

Water Quality Management Study
for
The Chickasaw National Recreation Area



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WATER QUALITY MANAGEMENT STUDY FOR
THE CHICKASAW NATIONAL RECREATION AREA

FOR

NATIONAL PARK SERVICE
U.S. DEPARTMENT OF INTERIOR

BY
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INTRODUCTION

This report is the culmination of a 12 month study designed to provide information necessary to evaluate the quality of water in the Rock Creek watershed. The report contains much physical and chemical data on the watershed and an extensive literature review on the Chickasaw National Recreation Area and other areas deemed pertinent to this study.

The University of Oklahoma, School of Civil Engineering and Environmental Science, has been involved in this study since June of 1976. Many individuals have participated in this project including members of the faculty and a team of graduate research assistants.

The objectives of this study were to: 1) determine the existing water quality of Rock Creek, its major tributaries Travertine, Guy Sandy and Buckhorn Creeks, and the Lake of the Arbuckles; 2) isolate sources of pollution, both point and dispersed, and characterize their pollutants; 3) determine the effects of land use on the water quality of Rock Creek, its tributaries, and the Lake of the Arbuckles; 4) compare the quality of water entering the park area with that leaving and ascertain the significance of any change in that quality; and, 5) determine the effects of recreation on the quality of water in Travertine Creek.

DESCRIPTION OF THE WATERSHED

The Rock Creek Watershed covers an area of 170.4 sq mi in the central part of Murray County, the southeastern part of Garvin County, and the southwestern part of Pontotoc County. The main tributaries are Guy Sandy and Buckhorn Creeks. The topography of the watershed ranges from gently rolling hills in the north to rough and broken terrain in the south.

Sulphur, the Murray County seat, had an estimated population of 5,600 for 1975. The present source of the city's drinking water is seven untreated water wells; future needs will be met by using the Lake of the Arbuckles. The city has an extended aeration treatment plant that discharges into the Washita River.

Also contained within the Rock Creek Watershed is the Chickasaw National Recreation Area. It is composed of the Platt Section adjacent to the City of Sulphur, the Lake of the Arbuckles (approximately 8 miles southwest of the Platt Section in the Arbuckle Mountains), and the land around these areas (Figure 1).

The Chickasaw National Recreation Area was designated in March 1976 by Congress to honor the Chickasaw Indian Nation. Prior to renaming, the Platt Section was Platt National Park, a recreation area located in the foothills of the Arbuckle Mountains. It covered approximately 910 acres of woodlands and gently rolling grass covered hills. In addition to containing a wide range of native vegetation, birds and animals (the western part is a bison range) the park provides opportunities for picnicking, camping, hiking and swimming or wading.

The Platt Section contains two major waterways, Rock Creek (a tributary of the Washita River) and Travertine Creek (which is fed by two large freshwater springs, Buffalo and Antelope Springs). This section's unique attraction is the cold-water mineral springs. Most of these are sulfur springs but three are bromide springs.

The Lake of the Arbuckles on Rock Creek is in the Arbuckle Mountains about 8 miles southwest of the Platt Section. The Arbuckle Mountains in southcentral Oklahoma are low, rugged limestone mountains rising to an

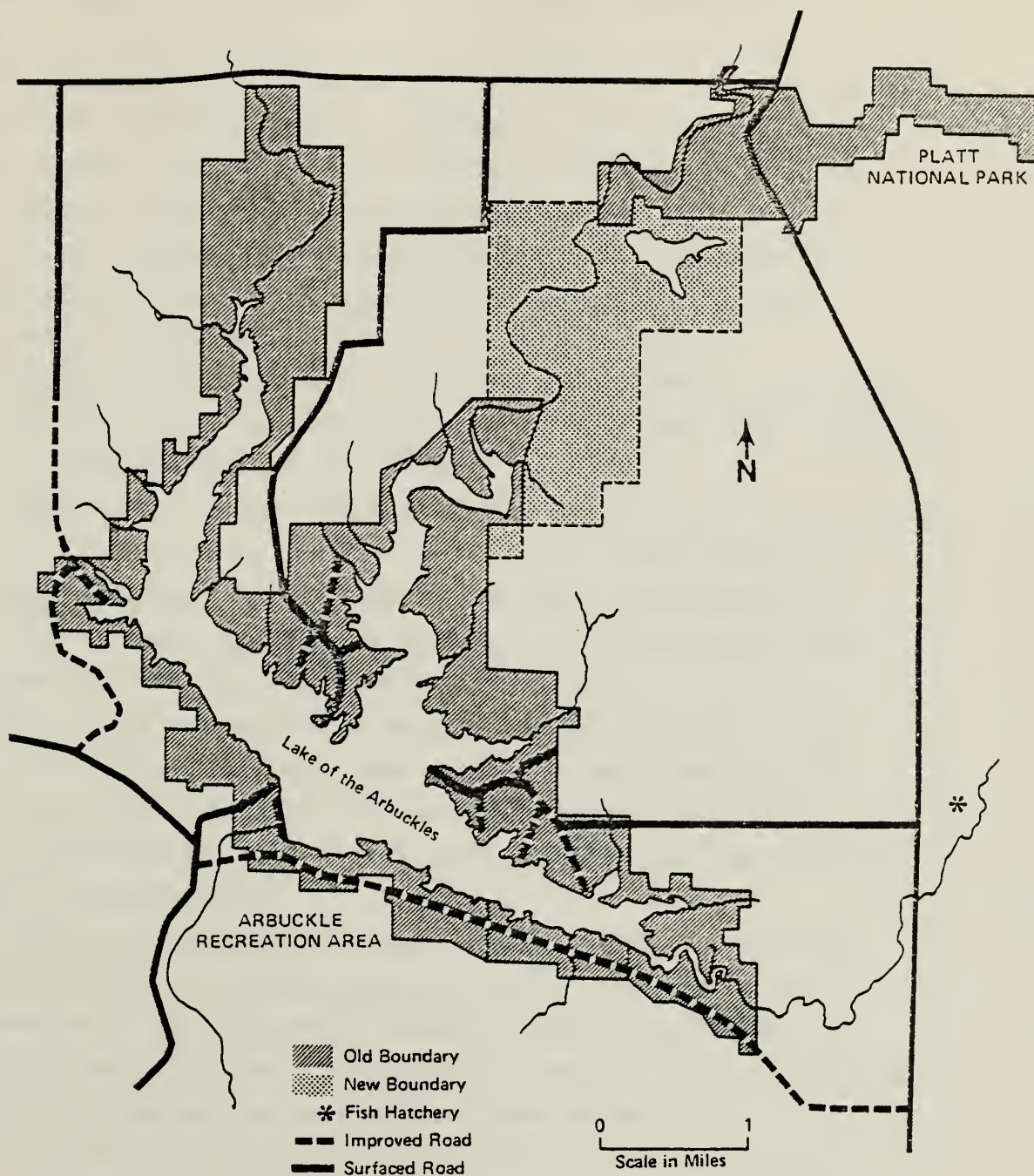


Figure 1. PLATT SECTION AND LAKE OF THE ARBUCKLES IN CHICKASAW NATIONAL RECREATION AREA

elevation of about 1,450 feet above mean sea level. The prairie lands to the north and east of the mountain range are called the Sandstone Hills. On the north and west the prairie lands are referred to as the Red Bed Plains. South and east of the reservoir is the Red River Valley.

The Arbuckle project consisting of the dam, reservoir and related pipelines was completed in 1966. Initially, it was a Bureau of Reclamation project but its operation and maintenance was transferred to the Arbuckle Master Conservancy District in 1968. The National Park Service, however, is primarily responsible for administering the recreational uses of the 5,600 acre project area. Some physical data on the dam and reservoir is listed in Figure 2.

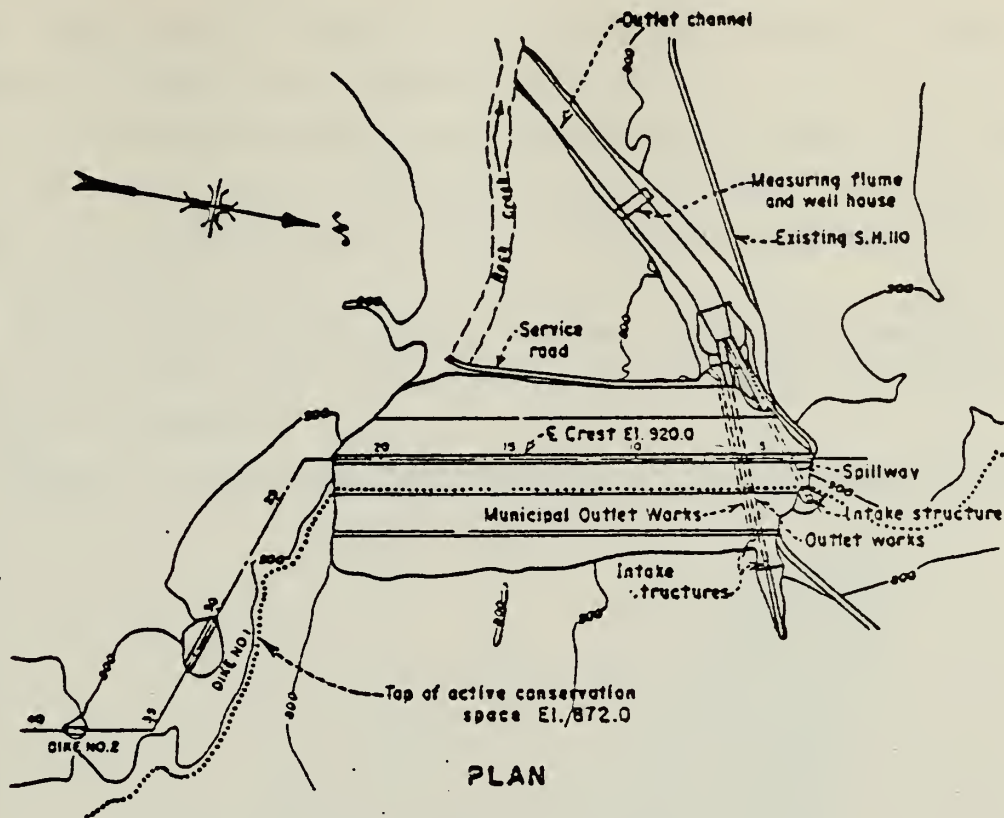
According to Soil Survey Map, USDA Bureau of Chemistry and Soils, the major soils in the watershed are: Denton clay loam; Gilson gravelly loam; and, Gilson soil material (rough broken land).

1) Denton clay loam is the most important arable soil in the county. It is a fairly dark heavy prairie soil developed from limestone and interbedded calcareous shales. Denton clay loam, deep phase, has a gently rolling relief and is well drained. It is moderately fertile and is particularly suited for oats production.

This soil is susceptible to erosion because the fine granules of the dried surface soil are moved easily by running water. The principal areas of this soil occur mostly in the Guy Sandy sub-basin, and the western half of Rock Creek sub-basin and the northern portion of Buckhorn basin.

2) Denton stony loam is somewhat similar to Denton clay loam, but is more shallow and stony than that soil. It cannot be cultivated because of the abundance of limestone gravel and the broken relief, but most of the soil is utilized as pasture. This soil occurs principally in the eastern part of Rock Creek sub-basin.

3) Gilson gravelly loam is light-colored forested soil which is developed from limestone conglomerate. The material is very loose, and erosion is severe on the unprotected cultivated soil. It is associated in most places with Gilson soil material (rough broken



PHYSICAL DATA

DAM

Type		Zoned earthfill
Hydraulic height . . . (above streambed)	 (feet)	140
Crest length . . . (exclusive of dikes)	 (feet)	1,390
Crest width	 (feet)	30
Base width	 (feet)	770
Crest length of dikes	 (feet)	320
Volume	 (cu. yds.)	2,850,000
Spillway capacity	 (c. f. s.)	3,410
Outlet capacity (river)	 (c. f. s.)	2,340

RESERVOIR

Capacity at spillway crest, elevation 885.3	... (Acre-feet)	108,800
Area at spillway crest, elevation 885.3	... (Acres)	3,127
Area at top of active conservation surface, elevation 872.0		2,349
Municipal and industrial water yield		
Acre-feet annually		24,000
Million gallons daily		21.42
Wynnewood pumping plant capacity	... (c. f. s.)	3.6
Wynnewood pipeline (includes Davis Branch)		
Length	... (miles)	19.8
Diameter		24 inches to 12 inches

Municipal & industrial water allotment:-

Water User	Million Gallons Daily	Acre-feet Annually
Sulphur	1.21	1,359
Wynnewood	0.70	780
Davis	1.32	1,488
State of Oklahoma	18.19	20,378
Total	21.42	24,000

(USDI pamphlet).

Figure 2. PHYSICAL DATA FOR LAKE OF THE ARBUCKLES

land). The relief is rolling or gently rolling principally in the breaks of Guy Sandy Creek southwest of Sulphur.

4) Gilson soil material (rough broken land) is similar to Gilson gravelly loam but occurs on steep slopes or low hills. It is unsuited for crop growing and most of the land is covered with post oak, blackjack oak, elm...

Fairly large areas of rough broken land (Gilson soil material) occupy the breaks of Rock Creek and Guy Sandy Creek in the vicinity and north of Dougherty.

Figure 3 is the generalized soils map of the Rock Creek Watershed.

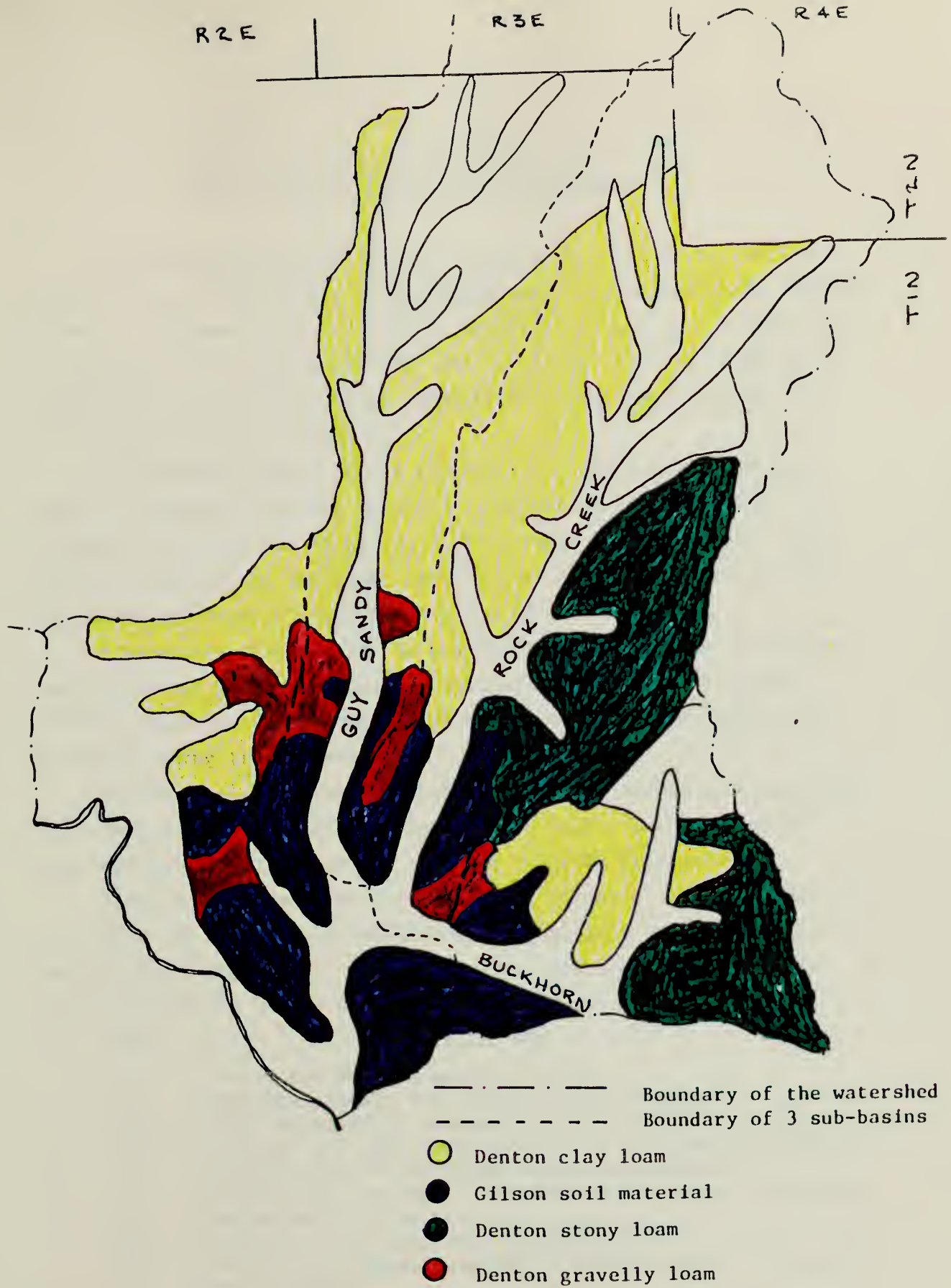


Figure 3. GENERALIZED SOILS MAP OF THE ROCK CREEK WATERSHED.

BENEFICIAL USES AND WATER QUALITY OF ROCK CREEK AND LAKE OF THE ARBUCKLES

The Chickasaw National Recreation Area is a unique recreational facility within easy access to many Oklahomans and out-of-state visitors as well. The annual visitor days of use for the Lake of the Arbuckles is 358,000 (1975 figure by USDI). The beneficial uses provided by the lake and streams make it an attractive recreational area as well as a valuable natural resource.

The primary purpose of the lake is for flood control and water supply. Storage within the Lake of the Arbuckles has been allocated to supply water for the towns of Sulphur, Davis and Wynnewood. Recreational uses of the reservoir include boating, fishing, water skiing, swimming, scuba diving, camping and picnicking.

A major use of the water in the Platt Section of the recreation area is devoted to recreational activities. There are many public swimming areas and during the summer thousands of people camp, swim, and picnic along the streams.

The Chickasaw National Recreation Area also serves as a sanctuary for a variety of birds, animals and aquatic life. Thus, the waters serve another important use for fish and wildlife propagation.

Water quality is used to describe the nature of water in terms of its components and it is determined by the stream's beneficial uses. The Oklahoma Water Quality Standards (1973) set forth the beneficial uses of the waters of the state as listed below:

CODE	BENEFICIAL USE
A	Public and private water supplies
B	Emergency public and private water supplies
C ₁	Fish and wildlife propagation
C ₂	Fish and wildlife propagation to the extent allowed by specifically stated water quality parameters
D	Agriculture (includes livestock watering and irrigation)
E	Hydroelectric power
F ₁	Industrial and municipal cooling water
F ₂	Receiving, transporting and/or assimilation of adequately treated waste

G ₁	Recreation, primary body contact (includes recreational uses where the human body may come in direct contact with the water to the point of complete body submergence)
G ₂	Recreation, secondary body contact (includes recreational uses, such as fishing, wading and boating, where ingestion of water is not probable)
H	Navigation
I	Aesthetics
J	Small-mouth bass fishery excluding lake waters
K	Trout fishery (put-and-take)

Rock Creek and the Lake of the Arbuckles have been designated as A, C₁, D, F₁, F₂, G₁ and I. These designations characterize the various uses of the water in Rock Creek and the Lake of the Arbuckles.

The quality of water in a stream or reservoir determines its uses and effects on the environment. According to the beneficial use categories for Rock Creek and the Lake of the Arbuckles as listed in the Oklahoma Water Quality Standards, the following water quality criteria are established:

Bacteria. Bacteria of the fecal coliform group shall not exceed a monthly geometric mean of 200/100 ml as determined by the membrane filter procedure and based on a minimum of not less than five samples for any 30-day period, nor shall more than 10% of the total samples during any 30-day period exceed 400/100 ml.

Dissolved oxygen (DO). The dissolved oxygen concentration shall not be less than 5 mg/l for all warm waters.

pH. The pH shall be between 6.5 and 8.5. pH values below 6.5 and above 8.5 must not be due to waste discharge.

Turbidity. Turbidity of other than natural origin shall be restricted to the following in-stream numerical values:

warm water streams	50 Jackson units
warm water lakes	25 Jackson units

Temperature. During any month of the year, heat shall not be added to any stream in excess of the amount that will raise the temperature of the water more than 5° F. In lakes, the temperature of the epilimnion shall not be raised more than 3° F above which existed before the addition of heat of artificial origin.

Nutrients. The total phosphorus concentration and nitrogen/phosphorus ratio shall be limited to prevent eutrophication problems.

Toxic substances. Toxic substances shall not be present in such quantities as to cause the waters to be toxic to human, animal, plant and aquatic life, not detrimental to any beneficial use including continued ingestion by livestock or continued use for irrigation. For aquatic life, using bioassay techniques, the toxic limit shall not exceed one-tenth of the 96-hour median tolerance limit for the most sensitive species common to the stream.

Water quality criteria data has been obtained for the Lake of the Arbuckles through various studies made on the effects of the water quality on the biotic community of the lake, specifically the game fish. The Oklahoma Fishery Research Laboratory performed a pre-impoundment study of Arbuckle Reservoir. (1) Their conclusion, based on data projected from lakes in the area, was that the complete lake should be highly productive. Game species-- large-mouth bass, spotted bass, white bass, channel catfish and the crappies-- should be favored by the conditions expected to exist in the lake. The panfish--bluegill, redear, warm-mouth, green sunfish and long-ear--would be abundant and should attain a size suitable for the angler. Coarse fish-- yellow bullhead, black bullhead catfish, flathead catfish and drum-- were expected to be sufficiently abundant to satisfy the demands of those anglers desiring those species. The rough fish and forage species would exist in the lake though it is thought that the carp and carpsuckers would not be overly numerous. The buffalo and suckers would not be too abundant since preferred bottom types which would serve as feeding grounds would be comparatively restricted. Gizzard shad should be the primary forage fish during the early years of life on the project. The threadfin shad was expected to be present in the lake though the extent of development and its existence as a significant forage species was not known.

The lake temperature was expected to result in an annual turnover in the late fall or early winter. A thermocline was expected to develop in the sheltered arms and near the dam during the months of July, August, September and part of October, or until turnover rearranges and mixes the strata of different densities. The depth of the thermocline during this period was predicted to be from 14 ft to 18 ft below the surface. The area to the north of the deep water and in the upper extremities was not expected to develop a permanent or pronounced thermocline since the prevailing winds and subsequent wave action would have a tendency to break up and mix the different strata of water.

Summerfelt and Gebhart (2) presented observations on depth distribution, growth and a measure of condition on five species of fish

collected from Lake of the Arbuckles, Oklahoma, 1973 through 1975. This investigation was undertaken to describe certain responses of the fish community which might be expected as an ecological consequence from engineering efforts to artificially prevent summer stratification. Destratification was attempted as a means for in situ improvement of reservoir water quality since there was a history of taste and odor problems when hypolimnetic water from this reservoir was used for a municipal water supply.

In the study by Summerfelt and Gebhart they used the 2 mg/l DO isopleth (the lake contour at which 2 mg/l DO was present) as the lower level of suitable fish habitat since fish generally avoid water containing less than 2 mg/l DO. Generally, the water became anoxic within two meters below the 2 mg/l DO isopleth. In each of the three years of study, 1973-75, Arbuckle Lake was thermally stratified by mid-May and DO profiles were clinograde (Figure 4). The area and volume of suitable fish habitat in Arbuckle Lake was calculated weekly for each of the three years of study. In 1973, the volume of the lake with more than 2 mg/l DO declined from 100% on 18 May to 89% on 31 May; in 1974, oxygen depletion had begun as early as 19 May and depletion reduced available habitat to 18% of the total volume by 3 June. In 1975, 98% of the volume contained more than 2 mg/l DO on 12 May, but by 2 June only 70% of the lake's volume contained more than 2 mg/l DO. The average volume of Lake Arbuckle with more than 2 mg/l DO present in the 163-day interval between May 11 through October 20 for 1973-75 was 72.9% and 72.7% respectively of a total of 89,304,166 cubic meters of total lake volume. Available fish habitat was substantially reduced in Arbuckle Lake during summer stratification.

Using the 2 mg/l DO isopleth as a boundary defining the limit of suitable fish habitat there was as much as 48, 39, and 59 percent unsuitable in 1973, 1974 and 1975 respectively.

Depth distribution of gizzard shad, white crappie, freshwater drum, black bullhead and channel catfish were influenced by physiochemical conditions of lake stratification. The mean depth of capture of all species was substantially greater in September and October collections when the depth of the 2 mg/l DO isopleth deepened.

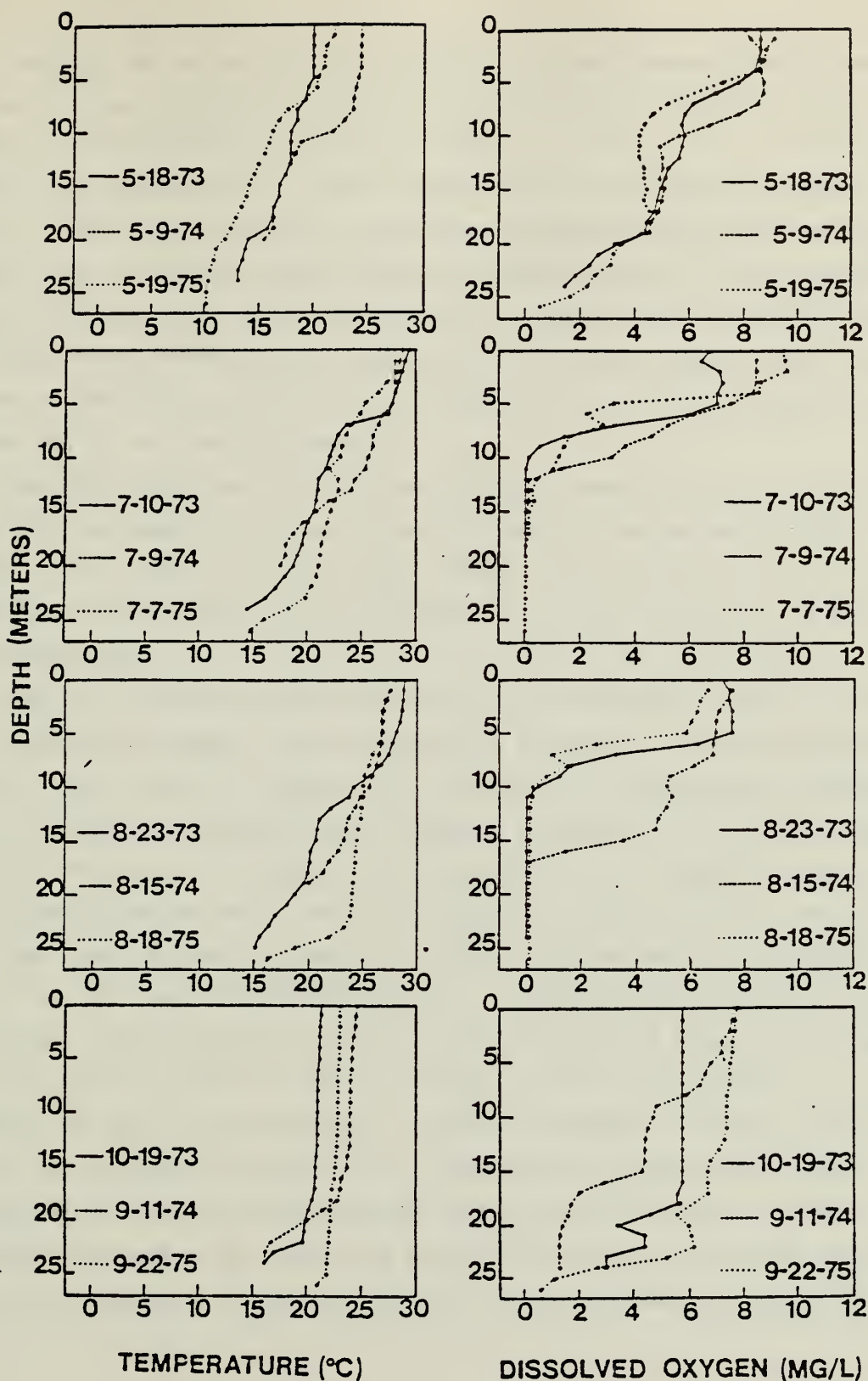


Figure 4. TEMPERATURE AND DISSOLVED OXYGEN PROFILES FOR ARBUCKLE LAKE AT THE DAM SITE ON SELECTED DATES, 1973-75. (2)

In many age groups for most species, instantaneous growth rates indicated that the major portion of the population growth occurred during the destratified overwinter period. In fact, the population growth rate is negative in many cases during the stratified summer period. This could be due to selective mortality operating on the larger fish of an age class during the summer months or the negative growth rate could be an actual individual weight loss resulting from the higher maintenance energy required at the high summer water temperatures, especially when fish are forced into the hot epilimnion by the anoxic waters of the hypolimnion.

Feeding efficiency of fish may decrease when they are forced to live in water which produces thermal stress and excess metabolic demand. Also, the fish may exhaust their food supply as the summer progresses and stratification shrinks the available habitat of the prey organisms.

The mean condition factors by age groups showed a trend of decreasing through the summer when the lake was stratified. The condition factors were generally larger in the fall and spring period reflecting in part gonadal development and improved condition in the destratified part of the year. It appears from the analysis of Summerfelt and Gebhart that stratification has a negative impact on fish growth and well-being.

The total number of species of fish captured each year, 1973-75, was 19 in 1973 and 18 in 1974 and 1975. In 384 gill net days of effort each year, the numerical catch rate (C/f)* declined from 13.13 fish per gill net day in 1973 to 8.72 in 1974 and 7.61 in 1975 (Table 1). A substantial part of the decline in the C/f between 1973 and 1975 is due to the decline in catch (i.e., abundance) of gizzard shad; the catch rate of shad in 1975 was only 20% of the C/f value in 1973. Removing the number of shad from the total number captured in 1973 and 1975, the overall C/f value would be 6.57 in 1973 and 6.29 in 1975.

* Catch per unit effort: the catch of fish, in numbers, taken in one gill net fished for 24 hours.

