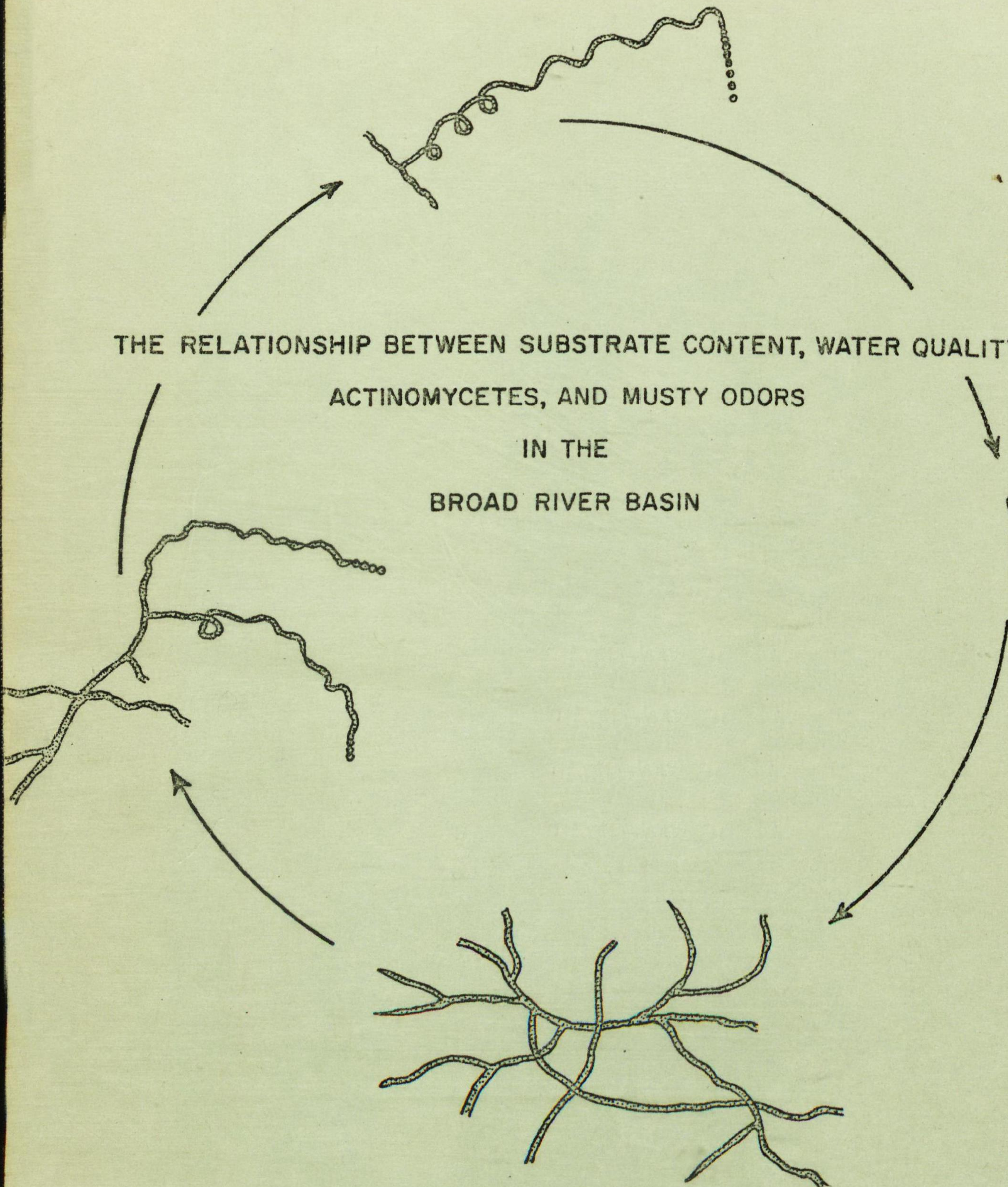

THE RELATIONSHIP BETWEEN SUBSTRATE CONTENT, WATER QUALITY ACTINOMYCETES, AND MUSTY ODORS IN THE BROAD RIVER BASIN

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Environmental Protection Agency
Surveillance and Analysis Division
Athens, Georgia

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All Environmental Protection Agency personnel are assigned to the Surveillance and Analysis Division located at Athens, Georgia. The Division is under the direction of Mr. J. A. Little.

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SUMMARY

1. During the spring of 1972, personnel from Region IV, Surveillance and Analysis Division of the Environmental Protection Agency conducted an investigation for the South Carolina Pollution Control Authority to determine the source and cause of musty odors in the Columbia, South Carolina, water supply.
2. At approximately 3-week intervals between April 4 and June 12, 1972, biological and chemical samples were collected from 19 stations along the Broad River and its tributaries in North and South Carolina.
3. Samples collected during the high rainfall and increasing flows on May 9-10 contained the highest average water concentrations of TOC, total phosphate as phosphorus, ammonia-nitrogen, and TKN found during any one sampling period in the basin.
4. Water samples from tributary streams draining the Greenville-Spartanburg area and from the Broad River below Carlisle textile mill contained higher concentrations of nutrients than samples from other locations in the basin.
5. Concentrations of organic carbon (TOC) in water from tributary streams and in the main river below Carlisle textile mill were similar to TOC concentrations found in grossly-polluted Butler Creek, a tributary to the middle reach of the Savannah River.
6. Highest concentrations of organic materials (TKN and TOC) in sediments were found in samples collected from Parr Reservoir and the canal at Lockhardt, South Carolina. On three occasions,

concentrations of organic carbon at these locations exceeded 3 percent by weight.

7. Past data received from Columbia water plant personnel and data from the Broad River study indicate that odor production is dependent on air and water temperature, rainfall, and flow.
8. Musty odor in water samples reached its highest average values on May 9-10, 1972, in the basin, tributaries, rivers, and impoundments, coinciding with odor reports by Columbia water treatment plant personnel.
9. Leaf litter odors were considerably higher than water odors; and throughout the study period, leaf litter odor increased while leaf litter wet weight decreased.
10. All actinomycetes isolated from Broad River basin samples and maintained on agar subsequently produced characteristic musty odors.
11. Average stream substrate and leaf litter actinomycete counts generally increased throughout the study period.
12. Leaf litter actinomycete counts were generally higher than actinomycete counts from stream substrate and periphyton samples.

CONCLUSIONS AND RECOMMENDATIONS

The musty odors found in the Columbia, South Carolina, municipal water supply are not unique to that area, but are a widespread phenomenon in the Broad River Basin. Actinomycetes, common throughout the basin, are the organisms producing the musty odors; however, actinomycete growth and musty odor production appear to be dependent on the influx and storage of organic matter and other nutrients, air and water temperature, rainfall, and stream flow during the spring season. The major tributaries in South Carolina appear to be a primary source of organic matter and other nutrients, while the canals and reservoirs act as a "sink" for these nutrients, thus providing a substrate conducive to actinomycete growth and odor production.

Columbia water treatment plant personnel should create an odor panel and regularly sample upstream in the vicinity of Parr Dam for odors during the spring of the year. Personnel should be prepared to treat the water with activated carbon when air temperatures and water temperatures of 17°C or greater occur during extended spring-time low-flow (less than 6,500 cfs) periods (2 to 5 weeks) and upstream threshold odors are 4 or greater. When the above conditions occur, severe odor problems can be expected; therefore, treatment should begin as soon as possible.

Inputs of wastes from municipalities and industries in the Broad River Basin should be reduced to levels commensurate with available waste treatment technology. Particular attention should be given to wastes from Lockhardt and Carlisle textile mills and discharges into tributary streams draining the Greenville-Spartanburg area.

INTRODUCTION

The Columbia, South Carolina, water treatment plant has experienced taste and odor problems since the spring of 1969. Water from the Broad River reportedly had a "musty" or "earthy" smell accompanied by a foul taste.

On February 22, 1972, the South Carolina Pollution Control Authority (PCA) requested the Surveillance and Analysis Division (S&A) of Region IV, Environmental Protection Agency, to initiate a comprehensive study in the spring of 1972.

The study encompassed three objectives: (1) to determine the source or sources of the odor, (2) to identify the odoriferous compound, and (3) to recommend remedial measures.

DESCRIPTION OF STUDY AREA

The Broad River originates on the eastern slope of the Blue Ridge Mountains of southwestern North Carolina at an elevation of approximately 4,000 feet. It flows southeasterly, entering South Carolina near Gaffney. It then flows southerly, impeded only by a few run-of-the-river type reservoirs, to the vicinity of Columbia where it is joined by the Saluda River to become the Congaree River (Figure 1).

The principal tributaries to the Broad River are the First Broad, Second Broad, Pacolet, Tyger, and Enoree rivers. The First and Second Broad rivers lie wholly in North Carolina and join the Broad River prior to its entering South Carolina (Figure 1).

Geologically, two counties (Polk and Rutherford) lie in the Blue Ridge; eight counties (Cherokee, Chester, Fairfield, Greenville, Newberry, Spartanburg, Union, and York) lie in the Piedmont; two counties (Lexington and Richland) lie in the Sandhills.

The basin has a mild climate with average annual temperatures of about 58°F, ranging from a low monthly mean of 40°F in January to 75°F in July and August. Although freezing temperatures occur about 80 days each winter, summers are warm and winters are relatively mild. Rainfall over the basin averages about 54 inches per year.

The present study was conducted from April 4 to June 13, 1972. During this period, a total of five 2-day sampling trips were made in South Carolina. Rain occurred 60 percent of the time while personnel were sampling the area and 80 percent of the time on the two days preceding each sampling trip (Table I).

FIGURE I.

STATION LOCATIONS ON THE BROAD RIVER AND ITS MAJOR TRIBUTARIES

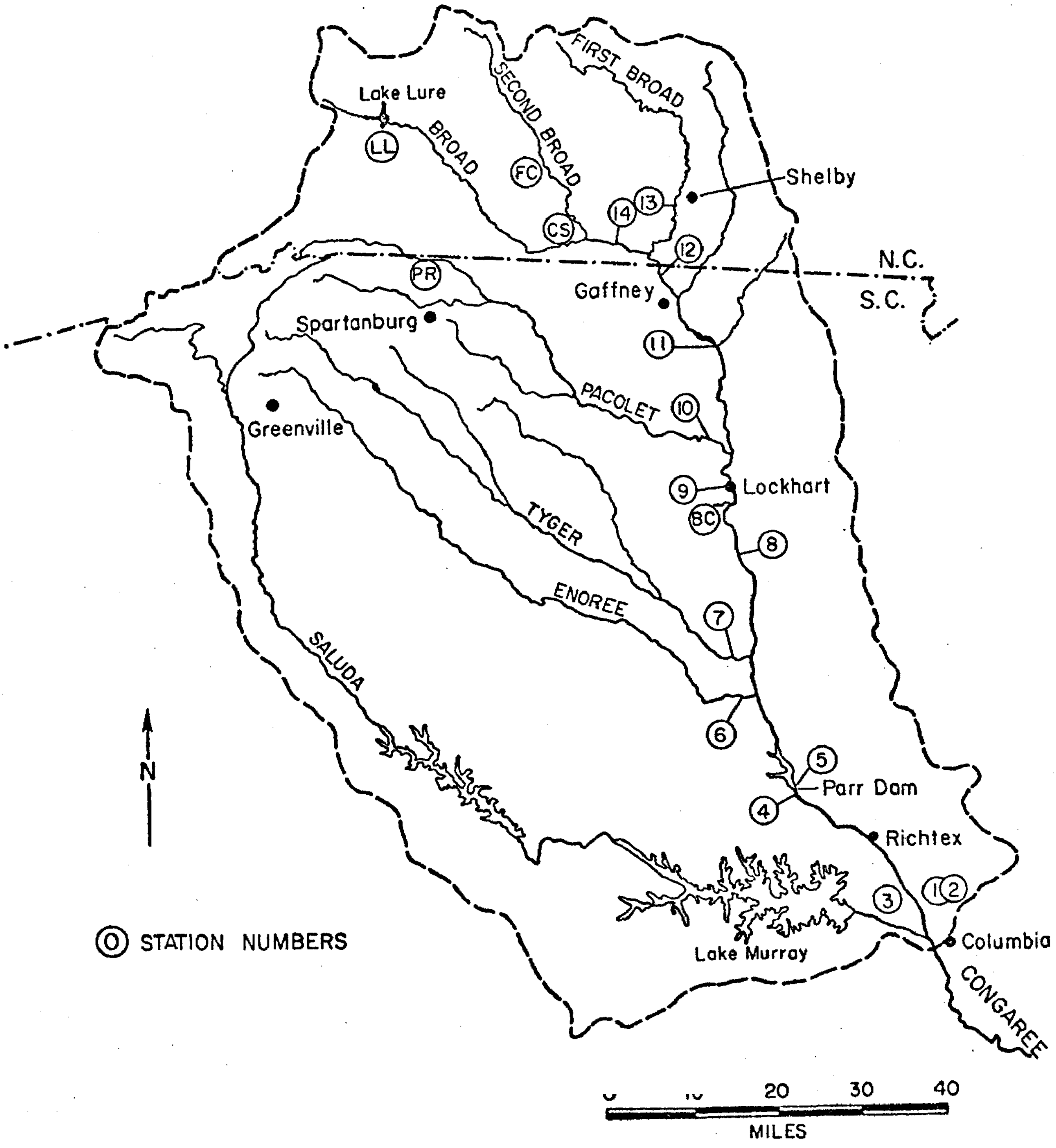

TABLE I.—Average Rainfall Throughout the Broad River Basin, South Carolina, April-June 1972

Days	Average Rainfall[1] (inches)																			
	4/2	4/3	4/4	4/5	4/22	4/23	4/24	4/25	5/7	5/8	5/9	5/10	5/28	5/29	5/30	5/31	6/10	6/11	6/12	6/13
Daily	0.01[1]	0.01	0.04	0.05	0.28	0.20	0.01	0.00	0.00	0.65	0.61	0.00	0.08	0.17	0.05	0.09	0.14	0.00	0.00	0.00
4-day Total[2]	0.11				0.49				1.26				0.38				0.14			
2-day Total[2] during sample collection	0.09				0.01				0.61				0.14				0.00			

[1] Average based on rainfall from 22 gauging stations in South Carolina.

[2] Summation of daily averages.

The United States Geological Survey (USGS) has four streamflow gauging stations on the Broad River between Casar, North Carolina, and Richtex, South Carolina, and one on a major tributary, the Enoree River at Enoree, South Carolina (Table II).

The high amount of rainfall throughout the May 7-10, 1972, period (Table I) was reflected in the highest flows on May 9-10, 1972, at the USGS gauging stations for any 2-day sampling period (Table III).

The Richtex, South Carolina, gauging station is a short distance above the Columbia water treatment plant in the downstream portion of the study area. Over a 42-year period of record, the 7-day minimum flow at Richtex was 593 cfs. The 7-day maximum flow recorded during the record period was 80,500 cfs (Table II).

During the period of this study, stream flow at Richtex ranged from a low of 3,740 cfs on June 12, 1972, to a high of 31,100 cfs on May 16, 1972 (Figure 12).

The basin contains a total population of about one million people, and approximately 66 percent are located in the metropolitan areas of Greenville-Spartanburg and Columbia, South Carolina. Industry is found throughout the basin; however, the two major areas of concentration are in the vicinity of Greenville-Spartanburg and Columbia. Major industries in the area include the manufacture of textiles, paper, plastics, and foods.

Numerous waste sources exist on the Broad River and its tributaries. Examination of STORET waste source data reveals that 55 waste sources in North and South Carolina discharge municipal wastes into the Broad River or its tributaries (Table IV).

