ROANOKE RIVER WATER FLOW COMMITTEE REPORT

NOAA TECHNICAL MEMORANDUM NMFS-SEFC-216

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A RECOMMENDED WATER FLOW REGIME FOR THE ROANOKE RIVER, NORTH CAROLINA, TO BENEFIT ANADROMOUS STRIPED BASS AND OTHER BELOW-DAM RESOURCES AND USERS

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

A Committee of 20 representatives of State and Federal agencies and university scientists was formed in 1988 to gather information on all resources of the lower Roanoke River watershed in North Carolina and recommend a flow regime that will be mutually beneficial to these resources and their downstream users. The Committee has a combined record of experience on the ecology and fisheries of the Roanoke watershed and Albemarle Sound totaling over 190 years. Following is a brief summary of the observations, conclusions, and recommendations of the Water Flow Committee:

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. The diverse habitats of the system support a rich array of wildlife and fish species. It is imperative that the Roanoke River bottomlands and the water resource be protected.

The Roanoke River has historically carried more water than any other river in North Carolina, averaging about 8,500 cfs (cubic feet per second) annually. Surface waters of the river are used for municipal, industrial, and agricultural purposes and to maintain habitats for wildlife and fish species.

The construction of six upstream dams in the 1950s and 1960s and the resulting water flow regulation has had an impact on downstream resources and those that use them, particularly during the spring. While water regulation has prevented the magnitude of pre-impoundment floods, unnatural, extended flooding during post-impoundment years has negatively influenced the production and harvest of agricultural row crops and timber, impaired the distribution and reproduction of certain wildlife species, especially wild turkey and deer, reduced the survival of young striped bass (*Morone saxatilis*) and perhaps other anadromous species, caused water use problems for industries and municipalities, reduced recreational opportunities within the floodplain, and caused damage to roads and bridges. Extremely low water releases have negatively impacted the survival of young striped bass and perhaps other anadromous species, created unsuitable nesting and brooding habitat for waterfowl, compounded effluent problems for industries and municipalities, and prevented the public use of State maintained boat launching facilities.

The striped bass-water flow issue is the most sensitive of those mentioned above because of the national importance of the species. The Albemarle-Roanoke population has generally experienced a decline since the 1970s based on estimates of population size and landings. A combination of factors including flow regulation on the lower Roanoke River, deteriorating water quality, and heavy fishing pressure on immature fish has taken its toll on the population as evidenced by extremely poor juvenile production.

Factors dictating the formation of a successful or dominant year class of striped bass are not completely understood. However, it is clear that one of the major forces influencing the aquatic environment and, therefore, striped bass stocks is water flow. Water flow affects striped bass in all facets of its complex life history. The Albemarle Sound-Roanoke River population is unique from almost every other striped bass population because it travels a great distance upstream (130 miles) to spawn. This migration must take place because there is no tidal influence in the extreme lower river to support the semi-buoyant eggs.

By examining pre- and post-impoundment water flows, the Committee concludes that there has been a significant change in the flow regime since post-impoundment, particularly since 1977. The frequency of times in which the Roanoke River flows were within the Committee's negotiated flow bounds (upper and lower limits, approximating historical levels as presented in this document) has decreased over the years.

Upon examination of striped bass egg viability data and water flow data, the Committee found a statistically significant relationship between egg viability and the percentage of days in which flows were within the negotiated flow Q_1-Q_3 bounds. However, the possible reasons for this phenomenon were not discussed.

The Committee concludes that the flows in the post-impoundment years of relatively high Juvenile Abundance Index (JAI) are more similar to the pre-impoundment flows than are those of low JAI. This population of striped bass evolved under unregulated flows. Since the fishery was successful prior to flow regulation by the reservoirs, making the flows consistent with pre-impoundment flows is likely to improve the production of striped bass. And indeed this was observed in 1988 when flow more closely resembled the pre-impoundment model.

The Committee finally concludes that best young-of-year recruitment to the year class occurs when the Roanoke River flows are moderate (neither too low or too high). This conclusion reaffirms the analyses of Hassler et al. (1981), in which it was reported that the best JAI values occurred in years of low to moderate flow.

The Committee recognizes that changes within the basin and water withdrawal projects may cumulatively have an adverse impact upon the ability of the reservoir system to meet a stringent flow regime requirement. Therefore, the Committee's recommendations on flow should be considered whenever potential impacts of water withdrawal on striped bass and other resources of the watershed are considered.

The following flows were recommended and accepted after negotiating with the U.S. Army Corps of Engineers (Wilmington District) and Virginia Power Company. The original Committee recommendations were changed to stay within the FERC license requirements of flow augmentation starting 1 April and ending 15 June. At no time must flows be greater than those specified for the dates indicated in Table 17 of this document. In general, the minimum allowable flows range from 4,000 cfs (1-15 June) to 6,600 cfs (1-15 April), and maximum allowable flows range from 9,500 cfs (1-15 June) to 13,700 cfs (1-15 April). In addition, a maximum rate of change in flow of 1,500 cfs per hour is recommended. Flows can change hourly but cannot exceed the upper or lower limits for that date. The Committee underscores the importance of moderate, sustained flows during the actual spawning period; therefore, as little flow variation as possible during this period is preferred.

Further, the Committee recommends that this negotiated flow regime be evaluated over a four-year period. During the evaluation period, the flow augmentation dates, flow limits, hourly variation in flow, and subsequent impacts on other resources and users, shall be studied and subject to revision. Also, the Committee urges that the tri-party Memorandum of Understanding be reexamined to incorporate the recommendations of the Committee.

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COMMITTEE REPRESENTATION, OBJECTIVES, MEETINGS

The intent of this report is 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. The Committee is composed of 20 representatives of State and Federal agencies and university scientists. A list of Committee members and the affiliation of each has been previously provided.

The Committee has a combined record of experience on the ecology and fisheries of the Roanoke watershed and Albemarle Sound totaling over 190 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 our State; 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 overfishing may be contributing factors to the decline; 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 wildlife refuge proposed by the U.S. Fish and Wildlife Service and the proposed water withdrawal from Lake Gaston by the City of Virginia Beach.

The full Committee held three meetings during 1988: 8-9 March at East Carolina University, 12 April at the NMFS, Beaufort Laboratory, and 11 August in Raleigh at the NC Wildlife Resources Commission Office.

A Recommendations Subcommittee selected from the full Committee met on two occasions: in Greenville on 3 May and in Beaufort on 23 June 1988. One member from each agency, university, and study group within the full Committee was selected for representation on the Subcommittee to provide a balance of local expertise in biology, statistics, and hydrology. The Department of Agriculture had one member on the Subcommittee because of its role as steward of the agricultural and timber resources. In addition, three advisors -- one from the Corps of Engineers, one representing Virginia Power Company, and the third representing East Carolina University -- provided the Subcommittee with expertise pertaining to dam operations, power generation, and data analyses. The following were members of the Recommendations Subcommittee: M. Clemmons, W. Cole, D. Crawford, T. Ellis, L. Henry, C. Manooch, R. Monroe, T. Mullis, R. Rulifson, and L. Zincone. M. Grimes, J. Mitchell, and M. Shepherd served as advisors to the Subcommittee.

Significant work was accomplished by the Subcommittee; meetings were designed to present findings of assigned investigations and to direct future studies. All of the work was summarized and endorsed by the full Committee. Detailed findings are presented in this formal report developed by the full Committee. The U.S. Army Corps of Engineers, Wilmington District, has participated in all meetings and has endorsed the recommendations of the Subcommittee.

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 towards the understanding of the interaction between the flow regime and the ecology of the river and floodplain. Data and analyses presented in this report could have been developed further, but time constraints and the nature of an *ad hoc* Committee limited some aspects of our investigations. It is the goal of Committee members to continue these efforts.

INTRODUCTION TO THE SYSTEM

Watershed Description

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.

The Roanoke River in Virginia and North Carolina drains an area of 9,666 square miles (Moody et al. 1985), arising in the Blue Ridge Mountains of central Virginia and flowing east-southeast into north central North Carolina, where it empties into Albemarle Sound in the northeastern part of the State (Figure 1). Near the Virginia-North Carolina line, a series of dams was established between 1950 and 1963 for hydroelectric power and flood control from three reservoirs. These are the John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake, upstream to downstream, respectively. The John H. Kerr Dam and Reservoir is operated by the U.S. Army Corps of Engineers for flood control, hydropower, low-flow regulation, recreation, water supply, and fish and wildlife. 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.

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. 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. A drawbridge still exists across U.S. Highway 17 at Williamston but is seldom opened for barge traffic. In 1988, construction of a high-rise bridge to replace the existing structure was initiated. 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.

Hunting and fishing are the primary recreational activities conducted on the Roanoke River.

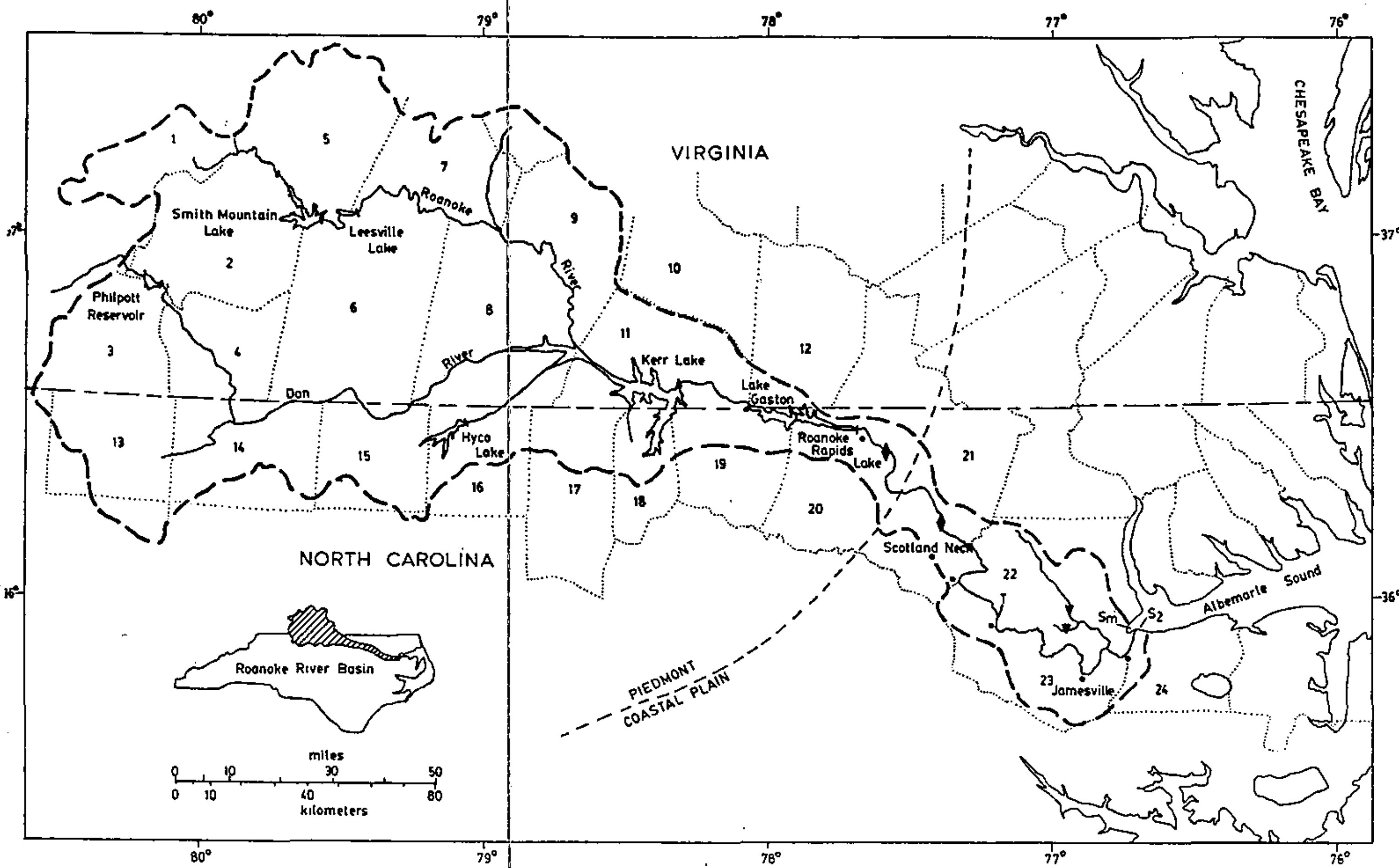

Figure 1. Drainage area of the Roanoke River Basin. Dashed line indicates approximate location of the fall line; diamonds = locations of USGS water quality and gaging stations; inverted triangle = USGS water quality station; T = upstream limit of tidal influence; S2 = mean upstream intrusion limit of 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. Halifax
19. Warren
20. Halifax
21. Northampton
22. Bertie
23. Martin
24. Washington

Forestry

The forest industry has a major role in management of the Roanoke River bottomland hardwoods and thus will have a major influence on the future value of the area for fish and wildlife. The floodplain forests upstream from Williamston are those altered most by logging operations, presumably due to relatively easier access. The least disturbed areas occur near the river mouth downstream from Jamesville (Lynch and Crawford 1980). Presently some old-growth tracts occur along the entire floodplain. The modification of the landscape by construction of permanent access roads, canals, and ditches is at present limited mainly to the upper sections.

Forestry practices vary: some companies clear-cut mature stands of most species and usually rely on natural regeneration. Others have clear-cut large tracts at slightly higher elevations along the river, provided rudimentary drainage by cutting through the natural ridges and levees, and replanted uniform stands of sycamore, sweetgum, and pine for short term pulp production. In some areas hardwood bottoms have been clear-cut, a drainage system constructed, and the area converted to pine plantation. In recent years, some logging by helicopter has been done in the normally flooded timberlands, while most logging has been done by more conventional methods during dry periods. Lumber or pulp mills are located along the river at Roanoke Rapids and at Plymouth. A new Champion International plant is proposed for Halifax County.

Agriculture

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 1953 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.

Soils

Annual floods over the centuries have over-topped the river banks, dropping suspended sediments originating from upstream areas to form the levees and ridges of the floodplain. The coarser, heavier sediments fall out closest to the river, forming the natural levees immediately adjacent to the river channel, while the finer, lighter sediments (clays) gradually settle in the slack water areas ponded behind the levees. These sediments are supplemented each year by humus from abundant leaf litter decay resulting in deep, rich soils. The presence of the three reservoirs upstream has reduced the amount of sediment deposition in recent years. Soil types identified from the Roanoke River floodplain include Altavista, Augusta, Bibb*, Chewacla, Conetoe, Congaree, Dorovan*, various Hapludults, Roanoke*, Una*, Wahee, Wehadkee*, and Wickham. Soils with an asterisk are recognized as hydric by the Soil Conservation Service (1985). Hydric soils are "... soils that in their undrained condition are saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic (water loving) vegetation" (Soil Conservation Service 1985).

Floodplain Habitats

The Roanoke River floodplain below Weldon is an extensive wetland ecosystem containing excellent examples of a number of the major alluvial plant communities found in the Southeast. Lynch (1981) described 15 different natural communities on the basis of vegetation and physical characteristics. These can be grouped into three natural community types: levee forest, cypress-gum swamp, and bottomland hardwoods (Schafale and Weakley 1985).

Levee forests occur along the natural levees that are built up parallel to the river during flood stages. The dominant canopy species are sugarberry, sycamore, and green ash. Other species include cherrybark oak, eastern cottonwood, swamp cottonwood, water hickory, black walnut, American elm, and sweetgum. The subcanopy is typically dominated by box elder. Dominant shrubs include spicebush, pawpaw, and buckeye with a 100-percent ground cover of mixed grasses, sedges, and cane. This diverse wetland community is classified as palustrine forested wetlands, broad-leaved deciduous, temporarily to seasonally flooded (Cowardin et al. 1979).

Cypress-gum swamps occur landward of the natural levees, in sloughs and in lower parts of ridges and swale systems, and are areas of low elevation where the seasonal floodwaters may become trapped for long periods of time. In some areas the water table may remain at or near the surface year-round. These areas are dominated by bald cypress and tupelo gum with a shrub layer of Carolina water ash and very little ground cover. Some of these cypress-gum stands are very dense and of uniform height and age. These areas are classified as palustrine forested wetlands, broad-leaved deciduous or needle-leaved deciduous, seasonally to semipermanently flooded (Cowardin et al. 1979).

Bottomland hardwoods are found on slightly higher ridges formed through the years by the migrating river channel. This community type is often found on parallel ridges alternating with fingers of cypress-gum slough (filled-in ancient river channels). This seldom-flooded community is dominated by a variety of oaks and other hardwoods, including cherrybark oak, swamp chestnut oak, laurel oak, willow oak, bitternut hickory, green ash, and sweetgum. The highest ridges may occasionally have upland trees such as beech and white oak. The understory includes iron-wood, American holly, and deciduous holly. Shrubs include dogwood, ironwood, blueberry, and gallberry. The ground cover may be sparse to dense and includes grasses, sedges, giant cane, and false stinging nettle. This community is classified as palustrine forested wetlands, broad-leaved deciduous, temporarily flooded (Cowardin et al. 1979).

The occurrence of rare plants in the Roanoke basin contributes to the importance of this natural area to the State of North Carolina and to the Nation. The shumard's oak along the Roanoke is disjunct from its normal range, and wild hyacinths (Camassia), Atlantic isopyrum, purple larkspur, and blue phlox create an exemplary and extensive plant community perhaps best observed on the Roanoke bluffs in Northampton County in the Camassia Slopes Preserve (Charles Roe, North Carolina Natural Heritage Program, personal communication). A complete floral listing for one such tract, Company Swamp in Bertie County is provided in Appendix A.

The Roanoke River floodplain is relatively narrow from Weldon to Scotland Neck, at times only a mile in width, with natural levees and ridges alternating with sloughs and backswamps in rapid succession. In the middle reaches of the river, the floodplain becomes flatter and broader, commonly reaching widths of two to three miles, with cypress-gum backswamps increasing in size, but the continued presence of levees and ridges make this stretch of the floodplain the most diverse and productive. Below Jamesville the river is essentially at sea level and broad expanses of cypress-gum swamp, as much as five miles across, predominate. In addition to the major vegetative communities described above, occasional oxbow lakes, beaver ponds, and blackwater streams can be found throughout the floodplain, adding to the rich mosaic of habitat types available in the Roanoke River floodplain.

Several large tracts along the Roanoke River contain more than 10,000 acres of roadless bottomland hardwood and swamp forests (USFWS 1981). The protection afforded by the size of these tracts, combined with the richness of the Roanoke River floodplain, provide some of the best remaining habitat in North Carolina for many wildlife species (USFWS 1981).

Wildlife Resources

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 1950's to the present.

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 crops. 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.

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 percent 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.

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.

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

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

At least 14 species of waterfowl utilize the Roanoke River floodplain regularly, with wood ducks, mallards, and black ducks the most abundant according to harvest data (USFWS 1983). Other frequently observed species include pintail, widgeon, gadwall, green-winged teal, bluewinged 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.

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.

Fishery Resources

The Roanoke River and its tributaries provide excellent habitat for a diverse assemblage of fish species and their value to fishery resources is well documented. Fish (1968) ecologically classified the section of the Roanoke River between Williamston and the Roanoke Rapids dam as a carp-catfish stream and Coniott Creek was classified as a redfin-warmouth tributary. Sampling by Carnes (1965) was conducted in the Roanoke River and in Conoho Creek. Stations within the Roanoke were classified as carp-catfish and Conoho Creek was determined to be a redfin-warmouth stream. Classifications are based on a modification of Van Deusen's (1953) system for ecologically classifying streams.

The Roanoke River and the associated floodplain wetlands are especially critical to anadromous species (Hassler et al. 1981, Johnson et al. 1981). Anadromous fish utilizing the river include striped bass, blueback herring, alewife, hickory shad, American shad, and Atlantic sturgeon. The river near the town of Weldon provides critical spawning habitat for striped bass. This striped bass population within the Roanoke River/Albemarle Sound ecosystem has long been a significant component of both commercial and recreational fisheries catches in North Carolina (Rulifson et al. 1982). The life cycle of this population is complex and has co-evolved with the Roanoke River where spawning adults, eggs, larvae, and juveniles are all dependent upon the presence of appropriate parameters within the system for successful progression to the next life cycle stage.

Other recreationally important species within the Roanoke River watershed include bluegill, redbreast sunfish, pumpkinseed, warmouth, flier, redfin and chain pickerel, white perch, yellow perch, black crappie, carp, white and channel catfish, and largemouth bass. Yellow and brown bullheads are caught incidentally while fishing for other species. The bowfin, longnose gar, American eel, tadpole madtom, margined madtom, and creek chubsucker are likely inhabitants of both the creeks and associated beaver ponds. Many other species such as the swampfish, pirate perch, mosquitofish, cyprinids such as the golden shiner, ironcolor shiner, and creek chub, and percids, such as the swamp darter and tessellated darter, contribute to a high level of diversity and provide forage for many of the game species. A complete faunal listing for one such tract, Company Swamp in Bertie County, is provided in Appendix A.

CHRONOLOGICAL RECORD OF WATERSHED IMPOUNDMENT 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' 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 impacted 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'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' stage) from late March-late May, and a minimum stage of 15' (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 study 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 and quality 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' 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') between 1 April and 25 April; 5,550 cfs (13') between 26 April and 4 May; 8,950 cfs (15') 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."

1963 Lake Gaston is completed.

1970 Water shortage problems are projected for southeastern Virginia municipalities.

1971 Memorandum of Understanding 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' and 302' for augmentation flow for striped bass spawning; 13' 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 eggs and 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. City of Virginia Beach, VA, applied for and received a permit from the U.S. Army Corps of Engineers to withdraw 60 MGD 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 State, Federal and university scientists formed to propose a flow regime for the Roanoke River that would benefit striped bass and other downstream resources and users.

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...".

1989 Roanoke River Water Flow Committee publishes findings of one-year study and makes recommendations on flow conditions for March through June each year (this document).

HYDROLOGY

The Roanoke-Chowan River drainage basin encompasses 17,500 mi^2 draining major portions of southern Virginia and northern North Carolina. Approximately 55 percent (9,666 mi^2) of the drained land area is within the Roanoke River basin. Nearly six percent of North Carolina's land surface is drained by the Roanoke River watershed (Moody et al. 1985). Major tributaries include the Dan, Mayo, Smith, and Hyco Rivers (Figure 1).

The Roanoke River carries more water than any other river in North Carolina, with a daily average of about 8,500 cfs (cubic feet per second). Surface waters of the river are used for municipal, industrial, and agricultural purposes and to maintain fish and wildlife habitats.

Flow is regulated by six major dams on its main stem or tributaries. Philpott Lake, Smith Mountain Lake, and Leesville Lake are in Virginia. The John H. Kerr Reservoir and Lake Gaston are situated on the North Carolina-Virginia border. Roanoke Rapids Lake, the most-downstream reservoir on the watershed, is within North Carolina (Figure 2). These dams and powerhouses affect daily streamflow variability and flood peaks. Total water volume held by these dams is 4,372,000 acre-feet or 1,420,000 million gallons (MG) (Moody et al. 1985).

The most important of these reservoirs to the lower Roanoke River and western Albemarle Sound is Kerr Lake because of its storage capacity and its direct influence on the operation of the two dams downstream. Regulation of flow by the reservoir system virtually precludes intrusion of saltwater into the lower Roanoke River except in cases of extreme drought or unusual wind-tide conditions (Geise et al. 1979).

Importance of Water to Floodplain Habitats

On a national basis, forested wetland habitat losses have been occurring at a high rate in recent years (Frayer et al. 1983; Tiner 1984). Statistics indicate that during the 20-year period between the mid-1950s and 1970s, fully 92 percent of the national losses in forested wetlands occurred in the southeastern United States (Hefner and Brown 1984). These habitat losses have resulted in population declines in many fish and wildlife species, making the remaining wetlands even more valuable to fish and wildlife. Waterfowl, striped bass, black bear, wild turkey, red-shouldered hawk, barred owl, and bald eagle all use the Roanoke River bottomlands.

Water is the driving force of bottomland hardwood communities such as those described above (Wharton et al. 1982). Water forms and maintains the floodplain by transporting and redistributing sediments. It also provides seasonal access for aquatic organisms to the floodplain and transports nutrients and detritus across the floodplain and to downstream estuarine areas. Precipitation and subsequent surface and sub-surface runoff are the principal sources of water to the Roanoke River system.

Hydrological data for the lower Roanoke River basin are summarized by the U.S. Army Corps of Engineers (1968, 1984). Precipitation within the lower basin averages from 41 to 53 inches per year, depending upon location. Annual snowfall within the lower basin ranges from 3 to 10 inches. Widespread precipitation throughout the entire basin causes

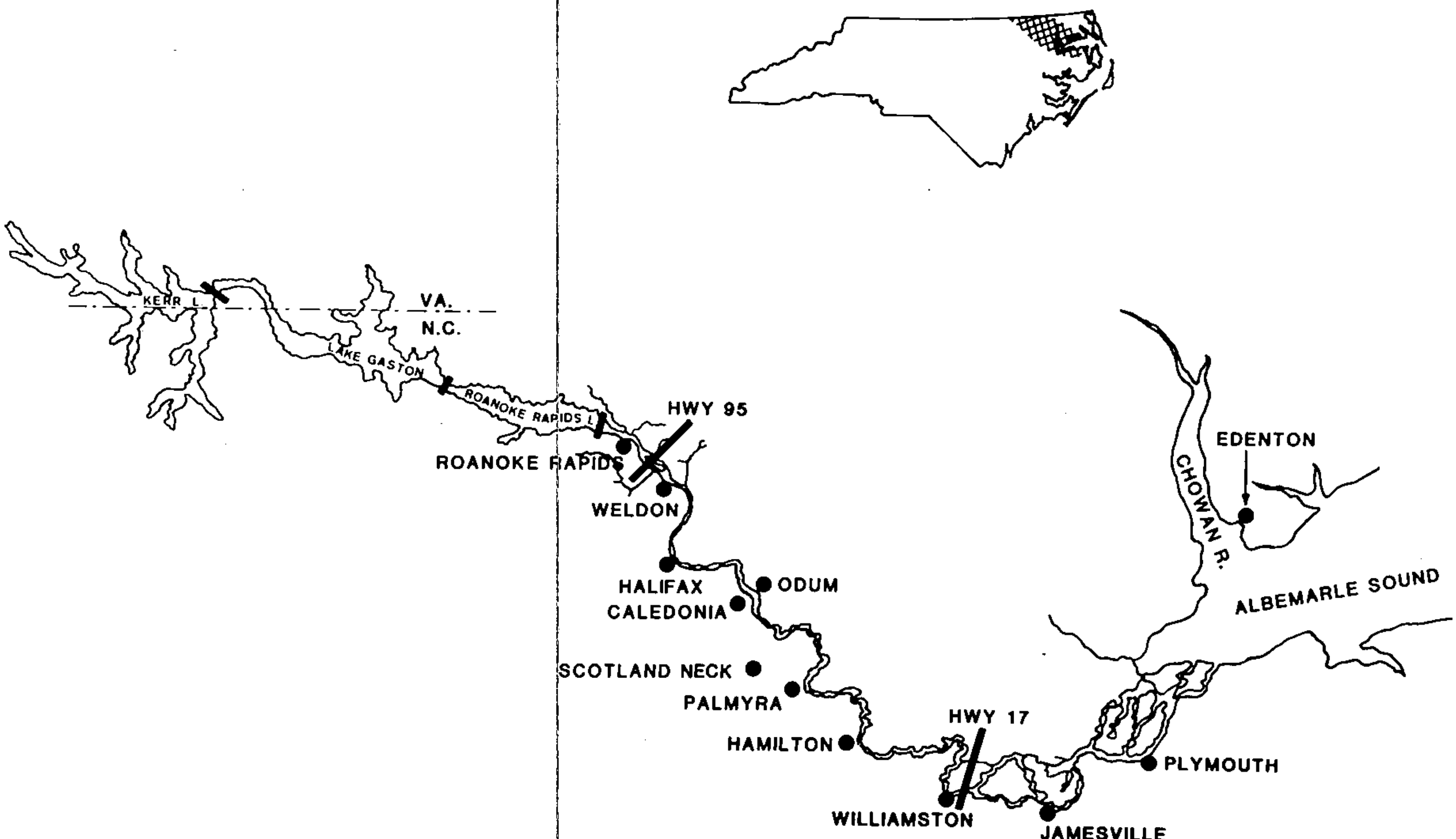

Figure 2. Lower Roanoke River watershed.

discharge of the mainstream tributaries to increase, while localized rainfall events usually result in increased discharge only in smaller tributaries. Precipitation usually constitutes the only source of water input to a river basin, unless interbasin transfer of water is occurring. Both run-off and groundwater are derived from precipitation, although usually they are treated as separate components of the water budgets.

Organisms that depend on alluvial river systems for life have evolved adaptations to the seasonal fluctuations inherent in these floodplain systems. Winter and spring flooding provides accessibility and creates seasonal habitat for fish and waterfowl, which forage and depend on the abundant mast (acorns) and macroinvertebrates on the floodplain, or which utilize the floodplain for reproduction. Sniffen (1981) determined that the aquatic area created by floodplain inundation in Creeping Swamp (Pitt County, NC) represented over 90 percent of the annual aquatic area of the ecosystem on an inundated-per-day basis. Sniffen also found that production of macroinvertebrates on the floodplain constituted 80 percent of the total production within Creeping Swamp. Accessibility to and foraging upon these seasonally-available macroinvertebrates is necessary for wintering waterfowl to ensure that they are in satisfactory condition for successful breeding after their return migration (Fredrickson 1980; Heitmeyer and Fredrickson 1981; Drobney 1982, 1984; Rundle and Sayre 1983).

Fish production in such systems not only depends upon access to this macroinvertebrate prey but also is dependent upon access to the floodplain for breeding sites (Bryan and Connor 1981, Wharton et al. 1981). Species such as carp, fliers, yellow and brown bullheads, warmouth, and chain pickerel are documented as breeding on the floodplain, which subsequently serves as nursery habitat for their larvae and juveniles.

The annual drying out of the floodplain is also of critical importance to maintaining the integrity and health of the system. Such a drying out process is necessary to allow aeration and growth of tree roots and saplings and ensure that seed germination will occur in order to maintain the vegetation within the system.

Pre-Impoundment Conditions

The mainstem of the Roanoke River is formed by the confluence of the Dan and Stanton Rivers approximately 200 miles above the river mouth. Between River Mile (RM) 150 and RM 128, the Roanoke crosses the eastern escarpment of the Piedmont Plateau (the "fall line") into the broad and flat Coastal Plain. Across the Piedmont Plateau the riverbed gradient is about 1.5 feet per mile. Across the fall line, the gradient steepens to 6 feet per mile and averages about 0.2 foot per mile across the Coastal Plain (Fish 1959).

The Roanoke River influences the hydrological conditions of Albemarle Sound. Posner (1959) reported that "the water mass from Edenton (in Albemarle Sound) to the Long Shoal area (in Pamlico Sound) is principally sensitive to a single fact: run-off from the Roanoke River." The Roanoke River provides, on average, about 87 percent of the freshwater flows to the coastal watershed (Giese et al. 1979).

Roanoke River flows were natural and unregulated until August 1950, when construction activities of the Philpott project in Virginia and the John H. Kerr project downstream first affected (to a minor degree) the flow records at the USGS gage at Roanoke Rapids. Construction of the John H. Kerr Dam continued to influence Roanoke River flows until 20 November 1952, when the powerhouse began operation. Permanent regulated flow downstream of RM 137 were further achieved by the closure of the gates at the Roanoke Rapids project on 25 June 1955 (Fish 1959).

Before 1951, flows in the Roanoke River were driven by prevailing weather conditions. Typically, flows were highest during winter and early spring caused by abundant storm weather patterns. River flows then gradually tapered to minimum flows during early fall months, especially September through November (Figure 3). The late summer-early fall low-flow period was often interrupted by one or more extremely high river discharges caused by rainfall events from coastal hurricanes. The greatest river discharge on record was the result of the inland movement of a large unnamed hurricane in August 1940 (the practice of naming hurricanes began in 1950). At the site where Kerr Dam is now located, it was estimated that flows were about 270,000 cfs for the 1940 flood. Figures 4 and 5 show the change in flow regime of the river by depicting the frequency of flows at the Roanoke Rapids (USGS) gage before 1951 and after 1955. The maximum pre-project flows ranged frequently above 45,000 cfs (Figure 4). Post-project flows are seldom above 35,000 cfs with a definitive peak flow period in April and May (Figure 5).

Descriptions of Impoundments

The lower Roanoke River became a fully regulated stream in 1955 following a transitional five-year period of construction and operation of the Philpott, John H. Kerr, and Roanoke Rapids projects. The original Steering Committee for Roanoke River Studies documented the specifications of the various projects in the report prepared by Fish (1959). The following information is from that study.

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

Construction of the John H. Kerr project was initiated by the U.S. Army Corps of Engineers in February 1946. The first power was generated in December 1952, and flood control measures were used in the spring of 1953. The dam created a lake 39 miles long, with a shoreline of 800 miles and a surface area of 48,900 acres at the normal summer water-surface elevation of 300 feet above sea level. At this elevation, water depth at the powerhouse is 112 feet. Water storage in the impoundment includes 1,046,000 acre-feet for power production, and an additional 1,278,000 acre-feet available for flood control. These estimates may be high for Kerr Reservoir for the 1980s due to extensive siltation within the system. The Kerr powerhouse contains seven generators with a total capacity of 204,000 kilowatts. Power production is primarily during peak energy demands. Some water is always released during off-peak periods. Power production contributes to the Southeastern Power Pool and is marketed by the Southeastern Power Administration.

ROANOKE RAPIDS DAM. On 6 October 1948, the Virginia Electric and Power Company (VEPCO, now known as Virginia Power, a subsidiary of Dominion Resources) applied to the Federal Power Commission (FPC) for a license to construct the Roanoke Rapids Dam at RM 137. The license was granted to VEPCO by the Federal Power Commission's Opinion and Order Number 204, effective on 1 February 1951, giving

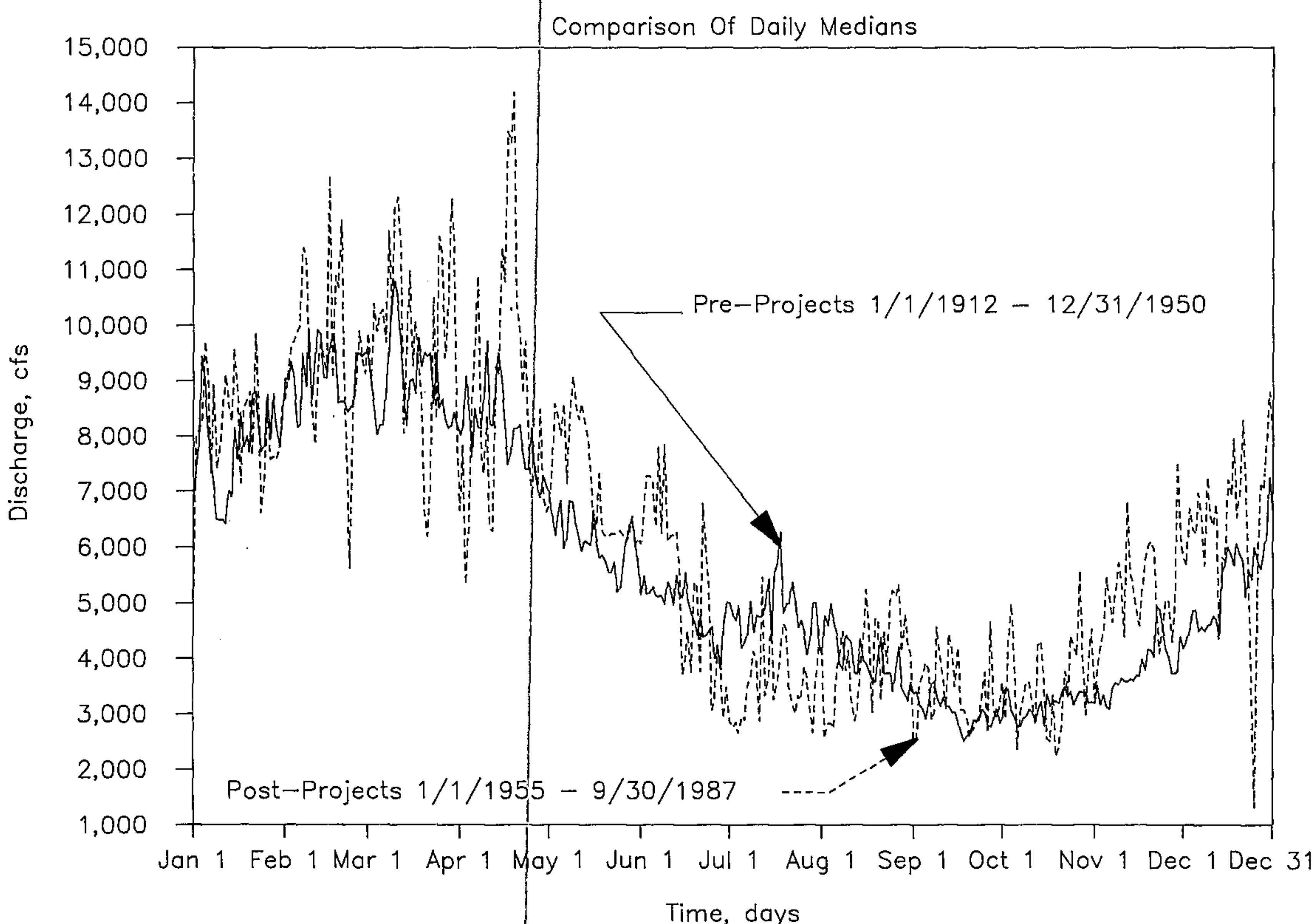

Figure 3. Daily median flows of the lower Roanoke River for pre-impoundment (1912-1950) and post-impoundment (1955-1987) conditions.

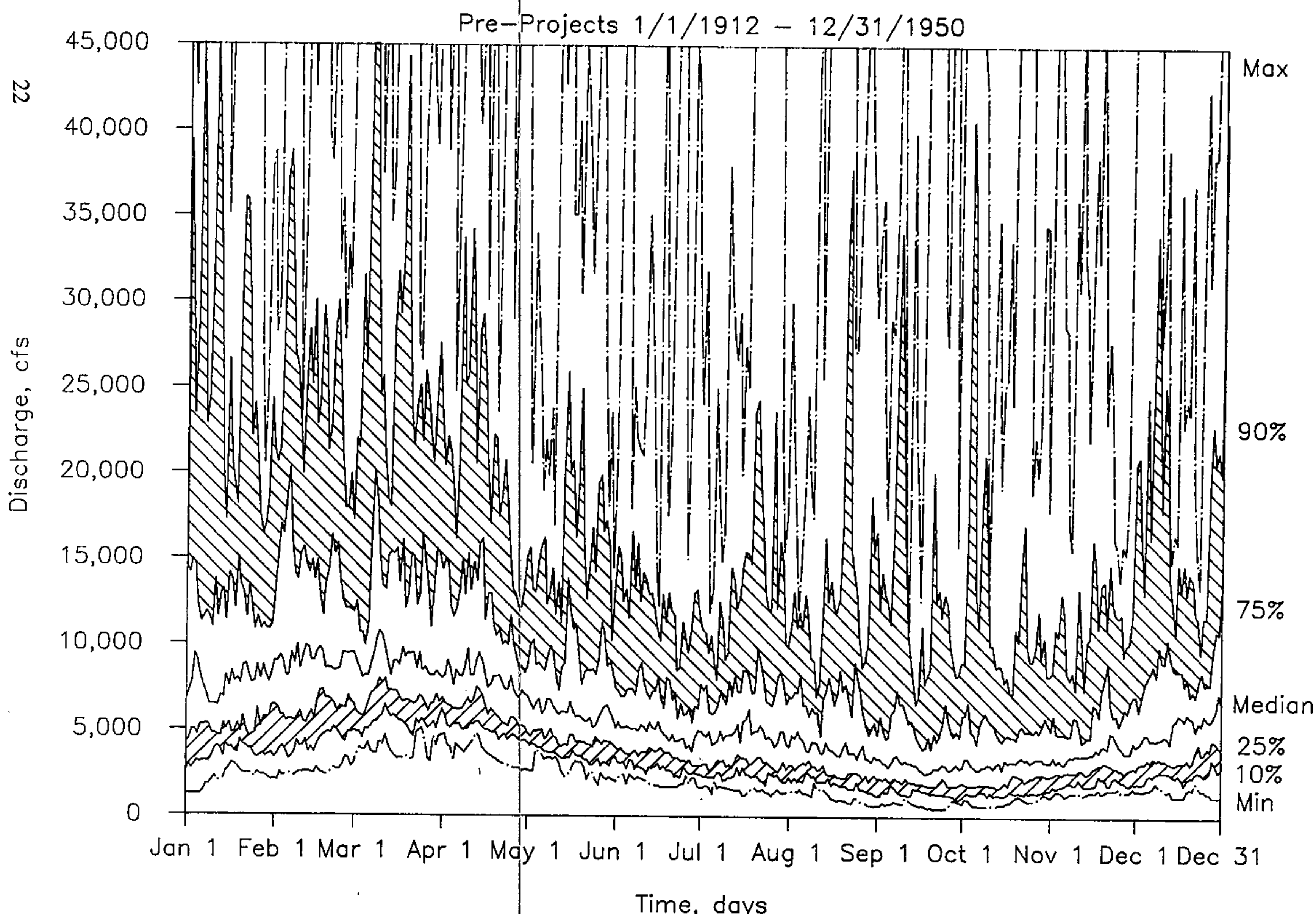

Figure 4. Range of daily flows of the lower Roanoke River under pre-impoundment (1912-1950) conditions.

permission to build VEPCO Project 2009 (the Roanoke Rapids project). The FPC envisioned that the Roanoke Rapids project would act as a re-regulator of river flow, providing a continuous 2,500 cfs downstream so that the John H. Kerr could be used as a peak energy facility without serious harm to future navigation below Weldon. However, the 2,500 cfs minimum continuous flow was not required because the navigation from Palmyra to Weldon was of no consequence at the time, nor did it appear as a distinct possibility in the future. However, the Federal Government did reserve the right to require a continuous flow up to 2,500 cfs below the Roanoke Rapids project for navigation. Additionally, the FPC stated that the water release requirements during off-peak hours for pollution abatement and preservation of fish life were the same as for the Buggs Island project. Therefore, VEPCO's proposed Roanoke Rapids project could relieve the Buggs Island project of the off-peak water release burden.

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

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

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

Reservoir Operation

The flow regime in the Roanoke River is dictated by the releases from the Roanoke Rapids power plant. The release from the dam is dependent upon the release from Lake Gaston. These two projects have limited storage and therefore are driven by releases from Kerr Reservoir. The release is a function of the lake level in Kerr (as defined by the Rule Curve, Figure 6) and power demands or commitments to supply power and energy.

Kerr operation distributes higher winter run-off to the spring and more importantly decreases the peaks of flood events. The storage available at Kerr dictates the operation of all three reservoirs on a weekly basis. That is, the storage available for release is known for any given point in time and a determination made as to the amount of water available

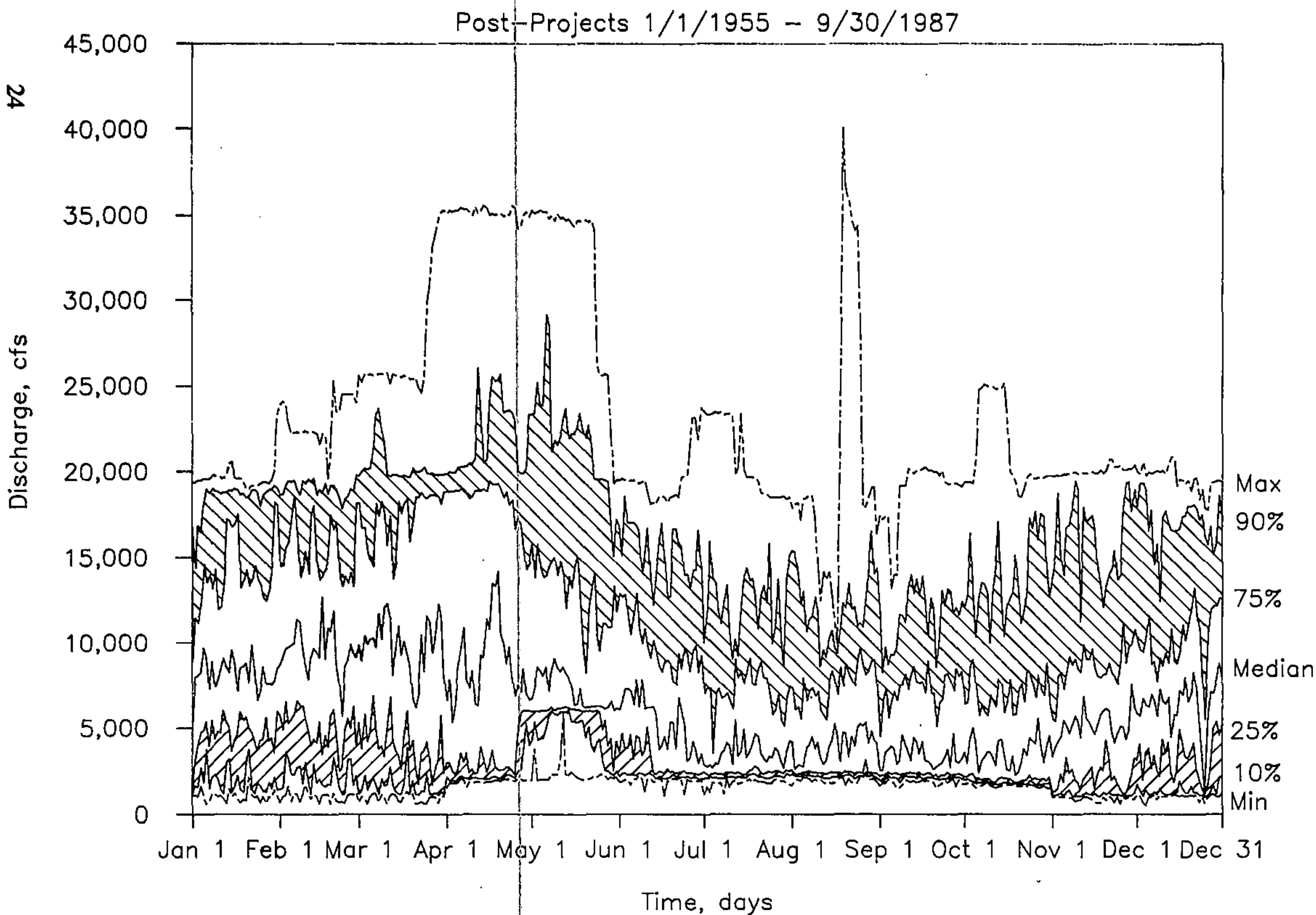

Figure 5. Range of daily flows of the lower Roanoke River under post-impoundment (1955-1987) conditions.

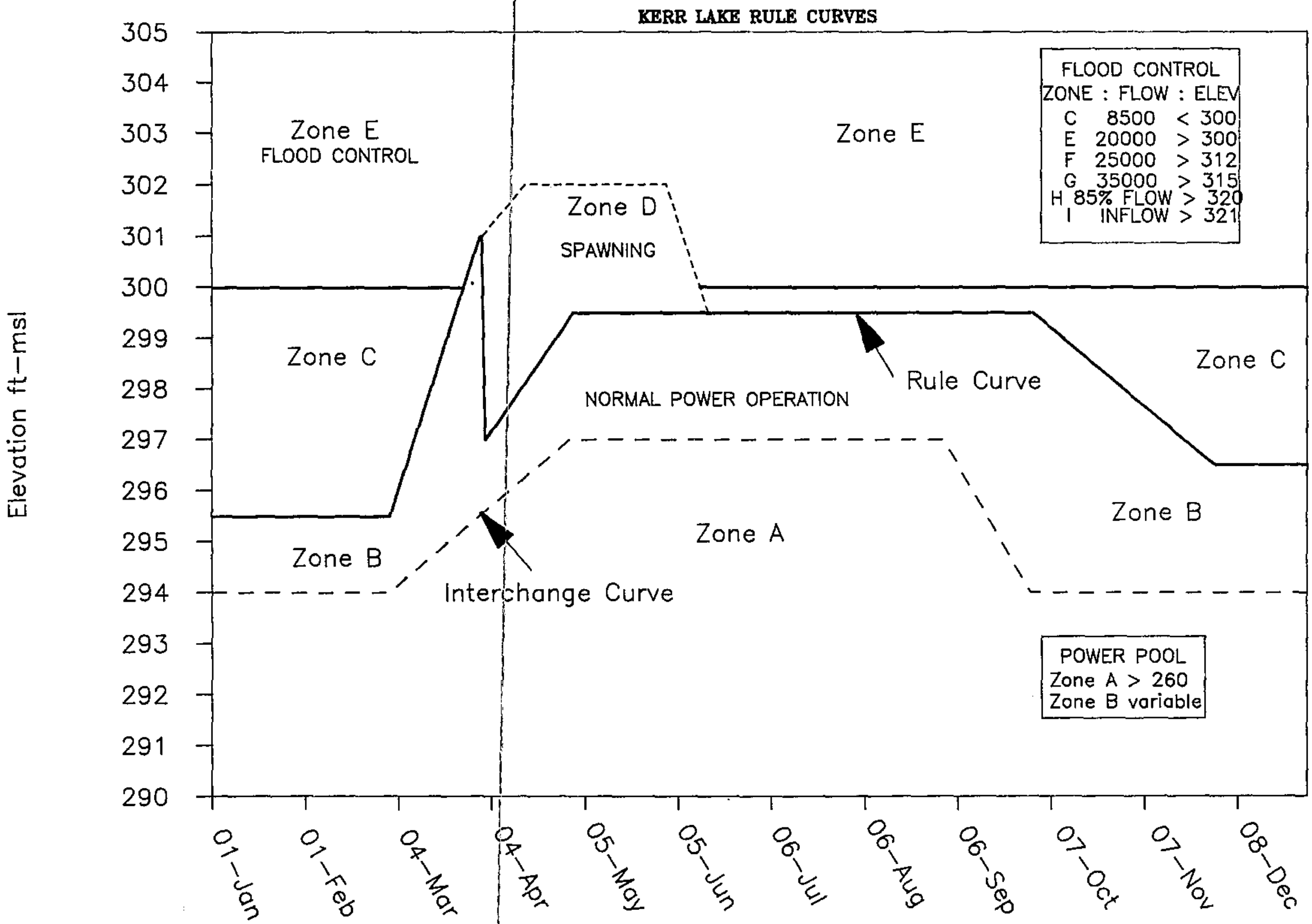

Figure 6. U.S. Army Corps of Engineers Rule Curve for John H. Kerr Reservoir. MSL = height (in feet) above mean sea level.

for power generation for the upcoming week. Forecasted higher flows or flood events will at times modify the release schedule. On an hourly basis, the operation of Roanoke Rapids has control of flows in the lower Roanoke River.

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

The potential for flood control varies with the seasons and in coordination with the two primary purposes of the project. This planned seasonal fluctuation in reservoir surface elevation is known as the "Rule Curve" for power generation (Figure 6). The surface water elevation of 300 feet is known as the "maximum power-pool elevation". During the usually wet months of November through January, a target water surface of 295.5 feet above sea level exists to provide maximum volume of floodwater storage while maintaining sufficient height for efficient power generation. Inflow conditions dictate the magnitude and duration of deviations from target elevations. Generally the Corps operates the project to bring the lake elevation to the target elevation as quickly as possible, consistent with flood control and power production objectives. During March the surface elevation is raised so that by 1 April the reservoir surface is between Elevation 299.5 and 302.0. This elevation zone is to provide additional storage for spawning flows from April to June. The normal upper target elevation for power operations is 299.5 from April to September. The elevation target is lowered from 299.5 to 295.5 during October and November to restore flood control storage.

Associated with specific elevation zones are maximum releases from Kerr powerhouse or dam. These zones are given in Figure 6. Zone "C", for example, is between elevations 295.5 and 300.0 from December through March. If lake elevation is within this zone, then the Corps would normally release 8500 cfs. Zone "E" is between elevations 300.0 and 312.0 and is the first flood control zone (except during the striped bass spawning period). In this zone Kerr would normally release 20,000 cfs. Figure 5 shows that maximum recorded controlled flows at Roanoke Rapids seldom exceed 35,000 cfs (equivalent to Zone "G"; elevations 315 to 320 at Kerr). For 90 percent of the time and for most of the year the flows are below 20,000 cfs (i.e., Kerr elevations below or in Zone "E").

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

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

For the 35-year period from 1953 to 1987, Kerr Lake has achieved or exceeded the target elevation of 302.0 a total of 18 times by 1 April of that year (Figure 7). On 1 May of the year, the target has been equalled or exceeded 25 times (Figure 8).

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

The coordination of the three entities involved -- the Corps of Engineers, Virginia Power, and the N.C. Wildlife Resources Commission -- could be improved to ensure: (1) that releases are made during critical periods particularly when storage is limited; and (2) that flood control objectives are weighed against spawning or subsequent life stage needs when storage is excessive. The apparently short time frame of the spawning cycle indicates that flood control and power operations could be changed during that time for potential significant enhancement of the cycle. However, the initiation of the spawning cycle and the subsequent needs of life stages after spawning require better definition.

Downstream Water Demands

AGRICULTURE. In the 1950s, agriculture accounted for approximately 60 percent of the occupational activity of the region (Fish 1959). Typical cash crops were tobacco, cotton, peanuts, soybeans, and livestock. In the 1980s, agriculture remains a dominant industry with little change in crop types except for corn. However, irrigation of the principle crop types and of specialty crops, such as fruits and berries, has grown significantly. Unfortunately, detailed water use data for purposes of irrigation have not been available until recently.

In 1984-85, a detailed survey of the Roanoke River Basin was conducted in both North Carolina and Virginia to determine water use in three categories: municipal, industrial, and irrigation. Irrigation estimates for each county (also by Roanoke River sub-basin) were compiled for 1983. The heaviest use of water for irrigation was in counties adjacent to Kerr Lake and to the lower Roanoke River (Figures 9-10). In the Roanoke River Basin, use of water for irrigation was estimated at 9,746 MG over the growing season. For the lower Roanoke River, the estimated use was 4,515 MG over the season. This figure is approximately equal to 25 MGD of irrigation water use for the lower Roanoke River, assuming a six-month irrigation period. Because irrigation does not occur every day, there is a potential for high rates of water use during irrigation days. Of the water used, 72 percent was from surface water sources (i.e., directly from streams, lakes, and impoundment ponds). The water from surface sources has a direct effect on Roanoke River flows. Table 1 presents the acreage of irrigated lands and the amount of water used (MG) for major Roanoke River sub-basins.

Irrigation potential in the seven-county region of north central North Carolina may be as much as 530 MGD for a three-month period, and possibly as high as 650 MGD for

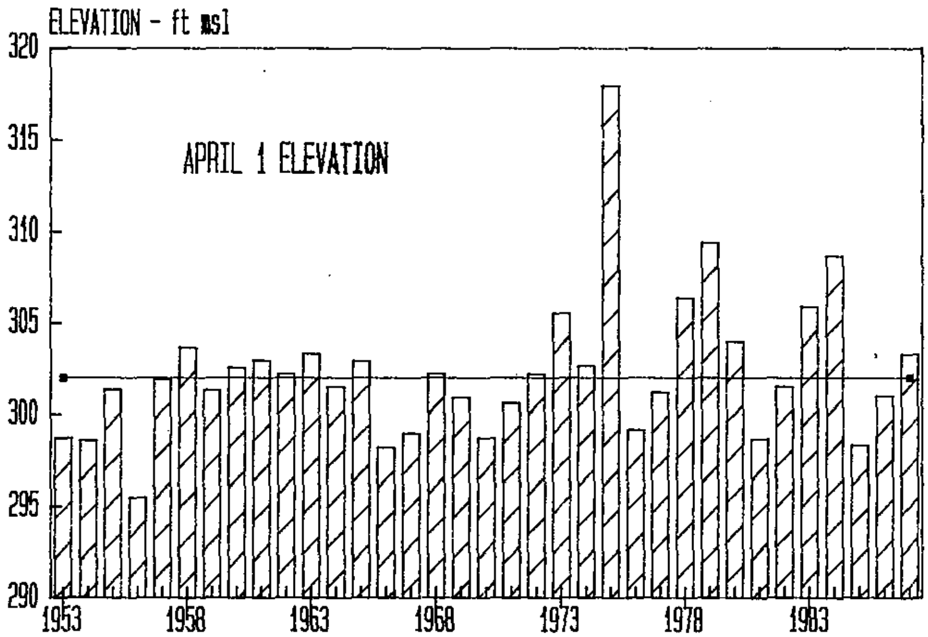

Figure 7. Kerr Reservoir water elevations on 1 April, 1963-1987. Target elevation needed for striped bass spawning in lower Roanoke River is 302 feet.

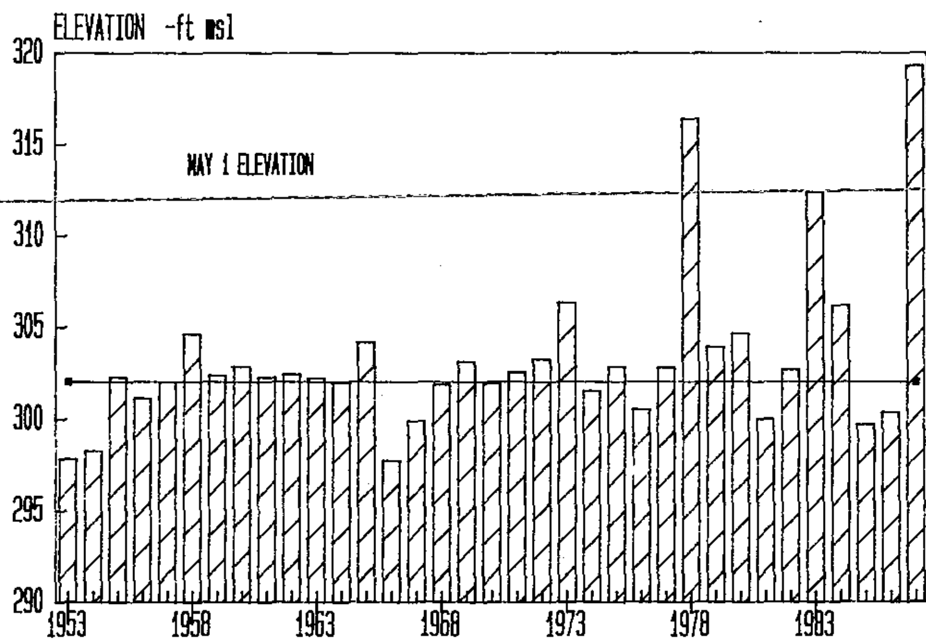

Figure 8. Kerr Reservoir water elevations on 1 May, 1963-1987. Target elevation needed for striped bass spawning in lower Roanoke River is 302 feet.

August (Sneed 1982). This growth in irrigation water use has a high potential for altering Roanoke River flows by reducing inflow to Kerr Lake (resulting in lower lake levels and releases) and through direct withdrawal from the river and tributaries.

WILDLIFE AND FISHERY RESOURCES. Adequate water flows are required to maintain natural habitats for a variety of wildlife and fish species. Some groups, such as waterfowl and river herring, require periodic flooding of the forested wetlands for the completion of certain life history aspects. Some anadromous fish species require adequate flows to attract them upstream to the spawning grounds.

MUNICIPALITIES AND INDUSTRY. Population size of the Roanoke basin has remained rather stable from the 1940s to the 1980s. Halifax County has the largest population (about 56,000) followed by Martin, Northampton, Bertie, and Washington counties (Table 2). The six municipalities of the lower watershed have had relatively stable populations in recent times (Table 3). The towns of Gaston, Weldon, and Jamesville have experienced little growth since the 1920s. Roanoke Rapids and Williamston experienced rapid population growth between the 1950 and 1960 census periods. Currently, Roanoke Rapids is the largest community bordering the lower Roanoke River (over 15,000), followed by Williamston, Plymouth, Weldon, Gaston, and Jamesville. Also worthy of consideration is the Caledonia Correctional Institution near Scotland Neck, which at present has an inmate population of over 1,000 individuals (Caledonia and Tillery units combined).

Gaston. The water supply for the town of Gaston was a three-well system installed in 1969. Currently, Gaston residents rely on the Roanoke Rapids Sanitary District for water supply and treatment. Water usage is strictly domestic; no industry is present (Mrs. Manning, Gaston Town Clerk, personal communication).

Roanoke Rapids Sanitary District. Reliance on the Roanoke River for domestic and industrial water supply has nearly tripled since the original Roanoke River studies report by Fish (1959). In the 1950s, the District treated about 61 MG/month of Roanoke River water supplied from a 24-inch pipe installed in the Roanoke Rapids Reservoir (Table 4). The District supplied four J.P. Stevens textile mills (now owned by Bibb Towel Co.) with 26 MG/month, Halifax Paper Company (now Champion International Corp.) with 3 MG/month, and the remainder went to domestic (3,200 water meters) and small industry uses. Halifax Paper Company supplemented the 3 MG/month from the Roanoke Rapids Sanitary District with 560 MG/month pumped directly from the lower Roanoke for use as plant process water. Also, the District supplied the town of Weldon with approximately 7 MG/month. In addition to water withdrawal from Roanoke Rapids Reservoir, the District had an emergency pumping station below the intake for the Halifax Paper Company. Presently, the District uses 173 MG/month, with slightly over 80 MG/month allocated for the four textile mills. Domestic and small industry users now consume nearly 61 MG/month alone; this value includes water supplied to Champion International Corporation. Domestic water meters now total 7,043, a figure that is slightly misleading since one of those water meters is for Halifax County (which subdivides into 2,000 additional water meters). On average, each water meter represents approximately 3.5 people. The District service area represents over 30,000 people; the western boundary is Myrick Estates on Lake Gaston (25 MG/month) and the eastern boundary is the Caledonia Correctional facility (including the cannery) (Macon Reavis, Superintendent, Roanoke Rapids Sanitary District, personal communication). The Champion plant uses an additional 30 MGD of Roanoke River water. Approximately 13 to 14 MGD is used as noncontact cooling water and is returned to the river untreated. Demand for this portion of the total withdrawal varies considerably with season; more noncontact cooling water is required during summer

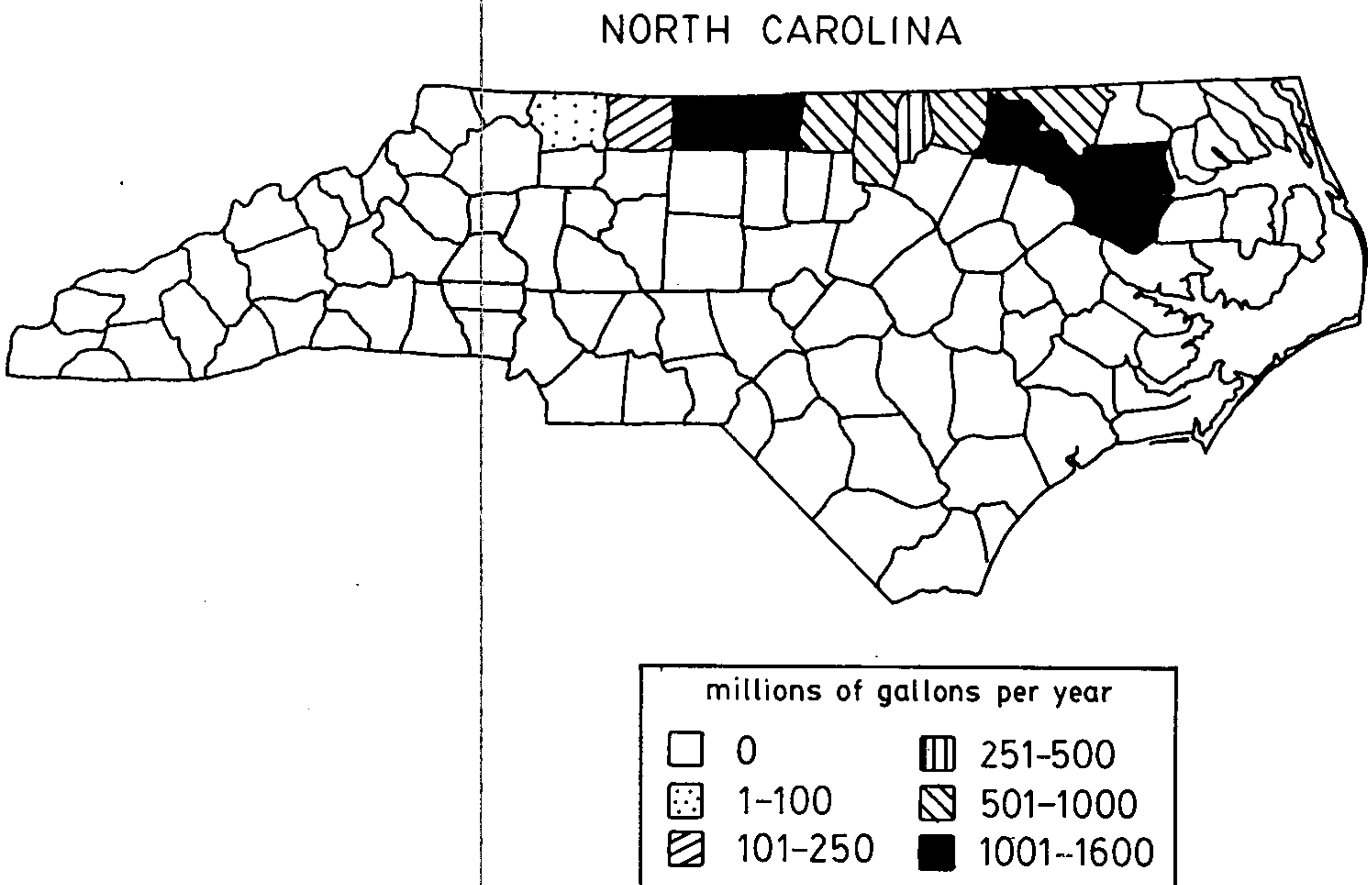

Figure 9. Irrigation water use (million gallons per year, MGY) in the Roanoke Basin, North Carolina, in 1983.