Table 1. NUMERICAL ABUNDANCE, PERCENT OF TOTAL CATCH,
AND CATCH PER GILL NET DAY OF 20 SPECIES OF
FISHES COLLECTED BY GILL NETTING IN LAKE
ARBUCKLE IN 1973-75. (2)

Species	1973			1974			1975		
	No.	%	C/f ^a	No.	%	C/f ^a	No.	%	C/f ^a
Gizzard shad	2522	49.98	6.57	1005	29.99	2.62	510	17.43	1.33
White crappie	833	16.51	2.17	977	29.16	2.54	843	28.81	2.20
Black bullhead	579	11.47	1.51	506	15.10	1.32	470	16.06	1.22
Freshwater drum	409	8.11	1.07	299	8.92	0.78	431	14.73	1.12
Channel catfish	311	6.16	0.81	176	5.25	0.46	113	3.86	0.29
White bass	159	3.15	0.41	266	7.94	0.69	277	9.47	0.72
Carp	89	1.76	0.23	32	0.95	0.08	32	1.09	0.08
Walleye	49	0.97	0.12	36	1.07	0.09	19	0.65	0.05
Largemouth bass	28	0.55	0.07	20	0.60	0.05	14	0.48	0.04
River carpsucker	23	0.46	0.06	7	0.21	0.02	28	0.96	0.07
Black crappie	22	0.44	0.06	11	0.33	0.03	9	0.31	0.02
Longnose gar	8	0.16	0.02	4	0.12	0.01	1	0.03	0.00
Flathead catfish	4	0.08	0.01	8	0.24	0.02	12	0.41	0.03
Yellow bullhead	5 ^b	0.10	0.01	0 ^b	0.00	0.00	0	0.00	0.00
Warmouth	0 ^b	-	-	0 ^b	-	-	26	0.89	0.07
Green sunfish	0 ^b	-	-	0 ^b	-	-	9	0.31	0.02
Longear	0 ^b	-	-	0 ^b	-	-	15	0.51	0.04
Golden redhorse	0 ^b	0.00	0.00	0 ^b	0.00	0.00	3	0.10	0.01
Bluegill	0 ^b	-	-	0 ^b	-	-	114	3.90	0.30
Blue catfish	5	0.10	0.01	4	0.12	0.01	0	0.00	0.00
Total	5046	100.00	13.13	3351	100.00	8.72	2926	100.00	7.61

^aCatch per unit of effort: the catch of fish, in numbers, taken in one gill net fished for 24 hours.

^bThese species were collected but not recorded due to time limitations.

The numerical abundance of individual species of fish in the gill net catch dictated which species would be described in the growth study. The five most numerous species captured in 1973, together they made up 92.23% of the total catch, were gizzard shad (Dorosoma cepedianum), white crappie (Pomoxis annularis), black bullhead (Ictalurus melas), freshwater drum (Aplodinotus grunniens) and channel catfish (Ictalurus punctatus). (Table 1)

These same five species predominated in the catch in 1974 and 1975 with the exception that compared with 1973, the catch of channel catfish dropped from fifth to sixth ranking in abundance in 1974 and 1975 behind white bass (Morone chrysops). For the sake of continuity, the five most abundant species of fishes in the 1973 catch were studied in all three years.

An areal comparison of overall-metabolic rates of Mendota Lake and Arbuckle Reservoir is meaningful since both have about the same maximum depth. Mendota Lake, an old and productive system, has an overall metabolic rate of about one-third that of the Arbuckle Reservoir. Metabolism rates greatly exceed the rates given by Hutchinson for eutrophic lakes. (Table 2)

Comparing the predictions by the Oklahoma Fishery Research Laboratory from their pre-impoundment study with the studies performed by Summerfelt and Gebhart it is obvious that the Arbuckle Reservoir is not nearly as productive as envisioned. For example, of the five most abundant species captured in 1973, the five species make up 92.23% of the total catch, three were coarse forage species. Only the crappie and the channel catfish were caught in significant numbers. In 1974 and 1975 the channel catfish dropped to sixth ranking behind white bass. The forage and coarse fish accounted for 69.56, 54.01 and 48.22 percent of the total catch for 1973, 1974 and 1975 respectively. This lower productivity and unbalanced catch is undoubtedly due to stresses placed on the ecosystem as a result of the available nutrients.

Duffer and Harlin (3) determined the water quality for a period of two years following dam closure. The location of the sampling stations are given on Figure 5. Their data on tributary streams

Table 2. AREAL RELATIVE OXYGEN OF THE HYPOLIMNION
DEFICITS IN RELATION TO PRODUCTIVITY. (3)

Lake or Reservoir	Maximum <u>Depth</u> m.	Hypolimnetic <u>Oxygen Deficit</u> mg cm ⁻² day ⁻¹	Reference
Arbuckle Reservoir			
Summer, 1968	26	0.231	Present Study
Summer, 1969	26	0.239	Present Study
Green Lake	72.2	0.14	Hutchinson
Mendota Lake	25.6	0.109	"
Geneva Lake	43.3	0.090	"
Okauchee Lake	28.6	0.097	"
Oligotrophic Lakes	20-75	0.004-0.033	"
Eutrophic Lakes	20-75	0.05-0.14	"

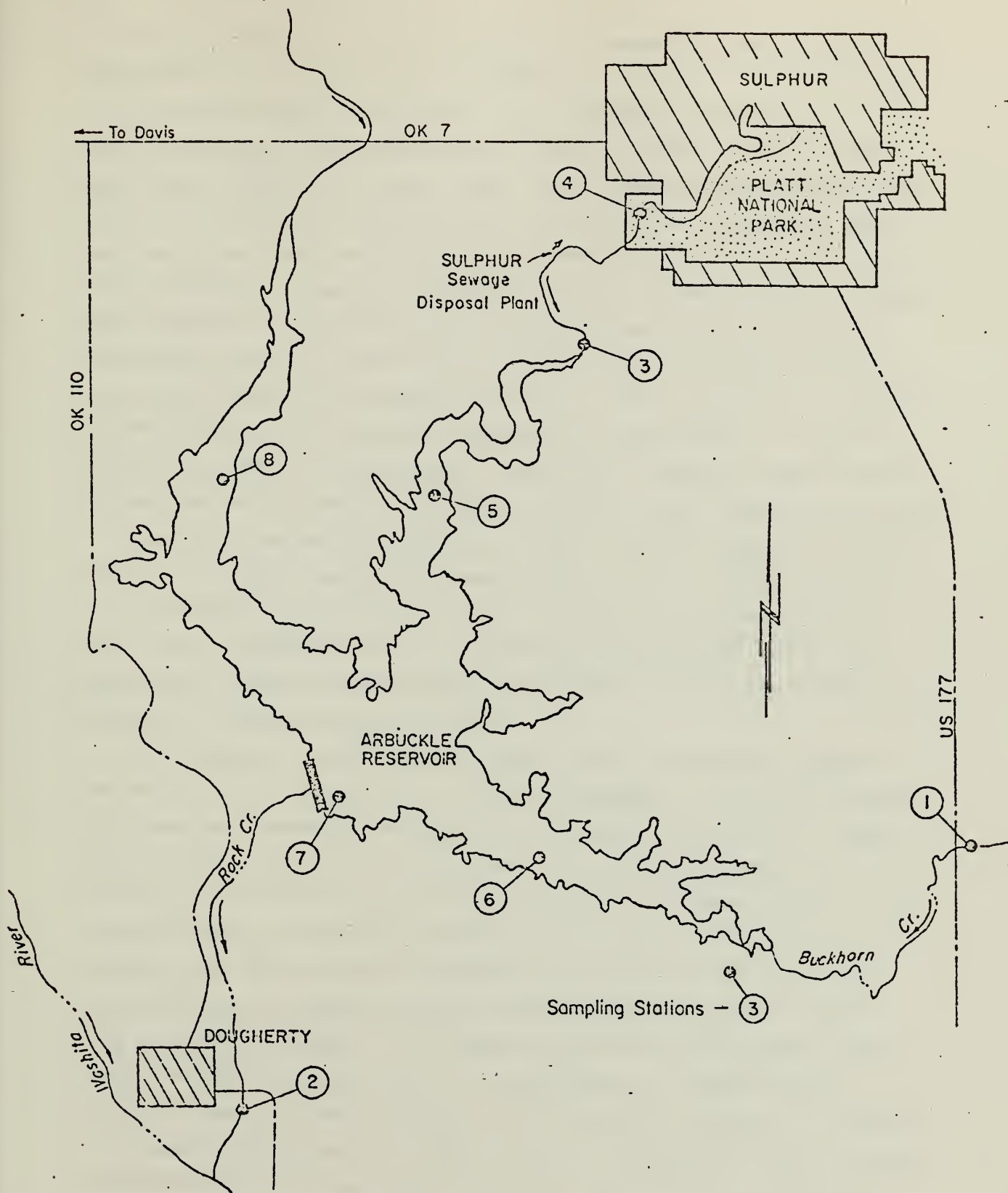


Figure 5. MAP OF LOCATIONS OF SAMPLING STATIONS. (3)

entering the lake is reported in Table 3. Temperature and dissolved oxygen data for selected dates in 1968-69 at station 7 in the vicinity of the dam are given in Figures 6 to 9. During the month of July the dissolved oxygen in the hypolimnion, below 25-20 feet, was zero for both years. Duffer and Harlin stated that, "Based on the respiration rate of the hypolimnion during thermal stratification, Arbuckle Reservoir had a very high rate of oxidative metabolism". They stated that the hypolimnetic oxidative decomposition of the organic debris covering the inundated area produced a high oxygen demand which resulted in a downstream increase in the annual amount of BOD₅ following filling to the active conservation elevation of 872 ft. above sea level. Therefore, one would expect zero dissolved oxygen in the hypolimnion. They also stated that within the impoundment significant changes in water quality occurred due to influences of seasonal variation, year, depth and location.

Toetz's discussion is limited to data collected during the summer months, when water quality problems are most acute. During his study the epilimnion existed down to 7-10 m, the exact depth shifted from day to day, depending upon how deep wind-driven currents eroded the hypolimnion. Another thermocline existed below 20 m, which effectively remained in place from May to October.

His analysis focused on the region 8-20 m because this region is frequently anoxic and contains reducing compounds. He found frequently that reducing compounds were highest in concentration at 20 m. Since outlet depth is at 6.4 m (21 ft), which is in the epilimnion, Toetz (4) stated it is difficult to see why water quality problems develop. The concentrations of reducing compounds are far lower at 8 m than 20 m. However, both BOD and DOC are frequently very high at the bottom of the epilimnion and organic matter in this region may exert a higher than expected Cl₂ demand. The reason for the relatively high concentration of DOC is probably due to decomposition of organic matter "raining" down from the epilimnion. Water quality between 8-20 meters is compared between years in Table 4 and 5. Comparison is made between samples taken in July and August for 1968, 1973 and 1975. BOD data are compared for data taken during late June in 1968 and 1975.

Table 3. STUDY PARAMETERS AT STREAM STATIONS IN
ARBUCKLE SYSTEM AFTER CLOSURE OF THE DAM. (3)

Water Constituent or Characteristic	Station 2	Station 3	Station 4	Station 1
Total Coliform/100 ml ²	492.0	19360.	1274	3508.
Fecal Coliform/100 ml ²	67.30	3459.	249.5	1035.
Fecal Streptococci/100 ml ²	235.0	1315.	514.0	1069.
Total Plate Count/ml 35°C ²	1637.	19630.	2466.	2972.
Total Plate Count/ml 20°C	959.4	10380.	946.2	1005.
BOD, mg/l	2.230	5.544	1.912	1.840
COD, mg/l	20.481	28.366	19.358	11.492
pH	7.862	7.926	8.253	8.142
Alkalinity - HCO ₃ , mg/l	243.6	224.4	216.8	265.9
Alkalinity - CO ₃ , mg/l	24.7	25.3	30.8	20.7
Hardness as CaCO ₃ , mg/l	304.0	308.8	308.3	296.7
Conductivity - micromhos/cm @ 25°C	865.4	1491.4	1725.6	560.6
Magnesium, mg/l	23.8	27.1	29.5	34.3
Calcium, mg/l	68.4	79.2	72.7	62.6
Chlorides, mg/l	136.2	328.8	372.2	12.4
Sulphate, mg/l	74.1	50.8	52.5	16.0
Total Residue, mg/l	512.2	808.6	822.1	341.9
Filterable Residue, mg/l	461.7	817.9	868.0	335.0

Table 3. (continued)

Water Constituent or Characteristic	Station 2	Station 3	Station 4	Station 1
Ammonia, mg/l	0.334	0.937	0.128	0.160
Organic Nitrogen, mg/l	0.361	0.491	0.183	0.476
Nitrite, mg/l	0.011	0.148	0.006	0.004
Nitrate, mg/l	0.100	0.242	0.181	0.602
Total Phosphate, mg/l	0.565	1.648	0.181	0.077
Ortho Phosphate, mg/l	0.405	1.355	0.122	0.040

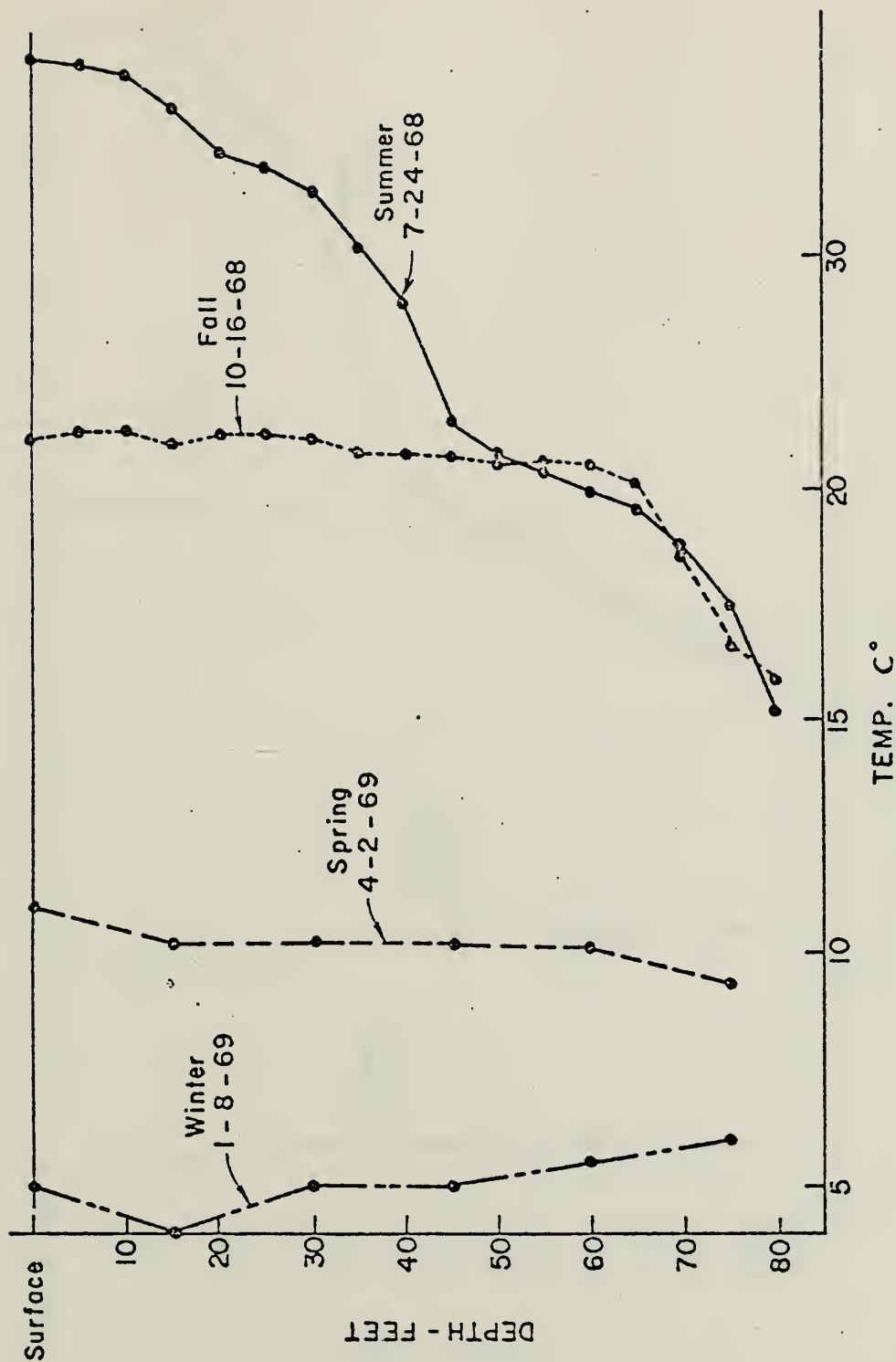


Figure 6. VERTICAL PROFILES OF WATER TEMPERATURE AT STATION 7
FOR SELECTED DATES DURING 1968-69. (3)

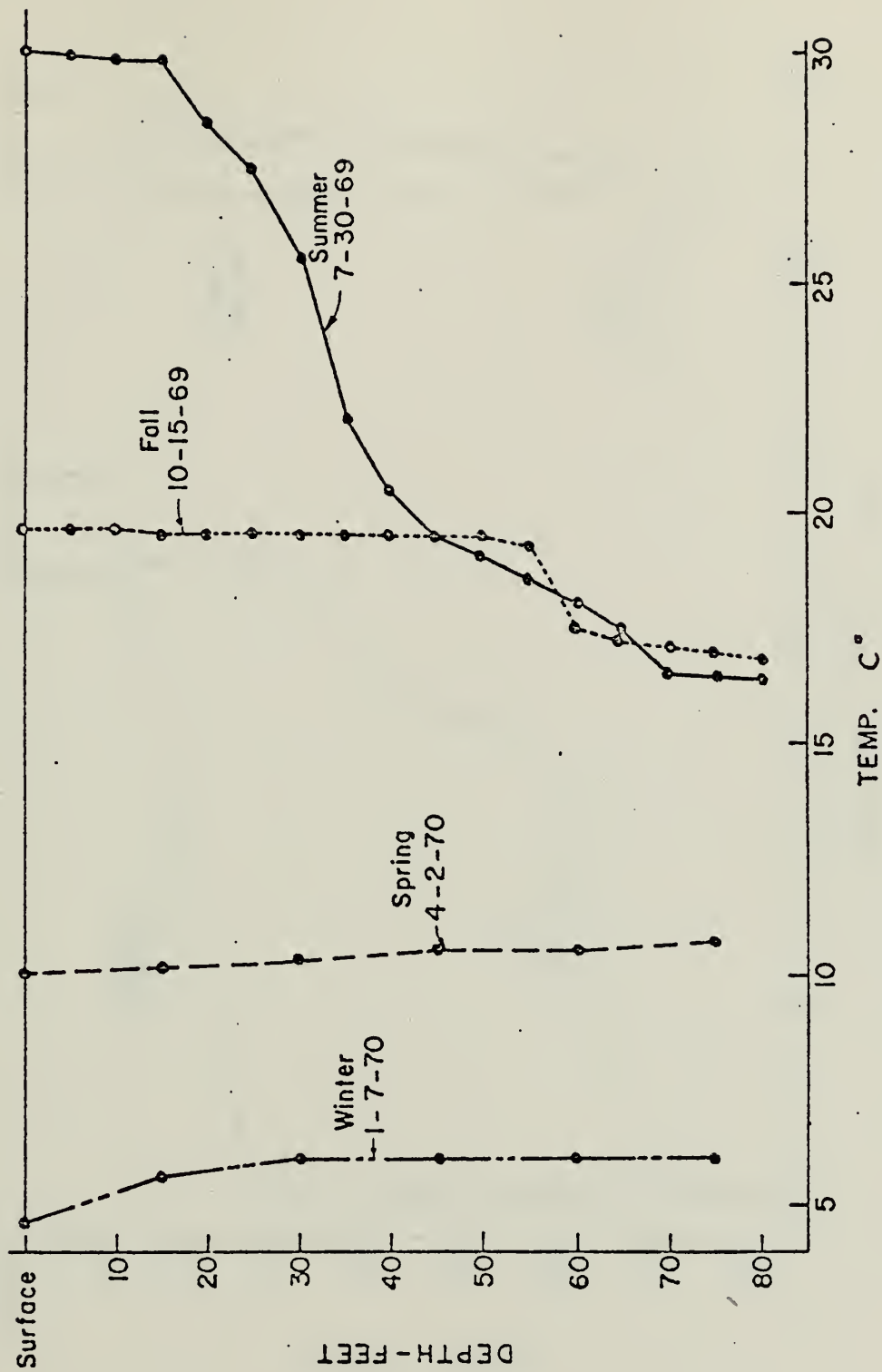


Figure 7. VERTICAL PROFILES OF WATER TEMPERATURE AT STATION 7
FOR SELECTED DATES DURING 1969-70. (3)

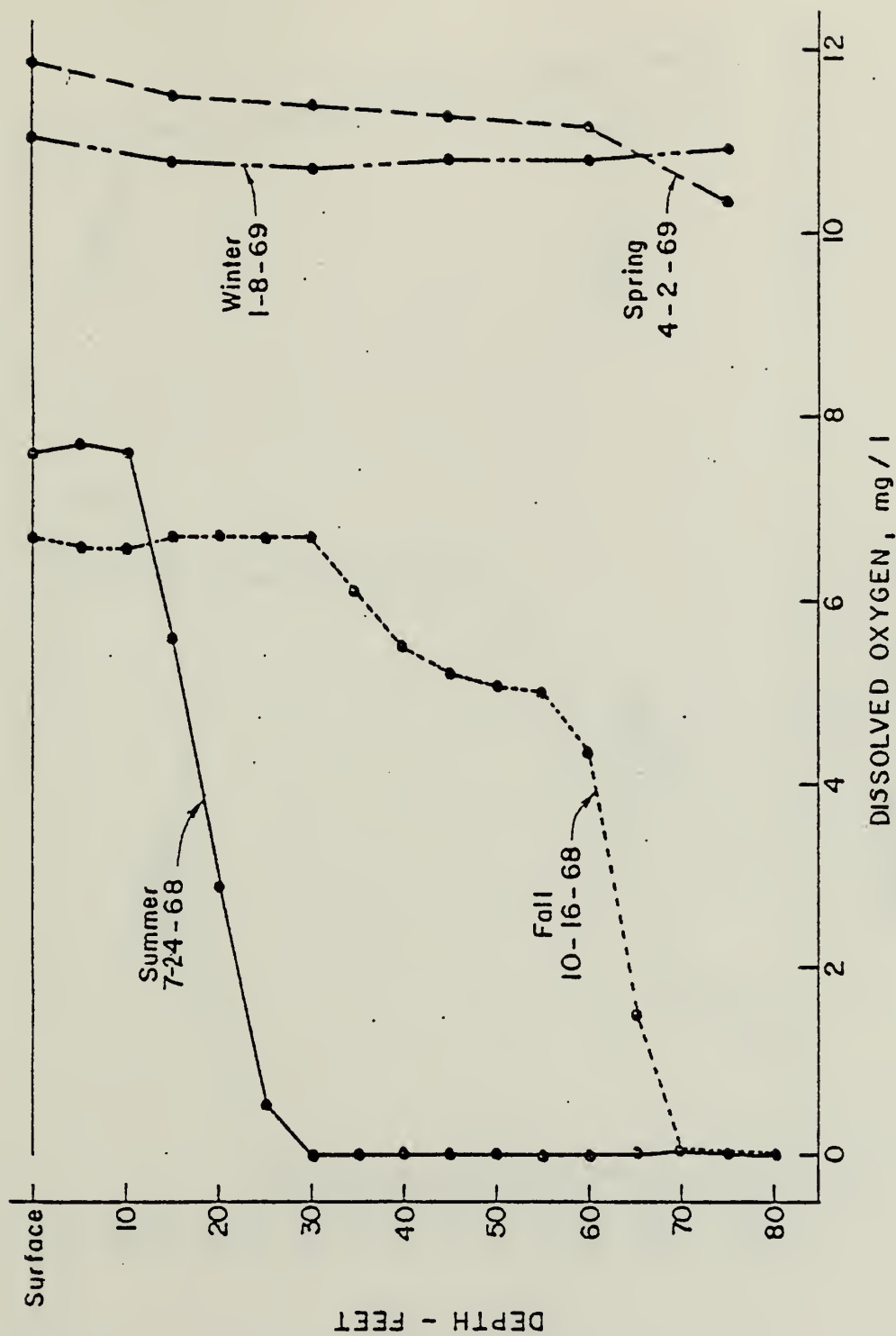


Figure 8. VERTICAL PROFILES OF DISSOLVED OXYGEN AT STATION 7
FOR SELECTED DATES DURING 1968-69. (3)

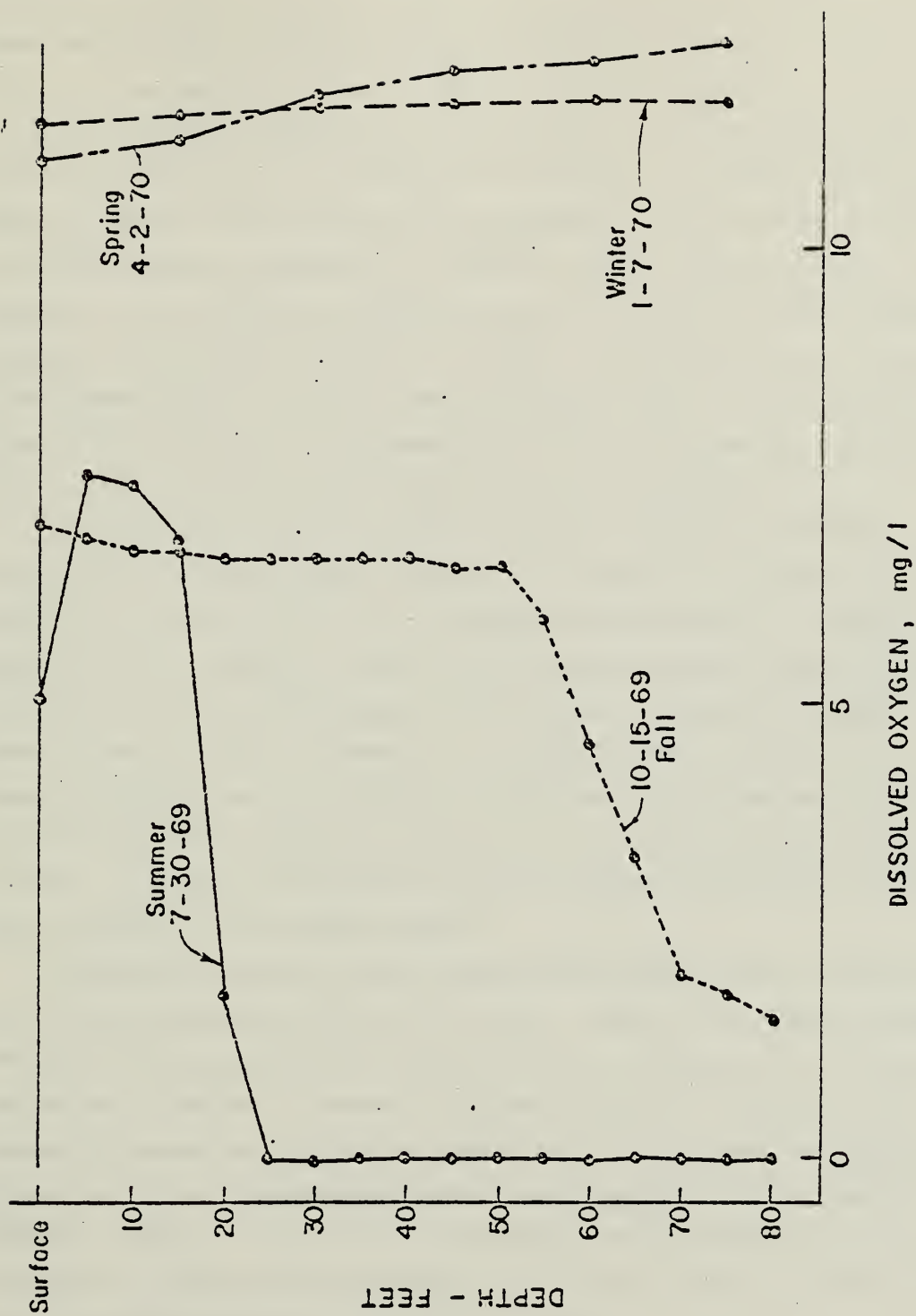


Figure 9. VERTICAL PROFILES OF DISSOLVED OXYGEN AT STATION 7 FOR SELECTED DATES DURING 1969-70. (3)

Toetz concluded that the water quality has not appreciably changed since 1968. Some parameters, such as pH, are remarkably constant from year to year. Plant nutrients such as PO_4^{+3} and NH_4^+ show considerable variation, but considering their high rates of turnover, the variability shown in Table 4 is not surprising. Alkalinity and $\text{S}^{=}$ apparently decreased over the years, but such changes could have been the result of differences in methods of making measurements. Table 5 showed that Secchi disc transparency and dissolved oxygen at 10 m have remained relatively constant between 1968 and 1975. Temperature at 10 m showed considerable year to year variation, depending perhaps on the heat budget for the year. Concentrations of conservative elements such as Na, Ca and K did not change. Toetz concluded there was no evidence to suggest that the water chemistry of Arbuckle Lake during the summer had changed between 1968 and 1975.

Jerry Wilhm (5) did a study on benthic macroinvertebrates and zooplankton in the Arbuckle Reservoir. Variation with depth of the density and diversity of benthic macroinvertebrates and zooplankton were observed. Samples of benthic macroinvertebrates were collected from July, 1974, through August, 1975, while zooplankton sampling began in April, 1975. Temperature and dissolved oxygen of the water collected near the bottom at different depths during the benthic macroinvertebrate sampling were relatively uniform with depth in winter. In spring and summer dissolved oxygen progressively became more limiting in the deeper waters.

Ninety-five taxa of benthic macroinvertebrates were collected in the Arbuckle Reservoir during the study. One or two common species and many rare species were taken from the 1 m depths and the deeper depths were limited to several abundant species. Tubificids were generally common at 1 m during summer, 1974. The amphipod Hyaella azteca, elmids beetle Dubiraphia sp. and Tanypus sp. were the most abundant species. The benthic assemblage was dominated by the phantom midge, Chaoborus punctipennis, at 10 and 15 m and by the tubificid worm, Aulodrilus pigueti, at the 24 m depth.

Table 4. CONCENTRATION OR VALUE AND 95% CONFIDENCE INTERVALS FOR
SELECTED WATER QUALITY PARAMETERS DURING JULY AND AUGUST
BETWEEN 8 AND 20 M IN ARBUCKLE LAKE AT STATION 7. (4)

<u>Parameter</u>	<u>Year</u>	<u>Units</u>	<u>Mean</u>	<u>95% Confidence Limits</u>
NH ₄ -N	1968	micrograms/l	283	72-546
"	1973	"	61	22-124
"	1975	"	171	112-228
Alkalinity	1968	milligrams/l	170	161-179
"	1973	"	150	142-156
"	1975	"	128	125-132
pH	1968	-----	7.28	7.04-7.52
"	1973	-----	7.55	7.41-7.69
"	1975	-----	7.30	7.26-7.34
Sulfide-S	1968	milligrams/l	0.27	0.06-0.46
"	1973	"	0.02	0.01-0.02
"	1975	"	0.06	0.01-0.11
Manganese	1968	milligrams/l	0.53	0.05-1.01
"	1973	"	0.40	0.21-0.59
"	1975	"		
Phosphate-P	1968	micrograms/l	117	15-219
"	1973	"	13	3-23
"	1975	"	9	3-15
BOD- ₅	1968	milligrams/l	2.10	0.98-3.22
"	1975	"	2.82	2.42-3.21

Table 5.. CONCENTRATION OF IMPORTANT WATER QUALITY PARAMETERS AT 10 M
AND DEPTH OF THE SECCHI DISC IN ARBUCKLE LAKE DURING JUNE,
JULY AND AUGUST. (4)

<u>Parameter</u>	<u>Year</u>	<u>Units</u>	<u>Mean</u>	<u>95% Confidence Interval</u>
Dissolved oxygen	1973	mg/l	0.66	0-2.45
	1974	"	0.56	0-2.32
	1975	"	0.53	0-2.36
Temperature	1973*	°C	20.5	16.5-24.5
	1974	"	26.1	25.5-27.0
	1975	"	24.8	23.3-26.3
Secchi disc	1973	m	1.80	1.17-2.43
	1974	m	1.50	1.28-2.72
	1975	m	1.60	0.97-2.23

*1973 data are systematically too low by 2° C.

