-1$ only (i.e., yesterday's flow [Table 2]).

TABLE 2

Expanded time series model equations for Roanoke River average instream flow in postimpoundment years of good striped bass recruitment (JAI > 5.0, n = 7) and bad recruitment (JAI < 5.0, n = 16). Refer to Appendix for model equation derivations.

Good recruitment years

Segment 1 (1 March–30 April):

$$y_t = 0.58y_{t-1} + 0.35y_{t-6} - 0.2y_{t-7} + 1{,}475 + a_t$$

Segment 2 (1 May–30 June):

$$y_t = 0.89y_{t-1} - 0.35y_{t-3} + 0.31y_{t-4} + 900 + a_t$$

Bad recruitment years (1 March–30 June):

$$y_t = 0.84y_{t-1} + 1{,}560 + a_t$$

Comparison of river flow models for good and bad striped bass recruitment indicates both similarities and differences. Both sets of models contain a positive term that relates average flow at time t and time $t-1$ (Table 3). This positive association between the average flows on successive days indicates that the average instream flow changes slowly from day to day. Thus, in both good and bad recruitment years, average flows on adjacent days were similar.

Models differ in that those for the good recruitment years have higher order autoregressive terms, whereas the model for bad recruitment years lacks those terms (Table 2). The AR6 and AR7 terms reflect the weekly pattern of electricity demands; less electricity is needed on weekends than during the week. Also, stabilization of the lake level for weekend recreational use would result in a lower instream flow on weekends and reinforce the observed pattern. The appearance of the AR3 and AR4 terms in the segment 2 model for good recruitment years can occur for two reasons. First, the harmonics of significant cycles often are reflected in time series analysis. Data indicate a 7-day cycle in the water release schedule at Roanoke Rapids Dam. The harmonic of 7 days is 3.5 days, a number that is not an option when trying to apply the time series model. Consequently, the harmonic would likely appear in the adjacent lag coefficients 3 and 4. Second, another possible explanation is that May and the first portion of June are transition months for electricity generation in the utility service area; that is, a time when peaks in electrical demand are not well defined and when cool days alternate with warmer ones. However, these explanations do not seem adequate in light of the known pattern of electrical demand.

Interestingly, there is no indication of electrical generation patterns in the model for years of bad juvenile recruitment (Table 2). This probably results from excessively high or excessively low springtime river flows. Rulifson and Manooch (1990b) reported that poor striped bass recruitment in western Albemarle Sound occurred in

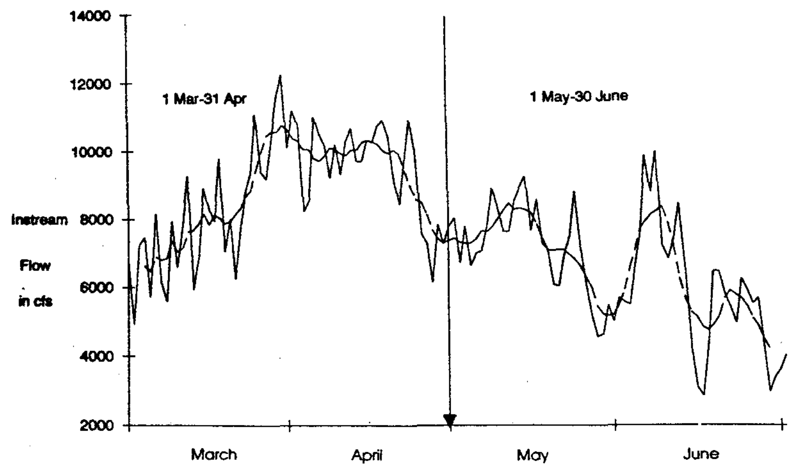

FIGURE 2. *Average daily instream flow (and 7-day moving average) of the lower Roanoke River for postimpoundment years (1965–1986) that had good juvenile striped bass recruitment (JAI > 5.0).*

years of excessively high or low flows in the lower Roanoke River. Under either of these conditions, the connection between electricity generation and river flow would be tenuous at best. During drought years, there would not be enough water to vary reservoir releases to match peak electrical demand. In flood years, water is released at the maximum rate possible (20,000 cfs) to regain flood storage capacity in Kerr Reservoir, regardless of electrical demand. In neither case would electrical generation change river flow, but in both instances the consecutive daily flows would be similar.

It is important to note at this point that the random walk model,

$$y_t = y_{t-1} + a_t,$$

is also an adequate description of average river flow in bad recruitment years. Indeed, there is no statistically significant dif-

TABLE 3

Parameters of the ARIMA models for Roanoke River average flows in postimpoundment years (1965–1986) as related to striped bass recruitment.