TABLE II

Mean Discharge[1] on the Broad River and its Tributaries

River & Gauging Station	Period	7 Consecutive Days				14 Consecutive Days				30 Consecutive Days			
		Low		High		Low		High		Low		High	
	of Record	Year	cfs	Year	cfs	Year	cfs	Year	cfs	Year	cfs	Year	cfs
Broad - Casar, N. C.	1960-1969	1964	19.60	1960	723.00	1964	22.20	1965	548.00	1964	24.10	1960	341.00
Broad - Boiling Springs, N. C.	1926-1969	1957	185.00	1928	22,400.00	1955	214.00	1928	12,500.00	1955	228.00	1928	8,000.00
Broad - Carlisle, S. C.	1939-1969	1955	475.00	1945	33,200.00	1955	482.00	1965	24,900.00	1955	507.00	1952	15,300.00
Enoree - Enoree, S. C.	1930-1968	1955	20.70	1936	6,060.00	1955	23.00	1936	3,710.00	1955	26.10	1936	2,240.00
Broad - Richtex, S. C.	1926-1969	1955	593.00	1930	80,500.00	1955	608.00	1936	50,800.00	1955	646.00	1936	32,700.00

[1] Data obtained from STORET.

TABLE III.--Average Flow[1] on the Broad River and Its Tributaries, April-June 1972

Station	Daily Average Flow (cfs)											
	4/4	4/5	4/6	4/24	4/25	4/26	5/9	5/10	5/30	5/31	6/12	6/13
Broad River near Richtex, S.C.	7,080	6,640		6,020	5,930		5,850	10,200	5,600	5,360	3,740	3,860
Enoree River near Enoree, S.C.	551	545		574	488		1,180	723	434	422	342	316
Broad River near Carlisle, S.C.	4,260	4,450		3,420	4,530		6,230	6,500	3,860	4,240	2,710	
Broad River near Boiling Springs, N.C.	1,640	1,600	1,520	1,120	1,460	1,350	2,410	1,950	2,030	2,090	1,040	1,280
First Broad River near Casar, N.C.	97	91	89	85	86	78	143	106	94	86	60	60

[1] Data obtained from STORET.

TABLE IV.--Municipal Waste Sources[1]

State	Totals		Sources with Primary or No Treatment		Sources with Secondary Treatment	
	Sources	Pop. Served	Sources	Pop. Served	Sources	Pop. Served
North Carolina	10	37,360	2	1,560	8	35,800
South Carolina	45	143,564	26	56,385	19	87,179
TOTALS	55	180,924	28	57,945	27	122,979

[1]Data obtained from STORET.

In addition to these municipal waste sources, 56 industrial waste sources are located in the basin. Consequently, organic wastes and suspended solids are major pollution problems on the Broad River and its tributaries (1).

The Broad, Tyger, Enoree, and Pacolet rivers are Class B waters, suitable for domestic supply after complete treatment, propagation of fish, industrial and agricultural uses, and other uses requiring water of lesser quality.

STATION LOCATIONS AND DESCRIPTIONS

The 19 stations sampled can be divided into seven categories:

1. Broad River main stem and headwater stations - 4, 8, 12, 13, 14.
2. Impoundment stations - 5, 11.
3. Canal stations - 1, 9.
4. Tributary stream stations - 6, 7, 10.
5. Terrestrial stations - 3.
6. Water treatment plant station - 2.
7. Special stations - CS, FC, LL, PR, BC.

road River Main Stem and Headwater Stations

Station 4 - This station (Figure 1) was located on the Broad River ust below Parr Dam and Power Plant next to South Carolina Highway 213 ridge. It was designated for periphyton sampler placement. However, he river was high; and suitable objects could not be used to secure the amplers on April 4, 1972. This station was abandoned and the samplers ere placed at Station 5.

Station 8 - This station (Figure 1) is located on the Broad River t South Carolina Highway 72 bridge near Carlisle, South Carolina. It as sloping, high clay banks that level off for about 20 yards before reaching the edge of the river channel. The banks are covered with hardwoods and a dense undergrowth of perennials.

Station 12 - This station (Figure 1) is located on the Broad River at South Carolina Highway 18 bridge just north of Interstate 85.

Station 13 - This station (Figures 1 and 2) is located on the First Broad River just upstream from North Carolina Highway 150 bridge, 5 miles east of Boiling Springs and 4 miles south-southwest of Shelby, North Carolina. The bottom substrate consists of sand and silt.

Station 14 - This station (Figures 1 and 3) is located on the Broad River at the North Carolina Highway 150 bridge, 2 miles south of Boiling Springs, North Carolina. The river is wide and shallow with an extensive riffle area and a sand-clay bottom.

Impoundment Stations

Station 5 - This station (Figures 1 and 4) is located on the Broad River just above Parr Dam at the Duke Power Company hydroelectric plant. This dam is considered a "run-of-the-river" type dam; however, it forms a "reservoir" approximately 1 mile long. The water depth is about 10 feet, and the bottom consists of silt and clay sediments which have accumulated to considerable depths behind the dam. The river banks sustain dense hardwood forests.

Station 11 - This station (Figures 1 and 5) is located on the Broad River at the Duke Power Company hydroelectric plant and dam at the end of county Highway 43, approximately 4miles south of Blacksburg, South Carolina. The site includes another "run-of-the-river" dam in which substantial amounts of silt and sand have accumulated to form an island behind the dam; therefore, the water depth is only 10 to 11 feet.

Canal Stations

Station 1 - This station (Figures 1 and 6) is located on the Broad River diversion canal near the Columbia, South Carolina, water treatment

FIGURE 2.--Station 13, First Broad River south of Shelby, North Carolina.

FIGURE 3.--Station 14, Broad River below Boiling Springs, North Carolina.

FIGURE 4.--Station 5, located at the Duke Power hydroelectric plant.

FIGURE 5.--Station 11, located at the Duke Power hydroelectric plant.
Note the island in background formed from sediment deposition.

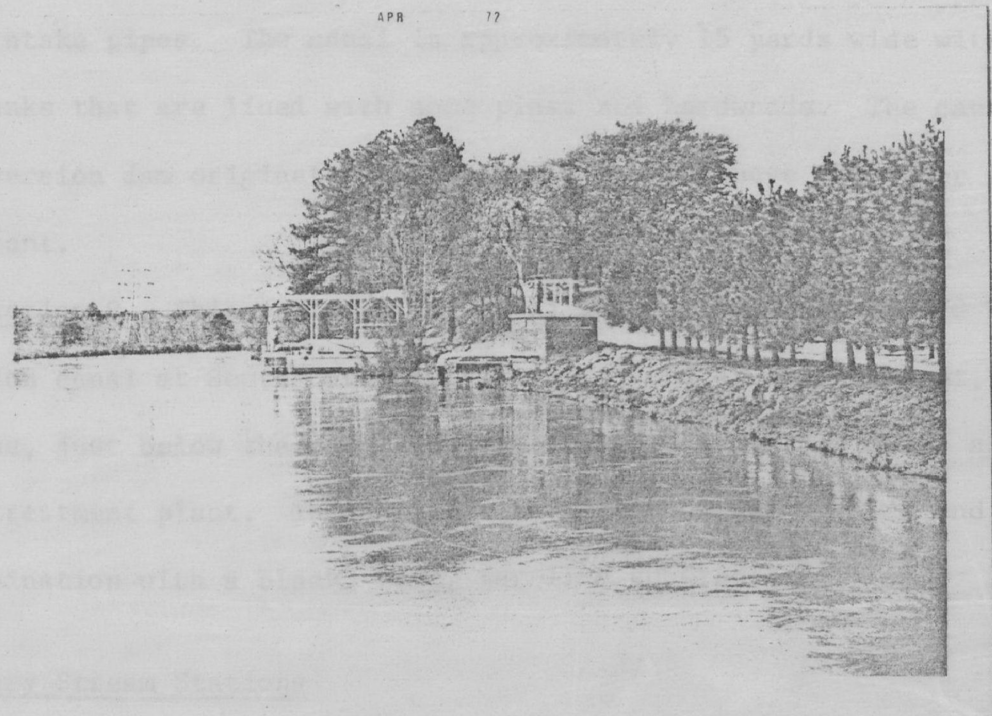

FIGURE 6.--Station 1, located at the Columbia water treatment plant Broad River diversion canal.

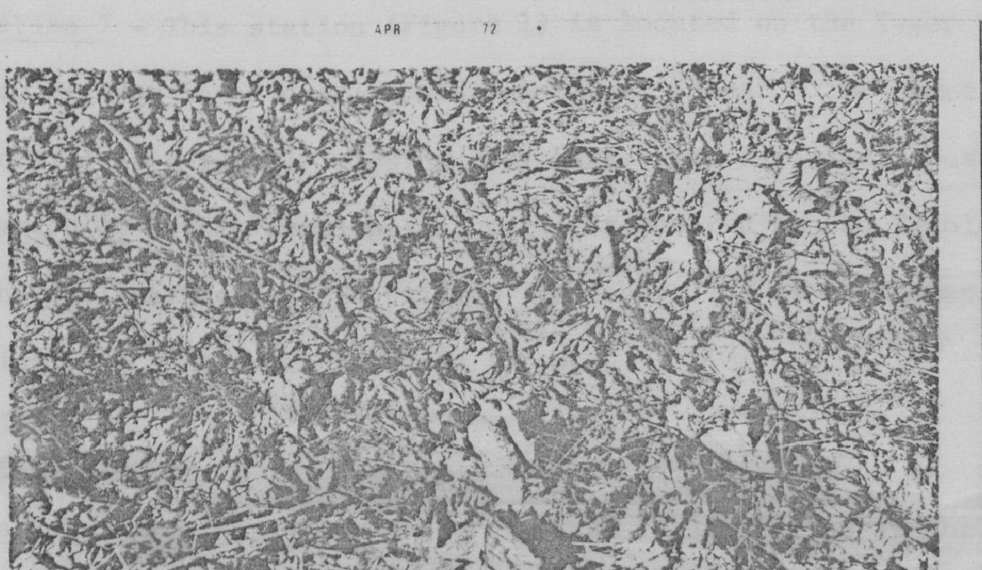

FIGURE 7.--Leaf litter at Station 3, Harbison State Forest.

plant intake pipes. The canal is approximately 15 yards wide with steep clay banks that are lined with some pines and hardwoods. The canal and its diversion dam originate approximately 1 mile above the water treatment plant.

Station 9 - This station (Figure 1) is located on the Broad River diversion canal at South Carolina Highways 9 and 49 in Lockhardt, South Carolina, just below the diversion dam, Lockhardt Textile Mill, and the water treatment plant. The bottom substrates consist of clay and silt in combination with a black, hard, tar-like substance.

Tributary Stream Stations

Station 6 - This station (Figure 1) is located on the Enoree River at county Highway 45 bridge in Sumter National Forest. The shoreline is characterized by gradually sloping clay banks with hardwood forests.

Station 7 - This station (Figure 1) is located on the Tyger River at county Highway 54 bridge in Sumter National Forest. The shoreline is characterized by gradually sloping clay banks with hardwood forests.

Station 10 - This station (Figure 1) is located on the Pacolet River at South Carolina Highway 105 bridge. The shoreline is characterized by sloping clay banks with hardwood forests.

Terrestrial Station

Station 3 - This station (Figures 1 and 7) is located in the hardwood forest section of Harbison State Forest near Nicholas Creek. Harbison State Forest is located approximately 4 miles north-northwest of the South Carolina Correctional Institution for Girls and borders the west bank of the Broad River. Leaf litter samples from the forest terrain were collected for odor and microbiological analyses at this station and proximal to Stations 5, 6, 7, 8, 10, 11, 13, and 14.

Water Treatment Plant Station

Station 2 - Water samples for biological and chemical analyses were collected in the Columbia water treatment plant after chlorination.

Special Stations

During the reported musty odor problem on May 5-10, the following additional stations were sampled by EPA personnel:

Cliffside (CS) - This station (Figure 1) is located on the Second Broad River just south of Cliffside, North Carolina, on U. S. Alternate Highway 221. The bottom substrate consists of clay and sand.

Forest City (FC) - This station (Figure 1) is located at the Forest City, North Carolina, water treatment plant. Raw water samples piped into the treatment plant from the Second Broad River were collected at this station.

Lake Lure (LL) - This station (Figure 1) is located about 2 miles below Lake Lure Dam, North Carolina, along U. S. Highway 74.

Pacolet River (PR) - This station is located on the Pacolet River above Spartanburg, South Carolina, at S. C. Highway 9 bridge. The river bottom was sandy and the banks were lined with hardwoods.

Browns Creek (BC) - This station is located at County Highway 86 crossing about 5 miles below Lockhardt, South Carolina.

All stations were located in the South and North Carolina Piedmont except Stations 1, 2, and 3, which were in the Sandhill counties of Lexington and Richland, South Carolina.

MATERIALS AND METHODS

Samples were collected at Stations 1, 3, 5, 9, 10, 11, 13, and 14 over a 2- to 3-day period at approximately 3-week intervals on five occasions between April 4 and June 13, 1972. All 14 sampling sites were visited only on the initial sampling trip (April 4-6, 1972) and on the May 9-10 sampling trip.

Between May 5 and 10, 1972, Columbia water treatment plant personnel received 15 complaints regarding musty water odors. On the subsequent sampling trip (May 9-10) other special stations (see station list) also were sampled for odor and chemical analyses.

Chemistry

One water sample was collected for odor analysis at each station, refrigerated, and shipped to the Region IV Surveillance and Analysis Division laboratory the same day. The odor test was conducted according to Standard Methods, 13th Edition (2). Odor tests in the field were conducted according to Standard Methods (2) except two to three people were on the panel and the test was at ambient temperature. Also, on May 9, 1972, dilution water with a chlorine residual was used with the regular dilution water in the field.

Forest leaf litter odor tests were conducted according to the following scheme:

Two replicate leaf litter samples were collected at random with a 6-inch diameter plexiglass pipe, weighed, placed in a bag, chilled, and sent to SERL. Laboratory analysis consisted of:

1. Chopping up the leaves.
2. Placing the contents in a 500-ml graduated cylinder.
3. Adding 200 ml of chlorine-free distilled water.
4. Mixing for 5 minutes.
5. Waiting for 5 minutes.
6. Filtering the sample through Whatman filter paper.
7. Conducting the test on the supernatant according to Standard Methods (2).

On each sampling trip, three replicate (reduced on May 30 to two replicate) water samples and one replicate (increased on May 9 to two replicate) substrate sample were collected at certain stations and analyzed for nitrogen, phosphorus, chemical oxygen demand (COD), and total organic carbon (TOC). Substrate COD was determined according to Standard Methods (2), and substrate total Kjeldahl nitrogen (TKN) was determined according to the Chemistry Laboratory Manual for Bottom Sediments (3). EPA Methods for the Chemical Analysis of Water and Wastes (4) was used to determine TOC, total phosphate, nitrate-nitrite-nitrogen, ammonia-nitrogen, and TKN in water and total phosphate in the substrates.

In an attempt to identify the odoriferous compound, one replicate water sample and one replicate substrate sample were collected at Stations 1, 5, 9, and 14.

Diel dissolved oxygen (DO) and temperature were collected and determined by Columbia water treatment personnel at Station 1.

Biology

Two replicate plankton samples were collected at all aquatic stations each sampling period, and Sedgwick-Rafter analyses were conducted according to Standard Methods (2).

Periphyton diatometers were placed in the river at Stations 1, 5, and 11. Two slides were extracted from each station at 2-, 3-, 4-, and 9-week intervals, and Sedgwick-Rafter analyses were conducted according to Standard Methods (2). Due to flooding, samplers were lost at Station 11 the first week.

Microbiology

Water, substrate, leaf litter, and periphyton samples were analyzed for the presence and relative distribution of actinomycetes, using a pour plate technique (2). Known amounts of the various samples were diluted using buffered dilution water, pH 7.2. Either 1.0 ml or 0.1 ml of inoculum from the appropriate decimal dilution was plated.

Actinomycete Isolation Agar (5) was employed for isolation. After plating, the plates were incubated for 7 to 10 days at room temperature (25° to 28°C). Following incubation, characteristic actinomycete colonies were counted. Selected colonies exhibiting characteristic morphologies were picked and examined microscopically for filament and spore arrangement.

Actinomycete counts made using the above-mentioned techniques should be regarded as relative. Factors such as bacterial overgrowth, fungal overgrowth, atypical colony characteristics, and failure to recognize characteristic colonies may affect the accuracy of such a counting procedure.

