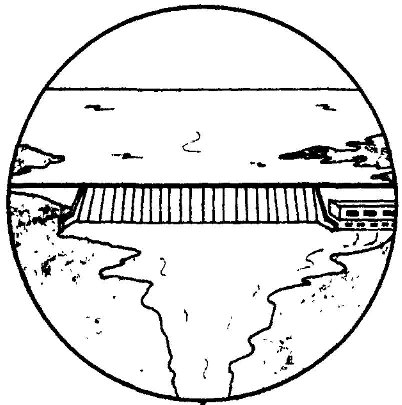
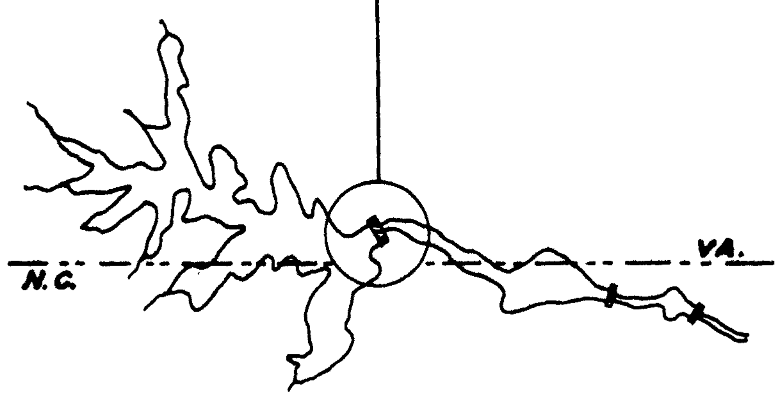


INVESTIGATION OF THE
LOWER ROANOKE RIVER BASIN
VIRGINIA AND NORTH CAROLINA

EFFECTS OF THE JOHN H. KERR PROJECT ON WATER QUALITY



U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
REGION III
Public Health Service
Division of Water Supply and Pollution Control
Charlottesville, Virginia

November 1962

INVESTIGATION OF THE LOWER ROANOKE RIVER BASIN

Report on the Effects of Possible Modification of
John H. Kerr Project to Improve Water Quality
of the Lower Roanoke River

Prepared at the request of and in cooperation with
the District Engineer, Norfolk District
Corps of Engineers, U. S. Army

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control

Region III, Charlottesville, Virginia
and
Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

November 1962

SYNOPSIS

At the time John H. Kerr Dam was planned provision was made for minimum flows necessary to assimilate municipal and industrial wastes then reaching the Roanoke River at Roanoke Rapids, North Carolina. The minimum assimilative capacity of the stream under natural low flow conditions is estimated to have been 51,000 pounds of BOD per day. Possible discharge from the reservoir of water low in dissolved oxygen was not considered serious since it was felt that adequate dissolved oxygen would be available through reaeration before oxygen consuming wastes would be discharged to the river at Roanoke Rapids.

Prior to construction of Roanoke Rapids Dam reaeration resulted in dissolved oxygen conditions at Roanoke Rapids of near saturation and generally satisfactory conditions below that point. Following construction of Roanoke Rapids Dam reaeration between Kerr Dam and Roanoke Rapids was substantially reduced. The proximity of Roanoke Rapids to the waste sources also increased the period over which minimum flow conditions persist. Together with increasing waste loads these factors resulted in dissolved oxygen levels below reasonable quality objectives and occasional fish kills. Reduction in waste loads by in-plant control and release in proportion to flow, provision of a submerged weir in Roanoke Rapids Reservoir, and increases in minimum flow releases at Roanoke Rapids Dam have greatly improved conditions below Roanoke Rapids. Construction of Gaston Dam is now essentially complete with a submerged weir installed to prevent density underflow. Conditions at Roanoke Rapids are expected to be improved still further with Gaston Dam in operation.

The initial source of low dissolved oxygen water is the hypolimnion of John H. Kerr Dam. Biochemical degradation of organic materials of natural, municipal, and industrial origin in and above Kerr Reservoir and restriction of mixing caused by thermal stratification contribute to this depletion of the dissolved oxygen in the hypolimnion. Such depletion occurs in most lakes or reservoirs, the degree depending on such factors as depth, organic load, nutrient load, and weather. Since construction of John H. Kerr Dam concern for adequate dissolved oxygen levels has been extended to the entire length of the river rather than to reaches affected by organic waste discharges alone. Kerr Dam can be considered as the equivalent of a source of pollution from the standpoint of altering water quality in the Roanoke River below the reservoir even though no addition of organic waste is involved. It is recommended that facilities be provided or operation modified to the extent that adverse dissolved oxygen conditions be corrected at least to the level required of other water users. No need for increased minimum flow at Kerr Dam is indicated at the present time.

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INTRODUCTION

In a letter dated May 16, 1961, the District Engineer, Corps of Engineers, Norfolk District, authorized the Public Health Service to prepare a report on the lower Roanoke River in Virginia and North Carolina to assist in the determination of whether modification of the John H. Kerr Project is advisable in the interest of pollution abatement. The resulting report is to be incorporated as an appendix to a report of a study of the lower Roanoke River which is being made by the Norfolk District in accordance with a resolution adopted in 1956 by the Committee on Public Works of the House of Representatives. The resolution states:

> "That the Board of Engineers...review report on Roanoke River Basin... published in Document 650...insofar as said reports relate to that portion of the basin which extends as far upstream as and includes John H. Kerr Dam and reservoir, and submit to the Congress...recommendations for any modification of project plans that are advisable with respect to water releases required and with respect to storage required for flood control, power production, pollution abatement, navigation, and fish preservation."

The present report summarizes the existing information on water quality in and below the John H. Kerr Reservoir, discusses water quality and factors affecting such quality, makes recommendations relative to minimum flows and quality below John H. Kerr Dam, discusses possible engineering measures for improving the quality of reservoir discharges and considers the benefits to water quality resulting from possible modification of the discharges from the John H. Kerr Reservoir.

Grateful acknowledgment is extended to the following aggncies whose cooperation and assistance contributed substantially to the preparation of this report:

Corps of Engineers, Norfolk District
North Carolina State Stream Sanitation Committee
Virginia State Water Control Board
Virginia Electric and Power Company
United States Fish and Wildlife Service
North Carolina Department of Conservation and Development
Virginia Departmen of Conservation and Economic Development
United States Geological Survey

Particular note is made of the work of the Steering Committee for Roanoke River Studies.

Report and publications consulted are listed at the end of this report.

SUMMARY

1. Conflicts between power production, water supply, waste disposal, and fish propagation have developed on the Roanoke River in the vicinity of Roanoke Rapids as the result of increasing industrial activity at Roanoke Rapids and flow regulation for peaking power production at John H. Kerr, Gaston, and Roanoke Rapids Dams.

2. At the time of the 1947 Public Health Service evaluation of John H. Kerr Dam, summer flows of 2,000 cfs on weekdays and 1,000 cfs on weekends were established for the Roanoke River at Roanoke Rapids for water quality control. These flows were based on observed waste loads and initial dissolved oxygen conditions (7.8 mg/l at 25°C.) above Roanoke Rapids waste sources.

3. It has been estimated that under natural flow conditions (925 cfs) prior to construction of John H. Kerr Dam, the assimilative capacity of the Roanoke River below Roanoke Rapids was 51,000 pounds of 5-day, 20°C. BOD per day.

4. The development of thermal stratification in the John H. Kerr Reservoir each summer has resulted in dissolved oxygen levels as low as 1.2 mg/l in the tailrace and as low as 7.0 mg/l above Roanoke Rapids waste sources (prior to completion of Roanoke Rapids Dam).

5. The North Carolina State Stream Sanitation Committee estimated that the waste assimilative capacity of the Roanoke River below Roanoke Rapids, following construction of John H. Kerr Dam (prior to completion of Roanoke Rapids Dam), was 109,000 pounds of 5-day, 20°C. BOD per day at the minimum weekday flow of 2,000 cfs.

6. Minimum weekday and weekend flows provided at the time John H. Kerr Dam was constructed were adequate to receive the waste loads discharged at that time and to maintain the dissolved oxygen objective of 4.0 mg/l below Roanoke Rapids. However, no provision was made for increased waste resulting from municipal and industrial growth.

7. Since construction of Roanoke Rapids Dam, flows at Roanoke Rapids have been controlled by the Virginia Electric and Power Company. Federal Power Commission License 2009 provided for minimum summer flows of 2,000 cfs on weekdays and 1,000 cfs on weekends. The dissolved oxygen content of the Roanoke River above Roanoke Rapids waste sources was reduced from 7.3 mg/l to 5.4 mg/l during summer months of 1956. A minimum dissolved oxygen value of 3.2 mg/l was observed.

8. Minimum weekend flows at the reduced dissolved oxygen concentration existing after construction of Roanoke Rapids Dam were not adequate to assimilate the increaased waste loads resulting from municipal and industrial growth between 1951 and 1955 and still maintain the dissolved oxygen objective of 4.0 mg/l below Roanoke Rapids.

9. Weekend flows, increased waste loads, and reduced D.O. in the Roanoke Rapids Dam discharge resulted in fish kills in the Roanoke River below Roanoke Rapids in the summer of 1956. Since then, weekend flows have been increased, waste loads reduced, and a submerged weir installed in Roanoke Rapids Reservoir to improve the D.O. discharged.

10. Although low dissolved oxygen conditions continue to appear below John H. Kerr Dam, completion of a submerged weir in Roanoke Rapids Reservoir has resulted in an improvement of the observed average dissolved oxygen content of the Roanoke River above Roanoke Rapids waste sources from 5.4 to 6.3 mg/l.

11. Provisions of Federal Power Commission License 2009, as amended to authorize the Gaston Project, include requirements for minimum dissolved oxygen releases below Roanoke Rapids Dam, for a submerged weir in Gaston Reservoir, and for elimination of reduced weekend flows. It is expected that these requirments will assure that a minimum waste assimilative capacity of 109,000 pounds of BOD per day will be available at Roanoke Rapids.

12. The waste assimilative capacities available at summer temperature conditions and various impoundment and minimum flow conditions have been estimated. The assimilative capacities are shown in terms of pounds of 5-day, 20°C. BOD in the following tabulation:

	1,000 (cfs)	2,000 (cfs)	Minimum 7-Day Mean Flow Occurring 1 Yr in 10	Minimum Monthly Mean Flow Occurring 1 Yr in 10	Minimum Monthly Mean Flow Occurring 1 Yr in 2
Natural Flow (Prior to 1952)	-	-	51,000	73,000	177,000
Post-Kerr Dam (1952 to 1955)	55,000	109,000	-	131,000	206,000
Post-Roanoke Rapids Dam Before Installation of Submerged Weir (1955 and 1956)	40,000	80,000	-	104,000	161,000
After Installation of Submerged Weir (1957 to Present)	-	93,000	-	119,000	184,000
Post-Gaston Dam (After 1963) Provided by License 2009 (Amended)	-	109,000	-	-	-
At Minimum D.O. Predicted in Special Report No. 1	-	-	-	113,000	176,000

This tabulation indicates that the assured capacity of the lower Roanoke River to assimilate wastes has been increased from 51,000 pounds of BOD per day to 109,000 pounds per day by storage provided by John H. Kerr Dam and dissolved oxygen and flow reregulation provided by Roanoke Rapids Dam.

CONCLUSIONS

1. The North Carolina State Stream Sanitation Committee has established a minimum dissolved oxygen objective of 4.0 mg/l for the Roanoke River from the Virginia-North Carolina State line to tidewater. Although the Virginia State Water Control Board has not established water quality objectives for the stream below John H. Kerr Dam, 4.0 mg/l is widely accepted as a reasonable minimum dissolved oxygen objective in warm water streams for the protection and preservation of fish and aquatic life and for the protection of other legitimate uses, and it has therefore been considered reasonable for purposes of this report to apply the same value over the entire length of the Roanoke River from Kerr Dam to tidewater.

2. As a result of thermal stratification and low level intakes, dissolved oxygen levels in John H. Kerr Dam tailrace have been below the water quality objective of 2.0 mg/l for an average of 82 days each summer Dissolved oxygen levels have been below 3.0 mg/l an average of 61 days and below 2.0 mg/l an average of 20 days each summer.

3. Since completion of John H. Kerr Dam, the mean dissolved oxygen content of the Roanoke River at the Virginia-North Carolina State line has been below the water quality objective of 4.0 mg/l for an average of 33 days per year; it has been below 3.0 mg/l for an average of 3 days per year

4. The minimum flow and dissolved oxygen requirements below Roanoke Rapids Dam included in the Federal Power Commission License 2009, as amended to include the Gaston Project, provide for sufficient waste assimilative capacity for the residual wastes from present and anticipated municipal and industrial wastes after adequate treatment or other means of controlling wastes at their source. Therefore, additional flow at Federal expense for water quality control below Roanoke Rapids is not warranted at this time.

5. There is a definite need to improve the dissolved oxygen content of discharges from John H. Kerr Dam at least to the extent necessary to achieve the minimum objective of 4.0 mg/l. An average increase of 0.6, 2.0, and 1.2 mg/l is required in the summer months of July, August, and September, respectively, to assure a daily average dissolved oxygen concentration of 4.0 mg/l in the tailrace.

6. Under conditions of water resources development prior to completion of Gaston, it is estimated that an increase of 1.0 mg/l in the dissolved oxygen content of the John H. Kerr tailrace will result in a 0.2 mg/l increase in the tailrace of Roanoke Rapids Dam; however, installation of Gaston Dam with a submerged weir having a crest 15 feet below the full pool elevation will modify the effects of low dissolved oxygen discharges from Kerr Dam on downstream water quality. It is expected that density underflow problems will be of much less significance and dissolved oxygen changes at Kerr Dam will have very little effect on the dissolved oxygen discharged from Roanoke Rapids Dam.

7. Any user of public waters has the responsibility of applying measures which will assure that the resulting water below the installation meets reasonable quality objectives. Thermal stratification and deoxygenation of hypolimnetic water is a natural process in deep bodies of water, and provision for meeting reasonable water quality objectives in the reservoir discharge is a necessary part of utilizing impoundments for beneficial purposes.

RECOMMENDATIONS

1. Although the Federal Power Commission has made control of minimum flows at Roanoke Rapids the responsibility of the Virginia Electric and Power Company, the Corps of Engineers should provide sufficient discharge from John H. Kerr Dam, in combination with runoff from the intervening area, to assure that required minimum flows can be met at Roanoke Rapids Dam within the stage requirements established by the Federal Power Commission for the Gaston and Roanoke Rapids Dams.

2. The facilities and operation of John H. Kerr Dam should be modified to the extent that the quality of water discharged, as measured in the tailrace, meets the generally accepted minimum dissolved oxygen objective of 4.0 mg/l during all seasons of the year.

3. The Corps of Engineers should continue its program of stream and reservoir sampling and coordinate it with other agencies, especially for the period June 1 to October 30 of each year when critical dissolved oxygen conditions have occurred in the past so that information on the effectiveness of quality control measures will be available. The installation of continuous dissolved oxygen and temperature recording equipment below Kerr Dam is recommended as an especially valuable addition to the stream monitoring program. The coordination of sampling with the program of the Virginia Electric and Power Company will enhance the value of samples collected under each program.

4. Any facility installed at Kerr Dam for the purpose of water quality control should be subject to detailed field observation to determine the effectiveness of the facility and information obtained in such studies should be made available for possible future use in designing and/or evaluating similar projects.

5. In the interests of advancing knowledge and understanding of dissolved oxygen relationships in reservoirs, the effect of improvement of the dissolved oxygen content of John H. Kerr discharges on dissolved oxygen conditions below Gaston and Roanoke Rapids Dams and on the assimilative capacity of the Roanoke River below Roanoke Rapids Dam should be determined after Gaston Dam has been in operation for several years.

SECTION 1

DESCRIPTION OF THE BASIN

THE AREA[1, 39, 40]

From its headwaters on the eastern slope of the Appalachian Mountains, west of Roanoke, Virginia, the Roanoke River flows southeasterly for 400 miles and discharges into Albemarle Sound near Plymouth, North Carolina. The total area of the Roanoke River Basin is 9,580 square miles of which 6,160 square miles are in south-central Virginia and 3,420 square miles are in northern North Carolina. Figure 1 shows the location of the basin and indicates reservoir development projects.

The Dan River, the principal tributary, joins the Roanoke at the upper end of the John H. Kerr Reservoir near Clarksville, Virginia. It has a drainage area of 2,850 square miles and, like the Roanoke River, is an interstate stream.

In its trip from the headwater to the mouth, the Roanoke River traverses three distinct topographical regions: (1) the mountainous region of the headwaters, (2) the rolling hills of the Piedmont Plateau, and (3) the broad, flat lands of the Coastal Plains. Streams in the mountainous region are typically swift and contain series of riffles and pools. Moderately swift streams with well-defined, V-shaped valleys are found in the Piedmont Plateau, while streams of the Coastal Plains are generally shallow and meandering with wide flood plains.

Land use in the basin is primarily agricultural; the principal cash crops are tobacco, cotton, and peanuts. In addition to agriculture, manufactured and forest products are important to the economy of the area. Manufactured products include textiles, pulp, paper, building materials, and furniture, while forest products include lumber, pulpwood, and veneer.

A wide variety of minerals are found in the area but, because of limited quantities, their commercial importance is small. Granite, mica, clay, tungsten, sand, and gravel are mined, while asbestos, limestone, coal, carbonaceous shale, copper, and ilmenite are available but not economically produced.

CLIMATE

The average annual temperature of the basin is about 56° and ranges from 54° in the Appalachian highlands to 59° in the tidewater or coastal area. According to a statistical summary of air temperatures at Weldon, North Carolina, for the period of 1928 to 1952,[84] the most probable high monthly average temperature of approximately 80° occurs in July, while the most probable low monthly average of about 42° occurs in December.

The precipitation which is relatively uniform over the drainage basin averages approximately 43 inches annually. The dryest year of record was 1930 when the annual precipitation in the basin was 27.36 inches. The wettest year was 1937 when the annual precipitation reached 54.34 inches.[2]

HYDROLOGY

General streamflow characteristics of the lower Roanoke River have been in a state of change since August 1950 when Philpott Dam on the Smith River showed its first, although minor, effects on downstream flow patterns. The John H. Kerr Dam and Roanoke Rapids Dam were completed November 1952 and June 1955, respectively, and their operation has resulted in full regulation of the lower Roanoke.[64] The John H. Kerr Reservoir is a federally owned project which operates primarily for flood control and peaking power production, while Roanoke Rapids Reservoir is privately owned and operates for the single purpose of peaking power production.

There are three U. S. Geological Survey gages on the Roanoke River below the John H. Kerr Dam. These gages are described as follows:

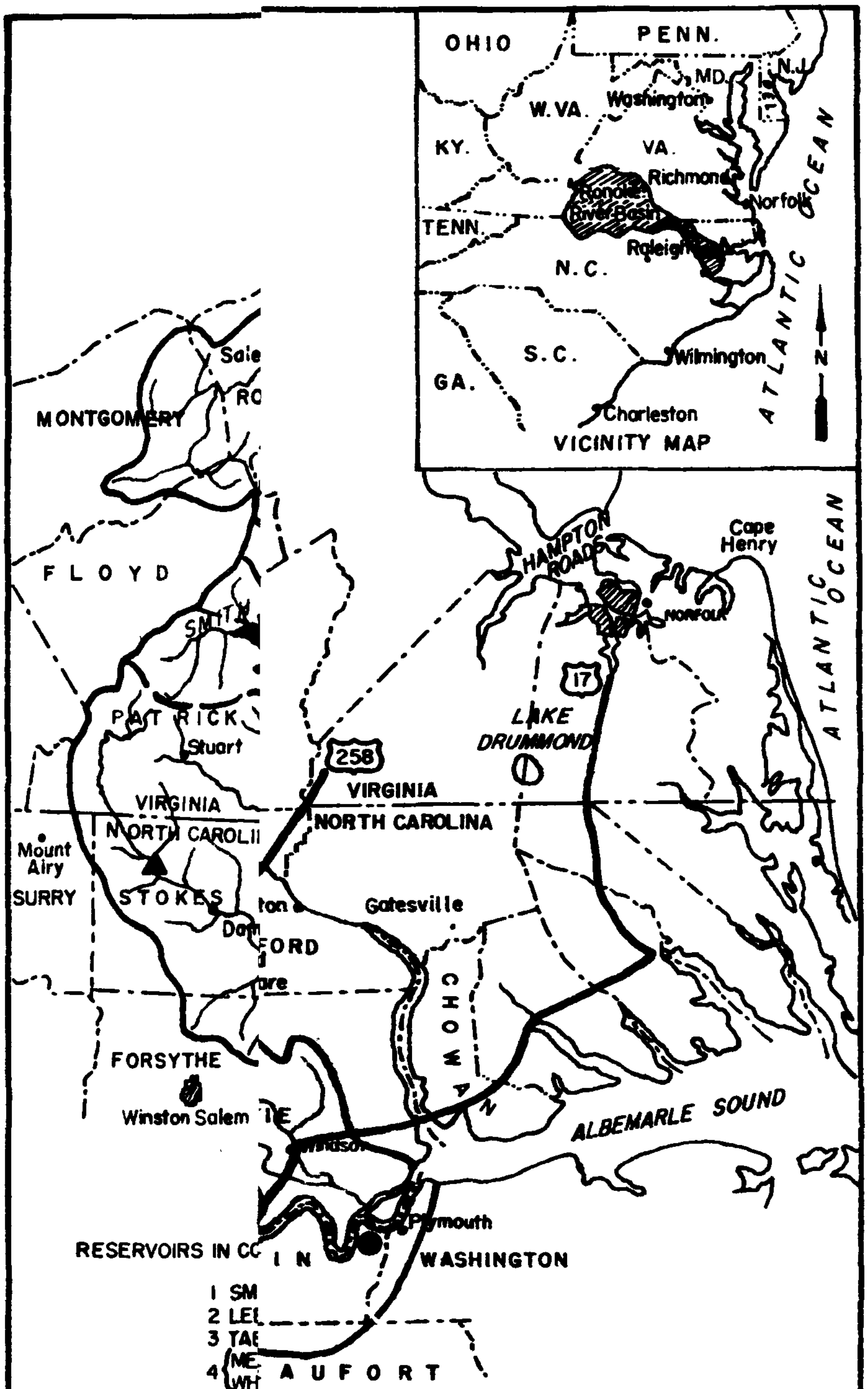

FIGURE I

ROANOKE RIVER BASIN

ROANOKE RIVER PROJECT

ROBERT A. TAFT SANITARY ENGINEERING CENTER

Cincinnati, Ohio March 1, 1962

Location	Period of Record
1. Buggs Island, Virginia river mile 178.4, 1200 feet downstream from Kerr Dam	November 1921 to August 1932 April 1947 to present
2. Roanoke Rapids, North Carolina river mile 133.6, 1-1/4 miles downstream from North Carolina 48 bridge	December 1911 to December 1932 (Old Gaston gage) February 1930 to present
3. Scotland Neck, North Carolina river mile 102.5, 10 feet upstream from U. S. 258 bridge	July 1896 to May 1903 (Neal gage) August 1940 to present

The Roanoke Rapids gage is located downstream from all reservoirs in the basin, and its records are therefore used to compare flow characteristics in the lower Roanoke River before and after regulation.

Under natural (unregulated) conditions, the maximum daily flow of record was 261,000 cfs on August 18, 1940, the average flow for 44 years of record was 8,364 cfs, and the minimum daily flow of record was 472 cfs on September 21, 1932.

The minimum 7-day mean low flow with a recurrence interval of once in 10 years* was 925 cfs prior to construction of major impoundments.[23]

Impoundment and subsequent regulation of discharges have not significantly altered annual streamflows; however, certain changes have occurred within the yearly periods. U. S. Geological Survey discharge records for the Roanoke Rapids gage indicate the following changes:

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*The minimum 7-day mean low flow with a recurrence interval of once in 10 years is the value of the lowest flow averaged over 7 consecutive days for each of the years for which observations are available which was exceeded in 90 percent (9 in 10) of the years, assuming a normal probability distribution. Thus, in 90 percent of the years the lowest mean of the flows occurring on 7 consecutive days was equal to or greater than the value indicated, while in 10 percent of the years (once in 10 years) it was less.

1. Winter storage and regulation of discharges have tended to reduce flows occurring in February, March, and April.

2. Storage and flow regulation for power production have increased the mean daily and monthly flows for the summer months, except in very wet years.

3. Storage and flow regulation for power production have increased the minimum 7-day mean low flow with a recurrence interval of once in 10 years from 925 cfs to 1,930 cfs (based on the period 1952-1961). The meeting of present minimum flow requirements assures that the minimum flow will equal 2,000 cfs.

4. Minimum flow restrictions imposed on power production operation increased the minimum summer daily flow from 472 cfs to 1,000 cfs on weekends. Agreements between the North Carolina State Stream Sanitation Committee and the Virginia Electric and Power Company (approved by the Federal Power Commission) and provisions of the Federal Power Commission's revised License 2009 have assured minimum daily flows of 2,000 cfs during the critical summer season since 1956. However, these flows occur more frequently than they would under natural flow conditions.

5. Use of water for peaking power production results in wide variation in flows within the daily flow pattern. Minimum instantaneous flows have been increased from 472 cfs, or lower, to 1,600 cfs. The minimum instantaneous flow under regulation conditions occurs on most weekdays during the summer months.

Downstream water users are primarily concerned with changes in frequency and duration of periods of low flow such as the changes indicated in items 4 and 5. Further discussion of these changes is presented in the "Water Resources Development" section.

SECTION 2

ECONOMIC ANALYSIS*

Water demands for direct municipal, industrial, and irrigational uses as well as for stream quality control, recreation, and other purposes, depend, in large part, on the population and industrial production. An analysis of the economic growth potential in the Roanoke River Basin serves as a basis for assessing the future water needs in the study area.

Economic growth in the Roanoke River Basin will be influenced by the expansion of the national economy and the basin's competitive advantage in supplying the increasing demand for goods and services. The rate of expansion of national population and production is anticipated to continue for the next 50 years at approximately the same rate as it has in the past 50 years. Such a forecast assumes that the forces that have produced this growth will continue to exert a similar influence for at least this long in the future. Accordingly, the national population is expected to increase 1-1/2 percent per year to 380 million in 2010. Production is esitmated to increase 3 percent annually, resulting in approximately a fourfold increase in output of goods and services during the period between 1960 and 2010.

Projections of economic expansion of the study area are based on the "share" of the national growth which will take place in the study area as indicated by past relationships (in employment and/or production) between the study area and the nation among the major industrial categories. In the projections of the resource-oriented industries, these relationships were modified as appeared warranted according to the quality and quantity of available natural resources.

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*Data in this chapter were largely obtained from the following publications of the U. S. Department of Commerce, Bureau of Census: Historical Statistics of the United States, Census of Population, Census of Agriculture, Census of Manufacturers, and Census of Mineral Industries. Valuable additional information was obtained from representatives of the State government, universities, and industries. Data published or tabulated by these groups are indicated in the bibliography.

For purposes of analyzing the economic growth potential, the Roanoke River Basin has been divided into two parts. Considered separately are the area above John H. Kerr Dam, which potentially contributes waste or treatment plant effluent and nutrient to the reservoir system, and the area below Kerr Dam, which uses water from the Roanoke River and discharges residual wastes to the river after treatment and/or in-plant waste control. Of the area above Kerr Dam, 27 percent lies in North Carolina and 73 percent in Virginia. The areas in each of the States are subject to similar development and have been considered together. Below Kerr Dam, 81 percent of the area and almost the entire manufacturing development are in North Carolina.

PRESENT DEVELOPMENT

Agriculture[76]

Agriculture is one of the most important industries in the basin; its importance, however, is declining. Of the 77,663 working on farms in the basin above Kerr Dam in 1940, only 43,350 remained by 1960, decreasing the percentage of the labor force devoted to agriculture from 31 percent to 15 percent in the 20-year period. Although agriculture is relatively more vital in the area below Kerr Dam, a similar trend exists. Farm employment in that area dropped from 52 percent to 28 percent of the labor force.

The soils of the basin are well adaptable to diversified farming. A great variety of farm products are produced, but production is primarily in field crops (tobacco and cotton), peanuts, and livestock and livestock products. From 1939 to 1959 total output of all crops and livestock and livestock products, in terms of the 1959 price base, increased 49 percent to $133,242,000 in the area above Kerr Dam and 52 percent to $61,267,000 in the area below. Thus, on both areas mechanization and advances in agricultural science have reduced manpower requirements while contributing to increased output.

The trends for the past 20 years have generally followed those of the nation both in employment and production. The value of farm production per worker in the study area has been less than the national average. However, the differential in output per worker has been decreasing as the lag in the introduction of technological innovations relative to the national farm economy has narrowed.

Mining[86, 93]

Mineral extraction is of minor importance to the economy of the basin. Employment in the mining industry in the basin above Kerr Dam has varied between 500 and 700 during the 1940-1960 period. The total value of all minerals extracted in this area in 1959, which included granite, mica, clay, tungsten, sand, gravel, feldspar, manganese, soapstone, and limestone, was estimated to be less than 6 million dollars. Other minerals that exist but which are not economically feasible to produce because of their quality, the condition of the present market, or state of technology include asbestos, coal, carbonaceous shale, copper, ilmenite, iron, nelsonite, barite, lead, zinc, ocher, marble, magnetite, kaolin, kyanite, corundum, vermiculite, gold, and silver.

Below Kerr Dam the number employed in mining did not exceed 65 during the last two decades. The minerals extracted in 1959 (clay, sand, and gravel) were valued at approximately one (1) million dollars. Molybdenum, ilmenite, granite, and mica were present but were not commercially produced.

Forestry[87, 34, 38, 93]

The area in commercial forests in the 22 counties considered in the basin above Kerr Dam totals 3,465,000 acres, or 56 percent of the total land area. Ninety-seven percent of the forest land is privately owned.

A large part of the timber resources is being utilized; however, growth exceeds cutting. The annual net growth is approximately 1.9 million cords, while the average annual harvest in recent years has been 1.2 million cords. That part of the growing stock designated as sawtimber has experienced the greatest rate of harvest. The annual net growth of sawtimber has been approximately 360 million board feet with an average cutting rate of 83 percent.

The extraction and manufacture of forestry resources have been a significant part of the economic base. In 1960, approximately 2,000 were employed in logging operations alone; an additional 16,500 were employed in lumber, furniture and other wood products, and paper production. Total employment associated with the forestry industry increased from 11,800 in 1940 to 18,500 in 1960.

In the six counties in the study area below Kerr Dam, 1,309,000 acres, which comprise 61 percent of the total land area, are in commercial forests and all but 2 percent are in private ownership. The greater portion of the harvest is used as pulpwood. The annual net growth of 900,000 cords exceeds the current cutting rate of approximately 650,000 cords. Pulpwood consumption reported by the firms located in the area for 1960 was one (1) million cords, which is in excess of the estimated net annual growth. Although pulpwood is both imported to and exported from the basin, there is a net importation of approximately half a million cords. The current harvest of 200 million board feet of sawtimber is approximately 95 percent of the annual net growth.

Total employment in the wood-based industries has increased 55 percent since 1940 and in 1960 amounted to 700 in logging operations. An additional 5,400 were employed in lumber, furniture and other wood products, and pulp and paper production.

Manufacturing[40, 73, 77, 93*]

Employment and production in manufacuturing have been expanding in the basin. In the area above Kerr Dam employment increased 58 percent from 58,705 in 1940 to slightly over 93,000 in 1960. The leading manufacturing industries, in terms of numbers employed, are textiles, forest products, fabricated metals, apparel, food, and tobacco. The total number of workers in each of these major industries has risen during the 1940-1960 period and now accounts for 84 percent of the manufacturing labor force. The area employs a greater proportion of its labor force in the textiles, forest products, apparel, and tobacco manufacturing categories than does the nation as a whole. The growth rate in total manufacturing employment was the same in the region as in the nation during the last two decades. Reported employment at the last three census periods for the various industries is shown in Table I.**

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*Unpublished data from North Carolina Department of Conservation and Development, Division of Commerce and Industry; Employment Security Commission of North Carolina, Bureau of Research and Statistics; and Virginia Employment Commission.

**Employment data were tabulated on the basis of the residence of the worker, not the site of employment. In manufacturing, approximately 4 percent of those in the basin above the dam and 6 percent of those below the dam worked outside the basin.

Table I

Population and Employment in the Roanoke River Basin for the Years 1940, 1950, and 1960

Basic Employment Category	Upper Basin 1940 No.	Pct.	1950 No.	Pct.	1960 No.	Pct.	Lower Basin 1940 No.	Pct.	1950 No.	Pct.	1960 No.	Pct.
Agriculture*	77,663	31.3	60,841	22.4	43,350	14.9	29,390	51.7	28,685	47.5	16,712	28.0
Mining	535	.2	718	.3	624	.2	65	.1	49	.1	30	.1
Manufacturing	58,725	23.7	75,414	27.8	93,043	31.9	9,139	16.1	10,885	18.0	12,110	20.3
Logging & Sawmilling	5,212	2.1	15,495	5.7	4,029	1.4	2,627	4.6	4,679	7.7	2,410	4.0
Furniture & Wood Products	5,795	2.3			12,854	4.4	294	.5			1,515	2.5
Primary Metals	409	.2	1,305	.5	2,317	.8	0	0	8	0	0	0
Food & Kindred Products	2,478	1.0	3,556	1.3	4,882	1.7	334	.6	462	.8	820	1.4
Chemicals & Allied Products	4,053	1.6	4,348	1.6	3,406	1.2	196	.3	153	.3	185	.3
Stone, Clay & Glass	779	.3	1,411	.5	1,492	.5	82	.1	162	.3	130	.2
Other Durables	635	.3			200	.1	0	0			255	.4
Pulp & Paper	777	.3			1,616	.6	991	1.7			2,169	3.6
Tobacco	2,043	.8	8,174	3.0	4,729	1.6	103	.2	1,337	2.2	106	.2
Other Nondurables	2,948	1.2			4,890	1.7	0	0			0	0
Fabricated Metals**	1,593	.6	2,181	.8	9,301	3.2	75	.1	90	.1	200	.3
Textiles	27,381	11.1	31,877	11.8	34,196	11.7	4,213	7.4	3,815	6.3	3,395	5.7
Apparel	3,153	1.3	5,018	1.9	6,809	2.3	8	0	9	0	715	1.2
Printing & Publishing, NEC	1,469	.6	2,049	.8	2,322	.8	216	.4	170	.3	210	.4
Basic Employment	136,923	55.2	136,973	50.5	137,017	47.0	38,594	67.9	39,619	65.5	28,852	48.4
Service Employment	90,573	36.6	125,910	46.5	140,249	48.2	14,298	25.1	19,397	32.1	27,808	46.6
Unemployment	20,254	8.1	8,221	3.0	14,050	4.8	3,970	7.0	1,454	2.4	2,980	5.0
Total Employment	247,750	100.0	271,104	100.0	291,316	100.0	56,862	100.0	60,470	100.0	59,640	100.0
Population	659,929		713,928		764,586		172,591		177,905		170,396	

*Includes a small number (less than one (1) percent) employed in fisheries.

**Includes fabricated metals, machinery, electrical equipment, motor vehicles, and transportation equipment.

Total value of production in the area above Kerr Dam, as measured by value added by manufacturing, was 633 million dollars in 1958. The real increase in output between 1939 and 1958 has closely coincided with the national trend of 4-1/2 percent per year over this same period.

Employment in manufacturing increased at a less rapid rate in the area below Kerr Dam. The number of workers engaged in manufacturing increased 32 percent from 9,139 in 1940 to 12,100 in 1960. The two leading manufacturing industries, forest products (including logging, lumbering, wood products, and pulp and paper production) and textiles, employed 6,094 and 3,395, respectively, in 1960, or 78 percent of the total in manufacturing. Although employment in the pulp and paper industry has been expanding, contraction in logging, lumbering, and manufacturing of wood products has resulted in little change in total employment in the forest products industries between 1950 and 1960. In textile manufacturing employment showed a steady decline in the decennial years from 1940 to 1960.