Statistical parameters	Good recruitment (JAI > 5.0) 1 Mar–30 Apr Value	*t* ratio	Good recruitment 1 May–30 Jun Value	*t* ratio	Bad recruitment 1 Mar–30 Jun Value	*t* ratio
Differencing for stationarity	0		0		0	
Constant term	1,475		900		1,560	
Autoregressive lag coefficients						
AR1	0.58	5.51	0.89	13.06	0.84	16.98
AR3			−0.35	2.63		
AR6	0.35	2.71				
Q	10.16		9.66		17.06	
P > *Q*	0.337		0.38		0.09	

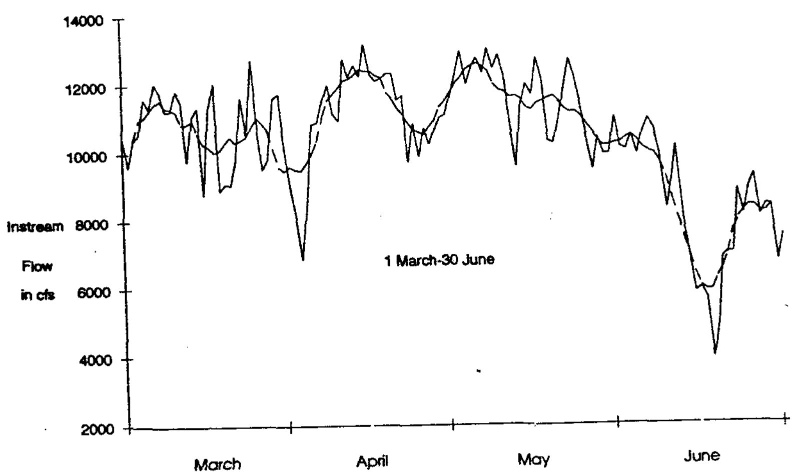

FIGURE 3. *Average daily instream flow (and 7-day moving average) of the lower Roanoke River for postimpoundment years (1965–1986) that had poor juvenile striped bass recruitment (JAI > 5.0).*

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ference between the residual variation of the random walk model and the model presented in Table 2. In a very real sense, then, river flow in years of poor striped bass recruitment can be described as a random walk, because day-to-day variability in streamflow is random. This pattern is quite different from the organized pattern observed for river flows in years of good striped bass recruitment.

Preimpoundment Data

Although preimpoundment data on striped bass are sparse, there is every indication that the Roanoke/Albemarle striped bass population evolved and thrived under natural, unregulated river flow conditions (Rulifson and Manooch 1990b). The Roanoke River Water Flow Committee believed that making postimpoundment instream flow patterns consistent with preimpoundment patterns would probably improve production of striped bass. To address this hypothesis, we modeled the preimpoundment flow data (1912–1950) and compared the patterns to those obtained in Table 2. Preimpoundment data analysis indicated that average flows should be divided into three segments to produce the appropriate models: 1 March to 16 April, 17 April to 12 May, and 13 May to 30 June. The first segment (Figure 4) could be described as a stationary plateau with a mean of 8,434 cfs and a standard deviation of 178 cfs. The second segment could be described as a stochastic downward trend characterized by a day-to-day change of −86 cfs with a standard deviation of 366 cfs. Finally, the third segment is a second, lower plateau with a mean of 6,146 cfs and a standard deviation of 450. This pattern is indicative of a typical spring, characterized by an early flood followed by gradual diminishing instream flow that finally stabilizes at a lower plateau.

Comparing the preimpoundment flow patterns to those obtained for good and bad years of striped bass recruitment, we can visually identify the similarities in patterns between preimpoundment flows (Figure 4) and those observed in years of good recruitment (Figure 2). However, there are two general differences: (1) the average instream flow in postimpoundment years is higher throughout the 3-month period and has a greater standard deviation than preimpoundment data, and

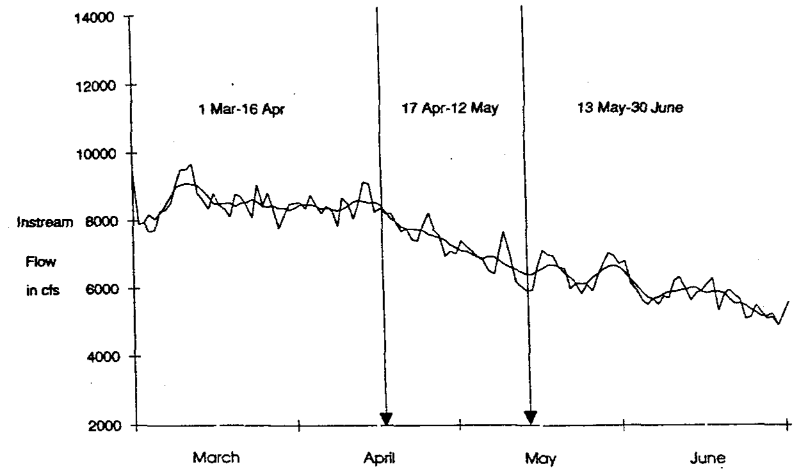

FIGURE 4. *Average daily instream flow (and 7-day moving average) of the lower Roanoke River for preimpoundment years (1912–1950).*

(2) the March postimpoundment pattern is characterized by a steep upward trend rather than as a part of a plateau characteristic of the postimpoundment data. These differences no doubt reflect water storage in the reservoirs during the late winter and the gradual increase in streamflow in March to stay within the operational water level dictated by the Corps. The downward trend in river flow toward the May–June plateau is similar for both data sets. All similarities disappear when preimpoundment patterns (Figure 4) are compared to those observed in years of poor striped bass recruitment (Figure 2).