ANALYTICAL SAMPLING RESULTS

Total Organic Carbon

Water

During the study period, TOC in water samples ranged from 0.80 mg/l to 17.16 mg/l (Table V).

Averaged over the entire study period, the canal stations (1 and 9) and one impoundment station (11) had somewhat higher TOC concentrations. Station 14, in the headwaters of the Broad River, had the lowest average TOC concentration.

Samples on May 9 and 10, 1972, were collected during and just after a period of high rainfall (Table I) with concomitant increasing streamflow (Table III and Figure 12), and the river waters were visibly roiled and turbid. Streamflow had been decreasing immediately prior to this time. Concentrations of TOC on May 9-10, 1972, were considerably higher than concentrations in samples collected on the other four sampling trips. TOC at stations on tributary streams (6 and 7) draining the urbanized and industrialized Greenville-Spartanburg area were unusually high, as was Station 8 just below Carlisle Textile Mill (Table V). The impoundment stations (5 and 11) were 1.2 to 1.9 times higher than the river and tributary stations, respectively, during the low-flow periods of April and June (Table III).

In a comparison with available STORET TOC data from the Savannah and Chattahoochee Rivers, the maximum TOC concentrations in the Broad River were considerably higher than maximum concentrations reported from the Savannah River and were near the maximum concentration reported from the

Chattahoochee River below Atlanta, Georgia. TOC concentrations from tributary stations (6 and 7) and Station 8 on May 9 and 10, 1972, were comparable to concentrations reported from Butler Creek, a grossly-polluted tributary to the Savannah River (6).

Bottom Substrates

Concentrations of TOC in substrates ranged from 971 mg/kg dry weight to 36,704 mg/kg dry weight (Table VI).

On three occasions TOC concentrations exceeded 3.0 percent -- twice at impoundment Station 5 during low-flow periods and once at canal Station 9 on May 9, 1972. These two stations have been associated with past odor problems. Highest TOC concentrations were generally found in the canals and impoundments (especially Parr reservoir) and the lowest concentrations at the headwater stations.

Finger and Wastler (7) found that Charleston Harbor muds contiguous to industrial and domestic waste sources contained 2.34 to 5.87 percent TOC by weight. Average TOC concentrations from Parr Reservoir (Station 5) and canal Station 9 for the entire study were 2.22 and 2.06 percent, respectively -- slightly less than the minimum TOC limit of 2.34 percent found by Finger and Wastler (7).

Chemical Oxygen Demand

Chemical oxygen demand (COD) was used to derive the TOC values in the bottom substrates; however, the COD results are of interest in themselves because Environmental Protection Agency (EPA) guideline limits for open water dredging disposal have been set at a minimum of 5 percent

(50,000 mg/kg dry weight) in bottom substrates. Seven times during the study, COD values exceeded the 5-percent guideline limit (Table VII). The seven high values were from samples collected at canal stations (1 and 9), Parr Reservoir (Station 5), and Station 13, where odor problems have occurred in the past.

Phosphorus

Water

Total phosphate concentrations ranged from 0.005 mg/l to 0.316 mg/l (Table VIII).

Lowest total phosphate concentrations for the entire study period were found in samples from headwater stations (13 and 14).

During the high-flow and precipitation period of May 9-10, 1972, (Tables I and III), the tributaries had the highest total phosphate concentrations. Stations 6 and 7, especially, contributed considerable amounts of total phosphate to the system during the May 9-10, 1972, period.

Historical STORET total phosphorus data from stations on the Broad River near Carlisle and Gaffney, South Carolina, from April 1, 1968, to December 15, 1971, averaged 0.034 and 0.028 mg/l, respectively -- considerably lower than concentrations found during the present study of the Broad River.

Phosphorus in flowing waters originates from a number of possible sources (8):

1. Groundwater - Water percolating through soils dissolves phosphorus compounds from minerals. This phosphorus enters surface waters via seepage or springs and the pumping of wells.

2. Rainfall - Most of the phosphorus in rainfall is the result of "washout" of atmospheric particulate material whose composition and quantity govern the concentration in rainfall.
3. Land runoff - Surface drainage is often the major contributor of phosphorus to a waterway. The quantity entering by drainage is dependent upon:
    a. Quantity of phosphorus present in soils.
    b. Topography.
    c. Vegetative cover.
    d. Quantity and duration of runoff.
    e. Land use.
    f. Pollution.

The high phosphate values in the tributaries during the high precipitation period on May 9-10 indicated that much of the phosphorus coming into the Broad River was probably from land runoff.

Substrates

Total phosphate concentrations in substrates ranged from 44 mg/kg dry weight to 985 mg/kg dry weight (Table IX).

The maximum total phosphate concentration was found at tributary Station 10 during the high flow period of May 10, 1972. On all other dates, maximum phosphate concentrations were found at the canal stations and in Parr Reservoir (Station 5)

Phosphate concentrations in Parr Reservoir (Station 5) were consistently high throughout the study, while concentrations in headwater stations (13 and 14) in North Carolina were consistently low.

Total phosphorus in the Broad River Basin substrates was comparable to concentrations in substrates found in recent studies of the Mobile River where the range was 44 to 1,300 mg/kg dry weight. In the Mobile River studies, sandy sediments generally contained the lowest concentrations of total phosphorus and clay sediments were higher. The Broad River phosphate concentrations followed the same general pattern. Reservoir Station 11 (sand-clay sediments) yielded the lowest average total phosphate concentration throughout the study period while canal stations (1 and 9) and reservoir Station 5 (clay sediments) were considerably higher.

Nitrogen

Water

Average nitrate-nitrite concentrations ranged from 0.03 to 0.82 mg/l (Table X).

Throughout the study period, samples from headwater Station 14 had the lowest nitrate-nitrite concentration; whereas samples from Station 13 below Shelby, North Carolina, had the highest concentration.

Tributary stations had higher nitrate-nitrite concentrations on April 4-6 and May 9-10, 1972, than impoundment or river stations.

During the period of this study, ammonia nitrogen concentrations ranged from 0.005 to 0.340 mg/l (Table XI).

Semimonthly averages indicate that highest concentrations of ammonia were found on May 9-10 and June 12-13. The highs were consistent at all categories of stations sampled -- tributaries, impoundments, and main river. Both the May 9-10 and June 12-13 sampling periods were preceded by periods of decreasing streamflow and low rainfall.

On May 9-10 during high rainfall, the tributary stations sampled had appreciably higher concentrations of ammonia nitrogen than did the Broad River and its impoundments.

Of the special stations studied on May 9-10, unusually high concentrations of ammonia nitrogen were detected at Second Broad River stations near Forest City and Cliffside, North Carolina (Table XI).

Total Kjeldahl nitrogen (TKN) is a measure of total unsatisfied nitrogen as both nitrogen and ammonia. Average concentrations ranged from 0.07 to 0.73 mg/l (Table XII).

Stations did not appreciably differ for the entire study period except that Station 14 was slightly lower than other stations.

During the high rainfall and flow period of May 9-10, 1972, TKN averages in the tributaries were almost twice as high as the impounded stations.

The nitrate-nitrite nitrogen values and TKN concentrations at various times throughout the study period were not limiting to algal growth (9).

Substrates

TKN concentrations in substrates ranged from a low of 250 mg/kg dry weight to a high of 4,500 mg/kg (Table XIII).

For the period of study, reservoir Station 5 and canal Station 9 had considerably higher TKN concentrations; whereas, headwater Stations13 and 14 had the lowest average TKN concentrations.

Semimonthly average concentrations were considerably higher at all categories of stations during the high rainfall and flow period of May 9-10. River stations had considerably higher concentrations than the impoundments and tributaries during the high-flow period.

EPA places restrictions on dredging activities in areas where substrate TKN concentrations exceed 0.10 percent. During the Broad River Study, TKN values exceeded the 0.10-percent limit 54 percent of the time.

Dissolved Oxygen

Dissolved oxygen (DO) concentrations in the Columbia canal ranged from 4.8 mg/l to 9.3 mg/l (Table XIV and Figure 8). The minimum DO of 4.8 mg/l was above the minimum standard of 4.0 mg/l set for Class B waters. The greatest difference during any one diel cycle was 3.2 mg/l on June 22-23. Most diel dissolved oxygen differences during the study ranged from 0.5 to 1.7 mg/l.

Whenever marked supersaturation is encountered, it is presumably attributable to photosynthesis. None of the DO concentrations in samples from the canal exceeded 100 percent saturation.

There are a number of factors or combination of factors which may directly affect DO in an aquatic system, such as stabilization of soluble or suspended oxygen-demanding materials, stabilization of bottom deposits containing high organic content, photosynthesis and respiration, and reaeration. The unusual lows at midday and highs in the evening probably are due to a combination of the above factors. According to water treatment plant personnel, a number of samples were collected on overcast days. Also, oxidation pond effluents and runoff from the suburbs were known to enter the diversion reservoir. Parr Dam, 25 miles and 6 to 8 hours flow time upstream from Columbia, may also influence the DO concentrations in the canal.

The oxygen content of samples collected on May 4-5, when odor complaints were received by the Columbia water treatment plant personnel, was not unusually high and exhibited only a 0.5 mg/l difference throughout the diel period (Table XIV).

Musty Odor

On May 5, 1972, Columbia water treatment plant personnel received musty odor complaints from consumers at the end of the water lines. The odor complaints continued through May 10, 1972, and totaled approximately 15. The Biological Services Branch of Surveillance & Analysis Division was informed of the problem on May 8 and initiated sample collection on May 9. Mr. Keeler, superintendent of the Columbia water treatment plant, immediately started treating the water with activated carbon after the complaints were received and continued carbon treatment for the duration of the study period. No further complaints were received throughout the study period.

Average threshold odors in the field ranged from 0.0 to a distinct 4.0 when chlorine residual water was used on May 9-10, 1972 (Table XV).

Average laboratory threshold odor numbers ranged from 1.0 to a distinct 4.0 at Station 14 on May 9 (Table XVI). In general, laboratory odor numbers (Table XVI) were higher than field odor numbers (Table XV). Throughout the study period, reservoir Station 5 and canal Station 1 had a slightly higher average odor of 2.2 and 2.1, respectively. The high basin, tributary, and river odors were recorded on May 9-10, and the high impoundment odors were recorded on May 9-10 and during the low flow period of June 12-13.

Unfortunately, the compounds causing odors could not be chemically or physically isolated from the water.

Leaf litter odors (Table XVII) were considerably higher than water odors (Table XVI), ranging from 15.3 to 200.0.

Station 5 (Parr Reservoir) had the highest average leaf litter odor number of 85.0 for the entire study period, with Stations 11, 13, and 14 near the North and South Carolina border having the lowest average odor numbers. Throughout the study period, average basin leaf litter odor numbers (Table XVII) increased, while average basin leaf litter wet weights decreased (XVIII). The increased odor and decreased leaf litter weight would be expected if actinomycetes were actively degrading the leaf biomass and releasing various biochemical products.

From an historical standpoint, Columbia water treatment plant records show that during the May 15, 1969; March 15, 1971; May 24, 1971; and May 5, 1972, periods musty odors were present but were mild for approximately 3 to 5 days (Figures 9, 11, and 12). During the May 18, 1970, and June 7, 1971, periods musty odors were severe for approximately 2 weeks (Figures 10 and 11)

The mild odors during the May 15, 1969, period occurred after a period of high flows (greater than 6,500 cfs) from April 14 through April 29, 1969, followed by a 2-week period of low flows (less than 6,500 cfs). The odor disappeared on May 20, 1969, when flows exceeded

6,500 cfs. The musty odor occurred when average maximum air temperatures exceeded 20°C.

Three times during the spring of 1971 musty odors occurred -- two were mild occurrences, and one was severe. The two mild odors occurred during the March 15 and May 24, 1971, periods, immediately following high flow periods (Figure 11). In March, the average maximum air temperature was 17°C, while the water temperature was 12°C. The air and water temperatures continued to increase throughout April; and in May, when the second mild odor occurred, the average maximum air temperature was 28°C, and the water temperatures were 19° to 21°C.

During the 1972 sample collection period, rainfall was prevalent throughout the basin (Table I) and the Columbia area (Figures 13 and 14). The prevalent rainfall resulted in relatively high flows (6,500 cfs or greater) except during the June 12-13, 1972, period (Figure 12). Although subtle musty odors were noticed throughout the sample collection period, mild odors were not noticed by the Columbia, South Carolina, public until May 5, 1972. The mild musty odors occurred approximately 3 weeks after a relatively high-flow period (March 23 to April 16, 1972) and when the average maximum air temperature ranged from 25°C to 32°C and the water temperatures ranged from 18° to 20°C. The odor problem ended on May 10 following high rainfalls and increased flows (Figures 12, 13, and 14).

Severe musty odors were noticed twice during the past 4 years -- once on May 18, 1970, and once on June 7, 1971 (Figures 10 and 11). On both occasions, the average minimum air temperature was 20°C or greater, and the water temperature ranged from 22° to 27°C. The June 7, 1971, musty odor period occurred approximately 2 weeks after high flows

(May 13 to 22, 1971, period) and disappeared on about June 18, 1971, when flows exceeded 6,500 cfs (Figure 11). The May 18, 1970, period occurred approximately 5 weeks after high flows (March 20 to April 10, 1970) and disappeared on about June 3, 1970.

Biology

Plankton and Periphyton

Phytoplankton counts were low, ranging from 0/ml to 174/ml (Table XIX). Highest average counts for the basin were recorded on June 12-13 during the low-flow period (Table III). Based on observations at the station sites, the phytoplankton did not contribute to any water discoloration during the study period, and the counts were considerably lower than 500/ml as defined by Lackey (8) for algal blooms.

Zooplankton organisms were sparse, ranging from an average of 0/1 to 130/1 throughout the study period (Table XX).

Average periphyton counts were low, ranging from $4/mm^2$ at Station 1 to $50/mm^2$ at Station 5 (Table XXI).

Microbiology

Actinomycetes

All of the actinomycetes isolated from Broad River Basin samples and maintained on agar subsequently produced the characteristic musty odor.

Actinomycetes in the water ranged from 100/100 ml to 22,500/100 ml (Table XX). On May 9-10 reservoir stations had a low average actinomycete count of 2,612/100 ml, while the river stations had the highest actinomycete counts of 11,385/100 ml.

Average actinomycete counts in the substrates ranged from 500/g to 765,000/g (Table XXIII). Station 5 had the greatest average actinomycete counts for the entire study period, and Station 13 had the lowest average counts. There was a general increase in the average actinomycete counts during the study, culminating in a high of 172,375/g for the basin and 390,000 for the reservoirs. River stations had higher average actinomycete counts than impoundments except on June 12-13 when the average actinomycete impoundment count was higher.

Average leaf litter actinomycete counts ranged from 7,000/g to 12,500,000/g (Table XXIV). Actinomycete counts in the basin generally increased throughout the study period. Leaf litter odor (Table XVII) also increased throughout the study period. Average actinomycete counts in periphyton ranged from 0/g to 7,500/g (Table XXV).

Average leaf litter actinomycete counts were generally higher than average substrate and periphyton actinomycete counts at Stations 1, 5, 9, 11, 13, and 14 (Figures 15, 16, 17, 18, 19, and 20).

DISCUSSION

The city of Columbia has experienced the "musty" odor problem since 1969; however, this problem is not unique to the Columbia area. It is apparently widespread throughout the Broad River Basin and also occurs in the Savannah River Basin. The communities of Lockhart, Union, and Carlisle, South Carolina, have reported musty odor problems in the past (11). Shelby, North Carolina, has had some problems as far back as 1952 (12). Forest City, North Carolina, has had an occasional musty odor smell in the fall (13); and Norris, South Carolina, in the Savannah River Basin, has had musty odor problems in the past few years in their reservoirs (14). Musty odors, on occasion, permeate the shallow wells in the northern counties of South Carolina, especially when the area has a dry fall and a wet spring (15). Musty odor is accentuated when chlorine residual water is used in an odor test (16), as the results in Table XV revealed.

