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Candidate: ROGER D. POPPLE

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Joe M. King
Seminar Paper Advisor

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Date

James W. Erickson
Dean, Graduate College

Quantitative Analysis of the Nutrient Uptake by Lake Redstone (Sauk Co., Wis.)

Roger D. Popple

University of Wisconsin

La Crosse

ABSTRACT

Water was collected at four sites and analyzed for ammonium nitrogen, nitrate nitrogen, ortho phosphate, pH, temperature and turbidity. Volume of inflow and outflow water was also determined. Lake Redstone received 5,250 kg of nitrate nitrogen, 3,525 kg of ammonium nitrogen and 1,680 kg of ortho phosphate. Of this, 1,030 kg of nitrate nitrogen, 1,150 kg of ammonium nitrogen and 830 kg of ortho phosphate was retained by the lake. This represented a filtering efficiency of 19.66% for nitrate nitrogen, 32.62% for ammonium nitrogen, and 49.49% for ortho phosphate removed from the inflow waters. Lake Redstone also received 111.3 metric tons of sediments during the test period. Of this, 79.3 metric tons of sediments were retained by the lake. This represented a filtering efficiency of 71.0% removal of sediments from the inflow waters.

INTRODUCTION

Eutrophication, the enrichment of waters by nutrients, is a much discussed phenomenon and has stimulated extensive investigations into the factors involved in lake aging. Curl (1957) states, "There are essentially two ways in which nutrient materials are made available to lakes. One was constitutes a closed system in which there is a continuous cycle of uptake and release of nutrients that remain, for the most part, permanently within the lake and its basin. . . . The other way of supplying nutrients is by an open system in which the materials are added to the lakes by tributaries, surface runoff, and springs, take part in one or two seasonal cycles, and are then removed by either outflow or permanent retention in bottom sediments."

Present information indicates that the fertilizing elements which contribute most to lake eutrophication are nitrogen and phosphorus (Mackenthun and Ingram, 1967). Mackenthun (1969) writes: "(1) High phosphorus concentrations are associated with accelerated eutrophication of waters, when other growth promoting factors are present; (2) aquatic plant problems develop in reservoirs or other standing waters at phosphorus values lower than those critical in flowing streams; (3) reservoirs or other standing waters collect phosphates from influent streams and store a portion of these within consolidated sediments; and (4) phosphorus concentrations critical to noxious plant growths vary, and they produce such growths in one geological area, but not in another." Lund (1965) concluded that nitrogen and phosphorus can still be considered as two of the major elements limiting primary production and in some highly eutrophic lakes, nitrogen may be a more important limiting factor than phosphorus.

A survey of the literature, however, revealed few references to quantitative assessments of nitrogen and phosphorus compounds in impoundments. Sawyer et al (1945) and Lackey and Lenz (1945) assessed the nitrogen contributed to the Madison, Wisconsin lakes. Sylvester (1960) in Yakima Valley (Washington), Engelbrecht and Morgan (1961) in the Kaskaskia River basin of Illinois, and Mackenthun (1969) at the Ross E. Barnett Reservoir (Mississippi) were notable in performing quantitative analyses of stream nutrients.

In considering the uptake of nutrients by Lake Redstone, the author confined the assessment of chemical parameters to ammonium nitrogen, nitrate nitrogen and ortho phosphate (soluable inorganic phosphate).

STUDY AREA

Lake Redstone is a 253 ha impoundment on Big Creek, which is located in parts of Sections 11, 12, 13, 14, 23 and 24, T13N, R3E, Sauk County, Wisconsin. Big Creek was dammed during the summer of 1965 and the lake reached capacity during the summer of 1966, with a maximum depth of 12 m.

The Big Creek watershed is composed of 6200 ha of steep, hilly land with a land utilization of approximately 55% forest, 30% cropland, and 15% permanent pasture (Sauk County Soil Conservation Service estimate). Big Creek is composed of two stream courses (West and East Forks) which, prior to impoundment, joined at a point which is now flooded by the lake. As a result, the main water sources of Lake Redstone are the West and East Forks of Big Creek. Additional water enters the lake from intermittent streams, seepage and subsurface springs (Carlson,1971).

The discharge of water from the lake enters the Baraboo River 400 m southwest of the lake outlet.

Lake Redstone has experienced nuisance algal blooms during the summers of 1969, 1970 and 1971. The algal populations reached such densities that an algacide was applied to reduce algae numbers (Carlson, 1971). Only short term improvements were realized by the algacide treatment.

Because of the small watershed size and since there are only two major surface sources of water, Lake Redstone was considered an ideal location for assessing the quantitative uptake of nutrients by a small lake. The Big Creek watershed is sparsely populated and, despite the topography, is extensively farmed. This situation presented a means of determining the impact of agricultural runoff on lake water quality.

METHODS AND MATERIALS

In addition to ortho phosphate, ammonium nitrogen and nitrate nitrogen, measurements were made of temperature, pH and turbidity. With the exception of temperature, all tests were made with a DC-DR Colorimeter (Hach Chemical Company, Ames, Iowa). Temperature was determined with an armor-clad alcohol thermometer.

Volume determinations were made at three test sites: East Fork - Big Creek, C.T. Highway "F", 4.8 km east of the intersection of U.S. 58; West Fork - Big Creek, C.T. Highway "F", 4.0 km east of the intersection of U.S. 58; Outlet, 400 m northeast of the confluence of Big Creek and the Baraboo River. The confluence is located 400 m north of the C.T. Highway "V" bridge, 3.2 km east of the intersection of U.S. 33.