The ARIMA models for segment 1 and segment 3 of the preimpoundment period illustrate that the river flow today is similar to the river flow yesterday on the average (Tables 4 and 5). That is, the only parameter significantly different from zero was the autoregressive parameter at $t - 1$ (AR1). The import of this is that there were no large changes from one day to the next and no influences from other time lags in the natural state of the river. It is also striking that, even though the first autoregressive coefficients for the first and third segment models are different, the model structure is identical. Again, the fundamental characteristic of the first and third segments of the preimpoundment average flow is the steadiness of that flow.

During the second segment, the preimpoundment model shows that today's flow equals yesterday's flow minus 86 cfs. It should be noted that first differencing removes an estimated trend (rather than the unknown actual trend) and thereby may introduce some spurious correlation into the differenced series. This is not a problem here, however, because there are no significant autocorrelations present in the differenced series.

TABLE 4

Expanded time series model equations for Roanoke River average instream flow in preimpoundment years (1912–1950). Refer to Appendix for model equation derivation.

Segment 1 (1 March–16 April):

$$y_t = 0.48y_{t-1} + 4{,}396 + a_t$$

Segment 2 (17 April–12 May):

$$y_t = y_{t-1} - 86 + a_t$$

Segment 3 (13 May–30 June):

$$y_t = 0.81y_{t-1} + 1{,}065 + a_t$$

TABLE 5
Parameters of the ARIMA models for Roanoke River average instream flows for preimpoundment years (1912–1950).

Statistical parameters	Segment 1		Segment 2		Segment 3	
	1 Mar–16 Apr		17 Apr–12 May		13 May–30 Jun	
	Value	*t* ratio	Value	*t* ratio	Value	*t* ratio
Differencing for stationarity	0		1		0	
Constant term	4,396		−86		1,065	
Autoregressive lag coefficients						
AR1	0.48	3.73			0.81	10.19
Q	8.25		16.32		16.2	
$P > Q$	0.61		0.77		0.094	

Recommended Flow Regime

Having produced the results described above, the challenge to the Flow Committee was to design a water release schedule that would approximate the preimpoundment flow pattern. This was deemed necessary because the spring flood is known to stimulate spawning behavior in anadromous fish and wash additional nutrients and food into the stream. The decline to the lower plateau later in the season also is necessary to ensure that striped bass larvae reach Albemarle Sound at the proper stage of maturity (Rulifson et al. 1988).

The models for the preimpoundment average flows will reproduce these flows up to a random error. Therefore, the models could have been used to specify a mean flow for each day in the period. However, this approach ignored two facets: any water release schedule must be easy to understand and implement, and it must also provide flexibility for operators at the dam. The initial flow values recommended by the Flow Committee were obtained by calculating the daily median flows of the preimpoundment period from 1912 to 1950. To provide flexibility in water release schedules, upper and lower discharge limits around the daily median were set to the historical 25th (Q1) and 75th (Q3) percentiles (first and third quartiles) of the median flow (Table 6). The intended management objective was to have the Corps and Virginia Power Company adjust water releases to the daily target flow, but flows could be adjusted 25% above or below the target value as needed to meet hydroelectric and reservoir management needs.

The original set of recommended flows from 1 March to 30 June was unacceptable to the Corps because the time frame was not compatible with the guidelines mandated within the FERC license requirements agreed to by the Corps, Virginia Power Company, and the North Carolina Wildlife Resources Commission. Therefore, a second, negotiated set of target values was constructed that was acceptable to the Corps and Virginia Power Company (Table 7). The negotiated Q1-Q3 flow regime was a much shorter period than the original recommendation, but was within the FERC license guidelines of 1 April to 15 June. The water release schedule was changed from weekly to biweekly adjustments as an additional management compromise. In addition to recommending minimum, maximum, and target flows, the Flow Committee recommended that hourly variation in discharge should not exceed 1,500 cfs to provide moderate, sustained flows during the actual spawning period (Manooch and Rulifson 1989). The negotiated set of criteria will be implemented for a 4-year trial period (1989–1992), after which the Flow Committee will compile the results and issue a formal report detailing management options.

Although this management approach may not be new, certainly the Flow Committee's efforts were enhanced by the availability of long-term data bases, both physical and biological, for trend analyses. Better predictability about how springtime instream flow patterns affect striped bass spawning could have been obtained with long-term biological information in preimpoundment years, but this was not an option. We are more fortunate than most in having had the foresight to initiate and maintain long-term postimpoundment data sets to enable present and future management decisions.

Elfring (1990) expresses well the ultimate controversial question surrounding most hydroelectric facilities facing FERC relicensing: should hydroelectric operations be set to maximize power production, or should some operational compromises be in place to protect environmental values? In the case of the lower Roanoke River, natural resources, such as timber, agriculture, waterfowl, fisheries, and both small and large game, provide the basis for multimillion dollar industrial, commercial, and recreational uses (Manooch and Rulifson 1989). Hopefully, the approach of the Roanoke River Water Flow Committee and its efforts to understand the resource will be successful in providing the answer to this difficult question.

TABLE 6
Roanoke River instream flow criteria (cfs) initially recommended by the Roanoke River Water Flow Committee (Manooch and Rulifson 1989). Q1 = 25% low flow value; Q3 = 75% high flow value.