Musty or earthy odor has been associated with a number of different algal and fungal organisms in the past. Thirty-nine species have been selected by Palmer (17) as representative of the more important taste and odor algae. Musty odoriferous substances have only been identified from the blue-green algae <u>Symploca muscorum</u> (18) and <u>Oscillatoria tenuis</u> (19) and a few actinomycetes such as <u>Streptomyces</u> species (20, 21, 22, 23, 24, 25, 26). <u>Symploca muscorum</u> and <u>Oscillatoria tenuis</u> were not found in our plankton and periphyton samples. Due to the absence of <u>S. muscorum</u> and <u>O. tenuis</u> and the low zooplankton, algal plankton, and algal periphyton counts in the Broad River Basin samples, the algae and zooplankton are not considered major contributing factors to musty odors in the Broad River.

According to Silvey, _et al_. (16), actinomycetes of the genus _Streptomyces_ are especially responsive to changes in temperature. The minimum temperature at which the spores will germinate and produce a vegetative growth is 15°C. At this temperature, few byproducts of the organisms are apparent. At 17°C the byproducts may be extracted either from water or from a culture medium, although the total concentration of chemicals will be minimal. As the temperature increases, the activity of the organisms is enhanced and the concentration of the actinomycetes is in direct proportion to available organic matter. This was exemplified with the leaf litter biomass decreasing and the actinomycete counts and the threshold odor numbers increasing throughout the study (Tables XVIII, XXIV, and XVII).

Past data (Figures 9 through 14) from the Columbia area indicate that air and water temperatures, rainfall, and flows are important to musty odor production in the Columbia, South Carolina, vicinity of the Broad River.

Rains and increased flows bring a considerable amount of organic matter and other nutrients via land runoff into the river. The importance of rainfall and increased flows are shown by data collected May 9-10 when the highest average TOC (Table V), total phosphate (Table VIII), ammonia nitrogen concentrations (Table XI), and TKN (Table XII) were recorded in the basin. The Tyger, Enoree, and Pacolet rivers appear to contribute a considerable amount of nutrients and organic material (Tables V, VIII, XI, and XII) to the Broad River via land runoff.

If the air temperatures are 17°C or greater, musty odors produced from actinomycete activity in the woodlands and fields can be flushed into the rivers with nutrients via rainfall and increased flows and cause mild odor problems like those occurring on March 15, 1971; May 24, 1971 (Figure 11); and possibly May 5, 1972 (Figures 12, 13, and 14).

Much of the organic material and other nutrients entering the water via land runoff accumulates in the substrates (Tables VI, IX, and XIII); and the reservoir (Parr) and canals act as a "sink" (Tables VI, IX, and XIII). During the "culture-like" conditions (a 2- to 5-week period with little or no rain, average flows less than 6,500 cfs, and water temperatures 17°C or greater) that can exist in the reservoirs, the actinomycetes, with a plentiful nutrient supply, multiply and produce musty odors which can affect the water supplies. Apparently the only natural phenomena that will stop this population "explosion" are depleted food sources or increased flows. Depleted food sources probably eliminated the severe musty odor problem during the May 18, 1970, period (Figure 10). Increased flows probably eliminated the mild odor problem on June 7, 1971 (Figure 11). Middleton, *et al.* (27) have shown that odor thresholds are inversely related to river flow.

The slight odor problems noted by complaining water users during the May 5-10, 1972, period were predictable on the basis of high accumulation of organic constituents and other nutrients in Broad River sediments, together with increasing counts of actinomycetes in leaf litter and river sediments. A severe odor problem was not realized because of the flushing action of high rainfall and flows occurring on May 9-10 (Figures 12, 13, and 14).

Conditions similar to the above were apparent at the time of the June 12-13 sampling; however, a severe odor problem was circumvented by flushing rains and flows occurring during late June (Figures 12, 13, and 14).

TABLE V.—Total Organic Carbon in Water
Broad River Basin, April-June 1972

Station	TOC[1] (mg/1)					Station Averages[7]
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	(All Sampling Dates)
1	4.00	3.27	2.76	2.95	2.65	3.13
2	3.00					
5[2]	2.60	3.63	3.17	2.75	2.75	2.98
5[3]	3.00					
6	3.00		9.77			
7	2.30		7.43			
8	2.00		17.16			
9	2.30	2.30	6.17	2.65	2.20	3.12
10	2.00		3.87			
11[2]	3.00	2.03	4.53	3.15	2.85	3.11
11[3]	2.00					
12	2.00					
13	2.00	0.80	5.77	3.25	2.35	2.83
14	2.00	1.30	3.63	3.00	2.25	2.44
FC[4]			2.50			
CS[5]			4.60			
LL[6]			2.20			
Semimonthly Averages						
Basin[7]	2.51	2.22	5.66	2.96	2.51	
Tributaries[7] (6, 7, 10)[8]	2.43		7.02			
Impoundments[7] (5, 11)	2.65	2.83	3.85	2.95	2.80	
Rivers[7] (1, 8, 9, 12, 13, 14)	2.38	1.92	7.10	2.96	2.36	

1 Arithmetic average of all sample values for each station and date.
2 Subsurface.
3 Above bottom.
4 FC = Second Broad River, Forest City, N.C.
5 CS = Second Broad River, Cliffside, N.C.
6 LL = Broad River below Lake Lure, N.C.
7 Arithmetic average computed by assigning equal importance to each station or date.
8 Stations.

TABLE VI.--Total Organic Carbon in Bottom Substrates
Broad River Basin, April-June 1972

Station	TOC[1] (mg/kg dry weight) 4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	Station Averages[2] (All Sampling Dates)
1	19,546	19,204	15,434	6,730	7,696	13,722
5	8,380	33,153	20,601	12,418	36,704	22,251
6			8,810			
7			2,657			
8			13,350			
9	18,228	19,551	31,662	17,039	16,418	20,580
10			6,535			
11			971	6,226	1,688	
13	3,494	15,913	17,020	10,181	3,102	9,942
14	9,382	10,631	7,214	17,134	6,658	10,204
CS[3]			4,406			
Semimonthly Averages						
Basin[2]	11,806	19,690	11,696	11,621	12,044	
Tributaries[2] (6, 7, 10)[4]			6,001			
Impoundments[2] (5, 11)	8,380	33,153	10,786	9,322	19,196	
Rivers[2] (1, 8, 9, 12, 13, 14)	12,663	16,325	16,936	12,771	8,469	

1 Arithmetic average of all sample values for each station and date.

2 Arithmetic average computed by assigning equal importance to each station or date.

3 CS = Second Broad River at Cliffside, N.C.

4 Stations.

TABLE VII.--Chemical Oxygen Demand in Bottom Substrates Broad River Basin, April-June 1972

Station	COD[1] (mg/kg dry weight)				
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13
1	52,188	51,275	41,208	17,972	20,548
5	22,374	88,519	55,006	33,158	98,000
6			23,526		
7			7,095		
8			35,644		
9	48,668	52,202	84,540	45,490	48,838
10			17,540		
11			2,594	16,625	4,507
13	9,328	42,489	45,446	27,185	8,284
14	25,050	28,386	19,264	46,228	17,778
CS[2]			11,765		

Arithmetic average of all sample values for each station and date.

CS = Second Broad River at Cliffside, N.C.

TABLE VIII.--Total Phosphate as Phosphorus in Water
Broad River Basin, April-June 1972

Station	Total Phosphate[1] (mg/l) 4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	Station Averages[7] (All Sampling Dates)
1	0.100	0.077	0.107	0.078	0.132	0.099
2	0.010					
5[2]	0.105	0.064	0.102	0.078	0.075	0.085
5[3]	0.292					
6	0.093		0.316			
7	0.140		0.292			
8	0.091		0.130			
9	0.104	0.076	0.171	0.079	0.044	0.095
10	0.132		0.129			
11[2]	0.307	0.088	0.158	0.129	0.040	0.144
11[3]	0.134					
12	0.136					
13	0.070	0.065	0.133	0.046	0.030	0.069
14	0.064	0.044	0.089	0.106	0.044	0.069
FC[4]			0.025			
CS[5]			0.120			
LL[6]			0.005			
Semimonthly Averages						
Basin[7]	0.127	0.069	0.137	0.086	0.061	
Tributaries[7] (6, 7, 10)[8]	0.122		0.246			
Impoundments[7] (5, 11)	0.210	0.076	0.130	0.104	0.058	
Rivers[7] (1, 8, 9, 12, 13, 14)	0.094	0.066	0.126	0.077	0.062	

1 Arithmetic average of all sample values for each station and date.
2 Subsurface.
3 Above bottom.
4 FC = Second Broad River at Forest City, N.C.
5 CS = Second Broad River at Cliffside, N.C.
6 LL = Broad River below Lake Lure, N.C.
7 Arithmetic average computed by assigning equal importance to each station or date.
8 Stations.

TABLE IX.--Total Phosphate as Phosphorus in Bottom Substrates Broad River Basin, April-June 1972

Station	Total Phosphate[1] (mg/kg dry weight) 4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	Station Averages[2] (All Sampling Dates)
1	650	710	540	270	205	475[2]
5	475	835	715	650	690	673
6			435			
7			380			
8			535			
9	500	575	495	650	540	552
10			985			
11			64	117	50	
13	160	270	325	255	44	211
14	290	360	172	240	160	244
CS[3]			225			
Semimonthly Averages						
Basin[2]	415	550	443	364	282	
Tributaries[2] (6, 7, 10)[4]			600			
Impoundments[2] (5, 11)	475	835	390	384	370	
Rivers[2] (1, 8, 9, 12, 13, 14)	400	479	413	354	237	

Arithmetic average of all sample values for each station and date.

Arithmetic average computed by assigning equal importance to each station or date.

CS = Second Broad River at Cliffside, N.C.

Stations.

TABLE X.--Nitrate-Nitrogen and Nitrite-Nitrogen in Water
Broad River Basin, April-June 1972

Station	Nitrate- and Nitrite-Nitrogen[1] (mg/l) 4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	Station Averages[7] (All Sampling Dates)
1	0.37	0.38	0.34	0.30	0.35	0.35
2	0.38					
5[2]	0.82	0.37	0.34	0.28	0.36	0.43
5[3]	0.47					
6	0.70		0.45			
7	0.57		0.47			
8	0.40		0.30			
9	0.63	0.35	0.39	0.26	0.30	0.39
10	0.57		0.43			
11[2]	0.45	0.34	0.37	0.22	0.33	0.34
11[3]	0.38					
12	0.42					
13	0.70	0.42	0.44	0.34	0.45	0.47
14	0.40	0.14	0.21	0.16	0.15	0.21
FC[4]			0.13			
CS[5]			0.31			
LL[6]			0.03			
Semimonthly Averages						
Basin[7]	0.52	0.33	0.32	0.26	0.32	
Tributaries[7] (6, 7, 10)[8]	0.61		0.45			
Impoundments[7] (5, 11)	0.53	0.36	0.36	0.25	0.34	
Rivers[7] (1, 8, 9, 12, 13, 14)	0.49	0.32	0.34	0.26	0.31	

1 Arithmetic average of all sample values for each station and date.
2 Subsurface.
3 Above bottom.
4 FC = Second Broad River, Forest City, N.C.
5 CS = Second Broad River, Cliffside, N.C.
6 LL = Broad River below Lake Lure, N.C.
7 Arithmetic average computed by assigning equal importance to each station or date.
8 Stations.

TABLE XI.--Ammonia-Nitrogen in Water
Broad River Basin, April-June 1972

Station	Ammonia-Nitrogen[1] (mg/l)					Station Averages[7] (All Sampling Dates)
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	
1	0.005	0.030	0.130	0.060	0.080	0.061
2	0.005					
5[2]	0.037	0.040	0.060	0.050	0.080	0.053
5[3]	0.005					
6	0.006		0.130			
7	0.005		0.090			
8	0.005		0.020			
9	0.005	0.020	0.110	0.020	0.040	0.039
10	0.040		0.120			
11[2]	0.005	0.010	0.040	0.040	0.120	0.043
11[3]	0.030					
12	0.027					
13	0.005	0.020	0.067	0.100	0.130	0.064
14	0.022	0.010	0.030	0.040	0.160	0.052
FC[4]			0.010			
CS[5]			0.340			
LL[6]			0.250			
Semimonthly Averages						
Basin[7]	0.014	0.022	0.107	0.052	0.102	
Tributaries[7] (6, 7, 10)[8]	0.017		0.113			
Impoundments[7] (5, 11)	0.019	0.025	0.050	0.045	0.100	
Rivers[7] (1, 8, 9, 12, 13, 14)	0.012	0.020	0.071	0.055	0.102	

[1] Arithmetic average of all sample values for each station and date.
[2] Subsurface.
[3] Above bottom.
[4] FC = Second Broad River, Forest City, N.C.
[5] CS = Second Broad River, Cliffside, N.C.
[6] LL = Broad River below Lake Lure, N.C.
[7] Arithmetic average computed by assigning equal importance to each station or date.
[8] Stations.

TABLE XII.--Total Kjeldahl Nitrogen in Water
Broad River Basin, April-June 1972

Station	Total Kjeldahl Nitrogen[1] (mg/l) 4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	Station Averages[7] (All Sampling Dates)
1	0.18	0.22	0.37	0.31	0.50	0.32
2	0.17					
5[2]	0.25	0.57	0.29	0.12	0.22	0.29
5[3]	0.15					
6	0.18		0.63			
7	0.15		0.67			
8	0.07		0.49			
9	0.14	0.09	0.73	0.11	0.12	0.24
10	0.30		0.49			
11[2]	0.31	0.16	0.38	0.24	0.38	0.29
11[3]	0.37					
12	0.27					
13	0.19	0.09	0.35	0.36	0.32	0.26
14	0.30	0.07	0.20	0.08	0.37	0.20
FC[4]			0.19			
CS[5]			0.40			
LL[6]			0.30			
Semimonthly Averages[7]						
Basin[7]	0.22	0.20	0.42	0.20	0.32	
Tributaries[7] (6, 7, 10)[8]	0.21		0.60			
Impoundments[7] (5, 11)	0.27	0.36	0.34	0.18	0.30	
Rivers[7] (1, 8, 9, 12, 13, 14)	0.19	0.12	0.43	0.22	0.33	

1 Arithmetic average of all sample values for each station and date.
2 Subsurface.
3 Above bottom.
4 FC = Second Broad River, Forest City, N.C.
5 CS = Second Broad River, Cliffside, N.C.
6 LL = Broad River below Lake Lure, N.C.
7 Arithmetic average computed by assigning equal importance to each station or date.
8 Stations.

TABLE XIII.--Total Kjeldahl Nitrogen in Bottom Substrates
Broad River Basin, April-June 1972

Station	Total Kjeldahl Nitrogen[1] (mg/kg dry weight)					Station Averages[2] (All Sampling Dates)
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	
1	1,300	1,250	3,050	485	550	1,327
5	750	1,870	3,500	850	2,335	1,861
6			2,200			
7			850			
8			2,500			
9	1,300	900	4,500	1,450	1,175	1,865
10			1,100			
11			900	400	375	
13	500	1,200	3,400	700	250	1,210
14	1,200	770	1,900	675	550	1,019
CS[3]			1,100			
Semimonthly Averages						
Basin[2]	1,010	1,198	2,273	760	872	
Tributaries[2] (6, 7, 10)[4]			1,383			
Impoundments[2] (5, 11)	750	1,870	2,200	625	1,355	
Rivers[2] (1, 8, 9 13, 14)	1,075	1,030	3,070	828	631	

1 Arithmetic average of all sample values for each station and date.
2 Arithmetic average computed by assigning equal importance to each station or date.
3 CS = Second Broad River at Cliffside, N.C.
4 Stations.

