WATER QUALITY ASSESSMENT OF

REND LAKE

and

ITS TRIBUTARIES

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CONTENTS

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INTRODUCTION

Study Area

Rend Lake, situated in Jefferson and Franklin Counties in southern Illinois, is a man-made impoundment created in 1970 by damming the Big Muddy River. In addition to the Big Muddy River, major tributaries to the lake include Casey Fork, Atchison Creek, Gun Creek, and Rayse Creek. The lake was created to provide flood control and water supplies as well as for recreational activities including fish and wildlife management. It also serves as a source of public water supply for about 55 communities, under the auspices of the Rend Lake Conservancy District. Water treatment facilities, managed by the Rend Lake Intercity Water System, treat and distribute about 10 million gallons per day.

The lake is formed by a main body and three forks or branches as shown in figure 1. The two northernmost branches are formed by the Rayse Creek-Muddy River watersheds and the Casey Fork-Atchison Creek watersheds; the eastern branch is formed by the Gun Creek watershed. The lake is managed by the St. Louis District of the U.S. Army Corps of Engineers. The two sub-impoundments on the northern forks of the lake are operated by the Illinois State Department of Conservation, mainly for wildlife management. Morphometric details of Rend Lake are shown in table 1.

Table 1. Morphometric Details of Rend Lake

Normal pool elevation	405.0	feet msl
Storage	185,000	acre-feet
Surface area	18,900	acres
Mean depth	9.8	feet
Maximum depth	31	feet
Normal pool length	13	miles
Normal pool width	3	miles
Length of shoreline	162	miles

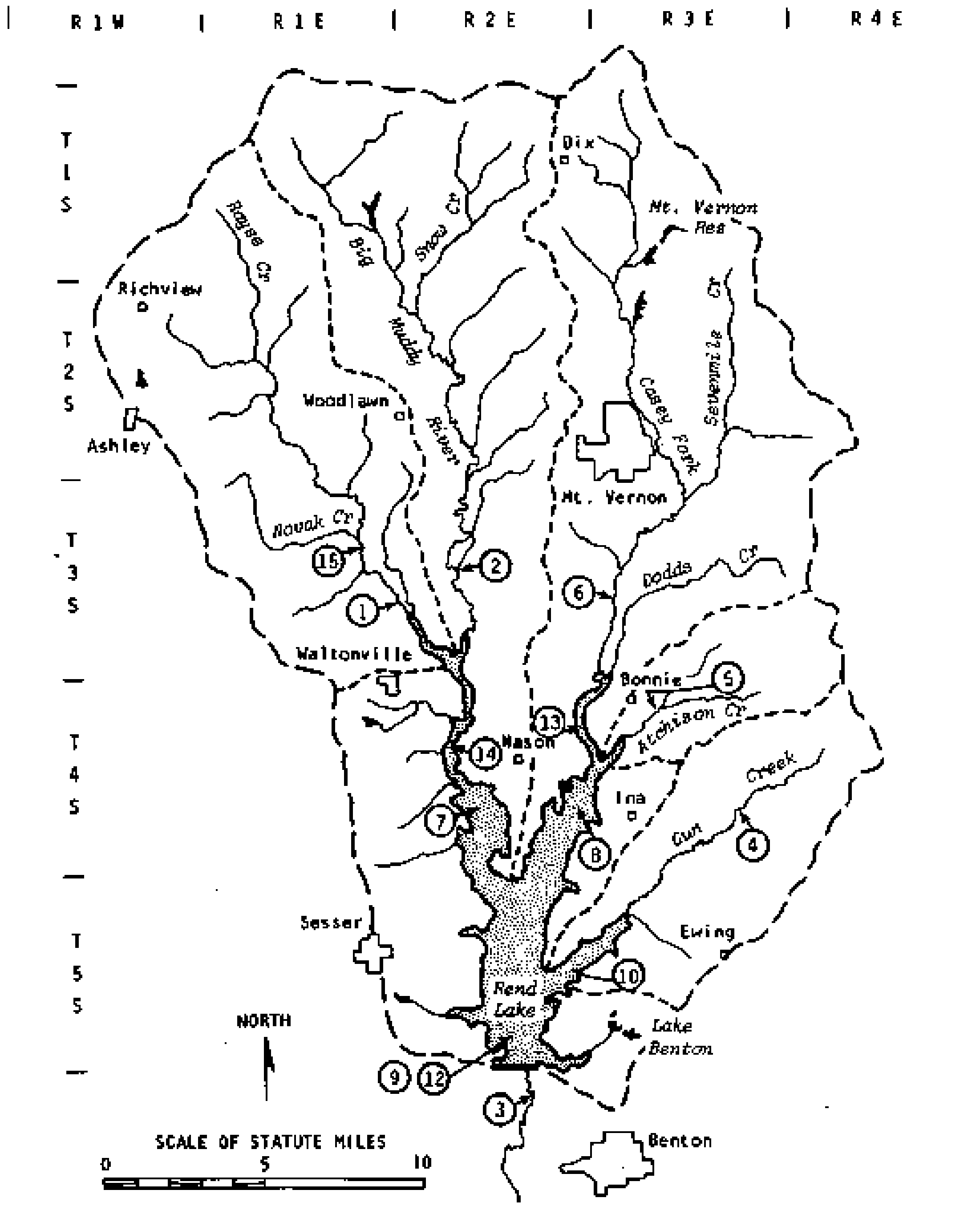

Figure 1. Rend Lake watershed and sampling stations

The impoundment drains approximately 488 square miles of watershed area which is characterized generally by gently rolling upland topography and almost flat lowlands along principal streams. Maximum topographic relief varies from about 620 feet msl near the headwaters to about 380 feet msl at the main dam site. Agriculture is the major land use in the watershed. Cropland and pasture constitute about 67.3 percent, woodland 21.9 percent, and urban development 2.9 percent. Coal mining and oil production are pursued to a certain extent in the Rayse Creek and Big Muddy River watersheds.

Mt. Vernon, with a population of about 17,000, is the major urban development within the lake's watershed. The city, located about 10 miles north of the lake, discharges effluent from its waste treatment facilities into Casey Fork. Sesser with a population of about 2100 is next in importance. There are about nine other small communities ranging in population from approximately 150 to 400 persons.

The point sources of domestic waste discharges within the Rend Lake watershed, along with the type of treatment rendered and the names of receiving streams, are shown in table 2. Except for wastewater discharges from Mt. Vernon and Sesser, discharges were so low that the effluent percolated into the creek bed before reaching the main tributaries to Rend Lake. The two major industries in Mt. Vernon, Precision National Corporation and General Tire and Rubber Plant, have treatment facilities of their own and operate on a closed loop system. Thus, there is no industrial waste discharge in the Rend Lake watershed.

Objectives and Scope

The principal objectives of this study were to assess the impact of land uses in the lake's watershed on stream water quality, and to identify the principal causes for changes in water quality, if any, within the lake's waters. In terms of impact on stream water quality, the main concern was those land use activities associated with non-point sources of pollution. To achieve these objectives, a program for sampling the waters of the lake and its major tributaries was established. Efforts were directed to documenting the temporal and spatial variations in physical, chemical, and biological characteristics of the water, to defining the extent of thermal and dissolved oxygen stratifications in the lake, and to developing a nutrient budget for the lake. A detailed field reconnaissance and reviews of reports and aerial photographs of the watershed were made to ascertain the principal land uses and the extent of each land use. In tributaries where flow records were not available gaging stations were established, rating curves were developed, and streamflows were determined.

This report provides a detailed summary of the various investigations, and an Open File Data Supplement, available at the Water Survey's Water Quality Section (Box 717, Peoria, Illinois), contains the raw data and other details.

Table 2. Wastewater Discharges in the Rend Lake Watershed

Name	Type of treatment	Receiving stream
Dodds Community Consolidated School	Imhoff tank sand filter, effluent land disposal	
Mt. Vernon	Trickling filter, tertiary lagoons, chlorination	Casey Fork
Sesser	Imhoff tank, trickling filter chlorination	Unnamed stream discharging into the lake
Archway Trailer Park on Route 15	Primary sedimentation sand filter, and chlorination	Big Muddy River via an unnamed stream
Waltonville Grade School	Imhoff tank, sand filter	
Waltonville High School	Imhoff tank, sand filter	
Shady Oak Camping Area on Rend City Road	Sedimentation sand filter, and chlorination	Rend Lake
Dix	Three cell lagoon	Casey Fork via an unnamed stream
Field Community Consolidated School	Imhoff tank	Casey Fork via an unnamed stream
Grand Prairie School	Imhoff tank, sand filter effluent land disposal	
Woodlawn Grade School	Imhoff tank, sand filter	Rayse Creek via unnamed stream
Woodland High School	Imhoff tank, sand filter	Rayse Creek via unnamed stream
Woodlawn Sewage Treatment Works	Package plant	Big Muddy via an unnamed creek
Country Air Mobile Home Park on Illinois Route 37	Three cell lagoon	Casey Fork via an unnamed creek

Materials and Methods

In order to assess the physical, chemical, and biological characteristics of the tributaries, field trips were made on a weekly basis from January 21, 1976, to January 19, 1977. Figure 1 shows the location of the water sample collection sites. The sampling stations on the Rayse Creek and Casey Fork tributaries, stations 1 and 6, respectively, coincide with the stream gaging stations maintained and operated by the St. Louis District of the U.S. Army Corps of Engineers. Partial flow records since

1966 are available for these tributaries. Staff gage, wire weight gage, or the permanent reference mark were used at the water sampling stations for the Big Muddy River (station 2), Gun Creek (4), Atchison Creek (5), and the Big Muddy River downstream of the dam (3). Stream stage observations were made for these four locations during every field trip. Field measurements were made by U.S. Geological Survey standard procedures at these sites to determine the actual stream flows. With the rating curves thus developed, and the weekly observations of stream stages, estimates of instantaneous stream discharges for these four sampling stations were made. The Corps of Engineers operates and maintains a flow gaging station on the Big Muddy River approximately 5 miles upstream of sampling station 2.

In addition to the stream sampling stations mentioned above, an additional sampling station, 15 in figure 1, for Rayse Creek was established on August 11, 1976, and samples were collected on a weekly schedule whenever there was flow in the creek until December 8, 1976. This station was established to assess the impact of the existing oil wells between sampling stations 1 and 15 on Rayse Creek.

In situ observations of temperature and dissolved oxygen were made at all stream sampling stations. Dissolved oxygen was measured by a modified Winkler method as outlined by the American Public Health Association (1971) •

Surface water samples for chemical analyses were collected in plastic bottles, transported to the laboratory, and refrigerated until chemical analyses were performed. For ammonia determinations, 50 milliliters (ml) of the water sample was filtered through 0.45 μ millipore filters, 37 millimeters (mm) in diameter. The filters were placed over filter pads which were held between two-piece circular plastic holders. A set of eight such holders was held in a wooden frame designed and fabricated at the Survey laboratory. Positive pressure for filtering the samples was provided by a syringe to force the sample through the filters. Micropore filtration eliminates any bacterial activity that could alter the ammonia concentration in the collected samples. Laboratory tests extending over a period of 4 weeks indicated that the ammonia concentrations remained stable in the filtered samples. This method of sample preservation is considered superior to acidification or other chemical additives.

The following chemical determinations were made in the laboratory on stream water samples: turbidity; pH; alkalinity; hardness; nitrate; ammonia; total and dissolved silica; iron; chloride; dissolved, suspended, and total solids; algal growth potential; total phosphorus and total dissolved phosphorus; sodium; potassium; calcium and magnesium in both dissolved and particulate forms; and the heavy metals lead, copper, zinc, and mercury in particulate forms. Determinations of cation exchange capacities (CEC) were carried out on most of these stream samples.

In performing the chemical analyses, procedures set forth in *Standard Methods* (American Public Health Association, 1971) were used, with the exception that lead, copper, zinc, and mercury in water samples were measured in particulate form. These measurements were done by filtering a 50-ml raw water aliquot through a 0.45 µm membrane filter. For lead, copper, and zinc, the residue along with the filter was placed in a 125-ml flask and digested with 10 ml sulfuric and nitric acid mixture 1:1 (v:v) on a hot plate for 1 hour. The digested mixture was diluted to 50 ml and the analysis was done by an atomic absorption spectrophotometer. Mercury was determined by cold vapor atomic absorption spectrophotometry after digestion with potassium permanganate as described in *Standard Methods.* Four sets of sediment samples for heavy metal analyses were taken. They were oven-dried, ground, sieved through a 64-mesh sieve, and digested and determined by atomic absorption spectrophotometry.

Algal growth potential (AGP) is a laboratory test to determine under optimum conditions the maximum potential growth of algae in a specific water sample. The methodology has been previously reported (Wang et al., 1973)-

Water turbidity was determined by the nephelometric method with a G. K. Turner Fluorometer. The emission light was reduced with 1-percent and 10-percent light transmission filters. With formazin as an artificial standard, as described in *Standard Methods*, the calibration curve showed a linear relationship up to 80 units. Proper dilution is necessary as the response flattened at the higher concentration. Turbidity is expressed as nephelometric turbidity units (NTU).

Cation exchange capacity (CEC) is an important characteristic of soil particles. The major role it plays in the physicochemical properties of soil has been extensively studied. Because soil particles constitute the bulk of suspended solids in water, it is logical to determine the cation exchange capacity of suspended solids. The procedure used was developed by Wang (1975). The cation exchange capacity is determined from the amount of potassium ion adsorbed and desorbed per unit of suspended sediment content, expressed conventionally as milliequivalents per 100 grams (me/100g).

Cationic sodium, potassium, calcium, and magnesium were determined in both dissolved and particulate form. The sample for the dissolved form was essentially the filtrate from membrane filtration. For the particulate form, a 100-ml raw water sample was filtered through a 0.45 µm membrane filter. The residue and the filter were placed in a 125-ml flask. To this was added 10 ml of 0.5 N barium chloride solution. The mixture was shaken for 1 hour. It was then filtered through a glass fiber filter disc. The filtrate was captured. The residue was returned to the flask, added with barium chloride, shaken, and filtered again. The determinations for sodium, potassium, calcium, and magnesium were then made with an atomic absorption spectrophotometer.

Water samples in a volume of 390 ml were collected for algal identification and enumeration. The samples were preserved with 10 ml formalin at the time of collection and stored at room temperature until examined.

Phytoplankton identification and enumeration were performed within a month, at which time the sample was thoroughly mixed and a 1-ml aliquot was pipetted into a Sedgwick-Rafter counting cell. An inverted phase contrast microscope equipped with 10X eyepieces, 20X objective, and a Whipple disc was used for identification and counting purposes. Five short strips (about 280 fields) were counted.

Phytoplankton were identified to species by employing several keys (Palmer, 1959; Patrick and Reimer, 1966; Prescott, 1962, 1970; Smith, 1950; Tiffany and Britton, 1951). They were classified in five main groups, i.e., blue-green, green, diatom, flagellate, and desmid.

For enumeration, in general, blue-green algae were counted by the number of trichomes. Green algae were counted by individual cells except *Aatinastrum*, *Coelastrum*, and *Pediastrum*, which were recorded by each colony observed. *Scenedesmus* was counted by each cell packet. Diatoms were counted as one organism regardless of their groupings or connections. For instance, a unit was considered to be a filament of *Melosira*, a cluster of *Asterionella* or *Fragilaria* cells, or single cells of *Stephanodiscus* or *Surirella*. For flagellates, a colony of *Dinobryon* was recorded as a unit.

The stream sampling stations, except station 15 on Rayse Creek, were sampled for macroinvertebrates during the period March 30, 1976, to March 22, 1977. The streams were sampled with a modified Hester-Dendy multiple plate sampler described by Fullner (1970). Each sampler was suspended in the stream and replaced every month. In the field, the recovered samplers were placed in ziplock bags, and returned to the laboratory. The samplers were then disassembled and washed down in a U.S. Standard 30-mesh sieve bucket. The organisms were picked from the detritus, identified, counted, and preserved in 70 percent ethyl alcohol.

Samples for bacterial examinations were collected several inches below the water surface in mid-channel from all the stream sampling stations except 15. The samples were collected in 250-ml sterile glass bottles, and placed in ice immediately. The bacteriological analyses were performed by personnel of the Illinois Environmental Protection Agency in Champaign. Membrane filter techniques were used in determining total coliform (TC), fecal coliform (FC), and fecal streptococci (FS) counts in accordance with *Standard Methods* (American Public Health Association, 1971). The media M-Endo broth, M-FC broth, and M-Enterococcus agar respectively were used for TC, FC, and FS determinations.

In order to assess the physical, chemical, and biological characteristics of the lake, samples were collected from four lake stations on a biweekly basis from April 7, 1976, to December 7, 1976. These stations, shown in figure 1, are designated as 7 for the Rayse Creek-Big Muddy branch, 8 for the Casey Fork-Atchison Creek branch, 9 for the deep portion of the lake near the dam, and 10 for the Gun Creek branch. In addition to taking surface water samples at all four lake stations for chemical and algal analyses, water samples were obtained at depths of 1 foot from the bottom at station 9, and this location is designated as 12 in figure 1. In addition, water samples were collected on a weekly basis from August 11, 1976, to January 19, 1977, from the Casey Fork and Big Muddy River sub-impoundments. These two sampling

Table 3. Sampling Locations and Station Number Designations

Station	1	Rayse Creek near Waltonville
	2	Big Muddy River near Mt. Vernon
	3	Big Muddy River-downstream of dam (lake outlet)
	4	Gun Creek
	5	Atchison Creek
	6	Casey Fork near Mt. Vernon
	7	Rayse Creek-Big Muddy River branch of lake
	8	Atchison Creek-Casey Fork branch of lake
	9	Surface of the main lake near the dam
	10	Gun Creek branch of lake
	12	One foot from the bottom of the main lake near the dam
	13	Casey Fork sub-impoundment
	14	Rayse Creek-Big Muddy River sub-impoundment
	15	Rayse Creek at U.S. Highway 1

locations are designated 13 and 14, respectively, in figure 1. Water sampling locations and number designations for Rend Lake and its tributaries are summarized in table 3.