Approximate dates	Median or target flow	Q1	Q3
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[a]	7,663
7–13 Jun	5,139	3,701[a]	7,814
14–20 Jun	5,124	3,871[a]	7,301
21–27 Jun	4,447	3,394[a]	6,607
28 Jun–4 Jul	4,413	3,058[a]	6,173

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

TABLE 7
Negotiated (Q1-Q3) 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 4-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

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APPENDIX

Below are the steps involved in deriving the expanded equations from the ARIMA coefficients presented in Tables 1 and 3 in the text. The following definitions are required:

y_t = average flow for time t.

B = the backshift operator, that is, $By_t = y_{t-1}$.

a_t = random error term.

The derivations are as follows:

Bad recruitment years:

$$(1 - 0.84B)y_t = 1{,}560 + a_t$$

Clearing the backshift operator and parentheses yields:

$$y_t - 0.84y_{t-1} = 1{,}560 + a_t$$

or

$$y_t = 0.84y_{t-1} + 1{,}560a_t$$

Good recruitment years, segment 1:

$$(1 - 0.58B)(1 - 0.35B^4)y_t = 1{,}475 + a_t$$
$$(1 - 0.58B - 0.35B^4 + 0.2B^5)y_t = 1{,}475 + a_t$$
$$y_t - 0.58y_{t-1} - 0.35y_{t-4} + 0.2y_{t-5} = 1{,}475 + a_t$$
$$y_t = 0.58y_{t-1} + 0.35y_{t-4} - 0.2y_{t-5} + 1{,}475 + a_t$$

Good recruitment years, segment 2:

$$(1 - 0.89B)(1 + 0.35B^3)y_t = 900 + a_t$$
$$(1 - 0.89B + 0.35B^3 - 0.31B^4)y_t = 900 + a_t$$
$$y_t - 0.89y_{t-1} + 0.35y_{t-3} - 0.31y_{t-4} = 900 + a_t$$
$$y_t = 0.89y_{t-1} - 0.35y_{t-3} + 0.31y_{t-4} + 900 + a_t$$

Preimpoundment, segment 1:

$$(1 - 0.48B)y_t = 4{,}396 + a_t$$
$$y_t - 0.48y_{t-1} = 4{,}396 + a_t$$
$$y_t = 0.48y_{t-1} + 4{,}396 + a_t$$

Preimpoundment, segment 2:

$$(1 - B)y_t = -86 + a_t$$
$$y_t - y_{t-1} = -86 + a_t$$
$$y_t = y_{t-1} - 86 + a_t$$

Preimpoundment, segment 3:

$$(1 - 0.78B)y_t = 1{,}065 + a_t$$
$$y_t = 0.78y_{t-1} + 1{,}065 + a_t$$

A RE-EXAMINATION OF PREIMPOUNDMENT FLOWS IN THE ROANOKE RIVER, NORTH CAROLINA

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In a previous issue of the journal *Rivers*, we published a times series analysis of the preimpoundment (1912-1950) and postimpoundment (1965-1986) instream flows of the lower Roanoke River in North Carolina (Zincone and Rulifson 1991), and described how preimpoundment analyses compare to that for years in which juvenile striped bass (*Morone saxatilis*) recruitment was "good" (yearly index greater than five fish per trawl) or "poor" (index less than five fish per trawl) in western Albemarle Sound. Subsequently, an independent analysis of the same data set conducted by others (City of Virginia Beach, Virginia, unpublished documents) indicated a potential problem with the way in which the preimpoundment data were treated prior to the analyses. The purpose of this manuscript is to present a revised analysis of the preimpoundment data presented in the first manuscript.

Daily instream flow data were those published in U.S. Geological Survey (USGS) annual reports recorded by USGS gage 0208050, located 2.8 mi downstream from the Roanoke Rapids Dam, which is the most downstream hydroelectric facility on the watershed. Preimpoundment refers to the period of record from 1912 to 1950, the year in which the Buggs Island (Kerr Reservoir) project at River Mile (RM) 178.7 first affected the natural unregulated instream flow. The postimpoundment period begins in 1955, the year in which the Roanoke Rapids Dam was completed. In the original analysis, we used the period 1965-1987 (the published manuscript erroneously reports 1965-1986), with 1965 representing the first year after completing all reservoir construction activities downstream of Kerr Reservoir (i.e., Gaston Dam situated between Kerr and Roanoke Rapids dams). Seasonally, we examined the period 1 March to 30 June because it encompassed striped bass prespawning, spawning, and postspawning activities. Juvenile striped bass data, represented as a Juvenile Abundance Index (JAI), were those compiled by Hassler et al. (1981) and his subsequent unpublished annual reports through 1986; these data were presented in Table 1 of the original manuscript.