TABLE XIV.--Diel Dissolved Oxygen and Temperature
Broad River Canal, April-June 1972

Date 1972	Time	Dissolved Oxygen (mg/l)	Water Temperature (°F.)	Date 1972	Time	Dissolved Oxygen (mg/l)	Water Temperature (°F.)
4/12	1000	8.9	59	5/24	0900	8.6	68
"	1300	8.9	59	"	1200	8.2	68
"	1600	9.0	59	"	1500	8.3	68
"	1900	9.3	59	"	1800	7.7	68
"	2200	9.2	59	"	2100	7.6	68
4/13	0100	9.3	59	"	2400	7.4	68
"	0400	9.3	59	5/25	0300	6.9	68
"	0700	8.9	59	"	0600	7.9	68
"	0900	8.7	59				
4/19	0900	7.5	68	6/1	0900	8.0	71
"	1200	7.4	68	"	1200	7.8	71
"	1500	7.2	68	"	1500	7.5	71
"	1800	7.5	68	"	1800	8.2	71
"	2100	7.7	68	"	2100	7.9	71
"	2400	8.1	68	"	2400	7.7	71
4/20	0300	8.0	68	6/2	0300	7.4	71
"	0600	7.5	68	"	0600	7.1	71
4/27	0900	8.9	65	6/8	0900	7.7	76
"	1200	8.7	65	"	1200	7.6	76
"	1500	8.7	65	"	1500	7.3	76
"	1800	9.1	65	"	1800	7.3	76
"	2100	9.1	65	"	2100	6.0	76
"	2400	9.2	65	"	2400	7.3	76
4/28	0300	9.2	65	6/9	0300	6.6	76
"	0600	8.8	65	"	0600	6.7	76
5/4	0900	8.3	68	6/14	0900	8.0	75
"	1200	8.3	68	"	1200	7.8	75
"	1500	8.4	68	"	1500	7.2	75
"	1800	8.2	68	"	1800	7.8	75
"	2100	8.4	68	"	2100	8.0	75
"	2400	8.6	68	"	2400	8.0	75
5/5	0300	8.1	68	6/15	0300	8.3	75
"	0600	8.2	68	"	0600	7.8	75
5/11	0900	7.8	67	6/22	0900	7.5	76
"	1200	8.5	67	"	1200	7.3	76
"	1500	8.5	67	"	1500	7.4	76
"	1800	8.2	67	"	1800	6.4	76
"	2100	8.0	67	"	2100	6.3	76
"	2400	7.9	67	"	2400	5.3	76
5/12	0300	7.8	67	6/23	0300	4.8	76
"	0600	7.8	67	"	0600	8.0	76
5/18	0900	8.2	69	6/29	0900	7.9	78
"	1200	7.5	69	"	1200	7.8	78
"	1500	7.7	69	"	1500	7.4	78
"	1800	7.8	69	"	1800	7.1	78
"	2100	7.5	69	"	2100	7.5	78
"	2400	7.6	69	"	2400	5.7	78
5/19	0300	7.7	69	6/30	0300	7.4	78
"	0600	7.1	69	"	0600	7.1	78

TABLE XV.--Water Threshold Odor Numbers in the Field
Broad River Basin, April-June 1972

Station	Threshold Odor Number[1]						
	4/4-6	4/24-26	5/9[2]	5/9	5/10	5/30-31	6/12-13
1	0.3	0.0		0.7		1.1	1.1
2	0.3			0.3			
5	0.3	0.3	1.0	0.5		1.1	1.1
6	0.3		1.0	0.0	1.0		
7	0.3		2.5	0.5	2.0		
8	1.3		4.0	3.2			
9	0.3	2.0		2.0		2.1	1.3
10	0.3			1.0	0.0		
11	1.3	2.0		1.5		1.1	1.1
12	0.3						
13	0.3	0.3	3.0	0.0		1.5	1.5
14	0.3	0.0	2.5	0.0		1.0	1.1
FC[3]					0.0		
CS[4]					0.0		
LL[5]					0.0		
PR[6]					0.0		
BC[7]					0.0		
Semimonthly Averages							
Basin[8]	0.5	0.8		0.7[9]		1.3	1.2
Tributaries[8] (6, 7, 10)[10]	0.3			0.5[9]			
Impoundments[8] (5, 11)	0.8	1.2		1.0[9]		1.1	1.1
Rivers[8] (1, 8, 9, 12, 13, 14)	0.5	0.6				1.4	1.2

1 Arithmetic average of all sample values for each station and date.
2 Chlorine residual in dilution water.
3 FC = Second Broad River at Forest City, N. C.
4 CS = Second Broad River at Cliffside, N.C.
5 LL = Broad River below Lake Lure, N.C.
6 PR = Paceolot River above Spartanburg, S.C.
7 BC = Browns Creek, S.C.
8 Arithmetic average computed by assigning equal importance to each station or date.
9 Determinations with chlorine residual water were not included in this average.
10 Stations.

TABLE XVI.--Water Threshold Odor Numbers in the Laboratory
Broad River Basin, April-June 1972

Station	Threshold Odor Number[1] 4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	Station Averages[4] (All Sampling Dates)
1	1.0	3.0	3.0	2.0	1.4	2.1
2	1.0		3.0			
5[2]	1.0	2.0	3.0	2.0	3.0	2.2
5[3]	1.0					
6	1.0		1.4			
7	1.0		1.0			
8	1.0		2.0			
9	1.0	2.0	1.4	1.4	2.0	1.6
10	1.0		1.4			
11[2]	1.0	2.0	1.4	1.4	1.4	1.4
11[3]	1.0					
12	1.0					
13	1.0	1.0	1.4	1.4	2.0	1.4
14	1.0	1.0	4.0	2.0	1.0	1.8
Semimonthly Averages						
Basin[4]	1.0	1.8	2.1	1.7	1.8	
Tributaries[4] (6, 7, 10)[5]	1.0		1.3			
Impoundments[4] (5, 11)	1.0	2.0	2.2	1.7	2.2	
Rivers[4] (1, 8, 9, 12, 13, 14)	1.0	1.8	2.4	1.7	1.6	

1 Arithmetic average of all sample values for each station and date.

2 Subsurface.

3 Above bottom.

4 Arithmetic average computed by assigning equal importance to each station or date.

5 Stations.

TABLE XVII.--Leaf Litter Threshold Odor Number
Broad River Basin, April-June 1972

Station	Threshold Odor Number[1] 4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	Station Averages[2] (All Sampling Dates)
3	58.3	87.5	35.0	85.0	100.0	73.2
5	56.7	35.0	33.5	100.0	200.0	85.0
6	53.0		105.0			
7			80.0			
8	17.3					
10	31.3	42.5	52.5	120.0	140.0	77.3
11	20.0	42.5	60.0		80.0	50.6
13	15.3	35.0	60.0	105.0	50.0	53.1
14	24.0	29.5	75.0	85.0	50.0	52.7
Semimonthly Basin Averages[2]	34.5	45.3	62.6	99.0	103.3	

1 Arithmetic average of all sample values for each station and date.

2 Arithmetic average computed by assigning equal importance to each station or date.

TABLE XVIII.--Leaf Litter Wet Weights
Broad River Basin, April-June 1972

Station	Leaf Litter Wet Weight[1] (g)				Station Averages[2]
	4/24-26	5/9-10	5/30-31	6/12-13	(All Sampling Dates)
3	22.0	11.8	9.6	9.0	13.1
5	20.2	22.4	9.6	10.4	15.6
6		23.6			
7		14.8			
10	16.3	27.2	29.6	9.4	18.1
11	18.0	25.5	40.4	26.4	
13	21.6	15.4	6.1	7.6	12.7
14	19.2	31.8	8.9	12.0	18.0
Semimonthly Basin Averages[2]	19.6	21.6	15.7	12.5	

[1] Arithmetic average of all sample values for each station and date.

[2] Arithmetic average computed by assigning equal importance to each station or date.

TABLE XIX.--Total Phytoplankton Counts
Broad River Basin, April-June 1972

Station	Total Phytoplankton Count[1] (No/ml)					Station Averages[2] (All Sampling Dates
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	
1	19	34	28	9	174	53
2	0					
5[3]	24	56	37	18	124	52
5[4]	3					
6	12		40			
7	22		46			
8	25		52			
9	43	55	24	37	122	56
10	31		22			
11[3]	28	50	38	58	99	55
11[4]	6					
12	19					
13	22	28	40	9	22	24
14	25	42	86	87	98	68
Semimonthly Basin Averages[2]	19.9	44.2	41.3	36.3	106.5	

1 Arithmetic average of all sample values for each station and date.
2 Arithmetic average computed by assigning equal importance to each station or date.
3 Subsurface.
4 Above bottom.

TABLE XX.--Zooplankton Counts
Broad River Basin, April-June 1972

Station	Zooplankton Count[1] (No./1)				
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13
1	0	0	0	0	0
5[2]	130	0	0	0	0
5[3]	0				
9	0		0	0	65
11	65	0	0	0	0

[1] Arithmetic average of all sample values for each station and date.

[2] Subsurface.

[3] Above bottom.

TABLE XXI.--Periphyton Counts
Broad River Basin, April-June 1972

Dates	Days of Exposure	Periphyton Count[1] (No./mm^2) Station 1	Station 5
4/4-17	13	4	38
4/4-24	20	44	33
4/4-5/8	34	36	34
4/4-6/12	69	33	50

[1] Arithmetic average of all sample values for each station and date.

TABLE XXII.--Actinomycete Counts in Water
Broad River Basin, April-June 1972

Station	Actinomycete Count[1] (No./100 ml)				
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13
1	300		625	650	8,000
5	450	150	725	4,500	10,000
6	500		2,925		
7	400		5,000		
8	450		12,750		
9	300	650	17,500	3,000	15,000
10	200		6,000		
11	625	600	4,500	250	
12	300				
13	1,000	100	3,550	1,000	
14	300	550	22,500	450	
Semimonthly Averages					
Basin[2]	439	410	7,608	1,642	11,000
Tributaries[2] (6, 7, 10)[3]	367		4,642		
Impoundments[2] (5, 11)	538	375	2,612	2,375	10,000
Rivers[2] (1, 8, 9, 12, 13, 14)	442	433	11,385	1,275	11,500

[1] Arithmetic average of all sample values for each station and date.

[2] Arithmetic average computed by assigning equal importance to each station or date.

[3] Stations.

TABLE XXIII.--Actinomycete Counts from Bottom Substrates
Broad River Basin, April-June 1972

Station	Actinomycete Count[1] (No./g wet weight)					Station Averages[2]
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13	(All Sampling Dates
1	24,000	55,000	12,750	140,000	75,750	61,500
5	10,500	35,000	33,000	105,750	765,000	189,850
6			117,500			
7			6,750			
8			71,750			
9	12,000	80,000	155,000	40,250	155,000	88,450
10			16,250			
11			500	61,750	15,000	
13	1,700	30,000	24,500	192,500	6,750	51,090
14	10,000		10,250	1,750	16,750	
Semimonthly Averages						
Basin[2]	11,640	50,000	44,825	90,333	172,375	
Tributaries[2] (6, 7, 10)[3]			46,833			
Impoundments[2] (5, 11)	10,500	35,000	16,750	83,750	390,000	
Rivers[2] (1, 8, 9, 12, 13, 14)	11,925	55,000	54,850	93,625	63,562	

1 Arithmetic average of all sample values for each station and date.

2 Arithmetic average computed by assigning equal importance to each station or date.

3 Stations.

TABLE XXIV.--Actinomycete Counts from Leaf Litter
Broad River Basin, April-June 1972

Station	Actinomycete Count[1] (No./g wet weight)				
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13
3	27,500	95,000	300,000	85,000	4,250,000
5		195,000	75,000	1,400,000	6,000,000
6	7,000		1,550,000		
7			600,000		
8	46,000				
10	45,500	40,000	1,600,000	125,000	12,500,000
11	28,500	1,700,000	100,000	300,000	5,000,000
13	16,000	50,000	300,000	45,000	8,500,000
14	83,500	39,000	250,000	1,500,000	6,500,000
Semimonthly Basin Averages[2]	36,286	353,167	596,875	575,833	7,125,000

1 Arithmetic average of all sample values for each station and date.

2 Arithmetic average computed by assigning equal importance to each station or date.

TABLE XXV.--Actinomycete Counts from Periphyton
Broad River Basin, April-June 1972

Station	Actinomycete Count[1] (No./g wet weight)				
	4/4-6	4/24-26	5/9-10	5/30-31	6/12-13
1	1	500	750	100	
5	40	0	18	100	450

[1] Arithmetic average of all sample values for each station and date.

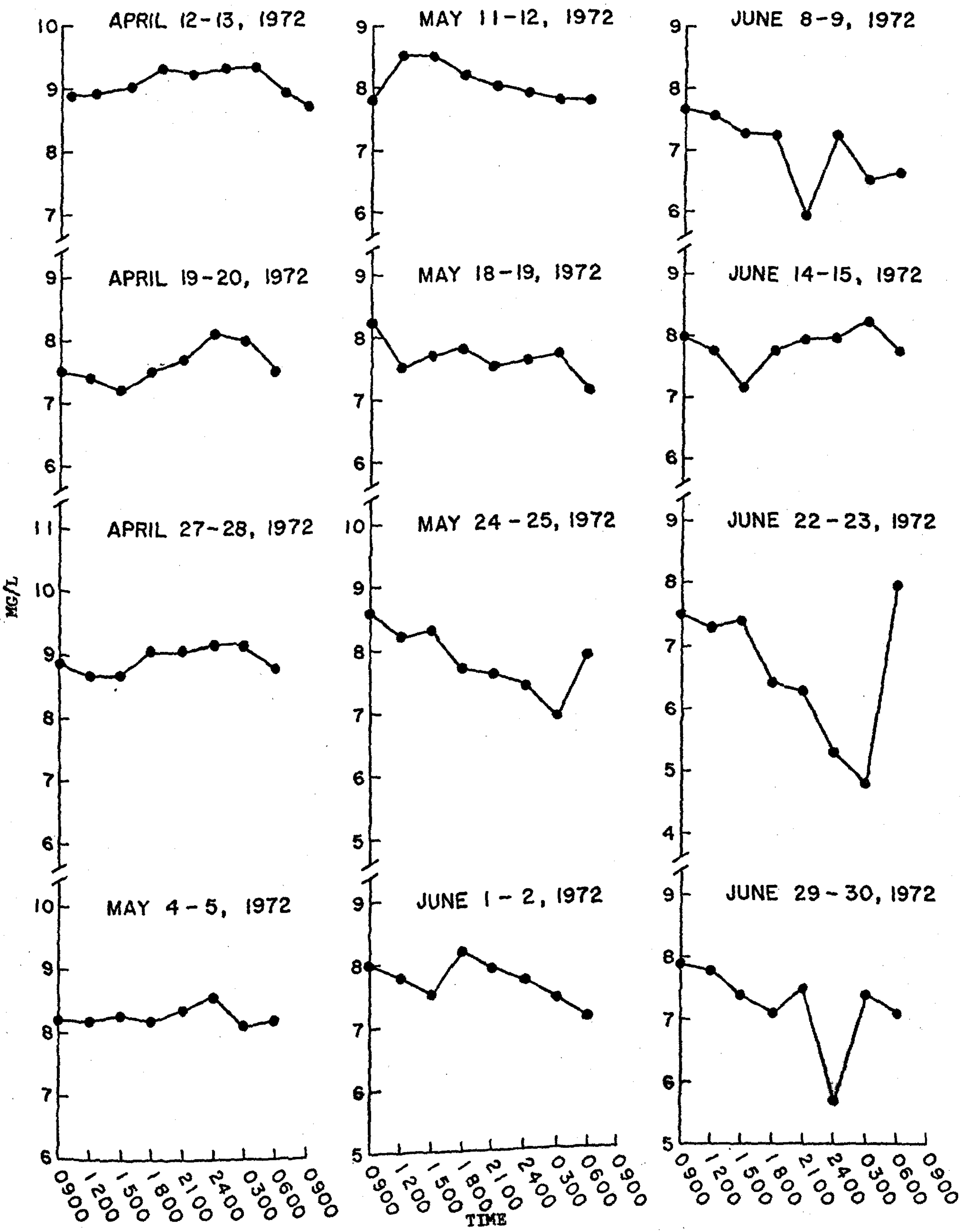

FIGURE 8.--Diel dissolved oxygen profiles, Broad River Canal, South Carolina.