The number of species in the preliminary study ranged from two to nineteen. The number of species tended to decrease with depth, with an abrupt decrease occurring between 1 and 5 m and generally a second sharp decrease between 5 and 10 m. Diversity of benthic macro-invertebrates provided a reasonable indicator of the limiting environment of the deeper areas.

Twenty-four taxa of zooplankton were taken from Arbuckle Reservoir. Since the lake was stratified during the study, the trends resulted from seasonal changes. The rotifer Conochilus sp. was abundant at the depths in the spring but was rare in later subsequent samples. Although Keratella sp. was generally collected throughout the study at all depths, it was most common in late May. A species of the genus Trichocerca was common at the surface and 2 m in the late spring but rare in later samples. The cladoceran Bosmina longirostris was relatively common throughout the summer samples.

NON-POINT SOURCES OF POLLUTION

The water quality of a receiving stream can be significantly affected by non-point sources which are described as non-discrete, diffuse discharges to the environment non-amenable to treatment.

Non-point sources can be natural or attributed to man's activities. Natural sources include: precipitation; vegetation decay; wild animal wastes; and, erosion.

Non-point sources for which man's activities are responsible include: agriculture; construction; mining; urban storm runoff; animal feedlot; recreational activity; and, silviculture.

The purpose of this section is to summarize available information on the characteristics and relative magnitude of some categories of non-point sources pertinent to this specific study area.

Sources and Characteristics

Precipitation

Precipitation characteristics are influenced by natural and man-made activities, such as fuel burning, automobile exhaust, manufacturing operations and wind erosion. Precipitation is a variable and intermittent source of contaminants to surface water. Once the contaminants are in precipitation they are uncontrollable. The only abatement measure is to minimize the amount of particulates and gases emitted from combustion processes and industrial operations (6). Tables 6 and 7 give the constituent concentrations and annual area yield rates, respectively.

Kluesener and Lee (7) compared the amount of nutrients present in the urban runoff with that which would have come from the rain itself. They pointed out that most of the ammonia nitrogen and about one-third of the nitrate nitrogen in urban runoff seem to originate from rainfall. The rainfall accounted for generally less than 10% of the organic nitrogen and phosphorus in urban runoff.

Table 6. PRECIPITATION CHARACTERISTICS. (6)
(CONCENTRATIONS)

	Concentration under given conditions* (mg/e)						
	NH ₄ -N	NO ₃	inorg-N	Total-N	Total-P	SS	COD
1963-64 Urban	--	--	0.7	1.27	0.24	13	16
1963-64 Rural	--	--	0.9	1.17	0.08	11.7	9
Cooper	--	0.14	--	--	--	--	--
Northern Europe	0.06	0.31	--	--	--	--	--
1963-69 Forest	0.16	0.30	--	--	0.008	--	--
Feth	0.17-1.5	0.56	--	--	--	--	--
4 year-Ohio	1.1	1.15	--	--	0.02	--	--

* Data are primarily yearly average

** Inorganic N = NH₄, NO₂ and NO₃N

Table 7. PRECIPITATION CHARACTERISTICS. (6)
(AREA YIELD RATE)

	Area yield rate* (Kg/yr/ha)			
	NH ₄ -N	NO ₃ -N	SS	COD
Cooper 1969	--	1.5	--	--
Fisher 1964-65	1.6	1.5	--	--
Fisher 1965-68	2.2	4.1	--	--
Weibel 1969	--	--	100	124

Rural Activities (Agriculture)

The pollutants in surface water which resulted from rural activities include (6): a) sediments from soil erosion; b) nutrients and organics initially in the soil or from applied fertilizers; c) wastes, including pathogens, from pastured animals and from livestock feedlot; d) dissolved minerals from irrigation waters; e) leaf and plant residue decay; and, f) pesticides.

Sediments are primarily soil particles washed into streams by flowing water. They are the product of soil erosion which occurs in 2 basic steps: 1) detachment of fine particles from adjacent particles by raindrop impact and splash and 2) transport of detached particles by flowing water (8). Agricultural lands, particularly cropland, are large contributors of sediments. It was estimated that at least 50% of the four billion tons of sediments washed annually came from agricultural lands (6). Slope modifications combined with soil-conserving tillage practices can be effective in reduction of soil erosion from cropland.

Sediments also carry with them significant quantities of nutrients, organic and inorganic matters, pesticides and pathogens (6). Livestock wastes from enclosed feedlots and pasture and lands used for manure disposal can contribute significant amounts of pollutants to water by seepage or direct discharge from runoff. Gillham and Webber (9) reported that barnyard leachate contributed significant amounts of nitrogen to the ground water. However, no significant contamination of the ground water with nitrate from farm fertilizers or extensive cattle feeding operation was found in preliminary studies in north-eastern Colorado. But other studies indicate that substantial amounts of nitrate can eventually reach the ground water under heavily fertilized irrigated fields and feedlots (10). It is difficult to single out the source of nitrate in ground water, but it was shown that leachates from highly fertile, unfertilized agricultural lands may have a higher content of nutrients than the percolating water from nearby fertilized, well-managed cropland low in natural fertility (11). Table 8 shows the nitrogen and phosphorus content in surface water, in subsurface drains and in shallow wells.

Table 8. NITROGEN AND PHOSPHORUS CONTENT OF WATERS IN
SURFACE AND SUBSURFACE DRAINS AND IN SHALLOW WELLS. (11)

Constituent	Surface Drain	Subsurface Drain	Shallow Well
		mg/l	
NO_3^- -N	0.8	Irrigation Season 2.5	2.3
Dissolved P	0.19	0.22	0.12
Total P	0.27	0.28	0.12
		Nonirrigation Season	
NO_3^- -N	1.9	2.5	0.16
Dissolved P	0.20	0.23	0.08
Total P	0.26	0.26	0.10

A task group preparing a sedimentation manual for the Hydraulics Division of ASCE (12) presented a discussion on sediment sources and yields. They discussed methods for determining sediment production and defined terms associated with erosion. There is, of course, normal geologic erosion but man's activities often accelerate this natural process. The task group defined the land management goal as "the economic management of our land resource so that the rate of normal geologic erosion, plus an allowable rate of man-made erosion, will not exceed our ability to sustain soil".

Studies to determine the normal geologic erosion for various soils indicated that vegetated areas have a rate usually less than 0.3 tons per acre annually. The erosion rate under conditions of natural vegetation will vary with the mean annual rainfall of a region. When the mean annual rainfall is between 10-15 inches, the erosion rate reaches its peak. Rainfall amounts exceeding that range will encourage the growth of different vegetation which can effectively inhibit erosion. At amounts less than 10 inches runoff carrying sediment becomes rare (12).

The sediment contribution due to a given large rainstorm is highly variable especially for small drainage basins. From storm statistics on small plots, most of the sediment was contributed by rainstorms smaller than 3 inches. Studies in Kansas (Smith and Miner, 1964) (13) showed what happens in a stream receiving drainage from a feedlot after a storm. Their studies were made on the Fox River at a point about a mile below a feedlot. They described water quality of feedlot runoff as follows: 1) very high organic content; 2) concentrations of $\text{NH}_3\text{-N}$ frequently in excess of 10 ppm; and, 3) heavy bacterial populations. They found that in 20 hours after a 1-inch storm, the water in the stream 1 mile below the feedlot contained 90 ppm of BOD and only a trace of dissolved oxygen. They pointed out that the fecal coliform concentration rose to a tremendous level 20 hours after the storm and then dissipated rather rapidly whereas the count for fecal streptococci rose to an enormous level and continued at a high level for several days after the sampling period (13).

Concentration levels of nitrogen and phosphorus are found to be high when stream flow is high i.e., when rainfall has the greatest opportunity to leach and transport the soluble nitrate and phosphorus from the soil. On the average, no more than 50% of the applied nitrogen in fertilizers is used by crops (grass may recover up to 80% or more of applied nitrogen) (6). Generally, only 5 to 10% of the phosphorus applied to soil is taken up by crops (14). The rest is leached by runoff or percolation. According to Hanson and Fenster (15), snowmelt carries higher amounts of phosphorus than runoff waters during other seasons. There will also be appreciable amounts of other nutrients and organics moving off the land and into the streams during periods of rapid snowmelt especially in areas such as fields or feedlots where manure is spread or deposited on top of the accumulated snow of winter.

Some sediment yields based on reservoir surveys were presented by the task group preparing a sedimentation manual for the Hydraulics Division of ASCE. A sediment survey measures the volume of accumulated sediment deposits. A mean annual sediment yield of 1,300 tons/mi² was reported for the Altus Reservoir (reservoir volume-62 acre-ft/mi²). The watershed land use for this reservoir consisted of 60% cropland, 30% pasture-idle and 5% forest. The mean annual precipitation was 24 inches and the mean annual runoff was 0.9 inches. (12)

Flaxman (16) in his study pointed out the need for methods to evaluate the environmental impacts, including erosion and sediment yield resulting from various land uses. Watersheds vary widely in their susceptibility to erosion. He attempted to determine the major factors that caused the variation. His study was based on data gathered from an area composed of 11 western states. The objective was to determine if a few variables could explain the relationship between watershed conditions and the variation in sediment yield.

According to his multiple regression analysis, the four independent variables found to contribute significantly to predictions of sediment yield were: climate (average annual precipitation in inches divided by the average annual temperature in °F); watershed

slope (the weighted average slope of the watershed as a percentage); coarse particles (the percentage of soil particles coarser than 1 mm in the surface two inches of the soil profile); and, soil aggregation (an indication of the aggregation or dispersion characteristics of clay-size particles 2 microns or finer in size). The theory, based partly on field observation, is that particles that tend to aggregate resist erosion while particles that disperse are easily erodible. The pH of the soil is used to classify it into the two categories. A soil with a pH greater than 7 is generally associated with low precipitation and, therefore, little vegetative cover. This results in poor aggregation. Conversely, soils with a pH less than 7 are generally associated with more precipitation and more vegetative cover. This produces well aggregated soil. Exceptions to the rule do exist. Aggregation and dispersion are also influenced by the amount of clay present in the soil (16).

Urban Activities

The major non-point sources of pollution from urban areas are: urban stream runoff; combined sewer overflow; seepage from septic tanks and cesspools; and, infiltration from inadequate sewer lines due to overloaded or improperly maintained sewer system (7, 17).

Urban runoff is an important factor in the overall organic and nutrients loading from urban areas since it may reach surface waters by natural drainage channels without any treatment.

The pollutant constituents in urban runoff included: street litter; gas combustion products; domestic pet wastes; fallout from residential and industrial combustion products; vegetation decay; and, chemicals used for lawns and parks (6).

A recent study of the character of urban runoff (by AVCO Economic System Corporation) indicated that the increase in nutrients from urban runoff due to the continued growth in the Tulsa metropolitan area would likely offset any reduction in urban pollutional loadings brought about by improvement in waste water treatment procedures (7).

Colston (18) in his study characterizes the urban runoff in Durham, N.C. and evaluates the applicability of treating it with chemical-physical methods. Some of his conclusions from the study are:

1. The organic concentration in urban runoff is approximately 50% of that of typical raw waste.
2. Land use variations within the study area were not found to influence the quality of urban runoff.
3. The COD test was more reliable than the BOD test for urban runoff, because the COD results were reproducible and were not affected by particle size and inhibitory compounds whereas the heavy metals apparently interfered with the BOD test.
4. Approximately 20% of the time downstream water quality was influenced by dispersed urban runoff.
5. Fifteen minutes of ideal settling of urban runoff removes approximately 60% of the COD and 70% of the suspended solids.
6. During this study critical water quality conditions were typified by the period immediately following low flow when rainfall washes urban filth into the receiving stream, increasing the pollutant load while not substantially increasing the water quality. The study suggested that the use of the 7 day, 10 year low flow criterion for controlling water quality was misleading.
7. Storm water treatment is necessary if a desired water quality is to be maintained.
8. Improvements in downstream oxygen levels occur through the use of storage impoundments.

Table 9 shows the concentration of pollutants for all the storm water samples. Table 10 is the comparison of yield rates from storm periods (19% of the time during 1972) and raw municipal wastes in terms of COD, BOD and SS.

Kluesener and Lee (7) reported the following results from a study on the nutrient loading from a storm sewer in Madison, WI:

1. Nutrients and SS concentrations were usually greatest during the early stages of the runoff event, decreasing with time.
2. Rainfall seemed to be the major source of inorganic nitrogen in runoff from the urban area.
3. Phosphorus generally resulted from accumulated litter and possibly automobile exhaust discharged to the street.
4. Urban runoff data from this basin as extrapolated to the entire Lake Wingra basin indicated that approximately 80% of the total phosphorus and 35-40% of the total nitrogen influent to Lake Wingra arises from urban runoff.

Their data on average chemical concentrations in urban runoff is compared with data from different locations reported by other investigators. (Table 11)

Table 9. AVERAGE RANGE, AND STANDARD DEVIATIONS OF POLLUTANT CONCENTRATION FOR ALL STORM SAMPLES. (7)

Pollutant	Mean mg/l	Standard deviation	Range (mg/l)	
			Low	High
COD	170	135	20	1042
TOC	42	35	5.5	384
Total Solids	1440	1270	194	8620
Volatile Solids	205	124	33	1170
Total Suspended Solids	1223	1213	27	7340
Volatile Suspended Solids	122	100	5	970
Kjeldahl Nitrogen as "N"	.96	1.8	.1	11.6
Total Phosphorus as "P"	.82	1.0	.2	16
Fecal Coliform (#/ml)	230	240	1	2000
Aluminum	16	8.15	6	35.7
Calcium	4.8	5.6	1.1	31
Cobalt	.16	.11	.04	.47
Chromium	.23	.10	.06	.47
Copper	.15	.09	.04	.50
Iron	12	9.1	1.3	58.7
Lead	.46	.38	0.1	2.86
Magnesium	10	4.0	3.6	24
Manganese	.67	.42	.12	3.2
Nickel	.15	.05	.09	.29
Zinc	.36	.37	.09	4.6
Alkalinity	56	30	24	124

Table 10. TOTAL YIELD OF POLLUTANTS DURING STORM PERIODS FROM URBAN RUNOFF AND RAW MUNICIPAL WASTES IN LBS/ACRE DURING 1972. (7)

Parameter	Raw municipal wastes	Urban runoff	Total	Percent	
				Municipal	Runoff
COD	195	895	1090	18	82
Ultimate BOD	130	447	577	23	77
Suspended Solids	64	6617	6681	1	99

Table 11. COMPARISON OF AVERAGE CHEMICAL CONCENTRATIONS
IN URBAN RUNOFF FROM DIFFERENT LOCATIONS. (7)

	Runoff (%)	NH ₃ -N (mg/l)	NO ₃ ⁻ -N (mg/l)	Organic-N (mg/l)	OR-P (mg/l)	Total-P (mg/l)	Solids (mg/l)	Lead (mg/l)
Sawyer et al.	--	0.28	--	--	0.22	0.56	87	--
Sylvester	--	--	0.53	2.0	--	0.15	--	--
Weibel	37	0.60	0.40	1.7	0.26	--	227	--
Bryon	60	--	--	--	0.14	0.19	--	0.32
AVCO	16	--	--	0.8	0.22	--	84	--
Kluesener	15	0.45	0.60	3.5	0.57	0.98	280	--



Sartor, et al (19), investigated the water pollution aspects of urban storm water discharges of 12 cities in the U.S. and suggested possible ways for reducing the pollution from this source. This study led to the following conclusions:

1. The runoff from street surfaces is generally highly contaminated.
2. A great portion of the pollution potential is associated with the fine solids fraction of the street surface contaminants. Catch basins are not effective in removing fine solids or most organic matter.
3. The rate at which rainfall washes loose particulate matter from street surfaces depends on 3 major factors: rainfall intensity; street surface; and, particle size.

Urban activities also produce a significant amount of sediment which can cause a number of problems. Sediment can hinder the efficiency of sewage treatment systems causing increased operation and maintenance costs. Sediment loads reaching urban ponds and lakes accelerate eutrophication. Construction activities cause erosion and sediment problems (6). Current research (20) suggests that sediment yields in areas experiencing suburban development can be 5 to 500 times greater than in rural areas. Temporary or permanent control measures are possible to reduce the sediment load from this source. The measures should be implemented as soon as possible after disturbing the landscape. Good preconstruction planning can also control the amount of erosion and sediment produced.

Recreational Activities

The effects on water quality from the recreational uses of an area depend on whether the activity is water contact or non-water contact. The major effect from water contact activities is an increase in bacterial contamination.

King and Mace (21) studied a recreational area in northeastern Minnesota to determine if increased use of camp sites was noticeably affecting the adjacent water quality. The following parameters were chosen as indicators of water quality: pH; DO; specific conductance; turbidity; total coliform; nitrate (plus nitrite); total Kjeldahl nitrogen; and, total available phosphate. The water quality was initially high with low nutrient concentrations.

The results of the comparison of test sites to the control sites indicated recreational uses had no measurable effect on DO, specific conductance or nitrate concentrations. However, the recreational activities did appear to affect the total coliform population, the available phosphorus and total Kjeldahl nitrogen.

The observed increase in total coliforms was thought to result from effluent of pit toilets leading into the lake or possibly from swimming, dishwashing or boat landing. The increase in total Kjeldahl nitrogen was explained by the morphology of the lake and the location of sampling sites, while the phosphorus increase was attributed to the use of detergents, organic wastes and outboard motor fuel.

Barbaro, et al (22), studied the bacteriological water quality of several recreational areas in a reservoir near Jackson, Mississippi. They recorded significant increase in fecal coliform and fecal streptococci counts, due to increased recreational activities.

Comparison of Magnitude of Pollution Sources by Land-Use Patterns

Non-point sources are the result of complex interactions in and on the soil, making definitive comparison difficult. Additional problems in comparing data from various studies are variations in sampling methods and the fact that all studies do not measure comparable parameters.

Two approaches are generally used for comparison of characteristics of non-point sources; the first based on concentrations and the second on the area yield rates.

Comparison based solely on concentration is difficult and inappropriate because of the intermittent, flow-dependent nature of the sources. A better method of comparison is the use of area yield rates, such as quantity of pollutants per unit of drainage area per unit runoff. However, adequate data rarely are available to develop this type of yield rate.

In the report prepared for EPA on the "Methods for Identifying and Evaluating the Nature and Extent of Non-Point Sources of Pollutants" (23), it is concluded that the major pollutant is sediment whose

major source is credited to cropland. Table 12 presents the approximate ranking of the contributions of sediment from various non-point sources on a nationwide basis.

The relative area yield rates of sediment from various types of land uses compared to that of forest land are shown in Table 13. The activities in construction sites and active surface mines yield the highest rate of erosion, even though each of these activities is a less significant source of sediment than cropland on a nationwide basis.

Harms, Dorbush and Andersen (24) investigated the physical and chemical quality of agricultural land runoff resulting from rainfall and snowmelt at selected sites in South Dakota. The objectives were to find the concentration of various pollutional constituents in surface runoff and determine their annual contribution.

The mean concentration of runoff parameters by land uses are presented in Table 14. In the South Dakota basin few rainfall runoff events occurred on cultivated lands. The nitrogen and phosphorus levels exceeded those suggested as capable of producing nuisance algae growth.

Table 15 shows the average yearly runoff contributions of selected parameters by land use. The maximum soil loss did not exceed 0.5 ton/acre/year on these sites. Some agricultural experts are seeking to establish soil conservation practices to allow a tolerable erosion of less than 3 to 4 ton/acre/year. The erosion rate for the sites considered in the South Dakota study was considerably less.

The study revealed that:

1. Major portions of the COD, P and TKN in runoff from cultivated lands were associated with sediments. However, for the sites permanently covered with grass a high percentage of the 3 constituents was soluble. This indicates that the crop grown is significant in determining runoff quality.
2. Considerable amounts of nutrients were available in agricultural runoff. Most of the annual nutrient loads came from snowmelt runoff, a large percentage being soluble.
3. Most of the sediment resulted from rainfall-runoff from cultivated land during short duration, high intensity rainstorms.

Table 12. RELATIVE EROSION FROM VARIOUS LAND USES -- NATIONWIDE^a (23)

<u>Land Use</u>	<u>Number</u>
Commercial forests	1
Abandoned surface mines	1
Active surface mines	2
Construction	6
Harvested forests	11
Grassland	11
Cropland	168

^aBased on total loading nationwide

Table 13. REPRESENTATIVE RATES OF EROSION FROM VARIOUS LAND USES. (23)

<u>Land Use</u>	<u>Thousands of kilograms per square kilometer per year (tons per square mile per year)</u>	<u>Relative to forest = 1</u>
Forest	8.5 (24)	1
Grassland	85.0 (240)	10
Abandoned surface mines	850.0 (2,400)	100
Cropland	1,700.0 (4,800)	200
Harvested forest	4,250.0 (12,000)	500
Active surface mines	17,000.0 (48,000)	2,000
Construction	17,000.0 (48,000)	2,000

Table 14. MEAN CONCENTRATION OF RUNOFF PARAMETERS BY LAND USE. (24)

Parameter	Ground Cover					
	Cultivated Land			Pasture		
	Snow	Rain		Snow	Rain	Alfalfa & Brome Grass
Total residue, mg/l	187	1241		150	222	134
SS, mg/l	51	1021		18	38	42
Total P, mg/l	0.44	1.05		0.67	0.49	0.43
Nitrate, mg/l N	1.0	1.5		0.9	0.4	0.8
TKN, mg/l N	2.1	2.6		3.3	1.7	2.8
COD, mg/l	49	148		69	49	62
No. of samples	44	28		16	2	31
						108
						40
						0.35
						0.3
						0.8
						22
						2

Table 15. AVERAGE YEARLY RUNOFF CONTRIBUTIONS OF RUNOFF PARAMETERS BY LAND USE (24)

Parameter	Contribution for Indicated Land Use (lb/yr/acre)			
	Cultivated land		Pasture	Alfalfa and Brome Grass
Total residue	298		51.9	28.9
SS	255		10.5	3.6
Total P	0.27		0.22	0.09
Nitrate, N	0.33		0.36	0.21
TKN	0.81		1.00	0.65
COD	43		25	12

Loehr (6) presents a comprehensive discussion on the nature and extent of non-point sources of pollution in which he identifies the characteristics and quantities of certain sources and comments on the feasibility of their control. He summarizes available information from various studies by several investigators on the characteristics of non-point sources which are categorized by their related land uses: forest land; rangeland; cropland (cultivated); land receiving manure; irrigation return flow; and, animal feedlot. The ranges of values of important parameters reported by several investigators are summarized in Table 16 (6).

Because of the interests in nutrient contribution to lake eutrophication, total nitrogen and total phosphorus contributions are compared in terms of both concentration and area yield rate. Figures 10 and 11 illustrate the ranges of nitrogen and phosphorus contribution from different types of land uses. The animal feedlot runoff and manure seepage have nutrients concentrations and area yield rates that are many orders of magnitude greater than the other sources. Comparison in terms of area yield rates (Figure 11) permit a more reasonable assessment of the contribution of nutrients from several non-point sources. Although these comparisons cover wide ranges they permit an assessment of the degree of pollutant contribution from the non-point sources that are controllable. Loehr suggests that those yield rates should be considered as potential rather than actual surface loading rates, i.e., the order of magnitude of the characteristics and the difference between sources are more significant than the values themselves.

Table 16. SUMMARY OF NON-POINT SOURCE CHARACTERISTICS. (6)

Source	Concentration (mg/l)					Area Yield Rate (kg/yr/ha)					Surface Area of Interest
	COD	BOD	NO ₃ -N	Total N	Total P	COD	BOD	NO ₃ -N	Total N	Total P	
Precipitation	9-16	12-13	0.14-1.1	1.2-1.3	0.02-0.04	124	--	1.5-4.1	5.6-10	0.05-0.06	Total land area
Forested land	--	--	0.1-1.3	0.3-1.8	0.01-0.11	--	--	0.7-8.8	3-13	0.03-0.9	Forest area
Range land	--	--	--	--	--	--	--	0.7	--	0.08	Range land
Agricultural crop land	80	7	0.4	9	0.02-1.7	--	--	--	0.1-13	0.06-2.9	Active crop land
Land receiving manure	--	--	--	--	--	--	--	--	4.13	0.8-2.9	Crop or unused land used for manure disposal
Irrigation tile drainage, western U.S.	--	--	0.4-1.5	0.6-2.2	0.2-0.4	--	--	--	3-27	1.0-4.4	Irrigated western soils
Surface flow	--	--	1.8-19	2.1-19	0.1-0.3	--	--	83	42-186	3-10	Irrigated western soils
Subsurface drainage	--	--	--	10-25	0.02-0.7	--	--	--	0.3-13	0.01-0.3	Active crop land requiring drainage
Crop land tile drainage	--	--	--	3	0.2-1.1	220-310	30-50	--	7-9	1.1-5.6	Urban land areas
Urban land drainage	85-110	12-160	--	--	--	--	--	--	--	--	Manure holding area
Seepage from stacked manure	25,900-31,500	10,300-13,800	--	1,800-2,350	190-280	--	--	--	3	--	Confined, unenclosed animal holding areas
Feedlot runoff	3,100-41,000	1,000-11,000	10-23	920-2,100	290-360	7,200	1,560	--	100-1,600	10-620	

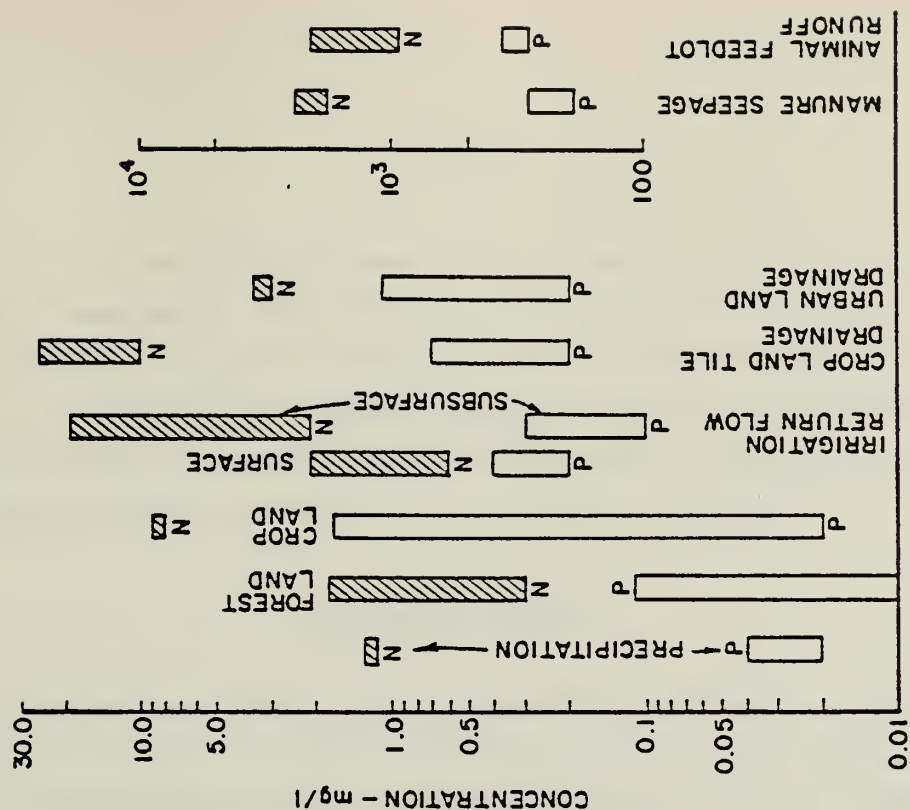


Figure 11. CONTRIBUTIONS OF TOTAL N AND P BY VARIOUS NON-POINT SOURCES. (6)

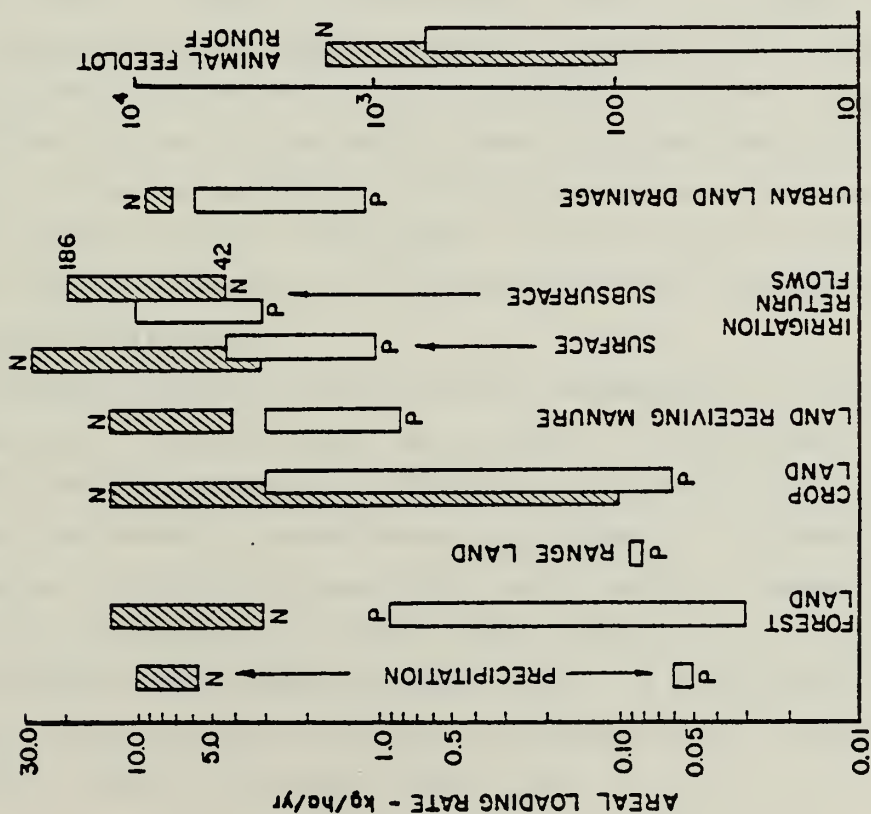


Figure 10. COMPARISON OF NON-POINT SOURCES, GIVING RANGE OF TOTAL N AND P CONCENTRATIONS. (6)

HYDROLOGY

One of the major influences on the water quality of any stream, lake or aquifer is the hydrologic characteristics of the associated watershed area. As the volume of water in the system varies so do many of the factors effecting its quality such as the residence time of pollutants in streams and lakes, pollutant transport and pollution concentration levels subject to continuous dilution.