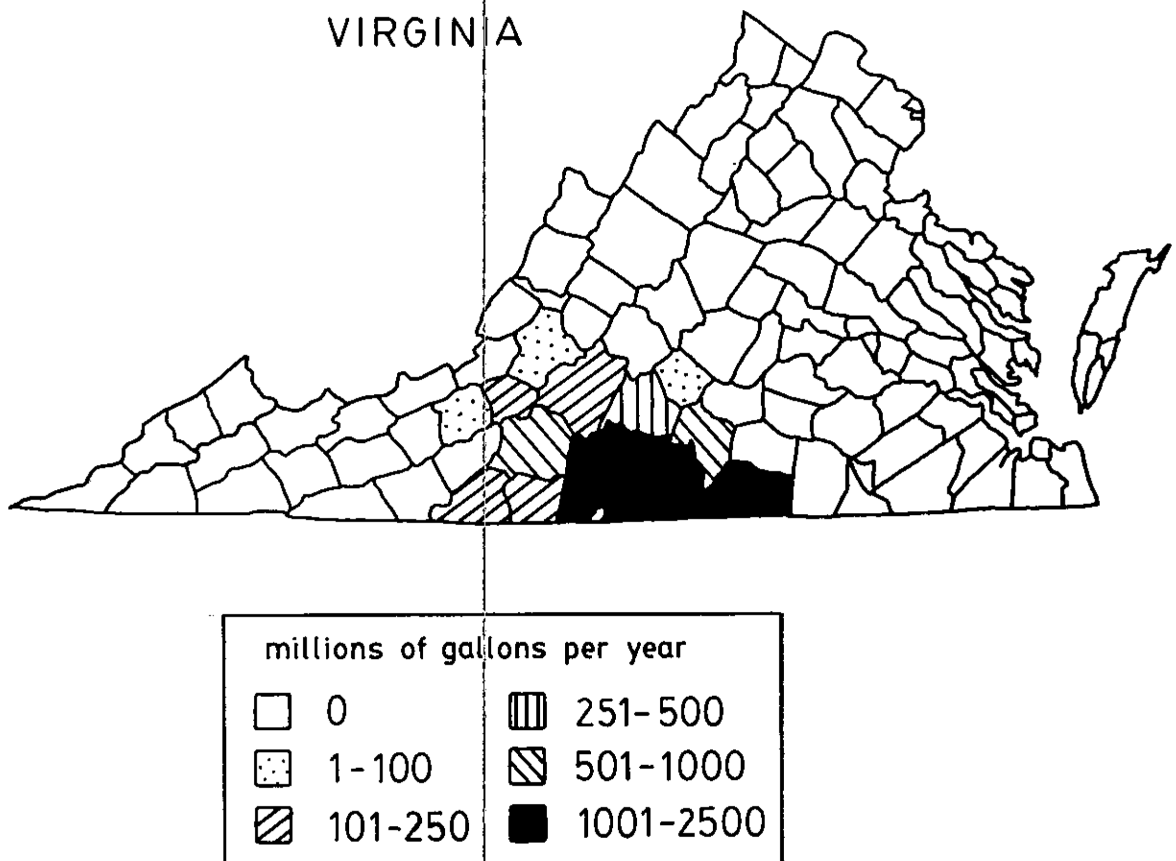

Figure 10. Irrigation water use (million gallons per year, MGY) in the Roanoke Basin, Virginia, in 1983.

Table 1. Roanoke River Basin irrigation water use for 1983. Values represent water applied in million gallons.

North Carolina				Virginia				Roanoke sub-basins		
Basin				Basin						
No.	Name	Acres irrigated	Water applied	No.	Name	Acres irrigated	Water applied	No.	Acres irrigated	Water applied
				1	Smith Mt.	2,839	1,107	1	2,839	1,107
				2	Upper Roanoke	3,798	1,445	2	3,798	1,445
				4	Smith River	171	148	4	171	148
5	Mayo	161	43	5	Mayo River	134	117	5	295	160
6	Upper Dan	911	287	6	Upper Dan	387	100	6	1,298	387
7	Dan-Eden	1,487	533					7	1,487	533
8	Dan River	4,278	1,545	8	Lower Dan	2,809	868	8	7,087	2,413
9	Hyco	1,900	651					9	1,900	651
				10	Banister	4,733	1,373	10	4,733	1,373
11	Kerr	2,836	1,331	11	Kerr	3,668	1,799	11	6,504	3,130
12	Roanoke Rapids	2,178	741	12	Roanoke Rapids	2,178	748	12	4,356	1,489
13	Buzzard Pt.	8,639	2,071					12	8,639	2,071
14	Williamston	7,173	2,094					14	7,173	2,094
15	Cashie	1,484	450					15	1,484	450
NC	Totals	31,047	9,746	VA	Totals	20,717	7,705		51,764	17,451

Notes:

- In cooperation with the Raleigh District, USGS

Table 2. Population size of four North Carolina counties bordering the lower Roanoke River, 1940 to 1987.

	Number of individuals					
County	1940	1950	1960	1970	1980	1987
Halifax	56,512	58,377	58,956	53,884	55,286	56,600
Martin	26,111	27,938	27,139	24,730	25,948	26,800
Northampton	28,299	28,432	26,811	24,009	22,584	22,200
Washington	12,323	13,180	13,488	14,038	14,801	14,700
Bertie	26,201	26,439	24,350	20,528	21,024	21,100

Table 3. Population size of six North Carolina municipalities bordering the Roanoke River, 1920 to 1987.

	Numbers of individuals							
Municipality	1920	1930	1940	1950	1960	1970	1980	1987
Gaston	-	-	-	1,218	1,214	1,105	883	1,042
Roanoke Rapids	3,369	3,404	8,545	8,156	13,320	13,508	14,702	15,747
Weldon	1,872	2,323	2,341	2,295	2,165	2,304	1,844	1,719
Williamston	1,800	2,731	3,966	4,975	6,924	6,570	6,159	6,264
Jamesville	389	344	499	529	538	533	604	678
Plymouth	1,847	2,139	2,461	4,486	4,666	4,774	4,571	4,922

Table 4. Major sources of water withdrawal from the lower Roanoke watershed, North Carolina, 1950s and present. Conversion to daily use assumes 30 days per month.

Source	1950s MG/mo.	1950s MGD	Present MG/mo.	Present MGD
Roanoke Rapids Sanitary District (four textile mills and residential)	61	2.03	173	5.77
Halifax Paper Company (now Champion International)	560	18.67	900	30.00
Weldon	-	-	12	0.40
North Carolina Pulp Co. (now Weyerhaeuser Co.)	1,500	50	3,240	108
Caledonia Prison Farm (irrigation)	-	-	258	8.6[1]
Total	2,121	70.7	4,583	152.77

[1]Maximum output during peak irrigation periods.

and less during winter. The remaining 17 to 18 MGD of river water is used in product manufacturing, and is returned to the river through the Champion primary clarification plant as treated wastewater. The discharge permit for Champion is based on pounds of biological oxygen demand (BOD) and total dissolved solids (TDS). The 30-day permitted average is about 6,700 pounds BOD and 13,000 pounds TDS; the 24-hour average can be more than these values. This permit does not consider river stage (Reid Henson, Champion International Corporation, personal communication).

Weldon. Originally, Weldon residents used Roanoke River water furnished by the Roanoke Rapids Sanitary District and treated by the Weldon water treatment facility. In the 1950s, the District supplied 7 MG/month, which in turn supplied about 900 domestic meters and several small industries (Fish 1959). Weldon eventually purchased the original Roanoke Rapids Sanitary District pumping station and now obtains its water directly from the river at the NC Highway 48 bridge, which is approximately 0.5 mile upstream of the Champion International outfall. Weldon now withdraws about 12 MG/month from the river, treating approximately 350,000 g/day (Table 4). The water treatment plant is capable of treating 2 MGD. Weldon's water treatment facility supplies 720 water meters in

Weldon, parts of Northampton County including Garysburg, and portions of Halifax County including South Weldon. The town stores water in a 1.5-MG reservoir outside of the water treatment plant (Donald Crowder, Weldon Public Works Director, personal communication).

Caledonia Correctional Institution. This state facility obtains water from the Roanoke Rapids Sanitary District. Average usage for the Caledonia and Tillery units combined is approximately 0.5 MGD. A substantial portion of the water is used for livestock, but approximately 75 percent enters the Caledonia sewage treatment facility. The permit for this primary treatment plant allows a maximum discharge of 12,500 g/day, although the capacity will be tripled within the year (Ed Nelson, Caledonia Maintenance Superintendent, personal communication).

Williamston. The town of Williamston's water supply is from four wells. The town is presently attempting to establish a fifth well on the west edge of town, which is the area for growth (the river borders the eastern side of Williamston). However, four test wells on the west edge of town have produced neither quantity nor quality of water necessary to meet future demands. A fifth attempt will be made near the river. Geologists from East Carolina University determined that the aquifer below Williamston is the same as that tapped by the Union Camp facility in Franklin, Virginia. The geologists also believe that the lower Roanoke River is Williamston's only long range source of water (10-20 years) (John T. Broykin, Williamston City Administrator, personal communication). Fish (1959) reported that the Williamston Packing Company and Atlas Plywood Company at Williamston were major industrial plants contributing wastes to the Roanoke River. Since Fish's (1959) report, the Packing Company burned down and the Atlas facility went out of business. First Carolina Industries, a coldcut meat packaging company, uses approximately 10,000 g/day of city water primarily for daily washdown. Williamston Yarn Company, a subsidiary of Fruit of the Loom, Incorporated, uses about 1.5 MGD from the Williamston system and plans to boost water use to 3 MGD within several months (Mr. Broykin, personal communication).

Plymouth. In the 1950s, North Carolina Pulp Company near Plymouth was pumping about 1500 MG/month for plant process water to supplement their well-water supply (Fish 1959). This facility is now owned by Weyerhaeuser Company and is permitted to withdraw an average daily volume of 118 MGD (55 MGD treated wastewater, and 63 MGD untreated noncontact water). Average daily use is about 45 MGD of process water, which is returned to the system through the plant treatment facility. Consumption of noncontact cooling water for the boilers varies with season; about 27 MGD are used in winter, and approximately 63 MGD during the hottest summer months (Mike White, Weyerhaeuser Company, personal communication). The Atlas Plywood plant at Plymouth was bought by Georgia Pacific in late 1959 or 1960, which then moved from the Plymouth area in the 1970s. During its operation, the plant used the river primarily for barges, and withdrew several thousand gallons of river water daily for use in boilers and sprinkler systems. In 1962, the veneer plant portion of the facility closed and the remainder was a hardwood sawmill until it was moved in the 1970s (Ralph Plumblee, Washington County Planning Office, personal communication).

Jamesville. Currently, Jamesville residents rely on two wells to provide a 30,000 g/day water supply to about 200 meters. One well is used for standby. The primary (aeration) sewage treatment plant discharges approximately 10,000 g/day into the Roanoke River. The only industry nearby is Penn Elastic, makers of rubberized material for bathing suits. The company has its own wells and treatment facility.

LOWER ROANOKE WATER QUALITY. The portion of the Roanoke River downstream of Roanoke Rapids is classified as a "C" stream by the North Carolina Division of Environmental Management (DEM). The river receives wastes from numerous municipal and industrial sources in addition to agricultural runoff. Table 5 shows NPDES (National Pollution Discharge Elimination System) permittees along the river and permitted wastewater flows.

DEM has assigned a "water quality limited" category to the lower Roanoke due to observed dissolved oxygen levels below the 5.0 mg/L limit; low dissolved oxygen values are observed especially near the Weyerhaeuser plant at Plymouth. Continued growth in water withdrawals and wastewater discharges will exacerbate existing water quality problems and causes concern regarding the ability of the lower Roanoke to assimilate additional waste loadings. Examples of water quality data during low flow periods are given in Tables 6-8. Loadings from NPDES for the same low flow periods are given in Tables 9-11.

Table 5. NPDES discharges to lower Roanoke River. Distance (river miles) is from the Champion International Paper outfall. WWTP = waste water treatment plant.

Discharger	Permitted Wastewater Flow (MGD)	Distance Downstream (river miles)
1. Champion International Paper Co.	21.0	0.0
2. Roanoke Rapids Sanitary District (RRSD)	8.3	3.5
3. Weldon WWTP	0.5	5.5
4. North Carolina Department of Corrections - Odum	0.07	21.5
5. North Carolina Department of Corrections - Caledonia	0.01	23.5
6. Perdue Farms	1.5	44.0
7. Hamilton WWTP	0.08	71.0
8. West Point Pepperell	1.5	71.5
9. Williamston WWTP	3.0	93.0
10. Penn Elastic	0.08	108.0
~~11. Jamesville WWTP~~	~~0.15~~	~~109.0~~
12. Weyerhaeuser	55.0	120.5
13. Plymouth WWTP	0.8	122.5

Table 6. Low flow, steady state water quality data for the lower Roanoke River for the period 5-15 October, 1980. Mile = distance downstream of Champion International Paper outfall.

	Temperature (°C)		Dissolved oxygen (mg/L)		BOD_5 (mg/L)		TKN	
Mile	Mean	Range	Mean	Range	Mean	Range	(mg/L)	Source
<0.0	20.3	21.0-19.5	8.6	9.0-8.3	0.9	1.0-0.8		1,2
14.0	19.5	20.0-19.0	7.9	8.0-7.8	1.0	1.0-0.9		1,2
62.4	18.0		8.2		0.7		0.5	3
92.0			7.5					4
119.8	21.4	22.6-19.0	6.9	7.3-6.4	2.6	5.0-1.0	0.3	4,5
121.2	21.5		5.5		2.0		0.5	4
122.0	19.9		5.6					4
123.5	19.1		4.8				0.5	4
124.9	21.8	25.0-19.0	4.1	5.6-2.4	2.8	4.0-2.0	0.4	4,5
125.2	20.5		3.9		3.0		0.7	4
126.2	19.3		2.1		3.8		0.6	4
126.9	22.5		3.3		4.1		0.7	4
127.6	19.1		3.1		3.5		0.7	4

Source 1 is Champion DMR (Discharge Monitoring Report)
~~Source 2 is Roanoke River Sanitary District DMR~~
Source 3 is STORET
Source 4 is DEM (NC Division of Environmental Management)
Source 5 is Weyerhaeuser DMR

Table 7. Low flow, steady state water quality data for the lower Roanoke River for the period 26 September to 12 October 1981. Mile = distance downstream of Champion International Paper outfall.

	Temperature (°C)		Dissolved oxygen (mg/L)		BOD_5 (mg/L)		TKN	
Mile	Mean	Range	Mean	Range	Mean	Range	(mg/L)	Source
<0.0	20.7	22.2-19.0	8.1	9.0-8.0	0.7	1.0-0.5		1,2,3
14.0	21.3	22.3-20.5	7.9	7.9-7.8	1.2	1.3-1.1		1
31.8	20.0		8.6		0.8		0.4	3
62.4	19.0		7.4		1.4		0.3	3
119.8	20.9	23.0-18.0	7.3	7.6-6.7	1.8	4.0-0.0		5
124.9	21.4	23.0-19.0	5.8	7.5-4.6	2.8	5.0-1.0	0.6	3,5

Source 1 is Champion DMR (Discharge Monitoring Report)
Source 2 is RRSD DMR
Source 3 is STORET
Source 5 is Weyerhaeuser DMR

Table 8. Low flow, steady state water quality data for the lower Roanoke River for the period 10 September to 11 October 1983. Mile = distance downstream of Champion International Paper outfall.

	Temperature (°C)		Dissolved oxygen (mg/L)		BOD_5 (mg/L)		TKN	
Mile	Mean	Range	Mean	Range	Mean	Range	(mg/L)	Source
<0.0	23.9	28.0-20.2	8.2	10.1-7.0	0.8	1.5-0.5		1,2,3
14.0	23.8	28.0-20.8	7.1	7.9-6.2	1.4	2.4-1.0	0.8	1,2,6
15.0	20.8		7.3		0.1		0.5	6
16.1	20.7		7.2		0.7		0.6	6
17.9	20.8		7.3		0.8		0.9	6
19.8	20.9		7.2		1.1		0.7	6
22.3	20.7		7.3		1.3		0.5	6
31.8	20.3	20.5-20.0	8.0	9.0-7.0	0.8	1.0-0.5	0.4	3,6
62.4	22.8	24.8-20.8	7.0	7.3-6.6	1.1	1.3-0.9	0.5	3,6
92.0	20.6		7.1		0.6		0.3	3
119.8	25.0	30.0-21.0	7.4	8.0-6.4	3.6	5.0-1.0		5
121.3	24.5		6.6		1.9		0.4	3
124.9	24.6	29.0-21.0	6.4	7.5-5.5	3.4	6.0-1.0	0.5	3,5

Source 1 is Champion DMR
Source 2 is RRSD DMR
Source 3 is STORET
Source 5 is Weyerhaeuser DMR
Source 6 is Weston

Table 9. Point source loadings for the lower Roanoke River for the period 5-15 October 1980. RRSD = Roanoke River Sanitary District; DOC = Department of Corrections.

Discharger	Flow (MGD)	BOD_5 (lb/day)	TKN (lb/day)
Champion Paper	17.8	2,702	2,672
RRSD	4.7	1,889	220
Weldon	0.34	158	43
DOC-Odum*	0.11	26	9
DOC-Caledonia*	0.01	3	1
Perdue Farms	0.96	395	301
Hamilton and West			
West Point Pepperell	0.80	64	9
Williamston	1.1	131	75
Penn Elastic	N/A	3	1
Jamesville	0.06	14	5
Weyerhaeuser	35.3	9,656	1,825
Plymouth	0.48	25	13
		15,066	5,174

*From NPDES permit limit.

Table 10. Point source loadings for the lower Roanoke River for the period 26 September to 12 October 1981. RRSD = Roanoke River Sanitary District; DOC = Department of Corrections.

Discharger	Flow (MGD)	BOD_5 (lb/day)	TKN (lb/day)
Champion Paper	14	4,157	2,102
RRSD	2.9	1,192	222
Weldon	0.34	158	43
DOC-Odum	0.11	26	9
DOC-Caledonia	0.01	3	1
Perdue Farms	0.96	395	301
Hamilton and West			
West Point Pepperell	0.80	64	9
Williamston	1.1	131	75
Penn Elastic	N/A	3	1
Jamesville	0.06	14	5
Weyerhaeuser	40.8	12,046	2,416
Plymouth	0.48	25	13
		18,214	5,197

Table 11. Point source loadings for the lower Roanoke River for the period 10 September to 11 October 1983. RRSD = Roanoke River Sanitary District; DOC = Department of Corrections.

Discharger	Flow (MGD)	BOD_5 (lb/day)	TKN (lb/day)
Champion Paper	25.0	3,128	3,753
RRSD	3.6	2,013	190
Weldon	0.34	158	43
DOC-Odum	0.11	26	9
DOC-Caledonia	0.01	3	1
Perdue Farms	0.96	395	301
Hamilton and West			
West Point Pepperell	0.80	64	9
Williamston	1.1	131	75
Penn Elastic	N/A	3	1
Jamesville	0.06	14	5
Weyerhaeuser	45.1	7,184	2,370
Plymouth	0.48	25	13
		13,144	6,770

IMPACTS OF HYDROLOGICAL EXTREMES ON DOWNSTREAM RESOURCES

Provisions for minimum flows during spawning have been established within the guidelines of the original agreements signed by the three agencies -- U.S. Army Corps of Engineers, North Carolina Wildlife Resources Commission, and Virginia Power. The required minimum flows for waste assimilation, navigation, and habitat change throughout the year. For example, during the striped bass spawning season in the spring, the minimum daily discharge specified by the Memorandum of Understanding is 2,000 cfs. This basic minimum release is supplemented by augmentation water from John H. Kerr Reservoir sufficient to maintain a minimum of 13 feet at the river gage at Weldon. The minimum flows required before spawning season is 1,000 to 1,500 cfs, and after spawning, only 2,000 cfs through September (Article 25 of the Federal Power Commission license).

The minimum flow guidelines established by the tri-party agreement do not consider maximum flows or the manner in which the average daily discharge is derived. Under high inflow conditions at Kerr, the dams provide controlled releases as given by the Rule Curve and release schedule, usually seen in the USGS gage records (below the Roanoke Rapids Reservoir) as about 20,000 cfs. Release of these large volumes of water causes extensive flooding downstream, which affects the pulp and paper industry, agriculture, nesting of wild turkey, fawning of deer, and spawning of a variety of commercially and recreationally important fish species. The flooding event *per se* is not new to the Roanoke watershed, but the timing of the flooding event or events is now controlled for the most part by the reservoir system. Historically, the worst flooding occurred during the late spring with some significant late summer floods. Figure 11 shows a comparison of the 90 percent of flows at Roanoke Rapids for pre- and post-impoundment conditions. In the majority of flood events, the dams have reduced flood peaks to the 20,000 cfs level in the spring and have greatly curtailed summer peaks. However, under most flood control conditions the duration of flood flows (higher than approximately 15,000 cfs) has been increased.

In addition to flood control, hydropower operations have also greatly affected daily flow magnitude. As early as July 1954, the downstream flooding problem associated with hydropower generation was recognized and documented. Velz (1954) presented the instantaneous hydrograph record from the Roanoke Rapids gage for the period 15-27 July 1953, which indicated routine changes in river flow of 8,000 cfs within a two-hour period (Figure 12). Even more dramatic changes in flow are commonly found in the USGS gage records from 1954 until the present time, many of which occur during striped bass spawning activity.

However, probable damages caused by disastrous floods would have been more extensive without the Kerr Dam. For example, the large flood that occurred in April 1987 had maximum regulated stages of 11.4 feet at Roanoke Rapids, 30.5 feet at Scotland Neck, and 12.1 feet at Williamston. Had flood control space in Kerr Reservoir not been in place during this event, the estimated maximums stage at Roanoke Rapids would have been 28.8 feet (17.4 feet higher), 36.8 feet (6.3 feet higher) at Scotland Neck, and 15.8 feet (3.7 feet higher) at Williamston. Other floods such as those in 1975 and 1978 produced stages one

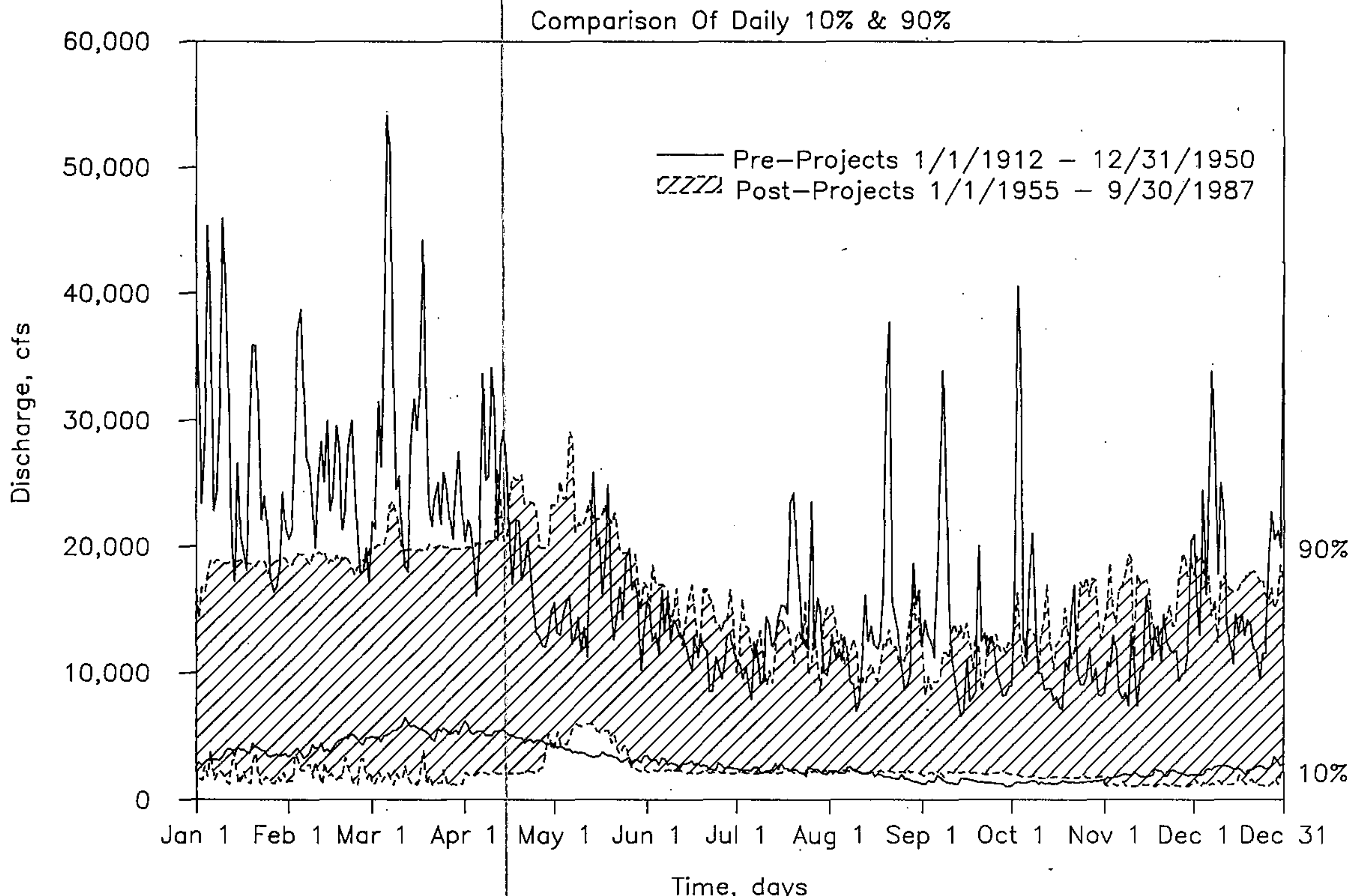

Figure 11. Comparison of daily 10 percent and 90 percent flows for pre-project (1912-1950) years and post-project (1955-1987) years.

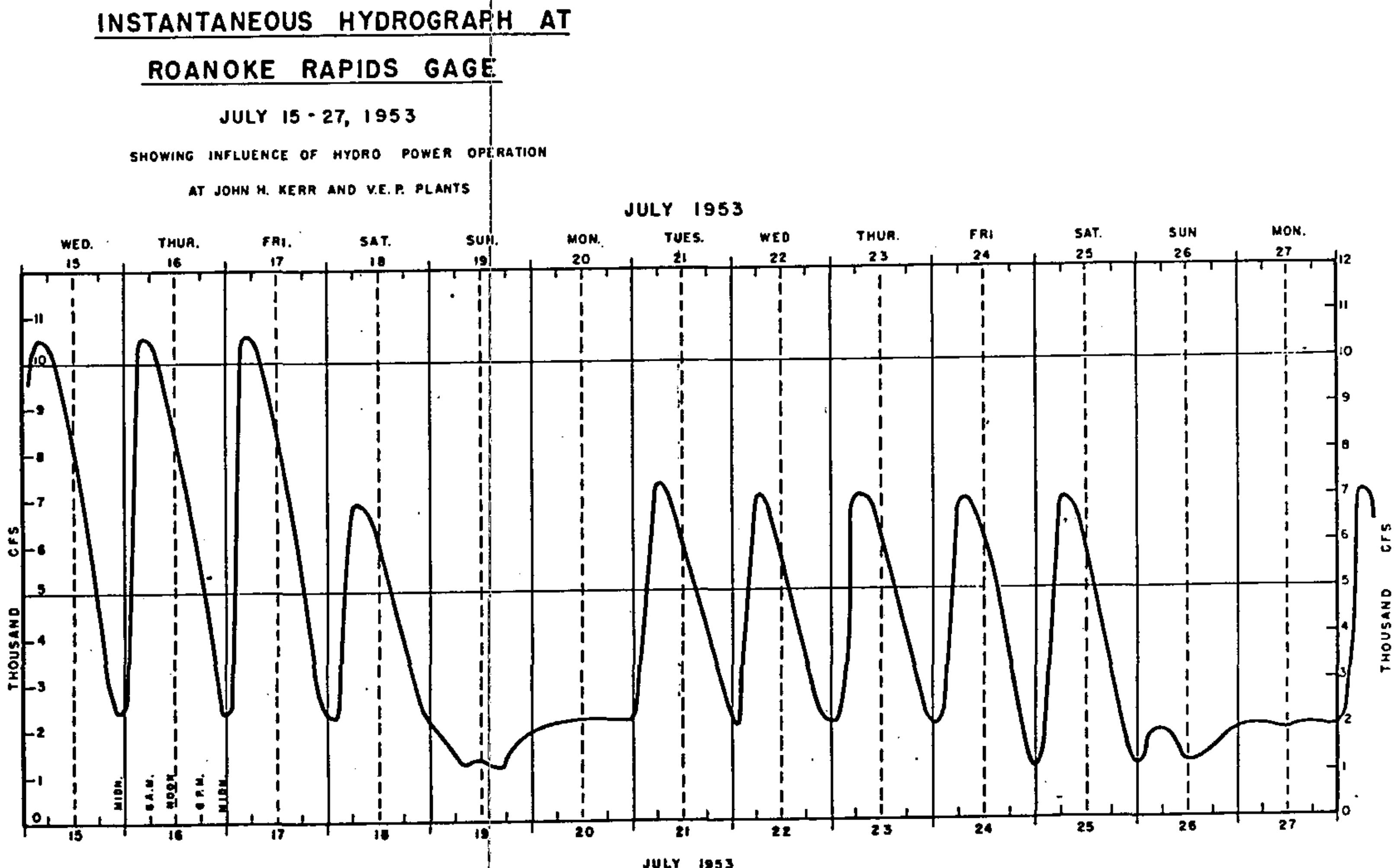

Figure 12. Instantaneous hydrograph at Roanoke Rapids gage for 15-27 July 1953, showing the influence of hydropower generation at John H. Kerr and Roanoke Rapids power plants (from Velz 1954).

to five feet lower at Williamston with flood control protection from Kerr Dam. Control of disastrous floods by Kerr Reservoir usually results in less acreage flooded but prolongs the duration of flooding.

Agriculture

Obtaining detailed financial information on damages and loss of production due to excessive moisture or delayed planting is impossible. Even a comparison of flood versus non-flood years for crop production on a county specific basis is of no assistance 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 standing crops. 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.

A 1980 survey of farmland affected by the spring floods of 1978 and 1979 in Halifax County indicated extensive 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.

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, thereby completely eliminating the potential for crop production in certain areas.

Infrastructure

Throughout colonial times, transportation in the lower Roanoke Valley was by boat. Goods produced on the plantations such as cotton and tobacco were shipped from river loading areas to the outside world. Ship and barge transportation is now minimal compared to colonial times. Major highways connect with secondary roads and farm roads. The historic knowledge of the floodwaters is such that no one currently lives in areas that are stranded when waters are high. However, farmland and livestock can be isolated for long periods due to the coverage of private and public roads by floodwater.

In 1975, the damage to public roads caused by flooding in Bertie ($7,521.88) and Martin ($500.00) counties totaled $8,021.88. 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. 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.

Wildlife

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

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 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 percent of the nesting took place in habitats usually inundated during floods. Approximately 65 percent 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 inundation 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 populations 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 scooter, ruddy duck, common merganser, and red-breasted merganser (Lynch 1973 through 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). Seasonal use of the Roanoke River forested wetlands by waterfowl is depicted in Figure 13.

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.

Municipalities and Industries

Municipalities and industries interviewed by telephone indicated that low flows (down to 1,000 cfs) had some negative impact on daily operations. There is concern that low flows (<2,700 cfs) do not adequately dilute and flush wastewaters from the river. Champion International's plant at Roanoke Rapids has a discharge permit that is independent of river flow. The Roanoke Rapids Sanitary District is concerned about low dissolved oxygen levels and aesthetic problems at the point of discharge. The District's waste pipe discharges into Choriak Creek just upstream of its merger with the Roanoke River. During low flow periods, pockets of wastewater build up within the creek and cause low dissolved

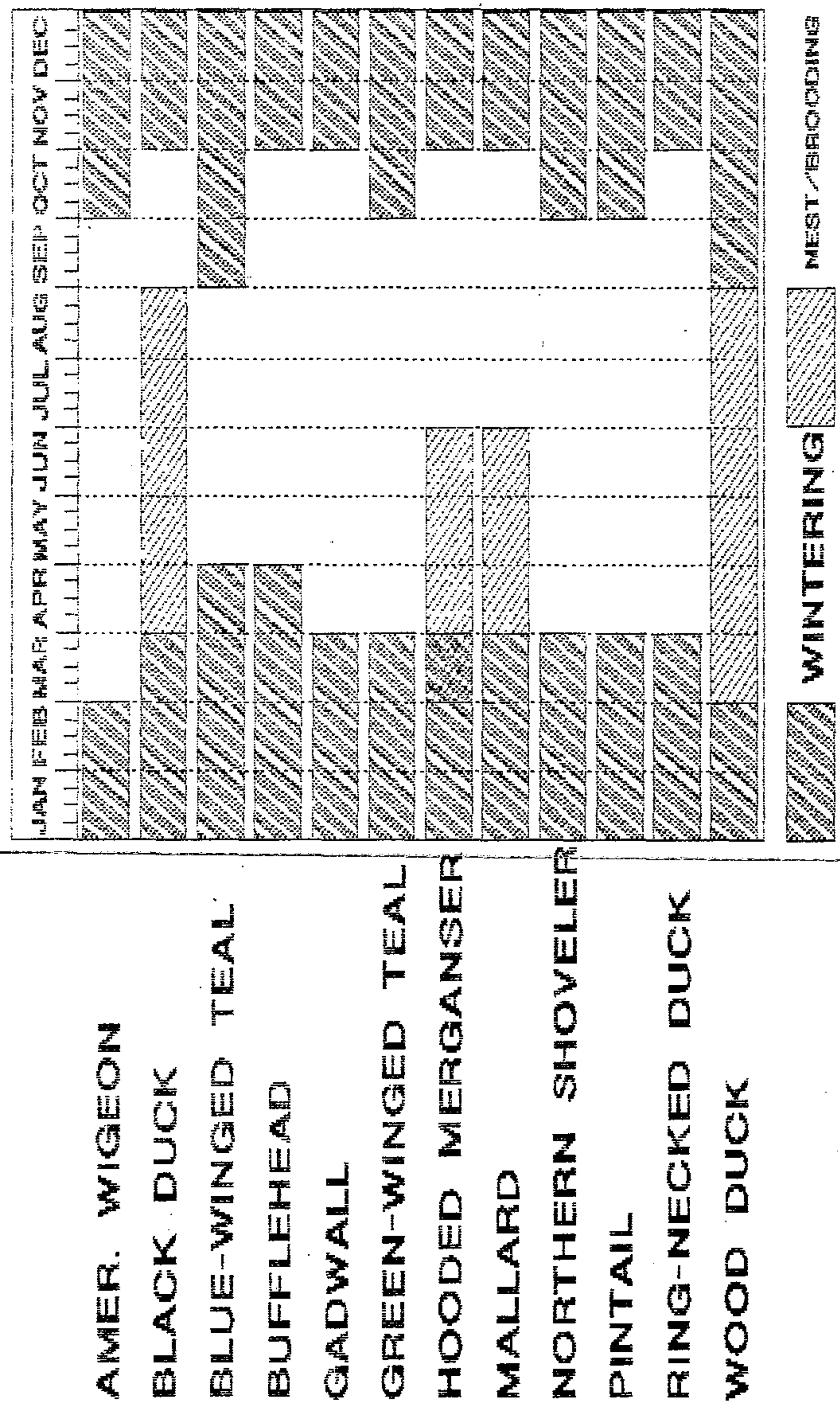

Figure 13. Seasonal use by waterfowl of the lower Roanoke River forested wetlands.

oxygen values. Variability of river flow from 2,400 cfs to 19,000 cfs within a 24-hour period is common. A 15,000 to 19,000 cfs flow would enhance the operation of their wastewater treatment plant. The Weyerhaeuser plant near Plymouth occasionally experiences plant shutdowns during low flow periods (< 2,500 cfs) because waters of the Roanoke mainstem actually flow upstream past the facility, resulting in increased conductivity values from the plant effluent (Robert G. Herrmann, Weyerhaeuser Company, personal communication). Under low flow conditions, the problem is exacerbated by the fact that 40 percent of the river flow exits the river via the Thoroughfare and Middle River, thereby effectively reducing the flow in the mainstem past the Weyerhaeuser plant to about 1,500 cfs.

Excessive discharge from the reservoirs upstream places additional burden on both municipalities and industry. Roanoke Rapids sewer plants are susceptible to flooding at 28,000 to 29,000 cfs because the head of the river exceeds the gravity flow of the treated discharge, closing the flapgate to the discharge pipe. The District had to add pumping facilities and dikes around the sewage treatment plant to reduce these problems during periods of excessive water release. Several other municipalities and industries indicated that faulty flapgates cause system flooding when river water levels are high. Another problem involves antiquated sewer systems and leakage problems. During periods of heavy rains, the sewer lines in several communities become inundated with freshwater infiltration, thus exceeding the capacity of the treatment system. For example, Williamston's sewage treatment plant normally discharges about 750,000 g/day, but heavy rains and subsequent infiltration through deteriorated sewer lines results in a discharge of over 2,000,000 g/day (John T. Broyken, Williamston City Administrator, personal communication). Williamston also suffers when the river level is higher than normal, causing the groundwater levels to rise and placing additional burden on the treatment plant from groundwater infiltration. The Caledonia Correctional facility has coped with flooding by constructing dikes along the periphery and adding pumps capable of removing 50,000 g/minute from the fields.

Recreation

The North Carolina Wildlife Resources Commission maintains five public boat ramps along the Roanoke River near the towns of Weldon, Scotland Neck, Hamilton, Williamston, and Plymouth. Extreme water level conditions, both high and low, reduce accessibility and make boat launching unsafe and difficult. Extreme high waters deposit silt that remains on ramp facilities as waters recede. Flood waters also effectively reduce parking areas. Extreme low water conditions may completely expose the ramps to the extent that boat trailers drop off the end of the ramp during launching and must then travel over soft sediments before waters are deep enough for boat launching. Under these conditions, facility users sometimes experience damage to personal property such as bent axles and trailer hitches, or more rarely twisted vehicle and trailer frames. In the most extreme cases, ramps are not usable.

Hunting, hiking, camping, and fishing activities in the floodplain are negatively impacted during flooding. Particularly affected are hunters and riverbank anglers, who are excluded from the floodplain during times of extreme high water. Access by boat to most areas of the lower river is not affected by extreme water conditions, although extensive sandbars and shoaling are common during low water periods.

HYDROLOGY AND STRIPED BASS: A KEY SPECIES

Life History Overview

Striped bass (also known as stripers, rockfish, or rock) have been commercially and recreationally important in North Carolina waters since the 1800s. Approximately 93 percent of the sportfishing landings in the State come each year from the Albemarle/ Chowan system, and only five percent from the Tar/Pamlico system (Baker 1968). The Roanoke/Albemarle striped bass population in North Carolina is an important contributor to the anadromous stock of the USA east coast, ranking third in size below the Chesapeake stocks (spawned in Maryland and Virginia tributaries) and the Hudson River population (USDOI and USDOC 1987).

The major spawning area for Roanoke/Albemarle stripers is located in the Roanoke River between the towns of Halifax (RM 120) and Weldon (RM 130), North Carolina (Figure 2). Spawning usually occurs from late April through early June (Hassler et al. 1981). The historical spawning grounds farther upstream were blocked by the construction of the Roanoke Rapids dam at RM 137 (McCoy 1959). Adult striped bass are broadcast spawners: one female and several males release eggs and sperm into the water column during the spawning act, or "rockfight". The fertilized eggs require lotic waters to ensure proper development. Transported downstream by the currents, eggs hatch into larvae which are then transported through the Roanoke River delta to the historical nursery grounds of western Albemarle Sound (Rulifson et al. 1988).

The striped bass is anadromous, which means that it utilizes a life history strategy of living in the ocean in the adult phase but must migrate to freshwater streams to spawn (Dadswell et al. 1987). Striped bass must have water movement at the site of spawning strong enough to keep the eggs in suspension, but not so strong that survival to the hatching stage is jeopardized.

This spawning strategy is maintained throughout the range of this species along the eastern seaboard of North America. However, there are two distinct sub-strategies: one using movements of tidal waters, and the other utilizing flow of freshwaters from upstream watersheds with no tidal influence present. The first sub-strategy is the best-known. Nearly all spawning stocks of striped bass north of the Roanoke watershed, and most stocks south of North Carolina, spawn in tidally-influenced waters just above the fresh-water-brackish water mixing zone typical of estuaries.

The Roanoke/Albemarle striped bass population is unique, however, because it travels a great distance upstream (130 miles) to spawn. There are two other populations, both in North Carolina, that mirror the Roanoke population in this respect: the Tar River population, and the Neuse River population. The common feature of all three watersheds is that there is no tidal influence on the rivers great enough to be utilized by spawning striped bass. The tidal effects are eliminated by the presence of the large lagoonal estuary/barrier island complex of the Albemarle and Pamlico Sounds. Therefore, these three populations must rely on freshwater discharge from upstream areas in order to complete the life cycle. If freshwater discharge is severely altered, striped bass cannot survive within the system.

Decline of the Roanoke/Albemarle Stock

The Albemarle Sound-Roanoke River striped bass population has generally experienced a decline since the 1970s based on estimates of population size (Table 12) and landings (Table 13). A combination of factors including flow regulation on the lower Roanoke River, deteriorating water quality, and heavy fishing pressure on immature fish have taken their toll on the population as evidenced by extremely poor juvenile production (Table 12).

During the mid-1970s, commercial and recreational fishermen complained that catches of striped bass in the Albemarle Sound-Roanoke River system were diminishing. During the same period, researchers at North Carolina State University noticed that reproductive success of striped bass was declining also (Hassler et al. 1981). Although no apparent trends were detected in the estimated total egg production, the viability rate of those eggs declined drastically beginning in the mid-1970s. Egg viability ranged from 80 to 96 percent from 1960 through 1974, but declined to 56 percent in 1975 and ranged from 23 to 74 percent in the succeeding years through 1987 (Table 12). In the past, the Roanoke/ Albemarle striped bass population has been supported by dominant year classes produced at approximately five-year intervals. A dominant year class, indicated by a juvenile abundance index (JAI) of at least 10 young-of-year fish per trawl tow, has not been produced since 1976 (Table 12). The estimated number of striped bass in the spawning migration remained within historical levels through the mid-1970s, but in 1980, that number also declined. Since 1981, the estimated spawning population has remained below 100,000 fish (Table 12).

Commercial landings of striped bass in the early 1980s dropped well below long term averages. Commercial landings in Albemarle Sound reached a peak during 1967 (1,296,700 pounds) and by 1982 landings had dropped to 228,004 pounds (Table 13). In 1971, commercial landings in the Roanoke River were 30,104 fish, but dropped to only 2,286 fish in 1980. Estimates of striped bass harvest by sport fishermen in the Roanoke River ranged from a high of 65,399 fish in 1971 to only 3,131 fish in 1985. A three-year creel census in Albemarle Sound was conducted by the North Carolina Wildlife Resources Commission (WRC) and sport fishing catches of striped bass ranged from approximately 33,000 fish in 1977-78 to approximately 5,000 fish in 1979-80 (Mullis and Guier 1982).

Interpretation of commercial and sport harvests and spawning population size estimates (Tables 12 and 13) should be tempered in the context of recent changes in fisheries regulations, which reduced the catch and also altered the traditional methods of calculating certain population dynamics statistics, such as exploitation rates. A synopsis of these regulation changes is presented in Table 14.

Factors dictating the formation of a successful or dominant year class of striped bass are not completely understood. However, it is clear that one of the major forces influencing the aquatic environment and therefore striped bass stocks is water flow. In the lower Roanoke River, water flow is principally controlled by water release from Roanoke Rapids Reservoir. Water is released through the turbines by Virginia Power to maximize hydropower production during peak load hours.

Water flow affects striped bass (and similar fish species) in all facets of its complex life history. These effects are described in the following paragraphs. Information describing the various life history aspects has been taken from many sources, including the numerous reports by W.W. Hassler at North Carolina State University, Rulifson and colleagues at East Carolina University, and personnel of both the North Carolina Wildlife Resources

Table 12. Historical reproduction information on the Roanoke/Albemarle striped bass population (from Hassler and Taylor 1986, except as otherwise noted).

	Number of eggs spawned	Percent egg viability	Number of fish in spawning migration	Juvenile abundance index	
				NCSU	NCDMF
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	337,024	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[d]
1984	703,879,559	22.73	59,890	0.36	0.00[d]
1985[b]	600,562,645[b]	72.21[b]	32,937[b]	1.24[b]	0.32[e]
1986[b]	2,279,071,483[b]	51.10[b]	61,656[b]	0.14[b]	0.11[f]
1987[b]	1,382,496,006[b]	42.87[b]	91,738[b]	0.06[b]	0.30[d]
1988	2,082,147,979[c]	89.00[c]			4.09[d]

[a] Partial season data only.
[b] Personal communication, W.W. Hassler, N.C. State University, Raleigh, NC.
[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 and Henry (1986).
[f] Winslow and Henry (1988).

Table 13. Historical harvest of striped bass from Albemarle Sound and Roanoke River (from Hassler et al. 1981, except as otherwise noted). Roanoke River sport harvest numbers include all legal sport harvest methods (e.g., bow nets, fight nets, rod and reel).

	Commercial harvest		Sport harvest		
	Albemarle Sound area[a]	Roanoke River above Jamesville[b]	Albemarle Sound		Roanoke River[b]
	(Pounds)	(Numbers)	(Numbers)	(Pounds)	(Numbers)
1956		2,209			16,434
1957		1,827			15,970
1958		4,240			9,931
1959		5,442			48,131
1960		13,820			28,821
1961		6,531			26,627
1962	504,800	7,526			14,688
1963	587,100	7,479			10,308
1964	564,200	9,300			28,114
1965	367,900	14,294			32,116
1966	547,400	18,508			13,368
1967	1,296,700	5,526	67,172		7,433
1968	296,700	10,050	49,476		31,988
1969	913,600	15,431	62,444		23,891
1970	773,600	16,485	96,170		28,257
1971	615,300	30,104	41,426		65,399
1972	314,434	24,691	35,698		45,650
1973	535,301	9,020	30,783		42,047
1974	449,477	15,609			38,826
1975	635,617	19,989			22,219
1976	676,401	7,156			40,799
1977	469,718	10,465	33,201[d]	71,720[d]	32,983
1978	524,999	16,253	16,599[d]	30,850[d]	28,016
1979	326,848	9,798	5,700[d]	12,526[d]	29,419
1980	376,510	2,286			15,239
1981	333,484	349			3,905
1982	228,004	398			7,324
1983	288,742	650			6,976
1984	475,640	1,023			5,523
1985	269,671	101[c]			3,131[c]
1986	172,683	76[c]			6,663[c]
1987	228,861	8[c]			10,027[c]
1988	114,183				16,657[e]

[a] Personal communication. Lynn Henry. N.C. Division of Marine Fisheries, Elizabeth City, NC. (from NCDMF-NMFS commercial landings data, including all tributaries and mouth of Roanoke River up to Jamesville).
[b] from Hassler and Taylor (1986).
[c] Personal communication. W.W. Hassler. N.C. State Univ., Raleigh, NC.
[d] from Mullis and Guier (1982).
[e] Mullis (1989).

Table 14. Regulations resulting in conservation and/or reduction in striped bass harvest in the Roanoke River-Albemarle Sound area, North Carolina, 1979-1987. DMF = North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries; WRC = North Carolina Wildlife Resources Commission.

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 8 fish per day in inland waters. (WRC)
	Field possession limit reduced to 1 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 the mouth of Roanoke, Middle, Eastmost, and Cashie Rivers proper. (DMF/Oct.)
1982	Minimum size limit of striped bass 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.)

Table 14. (Continued)

	Minimum mesh 3 1/2 inch October - December. (DMF/Aug.)
	Eliminated use of gill nets in Albemarle Sound and tributaries during June - September, except defined "Mullet Nets" (2 1/2 - 3.0 inch, floating, and within 300 yards of shore). (DMF/Aug.)
	First reduction in hook and line creel limit (8 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 3 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 provision for "Mullet Nets" in Albemarle Sound and tributaries. (DMF/Aug.)
	Hook and line creel reduced to 3 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 on 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.)

Table 14. (Continued)

	Established proclamation authority to open or close a portion of the striped bass season (October and April). (DMF/Nov.)
	Aligned Currituck Sound net regulations with the Albemarle Sound regulations relative to striped bass conservation measures. (DMF/Nov.)
	Eliminated the harvest and sale of striped bass from the spring Albemarle Sound gill net fishery and Roanoke River delta pound net fishery. (DMF) (Effected by Aug. 1985 regulation)
1987	Eliminated all trawling in Albemarle Sound and tributaries year round. (DMF/Dec.)
	Closed a portion of western Albemarle Sound to gill netting (Batchelor Bay area) and restricted the spring pound net fishery in the Roanoke River delta by proclamation. (DMF/April)
1988	Striped bass size limit in Atlantic Ocean will correspond to the recommendation of the ASMFC interstate striped bass plan. (DMF/Sept.)
	Proclamation authority established, reguarding use and attendance of "striped mullet gill nets" in Albemarle Sound and tributaries (June - December). (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/April)

Commission and the Division of Marine Fisheries. These reports are presented in the literature cited section of this document.

Spawning

Water release affects the seasonal timing of striped bass spawning. When water is released from the reservoir during the spring, the stored water is usually cooler than those waters below the dam. The result is a sudden drop in river temperature. If water releases are high (15,000 cfs or more) and consistent during April and May, striped bass adults remain in the Roanoke River delta and western Albemarle Sound waiting for water temperatures to rise to the optimum. If the optimum is not reached, some striped bass may spawn at less than optimum temperature. If high discharge is suddenly stopped or reduced, adults literally scramble upstream to spawn and retreat in the time remaining. Prolonged low discharges (during drought years) usually results in higher than normal water temperatures and the adults spawn earlier than normal.

Spawning location in the river is affected by water release from the Roanoke Rapids Dam. High prolonged discharges cause the adults to migrate farther upstream (sometimes above Weldon) seeking appropriate spawning waters of adequate depth. Prolonged low discharges cause spawning to occur far below the historical spawning grounds near the towns of Hamilton and Halifax.

The daily patterns of hydropower generation affect spawning on a daily and hourly basis. Striped bass spawn over a period of about 50 to 60 days, but the majority of spawning generally takes place during several one to three-day periods. Most spawning activity is at night. If water is discharged at a consistent rate with no sudden changes, the adults will proceed with spawning activity. Sudden starts and stops of water release (as shown in the water gage records) can cause drastic changes in water temperatures and water depth, which can completely shut off the spawning process. When this occurs, these fish appear to turn and swim downstream. Spawning may occur later in the season, but no information is available to document whether the adults affected by sudden water release ever return to complete the spawning act.

Eggs

Egg transport downstream is directly attributable to water release from the reservoir. Under moderate flow conditions, striped bass eggs pass gently downstream rolled by the current due to their semi-buoyant nature. These conditions are necessary in the Roanoke for the eggs to remain healthy and to hatch successfully in the correct habitat downstream. Under prolonged high flows, egg distribution is changed both vertically and laterally. The turbulence associated with high flows increases the sediment load, which has been documented to smother eggs and reduce chances of a successful hatch (Auld and Schubel 1978). Eggs are transported laterally to the floodplain reducing chances for successful hatch even more. Many of the eggs transported downstream under high flow conditions are washed directly into Albemarle Sound to conditions not suitable for the eggs to hatch. Under prolonged low flow conditions, eggs are transported too slowly downstream. Hatching of the larvae occurs too far upstream where the food supply is not available (Rulifson et al. 1988).

Water release also affects time to hatch of striped bass eggs. Hatching time is a function of water temperature. Low temperature delays hatching time; warm temperatures decrease the hatching time. Sudden temperature changes associated with hydropower generation cause shock to the eggs, which can result in death or deformed larvae.

Egg mortality caused by water release is altered by the mechanisms described above. Basically, sudden changes in water discharge affect the general water quality including temperature, turbidity, hardness, alkalinity, pH, and dissolved oxygen. Additionally, high or low flows will dictate the dilution factor of municipal and industrial wastes, which in turn affects egg mortality.

Striped Bass Larvae

Water release changes the time of larval transport downstream. Appropriate flow conditions are necessary to ensure that larvae are in the proper habitats of the river at hatch, including distance downstream from the spawning ground, vertical distribution, and lateral position (i.e., within the confines of the riverbank rather than onto the floodplain under prolonged high flow conditions).

Larval feeding success is also affected by water flow. Striped bass larvae are weak swimmers propelled by prevailing water currents for several days after hatch. Swimming ability increases with age. Striped bass larvae must make feeding strikes at zooplankton. Each feeding strike requires an expenditure of energy. Larvae must have a high success rate of feeding in order to survive. Those larvae too weak to feed successfully either sink to the bottom and die or are preyed upon. Greatest feeding success has been documented in those areas of the lower Roanoke River having the highest concentrations of zooplankton. Under conditions of high flow, larvae are swept into Albemarle Sound where the food resource is extremely poor, virtually ensuring high mortality. Under low flow conditions, larvae develop too quickly upstream of the highest food concentration and may be too weak to feed successfully as they pass through the highest food source downstream.

Larval mortality is affected by water flow. Poor feeding success was described above. General water quality, particularly dissolved oxygen, pH, and concentration of heavy metals, is an important factor controlled by flow. High flows have pH values lower than 7.0, making the waters acidic. High flows resuspend the fine silt clay particles from the river bottom. These particles are typical of the coastal plain soils in that they contain high concentrations of aluminum. As the aluminum-containing silt is resuspended, it is hypothesized that low pH water (entering from adjacent blackwater areas of the floodplain) causes the aluminum to change from non-toxic organic complexes to a monomeric form highly toxic to fish larvae. Laboratory studies (Mehrle et al. 1984) and field studies in Chesapeake Bay (Hall et al. 1986) have documented that low pH (6.0) and high monomeric aluminum (100 ug/L) are toxic to striped bass larvae. Limited studies have shown that the lower Roanoke River contains more than 100 ug/L of monomeric aluminum at reduced pH levels during high water discharge events. Under low flow conditions, aluminum levels are reduced but several other heavy metals, including mercury, have been detected in waters below Plymouth, indicating an insufficient dilution factor for industrial and municipal wastes (Rulifson et al. 1986). Low flow conditions also cause reduced oxygen levels at specific sites along the river, primarily those waters below waste discharge sites.

Striped Bass Juveniles

Water flow affects transport of young striped bass to the historical nursery grounds of Albemarle Sound. Prolonged high flows result in juveniles utilizing nursery grounds in eastern Albemarle Sound. Low and moderate flows allow the juveniles to use traditional sites of the western Sound. Both timing and position of juveniles on the nursery grounds is influenced by water flow. Water quality on the nursery grounds is influenced by Roanoke Rapids Reservoir discharge. High flow conditions cause low dissolved oxygen values in Albemarle Sound, perhaps due to the presence of organic matter swept from the floodplain and swampland streams into Sound waters. Prolonged low flow conditions cause high water temperatures, low dissolved oxygen under light wind conditions, and may be accompanied by algae blooms in the Chowan River and Western Albemarle Sound. Low flows allow nursery areas to be invaded by brackish water from the Atlantic Ocean. Poor water quality limits the areas suitable as nursery habitat.

Zooplankton

Zooplankton is the primary food source for larvae of many fish species, including striped bass. Abundance, relative distribution in the estuary, and species composition are influenced by water releases from Roanoke Rapids Reservoir. Zooplankton communities start to develop far upstream but concentrations are low. As zooplankton are transported downstream, they reproduce and build the population over a period of several days or weeks. Upon reaching the Roanoke River delta the community has peaked in abundance. Under prolonged high flow conditions, zooplankton are swept downstream too quickly and the community does not increase in sufficient numbers. In addition, high flows may dilute the population which effectively reduces the chances of striped bass larvae to feed successfully. No information is available on the effects of pH, aluminum, and turbidity on zooplankton communities. Under prolonged low flow conditions, zooplankton develop highest concentrations in the Roanoke River delta, but the striped bass larvae cannot reach this area of highest concentration until it is too late (i.e., larvae become starved and are therefore too weak to feed successfully even though the food is available).

Phytoplankton

Phytoplankton, positioned at the base of the food chain, serve as the food source for zooplankton. Phytoplankton communities develop in the same manner as zooplankton. Phytoplankton are few in number at the headwaters but reproduce and grow as they are transported downstream. The size of the community is contingent on the length of time allowed for development and the amount of nutrients (especially nitrogen and phosphorus) present in the water column. High flow conditions result in low phytoplankton abundance; low flows result in greater abundance.

Adult Mortality

Water flow influences the susceptibility of adult striped bass to harvest by commercial gear in western Albemarle Sound and Roanoke delta during the first days of the spawning run (up to 30 April). Moderate flow attracts striped bass to the river mouth. By positioning the commercial gear correctly, catches of adults can be increased. Because river flow influences the location of the spawning grounds each year, it also serves to concentrate the adults in certain areas of the river. Sport harvest of striped bass increases when fish are concentrated at river bank access points (e.g., Weldon) and within reasonable motoring distance by boat from boat ramps.

Water flow also impacts the use of certain types of commercial fishing gear in the Roanoke River. During times of extreme high water, anchored gill nets and pound nets, unless set in specific areas, are ripped from their moorings by water surge and drifting logs, or if left intact, become clogged with debris. Extreme low waters also limit the locations where gill nets may be set; as water depths decrease, drift gill nets become entangled on obstructions on the bottom.

Extreme low water levels have caused mortality to adults on the spawning grounds by stranding fish (as in the spring of 1987), and by concentrating pollutants. One case in point occurred in 1963 as documented by Hassler, Trent, and Gray (1963). Hassler's tagging data indicated that the migration of striped bass occurred primarily during the first two weeks of April 1963. Initially it appeared as if another major run occurred during the week of 28 April-4 May. Hassler et al. (1963) stated that a re-ascension of the river by striped bass occurred during that week, but the run was "an aftermath of the fishkill which occurred on 21 April." For a period of 10 days prior to the fishkill the flow of the river was at the minimum level. During this low flow period, the report mentions some type of spill which poisoned the fish on the spawning grounds between Weldon and Roanoke Rapids.

CHARACTERIZATION OF PRE-IMPOUNDMENT AND POST-IMPOUNDMENT FLOWS

USGS Data

Discharge from the Roanoke Rapids Reservoir is monitored on an essentially continuous (quarter hourly) basis by the U.S. Geological Survey (USGS) water gage No. 02080500, Roanoke River at Roanoke Rapids. This gage is located in Halifax County on the right bank 2.8 miles downstream from the Roanoke Rapids Dam and 133.6 miles from the mouth in Albemarle Sound. The period of record is from 1911 to the current year. The unit (quarter-hour) values are used to determine an average daily discharge measured in cubic feet per second (cfs). The maximum discharge for the period of record was 261,000 cfs on 18 August 1940. The flood of 1940 was the maximum flow known since at least 1771. The minimum recorded discharge was 250 cfs on 16 December 1955.

Pre-impoundment data (PRE-USGS) for the purposes of our analyses were considered to be 1912 through Water Year 1950. Water flows were modified by Philpott Lake on Smith River in August 1950, and by John H. Kerr Reservoir since September 1950. However, flows were not completely regulated until fall 1952.

Post-impoundment data (POST-USGS) were considered to be 1955 through Water Year 1987. The John H. Kerr Dam first started power generation in the fall 1952, and flood control was first implemented during the spring 1953. Flows have been modified further since June 1955 by Roanoke Rapids Lake, since September 1962 by Leesville Lake, since October 1962 by Lake Gaston, and since September 1963 by Smith Mountain Lake.

In attempting to characterize the streamflow record, statistics were selected to allow comparison of pre- and post-impoundment conditions. Often simple daily means would provide an adequate statistic for comparison. But in the case of the Roanoke Rapids gage, it was believed that the daily mean would not provide good comparison because of the great amount of flow regulation provided by the basin's dams and reservoirs. The daily means are also greatly influenced by singular extreme events, such as large flood flows which bias the statistic upwards. This upward bias would not provide a true estimate of "typical" or "normal" expected flows. The regulation of the flows and effect upon the daily average flow is shown in Figure 14.

Figures 15 and 16 show the comparison of the average and median flows for pre- and post-project flows. The median flow was selected as a more appropriate measure of the expected flow. The greater variability in the median flow for post-project conditions over pre-project conditions is not readily explainable.

The availability of storage at Kerr Lake and the operating rules for spawning flows and low flow regulation has had a significant effect on low flows in the lower Roanoke River. During high temperature months, with probable lowest dissolved oxygen levels, the projects have essentially doubled the low flow (Figure 17). However, during the period of November through March the project has produced a flow record with low flows much lower than pre-project conditions (Figure 17). The absolute lows during the spawning season are not much different than that of the pre-project conditions, except for one day in May which appears to always have the 6,000 cfs target met.

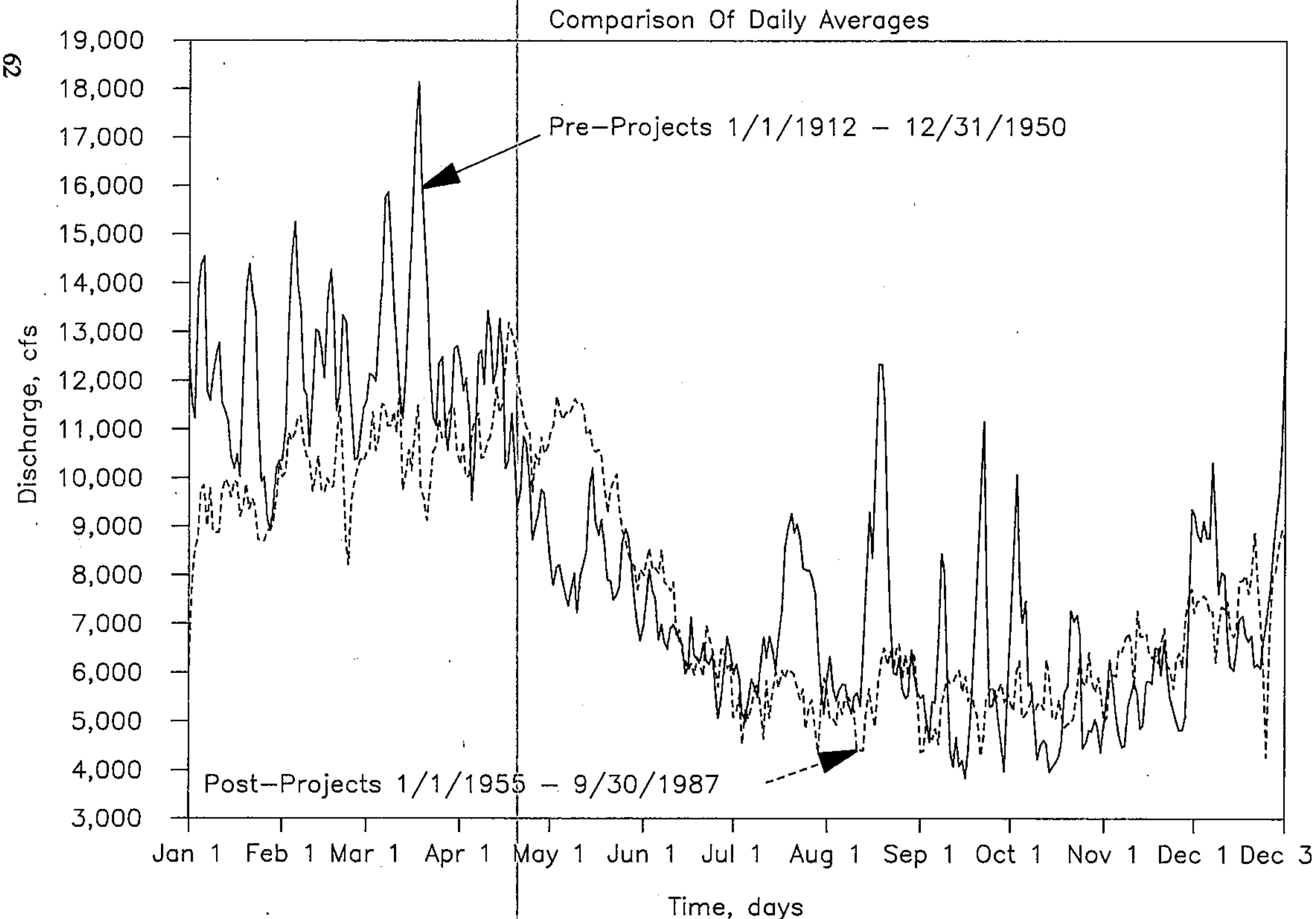

Figure 14. Daily average flows of the lower Roanoke River for pre-impoundment (1912-1950) and post-impoundment (1955-1987) conditions.