Volume determinations were made in culverts (one, 1.524 m diameter in East Fork; two, 2.44 m diameter in West Fork) on C.T. Highway "F" and in the dam at the outlet. Velocity of water flow was determined with a Flow Meter (Milwaukee Engineering Equipment Co.) and a calibrated water wheel. Volume calculations were made in accordance with Welch (1948).

Water samples for physical and chemical analysis were taken at the three sites listed above and from a well located at the Sauk county Park, which is adjacent to the dam impounding Lake Redstone. Samples from the well were included to determine the nutrient content of the seepage water that enters the lake. Volume of subsurface contribution was determined by the difference between stream input and lake discharge at the winter flow levels of Big Creek and the outlet. Subsurface contributions were considered to be constant throughout the monitoring period.

Collection of water samples and volume determinations began February 29, 1972. Samples were taken at this time to determine the winter flow level of the two streams and to determine the volume of subsurface water that is entering the lake. Samples were taken twice weekly until the spring runoff commenced. With an increase in water volume (March 14), samples were taken daily until the volume returned to near-normal (March 24), after which time they were taken every other day until the termination of the current monitoring period (April 18).

RESULTS

Nitrate Nitrogen

Nitrate nitrogen in Big Creek varied from 0.5 to 7.0 mg/l during the monitoring period (Figure 1). In all test sites, the concentration of nitrate nitrogen displayed a decreasing trend, with irregularities, until March 18 and then remained relatively stable until the termination of the current monitoring period.

Contribution of nitrate nitrogen from seepage water was rather insignificant, with the majority of the tests indicating levels at or near 0.0 mg/l. Concentrations varied from 0.0 to 3.0 mg/l throughout the test period and all tests were less than 0.5 mg/l after March 18.

Nitrate nitrogen content of discharge water from the outlet closely followed the trend displayed by the West Fork and East Fork but with a slightly reduced concentration level (0.5 to 3.0 mg/l).

Total contribution of nitrate nitrogen added to Lake Redstone from all tested sources was 5,252.2 kg. Individual sources of nitrate nitrogen were 3,882.3 kg, West Fork; 1,145.3 kg, East Fork; and 224.6 kg, subsurface sources.

During the same period, the water discharged at the outlet contained 4,264.8 kg of nitrate nitrogen. The net uptake of nitrate nitrogen by Lake Redstone, for the period February 29 through April 18, was 1,032.9 kg.

Ammonium Nitrogen

Unlike nitrate nitrogen, ammonium nitrogen displayed a very irratic pattern throughout the monitoring period and the concentration of ammonium nitrogen increased with an increase in volume at all test sites. Ammonium nitrogen concentrations varied from 0.2 to 2.5 mg/l in the two streams and from 0.0 to 0.6 mg/l in the seepage water. Ammonium nitrogen concentrations varied from 0.0 to 1.8 mg/l in the discharge water at the outlet (Figure 2).

Total contribution of ammonium nitrogen added to Lake Redstone from all tested sources was 3,523.3 kg. Individual sources of ammonium nitrogen were 2,790.8 kg, West Fork; 648.0 kg, East Fork; and 88.5 kg, subsurface sources.

During the same period, the water discharged at the outlet contained 2,373.2 kg of ammonium nitrogen. The net uptake of ammonium nitrogen by Lake Redstone, for the period February 29 through April 18, was 1,150.1 kg.

Ortho Phosphate

Ortho phosphate concentrations of the West Fork and East Fork displayed remarkable simularity in trend and quantities. Concentrations varied from 0.1 to 1.4 mg/l (Figure 3). Ortho phosphate concentrations increased with an increase in volume from spring runoff. There was also an increase in ortho phosphate concentration with stream flow increases occurring after the initial snow melt period.

Ortho phosphate concentrations of seepage water remained at 0.1 mg/l or less throughout the test period.

Ortho phosphate concentration of the discharge water at the outlet varied from 0.0 to 0.6 mg/l throughout the monitoring period. The graph indicated a lapse of approximately 10 days between the increase in concentration in the contributing streams and the increase in concentration at the outlet. The discharge water, however, had a longer period of high concentration (approximately 24 days as opposed to about 14 days in the contributing streams) but a much lower high point of concentration (o.6 mg/l as opposed to 1.4 mg/l in the contributing streams).

Total contribution of ortho phosphate added to Lake Redstone from all tested sources was 1,676.8 kg. Individual sources of ortho phosphate were 1,340.5 kg, West Fork; 302.7 kg, East Fork; and 13.6 kg, subsurface sources.

During the same period, the water discharged at the outlet contained 846.8 kg of ortho phosphate. The net uptake of ortho phosphate by Lake Redstone, for the period February 29 through April 18, was 830.0 kg.

Turbidity

The amount of turbidity occurring in Lake Redstone was significant when converted to a total weight of contribution. Total contribution of sediments added to Lake Redstone from all tested sources was 111.3 metric tons. Individual sources of turbidity were 88.9 metric tons, West Fork; 22.3 metric tons, East Fork; and subsurface sources were considered to be zero.

During the same period, the water discharged at the outlet contained 31.98 metric tons of sediments. A net of 79.3 metric tons of sediments was added to the Lake Redstone basin during the period February 29 through April 18 (Figure 4).

pH - Temperature

Observations of temperature and pH were taken throughout the monitoring period (Figures 5 & 6). No relationship between these factors and the uptake of nutrients was undertaken in this project. However, the pH of the discharge water was consistently lower than the pH of the contributing streams. The pH of the outlet was below 8.0

on 17 of 22 tests, the pH of the West Fork was below 8.0 on nine tests and the pH of the East Fork was below 8.0 on six tests.