Historical Review

The general complexity of a preurban hydrologic system is illustrated in Figure 12 (25). As the population in the vicinity of the Chickasaw Recreation Area increases, the amount of land needed for the urban areas will also increase. It is a well established fact that urbanization clearly affects the hydrologic system as is shown in Figure 13. Much research is still needed, however, to clearly understand all of the implications of urbanization on the hydrologic system. Figure 13 summarizes the qualitative water elements in the urban hydrologic system. If the water quality relationships were illustrated the figure would be further complicated. The vast array of available literature merely illustrates the complexity of man's influence on the hydrologic environment.

The major sources of water quality degradation in hydrologic systems are: 1) agricultural storm runoff; 2) soil erosion; 3) combined sewer overflows; 4) effluents from industry; 5) thermal effluents from electric power plants; 6) wastewater treatment plant effluents; 7) natural drainage from marsh lands; 8) seepage from septic tanks and cesspools; 9) urban storm runoff; 10) oil spills; 11) contamination from mining activities; and, 12) infiltration from inadequate sewer lines or wastewater discharged due to overloaded or improperly maintained sewage systems (25).

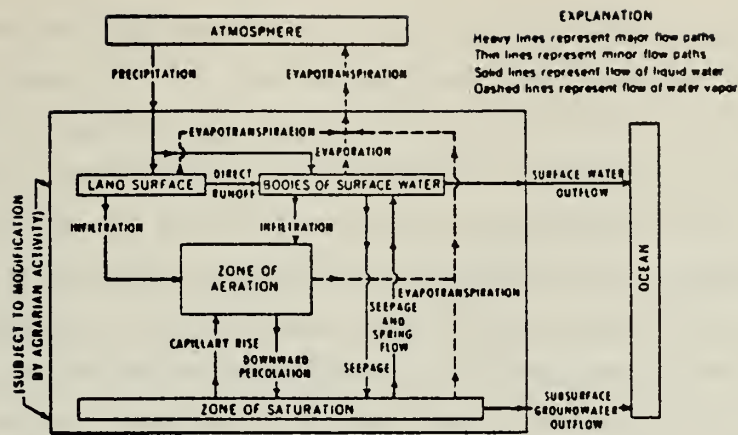


Figure 12. PREURBAN HYDROLOGIC SYSTEM. (25)

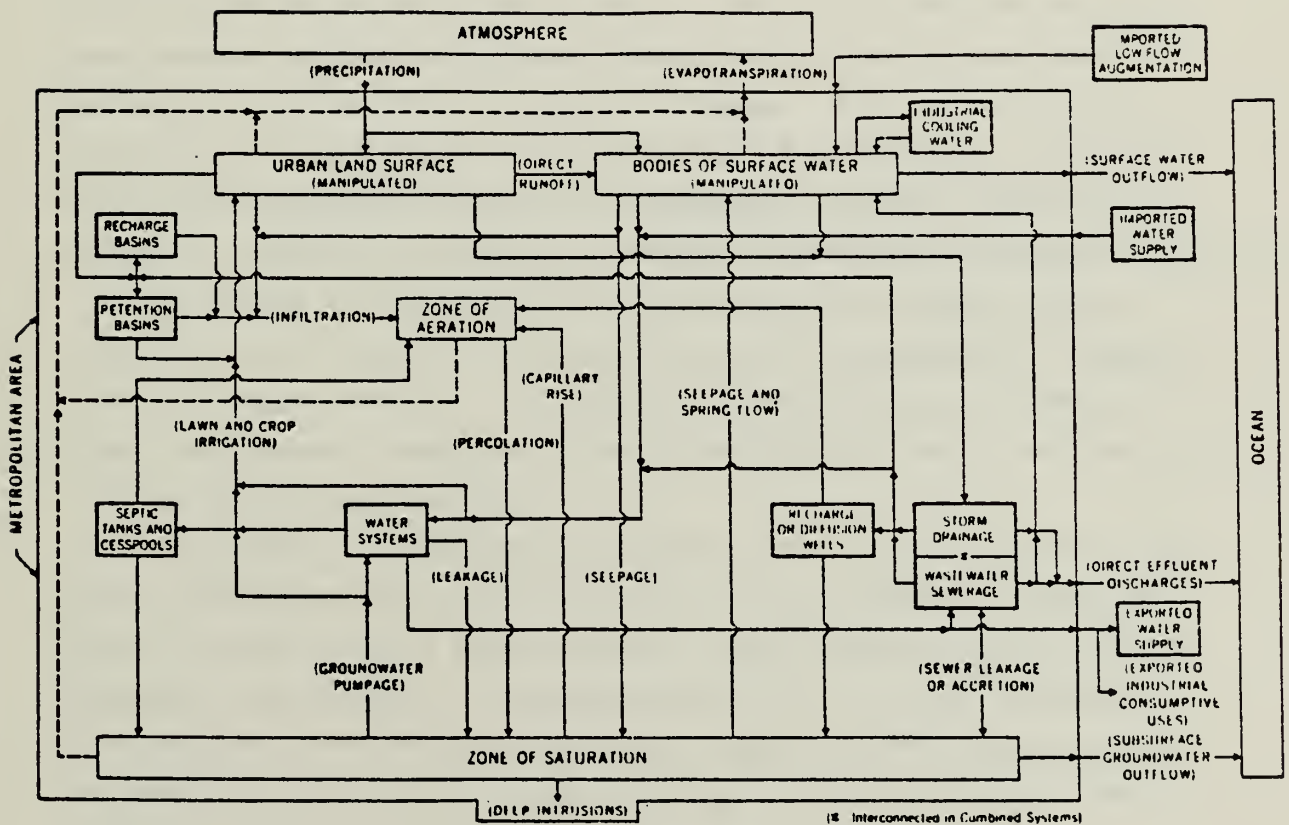


Figure 13. URBAN HYDROLOGIC SYSTEM. (25)

The concomitant degradation of water quality limits or adds to the economic burden of: 1) the use and reuse of urban surface water and ground water supplies; 2) water oriented recreation; 3) waterfront use; 4) aesthetic improvements; 5) commercial fisheries; 6) shipping and navigation; and, 7) fish and waterfowl propagation (25).

The urban environment contributes such hydrologic elemental factors as impervious roofs, streets and parking areas. These contribute to the increases in peak flows in streams and storm drains during flood events. Studies to compare urban versus rural drainage events indicate "that as the relative magnitude of flood peaks increases, the ratio of urban peak rate to rural peak rate declines, the effect of urbanization being more pronounced for the more frequent occurrences" (25).

The task committee (25) reviewed literature and discussed in great detail the effects of urbanization on low flow, total runoff, infiltration and ground water recharge. The task committee analyzed case studies substantiating that urbanization of a drainage basin can decrease or increase the low flow of streams. Data on low flow decreases were from streams on Long Island, N.Y. Increases in low flow resulted where urbanization caused increased irrigation practices, decreases in evapotranspiration and changes in quantity of sewage effluent (25).

The effect of urbanization on total runoff and water yield is linked with the changes in climate produced by urbanization. Examples of these changes include: an increase in precipitation in towns; a higher mean annual temperature than in the country; and, lower humidity than the rural counterparts.

The effects of urbanization on water yield, as determined by the data collected in the study (25), are: 1) an increase in volume of storm flow and of total annual yield; 2) modification in water yield resulting from changes in drainage patterns; 3) increase in the dry weather flow of streams in urban areas during dry years due to reduced evapotranspiration losses or the discharge of sewage effluent; and, 4) modification of infiltration, storage and discharge.

Additional urbanization effects that influence total runoff are 1) reduced opportunity for infiltration, reduction in vegetated surface

and change in cover, inhibiting and thereby decreasing infiltration and evapotranspiration; 2) increased seasonal evapotranspiration resulting from lawn watering and septic tank and cesspool drainage into the zone of aeration; and, 3) reduction in overall local recharge as the result of occlusion by man-made impervious cover.

The task committee (25) study indicated that there was few data available in the literature comparing infiltration measurements in rural with urbanized watersheds. The main contention regarding the effect of urbanization on infiltration is that infiltration decreases as urbanization increases because of the accompanying increase in impervious cover. The task committee found little quantitative work based on the effects on ground water recharge of: 1) leaky water systems; 2) leakage into and out of storm and wastewater sewer systems, cesspools and septic tanks; and, 3) impervious areas. A generally upheld opinion indicates that with respect to a given situation, ground water recharge in the urban environment will decrease.

A survey conducted by the American Public Works Association indicates:

"Infiltration of ground water is an important source of large volumes of water flow into sanitary and combined sewer systems in all areas, in jurisdiction of all sizes, with all types of sewer pipe construction and various types of jointing material... Infiltration may average as much as 15% of the total flows handled by affected sewer systems; peak infiltration may be 30%."

The survey also indicates that a major cause of reduced usable ground water recharge in urbanized areas in most parts of the U.S. is due to the effect of sewers laid beneath the water table.

The task committee further indicates that there is a scarcity of data relating changes in urban development to changes in the hydrologic systems. They caution that the data that is available has a limited transfer value, as is true with most hydrological processes and system analyses.

Bhutani, et al (26), discussed the impact of hydrologic modifications of water quality based on available data. These modifications included dams, impoundments, channelization, in-water construction, out-of-water construction and dredging. Some of their conclusions

which are particularly applicable to this literature search are:

1) runoff from highway and urban development construction sites has an adverse impact on surface water quality; 2) the major pollutant from out-of-stream construction operations is sediment; 3) major water quality problems resulting from out-of-stream construction operations are amenable to control; and, 4) operation of dams and impoundments can adversely affect water quality by several mechanisms, including sediment retention, thermal stratification, decomposition of trapped organic material and nitrogen supersaturation.

General Hydrological Description of the Chickasaw Recreational Watershed

The Chickasaw National Recreation Area is located in the hydrologic portion of the state drained by the Lower Washita River beginning on the western border of Grady County and sloping generally southeast. The largest nearby body of water is the Lake of the Arbuckles which is located at the southern extremity of the recreation area. It has a surface area of 2,300 acres and a storage capacity of 69,700 acre-feet.

Relief in the generally rolling terrain of most of the valley is afforded by the Arbuckle Mountains which lie in an east-west area north of Ardmore.

This area is primarily agricultural with short winters and long, hot summers. There is some erosive action in the area and in the past there has been a normal amount of flood damage.

Flood control and improved land management practices have generally contributed to a solution of these problems. There is some irrigation now and there would be more irrigation if water were available. The geology of the area is internationally famous and geologists from all over the world have come to study the "Arbuckle uplift" and its general effects. In fact, the Springs and unusual features of the Park were created by this action.

The climatology of Central Oklahoma, which encompasses the Chickasaw National Recreation Area, is a warm continental climate. Major

weather disturbances develop over the region when the prevailing warm moisture-laden air driven from the Gulf of Mexico conflicts with the cool, drier air arriving from the West Coast and Canada. Rainfall is adequate for most farming practices about 53% of the time, while droughts of severe to extreme intensity are present about 11% of the time. The occasional dry periods or untimely distribution of precipitation usually causes hardships since less than one percent of the croplands are irrigated.

The long, warm summers provide many hot days which are eased by the presence of relatively low humidity, prevailing southerly winds; and occasional rain showers or thunderstorms. However, drought conditions are greatly intensified during the extreme hot periods when brisk, hot winds out of the southwest accompany the high daytime temperatures. The cooling trend of fall usually begins with the secondary maximums of precipitation in September. Winter is the driest season and is usually mild and of short duration. The stronger outbreaks of cold and snow conditions last only a few days and the severe "northers" occur very infrequently. The 30-year mean temperature is about 63°F, the mean January temperature is about 40°F, while July means are about 83°F. Extreme temperatures at Sulphur, Oklahoma since 1892 have been recorded as -15°F minimum and 120°F maximum. Mean annual precipitation is about 36" per year, resulting in an average annual runoff of 5 to 10 inches per year. The average surface wind speed is about 13 mph. Actually less than 2% of the winds exceed 25 mph and nearly 50% of the observations are reported as calm. The area is subject to tornado activity, and although rare, do produce winds of up to 100 mph. Some hail activity is noted but is a rarity. The mean monthly relative humidity ranges from about 46% to 80%.

The climatologic rainfall from 1917-1977 published by the State Water Development Board in part are assembled from the National Weather Service and Park records and listed in Table 17. The mean values represent data from the earliest records to the present time. The means are different from the National Weather Service in that they present only 30 year means, using the most recent decade and dropping the oldest decade each ten year period, the most recent being 1970. For purposes of this study it is felt that all the data is important.

Table 17. PRECIPITATION RECORDS.

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Ann'l
*1917		.80	.17	4.68	2.28	3.04	3.12	2.15	3.09	T	1.72	T	
*1918	.62								4.15	4.37	2.56	3.92	
1919	1.21	2.39	2.18	3.40	5.35	3.67	3.81	7.24	.79	8.04	3.86	1.10	43.04
1920	2.65	.14	1.45	3.22	6.08	4.88	1.64	2.15	5.38	5.64	1.18	1.48	35.89
1921	1.66	2.17	4.91	4.27	2.80	8.00	3.90	2.83	.78	.05	1.11	1.06	33.54
1922	1.40	1.36	3.09	8.31	6.08	1.11	2.58	.79	.04	2.33	4.50	.40	31.99
1923	2.51	1.28	1.80	5.30	8.88	3.87	T	2.51	6.54	10.75	2.81	4.26	50.51
1924	.89	.79	3.42	5.88	3.10	3.63	.35	.72	1.98	.14	.49	2.85	24.24
1925	.99	.78	.08	2.19	4.83	.02	2.95	1.32	5.08	3.63	1.48	.32	23.67
1926	3.47	.72	2.56	2.56	4.40	3.17	6.19	8.28	5.84	5.39	.66	3.31	46.55
1927	4.78	2.97	1.95	9.99	.76	6.44	7.70	2.93	5.00	3.19	.77	3.65	50.13
1928	3.30	2.99	1.10	7.86	3.20	9.77	4.97	3.06	.76	3.55	2.68	1.74	44.98
1929	2.04	1.22	3.52	1.87	10.46	2.49	1.84	.14	5.05	6.76	2.36	2.78	40.53
1930	2.10	2.76	1.23	3.73	7.99	2.57	1.18	3.42	1.73	2.47	4.02	2.34	35.54
1931	.35	7.20	4.30	2.02	1.83	1.63	2.95	.72	.14	6.22	6.03	1.44	34.83
1932	7.33	3.41	1.73	3.71	2.11	4.06	1.48	1.76	.44	2.54	.22	9.30	38.09
1933	2.50	2.02	4.40	2.25	13.78	.54	2.22	5.95	4.96	.46	1.82	1.44	42.34
1934	2.40	2.72	3.80	2.97	3.00	2.81	.00	.87	6.38	1.06	5.98	.48	32.47
1935	1.89	.85	5.38	4.31	12.54	7.48	2.34	4.14	5.45	3.84	3.09	3.05	54.36
1936	.43	.40	1.61	1.07	8.38	.60	2.52	T	12.68	3.56	.30	1.62	33.17
1937	2.47	.18	4.06	3.68	2.22	2.79	4.63	4.38	.05	3.27	2.10	2.93	32.76
1938	2.60	9.55	4.61	2.35	6.05	4.83	2.57	1.43	2.44	.50	2.80	.68	40.41
1939	3.07	1.73	1.96	2.78	2.70	4.35	1.26	2.67	.59	2.91	2.28	1.20	27.50
1940	.45	2.87	T	6.82	9.33	6.58	6.83	2.47	.22	3.28	6.67	2.87	48.39
1941	2.88	3.18	.47	6.89	4.62	7.71	1.06	6.63	4.02	14.89	1.59	1.58	55.52
1942	.46	2.30	1.70	10.62	4.28	8.18	.77	4.76	3.68	5.41	2.24	2.53	46.93
1943	.15	.74	3.14	4.23	7.81	2.73	1.21	T	1.21	1.63	.12	3.87	26.84
1944	2.78	4.76	2.63	2.75	5.86	2.54	3.12	2.77	.85	4.44	3.82	2.65	38.97
1945	1.70	4.44	9.76	8.61	1.41	10.99	4.58	6.13	11.13	.78	.72	.08	60.33
1946	6.42	3.66	4.01	2.83	5.66	3.43	.84	6.71	2.72	.14	6.80	8.42	51.64
1947	.32	.34	1.21	9.04	8.04	4.28	1.57	1.13	3.33	1.61	2.87	2.70	39.34
1948	.98	4.19	2.51	.70	7.59	6.64	3.62	1.32	.12	.78	.48	1.27	30.20
1949	5.97	2.69	3.38	2.13	6.14	4.90	.58	2.75	6.28	4.54	.00	1.48	40.84
1950	3.02	1.86	.35	2.03	6.44	3.39	5.91	7.94	2.48	.71	.22	.10	34.45
1951	1.14	3.61	1.35	1.43	5.88	6.87	5.54	2.92	1.78	3.15	1.84	.31	35.82
1952	.31	1.23	3.33	4.72	4.86	.50	2.85	.90	.10	.03	4.47	1.45	24.75
1953	.55	.97	3.14	4.36	4.51	2.28	7.72	1.44	1.16	5.15	2.22	1.05	34.55
1954	1.49	.55	.93	5.45	8.21	4.34	.15	.83	.36	5.72	.36	3.08	31.47
1955	1.47	2.18	2.45	1.81	4.77	1.79	2.09	1.08	7.37	.21	.02	.40	25.64
1956	1.47	2.14	.39	2.89	4.81	1.55	1.43	1.39	.04	3.73	3.93	3.15	26.92
1957	2.13	2.09	4.37	9.14	13.24	6.09	2.34	1.68	11.41	2.25	4.86	1.46	61.06
1958	2.44	.51	4.15	2.06	4.85	3.52	4.30	1.91	.78	.33	1.94	.86	27.65
1959	.45	.79	3.36	2.74	4.45	2.87	3.04	2.07	1.81	8.96	2.50	2.77	35.81
1960	2.74	3.08	2.10	2.76	6.98	1.84	3.59	3.16	5.33	4.38	.20	4.95	41.11

Table 17. PRECIPITATION RECORDS. (continued)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann'l
1961	.10	2.00	3.62	.92	3.75	3.41	3.70	.64	6.87	3.72	3.20	1.74	33.67
1962	.34	.35	2.55	2.97	1.91	8.91	4.13	1.19	4.69	4.85	2.75	1.79	36.43
1963	.07	.04	5.02	3.22	.81	.56	2.28	1.99	1.77	.04	2.29	1.45	19.54
1964	.96	1.59	2.89	1.79	8.52	.98	.70	4.98	6.33	.47	6.70	.72	36.63
1965	2.14	1.55	1.65	2.60	5.90	1.69	1.58	2.48	2.04	1.95	.83	1.32	25.73
1966	1.26	1.87	1.26	5.09	.71	2.18	4.65	5.36	2.04	1.86	.94	.69	27.91
1967	.34	.80	1.05	8.17	6.68	6.73	3.89	.20	5.81	5.37	.79	2.13	41.96
1968	4.13	1.27	3.82	2.35	9.47	4.02	5.75	.97	4.43	2.87	5.73	2.04	46.85
1969	1.25	2.97	2.55	5.21	5.05	3.30	1.74	1.61	2.65	7.92	.51	3.47	38.23
1970	.18	1.74	3.90	4.97	2.26	4.82	1.68	.80	11.73	16.43	.79	.77	50.07
1971	1.89	1.15	.68	2.76	2.83	2.63	4.05	4.92	2.79	6.62	.57	5.46	36.35
1972	.36	.56	.61	3.95	4.05	2.39	1.41	3.56	2.52	7.69	3.87	.88	31.85
1973	3.01	3.00	6.44	6.04	2.72	8.12	3.94	.99	10.90	4.89	8.02	.86	58.93
1974	.90	1.76	1.45	4.91	3.64	3.47	2.10	5.49	8.65	7.10	2.48	1.53	43.48
1975	1.98	4.26	4.71	3.05	6.85	2.43	4.73	1.98	3.55	1.24	2.05	1.50	38.33
1976	.07	.29	3.70	3.88	7.78	1.33	1.90	1.18	1.36	4.71	.90	1.57	28.67
*1977	1.91	1.39	6.39	3.51	5.29	2.41							
Average	2.14	2.11	2.84	4.18	5.34	3.97	2.93	2.67	3.63	3.87	2.43	2.10	38.50

* Records Incomplete

Note: (Data furnished by the Oklahoma Water Resources Board and Platt National Park)

The base flows in Travertine Creek and Rock Creek are fed from the springs in the park, primarily Buffalo and Antelope Springs. The magnitude of the measured flows during the study period are given in Table 18. The springs in the park are directly associated with ground water recharge which is directly related to precipitation in the area. Prior to the period of this research effort, Buffalo and Antelope Springs ceased to flow on eight occasions: March 1926 to August 1926, September 1937 to June 1939, January 1951 to May 1951, October 1951 to June 1953, October 1953 to June 1956, February 1958 to December 1958, October 1962 to November 1963, and October 1964 to July 1966. The general ground water status in the area of the park has gradually deteriorated from strong to weak, or non-existent, artesian conditions. A comprehensive paper on the subject was reported by Harp and Laguros (27) in April, 1976.

As already mentioned, the base flows in Travertine Creek originate from the springs in the park. Peak flows are the result of surface runoff that enters the creek from rainfall. The drainage area of the Travertine Creek basin is very small and the runoff coefficient is estimated to be about 10%. It has been observed that after a significant rainstorm that the runoff hydrograph peaks and recedes rapidly.

Travertine Creek is a tributary to Rock Creek which is one of the three main sources of water for the Lake of the Arbuckles Reservoir which is only a few miles downstream. Rock Creek has a larger drainage area than does Travertine Creek and carries about 30% more surface flow. During the last five years the flow in Travertine Creek, as measured at the Travertine Nature Center, was as much as 9 cfs in magnitude. The flow in Rock Creek has been unofficially observed to be several times this amount.

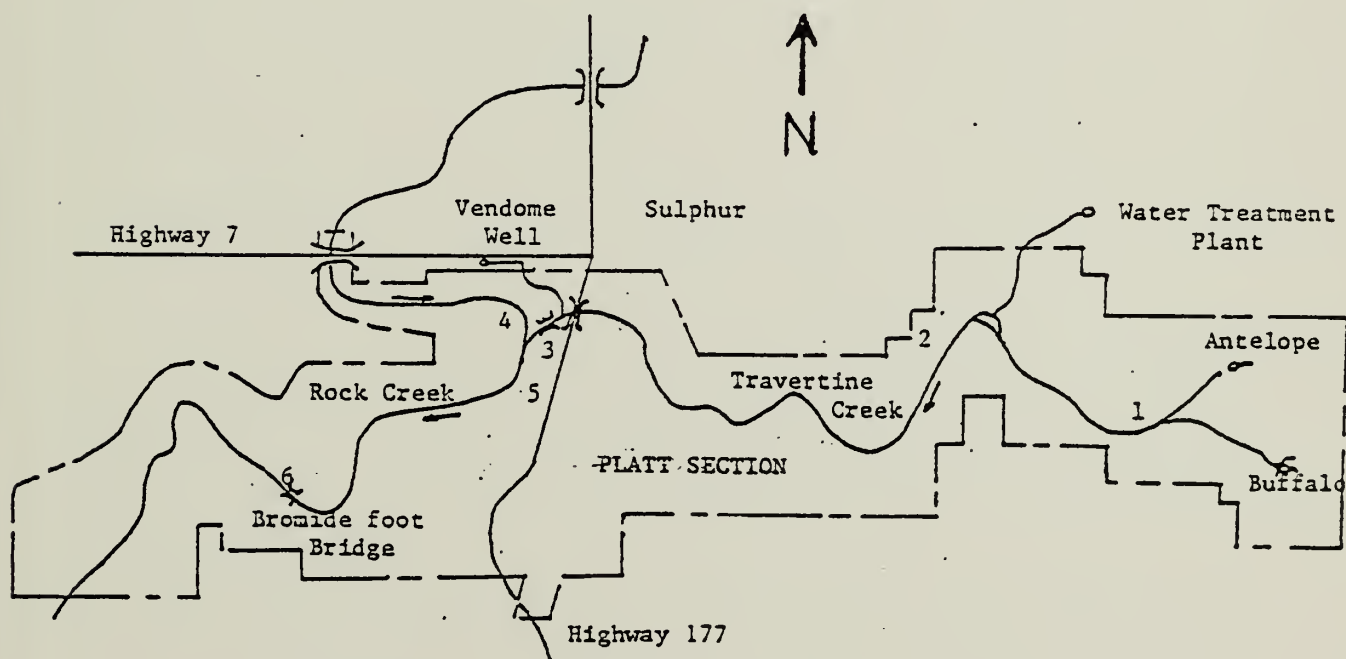
During December 1976 until late January 1977, during the observation period of this study, Buffalo and Antelope Springs ceased to flow. The fall months of 1976 were very dry and this condition existed until the spring rains, which were of lesser magnitude than normal. As determined by Harp and Laguros (27), the same aquifer that supplies water to the City of Sulphur well field also supplies Buffalo and

Table 18: STREAM FLOWS, ROCK CREEK.

Date	Stream Flows (CFS) for Selected Locations					
	1*	2	3	4	5	6
Oct. 16, 1976	0.62	0.38	2.13	2.68	4.81	4.88
Nov. 14, 1976	-0-	-0-	1.98	2.62	4.60	4.69
Nov. 30, 1976	0.1	0.1	2.35	3.30	5.65	5.78
Dec. 12, 1976	-0-	-0-	2.33	2.16	4.49	4.80
Dec. 19, 1976	-0-	0.1	2.23	3.92	6.15	6.50
Jan. 21, 1977	-0-	0.1	2.01	2.78	5.79	5.98
March 20, 1977	-0-	0.1	2.09	2.46	4.55	4.95
April 1, 1977	0.1	0.2	2.22	2.26	4.48	4.97
June 13, 1977	2.00	2.94	2.19	3.58	5.77	6.19
July 1, 1977	0.95	0.55	3.04	2.15	5.19	5.51
July 3, 1977	0.88	0.54	3.03	2.14	5.37	5.50

* Indicate gaging sites corresponding to Figure 14.

Figure 14. STREAM FLOW GAGING SITES, ROCK CREEK.



Antelope Springs. The city well field is about 70 feet lower in surface elevation than either Buffalo or Antelope Springs. Thus, except for isolated occasions, the city wells flow continually under artesian conditions. Artesian conditions exist north of the park boundary for several miles, exactly how far has not been determined. The fresh ground water is derived from the Arbuckle formation while the mineralized Springs originate in the Simpson formation which is shallow and has less artesian pressure. In fact, the mineralized Springs have for all practical purposes ceased to flow under artesian conditions, and the public springs in the park are pumped so that the park patrons can have access to the famous sulphur water of reputed medicinal value. The ground water supply from Buffalo and Antelope Springs to Traver-tine Creek will cease to exist if "mining" of the aquifer continues.

IMPACTS OF LAND USE ON WATER QUALITY

Land Use Activities

The water quality of the Rock Creek watershed is a function of the adjacent land use. Dispersed pollution from agricultural and forest lands, urban runoff and the point sources discharging into the creek affect its quality. Land use for the 124 square mile area of the Rock Creek watershed above the dam is shown in Figures 15 and 16 and summarized in Table 19.

Table 19. LAND USE, ROCK CREEK WATERSHED

Use	Acres	Percent of Total
Rangeland	42,930	54.0
Pastureland	19,080	24.0
Forest, Upland	7,950	10.0
Cropland	3,975	5.0
Water	3,180	4.0
Urban Area	1,590	2.0
Forest, Bottom	238	0.3

Note: Information from Oklahoma Conservation Commission

Croplands occupy only 5 percent of the total area of the watershed and are mainly located in the Guy Sandy Creek sub-basin. The principal crops grown are oats, alfalfa and wheat. Fertilizer is currently being applied on these croplands at the annual rate of 200 pounds of (10N-20P-10K) fertilizer per acre.

Pasturelands comprise about 24 percent of the total watershed area. Fertilizers are used at the average rate of about 20 pounds of nitrogen per acre to augment the growth of bermuda grass.

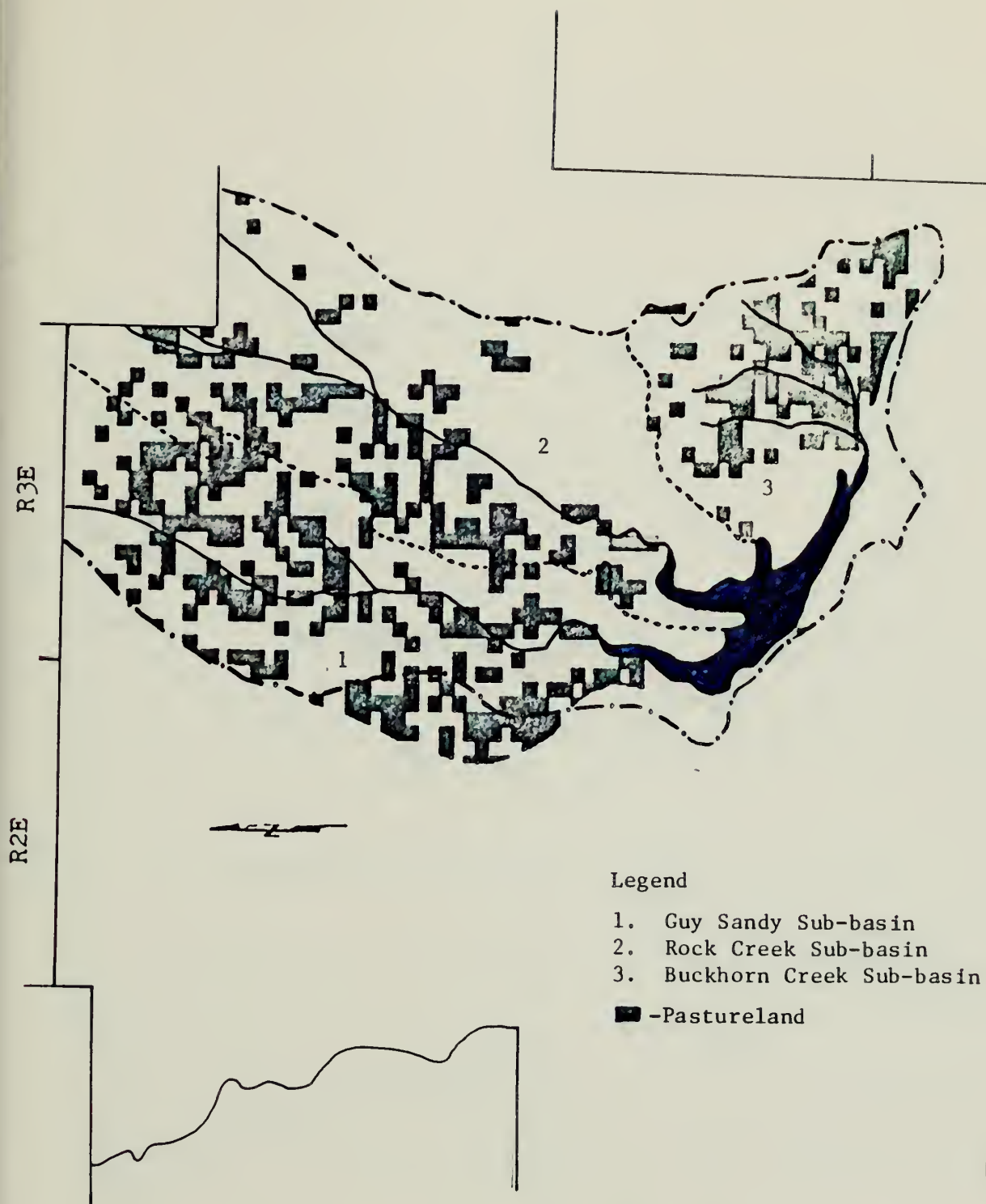


Figure 15. PASTURELAND DISTRIBUTION IN ROCK CREEK WATERSHED.