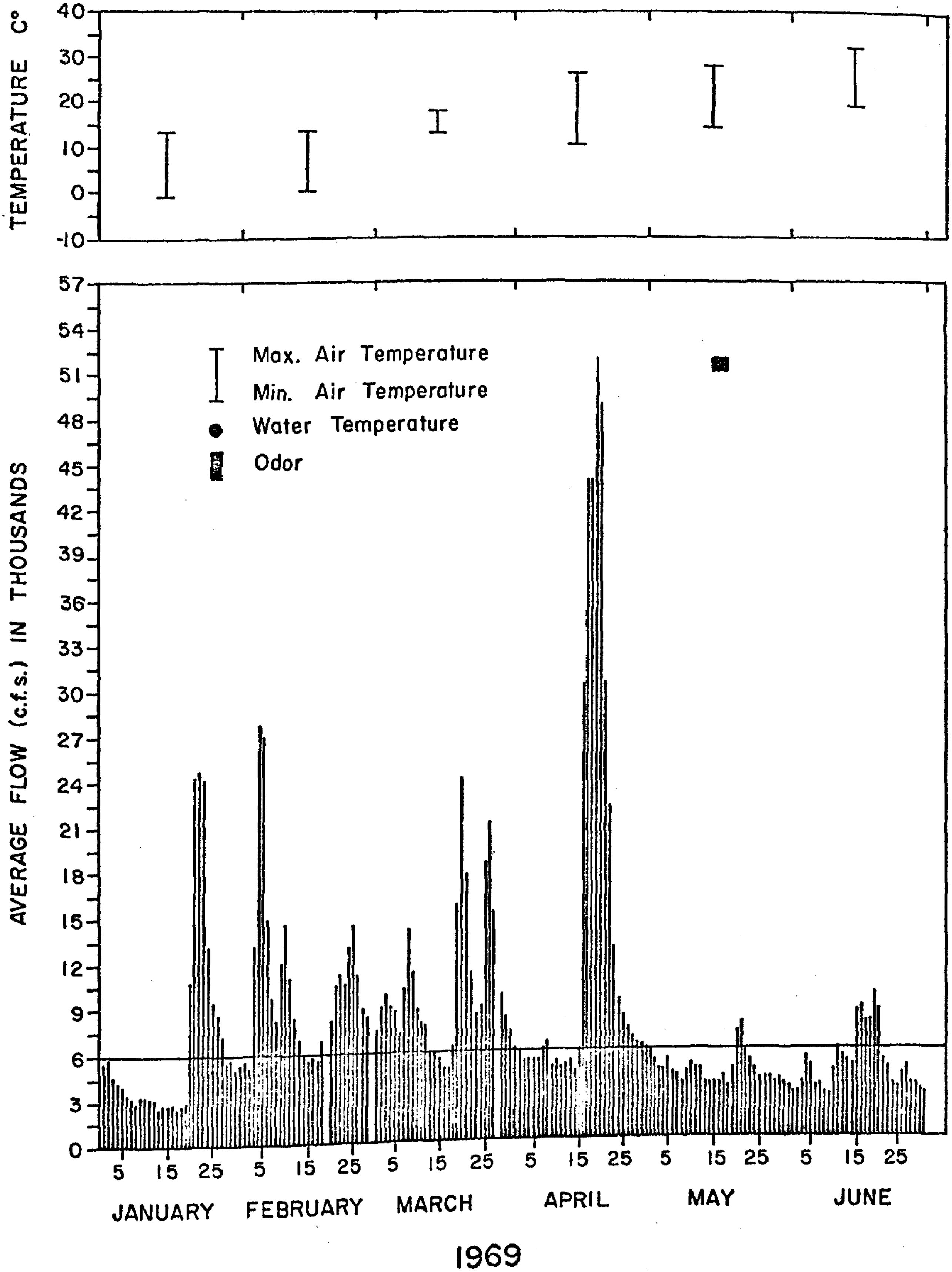

FIGURE 9.--Musty odors, flow, water temperature, maximum and minimum air temperatures for the Columbia-Richtex, South Carolina, vicinity from January-June 1969.

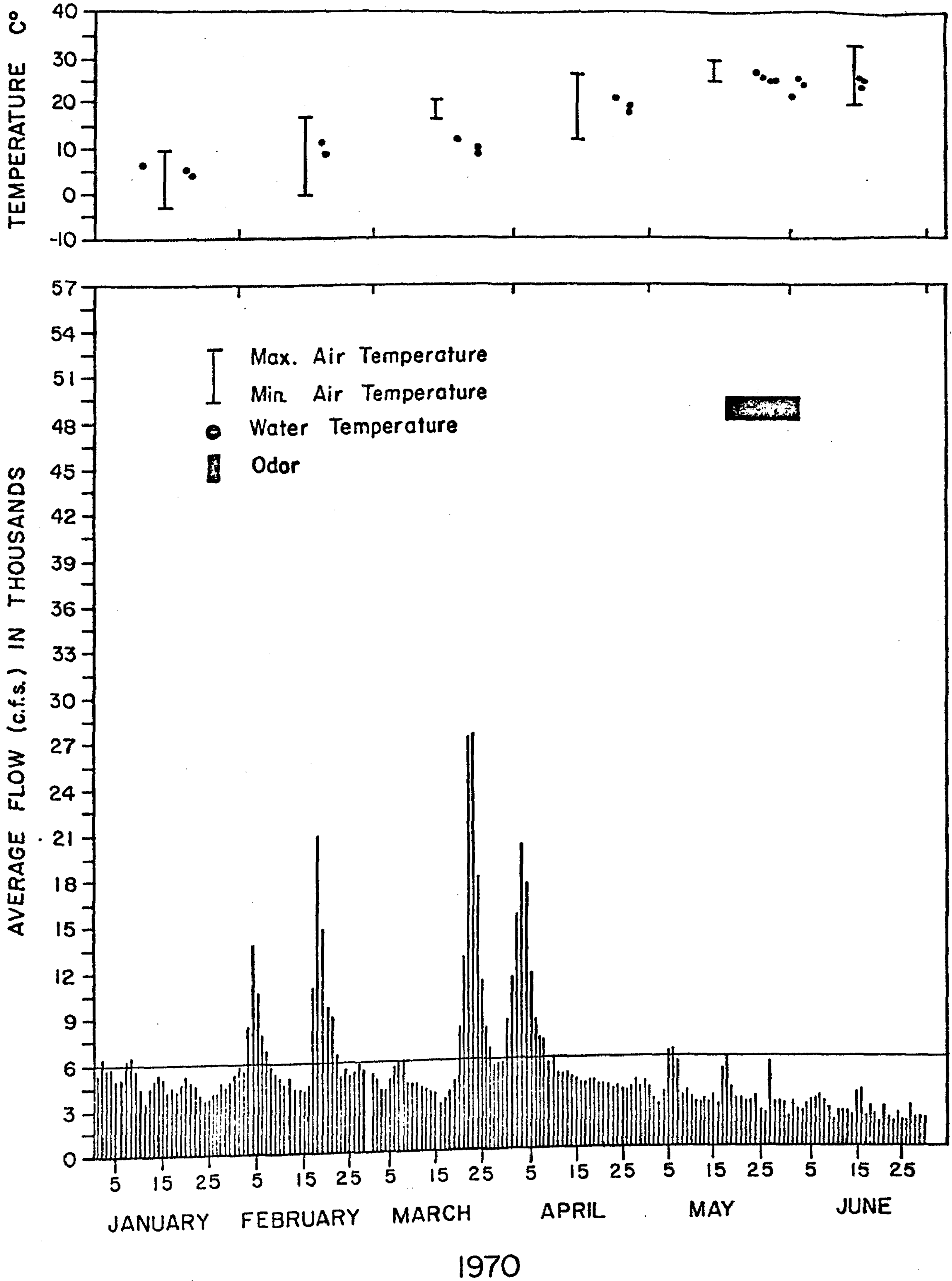

FIGURE 10.--Musty odors, flow, water temperature, maximum and minimum air temperature for the Columbia-Richtex, South Carolina, vicinity from January-June 1970.

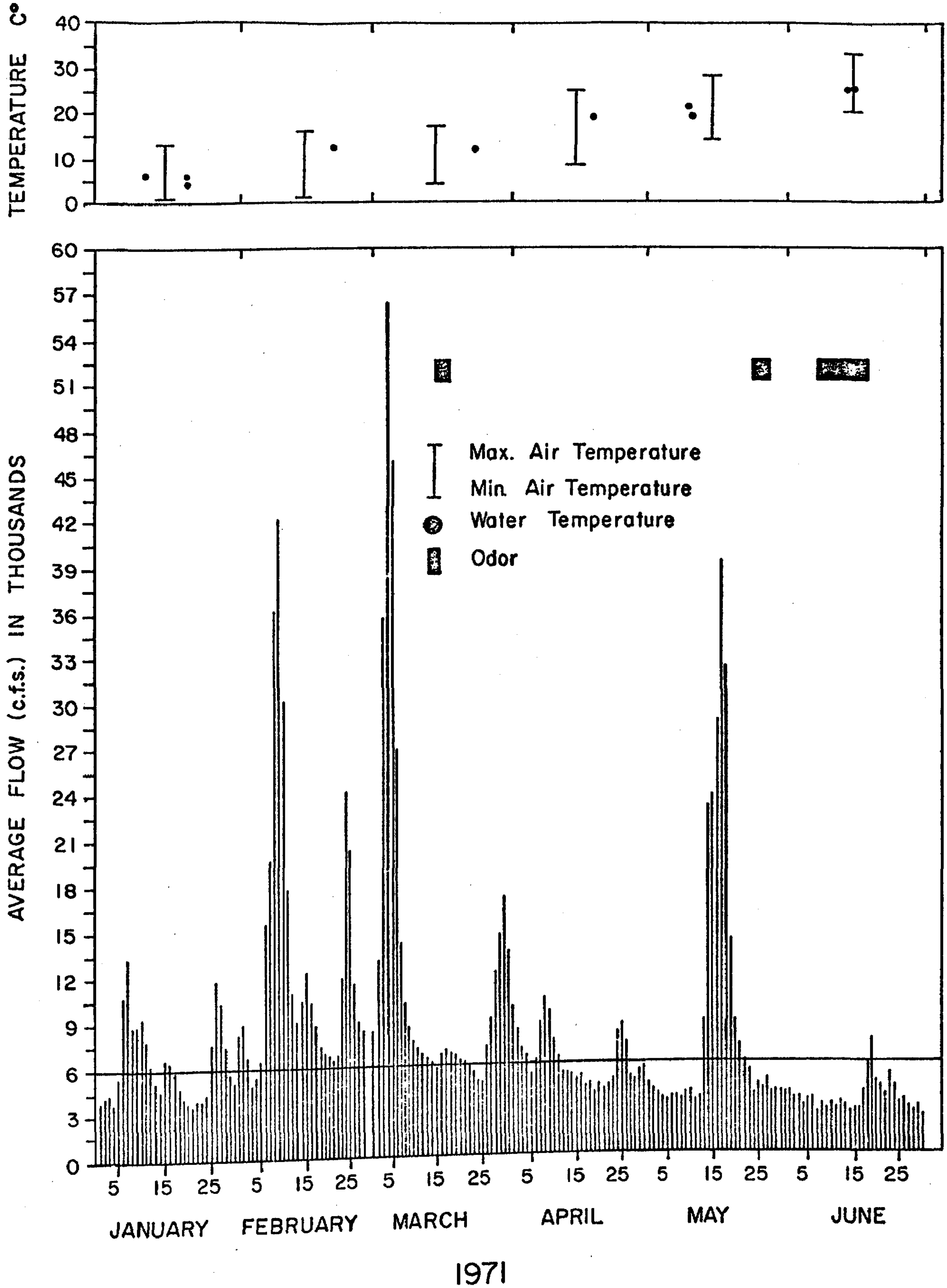

FIGURE 11.--Musty odors, flow, water temperature, maximum and minimum air temperature from the Columbia-Richtex, South Carolina, vicinity for January-June 1971.

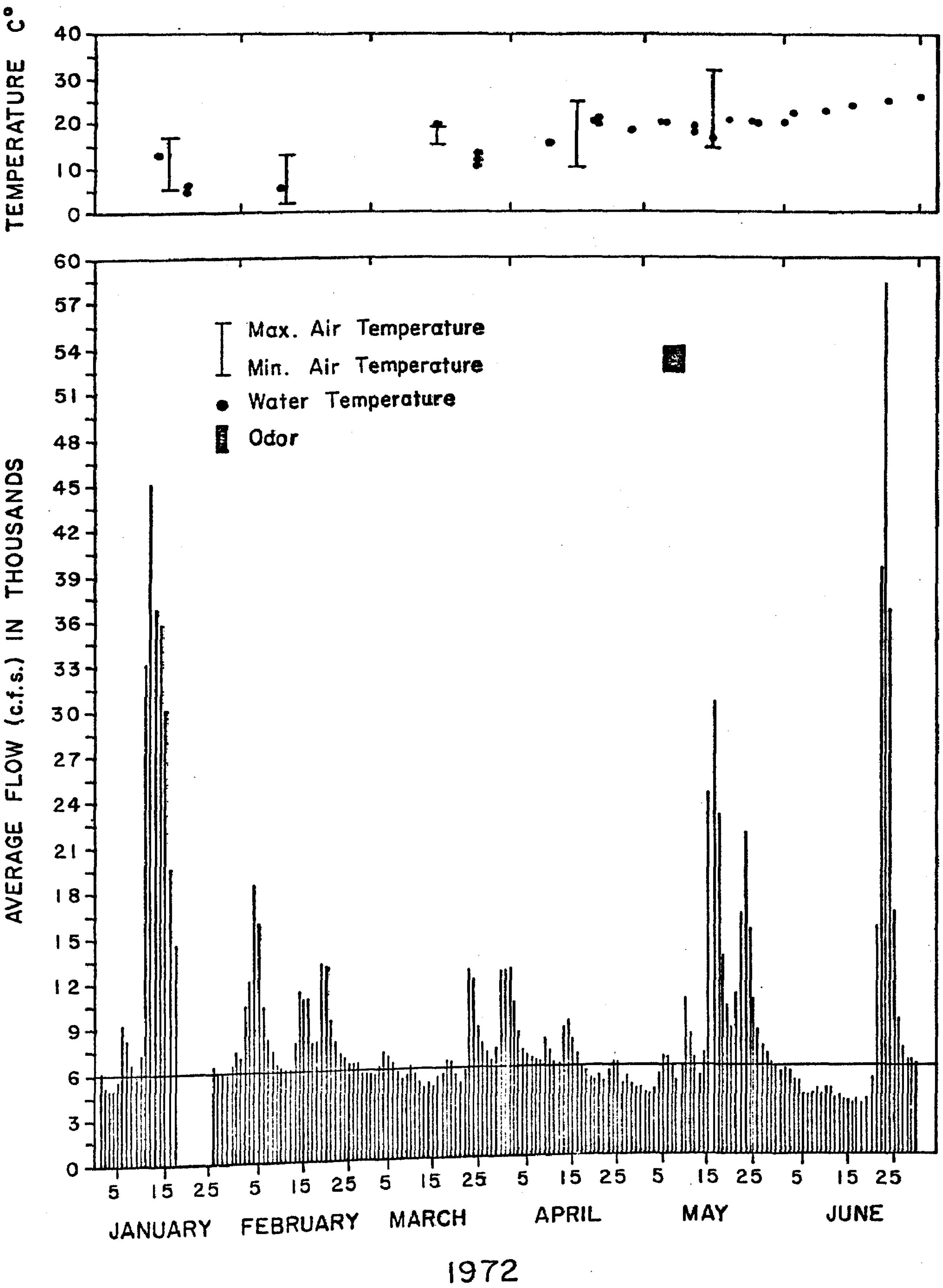

FIGURE 12.--Musty odors, flow, water temperature, maximum and minimum air temperature from the Columbia-Richtex, South Carolina, vicinity for January-June 1972.