DISCUSSION

During the monitoring period (February 29 through April 18), the Big Creek watershed lost 8,780 kg of nitrogen and 1,676.8 kg of phosphorus. This amounted to a loss of 1.51 kg of nitrogen and 0.27 kg of phosphorus per hectare. Sylvester (1961) suggested that wooded land experiences a loss of 0.034 kg of nitrogen and 0.0034 kg of phosphorus per hectare per year. Applying this formula to the Big Creek watershed, one might conclude that only 115.2 kg of nitrogen and 11.5 kg of phosphorus would be lost from the forested land per year. Eck, Jackson and Bay (1957) suggested that cropland and pasture experienced a loss of 0.067 kg of nitrogen and 0.045 kg of phosphorus per hectare per year. The application of this formula to the Big Creek watershed would indicate a loss of 138.5 kg of nitrogen and 125.7 kg of phosphorus from the cropland and pasture.

Sawyer (1947) found that agricultural drainage in Madison, Wisconsin is contributing 2,045 kg of nitrogen and 116 kg of phosphorus per square mile of drainage area per year. Engelbrecht and Morgan (1961) stated that one test station, which received runoff from a cultivated drainage area of 11 square miles, experienced a loss of 102.3 kg of ortho phosphate (plus hydrolyzable P_2O_5) per year per square mile of drainage area. The Big Creek watershed experienced a loss of approximately 366.0 kg of nitrogen and 70.0 kg of phosphorus per square mile during the critical spring runoff period.

Midgley and Dunklee (1945) indicated that about 3.37 kg of nitrogen and 1.11 kg of phosphorus were lost from a 22.0 metric ton per hectare application of manure on an 8% slope in Vermont when the ground was frozen. Assuming that all the cropland in the Big Creek watershed was treated with manure, an unlikely assumption at best, the watershed then experienced a loss of 4.7 kg of nitrogen and 0.9 kg of phosphorus per hectare.

The high concentration of ammonium nitrogen, as well as a high total nitrogen content, indicated that the waters of Big Creek, and ultimately Lake Redstone, were altered by the farming practices on the watershed.

Mackenthun and Ingram (1964) cited laboratory investigations by Gerloff and Skoog showing that 5 units of nitrogen plus 0.08 units of phosphorus would produce 100 units of algae. Their experimental work indicated a ratio of about 60 : 1, but in naturally occuring algae and submerged plants, the ratio is about 10 parts of nitrogen to 1 part of phosphorus (Gerloff and Skoog, 1957). Sawyer et al (1945), following a study of southeastern Wisconsin lakes, established inorganic nitrogen and phosphorus concentrations of 0.3 and 0.015 mg/l, respectively, as the minimum average annual concentrations that would result in frequent nuisance blooms. The latter ratio is 20 : 1.

The concentrations of 0.3 mg/l nitrogen and 0.015 mg/l phosphorus, as set forth by Sawyer et al (1945), was exceeded, and in most cases, many times over on every day of testing during the monitoring period.

A most interesting aspect of this project is the filtering characteristics that an impoundment exerts on inflow waters. Lake Redstone removed 32.64% of the ammonium nitrogen, 19.66% of the nitrate nitrogen and 49.49% of the ortho phosphate from Big Creek. Mackenthun and Ingram (1967) observed a 50.0% reduction in total phosphorus as a result of the filtering influence of the Ross E. Barnett Reservoir on the inflowing waters. Indeed, the nutrient content of the discharge water from Lake Redstone was more than ample to support nuisance blooms of algae despite a significant reduction in nutrient concentrations.

Allen (1955) postulated that the maximum algal crop that can be produced by one unit of phosphorus is 250 units (field conditions). Applying this formula to the uptake of nutrients by Lake Redstone, the total increase in algae during the monitoring period would exceed 207.5 metric tons (wet weight) or about 820 kg of algae per hectare of lake surface.

