



**Bulletin 23:**  
**SOME WATER QUALITY ASPECTS OF THE UPPER  
ROANOKE RIVER BASIN WITH SPECIAL EMPHASIS  
ON TEMPERATURE**

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RIVER BASIN WITH SPECIAL EMPHASIS ON TEMPERATURE

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## PREFACE

The successful development of a reversible pump-turbine has provided an additional source of hydroelectric power through pumped storage. This mechanical breakthrough has increased the number of potential sites where generators can be located. While most of America's electric power is still generated with conventional fuels, this new source of power provides additional peaking capacity through the utilization of surplus power. However, it represents another industrial device for altering water quality.

The report contains the results of a study undertaken by the Virginia Cooperative Fishery Unit on the Smith Mountain project. The study documents some of the before and after water quality features of the Roanoke River in the area of the pumped storage operation. Until now, there has been only a limited amount of data and little evaluation of the effects of such projects upon downstream water quality. While emphasis has been placed on water temperature regimes above, in, and below the project, there is considerable information on water chemistry and some of the operating dynamics which affect water quality.

The research is of particular interest because downstream water quality could affect the resident striped bass population of Kerr Reservoir. This species utilizes the long stretch of the Roanoke River between Clarksville and Altavista for spawning. This land-locked species relied on flowing water to suspend the semibuoyant eggs during the relatively short developmental stage. It has been shown repeatedly that water quality factors such as temperature and turbidity have a marked effect upon the successful spawning of anadromous fishes.

Nuclear power will cause the number of pump storage operations to increase throughout many sections of the country. Some sites which were considered less than ideal for conventional hydropower plants may be reevaluated as pump storage facilities. New and complicated water quality situations may develop in order to maintain water quality standards. To date very little thought has been given to the impact of a pumped-storage or water quality when the project was in the planning phases. Information from this study should contribute to water quality considerations in the initial planning of other pump storage projects.

William R. Walker  
Director



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## INTRODUCTION

The remarkable success of introducing several migrating fish species into inland waters has had its effect on reservoir operations. In fact, the planning, construction, and activity of some hydroelectric plants must take into account the protection of certain fishes. The unusual adaptability of striped bass, for example, has led to landlocked populations which are being "planted" all over the United States. These new "plants", in turn, are stimulating considerable interaction between industrial planners and governmental agencies for the purpose of effective management of both industry and natural resource.

It has long been known that striped bass moved up and down the Roanoke River near Weldon during their spawning run. After Kerr Reservoir was closed in 1952, an unexpected dividend was experienced in the observation that striped bass were present in the new impoundment. Whether they came from several large stockings by the North Carolina Wildlife Resources Commission in the time between 1953 and 1955 or from trapped specimens is uncertain. It was then found that yearling "rock fish" were creel in that reservoir in 1957 and 1958 which implied a reproducing population.

About this time final plans for the Smith Mountain and Leesville projects were being formed. Since a considerable distance of headwater stream is needed for successful spawning and recruitment of these bass, the Virginia Commission of Game and Inland Fisheries undertook a preliminary study of spawning and survival of the eggs from both the Dan and Roanoke Rivers. This was followed by a more detailed egg collecting study.

As a part of an amendment to the license arrangement, Appalachian Power Company agreed to maintain an increased flow not to exceed 2000 cfs for a 19-day period during the spawning season (April and May). The exact period was not specified but was to be designated by the Game Commission staff each year. Since the minimum average weekly flow was to be about 650 cfs, the 19-day augmented flow became an important component of the management for striped bass reproduction.

The effect of the Smith Mountain-Leesville complex on downstream water quality could only be conjectured prior to complete installation. Only a few pump-storage projects existed before the filling of Smith Mountain Reservoir in 1965. These were quite unlike Smith Mountain

as it has three penstock elevations and the lower two draw off very cold water year round. In addition, the pattern of downstream flow and water chemistry were also unknowns since the water was scheduled for daily cycling between the two reservoirs.

The present study was undertaken cooperatively by the Virginia Commission of Game and Inland Fisheries, Appalachian Power Company, and the Fishery Unit at Virginia Polytechnic Institute. The purpose was to document the water quality in Leesville Reservoir and the Roanoke River with special emphasis on temperature records. Information on the water quality during augmented flow was desired. Also, the thermal changes above and below Smith Mountain Dam were to be examined.

### Description of the Study Area

The Roanoke River rises in the Valley and Ridge Province west of Roanoke, Virginia. It flows in a general southeasterly direction through a short distance of Blue Ridge Province, meanders along the Piedmont Plateau for about 220 miles, descends the eastern escarpment at Roanoke Rapids, and travels over the Coastal Plain until it empties into Albemarle Sound, North Carolina about 410 miles total distance (1).

At its headwaters on the South and North Forks, its elevations are 2600 and 2900 feet, respectively. However, the river rapidly descends to 900 feet on the upper Piedmont at Roanoke, 580 feet at the mouth of the Pigg River at Leesville Reservoir and 260 feet at Clarksville. The latter two locations define the boundaries of the present study with the exception of some data at Smith Mountain Dam: this stretch of the Roanoke River is locally referred to as the Staunton River (2).

The total drainage of the Roanoke River Basin is 9580 square miles of which nearly two thirds lie in Virginia. There are 388 square miles above the city of Roanoke, 1802 square miles above Altavista, 3000 square miles above Randolph and 3546 above Clarksville (3, 4).

There are six subbasins which drain into the Staunton River (Fig. 1). Five enter from the Northeast and are: Goose Creek (mile 293), Big Otter River (mile 283), Falling River (mile 253), Cub Creek (mile 237), and Roanoke Creek (mile 224). The Pigg River enters the upper end of Leesville Reservoir from the southwest (mile 310). Together, they drain 1311 square miles of surrounding terrain. If the drainage from the minor creeks is added to these subbasins, there are approximately 2000 square miles of drainage

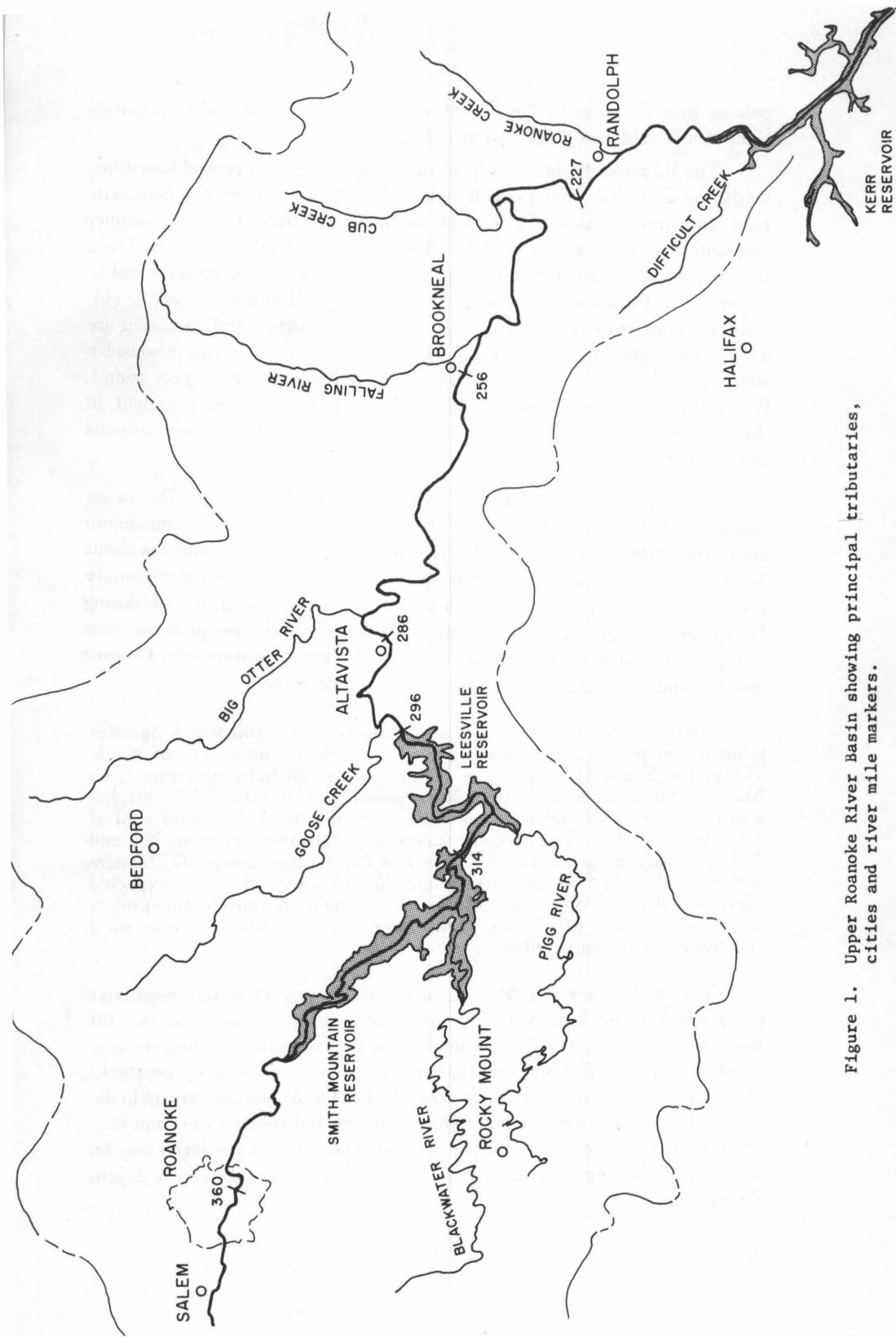


Figure 1. Upper Roanoke River Basin showing principal tributaries, cities and river mile markers.

coming into 87 miles of the Staunton River between the Smith Mountain Dam at mile 314 and Randolph at mile 227.

The Roanoke River at its headwaters passes through typical limestone, sandstone and shale valleys, and uplands: the water is of the carbonate type and mildly hard (5). Except during heavy runoff across summer cropland, the river is fairly clear. Then, from Lafayette to Niagra Dam, the river picks up an increasing load of assorted wastes and emerges highly colored and turbid into the upper end of Smith Mountain Reservoir (6). The Piedmont soils from Bedford County to the North Carolina border are derived from granite and schist (5). Thus, the tributaries contribute considerable suspended matter to the mainstream in the study area year round. Principally, the red-yellow podzolic soil group is the most prevalent in the Staunton River basin (7) the waters in tributaries of this area are siliceous and soft (5).

The climate of the area is mild to moderately severe. The mean minimum daily temperature is 29° F in January and the mean maximum daily temperature is 88° F in July. The average annual temperature is about 56° F. The mean annual rainfall is approximately 44 inches for the study area (8). The wettest season is usually in July and August but during December through March, one third of the annual precipitation gives rise to two thirds of the annual runoff: the driest season is in October and November. Average annual snowfall is 10-12 inches.

Smith Mountain Reservoir is a multipurpose reservoir which operates primarily for production of peaking power. The dam is located at river mile 314 in the Smith Mountain Gap which is about 28 miles upstream from Altavista, Virginia. The lake at maximum power pool elevation (795 feet), has a surface area of 21,000 acres and a storage capacity at maximum pool of 1,142,000 acre feet. The normal usable storage between elevations 787 and 795 (operating range) is 157,800 acre feet (9). Of this storage 37,760 acre feet is used for power production and 158,00 acre feet is the expected maximum demand on storage at Smith Mountain to provide the project license requirement of 650 cfs weekly average release from Leesville, for a repetition of the drought of record.

The total power generating capacity of the project is 400 megawatts (mw) which come from two 140 mw conventional turbines and two 60 mw pump-turbine units. Turbine intakes for the conventional units are centered at elevation 750 and are 26.0 feet in diameter. The pump penstocks are centered at elevations 665 (no. 1) and 610 (no. 5) and are 20 feet in diameter (10). The difference between the tailrace and forebay elevation may be as much as 195 feet or as little as 174 feet. Thus, three water levels may be drawn from during generation and water can be injected at two depths during pump back.

The operation of the power plant is under automatic load control. The control center in Roanoke directs the activities at the power station. A variety of information such as water level in the reservoir, runoff, rainfall, power demand, etc. is integrated by a computer and the operating cycle is controlled electronically. The usual operating procedure is to return part of the water to the upper reservoir during off-peak interval. Thus, pumping commonly occurs for approximately 8 hours each week day night and during part or all of weekend days, according to the water balance required during the week's activities (11).

Leesville reservoir serves primarily as the pumping pool for the upper reservoir although it also can be said to serve several purposes. The dam which is located at mile 296, two miles south from the town of Leesville, Virginia, creates an impoundment about 17 miles long. At maximum power pool, (613 feet), the surface area is 3,270 acres and contains 94,960 acre feet of water. Since the reservoir can operate between 600 and 613 feet, there is a large normal usable storage, 38,200 acre feet (9).

Two generators develop 40 mw and this electricity is used primarily for daily peaking energy. The intake gates draw off water from the surface but this may include water as much as 35 feet down from the maximum elevation.

This hydroplant is likewise operated remotely from Roanoke. It provides a weekly average flow of 650 cfs downstream of Leesville except during the spawning season of striped bass (April and May) when the flow is maintained between 1100-1900 cfs.

#### Historical Development of the Roanoke River Basin

The legislation which forms the base of the Roanoke River development is found primarily in two Congressional documents. The first was House Document No. 308 of the 69th Congress, First Session, adopted January 21, 1927. It authorized comprehensive plans to be developed for several rivers including the Roanoke. A plan was formed by the Corps of Engineers and published as House Document No. 65 of the 74th Congress, First Session. Very little positive action was proposed in this document (2).

Further study was authorized by acts passed in 1936 and 1938. A review of House Document 65 was made and the second important report, House Document 650 of the 78th Congress, Second Session was

completed in 1944. Congress adopted this report in Public Act 534 of the 78th Congress, Second Session and began construction of 2 out of the 11 proposed dams. Kerr and Philpott reservoirs were built as the 2 Federal projects and the remaining projects were arranged according to order to priority: Kerr 1952, Philpott 1953, Roanoke Rapids 1955, Gaston 1963, Leesville 1963, Smith Mountain 1965, Taber 7th, Melrose 8th, Randolph 9th, Stuart 10th, and Schoolfield 11th. The undated projects have not been built yet (12).

The Roanoke River Basin presently has fifteen hydroelectric projects (including small and older plants) and there are five more planned: nine have a power output of 30 mw or less. Three of the existing projects are on the upper Roanoke above Clarksville, three are below Clarksville and nine are on the Dan River drainage. Three of the planned reservoirs will be located between Kerr and Leesville Reservoirs (13).

The total generating capacity of the existing projects is about 995 mw. This will be increased by 140 mw when generator number 3 is installed at Smith Mountain Dam and by about 196 mw when the 5 proposed projects are completed.

## MATERIALS AND METHODS

The following temperature devices were used to record temperatures in the study area:

Ryan recorders: Waterproof Ryan Model D recording thermometers were used to measure stream temperatures in the Roanoke River at Brookneal, Clover and Clarksville. These instruments contain a spring wound clock mechanism that drives a role chart for 30 days. A stylus, which is connected to a bimetallic temperature sensor, impresses the record on the pressure sensitive chart paper. These instruments are stated to be accurate to  $\pm 2\%$  but are actually calibrated to  $1^\circ$  F.

Honeywell recorders: Brown type 602 thermometers were used for continuous records of the tailrace temperatures. An electric clock drives a paper chart for 7 days. A Class IV Bourdon tube thermometer (mercury filled) is used for the temperature sensing device: this is connected to an ink stylus which records on the circular chart. The calibrated accuracy is  $\pm 1\%$  of the total range.

Telethermometers: Two hydrographic thermometers, model FT-3 of Applied Research Company, were also used for temperature profiles. These

resistance thermometers indicate the temperature on a calibrated deflection meter: there is no recording component. These are accurate to  $\pm 0.5^\circ\text{F}$ .

**Bathythermograph:** A Tiernan bathythermograph, which has a Bourdon tube filled with xylene as the temperature sensing element, was used for the deep water temperature profiles. This has a depth range of 200 feet (60 m) and a temperature range of 28 to  $90^\circ\text{F}$ . Records were inscribed on gold and carbon coated slides and were interpreted by use of a calibrated grid viewer. The accuracy is  $\pm 0.1^\circ\text{F}$ .