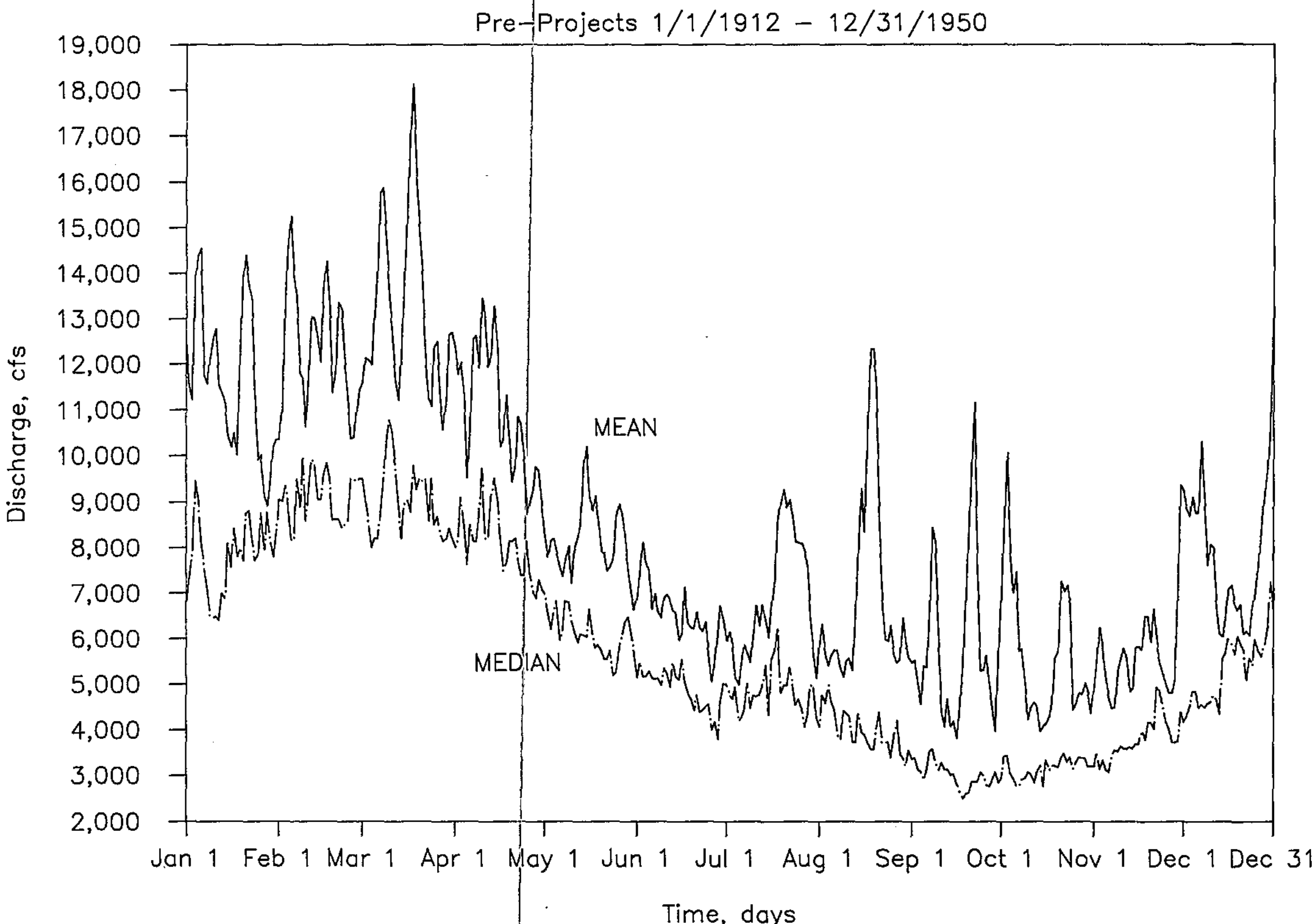

Figure 15. Comparison of daily mean and median flows for the lower Roanoke River under pre-impoundment (1912-1950) conditions.

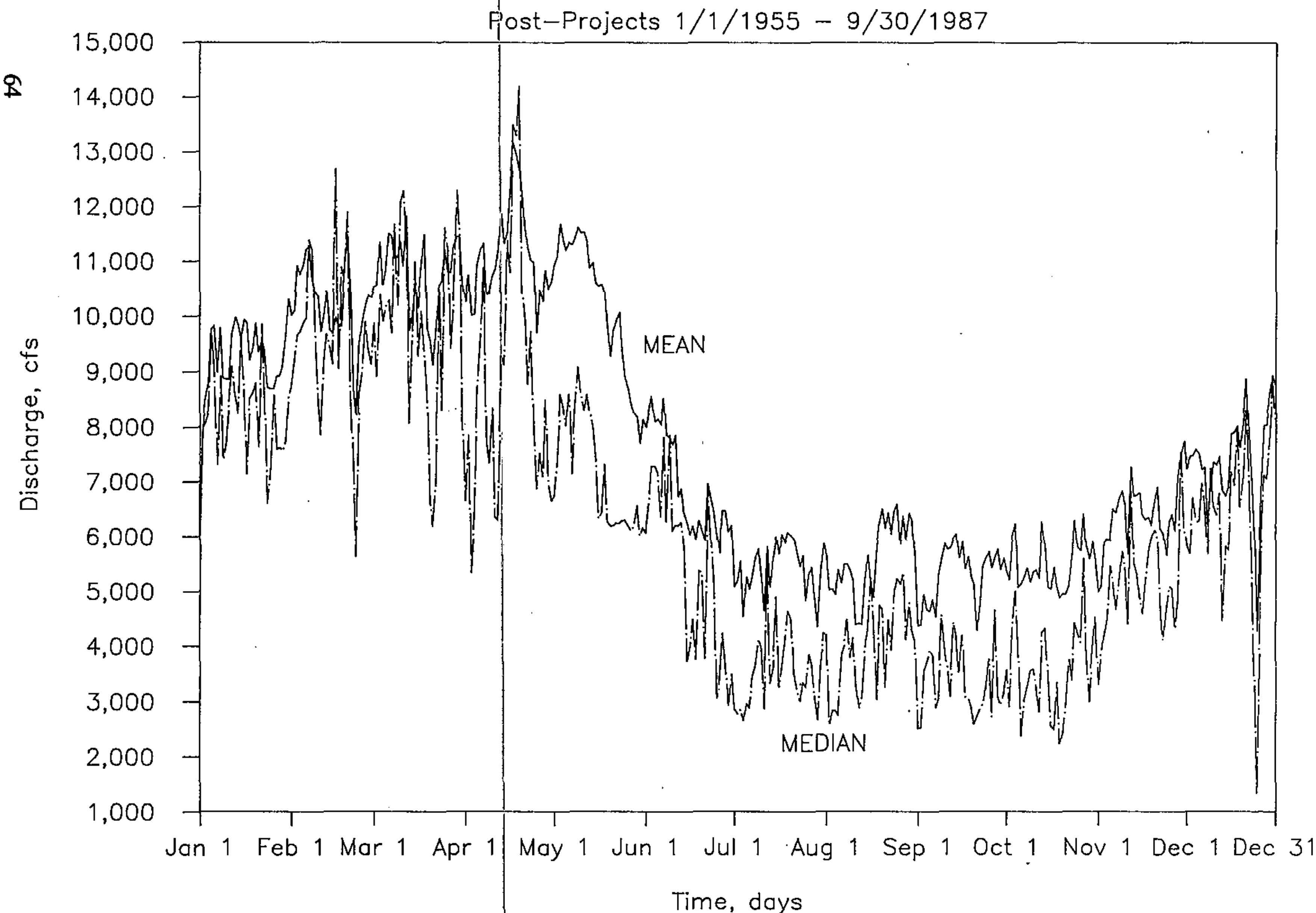

Figure 16. Comparison of daily mean and median flows for the lower Roanoke River under post-impoundment (1955-1987) conditions.

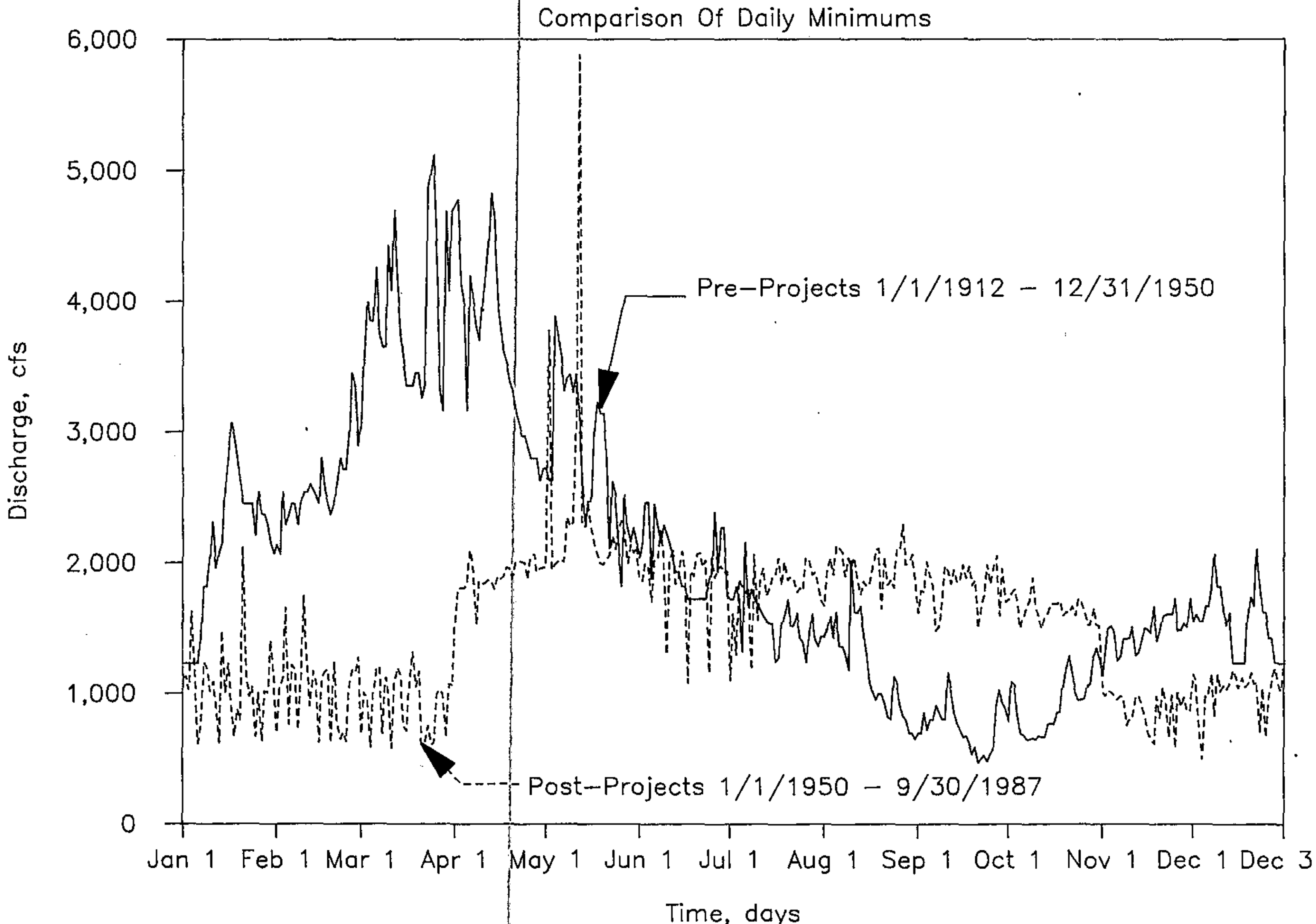

Figure 17. Comparison of daily minimum flows of the lower Roanoke River under pre-impoundment (1912-1950) and post-impoundment (1955-1987) conditions.

The occurrences of extreme high or low flows also make it difficult to determine a flow level or range of flows that are acceptable to spawning fish. To try and isolate a range of flows thought to be acceptable, it was decided that this range should occur for 50 percent of the time and be centered around the median flow; that is, within the 25 and 75 percentiles of flows. In other words, the bottom 25 percent (low flows) and the top 25 percent (high flows) were not considered to be representative of the best flow conditions of spawning or subsequent life stages. Obviously, this selection of the quartiles was arbitrary and it is possible that a broader or narrower range would provide a more optimal flow regime. The pre-project and post-project flow regime for various flow statistics (minimum, 10 percent, 25 percent, median, etc.) are depicted in Figures 18 and 19. More detailed analysis of the flow regime during the spawning period is presented below.

Virginia Power Company Data

The operation of the Roanoke Rapids power plant has a significant daily variation due to load demand and the ability of the hydropower facilities to respond to this demand at a rapid rate. This results in a possible daily flow change from about 1000 cfs to 20,000 cfs at the powerhouse. The flow change is limited by a mandated minimum flow, which is a function of the time of year and by an allowable rate of flow change. This rate of flow change is restricted to doubling or halving the flow in one hour for the duration of the spawning flow augmentation period (Article 26 of the Federal Power Commission license).

The effects of the flow changes are the most significant at the dam and diminish downstream as the flow is routed through the channel storage.

For this investigation, only data gathering was accomplished. The power plant operating records were obtained from Virginia Power for the Roanoke Power Plant for 1956 to 1986. These data consisted of daily operating logs giving hourly flow, power generation, and water elevations in the lake and in the tailwaters. The logs also contained periodic (about every six hours) measurements of water temperature and dissolved oxygen. The compilation of these data to a useful format was undertaken by the North Carolina Division of Marine Fisheries. Data are hourly flows and whatever temperature and dissolved oxygen data are available for the period of record.

To assist the analysis of a flow regime, several critical years were selected and hourly high and low flows were abstracted from the hourly records for each day during the spawning period. This was combined with the data base for average daily flows. The attenuation of the peaking flow pattern is illustrated by data collected by the U.S. Army Corps of Engineers at stage recorders downstream of the dam for April, May, and June 1956 (Figure 20).

The hourly change is given in Figures 21 through 27 for a series of years. The data plotted represent the maximum and minimum values from the hourly operating logs of the plant. The years plotted were selected to give a representation of "good" and "bad" years of the Juvenile Abundance Index (JAI).

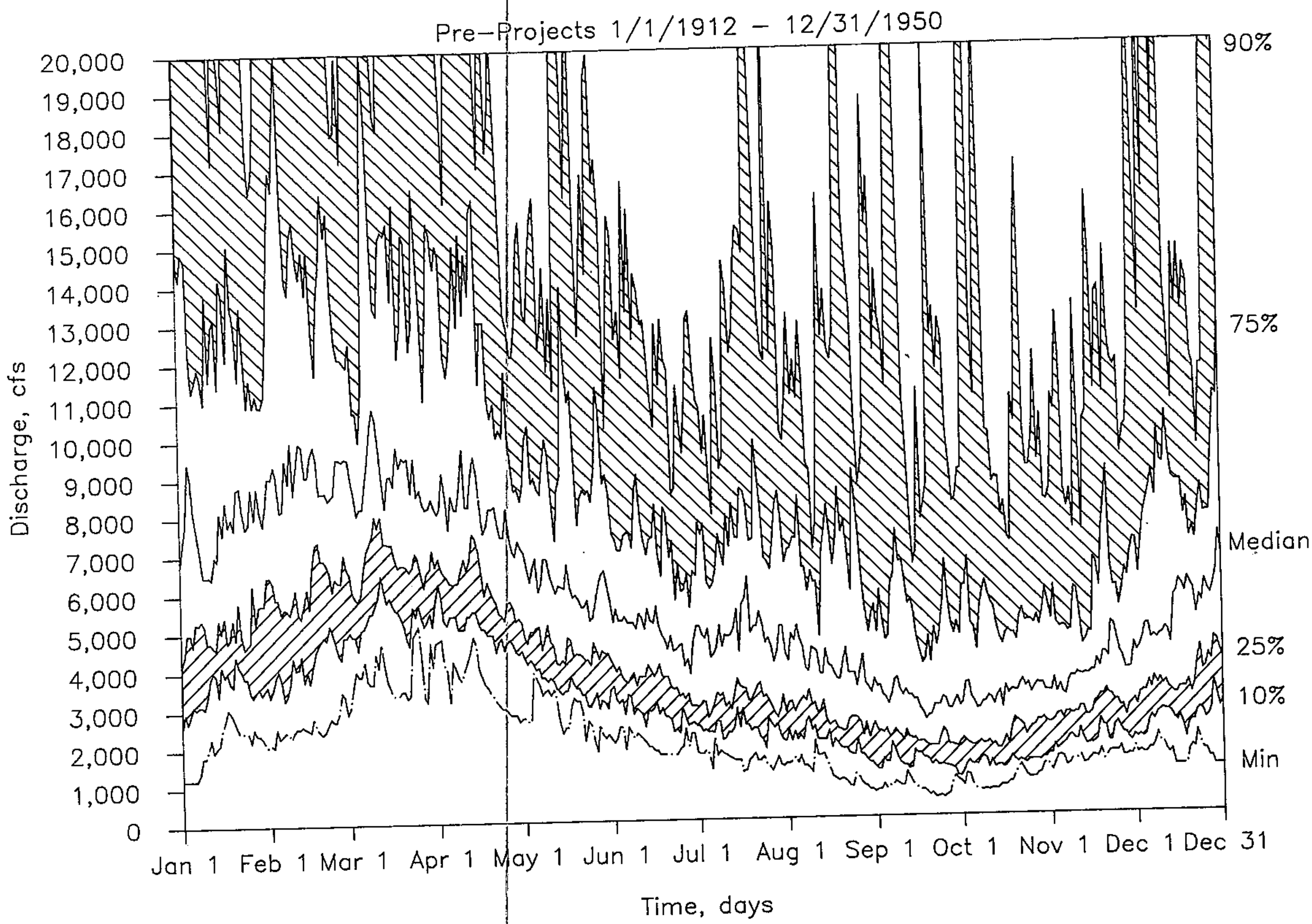

Figure 18. Pre-impoundment (1912-1950) flows of the lower Roanoke watershed.

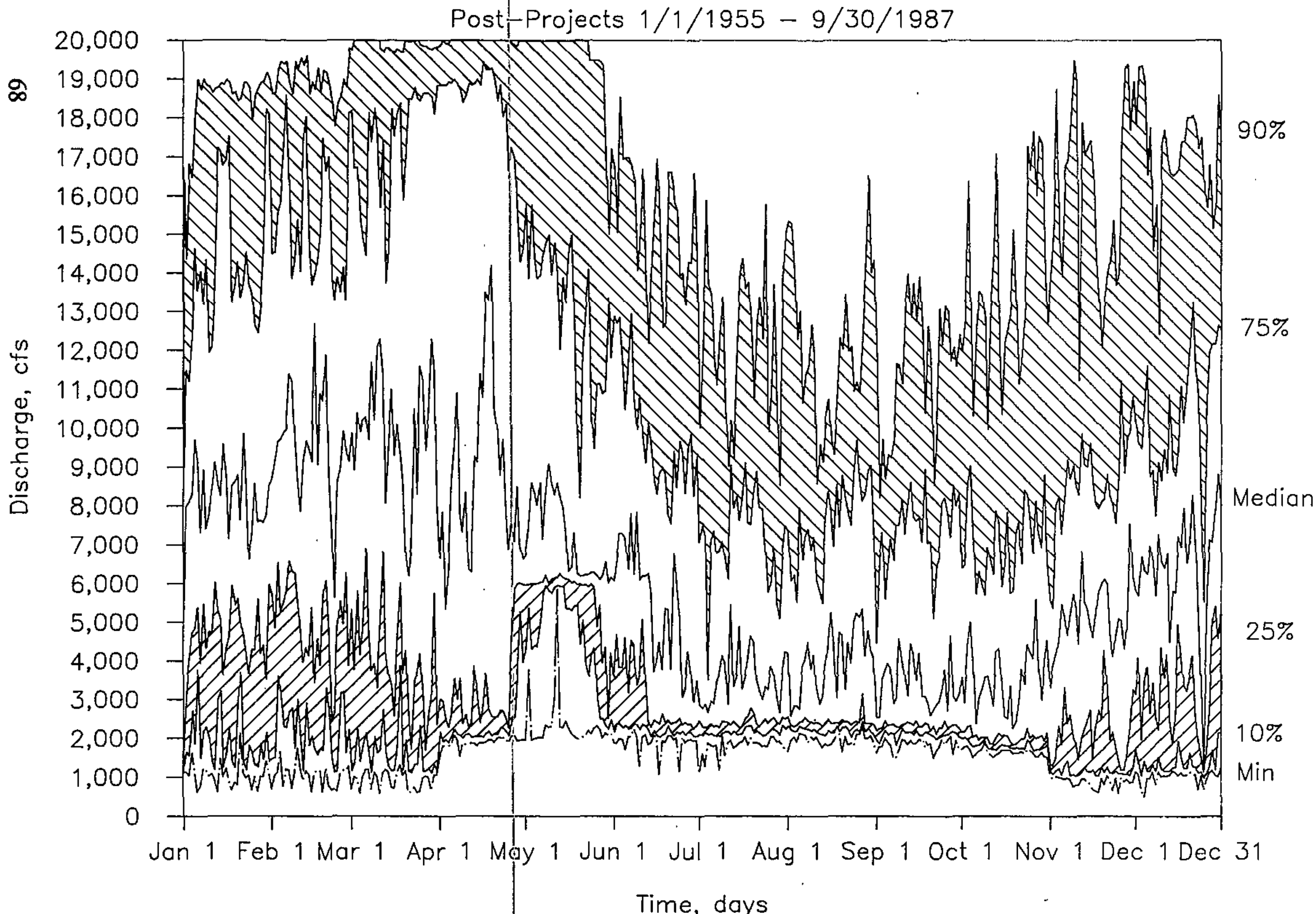

Figure 19. Post-impoundment (1955-1987) flows of the lower Roanoke watershed.

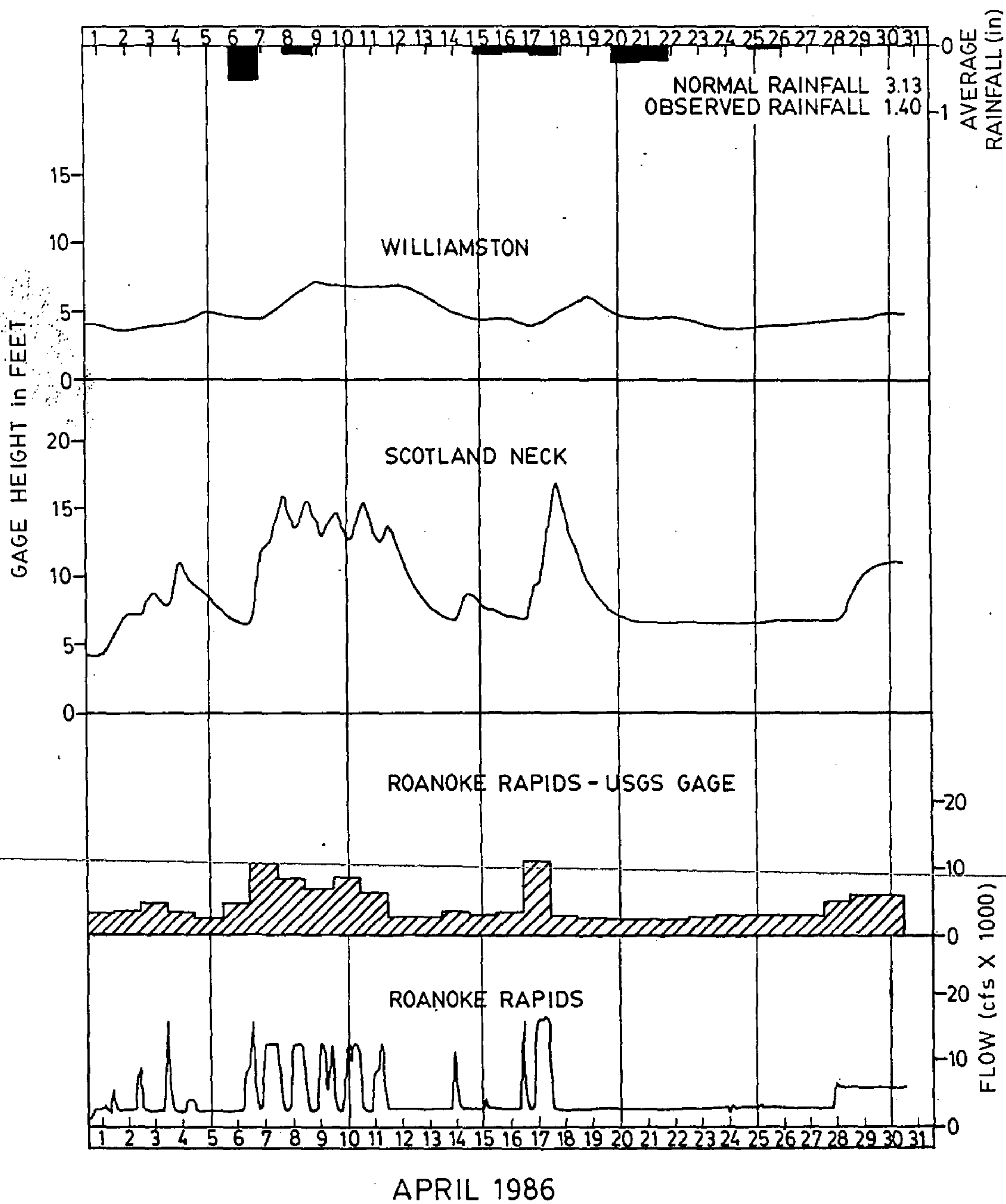

Figure 20. Lower Roanoke River flows for April-June 1986 as monitored by gages at Roanoke Rapids Dam, and USGS gages at Weldon, Scotland Neck, and Williamston.

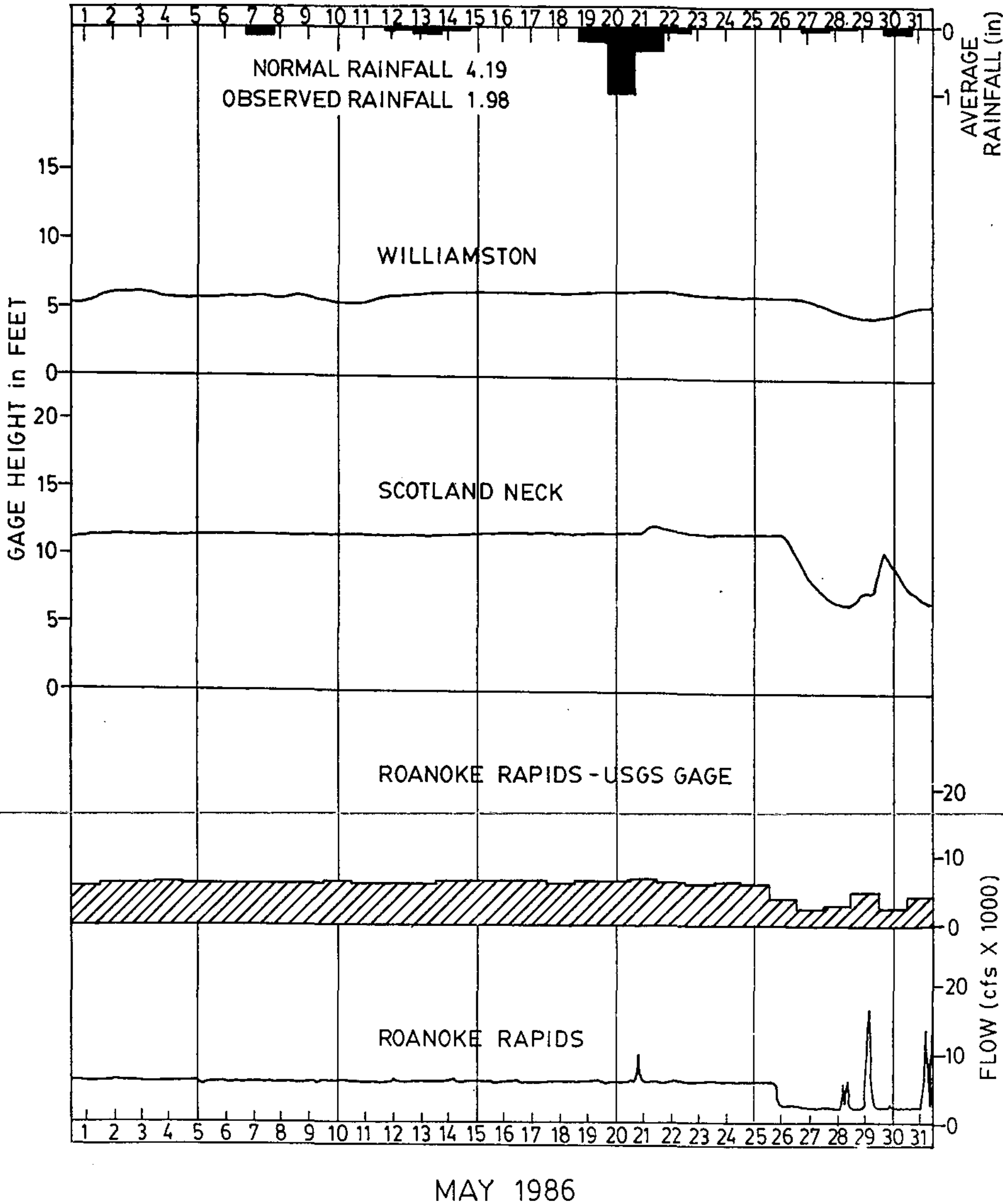

Figure 20. (Continued)

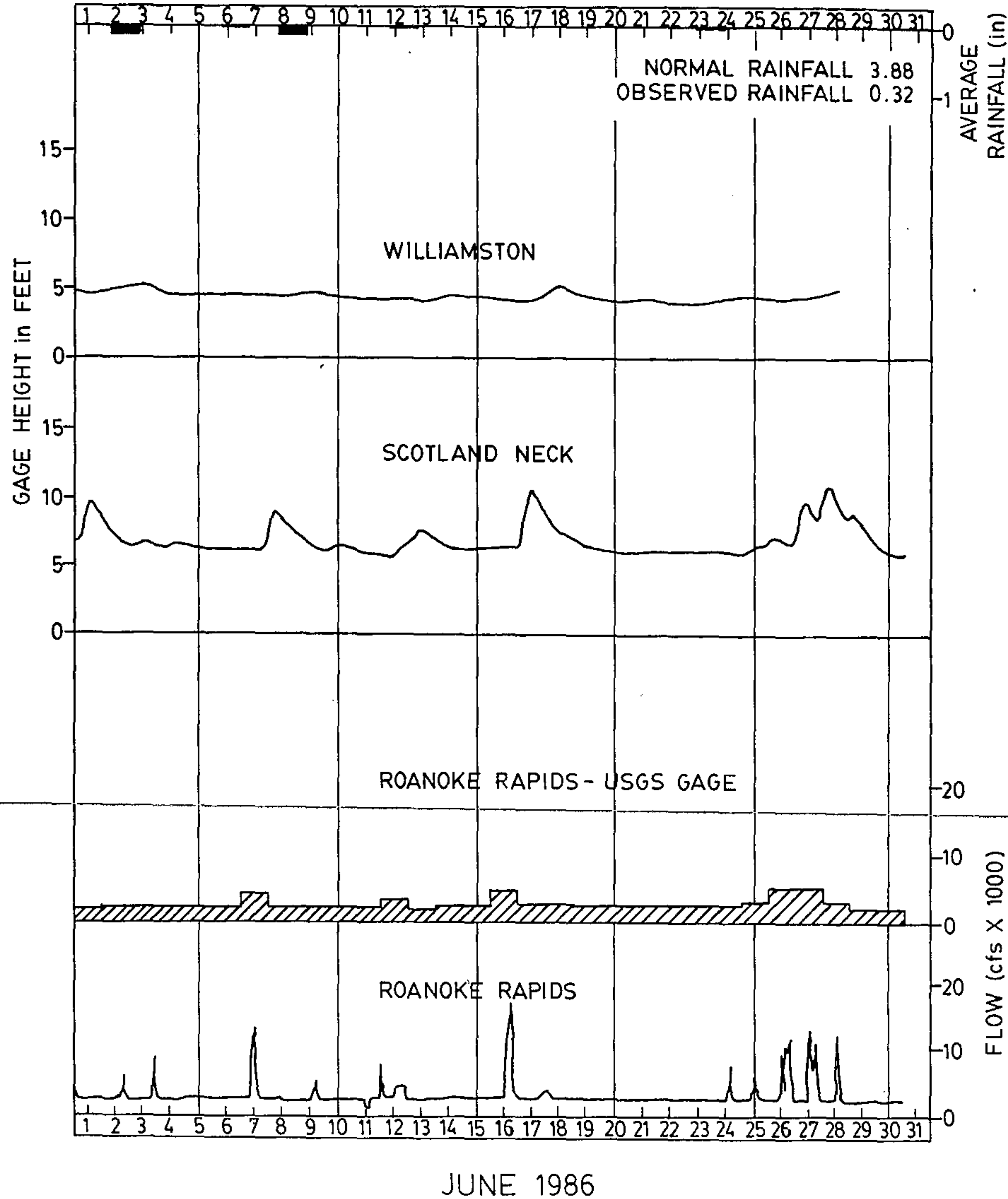

Figure 20. (Continued)

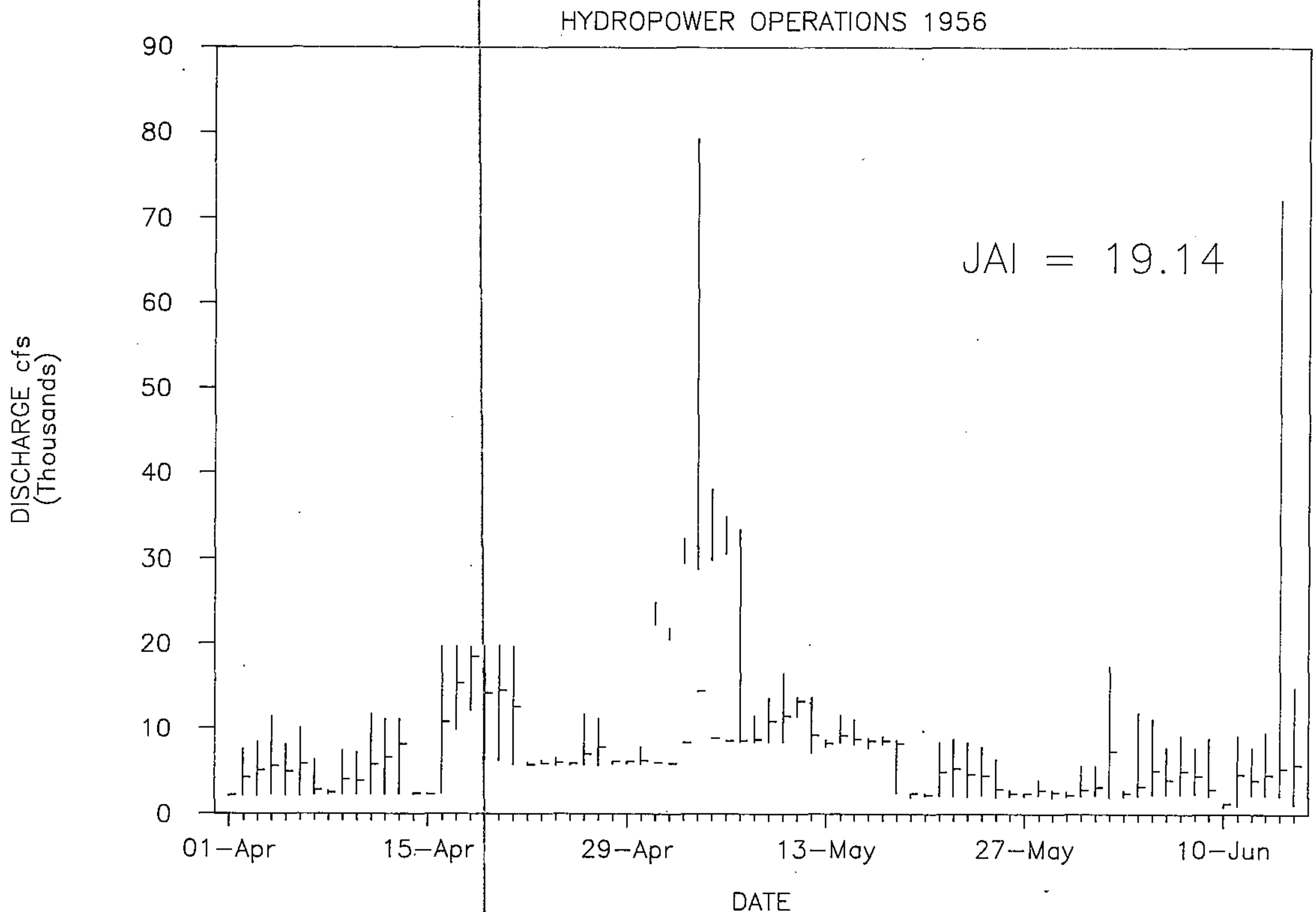

Figure 21. The maximum, minimum, and average flows (cfs) through the Roanoke Rapids Dam for April-June 1956 (juvenile abundance index (JAI)=19.14).

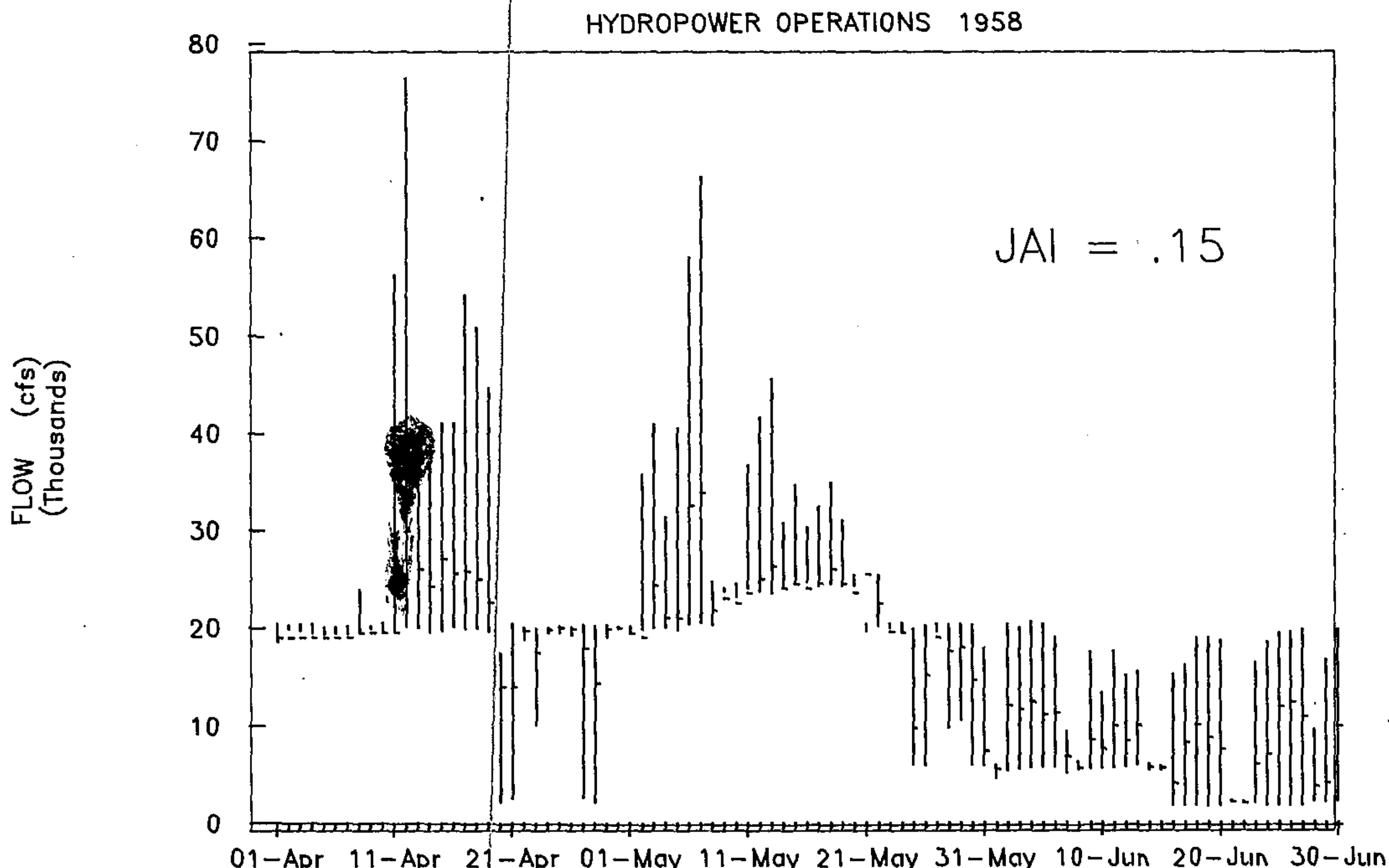

Figure 22. The maximum, minimum, and average flows (cfs) through the Roanoke Rapids Dam for April-June 1958 (JAI=0.15). Horizontal mark on each on the vertical bar equals the mean daily flow.

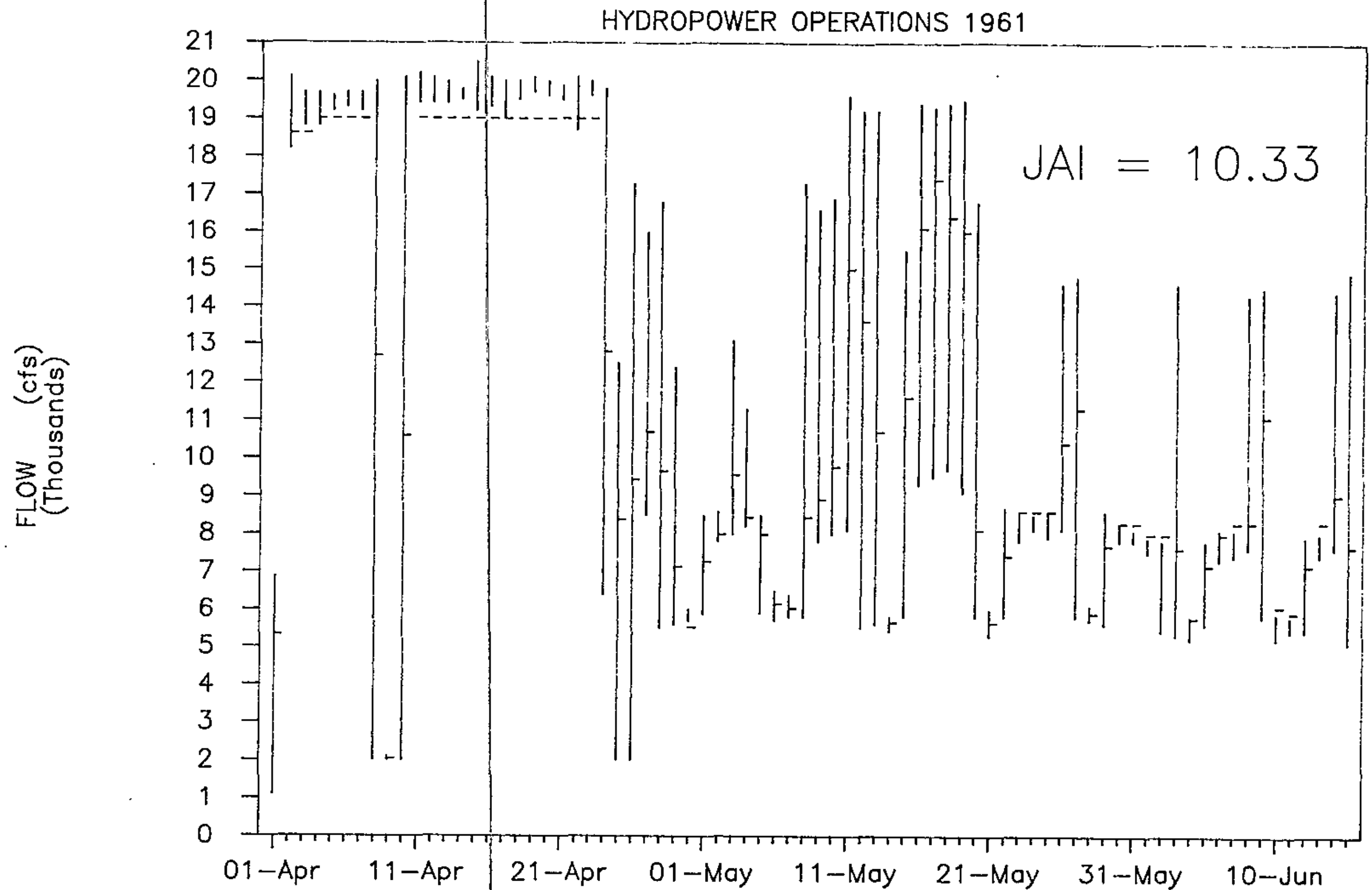

Figure 23. The maximum, minimum, and average flows (cfs) through the Roanoke Rapids Dam for April-June 1961 (JAI=10.33). Horizontal mark on each on the vertical bar equals the mean daily flow.

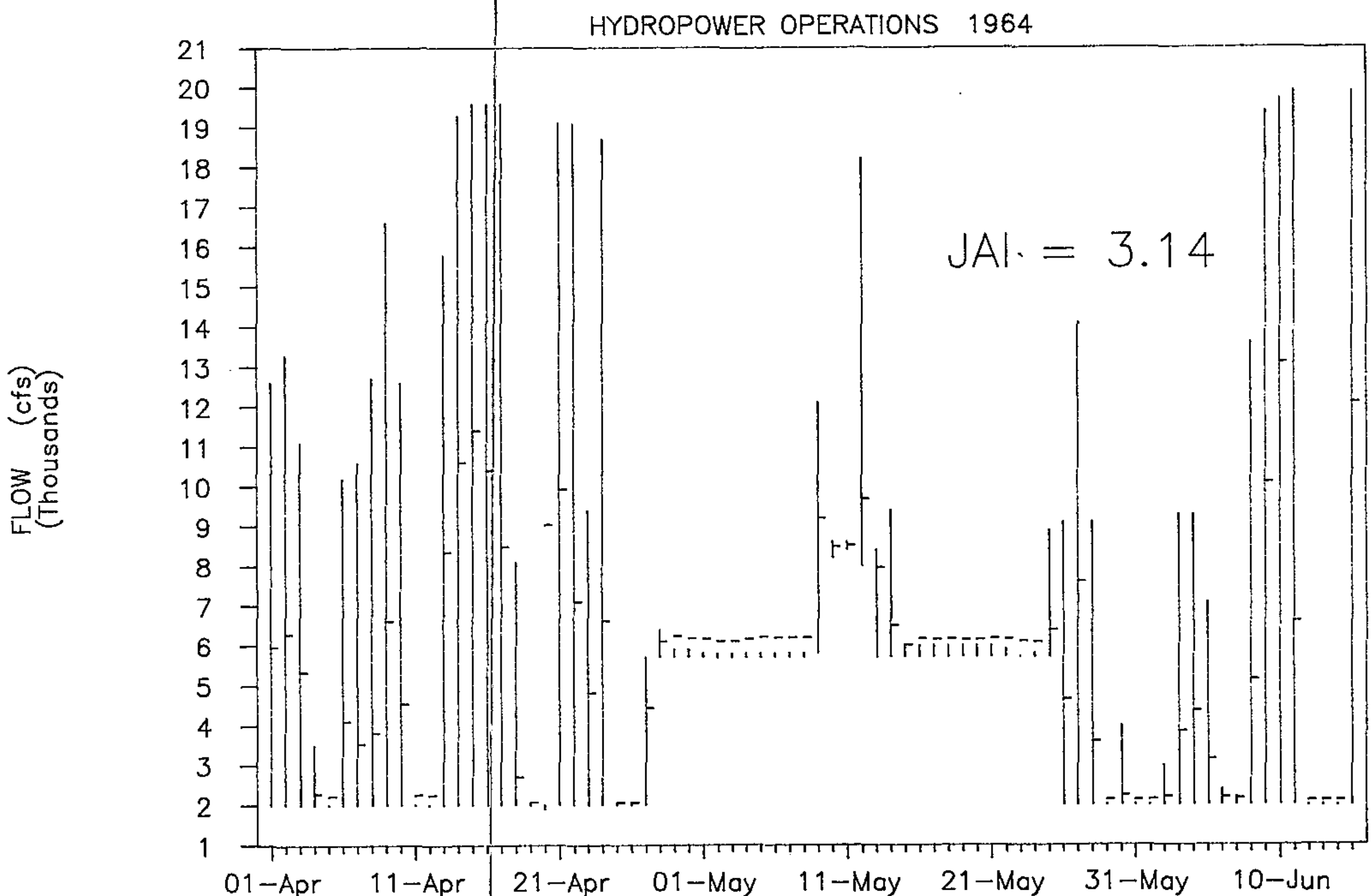

Figure 24. The maximum, minimum, and average flows (cfs) through the Roanoke Rapids Dam for April-June 1964 (JAI=3.14). Horizontal mark on each on the vertical bar equals the mean daily flow.

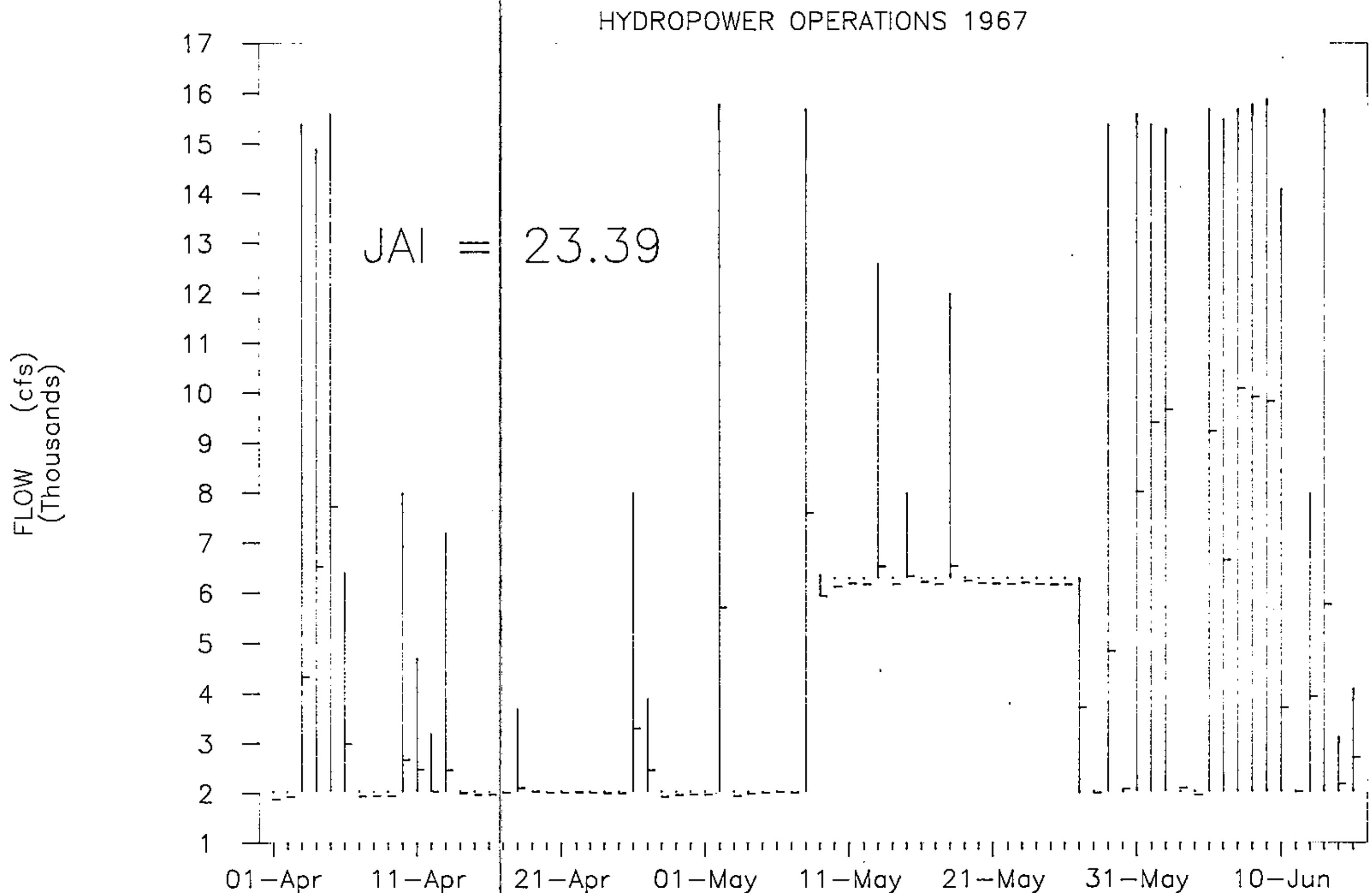

Figure 25. The maximum, minimum, and average flows (cfs) through the Roanoke Rapids Dam for April-June 1967 (JAI=23.39). Horizontal mark on each on the vertical bar equals the mean daily flow.

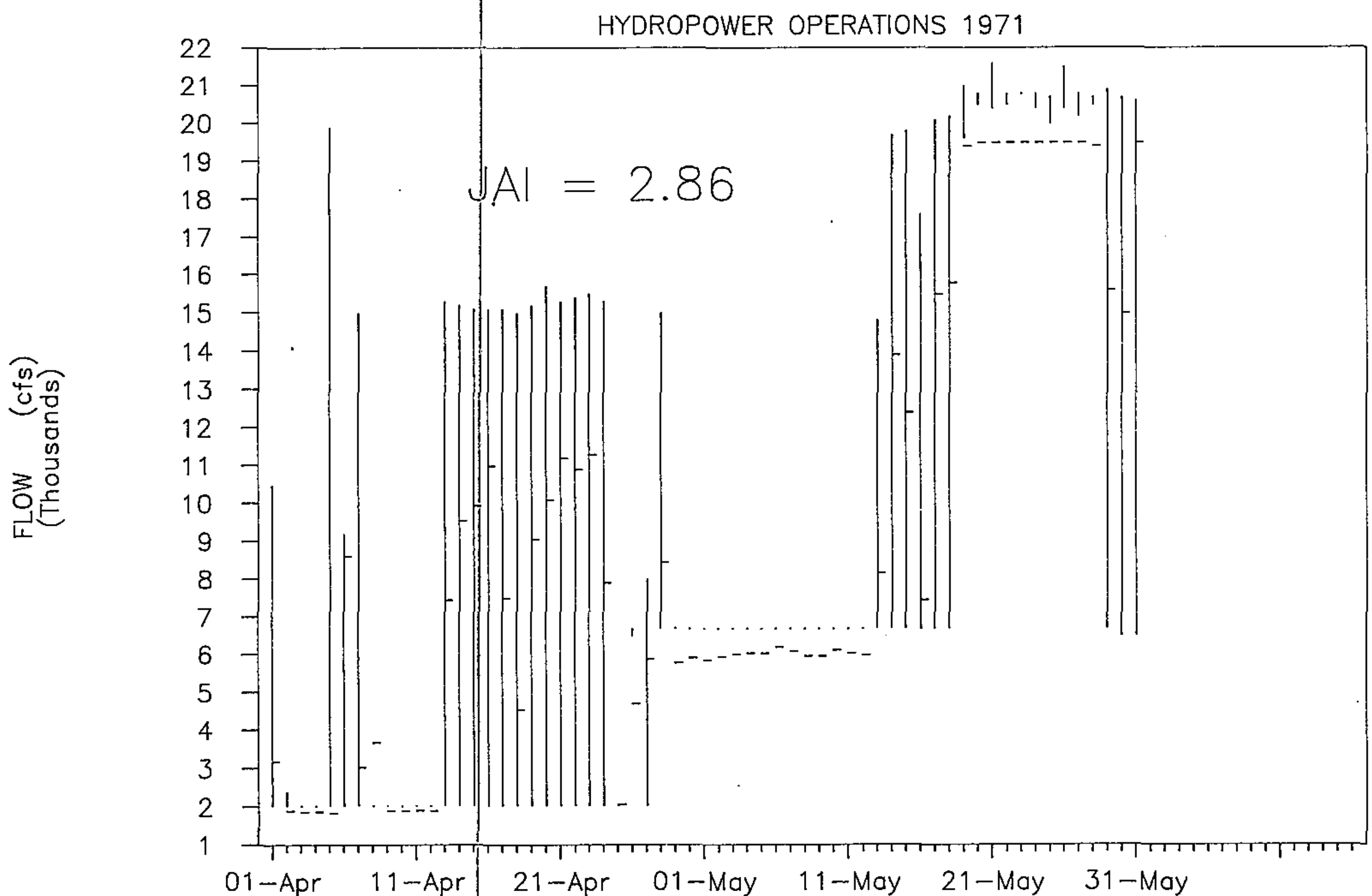

Figure 26. The maximum, minimum, and average flows (cfs) through the Roanoke Rapids Dam for April-June 1971 (JAI=2.86). Horizontal mark on each on the vertical bar equals the mean daily flow.

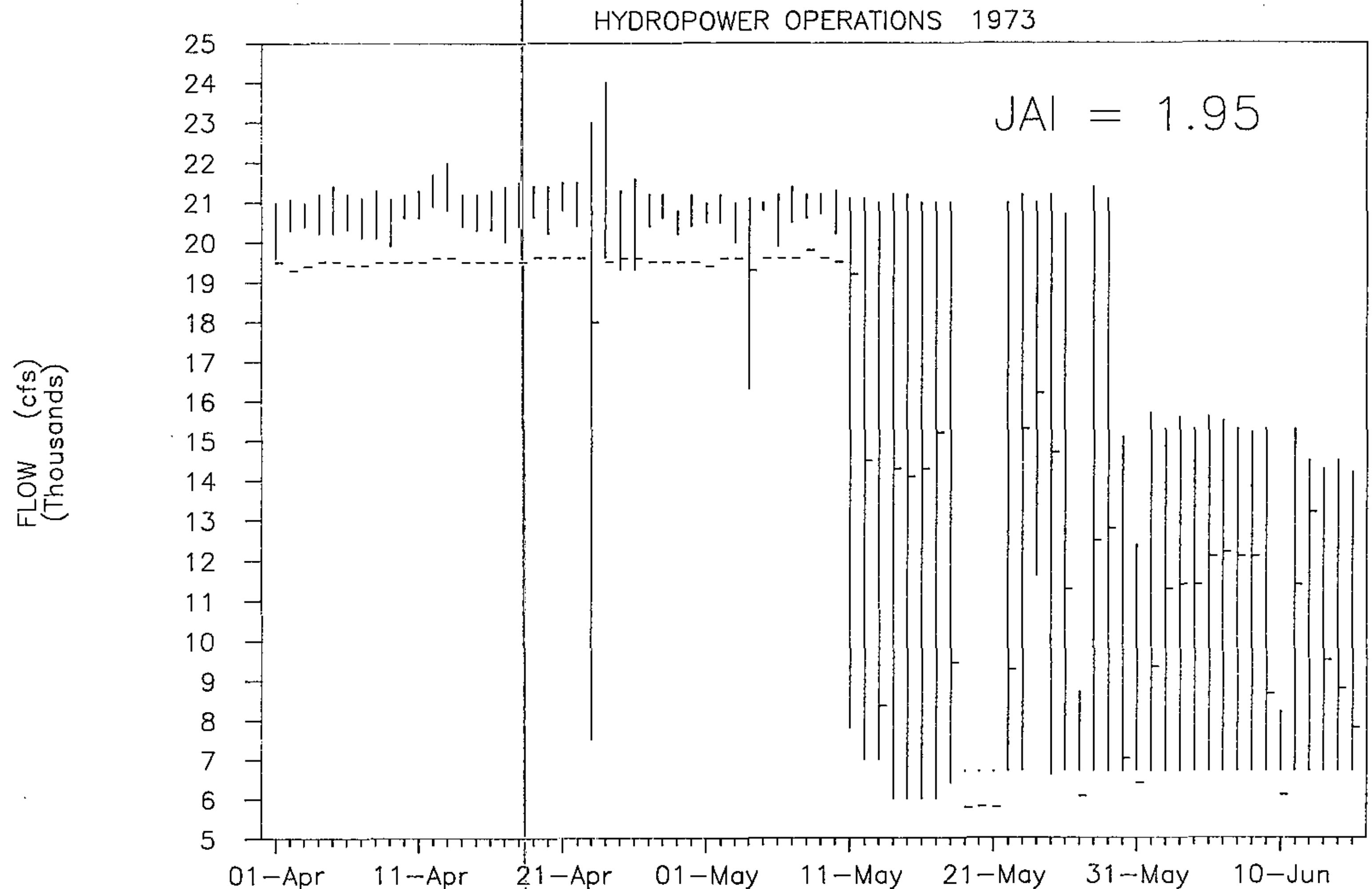

Figure 27. The maximum, minimum, and average flows (cfs) through the Roanoke Rapids Dam for April-June 1973 (JAI=1.95). Horizontal mark on each on the vertical bar equals the mean daily flow.

WATER SURFACE PROFILES AND WATER SURFACE AREA FOR RIVER REACHES

The Wilmington District, Corps of Engineers has developed a water surface profile model of the Roanoke River from the Roanoke Rapids Dam to the River's mouth in Albemarle Sound. This model was obtained by the N.C. Division of Water Resources and further model runs were made to determine water surface profiles and inundated areas at flow rates ranging from 5,000 to 35,000 cfs.

The model used is known as HEC2 - Water Surface Profiles (personal computer version). Limited calibration of the model was performed for the lower flow values. However, the results obtained are believed to be reasonable for the purposes of this investigation.

Water surface profiles of the Roanoke River for flows ranging from 4,000 to 35,000 cfs are given in Figure 28. Numerical values of the computed water surface elevation, depth, top-width, cumulative area inundated from Bachelor Bay, average flow velocity in the main channel, and total energy head, is given in Appendix B for each of the cross-sections and flows. Selected cross-sections of the river are plotted in Figures 29 to 32.

The first reach, from Bachelor Bay to U.S. Highway 17 bridge at Williamston, has by far the largest flooded surface area of more than 30,000 acres at 5,000 cfs (Table 15) and shows the greatest increase in flooded surface area as flow increases (from 30,000 acres at 5,000 cfs to 57,800 acres at 35,000 cfs). The uppermost reach, from near Halifax to the railroad bridge at Roanoke Rapids, has a variation in flooded surface area from 410 acres to about 3,000 acres for flows of 5,000 and 35,000 cfs, respectively.

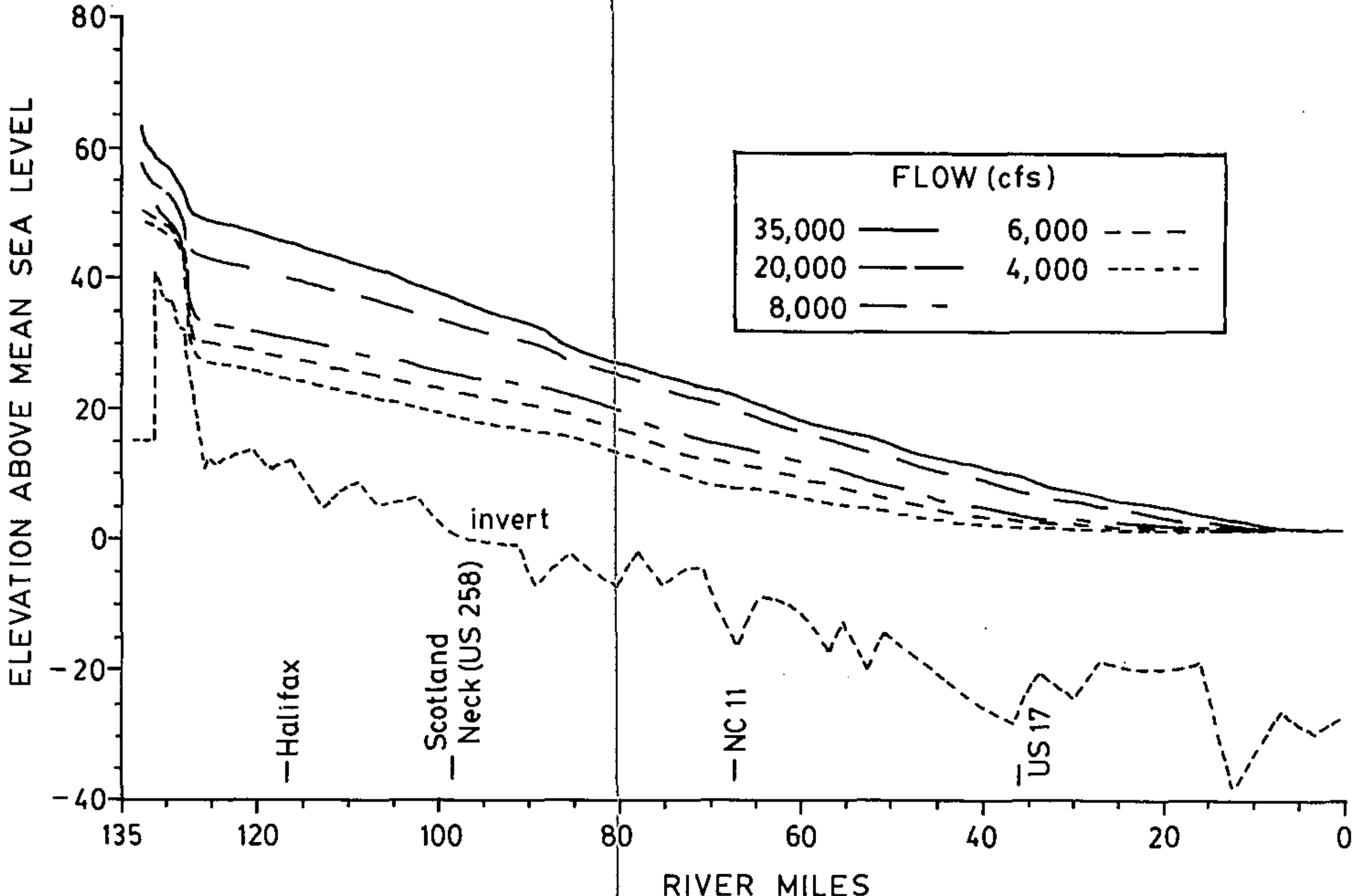

Figure 28. Elevation of water levels of the lower Roanoke River from the mouth to Roanoke Rapids Dam as a function of five different flow regimes.