Employment in each of the other manufacturing categories, while increasing, is a much smaller proportion of the manufacturing labor force in the area than are the same categories in the national economy as a whole.

Total value of production in manufacturing in 1958, as measured by value added, was 52 million dollars. Adjusted for changes in the value of the dollar, the value of output of manufactured goods between 1939 and 1958 increased 142 percent, which is the same as that for the nation for the 20-year period.

<u>Service Industries</u>

The administration of governmental services and facilities, the provision of business and professional services, the distribution and sale of goods, and the furnishing of financial and insurance services, as well as other similar conveniences, constitute a large segment of the economic activity of the area. Employment in these service categories increased markedly between 1940 and 1960 from 90,573 to 140,249, or 55 percent, in the upper basin and from 14,298 to 27,808, or 94 percent, in the lower basin. Growth in the service industries has been more rapid than that in the basic industries. By 1960 nearly one-half of the labor force in both subareas was thus employed. Although the relative number employed in service industries in the basin is below the national average of 60 percent, this is typical of areas which have a relatively large rural population and low per capita income.

Population

The population in the area above Kerr Dam increased between 1910 to 1960, but at a decreasing rate. From 1910 to 1930 the annual rate of increase was 1.1 percent, but has since dropped to 0.6 percent per year during the decade between 1950 and 1960. The rate of increase for the 50-year period averaged 0.9 percent annually as compared to the national average of 1.4 percent. In the area below Kerr Dam total population increased at a relatively slow rate of 0.7 percent per year between 1910 and 1950, but in the last census period it decreased 0.4 percent per year from 177,905 in 1950 to 170,396 in 1960. In both areas the municipal population is growing rapidly, while the rural population has been declining since 1940.

There are four cities in the basin with population in excess of 15,000; all are in the area above Kerr Dam. The largest, Roanoke, Virginia, had a population of 97,110 in 1960. Of the 114 municipalities in the basin only 28 had populations in excess of 2,500 in 1960; of the remainder, 64 had populations of less than 1,000.

Income and Production[93*]

The value of all goods and services produced in the area above Kerr Dam, as measured by personal income** in constant (1958) dollars, increased 36 percent from 1947 to 1,088 million dollars in 1958; in the area below Kerr Dam it increased 22 percent to 176 million dollars during the same period. The increase in both subareas was less than the national increase of 52 percent for the corresponding period.

The per capita income in the basin is significantly lower than for the nation as a whole. Per capita personal income in the basin was $1,442 in

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*Also unpublished data from North Carolina Department of Conservation and Development, Division of Commerce and Industry.

**Data on net value of production are the preferable measure of the volume of regional economic activities but these data are not available for subnational units for all industries. However, personal income provides a close approximation of the measure of total production.

1958, or 70 percent of the national average of $2,069. In the lower basin personal income was $1,030 per capita, or only one-half of the national average. Low per capita income in the basin is a reflection of the labor orientation of the major industries (textiles, apparel, wood products, and agriculture) and is manifested in part by a relatively low ratio of service workers to basic workers. Generally, low per capita income limits the demand for services.

FUTURE DEVELOPMENT

Economic Outlook

The outlook for an increase in agricultural production is promising. Farm output in the Roanoke River Basin is expected to follow the anticipated national trend and increase by 140 percent by 2010. The pattern of farm production is expected to continue with little change. Although a relative increase in truck crops and livestock and livestock products can be expected, these, along with cotton, tobacco, and peanuts, will be the dominant products. Agricultural employment, however, is expected to decrease because of the increased application of scientific and technological improvements. The wider application of presently known improvements as well as new developments will greatly increase farm labor productivity. On this basis the farm labor force is expected to decline in the upper basin from 43,350 to 26,000 between 1960 and 2010. During the same period, it is expected to decline in the lower basin from 16,602 to 10,000 (shown in Table II). In the lower basin employment in fisheries, including commercial fishing, the operation of fish hatcheries, oyster farming, and so forth is forecasted to increase from an average of 150 during the 1950 decade to 500 by 2010.

Mineral resources are not expected to make any major contribution to economic growth in the next 50 years. Although many minerals exist in the basin, known deposits are neither numerous nor, for some, are they of commercial grade. For the more important minerals currently mined (granite, mica, tungsten, feldspar, and soapstone) only a moderate increase can be anticipated. The present rate of extraction of tungsten can continue for 30 to 50 years. There are significant reserves of mica but its future demand is not anticipated to increase greatly; the same may be said for feldspar and soapstone. Granite deposits are excellent but equally good deposits are available that are more accessible to markets. The extraction of clay, limestone, sand, and gravel is expected to increase only to meet the needs

Table II

Forecast of Population and Employment
in the Roanoke River Basin
for the Year 2010

Basic Employment Category	Upper Basin		Lower Basin	
	No.	Pct.	No.	Pct.
Agriculture*	26,000	6.1	10,500	12.9
Mining	600	.1	100	.1
Manufacturing	131,500	30.9	20,400	25.1
Forestry Products(1)	22,500	5.3	8,700	10.7
Textiles & Apparel	50,000	11.8	5,800	7.1
Fabricated Metals**	25,000	5.9	(2)	-
Miscellaneous Durables	6,000	1.4	2,400	2.9
Miscellaneous Nondurables	28,000	6.6	3,500	4.3
Basic Employment	158,100	37.2	31,000	38.1
Service Employment	249,900	58.8	47,200	57.9
Unemployment	17,000	4.0	3,300	4.0
Total Employment	425,000	100.0	81,400	100.0
Population	1,150,000		220,000	

*Includes 500 employed in fisheries in the lower basin.

**Includes fabricated metals, machinery, electrical equipment, motor vehicles, and transportation equipment.

(1)Logging, sawmilling, wood products, and pulp and paper production.

(2)Included in miscellaneous durables.

of the local market. No significant exploitation of the mineral deposits currently considered to be submarginal is anticipated during the study period. Mineral production is expected to increase 150 percent but with little change in employment, Continued improvements in technology is expected to increase labor productivity in mining about 2 percent annually. Employment in mining which totaled 654 in the basin is 1960 is estimated at 700 for 2010.

The manufacture of forest products is expected to remain the dominant resource-based manufacturing industry in the Roanoke River Basin. Logging, sawmilling wood products, and pulp and paper production currently employ approximately 18,500 in the upper part of the basin and 5,100 in the lower basin. The supply of timber will limit the growth potential of the forestry resource-based industries. Not only is the present utilization of the timber growth at a high level, but much of the pulpwood processed in the lower basin is currently imported to sustain present operations. Expansion must depend on greater growth in the present forest stands and more importation, or both. Forest yield can be doubled by the application of extensive methods of forest management. If increased timber yield is realized and the shift toward more finishing work in furniture and wood products continues, a production increase of 150 percent in the upper basin can be sustained. No pulp production is known in the upper basin at this time. Allowing for a doubling of labor productivity, an increase in employment in the area above Kerr Dam to 22,500 is anticipated by 2010.

In the lower basin where much of the wood is utilized in pulp and paper production the same assumption relative to increasing forest yields has been made. A 150 percent expansion in pulp and paper production is predicted; however, this will entail an increase in the importation of pulpwood corresponding to the increase in production in the basin. On this basis it is expected that employment in pulp and paper production will increase to 6,000 during the study period.

The other major manufacturing industries (textiles, apparel, and fabricated metals) are expected to maintain their prominence in the local economy. Combined employment in textile and apparel plants has been increasing in the upper basin but remained essentially stationary in the lower basin during the 1940-1960 period. However, expansion of production facilities in these two industries is expected although the trend toward geographic dispersion of these industries suggests that the increase in production in the basin will be less than the national rate. In the upper basin employment is expected to increase in textiles and apparel from 41,000 to 50,000 between 1960 and 2010, and in the lower basin from 4,100 to 5,800 in the same period. Employment in fabricated metals has risen rapidly in the upper basin, increasing from approximately 1,600 in 1940 to 9,300 in 1960. Only 3.2 percent of the 1960 labor force was employed in this category as compared with 9.0 percent for the United States as a whole. Greater industrial diversification will accompany increased urbanization and growth of regional markets so that the proportion employed in fabricated metals and machinery can be expected to approach the industrial pattern of other cities of the size to which these in the basin are expected to grow. It is estimated that employment in fabricated metals in the upper basin will increase from 9,300 in 1960 to 25,000, or 5.9 percent of the labor force, by 2010. Growth in fabricated metals in the lower basin is relatively minor and may be expected to remain so.

Projected growth of all other categories of manufacturing, some of which are not associated with local availability of raw materials, has been tabulated in two groups: miscellaneous durables and miscellaneous nondurables. In 1960 the manufacturing of miscellaneous durable goods, which include primary metals; sand, clay, and glass products; and other durable goods, employed 5,994, or approximately 2 percent of the labor force in the basin. During the same period the miscellaneous nondurable goods manufacturing industries, which include food and kindred products, printing and publishing, chemicals, tobacco, and other nondurable goods (primarily leather products), employed 20,229 workers in the upper basin and 1,596 in the lower basin. This represented 7.0 percent and 2.7 percent, respectively, of the labor force in the two areas. Projections of production and employment in leather products and tobacco were based on expected increases in the national market, whereas the anticipated growth of the other industries in the durable and nondurable categories reflect the anticipated growth of local and regional markets. Based on these considerations, employment in miscellaneous durable goods industries will increase to 6,000 in the upper basin and to 2,400 in the lower basin. In the miscellaneous nondurable goods industries, employment is projected to increase to 28,000 in the upper basin and to 3,500 in the lower basin.

In all categories it was assumed that production per worker would continue to increase at the prevailing rate of 2 percent per year, which, when adjusted for an estimated reduction in the workweek to 30 hours, results in a doubling of production per worker by the end of the study period.

In addition to employment in the basic extractive and manufacturing industries, a large number is engaged in building facilities, financing, transporting and selling the goods producted by "basic" workers, and providing for governmental and personal services. The relatively greater increase in service workers as compared to basic workers is expected to continue in response to shifts in the pattern of production and distribution, increases in real income, and changes in cultural norms.

On the basis of intrabasin trends in employment in service industries relative to the size of the labor force as shown in Table I and on the basis of comparison of these trends with that of other regions as well as the nation, the number of service workers is projected to increase in the upper basin from 140,249 in 1960 to 249,000 by 2010, and in the lower basin from 27,808 to 47,200 during the same time period.

Total anticipated employment was projected on the basis of the preceding analysis. To estimate the total labor force, an unemployment rate of 4 percent was assumed. Total population was estimated by applying the historic trend of the ratio of labor force to population for each of the subareas.

Population Estimates

Population growth as determined by projected employment is indicated in Figure 2. Rural population in both parts of the basin is expected to decrease primarily as a result of a decline in farm employment and a decrease in the size of families living in rural areas. In the upper basin rural population is expected to drop from 385,000 in 1960 to 220,000 by 2010. In the lower basin the corresponding drop in rural residency will be from 112,000 to 55,000.

The population of the municipalities, on the other hand, will increase markedly. In the upper basin the population in municipalities will increase from 380,000 in 1960 to 930,000 by 2010 and in the lower basin from 58,000 to 165,000 during this time span.

The total population increase will be more modest because of the depresssing effect of the anticipated decline of the rural segment, which for both areas was the major part of the population in 1960. Total population is estimated to increase in the 50-year projection period from 765,000 to 1,150,000 in the upper basin and from 170,000 to 220,000 in the lower basin.

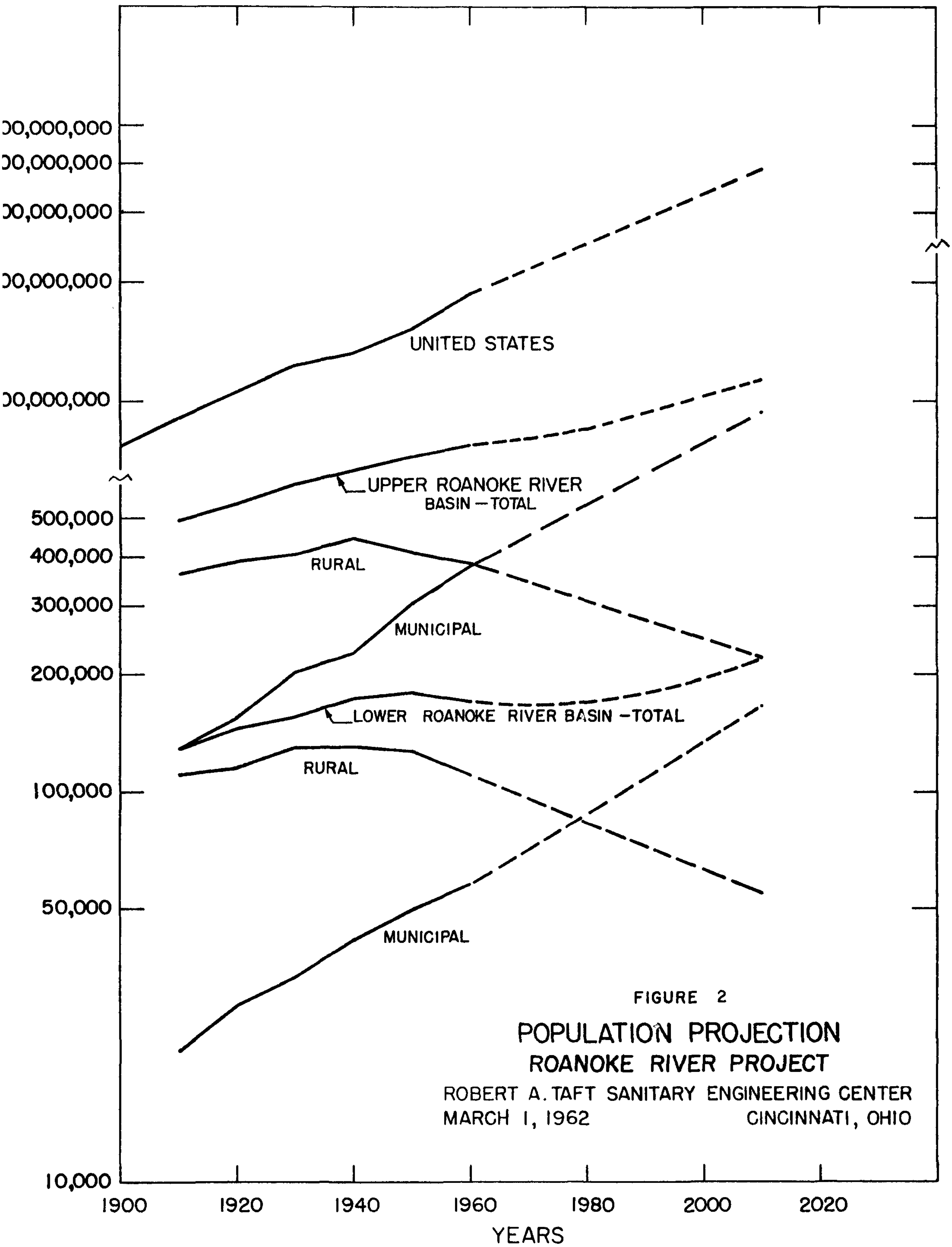

FIGURE 2

POPULATION PROJECTION
ROANOKE RIVER PROJECT

ROBERT A. TAFT SANITARY ENGINEERING CENTER
MARCH 1, 1962 CINCINNATI, OHIO

SECTION 3

WATER RESOURCES DEVELOPMENT

HISTORY OF DEVELOPMENT

Reports of studies concerning possible development of surface water resources in the Roanoke River Basin date back to 1934. In that year House Document No. 65, 74th Congress, 1st Session[1] outlined a comprehensive plan including 17 outstanding reservoir sites on the Roanoke and Dan Rivers worthy of consideration for hydroelectric power production. It was concluded, however, that implementation of the plan was not economically justifiable at that time although consideration was also given to flood protection, irrigation, navigation, and other possible improvements.

Following a severe flood in 1940 a detailed review of the 1934 study was made and in 1943, as a result of the re-study, House Document No. 650, 78th Congress, 2nd Session[7] contained a revised comprehensive plan for water resources development in the basin. The District Engineer, upon evaluating the revised plan, established a recommended plan which included 11 reservoirs and set up priority for construction. In the Flood Control Act of 1944[8] Congress approved the comprehensive plan recommended by the Corps of Engineers and authorized construction of the John H. Kerr Reservoir on Roanoke River and the Philpott Reservoir on Smith River. Table III shows the location and present status of reservoir development in the basin and indicates that 6 of the 11 sites recommended in the comprehensive plan have been developed, or, are being developed as private or Federal projects. Complete implementation of the comprehensive plan would result in a continuous impoundment of the Roanoke River from Roanoke Rapids Dam upstream to the headwaters of Smith Mountain Reservoir now under construction near Roanoke, Virginia.

Table III

Reservoirs in Corps of Engineers Comprehensive Plan for Development of Roanoke River Basin[7]

Project	River	Miles Above Mouth	Status
Roanoke Rapids	Roanoke	136.95	Private development. Power production began July 1955.
Gaston	Roanoke	144.90	Private development. Under construction.*
John H. Kerr	Roanoke	178.67	Corps of Engineers development. Power production began November 1952.
Randolph	Roanoke	227.75	Approved by Congress.
Melrose	Roanoke	262.90	Approved by Congress.
Taber	Roanoke	274.98	Approved by Congress.
Leesville	Roanoke	293.72	Private development. Under construction.
Smith Mountain	Roanoke	314.18	Private development. Under construction.**
Schoolfield	Dan	66.97	Approved by Congress.
Stuart	Smith	5.25	Approved by Congress.
Philpott	Smith	44.3	Corps of Engineers development. Power production began September 1953.

*Began filling in October 1962.

**Smith Mountain and Leesville are to be operated in combination. Operation is scheduled to begin in fall, 1963.

Specific discussion of water resources development is limited to the immediate study area which consists of John H. Kerr Reservoir, Gaston Reservoir, Roanoke Rapids Reservoir, and the Roanoke River below these impoundments.

DEVELOPMENT IN IMMEDIATE STUDY AREA

John H. Kerr Reservoir

The John H. Kerr Reservoir (often called Buggs Island Lake) is a multipurpose reservoir which operates primarily for flood control and peaking power production. The dam is located in Virginia approximately 18 miles above the North Carolina State line and creates a lake which, at maximum power pool elevation (300 feet), has a surface area of 48,900 acres. With the pool at this level, the depth at the powerhouse is 112 feet. Water storage for flood protection amounts to 1,278,400 acre-feet between elevation 300 and 320, while storage for power production is about 1,045,900 acre-feet between elevations 268 and 300.

The total power generating capacity of the project is 204,000 kilowatts provided by six 32,000-kilowatt units and one 12,000-kilowatt unit. Turbine intakes for each of the 6 larger units have a vertical height of 61.5 feet extending from elevation 204.5 to elevation 265. As a result of seasonal thermal stratification in the reservoir, water in the lower levels has had a significant dissolved oxygen deficit during summer months and discharge of water from these low levels has been of much concern to downstream water interests.

A statistical analysis of summer flow records immediately below Kerr Dam before and after impoundment indicates that daily low flows have decreased significantly, while low flows of longer duration have increased.* For example,

*The combined records of flow at Old Gaston and Roanoke Rapids gages, extending over the period 1921-1951, were analyzed by Velz[23] and have been adjusted on an area basis to estimate the Buggs Island gage discharge prior to completion of Kerr Dam. USGS records at the Buggs Island gage have been used for the postimpoundment period.

the minimum 1-day mean low flow with a recurrence interval of once in 10 years has decreased from about 740 cfs to about 145 cfs, whereas the minimum 7-day mean low flow with a recurrence interval of once in 10 years has increased from 855 cfs to about 1,775 cfs. The reason for the reduced daily low flows is that operation of the project for peaking power production is not required on weekends.

During development of the John H. Kerr (Buggs Island) Project, the Corps of Engineers obtained recommendations from the U. S. Public Health Service and the U. S. Fish and Wildlife Service concerning minimum flow releases required for pollution abatement and successful spawning of the striped bass in the lower Roanoke River. The Public Health Service recommended the following minimum flows for pollution abatement:[6, 12, 18]

January through April	500 cfs
May	1,250 cfs
June through September 15	2,000 cfs
September 15 through October	1,250 cfs
November through December	500 cfs

The U. S. Fish and Wildlife Service in its recommendations of May 1946,[11] stated:

> It is believed that an operating schedule that provides for minimum daily flows of 2,000 cfs and averages monthly flows of from 6,000 to 9,000 cfs during April and May will not be detrimental to successful spawning of the striped bass.

Neither recommendation provided for minimum dissolved oxygen levels either below Kerr Dam or above Roanoke Rapids although the Public Health Service report commented that "water released from the reservoir through the turbines during the warmer months, after thermal stratification is established, may be entirely or almost devoid of oxygen and relatively cold. However, it should have a very low biochemical oxygen demand, and turbulent flow in the stream below the reservoir should restore possible depressed dissolved oxygen levels to near saturation in a short distance. ...before the water reaches Roanoke Rapids, the critical point for water use and pollution below Buggs Island, the stream should have a normal dissolved oxygen content."[12]

The Corps of Engineers then assured the following low flows at Roanoke Rapids for pollution abatement and fish protection:

Month	Cubic Feet Per Second	
	Weekday	Weekend
January through April	500	500
May	1,250	600
June through August	2,000	1,000
September	1,600	800
October	1,250	600
November and December	500	500

These flows were supplemented as necessary to provide a minimum flow rate of 2,000 cfs from April 1 to June 1 to protect striped bass during their annual spawning period.

The reduced weekend flows were based on a letter report by the U. S. Public Health Service in response to a request by the District Engineer concerning possible minimum flow reductions predicated upon reduced waste discharges.[9] The letter stated:

> Relative to possible variations in flow over week ends, the fact that the Halifax Paper Company operates continuously while other industries, namely the Manchester Board and Paper Mill and the various textile mills, shut down over week ends, is an important consideration. The board mill plus the textile plants contribute 33 per cent of the pollution loads, and therefore a 33 per cent decrease at least would be allowable, due to this week-end shutdown. This reduction might be increased to a possible 50 per cent from the standpoint that a temporary reduction in flow is not immediately reflected in stream quality, particularly where a pool condition exists such as opposite and below Roanoke Rapids. In this case, however, it is presumed that average flows over a week's operation will be maintained. Further reductions other than those indicated would be undesirable, as serious upset in the aquatic life could easily result.

The reduced weekend flows during summer months have been of much concern to downstream water interests.

With the installation of Roanoke Rapids Dam between Kerr Dam and Roanoke Rapids waste sources, the Federal Power Commission assigned responsibility for release to provide continuous flow at Roanoke Rapids during off-peak periods to the Virginia Electric and Power Company* project. The Corps of Engineers therefore reduced off-peak flow to the minimum required for station generation purposes. Low releases during the off-peak periods have reduced the daily mean low flow and the instantaneous low flow at the Buggs Island gage below the values occurring under natural conditions. At the same time, however, storage for power production has provided greater average releases during natural low flow periods resulting in increases in mean low flows of longer duration.

Roanoke Rapids Reservoir

Roanoke Rapids Dam is a hydroelectric project constructed and operated by the Virginia Electric and Power Company. The dam, which is located just upstream from the town of Roanoke Rapids, North Carolina, creates an impoundment approximately 9 miles long with a surface area of about 4,900 acres at normal full power pool (elevation 132). At normal full power pool the reservoir has a storage capacity of 85,000 acre-feet and a maximum depth of approximately 62 feet near the dam measured to the unexcavated bottom (elevation 70).

The powerhouse has a total generating capacity of 100,000 kilowatts provided by four 25,000-kilowatt units. Turbine intakes each have a vertical height of about 41 feet extending from elevation 41 (the excavated forebay) to elevation 82. The minimum flow requirements included in the license issued by the Federal Power Commission to VEPCO for construction of the Roanoke Rapids Dam were the same as those originally established for John H. Kerr Dam prior to installation of the Roanoke Rapids Project and were listed in the preceding discussion of the John H. Kerr development. No dissolved oxygen provisions were included in the Roanoke Rapids Dam flow requirements.

The U. S. Geological Survey streamflow gage at Roanoke Rapids is located approximately 3-1/3 miles downstream from the Roanoke Rapids Dam and in combination with the data from Old Gaston gage provides a flow record

*The Virginia Electric and Power Company is generally referred to as VEPCO throughout the remainder of this report.

dating from December 1911. An analysis of summer flow records provided the comparison of low flow patterns before and after major impoundment of the Roanoke River as shown in Table IV.

Table IV

Comparison of Minimum Mean Low Flows Before and After Major Impoundment

Duration (days)	Recurrence Interval (years)	Preimpoundment[23] (1912-1951)	Postimpoundment (1952-1960)
1	2	1,950 cfs	1,500 cfs
	10	810 cfs	1,100 cfs
7	2	2,200 cfs	2,650 cfs
	10	925 cfs	1,930 cfs
30	2	3,300 cfs	4,000 cfs
	10	1,375 cfs	2,550 cfs

As a result of storage by the John H. Kerr Dam and the plan of reservoir operation, the minimum 1-day mean low flow with a recurrence interval of once in 2 years has decreased whereas the minimum 1-day mean low flow with a recurrence interval of once in 10 years has increased. The minimum 7-day and monthly mean low flows with recurrence intervals of 2 and 10 years have increased. Minimum daily low flows of about 1,300 cfs and greater occurred more often than under natural flow conditions, but flows of less than 1,300 cfs occurred less often than before impoundment. For example, prior to upstream impoundment the minimum daily low flows of 1,000 cfs or less occurred in approximately 17 percent of the years, whereas following impoundment the same flow occurred in only 5 percent of the years.

Flows below 1,000 cfs were observed at Roanoke Rapids in the first year after completion of John H. Kerr Dam, but with experience in operation of the facility the minimum daily and minimum instantaneous flows at Roanoke Rapids were increased to the minimum weekend level of 1,000 cfs. The flow fell gradually to this level and persisted only a few hours before flow increased to the weekday minimum of 2,000 cfs. However, after the Roanoke Rapids Dam was completed so that control of flow was exercised only a few miles above Roanoke Rapids gage, this flow occurred for almost the entire 2 days of each weekend, rather than at very infrequent intervals as before any of the impoundments were constructed. The minimum 7-day mean low flow could be as low as 1,714 cfs although such a low flow did not occur even during filling of Roanoke Rapids Reservoir.

As in Kerr Reservoir, dissolved oxygen deficiencies developed in the lower depths of Roanoke Rapids Reservoir during summer months and soon after impoundment a significant reduction and substantial variations in dissolved oxygen concentrations occurred downstream from the dam. It was apparent that reaeration of water flowing through the reservoir had not equaled that formerly provided by the natural stream bed.[48] The resulting reduction in dissolved oxygen reduced the waste assimilative capacity below that which had been available at the license flows. These effects of Roanoke Rapids Reservoir on downstream water quality raised serious question regarding the further effects of the Gaston Project on water quality. The importance of dissolved oxygen to downstream users caused the North Carolina State Stream Sanitation Committee, the North Carolina Wildlife Resources Commission, and the Halifax Paper Company to intervene with the Federal Power Commission against the license requested by the VEPCO for construction of the Gaston Dam. The purpose of the intervention was to delay approval of the license until the probable effects of further impoundment could be more adequately investigated and effective measures could be incorporated in the license to assure that further reduction in dissolved oxygen in the discharge from Roanoke Rapids Dam would not occur.

Following considerable investigation of possible methods to remedy detrimental effects which might be produced by the construction of Gaston Dam, VEPCO installed a submerged weir in Roanoke Rapids Reservoir to (1) improve water quality discharged from Roanoke Rapids Dam, and (2) study the performance of the weir and predict the effect of a similar weir on the discharge from the Gaston Dam.

Following installation of the Roanoke Rapids weir, a cooperative study was made in the summer and fall of 1957 to evaluate the effectiveness of the weir in improving water quality and to predict the performance of a weir in Gaston Reservoir. Principal conclusions of the study[48] state that (1) the weir in Roanoke Rapids Reservoir is effective in selecting water for discharge from the reservoir primarily from the layers above the crest of the weir, (2) the addition of oxygen by vacuum breaker operation can significantly increase the dissolved oxygen in the turbine discharges at minimum flows, but at a loss of power production, (3) at high discharge rates the increased dilution and higher dissolved oxygen resulting from selection of surface water by the submerged weir eliminate serious problems regarding pollution abatement downstream from Roanoke Rapids Reservoir, and (4) with a weir crest 15 feet below the full power pool level the dissolved oxygen content of the water discharged from Gaston Dam will be at least 6 mg/l and the water discharged from Roanoke Rapids Dam will be at least 6 mg/l, and in most cases even higher.

Gaston Reservoir

The Gaston Dam is presently under construction by VEPCO at river mile 145.5, and when completed will create a lake 34 miles long from the head of Roanoke Rapids Reservoir to the toe of John H. Kerr Dam. The surface of normal full power pool will be at elevation 200 and will have an area of 20,300 acres. Storage capacity of the power pool will be 400,000 acre-feet with an additional 63,000 acre-feet available for flood storage.

The Gaston Dam will operate in combination with the Roanoke Rapids Dam for the most efficient production of hydroelectric power. The generating capacity of the powerhouse will be 200,000 kilowatts provided by four 50,000-kilowatt units.

Each turbine intake or penstock will extend from elevation 125 (the excavated forebay) to elevation 155 and, to prevent the release of water from the lower levels of the reservoir, a submerged weir with a crest 15 feet below normal pool surface is being constructed upstream from the dam.

Flow releases from Gaston Dam will be controlled by peaking power operation with no requirements for minimum flows and will be discharged directly into the Roanoke Rapids Reservoir. Operation will be such that under normal conditions the Gaston Reservoir level will vary less than one (1) foot; therefore, this development is expected to have little effect on flows below Roanoke Rapids. Releases to provide continuous flow at Roanoke Rapids during off-peak periods will be supplied by Roanoke Rapids Dam in accordance with an amended license covering both projects.

The Roanoke Rapids weir served as a model for the Gaston weir; according to conclusions reached in a study of the former, it is expected that waters drawn across the proposed weir in Gaston will originate primarily in the upper 10 feet of the reservoir. Dissolved oxygen in the waters discharged from Gaston during the critical summer period will be at least 6.0 mg/l; the temperature of this discharge will approximate 78°F.[48]

Upon reviewing the Gaston Project, the Federal Power Commission concluded that "...the proposed Gaston development and the constructed Roanoke Rapids development shall be considered as units of one complete project and shall be designated as Project No. 2009."[70] The license for the Roanoke Rapids Project was amended to include Gaston Dam and the minimum flow requirements for Roanoke Rapids were continued as previously listed "...until the commencement of operation of the Gaston development...." However, effective with commencement of operation of the Gaston development, the following minimum instantaneous flows are to be provided by the Roanoke Rapids Project in accordance with Article 25, Requirement A of the license:

Month	Cubic Feet Per Second
January, February, March	1,000
April	1,500
May, June, July, August, September	2,000
October	1,500
November, December	1,000

These flow requirements are subject to special provisions including an allowable reduction of minimum flows up to 20 percent on weekdays and requirements for releases to protect striped bass spawning. Reduced weekend flows were eliminated by this revision.

In addition and closely related are Requirements B and C. Requirement B states, "Discharge from the Roanoke Rapids development shall be maintained to provide dissolved oxygen at an instantaneous rate of not less than 78,000 pounds per calendar day during months of May through October...."

Conditions to this requirement allow a "...reduction not in excess of 34 percent..." of the 78,000 pounds per day rate "...for periods not exceeding 14 consecutive hours." Any reduction, however, must be "...offset by greater discharges so that a cumulative average rate of discharge of 78,000 pounds per day will be attained within a period up to but not exceeding 16 hours from the beginning of the oxygen deficit flows...." The provision of minimum dissolved oxygen releases will assure a minimum assimilative capacity for downstream waste dischargers.

Requirements C provides for cooperation between the licensee and the North Carolina State Department of Conservation and Development, North Carolina State Stream Sanitation Committee and/or North Carolina Wildlife Resources Commission in the event of temporary emergency conditions arising in performance of Requirements A and B.

On July 12, 1956, the North Carolina State Stream Sanitation Committee had an emergency meeting with representatives of the various Roanoke River interests and made arrangements for minimum <u>weekend</u> discharges to be increased from 1,000 to 2,000 cfs and for minimum weekday discharges to be decreased from 2,000 to 1,500 cfs below Roanoke Rapids Dam for the period, June through August. The modified minimum flows have been re-established in subsequent low flow summer seasons.

Minimum flows have been further modified with the approval of the Federal Power Commission and will remain in effect until commencement of operation of the Gaston Project. Minimum flows now in effect are 1,500 cfs on weekdays and 2,000 cfs on weekends during the months of June, July, and August; 1,200 cfs on weekdays and 1,600 cfs on weekends during September; and 900 cfs on weekdays and 1,500 cfs on weekends during October.

SECTION 4

MULTIPLE WATER USES

The economy and general well-being of the Roanoke River Basin and much of the surrounding area depend upon surface waters for such multiple uses as power production, water supply, waste disposal, fish propagation, and recreation. These various uses often conflict in their utilization of streamflow. The following discussions describe the extent and interrelation of the principal water uses in the lower Roanoke River Basin.

POWER PRODUCTION

The total hydroelectric power potential of the Roanoke River Basin is rapidly being utilized. As shown in Table IV, 6 of the 11 reservoir sites listed in the Corps of Engineers' comprehensive plan for development of the basin have been or are presently being developed. Three of these projects (John H. Kerr, Roanoke Rapids, and Gaston) are located in the immediate study area. Completion of Gaston Dam, which is scheduled for the latter part of 1962, will complete the utilization of the power potential of the lower Roanoke River. These 3 projects will have a total generating capacity of 504,000 kilowatts and will serve customers in surrounding area of Virginia and North Carolina.

The John H. Kerr Project is operated by the Corps of Engineers, while the other two projects are owned and operated by the Virginia Electric and Power Company, a privately owned utility. Power produced by the Corps project is sold by the Southeastern Power Administration, U. S. Department of Interior.

Impoundment of water for power production has had both beneficial and detrimental effects on other water uses in the Roanoke River Basin. Beneficial effects incidental to power production include the creation of scenic lakes for recreational use, increased flow time resulting in reduced waste residuals, reduced coliform bacteria, reduced turbidity at points of downstream use, and the assurance of increased dependable flow for waste assimilation and fish life during natural low flow periods. Detrimental effects include the reduction in dissolved oxygen concentrations and increase in iron and manganese content below both John H. Kerr and Roanoke Rapids Dams as a result of thermal stratification and subsequent deoxygenation in the lower levels of the impoundments. The lowered dissolved oxygen significantly reduces the waste assimilative capacity otherwise available. Operation of the reservoirs for peaking power production results in large diurnal fluctuations in flow effectively usurping the flow from other uses unless reregulated to provide necessary minimum continuous flows of acceptable quality.

The John H. Kerr, Gaston, and Roanoke Rapids Projects utilize almost the entire power potential of the lower Roanoke River. It is not anticipated that the small remaining fall between Roanoke Rapids and Weldon will be developed in the foreseeable future.

WATER SUPPLY

At the present time there are no water supply withdrawals from the lower Roanoke River between John H. Kerr Dam and Roanoke Rapids Reservoir. The first withdrawal downstream from Kerr Dam is from the Roanoke Rapids Reservoir at the dam and supplies approximately 2 million gallons of water daily to about 17,800 persons and a portion of the industrial water needs in the Roanoke Rapids-Weldon area. Immediately below the dam, Halifax Paper Company withdraws approximately 29 MGD (45 cfs) and Manchester Board and Paper Company withdraws about 0.72 MGD for industrial uses. The only water supply intake below the Roanoke Rapids area is at Plymouth, North Carolina, where Weyerhaeuser Company (formerly the North Carolina Pulp Company) withdraws about 44 MGD (68 cfs) from Roanoke River.