In situ observations of temperature, dissolved oxygen, and transparency were made for the four lake stations. Dissolved oxygen and temperature were determined with a galvanic cell oxygen analyzer equipped with a thermistor. At the beginning of the survey, the oxygen probe was standardized in lake surface water in which the DO content was determined by a modified Winkler method as outlined by the American Public Health Association (1971). Temperature and dissolved oxygen measurements were obtained at 2-foot intervals starting from the surface at these four stations. Transparencies were measured with an 8-inch diameter Secchi disc with black and white quadrant markings attached to a calibrated line.

Sample collection and methods of analyses for chemical and biological characteristics were the same for lake samples as for the tributary samples. Only the following chemical determinations were made on lake water samples: alkalinity, pH, hardness, nitrate and ammonia nitrogen, total silica, total and total dissolved phosphorus, and algal growth potential.

Lake stations 7 through 10 were sampled for macroinvertebrates with modified Hester-Dendy samplers and an Ekman bottom dredge. Two multiplate samplers were suspended from a buoy at each of these four stations at a depth of 2 feet from the surface and at 2 feet from the bottom. Four benthic samples were collected at each lake station and each sample consisted of three 6x6-inch Ekman dredge grabs. Each benthic sample was washed at the site through a U.S. Standard 30-mesh sieve bucket and preserved in 95 percent ethyl alcohol. In the laboratory, the organisms were picked from the detritus, identified, counted, and preserved. Sample dry weights were obtained by drying each sample for 24 hours at 60°C.

Acknowledgments

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WATER QUALITY OF STREAMS

During the period January 21, 1976, to January 19, 1977, the major streams in the Rend Lake watershed were sampled. Six stream stations were established (figure 1 and table 3) and 53 visits were made to each. At the time of sampling, water temperature and dissolved oxygen content were recorded. Analyses in the laboratory were performed for mineral quality and certain cations in particulate and dissolved form, as well as certain heavy metals in particulate form. The analyses on particulate matter filtered from the water samples were considered pertinent because a main objective of the study was to relate stream water quality to land use. Water samples were also examined for bacterial quality.

Three basic criteria were used in selecting the sampling locations, i.e., accessibility, proximity to existing streamflow recording devices, and nearest proximity to Rend Lake. Three streamflow recorders are maintained by the U.S. Corps of Engineers on the watershed. They are located on Rayse Creek, Big Muddy River, and Casey Fork. The sites on Rayse Creek and Casey Fork were considered satisfactory for sampling purposes and collection stations were established near them. Another site was selected on the Big Muddy River downstream of the gaging station. During sampling at this station, as well as the ones established on Atchison and Gun Creeks and the lake outlet, flow measurements were performed at the time of sampling and flow rating curves were subsequently developed. These data are included, along with the rating curves developed by the U. S. Corps of Engineers for Rayse Creek and Casey Fork, in figures 2 and 3.

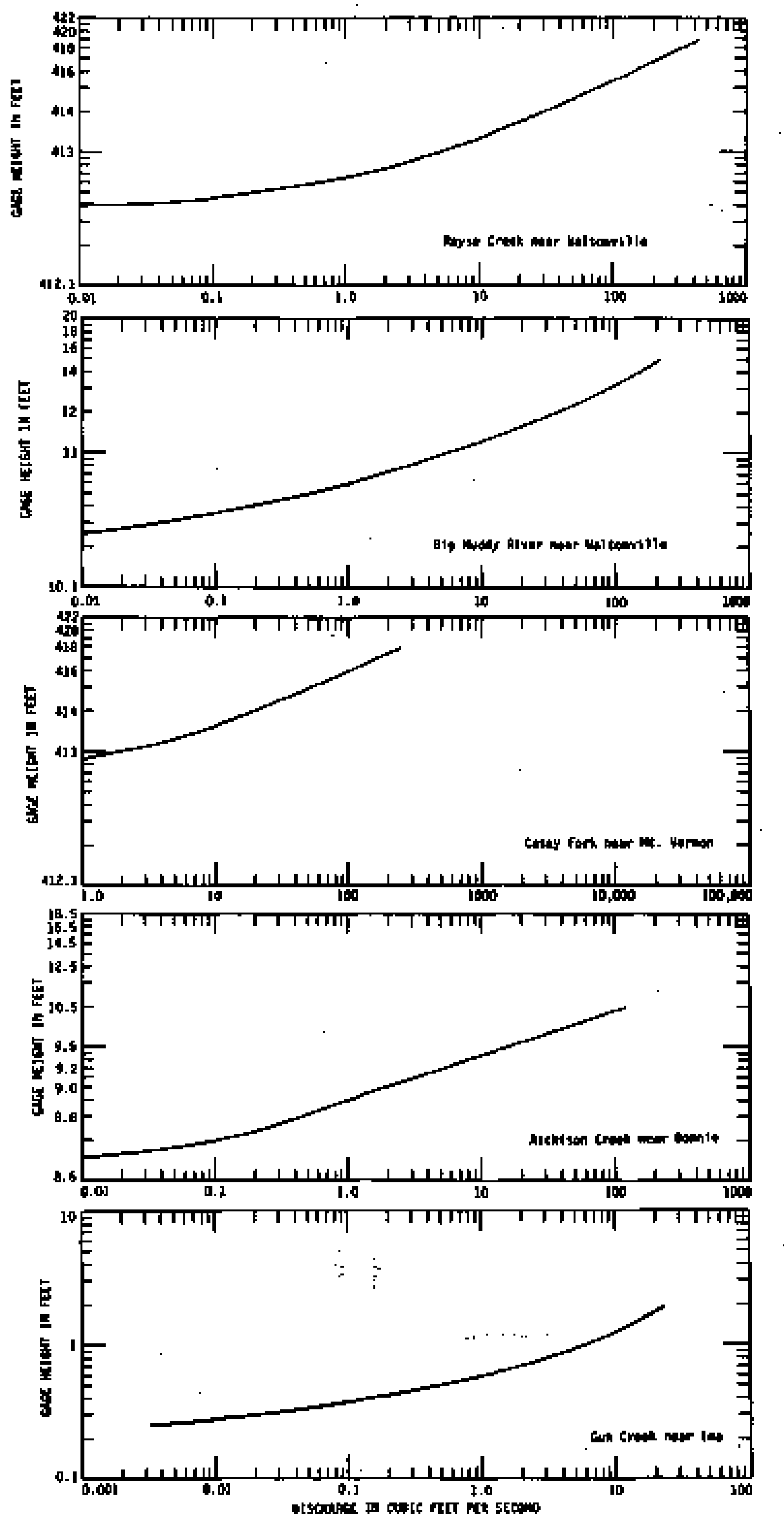

Figure 2. Rating curves for Rend Lake tributaries

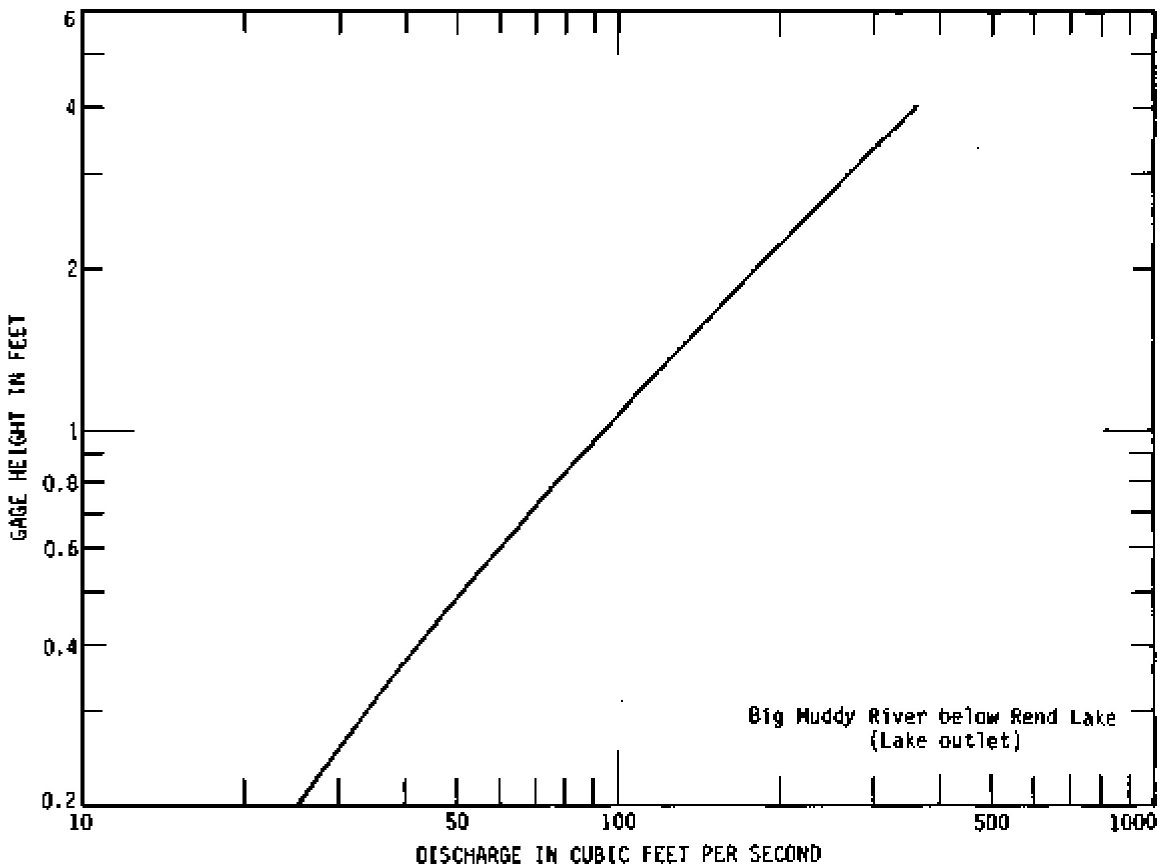

Figure 3. Rating curve for lake outlet

Table 4. Sampling Stations Relative to Drainage Area and Stream Length

	Drainage area at sampling station (sq mi)	*Total drainage area (sq mi)*	*Percent drainage area sampled*	*Total stream length (mi)*	*Sampling site to headwaters (mi)*	*Percent stream length sampled*
Rayse Creek (1)	87.50	101.56	86.2	21.56	17.88	82.9
Big Muddy (2)	83.95	100.27	83.9	25.10	23.37	93.1
Casey Fork (6)	87.02	116.20	74.9	23.79	18.86	79.2
Atchison Creek (5)	11.92	20.61	56.8	8.19	6.32	76.2
Gun Creek (4)	6.35	24.33	26.0	8.38	3.33	36.7
Non-trib. area		92.89				
Surface area of lake	31.88	31.88	100.0			
Totals	308.62	487.74	63.2	87.02	69.76	80.2

The drainage area serving Rend Lake is about 488 square miles. The location of each tributary sampling station with respect to its drainage area and stream length is given in table 4. For the larger stream basins (Rayse, Big Muddy, Casey Fork) representing 80 percent of the total tributary drainage area, the percent of the respective stream basin area upstream of the sampling stations varied from 74.9 to 86.2 percent. Lesser coverage was provided for Atchison and Gun Creeks, but their low flow characteristics compensated for the lack of coverage.

The collection of water samples from the five major stream tributaries was hampered by the periodic absence of streamflows. The following summarizes the flow conditions encountered on 53 sampling days at each stream.

Location	*Number of sampling days with no flow*
Rayse Creek	18
Big Muddy River	15
Casey Fork	0
Atchison Creek	33
Gun Creek	31
Lake outlet	0

To demonstrate the 'dryness' of the 53-week period, a review was made of the partial streamflow records maintained by the U.S. Corps of Engineers for the streams in the watershed during 1966-1973. From these, mean monthly flows were computed for Rayse Creek, the Big Muddy River, and Casey Fork. Because the drainage areas of the three basins are quite similar in size (table 4), the mean monthly flows for each month were combined to produce an average monthly flow for the area. Similarly, the monthly flows developed during days of sampling on the three streams were combined to produce monthly streamflows for the area on the days of sampling. Although partial records and arithmetic mean flows are not the ideal approach for defining streamflows, the procedure is satisfactory for comparing current fragmentary flow data with a partial short-term history of streamflow. The results are shown in figure 4.

As further evidence of the low streamflows during the period of sampling, average monthly rainfall data gathered at the National Weather Service station at Mt. Vernon are shown in figure 5. The departure from normal rainfall during 1976 was about minus 10 inches. Although the average monthly rainfall for the year 1976 exceeded the previous 5-year monthly average on three occasions (July, September, October), the prior months of below normal precipitation minimized runoff during rainfall events. The pattern and rate of streamflow for each of the stream stations during times of water sample collection are shown in figure 6.

The remaining portions of the discussion will deal with observations related to the water quality of the stream waters. Raw data are included in the Open File Data Supplement. A statistical summary of 17 elements reflecting the mineral content of the stream waters is given in table 5. Included in the tabulation are the low, high, and mean values for each measurement along with the standard deviation (SD). Most of the data displayed a normal distribution and therefore arithmetic means were relied upon. In some cases average values were misleading. Any aberrant value included in the data is noted in the text or on the tables.

Temperature

Water temperature will govern biological characteristics of a stream water and to a lesser extent its physical and chemical regime. The water pollution regulations of Illinois of 1972 stipulate for streams in the Rend Lake watershed that the maximum monthly temperatures for December through March of 15.6°C (60°F) and April through November of 32.2°C (90°F) shall not be exceeded more than 1 percent of the hours in the 12-month period ending in any month. Moreover, at no time shall the water temperature at such locations exceed the maximum limits by more than 3°F. There are no violations of this rule in the stream waters of the Rend Lake watershed.

Water temperatures, like air temperatures, are cyclic during an annual period. The use of air-water relationships for predicting water temperature in streams has been reported by Kothandaraman and Evans (1972). The annual variation in water temperature for the Big Muddy River and the lake outlet is shown in figure *1.* Water temperatures of other streams were similar to that shown for the Big Muddy River. Maximum water temperatures generally occurred during August and all of the stream waters froze during the months of December and January.

Mean annual water temperatures varied from 10.8°C (Atchison and Gun Creeks) to 14.4°C (Big Muddy River). High water temperatures varied from 22.2°C (Atchison and Gun Creeks) to 27.6°C (Big Muddy River). The lower temperatures recorded for the creeks are basically the result of lack of

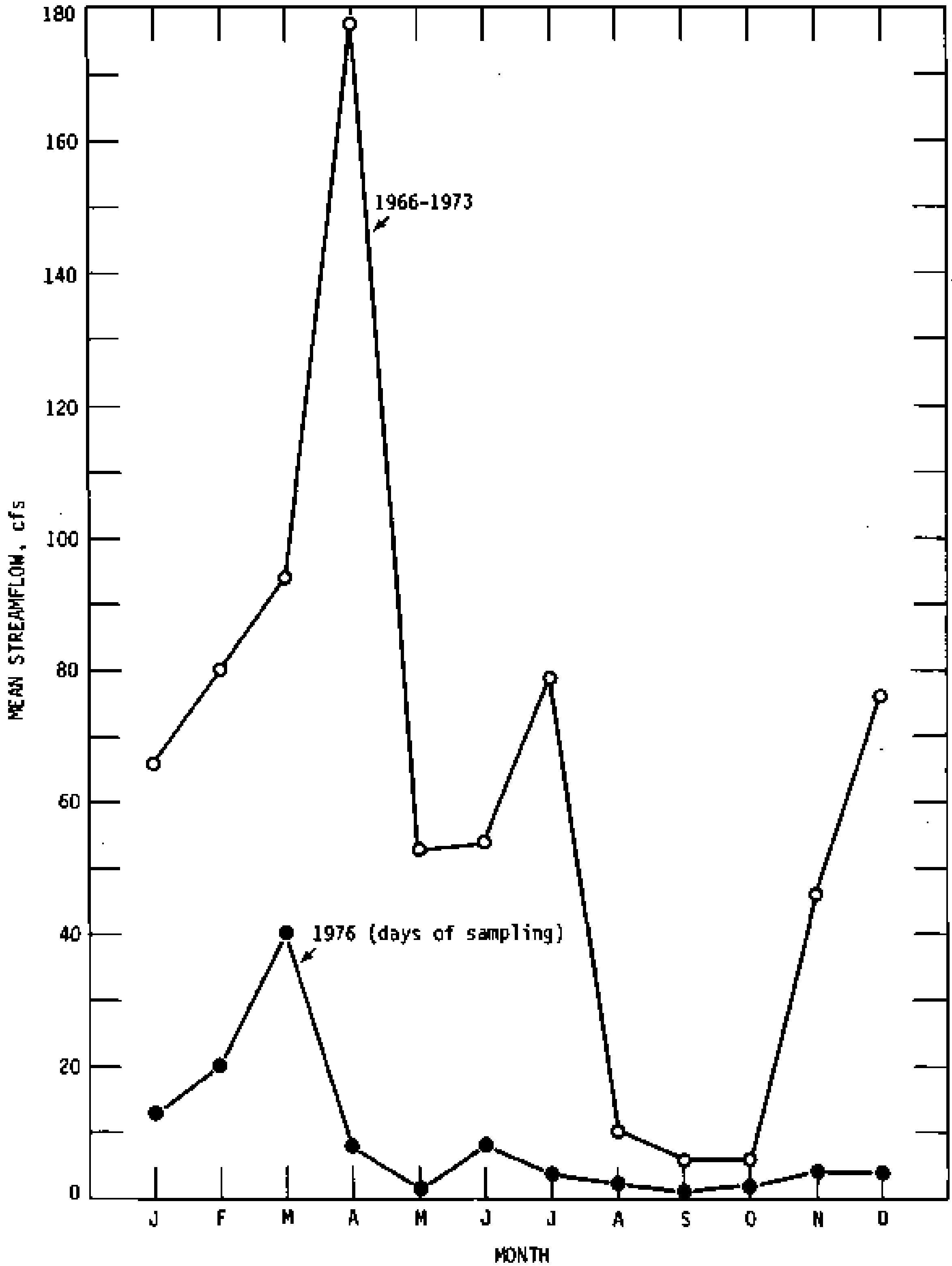

Figure 4. Comparison of estimated average streamflows with those on days of sampling