The instream flow data are variable from year to year, especially preimpoundment data. The original manuscript stated that "to eliminate extreme flow values, the highest 10% and lowest 10% of values were deleted, and the analysis was performed on the trimmed daily average flows. In other words, the data for 1 March in the analysis of preimpoundment data represent the trimmed average values for all 1 March flows for the preimpoundment period. Averages determined by the same method were obtained for good striped bass recruitment years and for bad recruitment years". This statement was incorrect in two ways. First, the postimpoundment data set was not trimmed at all; we used the original, unmodified data set because of the "natural trimming" effect to instream flow by the dam. Thus, all postimpoundment analyses presented in Zincone and Rulifson (1991) are correct. (Again, note the dates are 1965-1987, not 1986 as reported). Second, the preimpoundment data set was not trimmed as described above, but rather was modified by removing the top and bottom 10% of the values from the <u>entire</u> data set. This incorrect trimming eliminated a disproportionate number of high flows during the spring of the year, the period which was used in the analysis. To correct this problem, the preimpoundment data set was trimmed correctly and reanalyzed using the univariate autoregressive integrated moving average (ARIMA) approach (Box and Jenkins 1976).

The original analysis indicated that average flows should be divided into three segments to produce the appropriate ARIMA models: 1 March to 16 April, 17 April to 12 May, and 13 May to 30 June. The first segment was described as a stationary plateau with a mean of 8,434 cfs and a standard deviation of 178 cfs. Figure 1 depicts the differences in mean instream flow when the data set was trimmed correctly and incorrectly (original analysis). Immediately apparent is that the daily mean flows from 1 March to 16 April are higher when subjected to the proper trimming, although the plateau pattern remains. After 16 April, the two data sets are for all intents and purposes identical.

To determine the effect of incorrect trimming on the statistical results, we reestimated the ARIMA model for the 1 March to 16 April preimpoundment period. The original analysis produced the equation

(1) $$y_t = 0.48y_{t-1} + 4396 + a_t,$$

which suggests that the river flow of today is similar to the river flow yesterday on average. That is, the only parameter significantly different from zero (t ratio = 3.73, $P<0.05$) was the autoregressive lag coefficient at t - 1 (AR1). Analysis of the correctly trimmed means produced the equation

(2) $$y_t = 0.65y_{t-1} + 10102 + a_t$$

(t ratio=5.52, $P<0.05$). The standard error of the coefficient is 0.12 and that of the intercept is 263.

Comparison of equations (1) and (2) indicates differences in both intercept and the coefficient of the y_{t-1} terms. However, the y_{t-1} coefficient of equation (2) falls within two standard errors of the equation (1) coefficient, indicating that the coefficients are not significantly different. Since these coefficients reflect how the flow changes from one day to the next, we can conclude that there is no significant difference in these analyses in describing how the flows change from day to day during the first preimpoundment period. On the other hand, the intercept terms, which reflect the average flows, are significantly different. Since we already know that the daily (correctly) trimmed means are higher than the incorrectly trimmed means, this result is not surprising.

Examination of the second preimpoundment period (17 April to 12 May) using correctly trimmed means indicates that a random walk model is adequate to describe the flows of this period, as was reported in the original manuscript.

Interestingly, with the correctly trimmed means, the random walk model also is sufficient to explain mean flows of the third (13 May-30 June) preimpoundment period. Thus, we now conclude that, like the good (JAI>5.0) postimpoundment years, the preimpoundment data should have been modeled using two, not three subperiods. Using two subperiods, the first is represented by a plateau higher than that of the original analysis; the second subperiod represents a long decline from the high early spring plateau of instream flow to the lower summer plateau of low instream flow. Thus, the reanalysis of data trimmed correctly indicates a <u>stronger</u> resemblance between preimpoundment years and postimpoundment good years.

As stated earlier, the analysis for postimpoundment data did not change from the original manuscript. Briefly, there were two major differences in flow characteristics between postimpoundment years of good recruitment and poor recruitment. First, the bad recruitment year model was only one period (1 March to 30 June). Essentially, river flow in years of poor striped bass recruitment can be described as a random walk, because day-to-day variability in streamflow is random. This pattern is quite different from the organized pattern for the years of good striped bass recruitment and for preimpoundment data. Second, streamflow remains at a high level from 1 March through May, dropping in volume during June. This may reflect the poor recruitment of juvenile striped bass during high flow years, as reported by Hassler et al. (1981).