Water quality records made by Appalachian Power Company during 1966 were used for some of the Leesville section of this paper. Water samples were collected by a Kemmerer bottle and dissolved oxygen was determined by the modified Winkler method. Temperature was obtained using a telethermometer.

Much of the published data on surface water discharge and water quality was taken from the Geological Survey and the Virginia Department of Conservation and Economic Development Reports.

## RESULTS

### Smith Mountain Reservoir Forebay

A comparison of temperature profiles taken near or in the forebay of Smith Mountain Lake is shown in Fig. 2. The 1965 and 1966 data are abstracted from Reynolds (14). The 1965 data were a composite of profiles from three stations below the confluence of the Roanoke and Blackwater Rivers in the main part of Smith Mountain Lake. The 1966 data were taken in the forebay and may represent some of Simmons (15) work. The 1967 data were taken on the log boom in the forebay as part of the present study (Appendix A).

The cycling of water between Leesville and Smith Mountain Reservoirs has an effect on the pattern of thermal stratification in the forebay of Smith Mountain Lake. Reynolds (14) observed that stratification in Smith Mountain Lake differed from the more conventional Philpott Reservoir: stratification was more "intense", that is, the epilimnion was not as deep and the rate of temperature drop per unit depth at the thermocline was greater in Smith Mountain Lake than in Philpott Reservoir. ]

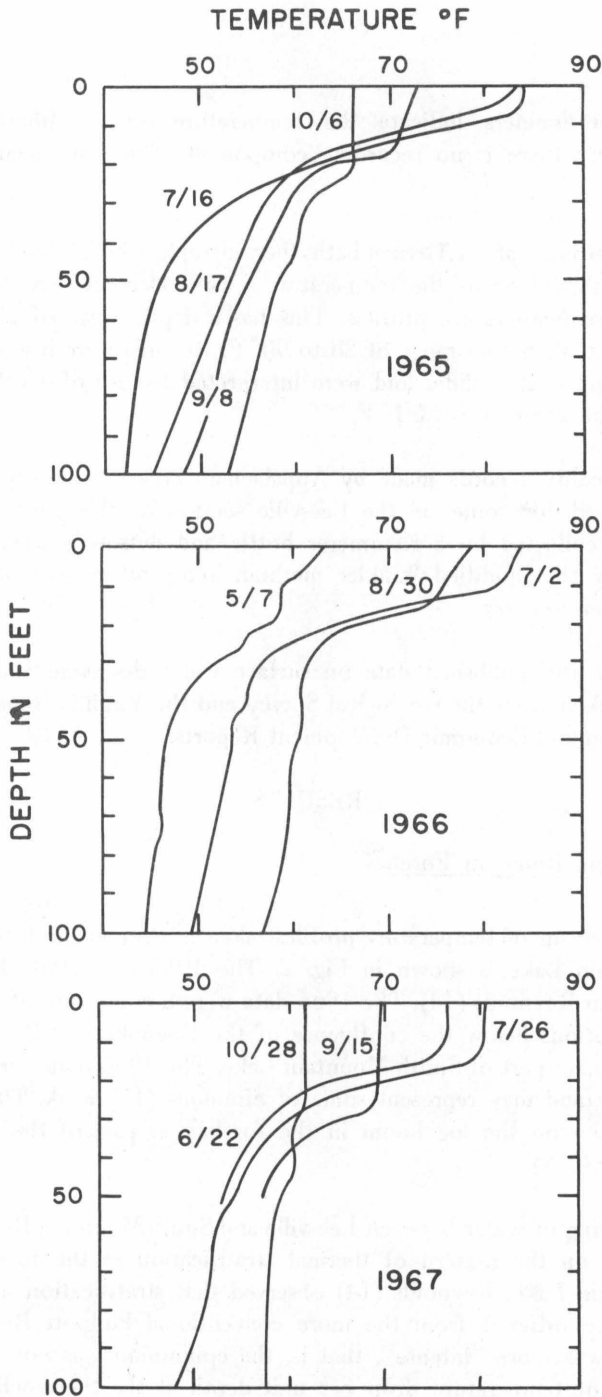


Figure 2. Temperature profiles in the forebay and basin of Smith Mountain Reservoir for selected dates in 1965, 1966 and 1967.

*(After Cumming & Ester 1969)*

Although it would be inappropriate to make a strict comparison between the depths of epilimnion from year to year, there does appear to be a trend toward deepening of the summer epilimnion since 1965. There is still a fairly sharp thermocline in 1967 and the deep water mixing continues to shift the mean temperature toward 60° F before fall overturn in late October. Fall and winter cooling drops the average profile temperatures to between 41 and 45° F in March (15).

Since the cycling action of the reversible turbines introduces a mixing factor into the upper reservoir, it is of considerable interest to see what the water column looks like during generation and during pumping in the forebay. A very comprehensive study was made of the temperature profiles in the forebay, gorge, and basin but only the first mentioned will be discussed here (Appendices B or C).

On July 21, 1966, a transect of thermal profiles was made about 1200 hours in the forebay along the log boom which is a series of floats used as a floating debris retaining device. The transect was made between two generation periods. The first period was from 0921 to 1040 hours using generator number 1. The second period was from 1523 to 1707 hours using number 4. It will be recalled that number 1 is centered at elevation 665 feet and number 4 at 750 feet.

An examination of the July 21 transect leads to several interesting observations (Fig. 3). First, although generation stopped at least 1 hour earlier, the water layers have not leveled out. There appear to be internal waves that are oscillating from side to side across the forebay. The lower circle on the figure indicates the approximate position of the number 1 penstock which has been drawing off 53-54° F water according to the tailrace recorder. This agrees with the thermal zone adjacent to the opening. There is a definite shift of deep cold water 46-48° F to the northeast side of the forebay which may have resulted from the pile up of the current of 52-53.5° F water that was stopped when the generator shut down. The second generation period resulted in 57-59° F water in the tailrace and this agrees well with the approximate position of the upper circle, number 4 penstock.

It is unwise to make too much out of the transect since it takes an hour or so to complete the profiles. How long the thermal layers hold their distorted configurations is unknown. What currents and internal waves are operating is also uncertain.



An even more phenomenal disturbance is seen in the July 24, 1966 transect. This was made around 1200 hours on a Sunday during pumping by both number 1 and 5 which had been operating since late the previous night. The temperature of the pumped water at the time of the transect, according to the tailrace recorder, was 65-67° F. Earlier on this day there had been a considerable volume of 59-61° F water pumped. Again the approximate positions of number 1 and 5 pumps are put on the figure.

The July 24 data illustrate extreme turbulence and distortion of thermal layers even to the point of fragmenting water masses. The pumped water is not seen at the injection levels by the time it reaches the log boom, but rather is seen as a stream near the surface of either side of the log boom. As would be expected this water rises to seek its proper density position. Here again it is difficult to know all the forces which are contributing to this very irregular transect.

#### Smith Mountain Reservoir Tailrace

The Smith Mountain tailrace is not always isothermal. During generation, it is probably well mixed but during and after pump back, there may be a substantial stratification if warm surface waters are being drawn up from Leesville. This results from the fact that there is a channel at least 34 feet deep near the power plant which shoals up at the tailrace bridge to only 17 feet or so deep: this acts as a sill for a pool of stratified water under certain circumstances. Therefore, any temperature profile at the tailrace is very transient and highly subject to phase of operations as well as thermal structure in the upper or lower reservoirs.

The highest, lowest, and daily average temperatures in ° F for the tailrace at Smith Mountain for 1967 are presented in Appendix D. From this table, the following information is noted. First, the maximum water temperature for the whole year was 78½° F on 8/6/67 while the minimum was 34° F on 2/26/67. Second, the maximum change in temperatures during one day was 29° F on 7/27/67 and the minimum was 0° F on 12/21/67. Seasonally, between October and March, the average daily change in temperatures was 2.3° F: between April and September, it was 6.5° F. There was an average daily change for the entire year of 4.4° F.

Maximum and minimum values for the first and fifteenth day of each month are plotted in Fig. 4. The temperature cycle appears to crest about the first of August at temperatures in the low 70s. The low part of the cycle

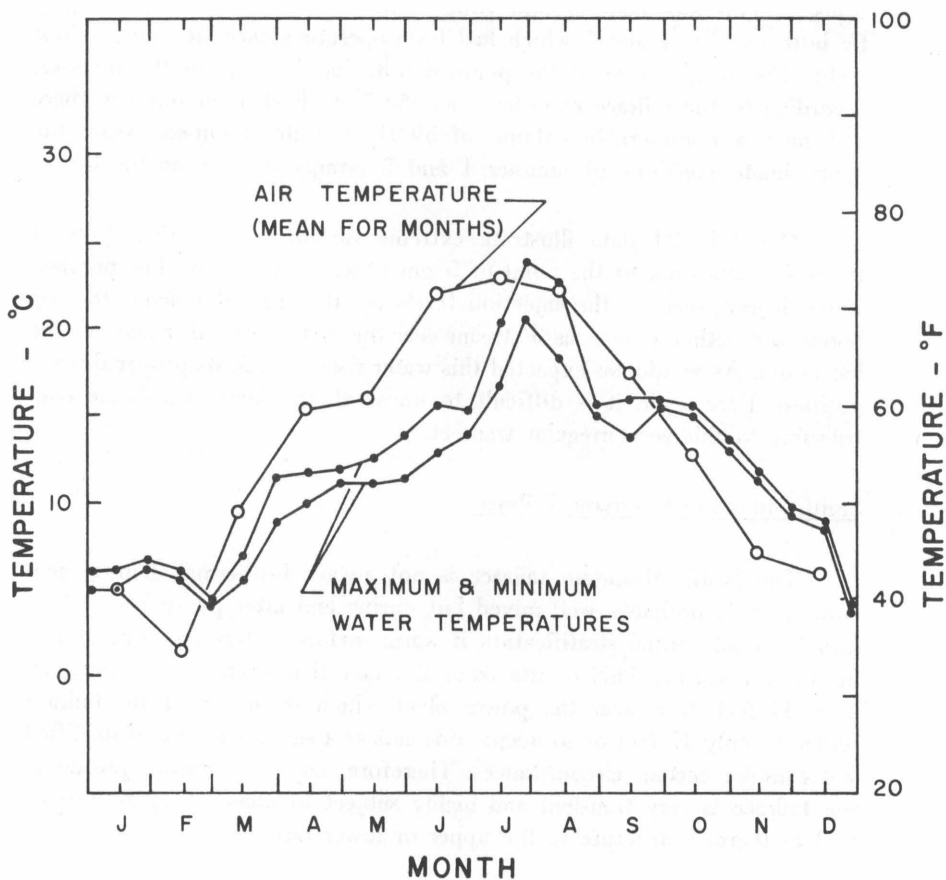


Figure 4. Maximum and minimum water temperatures for the first and fifteenth of each month during 1967 for Smith Mountain Tailrace.

occurs about the first of March with temperatures around 40° F. The temperature cycle for water lags behind the air temperature cycle by about 2 to 4 weeks.

Fig. 4 does not give any indication of what actually happens in the tailrace as the pump or generation units are operating. For this reason, a set of daily records are reproduced in Fig. 5 to show routine operations and the extreme temperature drop on July 17, 1967. The January 12 record indicates that water temperatures are between 40 and 43° F while the air temperature (lower trace) ranges between 17 and 38° F. On January 11 there was a little generation in the evening which was followed by pumping between 0000-0800 hours on the 12th. In this case, generated water is about 43° F while the pumped water tends to be cooler (40° F). Upon stopping the pump, the tailrace rapidly warms back up to 42° F.

The second record, June 19-20, demonstrates the opposite relationship of pumped and generated water temperatures as that in January. In this situation the water temperature ranges between 54.5 and 68.5° F (lower trace) while the air temperature is between 66 and 78° F (upper trace). The power plant had been generating in the afternoon of the 19th before starting to pump late that evening. Pumping continued until early morning on the 20th when generation started. It can be seen that pumping in this case, as with most summer situations, actually moves warm water while generation returns much colder water (14° F).

An extreme temperature drop is presented in the third chart record. On the morning of July 17, the tailrace temperature was quite high, 70-71° F. There had been only a little pumping the day before and no activity two days before. Thus, when generation started on this Monday morning there was an instantaneous drop in the tailrace temperature of 25° F! Three times in July a drop of 20 or more degrees occurred in a short space of time. Such a thermal shock could have serious effects on aquatic organisms in the tailrace. Further investigation of this effect is desirable.

### Leesville Reservoir

The temperature profiles for five stations in Leesville Reservoir are presented in Fig. 6. This information was plotted from data taken by Appalachian Power Company during 1966. The order of stations from downstream to upstream is: Leesville Dam forebay-mile 296, routes 609 and

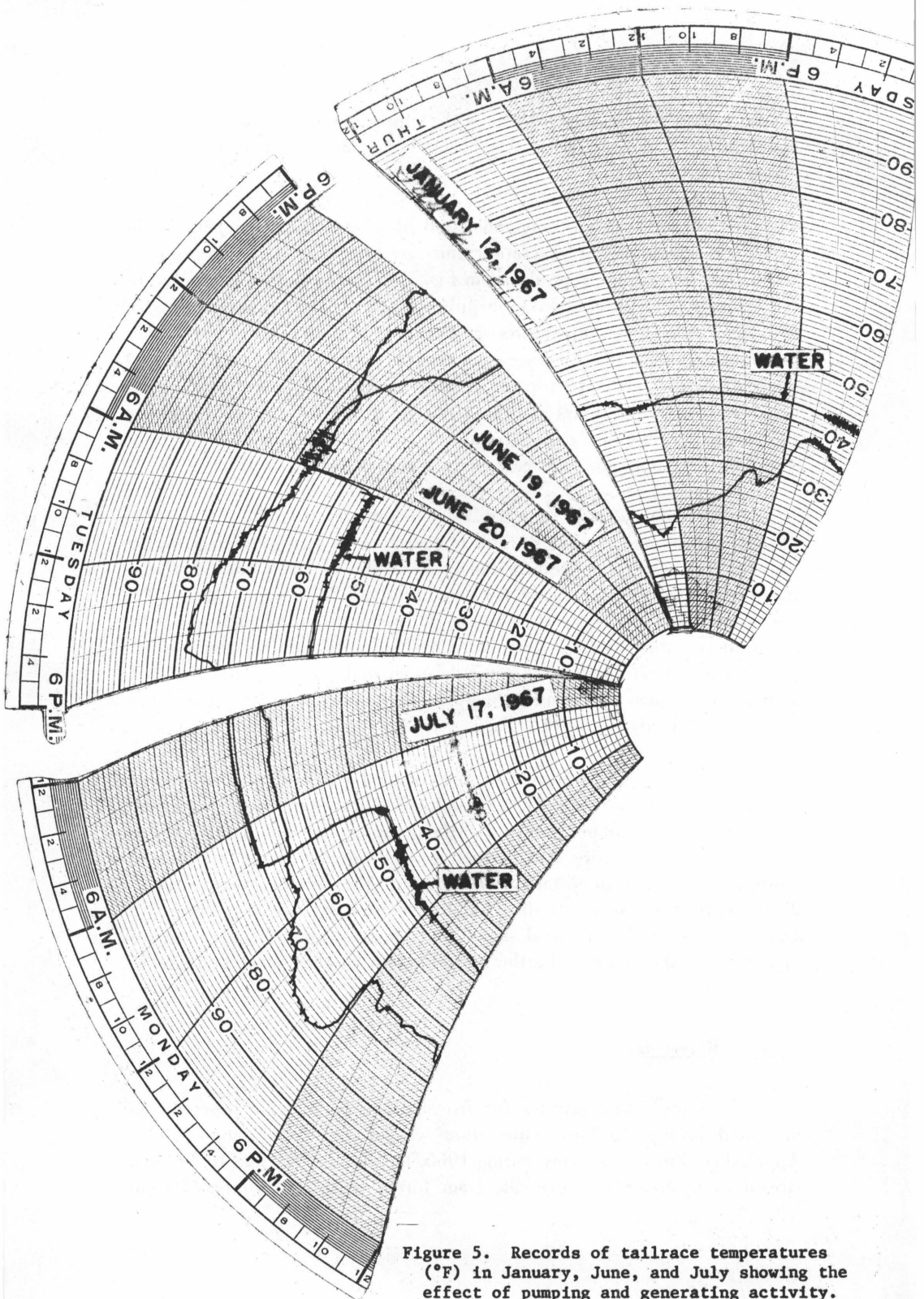
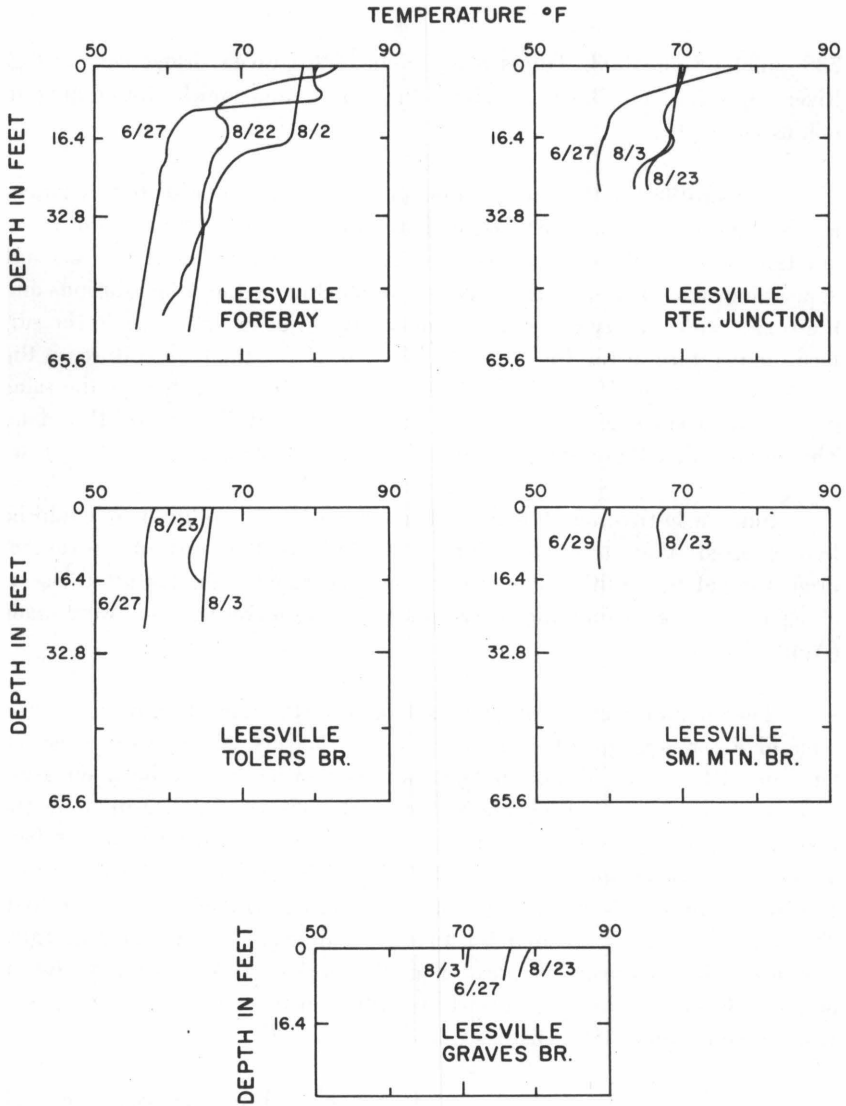