Ground water serves as a good source of supply for most of the smaller communities in the study area. Eleven ground water supplies provide approximately 20,900 persons with about 1.4 million gallons of water daily.[78] Data reported on 25 wells in the area indicate that the wells range in depth from 28 feet to 450 feet; their mean depth is about 220 feet.[40] Yield per well ranges from 8 gpm to 500 gpm and averages about 130 gallons per minute. The water is generally soft (mean total hardness = 28 mg/l), slightly acid (mean pH = 6.7), and has an average iron content of about 0.2 mg/l which is within the generally recommended limit of 0.3 mg/l.[89] Only one well that contains a measurable amount of manganese has a concentration of 0.09 mg/l, slightly above the recommended limit of 0.05 mg/l.

Future municipal and industrial water uses in the lower Roanoke Basin are projected in terms of the expected population and industrial growth of the area. The present per capita water use in the study area ranges from 40 to 120 gpcd (gallons per capita per day) and averages about 90 gpcd. This value is substantially below the national average per capita water use of 147 gpcd.[79] The national average value is expected to increase to perhaps 225 gpcd by the year 2000 with a possible leveling off thereafter. Such an increase would have an average rate of about 1.2 percent per year. Since the general population and economic growth of the study area have been and are expected to continue to be at a lesser rate than that of the nation as a whole, it is reasonable to expect that increases in per capita water use will also be at a lesser rate. It is therefore estimated that municipal water use in the lower Roanoke Basin will increase at a rate of about one (1) percent per year and will reach approximately 135 gpcd by the year 2010. On this basis the total municipal water demand in the study area will reach about 22 MGD by 2010.

Industrial water demand in the area is projected to be about 185 MGD, or 285 cfs, by 2010. This is an increase of 3 percent per year and is based on the industrial expansion projected in the "Economic Analysis" section. In estimating the future industrial water requirements it is assumed that water use per unit production will remain unchanged during the study period.

On the basis of the above, it is concluded that there is ample water available in the Roanoke River under existing conditions for present and anticipated municipal and industrial water supply purposes. Since there is little consumptive use and no diversion outside the basin, water supply withdrawal has little adverse effect on other water uses.

WASTE DISPOSAL

Waste disposal into a stream can have varied effects on water quality. It can reduce quality for subsequent municipal and industrial uses, reduce the dissolved oxygen below levels necessary for fish propagation, and accentuate the deoxygenating effects of impoundments. It may also result in destruction of fish or fish food organisms and directly or indirectly restrict recreational use.

The assimilation of municipal and industrial waste discharges is one of the major uses of Roanoke River flows. The river between Roanoke, Virginia, and the headwaters of Kerr Reservoir presently receives a waste load (after treatment) with a population equivalent of approximately 69,000 persons. Through treatment this waste load reflects an over-all waste reduction of about 55 percent (estimated P.E. before treatment was 154,000). The Dan River, the major tributary of the Roanoke River, receives a waste load with a population equivalent of approximately 271,000 persons after a reduction of about 8 percent (estimated P.E. before treatment was 295,700). Waste discharges in the immediate vicinity of Kerr Reservoir are estimated to have a total population equivalent of about 238,000 persons before treatment and 53,000 after treatment; this indicates a total reduction of approximately 78 percent. Sources of waste below John H. Kerr Dam are listed in Table V. These wastes total 574,900 P.E. Although little reduction in waste discharged after treatment is indicated, construction of waste treatment facilities is planned or under way at several locations. Considerable reduction in industrial waste loads has been accomplished through in-plant changes at the Halifax Paper Company and the Weyerhaeuser Company, pulp and paper plants.

According to future population and industrial growth projections, the total waste loads discharged to the stream are anticipated to be about 420,000 P.E. in the basin above Kerr Dam and 306,000 P.E. in the lower basin by the year 2010. These values assume that (a) productivity per worker will double during the study period, (b) measures will be provided to accomplish adequate reduction of waste loads prior to discharge,* and (c) waste load per capita and per unit production will remain unchanged during the study period. The total population equivalents before treatment are projected to reach about 2,100,000 in the upper basin (above Kerr Dam) and about 1,530,000 in the lower basin by 2010.

Continued use of the stream for waste disposal purposes, consistent with the water quality objectives established by the North Carolins State Stream Sanitation Committee will be a factor in the continued economic development of the lower Roanoke River Basin.

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*Adequate reduction of waste loads is interpreted as the maximum practicable degree of reduction which is technically and economically feasible. For purposes of the present report, secondary biological treatment of organic wastes (both municipal and industrial) is considered to be adequate, and it is assumed that an over-all reduction of about 80 percent of the organic waste load can be expected from such treatment.

Table V

Waste Discharges in Lower Roanoke River below John H. Kerr Dam

Location	Estimated Population Served	Volume of Waste, MGD	Population Equivalent Before Treatment	Population Equivalent After Treatment	Receiving Stream
Littleton	130	0.008	130	110	Little Stonehouse Creek
McPherson Bottling Company	--	0.02	2,800	2,800	Little Stonehouse Creek
Roanoke Rapids Sanitary District	9,000	1.7	17,300	17,300	Roanoke River
Halifax Paper Company	--	25	250,000[1]	250,000[1]	Roanoke River
Manchester Board and Paper Company	--	0.85	12,000[2]	12,000[2]	Roanoke River
Weldon	2,400	0.24	2,400	480	Roanoke River
Coca Cola Bottling Company	--	0.03	220	220	Roanoke River
Jackson	750	0.065	750	380	Lilly Pond Branch
Halifax	350	0.015	350	240	Quanky Creek
Caledonia Prison Farm	200	0.086	3,400	3,400	Conoconnara Creek
Rich Square	690	0.076	690	490	Bridgers Creek
Windsor	1,500	0.29	1,500	1,500	Cashie River
Williamston	4,000	0.13	4,000	4,000	Roanoke River
Williamston Packing Company	--	0.093	730	730	Sweetwater Creek
Atlas Plywood Company	--	0.096	4,800	4,800	Roanoke River
Jamesville	400	0.006	400	400	Roanoke River
Plymouth	4,650	0.12	4,650	4,650	Conaby Creek and Roanoke River
Atlas Plywood Company	--	0.029	1,400	1,400	Roanoke River
Weyerhaeuser Company (North Carolina Pulp Company)	--	44	270,000[3]	270,000[3]	Roanoke River

[1] Halifax Paper Company is limited by the North Carolina State Stream Sanitation Committee's Pollution Abatement Plan to a maximum waste discharge of 60,000 pounds of BOD per day (P.E. of about 353,000) when streamflow is 2,000 cfs. According to Halifax Paper Company the average waste discharge for September 1-20, 1961, was 41,750 pounds per day (P.E. of about 250,000).

[2] Manchester Board and Paper Company is limited to a maximum of 600 pounds of BOD per day (P.E. of about 3,500) when streamflow is 2,000 cfs.

[3] Weyerhaeuser Company is limited by the North Carolina State Stream Sanitation Committee's Pollution Abatement Plan to a maximum waste discharge of 45,000 pounds of BOD per day (P.E. of about 270,000) when streamflow is 4,200 cfs. According to the North Carolina State Stream Sanitation Committee, the present waste discharge is below the maximum allowed by the Plan.

Disposal of municipal and industrial wastes requires continuous flows for dilution since the wastes are discharged at relatively uniform rates. Minimum flows necessary so that residual wastes can be assimilated without reducing dissolved oxygen levels below established objectives reduces the effectiveness of hydroelectric power production for meeting peak power demands. The discharge of wastes in excess of the available dilution water, even for short periods of time, can restrict the use of long reaches of the stream for the propagation and taking of fish.

PROPAGATION OF FISH

Commercial and sport fishing both have prominent positions in the economy of the lower Roanoke River Basin. Sport fishes include large mouth bass, striped bass, bream, crappie, and catfish, while the commercial species are striped bass, herring, white perch, shad, and catfish. Of these species the striped bass is of greatest economic value to the area.

Maintenance of an adequate flow of satisfactory quality to support fish life has been a critical problem in the lower Roanoke River Basin in recent years. The first fish kill investigated by the North Carolina State Stream Sanitation Committee occurred in March 1954, Since that time several others have been recorded, but in most cases they were mot reported early enough to permit investigation of the causes. Probably the most serious and most thoroughly investigated fish kill occurred during a low flow period between June 20 and July 6, 1956.

With control of water quality and the conditions required for the spawning of the striped bass, it is expected that commercial fishing will expand in the lower Roanoke River and Albemarle Sound. Sports fishing will also increase substantially. The dissolved oxygen requirements for these commercial and sport fishing activities restricts the use of the Roanoke River for disposal of organic municipal and industrial wastes.

The flow requirements for the spawning of the striped bass are currently met, in large part, by a 2-foot encroachment on the flood control pool in the months of April and May. This causes a small reduction in flood control capacity and a reported increase in shore erosion between elevation 300 and 302. There is a possible increase in peaking power production in these mouths.

RECREATION

Recreational uses of the lower Roanoke River for fishing, boating, water skiing, and swimming have increased significantly in recent years, and are expected to increase further with additional water resources development. In conjunction with increased recreational uses there exists a potential for additional development of facilities to serve these uses. According to a Corps of Engineers map of Kerr Reservoir printed in June 1960, there are 18 public boat launching sites, 6 boat docking and mooring facilities, 3 overnight cabin areas, 8 developed camping areas, 9 primitive camping areas (without complete sanitary facilities), and 10 public bathing beaches in the immediate reservoir area.

Reservoir development has played an important part in stimulating recreational use of the lower Roanoke River Basin. Upon completion of the Gaston Project there will be continuous impoundment of approximately 100 miles of Roanoke River with a total shore line length of over 1,200 miles and a total reservoir surface of about 74,000 acres. In addition to recreational use of the reservoirs, the river below the impoundments continues to be an important sport fishing area.

Recreational use of Gaston and Roanoke Rapids Reservoirs is facilitated by the relatively steady pool elevation maintained as a result of their operation as run-of-river facilities. Total output is increased by storage in upstream reservoirs, including John H. Kerr. Recreational use of Kerr Reservoir will probably result in public displeasure in low flow years when greater drawdown is required to fill contract commitments. Such public pressure tends to place a limit on the maximum utilization of power storage in public structures.

OTHER USES

In earlier years the lower Roanoke River waterway was used very extensively to transport goods from the inland farms to markets. Although the farm-to-market navigational use has declined in recent years, the stream below river mile 55 continues to be used as a transportation route for cargo such as logs, oil, and pulpwood.

The Roanoke River is also used for agricultural purposes including irrigation. Quantities of water withdrawn for these uses are not known but are probably small in proportion to available flow. Since access to the lower main stem is limited, most irrigation pumpage would probably be from smaller tributaries.

SECTION 5

WATER QUALITY OBJECTIVES

Water pollution is defined as the addition of any substance to water or the changing of the physical characteristics of water in any way that interferes with its use for any legitimate purpose. Until recently, major emphasis was placed on the problem of sewage pollution, intially because of its relation to water-borne enteric disease and later because of the effects of organic pollution on streams and aquatic life. As areas became increasingly industrialized, the contribution of water-borne industrial wastes grew in importance. The quality of water determines the uses which can be made of it, and unless the quality is maintained at reasonable levels, possible benefits of its use will be lost and public health may be endangered.

A study of existing water quality and water uses indicates that under present conditions dissolved oxygen is the most critical parameter of water quality for the lower Roanoke River below John H. Kerr Dam. Low dissolved oxygen concentrations in the stream result primarily from a combination of the decomposition of organic waste loads and low dissolved oxygen concentrations in the discharges from reservoirs which experience seasonal thermal stratification. Propagation of fish and aquatic life and associated legitimate stream uses depend upon adequate dissolved oxygen concentrations; however, the adverse effects of low dissolved oxygen concentrations depend on other factors as well as the oxygen concentration itself. Toxic substances, very soft water, high or low pH, and increased temperatures tend to increase the susceptibility of fish to the adverse effects of low dissolved oxygen concentrations. Prior acclimatization, species, and age are also among the factors reported to affect the minimum dissolved oxygen level at which fish can survive. At increased temperature the metabolic activity of fish is increased thus requiring a high D.O. to sustain life. Warm water species such as carp and eel can withstand lower oxygen concentrations than the more active fish such as trout or salmon.

The water quality objectives used in evaluating conditions in the Roanoke River are based on a consideration of the objectives, standards, and criteria which have been applied by various States, interstate agencies, and other public health authorities. In accordance with the General Statutes of the State of North Carolina, waters of the lower Roanoke River in North Carolina have been classified to protect the stream for the best uses, and a Comprehensive Pollution Abatement Plan has been adopted.[39, 41, 44] The classifications and dissolved oxygen standards which became effective September 1, 1957, are listed in Table VI.

Table VI

Stream Classifications and Dissolved Oxygen Standards Applicable to the Lower Roanoke River in North Carolina

Stream	Classification and Best Use	Dissolved Oxygen Standard
Roanoke River from Virginia-North Carolina State line to Roanoke Rapids Dam.	A-II Water supply with complete treatment.	Not less than 4.0 mg/l.
Roanoke River from Roanoke Rapids Dam to Jamesville (river mile 18).	C Fishing	Not less than 4.0 mg/l.
Roanoke River from Jamesville to mouth.	C-Swamp Fishing	Not less than 3.0 mg/l.

The "A-II" classification is applicable to streams used as a source of public water supply whose quality must meet the Public Health Service Drinking Water Standards after treatment by coagulation, sedimentation, filtration, and postchlorination. Class "C" is intended to provide water that is suitable for the propagation of fish and wildlife. Class "C-Swamp" is intended to provide water suitable for propagation of fish and wildlife in areas subject to substantial swamp drainage. These are minimum standards which protect the designated reaches of the stream for the specified uses.

The classifications do not, however, limit the stream to the classification use so long as the standards are met. For example, the "C" classification is based on the protection of the stream for fish life, but also permits other uses including the disposal of treated wastes as long as this does not interfere with the "best" use.

The State of Virginia does not have stream classification standards, but rather considers each case on its own merits as it arises. To date the Virginia State Water Control Board has not had occasion to establish requirements for the reach of the Roanoke River between Kerr Dam and the Virginia-North Carolina State line.

Adopting a general requirement that the oxygen concentration be continuously at the level necessary to support all fish life in all phases of their life cycle would be unreasonably high. A minimum level widely quoted for waters favorable to a good mixed fish fauna suggests that the dissolved oxygen should not be less than 5.0 mg/l.[28, 60] However, fish can survive at D.O. levels somewhat below this value and in the absence of toxic substances or other adverse conditions, the above value is not merely sublethal but is actually favorable for a mixed warm water fish population and its food organisms. The higher the minimum dissolved oxygen concentration is, the less dissolved oxygen is available for the assimilation of organic wastes. In addition, it must be recognized that (1) minimum D.O. values do not occur over the whole length of the stream, (2) fish can survive short periods of lower dissolved oxygen concentration, and (3) spawning activity (at which higher D.O. concentrations are necessary) does not take place at the time when minimum flows and high temperatures result in minimum dissolved oxygen concentrations. In view of these factors, many of the States which have established dissolved oxygen standards have accepted 4.0 mg/l as a reasonable minimum allowable dissolved oxygen concentration in waters supporting a warm water fish population. As noted previously, this is the standard accepted by the State of North Carolina for waters suitable for fish and wildlife propagation. It has also been accepted by the States of New York and South Carolina which have also established stream classifications and water quality criteria. Since the standard of 4.0 mg/l applied to the Roanoke River below the State line by North Carolina is widely accepted as a reasonable minimum water quality objective in water water streams, it is considered reasonable to apply the same quality objective to the portion of the Roanoke River below Kerr Dam in Virginia. Therefore, a dissolved oxygen objective of 4.0 mg/l has been used in this report throughout the length of the Roanoke River from John H. Kerr Dam to Jamesville, 18 miles above Albemarele Sound.

Iron and manganese have been observed in the Roanoke River at concentrations which exceed limits of 0.3 mg/l for iron and 0.05 mg/l for manganese as specified in the Public Health Service Drinking Water Standards.[89] The increased iron and manganese in Roanoke River has been associated with reduced dissolved oxygen resulting from thermal stratification in reservoirs. Depending upon the methods used, improvement of water quality to increase the dissolved oxygen content of reservoir releases could, at the same time, contribute to a decrease in iron and manganese concentrations.

SECTION 6

STREAM CONDITIONS

Water quality conditions in the lower Roanoke River have been affected by the development of reservoirs above Roanoke Rapids and by municipal and industrial waste discharges to the river between Roanoke Rapids and Plymouth, North Carolina. The minimum streamflows to be released by the Corps of Engineer and/or the Virginia Electric and Power Company are influenced by the increased knowledge of the Roanoke River fishery and by increased interest in recreational use of the river, as well as by the quality changes resulting from impoundment and waste discharge. Water quality of the Roanoke River is considered under the following conditions of reservoir construction:

1. Natural conditions.

2. Post-Kerr Dam conditions.

3. Post-Roanoke Rapids Dam conditions.

4. Predicted post-Gaston Dam conditions.

NATURAL CONDITIONS

Above Roanoke Rapids

Prior to the time of the construction of John H. Kerr Dam, the Roanoke River in the immediate area of Kerr Reservoir received relatively small waste loads from Henderson, North Carolina, and Clarksville and South Boston, Virginia. The waste discharged from these sources was not stated in the earlier reports[6], but is now estimated to have been in the order of 10,000 pounds of BOD* per day (57,000 P.E.). Waste loads totaling an estimated 47,000 pounds of BOD per day (284,000 P.E.) were discharged to the Roanoke and Dan Rivers well above the Kerr Reservoir but were considered to have relatively little effect on the lower Roanoke since the waste would be stabilized before reaching the reservoir area or Roanoke Rapids. The mean values, listed on Table VII, of observations made by the Public Health Service in 1942 and 1946 show that the wastes had little effect on dissolved oxygen conditions at U. S. Highway 1 bridge, 6 miles below John H. Kerr Dam and 12 miles above the Virginia-North Carolina State line, and at North Carolina Highway 48 bridge, immediately above the Roanoke Rapids waste discharges. Sampling point locations are shown on Figure 3.

Table VII

Summary of Roanoke River Observations Above Roanoke Rapids Prior to Construction of John H. Kerr Dam

Location	Date	No. of Obs.	Flow cfs	Temp. °C.	Dissolved Oxygen Conc. mg/l	Dissolved Oxygen Sat. pct.	Dissolved Oxygen Def. mg/l	BOD mg/l
N. C. Hwy. 48 (Ri. Mi. 135)	Aug-Sept 1942	12	7,200	25	7.8	94	0.5	1.6
U. S. Hwy. 1 (Ri. Mi. 173)	Jul-Sept 1946	13	3,280	24	7.8	95	0.4	0.64
N. C. Hwy. 48 (Ri. Mi. 135)	Jul-Sept 1946	8	2,140	23.6	8.08	94	0.5	0.60

*Throughout the remainder of the report unless otherwise noted, "BOD" refers to the standard 5-day, 20°C. biochemical oxygen demand value.

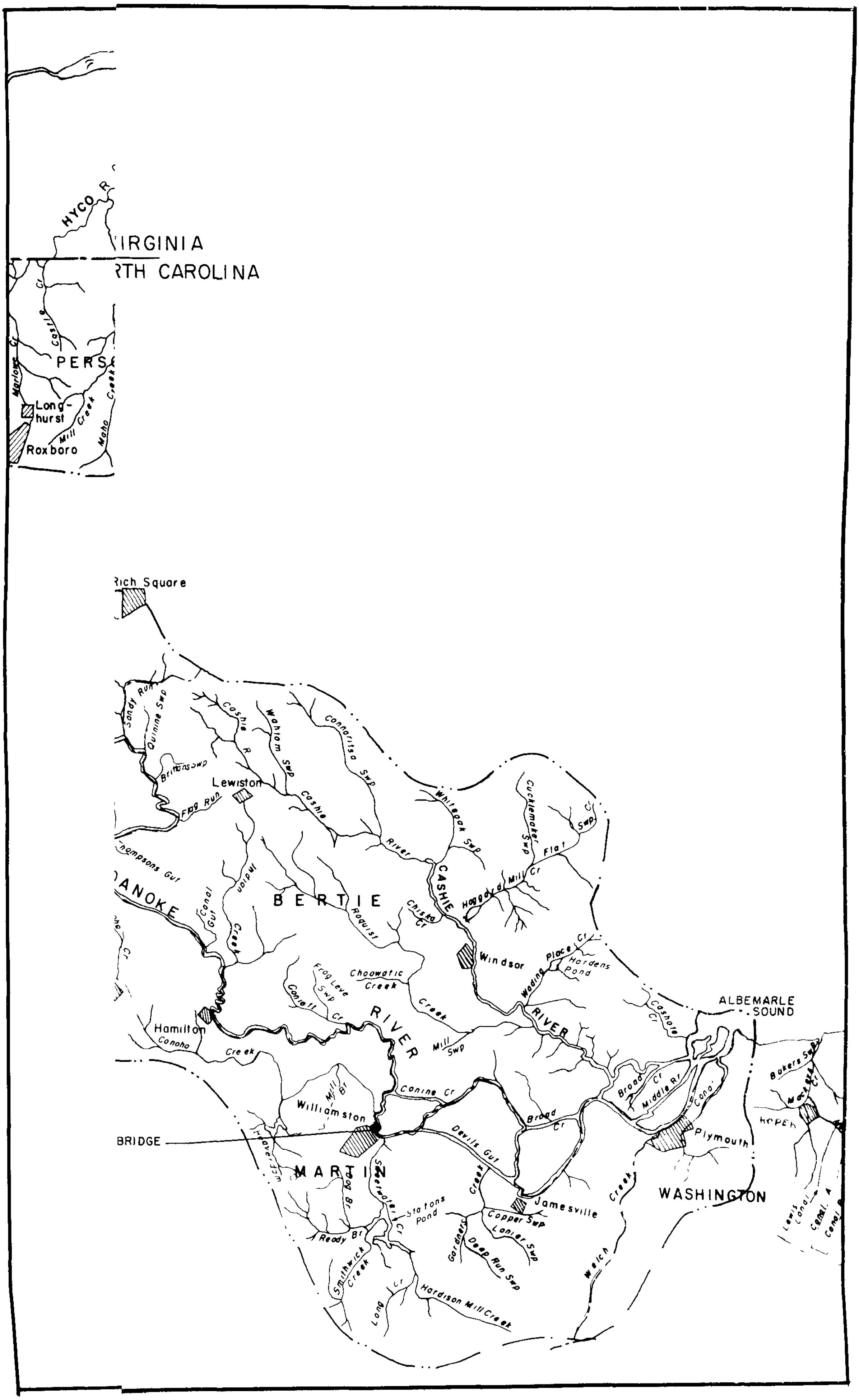
Comment was made in the 1943 report[6] on "the high natural organic content of the water indicated by the results of the biochemical oxygen demand of samples collected above Roanoke Rapids." Since this lower flow prevailed for a considerable time in 1946, the much lower BOD of samples collected in 1946 was considered "more nearly representative of conditions as they would be after Buggs Island Reservoir is constructed than the 1942 results."[12]

During the 1948-1949 water year, the iron (Fe) concentration of the Roanoke River at North Carolina Highway 48 bridge ranged from 0.01 to 0.56 mg/l and had an average annual content of 0.06 mg/l. A sample collected April 24, 1946, at Roanoke Rapids indicated that there was no measurable manganese in the stream.[40]

Below Roanoke Rapids

At the time of the 1942 Public Health Service survey, the most significant waste loads in the lower Roanoke River were discharged in the Roanoke Rapids-Weldon area. The total waste load discharged there was estimated to be 15,000 pounds of BOD per day (90,000 P.E.), almost 90 percent of which was discharged by industry. An estimated 10,000 pounds was discharged by the Halifax Paper Company. On the basis of subsequent survey data this value is felt to have been an underestimation of the total load discharged at that time.

The 1942 survey was for a project to be located near the present Roanoke Rapids Dam. An evaluation of minimum flows needed below the John H. Kerr Reservoir, then known as the Buggs Island Project, was made in 1946. A resurvey of waste discharges in September 1946 indicated no change since 1942. Although pulp production at Halifax Paper Company had increased, reductions in paper production and changes in plant practices were felt to have resulted in no change in total pollution load discharged. As noted before, these waste loads are now felt to have been underestimated. While the 1947 report[12] indicated no increase in waste discharge in the Roanoke Rapids area, correspondence dated June 28, 1948, indicated that a waste load of 21,700 pounds of BOD per day was reported in the 1946 municipal and industrial waste inventor This figure approximates the increase in BOD calculated from stream samples between North Carolina Highway 48 bridge and river mile 133, above and below major Roanoke Rapids waste sources, respectively. However, this information was apparently not available at the time the report was written. Stream data from the two reports are summarized on Table VIII.



HYCO R
VIRGINIA
RTH CAROLINA
Castle Cr
Marlowe Cr
PERS
Long-hurst
Roxboro
Mill Creek
Maho Creek
Rich Square
Sandy Run
Quinine Swp
Cashie R
Wahtom Swp
Connaritsa Swp
Britons Swp
Lewiston
Frog Run
Cashie
Whiteoak Swp
Cucklemaker Swp
Flat Swp Cr
River
CASHIE
Hoggard Mill Cr
Thompsons Gut
ROANOKE
Canal Gut
Indian Creek
BERTIE
Roquist
Chiska Cr
Windsor
Wading Place Cr
Hardens Pond
Choowatic Creek
Frog Leve Swp
Conaritt Cr
Creek
RIVER
Cashoke Cr
ALBEMARLE SOUND
Hamilton
Conoho Creek
Mill Swp
Conine Cr
Broad Cr
Middle Rr
Bakers Swp
Mill Br
Williamston
Broad Cr
Devils Gut
Plymouth
BRIDGE
MARTIN
Sweetwater Cr
Dog Br
Statons Pond
Creek
Jamesville
Welch Creek
WASHINGTON
Copper Swp
Lanier Swp
Ready Br
Gardners Creek
Deep Run Swp
Smithwick Creek
Long Cr
Hardison Mill Creek

Table VIII

Summary of Roanoke River Observations Below Roanoke Rapids Prior to Construction of John H. Kerr Dam

Location	Date	No. of Obs.	Flow cfs	Temp. °C.	Dissolved Oxygen Conc. mg/l	Dissolved Oxygen Sat. pct.	Dissolved Oxygen Def. mg/l	BOD mg/l
Roanoke Rapids (Ri. Mi. 133)	Aug-Sept 1942	4	5,650	23	7.95	92	0.8	2.1
U. S. Hwy. 301 (Ri. Mi. 131)		4		24	7.5	88	1.0	1.9
Halifax, N. C. (Ri. Mi. 122)		4		24	7.5	88	1.0	2.0
Roanoke Rapids (Ri. Mi. 133)	Sept 1946	2	2,140	24.3	8.10	95	0.4	2.60
U. S. Hwy. 301 (Ri. Mi. 131)		2		23.5	7.48	87	1.1	1.80
Halifax, N. C. (Ri. Mi. 122)		2		24.6	7.44	88	1.1	1.36

As a result of his investigation in 1942, LeBosquet stated that only a limited amount of artificial pollution could be assimilated without damage. Based on a minimum daily dissolved oxygen requirement of 5.0 mg/l, it was concluded that 2,500 cfs would be required to assimilate the natural, municipal, and industrial waste loads. Flow requirements for other seasons of the year were also listed. As a result of the 1946 survey during which streamflows of near 2,000 cfs prevailed, it was estimated that the minimum summer flow could be reduced to 2,000 cfs based on a minimum daily dissolved oxygen requirement of 5.0 mg/l. The minimum flows recommended in the early reports were not related to natural flows of specified duration and frequency of recurrence. The flows recommended were for the purpose of maintaining reasonably satisfactory water quality below the Roanoke Rapids-Weldon area under existing waste load conditions. As stated in the 1952 Public Health Service Report, no allowance was made "...for future growth, future increase in pollution, or future reduction of pollution by treatment or other corrective measures."

In addition to the Public Health Service studies, the Fish and Wildlife Service collected dissolved oxygen samples during the months of April, June, July, October, and November in the 5 years from 1936 to 1941, inclusive, at eight stations between Clarksville, Virginia, and Plymouth, North Carolina, including Roanoke Rapids, Weldon, Williamston, Jamesville, and Plymouth, North Carolina. In a report[5] which was submitted to the Corps of Engineers and included as an appendix in the 1942 Public Health Service survey report,[6] it was noted that values as low as 3.8 mg/l were observed and it was indicated that the "average midsummer" D.O. was 4.9 mg/l at one of the stations. Unfortunately, information on individual results, locations, and time of sampling is not available.

A reliable estimate of the "minimum assimilative capacity"* of the river cannot be made from the earlier observations. Therefore, it has been estimated by extrapolating the post-Roanoke Rapids assimilative capacity estimated by the North Carolina State Stream Sanitation Committee for a flow of 2,000 cfs, to the "design flow" of 925 cfs when the initial dissolved oxygen content is 95 percent of saturation (7.95 mg/l) and the critical temperature is 25°C. On the basis of such an extrapolation, the minimum assimilative capacity of the stream under natural low flow conditions is estimated to have been 51,000 pounds of BOD per day (306,000 P.E.). Such an estimate admittedly includes the complex effects of gradually varied flow and translatory waves, but for lack of more complete data, it is used for purposes of comparison in the present study. A comprehensive basin report was prepared in 1951.[18] No field observations were made in connection with this report. Industrial waste discharges were based on information provided by the State stream pollution control agencies supplemented

*The "waste assimilative capacity" is defined as the maximum amount of organic waste from municipal and industrial sources that can be added to a stream at a specified flow, temperature, initial dissolved oxygen, and BOD content without causing the minimum dissolved oxygen content to fall below the dissolved oxygen objective for the stream; the "minimum waste assimilative capacity" is defined as the maximum amount of organic waste which can be added to a stream at the "design flow" and at a temperature, initial dissolved oxygen, and BOD content which has been observed or could reasonably be expected without causing the minimum dissolved oxygen content to fall below the dissolved oxygen objective for the stream.

by data from particular industries. Available information indicated that waste loads in the upper basin amounted to an estimated 61,700 pounds of BOD per day (370,000 P.E.). The total waste load at Roanoke Rapids was estimated to be 15,700 pounds of BOD per day of which 10,000 pounds was estimated to be caused by Halifax Paper Company wastes. While this figure indicated no increase in waste load and was the best available at the time, subsequent data indicate that the waste load discharged by Halifax Paper Company was probably higher than reported.

The 1951 survey pointed out that the major industries at Roanoke Rapids operated 7 days per week so that no significant reduction in their waste discharge could be anticipated on weekends. The minimum flow recommendations in the 1947 report[12] were confirmed. No reduction in weekend flows was recommended.

The North Carolina Division of Weyerhaeuser Company at Plymouth (formerly known as the North Carolina Pulp Company) began operation about 1950 with an initial capacity of 800 tons of pulp per day. In 1951 the waste load discharged at Plymouth amounted to an estimated 16,700 pounds of BOD per day (100,000 P.E.).

Summary

Minimum flow recommendations for operation of John H. Kerr Dam were based on flows necessary to assimilate waste loads discharged at Roanoke Rapids, North Carolina. Only limited field observations were made. No consideration was given to reduction of waste discharges through treatment or to possible future increases resulting from population and industrial growth. Industrial waste data were limited and subsequent observations indicate that loads were probably higher than reported. Provision was made for more assimilative capacity than was available naturally. Reductions in dissolved oxygen concentrations below John H. Kerr Dam were anticipated but were not considered significant since no organic waste discharges were involved and reaeration would replace the oxygen before it was needed again at Roanoke Rapids.

POST-JOHN H. KERR DAM CONDITIONS

This discussion deals only with conditions in and below John H. Kerr Reservoir prior to impoundment of water by Roanoke Rapids Dam.

Above Roanoke Rapids

Temperature stratification and the reduction of D.O. of the water near the bottom are natural phenomena that occur in large natural lakes as well as reservoirs. Since the turbine intakes in John H. Kerr Dam withdraw water from near the bottom of the reservoir, it was not unexpected that the impoundment of water by Kerr Dam was followed by reduced dissolved oxygen conditions in the lower levels of the impoundment and in the discharge during the summer months.[6, 12] Dissolved oxygen samples collected on August 7, 1953, from the scroll case (probably through the penstock drains) were all zero.[29] These samples were taken at half-hour intervals throughout the power peaking period. No samples of the tailrace D.O. were taken at that time but the results of samples collected at half-hour intervals at U. S. Highway 1 bridge, 6 miles downstream, ranged from 7.1 mg/l to a minimum of 1.3 mg/l and averaged 1.7 mg/l during the 4 hours of peaking flow. Based on estimated reaeration rates for the river between the dam and U. S. Highway 1 bridge, the tailrace D.O. is estimated to have been about 0.5 mg/l or below. Thus, in the first year after its completion, Kerr Dam released water of degraded quality to the lower Roanoke River during the summer period.

The low dissolved oxygen levels observed in the scroll case of Kerr Dam and in the Roanoke River in 1953 intensified interest and concern over dissolved oxygen conditions at and below Roanoke Rapids. The increase in waste loads at Roanoke Rapids and the possible D.O. changes resulting from Roanoke Rapids Reservoir also increased the concern over the assimilative capacity of the river below Roanoke Rapids.

In 1954 the Virginia Electric and Power Company started sampling in Kerr Reservoir, in the Roanoke River between Kerr Dam and Roanoke Rapids, and downstream to U. S. Highway 258 bridge.* The North Carolina State Stream Sanitation Committee has collected samples in Kerr Reservoir, in the Kerr Dam tailrace, and further downstream in connection with its interest in the effects of Kerr Reservoir discharges and the establishment of the existing water quality conditions at the time of stream classification.[39]**

*Copies of data tabulations by VEPCO personnel have been made available for this study.

**Additional data not included in the Committee publications have been made available for this study.

A summary of data collected after the filling of Kerr Reservoir but prior to completion of Roanoke Rapids Dam is presented in Table IX.

The observation of zero D.O. in the scroll case of Kerr Dam was repeated in sampling by VEPCO in 1954 although the time of occurrence indicated that it was probably of shorter duration. The corresponding tailrace D.O.'s were about 1.5 mg/l in both years indicating that substantial reaeration was taking place in the tailrace or that the scroll case D.O. sample was water drawn from nearer the bottom of the reservoir and had not mixed with the turbine discharge as a whole. The latter explanation seems more likely since the dissolved oxygen values observed in samples drawn from the penstock drains by the North Carolina State Stream Sanitation Committee were substantially below the dissolved oxygen values observed at the 90-foot depth in the reservoir. The location of the scroll case sample outlet is similarly felt to represent water withdrawn from the very bottom of the reservoir and not to be representative of the water discharged. The low D.O. in the discharge from Kerr Dam and subsequently from Roanoke Rapids Dam lead the North Carolina State Stream Sanitation Committee to conclude that even though a hydroelectric project adds no pollutants to the water, it may from the standpoint of adversely affecting water quality be equivalent to a source of pollution. However, unlike low D.O. resulting from organic pollution, the low D.O. from a reservoir can be accompanied by a low BOD. This is the case with Kerr Reservoir as indicated by the results of samples collected by the Public Health Service and VEPCO listed in the previous table and by the North Carolina State Stream Sanitation Committee and others at later dates. Additional data are listed in the section, "Post-Roanoke Rapids Dam Conditions."

Temperature, dissolved oxygen, pH, and iron and manganese data collected from John H. Kerr Reservoir and below by VEPCO since mid-1954, together with data collected by the Public Health Service and the North Carolina State Stream Sanitation Committee, indicated the following:

1. Minimum tailrace D.O.'s were below 1.3 mg/l in 1953 and as low as 1.7 mg/l in 1954.

2. In the passage from Kerr Dam to Roanoke Rapids the dissolved oxygen of the water recovered from as low as 10 to 20 percent of saturation to approximately 90 to 93 percent.

3. Limited round-the-clock sampling indicated significant diurnal changes in D.O. and temperature in the scroll case, in the tailrace, and at all stations to and including the samples at North Carolina Highway 48 bridge.