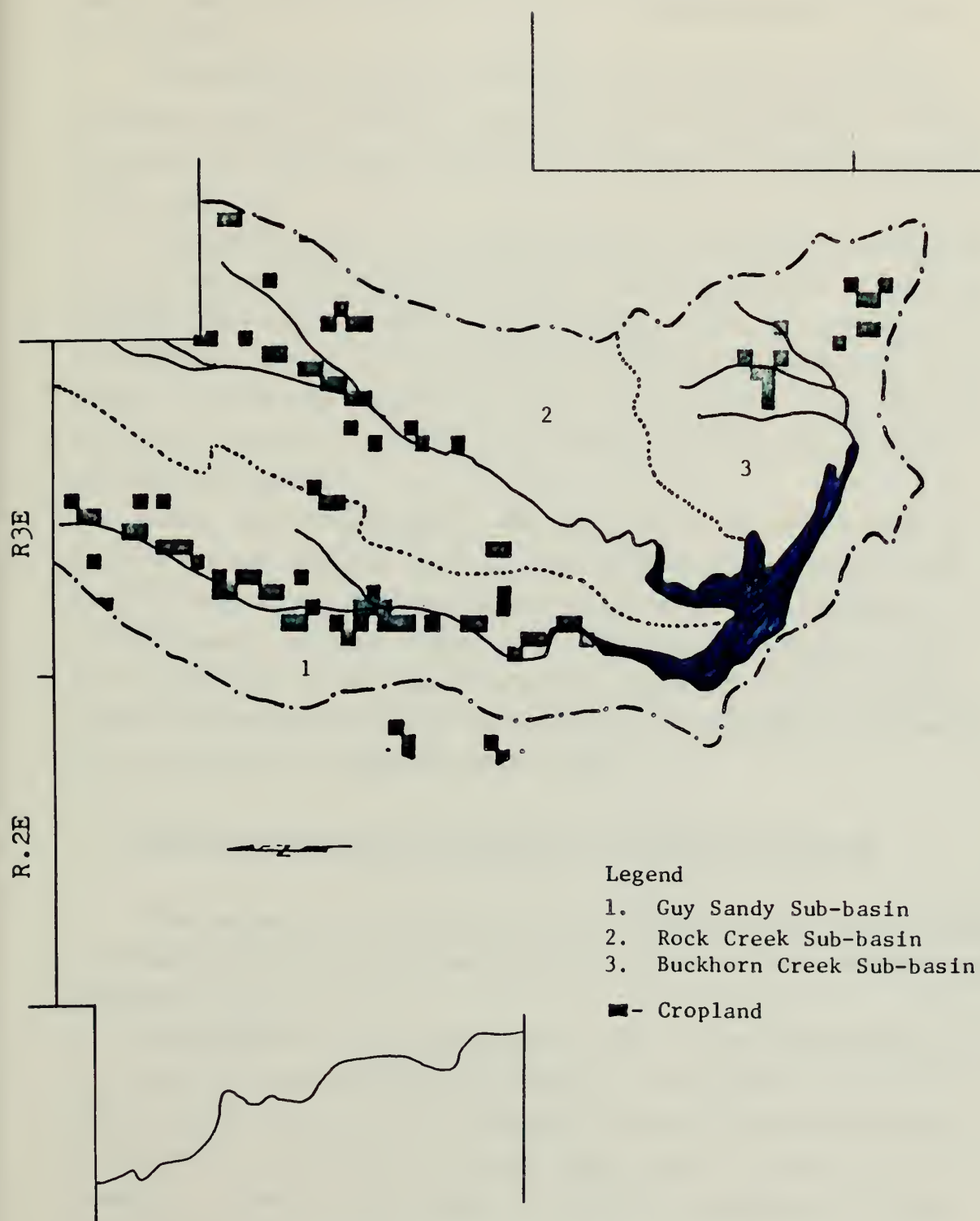


Figure 16. CROPLAND DISTRIBUTION IN ROCK CREEK WATERSHED.

Over half of the watershed area consists of rangeland scattered throughout the basin. About 10 percent of the total area is classified as forestland, principally located south of the lake. Some of the wooded areas along the Washita River are being eradicated for use as rangeland.

Although the urban area comprises only about 2% of the total watershed area, its land use activities are of significance. Listed in Figure 17 are the major industries of Sulphur and their locations in the city.

Increasingly more of the agricultural activities in Murray County are turning to poultry and dairy production with 21 dairy and poultry farms in the watershed area. The dairy farms range in size from 40 to 80 head of cattle per farm while the poultry populations range from 8,000 to 10,000 hens per house. The major reasons for this trend are poor soil structure, fertility and drainage resulting in marginally productive cropland.

Summer home development on the west side of the Lake of the Arbuckles may decrease the water quality by increasing erosion and by the discharge of wastes from improperly designed and constructed waste treatment systems. Since natural drainage is toward the Lake of the Arbuckles it will be the ultimate recipient of these wastes. Another environmental impact of the housing development is sedimentation resulting from highly erodible soils.

Estimates of Nutrient Contribution from Non-Point Sources

The estimates of the amounts of total nitrogen and total phosphorus contributed from different non-point sources in the watershed are shown in Tables 20 and 21.

The amounts of total nitrogen and total phosphorus contributed by runoff and precipitation are obtained by multiplying the yield rates by the surface area of different land uses. The yield rates are generally derived from the lower range given in Table 16 from Loehr (6). However, some values are modified according to data reported by other investigators or to existing land use. The yield

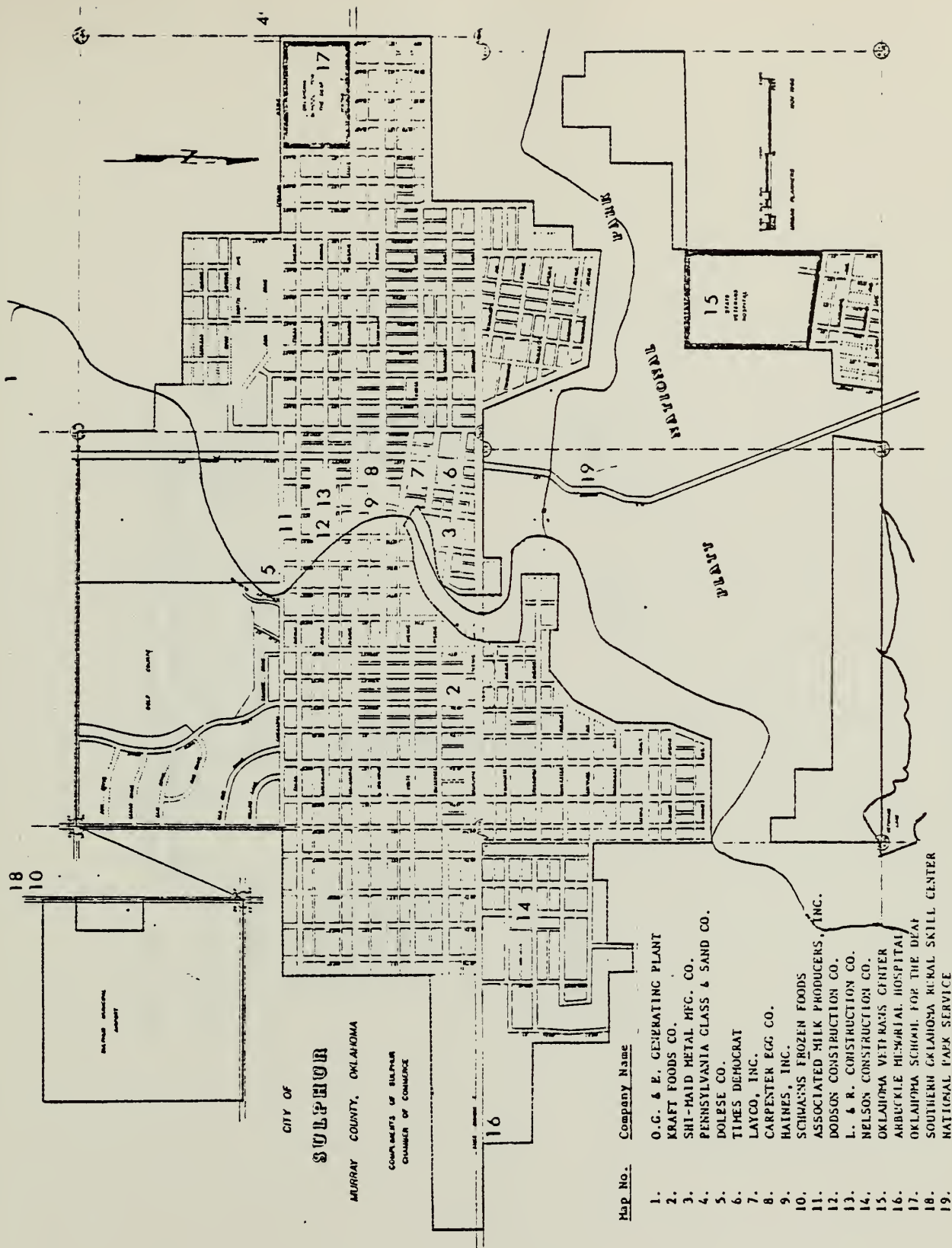


Figure 17. INDUSTRIES OF SULPHUR, OKLAHOMA.

Table 20. ESTIMATES OF ANNUAL AMOUNTS OF NITROGEN
CONTRIBUTED TO LAKE OF THE ARBUCKLES.

Sources	Acres	lbs/yr/ac	Pounds per watershed	Percent
1. Run-off				
Rural Area				
Cropland	3,975	6	23,850	10
Pastureland	19,080	4	95,400	40
Rangeland	42,930	1	42,930	18
Forestland	7,950	1	7,950	3
			<u>170,130</u>	<u>71</u>
Urban Area	1,590	8	12,720	6
2. Precipitation	3,180	10	31,800	13
3. Groundwater	--	--		
		Total	<u>24,350</u>	<u>10</u>
			<u>239,000</u>	<u>100</u>

Table 21. ESTIMATES OF ANNUAL AMOUNTS OF PHOSPHORUS
CONTRIBUTED TO LAKE OF THE ARUBCKLES.

Sources	Acres	lbs/yr/ac	Pounds per watershed	Percent
1. Run-off				
Rural Area				
Cropland	3,975	0.30	1,192	9
Pastureland	19,080	0.20	3,816	30
Rangeland	42,930	0.08	3,434	26
Forestland	7,950	0.05	398	3
			<u>8,840</u>	<u>68</u>
Urban Area	1,590	2.0	3,180	24
2. Precipitation	3,180	0.05	160	1
3. Groundwater	--	--	910	7
		Total	<u>13,090</u>	<u>100</u>

rate of total nitrogen from cropland is derived from those estimated by Sawyer in the studies of three lakes in Wisconsin as reported by Armstrong and Rolich (14). The yield rate of total nitrogen from pastureland is assumed to be equal to 2/3 of that from cropland.

For precipitation, the calculation of contribution of total nitrogen is based on the water area rather than the total land area as indicated by Loehr (6). It is thought that only the precipitation which falls directly on the lake would produce a direct input of nitrogen and phosphorus to the reservoir, the remainder of the precipitation falls on the land and reaches the reservoir by runoff or ground water flows. A value of 10 pounds of nitrogen per acre per year is used based on the results reported by Shah, K.S., on "Sulphur and Nitrogen Brought Down in Precipitation in Wisconsin", 1961 (14). The amount, 31,800 lbs., of nitrogen from precipitation (Table 20) is comparable to that obtained by calculation from an average concentration in precipitation (1.2 mg/l) and the mean annual precipitation in the area (38 in.).

For ground water, the contributions of nitrogen and phosphorus are estimated from flow measurements and analysis of concentrations of nitrogen and phosphorus in periods of low flow when the ground water appeared to be the predominant contributor and no effect of runoff was expected. The ground water flow is estimated at 10 mgd and concentrations of 0.8 mg/l of nitrogen and 0.03 mg/l of phosphorus are assumed.

Referring to Tables 20 and 21, the relative importance of various sources is estimated as follows:

1. The largest contribution is estimated to be from the rural area, accounting for 71% of nitrogen and 68% of phosphorus. In this category pastureland is the largest contributor with about 40% of nitrogen and 30% of phosphorus. The second largest contributor is rangeland which accounts for 18% of nitrogen and 26% of phosphorus. Cropland contributes only 10% of nitrogen and about 9% of phosphorus because of its small area.
2. Urban area contributes about 6% of the nitrogen but is a large contributor of phosphorus (24%).
3. Contribution from precipitation is more significant in terms of nitrogen (13%) than in terms of phosphorus (1%).

4. Ground water contributes about 10% of the nitrogen and 7% of the phosphorus but the amount of nitrogen contributed is many times greater than that of phosphorus.

No estimate was made for the discharge of nitrogen and phosphorus at Rock Creek below the dam nor for the lake sediments due to the lack of quantitative data.

RESULTS OF FIELD SAMPLING AND ANALYSES

Figure 18 designates the location of each sampling site in the vicinity of the Platt section of the Chickasaw National Recreation Area. Figure 19 gives the locations of the sampling stations on the Lake of the Arbuckles and the tributaries thereto. Several of the sampling sites located on Rock Creek, its tributaries and the Lake of the Arbuckles were chosen to establish a water quality baseline. This facilitates the recognition of the source of any pollutant discharge and assessment of any variation in that quality due to that source. These locations were monitored on a somewhat regular basis during the period beginning June, 1976 and ending July, 1977. Additional sampling sites were located and monitored periodically for the purpose of isolating and identifying sources of pollution.

Sites No. 19-21 are located on Rock Creek upstream from the City of Sulphur for the purpose of establishing background information, i.e., water quality prior to pollution from urban or recreational areas. Sampling sites No. 10-16 and No. 18 are located on Rock Creek throughout the City of Sulphur and the Platt section. Site No. 17 is located below the Sulphur municipal sewage treatment plant for the purpose of determining the extent of pollution originating from the plant.

The results of the analyses of samples collected over the period from June, 1976 through July, 1977 are listed in Tables I-V in the appendix. Table I lists the water quality data for Rock Creek and its tributaries Guy Sandy, Buckhorn and Travertine Creeks and the quality of discharge from a number of point sources of pollution. The water quality data compiled for the various locations on the Lake of the Arbuckles can be seen in Table II. The bacteria data consisting of fecal coliform, fecal strep and total coliform concentrations for the water of Rock Creek and its tributaries are tabulated in Table III. Table IV shows the relationship between recreational use, primary body contact and the water quality of Travertine Creek. Concentrations

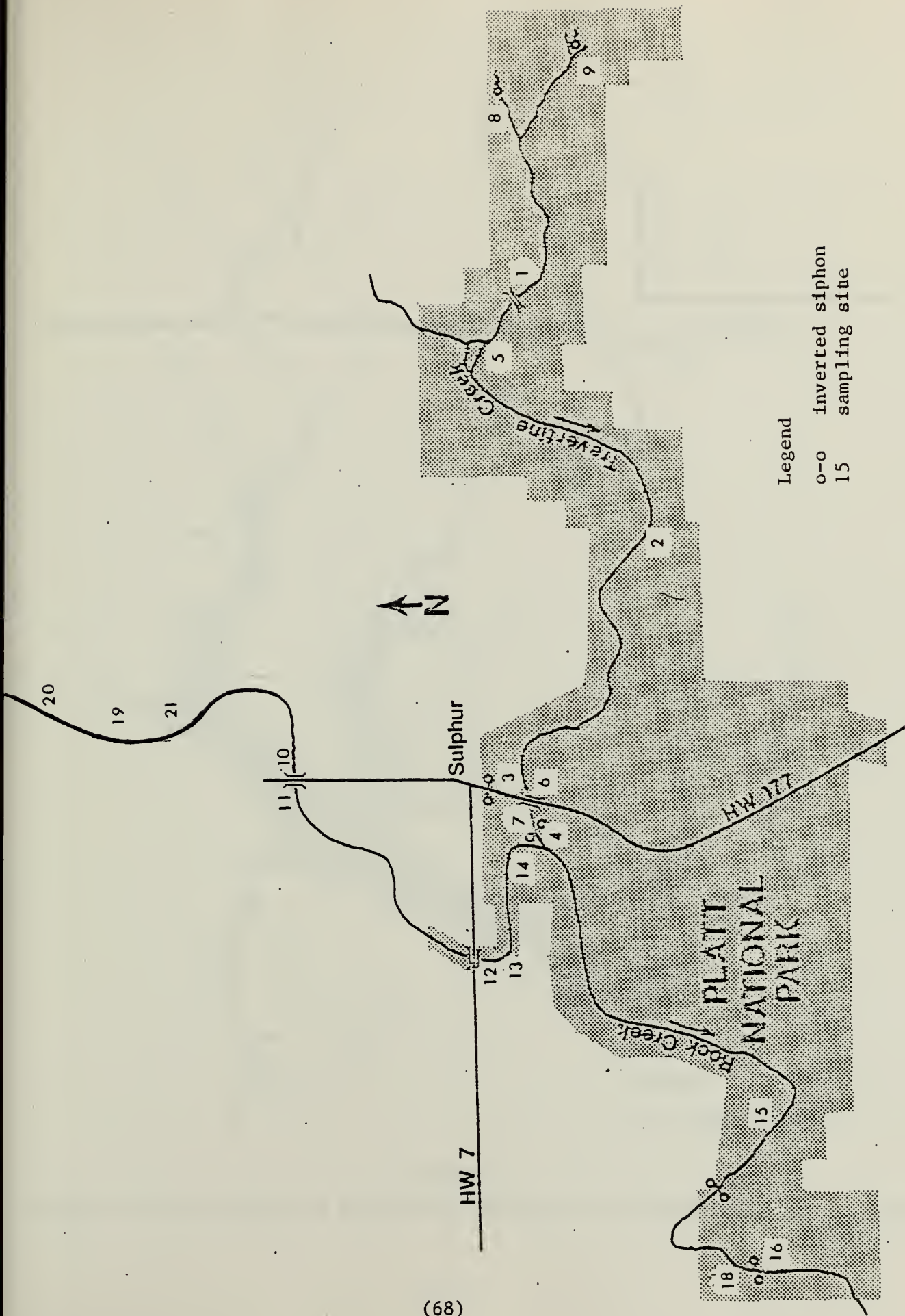


Figure 18. SAMPLING SITES—ROCK CREEK—CHICKASAW NATIONAL RECREATION AREA

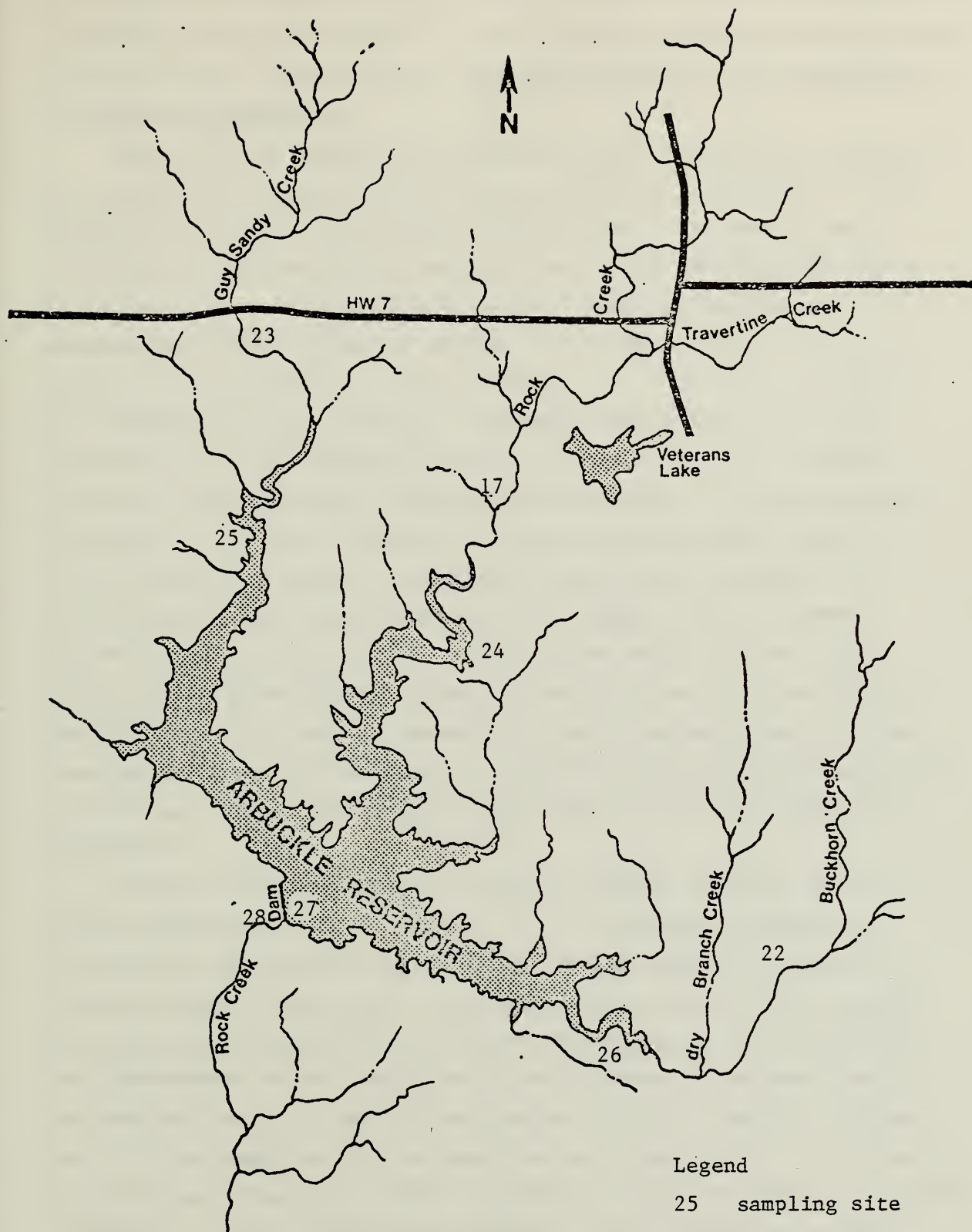


Figure 19.

SAMPLING SITES—ARBUTLE RESERVOIR—CHICKASAW NATIONAL RECREATION AREA

of trace metals present in Rock Creek and its tributaries at selected locations are given in Table V. The laboratory analyses were performed according to the 13th edition of Standard Methods for the Examination of Water and Wastewater.

Table 22 is a summary of the quality data listed in the Appendix. The influence of industrial and urban activities is apparent in the degradation of the water quality of Rock Creek. The most notable variations of the parameters measured are in the COD, TDS, Cl^- and bacterial concentrations. The sources of these pollutants are numerous and their points of introduction to Rock Creek are distributed over the entire reach from sites No. 19 to No. 14. The mean Cl^- concentration was observed to increase from a low of 51.7 mg/l at site No. 20 to a value of 516.0 mg/l at site No. 21. A similar increase in TDS was noted between these two points. These increases have been attributed to the cooling tower blow down water from the O.G. & E. Arbuckle Electric Generating Plant which is permitted by the Oklahoma Water Resources Board to discharge into Rock Creek. The water used by O.G. & E. for cooling water make-up is supplied from a highly mineralized aquifer and would account for the high concentrations of Cl^- and TDS measured in their discharge water. Also associated with this discharge is a high COD concentration, mean value of 50.9 mg/l, which contributes significantly to the COD loading of Rock Creek.

A more dramatic increase in the COD loading, however, was observed between sites No. 21 and No. 11. A livestock holding pen where cattle and hogs are held for the weekly auction in Sulphur is located between these sites. An artesian well flows freely through the pens and discharges over the creek bank directly into Rock Creek. One consequence of the condition is the increase of the mean COD concentrations from 18.6 mg/l at station No. 21 to 30.2 mg/l at station No. 11. The magnitude of the impact on Rock Creek from this source of pollution as a result of runoff following a rainstorm event is depicted in Figure 20. Also associated with this type of pollution source is an increase in the bacterial population of the receiving stream.

Table 22. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA.
(Mean & Standard Deviation for Selected Sites)

Sampling Site Location Site No.	Temp.	D.O.	B.O.D.	C.O.D.	pH	Alk.	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
Above														
O.G.&E. Site 20	mean	11.9	9.72	1.16	10.9	8.0	233.0	51.7	3.0	892	0.140	0.333	0.037	0.003
	S.D.	2.46	1.28	0.76	9.17	0.70	29.7	54.5	2.83	198.5	0.198	0.050	0.033	0.004
O.G.&E. Site 19	mean	22.9	9.60	---	50.9	7.4	---	1338.0	1.50	4892	2.20	0.150	0.00	0.00
	S.D.	2.19	1.8	---	52.8	0.37	---	67.2	0.71	162.5	---	0.057	---	---
Below														
O.G.&E. Site 21	mean	13.3	9.72	1.16	18.6	7.4	161.0	516.0	3.33	3118	0.070	0.215	0.033	.010
	S.D.	2.86	2.17	0.23	14.54	0.78	29.7	284.6	2.08	511.7	0.099	0.219	0.003	0.014
Rock Creek														
HY 177	mean	18.12	9.08	1.30	30.2	8.1	218.0	266.9	15.2	1490	0.748	1.304	0.044	0.010
Site 11	S.D.	6.8	1.74	0.45	37.96	0.53	50.3	214.8	20.7	871.6	1.244	2.16	0.035	0.014
Rock Creek														
HY 7	mean	17.3	9.62	1.49	29.1	8.1	168.6	250.0	3.2	1533	0.205	0.469	0.068	0.039
Site 12	S.D.	8.37	2.24	0.90	25.89	0.52	103.3	189.7	4.6	824.1	0.181	0.656	0.056	0.038
Sandy Beach														
Site 14	mean	18.0	8.99	2.28	28.3	8.1	225.0	199.5	8.8	1454	0.181	0.558	0.224	0.151
	S.D.	8.04	2.37	2.03	25.7	0.55	38.5	165.6	6.8	752.1	0.155	0.517	0.327	0.221

Temperature (°C)

TDS (micromhos)

All others (mg/l)

Table 22. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA. (continued)
(Mean & Standard Deviation for Selected Sites)

Sampling Site Location Site No.	Temp.	D.O.	B.O.D.	C.O.D.	pH	Alk.	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P	
Camp															
Grounds	mean	15.5	10.4	1.71	24.5	8.2	241.0	326.0	11.0	1528.4	0.613	0.110	0.572	0.095	0.260
Site 18	S.D.	7.71	2.28	1.25	23.0	0.61	18.4	157.7	11.4	650.3	0.770	0.076	0.636	0.091	0.324
N.C.	mean	20.5	8.6	0.47	11.9	8.3	342.0	2.3	3.9	548.6	-----	-----	-----	-----	-----
(Trav.)	S.D.	1.7	1.1	0.38	11.1	0.42	70.5	1.26	2.44	3.78	-----	-----	-----	-----	-----
Site 1															
Trav.															
Below															
Swim.	mean	14.25	10.0	1.44	30.3	8.2	252.0	5.5	-----	517.1	0.090	0.00	0.230	0.0	0.015
Site 2	S.D.	7.7	2.3	.65	39.1	.71	0.0	3.54	-----	23.6	-----	-----	-----	-----	-----
Lincoln															
Bridge	mean	15.6	9.7	0.78	19.7	8.0	250	216.0	11.3	1076.5	0.223	0.043	0.625	0.031	0.008
Site 7	S.D.	4.65	1.10	0.471	21.48	0.50	-----	37.69	8.33	438.7	0.271	0.012	0.675	0.029	0.008
Buckhorn															
Creek															
HY 177	mean	16.0	10.5	1.59	13.6	8.35	-----	15.5	15.0	489	0.303	0.485	0.773	0.040	0.003
Site 22	S.D.	6.68	1.50	1.59	9.56	0.34	-----	.71	-----	72.4	0.152	0.181	0.665	0.007	0.003
Guy Sandy															
Creek															
HY 7	mean	17.1	9.4	1.04	13.7	8.30	-----	25.0	14.0	466	0.079	0.165	1.03	0.053	0.020
Site 23	S.D.	7.82	1.45	0.74	9.8	0.4	-----	-----	-----	86.0	0.041	0.021	0.424	0.025	-----

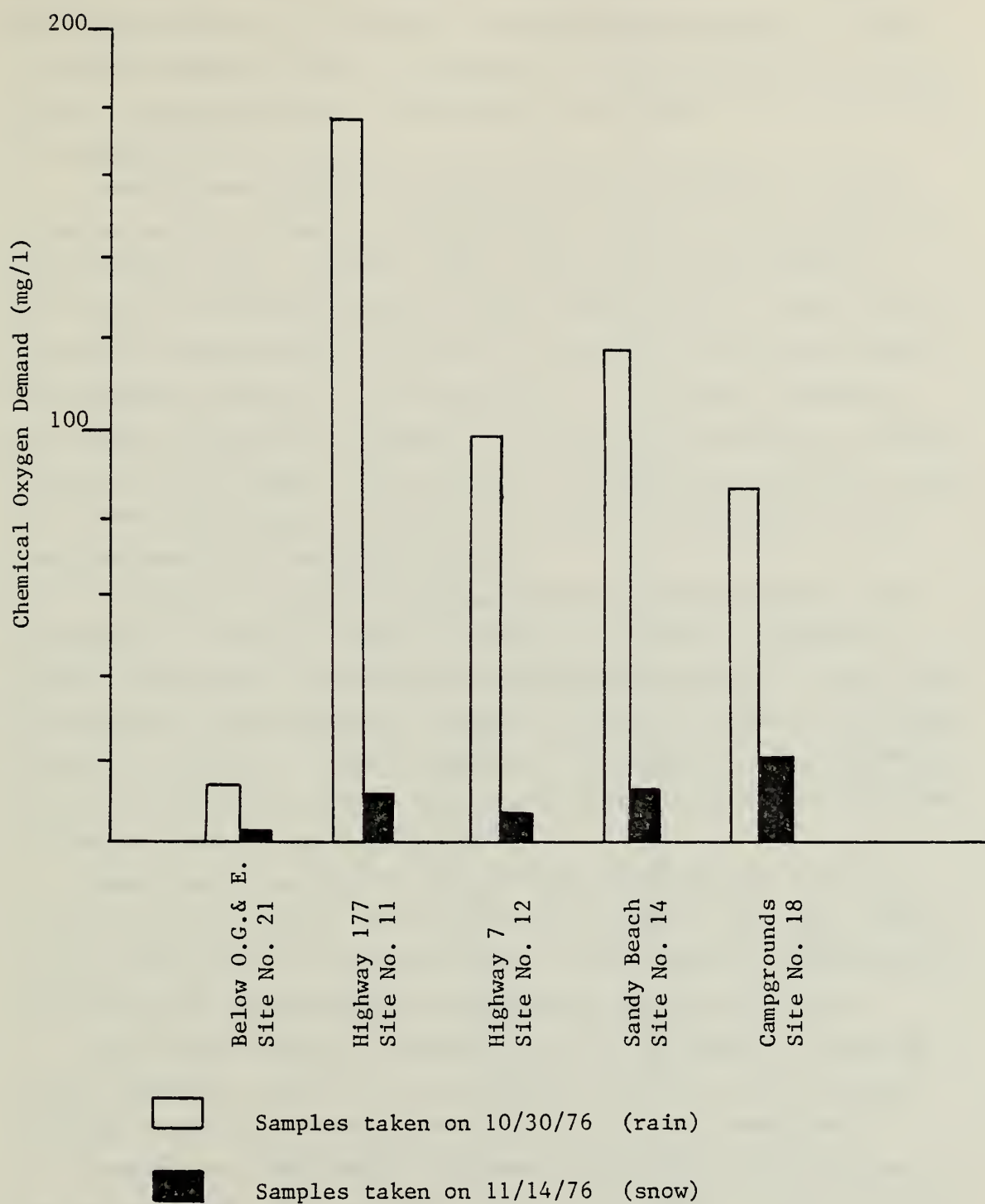


Figure 20. EFFECT OF URBAN RUNOFF ON WATER QUALITY OF ROCK CREEK, IN TERMS OF COD.