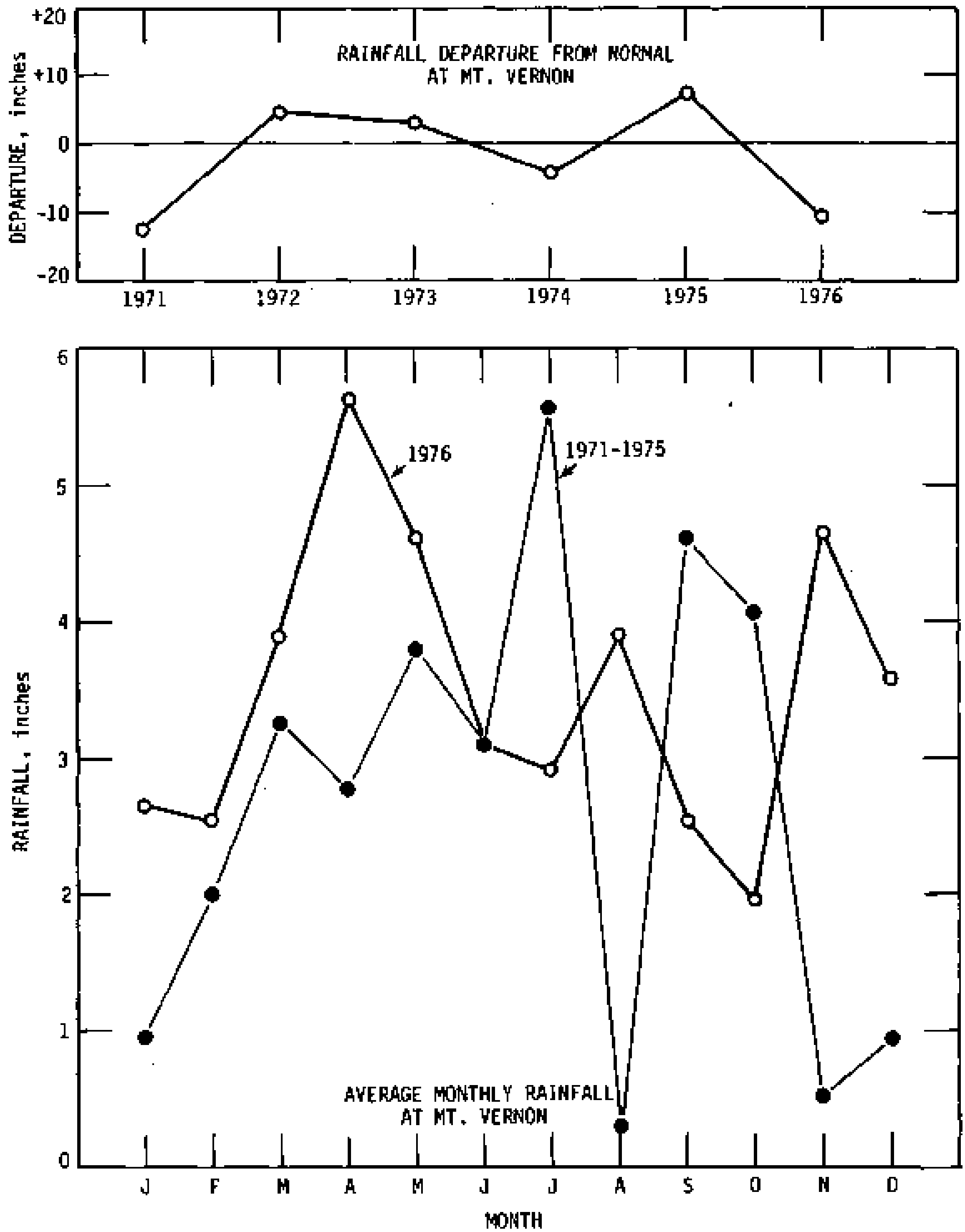

Figure 5. Average monthly rainfall at Mt. Vernon and departure from normal in 1976

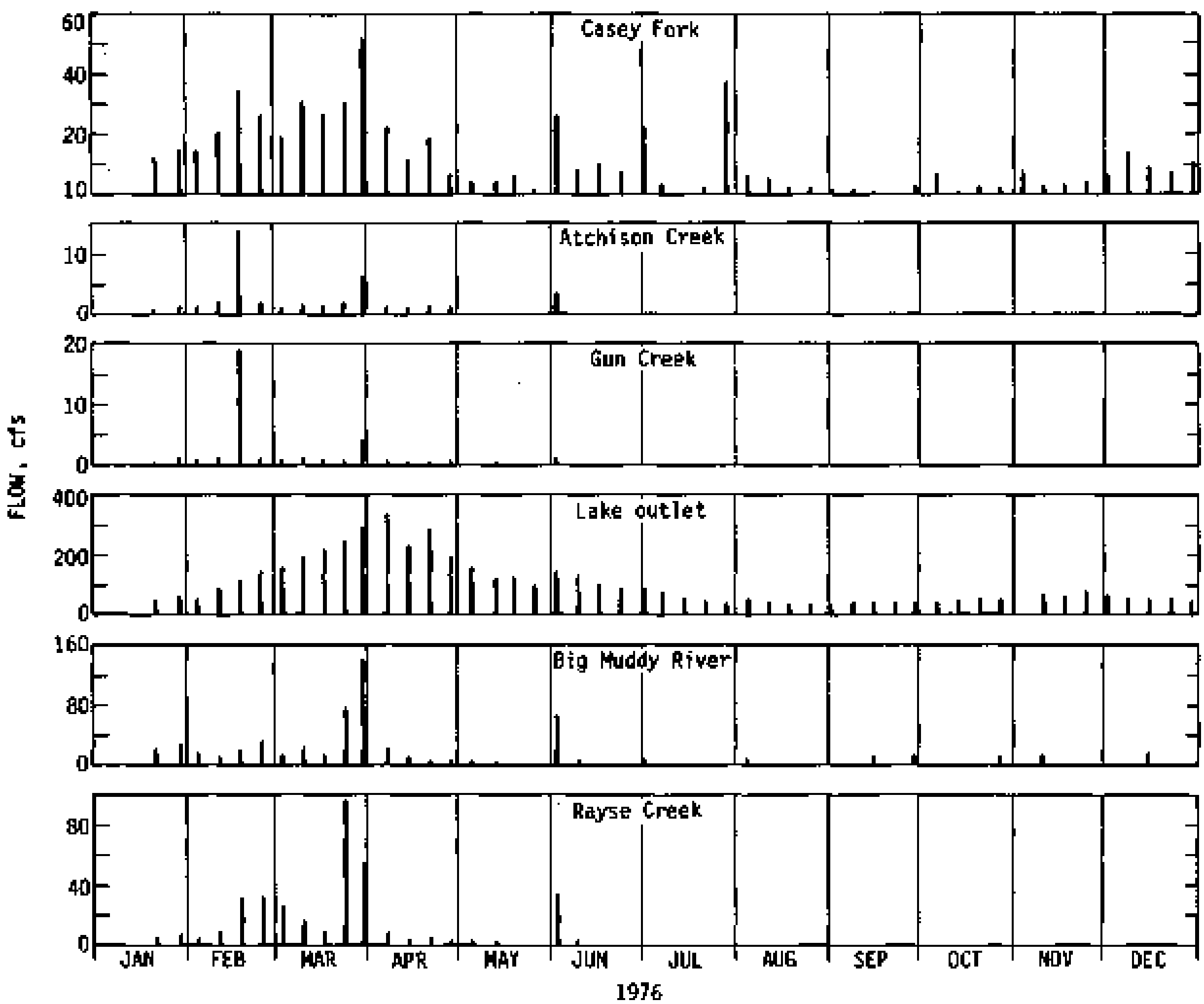

Figure 6. Pattern and rate of streamflow for streams during days of sample collection

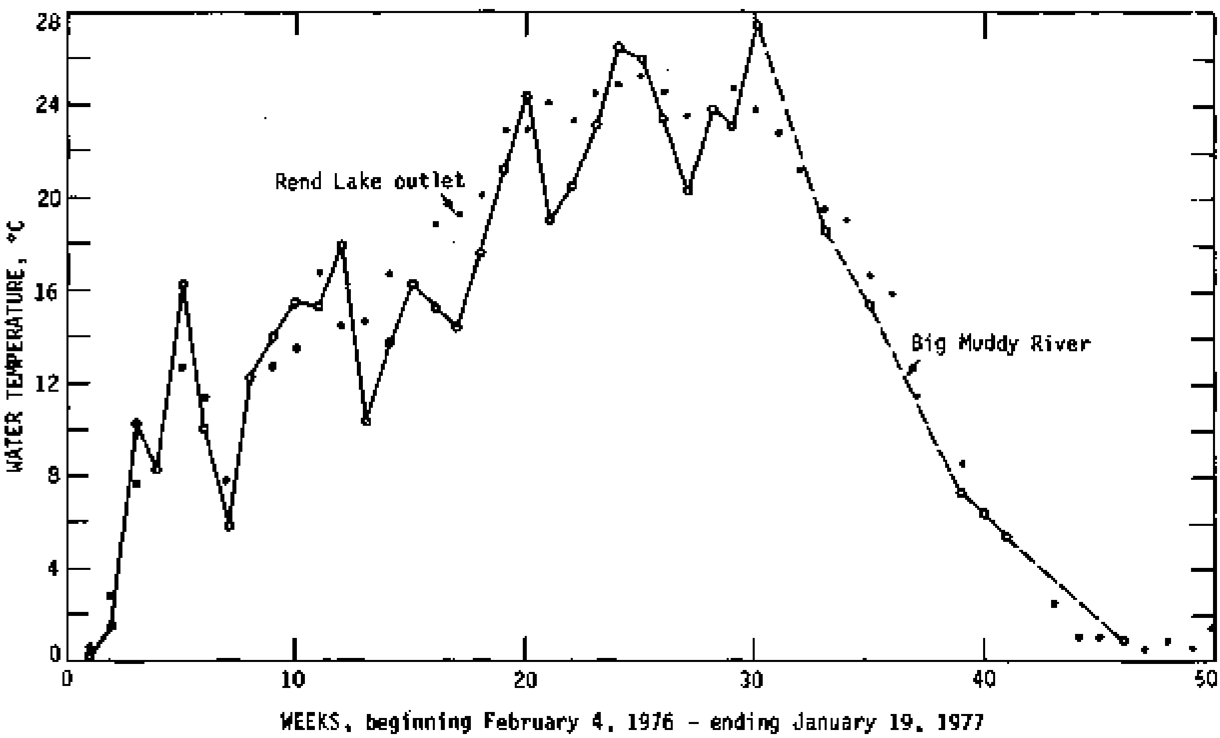

Figure 7. Annual variation in water temperature for Big Muddy and lake outlet

Table 5. Statistical Summary of Data for Stream Stations

	Low	High	Mean	SD
Station 1, Rayse Cveek, 35 samples				
Temperature, °C	0.00	25.0	11.8	
Dissolved oxygen	0.1	13.0	6.5	3.9
Turbidity, NTU	4.4	178.0	30.4	32.1
pH	6.5	8.1		
Alkalinity	34.0	312.0	112.0	54.0
Hardness	79.0	497.0	303.0	125.0
Chloride	14.0	333.0	129.0	77.0
Nitrate-N	0.1	17.0	1.0	2.9
Ammonia-N	0.02	0.87	0.20	0.17
Silica, total	1.6	10.9	6.5	2.5
Silica, dissolved	1.5	10.3	6.0	2.2
Phosphorus, total	0.00	0.84	0.21	0.18
Phosphorus, total dissolved	0.00	0.17	0.06	0.05
Algal growth potential	2.0	46.0	18.2	11.3
Solids, total	244.0	1197.0	714.0	272.0
Solids, dissolved	162.0	1187.0	656.0	289.0
Solids, suspended	4.0	278.0	58.0	57.0
Station 2, Big Muddy, 38 samples				
Temperature, °C	0.00	27.6	14.4	
Dissolved oxygen	1.9	11.1	7.4	2.0
Turbidity, NTU	5.0	234	39.8	39.6
pH	7.2	8.1		
Alkalinity	12.0	180.0	98.0	45.0
Hardness	81.0	531.0	279.0	128.0
Chloride	19.0	156.0	75.0	39.9
Nitrate-N	0.1	2.3	0.6	0.6
Ammonia-N	0.01	0.39	0.16	0.09
Silica, total	1.0	12.2	5.7	2.7
Silica, dissolved	0.6	9.5	5.1	2.4
Phosphorus, total	0.00	0.42	0.16	0.09
Phosphorus, total dissolved	0.00	0.13	0.04	0.03
Algal growth potential	2.0	34.0	17.1	8.7
Solids, total	207.0	1099.0	640.0	250.0
Solids, dissolved	173.0	1065.0	561.0	265.0
Solids, suspended	8.0	284.0	78.0	64.0

Continued on next page

Table 5. Continued

	Low	*High*	*Mean*	*SD*
Station 3, Lake outlet, 53 samples				
Temperature, °C	0.0	25.3	13.2	
Dissolved oxygen	5.0	15.2	9.6	2.9
Turbidity, NTU	2.0	17.0	9.0	4.0
pH	6.6	7.9		
Alkalinity	30.0	133.0	62.0	13.0
Hardness	102.0	192.0	135.0	23.0
Chloride	21.0	63.0	33.0	9.0
Nitrate-N	0.0	0.8	0.1	0.1
Ammonia-N	0.00	0.51	0.17	0.11
Silica, total	0.0	3.1	1.2	0.7
Silica, dissolved	0.0	3.1	1.1	0.6
Phosphorus, total	0.00	0.23	0.08	0.04
Phosphorus, total dissolved	0.00	0.17	0.02	0.03
Algal growth potential	1.0	33.0	12.0	6.7
Solids, total	194.0	481.0	289.0	49.0
Solids, dissolved	181.0	332.0	257.0	36.0
Solids, suspended	2.0	190.0	32.0	31.0

	Low	*High*	*Mean*	*SD*
Station 4, Gun Creek, 22 samples				
Temperature, °C	0.0	22.0	10.8	
Dissolved oxygen	2.2	12.7	8.6	2.9
Turbidity, NTU	6.4	400.0	22.0*	86.5
pH	7.1	8.1		
Alkalinity	20.0	116.0	64.0	27.0
Hardness	68.0	204.0	141.0	31.0
Chloride	6.0	18.0	10.0	3.0
Nitrate-N	0.1	4.6	0.9	1.2
Ammonia-N	0.00	0.91	0.19	0.21
Silica, total	2.8	12.3	8.4	2.7
Silica, dissolved	2.8	12.2	7.7	2.3
Phosphorus, total	0.00	0.74	0.13	0.17
Phosphorus, total dissolved	0.00	0.21	0.03	0.04
Algal growth potential	5.0	36.0	15.5	9.1
Solids, total	264.0	815.0	357.0	112.0
Solids, dissolved	138.0	388.0	280.0	52.0
Solids, suspended	10.0	677.0	77.0	141.0

* Excludes a single value of 400

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Table 5. Concluded

Station 5, Atchison Creek, 20 samples

	Low	High	Mean	SD
Temperature, °C	0.00	22.2	10.8	
Dissolved oxygen	4.1	16.8	9.6	3.0
Turbidity, NTU	6.7	325.0	15.0*	71.5
pH	7.5	8.6		
Alkalinity	48.0	136.0	90.0	27.0
Hardness	122.0	367.0	274.0	68.0
Chloride	8.0	31.0	16.0	5.0
Nitrate-N	0.0	6.3	1.0	1.5
Ammonia-N	0.01	0.91	0.19	0.22
Silica, total	0.9	11.1	7.0	2.9
Silica, dissolved	0.9	11.1	6.7	2.5
Phosphorus, total	0.00	0.62	0.12	0.13
Phosphorus, total dissolved	0.00	0.15	0.03	0.03
Algal growth potential	6.0	46.0	18.0	11.0
Solids, total	384.0	721.0	575.0	92.0
Solids, dissolved	221.0	705.0	514.0	123.0
Solids, suspended	5.0	500.0	61.0	110.0

* Excludes a single value of 325

Station 6, Casey Fork, 53 samples

	Low	High	Mean	SD
Temperature, °C	0.0	24.0	11.5	
Dissolved oxygen	1.9	11.7	5.3	2.5
Turbidity, NTU	8.0	815.0	29.4*	115.7
pH	6.9	8.1		
Alkalinity	32.0	137.0	101.0	23.4
Hardness	75.0	299.0	208.0	54.3
Chloride	9.5	279.0	71.9	44.0
Nitrate-N	0.6	5.6	1.5	0.9
Ammonia-N	0.18	21.36	4.16	4.43
Silica, total	1.3	13.3	9.4	2.0
Silica, dissolved	0.0	12.1	8.9	1.8
Phosphorus, total	0.57	7.05	2.75	1.64
Phosphorus, total dissolved	0.01	6.27	2.11	1.50
Algal growth potential	15.0	138.0	76.0	30.1
Solids, total	385.0	3007.0	622.0	347.0
Solids, dissolved	143.0	936.0	507.0	123.0
Solids, suspended	2.0	2864.0	61**	389.0

* Excludes single value of 815
** Excludes single value of 2864

measurement during summer months because of the 'no flow' conditions. The water temperatures observed on the Big Muddy River are most likely representative of stream waters in the watershed during year-round flow conditions. The modifying effect of the lake is evident in figure 7. Fluctuations in water temperature of the lake outlet are not as pronounced as that shown for the Big Muddy River.