Figure 5. Records of tailrace temperatures ( $^{\circ}$ F) in January, June, and July showing the effect of pumping and generating activity.



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Figure 6. Temperature profiles at selected stations in Leesville Reservoir in 1966.

733 junction-mile 303, Tolers Bridge-mile 309, Graved Bridge on the Pigg River approximately 3.5 miles above the mouth, and Smith Mountain Dam tailrace-mile 314.

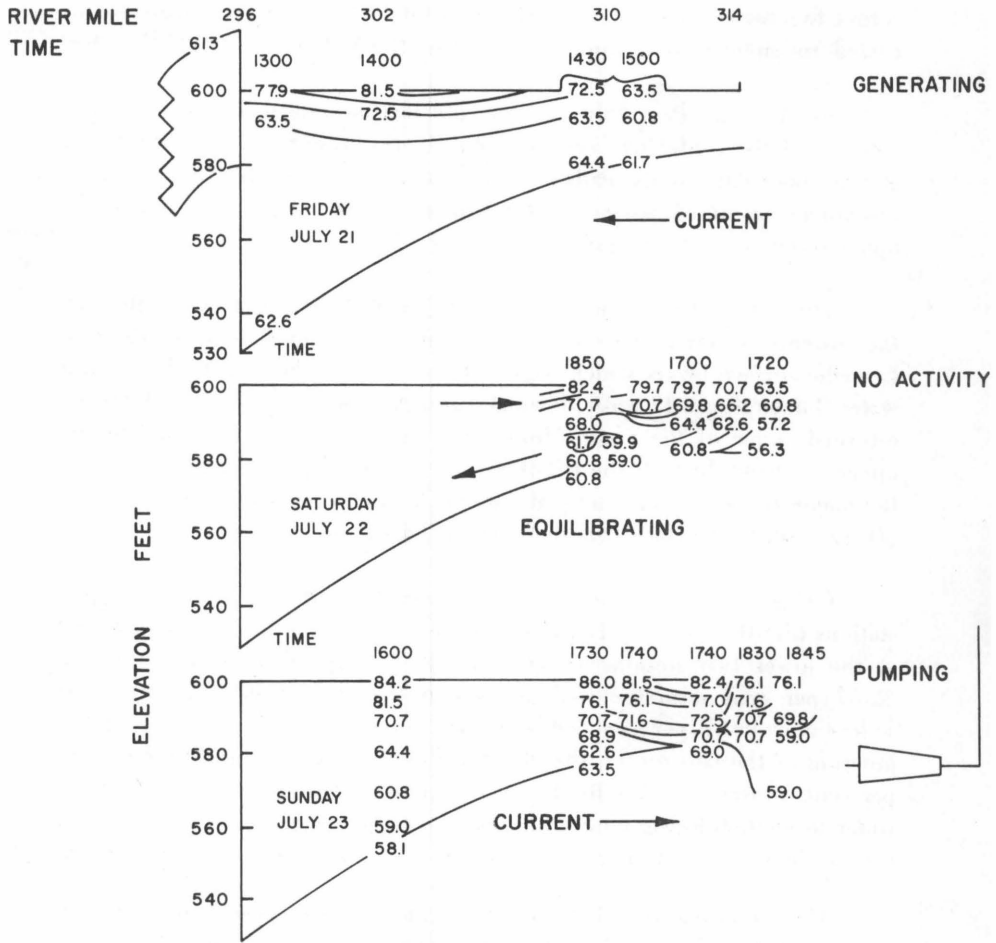
The profiles at the five stations give a hint of some of the dynamics involved in the pump-generating activity. In the forebay and at the route junction, thermoclines at various depths and temperature ranges do not appear unusual. However, there is no thermocline at the other stations and there is a wide variety of surface temperatures. For example, while the surface temperature in the forebay is 81° F on 6/27/66, the temperatures at the uplake stations are 78° F, 58° F, and 77° F at Graves Bridge for the same day: the average air temperature would be about 73° F for this date. This implies that there are definite horizontal zones of thermal stratification.

Since a horizontal stratification is an unstable condition, it could be hypothesized that this condition is related to the current movement originating at the Smith Mountain turbines. Therefore, temperature transects along the lake as a function of the phase of the operating cycle were made (Appendix E).

The demonstration of the back and forth current movements was seen in a series of profiles that were made on July 21-23, 1967 (Fig. 7). On July 21, Smith Mountain Dam was generating power between 1000 and 1600 hours. The discharge water in the tailrace as measured by the Honeywell recorder was 58-59° F. Stations were located at Leesville forebay, Tri-County Marina, and the mouth of the Pigg River between 1300 and 1430: a second profile was made at the latter station a half hour after the first. The Leesville Dam generated for two short intervals in the early morning and for 5 hours during midday. The discharge of this water at 63-64° F agrees well with the temperature stratification in the forebay as can be seen from the position of the penstock opening in the dam.

The temperature drop at the mouth of the Pigg River between 1430 and 1500 indicates movement of water by this station. The colder water, 58-59° F, from Smith Mountain pushed the Leesville water ahead of it as the downlake current increased. It should be noted that the cold water mass was just starting to reach the Pigg River station, which is only 4 miles downlake from Smith Mountain, after 5 hours of generating. The 61-62° F water more than likely represents some mixing of the cold water discharge with the 63-64° F Leesville water.

The next day, July 22, there was no activity at either dam and so the reservoir underwent an equilibrating period. The warm surface waters slid



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 Figure 7. Longitudinal transects of Leesville Reservoir on three successive days in 1967 for temperature profiles.

across the surface toward the tailrace, while the cold deeper waters continued to move downstream as is seen in the bubble of 59-62° F water.

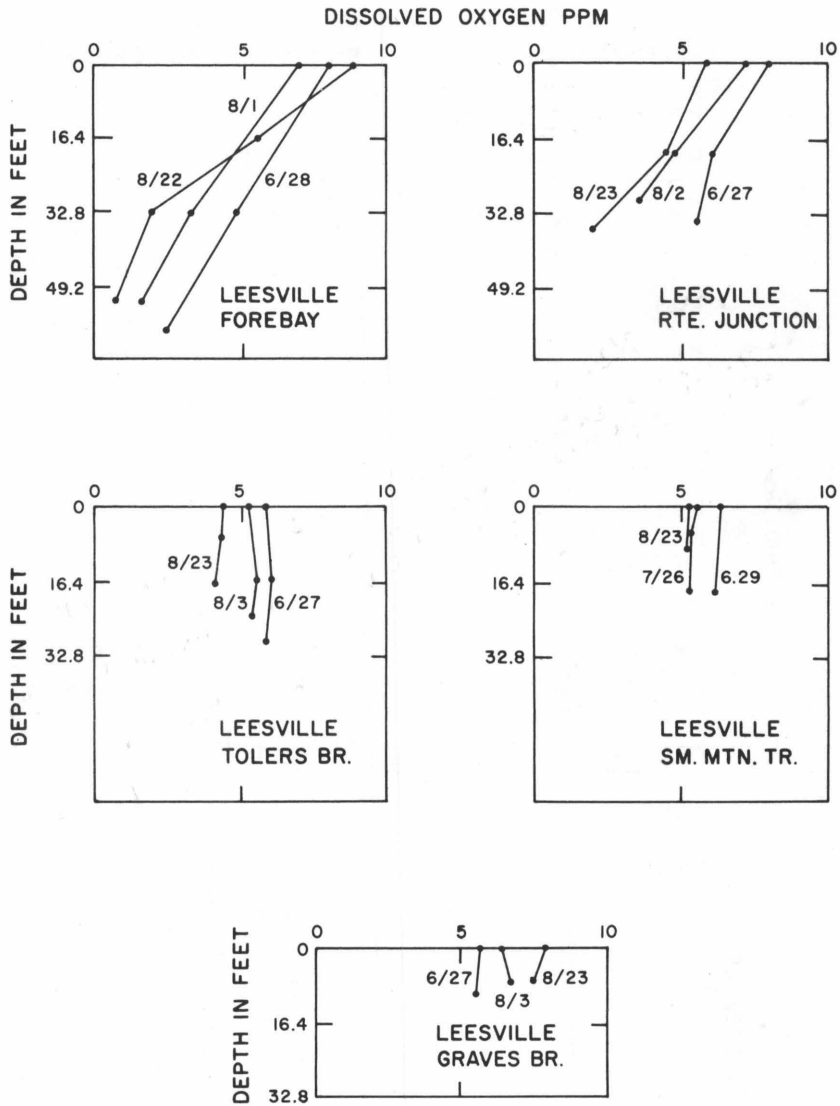
By the third day, July 23, the cold bubble moved on to the deeper sections of the center of Leesville Lake. In the meantime, pumping began at the upper dam in the early morning hours (0200-0800). This set up an upstream current of warmer water which was, in turn, pumped into the upper reservoir at temperatures between 67-70° F.

Thus, the cold discharge water from Smith Mountain traveled through the lower reservoir along the bottom while the pumped water came from Leesville surface layers which were 9-11° F warmer. Since it took the cold water 2 days to get 12 miles downlake and there was only warm water being returned, some of the Smith Mountain water may never be cycled to the upper reservoir. In fact, the tributaries such as the Pigg River may make up the major portion of the pumped water as the Leesville Dam discharge drains off the colder subsurface "Smith Mountain" discharge.

Oxygen concentrations are fairly uniform with depth at the upper stations (Smith Mountain Tailrace and Tolers Bridge) but are quite stratified at the lower two stations as seen in Fig. 8 (Appendix F). The water is 42-57 per cent saturated with oxygen in the three curves presented for Tolers and 45-61 per cent saturated for Smith Mountain tailrace. At the junction of the two routes, the water is 21-100 per cent saturated and 8-100 per cent saturated in the forebay. There is a definite trend for the surface water to contain higher concentrations of oxygen and the deeper waters to contain less oxygen as one proceeds down the lake toward Leesville Dam.

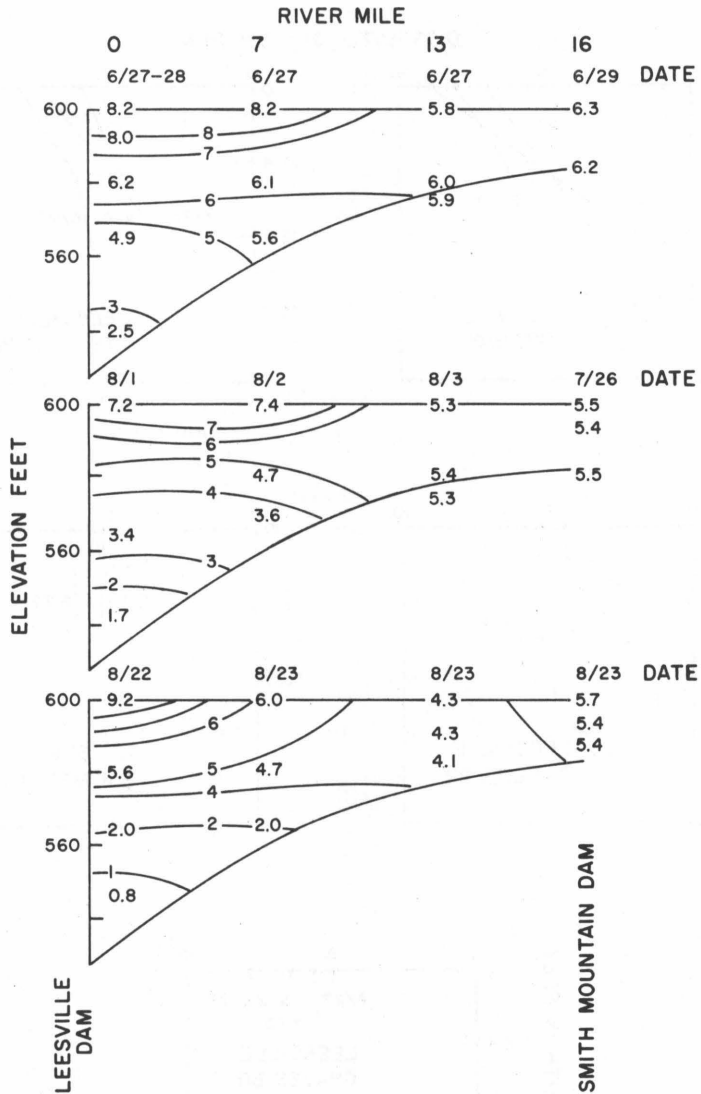
There is also a trend for most stations to decrease oxygen concentration as the summer advances. However, this is related to higher water temperatures since per cent saturation does not follow this decreasing trend. The Graves Bridge station on the Pigg River is a notable exception. Its oxygen concentration increases as does the per cent saturation. This is probably related to its shallow depth, complete mixing and high productivity as is inferred from the color but this was not quantitatively documented.

If the data are plotted along the longitudinal axis of the lake, the seasonal build up of low oxygen water is seen (Fig. 9). At the end of June, the volume of water containing 4 ppm or less is less than 4000 acre feet. At the first of August the volume of this type water has increased to 16,000 acre feet. By the end of August, this volume has not increased, but the oxygen concentration within the 2 ppm zone has gone from about 2000 acre feet to 8000 acre feet.



12

Figure 8. Oxygen profiles in Leesville Reservoir in 1966.



13  
 Figure 9. Longitudinal transects for oxygen concentrations (ppm) in Leesville Reservoir in 1966.

There is thus a definite zone of low oxygen water in the lower 7 miles of the reservoir. There is an indication from the shape of the isolines that there can be much variation in oxygen concentration in the water mass between Tolers and Smith Mountain tailrace, yet it is fairly uniform in concentration vertically.