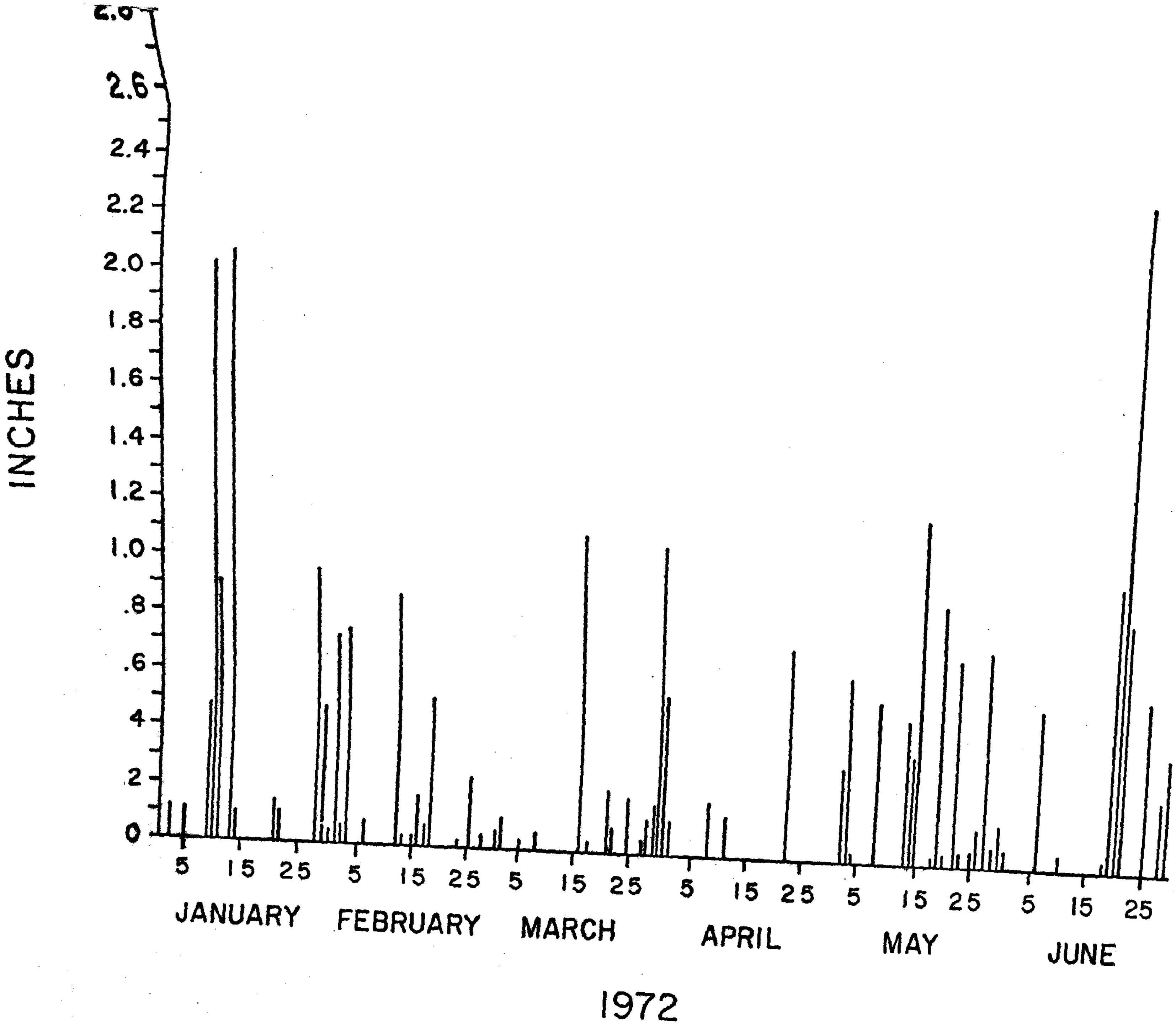

FIGURE 13.--Rainfall at the Columbia, South Carolina, airport from January-June 1972.

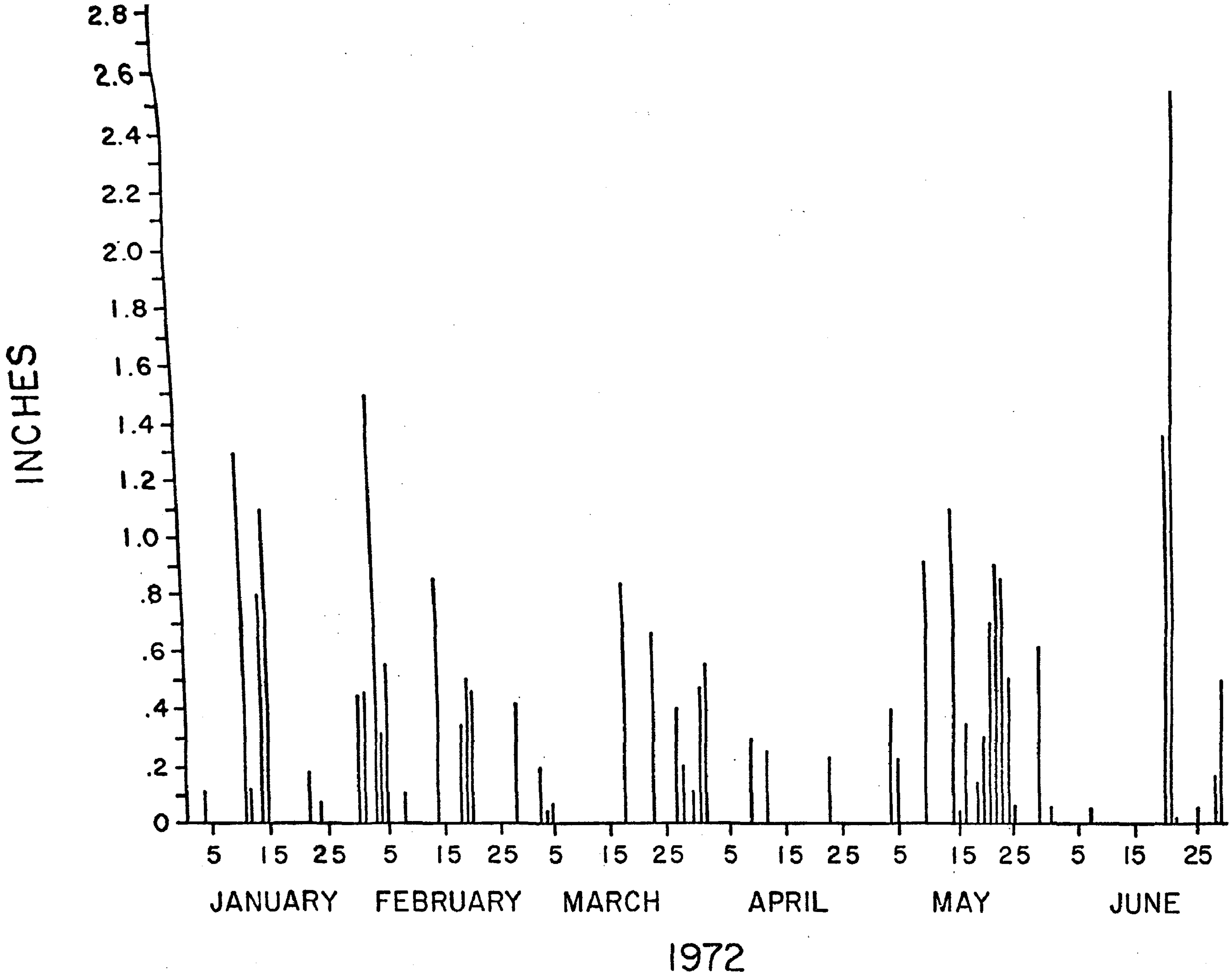

FIGURE 14.--Rainfall at Parr, South Carolina, from January-June 1972.

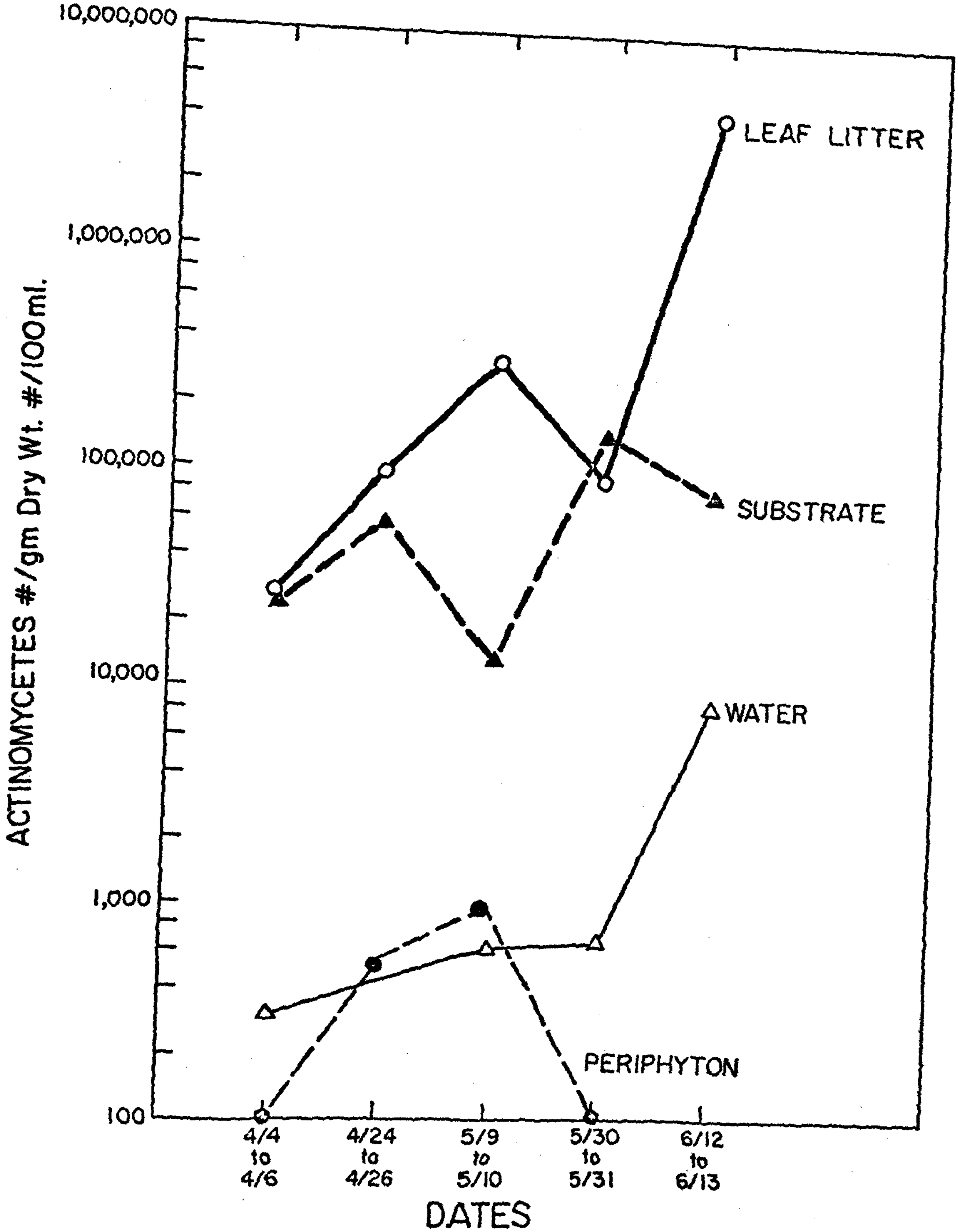

FIGURE 15.--Average actinomycete counts from Station 1 (water, #/100 ml; substrate, #/gm; and periphyton #/gm) and Station 3 (leaf litter #/gm), Broad River Basin, April-June 1972.

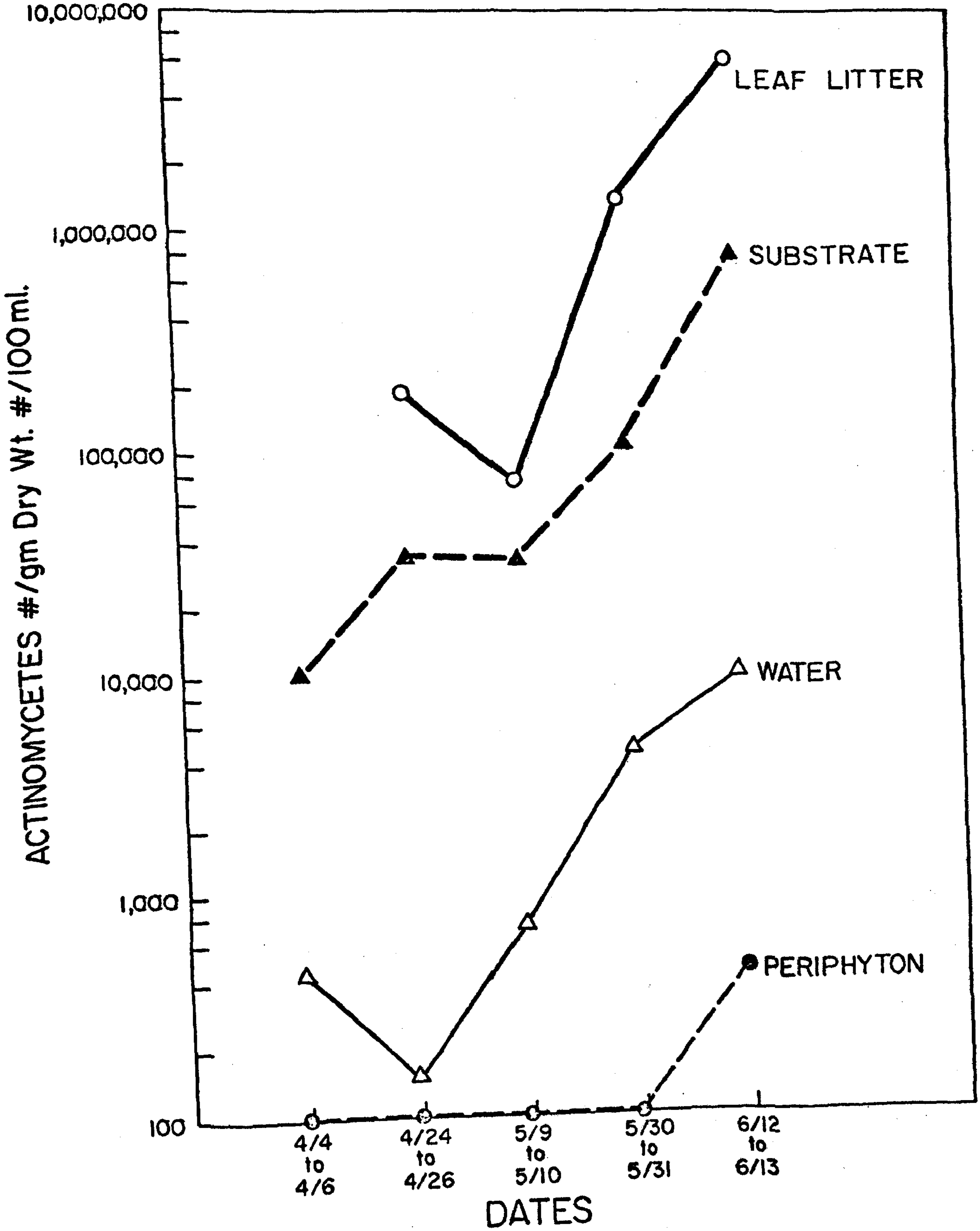

FIGURE 16.--Average actinomycete counts from Station 5 (water, #/100 ml; substrate, periphyton, and leaf litter, #/gm), Broad River Basin, April-June 1972.