Dissolved Oxygen

Regulations in Illinois stipulate that dissolved oxygen (DO) shall not be less than 6.0 mg/1 during at least 16 hours of any 24-hour period, nor less than 5.0 mg/1 at any time. As shown in table 5, DO mean concentrations ranged from 5.3 mg/1 (Casey Fork) to 9.6 mg/1 (Atchison Creek). However, mean values do not reflect actual conditions. A distribution of the DO data on probability paper is shown in figure 8 for Rayse Creek, the Big Muddy River, and Casey Fork. The waters of the Big Muddy River are generally satisfactory in meeting the 5 mg/1 limit. This is not the case for the waters of Rayse Creek and Casey Fork. A tabulation of the percentage of time dissolved oxygen was less than that required by regulations is shown in table 6. The waters of Rayse Creek and Casey Fork had DO concentrations less than 5 mg/1 40 and 58 percent of the time, respectively, and less than 6 mg/1 DO 46 and 67 percent of the time, respectively.

Low DO occurrences were warm weather events, but the probable cause for depressed DO concentrations was different for the two streams. In Rayse Creek, the accumulation of organic debris consisting mainly of leaves, often 2 to 3 feet deep, on the stream bottom was apparent during low DO conditions. The depressed DO conditions in Casey Fork are likely due to the demand imposed by waste effluents originating from the city of Mt. Vernon.

Table 6. Percentage of Time Dissolved Oxygen
Was Less Than Specified Values

	5.0 mg/l	*6.0 mg/l*
Rayse Creek (1)	40	46
Big Muddy River (2)	5	24
Casey Fork (6)	58	67
Atchison Creek (5)	5	10
Gun Creek (4)	18	18
Lake outlet (3)	0	8

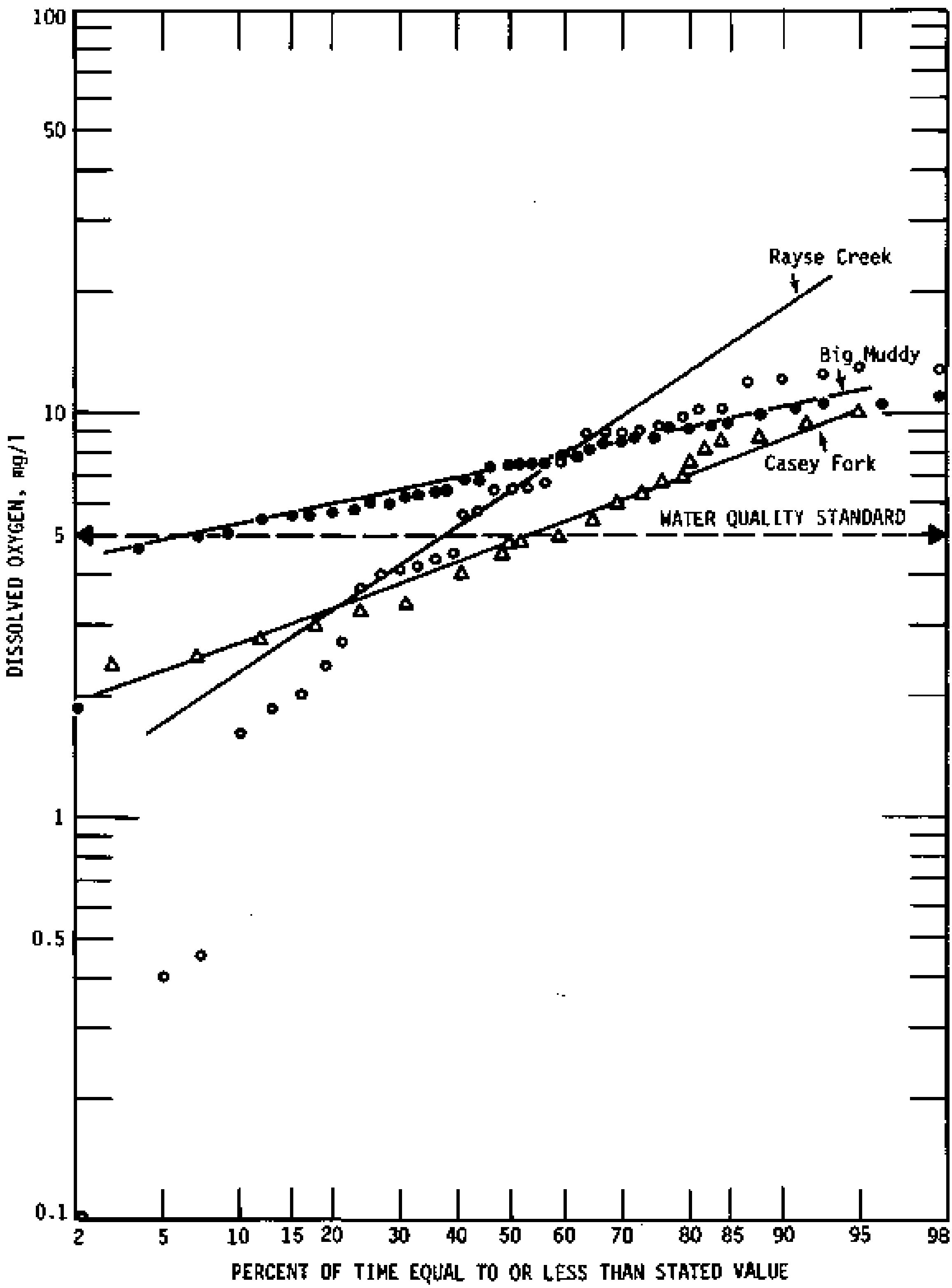

Figure 8. Distribution of dissolved oxygen data for streams

Values of pH

The pH value reflects the acid or alkaline nature of water. A pH of 7 is neutral; that above 7 is considered alkaline and that below 7 is considered acid. As shown in table 5, the general range is from 7.0 to 8.0. Illinois regulations stipulate a pH range of 6.5 to 9.0. There were no violations of the rule in the waters of the Rend Lake watershed.

Alkalinity and Hardness

For the pH ranges experienced in most Illinois surface waters, alkalinity is a measure of bicarbonate salts. It also provides the buffering capacity of the water to resist pH changes. It is an important source of carbon for photosynthetic activity. Hard water is caused principally by the salts of calcium and magnesium. Harmeson and Larson (1969) suggest classification as follows, in terms of mg/1 $CaCO_3$: soft 0-75; fairly soft 75-125; moderately hard 125-200; hard 250-400; very hard over 400.

From the standpoint of alkalinity and hardness, the waters of Rayse Creek and the Big Muddy River are very similar, though quite variable in terms of concentration. As shown in table 5, mean alkalinities are 112 and 98 mg/1; mean hardness values are 303 and 279 mg/1, respectively. From the classification mentioned, the waters of the two streams are hard. Though the water alkalinities of Casey Fork and Atchison Creek are quite similar in distribution, with means of 101 and 90 mg/1, respectively, their hardness values differ significantly with means of 208 and 274 mg/1, respectively. It is probable that effluents from the waste ponds maintained by the city of Mt. Vernon, which make up most of the streamflow in Casey Fork during low flow periods, reduce the hardness of the stream's waters.

A significant difference exists between the alkalinity and hardness concentrations in the waters of the lake outlet and that of the tributary streams. This modification of water quality by the lake system, in terms of functioning as a 'water softener,' converts a hard water to a moderately hard water producing a mean hardness of 135 mg/1. The corresponding lessening of alkalinity in the waters (mean of 62 mg/1) suggests that photosynthetic activity has reduced the alkalinity (HCO_3) by the uptake of carbon, thus upsetting the chemical equilibrium existing between calcium, magnesium, and HCO_3 and causing calcium and magnesium to precipitate which lowers the hardness. This has been observed in other lake systems in Illinois.

Chloride

Chloride is present in all natural water and its concentrations in Illinois streams vary widely. Streams in the southern part of the state generally have higher values than do those in other parts of the state. In a recent report (Butts et al., 1976) the excessive high concentrations of chloride in several southern Illinois streams were documented. Regulations in Illinois limit chloride concentrations to 500 mg/l for general streams. A limit of 250 mg/1 is required for drinking water. These requirements were not violated in the stream waters of the Rend Lake watershed.

However, on the basis of chloride concentrations, the streams fall in three categories. As shown in table 5, mean chloride concentrations for the waters of Rayse Creek, the Big Muddy River, Casey Fork, and Gun Creek are 129, 75, 72, and 10 mg/1. That for the lake outlet waters is 33 mg/1. A distribution of the chloride data for the four streams is shown in figure 9. Rayse Creek and Big Muddy River data appear to consist of two populations. This suggests that some erratic influence other than natural is governing chloride concentrations. Rayse Creek reflects the highest concentrations of chloride, and the Big Muddy River and Casey Fork show about the same concentrations with the waters of Casey Fork being more uniform in distribution. Chloride concentrations in Gun Creek are relatively minor and could, along with those for Atchison Creek, be considered background concentrations.

There is considerable oil well activity (discussed later) upstream of the sampling stations on Rayse Creek, the Big Muddy River, and Casey Fork. As stream sampling progressed, it became obvious that chloride concentrations were elevated in the waters of Rayse Creek. To determine the influence of oil well activity, another sampling station (station 15), as shown on figure 1, was established in August at a location above any major oil field. From the 11 samples collected from station 1 (downstream of the oil wells) and station 15 (upstream of the oil wells), the data in table 7 were developed.

Table *1.* Comparison of Chloride Content Upstream and Downstream of Oil Fields

(Values in mg/1)

Date	*Station 15 upstream*	*Station 1 downstream*	*Change*
8/11/76	23	38	+15
8/18/76	37	57	+20
8/25/76	30	62	+32
9/15/76	33	43	+10
9/29/76	48	19	-29
10/26/76	23	184	+161
11/2/76	31	48	+17
11/10/76	31	52	+21
11/17/76	35	57	+18
11/30/76	38	61	+23
12/8/76	53	76	+23

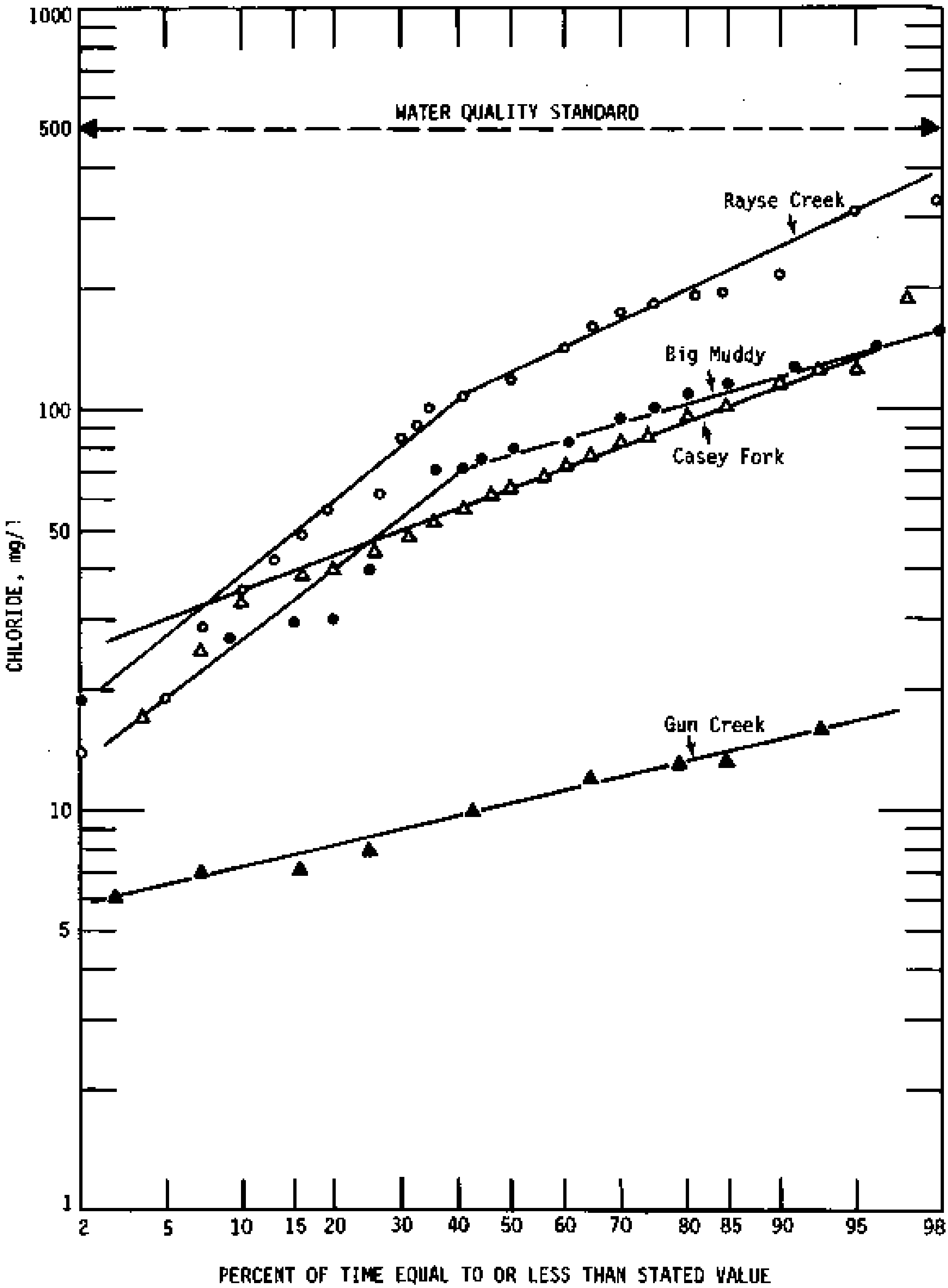

Figure 9. Distribution of chloride data for streams

Table 7 shows an increase in chloride content with downstream water movement in every case except on September 29, 1976. Increases ranged from 10 to 161 mg/l. This demonstrates the influence of oil well activity on Rayse Creek during the period of sampling, though this influence was not so intensive as to violate stream standards. It is probable that the waters of the Big Muddy River are similarly modified as indicated principally by the configuration of the data distribution for that stream in figure 9.

The chloride concentrations in Casey Fork are governed by treated waste effluents. Evans (1968) demonstrated that the addition of common ions to sewage solely by the domestic use of water will increase chlorides 200 to 300 percent.

If it is assumed that the chloride contents of Gun Creek and Atchison Creek are background at, say, 13 mg/1, then the average increase in chlorides for Rayse Creek, the Big Muddy River, and Casey Fork would be 169, 62, and 59 mg/1, respectively, from man-made influences.

Nitrogen

Two forms of nitrogen were examined, i.e., nitrate-nitrogen (NO3-N) and ammonia-nitrogen (NH_3-N) whfch included the ammonium (NH_4^+)and ammonia (NH_3) fractions. Except for public and food processing water supplies, where Illinois limits NO_3-N concentrations to 10 mg/1, there is no NO3-N stream standard. Ammonia-nitrogen is limited by water pollution regulations to 1.5 mg/1.

The pertinent NO_3-N concentrations observed are shown in table 5. Except in one instance on Rayse Creek where a high value of 17 mg/1 NO3-N was detected, values did not exceed 7 mg/1; mean values ranged from 0.1 mg/l for the lake outlet to 1.5 mg/1 for Casey Fork. A concentration of 1.0 mg/1 is representative of background levels for many Illinois streams. Nitrate-N is not a significant factor in terms of water quality degradation in the watershed.

As shown in table 5, the mean values for NH_3 -N range from 0.16 to 4.16 mg/1. Except for the waters of Casey Fork, high values never exceeded 1.0 mg/1. The high recorded for Casey Fork was 21.4 mg/l.

The data distribution shown in figure 10 for the Big Muddy River is typical of all stream waters except Casey Fork. Figure 10 shows that 50 percent of the time NH_3-N values will be equal to or less than 0.14 mg/1. A similar data distribution is shown in figure 11 for the NH3-N content of Casey Fork waters. The violations of the water quality standards are apparent. The extent of the departures from the stream quality standard is summarized in table 8. About 66 percent of the time NH3-N concentrations in Casey Fork exceeded 1.5 mg/1. The high ammonia content originates in Mt. Vernon.