### Leesville Tailrace

The Leesville power plant generates on a fairly predictable schedule. The main wattage is generated between 0900 and 1500 hours. A second production period happens between 1700 and 2200 hours but occurs much less frequently. There are a scattering of small generation periods especially in the early morning hours which are more than likely used to maintain the minimum flow requirements. While almost every week day has a generation period, very few weekends are used for power production.

On any individual day of the entire year (1967) the Leesville tailrace did not range more than 7° F (April 14 and June 22) and the average daily range is about 2° F. Between October and January, the average range for the interval is about 1° F per day. Between May and August the average range for the interval is 3° F per day with a high monthly average in July of 4° F per day (Appendix G).

The maximum and minimum temperatures on the first and fifteenth of each month for 1967 are found in Fig. 10. The maximum temperatures for the summer occur during the first two weeks in August and range between 64 and 68° F. In the winter, minimum temperatures occur about the first of March and lie between 36 and 38° F. There is also a time lag of the water temperature behind the air temperature which is from 2 to 4 weeks.

Information on the oxygen and temperature profiles in the Leesville tailrace are presented in Fig. 11 (Appendix F). The tailrace is fairly isothermal with depth as would be expected because of its shallow depth and complete mixing during generation. The dissolved oxygen is fairly uniform and lies between 4.8 and 8.3 ppm on the dates sampled. Downstream about 2 miles at the Norfolk and Western Bridge just above the Town of Leesville, the temperature is uniform through the shallow 3 foot depth. Also, the oxygen concentration is fairly uniform and lies between 4.9 and 7.9 ppm.

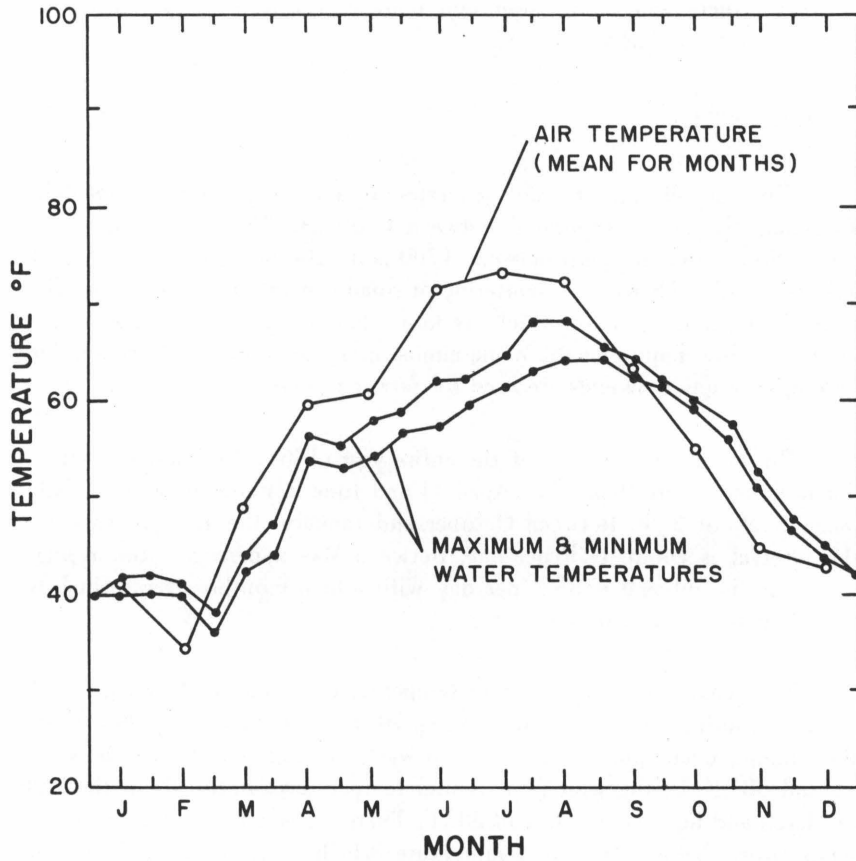


Figure 10. Maximum and minimum water temperatures for the first and fifteenth of each month during 1967 in Leesville Tailrace.

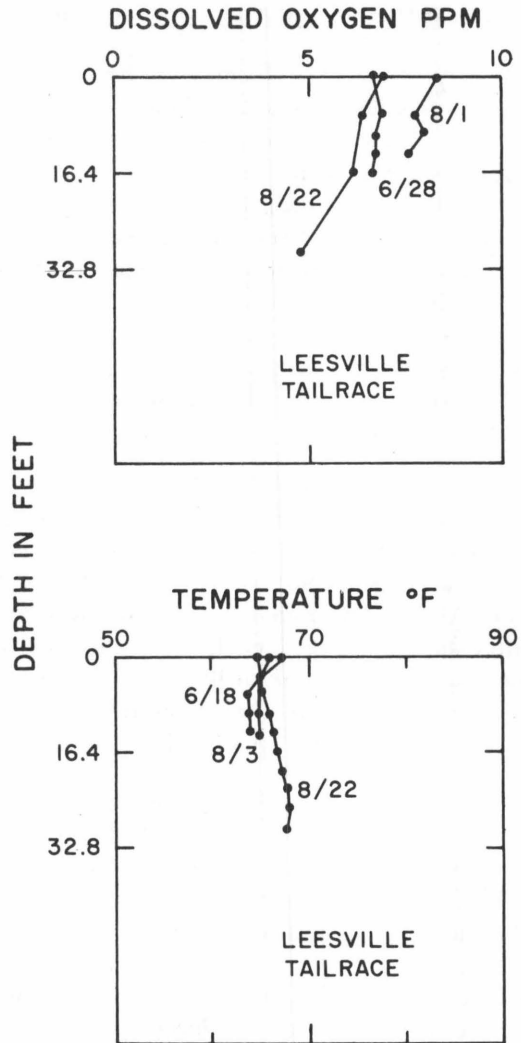


Figure 11. Dissolved oxygen and temperature of the Leesville Tailrace during 1966.

## River Basin Water Quality Before And After Impoundment

Water Chemistry Along The Basin--The change in water contents and properties below the Smith Mountain Project can best be understood by first examining the chemical analyses for representative sites along the entire upper Roanoke River Basin. For this reason, a series of analyses made in March of 1968 were obtained from the Geological Survey (16). These data include four main stream stations and four major tributaries between the headwaters and Kerr Reservoir (Table 1). Within two days, all stations were taken at approximately the same time. The average discharge for all records at the individual stations was used in the place of instantaneous discharge at the sampling hour as the latter values were unavailable. The fact that these data are pertinent to March seasonal conditions only must be kept in mind.

The tributaries below Leesville Reservoir are seen to add a considerable amount of silica to the main stream and yet the Randolph value at this time is not increased but rather decreased. It will be seen in Table 2, later, that the average silica content does increase slightly by the time the water reaches Randolph. Also, a lot of iron is added by these same tributaries: it is seen at Altavista but not at Randolph. This increase in iron may be a seasonal phenomenon and the lack of it at Randolph may be a result of precipitation after combining with the anions in the harder main stream water. There may also be a pH effect on solubility.

The majority of the calcium and magnesium comes from the mountain terrain and is diluted by the soft water tributaries below Leesville Reservoir. The sodium level gradually increases downstream except at Altavista where an unusually high value (18 ppm) appears in conjunction with a large value of chloride. The potassium doesn't change appreciably.

The high bicarbonate, sulfate, and nitrate containing mountain waters are diluted by the lower tributaries. The chloride and fluoride concentrations don't seem to change in any particular direction with the exception of the Altavista chloride mentioned previously.

Dissolved solids, hardness and specific conductivity are all decreased by the tributaries. In addition, the appreciable noncarbonate hardness is reduced to a negligible amount.

The pH is highly variable with the tributaries being approximately neutral and the headwaters being alkaline. An exception is the Altavista value which is quite alkaline.

TABLE 1. Chemical analyses of water of tributaries and main stream of the upper Roanoke River Basin in Virginia in 1968. Data for discharge is average discharge of all records and chemical analyses are in milligrams per liter. This data is subject to revision by the U.S. Geological Survey.

Date of Collection	Average Discharge (cfs)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )
3/24	235	6.9	0.03	27	11	2.8	1.2	120	14
<u>Lafayette - River Mile 382.5</u>									
3/24	373	5.8	0.05	28	11	2.8	1.6	123	14
<u>Roanoke - River Mile 360.6</u>									
3/24	171	12	0.20	10	4	3.2	1.6	42	12
<u>Goose Creek</u>									
3/24	1864	9.5	0.11	9.4	3.3	18	2.0	65	8.4
<u>Altavista - River Mile 286.5</u>									
3/24	331	12	0.12	4.2	1.9	3.7	1.2	23	3.6
<u>Big Otter River</u>									
3/24	140	12	0.10	4.8	2.2	3.9	1.2	26	3.6
<u>Falling River</u>									
3/24	89.4	15	0.15	4.4	2.3	4.6	0.8	27	5.2
<u>Cub Creek</u>									
3/23	3116	6.8	0.02	12	4.7	6.0	2.0	59	9.0
<u>Randolph - River Mile 227.3</u>									

Considerable color is added by the tributaries especially Goose Creek but this is diluted to a low value by the time the water reaches Randolph.

Temperature is seen to increase 15° F between Lafayette and Randolph which is a 155 mile trip and an elevation drop of 910 feet. Average air temperature would be about 52° F for this date.

**Water Quality In The Roanoke River Before And After Impoundment-**  
In order to appreciate the influence of the Smith Mountain Project on the Roanoke River, a comparison of water chemistry was made before and after the impoundment. Data were taken from the Geological Survey records of Virginia for 1956 and 1967 (Table 2). These dates were the closest to the start and completion of the Project which was between 1960 and 1965. Actual storage began in September of 1962 at Leesville Reservoir and in September of 1963 at Smith Mountain Reservoir. Leesville Reservoir reached minimum power pool (elevation 600 feet) in March 1963 and Smith Mountain Reservoir (elevation 787 feet) in May 1965: total operations began in July 1965. Although the State Water Control Board made analyses during 1958-1960, these were few in number and there are no comparable analyses after 1965.

Stations were chosen for the availability of water analyses and location on the Roanoke River. There are four water quality stations between Leesville and Kerr Reservoir on the Roanoke River: only a few records were made at Brookneal and Clover. The Altavista and Randolph locations are about 10 (river mile 286) and 70 (river mile 227) miles, respectively, downstream from Leesville Dam while the total distance to Kerr Reservoir at the confluence of the Roanoke and the Dan is 90 (river mile 206) miles.

Dates were chosen to include seasonal effects on water quality as well as to be roughly comparable between years. There are no fall values to compare, otherwise the seasons are represented. The 1956 values at Randolph appear to cover a 7-10 day interval, however, there was probably just one sampling date.

Since the Goose Creek tributary enters above the Altavista Station and there are several more which enter above the Randolph station, it becomes important to determine if the instantaneous flows which were sampled represent water discharge from Leesville Dam or whether the sample probably came from tributary water. The flow records from each station were examined for the day of analysis and also the previous two days to approximate the cubic feet per second contributed by the tributaries

TABLE 2. Chemical analyses of water at selected stream sites in the Roanoke River Basin of Virginia. Data for discharge is instantaneous discharge and chemical analyses are in parts per million.

Date of Collection	Discharge (cfs)	Silica (SiO <sub>2</sub> )	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )
Altavista-River Mile 286.5									
2/15/56	1150	9.0	.09	16	5.0	5.9	1.4	64	14
3/21/56	1880	11.0	.02	14	5.4	6.9	1.5	58	15
7/12/56	450	9.8	.00	15	7.0	13	2.6	73	19
8/8/56	330	5.0	.00	16	7.7	17	2.5	83	21
3/2/67	404	8.6	.01	13	4.4	7.6	1.7	58	9.6
4/12/67	380	7.8	.01	14	5.6	11	2.1	74	10
5/24/67	480	8.0	.03	15	5.4	11	2.2	75	11
7/7/67	58*	6.4	.01	17	6.3	6.8	2.3	78	12
8/15/67	408	6.0	.02	18	6.1	12	2.6	89	13
Average Change		-1.3	-0.01	--	-0.7	-1.0	+0.2	+0.5	-6
Randolph-River Mile 227.3									
2/21-28/56	2080	14	.07	12	4.7	6.6	1.2	54	13
4/1-10/56	2150	12	.07	11	4.1	6.5	1.3	52	11
5/21-31/56	1080	8.9	.00	13	5.9	9.7	1.7	66	14
7/1-10/56	718	9.6	.00	14	5.4	15	2.4	67	24
8/11-20/56	489	9.5	.03	15	5.0	12	2.3	72	15
2/28/67	4760	9.2	.02	11	3.9	5.2	1.6	46	8.6
4/10/67	700*	8.3	.05	12	4.1	6.8	1.8	56	7.4
5/22/67	1510	8.8	.03	13	5.1	7.1	2.0	64	8.4
7/5/67	1090	8.0	.01	15	5.2	5.7	2.3	66	11
8/14/67	318	8.7	.01	16	5.8	7.5	2.4	75	9.4
Average Change		-2.2	-0.01	--	-0.2	-3.5	+0.2	-1	-6

\* Values appear to indicate that very little if any Leesville Reservoir discharge is present.

TABLE 2. Cont.

Date of Collection	Chloride (Cl)	Fluoride (F)	Nitrate (NO <sub>3</sub> )	Dissolved Solids	Hardness as CaCO <sub>3</sub>		Specific Conductance (Micromhos at 25°C)	pH	Color	Temperature °F
					Ca, Mg	Noncarb.				
Altavista										
2/15/56	5.3	0.1	2.0	94	60	9	150	7.5	20	43
3/21/56	6.1	0.0	1.4	101	57	10	146	7.8	6	40
7/12/56	11	0.1	3.2	116	66	6	198	7.7	5	70
8/8/56	17	0.1	1.7	128	72	4	232	7.6	7	75
3/2/67	5.6	0.1	1.3	82	49	2	139	7.4	5	38
4/12/67	7.0	0.1	0.3	100	57	0	169	7.6	5	54
5/24/67	7.4	0.1	1.1	95	61	0	173	7.5	10	58
7/7/67	7.0	0.1	1.1	98	70	6	165	7.5	3	67
8/15/67	7.9	0.1	2.6	119	62	0	184	7.4	7	70
Average Change	-3.1	--	-0.8	-11	-4	-5	-16	-0.2	-4	--
Randolph										
2/21-28/56	5	0.0	1.2	87	49	5	136	7.4	5	45
4/1-10/56	4.8	0.1	1.0	94	44	2	125	7.4	10	43
5/21-31/56	6.7	0.1	0.9	94	57	3	158	7.3	5	68
7/1-10/56	8.5	0.1	0.8	114	57	2	190	7.4	8	80
8/11-20/56	11	0.1	0.6	110	58	0	189	7.3	10	79
2/28/67	5.3	0.1	1.2	73	42	5	116	7.4	7	37
4/10/67	6.0	0.1	0.5	81	46	0	128	7.4	7	55
5/22/67	6.1	0.1	1.0	78	54	1	142	7.2	5	58
7/5/67	6.3	0.2	1.2	92	58	4	144	7.0	6	68
8/14/67	7.8	0.2	0.9	97	63	2	153	7.2	4	76
Average Change	-0.7	--	+0.1	-16	--	--	-20	-0.2	-2	--

as opposed to the instantaneous flow. This was done because the Leesville Dam just generates intermittently during the day and has a minimum sustaining release of only 60 cfs, which is a license requirement. Therefore, it could be possible to sample, primarily, tributary flow at Altavista and Randolph if the discharge phase from Leesville Dam were just right. In fact, this appears to be the case on 7/7/67 at Altavista and 4/10/67 at Randolph. The remaining values for the 1967 dates were found to represent a substantial component of water from Leesville Reservoir.

As the water quality items are examined, for similarity or difference, it is imperative to keep in mind the substantial limitations in comparing the various figures or averages of figures. First, there is the unknown of exactly what fraction of the water in the sample came from which water source. Second, there is the substantial variation in each solute or water property according to environmental conditions at the source of contribution of the item as well as the resultant product after all interactions have occurred. Lastly, there are seasonal effects, man-made effects, physical effects related to flow volume, etc.