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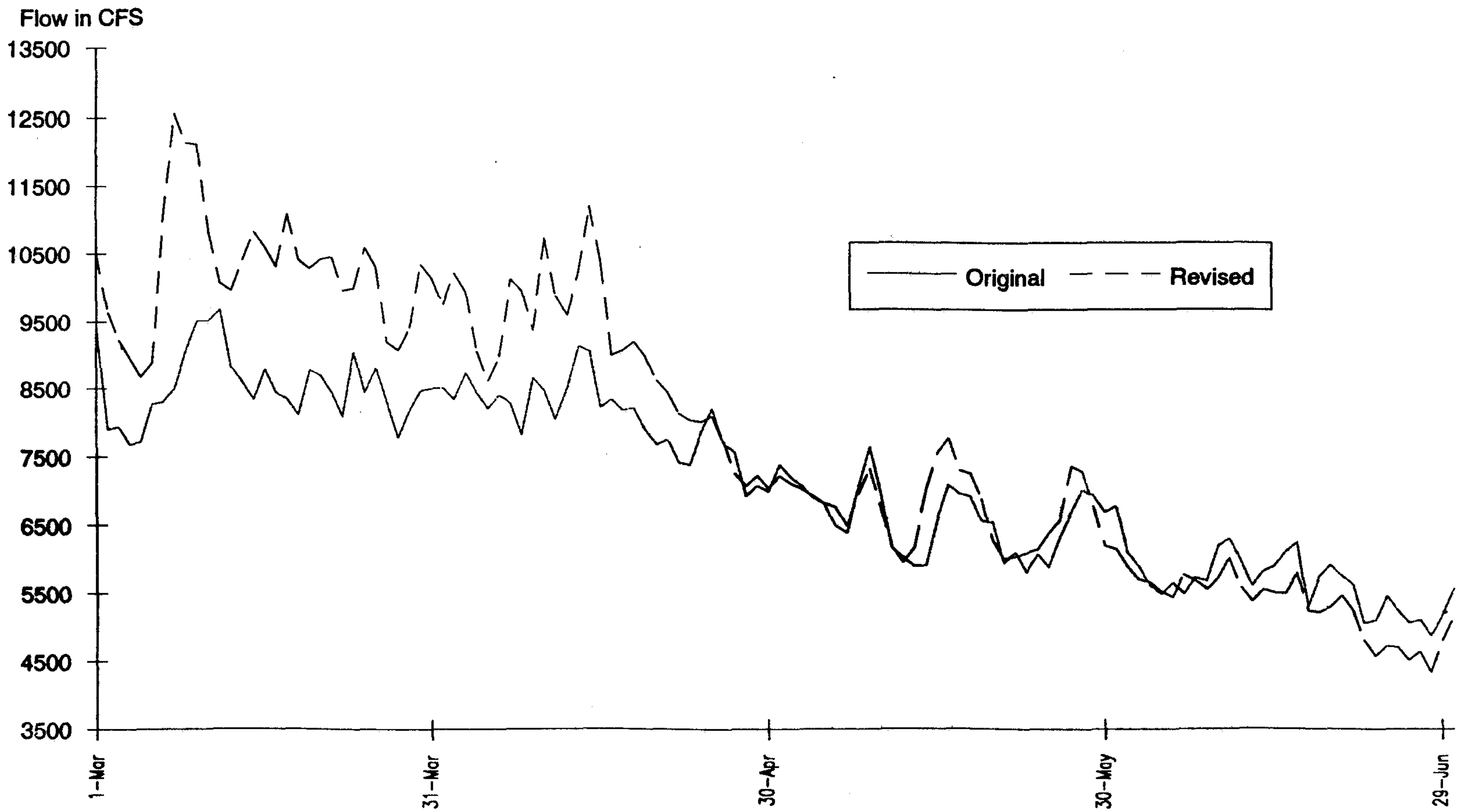

Figure 1. Average daily instream flow of the lower Roanoke River for preimpoundment years (1912-1950) plotted using the original (incorrectly trimmed) data and the correctly trimmed data (after Zincone and Rulifson 1991, Figure 4).

APPENDIX F

RECONCILIATION OF THE STRIPED BASS JUVENILE ABUNDANCE INDICES BY NCSU AND N.C. DIVISION OF MARINE FISHERIES FOR YEARS 1982-1987

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In the mid-1950s, Dr. W.W. Hassler of North Carlolina State University developed a method to determine the relative success of young-of-the-year (YOY) striped bass recruiting to the forming year class in western Albemarle Sound. The Juvenile Abundance Index (JAI) was initiated by Hassler in 1955 and was continued through 1987. The juvenile abundance estimation methods remained essentially unchanged during that time. The JAI was located in western Albemarle Sound extending about 12 miles eastward; the area contained seven permanent sampling stations. Samples were taken every two weeks, using a standard trawl, starting in July and ending in October each year. Each tow was for 15 minutes at a towing speed of about 2.75 miles per hour. At the end of the sampling season, the annual JAI was expressed as the average number of YOY striped bass per unit of effort.

In 1982, the North Carolina Division of Marine Fisheries (DMF) initiated their own JAI survey by using the same methods and stations used by Hassler. Data were collected concurrently with Hassler for the period 1982 through 1987. After 1987, the DMF index was the only one available and it has been continued to the present time in the same manner, and in most cases using DMF personnel formerly employed by Hassler to conduct his survey each year.

Phalen (1988) statistically compared the two data sets to validate similarities in trends of the two indices. Recently, these comparisons have been closely examined and questioned. Therefore, the purpose of this manuscript is to reexamine the striped bass JAI data of both NCSU and DMF during the period 1982-1987.

Rather than look at individual t-tests of the yearly differences in JAI between the NCSU and the DMF methods, a more compact analysis of variance was done on the full set. Results are presented in Table 1.

Table 1. Results of an analysis of variance comparing the NCSU and DMF data sets for striped bass juvenile abundance index in western Albemarle Sound, North Carolina.

Source	df	Mean square	F	P
Methods	1	1.7557	4.02	0.12
Slope within years	1	3.5616	8.17	0.05
Remainder (Years)	4	0.6735	1.55	0.34
Difference in slopes	1	2.1900	5.03	0.09
Remainder* Years	4	0.4357	5.37	0.0003
Total	11	1.0858		
Effective Error (Tow-Tow)	659	0.0810		

The analysis was done on the mean JAIs, and the Effective Error mean square was computed from the pooled tow to tow variance scaled down to the mean analysis by the harmonic mean of the number of tows per years ($\tilde{n}$=57.64).