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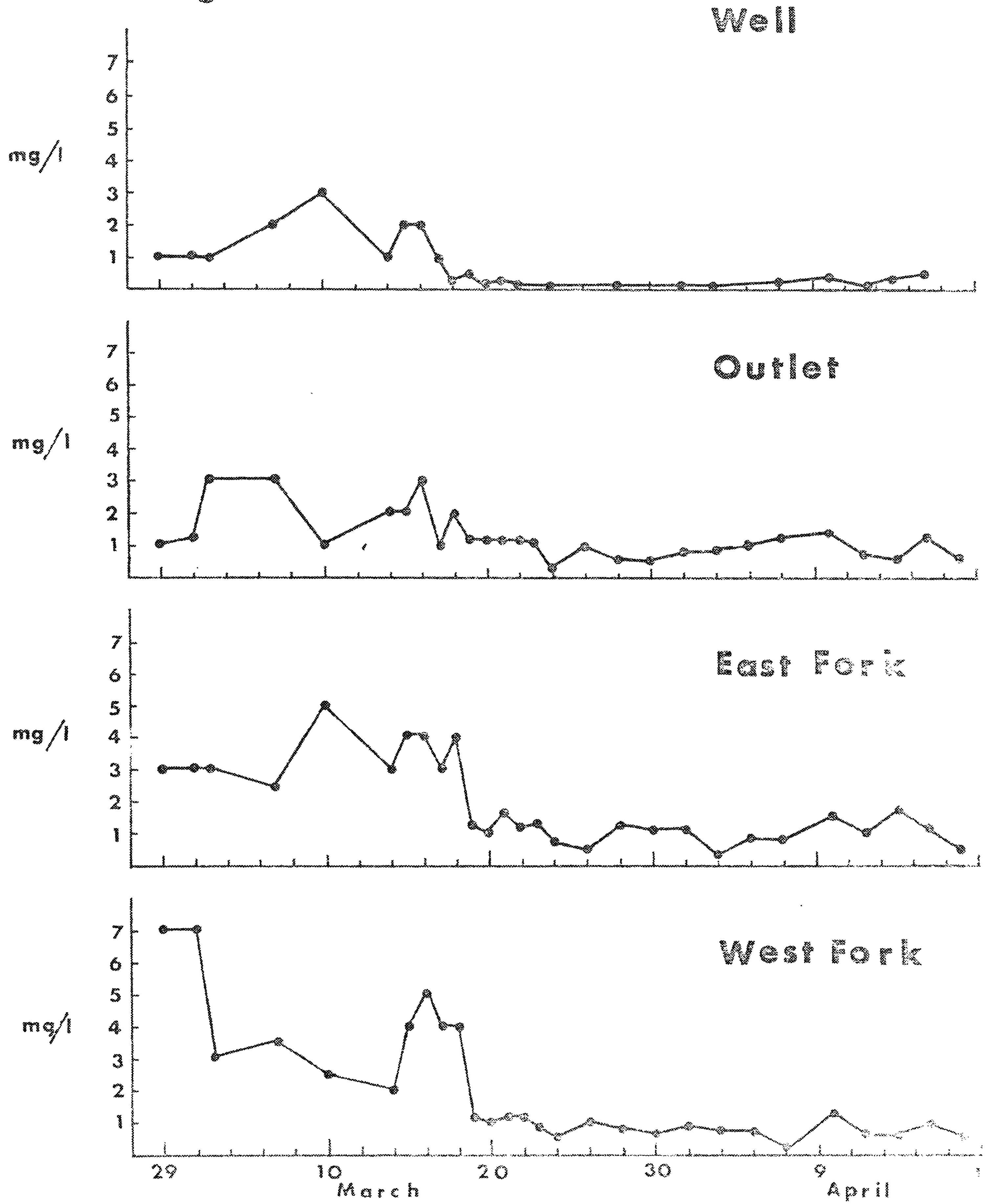
Figure 1. Concentration of nitrate nitrogen in milligrams per liter of water samples taken from the four sites indicated, during the period February 29 through April 18, 1972.