With the previous qualifications in mind it is still reasonable to look at simple averages and consider trends. The first observation is that all of the data approximate values which are common in the literature and could be said to be in a "normal" range for stream chemistry. There are no unusually high or low concentrations of constituents or outstanding physical properties. Overall, the river water can be said to be soft (calcium concentration between 10-25 ppm) with calcium being the principal cation and bicarbonate the major anion. The pH is quite stable and slightly alkaline. The color level is low, quite variable below 20 units, and yet well within "normal" conditions (less than 50 units). Temperatures are not easily compared because of the few values and direct dependence upon time of day and year. Dissolved solids average between 84 and 110 ppm and conductance between 140 and 182 micromhos: both properties are within the "normal" range of 100 and 500 ppm and 50 to 50,000 micromhos, respectively.

The remaining values for chemical constituents show a low level of silica, trace level of iron, normal ratio of calcium to magnesium (greater than one part of calcium to each part of magnesium) and sodium to potassium. Low levels of nitrate and fluoride are common findings. The principal contribution to hardness is from the carbonates.

If the simple average of values for chemical items before and after impoundment are considered, then there is a general trend for about a 10

per cent reduction in concentration between the two dates, 1956 and 1967. An exception is seen in the potassium concentration which increased about 10 per cent. Once again, this is a very qualitative appraisal limited primarily by inadequate sample numbers.

With the exception of silica, most chemical values are the same or lower at the Randolph station than at Altavista. This implies that dissolved solids in the tributaries between Altavista and Randolph are slightly less than in the Roanoke. The average discharge at Altavista for the 37 year record is about 1864 cfs while that at Randolph for 26 years is 3116 cfs. Thus, almost 60 per cent of the Randolph water comes from the Roanoke above Altavista. Also, with the exception of silica most chemical values stay the same or increase during the summer: this is probably directly related to greater solubility at warmer temperatures.

Flow Patterns--The flow patterns at Randolph for selected months during water years 1956 and 1967 are presented in Fig. 12 (Appendix H). The ordinate of mean discharge in cfs is split up on the left and right sides of the figure to indicate the change in scale. Each point represents the daily flow. The capital S stands for the date when Sundays occur. The months were chosen during medium (November), high (February), augmented (May), and low (August) flow periods.

The most obvious difference between the before and after flow patterns is due to the disruptive character of the after curve. Whereas the 1956 water year (WY) curve is variable but smooth, the 1967 WY curve is regularly interrupted by dips in the flow volume. If it is recalled from the earlier notes that Leesville Dam doesn't generate very often on weekends, and if it is remembered that it takes a day to a day and a half for Leesville water to get to Randolph, then the reason for the irruptive pattern becomes apparent. There is a fairly uniform week day flow volume which abruptly subsides as generation stops for the weekend.

The average flow volume is higher for all months in the 1967 WY than in 1956 WY. This is directly related to the total water flow of 774,311 cubic feet per second-year versus 549,215 cfs-year, respectively. No attempt has been made presently to find out if the average total volume of water has increased since the impoundments were built but this would be interesting to know.

The May record includes most of the period of augmented flow which ran from noon on April 27 to noon on May 16, 1967. With the exception

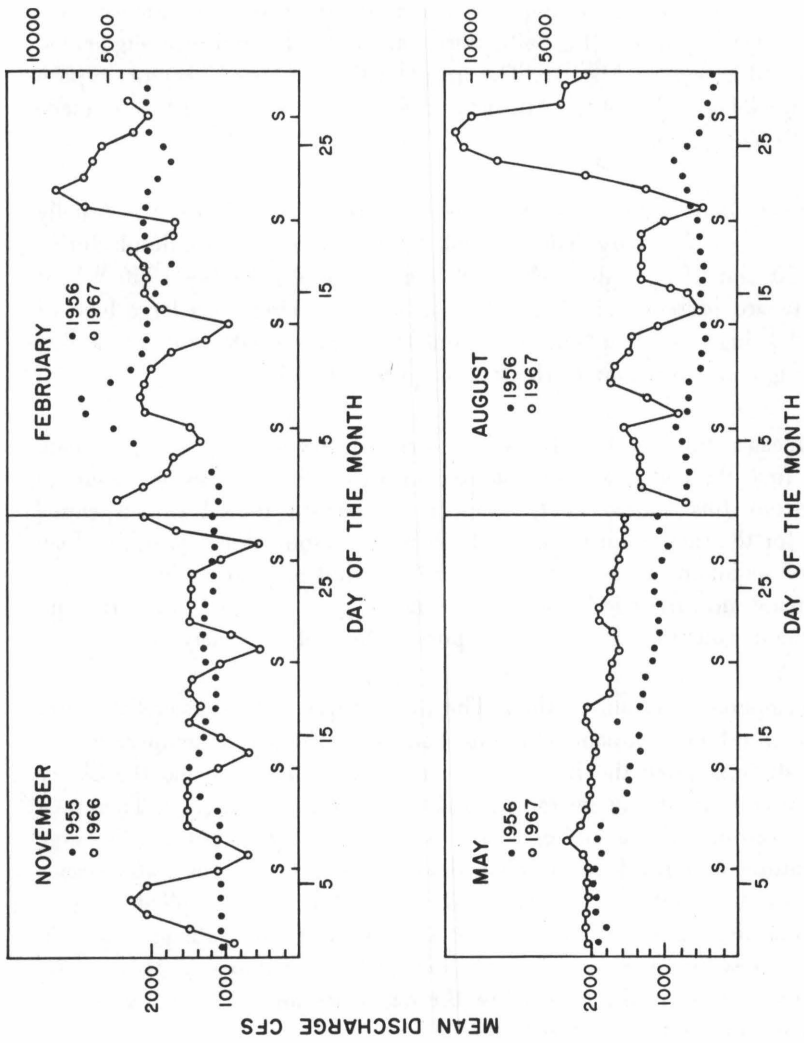


Figure 12. Flow patterns at Randolph for selected months before and after construction of the Smith Mountain Project.

of a little larger release on May 7 and probably a heavy rain in the watershed above Randolph during this date, the flow record is fairly uniform and slightly above the 1956 WY.

What these records don't show is that the daily flow fluctuation by a station is very irruptive (Fig. 13). Here, the end of the uniform augmented flow period is seen on May 16. The irruptive flow of May 17 is more typical of the weekday period at the Altavista station where these records were made by the Geological Survey.

Suspended Matter Levels--Sediment quantity in the river is usually related to runoff activity. The suspended matter levels for Randolph during the 1956 and 1967 water years and selected months of the 1956 WY at Altavista are presented in Fig. 14 (Appendix I). There is a large load of material being moved in the winter and then again in late summer. During the spring and early summer the load is quite reduced.

Because the Big Otter River is known to carry a heavy sediment load, it was first thought that the majority of the sediment load at Randolph came from this source. Yet, when the Altavista record of suspended matter for the same months in the 1956 WY is examined, it is seen that high levels of sediment are seen there too. So, it is not easy to see any decrease or increase in suspended matter that might have resulted from the impoundment construction from the present limited data analysis.

Temperature Changes Along The Basin--River waters generally warm as they travel downstream. On four occasions, the water temperature at several stations along the Roanoke River between Lafayette and the Clover Bridge near Randolph were recorded (Fig. 15 and Appendix J). There is a definite warming of the surface waters in the two reservoirs but the discharge temperatures at both dams are cool. Below Leesville Dam, the water warms again as measured at Randolph. Overall, for the four dates supplied, there is a net warming of 5 to 7° F over the 155 miles. In the data presented in Table 1, there was seen a 15° F rise for the same distance in March. The water temperature in the river below the reservoirs appears to be dependent upon operations within the reservoirs.

In 1957 before the two reservoirs were constructed, the rise in average monthly river temperature between Altavista and Randolph varied from 1 to 3° F according to season and year (Table 3) (17). This is one degree per 20 miles in the summer and one degree per 60 miles in the winter.

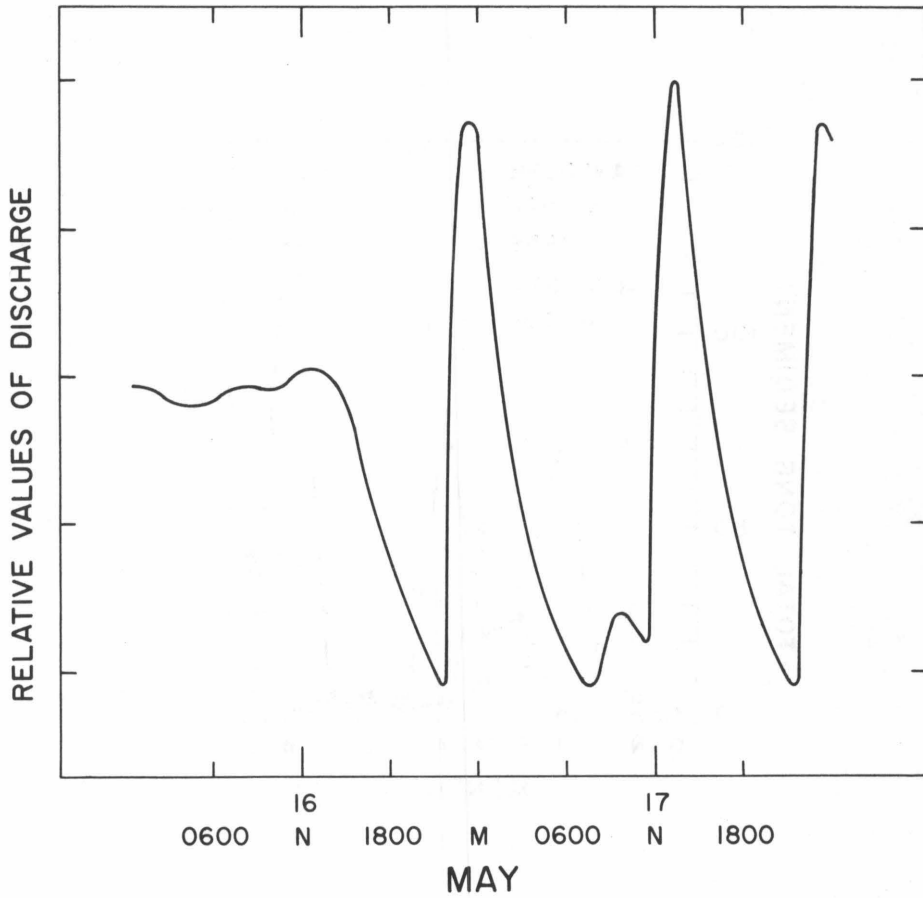


Figure 13. Roanoke River flow record at Altavista on the last day of augmented flow and first day of routine flow, 1967.

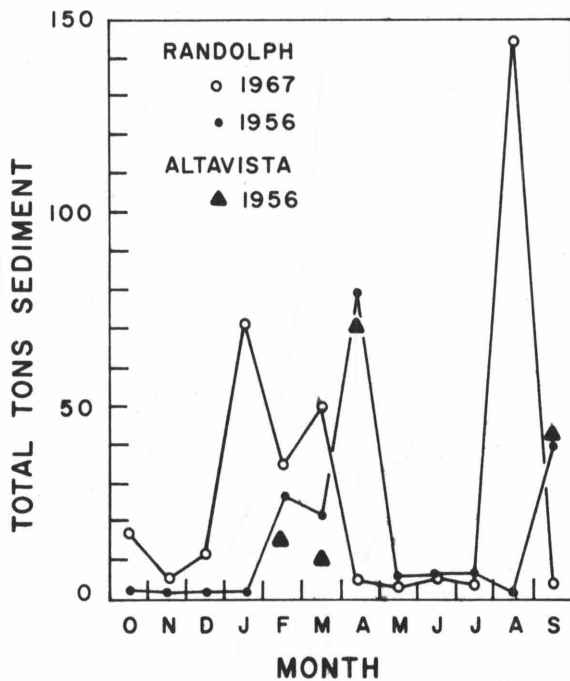


Figure 14. Total sediments per month at Randolph and Altavista on the Roanoke River in 1956 and 1967.

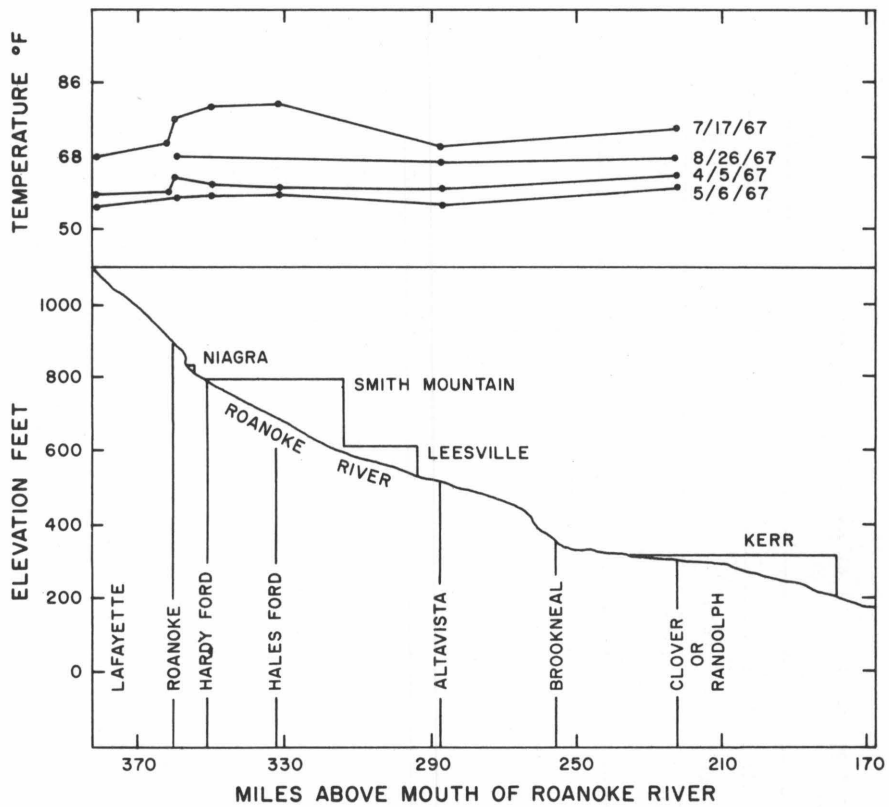


Figure 15. Roanoke River temperature profile related to river mile and elevation.

TABLE 3. Average monthly water temperature ( $^{\circ}$ F) at Altavista and Randolph for 1955 and 1956.

	1955				1956			
	Altavista	Randolph	Difference		Altavista	Randolph	Difference	
January	37	38	1		34	35	1	
February	39	40	1		41	43	2	
March	48	50	2		46	47	1	
April	56	58	2		52	54	2	
May	66	68	2		65	67	2	
June	60	70	2		71	73	2	
July	77	79	2		75	78	3	
August	75	76	1		73	76	3	
September	68	70	2		65	68	3	
October	55	58	3					
November	42	45	3					
December	34	35	1					

After the impoundments were operational, a continuous record of the April, May, and part of June temperatures were made at Brookneal and Clarksville (Fig. 16 and Appendix K). A record was also made at Clover Bridge but was incomplete and won't be discussed here. The mean monthly temperatures for April and May of 1966 at Brookneal (river mile 256) are 57 and 67° F, respectively. These values are close to what would have been expected for these months and that location which is midway between Altavista and Randolph.

The irregular pattern of high and low temperatures seen at Brookneal in Fig. 16 is hard to understand until it is recalled that the Leesville Reservoir elevation is subject to a weekly cycle of storage. On Monday through Friday, only a fraction of the generation water is returned by pumping to the upper reservoir. Then on Friday through Sunday, continuous pumping restores the remainder for the beginning of the next week's cycle on Monday. Thus, the Leesville elevation has a great deal of influence on the temperature of water that is discharged. If the Leesville Reservoir is low, then warm surface waters are discharged as would be expected on Monday of a normal operating week. On Thursday and Friday the water level is quite high which means that colder water occupies a greater depth in the reservoir and is first to be discharged. This phenomenon is seen several times between the last of April and first of June on the Brookneal record. Also, since there is seldom any generation on weekends, the temperature of the river can assume the temperature of the tributaries at that time. It must be remembered that the Brookneal water left Leesville about 1 day before (2 miles per hour for 40 miles).

At first sight, the augmented flow period does not contribute much to the temperature picture. However, if the hourly temperatures were examined, it would be noticed that there was a very uniform temperature gradient during the day which is not as subject to the influence of air temperature as under regular flow conditions.