Table IX

Summary of Roanoke River Observations Above Roanoke Rapids After Completion of John H. Kerr Dam

Location	Date	No. of Obs.	Flow cfs	Temp. °C.	Dissolved Oxygen Conc. mg/l	Sat. pct.	Def. mg/l	BOD mg/l
(1953 PHS Survey)[29]								
Kerr Scroll Case (Ri. Mi. 179)	Aug 1, 1953	11	11,400	21.0	0.0	0	9.0	0.0
U.S. Hwy. 1 Brdg. (Ri. Mi. 173)	Aug 1, 1953	15	-	22.1	3.52	40	5.3	-
Eaton's Ferry (Ri. Mi. 153)	Aug 8, 1953	2	-	19.0	4.50	47	5.0	-
N.C. Hwy. 48 Brdg. (Ri. Mi. 135)	Aug 1953	47	2,513	24.3	7.88	93	0.6	0.74
(Samples Collected by VEPCO)								
Kerr Scroll Case	Aug-Oct, 1954	4	-	21	2.0	22	7.0	-
Tailrace		4	-	21	2.9	32	6.1	0.55*
Buggs Island Gage (Ri. Mi. 179)	"	4	-	21	2.9	32	6.1	-
Clement's Island (Ri. Mi. 146)	"	4	-	22	7.0	80	1.7	-
Roanoke Rapids W.T.P.** (Ri. Mi. 136)	"	4	-	22	7.5	86	1.2	-

*Only two samples; the mean 20-day value was 2.9.
**One sample at North Carolina Highway 48 bridge.

Location	Date	No. of Obs.	Flow cfs	Temp. °C.	Conc. mg/l	Sat. pct.	Def. mg/l	BOD mg/l
(Samples Reported by Riddick)[33]								
N.C. Hwy. 48 Brdg.								
Mean	-	37	-	-	8.0	95		
Range					7-9	84-109		

Table IX (Cont.)

Location	Date	No. of Obs.	Flow cfs	Temp. °C.	Dissolved Oxygen Conc. mg/l	Dissolved Oxygen Sat. pct.	Dissolved Oxygen Def. mg/l	Fe mg/l	Mn mg/l
(Samples Collected by North Carolina State Stream Sanitation Committee)									
Kerr Dam									
4-ft Depth	*	7	-	27.0	6.5	81	1.5	0.2	0.0
	**	7	-	25.0	6.6	79	1.8	0.4	0.0
40-ft Depth	*	7	-	24.0	2.2	26	6.2	0.4	0.5
	**	7	-	24.0	6.1	72	2.3	0.5	0.0
90-ft Depth	*	7	-	20.0	2.0	22	7.1	2.8	1.3
	**	7	-	20.0	1.5	16	7.6	3.8	2.0
Penstock Drains	***	9	-	19.6	0.1	1	9.1	5.8	1.8
Roanoke Rapids W.T.P.	*	7	-	25.7	7.8	95	0.4	0.7	0.1
	**	5	-	24.3	8.2	98	0.2	1.8	0.1

*August 3 through September 3, 1954.
**September 8 through September 29, 1954.
***September 14 through October 13, 1954.

4. While the time of sampling was not recorded for all samples, it is reasonable to assume that samples were taken at about the same time for each set of observations for each station. Extreme values, both higher and lower than the results reported, would be expected for samples collected at different times of the day. However, the single daily samples available at the river stations can be used to indicate general seasonal trends.

5. The data available were inadequate to make an accurate estimate of the reaeration coefficient* for the river below Kerr Dam. A particular difficulty is the absence of accurate information on time of flow. However, rough estimates of time of flow indicated that the reaeration coefficient between Kerr Dam and U. S. Highway 1 bridge ranged from 0.4 per day for peaking flows of about 13,000 cfs to 0.7 per day for minimum flows between peaking discharges. From Kerr Dam to Roanoke Rapids the reaeration coefficient was estimated to be in the vicinity of 1.0 per day.

6. Iron and manganese concentrations, far in excess of the Public Health Service Drinking Water Standards, developed in the bottom layers of Kerr Reservoir (the layer from which much of the flow originates). Substantial amounts of iron and manganese remained in the water at the Roanoke Rapids raw water intake.

7. No appreciable operating difficulties at the Halifax Paper Company at Roanoke Rapids were occasioned by the low dissolved oxygen or high iron and manganese content observed in the Kerr Dam tailrace prior to construction of Roanoke Rapids Dam.[33]

Below Roanoke Rapids

Passage of Article 21 of the General Statutes of North Carolina in 1951 established the State Stream Sanitation Committee and authorized it to conduct surveys, hold hearings, establish stream standards, determine classi-

*The "reaeration coefficient" is an over-all constant of proportionality reflecting the rate of oxygen concentration change in a stream per unit of oxygen deficit, resulting from the combined effects of physical transfer and photosynthetic oxygen production. Physical transfer decreases as the mean depth increases and increases with increased turbulence of flow. Photosynthetic oxygen production increases as the algal production, light transmission, and light intensity increase.

fications for all of the streams of the State, and thereafter to establish and enforce a comprehensive pollution abatement plan for each river basin to protect the quality of all streams of the State for the highest possible, reasonable beneficial uses. Pursuant to the requirement that the stream first be surveyed, the Committee requested that the Public Health Service aid in a survey of the lower Roanoke River. The determination of waste loads in the Roanoke Rapids-Weldon and Plymouth areas constituted a major portion of the survey.[29] It was found that the waste load at Roanoke Rapids was substantially higher than previously estimated. In the spring of 1954 it amounted to an estimated 96,000 pounds of BOD per day, 90,000 pounds of which originated from Halifax Paper Company. The waste load in the vicinity of Plymouth was also found to have increased. In 1954 it amounted to an estimated 46,700 pounds of BOD per day, of which 45,800 pounds resulted from the operation of the North Carolina Pulp Company.

The waste loads at Halifax Paper Company and North Carolina Pulp Company constituted 900 and 275 percent increases, respectively, over the loads reported in 1952.[29] Waste loads reaching the Roanoke River at Roanoke Rapids were thus substantially increased over the loads on which earlier estimates of minimum discharges had been based. Major waste discharges measured as a part of this survey are listed in Table X. There are no

Table X

Major Waste Discharges to the Lower Roanoke River in 1953

Source	Location River Mile	Pounds of BOD Discharged Per Day
Roanoke Rapids Industries other than Halifax Paper Company	135	2,710
Halifax Paper Company	134.8	90,000
Roanoke Rapids	134.2	2,940
Weldon	129.6	400
North Carolina Pulp Company	8.4	45,800
Plymouth	6.8	760

major tributaries entering the Roanoke River between Kerr Dam and Plymouth and none carrying significant quantities of pollution. Other minor sources of pollution were listed in the survey report.[29]

Extensive stream sampling was conducted during the August 1953 Public Health Service survey. A summary of data collected below Roanoke Rapids is presented in Table XI. These data indicate that the lower Roanoke River was receiving excessive pollution in terms of the present classification requirement of not less than 4.0 mg/l D.O. at the critical point at the flows observed.

The minimum waste assimilative capacity of the Roanoke River was not explicitly stated in the 1954 Public Health Service Report as the stream was not classified at that time. The results were analyzed in terms of the statistical method proposed by M. A. Churchill,[24] the method proposed by LeBosquet and Tsivoglou,[15] and the dissolved oxygen-sag formula[3] for critical dissolved oxygen levels of 3.0, 4.0, and 5.0 mg/l. Based on the tabulated results of these analyses, the following waste assimilative capacities in pounds of 5-day, 20°C. BOD have been estimated for a critical D.O. condition of 4.0 mg/l and the discharge shown:

Method	925 cfs	1,000 cfs	2,000 cfs
Churchill	36,700	40,750	81,500
LeBosquet-Tsivoglou	24,000	26,000	52,000
Oxygen Sag	38,800	42,200	84,500

The report of Task Force No. 1 of the Roanoke River Cooperative Survey dated November 29, 1955, cited calculations based on the 1953 study in which the assimilative capacity was estimated to be 36.18 pounds of BOD per day per cfs. On this basis the assimilative capacity would be 33,500, 36,200, and 72,400 pounds of BOD per day at minimum discharges of 925, 1,000, and 2,000 cfs, respectively. These values compare favorably with the results derived above from the Public Health Service Report. Thomas M. Riddick cited[33] values of 25,900, 28,000, and 56,000 pounds of BOD per day at a critical temperature of 25°C. and 39,700, 43,000, and 86,000 pounds per day at a critical temperature of 20°C. for flows of 925, 1,000, and 2,000 cfs, respectively.

Table XI

Summary of August 1953 Public Health Service Survey
Data Collected Below Roanoke Rapids

Location	No. of Obs.	Mean Flow cfs	Temp. °C.	Dissolved Oxygen Conc. mg/l	Dissolved Oxygen Sat. pct.	Dissolved Oxygen Def. mg/l	BOD mg/l
Roanoke Rapids N. C. Hwy. 48 Brdg. (Ri. Mi. 135)	47	2,513	24.3	7.88	93.2	0.6	0.74
USGS Gage (Ri. Mi. 133.6)	24	1,709	27.0	5.90	73.6	2.2	14.30
Weldon Hatchery (Ri. Mi. 130)	39	2,667	25.4	5.39	64.1	2.9	7.59
(Ri. Mi. 127)	13	1,524	26.1	4.50	55.0	3.7	5.23
(Ri. Mi. 124)	6	1,665	28.2	4.01	51.1	3.9	4.62
Halifax Landing (Ri. Mi. 121)	20	1,808	27.3	3.10	43.9	4.9	5.13
Garry Landing (Ri. Mi. 118)	46	2,710	25.8	4.24	51.5	4.0	3.73
(Ri. Mi. 115)	6	1,919	26.9	3.14	39.0	5.0	2.68
(Ri. Mi. 112)	6	1,989	25.8	3.06	38.1	5.2	2.55
(Ri. Mi. 109)	6	2,043	26.4	3.30	40.5	4.8	2.18
(Ri. Mi. 106)	3	1,860	27.2	3.66	46.3	4.4	1.31
Scotland Neck U.S. 258 Brdg. (Ri. Mi. 102)	60 (18)	3,104 (2,138)	26.0 (25.8)	3.54 (3.48)	43.7 (42.5)	4.7 (4.8)	2.83 (1.69)
Palmyra Landing (Ri. Mi. 79.5)	36 (12)	4,190 (2,816)	26.9 (28.6)	4.01 (4.10)	50.0 (52.9)	4.1 (3.7)	2.56 (2.06)
Williamston U.S. 17 Brdg. (Ri. Mi. 37.5)	13 (6)	4,218 (3,200)	26.8 (28.4)	4.88 (4.39)	60.5 (56.3)	3.2 (3.5)	1.82 (1.57)

Observations in parentheses are for lower flows experienced during the survey.

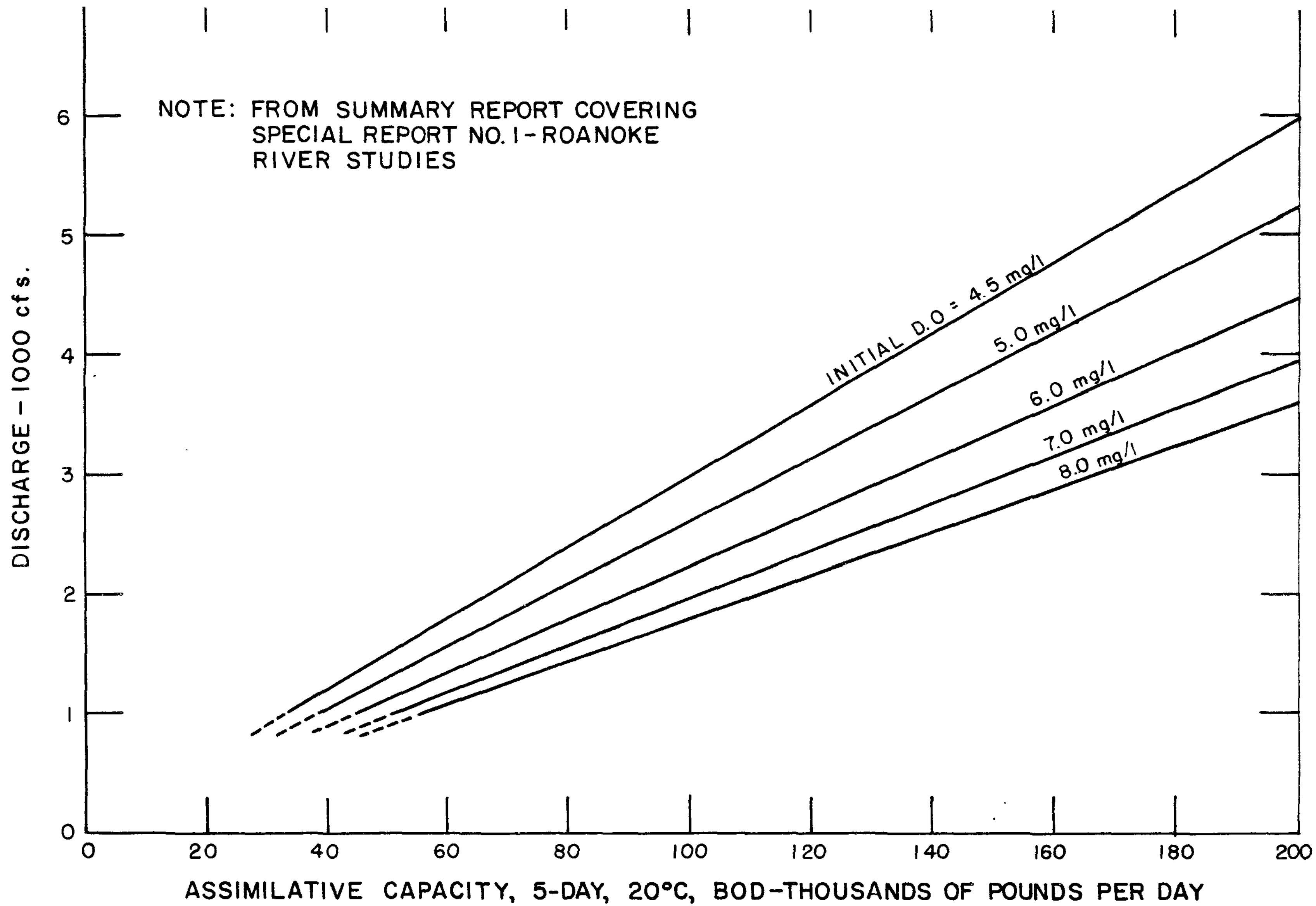
On the basis of the 1953 data and subsequent observations of the location of the critical sag point,[39] the North Carolina State Stream Sanitation Committee concluded that the summer waste assimilative capacity of the river below Roanoke Rapids was 109,100 pounds of 5-day, 20°C. BOD per day based on an upstream D.O. of 90 percent of saturation and a minimum weekday flow of 2,000 cfs as provided by Kerr Dam under the flow schedule in effect at that time. This conclusion was the basis for the chart of waste assimilative capacity in the Roanoke River below Weldon presented in the Summary Report covering Special Report No. 1, Roanoke River Studies[56] (reproduced as Figure 4). While a difference exists regarding the assimilative capacity at Roanoke Rapids in view of the responsibility of the North Carolina State Stream Sanitation Committee for the enforcement of the stream standards on the Roanoke River and its collection of additional waste and stream data, the Committee's estimate is accepted for all subsequent comparisons.

The design flow of the Roanoke River at Roanoke Rapids under natural flow conditions was 925 cfs and, based on extrapolation of the determinations made by the North Carolina State Stream Sanitation Committee, the assimilative capacity available at the design flow was about 51,000 pounds of BOD per day. The assimilative capacity at 1,000 and 2,000 cfs and the minimum instantaneous flows provided by Kerr Dam under weekend and weekday flow conditions were 54,600 and 109,100 pounds per day, respectively.

Since reduced weekend flows were predicated on a reduction in waste load on weekends and operation of the Halifax Paper Company was on a 7-day week basis with no provision for storage lagoons or other means of reducing weekend waste discharges, the North Carolina State Stream Sanitation Committee Comprehensive Pollution Abatement Plan[44] was based on the allocation of a waste assimilative capacity of 109,100 pounds of BOD available under minimum weekday flows of 2,000 cfs as provided by John H. Kerr Dam between 1952 and 1955.

Samples collected in the Roanoke River below Plymouth in 1954 indicated that the dissolved oxygen was completely exhausted at times. Subsequent sampling by the North Carolina State Stream Sanitation Committee indicated that the river was capable of assimilating 45,000 pounds of 5-day, 20°C. BOD per day from the North Carolina Pulp Company when the streamflow was 4,200 cfs.[44]

Increased minimum flows from storage provided by Kerr Dam resulted in an incidental benefit through increasing the assimilative capacity below Roanoke Rapids by 4,000 pounds of BOD per day on weekends and 58,000 pounds per day on weekdays. It increased the assimilative capacity at Plymouth by a substantial but unknown amount.



ROANOKE RIVER
WASTE ASSIMILATIVE CAPACITY BELOW WELDON
PROVIDED ABOVE THE REQUIRED MINIMUM 40 mg/l
AT A CRITICAL TEMPERATURE OF 25° C.

FIGURE 4

No data are available concerning iron and manganese concentrations at Roanoke Rapids after completion of Kerr Dam but prior to construction of Roanoke Rapids Dam; however, comment by Riddick in his report to the Halifax Paper Company[56] implies that problems had not developed at that time.

Summary

Discharges from John H. Kerr Dam were practically devoid of dissolved oxygen during the late summer period as a result of thermal stratification and low-level power intakes. Reaeration between the dam and Roanoke Rapids resulted in dissolved oxygen conditions above Roanoke Rapids waste sources only slightly lower than before Kerr Dam was constructed. Estimates by the North Carolina Stream Sanitation Committee indicated that minimum flows provided by Kerr Dam assured a waste assimilative capacity of 109,000 pounds of BOD per day on weekdays. Since industrial waste discharges were not reduced on weekends as postulated in establishing the lower weekend flow requirements, the North Carolina State Stream Sanitation Committee Pollution Abatement Plan for the Roanoke Rapids-Weldon area was based on the minimum weekday flows.

By 1954 industrial and municipal waste loads had increased to the extent that the dissolved oxygen content of the lower Roanoke River was reduced to 4.0 mg/l at the minimum flow rates provided by John H. Kerr Dam during the summer season.

POST-ROANOKE RAPIDS DAM CONDITIONS

The information contained in this section pertains primarily to (1) dissolved oxygen in Kerr Reservoir, in the discharges from Kerr Dam, and in the Roanoke River between Kerr Dam and the head of Roanoke Rapids Reservoir for the period since routine sampling was begun by VEPCO and the Corps of Engineers, and (2) dissolved oxygen conditions in and below Roanoke Rapids Reservoir for the period since completion of Roanoke Rapids Dam.

Above Roanoke Rapids

Observations of dissolved oxygen, temperature, pH, iron, and manganese have been made in the John H. Kerr Reservoir by VEPCO since 1954. Samples were collected at Buoy No. 1, 1,000 feet upstream from the face of Kerr Dam. Samples were originally collected at 10-foot intervals of depth but since 1959 have been collected at 5-foot intervals. Since 1957, samples were also collected at the 1-foot depth. Iron and manganese samples were collected at 20-foot intervals of depth. Samples were also collected from the scroll case and tailrace at Kerr Dam, U. S. Highway 1 bridge, Clement's Island (at the head of Roanoke Rapids Reservoir), Roanoke Rapids Reservoir, the scroll case and tailrace at Roanoke Rapids Dam, North Carolina Highway 48 bridge (at Roanoke Rapids), U. S. Highway 301 bridge (at Weldon), U. S. Highway 258 bridge (at Scotland Neck), and from the raw and treated water at the Roanoke Rapids Sanitary District water treatment plant. Samples were generally collected at two- to four-week intervals during the summer stratification period, although no sampling was conducted in Kerr Reservoir during the period of the 1957 joint studies by the Steering Committee for Roanoke River Studies and the Virginia Electric and Power Company.

The corps of Engineers has collected samples for dissolved oxygen and temperature since 1956. Samples were collected at Buoy No. 1 at 10-foot intervals of depth. Samples were also collected at Buoys No. 2, 3, and 4 further upstream from the dam in the summer of 1957. Samples were also collected from the Smith, Dan, and Roanoke Rivers above Kerr Reservoir, from the scroll case and tailrace at Kerr Dam, and from Eaton's Ferry and Clement's Island below the dam. Samples were collected at two- to four-week intervals during the summer stratification period.

Between August 3 and September 29, 1954, the North Carolina State Stream Sanitation Committee collected 14 sets of samples at 4-, 40-, and 90-foot depths from the platform in front of the powerhouse as reported in the previous section. They also collected 17 sets of samples from the tailrace in 1960. The Committee established D.O. recorders in the river at North Carolina Highway 48 bridge in 1960, at U. S. Highway 258 in 1960 and 1961, and at Eaton's Ferry in 1961. Other data were collected in connection with the Roanoke River Basin Pollution Survey Report and the 1957 studies by the Steering Committee for Roanoke River Studies.

Annual graphs of the temperature and dissolved oxygen observations prepared on the basis of the data obtained by the Corps of Engineers and VEPCO indicate that stratification developed as early as June 1 in Kerr Reservoir and that a thermocline is identifiable throughout the summer season. The thermocline is gradually lowered by discharge of hypolimnetic water through the power penstocks and wind induced mixing. Stratification is finally and abruptly eliminated in the fall (usually in October) by mixing due to surface cooling and/or seasonal storms.

The VEPCO and Corps of Engineers data indicate that the dissolved oxygen content of the water near the bottom of the reservoir was completely exhausted in only one (1) year was the lowest dissolved oxygen content of the bottom sample above 1.0 mg/l. The minimum dissolved oxygen level observed at the elevation of the top of the turbine intakes has been below 4.0 mg/l for periods up to 95 days (1957) and as low as 0.3 mg/l.* In only one (1) year has the minimum value remained above 4.0 mg/l. During summer stratification periods the dissolved oxygen content of the water in the top layers of the reservoir is generally substantially higher than at the elevation of the power intakes. At the 10-foot depth D.O. is generally between 7.0 and 9.0 mg/l. The minimum values at the 10-foot depth and at the elevation of the top of the turbine intakes are listed in Table XII for each year of observation. The period during which the dissolved oxygen at the elevation of the top of the power intakes was below 4.0 mg/l is also included to indicate the period over which minimum tailrace dissolved oxygen levels will occur.

Thirty-five percent of the dissolved oxygen samples collected at the 1-foot depth by VEPCO during July, August, and September exceeded saturation at the temperature observed. These samples were collected between 9 a.m. and 12:30 p.m. and it would be expected that a larger proportion would be supersaturated later in the day due to photosynthetic activity. Photosynthesis and surface reaeration will add to the dissolved oxygen of the reservoir. Both processes depend on mixing due to wind and temperature fluctuations to transfer oxygen to the lower levels of the epilimnion.

Samples collected by Kerr Dam personnel and analyzed by the National Water Quality Network laboratory of the U. S. Public Health Service for plankton late in September 1961 had a tenfold higher total algae count in the surface sample than in the sample taken at 50 feet indicating the greater productivity of the surface waters. Subsequent samples in October confirmed the evidence of temperature and oxygen observations that the fall overturn had occurred. However, even the surface sample collected in September was considered to indicate relatively unproductive water. Thus, photosynthetic activity may be of limited benefit in increasing the dissolved oxygen content of the surface layers of Kerr Reservoir, but further information should be secured before its importance in Kerr Reservoir and in the lower reservoirs can be properly determined.

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*This value was probably due to wind denivellation as are most of the other extremely low values at intermediate reservoir elevations. Wind denivellation is the setup or tilting of a lake or reservoir surface resulting from sustained wind. Of importance is the associated denivellation (or tilting) of the hypolimnion in the opposite direction than the water surface. This phenomenon is discussed in detail by Hutchinson.[46]

Table XII

Summary of Minimum Dissolved Oxygen Observations in John H. Kerr Reservoir

Year	10-Foot Depth Min. D.O. mg/l	10-Foot Depth Date	Top of Turbine Intakes (Elev. 265) Min. D.O. mg/l	Top of Turbine Intakes (Elev. 265) Date	Top of Turbine Intakes (Elev. 265) Period D.O. was below 4.0 mg/l
1954	6.4	Oct. 13	2.1	Aug. 31	Aug. 14-Sept. 9
1955	0.2 2.7	Aug. 10 Sept. 15	0.3 1.8	Aug. 10 July 25	July 1-Aug. 24
1956	6.3	Sept. 28	3.2	July 16	July 11-July 29
1957	5.4	Oct. 2	1.5	July 17	June 24-Sept. 26
1958	6.5	Oct. 1	3.2	Aug. 20	Aug. 12-Aug. 25
1959	5.8	Sept. 9	2.5	Aug. 25	June 25-Sept. 7
1960	4.2	Sept. 13	4.3	Sept. 13	None
1961	7.1	Aug. 16	1.4	Aug. 16	July 20-Sept. 15

The North Carolina State Stream Sanitation Committee D.O. observations in Kerr Reservoir were made from the platform above the power intakes in 1954. These observations probably were made during peaking flows and showed much higher dissolved oxygen concentrations than were observed at corresponding depths at Buoy No. 1, 1,000 feet upstream from the dam. The observations made at a depth of 40 feet (near the elevation of the top of the power intakes) correspond to observed dissolved oxygen levels as much as 50 feet higher at Buoy No. 1 in August and early September, and 30 feet higher in late September. At the high discharges during peaking flows, water is apparently drawn from substantially higher levels in the reservoir than the penstock opening. Fish commented on the variations in the dissolved oxygen content which might be observed in the "adclaustral zone" or area in which high exit velocities and inertial effects of reducing flow are prominent.[36] The drawdown of surface water indicated by these data undoubtedly occurs each day, the extent depending on the discharge rate, and is effective in improving the dissolved oxygen content of the discharge over that implied by the observations at the intake level at Buoy No. 1.

The elevation of the top of the hypolimnion at Buoy No. 1 (as indicated by the strata of the low D.O. water) has been observed to change over a fairly wide range. For example, on August 10, 1955, the hypolimnion extended to the surface and was observed to be at or below 0.4 mg/1 at all depths. On this day the VEPCO sampling party noted that a brisk northeast wind was blowing. Water was turbid in the deep water areas and a sharp line of demarcation existed between the clear and turbid water approximately 200 yards from the north shore. In the clear water the dissolved oxygen at the 10-foot depth was found to be 2.5 mg/1. On the same day the scroll case D.O. was observed to be 0.0 mg/1, but the tailrace D.O. was 1.2 mg/1. On August 30 the D.O. at the 10-foot depth was 6.8 mg/1 while the D.O. exceeded 4.0 mg/1 to a depth of 55 feet. The lowest sample collected at a depth of 90 feet had a D.O. of 2.8 mg/1. On September 15 of the same year relatively low dissolved oxygen levels (2.7 mg/1) were again noted from the top to near the bottom of the reservoir. Only 15 days later the dissolved oxygen concentration was 5.2 mg/1 and nearly uniform down to 80 feet. Similar changes in the levels of hypolimnetic water occurred in most of the years of observation, but generally involved elevation changes of 20 to 40 feet. These changes are believed due to wind denivellation and this phenomenon has an important bearing on the desirability of submerged weirs as corrective measures in improving the dissolved oxygen concentration of reservoir discharges.

Discharge of water through penstocks located deep in reservoirs has been reported to stem essentially from the layer in which they are located.[42] For deep reservoirs such as Fontana (TVA), only water located below the thermocline will be discharged. In Kerr Reservoir the thermocline is in the vicinity of the elevation of the top of the penstocks at the beginning of the stratification period. Wind mixing in the late spring and the rapidity with which the surface waters warm are probably the most important factors in determining the elevation of the thermocline at the beginning of summer stratification. Little control over these factors seems possible. As the season progresses, the thermocline is lowered so that an increasing proportion of the oxygenated epilimnetic water is discharged. The discharge over the summer stratification period (estimated as July 1 to October 15) exceeds the quantity of water estimated to be in the hypolimnion at the beginning of the season by a substantial factor as shown in Table XIII.

Table XIII

Summer Discharge from John H. Kerr Reservoir as Initial Volume in Hypolimnion

Year	Summer* Discharge acre-feet	Stratification Period Beginning	End	Volume of Hypolimnion acre-feet**	Discharge Volume of Hypolimnion ratio
1956	800,000	June 15	Sept. 25	718,000	1.1
1957	1,040,000	June 1	Sept. 30	880,000	1.2
1958	1,160,000	June 1	Oct. 31	400,000	2.9
1959	1,110,000	June 15	Oct. 15	482,000	2.3
1960	990,000	June 15	Oct. 10	310,000	3.2
1961	1,150,000	June 1	Oct. 10	718,000	1.6
Mean	1,042,000			583,000	2.0

*Estimated as July 1 to October 15.

**Based on the combined Corps of Engineers and Virginia Electric and Power Company observations.

The duration of dissolved oxygen levels below 4.0 mg/l at the top of the turbine intakes was generally inversely proportional to the ratio of discharge to initial volume stored. The inclusion of substantial amounts of water from the lower levels of the epilimnion during peaking power discharges is a significant factor in tailrace D.O.'s through much of the summer stratification period. The inclusion of this higher D.O. water, together with turbulence in the tailrace, results in a higher D.O. in the tailrace than that implied by observations in the hypolimnion opposite the intake.

Dissolved oxygen profiles observed at Buoy No. 1 immediately opposite the intake would not result in the D.O. value observed in the scroll case if complete mixing took place. Early in its sampling program, VEPCO personnel commented on this anomaly.* The scroll case values apparently represent water drawn into the turbine from near the bottom of the reservoir. Tailrace D.O. observations in the period of summer stratification are substantially higher than the scroll case values. The increase in dissolved oxygen between the scroll case and tailrace is apparently largely due to mixing of higher level, higher dissolved oxygen water rather than reaeration in the tailrace as has sometimes been supposed. Observations in Lake Wylie by Duke Power Company[82] showed that the tailrace D.O. could be estimated from the dissolved oxygen at the several depths, weighted in proportion to the velocity toward the turbine intake, implying relatively little reaeration in the tailrace, just as seems to be indicated by the observations reported for Kerr Reservoir.

Scroll case and tailrace dissolved oxygen observations were included in both the VEPCO and Corps of Engineers sampling programs. Annual graphs of the observations indicate that the lowest dissolved oxygen levels occur in August, although minimum values observed in July and September are almost as low on occasion. The lowest dissolved oxygen levels occurring in the summer months of each of the years observations have been made are listed in Table XIV.

Dissolved oxygen observations at the Kerr Dam tailrace were also made during the 1957 survey by the Steering Committee and VEPCO. On 15 days between July 22 and September 12 observations extending through most of the peaking flow period were obtained at maximum flows between 10,000 and 30,000 cfs. The summary of dissolved oxygen and temperature data reported by the Special Committee for Roanoke River Studies for stations on the Roanoke River above Roanoke Rapids are listed in Table XV.

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*J. D. Ristroph, Report on Water Quality - Roanoke River, VEPCO, September 3, 1954.

Table XIV

Minimum Dissolved Oxygen
Observations in John H. Kerr Dam Tailrace
During the Summer Months, 1954 to 1961

Year	Dissolved Oxygen, mg/l				
	June	July	August	September	October
1954	3.8	2.6	1.7	1.9	4.0
1955	3.6	1.4	1.2	3.0	6.0
1956	4.9	2.3	1.9	2.2	6.0
1957	2.5	1.8	1.9	2.2	4.5
1958	4.6	2.3	2.3	3.2	6.0
1959	3.7	2.0	1.8	1.8	4.3
1960	3.6	1.8	1.2	1.7	5.7
1961	5.0	1.6	1.4	1.4	4.5
Mean	4.0	1.9	1.7	2.2	5.1
Min.	2.5	1.4	1.2	1.4	4.0

Table XV

Dissolved Oxygen and Temperature Observations
in the Roanoke River between John H. Kerr Dam and Roanoke Rapids, 1957*

	Kerr Tailrace Ri. Mi. 179	Eaton's Ferry Ri. Mi. 152	Gaston Site Ri. Mi. 146	N.C. Hwy. 48 Brdg. Ri. Mi. 137 Observed	N.C. Hwy. 48 Brdg. Ri. Mi. 137 Adjusted**
			Dissolved Oxygen, mg/l		
Maximum	4.7	9.0	8.2	8.6	8.0
Upper Quartile	3.0	6.7	7.1	6.9	6.7
Arithmetic Avg.	-	-	6.6	6.3	6.0
Weighted Avg.	2.5	5.4	-	6.3	6.2
Median	2.3	5.6	6.8	6.3	6.1
Lower Quartile	1.7	4.5	6.0	5.7	5.5
Minimum	0.3	3.7	5.2	2.7***	2.7
Number Observed	323	336	303	1092	1092
			Temperature, °F.		
Maximum	76.3	87.8	87.0	84.2	
Upper Quartile	72.8	76.1	75.7	77.8	
Arithmetic Avg.	-	-	74.4	76.2	
Weighted Avg.	71.9	74.4	-	76.5	
Median	71.3	73.8	73.9	76.1	
Lower Quartile	69.5	71.7	72.9	74.3	
Minimum	64.0	68.0	68.4	71.0	
Number Observed	318	338	307	1082	

*Steering Committee for Roanoke River Studies.
**Data adjusted assuming single-wheel operation for flows less than 2,500 cfs.
***Extreme value was due to minimum flows following a density underflow resulting from a large release from John H. Kerr Dam requested by survey personnel.

In 1960 the North Carolina State Stream Sanitation Committee and VEPCO made 17 sets of observations at half-hour intervals in the tailrace of Kerr Dam below one of the operating turbines. At the same time composite samples were collected for long-term BOD tests. These data are summarized in Table XVI.

Table XVI

Dissolved Oxygen and BOD Observations in the John H. Kerr Dam Tailrace, 1960*

Date	Day	Maximum Discharge cfs	Dissolved Oxygen mg/l			Temperature °F.			20°C. BOD		
			Max.	Avg.	Min.	Max.	Avg.	Min.	5-Day	30-Day	k 1/Day
6-15	Wed	22,200	5.3	4.8	4.3	66	64	63	1.1	3.2	0.03
6-30	Thu	22,200	4.2	3.6	2.8	69	67	65	1.1	3.0	0.03
7-8	Fri	16,500	3.8	2.8	2.2	67	66	64	1.1	2.9	0.07
7-12	Tue	23,500	2.9	2.1	1.6	68	67	64	1.1	3.4	0.07
7-18	Mon	26,100	2.4	1.8	1.4	70	68	67	1.1	3.0	0.07
7-27	Wed	12,300	3.7	2.6	1.7	70	69	65	1.4	3.2	0.07
8-4	Thu	26,700	3.6	2.4	1.9	73	72	68	1.4	4.4	0.07
8-12	Fri	17,800	3.4	1.9	1.1	73	71	70	0.9	3.0	0.10
8-16	Tue	16,100	2.5	1.7	1.0	73	72	69	0.9	4.0	0.10
8-22	Mon	22,300	3.5	2.4	1.8	76	74	71	1.2	4.8	-
8-31	Wed	21,700	3.8	2.9	2.2	76	75	73	1.0	4.6	0.05
9-8	Thu	20,500	3.1	2.2	1.3	77	76	73	1.0	4.1	0.05
9-16	Fri	22,900	5.3	4.7	4.2	77	76	74	1.0	4.0	0.05
9-20	Tue	17,400	5.2	4.3	2.1	76	76	74	1.0	4.3	0.05
9-26	Mon	17,100	4.7	3.8	3.0	73.5	73	71.5	0.6	1.4	0.04
10-4	Tue	19,000	6.3	5.8	5.2	74.5	74	72.5	0.7	2.1	0.04
10-12	Wed	14,500	6.9	6.4	5.4	71	70	68	-	-	-

*North Carolina State Stream Sanitation Committee and Virginia Electric and Power Company.