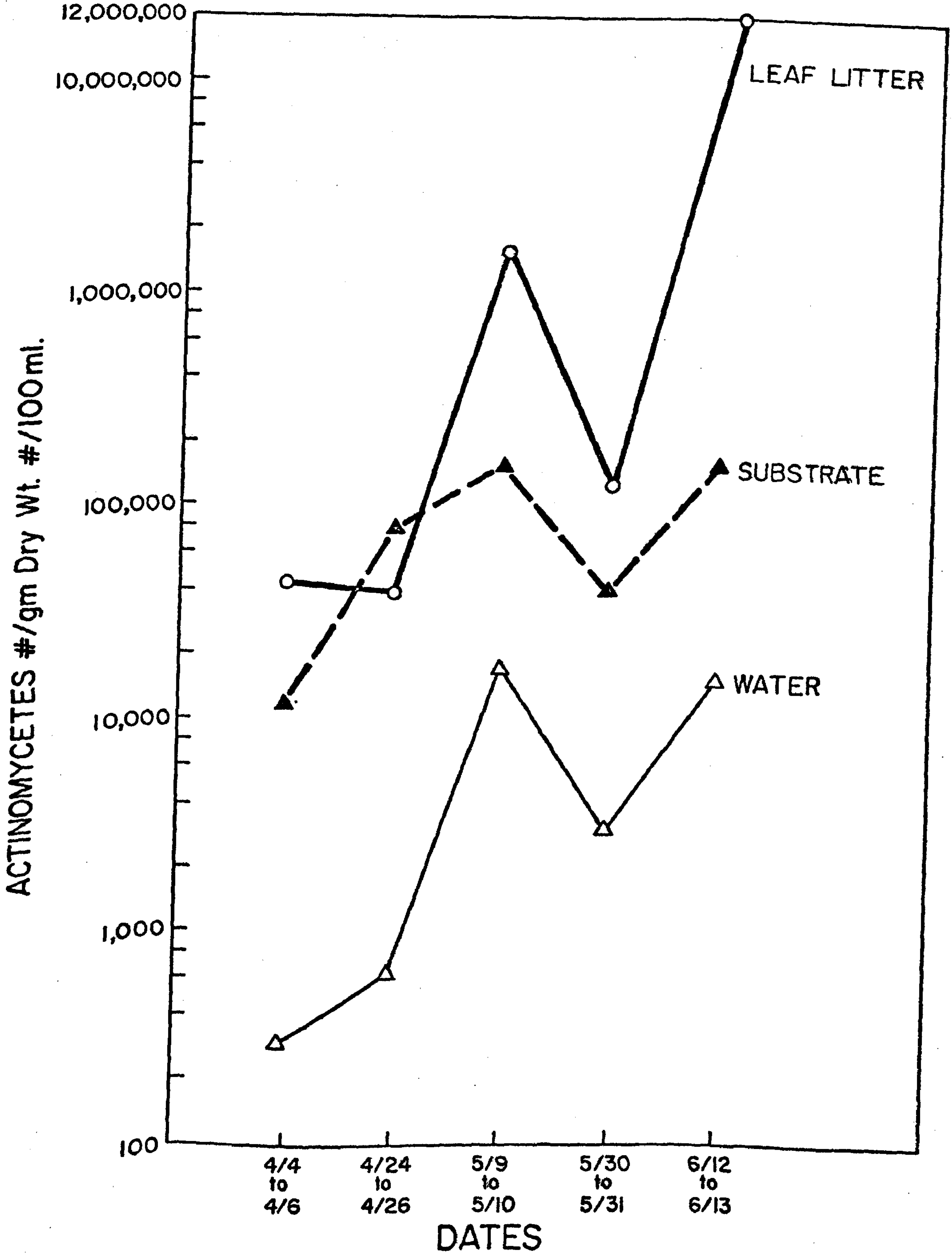

FIGURE 17.--Average actinomycete counts from Station 9 (water, #/100 ml; substrate, #/gm) and Station 10 (leaf litter, #/gm), Broad River Basin, April-June 1972.

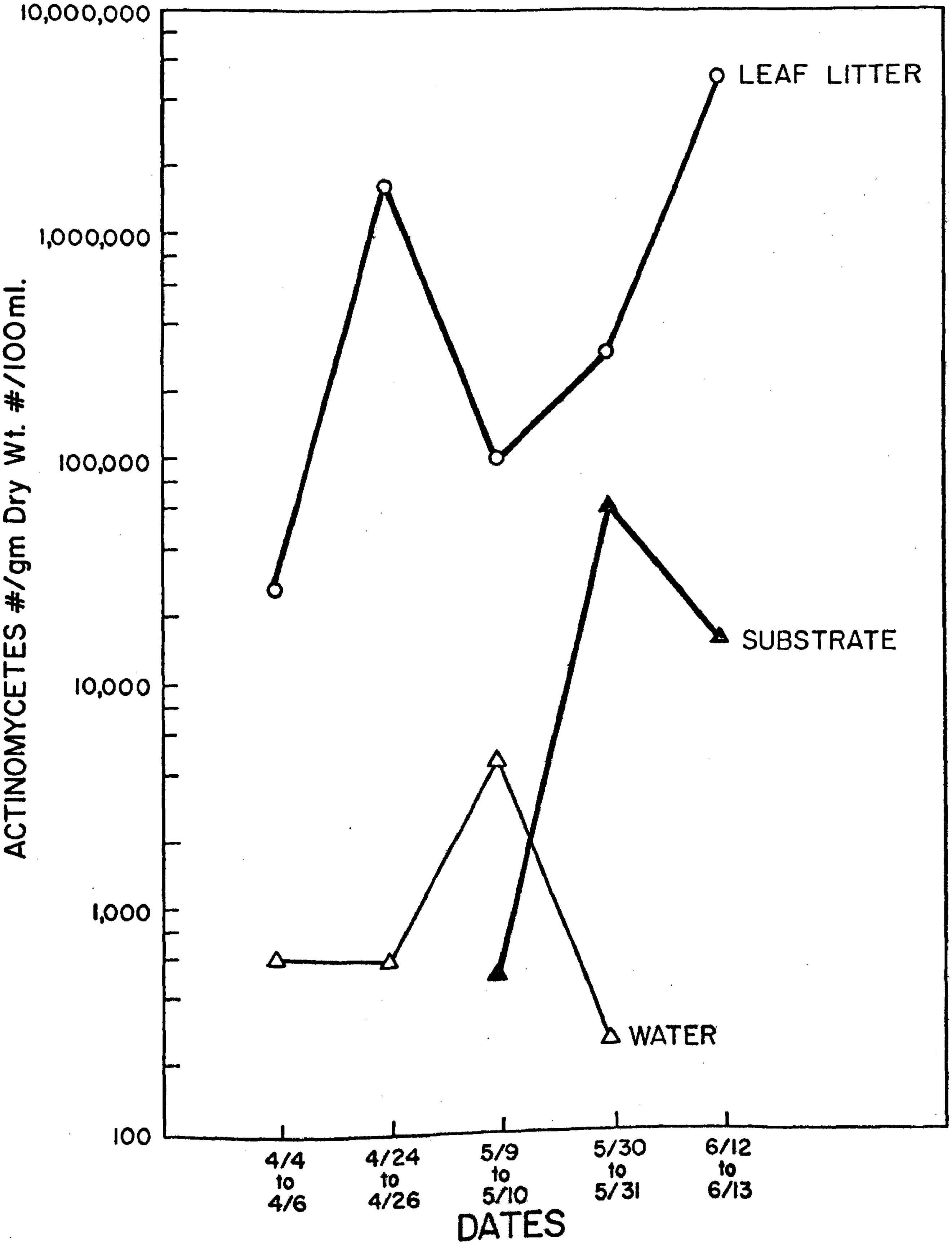

FIGURE 18.--Average actinomycete counts from Station 11 (water, #/100 ml; substrate and leaf litter, #/gm), Broad River Basin, April-June 1972.

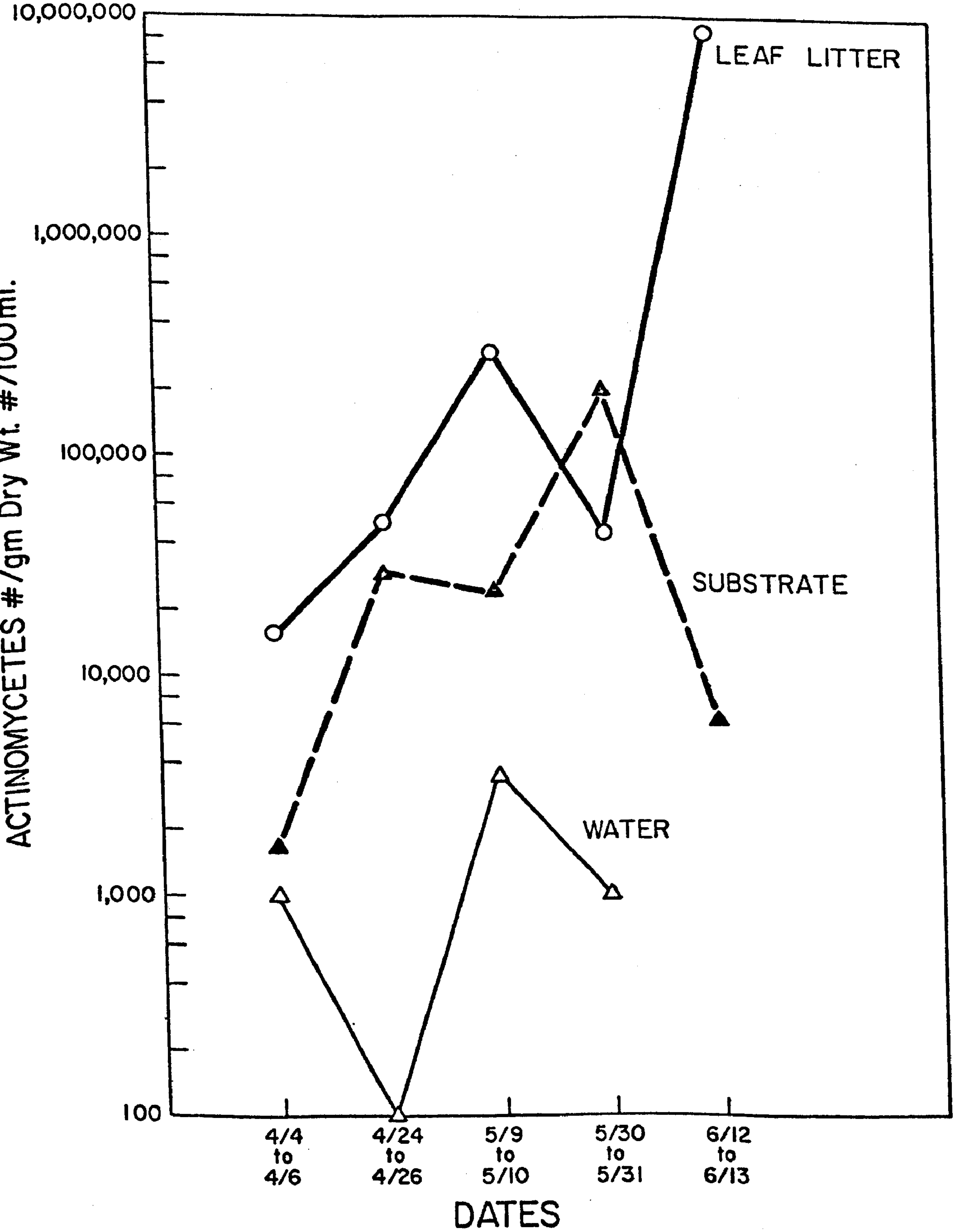

FIGURE 19.--Average actinomycete counts from Station 13 (water, #/100 ml; substrate and leaf litter, #/gm), Broad River Basin, April-June 1972.

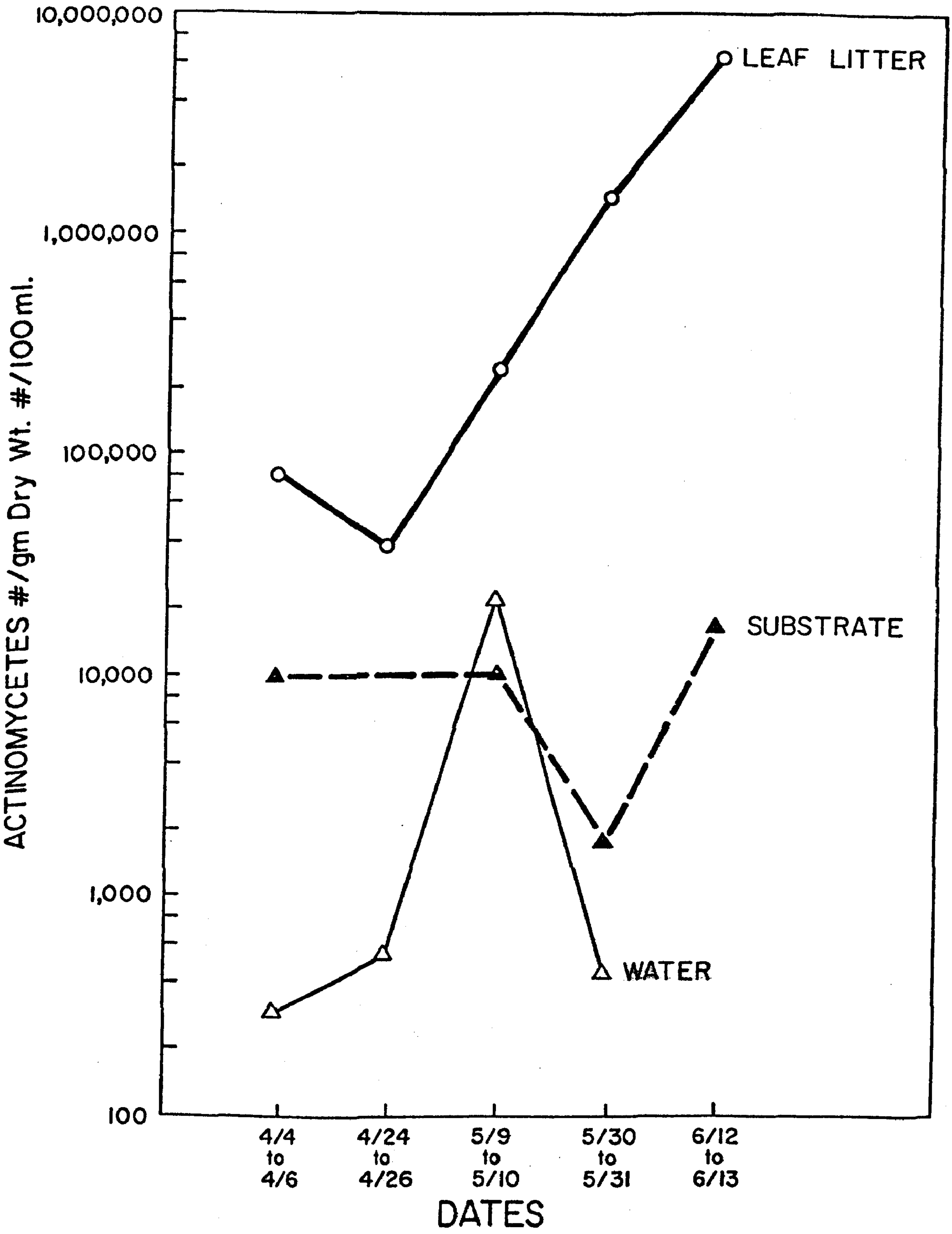

FIGURE 20.--Average actinomycete counts from Station 14 (water, #/100 ml; substrate and leaf litter, #/gm), Broad River Basin, April-June 1972.

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11. Personal Communication from South Carolina Water Pollution Control Authority and the South Carolina State Board of Health.

12. Personal Communication with Mr. D. Whittaker, Plant Operator; Mr. V. Wallace, Maintenance Supervisor; Mr. Caleson, Manager, City Utilities, Shelby, North Carolina.

13. Personal Communication with Mr. J. R. Jenkins, Water Plant, Forest City, North Carolina.

14. Personal Communication with Mr. H. Gains, Filter Plant Operator, Norris. South Carolina.

15. Personal Communication with Dr. Webb, South Carolina Water Pollution Control Authority, and Mr. T. C. Kurimcak, South Carolina State Board of Health.

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