The Clarksville station is located on the upper end of the Kerr Reservoir and is influenced by both the Dan and Roanoke River drainages. There is some correspondence of peaks in the Brookneal record to those in the Clarksville record: they are diminished in size and displaced in time as would be expected.

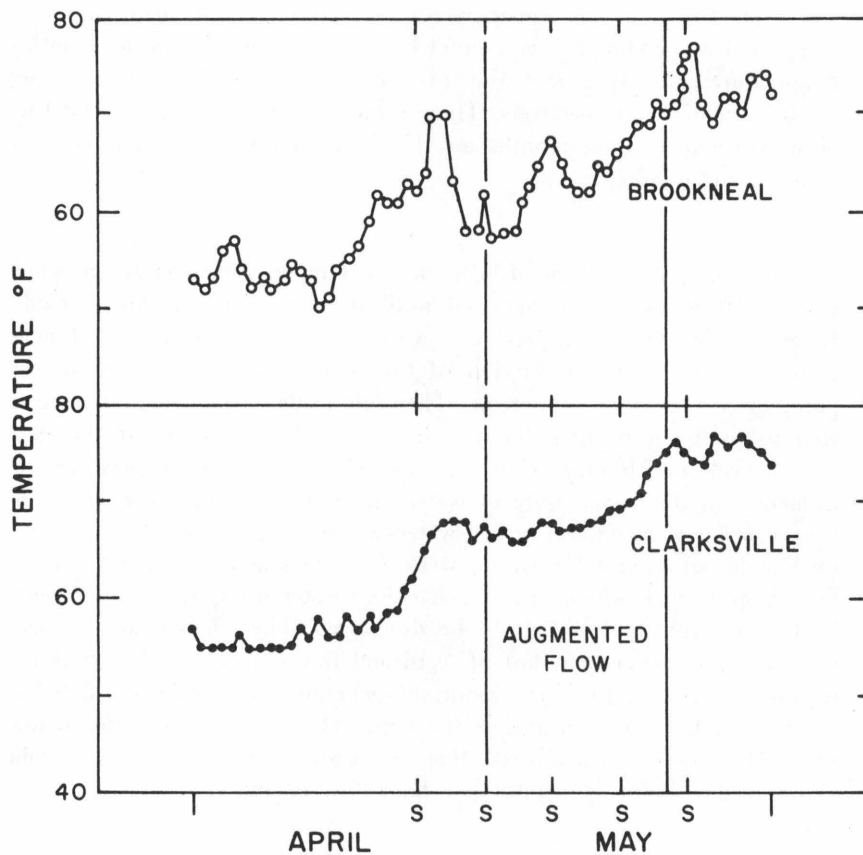


Figure 16. Roanoke River water temperatures before, during and after augmented flow at Brookneal and Clarksville.

## DISCUSSION

### General Water Quality of The Basin

The upper Roanoke River has its headwaters in the mountains where it is characterized as being the CO<sub>3</sub> type and hard. East of the Blue Ridge, it is fed by many soft water streams which are siliceous in type. By the time the water reaches the North Carolina border, its character has almost completely changed.

In March of 1968 at Roanoke, the dissolved mineral matter in the water was mainly HCO<sub>3</sub>, Ca and Mg and amounted to 132 ppm: the hardness was 115 ppm. The first tributary of any size to enter the Roanoke east of the Blue Ridge is the Blackwater River. It is a soft siliceous stream with dissolved solids averaging 42 ppm and hardness 18 ppm (5). By the time the Roanoke reaches Altavista, it has received more soft siliceous water from the Pigg River (5) and a little harder CO<sub>3</sub> type water from Goose Creek which has dissolved solids of 72 ppm and hardness of 42 ppm. The Big Otter River next adds more siliceous soft water and a fairly high average quantity of suspended matter. Falling River and Cub Creek continue to add soft siliceous water to the main stream. At Randolph the water is a mixed type, moderately low in mineral content and soft. The dissolved solids have decreased from 132 ppm at Roanoke to 77 ppm at Randolph and the hardness from 115 ppm to 49 ppm. While the average color increased from 18 units at Roanoke to 30 units at Altavista (most of which comes from Goose Creek) it decreases again to 5 units which is less than what it was at Roanoke.

The suspended matter increases from Roanoke to Randolph. For example, it has an average of 86 ppm at Roanoke and 240 ppm at Randolph (5). About half of the amount at Randolph during normal runoff comes from the tributaries below Altavista, principally the Big Otter River which probably carries the largest quantity of suspended matter in Middle Virginia (5). During high runoff, suspended matter is increased at all stations.

### Water Quality in the Impoundments

The forebay of Smith Mountain Lake is subject to severe mechanical action during draw-down and pump-back operations. Although the thermal layers are oscillated and distorted they still remain pretty much intact even at the log boom. The data isn't presented here, but from other unpublished material, it was found that the effect on thermal layering re-

sulting from two days of pump back isn't seen in lake transects beyond the confluence of the Roanoke and Blackwater Rivers (6.5 miles): it is seen as far as 3.0 mile up the lake in the form of slanted thermal profiles.

Probably one of the most significant observations in tailrace study of Smith Mountain Lake is that as cold water is used for generation during the summer, warm water is generally pumped back. Further, it is possible that the warm waters of the Pigg River are the main source of the returned water. If this is so, it would be interesting to know what effect the soft siliceous Pigg River water has on the main basin of the upper reservoir. Also, this may be a source of enrichment which would be an important factor in eutrophication of the main basin.

Fluctuation of water levels in Leesville Reservoir follows a weekly period dictated by the pump storage cycle. The interesting limnological observations found so far are that in the summer cold "Smith Mountain water" seems to slide along the bottom of the lake and drain off at the dam without being recycled. Also there is a gradual depletion of oxygen in the deeper waters as the summer season advances. It is not known if this deep water is decreasing in oxygen content as time goes by. Some oxygen data taken in the summer of 1968 in the forebay of Leesville Reservoir indicate that such is the case.

Water leaving Leesville Dam is an important component to the normal water quality of the Roanoke River. In the time that Smith Mountain Project has been operational, there has been a trend toward a softer water chemistry as measured at Randolph: this is not well proven by the present paper. Overall, the mean water chemistry, presently, isn't substantially different from preimpoundment times. The mean water temperatures likewise have not been altered by the Project. There has not been much clarification of how the Project influences the sediment levels in the river.

What is apparent from the present study is that the schedule of water releases has substantially changed the flow pattern in the river without altering the average volume of discharged water. This variable flow has led to variable temperatures on a weekly basis and there is inferred a variable water chemistry because of the low flow during weekends. What has happened to the river since impoundment may be thought of as the introduction of a new environmental cycle comparable to a tide.

### Regulated flow effect

The Project has added a new partial control over the river. This control consists of two elements: (1) low flow augmentation to establish 650 cfs minimum average release; (2) regulation of flows during the striped bass spawning period. This advantage has been used to regulate flow and volume during the striped bass run in April and May each year. When this augmented flow is being released, it stabilizes the river depth, discharge volume, temperature and probably water chemistry although this last aspect has not been documented here. Sediment levels appear to be substantially lower, though it doesn't look so visually. The temperature is stabilized on a daily basis but it still appears to be influenced by the pump-storage cycle on a weekly basis. This can lead to a 5°F difference per week during the augmented flow period.

### Questions Raised by the Study

The next stage in understanding the influences of the Smith Mountain Project on water quality in the upper Roanoke River basin would be to make a significant number of comparative water quality checks along the river basin as close to the same time as possible. This would lead to a quantitative measure of the contribution of each tributary and impoundment to the main stream.

An extension of the above study to the specific origin and fate of pumped water would be helpful for understanding the effect of pump storage on eutrophication in the basin of Smith Mountain Lake.

Not much has been mentioned on the effect of the Project on biota. There is an interesting problem to be studied in the effect of anaerobic zones within the impoundments upon the aquatic organisms. Also, the effect that a rapid change in water temperature has upon tailrace organisms is of interest. Fluctuating water levels is bound to alter reproductive habits of some fishes. Their solution to the problem would be important to know for they appear to be quite successful in Leesville Reservoir so far. It would be interesting to know if there are any polluting organisms in the Pigg River that might be concentrated in the upper reservoir. Lastly, there is not much knowledge about the preferred water quality for migrating striped bass. It may be possible to control the behavior of the migrating population to some extent through more sophisticated water releases.

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APPENDICES A THROUGH K



Appendix A. Temperature (°F) profiles in the forebay of Smith Mountain Lake in 1967.

Depth in feet	6/22	7/26	9/15	10/28
0	77	81	69	61.5
5	76	80	--	61.5
10	76	80	69	61.5
15	74	79	--	61.5
20	63	70	69	61.5
25	58	63	69	61.5
30	58	59	64	61.5
35	56	57.5	61	61
40	55	56	58	61
45	54	54	57	61
50	53	54	57	59
60	--	52	--	58
70	--	51.5	--	58
80	--	50.5	--	58
90	--	--	--	57.5
100	--	47.5	--	57.5

Appendix B. Temperature (°C) transect from SW to NE along the log boom in the forebay of Smith Mountain Dam on July 21, 1966 approximately 1300 o'clock.

Depth M.	Float # 1	Float # 3	Float # 5	Float # 7	Float # 7 (cont.)	Depth M.
0	25.4	25.3	25.7	26.1	11.2	41
1	25.3	25.3	25.6	25.9	11.1	42
2	25.1	25.1	25.3	25.6	11.0	43
3	24.8	24.9	24.9	25.3	10.2	44
4	19.8	19.8	19.9	18.3	10.1	45
5	17.4	16.9	17.0	17.4	10.0	46
6	16.7	16.2	16.4	16.7	9.9	47
7	15.9	16.0	15.8	15.9	9.8	48
8	15.6	15.7	15.5	15.8	9.8	49
9	15.3	15.3	15.3	15.7	9.8	50
10	15.1	15.1	15.2	15.5	9.8	51
11	15.0	15.0	15.1	15.4	9.8	52
12	14.9	14.9	15.1	15.3	9.8	53
13	14.9	14.9	15.0	15.2	9.8	54
14	14.8	14.9	15.0	15.1	9.8	55
15	14.8	14.8	14.9	15.0	9.8	56
16	14.8	14.7	14.8	14.9	9.8	57
17	14.8	14.5	14.7	14.8	9.8	58
18	14.6	14.3	14.5	14.8	9.8	59
19	14.3		14.3	14.6		
20			14.0	14.3		
21			13.8	14.1		
22			13.6	13.8		
23			13.3	13.4		
24			13.2	13.3		
25			13.1	13.3		
26			13.0	13.2		
27			12.9	13.1		
28			12.9	13.1		
29			12.8	13.0		
30			12.7	12.9		
31			12.3	12.6		
32				12.2		
33				12.2		
34				12.2		
35				12.1		
36				12.1		
37				12.0		
38				11.9		
39				11.9		
40				11.9		

## Appendix B. Cont.

Depth M.	Float # 9	Float # 9 (cont.)	Float # 11	Float # 11 (cont.)	Float # 13	Float # 13 (cont.)	Depth M. (cont.)
0	26.1	10.3	25.9	10.2	25.9	10.1	41
1	25.8	10.1	25.8	10.1	25.9	10.0	42
2	25.2	9.9	25.2	9.9	25.0	9.8	43
3	25.1	9.8	25.0	9.7	24.8	9.3	44
4	19.2	9.2	20.9	9.3	22.0	9.0	45
5	16.9	9.1	17.2	9.1	17.8	8.9	46
6	16.8	9.0	16.8	9.0	16.6	8.8	47
7	16.0	9.0	15.9	9.0	16.0	8.8	48
8	15.7	9.0	15.3	9.0	15.6	8.7	49
9	15.3	8.9	15.2	9.0	15.4	8.7	50
10	15.1	8.9	15.1	8.9	15.0	8.6	51
11	15.1	8.9	15.0	8.9	14.9	8.6	52
12	15.0	8.9	14.9	8.9	14.9	8.3	53
13	14.9	8.9	14.8	8.9	14.6	8.5	54
14	14.8	8.9	14.7	8.9	14.3	8.4	55
15	14.7	8.9	14.6	8.9	14.1	8.4	56
16	14.4	8.9	14.3	8.8	14.1	8.4	57
17	14.2	8.9	14.2	8.8	14.0	8.4	58
18	14.1	8.9	14.1	8.8	13.9		59
19	14.0		14.0		13.8		
20	13.9		13.8		13.5		
21	13.8		13.4		13.2		
22	13.3		13.2		13.0		
23	13.1		13.1		12.9		
24	13.0		13.0		12.8		
25	13.0		12.9		12.6		
26	12.9		12.8		12.4		
27	12.9		12.8		12.2		
28	12.8		12.7		12.0		
29	12.5		12.2		12.0		
30	12.2		12.2		12.0		
31	12.1		12.1		11.9		
32	12.0		12.1		11.9		
33	12.0		12.1		11.8		
34	12.0		12.1		11.8		
35	11.9		12.0		11.5		
36	11.9		11.9		11.3		
37	11.8		11.3		11.1		
38	11.1		11.0		11.0		
39	10.9		10.8		10.8		
40	10.8		10.5		10.2		

## Appendix B. Cont.

Depth M.	Float # 15	Float # 15 (cont.)	Float # 17	Float # 17 (cont.)	Float # 19	Float # 19 (cont.)	Depth M. (cont.)
0	25.8	9.9	25.9	9.8	26.6	10.0	41
1	25.9	9.8	25.9	9.4	26.2	9.7	42
2	25.0	9.6	25.0	9.0	24.4	9.5	43
3	24.8	9.2	24.8	8.9	21.4	9.4	44
4	23.5	9.0	24.0	8.7	19.2	9.4	45
5	17.6	8.8	18.0	8.5	17.8	9.4	46
6	16.4	8.8	16.4	8.4	17.2	9.4	47
7	15.9	8.6	15.9	8.3	16.8	9.4	48
8	15.4	8.4	15.4	8.3	16.5	9.4	49
9	15.2	8.4	15.0	8.2	16.2	9.4	50
10	15.0	8.4	14.8	8.2	15.9	9.4	51
11	14.9	8.4	14.7	8.2	15.7	9.4	52
12	14.8	8.4	14.5	8.2	15.6	9.4	53
13	14.5	8.4	14.3	8.2	15.4	9.4	54
14	14.3	8.3	14.1	8.1	15.2	9.4	55
15	14.1	8.3	14.0	8.1	15.1	9.4	56
16	14.0	8.2	14.0	8.1	14.9	9.4	57
17	14.0	8.2	13.9	8.1	14.8	9.4	58
18	13.9		13.8		14.5		
19	13.7		13.6		14.4		
20	13.5		13.4		14.2		
21	13.2		13.1		14.0		
22	13.0		13.0		13.8		
23	12.9		12.8		13.6		
24	12.8		12.6		13.4		
25	12.6		12.4		13.3		
26	12.4		12.3		13.2		
27	12.2		12.1		13.0		
28	12.1		12.0		12.9		
29	12.0		12.0		12.7		
30	12.0		11.9		12.5		
31	12.0		11.8		12.4		
32	11.9		11.6		12.1		
33	11.8		11.5		11.9		
34	11.5		11.3		11.7		
35	11.2		11.0		11.6		
36	11.0		10.9		11.3		
37	10.8		10.7		10.9		
38	10.5		10.3		10.5		
39	10.2		10.1		10.2		
40	10.1		10.0		10.0		

## Appendix B. Cont.

Depth M.	Float # 21	Float # 21 (cont.)	Float # 23	Depth M. (cont.)
0	26.6	9.7	26.6	41
1	26.1	9.5	26.1	42
2	24.4	9.4	23.9	43
3	21.8	9.3	20.2	44
4	19.4	9.3	18.8	45
5	17.6	9.3	17.7	46
6	16.6	9.3	16.9	47
7	16.3	9.2	16.5	48
8	16.1	9.1	16.1	49
9	15.8	9.1	15.8	50
10	15.6	9.1	15.5	51
11	15.4	9.0	15.4	52
12	15.3	8.9	15.2	53
13	15.1	8.9	15.0	54
14	15.0	8.9	15.0	55
15	14.9	8.9	14.9	56
16	14.7	8.9	14.6	57
17	14.5	8.9	14.4	58
18	14.4		14.2	
19	14.2		14.0	
20	14.0		13.8	
21	13.7		13.7	
22	13.5		13.4	
23	13.3		13.2	
24	13.2		13.1	
25	13.0		13.0	
26	12.8		12.9	
27	12.7		12.9	
28	12.6		12.6	
29	12.6		12.6	
30	12.5		12.5	
31	12.4		12.3	
32	12.3		12.2	
33	12.0			
34	11.8			
35	11.6			
36	11.3			
37	10.5			
38	10.3			
39	10.2			
40	10.0			

Appendix C. Temperature (°C) transect from SW to NE along the log boom in the forebay of Smith Mountain Dam on July 24, 1966 approximately 1200 o'clock.