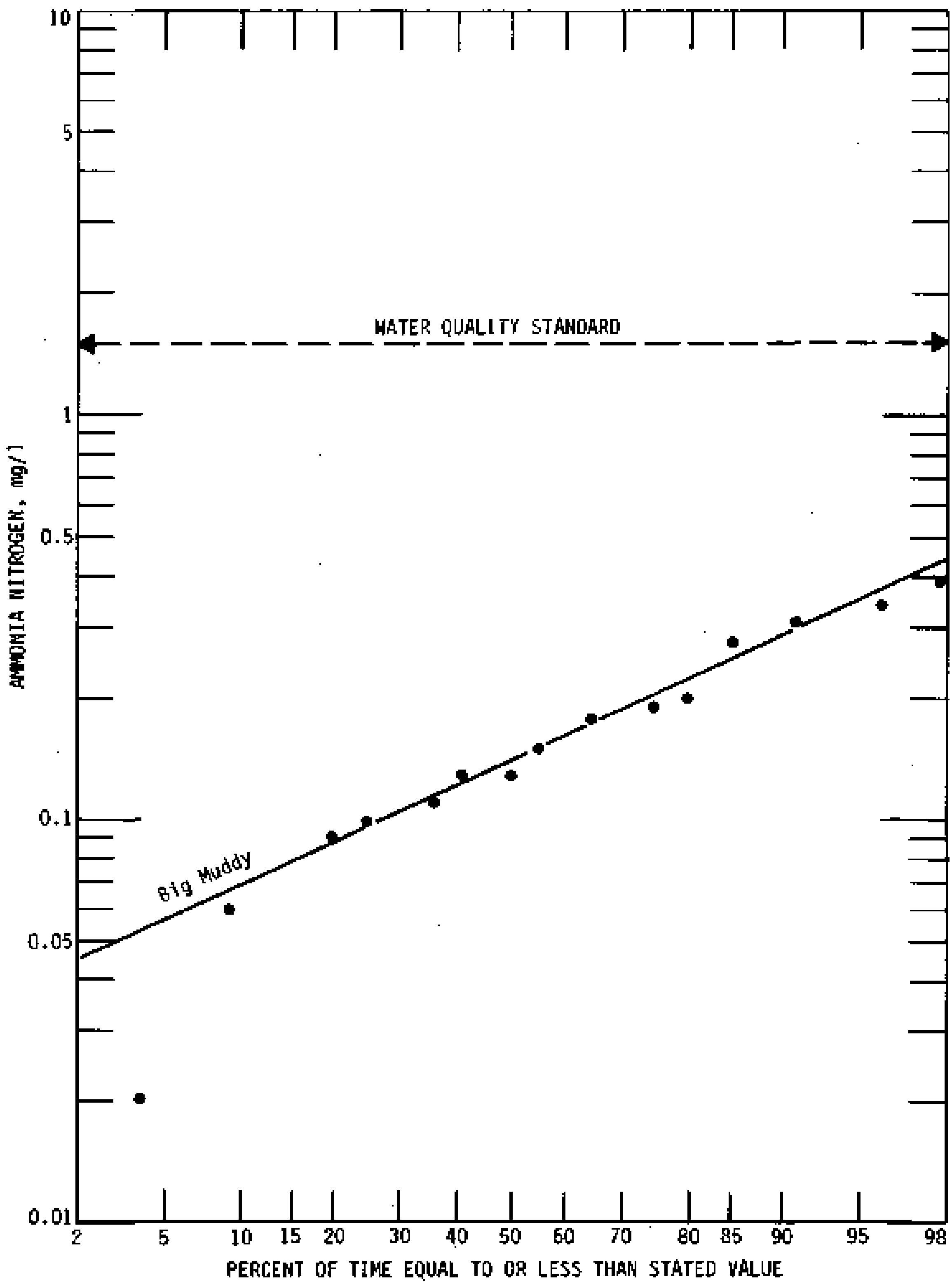

Figure 10. Distribution of ammonia data for Big Muddy

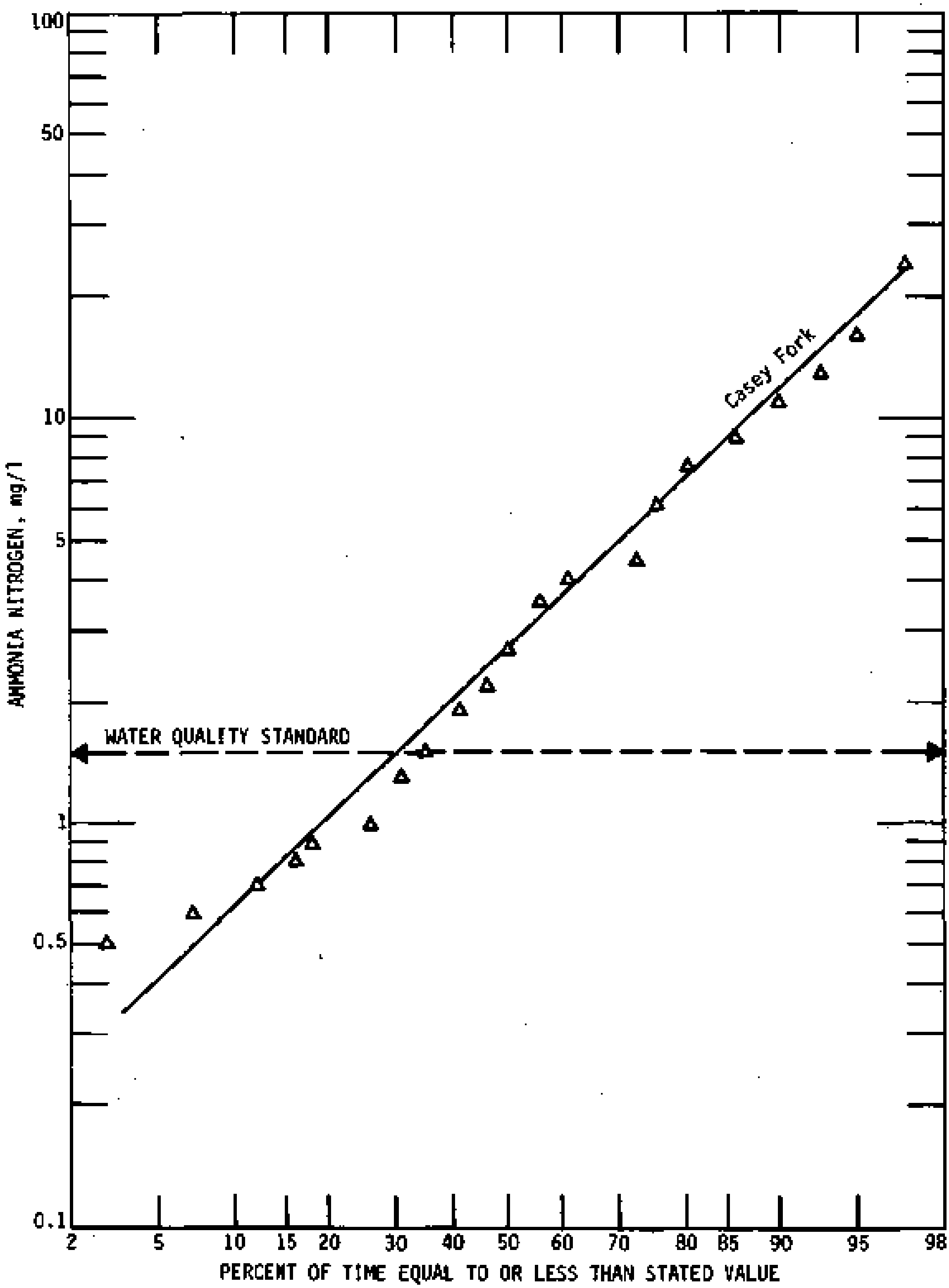

Figure 11. Distribution of ammonia data for Casey Fork

Table 8. Percentage of Time Ammonia-Nitrogen Was Greater Than Specified Value

		1.5 mg/l
Rayse Creek	(1)	0
Big Muddy River (2)		0
Casey Fork (6)		66
Atchison Creek (5)		0
Gun Creek	(4)	0
Lake outlet (3)		0

Ammonia-N is a nutrient source for algae growth. It is also a toxic substance for aquatic life, especially fish, if in high enough concentrations. The concentrations observed in Casey Fork are high enough to adversely affect fish in that stream.

Silica

Silica in the form of silicon dioxide (SiO_2) is a mineral constituting over 60 percent of the rocks and soils on the earth's crust. It would be an unusual occurrence not to find it in natural water systems. It is also a nutrient, and the principal one for the predominant type of algae in Illinois streams, diatoms. Wang and Evans (1969) showed that approximately 52 percent of the fluctuation in dissolved silica in the Illinois River is attributable to diatom productivity.

Total silica and dissolved silica concentrations were determined for the waters of the Rend Lake watershed. Dissolved silica was found to represent at least 90 percent of the total silica. As shown in table 5, the mean concentration of total silica in the tributary streams ranged from 5.7 mg/l in the Big Muddy River to 9.4 mg/l in Casey Fork. Generally the values are lower than observed in other southern Illinois streams (Butts et al., 1976). However, the most significant change is the mean concentration of 1.2 mg/l shown for the lake outlet waters in table 5. This suggests that aquatic organisms within the lake, and particularly diatom populations, are reducing the silica content of the water during its passage through the lake system.

Phosphorus

Phosphorus is probably the primary limiting factor for algal growth in Illinois waters. Gakstatter et al. (1975) reported on 623 lakes east of the Rocky Mountains and concluded that 67 percent were phosphorus limited. Similarly, Miller et al . (1974) found that 35 of 49 lakes located throughout the United States were phosphorus limited. In the waters of Lake Decatur and its tributaries (Evans and Schnepper, 1974) phosphorus was limiting. On the lakes of the Fox Chain, Kothandaraman et al. (1977) found the waters to be phosphorus and nitrogen limited. Because of the limiting status of phosphorus, the

Table 9. Percentage of Time Total Phosphorus Was Greater Than Specified Value

	0.05 mg/l
Rayse Creek (1)	91
Big Muddy River (2)	89
Casey Fork (6)	100
Atchison Creek (5)	80
Gun Creek (4)	70
Lake outlet (3)	84

Table 10. Average Percentage of Total Phosphorus Detected as Dissolved Phosphorus

	Average percent
Rayse Creek (1)	28
Big Muddy River (2)	25
Casey Fork (6)	77
Atchison Creek (5)	25
Gun Creek (4)	23
Lake outlet (3)	25

regulations in Illinois governing water quality limit total phosphorus concentrations to 0.05 mg/l in any reservoir or lake, or in any stream at the point where it enters any reservoir or lake.

As in the case of silica, determinations for phosphorus were made for total and dissolved forms. The dissolved form is the most accessible and therefore the most biologically active form. The range and mean values found at each stream station are given in table 5. Total phosphorus values for mean concentrations ranged from 0.12 mg/l in Atchison Creek to 2.75 mg/l in Casey Fork. The distribution of the data for the tributary streams, except Casey Fork, resembled that of the Big Muddy River. Figure 12 shows data distribution plots for the Big Muddy River and Casey Fork. All points fall above the water quality standard of 0.05 mg/l, but Casey Fork is exceptionally high.

As summarized in table 9, violations of the phosphorus limitation rule occur quite frequently.

Probably most important for algal growth considerations is the quantity of total phosphorus that is in the dissolved form. Table 10 lists the relative quantities of total phosphorus, on the average, that were detected to be in the dissolved form. For those waters other than Casey Fork the percent dissolved phosphorus ranged from 23 to 28. This is similar to other southern Illinois streams without major point sources of waste discharges. Butts et al. (1976) found the percent of dissolved phosphorus to range from 25 to 35 percent on the watershed of the North Fork of the Saline River. The 77 percent value for Casey Fork is similar to that found for a tributary of the North Fork, Bear Creek (69 percent) which receives sewage effluent from the city of McLeansboro.

Algal Growth Potential

As reported by Wang et al. (1973), AGP values show the maximum algal response to a specific water if mixed algae cultures are allowed to grow under optimum environmental conditions. AGP values can thus be used to compare

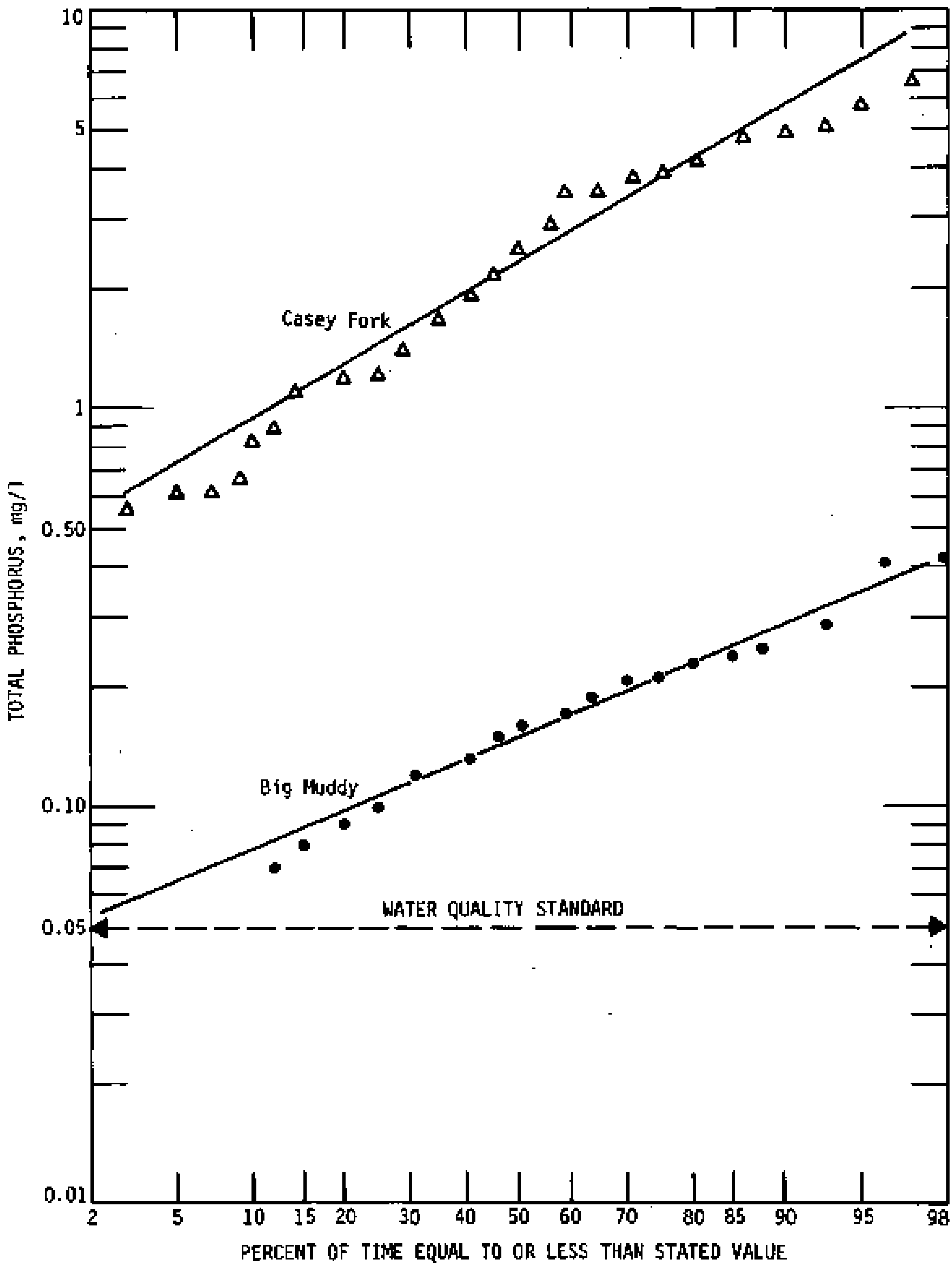

Figure 12. Distribution of total phosphorus data for two streams

waters from different sources, as done here, or a single source over an extended period of time to monitor trends. The pertinent results are shown in table 5.

With the exception of Casey Fork waters, all tributary streams showed a mean value of less than 20 mg/l. The range of means was 15 to 18 mg/l. Evans (1975) reported that waters having an AGP of less than 20 mg/1 would not have algal problems. The mean concentration for the waters of Casey Fork was 76 mg/1. Figure 13 compares the AGP data distribution for the Big Muddy River, considered representative of the other tributaries, with that of Casey Fork.

Solids and Turbidity

Total solids consist of suspended solids and dissolved solids. Turbidity is included here because it is usually related to suspended solids in Illinois streams. There are no stream standards in Illinois for suspended solids and turbidity for natural waters. There is a limitation of 1000 mg/1 for dissolved solids. The limit was exceeded in Rayse Creek in 2 of 35 samples and in the Big Muddy River in 3 of 38 samples. As shown in table 5, the maximum dissolved solids for Rayse Creek was 1187 mg/1 and for the Big Muddy River 1065 mg/l.

From the mean values for dissolved solids concentrations shown in table 5 it is apparent that the waters of Rayse Creek are the more mineralized of the five tributary streams. Of more importance is the modifying effect of the lake waters on the dissolved solids content of the incoming water. At a mean concentration of 257 mg/1 dissolved solids, the lake outlet reflects considerable uptake by organisms, adsorption, precipitation, and other physicochemical reactions.

The suspended solids concentrations, on the average, were about the same for the five tributary stations, as shown in table 5. The means ranged from 58 to 78 mg/1. Data distribution plots are shown for three streams and the lake outlet in figure 14. The suspended solids are not high in comparison with other southern Illinois streams coursing through agricultural land. It should be remembered, however, that most of the sampling was done during low flow periods. Efforts to relate suspended solids to streamflow were not successful.

Turbidity values were higher for the Big Muddy River than for the other tributary streams, as shown in table 5. Turbidity measurements were made with a nephelometer which compares the light scattered by a sample with the light scattered by a reference standard.

Often there is a relationship in stream waters between turbidity and suspended solids concentrations. The nature of suspended solids (size, color, shape), as well as concentration, may affect turbidity readings (Wang and Brabec, 1969). The relationships developed for the five tributary streams are shown in figures 15 and 16. The lines of best fit are developed from regression analysis factors set forth in table 11.