This is shown in Table III and graphically demonstrated in Figure 21. The fecal streptococci concentrations increase tremendously between these two sampling sites. The ratios of fecal coliform/fecal streptococci are consistent with published values (Table 23) for pollution from animal sources.

Another area of frequent high bacterial contamination on Rock Creek is in the proximity of Sandy Beach, site No. 14, also known as Black Sulphur Beach. However, this location generally exhibits a FC/FS ratio consistent with or at least suggestive of a human source. These high concentrations of fecal coliform and fecal strep prompted reconnaissance surveys of the upstream area. On several occasions raw sewage was observed flowing from breaks in the sewer line running parallel to Rock Creek. These breaks, discharging raw domestic wastes at a flow large enough to discolor the creek, were observed in the reach between Sandy Beach and Highway 7.

On several occasions following rainstorm events manholes, associated with inverted siphons crossing Rock Creek in a number of places (Figure 18), were observed overflowing directly into the creek. The sanitary sewer collection system of Sulphur in general and broken lines in particular are very important contributors to the contamination and degradation of Rock Creek as reflected in the data presented in Tables I and III in the Appendix.

Sandy Beach recorded the highest BOD concentration, 9.0 mg/l, of any location sampled. The mean value for BOD was 2.3 mg/l, which is also higher than for any other site. The relative significance of this source of pollution can be graphically shown in Figure 22.

The quality generally improves as the creek passes through the Platt section in part due to the dilution effect of the confluence of Rock Creek and Travertine Creek within the park boundaries.

Travertine Creek, which originates within the park boundaries, is fed by two fresh water springs, Antelope and Buffalo (sites No. 8 and No. 9, Figure 18), and the flow from the Vendome Well, which is highly mineralized water from the same aquifer as the cooling water make-up supply used by O.G. & E. The quality of Travertine Creek is generally higher than that of Rock Creek. The storm sewer drainage culvert

Figure 21. COMPARISON OF FECAL COLIFORM TO FECAL STREP CONCENTRATIONS

(No. of colonies/100 ml) (1/21/77)

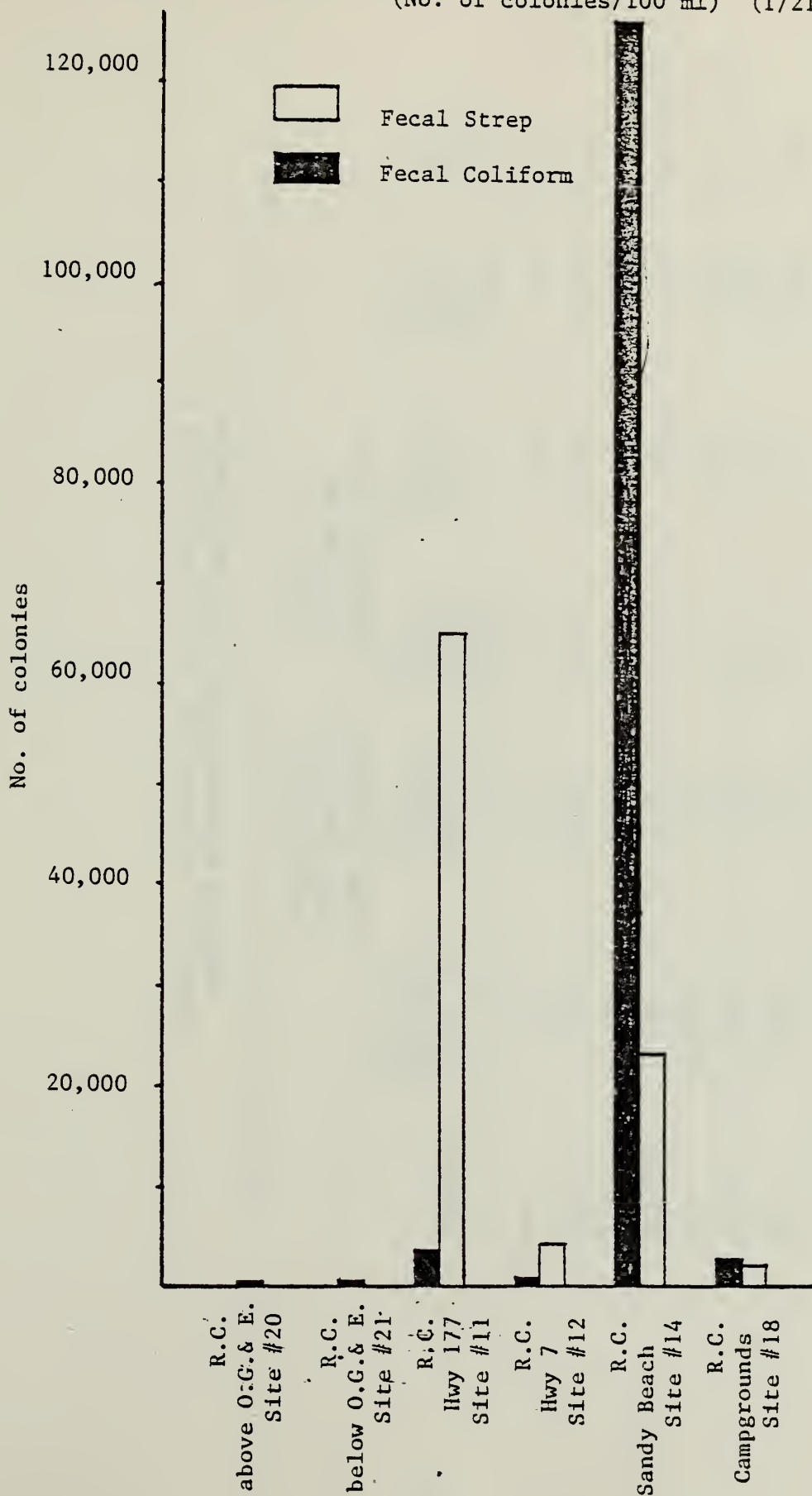


Table 23. ESTIMATED PER CAPITA CONTRIBUTION OF
INDICATOR MICROORGANISMS FROM SOME ANIMALS*. (28)

Animals	Avg wt of feces/24 hr, wet wt, g	Average indi- cator density per gram of feces		Average con- tribution per capita per 24 hr			Ratio FC/FS
		Fecal coliform, million	Fecal strepto- cocci, million	Fecal strepto- cocci, million	Fecal coliform, million	Fecal strepto- cocci, million	
Man	150	13.0	3.0		2,000	450	4.4
Duck	336	33.0	54.0		11,000	18,000	0.6
Sheep	1,130	16.0	38.0		18,000	43,000	0.4
Chicken	182	1.3	3.4		240	620	0.4
Cow	23,600	0.23	1.3		3,400	31,000	0.2
Turkey	448	0.29	2.8		130	1,300	0.1
Pig	3,700	3.3	84.0		8,900	230,000	0.04

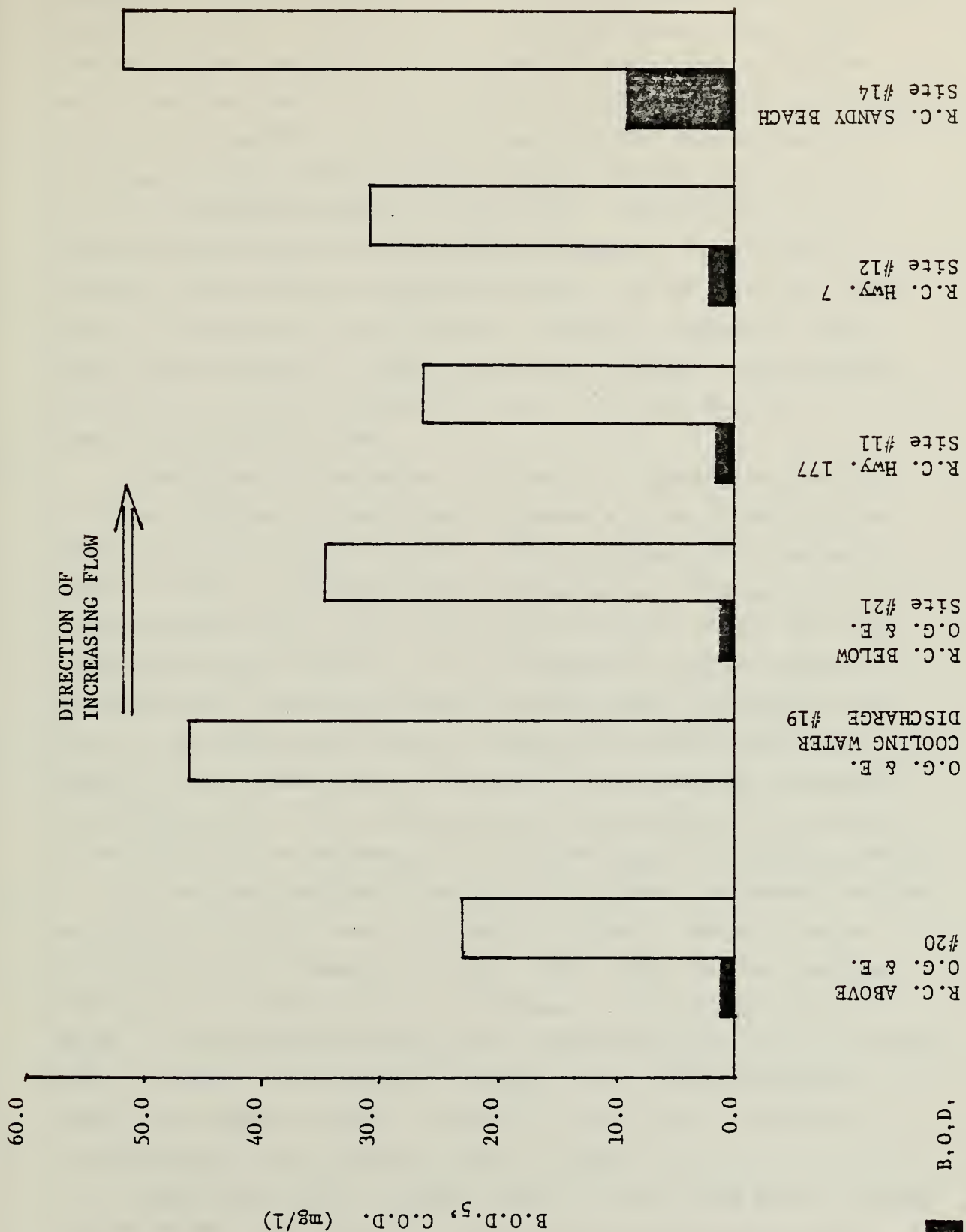


FIG. 22: B.O.D.₅, C.O.D. LOADINGS FOR REACH OF ROCK CREEK (1/21/77).

(site No. 3, Figure 18) was observed to be a constant source of pollution to Travertine. This culvert collects storm and other runoff from the streets and yards in this area of Sulphur and discharges into Travertine Creek. Although the flow from this culvert was generally very low, the BOD concentrations and bacterial populations were very high. During periods of storm runoff, however, both the flow and the polluttional loading are significant. The bacterial concentration upstream from this source was observed to be within the allowable limits for the intended beneficial use of Travertine Creek under low recreational use conditions. However, during the summer months and especially on high use days the bacterial concentrations were found to increase considerably due to swimming activities in the many pools along the creek.

A comparison of the number of swimmers in Travertine Creek and the total coliform concentrations indicates a close correlation between the two (Figures 23 and 24). The lag between the observed increase in number of swimmers and a corresponding increase in the coliform concentrations is due to the "time-of-travel" of the flow from the uppermost pool (site No. 5) to the sampling location (site No. 2). An examination of the FC/FS ratios produced mainly inconclusive results as the values were erratic, ranging from greater than one, suggestive of a human source, to values of less than one, suggesting a non-human source. The inconsistencies were thought to be a result of pet dogs observed swimming in Travertine during the sampling period.

The very high nutrients loading of Rock Creek has several sources. As the data of Table I and the graph of Figure 25 reveal, a major contributor to the inorganic nitrogen ($\text{NO}_3^- + \text{NH}_3$) is the discharge from O.G.& E. Another source of nitrogen, mainly in the form of $\text{NH}_3\text{-N}$, is the livestock holding pens upstream from site No. 11. Besides being a source of high organic loading to Rock Creek the broken sewer line between sites No. 12 and No. 14 is a major contributor of both phosphorus and nitrogen as seen in Figure 25.

A comparison of the pollutant levels of Rock Creek prior to entering the Sulphur area (site No. 20) and the concentrations as the

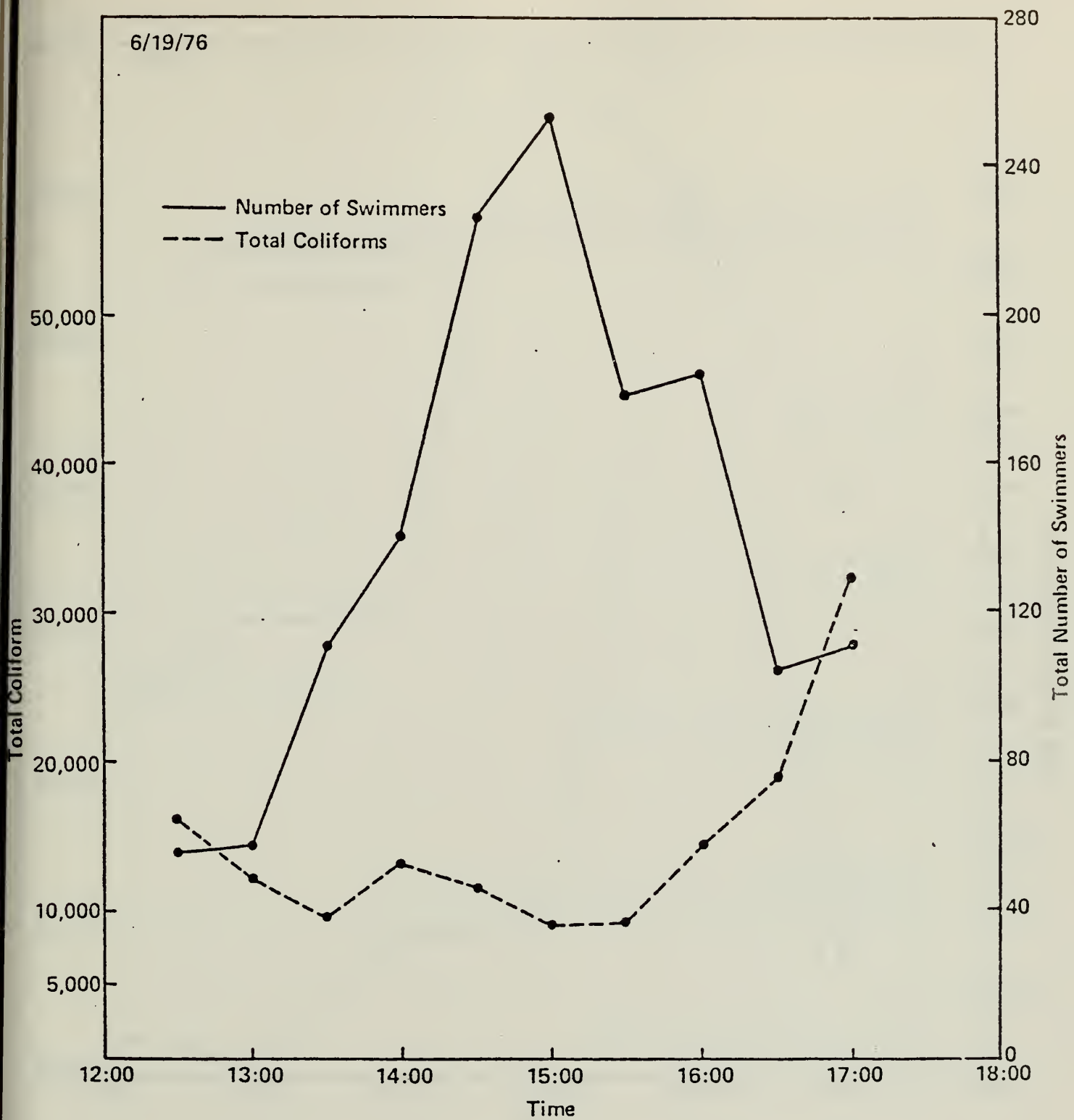


Figure 23. TOTAL NUMBER OF SWIMMERS vs TOTAL COLIFORM AT TRAVERTINE AT SITE NO 2.

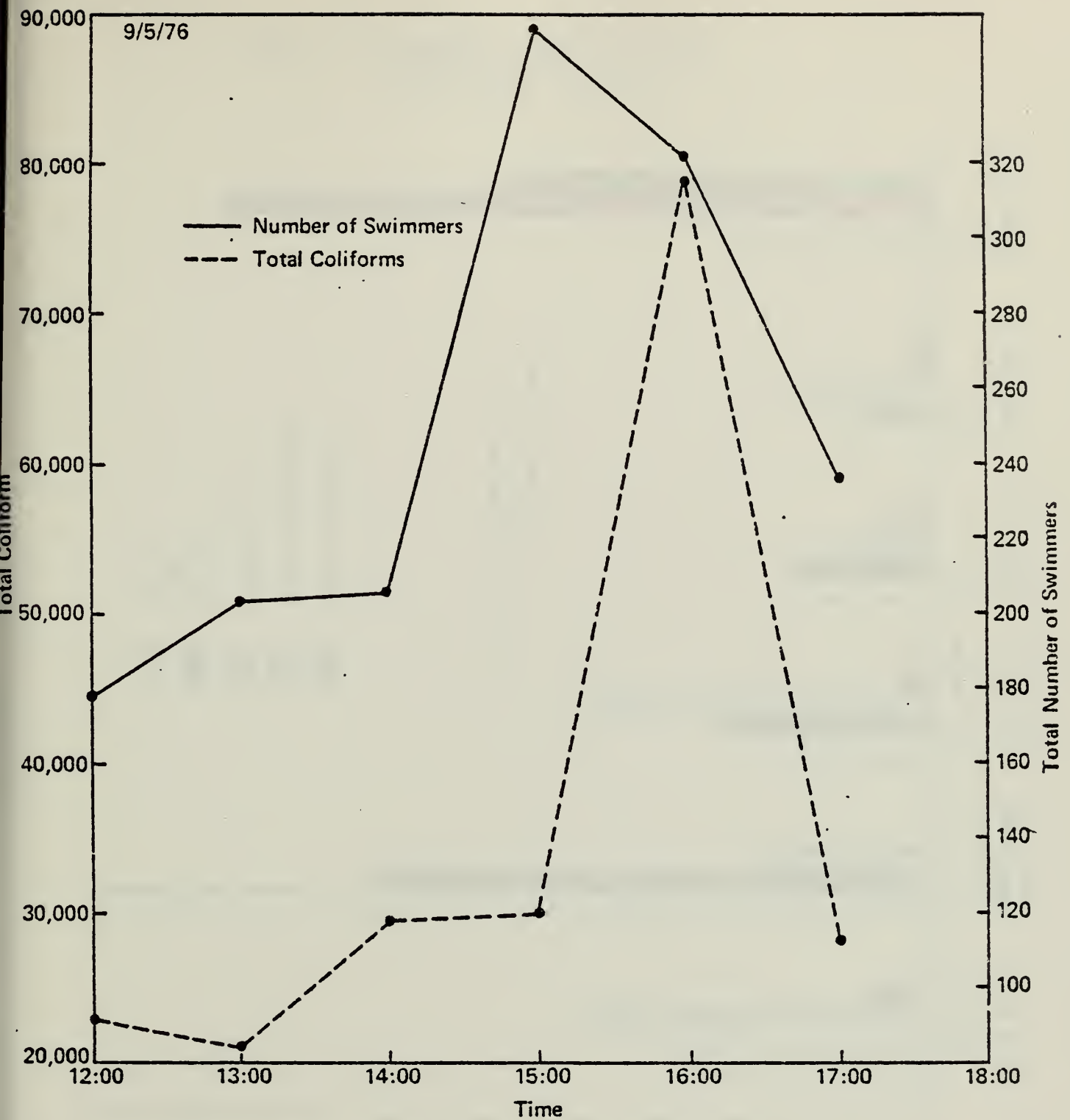
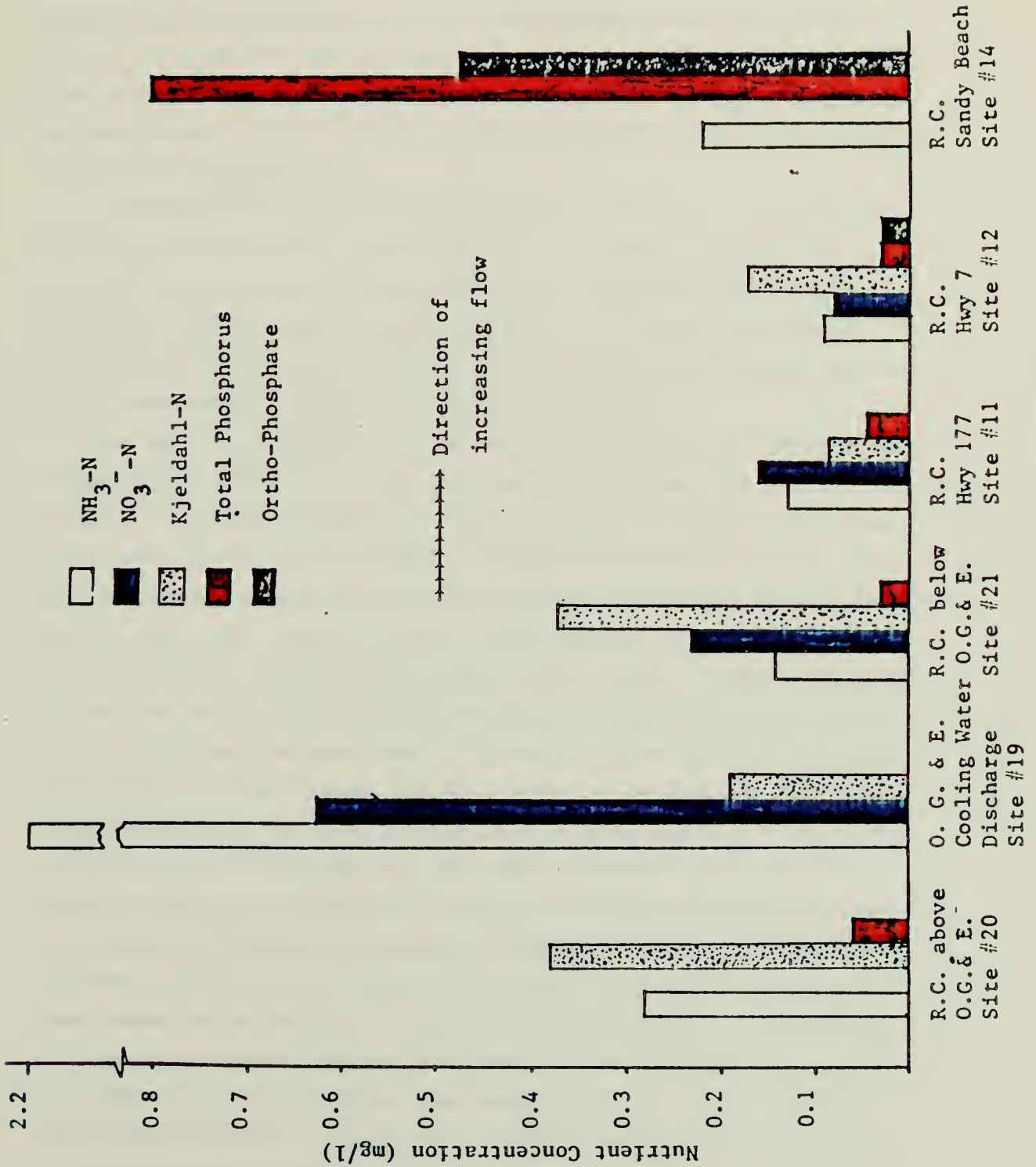


Figure 24: TOTAL NUMBER OF SWIMMERS vs TOTAL COLIFORM AT TRAVERTINE AT SITE NO 2.

Figure 25. NUTRIENTS LOADING FOR REACH OF ROCK CREEK (1/21/77).



creek leaves the park area (site No. 18) indicates a significant increase in organics (as indicated by BOD and COD concentrations), nutrients (nitrogen and phosphorus) and total dissolved solids. Coupled with the increase in flow of Rock Creek as it leaves the park it is clear the major contribution of organics and nutrients are from industrial, urban and recreational activities. The high TDS are associated with the highly mineralized aquifer supplying a portion of the flow of Rock Creek.

A comparison of the water quality of Rock Creek, Guy Sandy and Buckhorn Creeks provides some insight to the impact of land use activities. The relative distribution of pastureland and cropland in the Rock Creek watershed (Figures 15 and 16) and the industrial, urban and recreational activities of the Rock Creek sub-basin provide a considerable contrast of land use patterns.

The major tributaries to the Lake of the Arbuckles, Rock Creek, Guy Sandy and Buckhorn Creeks, were sampled at locations No. 18, No. 22 and No. 23 as seen in Figure 16. Comparison of the data from these sites leads to the conclusion that the total dissolved solids, ammonia nitrogen, phosphates and the organics as measured by the chemical oxygen demand are higher for Rock Creek than for either Buckhorn or Guy Sandy Creeks. The higher organic (COD) levels in Rock Creek than in Buckhorn or Guy Sandy Creeks are due to runoff from the urban area and the stock holding pens and to discharges from O.G. & E. and from the inadequately maintained domestic waste collection system of the City of Sulphur. The higher phosphates in Rock Creek are due to the municipal waste discharges and the higher ammonia level to both domestic wastes and wastes from O.G. & E. and the stock holding pens. The nitrate and organic nitrogen are higher for both Buckhorn and Guy Sandy than for Rock Creek. The primary contributor on the Guy Sandy basin is agriculture. The source of nitrogen to Buckhorn was not isolated; however, a possible source is the catfish farm located approximately $\frac{1}{2}$ mile upstream from sampling site No. 22. Further investigation would be necessary to isolate and identify the source of nitrogen in this sub-basin.

Although the data seems to indicate that industrial, urban and recreational activities are the major contributors to the nutrient loading of Rock Creek watershed, it must be realized that the study year was an unusually dry year. During periods of high runoff in the watershed, larger contributions from croplands, principally located in the Guy Sandy sub-basin and to a lesser extent in the Rock Creek sub-basin, will result. Pasturelands and rangelands, more densely located in the Guy Sandy and Buckhorn Creek sub-basins, will also result in much higher loadings of nutrients from the respective sub-basins than were observed during this study.

The ultimate impact of the quality of water of Rock Creek, Guy Sandy and Buckhorn Creeks is on the quality of the Lake of the Arbuckles, an important resource serving thousands of people annually. The lake provides recreational opportunities for the general public and water supplies for several municipalities of the area. The maintenance of the quality of water of this lake is of the utmost importance to insure the continued benefits of its intended use.

Figure 19 shows the sampling sites located on the Lake of the Arbuckles. Samples were collected from the three major arms of the lake, Rock Creek, Guy Sandy Creek and Buckhorn Creek, and from a site near the dam and the outflow from the spillway. These various sites are indicated by Nos. 24-28 on Figure 19.

Attention is focused on the degree of eutrophication of the lake since it impacts on the water quality and therefore on the beneficial uses of the lake. Eutrophy is defined in general terms as the enrichment due to nutrient addition to the lake system. The major constituents which either limit or increase the productivity of a lake are phosphorus, nitrogen and carbon. Phosphorus is generally considered to be the most important factor in the control of eutrophication since carbon is abundant from the atmosphere and nitrogen fixers are prevalent in natural aquatic systems.