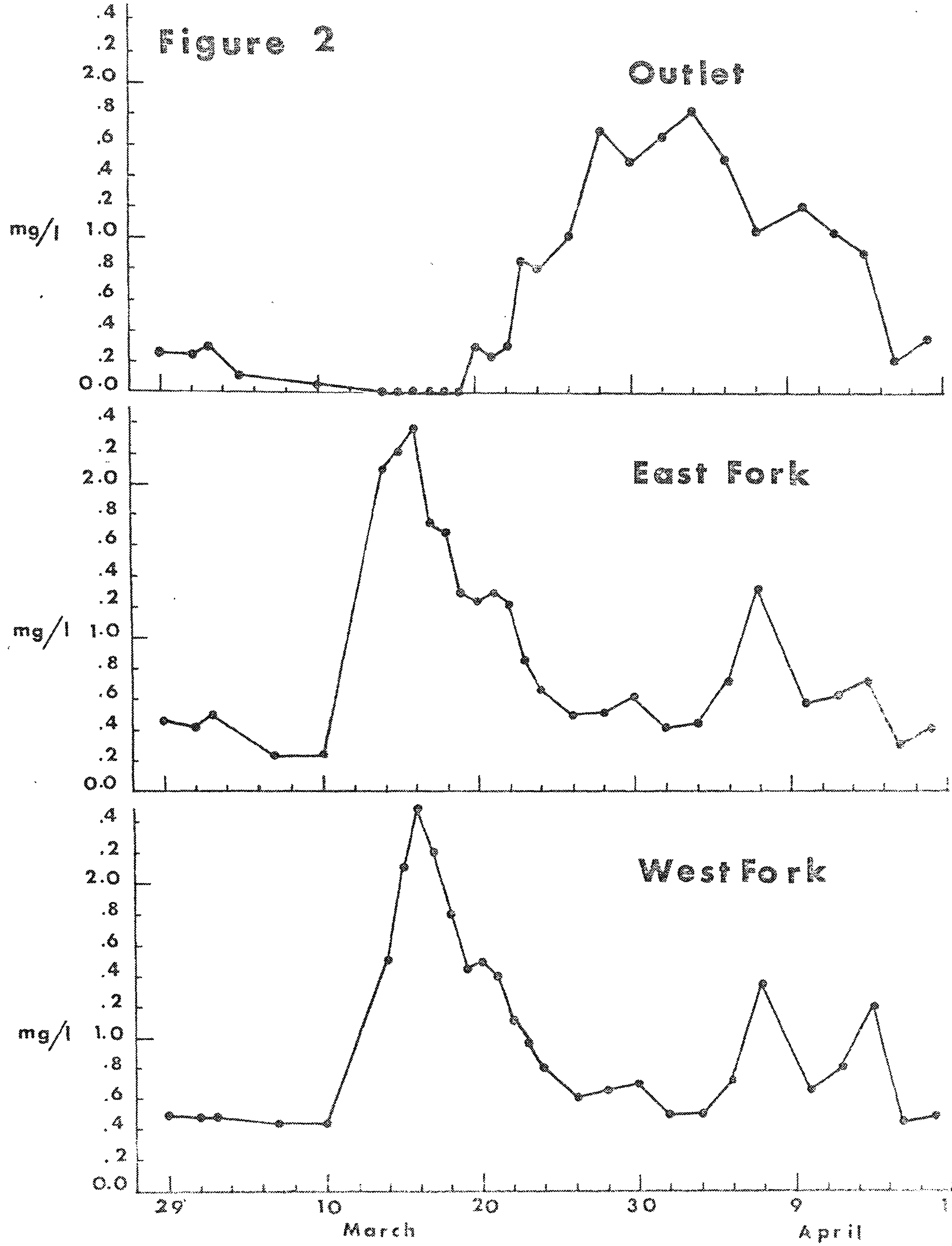
Figure 1



Nitrate Nitrogen

Figure 2. Concentration of ammonium nitrogen in milligrams per liter of water samples taken from the four sites indicated, during the period February 29 through April 18, 1972.

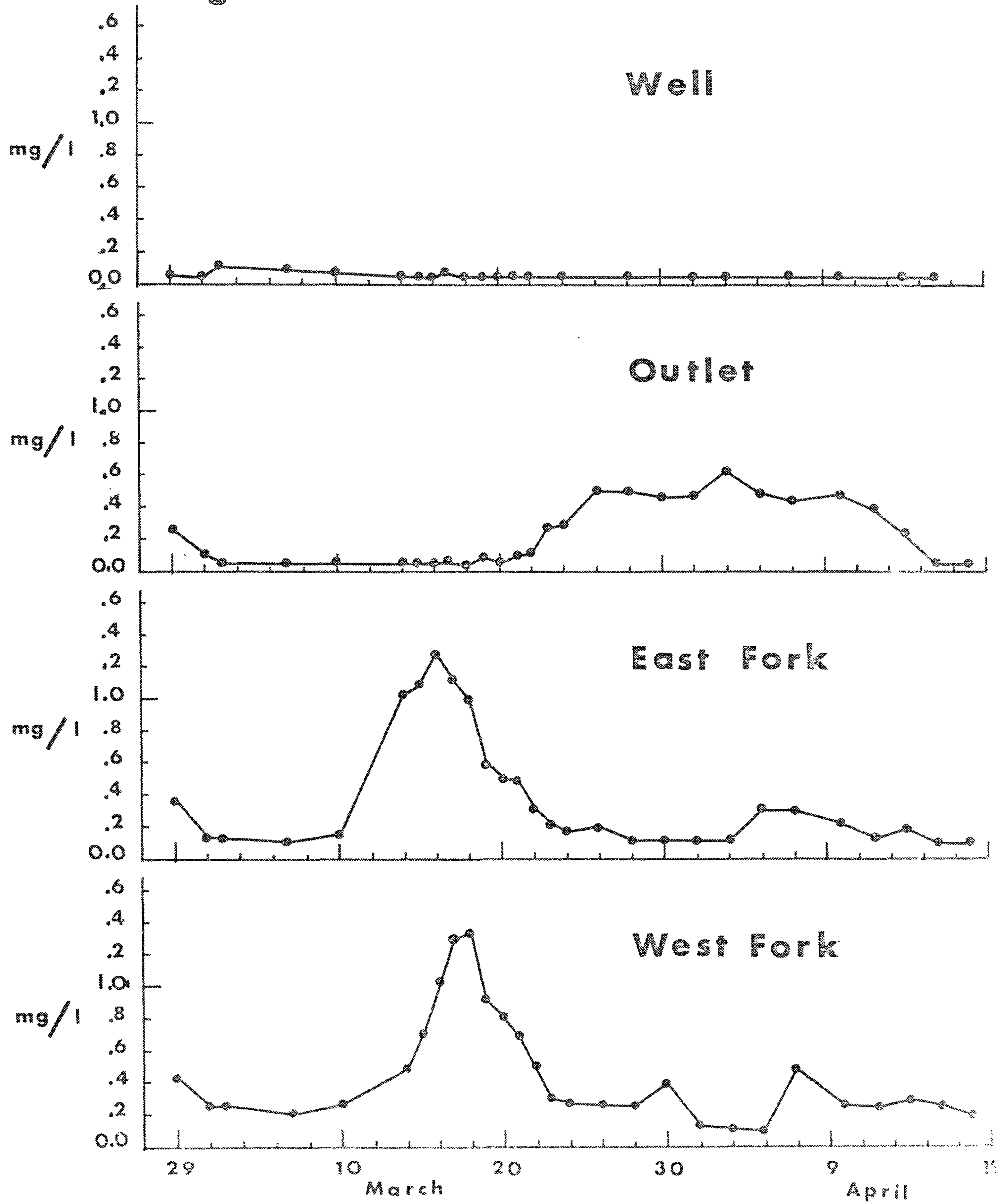
Figure 2



Ammonium Nitrogen

Figure 3. Concentration of ortho phosphate in milligrams per liter of water samples taken from the four sites indicated, during the period February 29 through April 18, 1972.