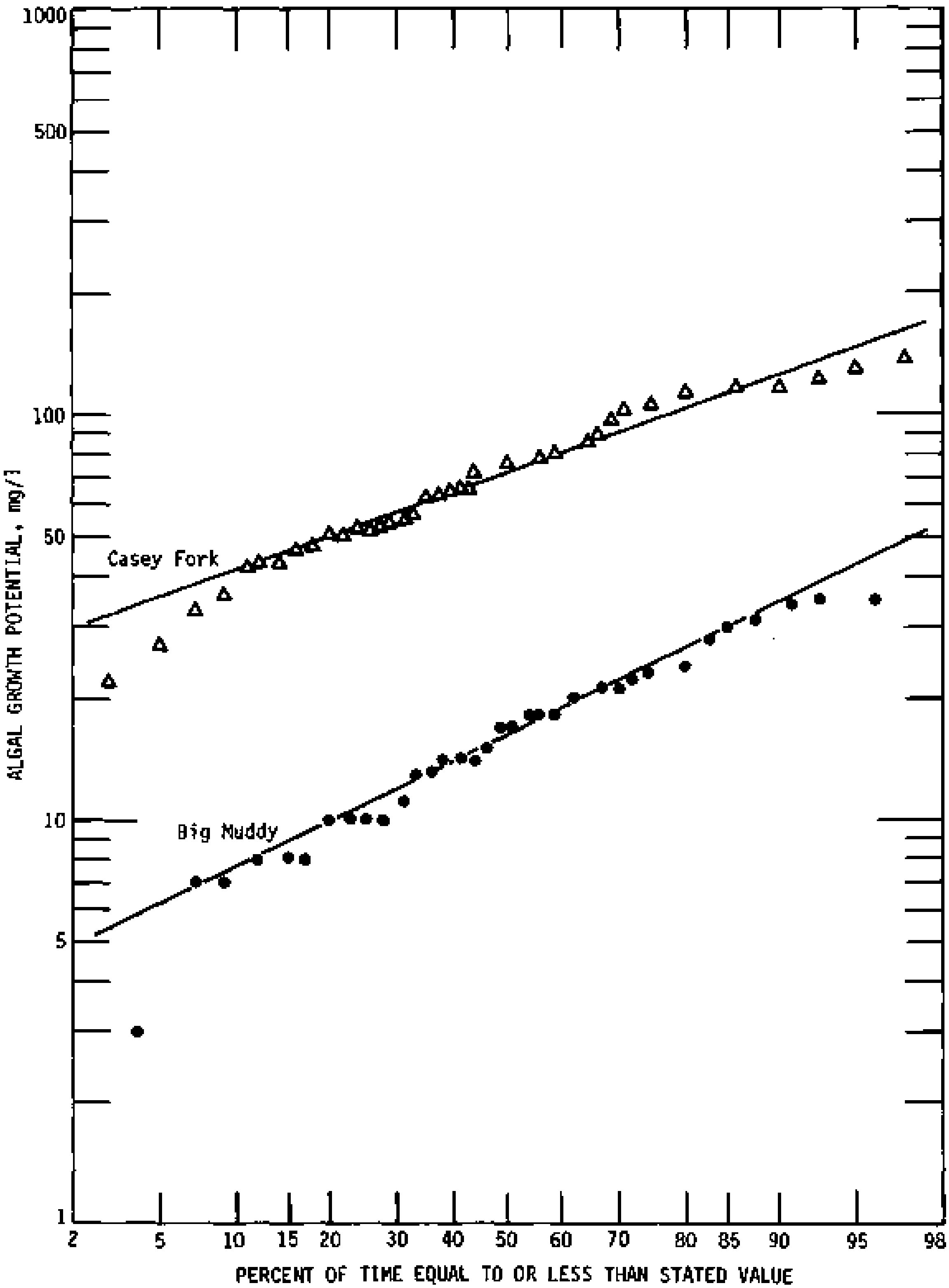

Figure 13. Distribution of algal growth potential data for two streams

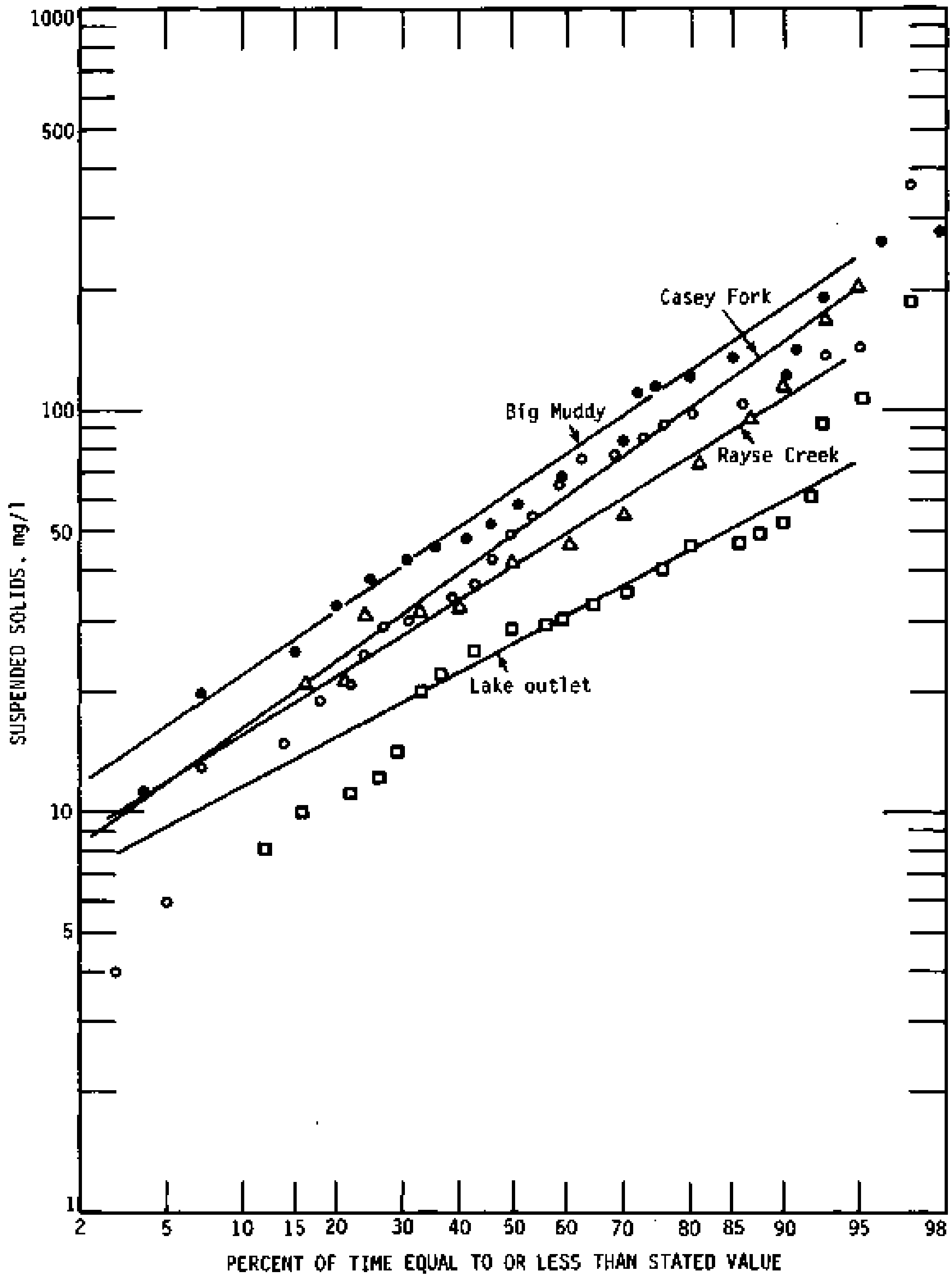

Figure 14. Distribution of suspended solids for streams

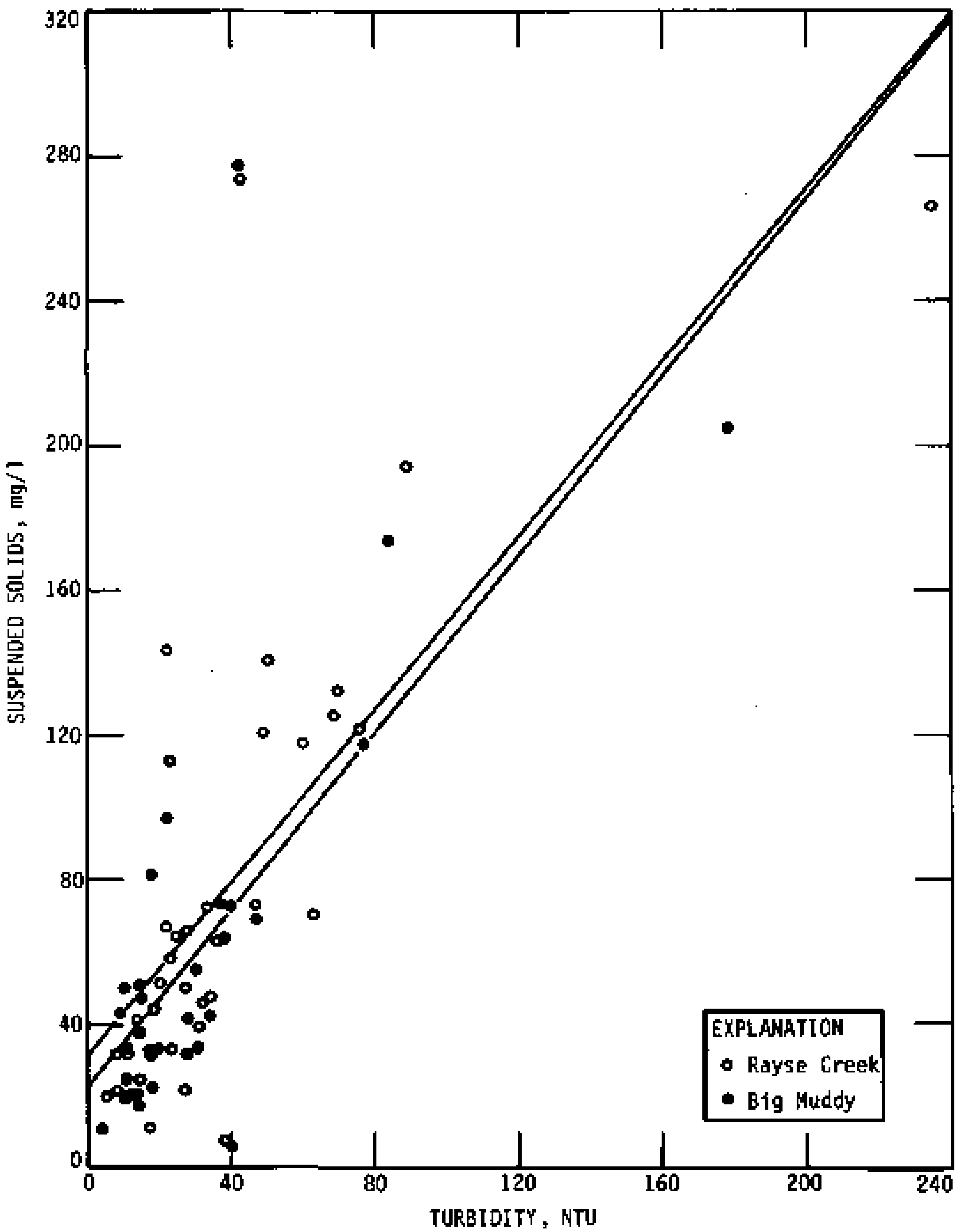

Figure 15. Relationship of suspended solids and turbidity for two streams

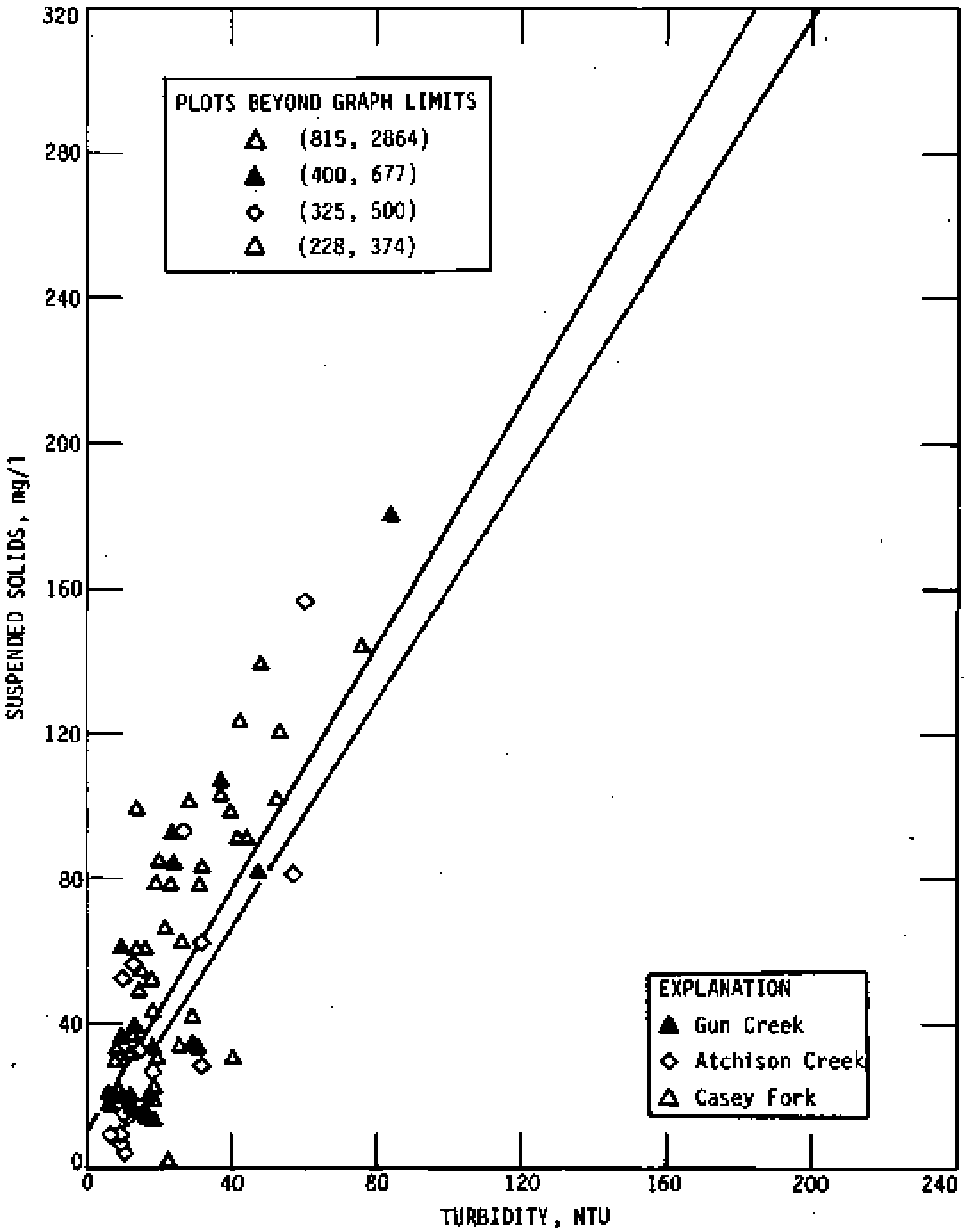

Figure 16. Relationship of suspended solids and turbidity for three streams

Table 11. Factors for Regression Analysis of Suspended Solids and Turbidity

	r	*K*	*C*	*Number of samples*
Rayse Creek (1)	0.68	1.23	23.1	33
Big Muddy River (2)	0.70	1.18	33.8	35
Casey Fork (6)	0.99	3.42	-32.8	50
Atchison Creek (5)	0.98	1.53	7.0	19
Gun Creek (4)	0.99	1.68	10.9	20

Where: Suspended Solids = C + (K) (Turbidity)
C = intercept
K = slope
r = correlation coefficient

The major clusters of data depicted in figures 15 and 16 are above the line of best fit. This suggests that the particle size of the suspended solids may be relatively small. Comparison of these figures with similar ones for the Spoon River (Illinois) shows this to be the case. The suspended solids in the waters of the Rend Lake watershed are of a smaller grain size than observed in the Spoon River, suggesting that it takes a larger concentration of suspended solids in the Rend Lake watershed to produce the same turbidity found in the Spoon River.

Sodium, Potassium, Calcium, and Magnesium

The cations sodium, potassium, calcium, and magnesium are generally not quantified for surface water quality study. Because this study was concerned with determining any relationships between land use and water quality, they were included for examination. The problem with introducing relatively new water quality indicators is the lack of similar data in other watersheds that might be useful for comparative purposes. For each of the cations, the concentrations of the particulate and dissolved form were determined. A summary of the results is given in table 12, along with some values for cation exchange capacity (CEC) which is discussed in a later section of this report.

It is quite obvious in table 12 that the greatest quantity of cations is in the dissolved form. In mean values the sodium (Na) of Rayse Creek prevails among all stream waters with a concentration of 69 mg/l. If it is assumed, as was done in the case of chlorides, that the mean concentrations of Na observed in Atchison and Gun Creeks represent background levels (say 25 mg/1), then the increase above natural conditions for Rayse Creek is 44 mg/1. For the Big Muddy River and Casey Fork, the mean values above natural levels are 29 and 27 mg/1, respectively. Presumably these increases are due to oil producing operations on Rayse Creek and the Big Muddy River and principally sewage effluents on Casey Fork.

Table 12. Concentrations of Certain Cations in Particulate Form versus Dissolved Form

(Concentrations in mg/l)

	Low	High	Mean	SD
Station 1, Rayse Creek, 35 samples				
Dissolved Na^+	0.0	256.0	69.0	67.5
Particulate Na^+	0.0	2.2	0.3	0.6
Dissolved K^+	0.0	11.2	6.9	2.4
Particulate K^+	0.0	1.5	0.1	0.3
Dissolved Ca^{++}	0.0	252.0	66.4	47.0
Particulate Ca^{++}	0.0	8.2	0.8	1.4
Dissolved Mg^{++}	0.0	59.6	20.9	17.4
Particulate Mg^{++}	0.0	1.4	0.2	0.3
CEC (me/100g)	0.0	141.7	33.2	37.3
Station 2, Big Muddy, 38 samples				
Dissolved Na^+	0.0	396.0	54.2	68.3
Particulate Na^+	0.0	2.5	0.2	0.5
Dissolved K^+	0.0	8.4	5.9	1.4
Particulate K^+	0.0	1.6	0.1	0.3
Dissolved Ca^{++}	0.0	249.0	65.1	44.2
Particulate Ca^{++}	0.0	10.8	0.8	1.7
Dissolved Mg^{++}	0.0	120.0	23.1	22.5
Particulate Mg^{++}	0.0	1.7	0.2	0.3
CEC (me/100g)	0.0	121.8	27.2	30.8
Station 6, Casey Fork, 53 samples				
Dissolved Na^+	0.0	176.0	57.2	43.9
Particulate Na^+	0.0	2.4	0.2	0.4
Dissolved K^+	0.0	15.9	9.2	4.0
Particulate K^+	0.0	2.6	0.1	0.4
Dissolved Ca^{++}	0.0	215.2	52.2	29.6
Particulate Ca^{++}	0.0	7.1	1.0	1.3
Dissolved Mg^{++}	0.0	181.6	17.1	25.0
Particulate Mg^{++}	0.0	1.5	0.2	0.3
CEC (me/100g)	0.0	161.0	31.4	40.5

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Table 12. Concluded

	Low	High	Mean	SD
Station 5, Atchison Creek, 20 samples				
Dissolved Na^{+}	0.0	70.0	27.9	20.6
Particulate Na^{+}	0.0	0.7	0.1	0.2
Dissolved K^{+}	4.1	6.9	5.5	0.6
Particulate K^{+}	0.0	2.6	0.2	0.6
Dissolved Ca^{++}	20.0	219.8	65.4	45.3
Particulate Ca^{++}	0.0	2.3	0.6	0.6
Dissolved Mg^{++}	2.3	37.4	19.0	13.3
Particulate Mg^{++}	0.1	1.5	0.3	0.3
CEC (me/100g)	0.0	232.3	37.7	53.4
Station 4, Gun Creek, 22 samples				
Dissolved Na^{+}	0.0	72.6	21.7	9.6
Particulate Na^{+}	0.0	0.3	0.1	0.1
Dissolved K^{+}	0.4	8.1	4.6	2.6
Particulate K^{+}	0.0	1.0	0.1	0.2
Dissolved Ca^{++}	8.5	123.9	33.0	18.8
Particulate Ca^{++}	0.0	2.9	0.4	0.6
Dissolved Mg^{++}	0.7	46.0	9.7	1.4
Particulate Mg^{++}	0.0	0.6	0.1	0.1
CEC (me/100g)	0.0	95.8	24.6	28.0
Station 3, Lake outlet, 53 samples				
Dissolved Na^{+}	0.0	53.0	22.4	13.6
Particulate Na^{+}	0.0	1.5	0.1	0.3
Dissolved K^{+}	0.0	5.8	4.2	1.1
Particulate K^{+}	0.0	0.8	0.1	0.2
Dissolved Ca^{++}	0.0	90.3	34.0	15.2
Particulate Ca^{++}	0.0	2.9	0.4	0.6
Dissolved Mg^{++}	0.0	24.0	9.0	5.1
Particulate Mg^{++}	0.0	0.5	0.1	0.1
CEC (me/100g)	0.0	211.0	21.4	40.9

Potassium (K^+) concentrations are the highest, 9.2 mg/1, in Casey Fork. This is probably due also to sewage plant discharges. Calcium and magnesium, being the principal constituents of hardness, follow the patterns previously discussed regarding hardness.