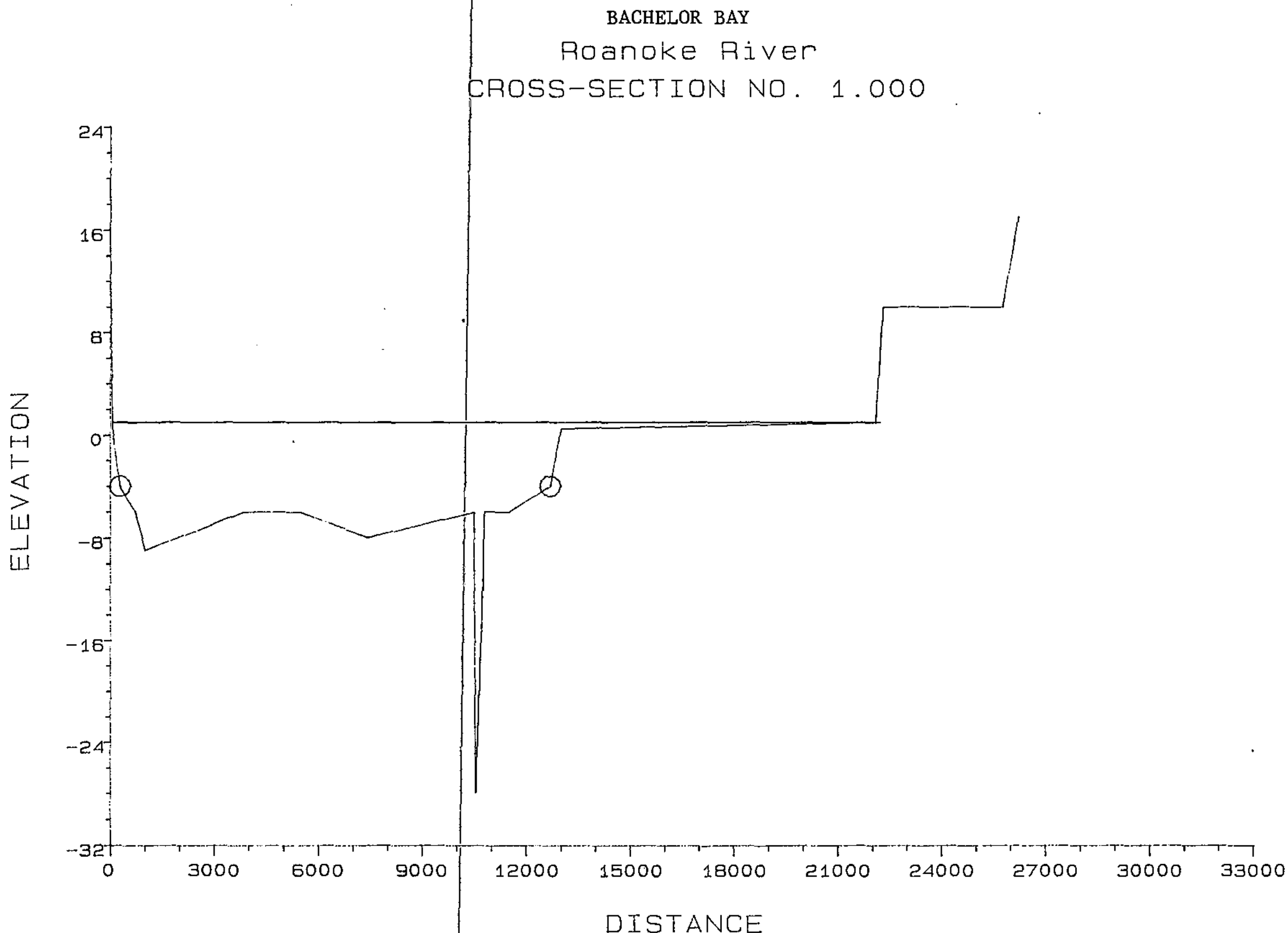

Figure 29. Cross-section of the Roanoke River and floodplain near the mouth at Bachelor Bay.

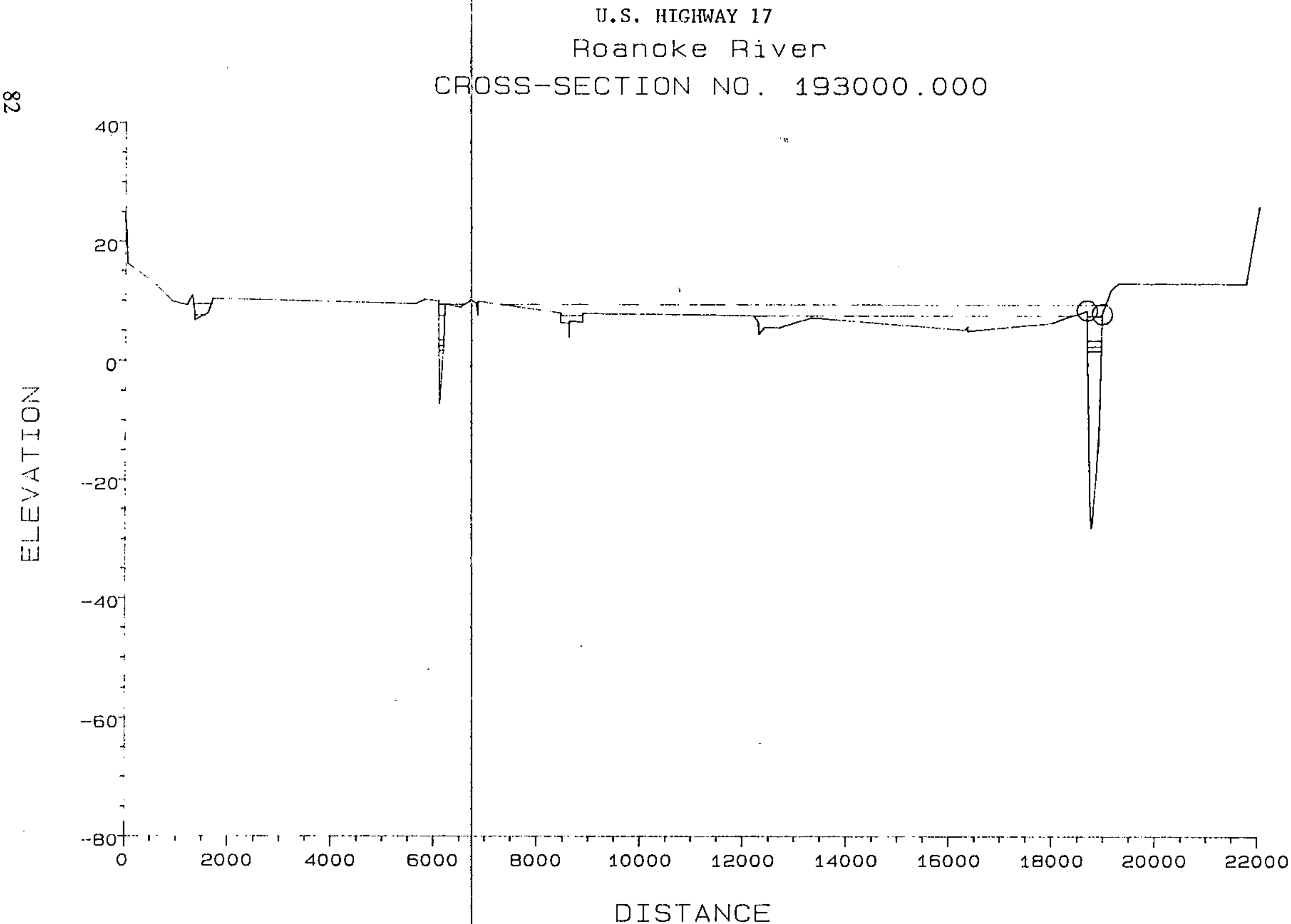

Figure 30. Cross-section of the Roanoke River and floodplain at the U.S. Highway 17 bridge near Williamston, North Carolina for five different flow regimes.

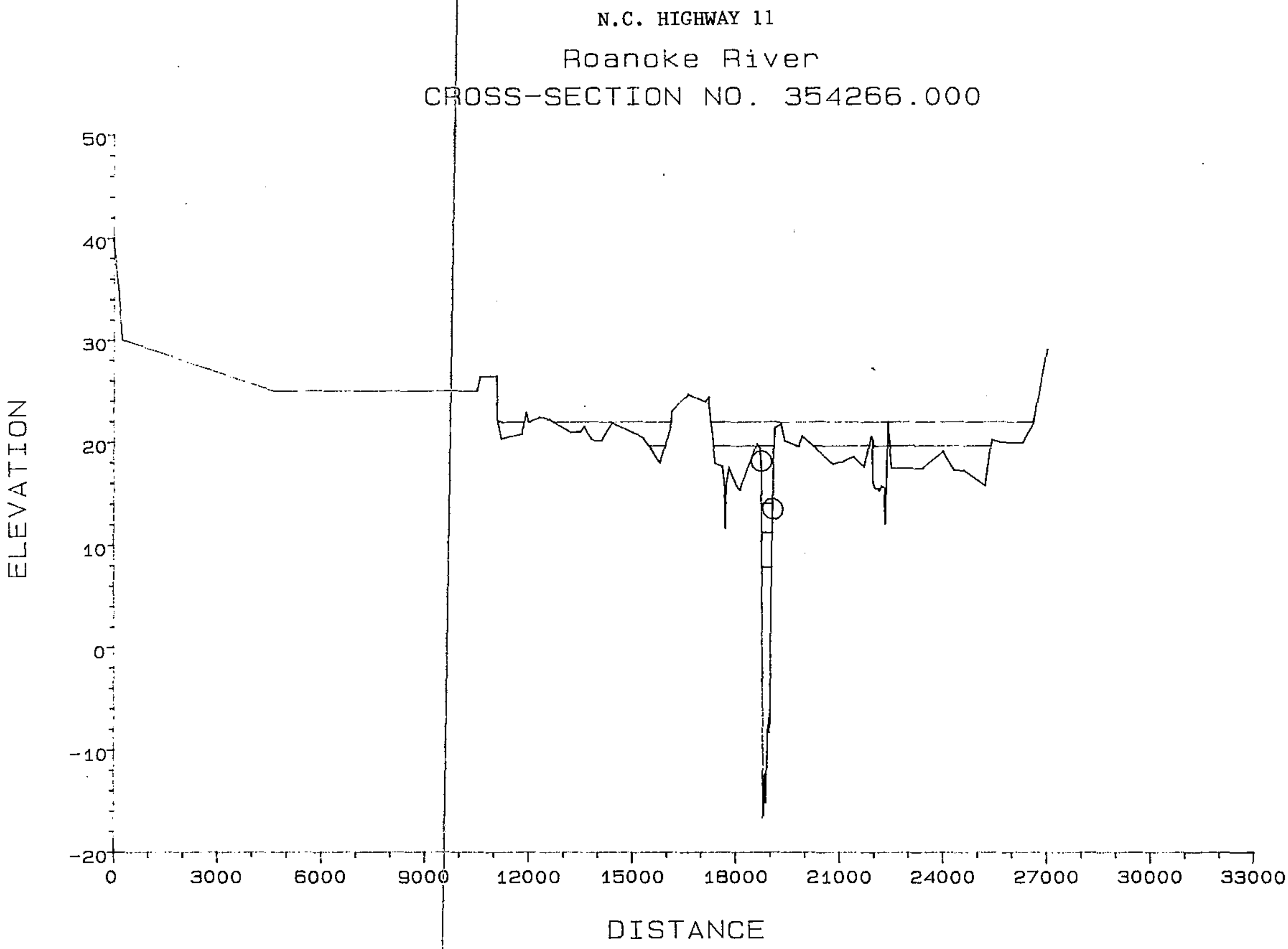

Figure 31. Cross-section of the Roanoke River and floodplain at the N.C. Highway 11 bridge between the towns of Hamilton and Palmyra, North Carolina for five different flow regimes.

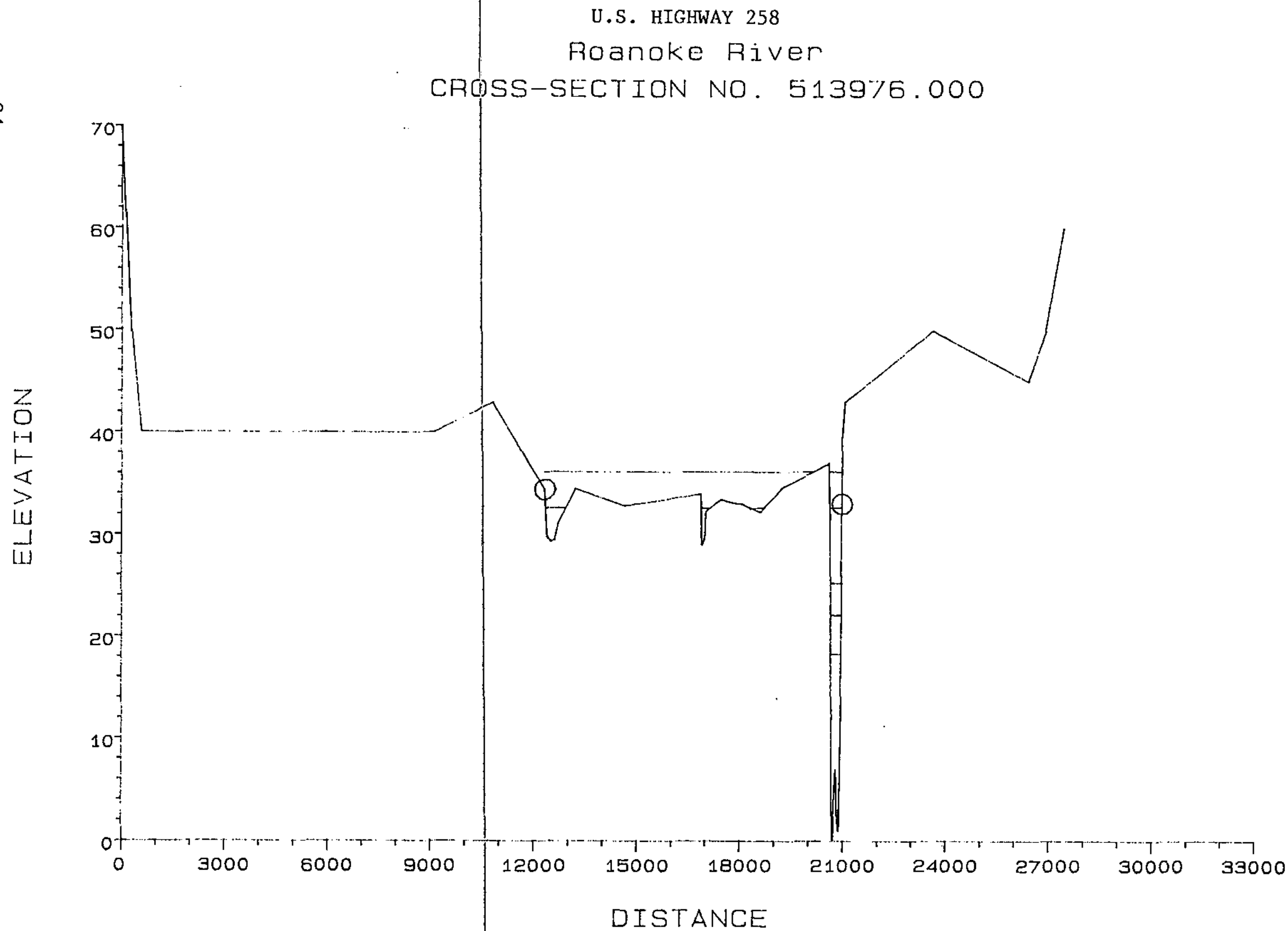

Figure 32. Cross-section of the Roanoke River and floodplain at the U.S. Highway 258 bridge near Scotland Neck, North Carolina for five different flow regimes.

Table 15. Surface area (acres) of the Roanoke watershed inundated at various flow rates at selected locations below the Roanoke Rapids Dam, North Carolina.

	Flow (cfs)						
Location	5,000	10,000	15,000	20,000	25,000	30,000	35,000
Bridge at Roanoke Rapids	414	463	515	983	1,196	2,036	2,952
Halifax	675	1,208	4,212	6,220	10,495	12,201	13,209
US 258	1,074	6,847	16,739	25,754	30,313	38,359	40,376
NC 11	952	10,064	24,210	27,706	30,334	31,365	33,609
US 17	30,305	33,248	48,667	52,881	55,115	56,659	57,837
Total	33,421	51,831	94,343	113,543	127,453	140,620	147,983

RECOMMENDED AND NEGOTIATED FLOW REGIMES

Summary

The Recommendations Subcommittee met in Greenville, NC, on 3 May with the understanding that control of low flows and high flows, as well as moderation of hydropower peaking activity at Roanoke Rapids, was necessary. The Subcommittee recommended that the flow be controlled between historical 25 percent and 75 percent quartiles of the daily flows between 1 March and 30 June each year; that is, between the 25 percent low flow value (Q1) and 75 percent high flow value (Q3) (Table 16). The rationale for choosing median rather than daily averages, and quartiles rather than other levels, was previously described. The Roanoke/Albemarle striped bass population evolved under conditions of unregulated flow; therefore, pre-impoundment data were used.

To show the historical trend of this flow regime, a simple diagram was provided (Figure 33) which depicts the percentage of time that flows stayed within the Q1 and Q3 range over a number of years. The figure shows the expected variation of about 50 percent for the pre-impoundment years. For the post-impoundment years, Figure 33 shows a definite trend away from the expected 50 percent variation.

The Recommendations Subcommittee re-convened in Beaufort, NC, on 23 June to formally adopt its recommendation for submittal to the full committee. After lengthy discussion, the Subcommittee constructed a negotiated (negotiated Q1-Q3) flow regime (Table 17) that was acceptable to the advisors from the U.S. Army Corps of Engineers, Wilmington District, and Virginia Power Company. It should be noted that the negotiated flow regime involves a much shorter period of time than does the flow regime analyzed on 3 May (Tables 16 and 17). This will be discussed later in the Committee Recommendations section. In addition to recommending minimum and maximum flows, the Subcommittee recommended that hourly variation in flow should not exceed 1,500 cfs. The negotiated flow regime was formally adopted unanimously by the full Committee on 11 August in Raleigh, NC.

The genesis of the recommendations outlined above was a statistical analysis of how the flow related to measures of striped bass spawning success. Specifically, we related percentage of days within the recommended flow regime to the juvenile abundance index and the passage of time. The remainder of this chapter and the next describe the statistical analyses which led to our recommendations.

The percentage of post-impoundment days having flows within the negotiated Q1-Q3 values were determined for the period 1 April to 15 June by inspection of the POST-USGS data (Figure 34). Data for these calculations are presented in Appendix B.

Juvenile Abundance Index Data Base

The Juvenile Abundance Index (JAI) is an indicator of relative success of juvenile recruitment to the forming year class of striped bass. Although the use of these indices is common to most states having striped bass stocks, the methodology used to determine the

Table 16. Roanoke River flow data, 1912 to 1950, in cfs (USGS data). Q_1 = 25 percent low flow value; Q_3 = 75 percent high flow value.

Week number	Median	Q_1	Q_3	Approximate dates
0	8,577	6,127	11,175	1-7 March
1	9,799	7,543	16,029	8-14 March
2	9,090	6,973	14,429	15-21 March
3	8,930	6,626	14,300	22-28 March
4	8,333	6,681	14,186	29-April 4
5	8,476	6,379	13,171	5-11 April
6	8,539	6,810	14,029	12-18 April
7	7,821	5,703	10,800	19-25 April
8	7,260	5,357	9,327	26 April-2 May
9	6,470	4,829	9,200	3-9 May
10	6,213	4,410	9,490	10-16 May
11	5,896	4,431	9,759	17-23 May
12	5,854	4,329	9,329	24-30 May
13	5,450	3,983*	7,663	31 May-6 June
14	5,139	3,701*	7,814	7-13 June
15	5,124	3,871*	7,301	14-20 June
16	4,447	3,394*	6,607	21-27 June
17	4,413	3,058*	6,173	28 June-4 July

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

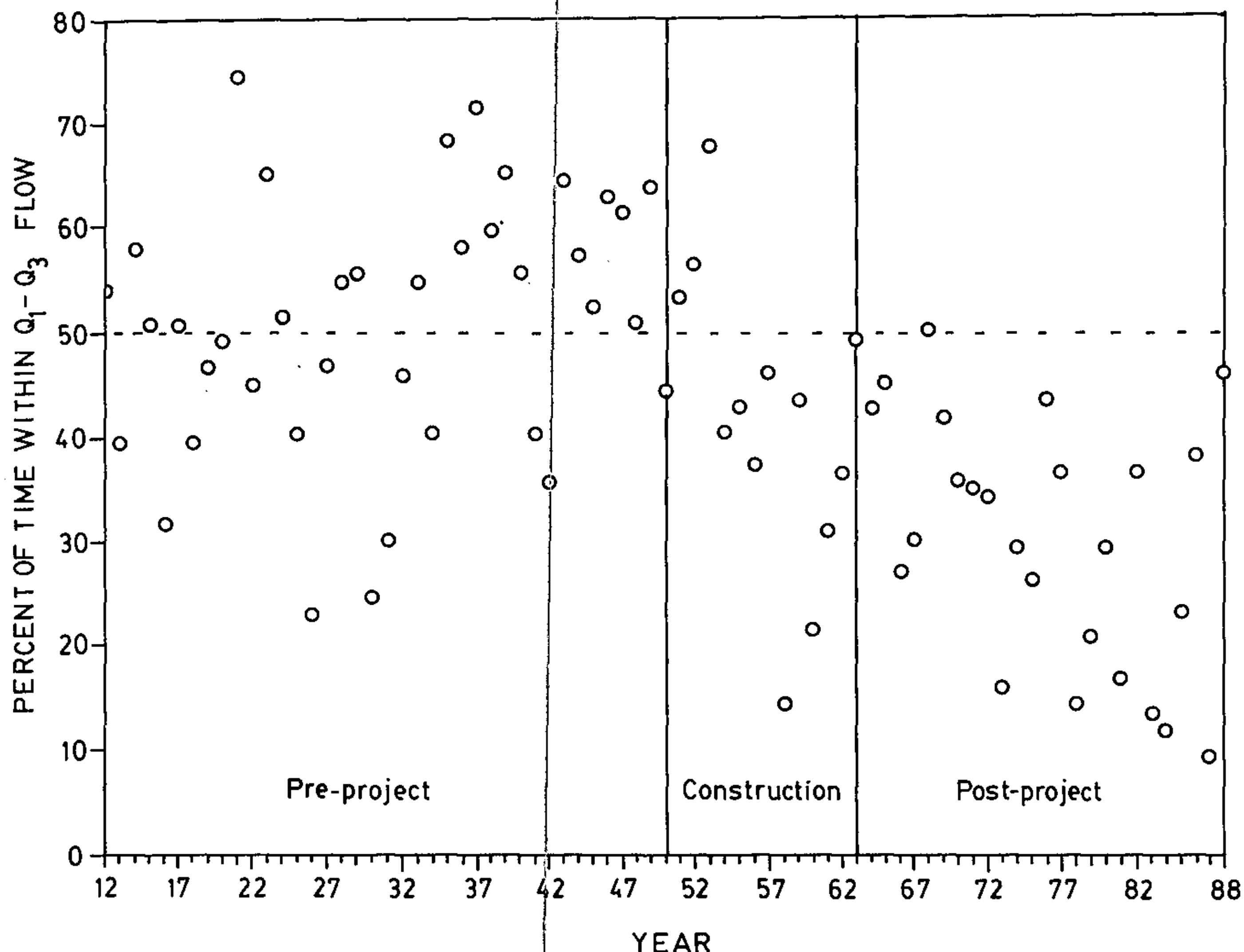

Figure 33. Percent of the time that water flows were within the Q_1-Q_3 bounds for 1912-1988.

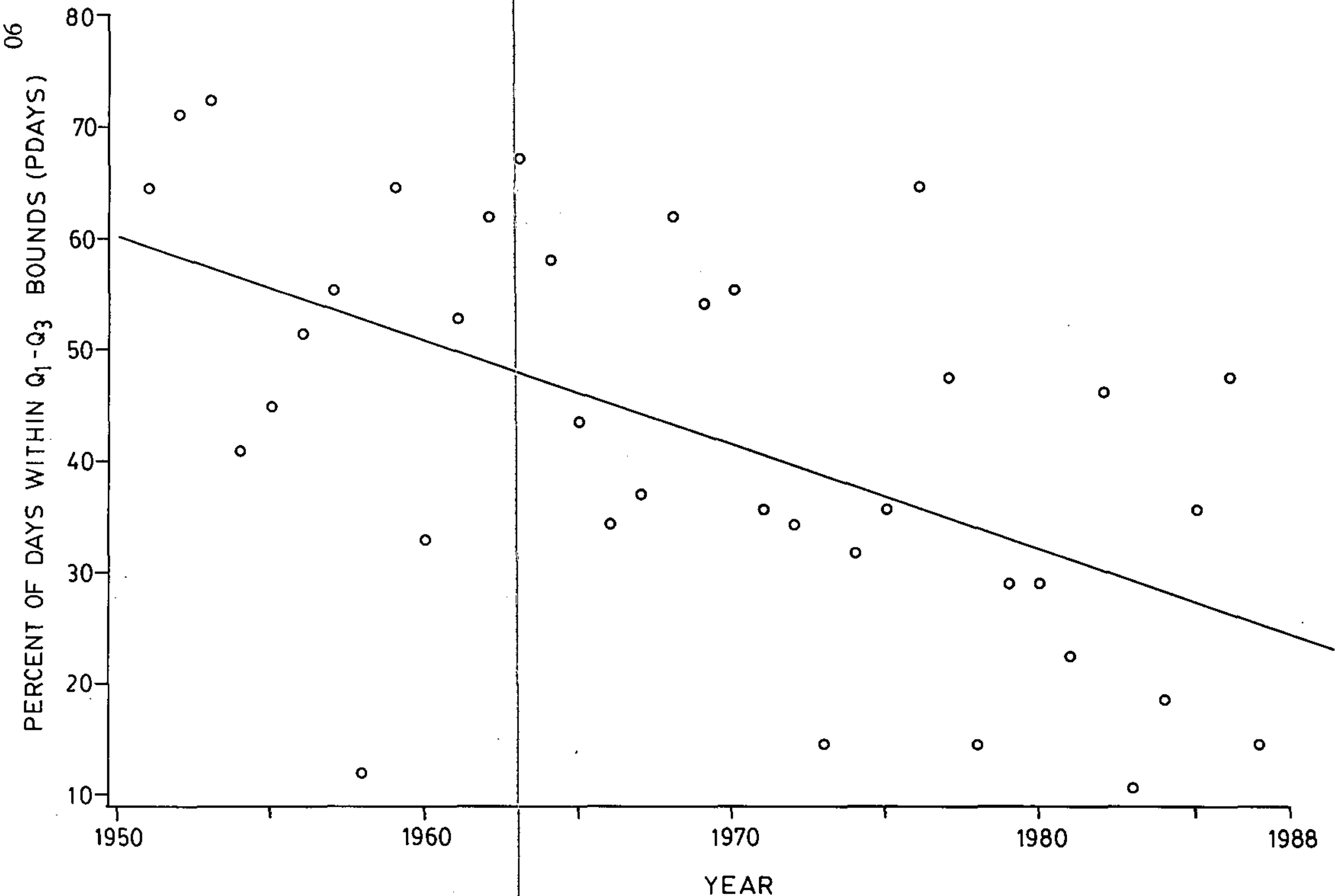

Figure 34. The relationship of the number of days (as percent) that Roanoke River flows were within the negotiated Q_1-Q_3 bounds (PDAYS) to year after post-impoundment.

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

JAI is unique to each state. The JAI for North Carolina is the oldest and other states designed their indices after North Carolina's.

The JAI for Albemarle Sound was initiated in 1955 by Dr. Hassler, and the methods used for JAI estimates have remained the same since that time. The sampling area is located in western Albemarle Sound extending eastward approximately 12 miles. Seven permanent sampling stations were established: Station 1, Black Walnut Point; Station 2, east of Edenton Bay; Station 3, north side between the Norfolk and Southern Railway bridge and the State Highway (NC) 32 bridge; Station 4, north side east of NC 32 bridge; Station 5, south side east of NC 32 bridge; Station 6, south side between bridges; and Station 7, Albemarle Beach (Figure 35). Hassler used a 5.49-m semi-balloon trawl to collect juvenile fish. Samples collected early in the sampling period were taken with a trawl of 6.35-mm stretched mesh cod end. Later samples were taken with a cod end of 12.7-mm stretched mesh. The sampling schedule was every two weeks starting in July and ending in October, for a maximum of 56 samples. Each trawl sample was of 15-minute duration at a towing speed of approximately 2.75 miles per hour. Trawling depth varied between six and 10 feet. Numbers were expressed as average number of juvenile striped bass per unit of effort (15-minute tow).

In 1982, the North Carolina Division of Marine Fisheries (DMF) initiated their own JAI survey using the same methods and stations as the Hassler (NCSU) study. The only changes to the study involved mesh size and number of samples collected. The DMF study used the 12.7-mm stretched mesh cod end exclusively from 1984 through 1987, a 6.35-mm stretch mesh cod end in 1983, and a combination of 6.35-, 12.7-, and 25.4-mm stretched mesh cod ends in 1982.

The JAI values generated by both studies were compared by Phalen (1988) for significant differences using the Student's t-test. Data for the NCSU Survey of 1983 were not complete, so the data were expanded assuming the lowest variance which would maximize the chances that the DMF value and the NCSU value for 1983 will be significantly different. The JAI values used in these analyses are presented in Table 12. In only two years (1982 and 1984) were the JAI values significantly different ($p<0.05$).

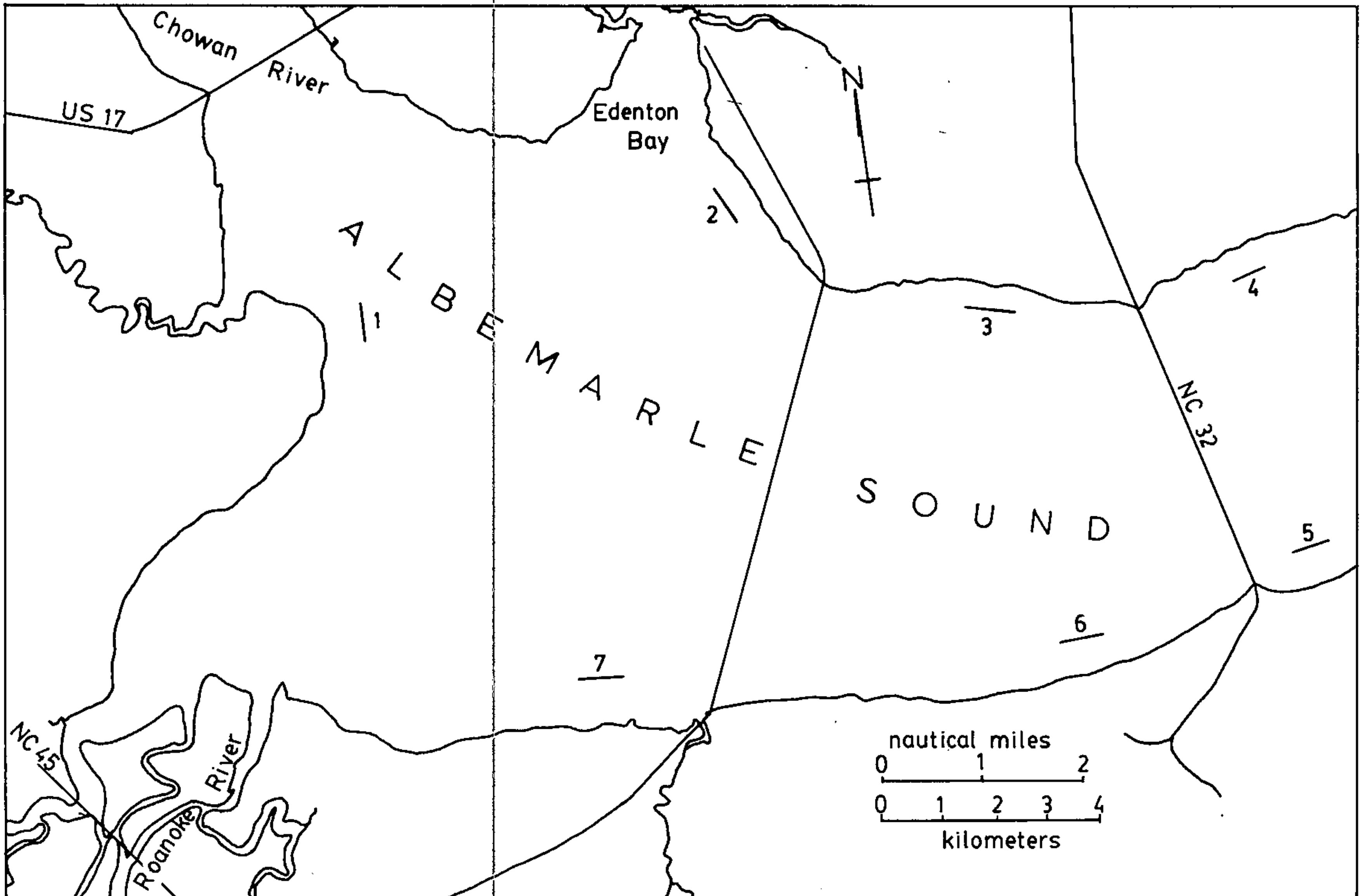

Figure 35. Sampling area and station locations for Hassler's striped bass juvenile abundance index survey in western Albemarle Sound, North Carolina.

Phalen also reported that the trends in the two index values were similar between the two surveys for all years except for 1987. Phalen (1988) urged caution in making inferences about trends in the JAI in years of low striped bass abundance and subsequent low precision estimates. However, the DMF survey should provide results comparable to the historical NCSU indices. For our report, we chose the historical NCSU data base for all years available, and used the DMF value for 1988.

Initial Analyses by Recruitment Subcommittee

During the first meeting at ECU (8-9 March 1988), a Recruitment Subcommittee (W. Cole, M. Clemmons, L. Henry, S. Winslow) was formed to develop a suggested flow regime based on striped bass recruitment. Data bases used were the POST-USGS flows (Appendix B) and the Juvenile Abundance Index (JAI, Table 12) developed by Hassler and continued by NCDMF. For the purpose of characterizing flows when recruitment of juveniles into Albemarle Sound was best, a JAI of 5.0 was used as the cut-off between desirable and less desirable recruitment.

When plotting May flows against the JAI for years 1955-1986, three distinct groups were identified (Figure 36):

a) Group 1 - low to moderate flows (5,000 - 11,000 cfs); JAI > 5.0; termed "optimum flows" (n = 13 for years 1956, 1957, 1959, 1960, 1961, 1962, 1965, 1967, 1968, 1970, 1974, 1975, and 1976).

b) Group 2 - high flows (8,000 and greater cfs); JAI < 5.0; (n = 9 for years 1958, 1971, 1972, 1973, 1978, 1979, 1980, 1983, 1984 -- 1985 was overlooked in the calculations).

c) Group 3 - low flows (3,900 - 7,700 cfs); JAI < 5.0; (n = 8 for years 1963, 1966, 1969, 1977, 1981, 1982, 1985, 1986 -- 1964 was overlooked in the calculations).

Hassler et al. (1981) concluded that May flows in the "low to moderate" range (5,091 - 9,741 cfs) were favorable for juvenile striped bass production, and high May flows were detrimental to the formation of good to strong year classes. Since Group 1 was the only group with acceptable JAIs, we agreed that moderate flows around 7,500 cfs were preferable for May. However, we were also concerned about the rest of the months during which the spawning run occurs. In order to estimate which flows would be best for this period (March through June), mean and median weekly flows were plotted for each of these groups and comparisons made (Figure 37). The data used to generate Figure 37 are presented in Appendix B.

The mean and/or median flow values, from the years in Group 1, is what the Recruitment Subcommittee believed to be the "optimum flow" regime for striped bass production in the Roanoke River (Figure 37). Although these data depict striped bass success after impoundment conditions, the Subcommittee felt that it was the only flow regime which could be evaluated in terms of recruitment.

Groups 2 and 3, which have high and low flow years, respectively, with low JAIs, were graphed for comparison with the proposed "optimum flow," Group 1 (Figure 37). The problem with high flow years (Group 2) is very apparent; flows do not drop below 10,000 cfs until the first part of June, which tends to push eggs and larvae out into Albemarle Sound away from the food source. Group 3 differed from Group 1 in that flows were low

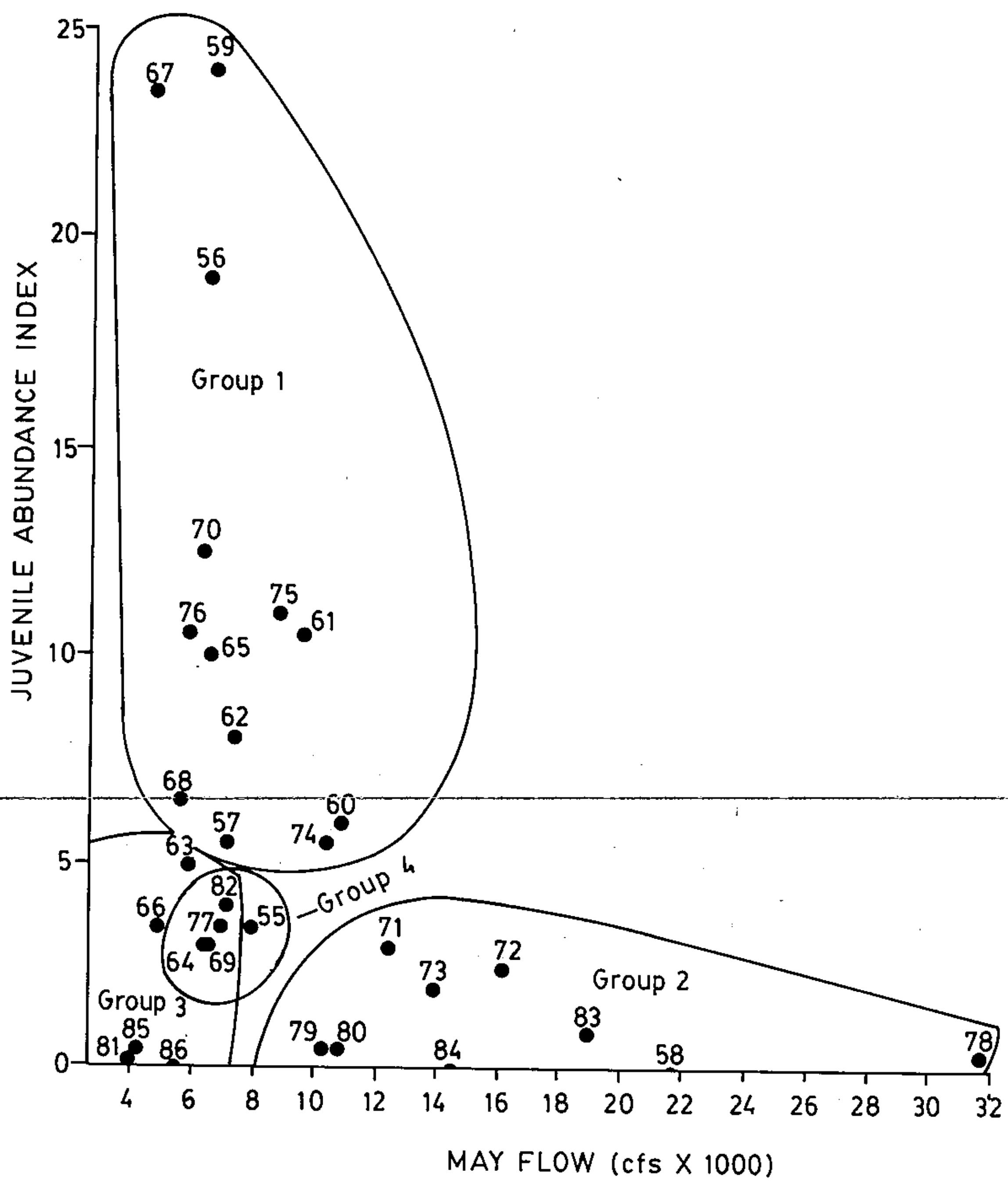

Figure 36. The relationship of lower Roanoke River May flows (cfs) to the striped bass juvenile abundance index, depicting several distinct groups. Group 1 = high flows, JAI>5; Group 2 = high flows, JAI<5; Group 3 = low flows, JAI<5; Group 4 = low-moderate flows, JAI<5.

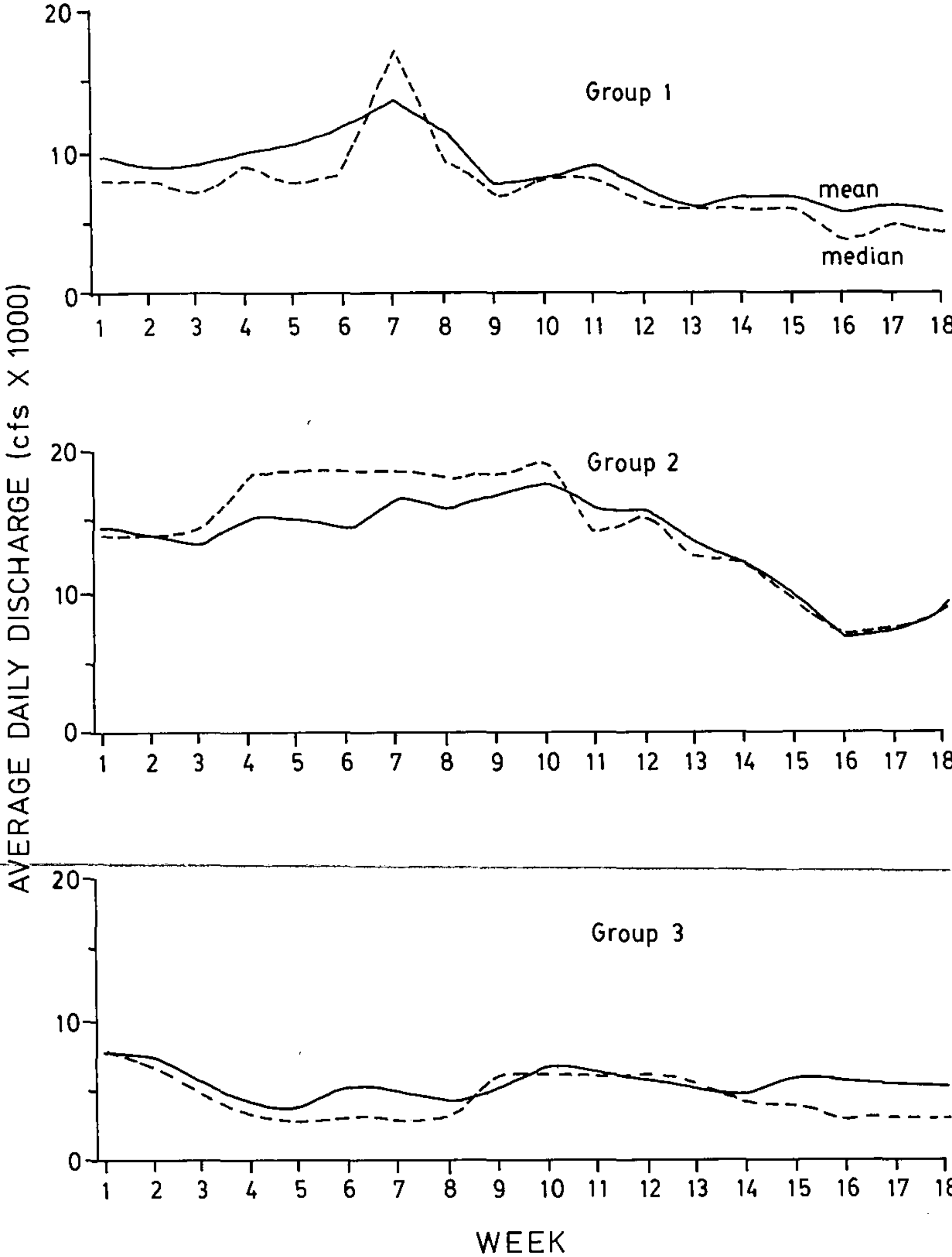

Figure 37. Mean and median weekly flows (cfs) of the lower Roanoke River for Group 1 ("optimum flow," JAI>5), Group 2 (high flows, JAI<5), and Group 3 (low flows, JAI<5).

throughout the period, which implies that the high flow earlier in the year is important to striped bass recruitment.

The Subcommittee examined a fourth group, characterized as having low to moderate flows (6,400 - 8,100 cfs) and a JAI less than 5.0 (n = 4 for years 1955, 1969, 1977, and 1982). Group 4 contained four years of May flow within the "optimum" range, but good year classes were not formed in these years. The primary difference between Group 4 and Group 1 was that the late March - early April flows of Group 4 were lower than what the Subcommittee believed were optimum. This suggests that a strong peak in early April flows, followed by low to moderate May flows is essential for strong year class formation.

The high flow period in April ranged from 7 to 20 days during the "optimum flow" years (Figure 37). This high flow, with its increased nutrient and detritus load, may be responsible for increased algal and zooplankton production, which is essential for increased larval survival. Thus, we suspect that high April flows followed by moderate May flows may result in proper food chain development and timely arrival of the larvae into the nursery area. Apparently both April and May flows are extremely critical to larval survival, and ultimately striped bass year-class formation.

The Recruitment Subcommittee recommended to the full Committee a flow regime closely resembling that of Group 1. If flow was 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 - 8,000 ± 1,000 cfs; April - 11,000 ± 4,000 cfs; May - 7,500 ± 1,000 cfs; and June - 5,000 ± 1,000 cfs.

Water Flow Time Series Analyses Using JAI

Dr. Louis H. Zincone, Jr. (ECU) was asked to model the flow of the Roanoke River prior to its impoundment and to compare that model with models of the flow during years defined as "good" or "bad" in terms of the JAI exceeding or falling short of five fish per trawl in a given year. The Committee asked Dr. Zincone to limit the analyses to those years following 1964, because it was the year in which the Roanoke Rapids dam began commercial hydropower production. The "good" post-impoundment years were: 1965, 1967, 1970, 1975, and 1976. All other JAI years were defined as bad. Additional analyses were conducted to determine whether the average flows during the good post-impoundment years were statistically different from those of the bad JAI years and whether the flow variances were statistically different. The analyses were conducted based on the assumption that flows during the period 1 March to 1 June do in fact contribute to the success of striped bass spawn.

ARIMA MODELING. The AutoRegressive Integrated Moving Average (ARIMA) modeling technique views the flow in the present time period as a function of past flows and past differences between the flow and what the model would predict the flows to be. As it turned out, the best models were "autoregressive", i.e., the present flows turned out to be functions of past flows.

To determine the model structure, the autocorrelation coefficients of the USGS data are analyzed at different lags to determine which values of the independent variable and which past error terms to include in the model equation. Usually, a number of models fit the data. A final decision on which model best represents the data is made on the autocorrelation structure of the model residuals. The smaller the residual autocorrelation, the better the model.

THE DATA. The first step in analyzing the USGS data was to reduce the year-to-year variability for the PRE-USGS and POST-USGS data bases. Models were estimated from the averages of the daily data; i.e., an average for 1 March in all years, 2 March in all years, etc. It was these averages to which the statistical analysis was applied.

It should be noted that the daily standard deviations are large relative to the daily means. In fact, only 50 of the 120 means were 1.66 times the corresponding standard deviations. Ordinarily, this would be cause for some alarm in that one would question whether the daily means truly represented the flows over the years. Two circumstances serve to minimize this problem.

First, measurements were recorded from the first gage downstream from Roanoke Rapids Dam as described above. A basic understanding of fluid dynamics is all that is necessary to recognize that, the closer the gage is to the dam, the more variable the flow. Below this point (e.g., Scotland Neck), the slight changes in discharge are dampened in the gage records.

Second, nature does not conform to the Gregorian calendar. Therefore, it is likely that some of the daily differences in flows is the result of natural variability in the onset of the conditions causing the annual spring floods: meteorological conditions ("April showers" in March) and the juxtaposition of cold and warm air masses causing thunderstorms and rain events which result in spring flooding. Clearly these phenomena do not begin precisely on 1 March and end on 30 June each year. Consequently, an unknown portion of the differences in the daily flows are the result of time displacement of the time path rather than true differences in daily flow. In other words, in order to know the true time path, one would have to know what day each year constituted Nature's onset of "spring." One could then compare the flows of days whose time was measured from the onset of Nature's spring, no matter what the calendar date was. Since there is no way to determine the onset of Nature's spring each year, we used calendar dates and accepted the fact that daily flows will be extremely variable over the years.

PRE-IMPOUNDMENT FLOW. Figure 38 depicts the average pre-impoundment flow of the Roanoke River after eliminating the top and bottom 10 percent of the flows. The line marked "AVG" represents this data item, while the line marked "AVGSM" represents a seven-day moving average of the daily average. This moving average was computed to illustrate and further smooth the daily averages. All statistical work was performed on the daily averages (AVG).

Inspection of Figure 38 suggests that pre-impoundment flow can be divided into three parts: (1) 1 March to 16 April; (2) 17 April to 12 May; and (3) from 12 May onward. The first segment appears as a plateau with a mean of 8,434 cfs and a standard deviation of 178 cfs. The second segment is a downward trend characterized by a day-to-day change of -88 cfs with a standard deviation of 416 cfs. The third segment appears as a second, lower plateau with a mean of 6,146 cfs and a standard deviation of 450 cfs.

Because of the different characteristics of the segments, each was modeled individually. It should be noted that the latter portion of Segment 3 might be better described as a downward trend, but the segment could not be subdivided because there were too few observations.

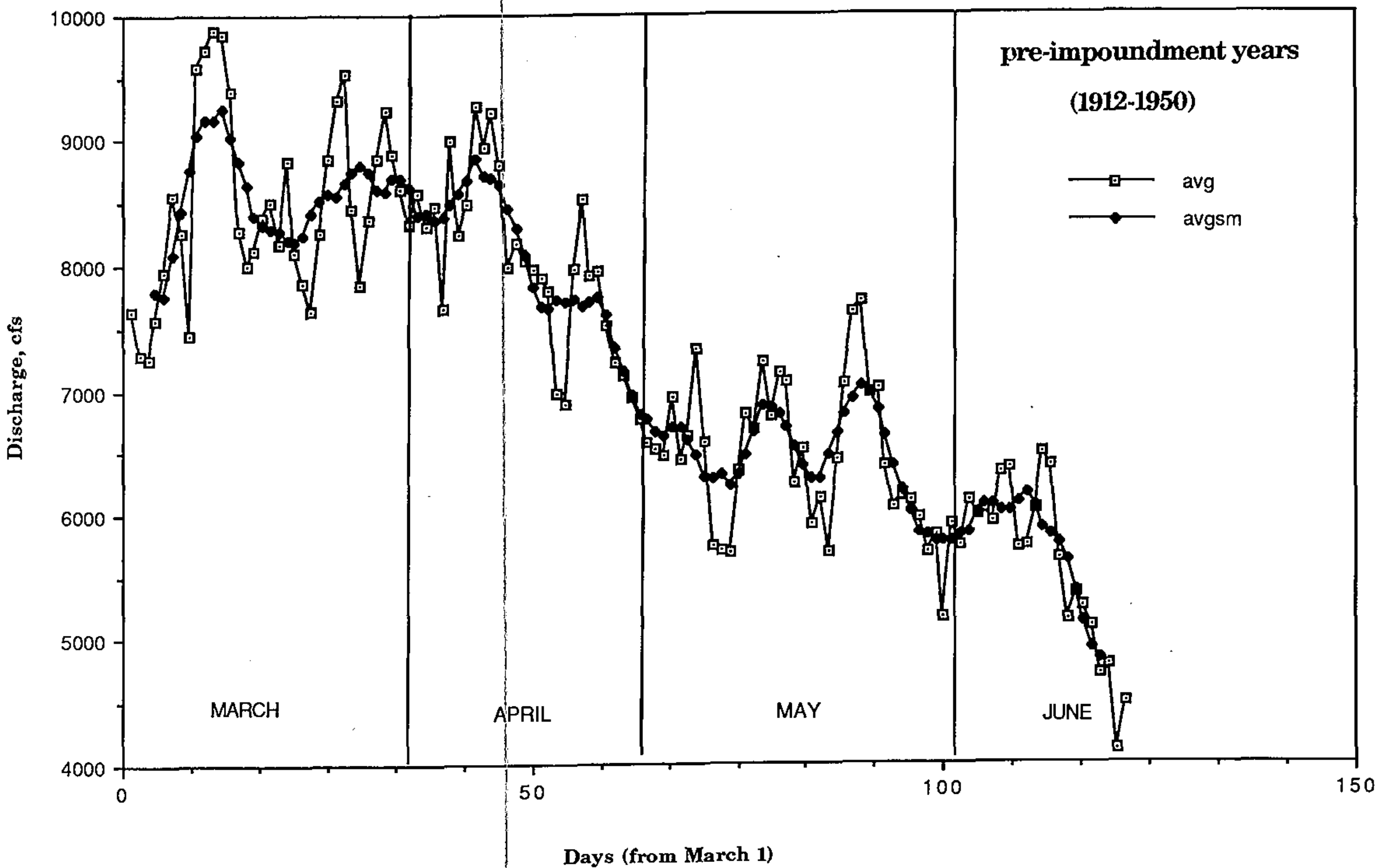

Figure 38. Time series analysis of Roanoke River pre-impoundment flows for the period March-June. Avg = average flow; avgsm = smoothed average flows.

The model for each segment is
Segment 1: $y(t) = 0.583y(t-1) + 3512 + a(t)$;
Segment 2: $y(t) = 0.456(y[t-2] - y[t-3]) + a(t)$; and
Segment 3: $y(t) = 0.788y(t-1) + 1301 + a(t)$;

where "y" is flow, "t" is a time indicator, and "a" is white noise or random error. All parameters and constants are significantly different from zero at $p=0.05$.

POST-IMPOUNDMENT JAI GOOD YEARS. It is the working premise of this report that, in years of good JAI values, the time path of the flows more closely resembles pre-impoundment flows than the post-impoundment flows in years with small JAI values. Figure 39 shows the average and smoothed average for post-impoundment flows of selected good JAI years. Two differences between pre-impoundment flows (Figure 38) and good JAI year (post-impoundment) flows are apparent. First, flows in JAI good years are higher throughout and have a higher standard deviation (indicating greater variability). Second, March is characterized by a steep upward trend rather than being part of a plateau. (The differences in average flow and the standard deviations of the flow in good JAI and bad JAI post-impoundment years is addressed in a later section). The downward trend toward the May-June plateau begins on 20 April just four days after the average pre-impoundment flows begin their descent.

For modeling, the data are divided into two segments. There are really four, but lack of observations precluded four models. Consequently, March and April are regarded as one segment and May and June as another segment. The models for the two segments are:

Segment 1: $y(t) = 0.61y(t-1) + 0.29y(t-6) - 0.177y(t-7) + 2338\ a(t)$. The mean for Segment 1 was 8,515 cfs and the standard deviation was 1,259 cfs.

Segment 2: $y(t) = 0.92y(t-1) - 0.35y(t-3) + 0.322y(t-4) + 737 + a(t)$.
The mean for this segment was 6,966 cfs and the standard deviation was 985 cfs.

That the models are different from those estimated from the pre-impoundment flows is not surprising. Of necessity, they would likely be different because of the different sub-periods for modeling. There are some other aspects implied, however, from the model structures as well as the graph.

The first aspect is the difference in the flows during March. While the natural pre-impoundment flow is high throughout the period, the post-impoundment flow rises throughout the month until it attains a level slightly higher than the pre-impoundment March-early April flow. This phenomenon is probably the result of flood control efforts as well as efforts to store water for later power generation and recreational use. Consequently, there is a logical explanation, in terms of the dams, for this difference.

The presence of the y(t-6) and y(t-7) terms is also explicable. What these terms say is that the flow today is related, in a significant manner, to the flows six and seven days ago. Clearly this is a reflection of the well known weekly fluctuation in electricity usage, especially the drop in usage on weekends.

On the other hand, the remaining terms y(t-1) in both segments, and y(t-3) and y(t-4) in Segment 2, are probably natural. One can say this because both the y(t-1) term and the y(t-3) term appear in the pre-impoundment equations. The remaining differences probably can be accounted for by the different segmentation. Overall, we conclude that the flows

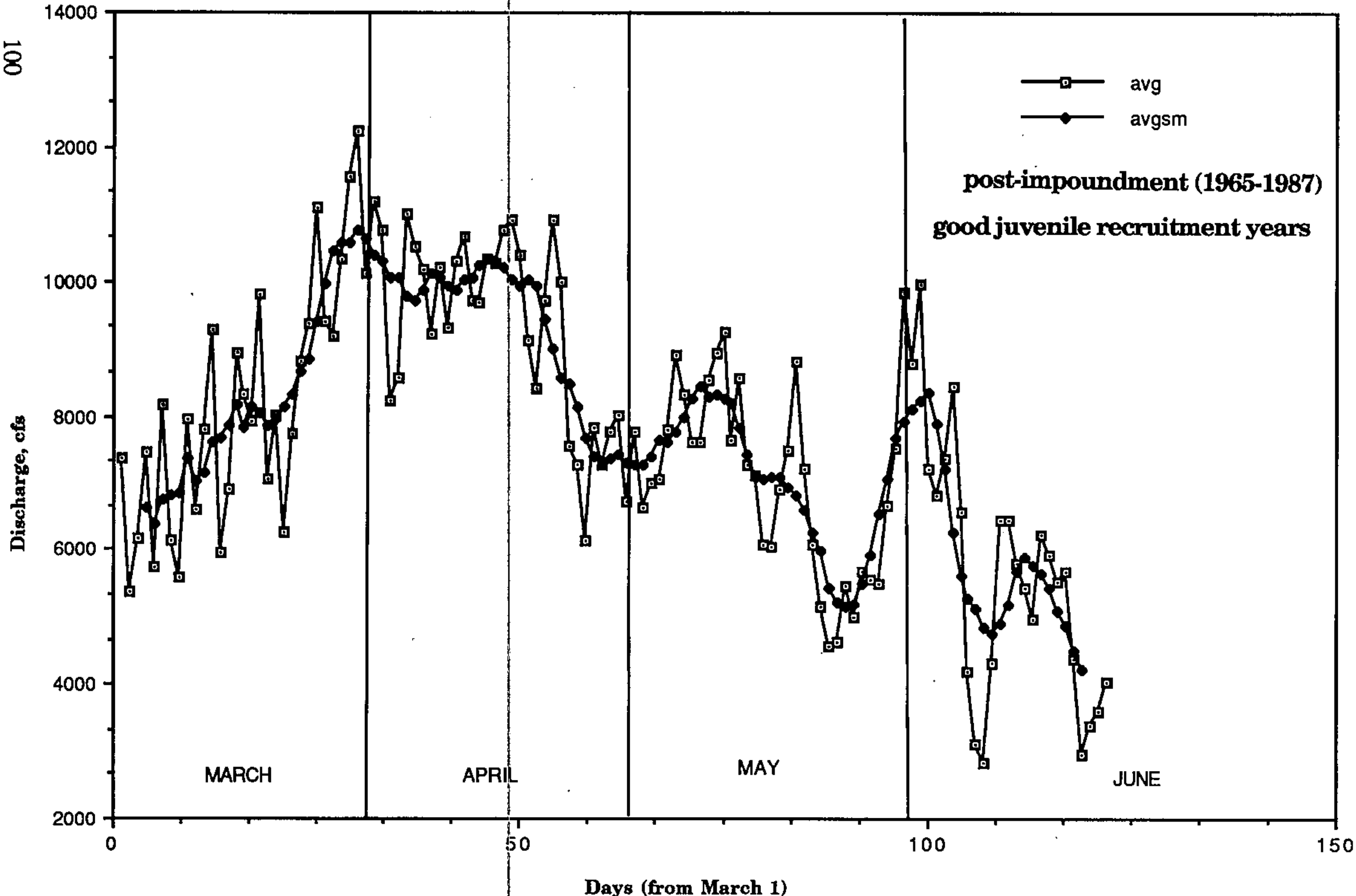

Figure 39. Time series analysis of Roanoke River flows for JAI "good years." Avg = average flow; avgsm = smoothed average flows.

from the post-impoundment JAI good years are reasonably similar to those from the pre-impoundment era.

POST-IMPOUNDMENT JAI BAD YEARS. In order to examine the differences, if any, between the flow models for the JAI good and JAI bad years, it is necessary to model the flow in the JAI bad years. This section addresses the result of that exercise. Figures 40, 41, and 42 illustrate the flow in the bad years. Perhaps the most instructive is Figure 42, which shows the seven-day moving average of the good and bad years. Immediately apparent from all three graphs is that during the JAI bad years the flow does not decrease from April to May. In fact, it remains at an average of 11,500 cfs until about 15 May. The May flow for JAI bad years is substantially above that for the JAI good years. This is observed more clearly in Figure 42, where the averages are smoothed. Moreover, rather than having three distinct segments, the bad year time path is essentially horizontal until mid-May, when it falls off precipitously.

Time series analysis of the JAI bad year mean flows produced the model

$$Yt = 0.84Yt\text{-}1 + 1560 + at.$$

The standard error of the residuals is 1033. Another model that adequately describes the JAI bad year data is

$$Yt = Yt\text{-}1 + at,$$

often known as the "random walk" model. Essentially, this model states that daily changes in the flow are simply white noise (random error) and represent no pattern at all. Not only is this second model adequate in the sense that there is no statistically-significant auto-correlation present in the residuals, but also that the standard error of the residuals (a common measure of fit) is 1067, essentially the same as that of the first model above (1033). Indeed, an F test for the differences in variances shows that the residual variation from the two models are not significantly different from zero, indicating that the difference between $(1067)^2$ and $(1033)^2$ is not significant. This means that the power of flow predictability for each model is the same. Clearly this is a different result from our results obtained from the JAI good years. Therefore, we conclude that Roanoke River flow in JAI bad years is NOT similar to that in the pre-impoundment years and that, in fact, it has no pattern at all: it is a "random walk".

FLOW LEVELS AND VARIABILITY. The previous sections have dealt with the time path of the flows in pre- and post-impoundment years. This section will deal with a question which bears on whether the average Roanoke River flow level and its variability affect striped bass spawning. Specifically, the committee theorized that extremely high and extremely low flows, and also extreme variability in the flows, affects spawning. If this is true, then the average flow in the JAI bad years will be either significantly higher or lower than flows for the JAI good years. Similarly, the variability in flow in JAI bad years will be greater than than flow variability in JAI good years.

These two hypotheses were tested by pairwise t-tests on the daily means and F-tests on the variances (Table 18). In the table, the JAI bad years and the corresponding mean flows and standard deviations are listed across the top; the same information for the JAI good years is listed along the left-hand side. As can be seen, all of the JAI bad years were years of extremely high or low flows. Also, all of the bad years except 1981 had relatively large variability in flows.

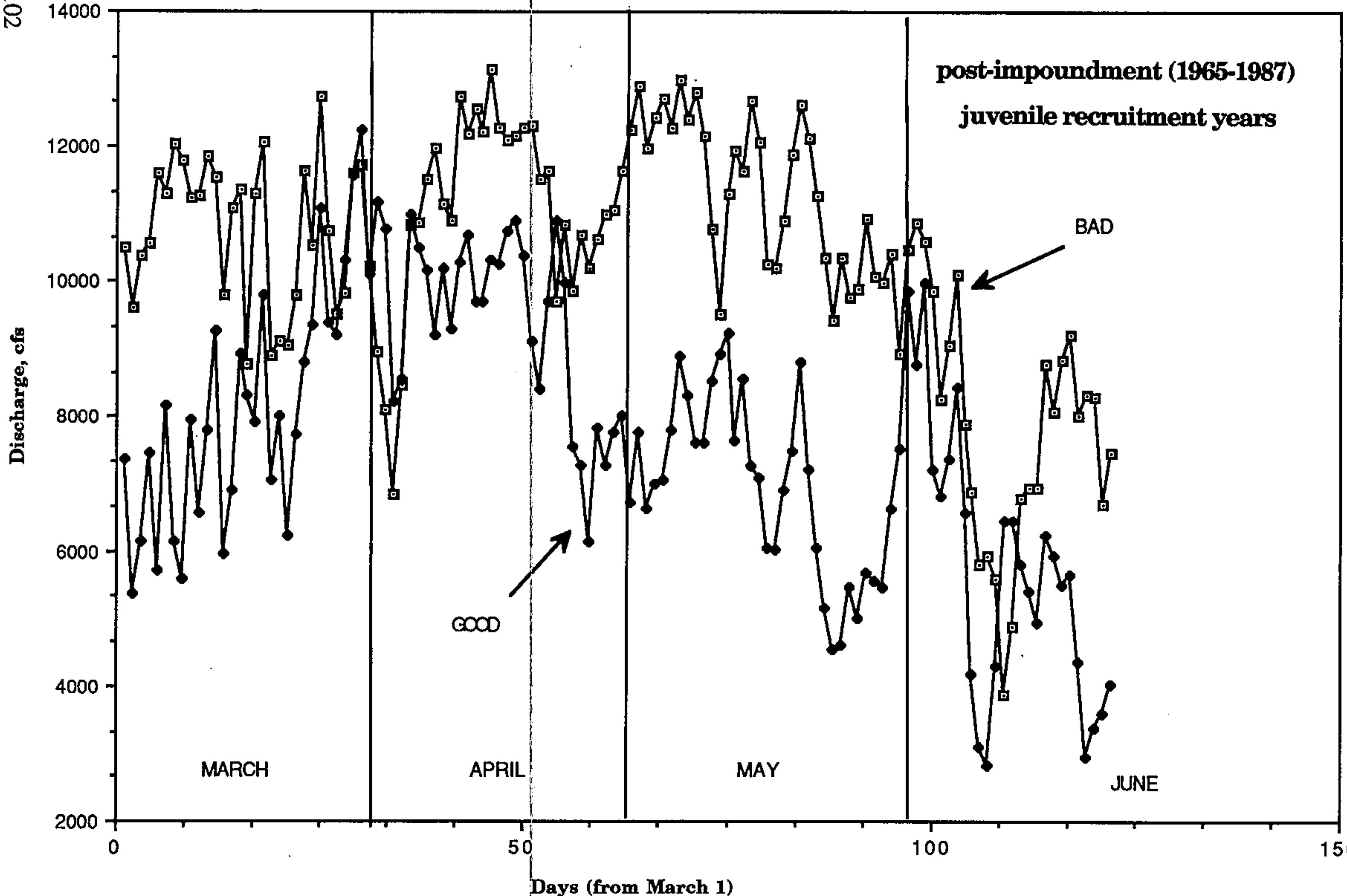

Figure 40. Time series analysis of Roanoke River flows for JAI "good years" and JAI "bad years," 1965-1987.