Depth M.	Float # 2	Float # 3	Float # 5	Depth M. (cont.)
0	23.3	23.3	23.9	41
1	21.9	20.8	21.7	42
2	20.2	19.4	20.0	43
3	18.4	19.0	18.8	44
4	17.6	19.0	18.0	45
5	17.2	18.9	15.3	46
6	17.2	18.9	16.6	47
7	17.2	18.9	16.6	
8	17.0	18.6	16.6	
9	16.6	17.8	16.6	
10	16.3	16.0	16.6	
11	16.0	14.8	16.6	
12	15.9	15.1	16.6	
13	15.8	14.8	16.6	
14	15.7	14.4	16.6	
15	15.5	14.4	16.4	
16	15.5		16.4	
17	17.3		16.4	
18	15.0		16.5	
19	14.9		16.6	
20	14.7		16.5	
21	14.7		15.6	
22	14.7		15.2	
23	14.7		15.0	
24	14.7		14.9	
25			14.7	
26			14.6	
27			14.4	
28			14.4	
29			14.4	
30			14.4	
31			14.4	
32			14.4	
33			14.4	
34			14.4	

## Appendix C. Cont.

Depth M.	Float # 7	Float # 7 (cont.)	Float # 9	Float # 9 (cont.)	Float # 11	Float # 11 (cont.)	Depth M. (cont.)
0	18.9	13.6	24.4	13.9	22.2	12.7	41
1	18.9	13.5	23.2	13.9	20.0	12.6	42
2	18.8	13.5	21.5	13.9	18.2	12.5	43
3	18.6	13.3	19.6	13.9	17.8	12.4	44
4	18.5	13.1	18.7	13.9	17.6	12.1	45
5	18.4	12.9	18.2	13.5	17.6	11.9	46
6	18.3	12.7	17.7	12.0	17.5	11.8	47
7	18.3		17.5	11.0	17.2	11.7	48
8	18.3		17.4	10.5	16.9	11.3	49
9	18.3		17.2	10.4	17.0	10.3	50
10	18.2		17.1	10.0	16.6	9.8	51
11	17.8		17.1	9.7	16.9	9.6	52
12	17.1		17.1	9.5	16.9	9.4	53
13	16.8		17.1		16.8	9.4	54
14	16.5		17.1		16.6	9.4	55
15	16.2		17.1		16.6	9.4	56
16	16.1		17.0		16.6		
17	16.0		16.9		16.6		
18	15.6		16.9		16.6		
19	15.5		16.6		16.5		
20	15.6		16.0		16.3		
21	15.7		15.9		16.2		
22	15.4		15.7		16.1		
23	14.7		15.5		16.1		
24	14.4		15.4		16.1		
25	14.4		15.2		16.0		
26	14.4		15.1		15.6		
27	14.8		15.0		15.3		
28	14.9		14.8		14.8		
29	15.0		14.7		14.4		
30	15.0		14.7		13.8		
31	14.8		14.7		13.5		
32	14.4		14.6		13.5		
33	14.4		14.5		13.4		
34	14.3		14.4		13.3		
35	14.1		14.4		13.3		
36	14.0		14.4		13.3		
37	13.9		14.3		13.3		
38	13.9		14.1		13.3		
39	13.9		14.1		13.3		
40	13.8		14.0		13.3		

## Appendix C. Cont.

Depth M.	Float # 13	Float # 13 (cont.)	Float # 15	Float # 15 (cont.)	Float # 17	Float # 17 (cont.)	Depth M. (cont.)
0	22.2	13.3	23.3	13.2	24.4	13.3	41
1	20.0	13.2	21.5	13.2	21.7	13.3	42
2	18.0	12.9	19.8	13.3	19.8	13.2	43
3	17.7	12.5	18.4	13.3	18.9	12.8	44
4	17.6	12.4	17.6	13.3	18.4	12.6	45
5	17.5	12.3	17.2	13.2	18.0	12.5	46
6	17.5	11.9	17.2	12.6	17.7	12.3	47
7	16.9	11.4	17.2	11.8	17.7	12.0	48
8	16.5	10.8	16.9	10.9	17.7	11.8	49
9	16.4	10.5	16.2	10.0	17.7	11.3	50
10	16.3	10.2	16.3	10.0	17.4	10.8	51
11	16.2	10.0	16.3	10.0	17.2	10.5	52
12	16.1	9.5	16.4	9.9	17.2	10.4	53
13	16.1	9.4	16.4	9.7	17.1	10.2	54
14	16.1	9.4	16.4	9.4	17.1	10.0	55
15	16.1	9.4	16.4	9.4	17.1	9.6	56
16	16.1	9.4	16.3	9.4	16.7	9.4	57
17	16.0	9.4	16.1	9.4	16.4		58
18	15.9		16.1	9.4	16.4		59
19	15.6		16.3	9.4	16.4		60
20	15.5		16.6		16.3		
21	15.1		16.6		15.9		
22	14.9		16.6		15.9		
23	14.6		16.6		16.2		
24	14.1		16.6		16.3		
25	13.9		16.6		16.3		
26	13.9		16.6		15.8		
27	13.5		16.6		15.7		
28	13.4		16.5		15.5		
29	13.5		16.5		15.3		
30	13.4		15.8		15.0		
31	13.3		15.5		14.7		
32	13.3		15.4		14.4		
33	13.3		15.1		13.9		
34	13.3		14.6		13.6		
35	13.3		13.7		13.5		
36	13.3		13.9		13.4		
37	13.3		13.8		13.3		
38	13.3		13.4		13.3		
39	13.3		13.2		13.3		
40	13.3		13.1		13.3		

Appendix C. Cont.

Depth M.	Float # 19	Float # 19 (cont.)	Float # 21	Float # 23	Depth M. (cont.)
0	23.3	12.8	25.0	24.0	41
1	20.8	12.6	22.0	21.4	42
2	19.1	12.6	19.3	19.6	43
3	18.3	12.5	17.0	18.9	44
4	18.1	12.3	18.6	18.5	45
5	17.9	12.2	18.5	18.0	46
6	17.4	12.2	16.1	17.3	47
7	17.3	12.2	16.0	17.2	48
8	17.2	12.1	17.6	17.2	49
9	17.1	11.7	18.0	17.2	50
10	17.1	11.6	18.1	17.0	51
11	16.9	11.5	18.0	16.7	52
12	16.3	11.2	17.8	16.3	53
13	16.1	11.1	17.7	16.1	54
14	16.3		17.4	16.1	
15	17.0		15.9	16.1	
16	17.3		15.5	15.9	
17	17.3		15.5	15.8	
18	17.2		15.5	15.6	
19	16.6		15.5	15.5	
20	16.0		15.5	15.5	
21	15.6		15.4	15.5	
22	15.5		15.2	15.5	
23	15.5		15.0	15.5	
24	15.4		14.8	15.5	
25	15.4		14.7	15.5	
26	15.3		14.7	15.5	
27	15.3		13.7		
28	15.2		13.3		
29	15.0		13.3		
30	14.6		13.7		
31	14.4		13.7		
32	14.4		13.3		
33	14.4		13.3		
34	14.3		13.3		
35	14.1		13.3		
36	14.1		13.3		
37	14.1		13.3		
38	14.1		13.3		
39	14.0				
40	13.8				

Appendix D. Smith Mountain Reservoir Tailrace Temperatures of 1967 for highest (H), lowest (L) and daily average (A) values in °F.

Day	January			February			March			April			May			June			July		
	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A
1	43	39	41	44	42	43	40	39	39½	52½	43½	48	53½	50½	52	57	51	52½	59½	56	57
2	44	39	42	44	43	43½	41½	38	39	53	47½	51	53	51	52½	53	50½	51½	68	57	63
3	45	44	44½	43	42	42½	41	38	39½	52	45	48	54	52	53	57	51	54	68	57½	62
4	45	44	45	43	41½	42	41	40	40	47	45	46	49½	48	49	63	55	58	63	58	59½
5	45	44	44½	43½	41½	42	43	40	41½	47	45½	46½	50	48	49	62	50½	55	60	56½	58½
6	44½	43½	44	44	42	43	43	41	41½	48	45	47	51½	49	50½	54	52½	53	64	56½	61
7	44	43½	44	43	40	41½	42½	41	41	50	46	47	54	50	52	57	52	54	58	55½	57
8	45	44	44½	42½	40	41	42	40½	41	51	48	49	55	51	52	56½	52½	54	68	56½	62
9	45	44	44	41½	39½	40½	42½	40½	41½	51½	50	51	53	51	52	59	53	55	75	66	70
10	45	43½	44	42	36½	38½	42½	41	42	51½	48	49	58	51½	54	62	54	58	75	57½	64
11	44	42	43	42	40	41	48	42	43½	50	46	48	53	48	51½	68	61	64	74	60	66
12	44	40½	42	41	40	40½	45½	45	45	49	44½	47	53	51	52	66	54	59	70	57	61
13	44½	41½	43	42	39½	40½	45½	41	42½	49½	44	46	55½	52½	54½	57	54½	55½	61	57	59
14	44	41	42	42½	40½	41½	43½	41½	42	49	45	47	56	54½	55	57	54	55½	63½	58	60
15	43	40	41	43	41½	42	44½	41½	42	53	48	50	54½	49½	52	60	53½	55	68½	59	62
16	43½	42	42½	43	42	42½	43	41½	42½	57	47½	53	53	51	52	59	55	56½	74	65	69
17	44	41½	42½	42	41	41½	44	42	43	48	46½	47½	54	51	52	69	57	62	71	45½	58
18	43	42	42½	42	40	40½	43	41	42	51	48	49	54½	50	52	67	64	65½	67	48	56
19	42½	40	41½	41	40	40½	44	42	43	52	50½	51	53½	50	52	68½	55½	57	72	58	62
20	43	39	41	41½	39½	40½	43	42	42½	51½	50	50½	58	53½	56	68½	54½	62	72	57	65
21	42	40	41	41½	41	41	42½	42	42	50½	49	50	59	57	58	58	55	56½	59	57	58
22	42½	38	40	41½	39	40½	43	42½	43	53	49	51	58	50½	53	58	56	56	63	58	59½
23	45	42	42½	41½	40	41	44	42½	43	53	50½	51½	55½	50	52½	62	56	58	73	61	68
24	44	43	43½	41½	39½	40½	44	44	43	51½	48½	50	52	49½	50½	67	57	61	72	51½	62
25	45	42½	43½	40	35½	37	46	43	44	51	49	49½	51½	49½	50	69	66½	67½	67	55	60
26	45	42	43	36½	34	35	48	44½	46	51	48	49	53½	51	52	71	56	64	68	60	64
27	46	43	44	40	35	37½	48	42	44	50	49	49½	59	52	55	57½	55½	56½	75	46	59
28	43½	42½	43	40½	39½	40	44	42	43	54	49½	51½	64	53	58	60	56	57½	60	46	53
29	42½	41	41½	-	-	-	45	43	44	53½	50	51½	61	52	55	66	57	62	63	60	61½
30	43	41	42	-	-	-	44½	43	44	54	52	53	58	51	55	67½	56	61	73	67½	70
31	43	41	42	-	-	-	48½	43	45	-	-	-	55	51	51½	-	-	-	74½	57½	67

Appendix D. Cont.

Day	August			September			October			November			December		
	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A
1	75	61½	69	60	58	59	60½	58½	60	56½	54	55½	49½	47½	49
2	69	58½	63	62	58	59½	61	56	59	56	54½	55½	49	47½	48
3	64	56	59	67	58	63	61	58	59½	56½	53½	55	47½	44½	46
4	61	48	59	68	65	66½	60	53	58	55½	54	55	49	43	47
5	66½	59	61½	68	59	63	60	55	59	54½	52	53	49	44	47½
6	78½	60	70	66	59	61	59½	55	57	55	51½	53½	48½	46½	47½
7	76	59	66	60½	58	59½	60½	58	59½	55	53	54	49	47	48
8	73	59	63	65	58½	60½	62	60	61	54	52½	53½	49½	48	48½
9	64	56½	60	62	58½	60	61½	58	59½	54½	51½	53	48½	46	46½
10	61½	56½	60	68	58½	64	59½	56	58	54½	51	53	46	45	45½
11	60½	58	59½	68	58	64	59	56	58	54	51	53	48	43½	46
12	68	58	60	59	55	58	58½	58	58	52½	50½	51½	48½	43	45
13	73	65½	70	59	50	55	58½	56½	57½	54	50½	52½	47½	42½	45
14	76	70½	73	60	55	58	59	51½	58	53½	52	53	48	42½	46½
15	72½	58½	65	60½	51	57	60	58	59	53	51	52½	48	47	47½
16	62½	58	59½	60½	57½	59	60	55	57	52½	51	52	47	44½	45½
17	60	58	59	63	59½	60½	59	56	58	52½	51½	52	45½	44	44½
18	60	59	59½	62½	58½	60	59	55	58	52	50	51½	47½	44	45
19	62	59	60	60½	55	58	59	54½	56	50	49	49½	48	46½	47
20	69	62	66	60	56	58½	58½	55	57	51½	48	49	47½	47	47
21	68½	59	62	60½	55	59	57½	55½	56½	51½	47	48½	47	47	47
22	63	59½	61½	62½	58	61	57½	50	56½	51½	47	48½	48	47	47½
23	65	48	61	65	62	63	58	55	56½	51½	49	50½	47	43½	45
24	63½	59	61	65	63	64	57½	54½	56	51	47	49½	44	42½	43½
25	65	59½	62½	63½	56	60	57½	55	56½	50½	49	50	44	43	43½
26	68	59	63½	60½	49	59	57	55	56	50	47½	48½	46	43	44½
27	61	59	59½	60	57½	59	57½	55	56	51	48½	50	45½	44½	45
28	62	59	60½	60	55	58½	56	54	55	50	48½	50	45	44	45
29	63	59½	60½	60	56	58½	55½	54	54½	50	47½	49½	45	44	45
30	72	60½	65	59	57½	58½	57	53	55	50	48½	49½	44	39	41½
31	69	59	62	-	-	-	57	55	56	-	-	-	39	37½	38½

Appendix E. Temperature profiles in Leesville Reservoir during 1967  
at selected stations. B stands for lake bottom.

Date	Location	Lake Mile	Time	Depth (feet)	Temperature °F	
7/21	Forebay	0	1300	0	77.9	
				8	63.5	
				B	62.6	
	Tri-County Marina	5	1400	0	81.5	
				8	72.5	
	Pigg River Mouth	13	1430	0	72.5	
				8	63.5	
				B	64.4	
				1500	0	63.5
					8	60.8
					B	61.7
	7/22	Phillips 66 Marina	15.5	1700	0	79.7
5					69.8	
10					64.4	
15					60.8	
B					60.8	
Opposite house		16	1710	0	70.7	
				5	66.2	
				B	62.6	
Tailrace bridge		16.5	1720	0	63.5	
				5	60.8	
				10	57.2	
				B	56.3	
Under power lines		14.5	1730	0	79.7	
				5	70.7	
				B	62.6	
Pigg River mouth		13	1735	0	80.6	
				5	70.7	
				10	63.5	
				15	59.9	
				B	59.0	
Tolers Bridge		12	1850	0	82.4	
				5	70.7	
				10	68.0	
				15	61.7	
	20			60.8		
	B			60.8		

## Appendix E. Cont.

Date	Location	Lake Mile	Time	Depth (feet)	Temperature °F
7/23	Tri-County Marina	5	1600	0	84.2
				5	81.5
				10	70.7
				20	64.4
				30	60.8
				40	59.0
	Tolers Bridge	12	1730	B	58.1
				0	86.0
				5	76.1
				10	70.7
				15	68.9
				20	62.6
	Confluence of Pigg River	13	1740	B	63.5
				0	81.5
				5	76.1
	Phillips 66 Marina	15.5	1825	B	71.6
				0	82.4
				5	77.0
				10	72.5
				15	70.7
Tailrace Bridge	16.5	1830	B	69.8	
			0	76.1	
			5	71.6	
			10	70.7	
Near power plant	16.9	1845	B	70.7	
			0	76.1	
			5	73.9	
			10	69.8	
			15	59.0	
			20	59.0	
			25	59.0	
30	59.0				
B	59.0				

Appendix F. Dissolved oxygen (DO in parts per million) and temperature (T in °F) in Leesville Reservoir and the Roanoke River as a function of depth (D in meters), date (1966), and location (R.M. - river mile).