In testing the residual error (REMAINDER*YEARS) against the Effective Error, the F=5.37 is clearly significant indicating a source of variation over and above the tow to tow variance. Therefore, using the REMAINDER*YEARS as a denominator the only source approaching significance is the regression on YEARS, which is hardly startling; i.e., the JAIs both decreased on the average. The tests given here are not as powerful as one would like, but certainly powerful enough to detect gross differences. Perhaps the bottom line is that there were really no fish during the period. The two regressions are shown in Figure 1 and, though the difference in slopes was apparently substantial, the analysis gives a P value of 0.09 for the difference.

Following through on a suggestion of VERSAR, Inc., orthogonal regressions were fitted to the set of means with little further light being shed. Both the regression through the means and through the origin were computed (Figure 2) with slopes of 8.44 and 5.27, respectively. The 95% confidence limits are very wide (3-19), hence of little use in making a judgement. It seems clear that the one NCSU value of 3.80 paired with the DMF value of 0.60 (in year 1982) completely dominates the orthogonal regression slope calculation and clouds the variability picture as well. Again, we reach the conclusion that the catches are not large enough to establish a solid relationship.

In summary, two analytical methods were used to examine the DMF striped bass JAI and the NCSU JAI for years 1982-1987. The data used in the analyses were taken concurrently with similar gear at the same locations and time. For many of the DMF sampling trips, the samples were taken by DMF personnel formerly employed in the same capacity by NCSU. Both analytical methods provided no statistically significant relationship between the two indices. The year 1982 dominates the relationship because of the disparity in the two values (NCSU=3.80; DMF=0.61). According to the records, the 1982 year was one of experimentation for DMF in that several net mesh sizes and gear modifications were made during the season, which may have been a factor in reduced catches compared to NCSU.

While no clear statistical relationship is apparent between the two data sets, the fact is that the DMF index is the only information available after 1987. For now, one must use all information available in making management decisions. As the DMF data base is extended over the years, it may be worthwhile to reexamine the two sets of information.

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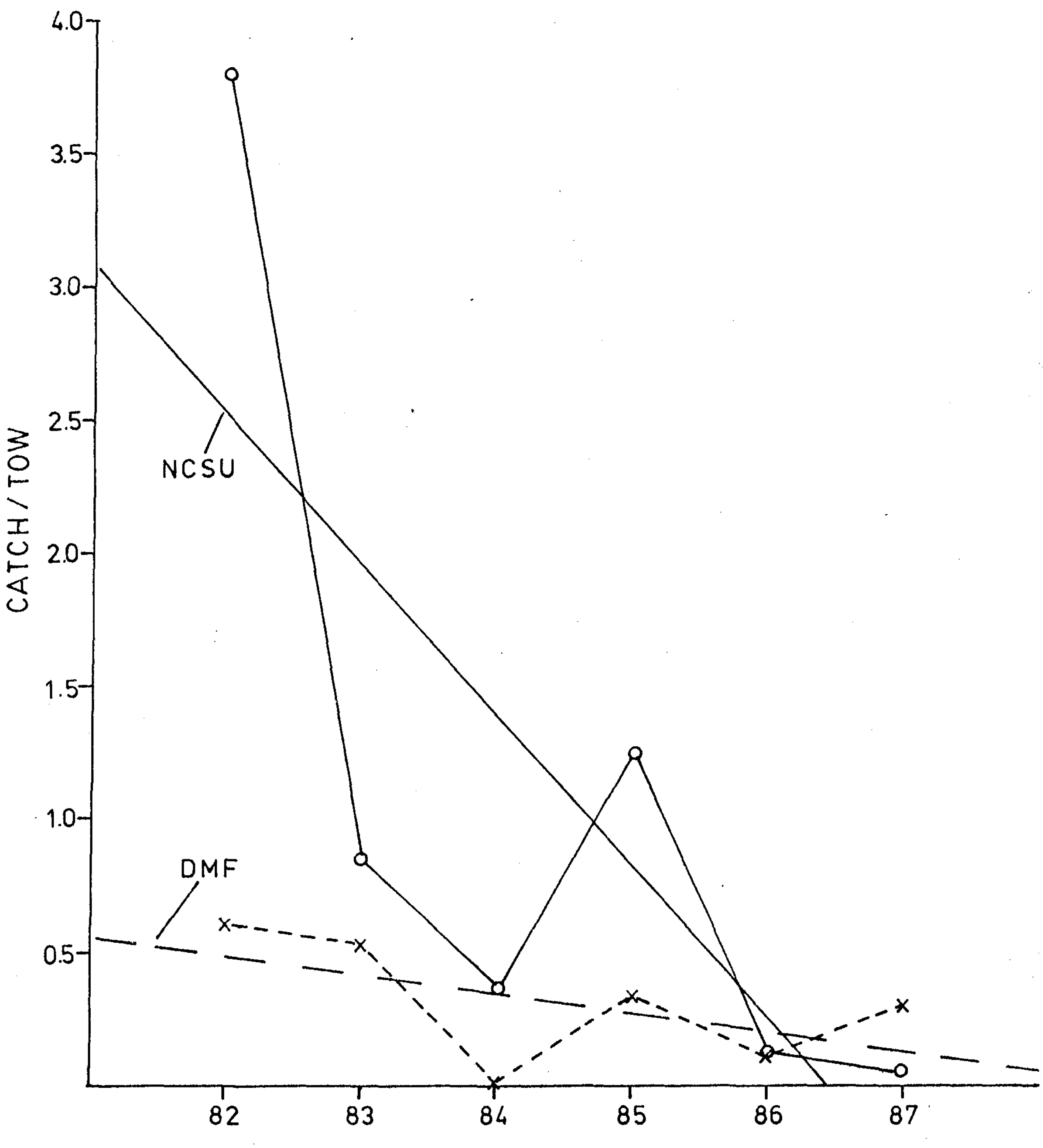