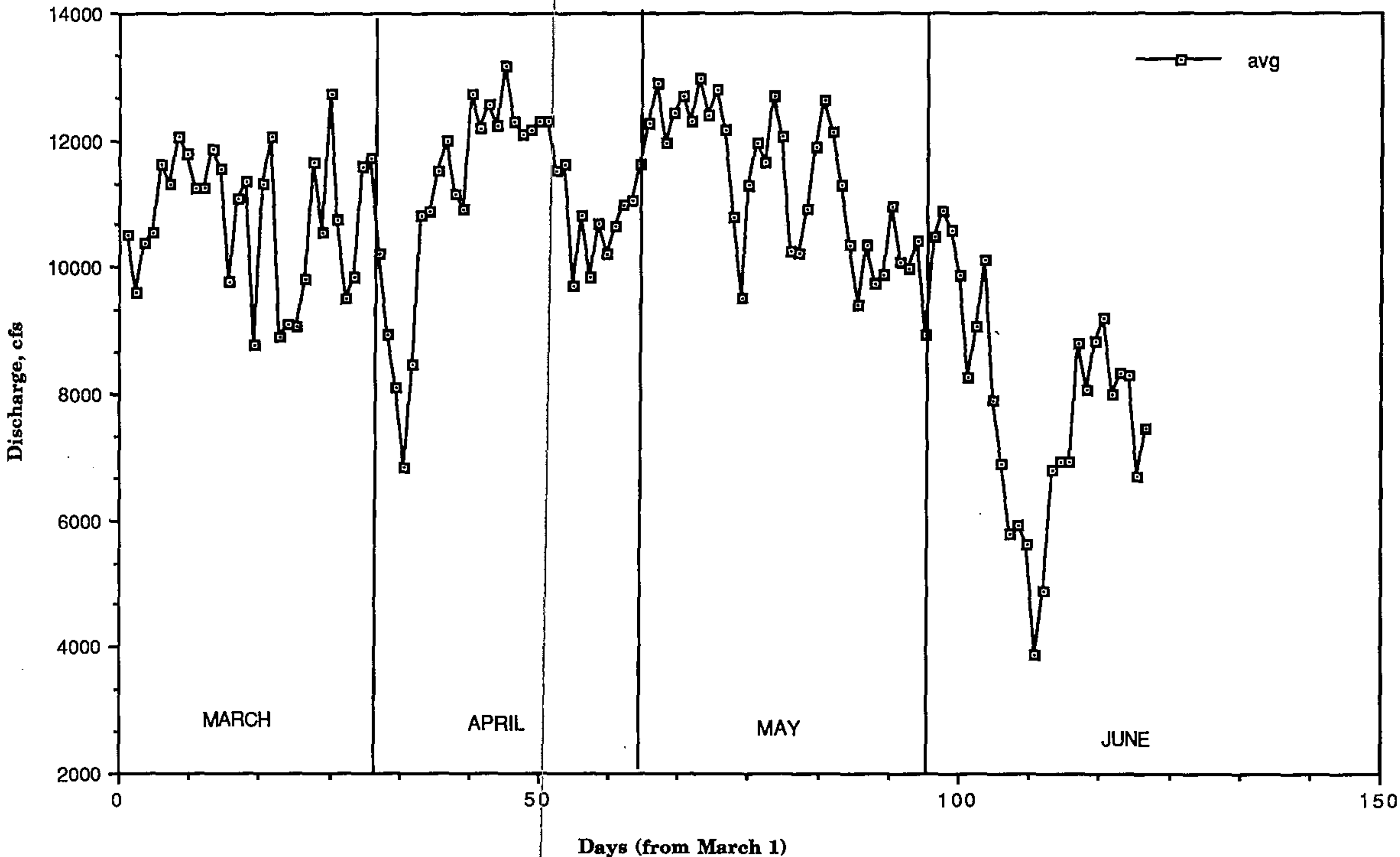

Figure 41. Time series analysis of Roanoke River flows for JAI "nongood" post-1965 years.

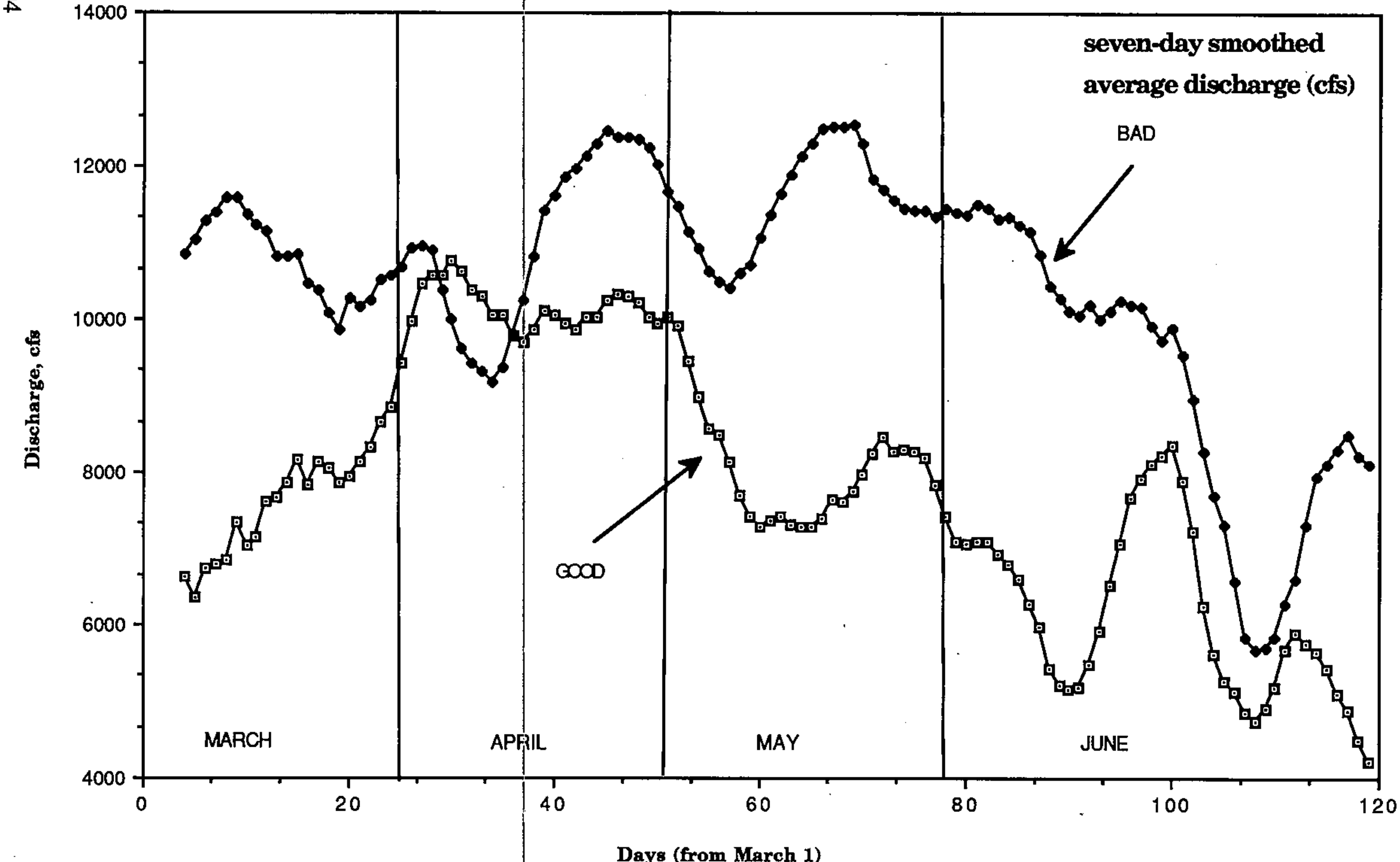

Figure 42. Time series analysis of Roanoke River post-1965 flows (smoothed averages) for JAI "good" years and JAI "bad" years.

Table 18. Results of t- and F-tests for differences in Roanoke River flow and variability among JAI good years and JAI bad years (JAI value <5). Critical t = 1.66 at p = 0.05; critical F = 1.22 at p = 0.05. All tests were significant except those indicated (NS).

JAI Good Years				JAI Bad Years									
				1978		1979		1980		1981		1983	
				Mean	S	Mean	S	Mean	S	Mean	S	Mean	S
Year	Variable		Test	11765	9351	15217	7007	11352	5348	3268	1941	16536	6896
1965	Mean	7225	t	12.338		10.59		6.58		-9.10		12.58	
	SD	4390	F		4.53		2.59		1.48		0.20		2.46
1967	Mean	4330	t	16.46		15.98		13.08		-3.65		18.3	
	SD	2557	F		13.37		7.66		4.37		1.73		18.8
1970	Mean	4797	t	15.73		15.01		11.86		4.79		17.29	
	SD	2946	F		10.07		5.77		3.30		2.30		5.48
1975	Mean	16471	t	1.49 (NS)		1.23 (NS)		4.62		12.51		0.66 (NS)	
	SD	11736	F		1.58		2.75		4.82		36.55		2.90
1976	Mean	5320	t	15.24		14.41		11.10		6.76		16.70	
	SD	2731	F		11.75		6.72		3.83		1.98		6.38

The top number in each cell is the result of a one-tail t-test for the difference in the means of the row year and the column year. The second number in each cell is the result of an F-test for difference in variance between the same years. For example, from the upper left-hand cell, 12.338 is the t-value for the difference between the means for 1978 and 1965, and 4.53 is the F-value for the difference in the variances. Since both of these values are above their respective critical values of 1.66 and 1.22, respectively, we conclude that the flow in 1978 (JAI bad year) was significantly above that in 1965 (JAI good year).

Recognizing the critical values for the t-statistic, Table 18 shows that all means are significantly different from one another except for the following pairs of years: 1975(good)/1978(bad); 1975(good)/1979(bad); and 1975(good)/1983(bad). Thus, out of 25 possible pairs of years, 22 mean flows were significantly different, supporting our hypothesis that extremely high or low flows affect the striped bass spawn.

Finally, consideration of the F-values leads to the conclusion that all of the variances are significantly different. Again, the variance in 1981 was <u>lower</u> than that in 1965, which is contrary to the biologists' hypothesis that it is the <u>high</u> variation that harms the spawn. However, in the remaining 24 combinations, the differences are positive.

CONCLUSIONS.

1) The models which describe the daily flows for the pre-impoundment and the JAI good (post-impoundment) years are clearly not identical. This is obvious from the examinations of the model structure. However, they are similar. Specifically, the models for Segment 1 and Segment 3 are autoregressive models, which means that the flow today is very similar to the flow yesterday, a phenomenon which none of us find surprising. The model for the middle period includes a first difference to eliminate the trend and then is an autoregressive model which relates the first difference of the flow today with that of two days ago. The first autoregressive term is present in both model segments for post-impoundment flows. In that sense, they are similar.

2) The differences between pre-and post-impoundment flow are strikingly similar to what one would expect given the nature of electricity demand and the use of the dams on the Roanoke as peaking units. Specifically, the six- and seven-day lag in the model for Segment 1 of the post-impoundment flows, and the four-day lag in Segment 2, find no rationale in natural phenomena. These are clear differences between the pre-impoundment flow time path and that of the JAI good (post-impoundment) years.

3) On the other hand, the differences in flows between the JAI good years and the JAI bad years is quite dramatic. Neither the models nor the graphs of the time paths look anything like the pre-impoundment era and, indeed, the JAI bad year flows can be characterized as a series of random changes from one day to the next, or as a "random walk.".

4) In terms of the level and variability of Roanoke River flows, it is likely that extreme differences from the "average" in either direction is likely to be harmful to the spawn. It would be interesting to perform an analysis of variance on the JAI using average flow, the flow variance, and an interaction term as independent variables. It is likely that the interaction of the high flow and extreme variability would be more important than either standing alone.

5) Finally, we conclude that the flows in the JAI good post-impoundment years are more similar to the pre-impoundment flows than those of JAI bad years. Consequently, since the fishery was successful prior to flow regulation by the series of reservoirs, making the flows consistent with the vast majority of the pre-impoundment flows is likely to improve the production of striped bass.

IMPACT OF THE NEGOTIATED FLOW REGIME ON STRIPED BASS

Subsequent to the meetings of the Recommendations Subcommittee, the full Committee, and the adoption of the negotiated flow regime, several additional analyses were performed using egg viability data and JAI data to ascertain potential effects of the negotiated flow regime on Roanoke/ Albemarle striped bass. Results of these analyses were not discussed by the full Committee, but are included in this report to provide additional information on the negotiated flows and Q_1-Q_3 bounds criteria.

Further Flow Analyses

A regression analysis (SAS 1985) was employed to determine how the percent of days (PDAYS) within the negotiated Q1-Q3 values changed as a function of year (YEAR). PDAYS was significantly correlated (n=36, p=0.0003, R^2=0.32) with YEAR; in general, the percentage of time that Roanoke River flows stayed within the bounds has decreased over time (Table 19, Figure 34).

Subsequently, an 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 YRCLASS designations were: 1951-1959, 1960-1969, 1970-1977, and 1978-1987. The 1970s decade was divided into two portions because year 1977 was the last year in a series of reasonably good juvenile abundance indices (Table 12). PDAYS was significantly related (n=37, p=0.0021, R^2=0.36) to YRCLASS; the average percentage of days in which

Table 19. 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 Q_1-Q_3 bounds (PDAYS).

Dependent variable	Independent variable	df	F	P>F	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

Table 20. Results of analysis of variance (SAS 1985) comparing the percent of flow days within negotiated Q_1-Q_3 bounds (PDAYS), striped bass egg viability (EGGCLASS), and the striped bass Juvenile Abundance index (JAICLASS) to decades of post-impoundment (YRCLASS). Means connected by underline are not significantly different at p = 0.05 (Duncan's).

Variable	Comparison	n	df	F	P> F	Means			
						1951-1959	1960-1969	1970-1977	1978-1987
PDAYS	YRCLASS[a]	37	3,33	6.07	0.0021	52.9	50.5	39.8	26.7
						1978-1987	1970-1977	1960-1969	
EGGCLASS[b]	YRCLASS	28	2,25	33.93	0.0001	1.0	0.4	0.0	
						1960-1969	1970-1979	1955-1959	1978-1987
JAICLASS[c]	YRCLASS	33	3,29	9.84	0.0001	2.9	2.9	2.8	1.1

~~[a]YRCLASS 1 = 1951-1959; 2 = 1960-1969; 3 = 1970-1977; 4 = 1978-1987.~~

[b]EGGCLASS 0 = ≥ 75% viability; 1 = < 75% viability.

[c]JAICLASS 1 = < 1.00; 2 = 1 to 4.99; 3 = 5-9.99; 4 = 10 +.

Example for reading this table: A common underscore indicates that the means in each year class were not significantly different. Thus, mean PDAYS for 1951-1977 are not significantly different. Similarly, the 1970-77 and 1978-87 means are not significantly different.

Roanoke River flow fell within the negotiated Q1-Q3 bounds was significantly less after 1977 than for the period before 1970, but was not significantly different from the 1970-1977 period (Table 20).

These analyses confirm a significant change in the flow regime since post-impoundment, particularly since 1977. The frequency of times in which the Roanoke River flows were within the negotiated Q1-Q3 bounds have decreased over the years.

One analysis, which would have been interesting for comparative purposes, would be to model the theoretical natural flows during the post-impoundment years. However, these data were not available to the Committee at the completion of our study.

Egg Viability

DATA BASE DESCRIPTION. Striped bass egg production and viability have been determined by Dr. Hassler since 1959 using techniques and procedures developed by McCoy (1959) and Cheek (1961). McCoy's study determined that 10-inch diameter nets were more efficient than 1-meter nets, and that tows of 5 minutes were more efficient than 10- or 15-minute tows. Cheek (1961) determined that sampling at three-hour intervals had the smallest variance.

Annual sampling for striped bass eggs was conducted below the spawning grounds near Weldon, NC. In 1959, the study site was located at RM 128; in 1960, samples were taken at Hill's Ferry (RM 78.5). From 1961 to 1974, eggs were collected at Halifax, NC, at RM 121 which is approximately nine miles downstream of the major spawning ground. From 1975 to 1980, the study site was located at Barnhill's Landing approximately two miles below Halifax.

The estimated number of eggs spawned daily was calculated by obtaining a mean number of eggs counted from the eight replicated samples taken over 24 hours and then extrapolating that mean for the average cross-section of the river. Details of the methodology were described by Hassler et al. (1981).

ANALYSES. Hassler's egg viability estimates (Table 12) show a declining trend since data collection was initiated in 1960. During the period 1960-1969, the average egg viability was about 90 percent (Table 21). From 1970 to 1977, the average egg viability dropped to about 74 percent; since 1978 the mean viability was less than 50 percent. For the post-impoundment period, the average percent of days with flows within the negotiated Q1-Q3 bounds have dropped from 53 percent to 27 percent (Table 21).

A regression analysis on egg viability indicated a significant negative correlation between viability and year ($n=27$, $p=0.0001$; $R^2=0.58$); that is, egg viability has exhibited a significant downward trend since the study was initiated in the 1960s. Also, egg viability was significantly related to the percent of flow days within the negotiated Q1-Q3 bounds ($n=27$, $p=0.0145$, $R^2=0.21$) (Table 19), but the strength of the relationship is too low, suggesting a need for further analysis.

Egg viability data were then stratified into those values less than 75 percent, and those values 75 percent or greater to examine effects of negotiated flows on relatively poor and good egg survival. Subsequently, we examined the mean percentage of flow days within negotiated Q1-Q3 bounds and the mean percentage of viable eggs by viability class. In years of egg viability less than 75 percent, the percent flow days within the negotiated Q1-

Q3 bounds averaged 31.9 percent, and egg viability averaged approximately 50 percent (Table 22). The second viability class had percent flow days within Q_1-Q_3 bounds averaging 45 percent and viability averaged 89 percent. Results of a t-test showed a significantly higher average percent flow days within the Q_1-Q_3 bounds for the 75-100% egg viability class.

Table 21. Percent of days Roanoke River flow was within the negotiated Q_1-Q_3 flow criterion by period, and mean values of the juvenile abundance index (JAI) and percent egg viability.

	Percent of days within Q_1-Q_3			JAI			Percent egg viability		
Period	n	Mean	SD	n	Mean	SD	n	Mean	SD
1951-1959	9	52.92	17.90	5	10.43	9.33	-	-	-
1960-1969	10	50.53	12.09	10	7.86	5.76	10	89.67	6.16
1970-1977	8	39.80	14.50	8	6.28	4.01	8	74.28	16.70
1978-1987	10	26.71	12.40	10	0.81	1.05	10	49.25	16.85

Table 22. Percent of days Roanoke River flow was within the negotiated Q_1-Q_3 bounds (PDAYS) and striped bass juvenile abundance index (JAI) by egg viability class. The critical t-value is 1.761 for df = 14 and p = 0.05.

		PDAYS		JAI		Egg viability	
% egg viability class	n	Mean	SD	Mean	SD	Mean	SD
<75.0	13	31.88	15.49	2.45	3.71	50.13	14.90
75.0 - 100	15	45.09	14.58	6.93	5.38	88.78	5.45
		t = 2.31		t = 4.01			

CONCLUSIONS. While there is a statistically significant relationship between egg viability and the percentage of days in which flows were within the Q_1-Q_3 bounds, the possible reasons for this phenomenon were not discussed by the full Committee. Further thought should be given to this relationship during the negotiated flow evaluation period.

JAI and Negotiated Flow Regime

In order to determine how the negotiated flow regime was related to the historical JAI records, we conducted several statistical analyses to define significant trends in the data. For these analyses, all available data were used instead of separating the data into JAI "good" years and JAI "bad" years.

ANALYSIS RESULTS. The juvenile abundance index shows a general post-impoundment decline. From 1955-1959, the JAI averaged 10.43; in the 1960s and 1970s, the value was about seven fish per trawl (Table 12, Figure 43). An alarming decrease was exhibited after 1977; the 10-year average was 0.81 (Table 21, Figure 43). This general decline was significant (n=32, p=0.0027, R^2=0.26), and matched the general decline in percent flow days within Q1-Q3 bounds (Tables 19 and 20, Figure 44). The decrease in JAI and corresponding decrease in percent flow days within was also significant (n=32, p=0.0027, R2=0.26).

The data were re-examined by subdividing the JAI values into four categories: those less than 1.00, those 1.00-4.99, 5.00-9.99, and those values 10.0 or greater. In general, the lowest JAI values had the lowest percent of flow days within the negotiated Q1-Q3 bounds (Table 23). The period from 1978 to 1987 was significantly different from the other post-impoundment periods (Table 20).

CONCLUSIONS. Based on these analyses, we conclude that best young-of-year recruitment to the year class occurs when Roanoke River flows are moderate. This conclusion reaffirms the analyses of Hassler et al. (1981) and the Recruitment Subcommittee; both reported that the best JAI values occurred in low to moderate flow years.

Table 23. Percent of days Roanoke River flow was within the negotiated Q_1-Q_3 flow bounds by JAI category.

		Percent of days within Q_1-Q_3		JAI		
JAI Category	n	Mean	SD	Mean	SD	Data Years
<1	9	21.93	11.73	0.36	0.27	'58, '78, '79, '80, '81, '83, '84, '86, '87
1.00 - 4.99	11	42.82	14.26	3.06	0.95	'55, '63, '64, '66, '69, '71, '72, '73, '77, '82, '85
5.00 - 9.99	5	48.68	13.65	6.32	0.85	'57, '60, '62, '68, '74
10.00+	8	50.49	10.48	15.07	5.66	'56, '59, '61, '65, '67, '70, '75, '76

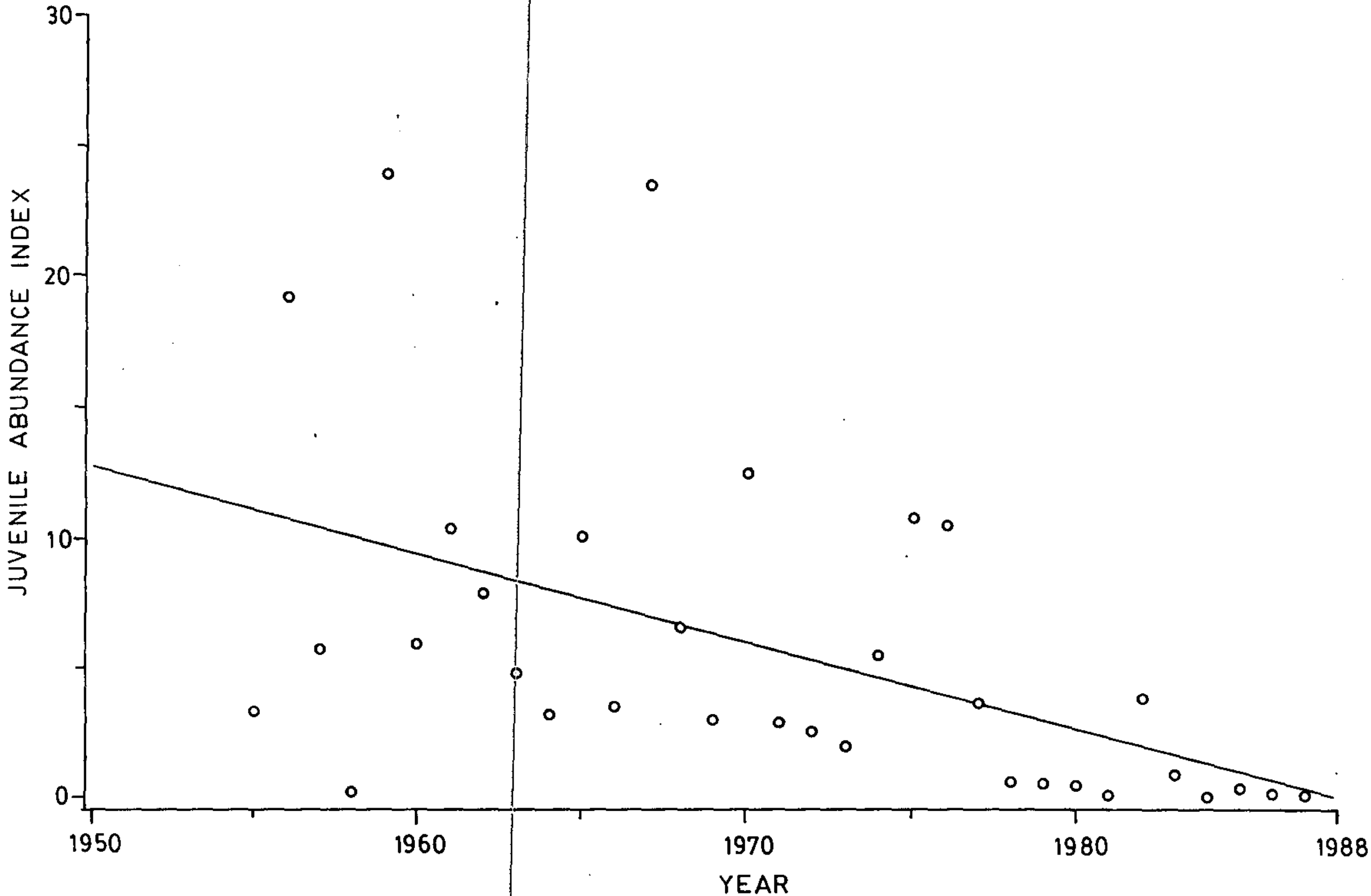

Figure 43. Relationship of the striped bass Juvenile Abundance Index to post-impoundment years (1955-1987).

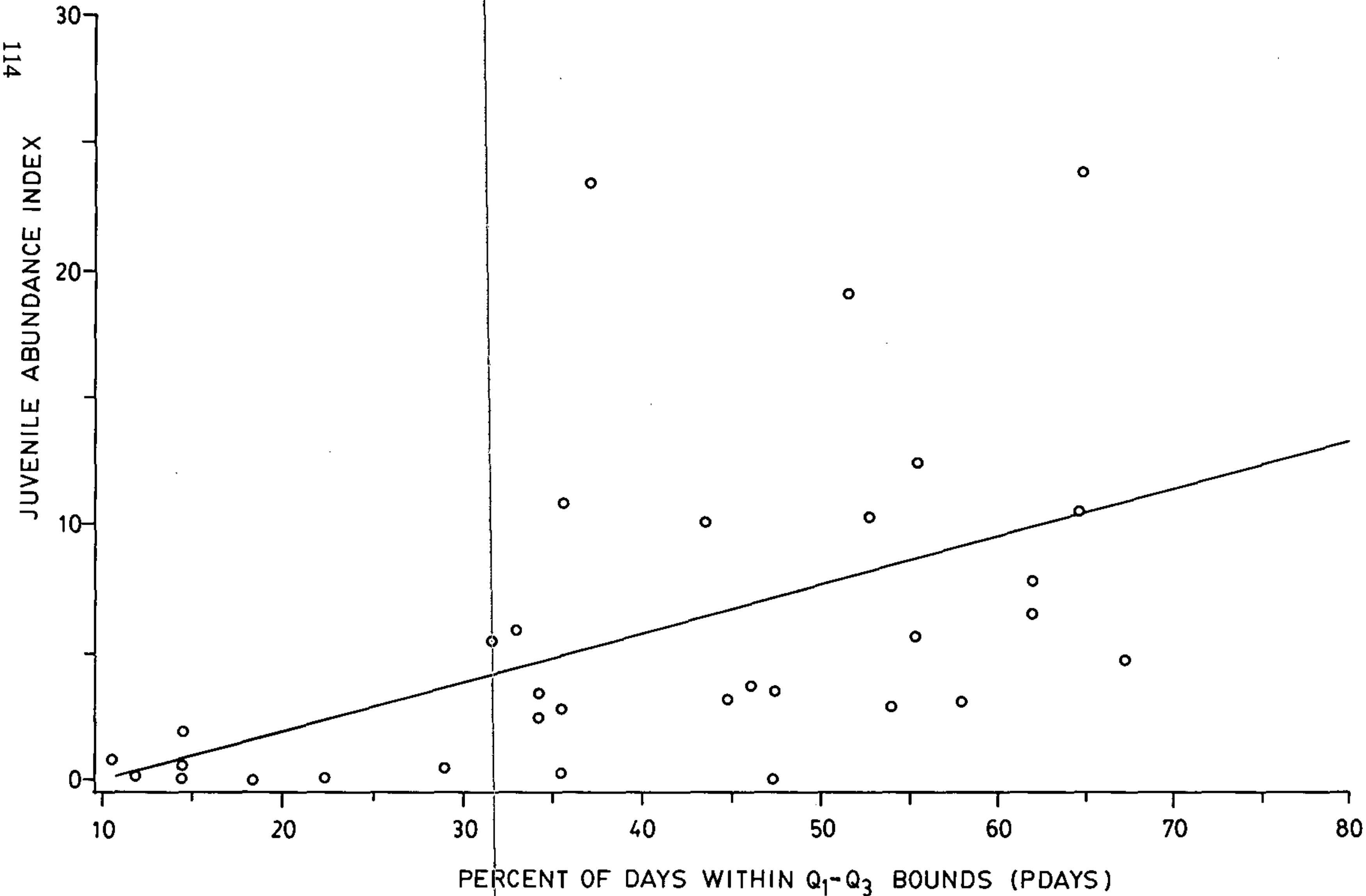

Figure 44. Relationship of the Juvenile Abundance Index (JAI) and the percentage of flow days within the negotiated Q1-Q3 bounds (PDAYS).

1988 WATER FLOW CONDITIONS AND RESULTS

Water Flows

The meetings of the Committee produced a desire to try and improve the operations of the reservoir projects. This desire, combined with reasonable manipulation of the hydrology of the system, resulted in the production of one of the better striped bass year classes in recent times. During this period, Virginia Power Company representatives conferred with fishery research biologists each week to plan water releases. The 1988 year class results will be presented later in the report. This review of 1988 operations will provide information on how the coordination and cooperation of the various agencies was used to take what nature provided and ensure better spawning conditions.

The flow records for the first six months of 1988 clearly depict a regulation of flood events by the reservoir early in the year, followed by the controlled releases for spawning flows in the spring. On 21 January the inflow to Kerr Reservoir reached a peak of over 30,000 cfs (Figure 45). This storm resulted in the reservoir rising from 295.62 on 16 January to a peak elevation of 299.35 on 25 January. As this elevation exceeds the Rule Curve and is in Zone C (Figure 6), the Corps initiated release of flood waters to evacuate this storage. However, continuing moderately-high inflows and the release requirement of 8,500 cfs resulted in the water surface elevation remaining close to 299 feet throughout January and into March. This event proved beneficial in that it was relatively easy to store additional water to meet the spawning flow target elevation of 302 feet, which was reached by 23 April. Flow augmentation was initiated earlier than normal (12 April) when striped bass were observed spawning in the first two weeks of April. The spawning target elevation was maintained by moderate releases until 12 May, when higher releases began to augment river flows for spawning. Spawning flows were maintained until 30 May, when the reservoir reached the top of power pool elevation 299.5. After 30 May, power operations resumed normal patterns of releases from Kerr Reservoir to meet power demands and conservation of power storage and daily rapid peaking changes from Roanoke Rapids. The last date for which striped bass eggs were found in the lower river was 2 June 1988 (R.A. Rulifson, personal communication).

In 1988, power operations from Roanoke Rapids showed a marked change between "normal" operating policy and operation during the spawning period. During January and February, it was not unusual for flows to fluctuate between 1,000 and 20,000 cfs.

The power operations show a curtailment of peaking in late March, which corresponds to a lower outflow from Kerr Reservoir (Figure 45). Lower Kerr outflow resulted in storage of water for spawning releases. When Kerr started releasing augmentation flows around 11 April, Roanoke Rapids also resumed peaking, although within the approximate limits set by flow regime guidelines. Throughout the rest of April and all of May, Roanoke Rapids operations limited flow fluctuations to within the limits of the proposed Committee flow regime guidelines and with a lower limit of 6,000 cfs (Figure 46). Kerr Reservoir throughout this period was the driving force by releasing water from storage (Figure 45). In early June, operations resumed normal patterns with Kerr attempting to maintain Rule Curve elevation and Roanoke Rapids resuming daily fluctuations between about 2,000 and 15,000 cfs.

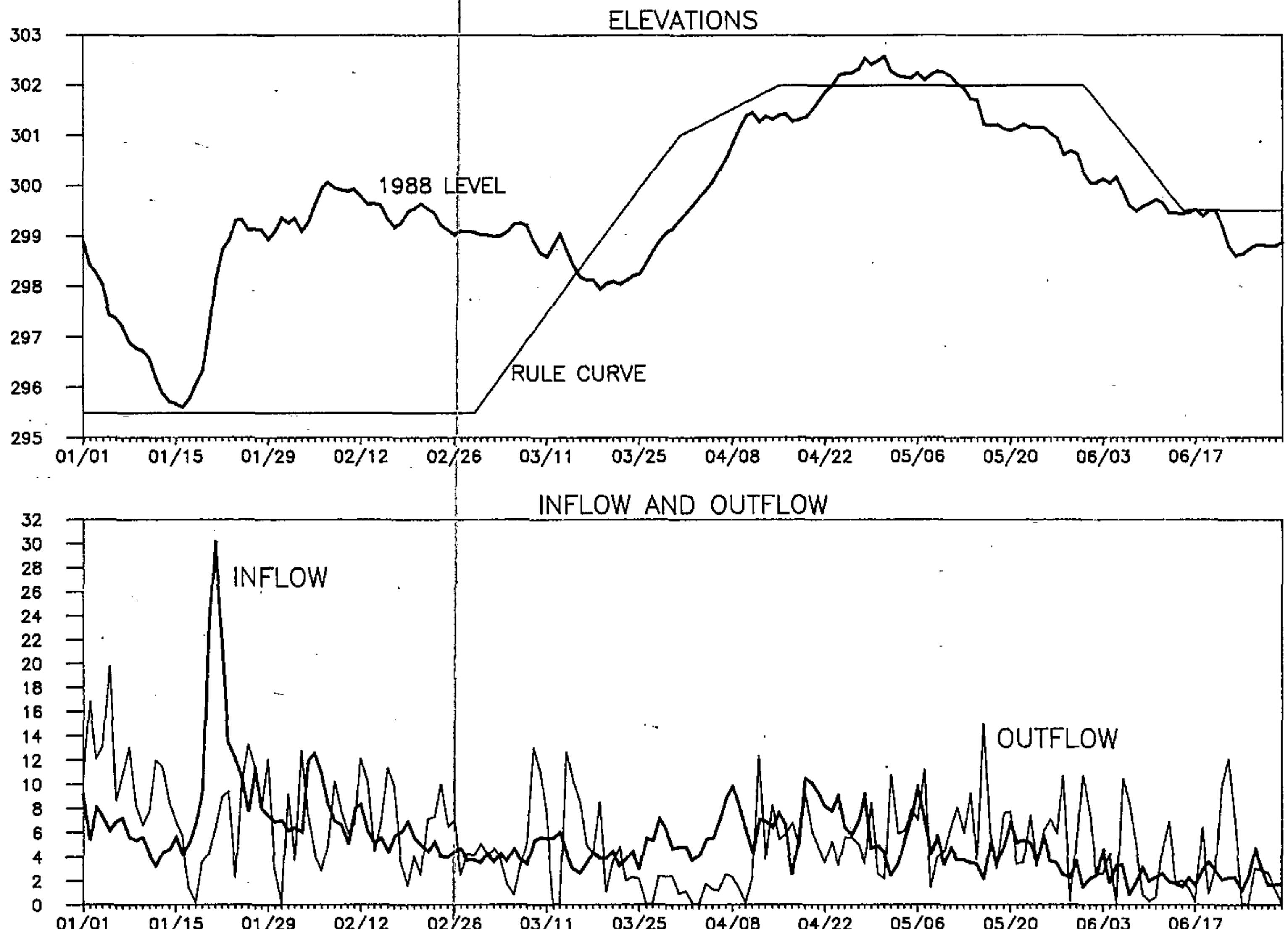

Figure 45. Kerr Reservoir daily elevations (feet above mean sea level) for 1988 and inflow and outflow in thousands of cubic feet per second (cfs).

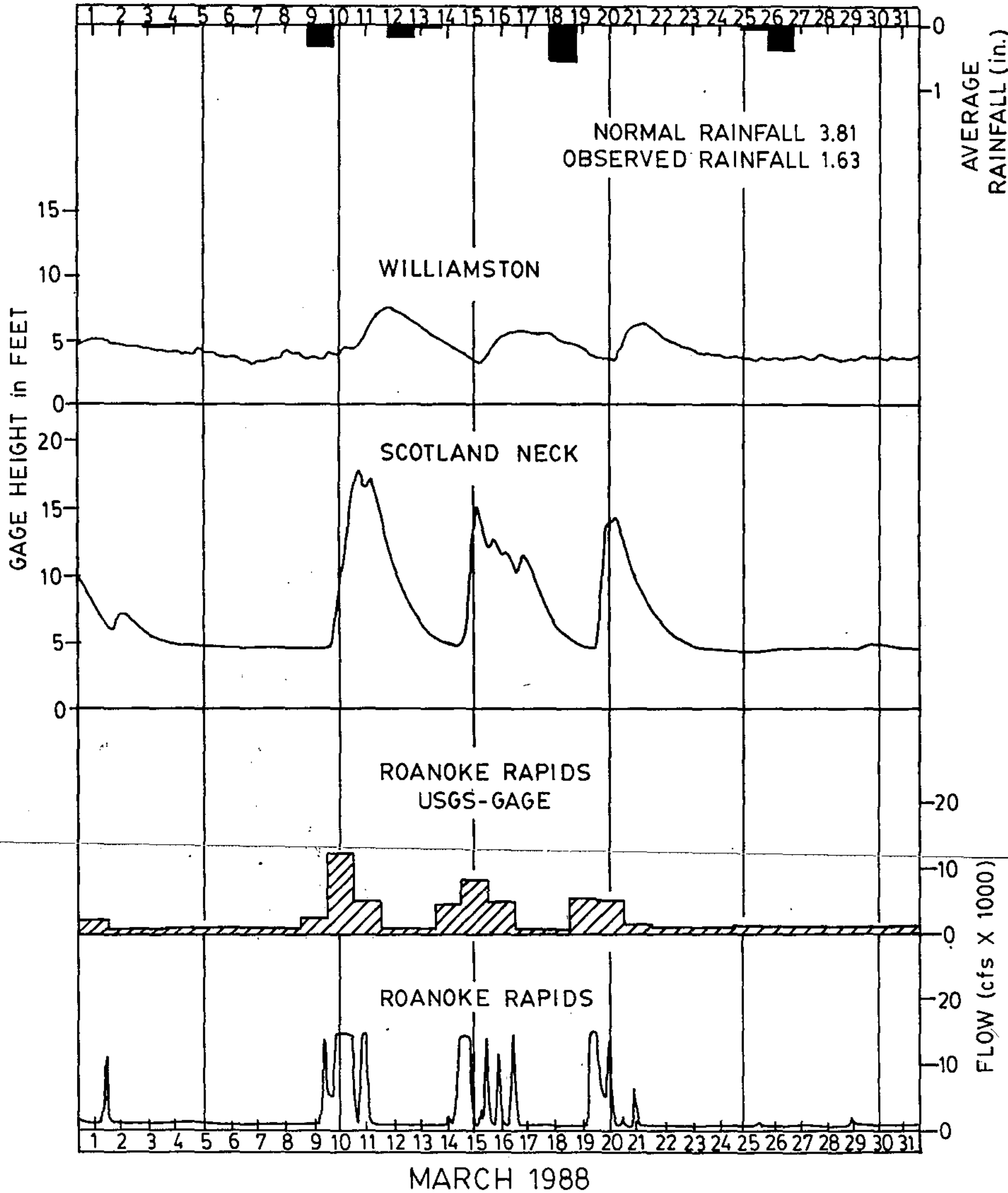

Figure 46. Lower Roanoke River flows for March - June 1988 as monitored by gage at Roanoke Rapids Dam, and USGS gages at Roanoke Rapids, Scotland Neck, and Williamston, North Carolina.

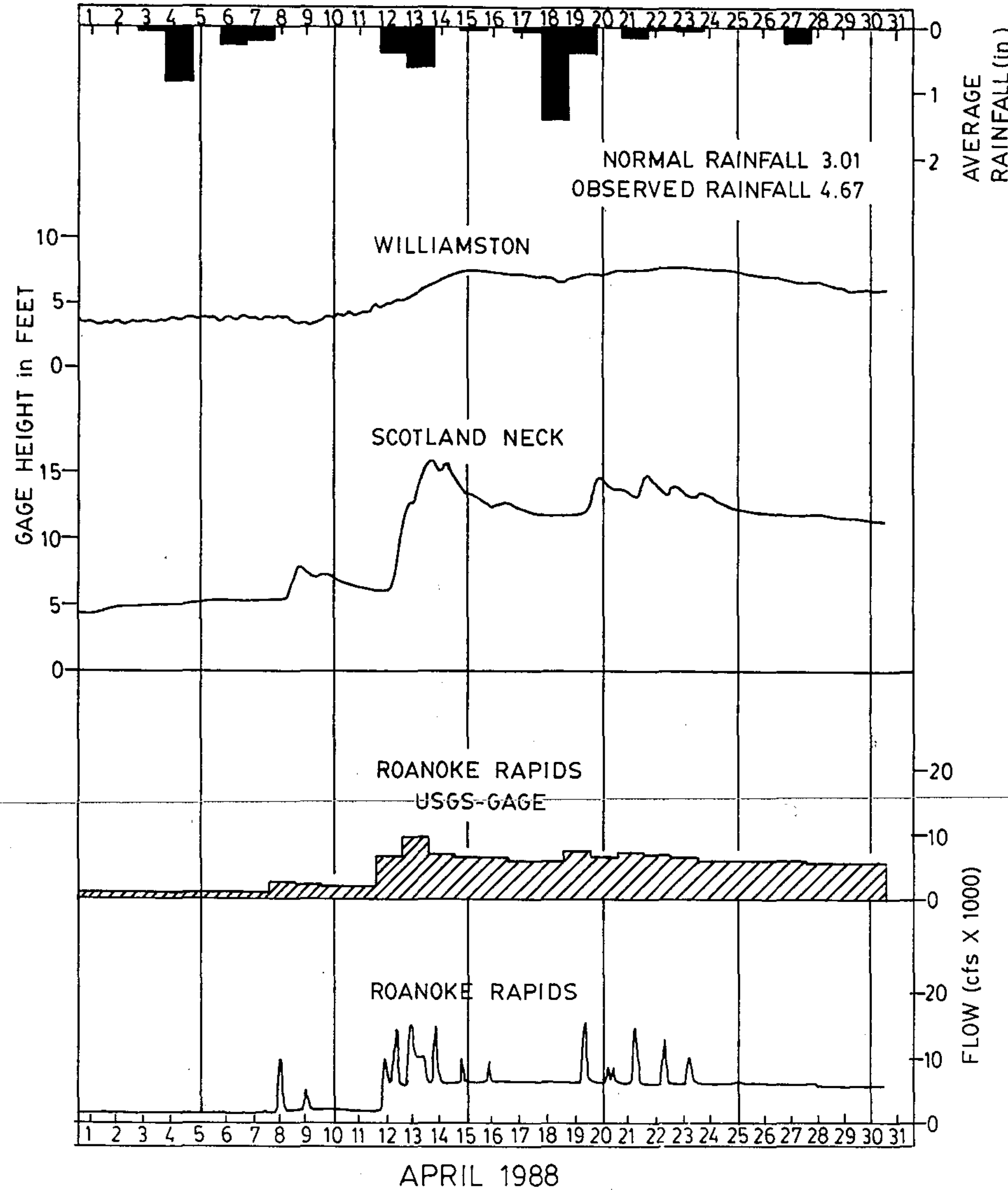

Figure 46. (Continued)

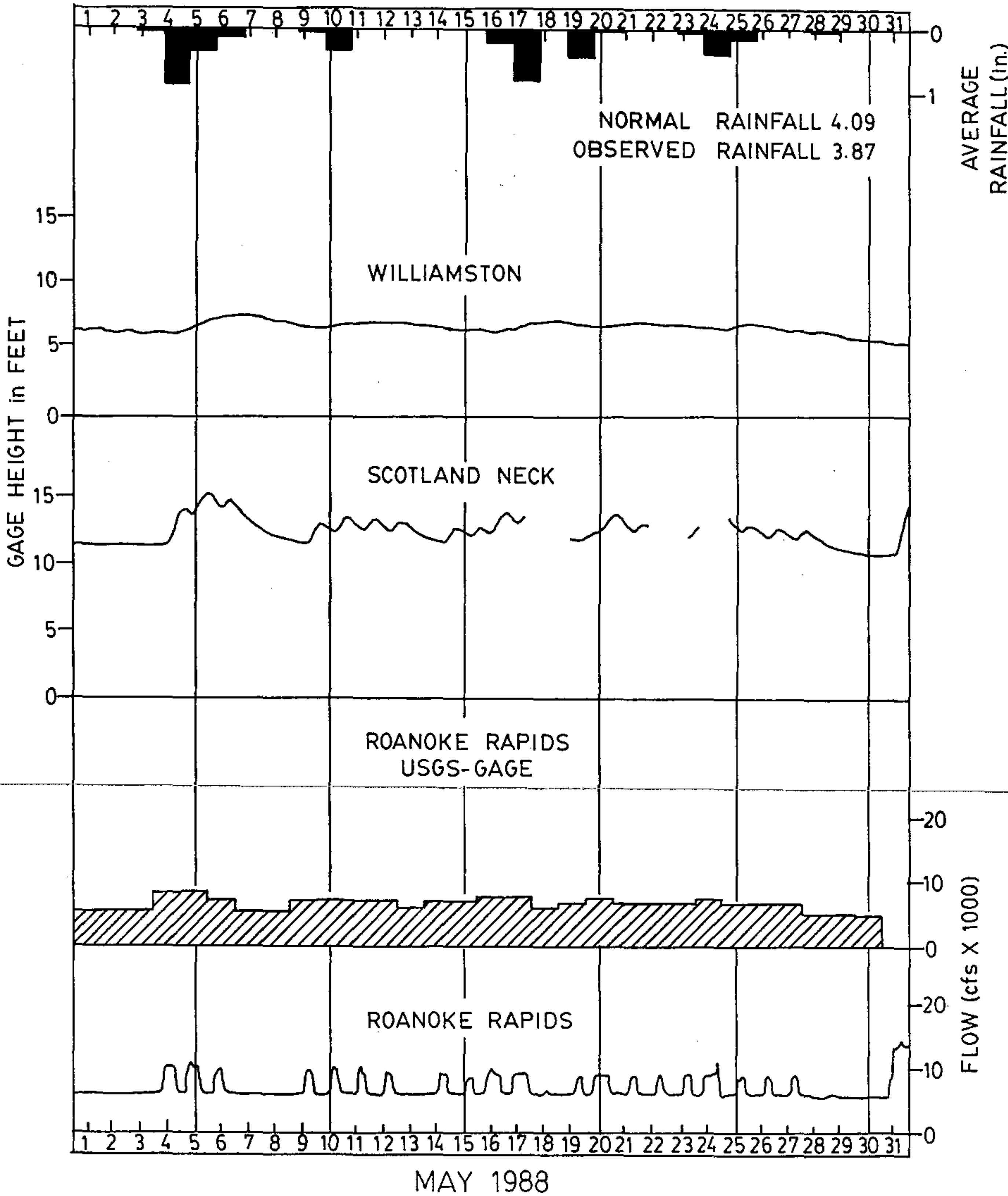

Figure 46. (Continued)

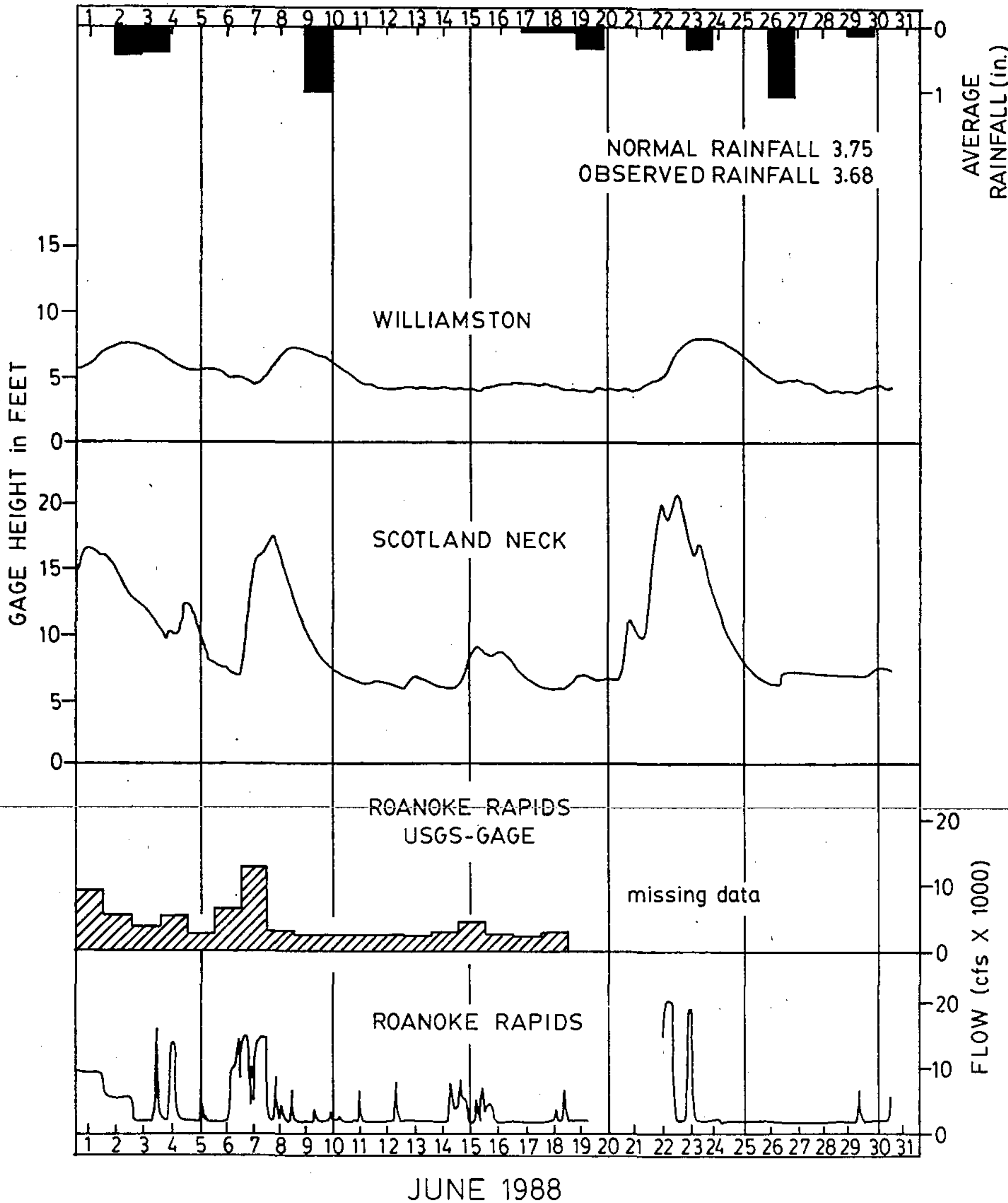

Figure 46. (Continued)

Water Quality

In 1988, water quality was monitored at several locations downstream of the Roanoke Rapids Dam. The work was a cooperative effort between East Carolina University and Weyerhaeuser Company and was funded, in part, from funds provided by the Company and by the Albemarle/Pamlico Estuarine Study. One sampling location was just downstream of the primary striped bass spawning area near Caledonia Prison, and four additional stations were located in the river delta near Plymouth. Samples for the various water quality measurements were taken using the standard methods established by the U.S. Environmental Protection Agency.

Water quality of the Roanoke mainstem, Middle, and Cashie rivers was generally good during the 1988 striped bass spawning period. While there were some changes in water quality between Scotland Neck and the lower Roanoke, there were no obvious diel variations in water quality at either area. This could be attributed to the moderation of hydropower releases at the Roanoke Rapids powerhouse during this period (Figure 46).

Many aspects of water quality were better than in previous years when similar measurements were recorded (e.g., Rulifson et al. 1986). Average pH ranged from 7.3 to 7.6. Alkalinities averaged about 26 mg/L as $CaCo_3$ except for the Cashie River, which averaged about 22 mg/L. The Roanoke and Cashie rivers had an average conductivity of about 100 umhos except at the Hwy 45 bridge; this portion of the river is below Weyerhaeuser's pulp mill and the Plymouth wastewater treatment discharge. Below the bridge, river conductivity rose to 125 uhmos. The color of water in the Roanoke delta was 50 color units, more than twice that recorded at Scotland Neck; this difference could be due to swamp land drainage or color from pulpmill discharge.

Increased values of turbidity and total suspended solids are often associated with storm events and the subsequent runoff and increased river flow. In 1988, however, both turbidity and total dissolved solid values were quite low. Turbidity at Scotland Neck averaged 12 ntu, and was 22 ntu in the Cashie River. Heavy metal concentrations and nutrient input were quite low for the April - June period (Table 24).

Striped Bass Resource

EGG VIABILITY AND PRODUCTION. Striped bass spawning activity was monitored by an egg sampling project conducted just below the spawning grounds near Scotland Neck. The work was performed by East Carolina University and funded by the Albemarle/Pamlico Estuarine Study. Eggs were collected every four hours for 60 days in the manner described by Hassler et al. (1981).

Preliminary results of the study suggest that the manner in which the dams are operated may directly affect egg viability. Rulifson and colleagues collected 41,719 striped bass eggs in 310 trips. Approximately 77 percent of the total were examined for egg viability. Total egg viability for 1988 was about 89 percent, the best value since 1972 (Table 12). This high viability corresponds with good water quality (described above) and moderate river flows. Total egg production for 1988 was 2,082,147,979 during the period 10 April to 2 June.

Table 24. Summary of mean lower Roanoke River water quality analyses, 15 April through 15 June 1988 (from Rulifson et al., in preparation).

Station	pH	Cond. umhos	Alknty. CaCo3 mg/L	Color APHA	Turb. ntu	TOC mg/L	SOC mg/L	TSS mg/L
RR @ Scotland Neck	7.6	101	27	22	12	5.6	3.3	13.82
Middle River	7.5	101	26	49	20	13.2	10.6	20.56
RR above Plymouth,NC	7.4	100	25	46	18	11.0	3.9	16.82
Cashie River	7.3	98	22	53	22	21.7	26.5	24.83
RR @ Hwy 45 Br.	7.4	125	26	57	17	7.4	8.1	15.54

Table 24. (Continued)

Station	VSS mg/L	BOD mg/L	TKN mg/L	NH3-N mg/L	NO2-N mg/L	NO2-NO3 mg/L	TPO4 mg/L	OPO4 mg/L	SO42-
RR @ Scotland Neck	2.54	1.3	0.33	0.062	0.006	0.146	0.15	0.05	10.5
Middle River	3.08	1.0	0.46	0.093	0.006	0.196	0.16	0.08	10.3
RR above Plymouth,NC	2.87	1.0	0.42	0.075	0.006	0.188	0.16	0.06	11.4
Cashie River	4.54	1.3	0.54	0.081	0.006	0.155	0.17	0.06	6.7
RR @ Hwy 45 Br.	3.13	1.3	0.63	0.146	0.007	0.176	0.18	0.09	14.4

Table 24. (Continued)

Station	Chl a ug/L	Ag ug/L	Al ug/L	B ug/L	Ba ug/L	Be ug/L	Bi ug/L	Ca ug/L	Cd ug/L
RR @ Scotland Neck	2.1	10	494	47	23	5	10	6689	5
Middle River		10	990	42	29	5	10	6616	5
RR above Plymouth,NC		10	689	45	27	5	10	6561	5
Cashie River		10	755	62	31	5	10	6417	5
RR @ Hwy 45 Br.		10	635	64	28	5	10	6877	5

Table 24. (Continued)

Station	Co ug/L	Cr ug/L	Cu ug/L	Fe ug/L	K ug/L	Li ug/L	Mg ug/L	Mn ug/L	Mo ug/L
RR @ Scotland Neck	10	5	10	644	2218	27	2788	50	10
Middle River	10	5	10	1386	2329	26	2777	95	10
RR above Plymouth, NC	10	5	10	1117	2286	26	2738	81	10
Cashie River	10	5	11	1510	2344	27	2642	119	10
RR @ Hwy 45 Br.	10	5	10	1072	2493	27	2797	85	10

Table 24. (Continued)

Station	Na ug/L	Ni ug/L	P ug/L	Pb ug/L	Sb ug/L	Sn ug/L	Sr ug/L	V ug/L	Zn ug/L	As ug/L	Se ug/L
RR @ Scotland Neck	8987	20	119	50	50	47	47	10	18	1	2
Middle River	9357	20	130	50	50	46	47	10	34	2	3
RR above Plymouth, NC	9429	20	117	51	51	46	47	10	17	1	2
Cashie River	9078	20	136	50	50	47	46	11	28	2	3
RR @ Hwy 45 Br.	13926	20	122	50	50	47	49	10	21	1	2

JUVENILE ABUNDANCE INDEX. Trawling for juvenile striped bass was conducted by NCDMF at all seven stations on eight different dates during 1988 resulting in the maximum number of 56 samples. The subsequent JAI was 4.09, which was the highest recorded since 1976 (Table 12). Monthly averages of young striped bass per tow for July (5.86 fish) and for October (5.43 fish) were particularly encouraging. Sampling the seven stations on 14 October yielded an average of 10.86 striped bass per tow, unquestionably the best daily index in many years. Also encouraging were the condition and growth of the fish, and the fact that additional sampling collected juvenile striped bass in the lower Pasquotank River and Currituck Sound, two areas where juveniles are rarely collected except in years of good abundance.

RECREATIONAL CATCH. Sport fishermen harvested an estimated 16,657 striped bass weighing a total of approximately 33,927 kilograms (74,796 pounds) from the Roanoke River during the spring of 1988 (Mullis 1989). An additional 8,898 striped bass were estimated to have been caught and released, presumably comprised of mostly sub-legal sized fish or those over the legal limit of three fish per angler. Most of the fish harvested (53 percent) were caught in the vicinity of the spawning grounds. Approximately six percent were caught in the area immediately below the traditional spawning area, and the remaining 41 percent were caught in the lower portion of the Roanoke River from Scotland Neck to the river mouth. Over 60 percent of the striped bass were harvested during the two-week period from 9 May through 22 May, a period which coincides with historical peak spawning activity (Hassler et al. 1981). Almost 30 percent of the striped bass were harvested during the month preceeding that period. Very few stripers were caught after the third week in May. The sport harvest of striped bass from the Roanoke River, as estimated by Dr. W.W. Hassler and his colleagues utilizing methods different from those used in 1988, has ranged from 65,399 fish in 1971 to a low of 3,131 fish in 1985. They estimated the sport harvest to be 6,663 fish in 1986 and over 10,000 fish in 1987 (Table 13).

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.

ACKNOWLEDGMENTS

The Committee is extremely grateful to those individuals who contributed to the preparation and completion of this document. Special thanks go to Sandy Bronson, John Cooper, Kay Evans, and Don Stanley of ECU's Institute for Coastal and Marine Resources, and to Herbert Gordy and Beverly Harvey of the National Marine Fisheries Service, Beaufort Laboratory.

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APPENDIX A

Listing of Fauna and Flora
of the Lower Roanoke Watershed

Appendix Table A-1. Scientific and common names for plant species of known or probable occurrence within Company Swamp, Bertie County, North Carolina (Laney et al. 1989).

Common Name	Scientific Name
American elm	*Ulmus americana*
American hornbeam	*Carpinus caroliniana*
Angle-pod	*Matelea suberosa*
Arrow arum	*Peltandra virginica*
Ash	*Fraxinus sp.*
Aster	*Family Compositae*
Baldcypress	*Taxodium distichum*
Barnyard grass	*Enchinochloa crus-galli*
Basswood	*Tilia sp.* possibly *floridana*?
Blackberry	*Rubus sp.*
Bladder sedge	*Carex intumescens*
Bluntleaf bedstraw	*Galium obtsum*
Box elder	*Acer negundo*
Bristlebract sedge	*Carex tribuloides*
broadleaf arrowhead	*Sagittaria latifolia*
Broomjute sida*	*Sida rhombifolia*
Carolina falsedandelion	*Pyrrhopappus carolinianus*
Catbrier	*Smilax bona-nox*
Cattail sedge	*Carex typhina*
Climbing dogbane	*Trachelospermum difforme*
Climbing hempweed	*Mikania scandens*
Cocklebur	*Xanthium strumarium*
Common greenbrier	*Smilax rotundifolia*
Common pokeberry	*Phytolacca americana*
Common ragweed	*Ambrosia artemisiifolia*
Common trumpetcreeper	*Campsis radicans*
Creeping burhead	*Echinodorus cordifolius*
Creeping cucumber	*Melothria pendula*
Dicliptera	*Dicliptera brachiata*
Dogfennel joepyeweed	*Eupatorium capillifolium*
Duckweeds	*Lemna sp.*
False nettle	*Boehmeria cylindrica*
Fowl mannagrass	*Glyceria striata* (flat grass)
Frog's-bit	*Limnobium spongia*
Gaping panicum	*Steinchisma hians*
Giant cane	*Arundinaria gigantea*
Grape	*Vitis sp.*
Grasses	*Family Poaceae*
Gray's sedge	*Carex grayi*
Green ash	*Fraxinus pennsylvanica*
Green hawthorne	*Crataegus prob. viridis*
Groundcherry	*Physalis sp.*
Hawthorn	*Crataegus sp.*
Horse nettle	*Solanum carolinense*

Appendix Table A-1 (Cont'd).

Common Name	Scientific Name
Indian heliotrope	*Heliotropium indicum*
Ironwood (See American hornbeam)	
Jump seed	*Polygonum virginianum*
Jungle rice	*Echinocloa colona*
Lambsquarters	*Chenopodium album*
Laurel oak	*Quercus laurifolia*
Lizard's tail	*Saururus cernuus*
Marsh dayflower	*Murdannia keisak*
Marsh mermaid weed	*Proserpinaca palustris*
Marsh purslane	*Ludwigia palustris*
Marsh yellow-cress	*Rorippa palustris*
Minute duckweed	*Lemna perpusilla*
Mistletoe	*Phoradendron flavescens*
Mosses	*Order Bryophyta*
Mustard	*Family Brassicaceae*
Nutgrass	*Cyperus rotundus*
Overcup oak	*Quercus lyrata*
Parrot's feather	*Myriophyllum brasiliense*
Paw-paw	*Asimina sp.*
Peppervine	*Ampelopsis arborea*
Persimmon	*Diospyros virginiana*
Pinkweed	*Polygonum pensylvanicum*
Poison ivy	*Toxicodendron radicans*
Primrose willows*	*Ludwigia decurrans*
Purple mecardonia	*Mecardonia acuminata*
Rattan-vine	*Berchemia scandens*
Red maple	*Acer rubrum*
Red mulberry	*Morus rubra*
River birch	*Betula nigra*
Sedge	*Cyperus sp.* or *Carex sp.*
Sharp-winged monkey-flower*	*Mimulus alatus*
Silver maple	*Acer saccharinum*
Small beggarticks	*Bidens discoidea*
Small-flowered thoroughwort	*Eupatorium semiserratum*
Small white morning-glory	*Ipomea lacunosa*
Smartweed	*Polygonum sp.*
Spotted touch-me-not	*Impatiens capensis*
Stinkweed	*Pluchea camphorata*
St. Johnswort	*Hypericum sp.*
Subcordate waterplantain	*Alisma subcordatum*
Sugarberry	*Celtis laevigata*
Swamp cottonwood	*Populus heterophylla*
Swamp rosemallow	*Hibiscus moscheutos*
Sweet gum	*Liquidambar styraciflua*
Swollen duckweed	*Lemna gibba*

Appendix Table A-1 (Cont'd).

Common Name	Scientific Name
Sycamore	*Platanus occidentalis*
Three-seeded mercury	*Acalypha rhomboidea*
Violet	*Viola sp.*
Virginia bugleweed	*Lycopos sp.* probably *virginicus*
Virginia buttonweed	*Diodia virginiana*
Virginia creeper	*Parthenocissus quinquefolia*
Virginia dayflower	*Commelina virginia*
Water hickory	*Carya aquatica*
Watermeal	*Wolffia papulifera*
Water oak	*Quercus nigra*
Water tupelo gum	*Nyssa aquatica*
Whorled penneywort	*Hydrocotyle verticillata*
Willow	*Salix sp.* probably *nigra* or *caroliniana*
Willow oak	*Quercus phellos*
Winged elm	*Ulmus alata*
Winterberry	*Ilex verticillata*
Woolgrass	*Scirpus cyperinus*
Yerba de tajo	*Ecilpta alba*

Appendix Table A-2. Scientific and common names for mammals of known or probable occurrence within Company Swamp, Bertie County, North Carolina (Laney et al. 1989).

Common Name	Scientific Name
Beaver	*Castor canadensis*
Black Bear	*Ursus americana*
Bobcat	*Lynx rufus*
Carolina short-tailed shrew	*Blarina carolinensis*
Cotton mouse	*Peromyscus gossypinus*
Eastern cottontail	*Sylvilagus floridanus*
Eastern mole	*Scalopus aquaticus*
Eastern pipistrelle	*Pipistrellus subflavus*
Evening bat	*Nycticeius numeralis*
Golden mouse	*Ochrotomys nuttalli*
Gray fox	*Urocyon cinereoargenteus*
Gray squirrel	*Sciurus carolinensis*
Hispid cotton rat	*Sigmodon hispidus*
Hoary bat	*Lasiurus cinereus*
House mouse	*Mus musculus*
Long-tailed weasel	*Mustela frenata*
Marsh rabbit	*Sylvilagus palustris*
Meadow vole	*Microtus pennsylvanicus*
Mink	*Mustela vison*
Muskrat	*Ondatra zibethica*
Norway rat	*Rattus norvegicus*
Opossum	*Didelphis virginiana*
Raccoon	*Procyon lotor*
Red bat	*Lasiurus borealis*
Rice bat	*Oryzomys palustris*
River otter	*Lutra canadensis*
Short-tailed shrew	*Blarina brevicauda*
Silver-haired bat	*Lasionycteris noctivagans*
Southeastern shrew	*Sorex longirostris*
Southern flying squirrel	*Glaucomys volans*
White-footed mouse	*Peromyscus leucopus*
White-tailed deer	*Odocoileus virginianus*
Woodchuck	*Marmota monax*

Appendix Table A-3. Scientific and common names for birds (Aves) of known or probable occurrence within Company Swamp, Bertie County, North Carolina (Laney et al. 1989).