In an effort to describe the various waters in terms of their cation concentrations, their mean values were plotted schematically as shown in figure 17a. If Gun Creek waters were representative of a 'natural' stream without significant man-made influences, then the configuration of the diagrams in figure 17a would be quite meaningful. Since the assumption regarding Gun Creek is not firm, the figure is useful only with qualification. But graphic presentations of this nature'will be of value for comparing land-use patterns as more data become available. Certainly they are useful in comparing the water quality of stream waters.

Figure 17b shows a similar set of diagrams with mean values for the major anions, phosphorus, nitrate-N, chloride, and alkalinity (HCO3 and CO3). Because analyses for these constituents are quite common, one can derive conclusions on the likelihood of probable causes for the different patterns with greater confidence.

Heavy Metals

Analyses were performed for the metals mercury, copper, lead, zinc, and iron in particulate form, except iron which is reported as total iron. Particulate form was considered desirable because of the interest in land use. Experience has shown that most of these metals exist in stream waters adsorbed to suspended matter. However, since comparisons will be made with stream standards, the concentrations reported here should be considered conservative estimates.

The pertinent results are given in table 13. Mean concentrations for mercury in the tributaries ranged from 0.09 micrograms per liter (μg/l) to 0.12 μg/l . Surprisingly, the highest mean value was found in Atchison Creek, but the significance of any high value within the limited range observed is questionable. The range of mean values for copper was 0.02 mg/l to 0.04 mg/l, that for lead was 0.01 mg/1 to 0.05 mg/1, and that for zinc was about 0.04 mg/l to 0.07. The highest mean values of lead and zinc were found in Casey Fork. This was true also for iron, where mean values for the tributaries ranged from about 2.4 mg/1 to 3.5 mg/l.

Table 14 is a tabulation of the frequency of occurrence of the metals in the water samples collected. Generally, the ranking order of prevalence in the streams waters was iron, zinc, mercury, copper, and lead. Exceptions to this include Casey Fork and Gun Creek where copper was more prevalent than mercury.

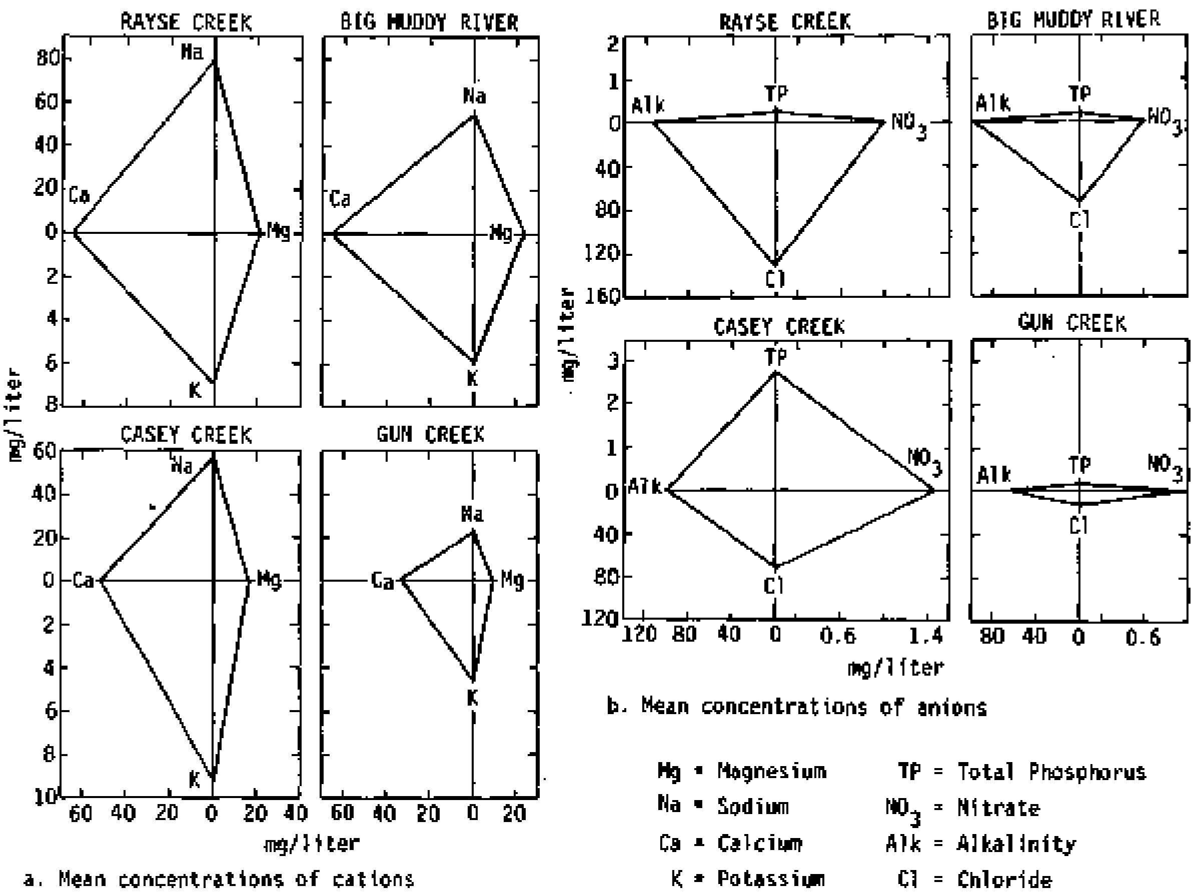

Figure 17. Mean concentrations of certain anions and cations

Table 13. Concentrations of Certain Metals for Stream Stations

	Low	High	Mean	SD
Station 1, Rayse Creek, 35 samples				
Mercury	0.00	0.50	0.09	0.12
Copper	0.00	0.08	0.02	0.02
Lead	0.00	0.36	0.02	0.06
Zinc	0.01	0.47	0.07	0.10
Iron	0.71	6.60	2.38	1.62
Station 2, Big Muddy, 38 samples				
Mercury	0.00	0.66	0.09	0.13
Copper	0.00	0.06	0.02	0.02
Lead	0.00	0.05	0.01	0.01
Zinc	0.01	0.34	0.05	0.06
Iron	0.66	8.00	2.39	1.79
Station 6, Casey Fork, 53 samples				
Mercury	0.00	0.50	0.11	0.09
Copper	0.00	0.89	0.04	0.12
Lead	0.00	0.60	0.05	0.13
Zinc	0.02	0.51	0.07	0.08
Iron	0.45	92.00	3.57	12.49
Station 5, Atchison Creek, 20 samples				
Mercury	0.00	0.31	0.12	0.09
Copper	0.00	0.05	0.02	0.01
Lead	0.00	0.30	0.02	0.07
Zinc	0.00	0.20	0.05	0.05
Iron	0,40	22.0	2.4	4.7
Station 4, Gun Creek, 22 samples				
Mercury	0.00	0.43	0.09	0.12
Copper	0.00	0.08	0.02	0.02
Lead	0.00	0.11	0.01	0.03
Zinc	0.00	0.16	0.04	0.04
Iron	0.54	22.00	2.52	4.46
Station 3, Lake outlet, 53 samples				
Mercury	0.00	0.44	0.08	0.11
Copper	0.00	0.27	0.03	0.05
Lead	0.00	0.28	0.02	0.05
Zinc	0.00	0.25	0.06	0.06
Iron	0.19	1.60	0.64	0.37

Note: Particulate form except iron which is total iron.
All values are mg/l except mercury which is µg/l.

Table 14. Percent of Samples in which Certain Heavy Metals Were Detected

	Rayse Creek	Big Muddy	Casey Fork	Atchison Creek	Gun Creek	Lake outlet
Mercury	75(24)	78(27)	83(43)	89(9)	63(11)	80(11)
Copper	71(35)	63(38)	91(53)	75(20)	73(22)	69(50
Lead	26(35)	27(30)	45(51)	25(20)	23(22)	35(52)
Zinc	100(35)	100(37)	100(53)	90(20)	91(22)	96(53)
Iron	100(35)	100(38)	100(53)	100(20)	100(22)	100(52)

Note: Particulate form except iron which is total iron.
Number of samples in parentheses.

The frequency with which heavy metal concentrations exceeded water quality standards is given in table 15. Not surprisingly, iron concentrations exceeded standards most frequently, ranging for tributary streams from 50 to 87 percent of the time. The most frequent violations for iron occurred on Rayse Creek and the Big Muddy River, i.e, 80 and 87 percent of the time, respectively. Mercury standards were exceeded only in the Big Muddy River, about 4 percent of the time. Zinc standards were exceeded only in Casey Fork, about 17 percent of the time. Copper concentrations uniformly exceeded standards in tributary waters from 17 to 26 percent of the time, and surprisingly were excessive in the lake outlet waters 20 percent of the time.

The only significant difference in mean concentrations of the heavy metals was that for iron (see table 13). Here, the relatively high mean value of 3.57 mg/l occurring in Casey Fork must be related to urban drainage.

Table 15. Percentage of Time Certain Heavy Metals Exceed Water Quality Standards

	Mercury 0.0005	Copper 0.02	Lead 0.10	Zino 1.00	Iron 1.00
Rayse Creek	0	17	26	0	80
Big Muddy River	4	26	0	0	87
Casey Fork	0	25	14	17	70
Atchison Creek	0	25	5	0	50
Gun Creek	0	23	5	0	59
Lake outlet	0	20	6	0	17

Note: Particulate form except iron which is total iron.
Standards are in milligrams per liter.

Cation Exchange Capacity

Cation exchange capacity (CEC) is basically a characteristic of soils and is useful in soil science. It was used here in an effort to determine differences that might exist in the CEC of suspended solids in streams. If significant differences were detected, then the source of the suspended particulate might be identified. The expression used for concentrations is milliequivalents per 100 grams (me/100g). As shown in table 12, mean values for the tributaries ranged from 24.6 to 37.7 me/lOOg. Distribution of the data suggested there was very little difference in the concentrations and therefore efforts to differentiate stream quality were futile.

Bacteria

Pathogenic bacteria indicators, total coliform (TC), fecal coliform (FC), and fecal streptococcus (FS), are used to determine the presence of disease-causing organisms originating from fecal pollution. The use of TC as a measure of fecal contamination of lakes and streams has been in practice for over 50 years. Total coliforms represent a heterogeneous mixture of bacteria species, most of which originate from the intestinal tract of humans and other warm-blooded animals. However, some bacteria species in the coliform group have origins from soil.

Fecal coliforms are a subgroup of TC, specific to the intestinal tract of man and animal. According to Geldreich (1966), the presence of FC in water is a direct correlation with fecal contamination from warm-blooded animals. The density and occurrence of FC have been adopted as a bacterial quality standard for wastewater effluents and surface waters in Illinois. Total coliform, however, is still used as the bacteriological standard for drinking water.

A shortcoming of the FC test is its inability to distinguish between the organisms originating from humans and those from other warm-blooded animals. Studies of FS by Geldreich and Kenner (1969) show that FS densities were significantly higher than FC densities in feces of all warm-blooded animals except humans. Fecal coliforms originate principally from human feces; FS originate principally from warm-blooded animals other than humans. Therefore, testing for FS and computing the FC:FS ratios provides a means for differentiating between the two sources, with some limitation.

Samples for bacterial examinations were collected several inches below the surface of the water at mid-channel, as previously described at the six stream stations (1-6) and the two sub-impoundments (stations 13 and 14).

Bacterial Densities. The number of samples, ranges, geometric means (Mg), and geometric standard deviations (SDg) of bacterial densities observed at the eight sampling locations are given in table 16. The number of collections for each station differed depending on streamflow. The sampling dates can be seen in figures 18 and 19. Table 16 shows a significant reduction in

Table 16. Summary of Bacterial Data

(Cells per 100 milliliters)

	Rayse (1)	*Big Muddy* (2)	*Outlet* (3)	*Gun* (4)
Total coliform				
No. of samples	32	34	49	19
Maximum	61,000	70,000	23,000	29,000
Minimum	10	40	0	0
Mg*	1,500	1,400	120	1,100
SDg**	7.59	5.65	16.76	10.24
Fecal coliform				
No. of samples	35	37	53	21
Maximum	40,000	13,000	3,800	7,500
Minimum	0	0	0	0
Mg	270	200	5.9	140
SDg	9.27	7.74	8.00	8.25
Fecal streptococcus				
No. of samples	35	38	53	22
Maximum	25,000	6,800	420	30,000
Minimum	0	0	0	0
Mg	230	130	11.3	210
SDg	10.82	10.73	8.34	10.89
FC/FS				
No. of samples	33	33	32	20
Maximum	7.71	13.00	93.75	6.68
Minimum	0	0	0	0.03
Average	1.66	2.02	3.5(.60)	1.61
SD	1.68	2.70	16.50(1.03)	1.78

	Atchison (5)	*Casey* (6)	*Sub-Imp* (13)	*Sub-Imp* (14)
Total coliform				
No. of samples	17	50	24	24
Maximum	15,000	48,000	4,000	12,000
Minimum	100	0	0	0
Mg	680	1,600	150	80
SDg	5.25	8.49	10.14	12.47
Fecal coliform				
No. of samples	20	52	24	24
Maximum	4,500	11,000	150	90
Minimum	19	0	0	0
Mg	180	170	6.7	2.8
SDg	4.55	9.57	6.04	4.65
Fecal streptococcus				
No. of samples	20	53	24	24
Maximum	7,400	25,000	9,500	130
Minimum	50	0	0	0
Mg	280	120	4.4	2.5
SDg	4.22	10.33	8.96	4.74
FC/FS				
No. of samples	20	47	10	7
Maximum	2.88	12.00	10.0	1.80
Minimum	0.07	0	0	0
Average	0.94	1.90	1.65	0.30
SD	0.75	2.08	3.03	0.67

*Mg = Geometric mean **SDg = Geometric standard deviation

SD = Standard deviation

bacterial densities resulting from impoundments (stations 3, 13, and 14).

For all data the maximum densities for TC, FC, and FS were, respectively, 70,000/100 ml at the Big Muddy River (station 2), 40,000/100 ml at Rayse Creek (station 1), and 30,000/100 ml at Gun Creek (station 4). Many samples contained no indicator organisms. At station 1 (Rayse Creek), the raw data show that maxima for TC, FC, and FS occurred on the same date, September 29, 1976. On this date the flow was low, about 0.45 cfs. Nevertheless, the higher bacterial densities were generally detected during or after high flow (32 to 97 cfs) in Rayse Creek.

As indicated by the raw data, at station 2 (Big Muddy) high bacteria counts were observed on February 11, March 31, June 2, July 28, and August 25, 1976. Generally, the bacterial counts were low for station 3 (lake outlet). Its maxima for TC, FC, and FS occurred on May 13, September 29, and June 6, respectively. The flow in Gun Creek (station 4) was generally low. There was no flow from July to the end of this study. The highest flow observed was 19 cfs on February 18, 1976, and the maxima of FC and FS occurred on that date. The maximum TC count, however, was found on July, 1. As streamflows significantly increased in Gun Creek, bacterial densities increased also.

The flow conditions in Atchison Creek (station 5) were similar to those in Gun Creek. The maximum TC was observed on June 2. During the summer months (June through August), bacterial densities in Casey Fork (station 6) were generally high. The maxima bacterial densities occurred on July 1 and July 28. Bacterial samples for the two sub-impoundments (stations 13 and 14) were collected only from August 1976 through January 1977. Bacterial densities of stations 13 and 14 were generally low, except for a high FS count at station 13 on August 25.

Comparison with FC Standards. The general rule for bacterial quality for most Illinois surface waters, adopted by the Illinois Pollution Control Board (IPCB) in 1972 is rule 203(g) as follows:

> Based on a minimum of five samples, taken over not more than a 30-day period, fecal coliforms shall not exceed a geometric mean of 200/100 ml, nor shall more than 10 percent of the samples during any 30-day period exceed 400/100 ml.

The FC densities recorded for the eight sampling stations from January 21, 1976, to January 19, 1977, were evaluated in terms of this rule, as shown in figures 18 and 19. For computation of the geometric mean, 1 FC/100 ml was considered the zero FC count. Also depicted on the figures is the FC standard adopted by the IPCB, i.e., the geometric mean of 200 FC/100 ml that must not be exceeded.