These data show that the lowest tailrace dissolved oxygen values generally occurred early in the morning when only the house turbine was in operation or else just after peaking operation began and before drawdown of surface waters might be expected to develop. Although the mean elevation of the house turbine intakes is higher than that of the main turbine intakes, and the discharge is almost negligible (hence allowing a greater time for surface aeration in the tailrace), the dissolved oxygen content is lower than later in the day under peaking flows. The data indicate that the D.O. discharged from Kerr Dam is higher than indicated by the scroll case observations and that, while the tailrace dissolved oxygen observations are subject to some variation, they may be expected to increase gradually during a normal peaking day, and be lowest at night or on weekends under minimum flow conditions.

VEPCO and Corps of Engineers samples at Kerr Dam were collected during peaking flows and have been considered to represent the dissolved oxygen content of the mass of the water discharged. Observations by VEPCO since 1954, the Steering Committee for Roanoke River Studies in 1957, and the North Carolina State Stream Sanitation Committee in 1960 show that the dissolved oxygen concentration in the water passing through both the scroll case and tailrace are subject to substantial variation. The 1954 and 1957 data tend to show increased D.O. with increased flow as was found by the Steering Committee at Roanoke Rapids Dam, although this was not always the case. The 1960 D.O. observations in the tailrace of Kerr Dam by the North Carolina State Stream Sanitation Committee showed an increase in D.O. with increased flow in about half the series of observations.

Dissolved oxygen samples collected in the river between the Kerr Dam and Roanoke Rapids since 1954 by VEPCO and the Corps of Engineers are summarized in Table XVII.

Observations in 1957 with graphical estimation of missing data (such estimates could be reasonably made for 7 days) indicated that the weighted dissolved oxygen passing Eaton's Ferry was only 0.1 mg/l lower than the estimated D.O. at 10 a.m., the usual time of observation. For the number of observations available, this is not a significant difference. The weighted D.O. for these same days was 0.1 mg/l higher than the estimated D.O. based on graphical extension of the available Corps of Engineers and VEPCO data at Eaton's Ferry reasonably represent the weighted mean dissolved oxygen passing that point. Since all observations were taken during weekday flows, the observed dissolved oxygen values would be below those obtained on minimum flow days on weekends. However, since the volume of flow on such days is estimated to be only 7 percent of the flow on power producing days (data from July, August, and September 1960), the added D.O. from this source is quite small.

These data show that under present conditions there is considerable absorption of dissolved oxygen between Kerr Dam and Eaton's Ferry under critical dissolved oxygen conditions.

Table XVII

Summary of Dissolved Oxygen Observations in the Roanoke River from John H. Kerr Dam to Clements Island, 1954 to 1961*

	Dissolved Oxygen, mg/l								
	July			August			September		
	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.
Kerr Scroll Case	2.6	1.3	0.1	2.2	0.7	0.0	6.4	3.3	0.0
Kerr Tailrace (Ri. Mil 179)	3.9	2.7	1.4	3.0	2.2	1.2	7.5	4.1	1.4
U. S. Hwy. 1 Brdg. (Ri. Mi. 173)	4.9	4.5	2.0	6.5	3.4	2.4	5.9	4.6	2.7
Virginia-North Carolina State Line (Ri. Mi. 161)									
Eaton's Ferry (Ri. Mi. 152)	7.5	6.2	5.1	5.7	5.0	4.6	8.4	6.6	3.6
Clement's Island (Gaston Site, Ri. Mi. 146)	8.6	7.3	6.5	7.4	6.7	6.1	9.3	6.9	5.7

*Corps of Engineers and VEPCO data.

Data since 1954 have been used to estimate the duration of mean dissolved oxygen levels below specified concentrations as shown in Table XVIII.

Table XVIII

Duration of Mean Dissolved Oxygen Concentrations Below Specified Values, Days

Location	Year	Mean Annual Flow, cfs	Mean July-Oct 15 Flow, cfs	Dissolved Oxygen, mg/l				
				4	3	2	1	0
Kerr Dam Scroll Case (Ri. Mi. 179)	1954	5,462	3,640	118	89	47	25	5
	1955	6,901	8,300	99	80	47	29	15
	1956	4,375	3,770	99	74	49	43	0
	1957	8,446	4,900	121	92	81	64	3
	1958	8,768	5,470	82	72	53	36	15
	1959	6,245	5,240	114	86	73	51	10
	1960	9,773	4,670	90	73	62	54	20
	1961	-	5,405	92	83	74	57	0
	Mean			102	81	61	44	8
Kerr Dam Tailrace (Ri. Mi. 179)	1954			87	64	9	0	0
	1955			85	55	5	0	0
	1956			68	47	17	0	0
	1957			105	85	10	0	0
	1958			55	36	0	0	0
	1959			88	62	38	0	0
	1960			83	66	26	0	0
	1961			82	72	55	0	0
	Mean			82	61	20	0	0
State Line* (Ri. Mi. 161)	1954			-	-	-	-	-
	1955			-	-	-	-	-
	1956			-	-	-	-	-
	1957			40	0	0	0	0
	1958			0	0	0	0	0
	1959			41	0	0	0	0
	1960			46	0	0	0	0
	1961			36	7	0	0	0
	Mean			33	1	0	0	0
Eaton's Ferry	1954			-	-	-	-	-
	1955			-	-	-	-	-
	1956			-	-	-	-	-
	1957			0	0	0	0	0
	1958			0	0	0	0	0
	1959			0	0	0	0	0
	1960			0	0	0	0	0
	1961			13	0	0	0	0
	Mean			3	0	0	0	0

*Based on interpolation between tailrace and Eaton's Ferry observations.

Although the curves from which the duration of low dissolved oxygen conditions was estimated are based on single observations at biweekly intervals, the samples were collected during peaking flows when the greatest portion of the water was discharged. The results show that the Roanoke River from Kerr Dam to as far as Eaton's Ferry is below the present North Carolina State Stream Sanitation Committee classification standard of 4.0 mg/l for considerable periods of time each summer. The following tabulation indicates the number of days the tailrace D.O. during peaking flows may be expected to be below 4.0, 3.0, 2.0, and 1.0 mg/l in 90, 50, and 10 percent of the years:

Dissolved Oxygen mg/l	Number of Days the Dissolved Oxygen will be Below the Indicated Value for the Proportion Years (Percent) Indicated at the Head of the Column.		
	90	50	10
4.0	62	80	102
3.0	40	60	86
2.0	3	18	60
1.0	None	None	None

Based on a similar analyses, the scroll case D.O. may be expected to be below 4.0 mg/l for 84 days, or more, in 90 percent of the years and for 122 days, or more, in 10 percent of the years. The data at the State line and at Eaton's Ferry were felt to be inadequate for such analyses.

The data on the duration of critical dissolved oxygen conditions for the scroll case and tailrace at Kerr Dam have been examined for a temperal trend. These analyses indicate that the problems associated with low D.O. as a result of thermal stratification may be increasing. The duration of scroll case dissolved oxygen levels of 2.0 mg/l and below appears to be gradually increasing, though the duration of values below 4.0 mg/l appears to have remained relatively steady at about 100 days per year. The increase in duration of tailrace dissolved oxygen levels of 4.0 mg/l or below has been much more pronounced. However, several more years of observation will be required to definitely establish these trends. Although the mean annual flow does not appear to have an influence on the duration of low D.O.'s in scroll case or tailrace samples, an increase in the mean summer flow appears to result in an increase in the duration of low D.O. value. A possible reason for this influence would be the lesser drawdown of the power pool during high flow years resulting in the thermocline being maintained at a higher level so that less admixture of surface water is possible.

Increases in mean summer flow resulting from upstream storage would probably not have the adverse effect on dissolved oxygen discharged from Kerr Dam implied by the previous analyses. Prior storage in these impoundments would reduce the first- and second-stage BOD load presently reaching Kerr Reservoir. It is further assumed that all future installations will include as a part of the original construction adequate consideration of intake structures or system operation to minimize the reduction in the dissolved oxygen content of the water discharged. The water stored during the winter period has a lower organic content because of the much greater dilution. The greater storage of this water will tend to dilute the summer flows. A possible adverse effect of upstream storage could be the development of density interflows resulting from lower stream temperatures. These interflows might reduce the amount of surface water reaching the present Kerr turbine intakes by maintaining the hypolimnion at a higher elevation, thereby resulting in less oxygen being added from the surface waters. The net effects of these changes depend on several opposing forces and must be observed before definite conclusions can be reached.

It should be noted that while the dissolved oxygen as measured in the scroll case and in the tailrace at the John H. Kerr Dam was below 4.0 mg/l for substantial periods of time, it was below this value only an average of 3 days per year by the time it reached Eaton's Ferry and in no case was it below 3.0 mg/l at that point. On an average of 33 days per year over the past 5 years the estimated mean dissolved oxygen at the State line has been below the North Carolina classification standard of 4.0 mg/l. On an average of about one day per year it has been below 3.0 mg/l.

Estimates of the increases in dissolved oxygen required in the Kerr Dam tailrace to meet the North Carolina classification standards indicate that:

1. Increases in D.O. during low flows when vacuum breaker operation could be applied will add relatively little to the mean D.O. at the State line since the volume is small and the reaeration of this water--at the low levels at which it flows--is already quite high.

2. Increases required during peaking flows amount to as much as 1.0 to 1.5 mg/l at the beginning of peaking flow on Monday and are as much as 0.7 to 0.9 mg/l during the maximum discharge from 10 a.m. to 2 p.m. However, during this short period, 80 to 90 percent of the daily flow occurs.

Reaeration coefficients based on the 1957 observations by the Special Committee on Roanoke River Studies ranged from 0.19 to 0.51 per day based on the increase from the indicated dissolved oxygen in the tailrace during peaking discharges to the minimum dissolved oxygen content observed at Eaton's Ferry. For observations made on a single day estimated reaeration coefficients ranged from 0.27 to as high as 0.92 per day. For the period of maximum discharge a value of 0.3 per day has been used for peaking flows, but a value of 0.6 per day is estimated for a streamflow of 1,000 cfs.

It has been noted that the dissolved oxygen values observed by VEPCO at Eaton's Ferry approximate the weighted mean value of dissolved oxygen values observed in connection with the Roanoke Rapids Study survey. This, however, masks the adverse effects of periods of lower D.O. resulting from the high instantaneous discharges during peaking flows. Both the 1957 observations and the dissolved oxygen recorder observations by the North Carolina State Stream Sanitation Committee in the summer of 1961 show that the dissolved oxygen levels are subject to wide variation. While the mean D.O. content was estimated to be below 4.0 mg/l for 13 days at Eaton's Ferry (including weekend days within the period), minimum values observed in 1961 were as low as 2.5 mg/l and the dissolved oxygen was below 4.0 mg/l for an estimated 230 hours, or almost 10 days. Based on the D.O. recorder data it is estimated that the D.O. was below 4.0 mg/l for parts of 22 days. The limited dissolved oxygen data available at John H. Kerr Dam for that period make it difficult to estimate the corresponding concentrations of dissolved oxygen in the tailrace, although consideration of the high flows associated with the lowest dissolved oxygen observations at Eaton's Ferry indicates that reduced reaeration below the tailrace was probably a more important factor than unusually low dissolved oxygen in the discharge from Kerr Dam.

The VEPCO and Corps of Engineers data indicate that the dissolved oxygen content of the water reaching Clement's Island, the head of Roanoke Rapids Reservoir, is about 80 percent of saturation. While the recovery at Clement's Island is not as great as was previously found at North Carolina Highway 48 bridge, it is substantial and the reaeration capacity of the natural channel of the Roanoke River above Roanoke Rapids Reservoir has been an important factor in correcting the low dissolved oxygen levels resulting from discharges from Kerr Dam.

At the upper end of Roanoke Rapids Reservoir, the variation in temperature and velocity of the inflowing water results in alternate recharge of surface and intermediate depth waters. The warmer water which reaches the reservoir passes into the surface layers. Just as it has been warmed by its greater relative exposure to the air and sun, it is also the most oxygenated water. The D.O. varies over a wide range as indicated by the results at

Eaton's Ferry and Clement's Island in 1957 and the D.O. recorder results at Eaton's Ferry in 1961. The results at Gaston site are parallel to the observations at Eaton's Ferry for the period that surface flow is occurring, but diverge from it in each case when the temperature and velocity of the flowing water decrease sufficiently that an underflow can develop. Observations at Clement's Island (river mile 146) therefore represent surface water from Roanoke Rapids Reservoir when density underflow is occurring. The D. O. measured thereafter is higher than the inflow because of (1) its higher original value, (2) mixing with the higher D.O. surface water of the reservoir, (3) reaeration resulting from physical transfer, and (4) reoxygenation resulting from photosynthesis.

The results imply a higher D.O. at Clement's Island than should have been expected based on the D.O. at Eaton's Ferry and the flow time involved. The implied high reaeration rates do not seem reasonable. These conclusions are in agreement with the discussion of density underflow presented in Special Report No. 1,[48] pages 33 through 40, and the relationship developed in that report between Kerr Dam discharge factor, Roanoke Rapids Dam discharge, and the dissolved oxygen at North Carolina Highway 48 bridge. They are not, however, in accord with the statement in Special Report No. 1 (page 5) that the increase in dissolved oxygen between Eaton's Ferry and Gaston site are due to increased rate of reaeration. This overestimation of the dissolved oxygen content of the inflow to Roanoke Rapids Reservoir would account for a part of the reduction observed between Clement's Island and Roanoke Rapids Dam tailrace.

Conclusions of the present review of the data are in general agreement with the conclusions stated in Special Report No. 1 by the Steering Committee for Roanoke River Studies and are summarized as follows:

"The minimum values, both D.O. and temperature, correspond to the high flows. This is a result of (1) the more rapid transit from Kerr Dam to Eaton's Ferry at high flows allowing a shorter time of exposure for reaeration, (2) the increased depth of the flowing water at high flows, and (3) the decreased surface area per unit of volume of the water. These factors outweigh the effect of increased turbulence at high flows which tend to increase reaeration.

"In summary, the water traveling from Kerr Dam to Eaton's Ferry is slightly improved in average D.O. quality and normally increased in temperature, but with occasional cooling when unseasonably low atmospheric temperatures occur. Low flows are reasonably well aerated, but such flows represent a relatively small portion of the total volume of water moving downstream."

The Roanoke Rapids Dam was closed on June 25, 1955. The first turbine was placed in operation on July 18, 1955. Dissolved oxygen observations reported by VEPCO and the Corps of Engineers at the Roanoke Rapids Dam tailrace and at North Carolina Highway 48 bridge prior to July 18, 1955, were 8.0 mg/l, or above, as a result of reaeration below Kerr Dam. However, immediately following the initiation of power production by VEPCO, observations by the Halifax Paper Company[33] in the tailrace immediately below the dam indicated that the dissolved oxygen content fell to as low as 3.2 mg/l. These low values were obtained until the low dissolved oxygen water resulting from the combination of the reduced reaeration and the relatively long period of storage during the filling of the reservoir was exhausted by the high flows occasioned by Hurricane Diane (August 17, 1955). High flows prevailed from August 17 to August 24; before and after this period of high flow, normal September flows prevailed. Following Hurricane Diane the tailrace dissolved oxygen level was almost 7.0 mg/l and gradually fell to 5.4 mg/l by mid-September. Thereafter, the dissolved oxygen gradually increased as the dissolved oxygen content of water discharged from John H. Kerr Reservoir improved.

Dissolved oxygen levels were observed in 1956 by VEPCO and the North Carolina State Stream Sanitation Committee. The VEPCO observations made during the peaking flows in the tailrace and at the North Carolina Highway 48 bridge indicated a minimum value of 4.7 mg/l. The North Carolina observations were made during minimum flow periods of the days sampled during late August and early September. The observations represent minimum dissolved oxygen conditions on the basis of subsequent observations that low flows are accompanied by low dissolved oxygen conditions. The minimum observation was 3.2 mg/l and the average of the 21 observations was 5.4 mg/l. Only the one value cited was below 4.0 mg/l.

The minimum dissolved oxygen observation of 3.2 mg/l was in contravention of the stream classification standards, subsequently established, so that no waste could have been discharged to the tailrace. However, observations made by the North Carolina State Stream Sanitation Committee indicate that reaeration between North Carolina Highway 48 bridge and Weldon exceeded the deoxygenation caused by waste discharges. Thus some waste could be added in the Roanoke Rapids-Weldon area without again lowering the dissolved oxygen below 4.0 mg/l. At the observed flow of 1,330 cfs it is estimated that a waste load in the order of 25,000 pounds of BOD per day could have been discharged.

Dissolved oxygen conditions were improved by the installation of the submerged weir in Roanoke Rapids Reservoir by VEPCO in early 1957. The discussions and negotiations leading to the construction of the submerged weir are contained in minutes of the Steering Committee for Roanoke River Studies. Briefly, a weir was proposed for inclusion in the Gaston Project. In the absence of experience with such an installation, the North Carolina State Stream Sanitation Committee could not agree to accept the project. The Roanoke Rapids weir was proposed, installed, and investigated as a prototype for the Gaston Project and to improve the quality of water discharged from Roanoke Rapids Dam itself. The study was to be the basis for determining whether a submerged weir would assure adequate water quality below Roanoke Rapids Dam during the summer period acceptable to the North Carolina State Stream Sanitation Committee and the Halifax Paper Company. The conclusions of the study and the comments of the special consultants are summarized in the section, "Summaries of Previous Studies." A summary of the observations made in 1953, 1956, and 1957 at North Carolina Highway 48 bridge presented in Special Report No. 1 is reproduced in Table XIX.

The routine VEPCO stream data collected since 1955 below Roanoke Rapids Dam relate to peaking flows. Since adverse dissolved oxygen conditions occur under minimum flow conditions these observations have not been extensively reviewed. The results of the 1957 Survey by the Steering Committee and VEPCO have been the primary basis for the analysis of the waste assimilative capacity below Roanoke Rapids since construction of the Roanoke Rapids Dam.

Below Roanoke Rapids

The development of reservoirs on the Roanoke River has been accompanied by economic development of the lower Roanoke River. The growth of municipal and industrial waste loads tributary to the stream has been an important factor accompanying the development of the area and has been a factor in the dissolved oxygen changes observed and in the adjustments in minimum flow for the river below Roanoke Rapids. Since the paper industries discharge the largest quantities of wastes in the lower Roanoke River area their wastes are of concern in discussing the changes in dissolved oxygen observed.

Data secured by the North Carolina State Stream Sanitation Committee in 1955 indicated that the waste loads at Halifax Paper Company had been reduced to 50,300 pounds of BOD per day, despite a 21 percent increase in pulp production.[39] The improvements made in plant equipment and operation

Table XIX

Roanoke River at North Carolina Highway 48 Bridge
Comparison of River Water Quality, 1953, 1956, and 1957[48]

	Temperature, °F.			Dissolved Oxygen, mg/l				5-Day, 20°C. BOD, mg/l		
	1953	1956	1957	1953	1956	1957 Obs'd	1957 Adj'd*	1953	1956	1957
Maximum	84.2	77.0	84.2	9.0	6.5	8.6	8.0	2.6	2.0	2.9
Upper Quartile	78.8	75.2	77.8	8.2	6.0	6.9	6.7	1.0	1.3	-
Median	78.8	73.4	76.1	7.9	5.6	6.3	6.1	0.6	1.0	-
Arithmetic Avg.	77.9	73.4	76.2	7.9	5.4	6.3	6.0	0.8	1.0	1.8
Weighted Avg.	77.7	72.9	76.5	7.8	5.9	6.3	6.2	1.0	1.1	-
Lower Quartile	77.0	71.6	74.3	7.5	4.7	5.7	5.5	0.5	0.7	-
Minimum	73.4	71.6	71.0	7.0	3.2	2.7	2.7	0.3	0.2	0.6
Number Observed	45	21	1082	47	21	1092	1092	51	14	4
Sampling Period	(1)	(2)	(3)	(1)	(2)	(3)	(3)	(4)	(5)	(6)

*Data adjusted by assuming single-wheel operation for all flows less than 2,500 cfs.

(1) August 9 to August 31
(2) August 28 to September 21
(3) July 15 to September 13
(4) August 9 to October 13
(5) August 28 to September 20
(6) August 2 to August 9

also substantially reduced the toxic and slime producing characteristics of the waste discharge.*

Additional data secured by the North Carolina State Stream Sanitation Committee in August 1956 indicated that both the waste load and production had increased slightly and equaled 57,400 pounds of BOD per day.[64]

During 1955 the North Carolina Pulp Company plant was expanded to a capacity of 1,300 tons of pulp per day.[64] Information supplied by the North Carolina Division of Weyerhaeuser Company (the present owner of the former North Carolina Pulp Company facilities) indicated that production in 1960 amounted to 1,060 tons of pulp per day.** The North Carolina State Stream Sanitation Committee has indicated that the plant is now discharging less than the amount of BOD allowed under the pollution abatement plan.

Data supplied by the Halifax Paper Company indicated that the mean waste discharge for September 1 through September 20, 1961, amounted to 41,700 pounds of BOD per day.

The untreated waste discharge from a modern unbleached kraft mill amounts to approximately 50 pounds of BOD per ton of paper produced.[75] New plants being placed in operation on the West Coast have reduced waste discharges per unit of production well below this figure. On the basis that some of the waste is due to loss of pulp in paper production, the present Halifax Paper Company waste discharge of 60 pounds of BOD per ton of pulp is approaching the value considered reasonable for unbleached kraft mills.

At the average dissolved oxygen level observed in the tailrace of Roanoke Rapids in 1956 after the dam was in operation but before the submerged weir was installed, the waste assimilative capacity at a minimum flow of 1,000 cfs on weekends was approximately 40,000 pounds of BOD per day, while

*Minutes of the Steering Committee for Roanoke Rapids Studies.

**Private communication through North Carolina State Stream Sanitation Committee.

at 2,000 cfs the capacity was 80,000 pounds per day. Although the weekend minimum flows have been eliminated by the interim agreements between the North Carolina State Stream Sanitation Committee and VEPCO the assimilative capacity available at 2,000 cfs was below that which was available at comparable flows in 1953 following completion of the John H. Kerr Dam.

Based on the average dissolved oxygen content of the tailrace after installation of the submerged weir, as found in the Steering Committee-VEPCO Survey,[48] the assimilative capacity at minimum weekend flows of 1,000 cfs would have been 47,000 pounds of BOD per day. Under minimum weekday flows the assimilative capacity was increased to 93,000 pounds per day. Thus, the weir resulted in a 16-percent increase in minimum assimilative capacity.

The capacity indicated in the previous paragraph for 2,000 cfs flows is higher than the critical instantaneous capacity which could occur under present operating practices. Whenever flow is below 2,500 cfs and the dissolved oxygen level is below 5.0 mg/l vacuum breaker operation is instituted to increase the dissolved oxygen level one (1) mg/l or more. The lowest assimilative capacity thus prevails when flow is just 2,500 cfs and the dissolved oxygen is at the classification value, or flow is reduced to 2,000 cfs while the dissolved oxygen is just 5.0 mg/l. (The minimum weekend flows are not considered.) The lesser of the assimilative values for the two above cases would be approximately 65,000 pounds of BOD per day.

The waste assimilative capacity of the Roanoke River below Roanoke Rapids was presented in Table 20 of Special Report No. 1 for selected times when the discharge rate exceeded 2,500 cfs and the observed dissolved oxygen level was below 5.0 mg/l. In only 3 of 26 observations cited was the assimilative capacity after installation of the submerged weir less than the minimum value of 109,000 pounds of BOD per day observed prior to construction of Roanoke Rapids Dam.

Data obtained from VEPCO indicate that in 1961 the dissolved oxygen discharged from Roanoke Rapids Reservoir tailrace was below 4.0 mg/l for a total of only about 15 hours. As a result of these low initial D.O. and associated waste discharges, the dissolved oxygen at Scotland Neck fell below 4.0 to a minimum of 3.8 mg/l for only 6 hours. The minimum assimilative capacity below Roanoke Rapids under conditions of the submerged weir and vacuum breaker operation is less than was available under post-Kerr Dam conditions but more than would have been available at the design flow under natural conditions. Further, minimum daily values substantially below the design flow, though of very infrequent occurrence, have been eliminated.

The adjustments of minimum weekday and weekend flows presently in effect have been described in the section on water resources development. They are essentially the same as will be in effect after the Gaston Project goes into operation. Together with the mixing resulting from the wide variations in flow and translatory wave action and present operating practice as regards vacuum breaker operation, the minimum assimilative capacity below Roanoke Rapids will be assured to be at least 76,000 pounds per day. Peaking flows following minimum weekday flows provide more than enough capacity to assure the daily average of 109,000 pounds of BOD per day which has been used as the basis for the pollution abatement plan established by the North Carolina Stream Sanitation Committee.

<u>Summary</u>

Thermal stratification restricted mixing of water between the various levels of Kerr Reservoir and, together with degradation of organic materials, resulted in complete depletion of dissolved oxygen at the bottom of John H. Kerr Reservoir in 6 of the 8 years of observation. Discharge of water from the lower levels of the reservoir resulted in minimum dissolved oxygen concentrations of 1.2 mg/l in the tailrace during peaking flows and as low as 0.3 mg/l during minimum flows.

Reaeration in the Roanoke River improved the D.O. considerably but at peaking flows was not sufficient to ensure a D.O. above 4.0 mg/l at Eaton's Ferry, 9 miles below the Virginia-North Carolina State line, at all times.

Immediately after installation of Roanoke Rapids Dam, the dissolved oxygen content of peaking discharges fell to as low as 3.2 mg/l as a result of density underflow of incompletely reaerated peaking discharges from John H. Kerr Dam. With installation of a submerged weir the D.O. was raised substantially but not sufficiently at minimum flows to prevent a reduction in waste assimilative capacity below Roanoke Rapids as compared with that available before Roanoke Rapids Dam was completed. Modification of minimum flow schedules by negotiations between the State Stream Sanitation Committee and VEPCO with the approval of the Federal Power Commission resulted in still further improvement in assimilative capacity on weekends below the Roanoke Rapids area.

The submerged weir in Roanoke Rapids Reservoir, together with the modified minimum flow schedule and current operating practices as regards vacuum breaker operation, assure a minimum weekend assimilative capacity of at least 76,000 pounds of BOD per day and peaking flows, following minimum weekday flows, assure a daily average capacity of 109,000 pounds per day.

PREDICTED POST-GASTON CONDITIONS

The initial purposes of the Steering Committee for Roanoke River Studies were to establish the flow releases from John H. Kerr Dam necessary to assure effective striped bass spawning and to assure reasonable dissolved oxygen conditions during the summer season below the Roanoke Rapids area.* With the construction of Roanoke Rapids Dam and application of the Virginia Electric and Power Company for a Federal Power Commission license for construction of Gaston Dam between John H. Kerr Dam and Roanoke Rapids Reservoir, primary interest turned to the determination of a basis upon which the State Stream Sanitation Committee and the State Wildlife Resources Commission could be assured that reasonable water quality would be maintained in the lower Roanoke River.

Above Roanoke Rapids

To correct the reduced D.O. resulting from construction of Roanoke Rapids Dam, the Virginia Electric and Power Company proposed installation of a submerged weir in Gaston Reservoir extending to within 30 feet of the maximum power pool elevation.[31] Consultants for VEPCO estimated that such an installation would assure that the dissolved oxygen content of the discharges from Gaston Dam would be at least 3.5 mg/l, after an initial 2-year period which would allow for stabilization of organic material inundated by the new reservoir, and at least 4.0 mg/l below Roanoke Rapids Dam. However, during the first 2 years of operation the minimum D.O. might be 0.5 mg/l lower than the above. The expected minimum dissolved oxygen concentration was at (or below) the value required under the proposed stream classification standards resulting in a reduction of the assimilative capacity of the lower river to approximately 50,000 pounds of BOD per day at the minimum weekday flow of 2,000 cfs. Reaeration in the reach between North Carolina Highway 48 bridge and Weldon was expected to be sufficient to supply the immediate demands of the waste.

The proposed installation of a submerged weir in Gaston Reservoir was considered by the Committee, but the reduction of the dissolved oxygen content of the discharges from Roanoke Rapids Dam to the extent predicted was unacceptable. It was further felt that a guarantee of a minimum assimilative capacity should be included in the Gaston Project license or that the effectiveness of the submerged weir to accomplish the same results should be conclusively proven. The installation of the submerged weir in Roanoke

*W. King, Fish and Water Resources Problems - Roanoke River, North Carolina. Report of Steering Committee, May 24, 1955, Raleigh (June 7, 1955).

Rapids Reservoir by VEPCO was to serve as a full-scale prototype for use in studying the benefits of such an installation for the proposed Gaston Reservoir, as well as to provide an immediate improvement in dissolved oxygen concentrations below Roanoke Rapids Dam. The results of the studies of the effectiveness of the submerged weir in Roanoke Rapids Reservoir were presented in Special Report No. 1, Roanoke River Studies.[48] The report presumes that the quality of water discharged from Kerr Reservoir would remain the same as had been observed in 1957 (after the initial stabilization period), and presents estimates of the dissolved oxygen levels to be expected in the Gaston Project discharge.

The presentation in Special Report No. 1 of the effectiveness of the submerged weir in Roanoke Rapids Reservoir to act as a high-level intake was prepared largely by Dr. D. W. Pritchard, director of the Chesapeake Bay Institute of the Johns Hopkins University, Baltimore, Maryland.[50,51] Since the effects of reaeration and photosynthesis extend over a relatively long period as the water passes through Gaston and Roanoke Rapids Reservoirs, average conditions under moderately high flows were considered in estimating the dissolved oxygen conditions. The estimates made in the report for mean daily flows of 5,000 cfs for July and August and 6,000 cfs for September were felt to provide "conservatively low estimates of the dissolved oxygen concentrations discharged from Gaston and subsequently from Roanoke Rapids." Most years will have lower flows providing longer exposure to the forces that supply oxygen to the surface waters which will be discharged from Gaston Dam. "On the infrequent years of higher flows, downstream assimilative capacity will be kept high as a result of the high dilution afforded by such high flows." However, even though total assimilative capacity would be increased, the capacity under minimum flow conditions could be reduced. It was concluded[48] that the water discharged from Gaston Dam with a submerged weir located 15 feet below the full power-pool elevation, would have a dissolved oxygen content of 7.5 mg/l if the water passed through the epilimnion of Gaston Reservoir and 6.4 mg/l if the water passed first into the hypolimnion. The minimum dissolved oxygen content of Roanoke Rapids Dam discharges should be at least as high as the 6.4 mg/l predicted for Gaston (in the conclusions this was rounded to "at least 6 ppm").

Since the water quality above Roanoke Rapids waste sources has such an important bearing on the assimilative capacity of the lower Roanoke River and since Special Report No. 1 was rather long and involved, the Steering Committee for Roanoke River Studies asked for comments from three consultants acquainted with reservoir quality problems. Comments on the estimates of the quality of water to be discharged from the Gaston and Roanoke Rapids Reservoirs were prepared by F. W. Kittrell of the U. S. Public Health Service,[54]

M. A. Churchill of the Tennessee Valley Authority,[52] and T. M. Riddick, consulting engineer and chemist, New York City.[53] Their comments were condensed and presented together with a short description of the Roanoke River problems and the recommendations of the Committee in a summary report.[56] The project description, summaries of the comments of the consultants, and Committee recommendations are presented in the section, "Summaries of Previous Studies."

Each of the three consultants reviewing Special Report No. 1 cautioned that there might be unusual conditions which could result in occasional low D.O.'s. The considered opinions of the reviewers were that the submerged weirs installed or proposed should generally result in the "discharge of water having a minimum dissolved oxygen concentration in the range of 5 to 6 parts per million" (Churchill),[54] should "not make conditions worse than they presently are and, in fact, holds promise of improvement in the present situation most of the time" (Kittrell),[54] and "any prediction of this type ... is extremely difficult and speculative" (Riddick).[53]

On the basis of the predictions of water quality from Roanoke Rapids Dam, VEPCO accepted license provisions providing for the assurance of sufficient dissolved oxygen in Roanoke Rapids Dam discharges to provide a daily assimilative capacity of 109,000 pounds of BOD per day as required by the State Stream Sanitation Committee and the Wildlife Resources Commission.

Since it is the initial source of low D.O. water there has been continual interest in the improvement of the dissolved oxygen content of discharges from John H. Kerr Dam as a means of improving conditions below Roanoke Rapids Dam. Each of the three consultants reviewing Special Report No. 1 expressed the opinion that improvement in the dissolved oxygen content of water discharged from Kerr Dam should be given serious consideration. The disparity of opinion on the effectiveness of the Gaston and Roanoke Rapids weirs indicates that all difficulties with occasional low D.O. below Roanoke Rapids probably will not be eliminated. Correction of low D.O.'s below John H. Kerr Dam may help minimize occurrences of low D.O. still further.

Factors affecting the dissolved oxygen content of discharges from Roanoke Rapids Dam following installation of the submerged weir in Roanoke Rapids Reservoir were discussed in Special Report No. 1.[48] For the summer period the D.O. was found to increase with increasing discharges from Roanoke Rapids Dam, but to decrease with increasing discharges from Kerr Dam. However, the dissolved oxygen content of the discharges from Kerr Dam was not considered as a variable. Since increased D.O. in the discharges from Kerr Dam would decrease the addition of oxygen by reaeration, the net effect would be less than the increase observed in the Kerr Dam tailrace. Based on the VEPCO and Corps of Engineers observations since completion of Roanoke Rapids submerged weir, it is estimated that an increase of 1.0 mg/l in minimum D.O. at Kerr Dam results in an increase of approximately 0.2 mg/l in the peaking flows of Roanoke Rapids Dam. However, density underflow in Roanoke Rapids Reservoir still results in low dissolved oxygen content during minimum flow periods requiring that VEPCO institute measures for meeting the license requirements. It is estimated that improvement of the dissolved oxygen content of peaking flows to a minimum of 4.0 mg/l at Kerr Dam will result in an average improvement in the D.O. of Roanoke Rapids Dam discharges during peaking flows of 0.1, 0.4, and 0.3 mg/l in the months of July, August, and September, respectively. A corresponding increase during minimum flows seems reasonable but has not been demonstrated. With completion of Gaston Dam conditions affecting dissolved oxygen changes between Kerr Dam and Roanoke Rapids will be completely altered. It is expected that the submerged weir in Gaston Reservoir will improve the dissolved oxygen concentration of the water entering Roanoke Rapids Reservoir and will alter the flow through pattern in Roanoke Rapids Reservoir. Under these conditions improvement in the dissolved oxygen content of Kerr Dam discharges is expected to have less influence on the D.O. content of Roanoke Rapids Dam discharges than in the past. The net effect is expected to be negligible, but should be confirmed by field observation after completion of Gaston Dam and completion of necessary facilities to improve the dissolved oxygen conditions below Kerr Dam.

Below Roanoke Rapids

The assimilative capacity available below Roanoke Rapids at the minimum dissolved oxygen level of 6.0 mg/l predicted by the Steering Committee for Roanoke River Studies in Special Report No. 1 will be 90,000 pounds of BOD per day at a minimum flow of 2,000 cfs. The dissolved oxygen and flow requirements of the Federal Power Commission license for the combined Roanoke Rapids-Gaston Project, License 2009, as amended, indicate that a minimum assimilative capacity of 109,000 pounds of BOD per day will be provided at Roanoke Rapids. This value exceeds the estimated capacity available at the design flow applied to natural streams in North Carolina by the State Stream Sanitation Committee, and also exceeds the capacity at minimum controlled flows which existed in 1953 after the construction of John H. Kerr Dam (however, reduced weekend flows have been eliminated since 1956).

The Comprehensive Pollution Abatement Plan for the Roanoke River Basin[44] developed by the North Carolina State Stream Sanitation Committee provided for the allocation of waste assimilative capacity in the Roanoke Rapids-Weldon area of 109,000 pounds of BOD per day at a flow rate of 2,000 cfs, and allowed for the discharge of greater quantities of waste when controlled in proportion to flow. The graph of waste assimilative capacity for given discharges and initial dissolved oxygen levels, presented by the Steering Committee for Roanoke River Studies in the Summary Report covering Special Report No. 1, Roanoke River Studies,[56] was included as Figure 3 in this report.