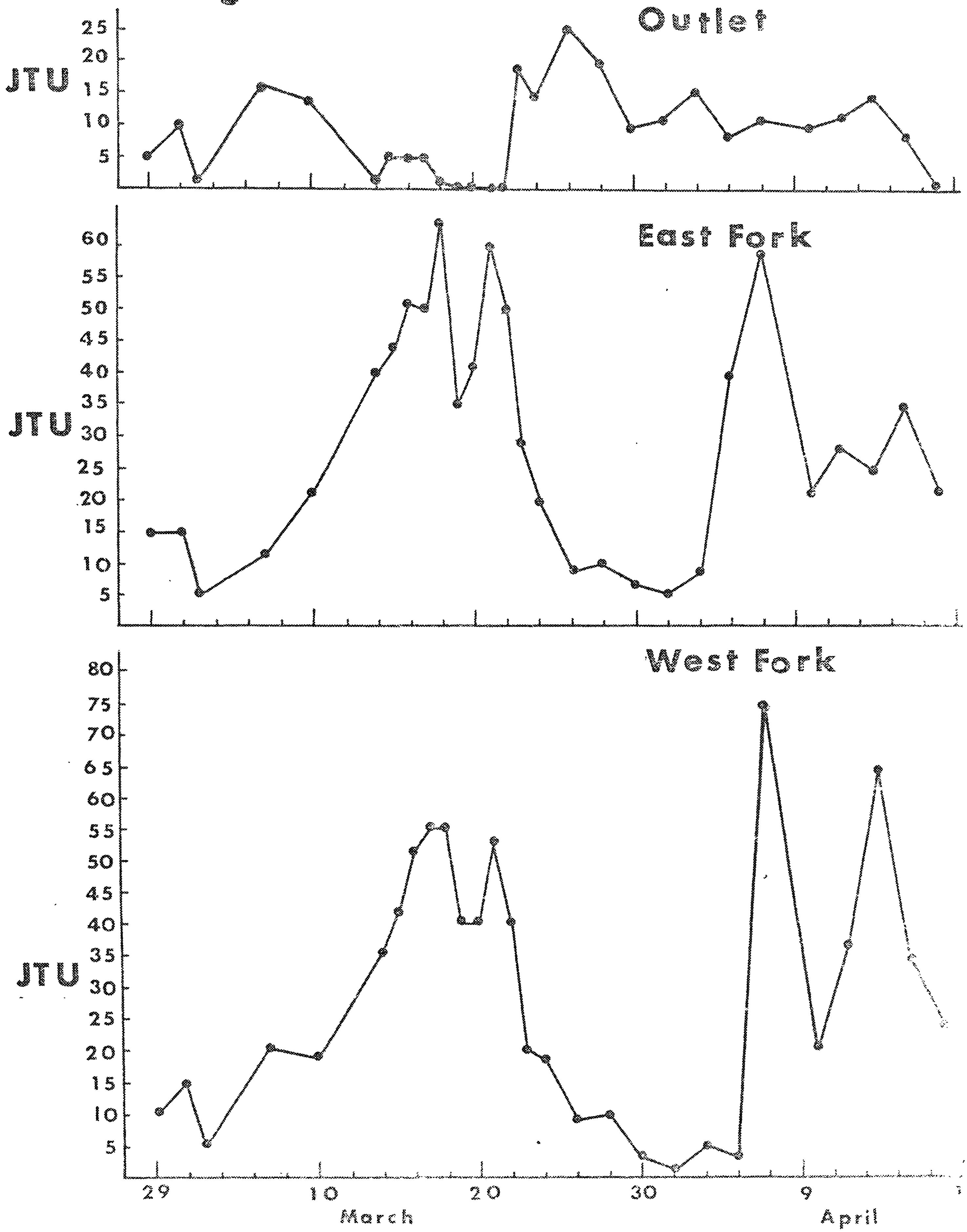
Figure 3



Ortho Phosphate

Figure 4. Concentration of turbidity in Jackson Turbidity Units of water samples taken from the three sites indicated, during the period February 29 through April 18, 1972.