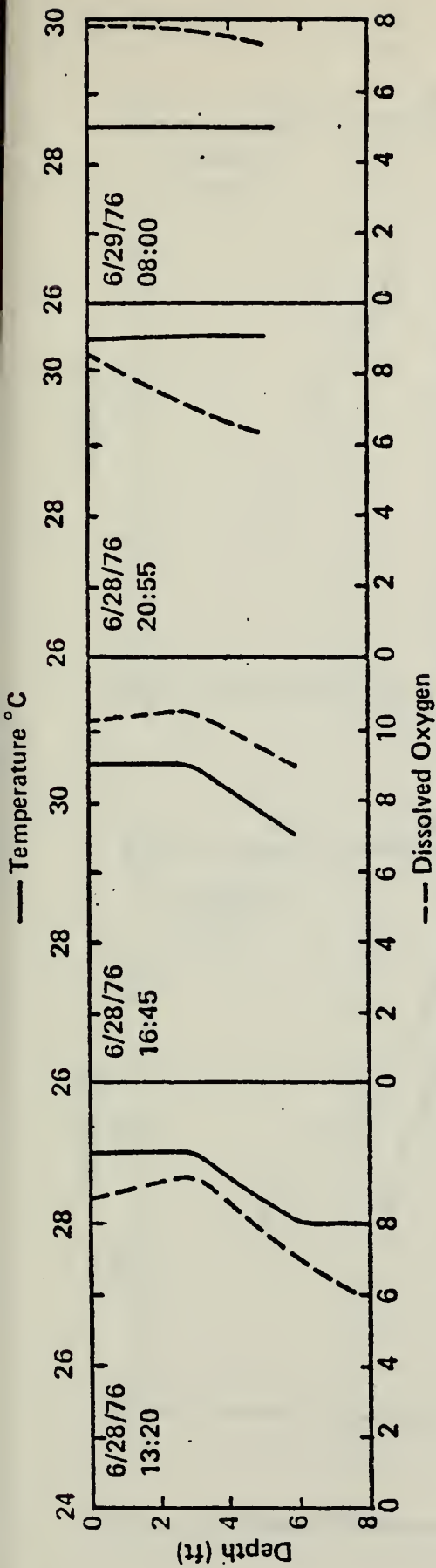
The nutrient loading from the Rock Creek watershed is sufficient to support accelerated growth of algae and other aquatic plants. In fact, during the summer months of 1976 and 1977 spectacular algal blooms

were observed often in Rock Creek and its tributaries. Further evidence of nutrient enrichment of these waters is the supersaturated dissolved oxygen conditions observed during sunlight hours in the spring and summer as a result of oxygen-producing algae.

In the Lake of the Arbuckles itself accelerated eutrophication is evident from the graphs of Figures 26-28. The variations in the dissolved oxygen profiles with time, i.e., the high concentrations during sunlight hours and the rapid depletion of oxygen during the hours of darkness, are indicative of accelerated eutrophication. The diurnal dissolved oxygen and temperature profiles of the waters near the dam (Figure 28) show the activity in the epilimnion and the oxygen depleted conditions of the hypolimnion. As fish generally require a minimum of approximately 2 mg/l of dissolved oxygen to sustain life, the extent of the oxygen depleted waters confines their activities to the reduced volume of the upper higher temperature epilimnion. This may result in a shift of species predominance and possibly the complete eradication of some species in the lake.

Another harmful effect of a highly eutrophied lake is the production of nuisance odors and tastes as a result of anaerobic decomposition of organic matter in the hypolimnion. The waters of the hypolimnion were found to be anaerobic during the summer stratification due to high organic concentrations (Table II). The high concentration of organics found near the bottom are likely the result of a highly productive epilimnion and the decomposition of vegetation remaining on the lake floor during initial filling of the lake. As phytoplankton rain down from the epilimnion into the hypolimnion and expire, they contribute to the organic loading in this region.

Illustrative of the change which occurs in the lake following the spring circulation and the occurrence of stratification during the summer is the graph of Figure 29. During the spring circulation the entire lake is mixed providing an adequate concentration of dissolved oxygen to the bottom of the lake. Following summer stratification the oxygen is rapidly depleted in the hypolimnion to the metalimnion region as a result of the organic loading and lack of re-



Diurnal Dissolved Oxygen and Temperature Study of Rock Creek Arm

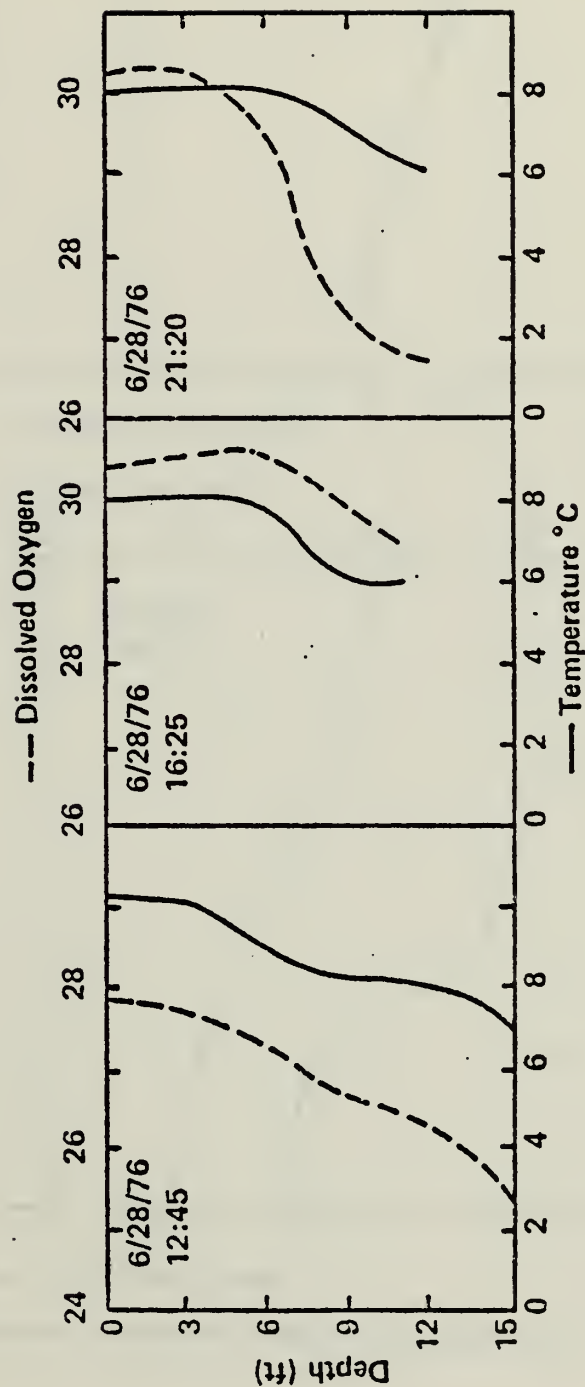


Figure 26. Diurnal Dissolved Oxygen and Temperature Study of Guy Sandy Arm

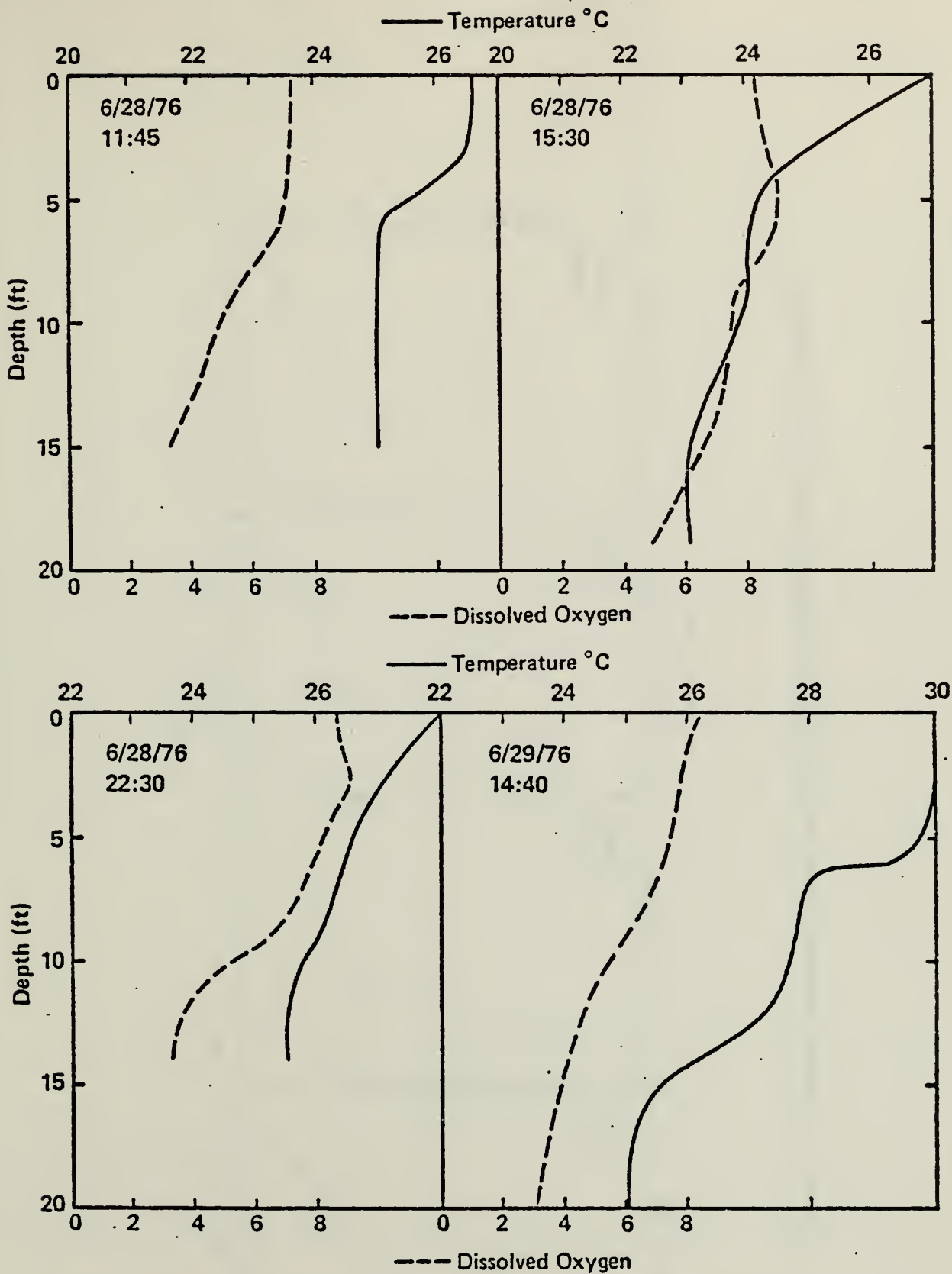


Figure 27. Diurnal Dissolved Oxygen and Temperature Study of Buckhorn Arm

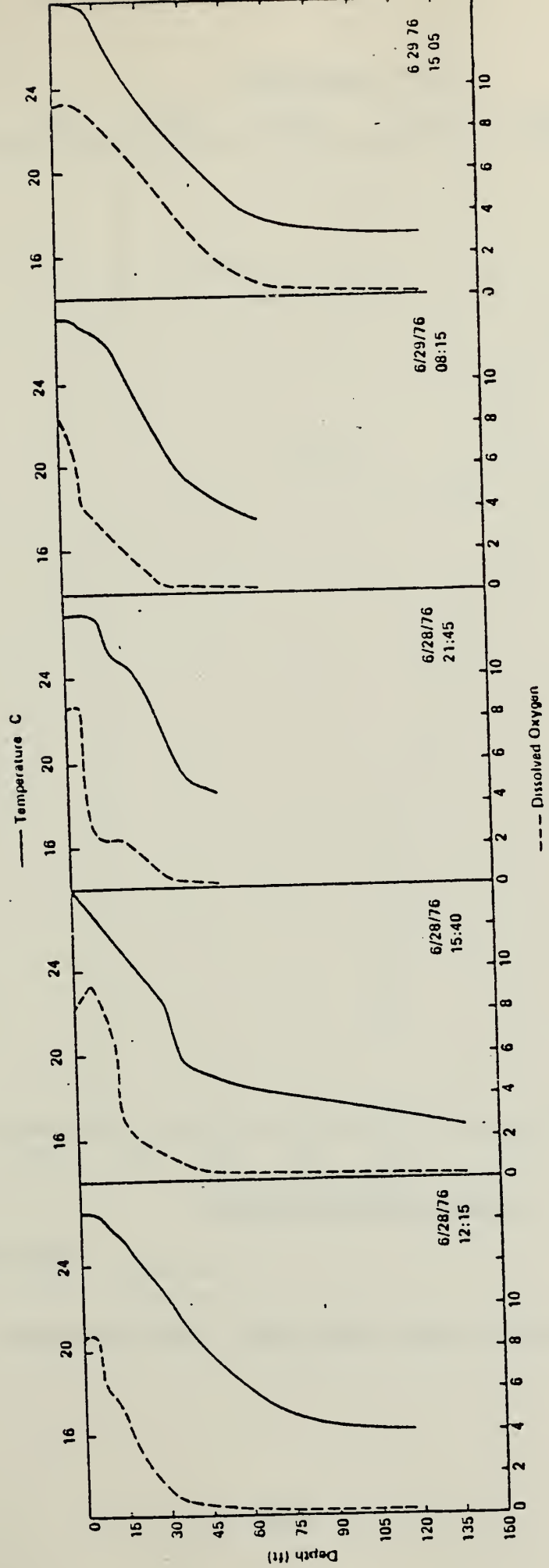


Figure 28. Diurnal Dissolved Oxygen and Temperature Study near dam of Arbuckle Reservoir

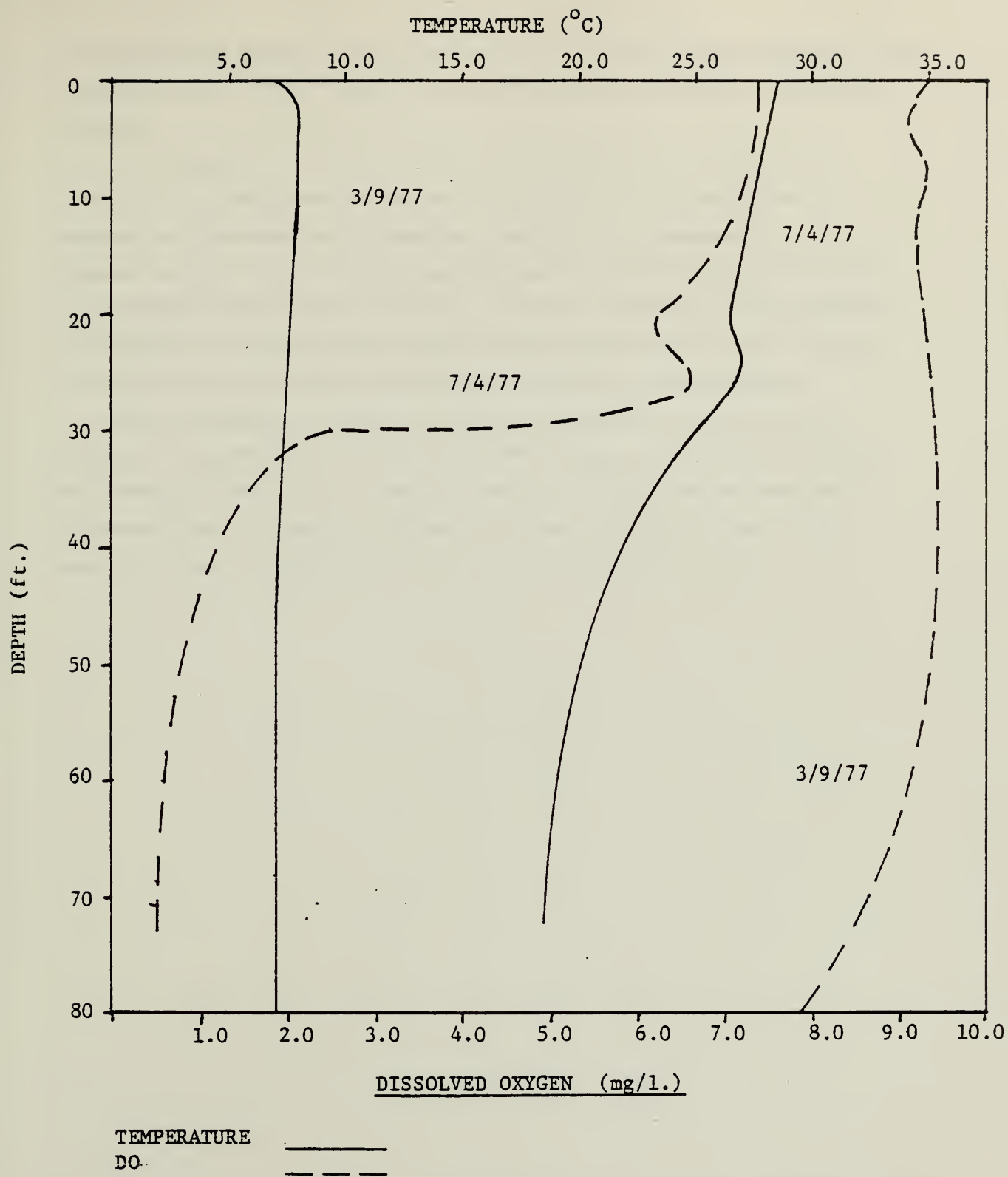


Figure 29. DISSOLVED OXYGEN, TEMPERATURE PROFILE, SITE 27 (SPRING, SUMMER, 1977)

plenishment of oxygen to the hypolimnion. A more direct measure of the eutrophication of the lake is the nutrient level present in analyzed samples.

As indicated in Table II the concentrations of nutrients observed in the lake from sites No. 25 and No. 27 are sufficient to support accelerated eutrophication. Sawyer (14) suggests a phosphorus level of 0.01 mg/l and nitrogen concentration of 0.3 mg/l as minimum concentrations required. Further evidence of the nutrient enrichment is the spectacular algal blooms observed in June of 1976 in Rock Creek just downstream from the Arbuckle Lake spillway.

The detrimental effects of lake eutrophication can be quite extreme. The depletion of the dissolved oxygen can result in sudden and massive fish kills. Odors and tastes produced by the anaerobic decomposition of organics detract from the aesthetic value of the lake and result in limited use as a municipal water supply.

SUMMARY AND CONCLUSIONS

The water quality of Rock Creek through the City of Sulphur and the Platt section of the Chickasaw National Recreation Area is below the standards established by the Oklahoma Water Resources Board for the designated beneficial uses of that stream. The sustained flow for Rock Creek, which is a result of runoff and spring flow from land area several miles upstream from the boundary of the recreation area, traverses through rangeland, livestock holding pens, industrial property and the City of Sulphur. Sources of pollution along this stream segment include: runoff from cattle and swine feeding and holding pens; waste discharge from O.G. & E.; runoff from city streets; and, inadvertant discharges from a poorly maintained, inadequate waste collection system from the municipality. As a result of these sources of pollution the nutrient concentrations and the fecal coliform levels are being violated. The fecal coliform levels from all sampling sites on Rock Creek, above and through the Platt section, were usually much greater than the established standard of 200/100 ml as a geometric mean determined by the membrane filter procedure.

The standard for nutrients was violated as determined by chemical analyses and visual observations. The standards limit the total phosphorus and the nitrogen/phosphorus ratio to concentrations which prevent eutrophication problems. These concentrations were exceeded resulting in observable algal blooms and concomitant water quality problems downstream in the Lake of the Arbuckles.

Other consequences of the degraded water quality of Rock Creek as a result of pollution from the industrial and urban activities are reduced aesthetic value and the loss of a very large portion of the waters of the Platt section to park visitors as a recreational facility. All of Rock Creek flowing through the park is contaminated to a degree requiring restriction of swimming for health reasons.

The water quality of Travertine Creek is higher than that for Rock Creek since the sustained flow for Travertine emerges within the boundary of the recreation area and therefore is not subjected to pollution from urban and industrial activities. It remains relatively unpolluted except for the impact of the recreational activities within the National Recreation Area. During periods of high use, however, a noticeable increase in the number of total fecal coliforms was observed below the swimming areas. A direct relation between the number of swimmers and the fecal coliform count was observed.

The sub-basins of Guy Sandy and Buckhorn Creeks, in general, produced a higher quality water than that of the Rock Creek sub-basin; however, the potential for a significant contribution of nutrient loading from agricultural activities has been demonstrated by virtue of the much greater percentage of land use for that activity.

The preservation of the Lake of the Arbuckles and maintenance of its water quality is of utmost importance and concern as it serves many people both as a recreational facility and a municipal and industrial water supply. This lake is now and has been for several years a highly eutrophied lake. Several investigators (2, 4, 5) have alluded to the fact that the lake is not as productive as envisioned due to its highly eutrophied state. Summerfelt and Gebhart stated that the fish catch declined from 1973 to 1975. They also stated that the fish production rate during the summer months was negative due to the anoxic condition in the hypolimnion which consisted of as much as 59% of the lake volume during the summer months. Jerry Wilhm studied the benthic communities and found the environment limiting which affects the game fish population. Toetz was the only investigator who failed to indicate a degradation in water quality. His conclusion was based on gross physical and chemical parameters which are not always related to biological impacts. This study supports the findings of these investigators. The water sources supplying the lake have been demonstrated to be a source of the nutrient enrichment. Water quality studies on the lake indicate nutrient concentrations adequate to support algal blooms. Algal activity

has been observed by measuring the variation in dissolved oxygen profiles and algal blooms have been observed visually. It is therefore the conclusion of this study that the Lake of the Arbuckles is a highly eutrophied lake and steps should be taken to limit further degradation and to hopefully enhance the water quality.

RECOMMENDATIONS

To insure the Lake of the Arbuckles' continued beneficial use, several corrective and preventive measures should be taken: 1) the elimination of identified point sources of pollution; 2) rerouting of the sanitary sewage collection system of Sulphur away from Rock Creek; 3) diversion of runoff from feedlot, dairy and other livestock facilities and consequent treatment of these waters; 4) elimination or reduction of infiltration to the Sulphur sewage system to reduce the overloading of its treatment plant resulting from rain-storm events; 5) collection and treatment of urban runoff prior to discharge to Rock Creek; 6) promote cultivation practices consistent with soil erosion and cropland runoff control; 7) promote responsible use of fertilizers and pesticides; and, 8) insure that development in the reservoir area does not result in excessive erosion and contamination through seepage of sewage systems.

In order to develop long term planning necessary for the preservation and enhancement of the water quality of the Lake of the Arbuckles a better understanding of the watershed system is in order. To evaluate the extent of eutrophication and the relative significance of various sources of pollution the following studies should be performed:

1) further monitoring of Rock Creek and its tributaries with emphasis on quality from storm runoff; 2) extensive analysis of the water quality of the Lake of the Arbuckles to establish the areal distribution of nutrient levels; 3) establish the nutrient balance of the lake system in terms of input and output and storage in sediment and aquatic life of the lake; 4) a determination of the relative contribution of nutrients from ground water, precipitation and surface runoff from all watersheds; and, 5) determine the intensity of water contact recreation which can be allowed and still maintain the required water quality to support the beneficial uses.

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APPENDIX

Table I. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA.

Sampling Site & Location	Date	Temp	DO	BOD	COD	pH	Alk	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
<u>Travertine Creek</u>															
Below	6/4/76	22.0	9.1	----	13.3	9.0	----	2.0	1.2	550	----	----	----	----	----
Nature	6/16/76	21.0	9.6	----	12.7	8.8	----	2.0	4.4	550	----	----	----	----	----
Center	6/23/76	21.5	7.3	----	27.4	8.0	391.7	4.0	----	550	----	----	----	----	----
Site 1	9/5/76	21.0	10.0	0.2	35.7	8.1	----	----	----	550	----	----	----	----	----
	9/18/76	20.0	8.7	----	----	8.0	----	----	----	550	----	----	----	----	----
	10/16/76	17.0	7.1	0.9	----	8.0	292.0	1.0	6.0	540	----	----	----	----	----
	6/23/77	21.0	8.4	0.3	10.42	8.3	----	----	----	550	----	----	----	----	----
Below	9/5/76	23.5	8.4	0.6	10.7	8.0	----	----	----	500	----	----	----	----	----
Swimming	9/18/76	22.0	8.0	----	----	8.1	----	----	----	500	----	----	----	----	----
Area	10/30/76	12.0	7.2	2.15	88.9	7.6	----	3.0	----	500	----	----	----	----	----
Site 2	11/14/76	----	11.1	1.40	----	8.2	----	----	----	500	0.0	0.0	0.0	0.0	0.015
	12/12/76	6.0	13.6	1.75	----	9.8	----	----	----	550	----	----	----	----	----
	12/19/76	11.0	9.8	0.75	10.0	8.0	----	----	----	520	----	----	----	----	----
	1/21/77	6.0	11.95	2.00	11.5	8.0	252.0	8.0	0.0	550	0.09	0.0	0.23	----	0.00
Culvert	6/14/76	24.0	10.4	----	----	9.0	----	58.0	47.1	500	----	----	----	----	----
East of	6/18/76	24.5	6.8	----	87.0	7.4	137.5	15.0	173.0	----	----	----	----	----	----
HY 177	6/29/76	23.5	8.9	----	9.7	8.3	343.7	4.0	8.0	500	----	----	----	----	----
Site 3	9/18/76	----	----	13.8	----	7.9	----	----	----	----	----	----	----	----	----
	12/19/76	11.0	----	----	22.1	8.0	----	----	----	800	----	----	----	----	----
	1/21/77	----	----	24.6	62.2	7.5	298.0	78.0	8.0	----	----	----	----	----	----
Inverted	6/16/76	22.0	9.3	----	8.5	9.0	212.5	70.0	6.4	690	----	----	----	----	----
Siphon	6/23/76	26.0	9.6	----	21.6	8.0	341.7	61.0	----	700	----	----	----	----	----
Below															
Lincoln															
Bridge															
Site 4															

Table I. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA. (continued)

Sampling Site & Location	Date	Temp	DO	BOD	COD	pH	Alk	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
<u>Travertine Creek</u>															
Little	9/5/76	21.5	9.5	0.6	25.0	8.1	---	---	---	550	---	---	---	---	---
Niagra	9/18/76	20.5	8.2	0.0	3.9	8.1	---	---	---	500	---	---	---	---	---
Site 5															
HY 177	9/5/76	24.5	8.1	0.3	32.1	7.9	---	---	---	500	---	---	---	---	---
Site 6	9/18/76	22.5	7.1	0.75	---	7.9	---	---	---	500	---	---	---	---	---
Lincoln	10/30/76	13.0	8.6	1.40	79.0	8.1	---	180	---	1000	---	---	---	---	---
Bridge	11/14/76	---	9.8	1.50	7.9	8.1	---	---	14.0	1550	0.0	0.03	0.0	0.0	0.015
Site 7	12/12/76	13.0	11.8	1.20	---	6.8	---	---	---	1550	---	---	---	---	---
	12/19/76	15.5	9.3	0.85	---	8.1	---	---	---	1600	---	---	---	---	---
	1/21/77	9.0	11.4	1.00	5.7	7.5	250.0	194.0	2.0	1250	0.08	0.05	0.42	0.03	0.00
	2/12/77	11.0	9.9	0.45	7.9	7.8	---	225.0	---	1150	---	---	---	---	---
	2/27/77	13.0	10.0	0.65	22.4	8.0	---	---	---	1600	---	---	---	---	---
	3/ 9/77	15.0	9.9	0.40	9.9	8.1	---	265.0	---	1350	0.67	0.05	0.24	0.025	---
	4/ 1/77	14.0	9.9	0.45	28.3	8.2	---	---	18.0	560	0.287	---	1.735	---	---
	4/23/77	16.0	10.4	0.50	8.1	---	---	---	---	560	---	---	---	---	---
	5/ 5/77	22.5	9.0	0.50	6.4	---	---	---	---	550	---	---	---	---	---
	6/13/77	23.0	7.95	0.20	9.75	8.9	---	---	---	650	---	---	---	---	---
	6/23/77	22.5	8.4	0.25	10.42	8.3	---	---	---	625	---	---	---	---	---
	7/ 1/77	---	---	1.55	40.00	8.3	---	---	---	---	0.08	---	0.73	0.07	0.01
Antelope	10/16/76	19.0	3.1	---	---	9.1	---	---	---	550	---	---	---	---	---
Springs	10/30/76	14.5	7.5	0.30	71.0	7.6	---	4.0	---	550	---	---	---	---	---
Site 8	11/14/76	---	9.4	0.90	4.0	8.1	---	---	1.0	550	0.0	0.06	0.0	0.035	0.005

Table I. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA. (continued)

Sampling Site & Location	Date	Temp	DO	BOD	COD	pH	Alk	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
<u>Travertine Creek</u>															
Buffalo	10/16/76	18.5	3.3	----	----	8.7	----	----	----	550	----	----	----	----	----
Springs	10/30/76	15.0	6.8	0.30	82.9	7.8	----	3.0	----	550	----	----	----	----	----
Site 9	11/14/76	----	5.1	0.55	----	7.6	----	----	2.0	550	1.12	0.42	0.0	0.028	0.005
	12/12/76	12.0	7.2	0.65	----	5.1	----	----	----	550	----	----	----	----	----
<u>Rock Creek</u>															
HY 177 Above Bridge															
Site 10	6/23/76	26.0	7.9	----	22.0	8.0	317.0	60.0	3.3	1065	----	----	----	----	----
HY 177	6/14/76	25.0	9.5	----	13.3	8.9	----	177.9	1.4	680	----	----	----	----	----
Below	6/16/76	27.0	8.8	----	----	8.9	204.0	64.0	3.6	610	----	----	----	----	----
Bridge	6/23/76	25.0	8.4	----	22.0	7.8	292.0	59.0	----	675	----	----	----	----	----
Site 11	9/ 5/76	24.0	8.4	1.8	42.8	7.8	----	----	----	2600	----	----	----	----	----
	9/18/76	22.5	7.1	0.75	----	7.9	----	----	----	500	----	----	----	----	----
	10/16/76	14.5	9.2	0.75	24.4	7.7	196.0	115.0	3.0	2500	----	----	0.22	----	----
	10/30/76	13.0	9.6	1.20	177.5	6.9	----	432.0	----	1900	----	----	----	----	----
	11/14/76	----	9.7	1.20	11.9	8.0	----	----	52.0	2500	2.97	0.08	0.0	0.005	0.01
	12/12/76	9.0	14.4	1.25	2.8	9.0	----	----	----	2200	----	----	----	----	----
	12/19/76	13.0	8.6	1.25	12.0	7.8	----	----	----	2350	----	----	----	----	----
	1/21/77	7.0	11.2	1.50	26.8	7.9	180.0	580.0	3.0	2300	0.13	0.16	0.085	0.045	0.0
	2/12/77	11.0	8.55	1.60	13.8	7.9	----	170.0	----	1000	----	----	----	----	----

Table I. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA. (continued)