Figure 1. Annual striped bass Juvenile Abundance Indices (JAIs) reported by Hassler (NCSU, solid line and open circles) and the N.C. Division of Marine Fisheries (DMF, dashed line and x's). Regression lines plotted for each data set.

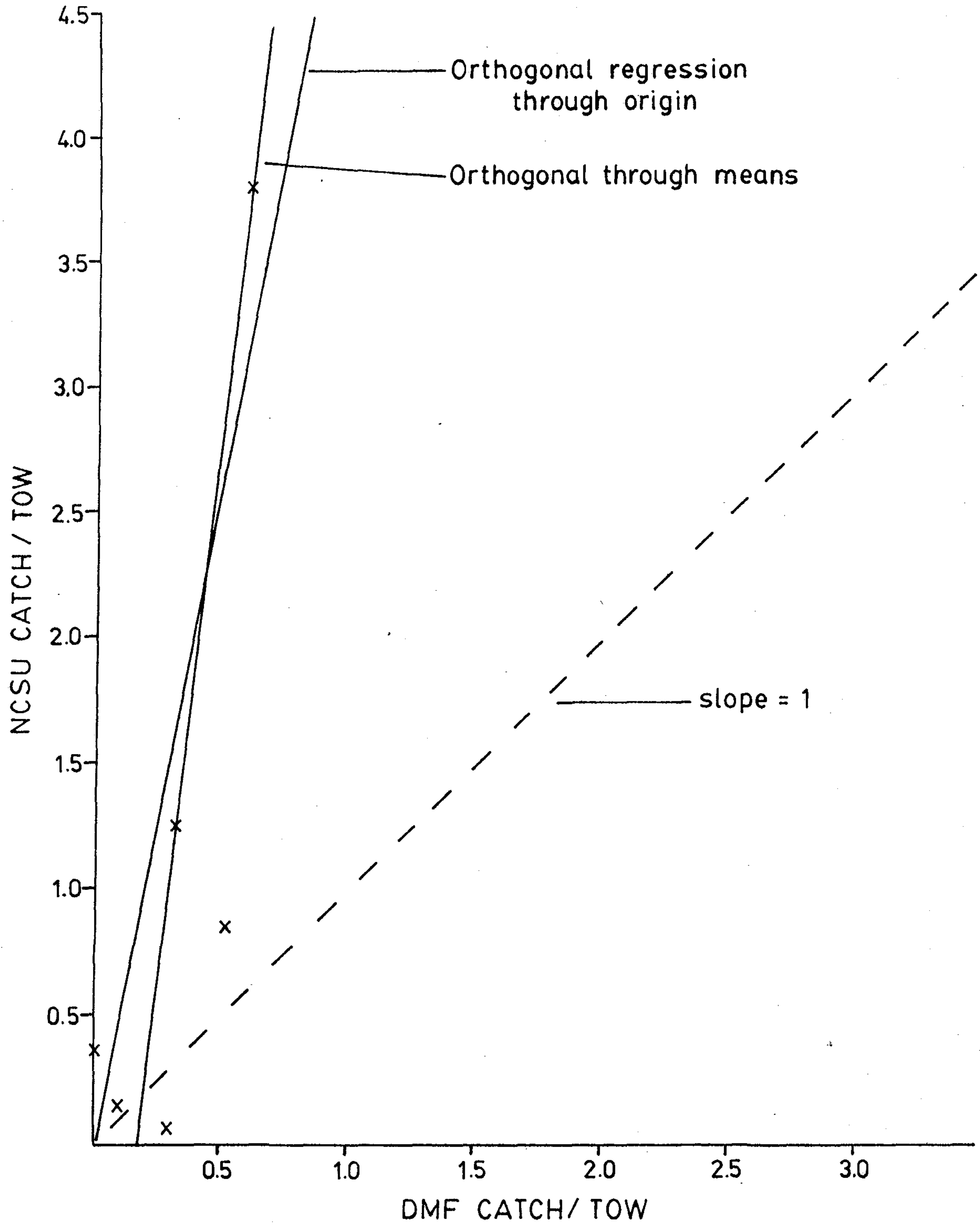

Figure 2. Orthogonal regression lines depicting the relationship between the Hassler (NCSU) and Division of Marine Fisheries (DMF) Juvenile Abundance Indices for striped bass.