Common Name	Scientific Name
Acadian flycatcher	*Empidonax virescens*
American goldfinch	*Carduelis tristis*
American redstart	*Setophaga ruticilla*
American robin	*Turdus migratorius*
American wigeon	*Anas americana*
American woodcock	*Scolopax minor*
Anhinga (water turkey)	*Anhinga anhinga*
Barn swallow	*Hirundo rustica*
Barred owl	*Strix varia*
Belted kingfisher	*Megaceryle alcyon*
Black duck	*Anas rubripes*
Black vulture	*Coragyps atratus*
Blue grosbeak	*Guiraca caerulea*
Blue jay	*Cyanocitta cristata*
Blue-gray gnatcatcher	*Polioptila caerulea*
Blue-winged teal	*Anas discors*
Bobwhite	*Colinus virginianus*
Brown creeper	*Certhia familiaris*
Brown Thrasher	*Toxostoma rufum*
Brown-headed cowbird	*Molothrus ater*
Cardinal	*Cardinalis cardinalis*
Carolina chickadee	*Parus carolinensis*
Carolina wren	*Thryothorus ludovicianus*
Cerulean warbler	*Dendroica cerulea*
Chimney swift	*Chaetura pelagica*
Chuck-will's-widow	*Caprimulgus carolinensis*
Common crow	*Corvus brachyrhynchos*
Common flicker	*Colaptes auratus*
Common grackle	*Quiscalus quiseula*
Cooper's hawk	*Accipter cooperii*
Dark-eyed junco	*Junco hyemalis*
Downy woodpecker	*Picoides pubescens*
Eastern kingbird	*Tyrannus tyrannus*
Eastern phoebe	*Sayornis phoebe*
Eastern wood pewee	*Contopus virens*
Fish crow	*Corvus ossifragus*
Gadwall	*Anas strepera*
Golden-crowned kingled	*Regulus satrapa*
Great blue heron	*Ardea herodias*
Great crested flycatcher	*Myiarchus crinitus*
Great egret	*Casmerodius albus*
Great horned owl	*Bubo virginianus*
Green heron	*Butorides striatus*
Green-winged teal	*Anas crecca*

Appendix Table A-3 (Cont'd).

Common Name	Scientific Name
Hairy woodpecker	*Picoides villosus*
Hermit thrush	*Catharus guttatus*
Hooded merganser	*Lophodytes cacullatus*
Hooded warbler	*Wilsonia citrina*
Indigo bunting	*Passerina cyanea*
Kentucky warbler	*Oporornis formosus*
Mallard	*Anas platyrhynchos*
Mockingbird	*Mimus polyglottos*
Mourning dove	*Zenaida macroura*
Orchard oriole	*Icterus spurius*
Osprey	*Pandion haliaetus*
Parula warbler	*Parula americana*
Pileated woodpecker	*Dryocopus pileatus*
Pintail	*Anas acuta*
Prothonotary warbler	*Protonotaria citrea*
Red-bellied woodpecker	*Melanerpes carolinus*
Red-eyed vireo	*Vireo olivaceus*
Red-shouldered hawk	*Buteo lineatus*
Red-tailed hawk	*Buteo jamaicensis*
Ring-billed gull	*Larus delawarensis*
Ring-necked duck	*Aythya collaris*
Ruby-crowned kinglet	*Regulus calendula*
Ruby-throated hummingbird	*Archilochus colubris*
Rufous-sided towhee	*Pipilo erythrophthalmus*
Screech owl	*Otus asio*
Sharp-shinned hawk	*Accipter striatus*
Song sparrow	*Melospiza melodia*
Spotted sandpiper	*Actitis macucaria*
Starling	*Sturnus vulgaris*
Summer tanager	*Piranga rubra*
Swamp sparrow	*Molospiza georgiana*
Tufted titmouse	*Parus bicolor*
Turkey vulture	*Cathartes aura*
Whip-poor-will	*Caprimulgus vociferus*
White-breasted nuthatch	*Sitta carolinensis*
White-eyed vireo	*Vireo griseus*
White-throated sparrow	*Zonotrichia albicollis*
Wild turkey	*Meleagris gallopavo*
Winter wren	*Troglodytes troglodytes*
Wood duck	*Aix sponsa*
Wood thrush	*Hylocichla mustelina*
Yellow-bellied sapsucker	*Sphyrapicus varius*
Yellow-billed cuckoo	*Coccyeus americanus*
Yellow-rumped warbler	*Dendroica coronata*
Yellow-throated vireo	*Vireo flavifrons*
Yellow-throated warbler	*Dendroica dominica*

Appendix Table A-4. Scientific and common names for reptiles of known or probable occurrence within Company Swamp, Bertie County, North Carolina (Laney et al. 1989).

COMMON NAME	SCIENTIFIC NAME
Banded water snake	*Nerodia fasciata*
Black racer	*Coluber constrictor*
Broadhead skink	*Eumeces laticeps*
Brown snake	*Storeria dekayi*
Brown water snake	*Nerodia taxispilota*
Carolina anole	*Anolis carolinensis*
Copperhead	*Agkistrodon contortrix*
Cottonmouth	*Agkistrodon piscivorus*
Eastern box turtle	*Terrapene carolina*
Eastern fence lizard	*Sceloporus undulatus*
Eastern garter snake	*Thamnophis sirtalis*
Eastern glass lizard	*Ophisaurus ventralis*
Eastern hognose snake	*Heterodon platyrhinos*
Eastern kingsnake	*Lampropeltis getulus*
Eastern mud turtle	*Kinosternum subrubrum*
Eastern musk turtle	*Sternotherus oboratus*
Eastern ribbon snake	*Thamnophis sauritus*
Five-lined skink	*Eumeces fasciatus*
Florida cooter	*Chrysemys floridana*
Ground skink	*Scincella lateralis*
Mud snake	*Farancia abacura*
Northern water snake	*Nerodia sipeodon*
Painted turtle	*Chrysemys picta*
Rat snake	*Elaphe obsoleta*
Redbelly snake	*Storeria occipitomaculata*
Redbelly water snake	*Nerodia erythrogaster*
Ringneck snake	*Diadophis punctatus*
River cooter	*Chrysemys concinna*
Rough earth snake	*Virginia striatula*
Rough green snake	*Opheodrys aestivus*
Slender glass lizard	*Ophisaurus atlenuatus*
Snapping turtle	*Chelydra serpentina*
Southeastern five-lined skink	*Eumeces inexpectatus*
Spotted turtle	*Clemmys guttata*
Timber (canebrake) rattlesnake	*Crotalus horridus*
Worm snake	*Carphophis amoenus*
Yellowbelly slider	*Chrysemys scripta*

Appendix Table A-5. Scientific and common names for amphibians of known or probable occurrence within Company Swamp, Bertie County, North Carolina (Laney et al. 1989).

Common Name	Scientific Name
American toad	*Bufo americanus*
Barking treefrog	*Hyla gratiosa*
Brimley's chorus frog	*Pseudacris brimleyi*
Bullfrog	*Rana catesbeiana*
Carpenter frog	*Rana virgatipes*
Dwarf mudpuppy	*Necturus punctatus*
Dwarf salamander	*Eurycea quadridigitata*
Eastern narrowmouth toad	*Gastrophryne carolinensis*
Eastern newt	*Notophthalmus viridescens*
Eastern spadefoot toad	*Scaphoplis holbrooki*
Fowler's toad	*Bufo woodhousii*
Gray treefrog	*Hyla versicolor*
Gray treefrog	*Hyla chrysoscelis*
Greater siren	*Siren lacertina*
Green frog	*Rana clamitans*
Green treefrog	*Hyla cinerea*
Lesser siren	*Siren intermedia*
Little grass frog	*Limnaoedus ocularis*
Mabee's salamander	*Ambystoma mabeei*
Many-lined salamander	*Stereochilus marginatus*
Marbled salamander	*Ambystoma opacum*
Mud salamander	*Pseudotriton montanus*
Northern cricket frog	*Acris crepitans*
Oak toad	*Bufo quercicus*
Pickerel frog	*Rana palustris*
Pine woods treefrog	*Hyla femoralis*
Redback salamander	*Plethodon cinereus*
Slimy salamander	*Plethodon glutinosus*
Southern cricket frog	*Acris gryllus*
Southern dusky salamander	*Desmognathus auriculatus*
Southern leopard frog	*Rana sphenocephala*
Southern toad	*Bufo terrestris*
Spotted salamander	*Ambystoma maculatum*
Spring peeper	*Hyla crucifer*
Squirrel treefrog	*Hyla squirella*
Three-lined salamander	*Eurycea guttolineata*
Tiger salamander	*Ambystoma tigrinum*
Two-lined salamander	*Eurycea bislineata*
Two-toed amphiuma	*Amphiuma means*
Upland chorus frog	*Pseudacris triseriata*

Appendix Table A-6. Scientific and common names for fish of known or probable occurrence in the Roanoke River and Coniot Creek in the vicinity of Company Swamp, Bertie County, North Carolina (Laney et al. 1989).

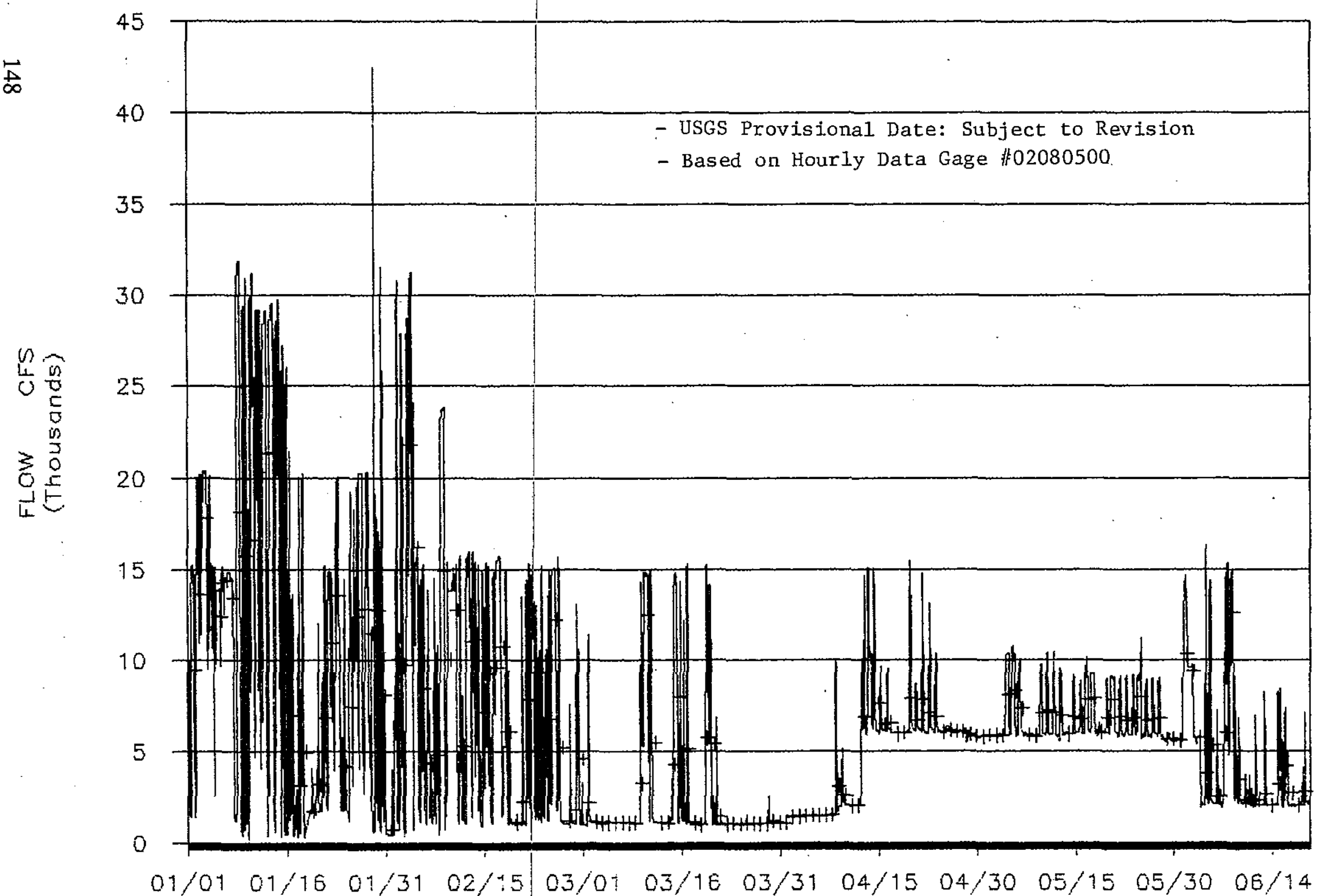
Family	Common Name	Scientific Name
Acipenseridae	Atlantic sturgeon	*Acipenser oxyrhynchus*
	Shortnose sturgeon	*Acipenser brevirostrum*
Lepisosteidae	Longnose gar	*Lepiosteus osseus*
Amiidae	Bowfin	*Amia calva*
Anguillidae	American eel	*Anguilla rostrata*
Clupeidae	Alewife	*Alosa pseudoharengus*
	American shad	*Alosa sapidissima*
	Atlantic menhaden	*Brevoortia tyrannus*
	Blueback herring	*Alosa aestivalis*
	Gizzard shad	*Dorosoma cepedianum*
	Hickory shad	*Alosa mediocris*
Umbridae	Eastern mudminnow	*Umbra pygmaea*
Esocidae	Chain pickerel	*Exos niger*
	Redfin pickerel	*Esox americanus*
Cyprinidae	Bluehead chub	*Nocomis leptocephalus*
	Carp	*Cyprinus carpio*
	Creek chub	*Semotilus atromaculatus*
	Golden shiner	*Notemigonus crysoleucas*
	Ironcolor shiner	*Notropis chalybeaus*
	Satinfin shiner	*Notropis analostanus*
	Silvery minnow	*Hybognathus regius*
	Spottail shiner	*Notropis hudsonius*
	Swallowtail shiner	*Notropis procne*
	White shiner	*Notropis albeolus*
Catostomidae	Creek chubsucker	*Erimyzon oblongus*
	Shorthead redhorse	*Moxostoma macrolepidotum*
	Silver redhorse	*Moxostoma anisurum*
	Suckermouth redhorse	*Moxostoma papallosum*
Ictaluridae	Brown bullhead	*Ictalurus nebulosus*
	Channel catfish	*Ictalurus punctatus*
	Margined madtom	*Noturus insignis*
	Tadpole madtom	*Noturus gyrinus*
	White catfish	*Ictalurus catus*
	Yellow bullhead	*Ictalurus natalis*

Appendix Table A-6 (Cont'd).

Family	Common Name	Scientific Name
Amblyopsidae	Swampfish	*Chologaster cornuta*
Aphredoderidae	Pirate perch	*Aphredoderus sayanus*
Cyprinodontidae	Lined topminnow	*Fundulus lineolatus*
Poeciliidae	Mosquitofish	*Gambusia affinis*
Percichthyidae	Striped bass	*Morone saxatilis*
	White perch	*Morone americana*
Centrarchidae	Banded sunfish	*Enneacanthus obesus*
	Black crappie	*Pomoxis nigromaculatus*
	Blackbanded sunfish	*Enneacanthus chaetodon*
	Bluegill	*Lepomis macrochirus*
	Bluespotted sunfish	*Enneacanthus gloriosus*
	Flier	*Centrarchus macropterus*
	Green sunfish	*Lepomis cyanellus*
	Largemouth bass	*Micropterus salmoides*
	Mud sunfish	*Acantharchus pomotis*
	Pumpkinseed	*Lepomis gibbosus*
	Redbreast sunfish	*Lepomis auritus*
	Warmouth	*Lepomis gulosus*
	White crappie	*Pomoxis annularis*
Elassomatidae	Banded pygmy sunfish	*Elassoma zonatum*
Percidae	Glassy darter	*Etheostoma vitreum*
	Johnny darter	*Etheostoma nigrum*
	Sawcheek darter	*Etheostoma seriferum*
	Swamp darter	*Etheostoma fusiforme*
	Tessellated darter	*Etheostoma olmstedi*
	Yellow perch	*Perca flavescens*

APPENDIX B

Listing of Data Bases Gathered
for This Report



Appendix Figure B-1. Roanoke River flow (cfs) below Roanoke Rapids dam recorded hourly for the period 1 January to 15 June 1988, showing effects of hydropower operation.

Appendix Table B-1. Summary of water surface profiles for the lower Roanoke River, North Carolina from the Wilmington District, Army Corps of Engineers water surface model HEC2.

Cross-section location	River flow (cfs)	Channel Depth (ft.)	Computed water surface (ft msl)	Computed water surface width (ft.)	Total area (acres)	Channel velocity (ft/s)	Total energy (ft.)
Bachelor Bay	5000	29.0	1.0	22000	0	0.05	1
	15000	29.0	1.0	22000	0	0.15	1
	25000	29.0	1.0	22000	0	0.25	1
	35000	29.0	1.0	22000	0	0.35	1
Plymouth	5000	27.6	1.0	20500	13300	0.24	1.01
	15000	27.7	1.1	20500	13300	0.73	1.07
	25000	27.8	1.2	20500	13400	1.2	1.18
	35000	27.9	1.3	20500	13400	1.66	1.35
US Hwy 17	5000	30.3	2.1	357	30300	0.95	2.11
	15000	34.7	6.5	2610	48700	2.27	6.56
	25000	36.4	8.2	3750	55100	3.28	8.39
	35000	37.5	9.3	4140	57800	4.16	9.52
NC Hwy 11	5000	24.6	9.6	423	31200	0.78	9.6
	15000	33.3	18.3	5570	72900	1.35	18.36
	25000	35.6	20.5	10500	85400	1.75	20.59
	35000	37.0	22.0	13500	91400	1.99	22
US Hwy 258	5000	20.2	20.3	297	32300	1.22	20.35
	15000	30.7	30.8	689	89600	2.02	30.84
	25000	33.8	33.9	6390	115700	2.8	34.06
	35000	35.9	36.0	8380	131800	3.43	36.21
Near Halifax	5000	13.7	25.9	328	33000	1.47	25.9
	15000	24.8	37.0	426	93800	1.96	37.09
	25000	29.7	41.9	720	126300	2.56	42.04
	35000	33.0	45.2	4840	145000	3.07	45.29
Roanoke Rapids railroad bridge	5000	15.3	28.8	504	33400	0.97	28.84
	15000	26.3	39.8	646	94300	1.37	39.78
	25000	31.9	45.4	795	127500	1.7	45.44
	35000	35.8	49.3	1020	148000	1.96	49.34

Appendix Table B-2. Discharge (cfs) of the Roanoke River at Roanoke Rapids, NC for the period 1912-1987 as measured by the USGS gage.

Month = March

Da	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
1	22100	14200	11900	11900	6870	15900	6240	10900	6620	9500	11500	22000	12100	6900	11000	9040	6120	69000	5480
2	13600	21400	12500	9960	8130	31500	5500	19900	5870	9000	17800	19200	11600	6900	8590	8590	6120	61300	5290
3	10700	13000	10400	9060	9020	31500	4430	29000	5500	9000	36500	14100	10500	6500	8150	8150	5740	54200	5100
4	9500	9060	9060	8210	9960	59600	4430	27400	4430	8000	55300	11000	9040	6500	7300	7720	5380	24700	4920
5	8420	8210	8210	8210	7700	64300	5500	17200	5500	8000	69400	8500	8150	6120	6900	9040	5030	35400	5100
6	9060	6620	8210	8210	9020	77100	7010	16600	7400	8000	54200	7540	7720	7300	6500	12100	5030	58900	5100
7	8840	5500	9060	15900	7700	77100	7010	21400	16600	7080	34700	10500	8590	8590	6120	16800	5380	51000	5100
8	11900	5320	11400	13600	6870	64300	7400	15900	10400	6660	32200	31300	9520	8150	6120	15600	5030	39000	5480
9	21400	4780	9060	17900	6470	22800	10400	11400	9060	7080	23500	40200	9040	6900	7300	13200	5380	20600	15200
10	22800	4430	8210	15300	5700	14200	9960	30700	8210	8000	25000	24200	8150	6500	8150	12100	7300	13200	31300
11	20600	4080	8210	12500	4630	10900	9500	47300	7400	10500	42100	14700	9040	6500	7300	12700	7720	10500	16600
12	15600	6620	9500	10900	6470	10400	8210	29000	6620	8500	48100	12000	13200	6500	8150	11000	8150	9520	10300
13	20200	6620	11900	9500	6080	7280	7010	22800	7010	8000	34700	15300	18000	6120	9520	9040	8150	8590	8880
14	29500	7400	14700	9060	4290	9020	6240	11900	16600	8000	22000	28100	15600	6120	9520	8150	7300	8150	8200
15	41600	57800	16600	8630	5340	9020	5870	9960	22800	8500	15300	25800	12100	5740	9520	7300	6900	9520	7320
16	96200	76900	15900	7800	5700	8570	5500	9500	15300	11500	16600	22800	10000	5380	9040	7720	6500	15600	6680
17	123000	112000	13600	8630	5340	8130	5140	8210	11400	10000	23500	52300	8590	6500	8590	6900	9520	17400	6070
18	151000	76600	11400	9960	4630	29800	6240	7400	10400	9000	22000	68200	7720	9040	7720	6500	17800	14400	6270
19	96200	22800	11900	8210	5340	31500	5500	7010	7400	8000	17200	88700	7300	10500	6900	6120	28300	11600	6480
20	21800	13600	12500	9060	4630	23600	5140	8630	28200	7080	12500	101000	6900	10500	6500	6120	22100	9520	7530
21	14000	11400	13000	7400	4290	15300	4780	7800	25100	6660	12500	52300	11600	10500	6120	5740	16800	8590	7320
22	11900	10400	11900	8210	4630	11900	4430	7400	22800	6280	15300	23800	18000	10500	5740	6900	12100	8150	6680
23	10900	9960	11900	6620	5340	10900	7010	7400	17200	6660	12000	17800	18000	8150	5740	7720	9040	8590	6270
24	11700	9060	12500	7800	5340	11400	9060	7010	9500	6280	10000	15300	13800	7300	5740	8590	8150	15600	5680
25	25900	8210	13000	7400	5700	39700	7400	6620	8630	8500	8500	17200	11000	6900	5380	6900	7720	19300	5680
26	45400	7400	10900	6620	4290	34200	9960	6240	7800	12500	8000	14700	9520	6500	5380	5740	7300	20600	5680
27	49300	7800	9960	4780	3310	25100	9060	5500	7400	10500	7540	12000	8590	6120	6120	5380	6500	14400	5680
28	25100	9060	9060	6620	3160	20600	9060	7010	7010	9000	7540	10500	8150	6120	6500	4690	6500	11000	5680
29	17500	13000	8210	4780	6470	14200	8210	9960	9500	8000	9000	9520	9040	7300	5740	4690	6500	9520	5480
30	45400	16600	8210	4080	9020	10900	7010	10900	8630	7080	14700	8590	15600	7720	5030	4690	6120	8590	5290
31	58600	10900	8210	6620	7700	9960	6620	9060	9960	6660	14100	8150	22100	7300	5740	4690	6120	8590	4920

Da	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
1	3070	4260	7850	11400	11600	9500	9610	7350	29700	8430	5000	3800	6420	13700	11700	9010	5470	9000	10200	6500
2	3550	4050	7250	9090	10500	9500	9610	7050	39800	7200	4880	3700	6040	18100	10900	8670	5470	9000	10600	6000
3	5300	4050	6950	8450	8520	9000	10700	6900	41400	7200	4880	4000	6040	16500	9820	8340	5710	11000	9850	5880
4	5560	3850	6810	20900	7570	9000	10700	7800	26300	7500	4530	5770	6040	11700	9460	8020	5710	14000	8900	5750
5	5050	3850	6530	46900	7420	8500	9950	9450	18700	12900	4420	7900	5920	9460	14500	7440	5950	13000	8300	5500
6	4260	10200	6110	58200	7120	8500	9610	9800	15400	12900	4420	6800	6440	10200	15700	7720	5950	11300	8300	5380
7	3750	61700	6250	58800	7270	8500	8940	9450	15400	10900	4760	7070	19300	14600	16900	7440	7540	10200	8000	5250
8	3650	64700	6530	25600	8740	8000	8620	9800	21300	8760	7240	7340	29800	35300	17300	7440	9460	20200	7550	5500
9	3650	66300	6530	13500	9500	8000	8620	9100	18300	7500	13700	11500	24500	39200	13700	9010	10900	23800	7550	5500
10	4470	37500	8450	11100	9170	7990	8940	9100	14100	6900	14100	21400	15300	23500	10900	10800	11300	25600	7400	5620
11	5050	13400	9090	10700	8200	10400	8620	17900	12100	6500	12500	26500	10500	14100	9460	11200	12500	21000	7700	5880
12	4700	11100	7250	9730	7650	15400	7990	20000	13700	6000	10900	18400	8820	10500	8780	9710	14900	15700	8300	5500
13	4150	9410	6530	8450	15200	15000	7390	17500	16200	5630	10200	10900	8200	18000	8140	8670	16900	12500	8300	5380
14	3750	8150	6110	7100	37400	15400	7100	12900	20400	5630	10200	8200	8200	32100	7840	7720	21000	10500	8000	5750
15	3550	7550	6110	6670	49800	13400	7390	10500	18700	8100	9100	7070	8500	31700	7260	7720	27100	9460	7100	9200
16	3350	7400	9440	6110	39300	10700	8620	10200	22100	12500	7800	6400	8200	19300	7260	7720	29200	8460	6950	10200
17	3350	6810	10000	5560	18300	10900	9950	10200	32400	12500	7050	5750	8200	14100	6980	9350	22800	8780	6650	8600
18	3350	5970	9410	5180	12500	44300	9950	9800	24000	10200	6460	5500	8500	10900	6720	12300	16100	16500	6650	7400
19	3450	5970	10700	4700	10900	70200	9270	10900	16600	7800	5760	5120	11300	9460	6720	10800	12100	18100	8000	7700
20	3450	5830	17300	5660	9840	90000	8940	11700	12900	7050	5760	4880	15300	11700	6720	11200	9820	12900	8600	8000
21	3260	5830	20400	18100	9500	100000	8620	9450	10900	6460	5250	4760	21600	20900	6720	15900	8780	10500	8600	7700
22	3350	6530	22700	21300	9500	50000	8300	8430	10200	5900	5380	4530	30300	26100	6460	15100	8140	9820	8000	9500
23	5990	7000	25100	18200	9840	26000	7690	7800	9450	5630	5000	4880	26000	27600	6460	12300	7540	10500	8300	19800
24	10400	12000	16900	12900	9530	21800	7690	7200	9100	5380	5120	5000	23000	26600	6460	10400	6980	10200	19900	25500
25	13200	15000	12200	10400	13500	17100	7690	6900	8430	5120	7260	5120	19800	26600	6220	9710	6460	16500	36000	19500
26	12200	10000	10400	12600	24300	15400	8620	6900	7800	5000	8430	4640	15300	22000	5980	8670	6460	19700	39500	14500
27	9410	8000	9410	15200	33800	15400	8300	7200	7500	5120	7200	4200	13300	16100	5620	8670	6200	16100	22200	12600
28	7100	10000	9090	21500	42600	20400	7990	7200	7500	5250	6750	4200	13700	13700	5620	8340	6330	16100	17000	9200
29	6950	20000	8450	39100	31000	29100	6960	7350	7500	5250	7800	5880	16600	13300	5980	7720	6590	24600	13800	8600
30	10900	27500	7850	46400	18400	30100	6670	6750	8430	5120	8110	7900	15700	25000	7540	7720	7260	22000	12300	8000
31	18600	17000	7400	34800	15400	23500	6260	6600	18300	5500	8430	7900	12900	39800	6980	8020	7540	15300	12000	7700

Appendix Table B-2. (Continued)

Month = March

Da	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
1	6500	10600	2710	1130	5480	5820	19000	19500	689	24500	19400	18500	6610	1210	6580	10400	8470	6590	2530	3150
2	6500	15800	1710	10100	8370	5260	20000	15100	6720	24500	19400	18500	1010	8920	7000	14200	7990	1200	2250	10400
3	6380	16600	6780	10600	8540	2380	17200	16300	4130	24500	19400	17200	956	9570	7150	14200	2310	1110	10400	8980
4	6380	24000	7390	10200	9580	588	13000	19500	1770	24000	14300	4090	5660	9990	8010	14300	2410	4200	5630	8530
5	6250	30600	8040	9910	10800	5630	19000	19500	2980	24000	1560	13700	11100	8870	9550	14200	1010	3540	9240	5140
6	6120	30600	7110	9210	8440	4380	14600	19500	5780	24000	12300	18500	13400	8030	13800	14200	8150	5090	1580	5710
7	6250	30600	8290	4340	22200	5060	17900	19100	1340	24000	18300	18000	19300	2050	13700	14200	7940	4660	3330	1400
8	6650	25000	9020	2500	23100	6190	16700	5260	697	24000	15000	16600	19300	1110	13600	14200	9130	5000	7110	1060
9	6950	16600	6380	3410	17000	6320	9400	2050	3850	24000	19000	18500	19300	7990	13700	14300	4110	1180	2060	8120
10	6950	10900	9260	3430	14600	3630	1780	13200	6090	22200	18500	18500	19200	8840	13700	14200	6230	1010	11800	2210
11	6650	9500	9460	3330	16400	588	4510	13800	8270	19000	13500	8740	19300	9130	15000	14200	1320	1630	12500	4150
12	6250	15000	10000	3240	14000	4090	7630	17400	8960	18800	2850	11400	19400	6680	16800	14200	1110	6250	12900	7450
13	5880	24500	10600	3400	4370	3850	8440	13700	7650	5500	13100	16500	19400	4040	8450	14200	8070	6730	6790	5950
14	7400	31200	10300	2440	1690	4200	8610	13000	1360	10500	18000	15100	19400	2090	1130	13500	6610	6220	2550	1250
15	17000	27600	10300	6640	15400	6540	8360	1470	746	13600	18600	18500	19300	1170	11000	14200	5120	4280	3010	1150
16	24000	19500	7860	16000	14700	7300	2820	713	4710	14000	17000	18500	19400	6220	11600	14200	5580	1620	1240	9450
17	21000	13000	10600	15200	15200	4660	1100	5550	2100	17100	17700	18500	19400	5720	12600	14200	9390	4730	5120	5090
18	13000	10600	12100	15300	16000	5120	5680	5800	3350	18500	6510	18500	19400	5860	13500	10500	9340	9810	9090	3470
19	10900	10200	10200	15300	12900	5470	8210	10600	5040	19000	1170	18500	19400	4920	11500	4790	1630	10400	5020	4440
20	12000	10200	9900	13200	6670	5250	7340	4940	8220	14600	6760	18500	19400	4590	6010	1970	5540	10600	1940	5830
21	19000	15000	9790	6220	5280	5400	6990	5000	602	18500	6790	18500	19400	2550	1380	6200	1080	10600	1310	1360
22	19000	18000	10600	5500	8170	5900	6980	1140	633	18500	12700	18500	19400	1090	12700	6090	4490	10600	1190	1440
23	15800	14600	6400	5190	12500	5110	1440	753	3870	19000	12300	18500	19400	3900	14100	8090	4570	10500	1200	7140
24	13800	13400	13800	6290	12000	609	1180	7770	3890	17100	12900	18500	19400	3340	14100	4430	3530	8310	1890	6650
25	11600	25000	22800	6530	12000	625	6380	11600	2990	18500	15800	11700	19400	3160	14100	3440	3020	10400	7120	1910
26	9500	31800	28600	7420	12000	3910	7390	18700	2910	19000	14400	13400	19500	4240	13900	1150	1070	10500	11200	1260
27	8600	35400	28200	7630	7500	15900	9100	19500	1840	19000	13100	16200	19400	6200	12600	1110	1310	10100	2170	1030
28	8000	35900	27400	7280	8380	14900	10600	19500	998	19000	18600	18500	19300	2590	18400	2110	2970	9810	5320	1040
29	7550	32500	26400	5980	12300	13600	8300	19000	665	17000	16300	18500	19400	1090	18200	3960	5790	8700	1250	1040
30	7400	27000	18200	7760	13200	5250	1800	11500	6440	18200	16300	16000	19400	6980	13900	8240	7850	1270	1180	6250
31	7250	20500	13900	7530	9750	2180	2180	19000	5530	19000	14700	1080	19300	6600	14600	6670	2520	1210	4530	4660

Da	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	9950	13500	8010	5330	5330	11800	3500	11500	25600	10000	1130	15500	18000	20000	9880	1080	19300
2	13200	13900	5200	2300	2300	3300	1560	14100	25200	13900	4230	15500	18100	20000	4490	1040	19700
3	14400	14200	5660	8550	13200	9380	2180	15100	25700	13800	2750	14000	18100	20000	5960	7290	20300
4	19600	8200	1050	10200	15000	3860	1290	15100	25600	9910	1550	15700	18100	20000	12000	5730	20200
5	18900	4470	10200	11300	7450	2090	1170	13600	25700	9150	2770	15600	11600	20000	13100	9670	20400
6	12100	10100	12900	13200	9900	1230	1200	18700	25600	9420	2970	9070	9380	20100	14300	10300	22400
7	12700	9710	14100	6300	7730	1200	11400	8180	25600	3620	2180	6720	15300	20100	6680	9420	25200
8	19400	7680	13000	2320	6320	1710	5490	13100	25700	1130	1150	13100	18200	20000	2490	11800	25000
9	19200	10200	10100	10400	6600	11500	2540	12000	25700	1120	2270	14000	18100	20000	4020	2050	25200
10	15600	10900	12100	1500	12500	8930	2970	12500	25700	9900	2250	17200	18200	20000	1530	2320	25600
11	19500	6950	5200	12700	12300	7540	2140	12300	25800	4250	1780	12600	18100	20000	5400	6740	25200
12	15800	2660	6960	9260	11300	12800	4380	18700	25100	7910	1980	17500	18100	20000	7910	15800	25100
13	1620	5990	13200	8000	1250	3160	1710	18600	25700	13800	1200	9310	13100	20100	3590	9690	25300
14	5540	7080	14500	10600	12900	9600	8690	18600	25600	10300	1160	12400	14900	20100	3110	6850	25500
15	13600	3490	14400	13800	18600	8540	4020	18500	25600	1630	1130	12500	18100	20000	3150	4270	25200
16	2820	4010	14800	9290	18800	1830	2320	18500	25500	1130	3950	17100	18100	19900	1150	1680	25400
17	12000	10100	19600	2670	19000	2070	2120	18600	25200	1480	4960	13900	17900	19900	1550	4360	25600
18	13200	1320	18300	6180	18900	7470	8270	18600	25600	9290	4520	13700	14300	19900	8030	6390	25400
19	12700	2800	13300	1050	19100	1260	1210	18500	25400	11000	2920	4700	10800	19900	8630	1100	24700
20	3110	11100	18700	4360	22500	1240	1170	18600	25400	10900	2760	4760	15900	19900	2490	4130	20400
21	1030	6500	18700	5230	22800	1270	2880	18600	25500	9990	4440	3480	16300	20100	4510	8820	19900
22	5350	6270	19600	942	22800	1290	8420	18600	24900	13900	1280	2020	17900	20000	4900	5040	19900
23	8670	12000	19700	1450	22600	1280	11500	18600	24600	13900	3670	2240	19100	20000	3380	3190	20100
24	13200	8560	19400	1500	25500	5940	6970	18500	24600	15500	1520	6750	20700	20100	6470	1190	19900
25	13600	6070	19400	14000	29600	4590	7790	18500	19600	17700	1230	6770	20700	20100	6250	3760	18400
26	12000	994	19100	6830	30900	1330	4010	18600	18800	17800	1170	2120	20600	20100	3280	7930	16500
27	9420	7870	19300	4900	33200	1270	1190	18700	18600	17900	1160	1530	20600	20100	1550	5470	17600
28	1840	10300	19500	2580	33900	3530	7160	18700	18600	17900	1130	1970	20600	20000	1380	6830	14900
29	11600	12700	19400	9710	34800	2770	5500	18600	18700	17900	1140	3660	20600	20000	1820	1270	13200
30	10300	12100	19400	12100	35200	9110	9170	18500	18800	18000	1560	1520	20600	20100	1380	1070	15800
31	8140	11000	19400	2590	35300	9940	8140	18600	18800	18100	2120	1160	20600	20100	1320	1060	18900

Appendix Table B-2. (Continued)

Month = April

Da	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
1	68700	19200	8210	5500	6870	8570	6240	7800	9060	8000	12500	7720	25900	6900	6500	6120	6500	8590	4740
2	22100	14700	8630	5870	4980	7700	4780	6240	8210	11500	14100	6900	21400	6120	7720	16200	8150	8590	5100
3	16900	10900	10400	6620	4120	6470	4430	5500	14700	11000	14700	6500	18000	5740	10000	15600	6500	8150	4920
4	16200	9060	10400	8630	3960	6870	5140	4430	14700	8500	12000	6900	14400	5740	7720	12700	6120	7300	5480
5	13900	7400	9500	11900	3160	7280	6240	3740	14200	7540	9000	10000	11600	5380	5380	9520	5740	6900	6070
6	11400	6620	8630	13000	5340	11900	5870	10900	34200	7080	8500	12700	10000	5380	6120	8590	5380	6500	6070
7	9960	5870	7400	11900	9960	36000	5500	9060	31500	6280	8000	13200	11600	5380	5740	7720	5030	6500	13200
8	10200	4600	8210	10900	10900	39700	6240	7400	19200	6280	7540	11000	15000	5030	5740	6900	5030	6120	13700
9	10200	5870	7400	9960	14700	18500	7010	7800	11400	5200	8000	9040	15000	5030	4690	9040	5030	5740	11800
10	9730	4600	8210	8210	14200	15300	34200	7010	10400	11000	7540	8150	12100	5030	5380	20000	5740	5740	9120
11	9500	4600	9060	5870	12500	11900	49300	6240	8210	8000	7080	7720	14400	5380	5740	18000	7300	5740	7320
12	8840	4430	8210	7010	11400	10900	47300	5500	7400	7540	7080	7300	15600	5380	5740	16200	16800	8150	6270
13	8420	8630	7010	9960	10900	9490	36000	14700	8210	5920	6280	7720	13800	5380	11000	12100	32600	9040	5870
14	8210	45400	5870	9960	8130	9020	22800	19900	15900	5560	6280	34300	12100	5740	16800	9520	29200	9040	5480
15	8420	53300	7400	9060	8570	9020	17200	10900	22800	5200	5920	36200	10000	5380	17400	8590	16200	7300	5480
16	7010	22100	10400	8210	6470	8130	8630	9500	8210	5200	5560	24400	9040	5030	15600	8150	11000	13100	5680
17	8210	14200	16600	6620	5700	7280	7400	11400	7400	5560	5560	16800	8150	5030	12100	8150	9520	45800	5680
18	8210	13000	14200	8210	4800	7280	7010	16600	6240	19900	5560	12100	8150	5030	9520	7720	8590	54200	5480
19	10200	10900	10400	7400	3800	6870	6240	9960	6240	23500	5920	10000	18000	5030	8150	8150	7720	34900	5480
20	9960	9060	8210	4960	3310	6470	5870	7400	6620	13600	5920	9040	23600	5030	7300	8150	7300	17400	5870
21	8840	8210	10900	4430	3630	5700	22800	7010	7010	9500	12000	8150	21400	5030	6900	7300	6900	11000	5680
22	8000	6620	11900	5140	3960	4460	60800	6620	9060	8000	11500	7720	15600	4690	6120	7300	6900	9520	5100
23	10200	7400	10900	4780	4800	3960	72300	7800	10900	6660	9000	6900	11600	5030	6120	10000	7300	10000	5100
24	15000	6620	9060	4430	4460	3630	70800	7400	9060	8500	7080	6900	9040	5030	5380	16800	11000	10000	5100
25	13300	5870	8210	5500	4800	3470	29000	9060	6240	9500	6280	6500	8150	5740	4690	13200	12700	9040	4580
26	9960	5870	7400	4780	4460	6470	13000	9500	7010	7080	5920	6120	7720	5740	5030	10000	10000	7720	4580
27	8210	5140	7010	4600	4800	6080	15900	6620	9500	6660	5560	6120	7300	5030	4360	8150	9040	7720	4420
28	7400	5140	6240	5320	3630	4980	22800	4780	11900	5920	5560	6500	6900	4690	4360	6900	42700	8590	4420
29	7800	5140	7400	4600	3960	5700	17200	6240	13000	5920	5560	11000	7300	5030	4360	6500	67600	10500	4100
30	8000	5870	7010	4600	4460	4460	13600	5500	10400	7080	6280	17400	7300	6900	4360	6120	55300	22100	4420

Da	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
1	14400	16000	7100	20400	19800	17000	6400	6320	14900	8890	7050	7070	10500	38800	6220	8020	7540	13300	10900	7700
2	16400	20000	6950	17300	38900	15000	6400	6600	12900	11300	7770	5880	9820	22100	5980	7720	7540	35000	9850	6950
3	21300	17000	6390	14800	44800	22000	5990	7200	12500	9100	12100	5250	8820	14500	5740	7440	7260	50600	9200	6650
4	19000	13000	6670	11400	38800	24000	5990	7200	10200	7200	11300	4760	8200	12100	5740	7020	10500	57900	8600	6380
5	16100	10000	6950	9410	24000	20000	5990	6900	9100	6310	12400	4310	7630	10900	5860	6740	14900	24800	8300	6380
6	25600	8600	6810	8450	20500	20000	15400	6190	8110	5900	25100	4200	7350	9820	5740	6480	12100	14500	9200	6380
7	33700	7600	8150	8150	19200	45400	22600	6060	13100	5760	36500	4000	6810	8780	5400	6220	9460	14700	11200	6800
8	33700	6950	9090	7400	23600	57800	18700	6460	16600	5500	25200	3800	6810	8140	5050	6220	8140	23800	12600	7250
9	26600	6530	10700	8680	45000	55200	14200	10800	12900	7130	14900	3700	6550	7540	4940	6740	7540	25600	11600	6500
10	18400	8180	10000	50100	43600	40400	11600	17900	10500	24200	11700	4000	6550	7260	4830	8670	6850	22000	9850	6000
11	13200	11700	8150	58600	30000	39800	9950	16200	8430	27800	9800	4200	6550	6720	4720	7440	6720	18100	8900	5750
12	10000	14800	8150	39800	20500	37600	8620	12500	7500	14900	9100	4880	6810	16300	4830	7440	6590	14500	8300	5500
13	8450	14400	13600	24100	17200	28100	7690	9450	7500	13700	9100	5000	7080	40400	4830	7720	10200	13300	8600	5500
14	7550	13600	21700	14400	15700	20000	7390	8110	6900	13300	8430	4640	7910	36700	4720	7720	10900	12900	11000	5250
15	6950	10700	15600	10400	14900	17000	7240	7350	6600	10200	7050	4000	7910	26600	4720	7720	10200	16400	25800	5120
16	5830	9410	11400	8450	13700	15000	7100	6750	6310	8430	6750	3800	7350	17700	4720	7160	10900	20200	30000	5000
17	5180	8450	19600	13600	12600	13000	6960	6460	5900	7500	6460	3600	6810	15700	4940	6740	12800	18500	17000	4880
18	4810	7400	32600	22200	11200	12000	6670	6190	7050	6900	6030	3510	6290	15300	6720	6350	26100	14900	13000	4880
19	4580	6670	28500	20400	10500	11000	6260	6060	9450	6170	5760	3380	7080	13300	14100	5960	22000	11700	10900	4880
20	4470	6530	20400	17300	9500	11000	6260	5810	9800	10100	5500	3320	19700	10500	16500	5840	14500	10200	10200	4880
21	4260	5830	18600	13600	10900	10000	5990	6600	8430	17700	5380	3140	38300	9120	10900	5600	10900	9460	9500	5000
22	4930	5430	22200	11400	20700	10000	6400	7200	7050	19400	5000	3060	48600	8140	7840	5480	8780	8780	8900	5120
23	4580	5430	20400	9730	17600	9500	6530	6190	6460	18100	4880	2970	37400	7840	6460	5240	8460	8460	13800	5380
24	5430	5050	15200	8450	14500	9500	6260	5940	6170	13300	4760	2970	14900	7540	6720	5240	9120	8140	17500	5120
25	11100	4810	12500	7850	13000	9500	8150	5690	5900	12900	4880	2880	11700	9580	12100	5720	8460	7540	15400	4750
26	9090	5430	10700	7100	11400	9000	46300	5570	6030	12900	5500	2800	10200	21000	10900	8030	7540	7260	11600	4750
27	7100	6530	9730	6670	9500	8500	75400	5100	6030	12100	7050	2800	8820	15300	10500	11200	6850	6980	9200	4620
28	6110	7100	8770	5970	8200	8500	66400	5220	6900	9800	7200	2800	8500	10500	12100	10100	6330	8460	8600	4620
29	5700	6250	8150	5300	7880	8500	38000	4980	10200	8110	5760	2630	8200	8460	9820	8670	5830	12900	8300	4620
30	4930	5300	7550	5180	7420	8500	15000	4760	9450	7500	5250	2720	7830	7540	8140	8340	5950	10900	8300	4750

Appendix Table B-2. (Continued)

Month = April

Da	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
1	7550	12000	13300	9510	6950	2180	4520	19000	2840	19000	5340	10800	19300	5950	14500	4550	1880	8430	3860	6490
2	12000	10200	13500	7880	6380	4240	3070	19000	10600	19000	18600	10500	19300	6290	13400	2020	1930	7850	3300	6870
3	15000	9500	13500	7700	6250	5110	4420	19000	7820	19000	18600	15300	19300	5340	4190	2030	4340	2830	2490	6730
4	21500	8900	13300	7290	6380	5630	6730	19000	2180	19000	19000	17400	19300	2280	1840	4620	6530	2770	2080	1920
5	26000	9500	12300	6380	6500	4960	8740	19000	2040	20600	19000	17200	14100	2230	8650	8450	7730	5940	2090	1900
6	25000	11200	2000	6380	6710	5810	19000	19000	5030	23000	19000	16700	2120	4110	9790	5420	2990	2610	2100	5200
7	17500	10200	9590	6500	8000	2830	19000	19000	7600	22000	19000	13200	2130	3530	9050	6140	1940	1970	2090	5200
8	15000	9850	10100	6500	6250	2520	18800	19500	8620	20500	12700	1530	7400	3820	6190	3980	1950	4620	2050	2090
9	15800	8300	9780	6500	6250	4020	29300	19500	9420	20500	2040	13300	7770	6610	8200	2040	1950	2690	2070	1860
10	24500	7550	11900	6120	6000	3870	30600	19500	8350	20500	10600	18500	5560	4550	2310	2000	2670	3430	2760	1840
11	26500	7100	12900	6250	6000	5790	31600	19500	2210	21000	19000	18500	2310	2250	2220	2050	2480	9320	6360	1850
12	27000	6950	12300	6120	6250	6660	29400	30000	5560	21000	19000	18500	2100	2250	5790	3020	2030	6120	2020	1870
13	27600	6800	9320	6380	6950	8170	25000	26000	14900	20500	19000	18500	2090	8350	5910	5150	2470	1960	2010	1860
14	26500	6650	14100	6380	8000	2400	19000	24300	19500	20500	19000	18500	2080	10600	6620	7210	2000	1800	3340	1930
15	24000	6000	13500	6380	12400	2270	18000	27100	19500	20500	19000	18500	2060	11400	5990	2050	1960	7080	4130	1900
16	19000	6380	13300	6250	29400	10800	19500	25600	19000	20500	19000	18000	2090	10400	3040	1970	1970	8670	5600	1880
17	12600	8300	10100	7100	31200	15400	17400	25800	19000	20500	19000	18500	6200	8490	2430	1980	2010	9040	4820	1900
18	11200	7550	9250	6950	31200	18500	17200	25000	19000	20500	19000	18500	6970	2700	2390	1970	2110	9210	8450	1980
19	10600	6120	4100	6250	31800	14200	17200	22600	14300	20500	19000	18500	5660	2070	2180	3090	2040	8940	1960	1980
20	9850	6120	6440	6820	28200	14500	6050	14000	19000	20500	19000	18500	2100	9050	2120	5210	2010	2300	1890	3870
21	8600	6000	9440	6650	13300	12600	5620	14000	18100	20000	19000	15600	2070	9920	2100	2030	2010	2080	8300	5710
22	8300	6250	9490	7100	12500	5750	6110	19700	17900	19000	19000	3290	2090	7100	2490	7400	2020	2870	9260	7050
23	7700	5750	9490	7650	12400	5880	5750	17500	15200	19000	19000	13200	2300	4820	3800	3020	2010	3500	5300	11100
24	8600	4200	9450	7450	6250	6000	8160	19800	14500	19000	12800	13600	2140	6630	2430	2010	2000	7880	7700	9520
25	11200	4100	8270	5750	7240	5880	9350	20000	15100	11300	8390	14200	2140	2060	2250	6110	2000	8550	2060	1880
26	11600	10300	4520	5380	13600	7030	8460	19900	18300	7530	9450	16300	4580	2060	6790	3410	3310	5540	4420	4090
27	9850	18400	2620	10600	12300	7840	5910	17900	9000	7840	10700	16000	5880	4440	9520	3200	2470	5960	6010	5200
28	8900	24000	6030	11200	16800	6120	8720	14300	10300	9920	9670	9180	5930	6100	12000	3290	1930	5990	6030	5310
29	8600	27000	6660	9850	15600	6120	8600	19900	9910	13000	7150	5250	6980	6240	11500	5520	1960	6010	6040	5340
30	8300	28200	6390	9850	11800	6250	8600	20000	10800	6000	5540	6650	6110	6180	9700	3200	1970	5960	6020	5080

Da	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	3190	1550	19500	3800	35100	8120	6660	18700	18700	18200	2530	2150	20700	20100	2340	2740	19300
2	1900	1810	19300	1910	35300	8130	6460	18600	18700	18200	2640	2750	20700	20100	2840	3650	20000
3	1860	1810	19400	1930	35200	2360	2320	16100	18700	16000	2580	2260	20600	20000	2510	4400	19800
4	1870	1810	19500	9410	35300	2310	5600	16300	18900	13900	2280	2270	20600	20200	2580	3810	18900
5	1840	5130	19500	14800	35300	2730	8760	18400	18800	13900	2260	6650	20600	20100	2550	2260	19300
6	8610	2230	19400	14800	35500	2690	11700	18500	18700	9530	2240	10600	20600	20200	2540	4440	19300
7	3040	10900	19400	14700	35400	2950	13700	18500	18700	13900	2320	12800	20600	20200	2550	10300	12200
8	3690	12300	19500	10900	35400	3390	18700	17400	18700	13900	2250	5750	20700	20100	2500	8230	7790
9	1890	6850	19500	15800	35200	5700	18100	2450	18700	15400	2290	2300	20700	20200	3360	7310	11200
10	1900	17600	19500	17600	35000	2370	2530	9060	18700	18000	2260	2290	20700	20000	3620	8350	12300
11	1910	12500	19500	17500	35500	3180	12800	9880	18800	18100	2280	2290	20700	19900	2550	5950	2830
12	1900	13900	19600	17500	35100	6300	13900	11100	18700	17900	2260	2330	20800	19600	2490	2540	2940
13	7450	13300	19600	17600	35300	2860	13200	9280	18800	17900	9880	4900	20800	20100	2510	2480	7290
14	9560	8250	19500	17600	35600	2310	10100	9130	18800	18000	3070	3500	20700	20300	2530	3880	4660
15	9950	12600	19500	17600	35400	2320	12000	2470	18700	18100	2280	2310	21100	20300	2970	2750	7060
16	11000	3970	19500	17600	35000	3670	9680	2330	18700	18000	2660	2350	22300	20200	2550	3840	19400
17	7500	13500	19500	17700	35100	7100	2540	8450	18800	18000	2280	2340	25300	20100	2550	10900	20400
18	4550	13300	19500	17000	35000	8630	3100	7870	18800	18000	2290	2320	25600	20100	2560	2800	21600
19	9070	14200	19600	14800	35100	7680	6690	9140	18700	18100	2260	2560	25400	20000	2540	2550	25300
20	10100	14300	19600	14400	35100	4040	10500	8490	18700	18000	2460	2280	25400	20100	2530	2530	26000
21	11200	11600	19600	8300	34900	3880	8670	7650	18700	18200	2250	2270	25500	20300	2580	2530	31300
22	10900	9160	19600	9610	35100	8780	4030	2590	18700	18200	2250	2300	25800	20200	2570	2520	34900
23	11300	2070	18000	11200	35000	9730	2880	2300	18700	18100	2240	2300	25900	20300	2540	2520	35000
24	7910	7880	19500	11200	34300	2560	2420	8750	18600	18100	2250	2300	25700	20100	2440	2590	35600
25	2070	6880	19600	11100	24800	2320	2330	4930	18700	18200	2260	2310	26100	20100	2070	2710	35400
26	4710	11100	19600	11500	14800	4950	5170	11300	18700	18200	2260	4680	25500	20000	2080	2700	34200
27	5890	8510	19500	6230	6490	7090	6260	19000	18700	18200	2250	6200	25600	20100	2070	2700	34400
28	8460	8300	19500	7160	14000	8500	6280	18900	18700	18300	4560	6200	25400	20100	2060	4830	35000
29	5790	6970	19500	11600	6470	8010	6220	20100	7010	18400	6130	6240	25500	20200	2120	6000	35200
30	5910	6770	19500	14800	10200	6650	6270	26100	14500	18100	6120	7840	25500	20100	2100	5930	34900

Appendix Table B-2. (Continued)

Month = May

Da	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
1	12200	4960	5500	4260	4290	6470	11400	4780	8630	7080	6660	15600	15600	9520	4040	5740	30000	20000	4420
2	11200	4260	4780	4430	3630	6470	17200	9960	7010	6280	6280	11600	15600	10000	3890	5380	20600	13200	4100
3	9280	4260	4960	4780	4290	5700	13000	10900	5500	5920	5920	8590	11600	8150	3740	5380	13200	11000	4100
4	8000	4080	4780	4080	4800	6470	11400	14700	4780	5200	5560	7720	8590	6900	3890	6120	10500	13200	4100
5	7010	3910	5500	4430	4980	7280	10400	10400	3740	5560	10500	7300	7300	6500	3740	5030	9040	15600	3950
6	6620	5870	5870	4780	3630	9960	9060	8630	4080	6660	16600	5740	6900	5380	3740	5030	7720	11600	3570
7	5870	4080	8210	4260	3310	9020	7010	11400	3740	8500	22000	5740	6900	5380	3440	4690	6900	9040	3950
8	9280	3410	9500	4780	8570	9020	6620	9960	4430	7080	15300	5380	12700	5030	3440	4690	6500	9040	3770
9	14400	3580	7400	5140	7700	9960	5500	15300	9060	5920	11000	5740	13200	4690	3440	4360	7720	9040	3660
10	12500	4080	6620	6240	6470	10400	4780	13600	8210	5560	8000	5740	10500	4690	3300	3740	10000	8590	3800
11	8420	3740	5140	5870	5160	9020	7010	13600	6240	5200	9000	6120	53200	4360	3440	4360	8150	7720	3660
12	11200	3580	4780	6240	3630	8130	6240	11400	4780	5920	10500	5740	63700	4360	3440	4040	7300	7300	3480
13	29000	3410	5500	5140	3160	6870	8630	9500	4080	19900	9500	5380	42800	11000	3440	3890	6120	6500	3230
14	60800	3740	6240	5320	3310	6080	16600	7010	5140	32200	9000	5030	25900	31700	3440	3740	5740	7720	3310
15	78000	3410	4960	5870	3000	5340	24300	6240	7010	16600	12000	5030	20000	25900	3740	3590	5380	15000	3510
16	35100	3250	7010	4780	6470	5700	14700	14700	5870	10500	12000	5380	21400	16200	3740	3300	5380	10500	4100
17	35100	3580	7400	4260	5160	4800	10400	10900	4080	9500	9500	5030	16200	11600	4040	3020	5030	7300	4260
18	40600	3410	3740	4780	3310	3960	9060	15300	3740	9000	14100	5740	13800	9520	4690	3590	5030	6500	4100
19	26600	5500	3250	3740	3160	3470	8210	9500	4780	7080	30500	7300	11600	7720	4360	3590	4690	5740	5870
20	15300	6620	4430	3580	3310	3470	3740	7400	4430	6280	46100	6500	10500	7300	3590	3440	4690	5740	7970
21	11700	6620	3580	3740	2840	3160	5500	9500	3740	5560	42100	5030	33400	6500	3300	3440	5740	8590	8420
22	10200	3910	3740	3580	2110	3310	5140	8630	4430	5560	17800	5030	38000	6120	3070	3740	5740	10500	7750
23	9280	4260	3580	2620	3310	3000	4780	9960	5870	5560	12000	5030	31700	5740	2790	3590	5740	9520	5480
24	8630	14200	3740	3580	3000	2520	5140	10400	5140	5200	11000	5030	22800	5030	2520	3160	5380	8590	3950
25	8000	31500	3410	3250	27400	2160	9500	10900	4780	5920	9000	4690	19300	5030	2270	3160	5030	7300	3800
26	7400	49300	3410	3580	41600	1820	11900	19900	5500	4520	8000	4690	13800	4690	2400	3590	6500	6500	3540
27	7200	40600	2930	3410	22800	3470	9960	14700	4080	4520	8500	5030	13800	4690	2520	3440	5740	5740	2920
28	6060	13000	3250	3910	9020	3470	10900	26600	4430	6660	9000	4690	19300	4690	2270	3590	4690	5740	3100
29	7010	17900	3090	3740	5700	3800	8210	10400	4080	10500	8500	4690	16800	4360	2270	3740	4360	6500	2840
30	5870	23600	2930	6620	7700	5700	7010	8210	3740	9000	6660	4360	13800	4360	2270	3740	5380	10000	2900
31	5500	13000	3740	7400	12500	6470	4430	7010	3410	8500	6280	4360	10500	4040	2160	3440	5030	9040	3150

Da	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
1	4150	4810	7100	4700	8130	8300	13800	4540	8760	6900	5000	2720	7350	6720	6980	8020	5470	8780	8300	10900
2	4360	4810	6950	4470	8040	7990	12200	4320	9450	6600	4640	2630	6810	6220	6460	9350	5360	7540	8900	10900
3	5180	5560	6390	4810	7880	7990	10300	4220	34000	6310	4420	2630	6810	5740	6220	11200	5360	7540	23200	12400
4	5430	7550	6810	4930	6980	7390	9270	4430	25500	6600	4200	8790	6290	5620	5980	10800	5360	6850	29400	17000
5	4580	7550	7550	5180	6840	7540	8940	4320	17000	6170	4100	8550	6040	5400	6100	10700	5470	7540	26000	20000
6	4580	5970	10900	5180	7120	7990	8300	4220	12500	5630	4000	5080	5920	5280	5980	19000	5830	7540	16200	17000
7	4470	4930	17300	4700	6980	7990	7990	4010	9100	5250	3800	3320	5670	6220	5860	18300	6330	8140	12300	11200
8	9780	4470	19900	3950	6840	7240	8620	4010	6900	5120	4100	3630	5670	19800	5400	12900	5470	9120	10200	8600
9	15600	3850	13200	3650	7880	6810	8620	4760	8460	5120	4310	6270	5550	23800	5160	10100	5120	13400	9320	7700
10	17000	3650	10000	3550	7420	6400	7540	4540	6030	5250	4880	4530	5550	11700	5160	8670	4670	11300	9500	7400
11	17000	3650	8770	3450	6660	6120	6530	4010	6030	5000	5120	3800	5430	8140	5050	7720	4560	8140	21400	7100
12	11100	3850	8450	3160	6840	6260	6400	3710	5500	4760	4640	3140	6160	6980	4940	7160	4120	7540	35400	5750
13	8150	4580	8770	3450	6430	5990	6260	3810	5380	4530	4000	2630	7080	6460	4940	10600	4230	6850	34200	6500
14	6390	7250	9090	4260	6170	7990	5990	3910	5380	4200	3320	2310	7080	5860	4830	13500	4120	7120	22000	11000
15	6530	7100	10400	3750	6040	8300	6400	4980	5250	4100	3320	2470	7080	5620	4720	13900	4010	14400	14200	16600
16	6670	6670	9090	6820	6170	6960	20700	6060	5250	4000	3420	2470	6810	5510	4500	13100	3900	13900	11600	21000
17	5180	5430	11100	16000	6300	6120	20500	6060	5000	4640	3320	8390	6040	5510	4720	12000	3800	9120	14200	29400
18	4700	4470	10700	15600	6170	5360	12200	5810	5000	4310	3230	33200	6550	5280	5980	11200	3900	7540	19000	22000
19	3950	6370	9090	10700	5780	5730	9270	4980	4760	3930	3140	26400	6420	4940	13900	12300	4120	7540	24900	12700
20	3950	6810	7100	6530	5660	4990	7690	4430	4530	3900	3140	11200	5670	4940	20400	15900	4340	6590	15000	10900
21	4510	5560	6250	4810	6230	5110	6810	4320	4310	5130	2970	7070	5310	4940	12600	18500	4230	5950	10200	10200
22	14500	4470	6810	3850	8040	5110	6260	4650	4200	8430	2630	8950	5310	4940	7540	21100	4230	5590	8600	8600
23	20600	4150	7850	3450	9170	5230	5990	5570	4200	6170	2970	23900	8500	4940	6220	16800	6360	5240	8000	6950
24	20800	4050	8450	3070	8520	4400	5600	5220	4310	4640	2800	40700	7910	5160	5510	13100	9820	5120	8300	6380
25	18600	3450	7100	4290	7120	4750	5230	5100	4640	5120	2630	49100	6420	6980	5280	9350	7540	5120	8300	5880
26	12200	3350	5430	13300	6840	4290	5360	6750	4420	5900	2550	21300	5790	10000	5270	9150	5590	5470	7700	5750
27	8150	3260	5050	15600	7120	4290	5990	8430	4200	16500	2550	10500	6550	11700	16600	17500	5710	11300	7400	6120
28	6390	3160	4930	10700	6980	4290	5480	10200	5380	12700	2470	7900	14300	8460	15700	17200	9120	19300	7100	6380
29	5300	9650	5300	8450	5910	3960	5600	8760	4640	8110	2160	6570	13500	8140	15700	18100	7540	13700	6250	6500
30	4700	7840	4930	8150	5420	3850	5230	7200	4200	6460	2310	5830	9480	10200	10200	11600	5360	10200	6090	9780
31	4150	5300	8480	13600	5060	3740	5730	5940	4200	6310	2310	5240	8200	6220	7260	9010	4560	14500	5620	13800

Appendix Table B-2. (Continued)

Month = May

Da	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
1	7700	30000	7080	7110	9850	6000	8600	19400	6880	6000	7280	5500	5970	6170	6760	3740	1970	5990	5970	5120
2	7550	29400	6590	4100	10600	5880	9480	19000	5750	7400	8000	8540	5930	6120	6120	3780	5720	6040	8840	5140
3	7700	26000	4370	4060	9640	8360	8600	24400	6000	10000	9570	6810	5950	6120	12500	3750	1950	8400	5930	5120
4	7700	20000	2770	9450	8360	14400	8600	21000	7080	10000	8450	5620	5950	6180	13700	3860	1990	5840	5990	5210
5	7700	15400	6860	9380	8370	8910	8600	21000	8020	11000	8000	5880	5920	6230	13800	3800	2010	5910	7010	5220
6	7700	13000	7220	8900	8680	8600	8600	32600	8620	11000	6160	5620	5950	6200	9500	4010	2030	5960	6330	5180
7	8000	8900	8160	8900	7660	8600	8300	33900	11300	6600	6040	7150	5940	6210	8600	3990	2010	5940	5830	5670
8	7250	7250	6870	5820	7700	8740	9440	21800	8240	9600	8450	7930	6430	6200	8300	3990	7600	5960	9740	8300
9	7100	6500	6820	2480	7700	10900	9150	23000	5750	14600	8920	9090	5960	9200	8600	3980	5940	5960	6790	10400
10	6250	6800	3270	2320	9220	11500	8000	22500	5700	14600	9780	10400	5970	8490	8600	6440	6130	8550	5830	5020
11	6250	6650	2570	7780	8300	13300	8300	23500	7370	14600	15000	9390	5980	8520	8600	6290	6190	5940	5790	13000
12	5750	6120	6790	8980	7980	9280	5880	25000	8110	14600	13600	8900	5980	9690	8600	6230	6170	5910	6270	12900
13	6380	6120	6770	9220	8560	8300	6990	26300	7550	14600	10700	8300	5920	7970	8270	6250	6530	5940	6470	13400
14	8900	6800	6800	9500	9720	9200	9190	24000	7960	14600	5660	8300	6010	6500	6010	6290	6170	5910	6380	13900
15	8300	9200	6790	7070	8000	8800	8610	24500	7400	14600	11600	8000	6060	6010	6200	6260	6340	5860	6430	5050
16	6380	9200	6440	2000	8300	8600	7530	24000	5750	12500	16100	8900	6020	6170	6210	6250	6220	6330	6000	5100
17	5620	8900	2590	1240	9390	8600	5750	24500	5610	9800	17400	8900	6040	6160	6210	6250	6170	5890	5990	5110
18	5120	8300	2540	3530	9140	8300	5880	26000	6870	8800	16400	8600	6010	6170	6180	6320	6540	5840	6010	5180
19	4500	7700	6260	4060	7670	2430	5880	24500	8070	9200	16000	8900	5980	6150	6160	6280	6240	5890	5990	5250
20	4750	7400	5880	4630	8120	2250	6000	23500	7660	9800	8110	8300	5940	6150	6110	6240	6190	5860	6050	5230
21	4750	7700	5100	8590	7490	4930	5880	25500	8100	6000	5660	8000	6000	6180	6150	6160	6180	5960	5930	5260
22	5000	4880	4840	7590	3150	5340	5880	22500	7600	6000	7420	8100	5970	6180	6170	6070	6170	5940	5990	5240
23	4750	4500	4750	3450	2880	4650	6000	19500	5750	7400	8600	6000	5950	6110	6140	5450	6200	5890	5890	8980
24	5000	7620	2430	2920	9140	4500	7810	19500	5880	8600	8600	8580	5930	6090	6260	3920	6170	6200	5980	5020
25	5000	8300	2390	10800	12900	2890	5750	9760	6000	9200	8600	6250	5930	6390	6160	3980	6160	5890	5800	5100
26	4750	8000	4690	10600	10600	2480	2320	15200	6000	11500	10400	6250	5950	4660	3890	3930	6160	2420	5920	5120
27	4400	8300	4570	10200	11700	2480	5750	19000	6420	11000	11300	5750	5970	7610	2740	3940	3720	2230	6050	5140
28	4100	9850	4430	10800	10800	2800	5800	17600	7480	11000	5910	5750	5970	3600	3460	3940	2000	4910	5940	5140
29	4000	9850	4490	10600	2720	2560	7960	18000	7180	15000	7700	5750	5910	2140	2430	3920	4840	6840	10100	5130
30	3900	9500	4430	3400	2560	2180	3250	14700	6000	15000	8300	5750	5940	2240	2440	3940	2080	2240	6020	5150
31	4000	8900	2250	2720	3460	2860	9080	7420	5880	15000	8300	5750	5940	2130	2210	3950	8030	6090	5900	5150