Graves Bridge on the Pigg River		Smith Mountain Tailrace		Tolers Bridge		Junction of routes 609 and 733		Leesville Reservoir Forebay		Leesville Reservoir Tailrace		Norfolk and Western RR Bridge		
R.M. - 3.5		R.M. - 314		R.M. - 309		R.M. - 303		R.M. - 297		R.M. - 297		R.M. - 294		
D	DO	T	D	DO	T	D	DO	T	D	DO	T	D	DO	T
6/23		6/23		6/23		6/24		6/23		6/24		6/29		
0	7.5	--	0	7.2	--	0	7.9	--	0	8.4	--	0	7.0	61.5
2	6.3	--	6	6.9	--	6	7.7	--	11	5.5	--	2	7.1	61.5
			10	6.4	--	12.5	5.8	57.5	21	3.5	--	3	7.0	61.5
									4	6.6	61.5	4	6.6	61.5
									4.5	6.8	61.5	4	6.8	61.5
6/27		6/29		6/27		6/27		6/27		6/28		6/29		
0	5.7	77.5	0	6.3	60.0	0	5.8	58.0	0	8.5	79.5	0	6.8	65.0
3	5.3	75.0	6	6.2	59.0	6	6.0	57.0	2	8.0	80.0	2	6.9	64.5
			9.5	5.9	57.0	10.5	5.6	59.0	6	6.2	60.0	3	6.8	64.0
												4	6.8	64.0
												5	6.7	64.0
7/6		7/6		7/6		7/6		7/5		7/18		7/17		
0	6.6	78.5	0	5.8	59.0	0	5.6	60.5	0	8.1	78.0	0	7.3	64.0
3	5.8	77.0	5	5.5	58.5	6	5.5	59.5	11	4.2	58.0	0.5	7.4	64.5
			9	5.4	59.0	12	3.7	59.0	17	2.1	56.5	1	7.3	63.5
7/26		7/26		7/26		7/26		7/25		7/25		7/26		
0	7.5	--	0	5.5	--	0	5.8	--	0	8.1	--	0	6.9	--
2.5	7.3	--	2	5.4	--	6	6.7	--	11	3.8	--	2	6.7	--
			6	5.5	--	10	5.9	--	17	1.4	--	3	6.8	--
									19	0.8	--	4	7.0	--

Appendix F .Cont.

Graves Bridge on the Pigg River			Smith Mountain Tailrace			Tolers Bridge			Junction of routes 609 and 733			Leesville Reservoir Forebay			Leesville Reservoir Tailrace			Norfolk and Western RR Bridge		
D	DO	T	D	DO	T	D	DO	T	D	DO	T	D	DO	T	D	DO	T	D	DO	T
	8/3						8/3			8/2			8/1			8/1			8/2	
0	6.3	71.0				0	5.3	66.0	0	7.4	71.0	0	7.2	--	0	8.3	--	0	7.2	67.0
2	6.6	71.0				6	5.4	65.0	6	4.7	68.5	11	3.4	--	2	7.8	--	0.5	7.9	66.5
						8.5	5.3	65.0	9	3.6	64.0	17	1.7	--	3	7.9	--	1	7.4	66.5
															4	7.6	--			
	8/9			8/9			8/9			8/9			8/9			8/8			8/8	
0	6.9	74.0	0	4.0	62.0	0	4.1	63.0	0	7.0	78.0	0	7.3	80.0	0	5.6	65.5	0	7.0	68.0
1.5	7.3	73.5				6	4.0	65.0	6	4.3	66.0	11	2.1	65.0	2	5.1	64.5	0.5	6.9	67.0
2	6.9	74.0				9	4.1	64.0	11	3.1	65.0	18	1.2	62.0	3	5.7	64.0	1	6.9	67.0
															4	4.7	63.5			
																8/15			8/15	
															0	6.0	69.0	0	7.3	68.0
															2	5.4	67.5	0.5	7.3	67.0
															5	5.2	67.5	1	7.3	66.0
															9	5.1	67.5			
	8/23			8/23			8/23			8/23			8/22			8/22			8/22	
0	7.8	79.5	0	5.7	68.0	0	4.3	65.0	0	6.0	69.0	0	9.2	83.0	0	7.0	67.5	0	7.9	68.0
2	7.3	77.0	2	5.4	67.0	3	4.3	65.0	6	4.7	70.0	6	5.6	68.0	2	6.5	65.0	0.5	7.5	67.0
2+	6.7	76.0	3	5.4	67.0	6	4.1	65.0	11	2.0	65.0	11	2.0	65.0	5	6.1	67.0	1	7.4	66.0
													16	0.8	63.0	9	4.9	68.0		
				9/19			9/19			9/19			9/19			9/20			9/20	
			0	8.1	58.0	0	7.2	58.0	0	8.5	60.0	0	5.5	61.5	0	5.5	57.0	0	7.9	58.0
			2	6.9	58.0	5	5.4	58.0	5	3.3	59.5	10	1.5	58.0	5	4.1	59.0	0.5	8.1	59.0
			3	6.8	58.0	8	5.2	58.0	8.5	4.2	57.5	17	1.0	56.5	9	4.1	58.5	1	7.7	59.0

Appendix G. Leesville Reservoir Tailrace Temperatures of 1967 for highest (H), lowest (L) and daily average (A) values in °F.

Day	January			February			March			April			May			June			July		
	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A
1	40	40	40	42	40	41	38	36	37	47	44	45	55	53	54	58½	56½	57½	62	59½	60
2	42	39½	40	43	41	41½	38	36	37	48	44½	46	58	53	55	61	57	58	61½	59	61
3	41	40	40	42	40	41	39	37	38½	51	46	48	56	54	54½	59	57	57½	64	60	62
4	41	39	40	42	39	40	39½	37½	38	51	47	49	56	54	55	59	57	57½	63	60	61
5	40	38	39	43	40	41	40	37	39	49	46½	48	56	53½	54	58	56	57	65	60	62
6	39	38	39	42	40	41	41	40	40	52	46	49	55	53	54	61	57	58	64	60	62
7	39	38	39	41	39	40	40	39	39	52	48½	50	52½	51½	52	60	56½	57½	63	61	61½
8	40	39	39	41	39	39½	40	38½	39	52	49	50	55	52	53	61	56½	58	63	61	62
9	40	39	40	40	39	39	42	39	41	53	48½	51	55	53	54	63	57	59	64	61	62½
10	41	40	40	40	39	39½	43	41	42	53½	50	51	56	53½	54	60	57	58	68	62	64
11	40	39	40	40	39	39½	44	42	43	53	49	51	57	54	56	60	57	58	68	62½	65
12	40	38	39	41	38½	39	44	41½	42	52	49	50	57½	55	56	62	57	59	67	62	64
13	41	39	40	40	38	39	42½	41	41½	50	48	49	55	54	54½	64	57½	59	67	63	64
14	41	40	40	41	39	40	45	42	43	56	49	52	55½	54	54½	61	57	59	67	63	65
15	41½	40	40	41	40	40½	44	42½	43	56	54	54	58	54	56	62	57	60	64½	61½	63
16	41	39	40	41	40	41	43½	41½	42	57	52	55	58	55	56	62	58	60	64	61	62½
17	41	39	40	40	38	40	44	42	43	53	51	52	59	56	57	60	57	58	64	62½	63½
18	40	39	39	40	39	39	44	42	43	55	53	53	58	56	57	59	57	58	66	63	64½
19	39	38	39	40	39	39	44	41½	42½	56	52	54	62	56	58	60½	58	59	65	62	63
20	40	38	39	41	39	39½	43½	42½	43	56	52	54	59½	57	58	61	58	59	65	62	63
21	40	38	39	40	38½	39	44	43	43	55	52	53	58½	54½	57	64	58	61	66	62	64
22	41	39	39	40	38	39	44	42	43	55	52	53	56	54	55	65	58	61	65	62	63
23	42	39	40	40	38	39	44	42	43	56½	55	55½	56	54	55	65½	58	60	65½	62½	63½
24	42	40	41	39½	37	38	44	42	43	58	53½	55½	56½	54	55	61	57½	59	68	63	65
25	43	40	41	38	37	37	44½	43	44	57	53	55	59½	56½	57½	61	58½	59½	69	64	67
26	43	41	42	39	36	37	45	42½	43	56	53	54	60	57	58	62½	58	60½	68	63½	66
27	44	41	42	38	36	37	44	43	43	56	52	53	60	57	58	64	58	61	67½	63	65
28	42	40	41	38	37	37	47	42	44	55	53	54	59½	57	58	63	59	61	69	65	67
29	41½	39	40	-	-	-	46	44	45	56	53	54	62	57	59	62	59	60½	66	63	65
30	40	39	40	-	-	-	47	44	45	55	53	54	58½	56	57	63	60	61½	64	62	63
31	41	39½	40	-	-	-	47	44	45	-	-	-	57	56	56½	-	-	-	67½	62	65

Appendix G. Cont.

Day	August			September			October			November			December		
	H	L	A	H	L	A	H	L	A	H	L	A	H	L	A
1	68	63	65	65	64	64½	62	61½	62	57½	56	56½	47½	46½	46½
2	68	63½	66	67	64½	65½	63½	61	62	57	55½	56	46½	46	46
3	69½	63½	67	67	64	65	64	62	62½	57	55½	56	47	45	46
4	69	64	67	66½	64½	65	63	61	62	57	54	55	47	45½	46
5	66	64	65	66	65	65½	63	61	61½	55½	54	54½	46½	45	45½
6	65	63	64	66	65	65½	63	60	61½	55	53½	54	46	45	45
7	68	63½	66	66½	65	65½	60	59½	60	55	53½	54	46	45	45½
8	68	65	66½	67	65	65½	60	59½	60	54	53	53	47	45	45½
9	70	64½	67	66	64½	65½	61½	60	60½	54	52	53	45½	45	45
10	68	64	66	66	63	64½	61	60	60	54	52½	53	45½	44½	45
11	68	65	66	64	63	63½	61	60	60	53½	52	52½	45½	44	44½
12	66½	63½	65	65	63	65	60	59	59½	54	52	53	46	45	45
13	66	63½	64½	65	63	64	60	59	59½	53½	52½	53	46	44	45
14	68	64	65	64	62½	63	60½	59	59½	53	52	53	46	44½	45
15	68	64	65½	65	63	63	60	59	59½	52½	51	52	45	44	44½
16	68	64	65½	65	63	63½	61	59	60	51½	50	50½	45	43½	44
17	68	64	66	65	63	63½	61	59½	60	51½	50½	51	45	43½	44½
18	69½	65	67	65	63	64	61½	59	60	52	50	51	45	43	44½
19	66½	64½	65	66	64	65	60	58½	59	51	49	50	46	45	45
20	65	64	64½	66	63	64	60	58	59	50½	49	50	45	44	44½
21	67	63	65	66½	63	64½	60	57½	58½	50½	49	49½	45	44	44½
22	67	64	65	64½	63	63½	59	57	58	50	49	49½	46	44½	45
23	65	63½	64½	64½	61	62½	59½	57	58	50	48	49	44½	43	43½
24	65	63	64	64½	61½	62½	59	57½	58	49	48	48½	44	43	43½
25	66½	65	65½	65	62	63	59	57	58	50	48	48½	44½	43	44
26	68½	65½	66½	67	62	63½	58½	57	57½	50	48	49	44½	43	43½
27	68	65	66	64	62	63	58½	57	57½	49½	48	48½	43½	42½	43
28	68	65	66½	65	62	63	58	56	56½	49	47	48	43	42	42½
29	68½	66	67	63	61½	62	57	55½	56	48	47	47½	43	42	42½
30	67½	65	66	65	62	63	57½	56	56½	47	46½	47	43	41½	42
31	66½	65	65½	-	-	-	57	56	56½	-	-	-	42	42	42

Appendix H. Mean discharge of the Roanoke River at Randolph for selected months of 1956 and 1967.

Day	Discharge (cfs)							
	November		February		May		August	
	1955	1966	1956	1967	1956	1967	1956	1967
1	1050	915	1080	4360	1860	2150	675	700
2	1050	1500	1080	2650	1780	2460	640	1380
3	1050	2530	1120	1800	1940	2470	615	1370
4	1050	3600	1740	1760	1980	2210	700	1370
5	1050	2330	3100	1320	2020	2150	780	1450
6	1050	1130	4460	1470	1980	2080	810	1590
7	1050	669	6430	2270	1860	2550	725	799
8	1050	1090	6710	2920	1900	3970	675	1260
9	1050	1530	4820	2640	1820	2930	640	1760
10	1080	1550	3400	2030	1620	2290	500	1690
11	1360	1570	2620	1740	1500	2020	480	1500
12	1540	1550	2440	1220	1470	2000	460	1440
13	1500	1080	2260	979	1440	2070	450	1050
14	1360	611	2180	1830	1360	1970	460	443
15	1260	1050	1980	2370	1330	1990	500	631
16	1220	1520	1820	2180	1620	2190	460	1370
17	1190	1490	1780	2620	1360	2090	480	1330
18	1190	1550	2100	3310	1300	1770	500	1300
19	1190	1520	2440	1700	1220	1740	520	1340
20	1220	1030	2530	1730	1190	1700	580	1000
21	1300	533	2350	6790	1120	1600	640	469
22	1300	957	2180	8840	1080	1680	680	1250
23	1260	1460	1940	6880	1080	1860	740	2120
24	1220	1450	1780	6040	1080	1870	810	8020
25	1190	1470	1860	5360	1190	1740	635	18500
26	1190	1490	2020	3090	1190	1670	545	22700
27	1190	1030	2260	2030	1050	1600	495	12100
28	1190	575	2260	3780	990	1580	400	4100
29	1190	1670	2100	----	1020	1560	370	3990
30	1160	2230	----	----	1050	1550	350	2200
31	----	----	----	----	1080	1570	350	1860

Appendix I. Sediment concentrations in the Roanoke River at Randolph in 1956 and 1967 and at Altavista in 1956.

Month	Tons per month		
	Randolph		Altavista
	1955-6	1966-7	1955-6
October	2121	15645	908
November	1765	4905	1104
December	1513	11711	898
January	1143	69271	813
February	25867	35020	15061
March	21556	50325	9650
April	79941	5091	70988
May	6176	3526	2882
June	6006	5139	4147
July	6408	3944	5477
August	2210	144377	1503
September	39203	3729	43374

Appendix J. Roanoke River temperature (°F) profile related to river miles and date.

Station	River Mile	Temperature - °F		
		4/15/67	5/6/67	7/17/67
Elliston	383	58.5	57.0	68.0
Salem	365	60.0		71.5
Roanoke	360	62.7	58.0	77.0
Hardy Ford	348	62.0	59.5	80.0
Hales Ford	332	61.0	60.0	80.5
Altavista	286	60.8	57.0	70.2
Clover Bridge	220	61.0	60.8	75.4
				68.0
				66.7
				68.0

Appendix K. Water temperature ( $^{\circ}$ F) records at Brookneal and Clarksville during 1966.

Day	Brookneal		Clarksville	
	April	May	April	May
1	53	62	56	67
2	52	57	55	66
3	53	58	55	67
4	56	58	55	66
5	57	61	55	66
6	54	63	56	67
7	52	65	55	69
8	53	67	55	68
9	52	65	55	67
10	53	63	55	67
11	55	62	55	67
12	54	62	57	68
13	53	65	56	68
14	50	64	58	69
15	51	66	56	69
16	54	67	56	70
17	55	69	58	72
18	56	69	57	73
19	59	71	58	75
20	62	70	57	76
21	61	71	59	76
22	61	75	59	75
23	63	77	61	74
24	62	71	62	74
25	64	69	65	77
26	70	72	67	76
27	70	72	68	77
28	63	70	68	77
29	58	73	68	76
30	58	76	67	75

**WATER RESOURCES RESEARCH CENTER**  
**VIRGINIA POLYTECHNIC INSTITUTE BLACKSBURG, VIRGINIA 24061**