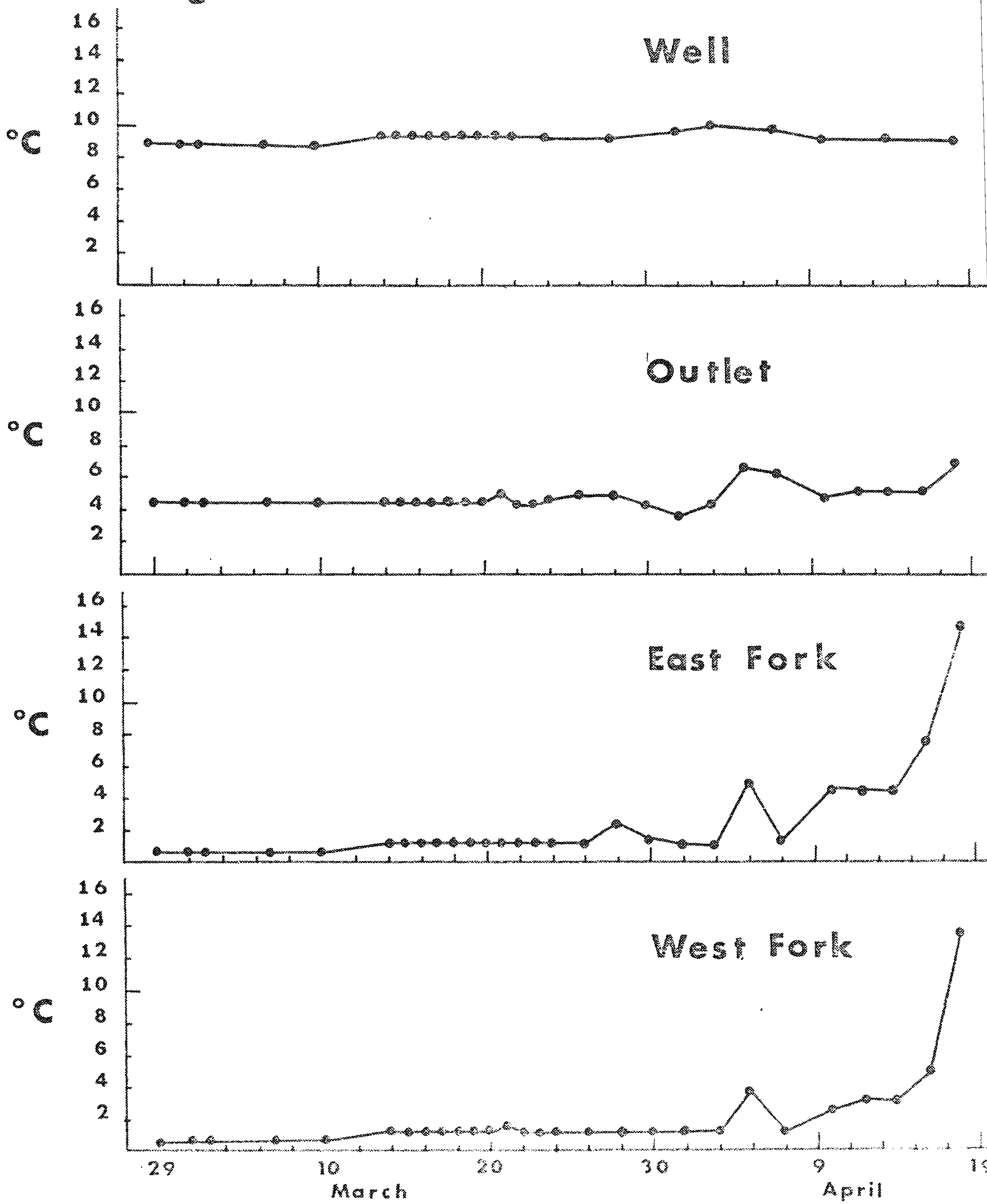
Figure 4



Turbidity

Figure 5. Temperature in degrees centigrade of water samples taken from the four sites indicated, during the period February 29 through April 18, 1972.

Figure 5



Temperature

Figure 6. pH of water samples taken from the four sites indicated, during the period February 29 through April 18, 1972.