Da	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	5860	11300	19400	14500	15700	6140	6220	35300	15900	18100	6110	7100	25700	20000	2080	5960	35000
2	5940	10300	19600	11300	6550	6140	12300	34600	15400	18100	6160	6260	25800	19900	4620	6010	35100
3	6010	11600	19600	14000	6210	6210	14400	34600	17400	17200	6160	9740	25800	19500	3320	5990	35200
4	6040	13400	19300	6950	6250	6400	14400	34700	18600	13800	6130	8650	25800	19900	2040	6000	35300
5	6040	18300	19600	6740	6260	9020	11900	34400	7380	13900	6170	11100	25900	20200	2040	5990	35200
6	6200	15700	19600	14000	6320	6390	9660	34700	6280	13900	6110	10600	24200	20200	4880	5980	35200
7	6090	15300	19600	15100	11100	6210	6210	34700	6390	13900	6080	11600	20300	20200	6110	5990	34800
8	5960	16300	19800	15700	10300	6200	6260	34600	13700	13900	2350	6290	20200	20100	6040	5950	35000
9	5960	19400	19600	11200	10000	6250	6230	34600	15400	13900	2280	6320	20200	20100	6060	5960	34700
10	6120	19400	19500	10100	8660	6340	6330	34700	13300	13100	2310	6350	20200	20100	6030	6040	35100
11	6040	19400	19200	6130	7220	6290	8640	34600	11200	6220	3100	6200	20200	19800	6040	5910	34800
12	5990	15300	14500	6200	12900	7050	6240	34100	6150	8660	8980	7530	20200	19500	6050	5950	34900
13	8170	7030	8360	8360	13700	6290	6210	34500	6250	9990	2290	10200	19900	19400	5930	5970	34700
14	13900	6610	14300	12000	13100	7680	6220	34400	6340	9100	2280	6110	19000	18700	6170	6070	34800
15	12400	14100	14100	12300	11600	6200	6240	34500	6170	6170	2870	6030	19000	17900	2450	6070	32400
16	7470	19500	14300	14800	15100	6240	6280	34300	6180	6160	2270	6030	19000	12200	2320	6060	29800
17	15500	19600	15200	14800	6450	6310	6230	34700	6890	6070	2270	8570	19100	12000	2130	6010	29800
18	15800	19400	9440	13500	6210	6300	11800	34700	10600	6120	2570	7330	19200	8400	2060	6000	26700
19	19400	19400	5770	6200	6380	6320	6240	34700	6190	10800	7480	5980	19200	6930	2000	6100	24600
20	19500	19500	5810	6200	6290	6300	6260	34700	6120	6180	3900	6010	19400	6180	1990	6010	24900
21	19500	19500	5780	6200	12300	6280	6340	34600	12100	6870	3690	5990	19200	11900	2030	6520	24800
22	19500	19600	9270	8870	13800	6250	6310	34700	12500	10100	2250	6050	19100	13600	2070	6040	24800
23	19500	19500	15300	14400	13800	6240	6320	34100	12900	11000	2240	6030	19100	8780	2210	6030	24000
24	19500	19400	16200	11600	8900	6290	6270	26300	6390	6160	2250	6020	19100	7920	2110	6030	20200
25	19500	19500	14700	6530	6290	6300	6180	25600	8830	8070	2260	6360	17900	8160	4980	6050	20100
26	19500	19500	11300	5900	6290	6310	6150	25600	11000	8140	4650	5940	15300	8070	6190	3920	20200
27	19500	19400	6070	5950	6260	5790	6100	25700	6270	10200	2530	6010	12600	6140	6190	2260	20100
28	19400	19300	12500	8330	6230	2280	2330	25600	6280	11000	3940	6600	9490	6220	8110	2820	20100
29	15600	6570	12800	10500	6270	2270	2270	22400	12300	11400	4020	6400	8120	9450	6150	4720	20000
30	15000	14700	7030	14500	6210	2330	2290	18900	13400	12400	4380	6050	8550	13300	6140	2220	19300
31	19500	19500	6400	9350	6190	2750	2300	18700	14300	9710	3100	6050	14400	14500	6170	4430	13900

Appendix Table B-2. (Continued)

Month = June

Da	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
1	5320	9060	4960	5140	11400	4460	3740	6240	3090	7080	5560	4690	8150	4040	2040	3590	4360	7720	3510
2	5680	7400	3580	11400	9020	3630	5500	5870	2770	5560	5560	5380	7300	3590	2160	3890	4040	7300	3570
3	5320	7010	3090	53300	6470	4290	5140	7010	2460	4520	7540	4360	6900	3740	3070	4360	3890	6120	3290
4	5680	7010	2460	60800	3160	4120	3740	9500	3410	4180	16600	4040	7300	3740	2660	4040	4040	6120	3200
5	4600	6620	1880	60800	3310	3470	3410	7400	4780	11500	26500	3890	6900	3440	2660	3740	6500	6120	2770
6	4780	5140	3580	17900	3960	3310	4080	16600	16600	14100	16600	3440	6500	3300	2520	3440	8150	6500	2670
7	4960	4780	3250	13000	6470	4460	3740	25100	25100	10000	19900	3440	6500	3300	2400	3740	7300	6500	2920
8	4960	5320	2620	5140	16600	5160	4430	22100	13600	7080	15900	3440	6120	3160	2160	6120	6500	5740	2770
9	7400	9960	2930	4430	21400	9020	3410	13600	9500	4520	12500	3300	6120	2890	2400	4690	5030	8590	3510
10	6620	9960	3580	6620	19900	14200	2770	9960	7400	4180	9000	3740	10000	3740	2400	3740	4360	15000	4920
11	4260	7400	2770	5870	9960	25100	3090	7400	5140	3860	8000	3740	13800	4360	2290	3300	4040	22800	6680
12	4960	4960	2160	4780	6870	35100	2460	7010	4430	4180	7540	3740	9520	3740	2040	3300	3740	22100	6890
13	5500	6620	2310	4960	4980	17900	3090	13000	4080	3860	6660	5380	6900	3300	1930	3590	4040	10000	6890
14	3910	8210	2020	4080	4980	15300	4430	22100	3740	3860	5920	7300	6500	3160	1930	4040	3890	7720	5480
15	4080	6620	2930	3740	6470	10900	3410	11400	3410	3540	5560	10000	8150	2890	1820	4040	3890	7300	3800
16	8210	5870	3250	5500	10900	8130	3090	7400	3090	3860	5560	9040	9040	2510	1820	5030	3740	9520	3200
17	4960	4080	2460	4430	53300	5340	2770	6240	3090	3540	6280	6900	7300	2640	1720	6900	3740	18600	2840
18	4960	4600	3410	4780	36900	4800	2160	5500	3410	2930	10000	5380	11000	3440	1720	5740	3440	12700	3660
19	6060	3740	2620	5870	13000	4290	1880	4780	3740	5920	13000	4690	13800	3740	1720	4360	3020	9520	4580
20	6430	3580	2460	4430	11400	3800	2160	3740	4430	4180	12000	4360	8590	3740	1720	3740	3160	7720	7100
21	6620	3580	2160	3740	8570	3470	4780	3410	4780	4180	17800	4040	6120	3300	1720	3160	3160	6120	6270
22	5500	3410	2310	3740	9490	2390	3410	3740	8210	3860	16600	3890	5030	3020	1720	3440	3590	5380	4260
23	4430	4430	2160	3580	6470	3160	4080	4430	12500	3540	11000	3590	4360	2760	1720	3440	3590	5380	3400
24	7010	9060	1880	3410	8130	3470	3740	6620	11400	3230	7540	3440	4690	2270	2270	3160	3440	5380	2820
25	5500	13000	1930	2930	9020	5160	3090	6240	7800	3540	6280	3300	5030	2510	3660	3020	3160	5740	3370
26	7600	7800	2460	2770	7280	3800	4430	5140	10400	3540	4860	3160	5740	2390	3220	3160	3160	9520	3800
27	6820	8630	1930	2620	6080	3470	11400	23600	9060	3540	4180	3300	5740	2390	2520	3300	3440	13200	3260
28	4960	9060	3740	2460	4460	3310	13000	45400	8210	3540	4520	3590	5030	2510	2270	2760	3440	16800	3020
29	15000	10400	7010	2310	4980	3630	11900	42500	7010	6280	5560	3160	5030	3300	2270	2510	3300	13200	3660
30	11200	9500	5870	1750	5340	9020	11400	29000	6240	5560	6280	2890	6500	4690	1930	2760	5030	11600	3230

Da	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
1	3850	3950	20800	15200	6160	3540	4990	4980	6460	18600	2160	4800	6810	5160	6220	7440	4230	20600	5620	15700
2	3980	3160	18900	15200	6530	3640	4070	5220	5250	36000	2160	4580	6040	4500	5620	6610	4560	14900	5500	31200
3	12500	2980	11300	11100	5180	3640	4520	5940	6030	27800	3000	4290	5670	4720	4940	6090	4010	12100	5380	33600
4	10900	2620	6950	8150	4500	3640	6260	6900	5630	13200	4780	6570	5190	4500	4500	5720	3490	10200	5250	24200
5	7400	2540	5300	7400	4220	3640	6120	6320	6750	9100	7500	6070	4840	4830	4060	7440	3490	7260	5120	13000
6	5050	2450	4810	7850	6780	3430	5990	5450	5900	7500	6900	6820	4610	4280	3860	8670	3590	6590	4880	11200
7	4360	2290	4050	13200	7570	3640	7690	5330	5120	7350	6460	5360	4390	3750	3750	7440	3390	6200	4750	9850
8	4050	2450	4050	18600	6350	3850	8940	5100	4200	6750	4640	8210	4610	3450	3650	6090	3290	7980	4880	8000
9	3550	2290	3650	14400	5420	4520	7100	4980	3900	6460	3510	7620	10800	3450	3750	5600	3010	12100	4400	6650
10	3260	2220	3850	13200	7170	5730	7390	6060	4310	5380	3320	7340	21100	3550	3960	5360	2840	11300	4300	5880
11	3070	2140	4150	9950	11800	5480	7390	13800	5250	5380	3140	6820	17000	3450	4280	4900	2680	7840	4200	5750
12	2800	2290	3950	6670	9080	4990	7690	18300	5380	6600	2880	11200	12900	3160	4280	4670	2760	6330	4100	7250
13	2890	5520	4700	5830	6150	4750	9950	13700	5900	7800	3600	30100	10200	4040	4280	5840	2610	5590	4200	6380
14	2620	11200	4260	5180	4950	5730	7240	12100	5380	8430	3900	24800	8200	5280	4500	6160	2840	5120	4300	5880
15	2450	14800	3750	5050	4390	6810	5110	8430	5910	8110	4420	13300	7350	4830	4390	9710	3390	5240	6500	5120
16	3450	12200	3350	4580	4280	7390	4290	6060	9810	8430	5250	10200	6420	4830	4060	10600	6660	6200	7700	4620
17	4360	8450	3350	4050	4400	4990	5860	5570	6310	7050	4530	7900	12900	5050	4170	5960	19700	6200	6250	4400
18	3850	5970	2890	3750	4700	3850	5990	6320	4530	7130	4310	6320	12900	5860	3960	4900	11300	6980	7100	4300
19	3450	4360	2710	4050	4500	3850	11800	16200	3700	17600	3710	5480	9480	5400	4910	4670	7120	8140	8300	4200
20	2980	4580	2710	7950	4700	10700	12200	21700	4000	16200	2880	5130	8820	4390	4280	4560	5470	6850	10200	4200
21	2710	4470	2620	8450	4300	14600	10700	38800	4640	10800	2630	4910	6810	3650	5400	4560	4780	11700	8900	4880
22	2290	3650	2290	8150	4200	7990	8300	48600	4880	7350	2470	4580	5430	3350	4390	5480	4780	8460	6500	7250
23	4950	3450	2220	5050	4000	5480	6120	55900	4760	5380	2390	5710	4960	3350	4830	6610	6590	6460	5620	8600
24	11400	3160	2220	4150	4000	4520	5110	54800	4000	4640	2720	5130	5070	3070	4060	5480	5830	9820	5380	11300
25	10400	3160	2290	3550	3440	5730	4870	28000	3700	4530	3700	4580	5920	2980	3350	4670	4900	9460	5120	12200
26	7440	2800	2600	3550	3140	5990	4180	15000	4000	4000	2720	4480	5430	2980	2980	3990	4230	10500	4880	8300
27	4810	2450	6530	3350	3050	5230	6400	10900	3700	4880	2470	4270	4840	3450	2810	3770	4120	8460	4400	6000
28	3750	2300	5560	3450	2960	4290	8150	16000	2890	5500	2720	4170	4170	2980	2730	3770	3800	6080	4400	5250
29	2710	2710	5050	2980	2870	3850	5360	31500	3140	4640	2550	6930	3960	2650	2810	5480	4120	6460	5250	5000
30	2450	2220	5050	2800	3050	3640	4870	25200	2970	4200	3590	6320	3350	2500	2650	6090	4230	6330	12800	5250

Appendix Table B-2. (Continued)

Month = June

Da	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
1	4000	8300	2250	2540	6070	3170	2180	5580	4180	15000	8000	5880	6020	2140	2100	3950	9420	1870	5900	5140
2	3900	7550	4040	3660	7180	7360	2180	12100	8070	15000	8000	5750	5960	2200	5280	3820	9670	1860	6090	5180
3	3700	6800	3860	3830	7300	2440	3980	11700	4610	15000	7610	5750	11500	3850	2660	3780	2110	9910	2000	5800
4	3600	6380	3910	3920	7290	3280	3150	12400	9080	14500	5780	5750	9360	4370	2470	3800	1960	4240	2200	5110
5	3800	6120	3840	2700	1700	5130	5820	11200	6060	6000	7160	6960	9000	3160	2270	3820	9250	8460	2380	9660
6	5620	5620	3650	1350	2040	4040	10200	11300	2220	4000	8000	6370	6090	2190	2580	3760	6660	11300	4270	5170
7	8600	5120	2400	2040	4030	5060	13800	6840	2040	5600	8300	7820	6200	2160	8070	3720	10100	9600	2190	5100
8	6800	4750	2250	3460	4090	4460	3080	5620	5780	4600	8300	8230	6000	5150	6870	6390	9930	9560	2430	3190
9	6500	4300	4330	4470	7900	2920	2040	8560	6930	4600	11100	5750	5990	10100	2570	5280	9840	2330	2500	2020
10	7400	4100	3980	3300	6880	1300	11800	7600	5230	5000	6080	5750	5990	13100	2600	3700	3720	8940	2280	1960
11	12000	3800	3890	2770	5730	4630	9640	10000	6810	2900	5910	5750	5630	6600	6220	3680	2030	8820	2370	7790
12	12300	3500	3750	3080	3880	3980	11600	8450	8040	2100	7160	7040	5850	2130	2560	3690	3950	6670	9750	5270
13	9500	3600	6470	1410	10500	4590	12300	9980	2280	6600	8300	12700	5240	2130	2480	3680	5770	3440	11400	2390
14	7100	3500	5650	2280	11700	5390	11500	5750	2040	7640	9030	15800	6160	2120	2580	3670	2190	2050	2750	2420
15	8550	3410	3130	4120	10300	5760	2190	5620	3200	8270	7660	18500	2280	12100	2700	3730	2720	2200	2760	2220
16	15000	3410	4240	3800	9920	2400	2040	4090	4010	8440	4000	18500	2440	6020	5840	2750	4170	2110	2840	2650
17	11600	3600	4110	3000	9830	1080	7120	8260	3590	9180	2020	16100	2440	2410	7820	2060	2580	5590	2330	10800
18	7700	4300	5860	3170	9070	3770	10300	10100	4200	2670	2020	15300	7030	3150	4450	2350	2670	8520	2680	10800
19	10100	4620	8240	2940	1900	3100	8820	8760	3460	2120	2630	18500	7230	11100	2420	2300	2270	9880	5380	5440
20	17500	4750	7720	1600	2320	3010	6840	7600	2520	6270	2960	18500	5910	8160	2330	2350	2460	7990	5340	2390
21	15000	4620	2480	2180	3780	5440	5280	2110	2110	7420	9340	18500	4880	2440	2520	2360	7300	4970	2640	2270
22	9200	4750	2390	3560	4870	4880	2110	1970	6800	9700	16700	18500	2390	7480	8040	7020	5030	9140	2530	2080
23	6950	3800	7530	3560	5120	2400	2040	6030	3080	9790	18200	8280	2600	6250	12000	7160	6510	5810	8500	2450
24	5880	3500	6100	3570	5280	1160	5250	7060	3100	10200	15300	2420	2630	7270	5150	2680	2810	11000	8030	2230
25	5500	4100	5080	3580	2040	4490	13700	11900	5000	3800	2320	7050	2360	2490	2300	2570	2530	10900	7520	2150
26	5120	5120	3810	3400	1900	4290	7080	12400	3930	2040	13800	9040	2410	2740	2500	2600	2640	10700	2700	2250
27	4880	5000	3800	1220	1970	4250	6040	1090C	2570	3110	19000	14200	4600	2420	2300	2750	2700	6570	8870	2190
28	4880	4300	2560	1900	2400	3540	5700	3710	2550	4110	16900	14200	5610	3060	4220	2710	2640	1980	9420	2090
29	6250	3800	2320	2440	2720	4290	2720	4140	5390	5840	19000	14200	2940	6680	5910	2900	2470	2010	2840	2080
30	9200	3230	4250	3400	2720	2020	2180	9970	4540	7840	19000	14300	3170	9810	4850	2660	6130	2210	4210	1970

Da	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	19500	17900	9340	5850	6200	8260	2290	18700	14200	13000	3220	8650	14900	13900	6110	2340	15100
2	19600	14400	11300	5830	6300	4190	3020	18600	6590	14000	4170	8830	15200	13900	6130	2600	13300
3	19500	18300	11400	5880	14100	6050	2350	18700	6190	14000	3040	9010	15100	10200	7680	2500	18700
4	19400	6180	11400	12100	18900	7900	2280	18600	12800	12000	3860	11200	6160	10000	7570	2240	10100
5	19500	11100	12100	14600	18800	5910	2300	18600	12200	8520	4070	9850	6140	9590	6650	2390	8500
6	19500	6470	12200	14600	18800	2370	2270	18600	14600	6210	2440	10500	14300	12600	6110	2360	11300
7	19400	6100	12100	14100	17900	4920	2360	18600	13900	9420	2680	11500	14200	15200	5960	4180	8430
8	19300	6130	12100	7580	6240	7210	2350	18700	13600	6160	4380	13800	11900	13100	2250	2310	18300
9	19400	6120	8660	7850	14200	8950	2390	18600	9480	6210	9570	13900	9660	11600	3840	2580	13900
10	19500	6050	6100	14700	14200	5530	2350	18600	11500	6140	2530	15300	10300	8920	8620	2180	8960
11	18800	6030	11400	14600	14200	5550	2360	18600	7710	6130	2630	18100	6160	12700	8180	2130	9630
12	6250	3430	13200	10800	14300	2380	2320	16000	6210	4420	2340	18100	6390	6970	2480	3680	10800
13	9810	1840	9510	3140	9730	2340	2320	12000	6270	2220	10300	18200	11500	9920	3860	2320	7950
14	12700	1890	8790	2050	6080	4360	2330	14800	6280	2230	10600	18100	6330	10100	2070	2530	8060
15	12300	9080	7820	2610	3720	3720	2330	18600	2360	2220	6920	18100	4500	4480	2090	2590	10600
16	15300	10700	4810	1960	11000	2470	2340	18600	2520	8170	2400	18100	3490	2030	2110	5590	5950
17	4820	2240	7540	1980	13900	2470	2300	18500	2400	6520	2400	18100	10300	2130	4500	2630	8550
18	10000	2050	2120	1940	13800	2920	2290	2850	5770	8730	2700	18200	2520	7200	2610	2670	8940
19	7620	9020	2000	8720	9500	2400	2310	13800	8070	8470	4100	18100	2480	7150	2170	2410	4450
20	8190	4060	7190	14600	5660	2490	2300	18600	6960	6120	2600	18000	3830	3400	2070	2380	7970
21	14600	4900	8620	12800	2360	2440	2300	18700	7670	3320	2200	18000	2350	2260	2080	2430	5240
22	13600	14600	9080	10100	2400	6890	2280	12400	7810	3010	3700	18000	2250	2020	2410	2410	8140
23	8850	19700	5180	4950	2360	7360	2340	11700	8470	7700	3000	18100	2370	2020	2180	2310	6740
24	11900	19800	11000	2030	6810	8520	2330	11400	2260	3960	3460	18200	2460	2010	3540	2710	9170
25	14200	19800	10800	2250	11600	7930	3070	2300	5980	2980	5360	17500	2260	2610	2270	2980	3010
26	11800	21700	8150	1890	2620	7960	2310	3280	8510	5760	2630	13700	3490	2150	2220	4830	2410
27	10100	23300	8630	1960	2350	2680	2280	12300	7990	10200	2730	14300	9060	2140	2230	5250	2350
28	13000	23100	9620	2140	2330	8260	2270	11200	10100	10300	2690	14300	9540	2160	2160	3240	2230
29	4800	21900	12900	1930	2330	8470	2270	8050	11900	8770	2500	18200	2260	2040	2210	2160	2130
30	8800	23700	11700	1940	2370	8680	2340	3500	9770	2580	2430	14000	5530	2070	2340	2190	3390

Appendix Table B-3. Group 1 flow data summary on a weekly schedule, 1 March-30 June, for "optimum flow" years in which the JAI was greater than 5.0 (n=13, years = 1956, 57, 59, 60, 61, 62, 65, 67, 68, 70, 74, 75, and 76).

Week	N	Mean	Max	Min	P5	Q1	Median	Q3	P95
1	91	9673.8	24500	588	1070.0	4090	7940	14600	2400
2	91	8818.3	24000	588	1090.0	4090	8070	12900	19000
3	91	8993.4	22800	602	1092.0	4360	6990	14000	19000
4	91	10042.2	33900	609	975.6	2910	9100	15800	27140
5	91	10360.3	35300	665	1246.0	2830	7820	16000	35200
6	91	11797.0	35500	1530	1884.0	2730	8620	19000	35340
7	91	13608.5	35600	1800	1892.0	2860	17400	19000	35100
8	91	11451.9	35100	1880	2006.0	3800	9520	17900	34940
9	91	7854.1	18300	1930	2270.0	5960	6880	9520	15160
10	91	8084.7	15700	1950	2022.0	6040	8300	9500	14160
11	91	9069.9	16100	5020	5684.0	6220	8300	11600	14680
12	91	7344.5	17400	2250	5038.0	5890	6210	8110	14560
13	91	6110.4	15000	2000	2236.0	4500	6000	7180	11540
14	91	6934.8	18900	1860	2106.0	4040	5880	8460	15000
15	91	6836.4	17900	1300	2036.0	3720	6080	8950	14240
16	91	5857.8	18500	1080	2004.0	2420	3720	8440	17060
17	91	6186.9	19000	1160	2036.0	2400	4970	8520	17300
18	39	5777.7	19000	1930	1940.0	2180	4110	7840	19000

Appendix Table B-4. Group 2 flow data summary on a weekly schedule, 1 March-30 June, for "high flow" years (>8,000 cfs) in which the JAI was less than 5.0 (n=9, years = 1958, 71, 72, 73, 78, 79, 80, 83, and 84). The year 1955 was overlooked in the calculation.

Week	N	Mean	Max	Min	P5	Q1	Median	Q3	P95
1	70	14669.1	25700	1050	4871.5	9860.0	14100	19500.0	25600
2	70	14060.9	25800	1120	1658.5	9402.5	13900	19250.0	25700
3	70	13424.5	25600	713	1234.5	6325.0	14550	18625.0	25500
4	70	15388.0	24900	753	1525.0	11900.0	18550	19600.0	22290
5	70	15205.0	20400	1550	1810.0	11575.0	18650	19400.0	20345
6	70	14553.1	20400	1840	1905.5	8457.5	18600	19500.0	20400
7	70	16855.1	31200	1900	3295.0	10737.5	18750	20325.0	29670
8	70	16071.0	31800	2070	2459.5	10700.0	18200	20000.0	25835
9	70	16902.4	35300	4710	5876.5	11300.0	18550	20000.0	25880
10	70	17919.4	34700	5960	6026.5	11110.0	19350	21000.0	34645
11	70	15930.9	34700	5990	6136.5	8267.5	14300	19900.0	34500
12	70	15899.1	34700	2880	5775.5	8330.0	15400	19500.0	34700
13	70	13608.3	26300	2560	6108.5	8415.0	12650	19075.0	25600
14	70	12405.6	19600	1700	4626.0	8245.0	12300	15800.0	19500
15	70	9998.4	19500	1840	3677.5	6137.5	9450	12800.0	19345
16	70	7237.1	18600	1890	2016.5	2872.5	7170	9852.5	18545
17	70	7768.7	23300	1900	1992.0	2397.5	7365	11475.0	19800
18	30	8490.3	23700	2040	2051.0	2720.0	8785	11325.0	23370

Appendix Table B-5. Group 3 flow data summary on a weekly schedule, 1 March-30 June, for "low flow" years (<8,000 cfs) in which the JAI was less than 5.0 (n=8, years = 1963, 66, 69, 77, 81, 82, 85, and 86). The year 1964 was overlooked in the calculation.

Week	N	Mean	Max	Min	P5	Q1	Median	Q3	P95
1	49	7707.76	15700	1130	1185.0	2390.0	8030	13550.0	15550.0
2	49	7311.43	17500	1110	1155.0	2260.0	6680	12750.0	15750.0
3	49	5513.06	17100	1130	1160.0	2405.0	4520	7125.0	14200.0
4	49	3874.29	11500	1090	1120.0	1450.0	3280	6225.0	9810.0
5	53	3568.87	9170	1090	1154.0	2100.0	2640	4980.0	8170.0
6	56	5140.71	18700	2000	2048.5	2260.0	3060	6640.0	14360.0
7	56	4724.11	13900	1970	1978.5	2332.5	2775	6807.5	12180.0
8	56	3786.07	10500	1890	2002.5	2262.5	2530	5112.5	9359.0
9	56	5087.14	12300	2060	2068.5	3320.0	5985	6195.0	7990.0
10	56	6470.18	14400	2040	2244.0	5855.0	6115	6327.5	12275.0
11	56	6005.36	10200	2270	2288.5	5977.5	6185	6345.0	9086.5
12	56	5442.50	11800	1990	2025.5	5560.0	6035	6237.5	7643.5
13	56	4873.21	10100	2110	2208.0	3920.0	5340	6130.0	7685.0
14	56	4388.21	11200	2000	2138.5	2352.5	3810	6080.0	9947.5
15	56	5692.50	18200	2130	2130.0	2350.0	3680	8510.0	18100.0
16	56	5382.14	18200	2060	2070.0	2330.0	2655	5537.5	18100.0
17	56	5297.50	18200	2080	2197.0	2372.5	2720	7125.0	18015.0
18	24	4983.33	18200	2160	2162.5	2287.5	2700	6062.5	17225.0

Appendix Table B-6. The number of days and percentage of time in which the average daily rate of Roanoke River flow (cfs as measured by the USGS gage near Weldon) was within the recommended Q1-Q3 bounds criteria established by the Committee.

	Mar-Jun		Apr-Jun	
Year	n	Percent Q1-Q3	n	Percent Q1-Q3
1912	69	54.76	50	59.18
1913	48	38.10	36	36.73
1914	68	53.97	44	44.90
1915	59	46.83	38	38.78
1916	40	31.75	33	33.67
1917	58	46.03	48	48.98
1918	48	38.10	35	35.71
1919	59	46.83	44	44.90
1920	55	43.65	42	42.86
1921	83	65.87	60	61.22
1922	63	50.00	55	56.12
1923	75	59.52	66	67.35
1924	64	50.79	42	42.81
1925	47	37.30	32	32.65
1926	26	20.63	12	12.24
1927	55	43.65	37	37.76
1928	58	46.03	49	50.00
1929	70	55.56	57	58.16
1930	28	22.22	20	20.41
1931	37	29.37	32	32.65
1932	54	42.86	42	42.86
1933	68	53.97	52	53.06
1934	45	35.71	35	35.71
1935	82	65.08	62	63.27
1936	69	54.76	52	53.06
1937	92	73.02	66	67.35
1938	72	57.14	47	47.96
1939	81	64.29	69	70.41
1940	69	54.76	57	58.16
1941	45	35.71	32	32.65
1942	45	35.71	38	38.78
1943	81	64.29	67	68.37
1944	65	51.59	56	37.14
1945	60	47.62	48	48.98
1946	79	62.70	54	55.10
1947	75	59.52	63	64.29
1948	63	50.00	48	48.98
1949	81	64.29	62	63.27
1950	53	42.06	42	42.86

Appendix Table B-6. (Continued)

	Mar-Jun		Apr-Jun	
Year	n	Percent Q1-Q3	n	Percent Q1-Q3
1952	67	53.17	58	59.18
1951	71	56.35	57	58.16
1953	78	61.90	58	59.18
1954	44	34.92	35	35.71
1955	56	44.44	41	41.84
1956	47	37.30	46	46.94
1957	58	46.03	46	46.94
1958	19	15.08	12	12.24
1959	54	42.86	49	50.00
1960	27	21.43	24	24.49
1961	38	30.16	31	31.63
1962	51	40.48	46	46.94
1963	59	46.83	57	58.16
1964	53	42.06	45	45.92
1965	53	46.03	37	37.76
1966	35	27.78		
1967	37	29.37	29	29.58
1968	62	49.21	50	51.02
1969	52	41.27	44	44.90
1970	45	35.71	38	38.78
1971	45	35.71	33	33.67
1972	44	34.92	32	32.65
1973	23	18.25	14	14.29
1974	38	30.16	26	26.53
1975	33	26.19	26	26.53
1976	55	43.65	48	48.98
1977	46	36.51	39	39.80
1978	16	12.70	11	11.22
1979	27	21.43	27	27.55
1980	38	30.16	24	24.49
1981	20	15.87	20	20.41
1982	45	35.71	33	33.67
1983	16	12.70	11	11.22
1984	16	11.11	14	14.29
1985	28	22.22	23	23.47
1986	48	38.10	38	38.78
1987	10	7.94	10	10.20
1988	51	45.13	49	57.65

Appendix Table B-7. The number of days (out of 76) and percentage of time that Roanoke River flows (cfs, USGS data) were within the negotiated flow regime Q1-Q3 bounds criteria established by the Committee for the period 1 April to 15 June. Number of days by visual inspection of the data.

Year	"n" days within	PDAYS within	JAI
1951	49	64.47	
1952	54	71.05	
1953	55	72.37	
1954	31	40.79	
1955	34	44.74	3.27
1956	39	51.32	19.14
1957	42	55.26	5.71
1958	9	11.84	0.15
1959	49	64.47	23.86
1960	25	32.89	5.93
1961	40	52.63	10.33
1962	47	61.84	7.86
1963	51	67.11	4.80
1964	44	57.89	3.14
1965	33	43.42	10.08
1966	26	34.21	3.48
1967	28	36.84	23.39
1968	47	61.84	6.59
1969	41	53.95	2.99
1970	42	55.26	12.45
~~1971~~	~~27~~	~~35.53~~	~~2.86~~
1972	26	34.21	2.52
1973	11	14.47	1.95
1974	24	31.58	5.52
1975	27	35.53	10.80
1976	49	64.47	10.52
1977	36	47.37	3.63
1978	11	14.47	0.59
1979	22	28.95	0.55
1980	22	28.95	0.46
1981	17	22.37	0.09
1982	35	46.05	3.80
1983	8	10.53	0.84
1984	14	18.42	0.36
1985	27	35.53	0.32
1986	36	47.37	0.11
1987	11	14.47	0.30

Appendix Table B-8. Estimated number of striped bass eggs produced in the Roanoke River, NC, for the period 1963-1985 (from the annual reports of W.W. Hassler). No data available for 1971 or 1978.

Mo Da	1963	1964	1965	1966	1967	1968	1969	1970	1972	1973	1974
Apr 15	0	.	.	.	.	.	.	.	.	.	.
Apr 16	0	.	.	.	.	.	.	.	.	.	.
Apr 17	0	.	.	.	.	.	.	.	.	.	.
Apr 18	8614574	.	.	.	.	.	.	.	.	.	.
Apr 19	4271554	.	.	.	.	.	.	.	.	.	.
Apr 20	29911101	.	.	.	.	.	.	.	.	.	.
Apr 21	32117818	.	2762766	.	2908310	.	.	.	.	.	.
Apr 22	1855181	.	1656220	.	21154599	.	.	.	.	.	.
Apr 23	524089	.	13328648	.	150653541	.	.	.	.	.	.
Apr 24	0	36535162	1258982	.	18378822	0	.	.	.	.	.
Apr 25	0	12065023	1666300	.	9403330	0	.	.	.	.	.
Apr 26	0	3240027	874293	3710602	23259897	385718	.	.	.	.	.
Apr 27	220408	12881936	5308913	10064655	6759004	2449460	0	.	.	.	.
Apr 28	221304	11226436	1843154	8190480	14326885	1262685	.	0	.	.	.
Apr 29	0	19080159	1080832	1053832	3186027	11753584	4982853	.	.	6453054	.
Apr 30	0	22633903	1332011	4323893	7610052	4670576	15776771	35856299	.	6453054	.
May 1	0	3679745	620337	5110757	47180502	760326	5838220	22730332	.	17736679	36489903
May 2	681779	7826908	1398869	39555072	34793416	6951555	20898894	14880364	19852699	38776643	58521364
May 3	904401	1785101	9563120	12955171	182248227	712086	70501548	37213716	35115216	27760551	44182651
May 4	2560150	1908016	53539132	3785174	3013071	12499716	118122127	75388845	184570485	24088521	7370392
May 5	2560150	1922416	9534937	42120321	5516377	65802377	263681626	3757403	166415924	2056337	30405235
May 6	1001798	3570201	14865244	6491574	3377188	113231229	128396716	23814712	98105997	2056337	257692612
May 7	528727	8238926	6771656	74009622	21974480	1138638	42389273	100974053	299484454	4810360	11983779
May 8	1850543	9749396	51544201	830261547	29417388	2024245	61164458	235580820	934838696	38996965	17176462
May 9	80829384	32236726	43793902	11978843	3157741	6578798	1210124370	61087929	1130351194	82400367	10502620
May10	64351584	250588831	21661895	17678513	6351481	11265008	134432886	15560461	11122518	16744459	18155875
May11	62612352	461626704	51099854	4150680	1823981	885585780	10780341	117431539	16955512	36499984	99675470
May12	60441790	25560213	176272898	4482037	6788628	9220191	16027848	150132308	16131822	328340839	1138623247
May13	8751815	30089051	125250187	5519309	12024203	4879018	20871637	464095	5985061	12928428	31988014
May14	23417020	13342760	14719597	8749821	16808643	32898154	97778872	27349428	39850007	28950516	15409568
May15	56892967	96545605	36628042	59358632	8146354	6283287	582872269	83190007	126995170	129341364	26132101
May16	48086286	115162388	14377080	897796	8662289	14618282	9923328	69769404	1664454739	15336128	73024448
May17	3926079	5159357	55872466	4710176	11880099	30730113	10884999	71329349	4021307	14134438	22084022
May18	970966	28376465	54085308	101411919	8309281	42656190	24306580	53212352	5671876	32676855	66240552
May19	90961201	32406442	20009892	433531401	38108889	18536349	42782499	40484909	10530502	10409744	29314530
May20	87372849	14829778	11146001	3330953	151046973	26981865	13545164	80172771	9918687	123141598	58934341
May21	72073774	15516644	3778591	10253091	106065524	52578438	37210167	44912946	1853907	299410175	10045317
May22	10455472	1647785	4535112	11448404	166484313	9754333	26745600	12242365	6785609	23926519	34766004
May23	56695959	2608993	3000316	14698511	1018294	11128258	38062645	22621971	12234245	19927297	19131588
May24	2575170	1716410	4238264	29083099	2199515	59226511	80261383	8728170	2333918	21800753	6197811
May25	7739582	188208	2139446	20192312	1126912	5868460	7087996	12191817	13890574	14302405	8469738
May26	9442291	317084	1427155	14040118	1588539	3384028	12822433	10641513	108944644	8691501	9564559
May27	7035984	26585	536919	7830066	4512892	3768603	35658297	9324138	5136069	7678144	5214798
May28	8907556	.	0	7863700	75844043	10876205	13082252	12016622	449875	20453313	1902050
May29	13565377	.	.	5168615	58286543	287282	27686339	11462370	.	10437516	4110616
May30	30254731	.	.	3375028	2403277	3782191	7283375	316282	.	18570395	3806566
May31	8302461	.	.	0	11583096	1475189	13826687	.	.	43848365	2568670
Jun 1	3109905	.	.	.	1860701	6157594	7400684	.	.	8434562	2249296
Jun 2	1785348	.	.	.	4651753	1944016	10130176	.	.	932305	1305268
Jun 3	1255726	.	.	.	4104343	0	4836897	.	.	3085637	.
Jun 4	4166567	.	.	.	15547810	0	1537316	.	.	.	.
Jun 5	4352086	.	.	.	7749425	.	0	.	.	.	.
Jun 6	288502	.	.	.	1395834	.	0	.	.	.	.
Jun 7	208075	.	.	.	2819646	.	.	.	.	.	.
Jun 8	0	.	.	.	946088	.	.	.	.	.	.
Jun 9	.	.	.	.	4854640	.	.	.	.	.	.
Jun 10	.	.	.	.	0	.	.	.	.	.	.
Jun 11	.	.	.	.	0	.	.	.	.	.	.
Jun 12	.	.	.	.	.	.	.	.	.	.	.
Jun 13	.	.	.	.	.	.	.	.	.	.	.
Jun 14	.	.	.	.	.	.	.	.	.	.	.
Jun 15	.	.	.	.	.	.	.	.	.	.	.
Jun 16	.	.	.	.	.	.	.	.	.	.	.
Jun 17	.	.	.	.	.	.	.	.	.	.	.
Jun 18	.	.	.	.	.	.	.	.	.	.	.
Jun 19	.	.	.	.	.	.	.	.	.	.	.
Jun 20	.	.	.	.	.	.	.	.	.	.	.

Appendix Table B-8. (Continued)

Mo Da	1975	1976	1977	1979	1980	1981	1982	1983	1984	1985
Apr 15	.	.	.	.	.	.	.	.	.	.
Apr 16	.	.	.	.	.	.	.	.	.	.
Apr 17	.	.	.	.	.	.	.	.	.	.
Apr 18	.	.	.	.	.	.	.	.	.	.
Apr 19	.	.	.	.	.	.	.	.	.	.
Apr 20	.	.	.	.	.	.	.	.	.	.
Apr 21	.	.	.	.	.	.	.	.	.	.
Apr 22	.	.	.	.	.	.	.	.	.	.
Apr 23	.	.	.	.	.	.	.	.	.	.
Apr 24	.	.	.	.	.	.	.	.	.	.
Apr 25	.	.	.	.	.	.	.	.	.	14636899
Apr 26	.	.	.	.	.	.	.	.	.	32579500
Apr 27	.	.	.	.	.	.	.	.	.	32866422
Apr 28	.	.	.	.	.	.	.	.	.	29589984
Apr 29	.	.	2463789	.	.	14807849	.	.	.	8604792
Apr 30	.	.	5779714	.	.	4466917	.	.	.	19839765
May 1	.	5331902	8879443	.	0	1450291		.	.	18465582
May 2	.	21438487	7530697	.	0	2049754	.	.	.	41106994
May 3	.	4380362	68871634	.	0	850841	9689224	.	.	82259811
May 4	.	25173981	43064716	.	1981431	2668548	15930133	.	.	40067922
May 5	.	77354359	2159941	.	8956067	4234870	12677068	.	.	15459557
May 6	.	13881705	4400204	.	11999671	3384028	24203403	0	.	50112418
May 7	82596620	81509822	24232908	.	28009776	6136315	36862867	0	.	50726171
May 8	316455493	475588983	616103292	.	26123463	3404646	52449125	2479392	.	52813880
May 9	17072885	65243524	72401103	.	26148931	231102640	195991599	31345564	2025531	18715939
May 10	16473737	6794799	78266967	0	547205	15980245	861737906	2778863	688681	4519169
May 11	44370473	121551413	20846694	7586415	823738	1624128	38727708	2274149	3362382	12669226
May 12	56276903	79457805	11393231	6753759	16381854	2643097	3368147	3921461	14065317	6794799
May 13	73530304	35642056	31295961	45912623	522546155	4567860	16831627	9761224	43624032	4676439
May 14	280246907	33359164	181985836	143738141	19530162	7747779	59829691	2159153	27501657	9494822
May 15	187269033	24715399	272427950	259433590	6781377	4107506	12813921	33880293	112312810	29721745
May 16	249083398	119165683	68501731	19195669	3492929	1996474	59403581	83007948	5363788	16397828
May 17	17100143	29187439	13659954	26920304	1424686	11995043	56412465	48137029	8205908	1316171
May 18	22823367	183082097	76195021	41458974	20725465	1068052	71883748	3562898	8427773	1734494
May 19	66838054	28498125	23617483	20625734	2619233	1097238	7889620	4151811	23981239	5078717
May 20	34431407	5601935	20974968	13459998	4096834	999523	17087491	1911615	119810027	111097
May 21	279541196	3938145	16672253	12048272	27211212	223840	37450084	1664998	64789122	.
May 22	245051468	10826381	17487341	23054335	6511158	1807590	14635665	729443	262107601	.
May 23	6546500	19508624	27212822	738671533	112060000	11015722	8746962	67953394	16621441	202502
May 24	8917789	9935507	25223610	35030740	459651	2840649	13016484	73328239	38770883	.
May 25	137161449	6794799	1168621	5618001	1104180	0	6761628	181935230	42405833	.
May 26	18519377	2385730	4753325	47193801	5008649	0	2192804	85173366	60284250	.
May 27	6117171	2521626	8708113	5962514	9921749	92613	17243938	78739084	34104524	.
May 28	15206527	1701914	7512080	1315636	657776	0	21834696	16695190	11072972	.
May 29	5317759	1711660	8898246	11868219	4643879	.	3412828	106866581	4377945	.
May 30	2828595	485233	2201907	24580105	485601	.	2398124	343217551	8399590	.
May 31	2957682	.	1065763	23805774	0	.	12577924	96575021	2845567	.
Jun 1	273859	.	.	10148999	0	.	3920536	2661662	267646	.
Jun 2	0	.	.	7121291	.	.	907856	3076379	1105724	.
Jun 3	.	.	.	43000970	.	.	.	3727573	7266918	.
Jun 4	.	.	.	14819451	.	.	.	7794064	9168762	.
Jun 5	.	.	.	4446304	.	.	.	22418003	1262171	.
Jun 6	.	.	.	8078467	.	.	.	16157706	560833	.
Jun 7	.	.	.	5032842	.	.	.	2134174	1382154	.
Jun 8	.	.	.	2779804	.	.	.	1668459	2385123	.
Jun 9	.	.	.	1536956	.	.	.	3106877	1211153	.
Jun 10	.	.	.	2182160	.	.	.	6551900	.	.
Jun 11	.	.	.	0	.	.	.	1064888	.	.
Jun 12	.	.	.	.	.	.	.	0	.	.
Jun 13	.	.	.	.	.	.	.	.	.	.
Jun 14	.	.	.	.	.	.	.	.	.	.
Jun 15	.	.	.	.	.	.	.	.	.	.
Jun 16	.	.	.	.	.	.	.	.	.	.
Jun 17	.	.	.	.	.	.	.	.	.	.
Jun 18	.	.	.	.	.	.	.	.	.	.
Jun 19	.	.	.	.	.	.	.	.	.	.
Jun 20	.	.	.	.	.	.	.	.	.	.

Appendix Table B-9. Estimated percent egg viability for striped bass in the Roanoke River, NC, for the period 1965-1985 (from the annual reports of W.W. Hassler). No data available for 1971 or 1978.

Mo	Da	1965	1966	1967	1968	1969	1970	1972	1973	1974	1975	1976	1977	1979	1980	1981	1982	1983	1984	1985
Apr	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	21	89.47	.	92.31	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	22	100.00	.	96.37	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	23	88.31	.	98.41	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	24	77.77	.	91.95	0.00	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	25	100.00	.	95.98	0.00	.	.	.	.	.	.	.	.	.	.	.	.	.	.	79.66
Apr	26	100.00	76.92	94.24	50.00	.	.	.	.	.	.	.	.	.	.	.	.	.	.	71.13
Apr	27	95.24	98.68	94.37	92.31	.	.	.	.	.	.	.	.	.	.	.	.	.	.	74.12
Apr	28	100.00	98.36	93.87	76.92	.	.	.	.	.	.	.	.	.	.	.	.	.	.	70.69
Apr	29	100.00	98.70	94.28	89.47	95.45	.	.	57.14	.	.	.	50.00	.	.	26.81	.	.	.	61.99
Apr	30	100.00	94.73	96.26	98.18	94.62	88.39	.	78.57	.	.	.	56.00	.	.	51.35	.	.	.	81.95
May	1	100.00	68.00	96.78	88.89	95.35	94.37	.	72.73	94.74	.	76.92	52.56	.	.	41.66	.	.	.	76.84
May	2	100.00	90.67	94.48	92.68	90.10	94.62	76.00	89.94	90.36	.	69.70	53.45	.	.	58.82	.	.	.	77.57
May	3	92.73	94.29	95.15	100.00	92.13	92.47	81.78	79.34	88.38	.	78.13	38.93	.	.	57.14	62.50	.	.	64.33
May	4	98.47	94.44	86.79	88.61	93.25	88.78	90.90	87.62	88.89	.	48.92	37.69	.	16.67	50.00	67.86	.	.	78.59
May	5	97.22	95.24	91.75	89.52	95.04	97.78	89.31	100.00	93.75	.	42.47	53.85	.	11.11	48.57	72.50	.	.	69.54
May	6	98.51	88.54	96.15	88.97	87.88	93.33	85.56	88.89	92.26	.	32.84	26.09	.	8.33	32.35	69.62	0.00	.	79.63
May	7	95.52	91.96	96.75	80.00	94.33	91.18	90.58	76.19	85.71	73.09	46.37	60.84	.	7.48	45.28	66.99	0.00	.	62.50
May	8	96.51	96.20	98.57	100.00	91.41	92.92	93.89	86.47	89.36	61.94	46.83	58.03	.	2.92	46.51	79.86	0.00	0.00	62.57
May	9	95.13	93.24	96.97	85.54	85.35	93.98	86.70	94.15	91.80	58.43	34.35	51.61	.	24.49	84.73	89.41	51.61	0.00	74.52
May	10	95.00	86.38	90.38	86.44	88.46	92.03	56.86	91.78	96.12	41.07	35.19	46.45	.	33.33	45.91	84.09	14.29	0.00	81.58
May	11	96.60	90.20	86.67	83.01	92.13	84.54	74.67	82.39	92.73	55.07	51.66	48.02	21.05	25.00	43.75	79.13	0.00	0.00	73.00
May	12	94.09	83.93	89.29	89.56	93.48	87.64	83.54	71.82	88.05	49.12	64.89	40.00	54.84	52.67	29.41	65.22	0.00	2.86	53.70
May	13	96.31	85.51	96.04	85.24	95.15	60.00	94.74	52.00	92.84	51.82	45.11	50.00	65.61	59.34	40.00	60.87	2.50	22.02	58.33
May	14	97.59	82.07	92.65	90.27	90.56	74.21	94.34	86.29	90.68	59.98	74.70	49.50	44.38	20.16	26.08	52.65	0.00	3.61	63.41
May	15	95.75	79.18	92.65	83.12	91.82	92.64	94.75	91.34	89.77	61.21	53.07	57.41	44.35	37.74	80.00	70.93	11.81	22.29	67.57
May	16	96.14	100.00	91.04	88.23	92.98	91.85	91.77	90.47	77.75	56.51	60.51	54.10	63.04	39.29	68.00	75.08	13.18	5.00	84.07
May	17	96.61	89.65	90.72	87.10	96.80	89.02	66.67	93.33	84.30	60.95	43.97	49.58	43.93	23.08	80.82	70.25	6.90	10.87	70.59
May	18	98.60	89.25	95.71	88.18	92.47	86.77	84.00	85.71	79.08	57.99	59.73	42.20	30.88	52.17	30.76	59.86	0.00	5.17	56.00
May	19	97.92	95.29	93.82	88.55	95.66	91.41	91.30	90.36	57.50	69.45	40.63	32.05	28.72	27.78	12.50	40.82	0.00	17.92	84.42
May	20	97.87	95.12	94.04	85.04	95.36	86.78	81.39	89.71	68.84	58.22	27.27	48.57	37.50	3.57	37.50	76.27	0.00	19.36	50.00
May	21	93.48	94.44	96.72	91.61	94.77	78.34	75.00	92.93	91.34	49.68	64.52	51.39	36.84	28.07	50.00	68.73	33.33	18.48	0.00
May	22	98.28	90.91	98.52	96.61	96.74	83.66	82.76	86.75	86.06	55.07	22.09	48.34	32.22	36.96	57.14	74.51	0.00	5.41	0.00
May	23	91.67	96.30	84.62	97.84	93.82	88.21	90.38	90.55	77.50	30.95	54.84	59.15	51.20	4.92	74.62	75.81	26.86	7.02	100.00
May	24	93.62	93.60	100.00	96.09	90.86	81.93	80.00	94.44	81.40	8.85	44.30	58.33	63.64	0.00	80.00	74.71	22.55	33.74	.
May	25	.	96.55	80.00	88.73	88.46	71.33	88.13	81.94	84.29	52.10	18.52	30.00	44.44	12.50	0.00	57.78	28.14	26.14	.
May	26	90.00	94.85	100.00	92.86	92.91	95.49	89.03	90.38	79.66	55.04	52.63	22.50	28.15	10.81	0.00	53.33	36.71	32.62	.
May	27	83.33	93.08	92.31	91.67	97.19	87.29	59.09	94.54	70.15	38.82	30.00	33.78	12.12	16.67	0.00	79.83	42.02	32.86	.
May	28	0.00	91.73	98.37	97.99	90.54	89.47	100.00	88.41	86.36	19.53	38.10	62.79	12.50	0.00	0.00	68.75	36.96	36.30	.
May	29	.	93.83	95.38	100.00	94.58	80.69	.	93.22	57.58	27.66	77.42	55.56	12.16	0.00	.	47.62	52.83	28.57	.
May	30	.	93.88	87.87	92.00	98.39	50.00	.	92.25	56.52	23.33	55.56	54.29	2.42	0.00	.	50.00	37.96	26.67	.
May	31	.	.	96.58	88.23	91.45	.	.	94.39	66.67	18.52	.	29.41	19.00	0.00	.	61.18	54.55	8.33	.
Jun	1	.	.	88.89	87.21	92.94	.	.	90.36	47.06	50.00	.	.	13.89	0.00	.	76.00	7.69	0.00	.
Jun	2	.	.	96.30	93.88	83.18	.	.	85.71	38.46	0.00	.	.	7.89	.	.	40.00	0.00	25.00	.
Jun	3	.	.	100.00	0.00	73.68	.	.	80.95	.	.	.	.	27.18	.	.	.	28.57	10.00	.
Jun	4	.	.	97.56	0.00	94.12	.	.	.	.	.	.	.	24.39	.	.	.	31.71	12.50	.
Jun	5	.	.	100.00	.	.	.	.	.	.	.	.	.	10.53	.	.	.	49.69	0.00	.
Jun	6	.	.	90.00	.	.	.	.	.	.	.	.	.	10.81	.	.	.	42.35	0.00	.
Jun	7	.	.	94.74	.	.	.	.	.	.	.	.	.	21.43	.	.	.	11.11	0.00	.
Jun	8	.	.	80.00	.	.	.	.	.	.	.	.	.	0.00	.	.	.	0.00	14.29	.
Jun	9	.	.	92.31	.	.	.	.	.	.	.	.	.	16.67	.	.	.	40.00	25.00	.
Jun	10	.	.	0.00	.	.	.	.	.	.	.	.	.	0.00	.	.	.	20.00	0.00	.
Jun	11	.	.	0.00	.	.	.	.	.	.	.	.	.	.	.	.	.	57.14	.	.
Jun	12	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.00	.	.
Jun	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Appendix Table B-10. Daily minimum temperature (F) of the Roanoke River near Halifax, NC, during the period 1963-1977 (from the annual reports of W.W. Hassler).

Mo	Da	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Apr	9	55.0	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	11	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	12	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	13	.	.	58.0	.	.	.	.	.	.	.	.	.	.	.	.
Apr	14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	18	57.0	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	19	58.0	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	20	60.0	60.0	.	.	.	59.0	.	.	.	.	.	.	.	.	.
Apr	21	60.0	.	57.0	.	62.0	.	.	.	.	.	.	.	.	.	.
Apr	22	60.0	.	57.0	.	62.0	.	.	.	.	.	.	.	.	.	.
Apr	23	60.0	.	58.0	.	62.0	.	.	.	.	.	.	.	.	.	.
Apr	24	60.0	61.0	60.0	.	60.0	60.0	.	.	.	.	.	.	.	.	.
Apr	25	60.0	59.0	56.0	.	60.0	60.0	.	.	.	.	.	.	.	.	.
Apr	26	60.0	58.0	59.0	62.0	59.0	59.0	.	.	.	.	.	.	.	.	.
Apr	27	60.0	59.0	.	61.0	59.0	60.0	61.0	.	.	.	.	.	.	.	.
Apr	28	61.0	60.0	59.0	60.0	58.0	60.0	.	62.0	.	.	.	.	.	.	.
Apr	29	59.0	62.0	58.5	60.0	59.0	59.0	63.0	.	.	.	45.0	.	.	.	61.7
Apr	30	60.0	59.0	58.0	60.0	61.0	60.0	63.0	63.0	.	.	50.0	.	.	.	.
May	1	59.0	50.0	62.0	61.0	63.0	60.0	63.0	61.0	.	.	54.0	65.0	.	65.0	61.3
May	2	59.0	59.0	61.0	60.0	64.0	60.0	61.0	62.0	.	63.5	63.0	64.0	.	65.0	61.7
May	3	58.0	59.0	63.0	59.0	63.0	62.0	61.0	62.0	.	62.0	59.0	62.0	.	65.0	63.5
May	4	59.0	59.0	63.0	61.0	62.0	63.0	63.0	61.0	.	62.0	51.0	63.0	.	65.0	62.2
May	5	59.0	59.0	65.0	60.0	62.0	64.0	63.0	61.0	.	62.0	47.0	61.0	.	65.0	63.1
May	6	59.0	59.0	63.5	61.0	63.0	62.0	64.0	62.0	.	63.0	45.0	61.0	.	66.0	63.5
May	7	59.0	59.5	63.5	64.0	63.0	62.0	63.0	62.0	.	64.0	55.0	62.0	61.0	67.0	65.3
May	8	59.0	60.0	63.0	65.0	63.0	62.0	64.0	63.0	.	63.0	58.0	62.0	61.0	66.0	65.6
May	9	64.0	64.0	63.0	60.0	62.0	62.0	66.0	63.0	.	63.0	61.0	62.0	60.0	66.0	65.3
May	10	62.0	67.0	64.0	61.0	61.0	63.0	65.0	63.0	.	63.5	59.0	63.0	61.0	66.0	63.8
May	11	66.0	65.0	65.0	61.0	62.0	64.0	64.0	66.0	.	63.0	63.0	63.0	60.0	67.0	63.3
May	12	63.0	67.0	67.0	62.0	64.0	65.0	63.0	66.0	.	63.0	62.0	64.0	62.0	66.0	63.5
May	13	64.0	66.0	65.0	62.0	63.0	67.0	63.0	68.0	.	63.0	55.0	63.0	63.0	67.0	63.8
May	14	64.0	68.0	67.0	63.0	63.0	65.0	65.0	68.0	.	63.0	59.0	65.0	64.0	66.0	64.7
May	15	65.0	67.0	66.0	62.0	.	65.0	66.0	68.0	.	64.0	53.0	66.0	64.0	67.0	66.2
May	16	62.0	64.0	67.0	63.0	.	65.0	64.0	66.0	.	64.0	46.0	66.0	64.0	68.0	64.9
May	17	62.0	67.0	69.0	63.0	.	66.0	65.0	67.0	.	64.0	45.0	67.0	64.0	68.0	65.6
May	18	63.0	70.0	70.0	66.0	.	67.0	65.0	67.0	.	64.5	45.0	69.0	63.0	70.0	69.1
May	19	65.0	68.0	70.0	66.0	.	68.0	65.0	67.0	.	64.5	50.0	69.0	64.0	69.0	68.9
May	20	.	69.0	69.0	67.0	.	68.0	67.0	68.0	.	63.5	57.0	69.0	64.0	67.0	68.0
May	21	67.0	69.0	69.0	67.0	.	67.0	67.0	70.0	.	63.5	52.0	68.0	65.0	67.0	66.9
May	22	67.0	71.0	67.0	67.0	.	66.0	64.0	67.0	.	.	53.0	69.0	64.0	69.0	68.5
May	23	67.0	73.0	69.0	68.0	.	68.0	68.0	69.0	.	.	58.0	71.0	65.0	69.0	70.2
May	24	65.0	72.0	.	67.0	.	68.0	66.0	70.0	.	.	65.0	70.0	66.0	68.0	68.7
May	25	65.0	76.0	.	68.0	.	68.0	67.0	69.0	.	.	59.0	70.0	69.0	68.0	68.7
May	26	65.0	74.0	.	67.0	.	67.0	68.0	70.0	.	.	54.0	71.0	68.0	68.0	68.5
May	27	65.0	71.0	.	67.0	.	65.0	66.0	70.0	.	.	60.0	69.0	69.0	68.0	69.8
May	28	64.0	70.0	.	67.0	.	63.0	67.0	72.0	.	.	61.0	69.0	73.0	68.0	68.5
May	29	65.0	69.0	.	71.0	.	64.0	67.0	69.0	.	.	66.0	70.0	70.0	69.0	71.4
May	30	68.0	.	.	67.0	.	65.0	69.0	70.0	.	.	67.0	70.0	71.0	69.0	70.2
May	31	65.0	66.0	.	66.0	.	67.0	69.0	70.0	.	.	67.0	70.0	72.0	.	70.0
Jun	1	65.0	.	.	.	.	66.0	68.0	68.0	.	.	68.0	71.0	72.0	.	.
Jun	2	65.0	.	.	.	.	69.0	70.0	.	.	.	70.0	72.0	73.0	.	.
Jun	3	66.0	.	.	.	.	69.0	72.0	.	.	.	70.0	.	.	.	.
Jun	4	68.0	.	.	.	.	68.0	72.0	.	.	.	.	.	.	.	.
Jun	5	67.0	.	.	.	.	.	72.0	.	.	.	.	.	.	.	.
Jun	6	.	.	.	.	.	.	71.0	.	.	.	.	.	.	.	.
Jun	7	69.0	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	8	69.0	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Jun	18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Appendix Table B-11. Daily maximum temperature (F) of the Roanoke River near Halifax, NC, during the period 1963-1977 (from the annual reports of W.W. Hassler).

Mo	Da	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Apr	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	11	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	12	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	18	59.0	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	19	60.0	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Apr	20	62.0	.	.	.	.	60.0	.	.	.	.	.	.	.	.	.
Apr	21	63.0	.	61.0	.	.	.	.	.	.	.	.	.	.	.	.
Apr	22	66.0	.	61.0	.	65.0	.	.	.	.	.	.	.	.	.	.
Apr	23	67.0	.	63.0	.	63.0	.	.	.	.	.	.	.	.	.	.
Apr	24	64.0	62.0	61.0	.	64.0	.	.	.	.	.	.	.	.	.	.
Apr	25	62.0	61.0	60.0	.	63.0	62.0	.	.	.	.	.	.	.	.	.
Apr	26	62.0	60.0	.	.	62.0	62.0	.	.	.	.	.	.	.	.	.
Apr	27	62.0	60.0	.	63.0	60.0	61.0	64.0	.	.	.	.	.	.	.	.
Apr	28	63.0	63.5	60.0	62.0	61.0	62.0	.	.	.	.	.	.	.	.	.
Apr	29	62.0	64.0	.	61.0	61.0	60.0	64.0	.	.	.	68.0	.	.	.	61.7
Apr	30	.	.	.	62.0	64.0	62.0	63.0	64.0	.	.	75.0	.	.	.	.
May	1	60.0	60.5	.	63.0	66.0	62.0	64.0	64.5	.	.	82.0	65.0	.	65.0	63.5
May	2	62.0	60.0	.	64.0	65.0	63.0	63.0	64.5	.	64.0	77.0	64.0	.	66.0	63.8
May	3	61.0	.	65.0	63.0	66.0	65.0	64.0	63.0	.	62.5	79.0	64.0	.	67.0	63.8
May	4	63.0	61.5	65.0	63.0	64.0	65.0	67.0	62.0	.	64.5	71.0	65.0	.	68.0	64.4
May	5	62.0	62.0	67.0	63.0	64.0	65.0	67.0	65.0	.	64.0	68.0	64.0	.	66.0	65.3
May	6	60.0	62.5	65.0	67.0	64.0	65.0	66.0	64.0	.	64.0	74.0	64.0	.	68.0	66.2
May	7	60.0	64.0	.	67.0	65.0	65.0	65.0	64.5	.	65.0	75.0	64.0	64.0	68.0	68.0
May	8	62.0	65.0	66.0	67.0	65.0	64.0	67.0	65.0	.	64.0	75.0	63.0	63.0	67.0	67.5
May	9	69.0	68.0	65.0	66.0	64.0	65.0	67.0	65.0	.	64.0	80.0	64.0	62.0	67.0	67.1
May	10	70.0	69.0	68.0	64.0	64.0	67.0	67.0	68.5	.	64.0	85.0	64.0	62.0	68.0	66.2
May	11	70.0	69.0	68.0	65.0	64.0	67.0	65.0	68.0	.	64.0	88.0	66.0	64.0	68.0	65.3
May	12	65.0	68.0	69.0	64.0	65.0	67.0	65.0	69.0	.	64.0	78.0	65.0	64.0	68.0	65.3
May	13	65.0	69.0	69.5	66.0	64.0	68.0	66.0	70.0	.	64.0	77.0	67.0	65.0	68.0	65.6
May	14	67.0	70.0	69.0	65.0	66.0	67.0	67.0	69.5	.	64.5	79.0	67.0	66.0	69.0	67.1
May	15	67.0	70.0	68.0	65.0	.	66.0	68.0	69.0	.	64.0	72.0	68.0	66.0	69.0	67.5
May	16	64.0	67.0	70.0	65.0	.	67.0	68.0	68.0	.	64.5	70.0	68.0	66.0	69.0	67.5
May	17	64.0	.	71.0	68.0	.	70.0	69.0	68.0	.	65.0	75.0	70.0	64.0	71.0	69.8
May	18	67.0	.	72.0	68.0	.	69.0	67.0	69.0	.	65.0	72.0	70.0	65.0	72.0	72.0
May	19	68.0	70.5	72.5	68.0	.	70.0	67.0	70.0	.	65.0	76.0	72.0	65.0	70.0	72.0
May	20	.	73.0	71.0	70.0	.	70.0	70.0	73.0	.	64.5	70.0	71.0	66.0	69.0	72.0
May	21	69.0	.	71.0	69.0	.	69.0	69.0	72.0	.	64.5	74.0	73.0	67.0	70.0	72.0
May	22	71.0	.	71.0	72.0	.	69.0	70.0	71.5	.	.	82.0	73.0	66.0	72.0	72.5
May	23	68.0	.	.	70.0	.	69.0	70.0	74.0	.	.	79.0	72.0	67.0	72.0	72.1
May	24	68.0	.	.	69.0	.	71.0	69.0	74.0	.	.	81.0	72.0	70.0	69.0	72.0
May	25	67.0	.	.	68.0	.	70.0	70.0	73.0	.	.	68.0	73.0	71.0	70.0	70.0
May	26	66.0	.	.	70.0	.	68.0	72.0	73.0	.	.	65.0	72.0	70.0	69.0	70.0
May	27	66.0	.	.	68.0	.	68.0	69.0	77.0	.	.	77.0	71.0	74.0	69.0	71.1
May	28	67.0	.	.	70.0	.	66.0	71.0	75.0	.	.	67.0	72.0	74.0	69.0	72.0
May	29	68.0	.	.	74.0	.	68.0	72.0	73.0	.	.	68.0	72.0	73.0	70.0	73.6
May	30	69.0	.	.	68.0	.	68.0	73.0	72.0	.	.	69.0	71.0	73.0	72.0	72.9
May	31	68.0	67.0	.	67.0	.	70.0	72.0	72.0	.	.	71.0	71.0	74.0	.	72.0
Jun	1	68.0	.	.	.	.	69.0	73.0	70.0	.	.	71.0	72.0	73.0	.	.
Jun	2	68.0	.	.	.	.	70.0	74.0	.	.	.	72.0	72.0	74.0	.	.
Jun	3	68.0	.	.	.	.	70.0	75.0	.	.	.	72.0	.	.	.	.
Jun	4	69.0	.	.	.	.	71.0	75.0	.	.	.	.	.	.	.	.
Jun	5	69.0	.	.	.	.	.	74.0	.	.	.	.	.	.	.	.
Jun	6	.	.	.	.	.	.	73.0	.	.	.	.	.	.	.	.
Jun	7	70.0	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Jun	17	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	18	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Jun	20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

APPENDIX C

Pertinent Correspondence

List of Pertinent Correspondence

06-24-88	Memo from Manooch to Roanoke River Water Flow Committee (RRWFC)
06-30-88	Memo from Rulifson (ECU) to Manooch
07-01-88	Memo from Zincone (ECU) to Manooch
07-04-88	Letter from Quay (Sierra Club) to Manooch
07-07-88	Memo from Cheek (NMFS) to Manooch
07-07-88	Memo from Mullis (NCWRC) to Manooch
07-08-88	Letter from Graham (Agriculture) to Manooch
07-12-88	Letter from Gantt (USFWS) to Manooch
07-15-88	Letter from Vithalani (USACOE) to Manooch
07-18-88	Letter from Ellis (Virginia Power) to Manooch
07-19-88	Memo from Hogarth (NCDMF) to Manooch
07-27-88	Letter from Crawford (NCDWR) to Manooch
08-01-88	Letter from Hassler (ABLTD) to Manooch
08-03-88	Memo from Rulifson to RRWFC
08-04-88	Memo from Rulifson to Interested parties
08-31-88	Letter from RRWFC Co-Chairs to Governor James G. Martin
09-12-88	Letter from Fullwood (NCWRC) to Manooch
09-13-88	Letter from Sanford (U.S. Senate) to Rulifson
09-20-88	Letter from Graham (Agriculture) to Manooch
09-22-88	Letter from Rhodes (NCDNRCD) to Manooch and Rulifson
09-23-88	Letter from Martin (Governor, NC) to Manooch and Rulifson
11-01-88	Letter from Jones (U.S. House of Representatives) to Rulifson
01-06-89	Letter from Bennett (NC Marine Fisheries Commission) to Jones
02-10-89	Letter from Manooch to Harris (NCWRC)
02-21-89	Letter from Fullwood (NCWRC) to Col. Woodbury (USACOE)

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, North Carolina 28516-9722

June 24, 1988

MEMORANDUM FOR: Roanoke River Water Flow Committee

FROM: Charles S. Manooch, III,
for the Recommendation Subcommittee

SUBJECT: Flow Recommendation

The Recommendation Subcommittee (listed below) met at the National Marine Fisheries Service Beaufort Laboratory on June 23, 1988. Attached is a tentative negotiated recommended flow regime with guidelines and information for your review. Please submit your endorsement, rejection or other comments to me in writing by July 8, 1988. If you are a representative of a state or federal agency, I suggest that you share the enclosures with your colleagues and solicit their input to include in your response.