Since improvement of the dissolved oxygen content of John H. Kerr Dam is expected to make little change in the D.O. of Roanoke Rapids discharges, little improvement in waste assimilative capacity is expected. Considering the variation in estimates of D.O. in Roanoke Rapids Dam discharges, the change in assimilative capacity can be ascertained only by field observation and should not be estimated at this time.

Summary

Water quality conditions below John H. Kerr Dam will be drastically altered by Gaston Reservoir. The Steering Committee for Roanoke River Studies estimated that the minimum dissolved oxygen content of discharges from Gaston-Roanoke Rapids Dams would be at least 6.0 mg/l based on the present dissolved oxygen content of discharges from John H. Kerr Dam. Considering the size of the Gaston Reservoir and the existence of submerged weirs in both Gaston and Roanoke Rapids Reservoirs, improvement of the D.O. in the discharge from Kerr Dam is not expected to have a significant effect on the dissolved oxygen content of discharges from Roanoke Rapids Dam.

The inclusion of provisions for a minimum discharge of dissolved oxygen as well as minimum flows in the license for the joint Roanoke Rapids and Gaston Project should assure a minimum daily waste assimilative capacity below Roanoke Rapids equivalent to that available on weekdays after completion of John H. Kerr Dam. It is not expected that improving the dissolved oxygen content of discharges from John H. Kerr Dam will affect the assured assimilative capacity of the lower Roanoke River.

SECTION 7

THE NEED FOR AND VALUE OF WATER QUALITY IMPROVEMENT

Interest in water quality management aspects of water resources development projects has increased considerably since the Public Health Service evaluation of the John H. Kerr Project in 1947. Water quality control is now recognized as a joint Federal, State, and local responsibility and water resources agencies are generally adopting the policy that water quality must be improved and maintained at as high a level as is reasonably possible to protect the water for all legitimate uses and to provide for future municipal and industrial growth.

The minimum flow and dissolved oxygen requirements included in the Federal Power Commission License 2009, as amended to include the Gaston Project, provide for sufficient waste assimilative capacity below Roanoke Rapids Dam for the residual wastes from present and anticipated municipal and industrial wastes after adequate treatment or other means of controlling wastes at the source. Therefore, additional flow at Federal expense for water quality control below Roanoke Rapids is not warranted at this time.

Minimum flows from Kerr Dam have been reduced to about 100 cfs since completion of Roanoke Rapids Dam. However, there are no municipal or industrial water uses between Kerr Dam and Roanoke Rapids Dam; therefore, no increases in minimum flow releases are needed at this time. There is a definite need, however, for improving the quality of discharges from Kerr Dam.

At the time John H. Kerr Dam was constructed, primary consideration was given to minimum flows necessary to assimilate municipal and industrial wastes reaching the Roanoke River at Roanoke Rapids, North Carolina. Minimum flow requirements stated in Public Health Service reports were based on the assimilation of wastes discharged at Roanoke Rapids. Requirements established in Fish and Wildlife Service reports for maintenance of fish, and especially for the spawning of the striped bass, were also based on conditions in the vicinity of Roanoke Rapids. While the possibility of the discharge of water of poor quality was considered, relatively little knowledge was available on the degree of depletion which might be expected in the discharge and it was further thought that reaeration in the tailrace and over a short distance downstream would quickly return the streamflow to near saturation. Since that time, however, considerable information has been accumulated, much of it on the Roanoke River, to substantiate the detrimental effects which can result from the combination of thermal stratification in reservoirs and low-level power intakes. Because of the reduction in dissolved oxygen concentrations in the hypolimnion associated with the natural phenomenon of thermal stratification, low-level discharges from Kerr Dam have resulted in significant reductions in dissolved oxygen concentrations in the Roanoke River below the dam. Dissolved oxygen concentrations of as low as 1.2 mg/l were observed in the tailrace in routine field observations by the Corps of Engineers and the Virginia Electric and Power Company between 1954 and 1961. Concentrations as low as 1.0 mg/l were observed in the tailrace in 1960 in special joint studies by the North Carolina Stream Sanitation Committee and the Virginia Electric and Power Company. One observation of 0.3 mg/l in the tailrace was reported in the studies conducted by the Steering Committee for Roanoke River Studies. In the years for which data are available the dissolved oxygen concentration was less than the minimum objective of 4.0 mg/l for an average of 33 days per year at the North Carolina State line and 82 days per year in the tailrace of Kerr Dam. Information on the seriousness and duration of such low dissolved oxygen conditions below Kerr Dam and at other locations has been a factor in the extension of concern for adequate dissolved oxygen levels to the entire length of the river rather than only to reaches affected by organic waste discharges alone. In the section entitled "Water Quality Objectives," a minimum dissolved oxygen content of 4.0 mg/l was established as a reasonable objective in the lower Roanoke River below Kerr Dam. This objective must be maintained to assure a good environment for fish, other aquatic life, and wildlife.

Thermal stratification in Kerr Reservoir and low-level power intakes in Kerr Dam have also resulted in measurable increases in iron and manganese concentrations in the stream below the dam. The iron and manganese concentrations were further increased by installation of Roanoke Rapids Dam, and immediately after completion of the dam (Roanoke Rapids) it became necessary for the Roanoke Rapids Sanitary District to change the location of their water supply intake. The intake was raised to near the surface of Roanoke Rapids Reservoir and with this change the Sanitary District has been able to produce satisfactory water.

Any installation which makes use of public waters should provide facilities or conduct its operations either alone or in combination with other water uses so that the resulting water quality below the installation meets reasonable quality objectives. Although no addition of organic waste is involved in the discharge of water low in dissolved oxygen content associated with thermal stratification and withdrawal from the lower levels of reservoirs, John H. Kerr Dam can be considered as the equivalent of a source of pollution from the standpoint of altering water quality in the Roanoke River below the reservoir. A definite need therefore exists for modification of Kerr Dam and its operations to the extent that the dissolved oxygen in the tailrace at least meets the minimum objective of 4.0 mg/l.

In evaluating the improvement of the quality of discharges from Kerr Dam it must be recognized that installation of the Dam resulted in a measurable degradation of water quality in the Roanoke River below the dam. While most water uses result in some quality degradation, it is important that such degradation does not interfere with other legitimate downstream uses. The minimum water quality objectives previously discussed are set forth to protect the stream for best usage and to provide for future municipal and industrial growth.

Maintaining water quality at satisfactory levels is the responsibility of all water users and the cost of any necessary treatment or other water quality control measures is considered to be part of the cost of water use. In areas where water quality and uses dictate, municipalities and industries must treat their wastes prior to discharge to assure adequate water quality for downstream uses. In the same sense, the cost of facilities and/or operation expense at John H. Kerr Dam necessary to meet the quality objective for the Roanoke River is a part of the cost of water use for power production.

Field observations conducted by the Special Committee for Roanoke River Studies indicated that the passage of water downstream with relatively little reaeration or warming resulting from peaking operation at John H. Kerr Dam resulted in density underflow and contributed to occasional problems even after installation of a submerged weir at Roanoke Rapids Dam. Maintaining water quality at or above the recommended minimum dissolved oxygen objective will reduce the possibility that downstream users will be adversely affected in their efforts to meet water quality control obligations.

Reservoir development in the lower Roanoke River is expected to play an important part in providing for increasing recreational demands. The full benefits of the developments as recreational areas will not be realized; however, unless water quality is adequate to support good populations of fish and wildlife.

Another important aspect of any water quality improvement at John H. Kerr Dam is the value such improvement would have in considering if similar corrective measures or design practices would be effective in water quality management problems in other reservoirs. The present water quality problem at John H. Kerr project is primarily the result of a lack of technical data at the time of project installation and any remedial measures taken could be of great experimental value in avoiding similar problems in future reservoir development. It is therefore recommended that any facility installed at Kerr Dam for the purpose of water quality control be subject to detailed field observation to determine the effectiveness of the facility and that such information be made available for possible future use in designing and/or evaluating similar projects.

The value of water quality control accomplished by a Federal project is often expressed in terms of the cost of providing the same improvement by the most likely alternative means that would be utilized in the absence of the project under consideration. At Kerr Dam, there is no alternative to project modification. According to a preliminary estimate by the Norfolk District, Corps of Engineers, remedial measures needed to improve the quality of water discharged may be as much as $1,000,000, based on the cost of a variable level submerged weir. Other methods of improving the D.O. content of the discharges are also under study. Such an estimate should not be looked upon as a measure of a benefit but rather as a measure of the cost to mitigate a damage. Accomplishment of water quality improvement would be of widespread benefit to all downstream users in that it would restore the quality of discharges from Kerr Dam to minimum acceptable levels.

SECTION 8

METHODS FOR IMPROVING THE DISSOLVED OXYGEN CONTENT OF KERR RESERVOIR DISCHARGES

Methods for improving the dissolved oxygen content of water discharged from impoundments have been discussed by H. Wagner,[37, 57] F. W. Kittrell,[47, 65] A. J. Wiley, et al.,[71, 91] and others.[43, 82] Their suggestions have been assembled in this section of the report. This discussion of specific methods is not intended to exclude the possibility of the development of other methods for improving the dissolved oxygen content of Kerr Reservoir discharges.

Several methods suggested for improving the quality of water discharged from impoundments have received considerable attention, and have been tried experimentally or in actual practice on small lakes or reservoir. However, the application of these methods to reservoirs as large as the John H. Kerr Reservoir has not been demonstrated at this time. The selection of the best method will depend largely upon the cost of installation and operation; this factor is not considered in the present discussion. These methods have the single purpose of improving the dissolved oxygen quality of the reservoir discharge. The addition of pumped storage features or thermal electric units requiring cooling water might also accomplish the same result incidental to their primary purpose. However, these have not been discussed herein because their effect on water quality would be a small factor in their economic justification.

SUBMERGED WEIR

A submerged weir is an underwater barrier used to retain the colder, hence heavier water below the hypolimnion within the reservoir; in this sense it acts much in the same way as a dam. It can also be considered an extension of the power intake to a point near the surface of the water.

A submerged weir has been installed in Roanoke Rapids Reservoir and a second is being installed in Gaston Reservoir. Special Report No. 1 by the Steering Committee for Roanoke River Studies[48] presents substantial data on the Roanoke Rapids weir indicating that the major portion of the flow is selected from above the weir with the proportion increasing with higher flow rates, such as occur with peaking flows. The Roanoke River Studies demonstrated the effectiveness of a submerged weir to raise the level from which the water is withdrawn. The dissolved oxygen content of the discharge would increase as the elevation of the crest of the weir is raised nearer to the water surface. Where a long weir crest can be provided, the elevation can be raised to very near the minimum power pool elevation if a fixed weir is installed and possibly above it if a variable level weir similar to the one being considered by the Corps of Engineers, Norfolk District, is installed in Kerr Reservoir. A submerged weir would increase the temperature of the water discharged so that the tendency for density underflow to develop in downstream reservoirs would be substantially reduced, thus allowing a greater proportion of the discharge to pass through the next reservoir above the thermocline. The effect of cold, high volume and low D.O. discharges from Kerr Dam on Roanoke Rapids Reservoir was discussed in Special Report No. 1[48]. Density underflow of low D.O. water resulting from Kerr Dam peak discharges maintained the thermocline and the elevation of low D.O. water near the elevation of the submerged weir crest in Roanoke Rapids Dam. During the minimum flow periods or after especially large discharges from Kerr Dam, the low D.O. water was raised above the weir and resulted in low D.O. discharges. While the same conditions will occur in Gaston Reservoir, it is expected that with the higher weir crest elevation, longer storage time, and operation primarily for peaking power the water discharged will be much less affected by density underflow. Density underflow is not expected to be serious in Roanoke Rapids Reservoir after Gaston Dam goes into operation.

The withdrawal of water from the highest level possible would reduce the iron and manganese content of the water discharged from the reservoir during the stratification season. Even with a submerged weir, there remains the possibility of infrequent discharges of low dissolved oxygen water during low flows when the thermocline is located near the level of the weir crest. Low D.O. water could also be discharged at very infrequent occasions as a result of wind denivellation.[46]

The installation of a fixed weir with a crest near the reservoir surface will tend to stabilize the thermocline slightly below the weir crest elevation. It therefore would be desirable to discharge water from the hypolimnion to the extent possible to lower the elevation of the thermocline. If some water can be discharged from the bottom of the reservoir the tendency to develop a large volume of water devoid of dissolved oxygen will be minimized. The effect of extended periods of zero dissolved oxygen water in the lower levels of the reservoir on the iron and manganese content might be quite serious, especially at the fall turnover period. The inclusion of ports at the bottom of the adjustable submerged weir which could allow hypolimnetic water to be discharged during periods when the dissolved oxygen content of the mixed flow was above 4.0 mg/l would add flexibility in handling this potentially serious problem.

A weir with provision for adjusting the depth of the crest to the lowest possible level during periods when the dissolved oxygen content of the discharge was above the minimum would also be effective in reducing the thermocline to the lowest practicable level. For a reservoir of the size impounded by Roanoke Rapids Dam, the possible effects of fall turnover would be negligible. However, unless hypolimnetic water is discharged to the extent possible during the summer season, some difficulty with the fall turnover may be experienced in the discharge from Kerr Dam.

TAILRACE AERATION

Increased reaeration in the tailrace could probably be induced by special tailrace construction to increase the turbulence at this point. The increased turbulence would involve some head loss, and hence, some reduction in efficiency of power production. The short period of turbulence, especially at peaking flows where additional dissolved oxygen is most needed, makes it highly questionable whether sufficient oxygen could be added by such a method.

The installation of air diffusion equipment in the tailrace could be used to increase the dissolved oxygen level. Experience in the Flambeau River below Pixley Dam in Wisconsin[71] indicated that appreciable oxygen could be added to the water, but that absorption was at a rather low level of efficiency (on the order of 6 to 8 percent of the oxygen introduced into the water). The introduction of air required substantial energy and has been abandoned by the Wisconsin group in its investigations.

Mechanical aerators floating in the tailrace might provide a possible means of introducing oxygen in the tailrace. This is currently under investigation by the Chicago Sanitary District. Improvements in mechanical aeration efficiency seem possible through the use of Kessner brush type equipment; however, both mechanical and diffusion aeration methods have been found to be relatively expensive in terms of capital and operating costs.[71] Where other methods are not practicable, mechanical aerators may prove useful.

INTRODUCTION OF AIR TO TURBINE PENSTOCKS

Admission of air through vacuum breakers has been successfully applied by VEPCO to increase the dissolved oxygen in discharges from Roanoke Rapids Dam.[48] Significant increases were accomplished; however, only through restriction of the flow rate to values of the order of 1,000 cfs per turbine, or half the normal minimum flow rate. No aeration was possible at peaking flow rates.

Similar admission of air at Pixley Dam on the Flambeau River in Wisconsin has been tried. The increases in D.O. reported[71,91] were not so large as those reported in the Special Report #1,[48] but much less detailed data are supplied so that reaeration under less advantageous conditions may have been included in the averages cited. In one turbine the water wheels were located in such a way that a vacuum was not formed and air was introduced under pressure. It should be possible to introduce air in this manner at higher flow rates. In such cases it is important to supply only as much air as is needed to accomplish the desired or possible aeration. The supply of excessive air reduces the aeration efficiency.

Turbine aeration seems to be the most promising for introducing oxygen by direct aeration. For discharges having low initial dissolved oxygen, Wiley concluded that "turbine aeration appears as a method which can be considered low in cost under most conditions." The cost of turbine aeration involves relatively small capital expenditures for turbine modification and compressors, but results in the loss of a certain percentage of the power production of the turbine. For low head plants, Wiley estimated the loss to be approximately 5 percent, but for higher head installations, the loss would be a smaller proportion of the normal power production.

Experimental studies by the Sulfite Pulp Manufacturers League and the Wisconsin Committee on Water Pollution indicate that 15 to 25 percent of the oxygen introduced through vacuum breakers could be absorbed by the water passing through the turbines at low discharge rates. It is unfortunate that the data on the efficiency of oxygen transfer at discharge rates near the rated capacity of the turbines have not been reported. Turbine aeration at discharge rates near the rated capacity would have to be considered experimental and it is possible that the efficiencies observed at the lowest discharge rates would not be applicable.

With adequate provision of facilities for ensuring the introduction of the air in the form of small bubbles, an efficiency of 25 to 35 percent is felt to be more reasonable and possible. This would indicate that approximately 100 cfm of air would be necessary per milligram per liter of oxygen to be added per 1,000 cfs of turbine discharge. Turbine aeration would not be effective as an addition to the use of the submerged weir since oxygen transfer efficiency would be reduced as the dissolved oxygen concentration is brought nearer saturation by the submerged weir installation.

AERATION OR MIXING IN KERR RESERVOIR

Aeration has been used in Lac de Bret, Switzerland, to prevent oxygen depletion in the hypolimnion which results in solution of iron, thus causing water treatment difficulties.[65] The water was pumped from the hypolimnion at a depth of 45 feet, passed through an aeration chamber, and returned to the same depth about 600 feet from the intake. A little less than one-fourth of the total lake volume was pumped and, since the aerated water remained at the same depth from which it was subsequently withdrawn by the water treatment plant, it was not necessary to reaerate the entire hypolimnion.

Circulation of water from the hypolimnion has been effective in several instances[65] in reducing stratification or significantly lowering the thermocline so that the dissolved oxygen content of water withdrawn was increased to acceptable levels. The largest reservoir in which this was reported* had a total volume of only 37,500 acre-feet and a mean annual flow of 970 cfs. Application of such a procedure to Kerr Reservoir involves an increase in scale of over one order of magnitude. The aeration and pumping equipment required for such large flows would be substantial. However, equipment reported to circulate large volumes of water in reservoirs was recently reported in the literature.[90]

*Private communication from equipment manufacturer.

SELECTION OF METHOD

Selection of the facilities and/or operational procedures for corrective measures to be taken at John H. Kerr Dam depends on the availability of equipment and on detailed estimates of the cost of fabrication, installation and operation.

Detailed design and cost estimates of possible corrective measures are not within the scope of this report. While no single method of water quality improvement should be expected to be best for all conditions, technical and operating data available on the submerged weir installed in Roanoke Rapids Reservoir and estimates of the effect of a similar structure in Gaston Reservoir indicate that the submerged weir being considered for Kerr Reservoir may be expected to result in satisfactory conditions most of the time. Further data on the cost of installation and operation of other methods would be needed before a final recommendation could be made.

The contribution to the understanding of quality changes in reservoirs possible through the study of Kerr Reservoir is a further important aspect of water quality improvement at John H. Kerr Dam. The lack of technical data on quality changes in reservoirs at the time the project was designed is a major reason for the present water quality problems. Development of effective corrective measures at Kerr Dam will therefore aid in the solution or prevention of water quality management problems in other reservoirs. The effectiveness of any facility installed at Kerr Dam for the purpose of water quality control should therefore be determined by detailed field observations. Such information should be made available for general use in designing similar projects.

Section 9

SUMMARIES OF PREVIOUS STUDIES

The Roanoke River has been the subject of numerous meetings, conferences, and studies involving various Federal, State, and local agencies, as well as local industries and interested groups. Three Public Health Service reports were made between 1943 and 1952 in which the minimum flows required to maintain existing water quality below Roanoke Rapids were recommended.[6, 12, 18] The 1954 report by the Public Health Service established water quality conditions following construction of the John H. Kerr Dam and refined the estimate of the waste assimilative capacity below Roanoke Rapids.[29] Reports prepared by VEPCO and Halifax Paper Company discussed the effects of the proposed Gaston Dam on the water quality at Roanoke Rapids and hence on the waste assimilative capacity.[31, 32, 33]

The North Carolina State Stream Sanitation Committee issued the Roanoke River Basin Pollution Survey Report[39] in 1956. The report presented data on water use and conditions existing in 1953 through 1956 and presented the proposed classifications for streams in the Roanoke River Basin in North Carolina. On the basis of the adoption of these classifications, the Committee issued its plan for the abatement of pollution in the basin in 1957.[44]

The Steering Committee for Roanoke River Studies investiaged the effectiveness of a submerged weir installed in Roanoke Rapids Reservoir to improve the dissolved oxygen content and projected the results to the proposed Gaston Dam.[48, 49, 64] Through the Committee, agreement was reached on minimum flows and water quality below Roanoke Rapids Dam acceptable to the North Carolina State agencies and economically feasible for VEPCO. On the basis of this agreement, the license for Roanoke Rapids Dam has been amended to permit the construction of Gaston Dam by VEPCO.[70] The reservoir will begin filling in the fall of 1962.

Summaries of the major reports on the Roanoke River are presented on the following pages.

ROANOKE RIVER, VIRGINIA AND NORTH CAROLINA[1]

Navigation, flood control, power development, and irrigation of the Roanoke River and its tributaries were considered. Seventeen reservoir sites worthy of consideration for power production, including Smith Mountain, Buggs Island, Gaston, and Roanoke Rapids but excluding Philpott and Schoolfield, were cited. It was concluded that a hydroelectric power potential existed but that comprehensive multipurpose development was not economically justified at that time.

STUDIES OF THE DRAINAGE BASINS IN VIRGINIA[2]

Power development possibilities on the Roanoke River in Virginia were discussed. It was noted that power development is generally associated with industrial development which in turn is associated with increased stream pollution unless adequate provision for its control is provided. Forty-five industrial waste discharges of unspecified magnitude were reported for the Roanoke River Basin in Virginia. A survey of stream pollution conditions was recommended. No data on stream conditions were included.

ROANOKE RIVER INVESTIGATION - FLOW RELEASES NECESSARY FOR POLLUTION CONTROL FROM ROANOKE RAPIDS TO WELDON, NORTH CAROLINA[6]

Minimum flow requirements for dilution of wastes in the river channel between a proposed Roanoke Rapids Dam and the point at which the power discharges would be returned to the main channel of the river below Weldon were estimated. The organic waste load reaching the Roanoke Rapids from municipalities and industries in the Roanoke Rapids-Weldon area was estimated to be 15,000 pounds of 5-day, 20°C. BOD per day, or an estimated 90,000 P.E.

Data indicated substantial pollution above Roanoke Rapids, presumably from natural causes. This substantially affected the minimum flows suggested. Minimum flows suggested to maintain dissolved oxygen at water quality objective of 5.0 mg/l between Roanoke Rapids and Weldon were:

January through April	500 cfs
May	1,000 cfs
June	2,000 cfs
July and August	2,500 cfs
September	1,500 cfs
October through December	500 cfs

Flow releases proposed were for the disposal of sewage and industrial waste discharged at that time (1942) without treatment. The possibilities of a sewer to the power plant tailrace and of treatment were discussed. Releases were based on the observed levels of dissolved oxygen above Roanoke Rapids and it was suggested that aeration might be necessary if the discharge from the reservoir was low in dissolved oxygen.

ROANOKE RIVER, VIRGINIA AND NORTH CAROLINA[7]

Eleven reservoirs were recommended for construction based on the prevention of flood damage and production of hydroelectric power. A significant portion of the flood control benefit occurred in the lower Roanoke River valley.

Philpott and Buggs Island (John H. Kerr) projects were recommended for initial development. These projects provided practically all of the flood control features included in the final plan. Possible use of the reservoirs for water supply and stream pollution abatement and as an aid in the industrial development of the lower basin were cited as intangibles not subject to direct monitary evaluation.

WATER QUALITY INVESTIGATION IN CONNECTION WITH
BUGGS ISLAND RESERVOIR[12]

Available information indicated that wastes equivalent to a sewered population of over 225,000 persons were being discharged to the rivers above Kerr Dam. Since the major portion reached the river about 170 miles above the dam, it was concluded that the residual demand would not appreciably affect the quality of water in the reservoir.

In discussing the quality of water to be discharged from the reservoir, it was noted that: "Water released from the reservoir through the turbines during the warmer months, after thermal stratification is established, may be entirely or almost devoid of oxygen and relatively cold. However, it should have a very low biochemical oxygen demand, and turbulent flow in the stream below the reservoir should restore possible depressed dissolved oxygen levels to near saturation in a short distance. The greater turbulence which would attend release of water through the sluice gates would restore any lowered dissolved oxygen content even more quickly. In either case, before the water reaches Roanoke Rapids, the critical point for water use and pollution below Buggs Island, the stream should have a normal dissolved oxygen content."

Lower BOD observed in the water reaching Roanoke Rapids in 1946 than was observed in 1942 was considered more representative of the conditions to be expected after completion of the Kerr Dam. Waste loads discharged at Roanoke Rapids were essentially the same as in 1942. Based on the satisfactory stream conditions observed at flows of approximately 2,000 cfs in 1946, the minimum summer flows were reduced somewhat as indicated below:

January through April	500 cfs
May	1,250 cfs
June through September 15	2,000 cfs
September 15 through October	1,250 cfs
November and December	500 cfs

Allowance was made for the greater depletions occurring along the south shore of the river because of poor lateral mixing.

No comment was made on the possibility of reducing the estimated minimum flows during a portion of the day or on weekends. However, it was noted that "appreciable changes in the pollution load by treatment of wastes or by changes in industrial plant practices or in plant output, may warrant changing these figures in the future."

ROANOKE RAPIDS DEVELOPMENT (F.P.C. PROJECT NO. 2009) - REPORT ON INVESTIGATION OF APPLICATION OF VIRGINIA ELECTRIC AND POWER COMPANY FOR LICENSE[13]

The Corps of Engineers review of the proposed VEPCO license for a Roanoke Rapids Dam indicated that the project should assure the same minimum flows at Roanoke Rapids as had been provided by the Corps' John H. Kerr Dam "(a) to ensure that pollution conditions remain unchanged in the stream and (b) for the conservation of fish." Table 3 of the report listing the low flow requirements recommended by the U. S. Public Health Service and the Fish and Wildlife Service is reproduced on the following page.

The Public Health Service flow recommendations in the report cited[12] were modified by the reduction of the minimum flow from 2,000 cfs to 1,600 cfs for the first 15 days of September with a compensating increase from 1,250 cfs to 1,600 cfs for the last half of the month. The reduction in weekend flows was based on the letter report by the Public Health Service dated December 11, 1945, which suggested that instantaneous flows might be reduced as much as 50 percent, provided there was a corresponding reduction in waste loading.[9] The earlier Fish and Wildlife Service daily flow recommendations were used for the striped bass spawning period. The revised Fish and Wildlife Service's recommendations were substantially higher but the report was based on the earlier requirements.

ROANOKE RIVER BASIN INVESTIGATION - REPORT ON EFFECTS OF PROPOSED HYDROELECTRIC DEVELOPMENTS ON POLLUTION PROBLEMS IN ROANOKE RIVER BASIN - UNITED STATES PUBLIC HEALTH SERVICE[18]

The effect of the entire proposed Corps of Engineers development for the Roanoke River Basin on the quality of water which would result and the minimum flows required was reviewed. It was emphasized that: (1) further

Table 3

Low Flow Requirements in Cfs

Month	For Pollution Abatement(a)		For Conservation of Fish		
	Weekly	Each Weekend	Each Week(b)	Each Day(b)	Each Day(e)
January	500	500	2,000	500	1,000
February	500	500	2,000	500	1,000
March	500	500	2,000	500	1,000
April	500	500	2,000(c)		2,000(d)
1-15				1,000	
16-30				2,000(c)	
May	1,250	600	2,000	2,000	2,000(d)
June	2,000	1,000	2,000	1,000	1,000
July	2,000	1,000	2,000	1,000	1,000
August	2,000	1,000	2,000	1,000	1,000
September	1,600	800	2,000	800	1,000
October	1,250	600	2,000	500	1,000
November	500	500	2,000	500	1,000
December	500	500	2,000	500	1,000

(a)Required to maintain minimum monthly average dissolved oxygen of 6.5 ppm and minimum daily dissolved oxygen of 5.0 ppm, U. S. Public Health Service, "Roanoke River Investigation," March 1947.

(b)Fish and Wildlife Service, "A Report on Fish and Wildlife Resources in Relation to the Buggs Island Reservoir, Roanoke River Basin," May 1946, Revised 14 February 1947.

(c)15,000 cfs for 3 days during last week in April if such flow has not normally occurred during latter half of month is required in addition to amount shown.

(d)Also minimum instantaneous.

(e)Ltr. Assistant Secretary of Interior to Chairman, Federal Power Commission dated 24 January 1949. This letter states that the volume of controllable releases of water shall not be permitted to increase to double, or decrease to half, of any prevailing discharge in less than one hour. In a conference at the Norfolk District office on 2 February 1949, the Fish and Wildlife Service personnel indicated this requirement applied only during striped bass spawning period.

studies should be made after the proposed impoundments were placed in operation in order to determine the quality of outflow from these impoundments (page 6), (2) readjustment of minimum flow releases presently suggested might have to be made (page 6), and (3) reaeration of the released water might need to be considered (page 5). Information on waste loads indicated that substantial increases had taken place in the Roanoke, Virginia, area above the John H. Kerr Reservoir and in the Plymouth, North Carolina, area, an area still subject to the effects of discharge flows from the John H. Kerr Reservoir. A small increase was noted at Roanoke Rapids. It was noted that no allowance had been made for further growth insofar as the waste load which might be imposed on the stream was concerned (page 24). Since the stream was excessively loaded at the time it was assumed that corrective measures would be taken by the industries and cities and that it was only necessary to maintain the existing water quality under the then existing waste loads not withstanding the fact that pollution abatement had been included as one of the ancillary benefits of the reservoir. The report concluded that the minimum flow requirements proposed by the 1947 report were still applicable to the existing pollution loads at Roanoke Rapids and commented that, while a reduction in water releases for pollution control over weekends might be made for an industry operating on a 5-day week schedule, pulp and paper mills such as at Roanoke Rapids customarily operate 7 days per week. Reductions in minimum releases on the weekend would therefore be inadvisable. By implication, if the paper mill were shut down, some reduction in flow might be made. For extreme drought periods (by implication occurring less frequently than once in 10 years) a reduction of not over 20 percent in the above flows might be necessary (page 41).

EFFECTS OF CONTROLLED WATER RELEASES FROM THE JOHN H. KERR RESERVOIR ON THE STRIPED BASS FISHERY OF THE ROANOKE RIVER, NORTH CAROLINA - FISH AND WILDLIFE SERVICE[20]

Provision for releases from the reservoir to abate pollution and to meet the specialized requirements of the existing striped bass fishery was made in the operating plan for the John H. Kerr Dam. The benefits of these were discussed in the definite project report but not evaluated as a part of the justification of the project.

A program to evaluate and refine the recommendations for future water releases for the maintenance of the striped bass fishery with a minimum power loss was set up. Described are the results of observations on the striped bass spawning success from April 6 to May 15, 1953, the first season following the closure of Kerr Dam. Bioassays of the effects of pulp and paper mill wastes on eggs and fry are also described. Detailed information on temperature changes and hydrographs for the striped bass spawning season are given for stations at Kerr Dam, Weldon, Halifax, Hamilton, Williamston, and Jamesville. Conclusions and recommendations of this report were:

CONCLUSIONS

29. From information obtained during the course of this study, which has been correlated with data presented in prior reports, the Fish and Wildlife Service concludes that:

(1) River stages and temperatures prevailing during the 1953 striped bass spawning season in Roanoke River downstream from John H. Kerr Reservoir were favorable to the migration of adequate numbers of breeding fish to sustain production. The extent to which pre-season high flows resulting from augmented discharges of 13,000 second-feet April 9, 10, and 11 contributed to this success was not determined.

(2) River stages and temperatures were favorable to egg maturation and spawning.

(3) After initiation of controlled releases in the interest of the striped bass fishery minimum river stages were prevented from falling below 11 feet at Weldon. This stage was adequate to sufficiently dilute the pollution load to ratios favorable to the survival of striped bass eggs and fry.

(4) A river stage of about 11.0 feet at Weldon is the minimum desired from a standpoint of satisfactory sport and commercial fishing operations.

(5) Impoundment of that segment of the Roanoke River from the proposed site of Roanoke Rapids Dam to John H. Kerr Dam for hydroelectric power purposes, may influence water temperature at Weldon to the extent that successful reproduction of striped bass will be jeopardized.

(6) A successful management program of the North Carolina striped bass fishery must include the following:

a. Measures to reduce or neutralize the more harmful pollutants discharged into the stream in the vicinity of Roanoke Rapids, and

b. Provisions in operational plans for proposed Gaston and Roanoke Rapids Dam and Reservoir projects and John H. Kerr Reservoir which will insure river stages and temperatures at Weldon favorable to striped bass migration, reproduction, and fishing success.

RECOMMENDATIONS

30. The following recommendations are advanced to supplement recommendations provided by the Fish and Wildlife Service in prior reports concerning the minimum flow requirements for the striped bass fishery.

a. Biological observations should be made each year to determine the periods when supplemental releases would be necessary for the preservation of the striped bass fishery.

b. Minimum stages of 11 feet at Weldon should be provided during the period adult striped bass are congregating in the rapids.

c. Minimum stages of 12 feet at Weldon should be provided during the period of actual spawning.

d. Supplemental releases should be made from the surface of the reservoir if cold-water discharges adversely affect the striped bass fishery.

e. Cooperation of industries and municipalities should be solicited to reduce pollution to a point commensurate with sound economic use of the water resources.

f. Future studies should be designed to acquire specific information on the movements of adult striped bass and the presence and survival of eggs and fry of this species in various reaches of Roanoke River.

REPORT OF STUDIES ON THE ROANOKE RIVER BELOW JOHN H. KERR RESERVOIR, AUGUST-SEPTEMBER, 1953 AND APRIL-MAY, 1954[29]

Stratification in John H. Kerr Reservoir resulted in the discharge of water devoid of oxygen at time. The D.O. was 40 percent of saturation, or 3.5 mg/l, 6 miles downstream and 93 percent of saturation 43 miles below, at Roanoke Rapids. It was suggested that impoundment behind Roanoke Rapids Dam might (1) result in substantial degradation of the dissolved oxygen quality above Roanoke Rapids (2) adversely affect the quality of water used for domestic and industrial water supplies by increasing the iron and manganese content, and (3) produce taste and odor resulting from plankton growth.

Data collected in 1954 indicated that the industrial wastes and domestic sewage discharged in the Roanoke Rapids-Weldon area had a population equivalent of 96,000 pounds of 5-day, 20°C. BOD, or 575,500 P.E. This represented a substantial increase since 1952. Most of the increase and 93.7 percent of the load in the Roanoke Rapids-Weldon area was the result of pulp and paper production by the Halifax Paper Company.

Extension of the survey area further downstream from Weldon indicated that the critical point was in the vicinity of Scotland Neck, 28 miles below Roanoke Rapids and below the area surveyed in earlier reports. Minimum flow requirements based on the new waste loading conditions, an assumed dilution water D.O. of 94 percent saturation and 5-day,20°C. BOD of 0.74 ppm and on the additional stream data, were higher than had been suggested in the past. The oxygen-sag curves and tables of flows necessary to meet a dissolved oxygen requirement of 4 mg/l indicated a waste assimilative capacity of about 70,000 pounds of 5-day, 20°C. BOD per day at 2,000 cfs. Data collected at the mouth of the Roanoke River were not sufficient to establish the assimilative capacity of the river in the vicinity of Plymouth.

Toxicity tests conducted in connection with this report indicated that the toxic components of the wastes from the pulp mills might be of more importance than oxygen consuming components as far as their effects on fish fry and freshly spawned eggs is concerned. Reduction of the concentration of toxicants, especially during the spawning season, might be required if the Roanoke River striped bass fishery is to be adequately protected.

It was concluded that requirements for public health protection, industrial water supply, fishing, and other uses could not be adequately met by reasonable sewage and industrial waste treatment alone, but could be achieved by a combination of reasonable treatment and adequate dilution.