Figure 6

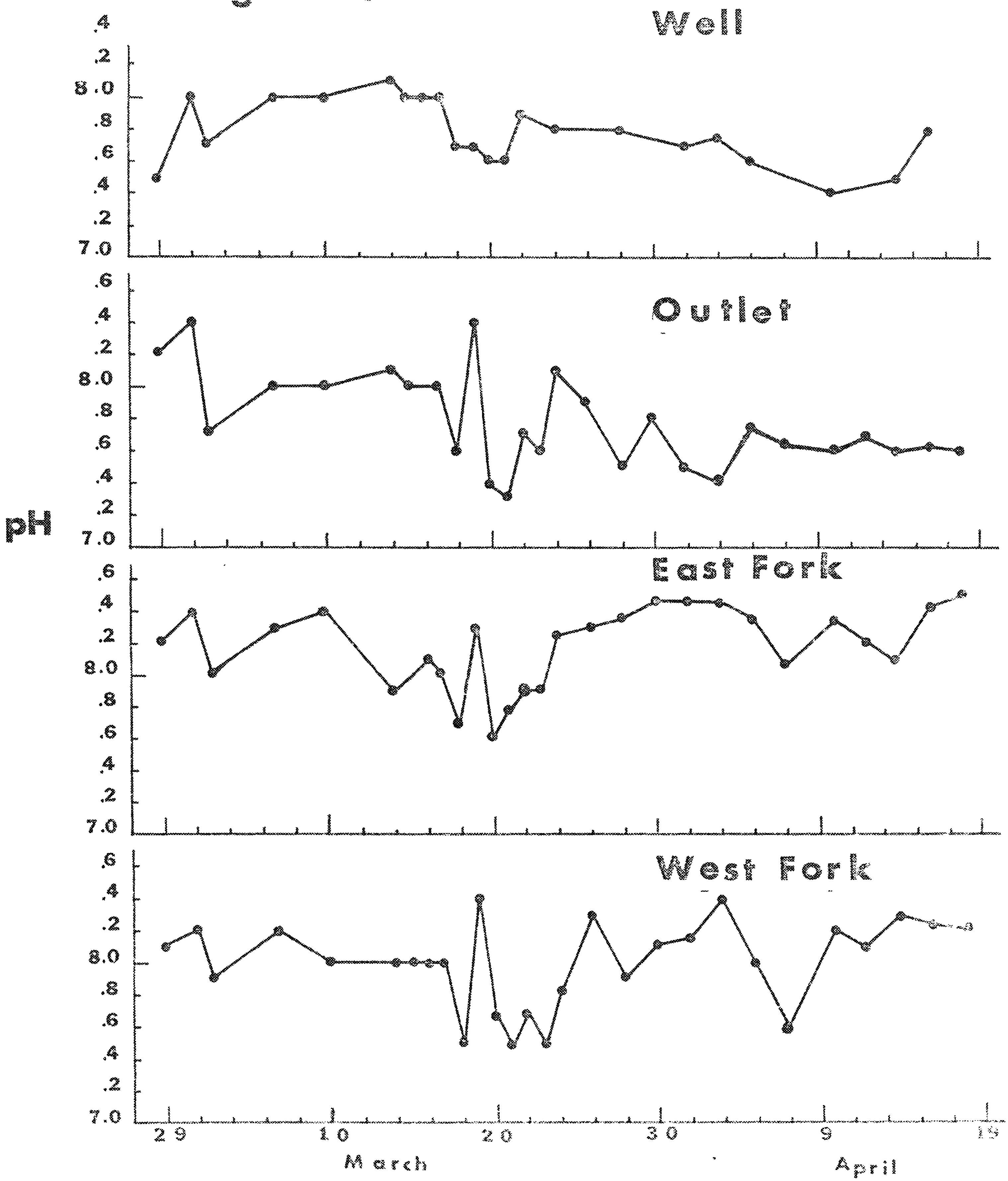
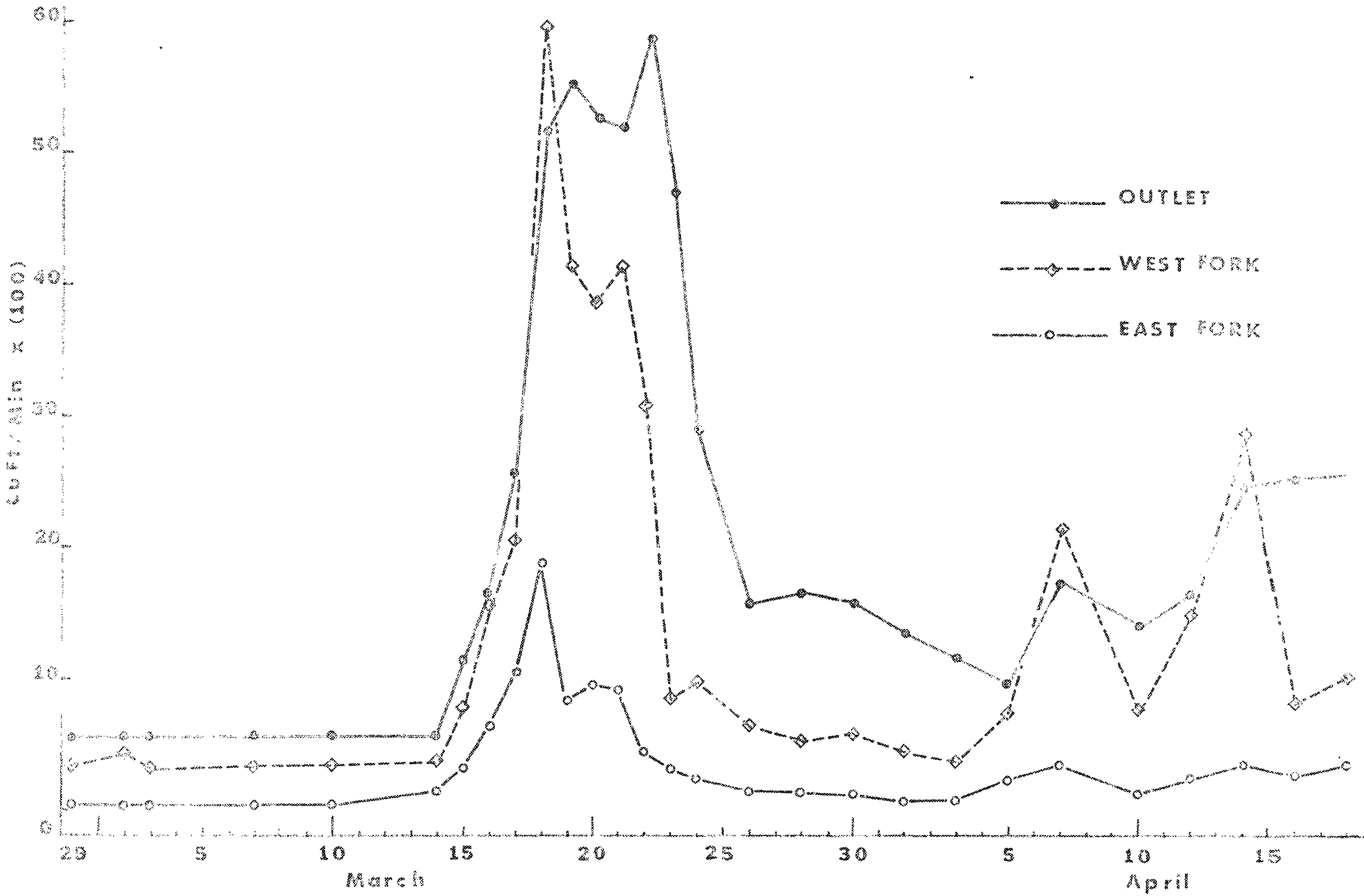

Well
Outlet
East Fork
West Fork
pH
7.0
.2
.4
.6
.8
8.0
29
10
20
30
9
19
March
April

Figure 7. Volume in cubic feet per minute of water flow taken at the three sites indicated, during the period February 29 through April 18, 1972.

Figure 7



OUTLET
WEST FORK
EAST FORK
Cu Ft/Min x (100)
60
50
40
30
20
10
0
25
5
10
15
20
25
30
5
10
15
March
April