Enclosures
as Stated

Subcommittee:
- 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
- L. Zincone, ECU

Advisors:
- M. Grimes, COE
- J. Mitchell, Virginia Power Co.
- M. Shepherd, ECU

EAST CAROLINA UNIVERSITY

GREENVILLE, NORTH CAROLINA 27858-4353

INSTITUTE FOR COASTAL
AND MARINE RESOURCES

(919) 757-6779

received 7/1/88

June 30, 1988

MEMORANDUM FOR: Dr. Charles S. Manooch, III
Co-Chair, Roanoke River Optimum Flow Committee

FROM: Roger A. Rulifson RAR

SUBJECT: Roanoke River recommended flow regime

I have reviewed the tentative negotiated recommended flow regime and guidelines concerning reservoir discharge from Roanoke Rapids dam during spring spawning activity of Roanoke/Albemarle striped bass. As requested in your memorandum of June 24, 1988, my comments and concerns are presented here for your consideration.

Duration. The dates of 1 April through 15 June for flow moderation is probably adequate for ensuring inclusion of striped bass spawning activity, egg and larval transport downstream, and maintenance of the zooplankton food base in the Roanoke River delta. Inclusion of dates prior to 1 April (e.g., 15 March et seq.) are not critical to the eggs or larvae but the prevailing flows may be important in attracting the adults upstream and providing the nutrients and initial zooplankton community to the Roanoke delta downstream. Inclusion of dates after 15 June is not necessary for striped bass.

Water Flow Regime. The average daily flows listed are reasonable because they represent pre-impoundment conditions (1912-1950). The limits of minimum and maximumn flows are also reasonable because they represent the majority of the flows for the same pre-impoundment period. We must keep in mind, however, that the upper and lower limits will represent only 50% of the years; in other years, flows will be above or below the limits listed because of extreme conditions caused by drought or flood.

Variation in Flow. A rate of change in flow of 1500 cfs per hour is more than I would like to see; however, Viriginia Power representative Jack Mitchell indicated that they cannot control the rate of discharge very precisely. A rate of 1500 cfs was reasonable for them, and so I will accept this rate of change for lack of better alternatives.

Criteria for Water Release and Storage. Use of the rule curve must be re-examined. Based on pre-impoundment records, our guidelines will be met in only 50% of the years. In order to maximize compliance to these guidelines, we must address the manner in which Kerr Reservoir is managed for flood control and hydropower generation. According to Corps of Engineers representative Max Grimes, reservoir discharge is reduced to 2000 cfs (during spawning activity) when the reservoir level drops to 299.5'.

Thus, no flow augmentation is released nor (at the moment) is it required. Also, all water storage below 299.5' is allocated, and none is allocated for flow augmentation. Therefore, under these conditions, Virginia Beach should be required to supply 60mgd for the City (using the proposed pipeline) and also supply the flow necessary for flow augmentation during striped bass spawning. The water is there and should be used, not only for striped bass but also for dilution of industrial and municipal wastes downstream.

Conversely, in times when Kerr lake level reaches 302.0', the Corps of Engineers releases water in anticipation that more runoff from the watershed will burden the reservoir system. The Corps should be required to use current technology in meteorology and reservoir management to release this water in a manner that will not cause downstream flooding (i.e., at rates below 20,000 cfs over a period of days, foregoing peak hydropower generation).

In conclusion, I recommend that the Subcommittee's guidelines be accepted, with the stipulation that the Corps of Engineers rule curve be scrutinized to optimize control of flooding downstream during the period in question.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, North Carolina 28516-9722

June 24, 1988

MEMORANDUM FOR: Roanoke River Water Flow Committee

FROM: Charles S. Manooch, III,
for the Recommendation Subcommittee

SUBJECT: Flow Recommendation

The Recommendation Subcommittee (listed below) met at the National Marine Fisheries Service Beaufort Laboratory on June 23, 1988. Attached is a tentative negotiated recommended flow regime with guidelines and information for your review. Please submit your endorsement, rejection or other comments to me in writing by July 8, 1988. If you are a representative of a state or federal agency, I suggest that you share the enclosures with your colleagues and solicit their input to include in your response.

Enclosures
as Stated

Subcommittee:
- 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
- L. Zincone, ECU

To Manooch
I concur
JHg

Advisors:
- M. Grimes, COE
- J. Mitchell, Virginia Power Co.
- M. Shepherd, ECU

received from
L. H. Zincone
7/1/88
CMIII

received 7/7/88 Csmiii 7/4/88

Thomas L. Quay
2720 Vanderbilt Avenue
Raleigh, NC 27607
Tel. (919) 828-9874

Dr. Charles S. Manooch, III
Chairman, Striped Bass/Roanoke River Optimum Water Flow Comm.
National Marine Fisheries Service
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, N. C. 28516

Dear Dr. Manooch:

Thanks for sending to me, in your letter of June 24, 1988, the Report of the Recommendation Sub-committee on the Optimum Flow Regime, which you and your 20 members of the whole study committee have been working on so intensively and scientifically since February of this year. It has been a pleasure and profit for me to have been in attendance at the successive meetings of Feb., March, and April and now to see these fine, full, and objective results. If you do call the entire Committee into another session, please do let me know. I support your proceeding further as you deem necessary. I have been in attendance this whole year both as the Coastal Coordinator of The Sierra Club, N. C. Chapter, and as a member of the Pamlico Citizens Advisory Committee of the Albemarle-Pamlico Estuarine Study. It is a matter of great personal satisfaction to me to have been able to use my exactly 50 years of knowledge and experience in the N. C. Coastal Zone in this extraordinarily important practical and basic endeavor, which I think you have conducted in the most open, forthright, and efficient manner. Let me know if I can be of further assistance and keep me posted on further developments. We are certainly not done yet, for now we must get the committee's recommendations into practice.

As requested in your letter, I do give you my full and unqualified endorsement of the Recommended Flow Regime. I shall share this set of recommendations with members of the Executive Committee of Sierra Club. As I stated in some of the meetings we had, Sierra Club is interested and wants to continue to be seriously involved in the conservation, management, and wise use of all of the renewable natural resources of North Carolina and I am enjoined in particular to be involved in projects like yours in the Coastal Zone. We recognize that most of, or a significant amount of, the wildlife and fisheries and wetlands resources of N. C. are in the Coastal Zone and that the rapidly increasing pressure of population and development are critically threatening to these same life-sustaining resources. We must continue to struggle to save and enhance these natural-resource bases of our economy and quality of life.

Sincerely yours,
Tom Quay
Thomas L. Quay, Ph. D.
Professor Emeritus, Ecology, NCSU
Coastal Coordinator, Sierra Club, NC

CC: Sierra Club, NC Chapter
Executive Committee

received
7/7/88
[handwritten initials]

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

Habitat Conservation Division
Pivers Island
Beaufort, NC 28516

July 7, 1988 F/SER111/RPC
919/728-5090

MEMORANDUM FOR: Charles S. Manooch, III
for the Recommendation Subcommittee

FROM: Randall P. Cheek
Member Roanoke River Water Flow Committee

SUBJECT: Flow Recommendations for Roanoke River, North Carolina, During Annual Striped Bass Spawning Seasons (April 1 - June 15)

I have reviewed the proposed water flow regime in cfs, April 1 - June 15, that accompanied your June 24, 1988, memorandum to members of the Roanoke River Water Flow Committee.

I concur in and endorse the proposed regime as a management option necessary to enhance the reproductive success of striped bass in the Roanoke River.

The striped bass resource should receive equal priority when ranked with flood control, hydropower, and above dam recreation interests in the Roanoke River Basin. After all, we are only asking for concessions for a short 76-day period each year to benefit striped bass. Hopefully, we can have several years in which the recommended flows will occur to evaluate the effects on striped bass reproduction. If the flows accomplish what we think will be beneficial to the survival of eggs and ~~larvae, we should seek through the FERC license and the Memorandum of~~ Understanding between the North Carolina Wildlife Resources Commission, U. S. Army Corps of Engineers, and Virginia Power Company requirements to maintain these flows even in flood and drought years.

In view of the cooperative efforts of the Corps of Engineers and Virginia Power Company in development of the proposed regime and the flows generated during the 1988 spawning season, I believe we should seek the above changes in regulations if the juvenile abundance indices show increases in response to recommended flows.

Received 7/11/88

North Carolina Wildlife Resources Commission

512 N. Salisbury Street, Raleigh, North Carolina 27611, 919-733-3391
Charles R. Fullwood, Executive Director

MEMORANDUM

TO: Dr. Chuck Manooch

FROM: Tony Mullis, Research Coordinator Tony/

DATE: July 7, 1988

SUBJECT: Roanoke River Flow Recommendations

Our staff in the Division of Boating and Inland Fisheries, including Fred Harris, Don Baker, and myself, have reviewed the Roanoke River flow regime suggested by the Recommendation Subcommittee.

The proposed flow regime appears to be suitable for striped bass spawning and reproduction. It is certainly preferable to the conditions which now exist during the period of April 1 to June 15 during most recent years. While the proposed flows are certainly not ideal, we probably cannot define exactly what conditions are ideal, and ideal conditions would probably be impossible to realize in combination with the other uses of the reservoirs and their water. Therefore we endorse the flow regime recommended by the subcommittee.

However, it should be specified in the recommendations that the proposed flow regime is to be utilized on a trial basis for a period of 3 to 5 years (to be specified). At the end of the trial period, the proposed flows will be reevaluated for their effectiveness in enhancing striped bass reproductive success and for their compatibility with other uses of the Roanoke River basin and its water. At that time the flow regime can be renegotiated to improve its suitability for striped bass reproduction or its compatibility with other uses.

Thank you for the opportunity to review and comment on the proposed flow regime for the Roanoke River.

received 7/12/88 Corr III

State of North Carolina
Department of Agriculture
Raleigh

JAMES A. GRAHAM
COMMISSIONER

July 8, 1988

Dr. Charles S. Manooch, III
National Marine Fisheries Service
Beaufort Laboratory
Beaufort, North Carolina 28516-9722

Dear Chuck:

I want to take this opportunity to thank you for providing the leadership necessary to organize a multi-disciplinary review of the flows of the Roanoke River. It is my opinion that the work done by this interagency group will enhance the protection of wildlife, fisheries, forestry and agriculture in the basin through strong water management.

Please consider this letter as an endorsement of the proposed flows by the North Carolina Department of Agriculture. As further needs arise to evaluate or seek adoption of these flows, please let me know how I can be of assistance.

Thank you again for your hard work and leadership.

With all good wishes.

Cordially,

Jim Graham

James A. Graham
Commissioner

JAG:RF:ek

cc: Dr. Ford A. Cross

United States Department of the Interior

FISH AND WILDLIFE SERVICE

Raleigh Field Office
P.O. Box 25039
Raleigh, North Carolina 27611-5039

received 7/13/88 CSM III

July 12, 1988

Dr. Charles S. Manooch, III
National Marine Fisheries Service
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, North Carolina 28516-9722

Dear Dr. ~~Manooch~~ Chuck:

This responds to your memorandum dated June 24, 1988, requesting comments on the tentative recommended flow regime for the Roanoke River below Weldon, North Carolina. The recommendations were developed by the Recommendation Subcommittee of the Roanoke River Optimum Water Flow Work Group (Group) during their last meeting on June 23rd. This response has been fully coordinated with Mr. Bill Cole, the Service's N.C. Fishery Coordinator.

The Service endorses the flow regime proposed by the Recommendation Subcommittee for ensuring adequate flows are present for migration, reproduction and support of striped bass within the Roanoke River Basin. Also, we concur with the assessment of the Recommendation Subcommittee that additional action and discussion is needed by the full Group on a number of issues including: the assessment of the impact of the proposed flow regime on other user groups and resources within the Roanoke River; what steps should be recommended for action by the appropriate State and Federal management agencies; and, what priority are striped bass relative to flood control, hydropower, recreational uses and water supply. We recommend that the full Group be reconvened to work on the preparation of a final report which will: document fully the derivation of the recommended flow regime; contain other analytical information developed by members of the Group; outline the impact of the proposed flow regime on other affected user groups and fish and wildlife resources; and, make recommendations for actions to be undertaken by the appropriate State and Federal agencies involved in natural resouce and water management in the Roanoke basin.

After a final report and recommendation is completed and released, the Service recommends that the full Group continue to meet on at least an annual basis for a three to five year period to evaluate the effectiveness of the The flows received. Further, we suggest it would be appropriate to formalize this new flow regime either through the revision of the existing Memorandum of Understanding between the N.C.

Wildlife Resources Commission, U.S. Army Corps of Engineers, and Virginia Power Company, or through preparation of a new agreement.

We appreciate this opportunity to provide comments on the draft recommendation. Please contact me, Bill Cole or Wilson Laney if you have any questions regarding these comments or recommendations.

Sincerely,

Mike

L.K. Mike Gantt
Field Supervisor

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

received 7/18/88
Comm II
"advisor" to Committee

IN REPLY REFER TO

July 15, 1988

Hydrology & Hydraulics Branch

Dr. Charles S. Manooch, III
National Marine Fisheries Service
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, North Carolina 28516-9722

Dear Dr. Manooch:

We have reviewed your memorandum for the Roanoke River Water Flow Committee dated June 24, 1988, regarding Roanoke River flow recommendation during the striped bass spawning season.

As stated by Mr. Max Grimes of this office at previous committee meetings, before we can implement changes such as the proposed recommendations in the operation of John H. Kerr Reservoir, we must assess and document the impacts of the changes and consider alternatives to the changes under the National Environmental Policy Act of 1969, as amended (NEPA). We must also coordinate the assessment with other Federal agencies, state agencies, and the public. Areas of concern that we must consider in the NEPA process would include, at a minimum, impacts on project purposes (flood control, hydropower, water supply, recreation and fish and wildlife conservation) and on striped bass spawning in the Roanoke River. We will need substantial time prior to proposed implementation to consider any changes under NEPA.

We are aware of the concerns of the resource agencies and the public regarding the decline in striped bass in the Roanoke River. Because of this concern, any changes in the operation of John H. Kerr Reservoir which may affect the striped bass, whether the changes are perceived to be beneficial or not, must be very carefully considered. We believe that it would be necessary to demonstrate that there is a need for changes in spawning flows, and, at the very least, that the changes would not have significant adverse impacts on striped bass.

As you know, before any changes could be implemented, a new memorandum of understanding must be developed among the Corps of Engineers, Virginia Power Company, and the North Carolina Wildlife Resources Commission.

If you have any questions, contact Mr. Grimes, Chief, Hydrology and Hydraulics Branch, at (919) 343-4759, or Mr. Frank Yelverton, Environmental Resources Branch, at (919) 343-4640.

Sincerely,

Jaman Vithalani, P.E.
Chief, Engineering Division

Larry W. Ellis
Vice President
System Planning and Power Supply

One James River Plaza
Post Office Box 26666
Richmond, Virginia 23261
804-771-3757

received 7/22/88
party on not a "voting" Committee: Advisor
Garrett

VIRGINIA POWER

July 18, 1988

Dr. Charles S. Manooch, III
National Marine Fisheries Service
Southeast Fisheries Center
Beaufort, NC 28516-9722

Dear Dr. Manooch:

In reply to your memorandum of June 24, 1988 requesting comments on the recommendations of the flow subcommittee, there are concerns to Virginia Power which the Roanoke River Water Flow Committee should consider in formulating any binding recommendations concerning the operation of the Company's Roanoke Rapids and Gaston projects.

The proposed upper limit of flow will deny the Company full use of the Roanoke Rapids project and could impose restrictions on operation of the Gaston project as a peaking facility. Virginia Power can schedule operation to meet these guidelines to the greatest extent possible, but we will not abandon our right to operate within the full authorization of our license when power system demands cannot be satisfied within the proposed guidelines. The most likely time of difficulty in keeping within these restrictions will be late May and June.

The variation of flow rate of 1500 cfs per hour is considerably below the present license authorized rate of change which allows up to double the pervious 60 minute flow. The 1500 cfs value was selected by the flow subcommittee to prevent elevation changes in excess of one foot per hour when increasing output from minimum flow. Virginia Power will schedule generation changes to minimize drastic elevation changes during normal operation in the spawning season, however it must be recognized that these will be considered as guidelines which may be exceeded during times of unforeseen power requirements.

It is suggested that Virginia Power's System Operation Center be kept informed of significant events during the spawning season when flow variations may be harmful to the striped bass. Day to day constraints may be more practical than full season limitations.

1081JDM040

We appreciate the opportunity to work with the Committee and we share your concern for the striped bass resource as well as for the entire Roanoke River Basin Resource. Mr. Mitchell will be available for further consultation if needed.

Sincerely,

Larry W. Ellis

1081JDM040

received 2/19/88

State of North Carolina
Department of Natural Resources and Community Development
Division of Marine Fisheries
P.O. Box 769 • Morehead City, North Carolina 28557-0769

James G. Martin, Governor
S. Thomas Rhodes, Secretary

William T. Hogarth, Director
(919) 726-7021

July 19, 1988

M E M O R A N D U M

TO: Dr. Charles S. Manooch
Co-Chairman, Roanoke River Water Flow Committee

FROM: William T. Hogarth
Director, NC Division of Marine Fisheries

SUBJECT: Flow Recommendation During The Striped Bass Spawning Season

The North Carolina Division of Marine Fisheries staff supports and endorses the "flow recommendation" (submitted by the flow group on June 23, 1988) as an initial step to achieve improved spring flows for a variety of user interests.

Our interest in the spring Roanoke River flows deals, primarily, with the production of striped bass and other anadromous fishes, as well as the resident species which utilize the Roanoke system.

Points of major concern, which may require additional evaluation with respect to the benefits and feasibility of instituting water use changes in the Roanoke River lakes system are:

1) Striped bass production should become a priority of water and flow management;

2) The recommendation does not encompass the entire time period (March - June), which our staff deems as critical for maximum striped bass production, and revisions may be necessary to better provide for striped bass needs in the future;

3) The recommendation does not address flood plain inundation (flows greater than 10,000 CFS) for a short time during April (recognized by the "Recruitment Subcommittee" as beneficial and consistently associated with striped bass juvenile adundance indices greater than 5.0);

4) Cooperative flow regulation should be considered after June 15 during years of late spawning, and for egg and larval transport;

5) The FERC license and the striped bass flow augmentation agreement, between the US Army Corps, Virginia Power, and the North Carolina Wildlife Resources Commission, should be renegotiated to require flows recommended by the "Flow Committee."

The efforts of the "Flow Committee" should be documented in a report containing history, methodology, participants and findings of the group.

The Division recommends that the evaluation of flows on the Roanoke River be a continuing process with an annual meeting during late fall or early winter to update concerned parties on recent developments. We plan to include the annual meeting of the "Flow Committee" as part of the North Carolina Striped Bass Management Plan being developed by the Division of Marine Fisheries and the Wildlife Resources Commission.

WTH:kbo

cc: Harrel Johnson
Lynn Henry
Bill Cole

received
7/29/88
[illegible]

State of North Carolina
Department of Natural Resources and Community Development
Division of Water Resources
512 North Salisbury Street • Raleigh, North Carolina 27611

James G. Martin, Governor
S. Thomas Rhodes, Secretary

John N. Morris
Director

July 27, 1988

Dr. Charles Manooch
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, NC 28516-9722

RE: Flow Recommendation - Roanoke River

Dear Chuck:

I wish to endorse the flow recommendation as agreed in the June 23, 1988 meeting of the flow recommendation sub-committee.

However, as the sub-committee discussed, this flow regime is a compromise to reflect the many practical restraints and inadequacies of our Roanoke River knowledge. Particularly, the restrictions on the time frame (April 1 to June 15) reflects a need at this time to not change current agreements and hence possible amendments to FERC licenses. A larger time period, possibly March 1 to June 30 would appear necessary, based on discussions of the sub-committee.

The agreement of the Corps to provide the flow regime without more detailed analysis and discussion on the effects on Kerr operation and possible rule curve changes requires the committees full attention. The Wilmington Corps have developed a new basin model which could evaluate the flow recommendation and what possibilities exist to modify rule curves to benefit the lower Roanoke River.

I would like to see the implementation of this flow regime for a multi-year trial period to determine possible impacts. Concurrent with this trial would be evaluations on the system operations and impacts and further work on the biological environment which effects the striped bass.

P.O. Box 27687, Raleigh, North Carolina 27611-7687 Telephone 919-733-4064

I am continuing my efforts on the flow regime, water surface profiles, and (time permitting) the analysis of peaking flows and the attenuation of these flows in the natural channel.

Sincerely,

David Crawford

David Crawford, Chief
Hydrology & Management Section

DC/bb

AB LTD
12 BAGWELL AVENUE
RALEIGH, NC 27607
(919) 834-1445

received 8/3/88
CWM

August 1, 1988

Dr. Charles S. Manooch, III
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, North Carolina 28516-9722

Dear Dr. Manooch:

Your proposed flow recommendations for the Roanoke River receive my approval and endorsement for striped bass spawning requirements. I regret that you did not have the opportunity thirty years ago to submit these recommendations.

It may be necessary to alter or modify these flows to enhance the spawning conditions after you have had the opportunity to observe results under a variety of conditions and empirical situations.

Your recommendations are an excellent foundation to manage the Roanoke River striped bass.

Sincerely yours,

William W. Hassler

William W. Hassler

EAST CAROLINA UNIVERSITY

GREENVILLE, NORTH CAROLINA 27858-4353

INSTITUTE FOR COASTAL AND MARINE RESOURCES

(919) 757-6779

August 3, 1988

MEMORANDUM TO: Roanoke River Water Flow Committee

FROM: Roger A. Rulifson, Co-Chair

SUBJECT: Adoption of Negotiated Flow Regime

Enclosed please find the agenda for our next meeting, which will be held in Raleigh at the Archdale Building on Thursday, August 11, 1988. At that time we will formally adopt the negotiated flow guidelines developed by the Recommendation Subcommittee. Unanimous written endorsement of these guidelines by all member agencies and university scientists has been received by Chuck Manooch. Copies of these endorsements will be sent to you under separate cover so that you will have an opportunity to review and prepare comments and suggestions regarding implementation of the recommended flows.

Also attached is a copy of the letter sent to the U.S. Army Corps of Engineers written on behalf of the Committee in response to the Supplement Environmental Assessment of the Lake Gaston Pipeline to the City of Virginia Beach. The letter, written by Crawford, Henry, Manooch, and Rulifson, describes the purpose, activities, and recommendations of our Committee for the record, and requests that the Corps consider this work in any water withdrawal projects.

If you have questions or suggestions, feel free to contact Chuck Manooch at 728-8716 or me at 757-6220.

Enclosures as stated

EAST CAROLINA UNIVERSITY

GREENVILLE, NORTH CAROLINA 27858-4353

INSTITUTE FOR COASTAL
AND MARINE RESOURCES

(919) 757-6779

August 4, 1988

MEMORANDUM TO: Parties interested in the recommendations of the Roanoke River Water Flow Committee

FROM: Roger A. Rulifson, Co-Chair

SUBJECT: Recommendations of the Committee

Your group or organization has indicated a written or verbal interest in the activities and findings of the Roanoke River Water Flow Committee with regard to the regulation of river flow below the Roanoke Rapids Dam. At your request, I am forwarding a copy of the agenda for our meeting on August 11, 1988, at which time the flow recommendations of the Committee will be adopted. A small block of time has been set aside for invited guests and interested parties to address the Committee. If you intend to present remarks on behalf of your group or organization, please extend the courtesy of advance notification in writing or by calling Chuck Manooch (919) 728-8716 or Roger Rulifson (919) 757-6220. Thank you.

EAST CAROLINA UNIVERSITY

GREENVILLE, NORTH CAROLINA 27858-4353

INSTITUTE FOR COASTAL
AND MARINE RESOURCES

(919) 757-6779

Roanoke River Water Flow Committee
c/o Institute for Coastal and Marine Resources
East Carolina University
Greenville, NC 27858

August 31, 1988

The Honorable James G. Martin
Office of the Governor
Administration Building
116 W. Jones St.
Raleigh, NC 27611

RE: Activities and Recommendations of the Roanoke River Water Flow Committee

Dear Governor Martin:

The intent of this letter is to inform you of the objectives, activities and recommendations of an ad hoc committee formed to investigate the improvement of Roanoke River water flows below Roanoke Rapids Dam for striped bass and other downstream resources. The Committee is comprised of 20 representatives of State and Federal agencies and university scientists. A list of Committee members and the affiliation of each is attached.

The Committee has a combined record of experience on the ecology and fisheries of the Roanoke watershed and Albemarle Sound totaling over 190 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 our State; however, other resources such as wildlife, timber, and agriculture have been considered as well.

The Committee's policy is 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 wildlife refuge proposed by the US Fish and Wildlife Service and the proposed water withdrawal from Lake Gaston by the City of Virginia Beach.

A Recommendations Subcommittee selected from the full Committee met on two occasions (May 3 and June 23 1988). One member from each agency or university was selected for representation on the Subcommittee to provide a balance of local expertise in biology, statistics, and hydrology. The Department of Agriculture has one member on the Subcommittee because of its role as steward of the agricultural and timber resources. In addition, two advisors -- one from the Corps of Engineers, and the other representing Virginia Power Company -- provided the Subcommittee with expertise pertaining to dam operations and power generation.

Significant work was accomplished by the Subcommittee; meetings were designed to present findings of assignments and direct future studies. All of the work was summarized and endorsed by the full Committee. Detailed findings will be presented to you in a formal report developed by the full Committee. The U.S. Army Corps of Engineers, Wilmington District, has participated in all meetings and has endorsed the recommendations of the Subcommittee. Since the work accomplished to date by the Committee will be presented to you at a later date, we have summarized key findings below:

Status of Striped Bass

The juvenile abundance index (JAI) is a measure of the relative abundance of the Roanoke/Albemarle striped bass stock. The JAI is determined in the same manner each year using the methodology developed by Dr. W.W. Hassler in the mid-1950s. The change in this index is depicted in Figure 1. Please note that after 1977, the index has had a value less than 1.0 with the exception of 1982, when the JAI was 3.8. This dramatic decline in abundance was manifested in the commercial and recreational catches; stocks have not recovered since the mid-1970s.

Significance of River Flows

The Committee studied the flow regime of the Roanoke River for the entire length of record (flow data from USGS records date to 1912). Most of our analyses subdivided the data into pre-impoundment and post-impoundment data bases. Analyses of these data bases in concert with JAI information led the Committee to the conclusion that river flow has a major impact upon the success of the striped bass in spawning and in subsequent life history stages. Control of low flows and high flows, as well as moderation of hydropower peaking activity at Roanoke Rapids, is necessary. These analyses are extensive and too cumbersome to include here. Our recommendation is to control the flow of the Roanoke River between historical 25% and 75% quartiles between March 1 and June 30 each year; that is, between the 25% low flow value (Q1) and 75% high flow value (Q3).

To show the significance of this flow regime, a simple diagram was constructed to depict the percentage of time that flows stayed within the Q1-Q3 range over a number of years. Figure 2 shows the expected variation of about 50% for the pre-impoundment years. For post-impoundment years, Figure 2 shows a definite trend away from the expected 50% deviation.

Flow Recommendations

The striped bass is affected by many phenomena, both environmental and man-induced. However, the Committee contends that the flow regime, particularly flow quantity, is an extremely important effect. Initially, a flow regime based on the Q1 and Q3 historic values was proposed. After lengthy discussion, the Subcommittee constructed a negotiated flow regimen that was unanimously endorsed by the full Committee. This negotiated flow regimen is presented in Table 1. The full Committee met to discuss and formalize this recommendation on 11 August 1988. The negotiated flow regimen was adopted unanimously by the full Committee, and several friendly amendments were added. The entire set of recommendations is appended for your file.

This negotiated flow regime represents a compromise from the original Committee objectives. The Corps of Engineers and Virginia Power Company indicated that the values presented in Table 1 were reasonable and workable within the present FERC license guidelines. However, this scheme was curtailed both in time (April 1 to June 15) and in magnitude of low and high flows. Further analysis and field studies may indicate that the regime should be broadened to the period March 1 to June 30, and may require changing flow limits and variability in flows.

1988 Conditions

Striped bass spawning began in the spring of 1988 prior to the development of the negotiated flow regime. However, the Corps and Virginia Power did try to maintain flows within the Q1 and Q3 values discussed at that time. These efforts resulted in a percentage of time within Q1-Q3 values of over 45%, the best percentage since 1968 (see Figure 2). Early field results indicate that 1988 may produce the best JAI in many years. These flows minimized downstream flooding and improved conditions necessary for fawning of deer, nesting of turkeys, access to timberlands, production and harvest of agricultural row crops, and boating by recreational fishermen.

Summary

The Committee will continue to investigate flow effects on downstream resources. Our goal is to continue to make recommendations to State and Federal agencies for water and natural resource management in the Roanoke River basin. It is hoped that these recommendations will start the restoration process of a number of these resources, and encourage proper utilization of all downstream resources.

The Committee concludes that the quantity of water passing through the Roanoke River system between March and June of each year has a significant effect on striped bass and other natural resources downstream. Changes within the basin and water withdrawal projects may cumulatively have an adverse impact upon the ability of the reservoir system to meet a stringent flow regime requirement. Therefore, the Committee's recommendations on flow should be considered whenever potential impacts of water withdrawal on striped bass and other natural resources of the watershed are considered.

Recommendations

A Standing Committee on Roanoke River Water Flows should be formed. The committee should meet at least annually and issue a progress report. We further recommend that the standing committee compile and issue formal reports at approximately five-year intervals.

The negotiated, recommended flow regime as adopted by the ad hoc Committee ~~should be evaluated over a four-year period. During the trial period, the~~ following aspects should be evaluated but are subject to change: a) the flow augmentation period (i.e., dates); b) upper and lower flow limits; c) hourly variation in flow; and d) impacts on other resources and users.

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 NC Division of Marine Fisheries participate in these discussions.

Anadromous striped bass should receive "high" priority status, at least equal to other resources and uses/users in the Roanoke River Basin.

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.

Sincerely,

Charles S. Manooch, III, Ph.D.
Flow Committee Co-Chair

Roger A. Rulifson, Ph.D.
Flow Committee Co-Chair

Enclosures as stated

ROANOKE RIVER WATER FLOW COMMITTEE

Randall P. Cheek, National Marine Fisheries Service - Beaufort Lab

Micky Clemmons, N.C. Wildlife Resources Commission

Willard J. Cole, U.S. Fish and Wildlife Service

David P. Crawford, N.C. Division of Water Resources

Tom Ellis, N.C. Department of Agriculture

L.K. (Mike) Gantt, U.S. Fish and Wildlife Service

Fred Harris, N.C. Wildlife Resources Commission

Dr. William W. Hassler, Professor Emeritus, N.C. State University

Lynn T. Henry, N.C. Division of Marine Fisheries

Dr. William T. Hogarth, N.C. Division of Marine Fisheries

Harrel B. Johnson, N.C. Division of Marine Fisheries

James W. (Pete) Kornegay, N.C. Wildlife Resources Commission

Dr. R. Wilson Laney, U.S. Fish and Wildlife Service

Dr. Charles S. Manooch, III, National Marine Fisheries Service - Beaufort

Dr. Robert J. Monroe, Professor Emeritus, N.C. State University

Anthony W. Mullis, N.C. Wildlife Resources Commission

Dr. Thomas L. Quay, Professor Emeritus, N.C. State University

Dr. Roger A. Rulifson, East Carolina University

Sara E. Winslow, N.C. Division of Marine Fisheries

Dr. L.H. Zincone, Jr., East Carolina University

Advisors:

Max Grimes, U.S. Army Corps of Engineers, Wilmington District

Jack D. Mitchell, Virginia Power Company

Marsha E. Shepherd, East Carolina University

FIGURE 1
JUVENILE ABUNDANCE INDEX

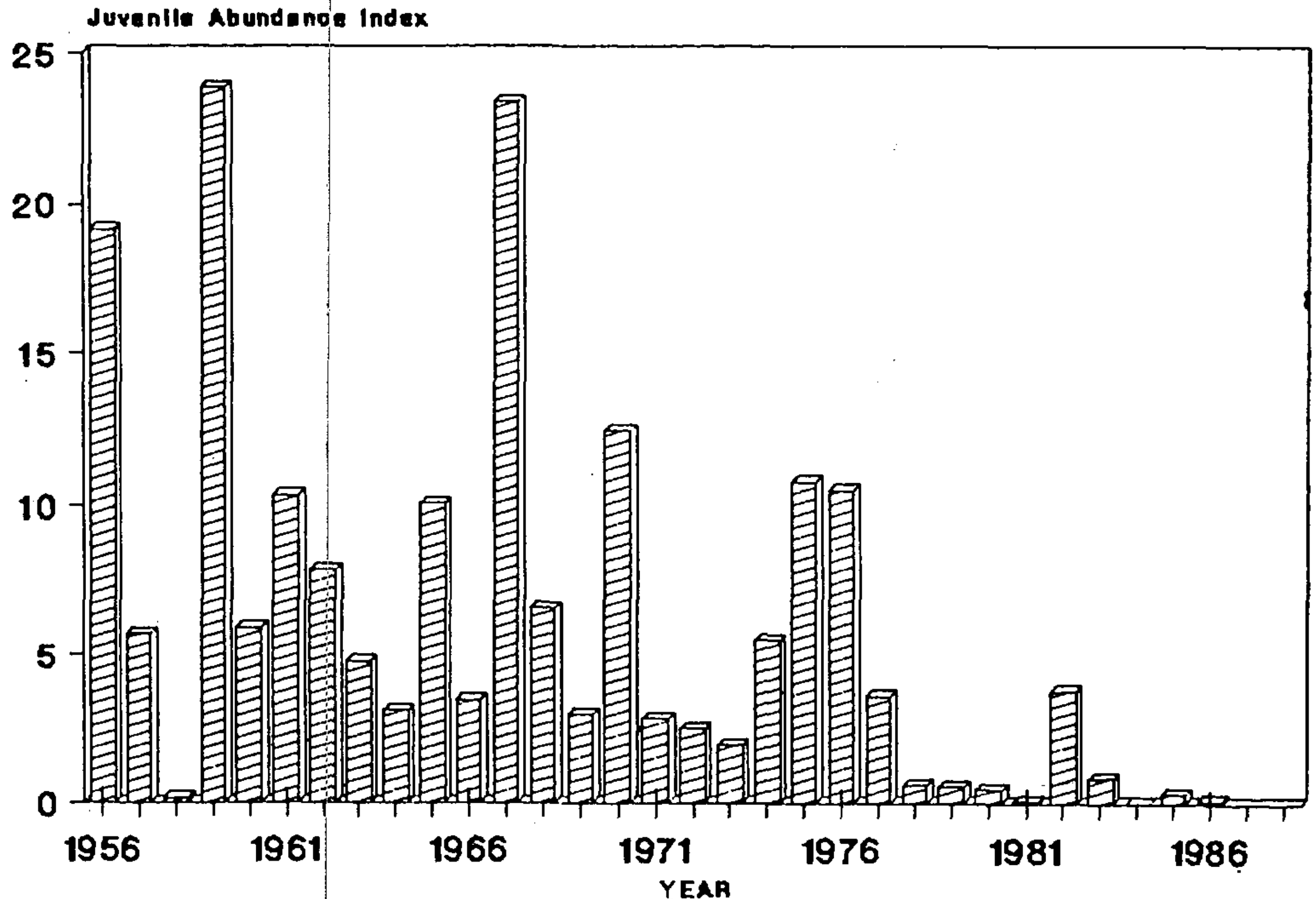
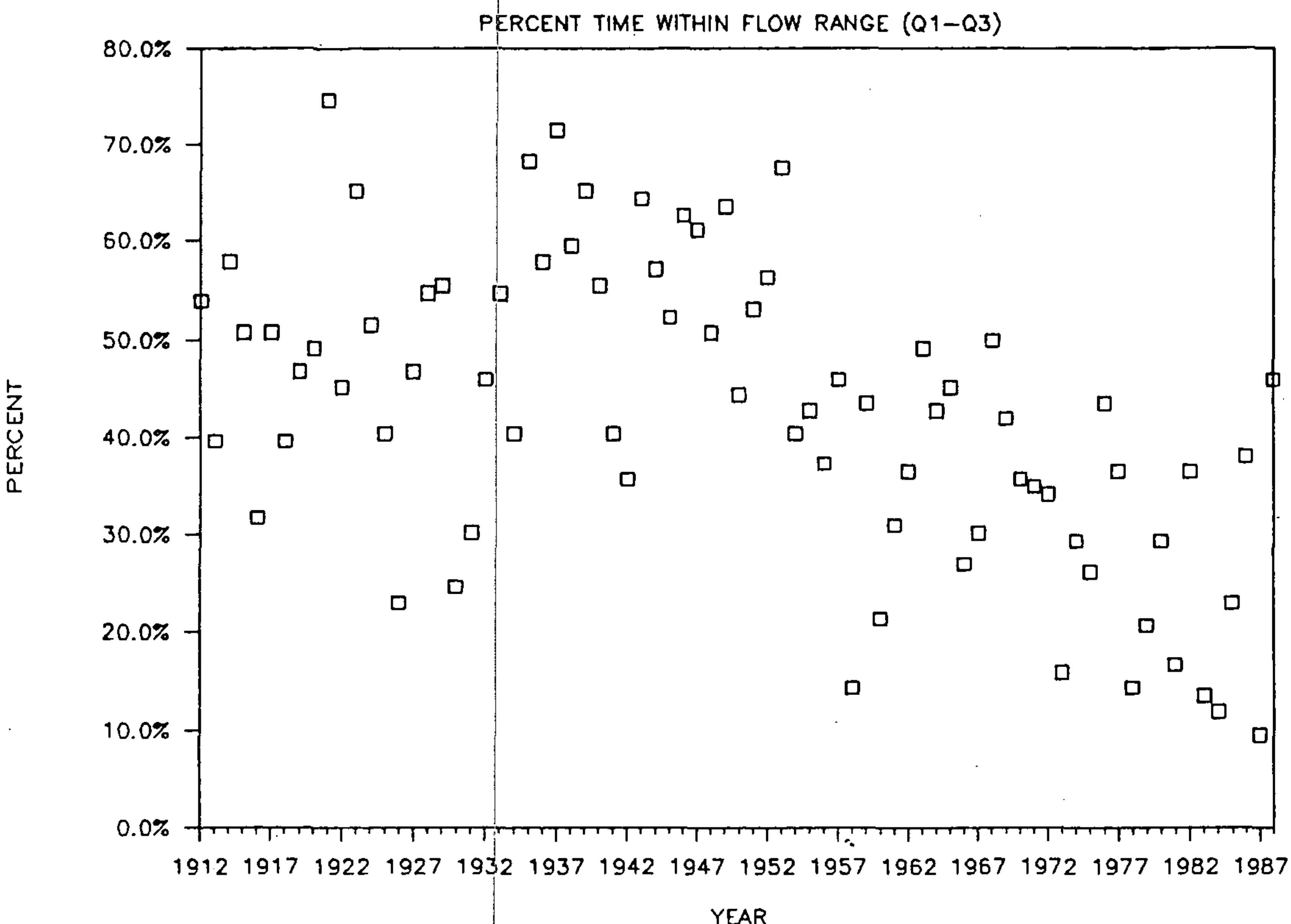


FIGURE 2



PERCENT TIME WITHIN FLOW RANGE (Q1–Q3)
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
PERCENT
1912 1917 1922 1927 1932 1937 1942 1947 1952 1957 1962 1967 1972 1977 1982 1987
YEAR

Water Flow Regime in CFS, April 1 - June 15

Dates	Expected Average Daily Flow	Lower Limit	Upper Limit
April 1-15	8500	6600	13700
April 16-30	7800	5800	11000
May 1-15	6500	4700	9500
May 16-31	5900	4400	9500
June 1-15	5300	4000	9500

Recommended flows presented on the previous page 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. Preimpoundment, USGS data for the years 1912-1950 were used to negotiate the recommended flows for the dates indicated, yearly.

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 limit flow = 9500, and the minimum, or lower limit flow = 4700. 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 best 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 (20000 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 is needed.

It should be noted that the recommended flow regime is not consistant 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 May 1 - June 15 are lower than those in the 1971 Memorandum. However, the timeframe of April 1 - June 15 is consistant with the FERC license requirement.

Variation in 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 limits for the dates indicated. The Subcommittee underscores the importance of moderate, sustained flows during the actual spawning periods(s). Therefore as little variation as possible in flow during this period of time is preferred.

TABLE 1

Proposed Water Flow Regime in CFS, April 1 - June 15

Dates	Expected Average Daily Flow	Lower Limit	Upper Limit
April 1-15	8500	6600	13700
April 16-30	7800	5800	11000
May 1-15	6500	4700	9500
May 16-31	5900	4400	9500
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Recommended flows presented on the previous page 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. Preimpoundment, USGS data for the years 1912-1950 were used to negotiate the recommended flows for the dates indicated, yearly.

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 limit flow = 9500, and the minimum, or lower limit flow = 4700. 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 best 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 (20000 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 is needed.

It should be noted that the recommended flow regime is not consistant 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 May 1 - June 15 are lower than those in the 1971 Memorandum. However, the timeframe of April 1 - June 15 is consistant with the FERC license requirement.

Variation in 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 limits for the dates indicated. The Subcommittee underscores the importance of moderate, sustained flows during the actual spawning periods(s). Therefore as little variation as possible in flow during this period of time is preferred.

August 11, 1988

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, preferrably by Spring 1989.

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 trial period, the following shall be evaluated 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 NC Department 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 insure a regularly maintained, new, recommended flow regime for the Roanoke River.

Passed unanimously by full committee (8/12/88)

North Carolina Wildlife Resources Commission

512 N. Salisbury Street, Raleigh, North Carolina 27611, 919-733-3391
Charles R. Fullwood, Executive Director

12 September 88

Dr. Charles S. Manooch, III
National Marine Fisheries Service
Beaufort Laboratory
Beaufort, North Carolina 28516

Dear Chuck,

Thank you for your letter informing me of the objectives, activities and recommendations of the ad hoc committee investigating water flows in the Roanoke River below Roanoke Rapids Dam.

It is obvious that the Committee expended considerable effort in investigating the problem and developing recommendations. I am appreciative of these efforts and I look forward to receiving the Committee's full report.

Yours truly,

Charles

Charles R. Fullwood

CRF/so

cc: Boating & Inland Fisheries

TERRY SANFORD
NORTH CAROLINA

United States Senate

WASHINGTON, DC 20510

September 13, 1988

Dr. Roger A. Rulifson
Co-Chair
Roanoke River Water Flow Committee
c/o Institute for Coastal and Marine
Resources
East Carolina University
Greenville, NC 27858

Dear Dr. Rulifson,

Thank you for your recent letter and the enclosed information regarding the Roanoke River Water Flow Committee's activities and recommendations.

I am pleased at the initiative taken by the Committee in studying the impact of changing water flows on the Roanoke's wildlife and fishery resources, particularly with respect to the striped bass. This is exactly the kind of information that is needed by policymakers as projects that could significantly affect water flow in the River are discussed.

I have noted with interest the Committee's recommendations and have taken the liberty of sending a copy of the information you enclosed to the Senate Environment Committee, which will soon be considering reauthorization of the Atlantic Striped Bass Conservation Act.

I hope you will continue to keep me informed of the Committee's work. Please don't hesitate to contact me, or John Blackburn of my staff, at (202) 224-3154 whenever my office can be of assistance.

With best wishes always,

Sincerely,

Terry Sanford

Terry Sanford

TS/jpb

State of North Carolina

Department of Agriculture

Raleigh

JAMES A. GRAHAM
COMMISSIONER

September 20, 1988

Dr. Charles Manooch, III, Ph.D.
Flow Committee Co-Chair
National Marine Fisheries Service
Beaufort Laboratory
Beaufort, North Carolina 28616-9722

Dear Chuck:

Thank you for your August 31 letter describing the purpose process and recommendations of the Roanoke River Water Flow Committee. I have followed the actions of this committee with great interest. The management of flows is vital to the striped bass, wildlife, timber industry and agricultural production in the Roanoke basin.

I fully concur with your findings and recommendations. The recommendation for a standing committee is excellent in that it is the only way to ensure consistent review and evaluation. I feel that due to the multiresource nature of these recommendations, a state agency such as the Division of Water Resources in the Department of Natural Resources and Community Development, would be appropriate to house the effort administratively.

I believe in multipurpose projects such as Kerr Dam. However without a formal review process, certain interests seem to dominate their management. Agriculture, forestry, wildlife and the striped bass need proper consideration in the management of the river.

Thank you for your hard work, leadership and concern.

With all good wishes.

Cordially,

Jim Graham

James A. Graham
Commissioner

JAG:RF:ek

State of North Carolina
Department of Natural Resources and Community Development
512 North Salisbury Street • Raleigh, North Carolina 27611

James G. Martin, Governor

S. Thomas Rhodes, Secretary

September 22, 1988

Mr. Charles S. Manooch, III., Ph.D.
Mr. Roger A. Rulifson, Ph.D.
Roanoke River Flow Committee Co-Chairmen
Institute for Coastal and Marine Resources
East Carolina University
Greenville, North Carolina 27834

Dear Drs. Manooch and Rulifson:

Thank you for your letter of August 31, 1988 concerning the work of the Roanoke River Flow Committee.

The expertise of this committee is very impressive and exemplifies what can be done when all interests come together with a common goal. Striped bass are extremely important to the commercial and recreational economy of the Roanoke-Albemarle region. I am well aware of the efforts the Marine Fisheries Commission has been going through over the last three years in order to conserve striped bass while maintaining a multi-species fishery in the Albemarle Sound.

The input of the ad-hoc flow committee is critical in order to set the optimum river flow regions necessary to protect the natural resources of the Roanoke River basin.

It appears from the juvenile index so far this year that a definite improvement in the spawning run this spring has taken place as we have the best index since 1976. I agree with the committee that this needs to be followed over several years to refine and verify the necessary flow regime for striped bass spawning success while protecting other resources in the basin. The committee will also be valuable to the formation of the State Striped Bass Management Plan that is being developed by the Wildlife Commission and the Division of Marine Fisheries. This plan will be required by the Atlantic States Fisheries Management Commission as part of the reauthorization of the Striped Bass Conservation Act.

P.O. Box 27687, Raleigh, North Carolina 27611-7687 Telephone 919-733-4984

I support the flow committee in their efforts and commit the services of my Department in these efforts.

If I can be of any assistance, please let me know.

Sincerely,

S. Thomas Rhodes

S. Thomas Rhodes

STR/WTH:jm

cc: William T. Hogarth

STATE OF NORTH CAROLINA
OFFICE OF THE GOVERNOR
RALEIGH 27603-8001

September 23, 1988

JAMES G. MARTIN
GOVERNOR

Dr. Charles S. Manooch, III
Dr. Roger A. Rulifson
Flow Committee Co-Chair
Roanoke River Water Flow Committee
c/o Institute for Coastal and Marine Resources
East Carolina University
Greenville, North Carolina 27858-4353

Dear Drs. Manooch and Rulifson:

Your letter of August 31, 1988 concerning the work of the ad-hoc flow committee on the Roanoke River has been reviewed with great interest. It is encouraging to see so many interests and agencies get together and work for the improvement of a traditional part of our State's heritage. I can assure you I will support these efforts to restore the striped bass populations to their historical levels. Since I have been Governor, I have been very aware of the hardships created on the fishermen in the Roanoke-Albemarle areas by the drastic declines in the striped bass population.

It is my understanding that so far this year, the juvenile index is approximately four which is the highest since 1976. This is a very good beginning to what I hope will be the recovery of the striped bass populations. Your committee is to be congratulated for their interest and results in this effort.

I agree the flow committee's work should continue in order to refine and verify the best flow regime for the users in the Roanoke River basin. Therefore, I will in the near future appoint a working group to continue the flow committee evaluations for the next three to four years.

Thank you and your committee for their important work. If I can be of further assistance, please contact my office or Secretary S. Thomas Rhodes of the Department of Natural Resources and Community Development.

Sincerely,

Jim Martin

James G. Martin

JGM:kew

Enclosures

cc: Secretary S. Thomas Rhodes
Mr. William T. Hogarth

BRIEFING

Striped bass catches have dropped from over one million pounds commercially to only 262,000 pounds in 1987. Recreation catches have dropped accordingly.

Marine Fisheries Commission has been forced to impose strict regulations on striped bass both commercially - short seasons, gear restrictions and three fish per day per fishermen for recreation fishermen.

Fishermen taking much of the blame for the decrease when in actuality it appears flow regime as a result of the operation of the dams is interfering with the striped bass spawning run.

Roanoke River is the major spawning area for striped bass in North Carolina stripes require attracting flow to move them from the Sound to the River and the 100 plus mile trip to the spawning area at Halifax-Weldon, North Carolina.

Proper flows are needed for spawning and to transport larvae to delta where feeding takes place. Since the dams have been in place the flows have not been conducive for striped bass.

Corp of Engineers and Virginia Power agreed to regulate flows as committee requested - results - best juvenile index in 10 to 15 years.

Roanoke River flow is operated by lake levels (recreation) first, hydroelectric power second.

Two news releases attached on striped bass as a result of flow committee work.

Working Group should include:

- Division of Marine Fisheries
- Wildlife Commission
- Dr. W.W. Hassler, retired NCSU Professor, has 25 plus years of data on Roanoke River Striped Bass
- National Marine Fisheries Service - Dr. Manooch
- U.S. Fish and Wildlife Service - Bill Cole
- Dr. Rulifson - East Carolina, has Albemarle-Pamlico, projects on striped bass
- N.C. Division of Water Resources
- N.C. Department of Agriculture
- Dr. Monroe, Statistician, NCSU, Consultant to Division of Marine Fisheries
- Corp of Engineers
- Virginia Power

James G. Martin, Governor

S. Thomas Rhodes, Secretary

North Carolina
Department of Natural Resources and Community Development

Release: IMMEDIATE

Date: 26 August 1988

Contact: Division of Marine Fisheries, Morehead City 1-800-682-2632

STATUS OF STRIPED BASS FISHERY IN ROANOKE/ALBEMARLE

Morehead City.....The future of the Roanoke-Albemarle striped bass fishery is more optimistic this year due mainly to the regulation of the Roanoke River flow and improved water quality conditions.

Dr. William T. Hogarth, Director, N.C. Division of Marine Fisheries explains, "the Roanoke River is the principal spawning area for the Albemarle Sound striped bass. Proper river flow and environmental conditions are critical for growth and survival during the early life stages of the striped bass. Adult striped bass spawn near Weldon. Egg and larval fish are totally dependant on river flow for their transport during the 100 mile trip from the spawning grounds to the nursery areas in the Roanoke River delta and western Albemarle Sound."

Roanoke River flow, which is regulated by three dams (Kerr, Gaston, and Roanoke Rapids), affects water quality conditions in the entire western Albemarle Sound, supplying approximately two-thirds of the inflow to this nursery area. Magnitude and duration of flow affect the timing distribution, abundance, and growth of the young striped bass and their food sources.

Earlier this year, the Division of Marine Fisheries participated in a Roanoke River Flow Committee which recommended a more favorable spring flow by lake management changes. Through cooperative efforts by the U.S. Army Corps of Engineers and Virginia Power, the recommended flows can normally be maintained.

Natural production and recruitment has remained at historically low levels for the eleven years prior to this season. During the 1988 spawning season, Roanoke River flows were maintained at a more biologically acceptable level for striped bass production.

"Samples of the juvenile striped bass population taken in July and August, 1988, indicate that reproduction and survival may be the best since the 1976 season," states Dr. Hogarth.

-more on reverse side-

Public Affairs Office
P.O. Box 27687, Raleigh, N.C. 27611
(919) 733-4984

Don Follmer
Director, Office of Public Affairs

"A Phase II Striped Bass Stocking Program, along with severe restrictions on commercial and recreational harvest, has helped to maintain the population," Hogarth continued.

"The increased number of young fish this year is evidence that the present striped bass population can provide sufficient reproduction for recovery, if proper river flow and environmental conditions are available. Continued harvest restrictions will be necessary to protect the 1988 year class until they spawn or until natural production reaches a consistently acceptable level," Hogarth concluded.

For further information contact the N.C. Division of Marine Fisheries by calling 1-800-682-2632 between the hours of 7:00 am and 11:00 pm, Monday through Friday.

-end-

James G. Martin, Governor

S. Thomas Rhodes, Secretary

North Carolina
Department of Natural Resources and Community Development

Release: IMMEDIATE Date: 17 August 1988

Contact: Division of Marine Fisheries, Morehead City 1-800-682-2632

MARINE FISHERIES OBJECTS TO LAKE GASTON PIPELINE

Morehead City...The planned withdrawal of 60 million gallons of water per day from Lake Gaston for use by Virginia Beach will have a significant long-term negative impact on striped bass in the Roanoke River/Albemarle Sound area.

Dr. William T. Hogarth, Director, Division of Marine Fisheries (DMF) adds that "striped bass are an extremely valuable commercial and recreational resource to the people of North Carolina and have been since colonial times. The Roanoke River (fed from Lake Gaston) is the major spawning river for striped bass in North Carolina. The dams on the River have historically been operated first for hydroelectric power generation, second for recreation, and third for striped bass spawning."

In a letter to the U.S. Army Corps of Engineers, Dr. Hogarth also requested a full Environmental Impact Statement (EIS) which he feels is absolutely necessary to determine the existing, proposed, and cumulative effects of water withdrawal on striped bass. Aspects such as spawning, egg and larval transport, food chain development, and adequate water quality maintenance must be address before irrevocable commitments in water management regimes are set.

The DMF strongly objects to the withdrawal of 60 million gallons of water per day from Lake Gaston and feels that is will severely limit current and future natural resource management options throughout the Roanoke River/Albemarle Sound system. The DMF has managed this system as a multi-species fishery in order to protect the livelihood of the fishermen utilizing the Albemarle Sound Estuary. The striped bass population is monitored constantly and appropriate actions taken to reduce the fish mortality. During the 1988 spawning season, the Roanoke River flows were maintained at a more biologically acceptable level.

"As a result, the July sampling by the DMF yielded the highest number of juvenile fish found since 1976", Hogarth continued. "The DMF believes that environmental conditions exert major influences on the reproduction of survival of all fishes in the Albemarle Sound and its tributaries. The Roanoke River flow directly affects the hydrology, water quality, and potential productivity of the western Albemarle Sound, delivering approximately two-thirds of the flow to these waters. Since the Roanoke River is the sole major spawning river for striped bass in North Carolina, it is critical that the flow not be diminished".

-end-

Public Affairs Office
P.O. Box 27687, Raleigh, N.C. 27611
(919) 733-4984

Don Follmer
Director, Office of Public Affairs

U.S. House of Representatives
Committee on
Merchant Marine and Fisheries
Room 1334, Longworth House Office Building
Washington, DC 20515-6230

November 1, 1988

Dr. Roger A. Rulifson, Ph.D.
Flow Committee Co-Chair
Roanoke River Water Flow Committee
c/o Institute for Coastal and Marine Resources
East Carolina University
Greenville, North Carolina 27858

Dear Dr. Rulifson:

Thank you very much for your past letter informing me of the activities and recommendations of the Roanoke River Water Flow Committee. I would like to offer my hearty congratulations on your timely and comprehensive work. The Committee's deliberations have already made a substantial contribution to conserving the resources of the lower watershed of the Roanoke River and promise to make a continuing contribution in the future. I find your recommendations regarding the future of the Flow Committee very attractive in terms of holding annual meetings, issuing formal reports, continuing to evaluate recommended flow regimes, incorporating the flow regime recommendations in Memoranda of Understanding with other agencies, and maintaining a high priority for the conservation and restoration of striped bass.

As you are probably aware, one of my highest priorities during the 100th Congress has been to establish a study of the status of striped bass in the Albemarle Sound and Roanoke River Basin. After considerable discussion and negotiation, the House and Senate recently agreed upon and passed such a study as part of H.R. 4124, a bill that reauthorized the Atlantic Striped Bass Conservation Act. I have enclosed a copy of H.R. 4124 and floor statements that serve as part of its legislative history for your reference.

I know that you and members of your Committee contributed actively in the formulation of this legislation. Thank you for your effective assistance. You will note that the study language and the floor statements are replete with references to the effects of water withdrawals and discharges; water flows before, during, and after critical striped bass spawning periods; reservoir management and water flow regulation; and other issues of interest to the Water Flow Committee and to North Carolina.

The provisions authorizing the North Carolina Striped Bass Study contain language that deals with participation by State agencies and consultation with other interested groups. While this provision does not refer specifically by name to the Water Flow Committee, it is obvious that your Committee can provide exactly the type of knowledge and expertise through its membership and deliberations that could make a great contribution to the North Carolina Striped Bass Study. It is certainly my intent that the Water Flow Committee be included among the groups that are consulted to the maximum extent practicable. I am aware that many of the 20 members of the Committee represent State and Federal agencies and will be involved in consultation because of their roles in those agencies. Nevertheless, I will contact the Director of the U.S. Fish and Wildlife Service (FWS) and the Assistant Administrator of the National Oceanic and Atmospheric Administration for Fisheries (NOAA) to urge that FWS and NOAA avail themselves of the expertise of your Committee during the Study.

I look forward to the continuing contributions of the Roanoke Water Flow Committee to the resources of the Roanoke River, their users, and the general population of the Albemarle Sound-Roanoke River Basin. Thank you again for your report, and do not hesitate to contact my office when I can assist you with your good work.

With warmest personal regards, I am

Sincerely,

Walter B. Jones

WALTER B. JONES
Chairman

Enclosure

State of North Carolina
Department of Natural Resources and Community Development
Division of Marine Fisheries
P.O. Box 769 • Morehead City, North Carolina 28557-0769

James G. Martin, Governor
William W. Cobey, Jr., Secretary

William T. Hogarth, Director
(919) 726-7021

January 6, 198~~8~~ 9

Congressman Walter B. Jones
241 Conner House Office Building
Washington, DC 20515

Dear Sir:

We appreciate very much your hard work in attaining reauthorization of the Atlantic Striped Bass Conservation Act (PL 110-589), including Section 5 providing for a cooperative state-federal study of Roanoke River-Albemarle Sound striped bass.

The North Carolina Marine Fisheries Commission is keenly aware of the biological and social problems of the striped bass fishery and intends to maintain its cooperative and responsible management approach. We feel that the study provided for in Section 5 is extremely important and merits a very high priority for funding in the federal FY 1990 budget. We urge as strongly as possible that funds be appropriated for the study as provided in the Act.

Attached is a resolution of the Commission in support of this request.

Again, thank you for your continued support.

Sincerely,

Thomas S. Bennett

Thomas S. Bennett, Chairman
NC Marine Fisheries Commission

TSB:WTH/ko

cc: Governor Martin
Secretary Cobey
NC Congressional delegation
Secretary of the Interior
Secretary of Natural Resources, Virginia
William T. Hogarth
NC Marine Fisheries Commission

RESOLUTION

OF THE

NORTH CAROLINA MARINE FISHERIES DIVISION

WHEREAS The One Hundredth Congress of the United States (2nd Session) has recognized the need for a study of striped bass in Albemarle Sound and Roanoke River Basin P.L. 589, approved November 3, 1988, 102 STAT 2984; and

WHEREAS The Division of Marine Fisheries has actively participated within the Atlantic States Marine Fisheries Commission under the Atlantic Striped Bass Conservation Act to develop and implement an Atlantic coast management plan for migratory striped bass; and

WHEREAS The Division is actively involved in a Cooperative Agreement with the US Fish and Wildlife Service and the North Carolina Wildlife Resources Commission to plan for and manage striped bass in North Carolina waters;

NOW THEREFORE BE IT RESOLVED that the North Carolina Marine Fisheries Commission urges the Congress to follow through on their authorization of appropriations by appropriating those funds authorized by P.L. 589 to complete these necessary and essential actions for this important North Carolina commercial and recreational fishery.

This the 9th day of December, 1988.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Fisheries Center
Beaufort Laboratory
Beaufort, N.C. 28516-9722

February 10, 1989

Mr. Fred Harris
Chief of Fisheries
North Carolina Wildlife
Resources Commission
512 N. Salisbury St.
Raleigh, NC 27611

Dear Fred,

As a followup to the planning meeting for the North Carolina striped bass study held in Raleigh 2-3 February, I wish to pursue the action recommendation made at that meeting by members of the Roanoke River Water Flow Committee. That is, for the three parties: NC Wildlife Resources Commission, US Army Corps of Engineers, Wilmington District, and Virginia Power Company to re-examine the Memorandum of Understanding pertaining to Roanoke River water flows and striped bass spawning. Since both the Corps and Virginia Power have expressed the willingness to follow our Committee's recommended flow regime, it would seem appropriate for the Wildlife Resources Commission to officially notify the Corps and arrange a meeting of the parties. This should probably be done as soon as possible to allow the Corps to make plans for this spring.

Sincerely,

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

cc: Tony Mullis, NCWRC, Greenville
Roger Rulifson, ECU, Greenville

North Carolina Wildlife Resources Commission

512 N. Salisbury Street, Raleigh, North Carolina 27611, 919-733-3391
Charles R. Fullwood, Executive Director

February 21, 1989

Colonel Paul Woodbury
U.S. Army Corps of Engineers
P. O. Box 1890
Wilmington, NC 28401

Dear Colonel Woodbury:

As you are aware the Roanoke River Water Flow Committee has been evaluating water flows in the Roanoke River and the impact of various flow regimes on the reproductive success of striped bass. Although the committee's final report has not been released, we think it is appropriate to implement the recommended flow regime during 1989. To this end we request that the 1971 Memorandum of Understanding signed by Virginia Power and Electric Co., the U.S. Army Corps of Engineers, and the Wildlife Resources Commission be amended as follows:

1. During the period April 1-15 establish a target flow of 8500 CFS with a range of 6600 - 13700 CFS.

2. During the period April 16-30 establish a target flow of 7800 CFS with a range of 5800 - 11000 CFS.

3. During the period May 1-15 establish a target flow of 6500 CFS with a range of 4700 - 9500 CFS.

4. During the period May 16-31 establish a target flow of 5900 CFS with a range of 4400 - 9500 CFS.

5. During the period June 1-15 establish a target flow of 5300 CFS with a range of 4000 - 9500 CFS.

We further recommend that this amendment become effective on April 1, 1989 and that it remain in effect until June 15, 1992 to allow a thorough evaluation of its impact upon striped bass spawning. Following this evaluation, we should negotiate a new long term agreement to provide acceptable flows in the Roanoke River during the time of striped bass spawning.

We appreciate your assistance in this matter.

Sincerely,

Charles R. Fullwood
Executive Director

CRF/lr

cc: Jack Mitchell, Virginia Electric Power Co.
Lois D. Cashell, Secretary, FERC
Charles Manooch, Co-Chairman, Roanoke Water Flow Comm.
Roger Rulifson, Co-Chairman, Roanoke Water Flow Comm.
Jaman Vithalani, Corps of Engineers