Good housekeeping, prevention of accidental spills or excessive loss of raw materials in the industrial establishments combined with lagooning, and a reasonable degree of treatment of domestic sewage should maintain a dissolved oxygen level satisfactory for water uses at that time. A combination of dilution water and reasonable treatment of waste should reduce pollution effects in the Roanoke River to the extent that the water resources will support the existing industry and aid in the expansion of industry important to the economy of the lower Roanoke and to over-all State productivity. The benefits of pollution abatement would not be limited to a single community, but would accrue to several communities and the State.

Additional studies of water quality with respect to dissolved oxygen below Roanoke Rapids appeared to be warranted following the completion of Roanoke Rapids hydroelectric project to determine the character of its discharges. Any significant change in dissolved oxygen at Roanoke Rapids would require adjustment of the proposed schedule of minimum releases and the degree of treatment of pollutional wastes now indicated in order to maintain the desired water quality.

REPORT TO VIRGINIA ELECTRIC AND POWER COMPANY ON EFFECT OF THE SUBMERGED WEIR UPON QUALITY OF WATER DISCHARGED FROM GASTON RESERVOIR[31]

The conditions leading to the development of density underflow were discussed. Density underflow of the low D.O. water discharged from Kerr Dam would likely proceed through Gaston Dam and Roanoke Rapids Reservoir, if both had low-level intakes. A submerged weir at a depth of 30 feet at Gaston Dam was proposed as a high-level intake for selecting surface water for discharge. It was postulated that withdrawal of water over the submerged weir would result in the discharge from Gaston Dam of the best quality water available. Data from projects in the Tennessee Valley Authority system were used to show the quality improvement which resulted when the downstream reservoirs had high-level intakes. It was concluded that model studies would not be feasible to investigate the effects of a high-level weir in Gaston as a result of problems of scaling.

While it was concluded that the water drawn through the turbines at Gaston Dam over a submerged weir would be the best quality water available from the reservoir, no estimate was made of the minimum D.O. of either the Gaston or Roanoke Rapids discharges.

A STUDY LEADING TO ESTIMATES OF THE PROBABLE DISSOLVED OXYGEN CONTENT OF DISCHARGE WATERS FROM ROANOKE RAPIDS TAILRACE[32]

Estimates were made of the minimum dissolved oxygen concentrations to be expected in the discharge from Gaston Dam if it were constructed with a weir 30 feet below the surface. The mean dissolved oxygen in the discharge from Gaston Dam was esitmated as the average (smooth) value of the dissolved oxygen observed in Kerr Reservoir at the 10-, 20-, and 30-foot depths during the fall of 1954 and spring of 1955. On this basis, the minimum D.O. was predicted to increase from 1.8 mg/l in the Kerr tailrace to 4.0 mg/l in the Gaston tailrace. The high-level intake at Gaston Dam would result in its discharge being relatively warm so that it would mix with the water in Roanoke Rapids Reservoir thus preventing the development of density underflow. On this basis and with no submerged weir in Roanoke Rapids Reservoir, it was estimated that the minimum D.O. discharge from Roanoke Rapids Dam would be 4.5 mg/l.

However, it was pointed out that the minimum dissolved oxygen level which would result in the first 2 years after Gaston Reservoir was filled could be as much as 0.5 mg/l lower than in subsequent years. Further, the dissolved oxygen might fluctuate somewhat, depending on weather so that in hot summers when there was little wind the D.O. could be 0.5 mg/l lower, while in cool, windy summers it could be 0.5 mg/l higher.

HALIFAX PAPER COMPANY, INCORPORATED, ROANOKE RAPIDS, NORTH CAROLINA, INVESTIGATION OF THE ROANOKE RIVER (AS RELATED TO PRESENT AND FUTURE OPERATION OF A PULP AND PAPER MILL BY HALIFAX PAPER COMPANY, INCORPORATED AT ROANOKE RAPIDS, NORTH CAROLINA)[33]

This report was prepared to advise the Halifax Paper Company regarding "(1) The anticipated effects on quality of river water at Roanoke Rapids occasioned by the construction of the proposed Gaston Dam, and (2) the effects of the present rates and durations of water released through Kerr and Roanoke Rapids Dams - as they influence Halifax's present and future paper mill operations."

Based on the waste assimilative capacity estimates prepared by the North Carolina State Stream Sanitation Committee, the condition of the river under natural flow and as modified by John H. Kerr Reservoir were compared with conditions in the first 3 months of operation of Roanoke Rapids Dam. Anticipated conditions after the installation of Gaston Dam (as then proposed by VEPCO) were also considered. The report summarized past uses of the stream, described the condition in 1955, and discussed probable effects of further development. Conditions which developed were not anticipated at the time Roanoke Rapids and Gaston Projects were initiated nor was the seriousness of the condition known until Roanoke Rapids Dam went into operation.

It was pointed out that the Halifax Paper Company has used the Roanoke River as a source of water supply and as a means of disposing of its industrial wastes since 1909 and, until construction of Kerr Dam 45 miles above Roanoke Rapids, the river off the mill had been of sufficiently good quality as to enable the disposal of the mill wastes without evident detrimental effects to the stream. Although poor quality water was discharged from Kerr Dam, open streamflow restored the dissolved oxygen to 90 to 100 percent of saturation and by implication, reduced the iron and manganese contents to acceptable values. Output gradually increased from 50 to 350 tons of pulp per day.

Completion of Roanoke Rapids Dam approximately 2 miles upstream from Halifax Paper Company in July 1955 reduced the reaeration above Roanoke Rapids and inundated decomposable vegetation resulting in a reduction of the D.O. of the Roanoke River off Roanoke Rapids to as low as 3.75 mg/l, which was below the then proposed State Stream Sanitation Committee standards. Construction of Gaston Dam would be expected to deplete the dissolved oxygen content of the river at Roanoke Rapids to as low as 4.0 mg/l, which would be the minimum allowed under stream classification. Such depletion would make the control of industrial wastes required at Halifax Paper Company "economically and practically impossible."

While the river would have a considerable waste assimilative capacity even with dissolved oxygen concentrations only slightly above 4.0 mg/l because of the continuous reaeration which occurs in the stream, it would have greater waste assimilative capacity at higher initial dissolved oxygen concentrations. This is of particular importance during critical periods of low flow. Furthermore, some dissolved oxygen potential in excess of the minimum should be present to satisfy the immediate oxygen demand of wastes and to prevent the stream from being in default immediately below the sources of pollution in the Roanoke Rapids-Weldon area.

Estimates of minimum dissolved oxygen below Roanoke Rapids Dam during the hot summer months following completion of Gaston Dam (3.5 mg/l in the first 2 years and 4.0 mg/l after the reservoir has aged) seemed reasonable but would not allow compliance with North Carolina State Stream Sanitation Committee objectives without requiring a prohibitive degree of waste treatment by Halifax Paper Company.

Production difficulties from iron and manganese seemed likely unless provision was made at water treatment plants to handle the situation. Conditions were made worse by the construction of Roanoke Rapids Dam and would be accentuated by Gaston Dam if both had low-level outlets.

The water use problem on the Roanoke River involves peaking power production, industrial and municipal waste disposal, and recreation and fishery interests. "The established positions of Halifax and municipalities are of long standing, those of VEPCO are recent or proposed, and those of the fishery interests will shortly be covered by specific law." Possible remedial actions which could be taken by VEPCO were suggested.

Particular note was made of the unreasonableness of reduced weekend flows since most of the industries producing waste at Roanoke Rapids operated 7 days per week.

For Halifax Paper Company to continue to operate satisfactorily sufficient quantities of water at sufficiently high dissolved oxygen concentrations should be assured to assimilate its wastes at all times. Data and arguments supporting the outline of the situation were presented and it was concluded that construction of Gaston Dam without the guarantee of satisfactory minimum flows and quality would result in serious impairment of downstream public and industrial rights.

POLLUTION SURVEY REPORT NO. 4, THE ROANOKE RIVER BASIN[39]

The General Statutes of North Carolina, Article 21, Sections 143-215, as revised in 1951, require that all the streams of the State be surveyed to establish existing pollution and be classified as to best use, and that a plan for the abatement of pollution be formulated and enforced. This report was prepared for the Roanoke River Basin in North Carolina in fulfillment of the first two objectives.

Data are presented showing the present uses of the Roanoke River, sources of pollution entering these waters, the effect of pollution on water quality, and the recommended classifications of the streams. The first studies were made in August 1953 for the high temperature, low flow period. In the spring of 1954 studies were made of stream conditions during the period anadromous fish (striped bass) were present in the river. As a result of changes in river conditions produced by the construction of Roanoke Rapids

Dam by VEPCO and by plant changes made by Halifax Paper Company, Incorporated, additional studies were made during both the spring and fall of 1955 and the summar of 1956. The report recognized that the pollution problems of the basin were complex and indicated that every effort had been made toward developing reasonable conclusions and recommendations pertaining to the proposed classifications of the various waters.

The data collected during the surveys were tabulated in the report but no additional pre-Roanoke Rapids Dam data were given. Data for the period after the reservoir was filled was given. The resurvey of the Halifax Paper Company waste discharge in 1955 indicated that plant changes had been effective in reducing the waste load 44 percent from 90,000 to about 54,700 pounds per day, while pulp production had been increased by 21 percent. Waste load data were presented in greater detail in the Report of Studies Conducted on the Roanoke River in the Roanoke Rapids-Weldon Area by the Task Force I of the Steering Committee for Roanoke River Studies for the period, August-September 1956.

In the discussion of the general survey findings for the lower Roanoke River, the following statements are of particular interest for the present report:

> Plans have been submitted to the Federal Power Commission for the construction of hydroelectric projects that will utilize practically all the hydroelectric power potential of the Roanoke River. Of the existing and proposed power projects the Kerr project is the largest. The Kerr Dam was built by and is operated by the United States Corps of Engineers for flood control and power generation. The Virginia Electric and Power Company has completed the construction of a hydroelectric project near Roanoke Rapids and has applied for a license from the Federal Power Commission for the construction of another dam to be known as the Gaston project. The backwaters of the Roanoke Rapids Dam extend to the site of the proposed Gaston Dam which if constructed will, in turn, create a pool extending upstream to the toe of the John H. Kerr Dam.
>
> Even though a hydroelectric project adds no pollutants to the water, it may from the standpoint of altering water quality be equivalent to a source of pollution. In large lakes or reservoirs the water near the bottom of the impoundment will be considerably colder than the water near the surface and be completely devoid of oxygen. If the turbine intakes draw water from near the bottom, the water discharged through the turbines may contain little or no dissolved oxygen.

Streams in this section receive an extensive pollution load made up of both domestic sewage and industrial waste. In many instances these discharges are resulting in conditions that seriously jeopardize the necessary uses which must be made of the receiving streams. The total sewage and waste load tributary to the stream, expressed as population equivalent (P.E.), is estimated to be 622,500 of which 597,000 is due to industrial waste discharges. The individual sources of pollution are discussed as follows:

Roanoke Rapids Reservoir - Even though no polluting material is discharged into the stream by Roanoke Rapids Reservoir, the dam, with its low level turbine intake structure, is the equivalent of a source of pollution. Water discharged through the turbines is low in dissolved oxygen and at times high in manganese and iron.

Halifax Paper Company - The United States Public Health Service in cooperation with the State Stream Sanitation Committee studied the volume and characteristics of liquid waste from the Halifax Paper Company during August and September, 1953. Results from this study show that the Halifax Paper Company discharged an average of 17.3 millions of gallons of untreated industrial waste daily into the Roanoke River. The plant study also shows that during the period of study the waste contained 90,000 pounds of 5-day 20°C BOD, or the equivalent of domestic sewage from a population of approximately 540,000 persons. These wastes, not only contain materials that are high in oxygen demand, but they also contain materials that are toxic to fish life when present in sufficient concentrations. As yet these substances have not all been identified, nor has lethal concentrations, as they affect striped bass, been determined. These wastes seriously jeopardize the necessary downstream uses.

During early 1955 certain changes were made at the mill. A second study was made to determine volume and characteristics of the waste. Results of this study showed that the waste load had been reduced by 44% while pulp production had increased by 21%. This reduction in pollution load has not appreciably improved river conditions, due to the reduction of dissolved oxygen by upstream impoundments.

North Carolina Pulp Company, Plymouth - This plant discharges an estimated volume of 40 MGD of untreated industrial waste into Welsh Creek and the Roanoke River. This waste contributes a five-day 20°C BOD load of 45,800 pounds, or a population equivalent of approximately 231,000. These wastes, highly colored as well as high in oxygen consuming material, almost completely delete the dissolved oxygen in the stream during periods of hot - dry weather. Not only are the wastes high in oxygen consuming material, but they contain substances that are toxic to fish life when present in sufficient concentrations. As yet these substances have not all been identified, nor have lethal concentrations been determined.

The report indicated that the area has excellent possibilities for industrial development and that such development will increase the need for suitable sources of water supply for domestic and industrial use.

The data presented in this report have been used by the North Carolina State Stream Sanitation Committee to establish the treatment or waste reduction necessary to meet the pollution abatement plan. The assimilative capacity of the river was not given.

The recommended classification given the Roanoke River from the North Carolina-Virginia State line to Roanoke Rapids Dam was "A-II," based on water supply use at Roanoke Rapids. The recommended classification for the reach below Roanoke Rapids Dam was "C," based on the fishery industry dependent on the lower river. Both of these classifications allow a minimum D.O. of 4.0 mg/l.

The conclusions included in the report are quoted in part:

1. The waters of the basin are not presently used to their utmost. There is an adequate quantity of water to sustain additional industrial expansion, population growth, recreational development and other legitimate uses provided a comprehensive water pollution control program is carried out.

2. Both population and industrial development are increasing in the basin. These trends are toward greater water use. To adequately protect the water resources of the basin for future use, steps must be taken to reduce existing pollution and to insure that future polluters provide effective waste treatment.

3. Industry has not kept pace with municipalities in the abatement of pollution. Of the wastes being discharged to the streams without any treatment, there are 11 points discharging domestic sewage with a population equivalent of 48,480 while there are 21 points discharging industrial wastes without treatment with a P.E. of 703,800.

4. Unsatisfactory operation and lack of proper maintenance have reduced the efficiency of many existing waste treatment plants.

WATER RESOURCES OF NORTH CAROLINA, ROANOKE RIVER BASIN[40]

Municipal, industrial, agricultural, recreational, and electrical power uses of the Roanoke River Basin in North Carolina were tabulated and discussed. Data on surface water flows and quality and availability of ground water were summarized. Sources of pollution in the basin together with data on the treatment provided, the stream to which it is discharged, and the significance of the discharge were tabulated.

The water pollution problems of the lower Roanoke River Basin were reviewed. The most important items considered at each of the various meetings and conferences on the lower Roanoke River held between April 1, 1954, and November 28, 1956, were reviewed. The metings were called in order to establish future programs for controlling river flows, primarily for the striped bass spawning season but also for the summer season. Through these meetings the Steering Committee for Roanoke River Studies was organized. The activities at the early meetings were outlined.

ASSIMILATION OF BOD IN NATURAL WATERS[45]

The policy of the North Carolina State Stream Sanitation Committee toward the allocation of the assimilative capacity of a major stream among several municipalities and industries contributing waste was described by means of a hypothetical, but typical, situation.

North Carolina policy recognizes that surface waters must serve many legitimate and necessary pruposes, some of which conflict with each other. The disposal of wastes depends on the ability of streams to dilute and assimilate waste materials while maintaining water quality acceptable for other beneficial uses. North Carolina first determined how much waste was being discharged to the stream. The cooperation of the municipalities and industries was usually secured in the installation of flow measuring devices and the collection of samples. An intensive study of the effects of the wastes on the dissolved oxygen content of the stream was then conducted. Sufficient streamflow, dissolved oxygen, temperature, long-term BOD, and waste load data were collected to yield statistically reliable results.

Based on the quality of water necessary for the highest stream usages to be protected, stream standards were established. From the existing loads and their effect on the stream, the permissible load at the critical design flow and temperature was estimated. Considering the type of stream, present uses, plans of existing industries for expansion, availability of possible sites for industrial development, and the rate of growth of municipalities a percentage of the total assimilative capacity was set aside for future municipal growth and industrial development.

Each municipality and existing industry was then required to reduce its waste discharges an equal proportion, applicable to all, to meet the allowable waste discharge under critical conditions. In any event, settleable solids were required to be substantially removed, toxic materials reduced to such a level as not to be biologically harmful, and slime producing materials essentially removed. Except for the above limitations, pollution abatement could be accomplished by treatment, or for industry, recovery systems, process changes, treatment in a municipal plant, or by storage and controlled discharge in proportion to flow.

The waste load resulting from subsequent development of a new industry is added to the load allowed existing industry and the percentage reduction required to again meet the allowable load is applied, the assimilative capacity being allocated from the reserve. As municipalities grow and existing industries expand, additional allotments from the reserve capacity may be made on the same basis as the original allotment.

SPECIAL REPORT NO. 1, ROANOKE RIVER STUDIES - A REPORT ON A STUDY OF THE EFFECTS OF A SUBMERGED WEIR IN THE ROANOKE RAPIDS RESERVOIR UPON DOWNSTREAM WATER QUALITY[48]

This report was prepared from data collected during special studies conducted during the period July through September 1957 for the purpose of determining the effects of a submerged weir in the Roanoke Rapids Reservoir upon downstream water quality.

Because of the volume and type of data presented, the report was quite lengthy and highly technical. A Summary Report was therefore prepared by the Subcommittee for Operations. This Summary Report gives the purpose of the studies reported, summarizes Special Report No. 1 and the consultants' reports on it, and expresses the subcommittee's conclusions and recommendations. The portion of that report summarizing Special Report No. 1 prepared by persons engaged in the survey activity and analysis of results is reproduced in the following. Some paragraphs summarize information already in this report.

1. Physical Description - Lower Roanoke River. The Roanoke River is an interstate stream which rises along the eastern slope of the Appalachian Mountains in Virginia and flows generally southeasterly to its mouth in Albemarle Sound about 6 miles below Plymouth, North Carolina. The portion of the river affected by the hydroelectric projects which alter water quality and regulate flow is the 179 mile reach between Kerr Dam in Virginia and its mouth. Over this section, the river traverses the gently rolling topography of the Piedmont Plateau for 30 miles, having an average fall of about 1.5 feet per mile whereas in the next 21 miles it crosses the fall line where the gradient steepens to about 6 feet per mile. Below this point (River Mile 129) it flows through the Coastal Plains and the gradient flattens to an average fall of less than 0.2 foot per mile.

2. Flows. 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 cubic feet per second. Since the construction of the John H. Kerr flood control and hydroelectric project by the Government, river flows have

been considerably altered and with the completion of the Roanoke Rapids Hydroelectric Project further reregulation of flows has been effected so that the river flow pattern is largely governed by the schedule of minimum discharges from the dam and the demands for peak power on the Virginia Electric and Power Company power distribution system.

3. Water Uses. The river possesses the greatest latent possibilities for further development of any river in the State, provided flow regulation and water quality are properly managed. It is presently used for the generation of hydroelectricity at the Government's John H. Kerr Project in Virginia and at the Roanoke Rapids Project of the Virginia Electric and Power Company located just above Roanoke Rapids, North Carolina; for municipal and industrial water supplies at Roanoke Rapids, Weldon and Plymouth; for agricultural purposes, including irrigation and livestock watering; for fishing and other recreational purposes; and for the carriage and absorption of municipal and industrial wastes. Skiing and boating have developed rapidly on the Roanoke Rapids Reservoir while the reach of the river from the Weldon - Roanoke Rapids area to its mouth constitutes the only known major spawning area for the entire Albemarle Sound striped bass population and furnishes spawning or nursery areas for large, commercially important, runs of menhaden, herring, and white perch as well as some shad.

4. Classifications Assigned. All of the above uses were considered by the North Carolina State Stream Sanitation Committee in assigning classifications to the waters of the Roanoke River. The Committee, recognizing the necessity of protecting those uses requiring the highest quality of water, assigned classification "A-II" for the protection of public water supplies to the reach of the river extending from the North Carolina - Virginia State line to the Roanoke Rapids Sanitary District Water Supply Intake at the Roanoke Rapids Dam and classification "C" for the protection of fish from the Roanoke Rapids Dam to Albemarle Sound. The portion of the river below River Mile 18 at Jamesville was, because of its topography and other characteristics, designated as swamp waters.

5. Flood Control and Hydroelectric Power. The first project for flood control and hydroelectric power production in the Lower Roanoke River Valley is the John H. Kerr Reservoir which was closed early in 1953. This is a Government sponsored project, constructed and operated by the Corps of Engineers, U. S. Army. Although the physical structure is located in Virginia, the pool formed by the impoundment extends into North Carolina. Likewise, the effects of flood control and flow regulation with respect to quantity and quality are felt primarily in this State.

   The second project, developed by the Virginia Electric and Power Company, was completed in 1956 and is operated primarily for the production of hydroelectric power. It is located on the river just above the Town of Roanoke Rapids, North Carolina and like the Kerr Reservoir, is operated as a peaking plant. This installation further reregulates downstream flows and adversely affects water quality from the standpoint of dissolved oxygen, particularly during periods when the impounded water is thermally stratified.

   In addition to the above, the Virginia Electric and Power Company has applied to the Federal Power Commission for a license to construct a similar hydroelectric power project on the river approximately nine miles above the Roanoke Rapids Dam. The proposed development, designated as the Gaston Project, would also be a peaking plant and would be so located as to create a pool extending from the headwaters of the Roanoke Rapids Reservoir to the tailrace of the John H. Kerr Dam. The Gaston Project, if licensed, will utilize the entire potential of the Lower Roanoke River for hydroelectric development and will completely canalize the river from the Roanoke Rapids Dam to the headwaters of the John H. Kerr Reservoir, thus eliminating the natural stream bed over the entire distance.

6. Proposal Relating to Water Quality and Quantity Problems. Since December 1953, Virginia Electric and Power Company has worked with interested North Carolina State and Federal Agencies and with certain affected downstream water users in an effort to find an equitable and economically sound solution to the problems concerning both quality and quantity of water available downstream from its Roanoke Rapids Dam.

The Company made two proposals: one, dated February 16, 1956, for the purpose of establishing a basis upon which the river stages required during the striped bass spawning period could be provided through joint efforts of the Company and the Federal Government; the other, dated May 16, 1956, for the purpose of establishing a program for providing additional waste assimilating capacity downstream from the Roanoke Rapids Dam, both before and after construction of the proposed Gaston Project. Neither of these proposals was acceptable to the State and Federal Agencies concerned, which position was concurred in by the Governor of the State of North Carolina in his letter of December 17, 1956 to the President of Virginia Electric and Power Company.

The Steering Committee, in rejecting the May 16, 1956 proposal suggested a joint study to collect adequate data to serve as a basis of a new proposal relative to the Roanoke Rapids Reservoir and the proposed Gaston Project which could reasonably be expected to produce downstream river conditions under which a minimum of 4.0 ppm of dissolved oxygen would be maintained at the critical sag point and, in addition, a minimum waste assimilating capacity of 109,000 pounds of 5-Day 20°C B.O.D. per day above that necessary to sustain the required 4.0 ppm dissolved oxygen.

On March 27, 1957, the Virginia Electric and Power Company withdrew earlier proposals and indicated the Company's willingness to proceed with the following major undertakings:

(a) The installation of a submerged weir at the Roanoke Rapids Project, having a uniform weir crest at elevation 107 thereby forming a curtain wall extending within 25 feet of the normal pool surface at elevation 132. It was proposed that this weir would promote better downstream oxygen content, both before and after Gaston, and would also serve as a full scale prototype for use in studying the benefits of a similar installation in the proposed Gaston Project upon downstream water quality.

(b) The Company's participation in a joint study during the 1957 critical summer-fall season to evaluate the the effects of a weir of this nature, and use of these data to predict the performance of Gaston with a similar weir. Following a joint meeting of the State agencies and the Virginia Electric and Power Company, held in Roanoke Rapids on May 31, 1957, a mutually agreeable study program, within the framework of the available manpower and equipment, was adopted. The Company initiated construction of the submerged weir about May 1, 1957, and completed it on July 10, 1957. Upon completion of the weir, water quality studies were begun and carried on through September 13, 1957. The nature of these studies together with the study findings, etc., are presented in Special Report No. 1, Roanoke River Studies prepared by an ad hoc Report Committee appointed by the Chairman of the Subcommittee for Operations. This report was presented to the Subcommittee for Operations on February 24, 1958, as a draft representing the majority viewpoint of the Report Committee

7. <u>Summary of Conclusions Presented in Special Report No. 1</u>
From the vast amount of data and the many calculations contained in the Report, the following salient conclusions were presented:

(a) The submerged weir in Roanoke Rapids Reservoir was hydraulically effective in selecting, for discharge from the reservoir, water primarily from the layers above the crest of the weir.

(b) Only a small percentage of the flow originated at depths below 35 feet.

(c) At discharges of 2,000, 6,000, and 12,000 cfs, 74.6%, 84.9%, and 83.6% of the flow originated above the crest of the weir, respectively.

(d) The layer, from which the maximum contribution to the flow originated, was centered at 10, 15, and 20 feet with flows of 12,000 cfs, 6,000 cfs, and 2,000 cfs, respectively.

(e) There was no significant change in the percent contribution of the layers below the weir crest with change in discharge rate, but there was a marked increase in the percent contribution for the upper 10 feet with increasing flow.

(f) A large discharge of cold, more dense water from Kerr Reservoir upon flowing into the lower Roanoke Rapids Reservoir can displace upwards into the surface layers of the latter reservoir, above the weir crest, older, somewhat degraded water from below the weir crest, thus making this low-oxygen water available for discharge across the weir. By this process of vertical displacement, this degraded water becomes centered in the 20 to 25 foot layer which is preferentially selected for discharge at low flows. At high flows from the Roanoke Rapids Reservoir, sufficient surface-layer water is incorporated in the discharge so that the effect of the degraded water is largely cancelled.

(g) As a result of the process described above, the dissolved oxygen content of the discharge from the Roanoke Rapids Reservoir increases or decreases as indicated in the conclusions contained in Special Report No. 1.

(h) At low total turbine discharges, the process of splitting the flow between two turbines, thus taking advantage of maximum addition of oxygen by vacuum-breaker operation but at a loss of power production, can effectively eliminate the problem of low dissolved oxygen at minimum flows.

(i) Because of increased dilution at higher flows and since the incorporation of increased amounts of surface layer water in the discharge drawn across the weir at high flows largely cancels the effect of the degraded water displaced upward by recent Kerr releases, no serious problem regarding pollution abatement downstream from Roanoke Rapids Reservoir exists at high discharge rates.

(j) From the standpoint of hydraulic performance the weir at Roanoke Rapids serves as a model for the proposed weir in the proposed Gaston Project.

(k) Because of greater storage volume and greater surface area of the Gaston Project, appropriate adjustments must be used when applying, to the proposed Gaston Project, the results of Roanoke Rapids Reservoir studies of water-mass displacement, degree of stratification, depth of the mixed layer, and effectiveness of photosynthetic oxygen production and atmospheric aeration.

(l) Significant quantities of degraded water will not likely be rapidly lifted above the weir crest in the proposed Gaston Project by large inflows from Kerr Reservoir as is the case in the Roanoke Rapids Reservoir. Instead, intermediate depth waters will be slowly lifted into the surface layer where photosynthetic oxygen production and atmospheric aeration are effective.

(m) The average time that the water passing through the proposed Gaston Project would be retained in the euphotic zone (18 to 24 days) would be sufficiently long to provide for significant additions of oxygen through photosynthetic production. During any periods of reduced yield by photosynthetic processes, atmospheric aeration would contribute significant quantities of oxygen to the upper layers of the proposed Gaston Project.

(n) Because of the low temperature of the oxygen-deficient waters that would be discharged from Kerr Reservoir into the proposed Gaston Project and the consequent likely location of the thermocline closer to the surface than that observed in Kerr Reservoir, the weir in the proposed Gaston Project should have a crest 15 feet below full power-pool level rather than the 25 feet as now constructed in the Roanoke Rapids Reservoir.

(o) Since the proposed Gaston Project would function for peaking power production only, the flow pattern associated with its weir would be that observed in Roanoke Rapids Reservoir for high discharge, as modified for a shallower depth of the weir crest. Thus, the waters drawn across the proposed weir in the proposed Gaston Project would originate primarily in the upper 10 feet thereof.

(p) It is calculated that the dissolved oxygen in the waters that would be discharged from the proposed Gaston Project during the critical summer period, would be at least 6 ppm and that the temperature of this discharge would approximate 78°F.

(q) The dissolved oxygen content in the waters released from Roanoke Rapids Reservoir would be at least 6 ppm and, in most cases, even higher.

(r) Catastrophic turnover would not occur either in the proposed Gaston Project or the Roanoke Rapids Reservoir. The deep pools of cold water retained behind the weirs would provide sufficient stability so that the fall overturns would proceed in a step-by-step manner, with the thermocline slowly increasing in depth as surface cooling continues.

A SUMMARY OF THE REPORT OF THE ROANOKE RIVER INVESTIGATION, SUMMER, 1957 - PREPARED BY C. H. HULL - BASED ON DISCUSSION BY DR. D. W. PRITCHARD[51]

This summary was presented at the meeting of the Steering Committee, Roanoke River Studies, March 27, 1958, as a simplified summary of Special Report No. 1.

Natural surface streams in the absence of contamination absorb oxygen from the atmosphere until near saturation. If wastes were added to the stream, dissolved oxygen is removed at an increased rate and, if it is removed faster than it can be replaced, it may be reduced to levels harmful to fish and other aquatic life. This is particularly true in summer periods when, at the increased temperature, the saturation value is lowered. If not overloaded with natural or manmade pollution, a shallow, swift, and turbulent stream absorbs oxygen from the air fast enough to replace that absorbed by pollution.

When a stream is impounded by a high dam, a deep lake is formed in which the water moves much more slowly, and the surface area of a given volume of water is much smaller than in the natural stream, resulting in reduced ability of the water to absorb oxygen from the air. In the upper part of the reservoir, this is partially balanced by the greatly increased time of exposure to the atmosphere. However, during the summer season the sun warms the surface layers so that they are lighter than the deeper layers of water resulting in thermal stratification. The deeper layers are thus cut off from circulation with the surface so that oxygen is not carried to these waters as it is used in the process of decay of natural organic matter and pollution. This results in lower dissolved oxygen in the deep waters which lasts until colder weather in the fall cools the surface waters, making them heavier. When the density reaches that of the deep water, the entire reservoir mixes again so that the oxygen content of the bottom waters is restored through mixing with the surface water and exchange at the water surface.

When hydreoelctric power plants are constructed so that the inlets to the turbines are located deep in the reservoir, it can be observed that the water discharged is selected exclusively from the layers at the intake depth. During the period of summer stratification when this water is low in dissolved oxygen, a problem results when the water is passed on downstream. If plant intakes are at relatively high levels in the dam, they select water from their own level, thereby passing on downstream surface water of relatively high oxygen content.

Data on year-round oxygen concentration of water discharged from reservoirs in the Tennessee Valley Authority were reviewed. During the critical summer period, dams with the deepest intakes discharged water of very low oxygen content, dams with intermediate-level intakes discharged water of higher oxygen content, and dams with high-level intakes discharged water of still higher oxygen content. "From these observations, it was reasoned that if in some way the effect of a high-level intake could be obtained in the Gaston Project, the anticipated condition of low oxygen in the water discharged downstream would be remedied."

A submerged weir was proposed for construction around the Gaston turbine intakes as a solution to the problem of low D.O. discharge from low-level intakes. The submerged weir would form an underwater baffle to obstruct passage of deep water into the turbines so that water would be selected for discharge from levels above the crest of the weir in the same manner as observed for high-level intakes.

Since the concept of a submerged weir was new, it was felt that the ability of such a device to perform as a high-level intake should be verified. Model studies were rejected because of the difficulty of scaling certain controlling hydraulic features and the impossibility of including the many factors found in nature. Other remedies for low oxygen content in reservoir discharges were also studied including artificial aeration of water immediately downstream from the dam and spillage of water over the top of the dam. These were all rejected in favor of the suberged weir method. In order to determine the effectiveness of the submerged weir in improving the dissolved oxygen discharged, VEPCO constructed a full-scale submerged weir in the existing Roanoke Rapids Reservoir in the summer of 1957.

"A comprehensive survey was planned jointly by the Steering Committee (Roanoke River Studies) and VEPCO and carried out during the late summer and early fall of 1957. This was one of the most intensive limnological studies ever performed anywhere, involving more than twenty engineers, chemists, biologists, limnologists, and samplers. Upwards of 15,000 separate chemical and physical measurements of water quality were made. Several thousands of man hours were consumed in carrying out the survey."

The survey resulted in the following findings and conclusions:

(1) The submerged weir in Roanoke Rapids functions effectively at all times as a high-level intake, selecting water almost exclusively from levels above the crest of the weir.

(2) The weir causes a significant improvement in average water quality. However, due to the relatively small storage capacity of Roanoke Rapids Reservoir compared to large releases from Kerr Dam, such releases cause occasional displacement of low-quality water from intermediate levels upward into the layers above the level of the weir. The water thus displaced upward then becomes available for withdrawal over the weir. Under an unusual combination of factors, water thus selected may at times be of undesirably low oxygen content. Although these unfavorable conditions represent a very small proportion of the time and of the total water released, they are severe enough to cause a downstream problem unless corrected. Means for correction are available, as explained later.

(3) The submerged weir has effectively solved the problem of water quality at high flows below Roanoke Rapids Dam. No other proven method of correcting the low oxygen conditions at high flows is available. Dissolved oxygen in these flows will meet the assigned stream classification of 4.0 ppm at all times, and the dissolved oxygen above 4.0 ppm, coupled with the large dilution factor of the high flows, provides an excess of waste capacity above that needed in the Roanoke Rapids-Weldon area. (During the survey, when the discharge from Roanoke Rapids Dam was higher than 2500 cfs, the D.O. at the N. C. 48 Bridge was never less than 4.0 ppm; ninety per cent of the time, it exceeded 5.5 ppm.)

(4) At discharge rates of less than 2000 cfs through a single turbine at Roanoke Rapids Dam, air is admitted to the turbine through a device called a "vacuum breaker" in order to relieve negative pressures in the turbine. The oxygen thus admitted is absorbed by the water, thus raising its oxygen content appreciably. This improvement can be increased by dividing the low flow between two turbines instead of one. The improvement resulting from this procedure can be seen in the graph, figure 6 [not included], which shows actual increases exceeding 2.25 ppm. Although it results in significant power loss, "split-wheel" operation can be used to eliminate the severe low oxygen conditions, as noted above, which can be expected occasionally until Gaston Dam is constructed. As noted below, the Gaston Project should eliminate the cause of these extreme low oxygen conditions, and thereby eliminate the need for split-wheel operation at low flows.

(5) Based on observations in Roanoke Rapids Reservoir, the weir in the proposed Gaston Reservoir should be redesigned to extend upward to within 15 feet of the surface, instead of the 25 feet depth originally planned.

(6) The weir in Roanoke Rapids Reservoir serves as an adequate "model" for predicting the hydraulic characteristics and functioning of the proposed Gaston Weir. However, because of its small size, Roanoke Rapids Reservoir can not be complete in all respects as a model for the much larger Gaston Reservoir. The increased size of Gaston will permit both greater retention times for all flows and greater buffering of high surge flows from Kerr Reservoir. Either of these two benefits of the in-

creased size of Gaston Reservoir over the Roanoke Rapids Reservoir would by itself provide a significant increase in water quality. Neither of these effects could be satisfactorily modeled. Other significant differences between the two reservoirs exist, including operationg methods. These differences must be considered in predicting the effect of the Gaston Project on downstream water quality. A most important item is that Gaston will operate as a peaking-power plant with no releases at low rates. Thus the conditions which combine to give low oxygen at low flows in Roanoke Rapids will not occur in the proposed project.