Sampling Site & Location	Date	Temp	DO	BOD	COD	pH	Alk	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
<u>Rock Creek</u>															
Site 11	12/19/76	13.0	8.6	1.25	12.0	7.8	---	---	---	2350	---	---	---	---	---
Continued	1/21/77	7.0	11.2	1.50	26.8	7.9	180.0	580.0	3.0	2300	0.13	0.16	0.08	0.045	0.0
	2/12/77	11.0	8.55	1.60	13.8	7.9	---	170.0	---	1000	---	---	---	---	---
	3/9/77	12.0	8.2	1.65	21.3	7.8	---	537.0	---	2350	0.25	0.07	0.04	0.035	0.0
	4/1/77	14.0	9.3	1.10	21.7	8.2	---	---	28.0	500	0.28	---	1.50	---	---
	4/23/77	17.0	10.0	---	20.3	---	---	---	---	460	---	---	---	---	---
	5/5/77	23.0	8.1	1.30	16.0	---	---	---	---	450	---	---	---	---	---
	6/13/77	26.0	9.8	0.70	28.0	8.8	---	---	---	1200	---	---	---	---	---
	6/23/77	25.0	5.8	1.10	31.25	7.8	---	---	---	2050	---	---	---	---	---
	7/1/77	---	---	2.40	36.0	7.9	---	---	---	---	0.11	---	1.28	0.09	0.03
<u>HY 7</u>															
Under	6/14/76	25.0	9.5	---	13.3	8.9	---	178.0	1.4	680	---	---	---	---	---
	6/16/76	28.0	11.4	---	25.4	8.8	204.0	---	3.6	670	---	---	---	---	---
Bridge	6/18/76	24.0	8.0	---	79.2	8.7	163.0	55.0	---	640	---	---	---	---	---
Site 12	6/23/76	24.5	7.8	---	---	8.3	283.4	77.0	---	640	---	---	---	---	---
	9/5/76	25.0	7.3	0.60	60.7	7.8	---	---	---	2450	---	---	---	---	---
	9/18/76	23.0	5.7	1.50	3.9	7.8	---	---	---	2350	---	---	---	---	---
	10/16/76	14.5	11.0	0.9	7.5	7.5	186.0	121.0	11.0	2650	---	---	0.22	---	---
	10/30/76	10.5	9.7	2.0	100.0	8.0	---	362.0	---	1600	---	---	---	---	---
	11/14/76	---	10.0	0.65	7.9	8.0	---	---	0.0	2400	0.17	0.10	0.19	0.035	0.035
	12/12/76	5.0	14.3	1.60	1.4	6.8	---	---	---	2150	---	---	---	---	---
	12/19/76	11.0	8.7	0.90	13.0	7.9	---	---	---	2300	---	---	---	---	---
	1/21/77	4.0	11.9	2.0	38.3	8.1	208.0	567.0	0.0	2350	0.09	0.08	0.17	0.03	0.03
	2/12/77	10.0	8.1	1.9	18.7	7.7	---	180.0	---	1050	---	---	---	---	---
	2/27/77	4.0	11.2	1.5	29.2	7.9	---	---	---	2150	---	---	---	---	---
	3/9/77	13.0	14.0	1.65	17.5	8.0	---	460.0	---	2200	0.09	0.01	0.12	0.07	0.0

Table I. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA. (continued)

Sampling Site & Location	Date	Temp	DO	BOD	COD	pH	Alk	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
<u>Rock Creek</u>															
Site 12	4/1/77	14.0	9.4	1.10	18.3	8.2	----	----	----	500	----	----	----	0.04	----
Continued	4/23/77	16.5	10.2	2.0	26.0	-----	----	----	----	465	----	----	----	----	----
	5/5/77	22.5	8.4	0.7	17.6	-----	----	----	----	420	----	----	----	----	----
	6/13/77	28.0	9.2	1.25	23.5	8.9	----	----	----	1200	----	----	----	----	----
	6/23/77	26.0	6.6	0.75	24.3	8.25	----	----	----	1800	----	----	----	----	----
	7/1/77	-----	-----	4.4	56.0	7.6	----	----	----	----	0.47	----	1.64	0.165	0.09
<u>Down- stream from HY 7</u>															
Site 12	6/18/76	31.0	6.0	-----	225.7	8.3	245.0	83	282	360	----	----	----	----	----
Culvert at HY 7	9/18/76	-----	-----	20.7	214.5	7.9	----	----	----	----	----	----	----	----	----
<u>Site 13</u>															
Sandy	6/14/76	24.0	8.5	-----	3.3	8.7	-----	82.0	0.6	680	----	----	----	----	----
Beach	6/16/76	27.0	9.9	-----	17.0	9.0	204.0	86.0	3.2	680	----	----	----	----	----
Site 14	6/23/76	26.5	9.1	-----	29.4	8.1	288.0	79.0	-----	690	----	----	----	----	----
	6/29/76	27.0	6.6	-----	-----	8.0	197.0	36.0	-----	1100	----	----	----	----	----
	9/5/76	24.5	6.3	0.6	46.4	7.8	-----	-----	-----	2350	----	----	----	----	----
	9/18/76	23.0	5.1	1.5	9.8	7.8	-----	-----	-----	2300	----	----	----	----	----
	10/16/76	16.5	9.5	0.9	18.8	7.8	200.0	105.0	9.0	2250	----	----	0.45	----	----
	10/30/76	11.0	8.3	1.9	122.4	7.9	-----	328.0	----	1400	----	----	----	----	----

Table I. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA. (continued)

Sampling Site & Location	Date	Temp	DO	BOD	COD	pH	Alk	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
<u>Rock Creek</u>															
Site 14	11/14/76	----	11.0	2.35	14.0	7.9	----	----	7.0	2250	0.0	0.21	0.084	0.06	0.035
Continued	12/12/76	5.0	15.5	1.85	----	9.8	----	----	----	2100	----	----	----	----	----
	12/19/76	11.5	9.5	1.85	15.6	8.0	----	----	----	2200	----	----	----	----	----
	1/21/77	5.5	8.4	9.0	51.7	7.7	236.0	484.8	14.0	2150	----	0.22	----	0.80	0.477
	2/12/77	11.0	7.4	4.58	19.7	7.6	----	185.0	----	1100	----	----	----	----	----
	2/27/77	6.0	12.0	1.85	28.2	7.8	----	----	----	2150	----	----	----	----	----
	3/9/77	16.0	11.2	2.10	18.2	7.8	----	410.0	----	2050	0.36	0.195	0.06	0.045	0.0
	4/1/77	14.0	9.1	0.90	20.0	8.1	----	----	19.0	500	0.243	----	1.077	0.04	----
	4/23/77	17.0	10.2	2.30	17.9	----	----	----	----	485	----	----	----	----	----
	5/5/77	22.0	8.1	1.30	14.4	----	----	----	----	440	----	----	----	----	----
	6/13/77	29.0	8.2	1.05	26.5	8.4	----	----	----	600	----	----	----	----	----
	6/23/77	25.5	5.8	0.70	27.8	8.3	----	----	----	1600	----	----	----	----	----
	7/1/77	----	----	3.95	36.0	----	----	----	----	----	0.12	----	1.12	.175	0.09
<u>Above Bromide</u>															
Foot-bridge															
Site 15	6/14/76	26.0	10.9	----	16.7	9.0	----	110.0	1.0	750	----	----	----	----	----
<u>Below</u>															
	6/14/76	24.0	9.2	----	16.7	8.8	----	81.0	0.40	1000	----	----	----	----	----
Inverted	6/16/76	27.0	12.0	----	12.7	9.0	233.0	126.0	0.4	1020	----	----	----	----	----
Siphon at	6/23/76	26.0	10.4	----	22.0	8.2	300.0	175.0	----	1030	----	----	----	----	----
Campgrounds	9/18/76	----	----	2.4	9.8	8.0	----	----	----	----	----	----	----	----	----
Site 16															
<u>Sulfur Treatment</u>															
Plant Effluent															
Site 17	6/16/76	----	----	----	2.6	----	300.0	172.0	20.4	----	----	----	----	----	----

Table I. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA. (continued)

Sampling Site & Location	Date	Temp	DO	BOD	COD	pH	Alk	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
<u>Rock Creek</u>															
<u>Campgrounds</u>															
Site 18	9/5/76	25.0	8.4	1.2	42.8	8.0	----	----	----	1850	----	----	----	----	----
	9/18/76	23.5	7.1	0.3	9.8	8.0	----	----	----	1950	----	----	----	----	----
	10/16/76	16.5	8.5	0.9	11.5	7.8	228.0	93.0	8.0	2000	----	----	0.11	----	----
	10/30/76	11.0	8.1	2.55	93.8	8.0	----	314.0	----	1350	----	----	----	----	----
	11/14/76	-----	13.2	2.60	19.8	8.3	----	----	9.0	2100	0.0	0.08	0.0	0.02	0.025
	12/12/76	5.0	14.6	2.45	3.7	10.1	----	----	----	2050	----	----	----	----	----
	12/19/76	12.0	11.0	0.80	10.0	8.2	----	----	----	2200	----	----	----	----	----
	1/21/77	5.0	12.6	2.85	17.2	7.9	254.0	475.0	0.0	1950	0.22	0.12	0.38	0.195	0.215
	2/12/77	11.0	10.0	2.55	13.8	7.7	----	280.0	----	1360	----	----	----	----	----
	2/27/77	5.0	13.9	1.10	35.0	8.1	----	----	----	2150	----	----	----	----	----
	3/9/77	12.0	12.3	0.85	16.7	8.0	----	470.0	----	2100	0.73	0.03	0.27	0.015	0.73
	4/1/77	15.0	9.5	0.85	16.7	8.3	----	----	27.0	640	1.904	0.21	1.032	----	----
	4/23/77	16.0	10.0	1.20	17.9	----	----	----	----	555	----	----	----	----	----
	5/5/77	22.5	8.8	1.0	16.0	----	----	----	----	500	----	----	----	----	----
	6/13/77	27.0	9.5	0.90	14.6	8.8	----	----	----	600	----	----	----	----	----
	6/23/77	25.5	8.6	----	13.9	----	----	----	----	1100	----	----	----	----	----
	7/1/77	-----	----	5.25	64.0	7.8	----	----	----	----	0.21	----	1.64	0.15	0.07
<u>OG&E</u>															
Cooling	10/16/76	24.0	12.0	----	154.2	----	----	----	----	5000	----	----	0.11	----	----
Water	10/30/76	24.0	8.6	----	38.8	7.3	----	1280.0	----	>65000	----	----	----	----	----
Discharge	11/14/76	-----	-----	----	6.0	7.8	----	----	2.0	4950	----	----	----	----	----
Site 19	12/12/76	22.0	9.8	----	20.2	6.9	----	----	----	4600	----	----	----	----	----
	12/19/76	25.0	7.9	----	40.2	----	----	----	----	4800	----	----	----	----	----
	1/21/76	19.5	-----	----	46.0	7.4	92.0	1375.0	1.0	>65000	2.20	0.625	0.19	0.0	0.0

Table I... QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA. (continued)

Sampling Site & Location	Date	Temp	DO	BOD	COD	pH	Alk	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
<u>Rock Creek</u>															
Above	10/16/76	13.5	8.6	0.45	5.6	7.9	212.0	43.0	5.0	1150	----	----	0.34	----	----
OG&E	10/30/76	13.0	8.5	2.50	4.1	6.9	-----	82.0	----	650	----	----	----	----	----
Site 20	11/14/76	----	8.7	0.80	3.0	8.0	-----	-----	1.0	1100	0.0	0.07	0.28	0.013	0.005
	12/12/76	11.0	11.2	1.55	7.4	9.1	-----	-----	----	800	----	----	----	----	----
	12/19/76	14.0	10.2	0.60	22.1	7.9	-----	-----	----	900	----	----	----	----	----
	1/21/77	8.0	11.1	1.05	23.0	8.0	254.0	110.0	0.0	750	0.28	0.00	0.38	0.06	0.0
Below	10/16/76	17.0	10.6	1.50	----	7.8	140.0	193.0	5.0	4000	----	----	----	----	----
OG&E	10/30/76	13.5	8.4	1.10	14.3	7.2	-----	625.0	----	2600	----	----	----	----	----
Site 21	11/14/76	----	8.2	1.20	2.0	7.8	-----	-----	1.0	3350	0.0	0.23	0.06	0.035	0.02
	12/12/76	11.0	13.4	1.15	9.2	8.5	-----	-----	----	2850	----	----	----	----	----
	12/19/76	15.0	7.5	0.80	33.1	7.1	-----	-----	----	3160	----	----	----	----	----
	1/21/77	10.0	10.2	1.20	34.5	7.5	182.0	730.0	4.0	2750	0.14	0.23	0.37	0.03	0.0
<u>Buck Horn Creek</u>															
HY 177	2/12/77	10.5	9.8	2.85	31.4	8.1	----	15.0	----	440	----	0.62	----	----	----
Site 22	2/27/77	8.0	13.2	0.50	3.0	8.2	----	-----	----	520	----	----	----	----	----
	3/ 9/77	13.0	12.0	1.40	3.0	8.4	----	16.0	----	525	0.27	0.28	0.1	0.045	0.0
	4/ 1/77	15.0	10.0	0.50	6.7	8.1	----	-----	15.0	550	0.468	0.556	1.429	----	----
	4/23/77	16.0	10.0	0.50	13.0	----	-----	-----	----	350	----	----	----	----	----
	5/ 5/77	22.5	9.2	0.90	16.0	----	-----	-----	----	550	----	----	----	----	----
	6/13/77	27.0	9.4	0.40	15.5	9.0	----	-----	----	490	----	----	----	----	----
	7/ 1/77	----	----	1.15	20.0	8.3	----	-----	----	----	0.17	----	0.79	0.035	0.005

Table I. QUALITY DATA FOR CHICKASAW NATIONAL RECREATION AREA.(continued)

Sampling Site & Location	Date	Temp	Do	BOD	COD	pH	Alk	Cl	TSS	TDS	NH ₃ -N	NO ₃ -N	K-N	P	O-P
<u>Guy Sandy Creek</u>															
HY 7	2/12/77	10.5	9.7	1.25	12.8	8.1	----	25.0	----	500	----	0.18	----	----	----
Site 23	2/27/77	9.0	11.5	0.25	3.9	8.2	----	----	----	550	----	----	----	----	----
	4/ 1/77	14.5	9.4	0.95	20.0	8.2	----	----	14.0	380	0.108	0.15	1.33	0.035	----
	4/23/77	16.0	10.0	1.30	13.8	---	----	----	----	555	----	----	----	----	----
	5/ 5/77	23.0	8.8	0.70	4.8	---	----	----	----	350	----	----	----	----	----
	6/13/77	29.5	7.1	0.40	8.65	9.0	----	----	----	460	----	----	----	----	----
	7/ 1/77	----	----	2.45	32.0	8.0	----	----	----	----	0.05	----	0.73	0.07	0.02

Temperature (°C)
TDS (micromhos)
All others (mg/l)

Table II. WATER QUALITY DATA, LAKE OF THE ARBUCKLES.

SAMPLING SITE AND LOCATION		DATE	C.O.D.	B.O.D.	T.O.C.	T.D.S.	T.S.S.	PHOS.	ALK.	CL ⁻	pH	K-N	NO ₃ ⁻	NH ₃
<u>Buckhorn Arm</u> Site #26														
Surface		6/21/76	-	-	-	-	12.7	-	187.5	39.0	-	-	-	-
		6/29/76	-	-	24.0	-	44.7	0.02	181.3	40.0	-	-	-	-
		7/ 4/77	15.36	1.40	-	400	-	-	-	-	8.4	-	-	-
Bottom		6/21/76	-	-	-	-	184.0	-	187.5	41.0	-	-	-	-
		6/29/76	-	-	28.0	-	44.7	-	165.6	39.0	-	-	-	-
		7/ 4/77	23.89	2.35	-	400	-	-	-	-	8.25	-	-	-
<u>Dam Site</u> Site #27														
Surface		6/21/76	-	-	-	-	4.7	-	179.2	41.0	-	-	-	-
		6/29/76	-	-	12.4	-	31.3	0.02	171.8	38.0	-	-	-	-
		3/ 9/77	10.7	1.20	-	485	-	0.015	-	53.0	7.9	0.03	0.16	0.12
		7/ 4/77	18.77	0.65	-	390	-	-	-	-	8.45	-	-	-
Middle		6/29/76	-	-	13.4	-	30.7	-	175.0	37.0	-	-	-	-
Bottom		6/21/76	-	-	-	-	29.0	-	225.0	41.0	-	-	-	-
		6/29/76	-	-	15.3	-	56.7	0.03	228.1	38.0	-	-	-	-
		3/ 9/77	21.3	1.25	-	485	-	0.05	-	-	8.2	0.52	0.33	0.86
		7/ 4/77	15.36	3.05	-	440	-	-	-	-	8.2	-	-	-
<u>Rock Creek</u> Site # 28														
Arbuckle Dam Spillway		6/23/76	-	-	-	-	63.3	-	191.7	37.0	-	-	-	-
		2/12/77	12.8	1.25	-	500	-	-	-	25.0	8.1	-	0.18	-

Table 11. WATER QUALITY DATA, LAKE OF THE ARBUCKLES. (continued)

SAMPLING SITE AND LOCATION		DATE	C.O.D.	B.O.D.	T.O.C.	T.D.S.	T.S.S.	PHOS.	ALK.	CL ⁻	pH	K-N	NO ₃ ⁻	NH ₃
<u>Rock Creek Arm</u> Site #24														
Surface		6/21/76	-	-	16.0	-	17.3	-	191.7	59.0	-	-	-	-
		6/29/76	-	-	-	-	27.3	0.02	184.4	64.0	-	-	-	-
		7/ 4/77	17.06	1.15	-	400	-	-	-	-	8.25	-	-	-
Bottom		6/29/76	-	-	25.6	-	2.7	0.02	184.4	54.0	-	-	-	-
		7/ 4/77	15.36	2.30	-	400	-	-	-	-	8.25	-	-	-
<u>Guy Sandy Arm</u> Site #25														
Surface		6/21/76	-	-	-	-	17.3	-	179.2	37.0	-	-	-	-
		6/29/76	-	-	63.0	-	-	0.02	162.5	37.0	-	-	-	-
		3/ 9/77	9.1	0.55	-	490	-	0.015	-	50.0	7.8	0.66	0.15	0.12
		7/ 4/77	15.36	0.60	-	390	-	-	-	-	8.5	-	-	-
Bottom		6/21/76	-	-	-	-	34.0	-	254.2	37.0	-	-	-	-
		6/29/76	-	-	155.0	-	11.3	-	165.6	38.0	-	-	-	-
		3/ 9/77	-	-	-	-	-	-	-	-	7.9	0.50	0.175	0.40
		7/ 4/77	20.48	2.45	-	400	-	-	-	-	8.4	-	-	-

Temperature (°C)

TDS (micromhos)

All others (mg/l)

Table III. BACTERIA DATA FOR CHICKASAW NATIONAL RECREATION AREA.

Site Number & Location	Date	Total* Coliform	Fecal* Coliform	Fecal* Strep	FC/FS
1. Travertine Below Nature Center	9/18/76	26,000	490	----	----
	10/16/76	2,000	210	510	.41
	6/23/77	-----	170	380	.45
2. Travertine	9/18/76	40,000	200	----	----
	10/30/76	5,100	80	240	.33
	11/14/76	1,600	40	30	1.33
	12/12/76	1,000	10	110	.09
	12/20/76	400	40	2,000	.02
	1/21/77	-----	10	20	.50
3. Travertine HY 177 Culvert	9/18/76	1,460,000	155,000	----	----
	12/20/76	TMTC	329,000	25,000	13.16
	1/21/77	-----	46,000	37,000	1.24
5. Travertine Little Niagra	9/18/76	36,000	270	----	----
6. Travertine 177	9/18/76	10,000	3,000	----	----
7. Travertine Lincoln Bridge	9/18/76	-----	-----	-----	-----
	10/16/76	-----	-----	-----	-----
	10/30/76	180,000	5,200	9,800	.53
	11/14/76	46,000	200	320	.63
	12/12/76	47,000	600	680	.79
	12/19/76	25,000	80	2,000	.04
	1/21/77	-----	260	300	.87
	2/27/77	-----	100	300	.33
	3/ 9/77	-----	140	160	.88
	4/ 1/77	-----	280	1,500	.19
	4/23/77	-----	560	590	.95
	5/ 5/77	-----	950	2,100	.45
	6/13/77	-----	200	1,600	.13
	6/23/77	-----	200	300	.67
8. Antelope Springs	10/16/76	2,200	0	10	----
	10/30/76	7,100	20	220	.09
	11/14/76	2,600	50	10	5.00
9. Buffalo Springs	10/16/76	800	0	120	----
	10/30/76	7,200	30	320	.09

* Count per 100 ml sample

Table III. (continued)

Site Number & Location	Date	Total Coliform	Fecal Coliform	Fecal Strep	FC/FS
9. Buffalo Springs (continued)	11/14/76	900	130	300	.43
	12/12/76	2,600	60	300	.20
11. Rock Creek HY 177	9/18/76	260,000	5,000	-----	-----
	10/16/76	90,000	1,400	4,800	.29
	10/30/76	220,000	18,500	31,200	.59
	11/14/76	82,000	1,800	7,700	.23
	12/12/76	20,000	600	21,000	.03
	12/19/76	43,000	900	10,900	.08
	1/21/77	-----	3,500	65,000	.05
	2/27/77	-----	-----	-----	-----
	3/ 9/77	-----	1,600	28,000	.06
	4/ 1/77	-----	600	3,600	.17
	4/23/77	-----	40	3,600	.01
	5/ 5/77	-----	1,000	15,000	.07
	6/13/77	-----	400	TMTc	-----
	6/23/77	-----	3,200	3,600	.89
12. Rock Creek HY 7	9/18/76	6,900	350	-----	-----
	10/16/76	32,000	280	660	.42
	10/30/76	350,000	32,100	37,500	.86
	11/14/76	14,000	480	4,300	.11
	12/12/76	9,000	500	14,500	.03
	12/19/76	16,000	260	9,000	.03
	1/21/77	-----	860	4,200	.20
	2/27/77	-----	700	2,400	.29
	3/ 9/77	-----	500	2,300	.22
	4/ 1/77	-----	100	1,000	.10
	4/23/77	-----	1,000	4,800	.21
	5/ 5/77	-----	1,600	14,000	.11
	6/13/77	-----	500	TMTc	-----
	6/23/77	-----	200	900	.22
13. Rock Creek, HY 7 Broadway Culvert	9/18/77	1,320,000	204,000	-----	-----
14. Rock Creek Sandy Beach	9/18/77	640,000	18,000	-----	-----
	10/16/76	40,000	300	140	2.14
	10/30/76	630,000	29,500	44,000	.67
	11/14/76	40,000	4,000	3,200	1.25
	12/12/76	10,000	200	7,100	.03
	12/19/76	1,930,000	30,900	14,700	2.10

Table III. (continued)

Site Number & Location	Date	Total Coliform	Fecal Coliform	Fecal Strep	FC/FS
14. Sandy Beach (continued)	1/21/77	-----	126,000	23,000	5.48
	2/27/77	-----	1,000	0	-----
	3/ 9/77	-----	650	1,100	.59
	4/ 1/77	-----	600	1,400	.43
	4/23/77	-----	3,000	9,000	.33
	5/ 5/77	-----	900	4,300	.21
	6/13/77	-----	7,000	500	14.00
	6/23/77	-----	8,000	100	80.00
16. Rock Creek Campgrounds Below Siphon	9/18/76	120,000	720	-----	-----
18. Rock Creek Campgrounds	9/18/76	830,000	350	-----	-----
	10/16/76	47,000	1,700	310	5.48
	10/30/76	101,000	29,600	39,500	.75
	11/14/76	50,000	320	190	1.68
	12/12/76	6,000	280	560	.50
	12/19/76	720,000	9,500	3,400	2.79
	1/21/77	-----	2,600	2,000	1.30
	2/27/77	-----	0	100	-----
	3/ 9/77	-----	220	90	2.44
	4/ 1/77	-----	600	1,300	.46
	4/23/77	-----	1,200	3,600	.33
	5/ 5/77	-----	600	3,500	.17
	6/13/77	-----	500	100	5.00
	6/23/77	-----	300	0	-----
20. Rock Creek	10/16/76	21,000	200	510	.39
	10/30/76	25,000	720	1,900	.38
	11/14/76	27,000	50	70	.71
	12/12/76	10,000	400	150	2.67
	12/20/76	13,000	30	190	.16
	1/21/77	-----	0	10	-----
21. Rock Creek Below OG&E	10/16/76	9,700	300	240	1.25
	10/30/76	55,000	1,500	2,100	.71
	11/14/76	56,000	80	230	.35
	12/12/76	9,000	200	110	1.82
	12/20/76	27,000	40	100	.40
	1/21/77	-----	0	60	-----

Table III. (continued)

Site Number & Location	Date	Total Coliform	Fecal Coliform	Fecal Strep	FC/FS
22. Buckhorn Creek HY 177	2/27/77	-----	500	500	1.00
	3/ 9/77	-----	360	250	1.44
	4/ 1/77	-----	1,300	410	3.17
	4/23/77	-----	580	820	.71
	5/ 5/77	-----	600	1,000	.60
	6/13/77	-----	380	380	1.00
23. Guy Sandy Creek HY 7	2/27/77	-----	100	200	.50
	4/ 1/77	-----	320	240	1.33
	4/23/77	-----	1,300	1,200	1.08
	5/ 5/77	-----	80	2,000	.04
	6/13/77	-----	0	100	-----

Table IV. EFFECT OF SWIMMING ON WATER QUALITY.

Site	Date	Time	No. of Swimmers	Total Coliform	Fecal Coliform	Fecal Strep	FC/FS
TRAVERTINE CREEK							
1. Below Nature Center	6/19/76	12:00	----	4100	----	----	----
		1:00	----	4400	----	----	----
		2:00	----	5500	----	----	----
		3:00	----	3700	----	----	----
		4:00	----	5300	----	----	----
		5:00	----	4200	----	----	----
2. Below Swimming Area	6/19/76	12:30	55	16200	----	----	----
		1:00	57	12300	----	----	----
		1:30	111	9600	----	----	----
		2:00	140	13200	----	----	----
		2:30	226	11400	----	----	----
		3:00	253	8700	----	----	----
		3:30	178	9300	----	----	----
		4:00	184	14400	----	----	----
		4:30	104	18900	----	----	----
		5:00	111	32400	----	----	----
1. Below Nature Center	9/ 5/76	12:00	----	----	860	----	----
		1:00	----	5000	220	----	----
		2:00	----	----	24	----	----
		3:00	----	----	410	----	----
		4:00	----	----	350	----	----
		5:00	----	38500	230	----	----
2. Below Swimming Area	9/ 5/76	11:30	96	23000	2150	----	----
		1:00	102	21000	1600	----	----
		2:00	138	29500	2300	----	----
		3:00	206	30000	2030	----	----
		4:00	137	78800	----	----	----
		5:00	141	28000	2450	----	----
1. Below Nature Center	9/18/76	12:00	----	16000	490	----	----
		1:00	----	20000	220	----	----
2. Below Swimming Area	9/18/76	12:00	----	22500	200	----	----
		1:00	11	23400	180	----	----

Table IV. (continued)

Site	Date	Time	No. of Swimmers	Total Coliform	Fecal Coliform	Fecal Strep	FC/FS
TRAVERTINE CREEK							
1. Below Nature Center	7/ 3/77	10:00	----	----	80	200	.40
		11:00	----	----	0	0	----
		12:00	----	----	70000	20000	3.50
		1:00	----	----	700	100	7.00
		2:00	----	----	200	900	.22
		3:00	----	----	100	200	.50
		4:00	----	----	600	500	1.20
		6:00	----	----	1500	200	7.50
		8:00	----	----	0	800	----
2. Below Swimming Area	7/ 3/77	10:15	10	----	250	250	1.00
		11:00	171	----	200000	0	----
		12:00	210	----	500000	0	----
		1:00	207	----	0	20000	----
		2:00	304	----	0	0	----
		3:00	440	----	0	30000	----
		4:00	370	----	0	0	----
		5:00	269	----	200000	20000	10.00
		6:00	169	----	10000	10000	1.00
		7:00	78	----	100000	0	----
		8:00	52	----	260000	10000	26.00
1. Below Nature Center	7/10/77	10:00	----	----	20	200	.10
		12:00	----	----	20	170	.12
		2:00	----	----	30	520	.06
		4:00	----	----	650	1800	.36
		6:00	----	----	40	260	.15
2. Below Swimming Area	7/10/77	10:00	10	----	9000	2000	4.50
		11:00	64	----	700	1300	.54
		12:00	116	----	1140	1100	1.04
		1:00	127	----	2500	630	3.97
		2:00	244	----	TMTC	5000	----
		3:00	231	----	3000	5300	.57
		4:00	179	----	300	1900	.16
		5:00	179	----	350	1200	.29
		6:00	127	----	1400	500	2.80
		7:00	65	----	1200	540	2.22
		7:45	----	----	400	440	.91

Table IV. (continued)

Site	Date	Time	No. of Swimmers	Total Coliform	Fecal Coliform	Fecal Strep	FC/FS
TRAVERTINE CREEK							
1. Below Nature Center	7/17/77	10:00	----	----	180	230	.78
		12:00	----	----	20	170	.12
		2:00	----	----	500	1700	.29
		4:00	----	----	20	300	.07
		6:00	----	----	0	300	----
2. Below Swimming Area	7/17/77	10:00	80	----	820	750	1.09
		11:00	116	----	100	2400	.04
		12:00	140	----	740	200	3.70
		1:00	165	----	100	1800	.06
		2:00	180	----	18200	1300	14.00
		3:00	250	----	150	2000	.08
		4:00	310	----	200	660	.30
		5:00	180	----	2000	1300	1.54
		6:00	110	----	1500	340	4.41
		7:00	25	----	750	410	1.83

Table V. CONCENTRATION OF TRACE METALS OF ROCK CREEK
AND ITS TRIBUTARIES (DATE: 4/23/77).

Location & Site Number	Cadmium	Chrome	Copper	Lead	Zinc
TRAVERTINE CREEK					
Swimming Area Site #2	<0.001	0.010	0.007	<0.010	0.010
Lincoln Bridge Site #	<0.001	0.006	0.007	0.016	0.010
ROCK CREEK					
HY 177 Site #	<0.001	0.006	0.006	0.016	0.010
HY 7 Site #	<0.001	<0.005	0.006	<0.010	0.010
Sandy Beach Site #	<0.001	0.010	0.008	<0.010	0.020
Campgrounds Site #	<0.001	0.011	0.006	0.010	0.010
GUY SANDY CREEK					
HY 7 Site #	<0.001	0.011	0.006	0.013	0.010
BUCKHORN CREEK					
HY 177 Site #	<0.001	0.007	0.008	<0.010	0.010

**Units in mg/l