(7) Taking all factors into account, it is predicted that Gaston Dam, if provided with a submerged weir extending to within 15 feet of the surface, will discharge water with minimum dissolved oxygen concentrations of 6.0 ppm. (This prediction is based on voluminous records acquired during the survey and translated to conditions as they will exist in the Gaston Reservoir.) The average oxygen content will be considerably greater. This will provide higher oxygen content in the inflow to Roanoke Rapids Reservoir than the minimum of 5.2 ppm observed under present pre-Gaston conditions. Furthermore, it is estimated that dissolved oxygen values as low as 3.0 ppm can occur in the natural river at the Gaston Dam site prior to completion of the Gaston Dam.

(8) Gaston Dam, with a submerged weir, will discharge water of about 75° temperature. This is considerably warmer than the water now entering Roanoke Rapids Reservoir. This change will eliminate the displacement effect in the smaller reservoir, noted previously, which causes the occasional low oxygen values observed. The water released from Gaston Dam will flow through the surface layers of Roanoke Rapids Reservoir, and as a result, should gain more oxygen on the way.

(9) The water released from Roanoke Rapids Dam following construction of Gaston Dam with the proposed weir will have oxygen content greater than can be expected under present conditions. The post-Gaston minimum values are predicted to be not less than 6.0 ppm, compared to the observed minimum of 2.7 ppm under existing conditions for single-wheel operation.

COMMENTS ON PROBABLE EFFECTS OF A SUBMERGED WEIR IN GASTON RESERVOIR ON DISSOLVED OXYGEN CONCENTRATIONS DOWNSTREAM[52]

Comments on Special Report No. 1 by Mr. M. A. Churchill, chief, Stream Pollution Control Section, Tennessee Valley Authority, were made at the request of the Subcommittee for Operations of the Steering Committee for Roanoke River Studies. The Subcommittee summarized his comments in the Summary Report Covering Special Report No. 1, Roanoke River Studies, as follows:

> In his statement, Mr. Churchill points out that his comments are based not only on the reported data contained in Special Report No.1, but also on observations of a similar nature on TVA reservoirs having both high-level and low-level power intakes. He then offered the following comments and observations:
>
> (a) The main points made in Special Report No. 1 concerning the way in which water will flow through the proposed Gaston Reservoir are correct. The proposed weir will produce essentially the same hydraulic flow pattern through the pool as power intakes located high on the face of the dam. The weir should, however, be constructed at as high a level as permitted by the lowest level to which the pool must be drawn so that it will skim water off the surface only in order that the released water will have the highest possible dissolved oxygen concentration.
>
> (b) The weir crest should not be so long as to allow velocity distribution over it similar to those observed over the Roanoke Rapids weir at low flows.
>
> (c) Cold inflows from upstream storage reservoirs will move through downstream pools at their corresponding density level. Therefore, if the proposed Gaston Reservoir could be kept filled to weir crest level with water colder than that entering from Kerr, this would force the inflow to pass through Gaston in the surface layers where it will be oxygenated by natural reaeration and by algae-produced oxygen.

(d) Based on reaeration coefficients for TVA reservoirs, the dissolved oxygen concentration in the Gaston outflow should, except possibly for a very rare event, be in the range of five to six ppm if the weir is submerged no more than 15 feet (below full power-pool level) and the discharge rates are not less than 5,000 cfs.

(e) With a submerged weir in the Gaston Reservoir, it is reasonable to assume that the released water would be warm enough to flow through Roanoke Rapids Reservoir at a depth not greater than 20 feet; therefore, low D.O. water from below the weir crest level in the lower pool would not be lifted above the weir crest. This being the case, D.O. in the outflow from the Roanoke Rapids Reservoir should not drop below about 5 to 6 ppm.

(f) If flows were cut off at both Gaston and Roanoke Rapids for a week or more in midsummer, it is possible that subsiding dead algae could produce a layer of low D.O. water above weir crest level in Roanoke Rapids. Subsequent low releases from Roanoke Rapids would then show low D.O. concentrations. The occurrence of such a situation would appear to be a very rare event.

(g) On the off chance that low D.O. water might be discharged over the existing weir in Roanoke Rapids Reservoir, this weir might be effectively raised by a number of means that would still permit the desired pool level fluctuations for pondage. Steel plate extensions could be added to the existing fixed weir in such manner as to stand vertically at full-pool level and rotate to a nearly horizontal position at low pool levels. The steel plate extensions could be float supported and hinged at the bottom to a concrete slab laid on top of the existing stone weir. Tight joints would not be necessary.

(h) If releases of water of low oxygen content at Kerr Reservoir could be converted into high-oxygen releases, most of the problems downstream would be eliminated or greatly reduced in magnitude. Float supported extensions of existing power penstocks in Kerr would effectively prevent such low oxygen releases. This would present a number of design problems and would be expensive but the over-all downstream benefits would also be high.

LETTER REVIEW OF SPECIAL REPORT NO. 1
ROANOKE RIVER STUDIES[53]

Comments on Special Report No. 1 by Mr. T. M. Riddick, consulting engineer and chemist, and engineer who has represented Halifax Paper Company, were made at the request of the Subcommittee for Operations of the Steering Committee for Roanoke River Studies. The Subcommittee summarized his comments in the Summary Report Covering Special Report No. 1, Roanoke River Studies, as follows:

> Mr. Riddick in his review takes issue with many of the individual statements contained in Sprical Report No. 1. He points out the importance of the Roanoke River from the standpoint of established uses and expresses concern over the possibility that the dissolved oxygen in the river, after further impoundment, will be insufficient to satisfy the waste loadings which have been assigned and provide a suitable habitat for fish. The following is a summary of his comments:
>
> (a) Whereas average values as quoted in Special Report No. 1 are significant in evaluating the overall waste assimilating capacity of the river, only minimum values have real significance in relation to the preservation of the fishery.
>
> (b) Aside from the potential threat of low quality water to the fishery, the downstream water users are incumbered by the wide variation in dissolved oxygen concentrations that have accompanied impoundment of the Roanoke River as well as the association of low dissolved oxygen concentrations with minimum river discharges.
>
> (c) The report points out the advantages of the high level weir in improving average conditions (compared with those which would have prevailed had no weir been installed), but it does not show that the weir will, under conditions of low flow and low-dissolved oxygen concentrations, prevent intolerable conditions as far as downstream waste assimilating capacities are concerned.
>
> (d) The potential reaeration capacity of the proposed Gaston Reservoir has been over-estimated by placing primary reliance upon photosynthesis. While photosynthesis is undoubtedly

helpful, the principal reaeration takes place at the water surface and the oxygen dissolved from the atmosphere is transferred to the lower depths of the zone of circulation by diurnal changes in temperature at the water surface, and by wind action.

(e) The real crux of the situation is the poor quality of water discharged, and which will be discharged into perpetuity by Kerr Reservoir unless corrective measures are taken. This condition can probably be corrected by the installation of a half-moon shaped cut-off wall of sheet steel piling in Kerr Reservoir to permit withdrawal of top lying waters only. It is not too much for the State and other concerned parties to request Kerr Dam and VEPCO authorities to spend another sum from $250,000 to $1,000,000 for correcting a condition that should not have been created in the first place.

(f) A floating weir consisting of structual steel members with a 1/2 " plastic face could be constructed for the proposed Gaston Dam so as to permit withdrawal from the top five feet only. If this was done and Kerr Reservoir similarly corrected, it is believed that all concerned parties would quickly and heartily approve such a solution.

A REPORT ON A STUDY OF THE EFFECTS OF A SUBMERGED WEIR IN THE ROANOKE RAPIDS RESERVOIR UPON DOWNSTREAM WATER QUALITY

Comments on Special Report No. 1 by Mr. F. W. Kittrell, in charge, Stream Sanitation Studies, Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, were made at the request of the Subcommittee for Operations of the Steering Committee for Roanoke River Studies. The Subcommittee summarized his comments in the Summary Report Covering Special Report No. 1, Roanoke River Studies, as follows:

> At the outset of his statement, Mr. Kittrell recognized the pioneer nature of the investigation reported in Special Report No. 1 and observed that almost certainly there is no precedent for the projection of such an investigation and evaluation to the prediction of the performance of a proposed reservoir which would be similar

to an existing reservoir in some respects, but dissimilar in others. He states that in view of this lack of precedent as well as the limited amount of time for the performance of the investigation and preparation of the report, his coments were presented with understanding of and sympathy with the complexity of the situation. His presentation discusses the various weaknesses in material, in logic, in assumptions made, and in conclusions reached. The conclusions given in his statement are summarized as follows:

(a) Both the lack of precedent for this particular type of investigation and the limited time available for its performance made necessary the use of a number of assumptions in predicting the probable dissolved oxygen content of the water that would be discharged from the proposed Gaston Reservoir. The soundness of judgement exercised in selection of these assumptions largely governs the accuracy of the predictions.

(b) Two examples are offered wherein relatively conservative changes in basic assumptions markedly affected the resulting predictions. Evaluation of the report is made difficult because details are omitted which are necessary to trace all of the steps used in development of the data. It is recognized that these details could not be included without the report becoming excessively lengthy.

(c) The philosophy of the report deals with averages rather than minimum conditions. The report would be strengthened if the worst combination of conditions that might occur were examined and their probable frequency of occurrence estimated.

(d) In spite of the adverse coments on certain features of the report, it has shed light on details of reservoir mechanism that previously were not so well understood. In the light of this new knowledge and on the basis of considerable experience with reservoirs he expressed the opinion that creation of Gaston Reservoir, with the proposed submerged weir 15 feet below the surface (i.e., full power-pool level), would not make conditions worse than they presently are, and in fact hold promise of improvement in the present situation most of the time. At times, however, there may be combinations of unusual circumstances that can produce conditions, for short periods, that will be as bad as, or possibly worse than, those at Roanoke Rapids Dam.

(e) The experimental operation of vacuum breakers at Roanoke Rapids Dam showed promise as a possible expedient for dealing with temporary low dissolved oxygen conditions. Uses of similar devices, possibly specially designed for the purpose of adding D.O. to the water in the penstocks at Gaston, might well receive consideration.

(f) The part played by Kerr Reservoir in the overall Roanoke River situation is important, because it is within the depths of Kerr that the initial dissolved oxygen depletion occurs. Based on technical consideration only, "it appears reasonable to suggest that the feasibility of improvement in the dissolved oxygen of water discharged through Kerr Dam should be examined." Unless such improvement can be made, the threat of occasional low dissolved oxygen concentrations in the Roanoke River below the Roanoke Rapids Dam will persist despite the best efforts of those responsible for Roanoke Rapids Reservoir and the proposed Gaston Reservoir.

SUMMARY REPORT COVERING SPECIAL REPORT NO. 1, ROANOKE RIVER STUDIES ENTITLED: "A REPORT AND STUDY OF THE EFFECTS OF A SUBMERGED WEIR IN THE ROANOKE RAPIDS RESERVOIR UPON DOWNSTREAM WATER QUALITY - FEBUARY 6, 1958[56]

This report was prepared to summarize Special Report No. 1, to summarize the consultants' reports on it, and to express the conclusions and recommendations of the Subcommittee for Operations, Roanoke River Studies. The conclusions and recommendations of the Subcommittee for Operations are reproduced below.

> A through review of both Special Report No. 1, Roanoke River Studies, and the comments submitted by the Special Consultants (Churchill, Kittrell, and Riddick) has been made by the Subcommittee for Operations. While there is not unanimous agreement on the part of all members of the Subcommittee concerning certain statements and conclusions presented in that report and comments cited above, it is recognized that the special reservoir study and report have made available invaluable data and a much clearer understanding of the problems involved. The Subcommittee, in accordance with its assigned responsibilities, has reached certain conclusions which are presented below together with recommendations concerning the problems under consideration.

CONCLUSIONS

1. The Lower Roanoke River, because of the large volume of water it carries, the present uses served by it, and its latent possibilities for further development is the dominant factor in maintaining and improving the economy of the entire Lower Roanoke River Valley. It is, accordingly, an inescapable responsibility of all users of the river to establish and carry out such measures as are necessary for the conservation of these waters.

2. The existing flood control and hydroelectric projects (Kerr and Roanoke Rapids Reservoirs) are both desirable and beneficial; however, they have, because of low-level intakes which discharge water of low or depleted oxygen content, seriously reduced water quality in Roanoke River below the dams. This has greatly reduced the capacity of the river to assimilate existing waste discharges in the Roanoke Rapids - Weldon Area, and during periods of critical stream flow and temperature conditions, the dissolved oxygen in the river has been reduced to levels dangerous to fish and wildlife. These levels have been less than those specified by the classification assigned to the river by the State Stream Sanitation Committee.

3. Extensive studies of the effects of impoundment and waste discharges upon water quality in Roanoke River have indicated the need for (1) improving the dissolved oxygen content of water discharged from the Kerr and Roanoke Rapids Reservoirs and (2) for providing treatment for the municipal and industrial wastes discharged to the river.

4. The following means for obtaining the highest quality water from the existing and proposed reservoirs are suggested: (1) raising the weir at the Roanoke Rapids Dam to not more than 15 feet below the full power-pool level; (2) installing a weir in the proposed Gaston Project at a depth of not more than 15 feet below full power-pool level; and (3) so modifying the intake structures at Kerr Reservoir as to permit withdrawal of top lying waters only; and, further (4) employing other feasible means for increasing dissolved oxygen, including split-wheel operation or by introducing oxygen into the discharge.

RECOMMENDATIONS

1. It is recommended that the Steering Committee for Roanoke River Studies endorse the proposed Gaston Project subject to agreement on the part of Virginia Electric and Power Company to the following license provisions:

   (a) The reservoir shall be constructed with a submerged weir having a uniform crest at an elevation no more than 15 feet below the full power-pool level.

   (b) The licensee shall take such additional measures as may be required to discharge water of such quantity and quality from the Roanoke Rapids Reservoir as to maintain adequate dissolved oxygen, above the required minimum of 4.0 ppm at the first major oxygen pounds per day as determined by the North Carolina State Stream Sanitation Committee in terms of 5-day 20°C B.O.D., but under no circumstances shall the instantaneous discharges be reduced to the extent that the dissolved oxygen, above 4.0 ppm, is less than that required to produce a waste assimilative capacity at the rate of 70,000 pounds per day.

   The attached graph entitled "Roanoke River - Graph Showing Assimilative Capacity in River Below Weldon for Various Discharges and D.O.'s at Critical Temperature of 25° Centigrade" has been prepared from available data. The assimilative capacity given represents that which is provided by the dissolved oxygen above the 4.0 ppm required for fishing waters. The discharges required to provide a minimum daily waste assimilative capacity for various dissolved oxygen concentrations may be determined from the graph. It is believed, therefore, that the attached graph will serve as a useful tool for scheduling discharges from the Roanoke Rapids project in relation to the dissolved oxygen content of the water as measured at Highway 48 Bridge to produce the minimum instantaneous and minimum daily assimilative capacities of 70,000 and 109,000 pounds per day. The chart maybe verified and amended as required to include other D.O. values if needed.

Note: The graph of assimilative capacity referred to in subsection (b) is reproduced as Figure 3 in this report.

(c) The licensee shall provide special flows during the striped bass migration and spawning season in accordance with the recommendations of the Steering Committee for Roanoke River Studies and/or the North Carolina Wildlife Resources Commission and the U. S. Fish and Wildlife Service.

2. The Steering Committee should request the Corps of Engineers, U. S. Army, to study and develop appropriate methods for improving the dissolved oxygen content of the water discharged from the John H. Kerr Reservoir.

REPORT OF THE STEERING COMMITTEE FOR ROANOKE RIVER STUDIES, 1955-1958[64]

The results of the activities of the Steering Committee for Roanoke River Studies are consolidated in this report. The Committee, formed at the suggestion of Congressman Herbert C. Bonner in May 1955, had as its objective the development of a comprehensive solution to the problems of the lower Roanoke River which would protect all legitimate river uses, yet, permit the optimum beneficial use of the limited resources of the river. Of primary concern was the establishment of minimum flows for the Roanoke River below Roanoke Dam which would be equitable to all legitimate river interest. The report presents a review of past river studies and discusses in detail the toxicity and spawning activity studies carried out in connection with the spawning flows. The engineering studies of the effectiveness of the submerged weir in Roanoke Rapids Dam were not included since a separate report[48] had already been prepared.

The summary and conclusions of the Steering Committee are presented as follows:

1. Minimum Flow Requirements

The primary objective of the Roanoke River Cooperative Study was to establish a schedule of minimum flows for the Roanoke River below below the Roanoke Rapids Dam, founded upon the facts of river performance, that would be equitable to all legitimate river interests.

For convenience, considerations of minimum flows are divided between two unrelated categories: (1) the minimum flows required to maintain legally assigned classification standards; and (2) the river flows that are required to fulfill physiological requirements of the striped bass, and other anadromous fishes, during their short annual migrations and spawning.

a. Minimum Flow Requirements Respecting River Sanitation

The need for a final decision by the Steering Committee regarding the minimum flows required in the Roanoke River for waste assimilation and the maintenance of the classification standards assigned by the State Stream Sanitation Committee arose early in 1959. Following a series of negotiations over minimum flows with the various river interests, the Virginia Electric and Power Company filed an amended application with the Federal Power Commission during April of 1959. The amended application requested immediate consideration of License 2093 which would authorize the construction of the Gaston Project by the power company. Action upon the applicant's previous request for License 2093 had been deferred by the Federal Power Commission following receipt of a petition for leave to intervene filed by the Halifax Paper Company under date of June 20, 1955, and written objections to the Gaston project, as then planned, by the North Carolina Wildlife Resources Commission and the State Stream Sanitation Committee.

The Steering Committee has concluded that, it is reasonable that the Roanoke River water quality in terms of waste assimilation capacity as measured at the NC-48 Highway bridge must be maintained at a level equivalent to that which prevailed under the weekday minimum river flows of August, 1953. The average quantity of oxygen dissolved in the river water at that point during the 2,000 cfs weekday minimum flows of August, 1953, coupled with the dissolved oxygen added to the river water by reaeration as it moved downstream, would permit loading the Roanoke River in the Roanoke Rapids-Weldon area with organic wastes equivalent to 109,000 pounds of 5-day, 20°C., BOD without reducing dissolved oxygen concentrations downstream below the assigned minimum classification standard of 4.0 parts per million. The strength of BOD loading that a river will absorb at any given point without subsequent reduction of the dissolved oxygen below a fixed value generally is known as the "assimilative capacity" of the river at that point. The State Stream Sanitation Committee based its Comprehensive Pollution Abatement Plan for the lower Roanoke River upon on assimilative capacity at the NC-48 Highway bridge sufficient to absorb 109,000 pounds of BOD waste loading per day and required the polluters in the Roanoke Rapids-Weldon area to provide waste treatment facilities sufficient to restrict the BOD river loadings at minimum flows within that limit. The 72,500-pounds-per-day difference between the 214,000 pounds of BOD assimilative capacity estimated available per day under the average flows of August, 1953 (3,980 cfs), and the 141,500 pounds of BOD assimilative capacity present at the same average daily river flow with the oxygen content of the river water reduced to agree with the Virginia Electric and Power Company's post-Gaston river-water oxygen predictions constituted the power company's equitable share in the assimilative capacity of the river. The Steering Committee for Roanoke River Studies reaffirmed its position at a meeting held on November 28, 1956.

The Virginia Electric and Power Company firmly rejected the proposed restrictions placed upon their future Roanoke River operations by the Steering Committee. The controversy finally resulted in the Virginia Electric and Power Company submitting an application to the Federal Power Commission requesting immediate consideration of the Gaston project and thus referring the issue to the Commission for final decision.

The Steering Committee for Roanoke River Studies was called into session on March 26, 1959, to clarify its position in respect to the proposed Gaston project. The Steering Committee voted to withdraw objections to the Gaston project subject to agreement by the Virginia Electric and Power Company that, in the future, the Roanoke Rapids powerhouse would discharge water of such quantity and quality as to:

> ...maintain adequate dissolved oxygen, above the required 4.0 ppm at the critical point of the first major sag, to provide a minimum waste assimilative capacity of 109,000 pounds per day, as determined by the State Stream Sanitation Committee, in terms of 5-day, 20°C, BOD using the Thomas modification of the Streeter-Phelps oxygen sag equation.

The Steering Committee further recognized that circumstances might arise beyond control of the power company wherein the dissolved oxygen concentrations of the water discharged from their Roanoke Rapids powerhouse might fall below that quantity required to sustain the assimilative capacity of 109,000 pounds per day at minimum flows. Under these circumstances, the assimilative capacity of the river could be maintained at the 109,000-pounds-per-day rate only by the release of water in excess of the minimum flow schedule. To avoid the unnecessary wastage of water at times when no peak power demand existed, the Steering Committee further acceeded to the Virginia Electric and Power Company the right to provide an instantaneous waste assimilative capacity as low as the rate of 70,000 pounds per day. The reduced assimilative capacity rate, however, could not prevail for longer than eight hours and must be followed immediately by flows of sufficient magnitude to provide assimilative capacity in excess of the 109,000-pound-per-day rate. The excess rate of assimilative capacity would be maintained at such a level as would compensate for the accumulative deficit within a maximum period not exceeding one-half the duration of the oxygen-deficient flows.

The Steering Committee further stipulated that under all circumstances, the Roanoke Rapids powerhouse must maintain instantaneous discharges of not less than: 1,000 cfs during the period November through March, inclusive; 2,000 cfs during April and October.

The Steering Committee for Roanoke River Studies acted with the conviction that the foregoing stipulations regarding the proposed Gaston project are essential--in light of the known facts of river performance--if the terms of the State's Pollution Abatement Plan for the lower Roanoke River are to be met. Any compromise towards less stringent requirements for the Gaston project inevitably must result either in abrogation of the assigned minimum classification standards for the lower Roanoke River or in the imposition of more drastic requirements for waste treatment placed upon the downstream polluters to compensate for the further reduction of the river's assimilative capacity by the Virginia Electric and Power Company's impoundments.

b. Minimum Flow Requirements Respecting the Physiological Needs of the Striped Bass

The minimum river flows required to satisfy the physiological requirements of the striped bass during their annual spawning in the Roanoke River are less susceptible to conclusive proof than are the minimum flows required for river sanitation.

The duration of the period when minimum flows in excess of those required for river sanitation are required for striped bass spawning can be reliably estimated. The adult fish participating in the annual spawning migration first enter the mouth of the Roanoke River during late February or very early March--the time depending in large part upon climatic conditions. Successive recruitments of adult fish to the spawning population continue until well into May when the last of the spawning fish enter the river. The first adult migrants of the season are caught in the vicinity of Roanoke Rapids-Weldon around April 1. The spawning migrants then accumulate over the rapids area in ever-increasing numbers until the time of first spawning--which is rather clearly defined by water temperature. The time of first spawning usually occurs sometime during the late April or early May, depending upon climatic conditions of the year in question. Following the initial spawning of the season, which may be very intense if water temperatures rise rapidly, large numbers of the spent females apparently return to the Sound. The size of subsequent populations on the spawning grounds is then governed by the rapidity of recruitment from later-running fish from the Sound. Spawning usually subsides in the Roanoke Rapids-Weldon area between June 1 and June 15, depending upon seasonal water temperatures and stream flows. The spawning population of striped bass, therefore, are within the zone of direct river influence during a period of some 120 days--extending from the time the first adult migrant enters the river about March 1 until the last fry has left the river sometime around July 1. The time of most critical exposure to river conditions extends over a much shorter period from the time adult fish have congregated in the rapids area in large numbers (about mid-April) to shortly after the last significant spawning has occurred in the river above Scotland Neck--about June 15 under present conditions. The period during which supplemental minimum river flows are required for protection of the striped bass spawning therefore extends from April 1 to June 30--with the most critical requirements existing between April 25 and June 10.

The location within the river where supplemental flows are most favorable to spawning conditions for the striped bass are even less well defined. Generally, it may be considered as that part of the river accessible to striped bass above the US-258 Highway (Scotland Neck) bridge at River Mile 102.4. The rapids area--extending from the downstream end of the Roanoke Rapids powerhouse tailrace (approximately River Mile 135.4) across the eastern margin of the fall line to the "Sluice" immediately below the US-301 Highway bridge (approximately River Mile 129.6)--is believed to represent the most valuable spawning area for the striped bass. This belief admittedly has not been subjected to accurate evaluation, and it is predicted upon the following assumptions:

(1) Some reason must underlie the choice of the Roanoke River as a spawning ground by the overwhelming majority of the Albemarle Sound striped bass. The Tar River forms the second, and numerically a far less consequential, spawning ground for the Albemarle Sound striped bass. These two tributaries apparently have some factor in common which the striped bass prefer for a spawning area. The most apparent common factor is that, unlike the other tributaries of Albemarle Sound, the Roanoke and the Tar contain rapids and the degree of usage of these two tributaries by the spawning striped bass appears roughly proportional to the original extent of their rapids sections. In this connection, it is noteworthy that in 1884 the U. S. Fish Commission--with the entire Atlantic Coast at their disposal--selected for hatchery site the Roanoke River rapids area as the location where the greatest concentration of striped bass were available for artificial propagation.

(2) The buoyancy of the striped bass egg changes markedly during incubation. As shown in Figure 10, these changes are most rapid during the first three hours of life. The fast, turbulent waters of the Roanoke River rapids provide a maximum rate of vertical water movement and, therefore, the most probable assurance that eggs will be held in suspension during the heavy stages immediately following spawning. After waterhardening, when the specific gravity of the egg more closely approximates that of the surrounding medium, buoyancy of the egg would be assured by much less rapidly moving water.

(3) When an abundance of water exists in the river, the striped bass demonstrate a marked preference for spawning in the rapids area. Conversely, spawning downstream from the rapids section appears to result, in most instances, from the fish being unwilling (or unable) to negotiate the rapids on low-water stages rather than from any preference on the part of the fish for the quieter, downriver area.

Considerable spawning by striped bass does occur each year in the quieter river sections below the rapids. Presumably, the products from spawning in the quieter river areas are not entirely lost, even though the probability of egg survival may be somewhat lower than in the fast water of the rapids. Quantitative data are lacking which demonstrate the comparative utilization of the rapids and the quieter downriver areas by spawning striped bass. There is, however, no convincing evidence contradicting the contentions of the of the Beaufort Laboratory staff of the U. S. Fish and Wildlife Service that: on a 13-15-foot Weldon stage, the majority of spawning occurs below River Mile 133; the fish move farther upstream to spawn when water levels and velocities are higher, and river discharges in excess of 15 feet at Weldon are required for full utilization of the rapids' spawning areas.

With the general limits established for the time period and the area of the Roanoke River over which supplemental flows may be required to meet the physiological requirements of the spawning striped bass, the question then follows as to what magnitude of minimum river flows is required.

The results obtained during the three-year Roanoke River Cooperative Study have not produced data by which the water flows required for optimum spawning conditions for the striped bass can be conclusively demonstrated. The results have conclusively demonstrated, however, that river conditions did produce one dominant year class (1956 brood) of striped bass during the study period. The minimum flows of 1956, per se, did not produce the dominant year-class. Minimum flows could have been but one--of presumably many--factors which, in the right

> combination, were responsible for the dominant year class. By the same reasoning, the minimum river stages that prevailed during the 1956 season patently did not preclude the development of a dominant year class when the remaining pertinent factors happened to line up the right way. The 1956 minimum river flows, therefore, may be accepted as a pattern for a minimum flow schedule that has demonstrated its efficacy.

Examination of the 1956 Weldon stage hydrograph during the striped bass migration and spawning season (see Figure 8), reveals an attraction flow reaching 23-24 feet on March 27, 28, and 29. A minimum river stage of 10.8 feet (2,000 cfs) then prevailed each day (and was sustained over week ends) between March 30 and April 15 inclusive. The disposal of surplus water from Kerr Reservoir occurred between April 16 and 21 during which period the daily river discharges at Weldon varied between the turbine capacity at the Roanoke Rapids powerhouse (ca. 24.6 feet, 20,000 cfs) and a minimum stage exceeding 20 feet. A single exception during this period was a minimum stage of 15.5 feet recorded on April 20. Between April 22 and May 2, inclusive, a steady 13-foot stage (5,550 cfs) was maintained except for occasional very brief power peaks slightly in excess of 15 feet (8,950 cfs) on April 26 and 27. On May 3, a minimum daily stage of 15 feet was established and maintained through May 18--with many power peaks and periods of sustained high flows (ca. 20 feet, 15,000 cfs) on at least four days during the 16-day period. Available evidence indicates that the bulk of the 1956 spawning occurred during the period of high minimum river stages between May 3 and 18. On May 19, the minimum river stage was reduced to the summertime weekday level of 10.8 feet (2,000 cfs). That year, it was very apparent that concurrently with the drop in minimum stage to 10.8 feet, virtually all fishing effort--and, presumably therefore, most of the fish then in the rapids area--immediately moved downstream several miles below Weldon.

It was concluded, in the light of all available evidence and observations, that the physiological requirements of the spawning striped bass will be fulfilled, at least in minimum degree, by the following schedule of minimum discharges--to be measured at the U. S. Geological Survey gage on the US-301 Highway bridge at Weldon:

(1) Instantaneous discharges of not less than 2,000 cfs from April 1, when the first of the spawners appears in the Weldon area, to the date when eggs are first detected in the river above Halifax--usually about April 25.

(2) Immediately following identification of first spawning, the instantaneous minimum river discharge of 8,950 cfs should be maintained to May 20, then reduced and held at 5,550 cfs until June 1 and as long thereafter as water conditions will permit.

Definite provisions should be effected with the Corps of Engineers and the Virginia Electric and Power Company whereby some flexibility will be permitted in scheduling minimum flow changes on the exact dates specified in the event of unusual climatic developments during certain years, or should the Gaston Reservoir--if constructed--significantly alter the current striped bass spawning pattern.

The recommendations of the Steering Committee for Roanoke River Studies are present below:

The Steering Committee for Roanoke River Studies recommends that:

A. Respecting Roanoke River sanitation, minimum river discharges--as measured at the U. S. Geological Survey Roanoke Rapids gage--be maintained in sufficient volume as to provide adequate dissolved oxygen above the required 4.0 parts per million at the critical point of the first major sag, for maintaining a minimum waste assimilative capacity at the NC-48 Highway bridge of 109,000 pounds per day--as determined by the State Stream Sanitation Committee in terms of 5-day, 20°C, BOD using the Thomas modification of the Streeter-Phelps oxygen sag equation. In the interests of more efficient power generation and to avoid a needless waste of water, an instantaneous waste assimilative capacity at a rate not less than 70,000 pounds per day shall be permitted under the conditions that the reduced assimilative capacity rate must not prevail for longer than eight consecutive hours and it must be followed immediately by discharges of sufficient magnitude to provide an assimilative capacity in excess of the minimum 109,000-pounds-per-day rate. The excess assimilative capacity rate must be maintained at a level sufficient to compensate for the accumulated oxygen deficit within a maximum period not exceeding one-half the duration of the oxygen-deficient flows. In addition, instantaneous discharges must be maintained in the river at the Roanoke Rapids gage site not less than 1,000 cfs during the period November through March, inclusive; 2,000 cfs during the period May through September, inclusive; and 1,500 cfs during April and October.

B. Supplemental river flows--as measured at the U. S. Geological Survey gage on the US-301 Highway bridge at Weldon--be provided during the annual spawning migrations of the striped bass and other anadromous fishes, in accordance with the following schedule: Instantaneous river discharges not less than 2,000 cfs between April 1 and April 25; instantaneous discharges not less than 5,550 cfs between April 26 and May 4; instantaneous discharges not less than 8,950 cfs between May 5 and May 20; instantaneous discharges not less than 5,550 cfs between May 21 and June 1 and as long thereafter as water conditions will permit.

C. The effective dates for the supplemental flows provided to meet the physiological requirements of anadromous fishes be susceptible to some modification to conform with climatic conditions of atypical seasons or to encompass any effects that the proposed Gaston Reservoir, if constructed, may exert upon the current striped bass spawning pattern.

D. Use of the water provided to meet the physiological requirements of anadromous fishes in excess of that provided under the terms of the sanitation flow schedule be denied to river polluters with controlled waste discharges. In other words, where wastes are proportioned to river flow, the proportion should continue to be coordinated with the appropriate sanitation flow and not increased to take advantage of the supplemental flows provided for the anadromous fishes.

E. A continuing investigation of the Roanoke River, the general areas of which should include:

1. Surveillance

   a. Respecting Water Quality

   Year-round monitoring of water quality with emphasis upon dissolved oxygen in the critical areas; to evaluate reservoir performance; to determine the efficacy of the pollution abatement plan recommended by the Steering Committee; and to provide a framework of reference against which post-Gaston river conditions can be compared. Toxicant monitoring also should be maintained in the critical areas--particularly during the striped bass season.

b. Respecting the Fisheries of the Roanoke River

Continuing studies of river and Sound catches of striped bass by number, gear, and age composition; spawning populations and escapement; egg production in terms of total numbers, location of spawning, and viability; young-of-the-year abundance estimates--all pointed towards an annual evaluation of the contribution with prevailing river conditions.

F. An informal organization of the river interests be formed to supplant the Steering Committee for Roanoke River Studies which, as an ad hoc committee, fulfills its purpose with the adoption of the Comprehensive Report of its study program. The organization should function primarily as a continuing forum for the expression and discussion of mutual interests of the river-water users in the orderly development of the lower Roanoke River basin.

THE RIVER DISCHARGES REQUIRED FOR EFFECTIVE SPAWNING BY STRIPED BASS IN THE RAPIDS OF THE ROANOKE RIVER OF NORTH CAROLINA (DECEMBER 1, 1959)[67]

The objective of this report was to present minimum river discharges considered necessary by the North Carolina Wildlife Resources Commission to assure effective spawning by the Albemarle Sound striped bass. The report reviews current knowledge of the life cycle of striped bass, emphasizing the necessity of a current speed sufficient to assure buoyance for the survival of the eggs.

The U. S. Fish and Wildlife Service estimated in 1946 that successful spawning could be maintained if minimum daily flows of 2,000 cfs together with average monthly flows of 6,000 to 9,000 during April and May were provided by the John H. Kerr Dam. In 1951 the Federal Power Commission license for Roanoke Rapids Dam provided for a minimum rate of flow of 2,000 cfs during the striped bass season for a period of up to 75 days between March 15 and June 15. It also required that flows should not be increased to double nor decreased to half in less than one (1) hour during the spawning season.

The North Carolina Wildlife Resources Commission, the State agency responsible for protection of the striped bass, has contended that the minimum flow schedule was inadequate to maintain successful spawning. VEPCO and the Corps of Engineers have cooperated with the Commission and provided minimum flows in excess of those stipulated by the Federal Power Commission.

Two reports were submitted to Task Force 3 of the Roanoke River Cooperative Study relative to the striped bass spawning area in the Roanoke River. Drs. Brandt and Hassler concluded that the majority of the spawning originated between river mile 108, above Scotland Neck, to river mile 130, at Weldon.

The U. S. Fish and Wildlife Services' Beaufort Laboratory concluded that spawning occurs predominantly from river mile 106 to river mile 137 but that at flows below 5,500 to 8,350, most spawning is confined below river mile 133. A minimum flow of 5,550 was recommended for access of both fish and fishing boats from Weldon to the vicinity of river mile 133.

THE MINIMUM RIVER DISCHARGES RECOMMENDED FOR THE PROTECTION OF THE ROANOKE RIVER ANADROMOUS FISH (DECEMBER 1, 1960)[74]

The objective of this report is to present further information on the minimum flows considered necessary by the North Carolina Wildlife Resources Commission to assure effective spawning by the Albemarle Sound striped bass. The Roanoke River is the most important spawning area for striped bass in North Carolina and is important in sustaining an annual harvest of approximately 600,000 pounds, economically one of the largest fishing industries in the State. The report reviews the information on the life cycle of the striped bass and the flow requirements which are or have been in effect since John H. Kerr Dam was completed. The conclusions of the 1959 report are repeated except that the recommendations for minimum flow releases are based upon the maximum peaking flow in the previous 24-hour period. This report further makes provisions for reducing the draft on water stored for maintaining spawning flows in exceptionally dry years so that it will not be prematurely exhausted.

It is the responsibility of the North Carolina Wildlife Resources Commission to protect the striped bass fishery in the Roanoke River

SECTION 10

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