Figures 18 and 19 show that bacterial qualities at stations 3, 13, and 14 complied with the 200 FC/100 ml limit. For station 3, only one out of 53

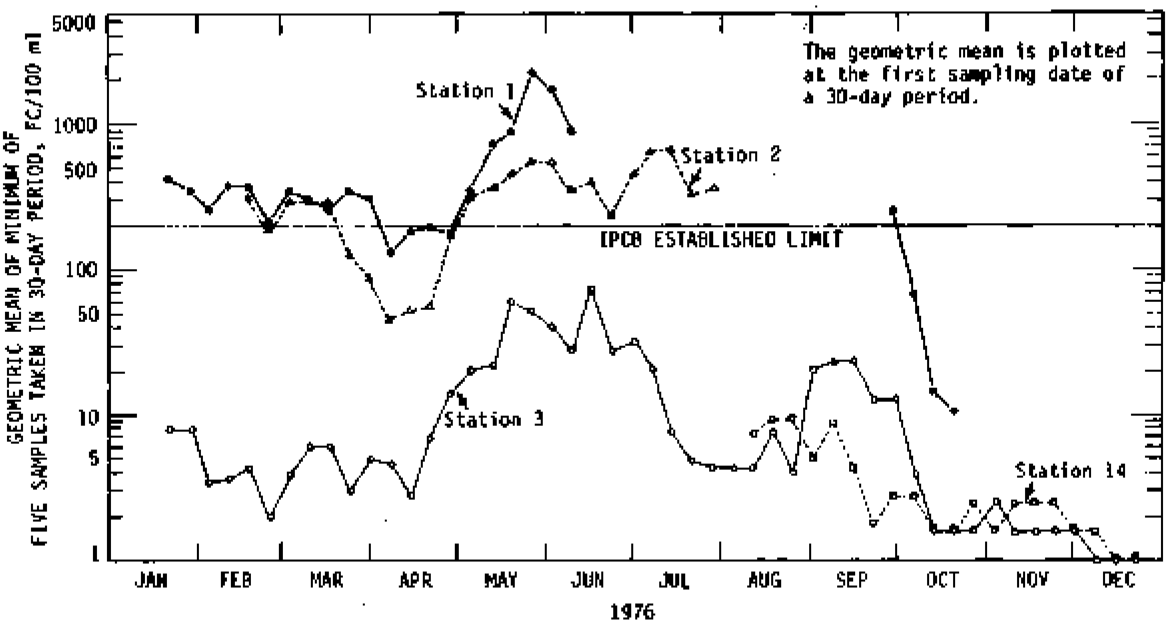

Figure 18. Geometric means of fecal coliform densities, stations 1, 2, 3, and 14

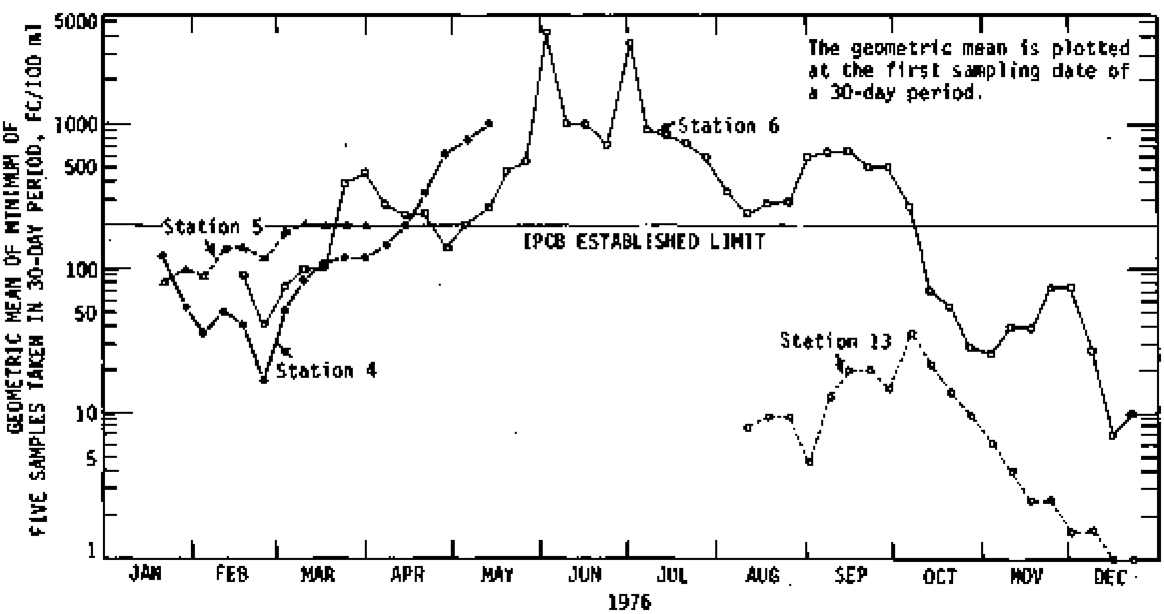

Figure 19. Geometric means of fecal coliform densities, stations 4, 5, 6, and 13

samples had a bacterial density over 400 FC/100 ml. For the stream samples, only during April and May was acceptable bacterial quality achieved in Rayse Creek (station 1) and the Big Muddy River (station 2). In contrast, acceptable bacterial quality occurred at the other three creeks (stations 4-6) during the cold periods. The bacterial standard was violated in Casey Fork (station 6) from April through September.

A comparison of the observed FC densities with bacterial quality standards is summarized in table 17. The results show that bacterial quality after impoundment complied with the IPCB rule. The stream waters violated the bacterial standards for most of the study period. It would appear that the portion of the rule limiting the geometric mean density is not the governing factor in assessing the bacterial quality of the Rend Lake system. Rather, the limiting factor is that portion of the requirement whereby no more than 10 percent of the samples shall exceed 400 FC/100 ml. This was found to be the case for the Spoon River also (Lin et al., 1974).

FC:FS Ratios. As indicated earlier, the use of FC:FS ratios is a more valuable tool for assessing pollution sources than relying solely on FC densities. However, in applying the FC:FS ratio to a natural stream system, best results are obtained if the stream samples are taken within a 24-hour streamflow time from a pollution source. FC:FS ratios greater than 4 are indicative of fecal contamination primarily of human origin such as domestic wastewater, whereas ratios less than 0.7 are indicative of a pollution source principally from non-human warm-blooded animals, such as livestock, poultry, and wildlife. Ratios intermediate between 0.7 and 4.0 result from mixed human and other warm-blooded animal sources or from remote sources.

Table 17. Comparison of FC Densities with IPCB Rule

	Total number of 30-day periods evaluated	*Compliance with geometric mean (<200/100 ml)*		*Compliance with 90% of samples during 30 days (<400/100 ml)*	
		Number of 30-day periods	*Percentage of 30-day periods*	*Number of 30-day periods*	*Percentage of 30-day periods*
Rayse (1)	25	7	28	3	12
Big Muddy (2)	24	7	29	4	17
Big Muddy below dam (3)	49	49	100	44	90
Gun Creek (4)	17	13	76	6	35
Atchison (5)	12	11	92	2	17
Casey Fork (6)	45	17	38	7	16
Casey Fork sub-impoundment (13)	20	20	100	20	100
Big Muddy sub-impoundment (14)	20	20	100	20	100

The results of FC and FS counts obtained from the five stream stations are plotted in figures 20 and 21. These figures suggest that this procedure does not provide a clear-cut identification of human wastes. Figure 21 shows that the FC:FS ratios for stations 4 and 5 are generally less than 4.0. This indicates that human wastes were not principal sources of pollution in Gun Creek and Atchison Creek.

Summary

This study was performed during very low streamflow conditions. As the result, those constituents likely to originate from non-point sources (suspended solids, bacteria, etc.) were probably found in near minimal concentrations, whereas those constituents originating from uniform flow point sources were probably found in near maximum concentrations.

Violation of stream standards for dissolved oxygen frequently occurred in Rayse Creek and Casey Fork for different reasons. Elevated chloride concentrations were observed in Rayse Creek, the Big Muddy River, and Casey Fork, but stream standards were not exceeded. Ammon?a-N concentrations exceeded stream standards in Casey Fork about 66 percent of the time, and the total phosphorus content in all streams exceeded the standard of 0.05 mg/l most of the time. The order of metal prevalence in the streams was generally iron, zinc, mercury, copper, and lead with the concentrations of copper, lead, and iron being most frequently in violation of stream standards.

That part of the regulations governing bacterial densities in stream water most applicable to the Rend Lake watershed is the condition in which fecal coliform densities shall not exceed 400/100 ml in more than 10 percent of the samples during any 30-day period.

LAND USE

The uses of land in the Rend Lake watershed have been classified for this study into six categories. These include cropland, pasture, woodland, mineral resources, urban, and water. Maps made available by the Greater Egypt Regional Planning and Development Commission were used to determine land use on each of the five tributary streams and the non-tributary area, i.e., Rend Lake.

For classification purposes the urban areas were clear-cut in that only incorporated communities were included in the category. Other categories, however, consist of several entities. Pasture includes dairy and stock pasture, unused agricultural land, cemeteries, interstate interchanges, game farms, and the Rend Lake Junior College land. Woodlands include locally and government owned open spaces, private woods, and property owned by the Rend Lake Conservancy District. Cropland includes not only that land used for row crops but also orchards, truck farms, greenhouses, and nurseries.

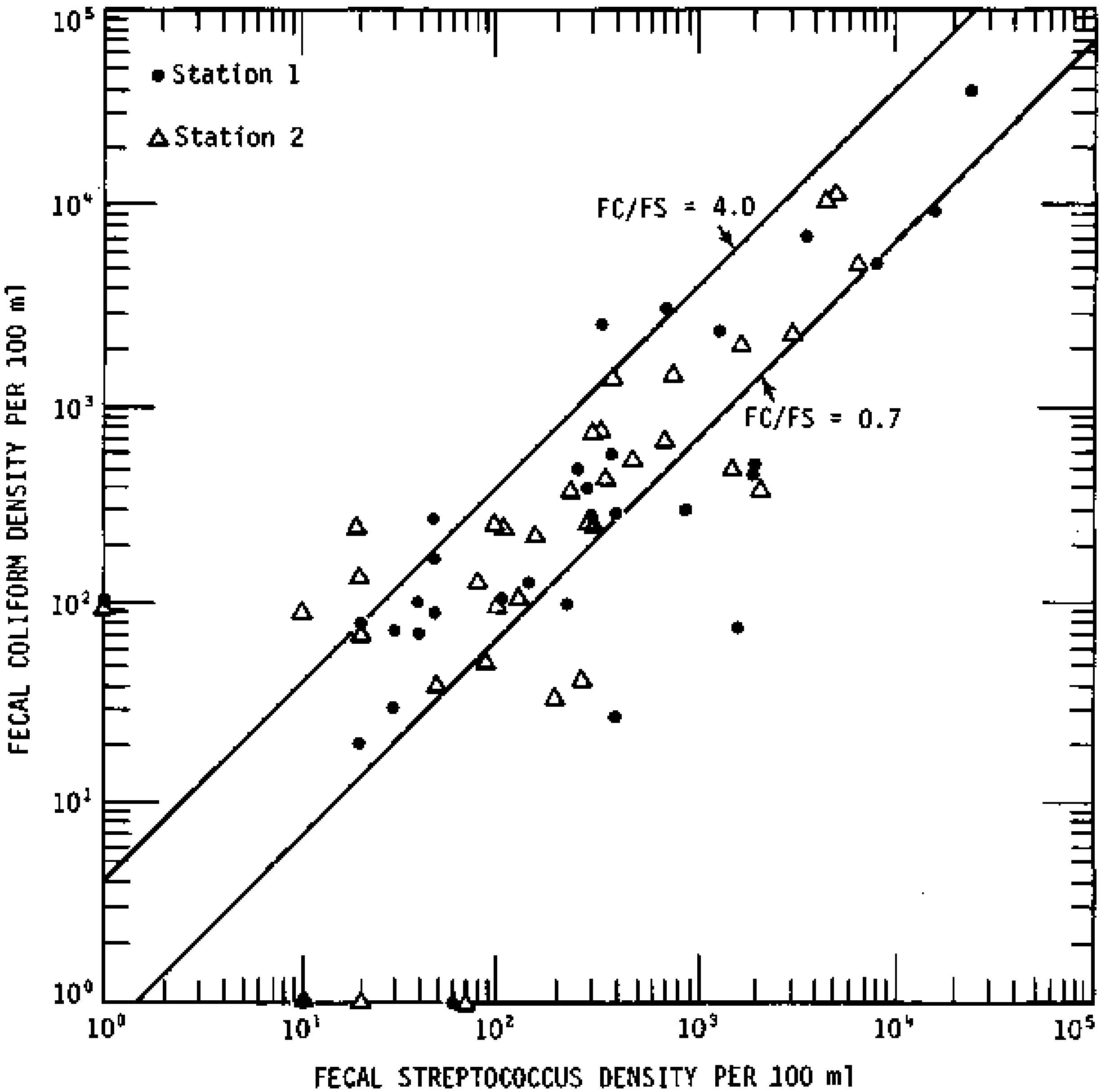

Figure 20. FC:FS ratios for stations 1 and 2

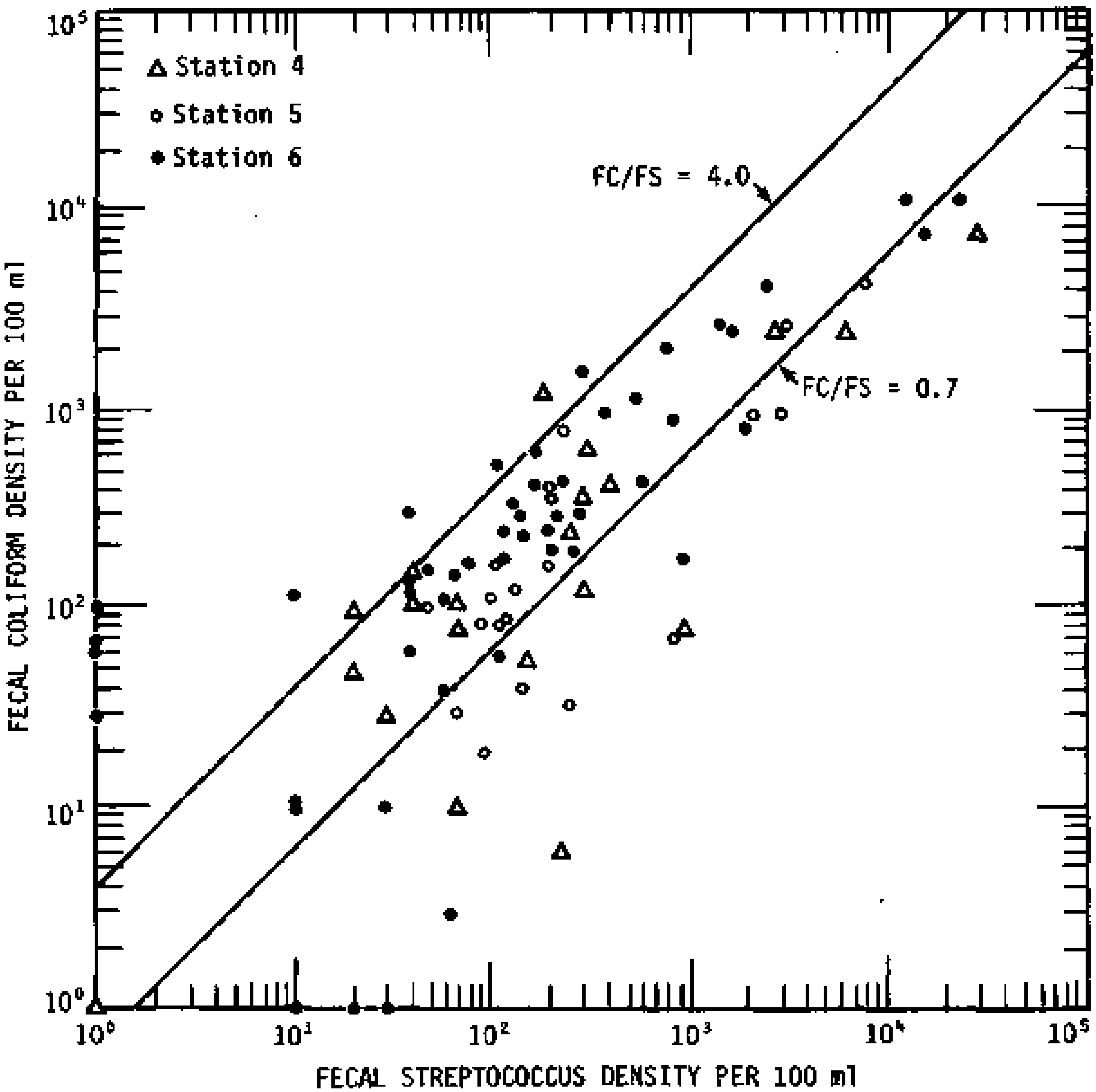

Figure 21. FC:FS ratios for stations 4, 5, and 6

Mineral resources (active and inactive) include mines, quarries, and oil fields.

Land uses for each of the stream watersheds are shown in table 18. Cropland acreage is highest in the Rayse Creek watershed, but in general cropland is about equally divided between the watersheds of Rayse Creek, the Big Muddy River, and Casey Fork. Approximately 255 square miles consist of cropland representing about 52 percent of the total drainage area. Pasture land is mostly located in the watershed of the Big Muddy River and Casey Fork. Over 50 percent of the woodlands lie along Rend Lake and the Casey Fork watershed, and most of the urban area lies in the watershed of the Big Muddy River and Casey Fork. The mineral resources use is located in the watersheds of Rayse Creek and the Big Muddy River. These drainage areas account for about 74 percent of the total area sustaining mineral resources.

Table 19 gives a summary of the number of oil wells and their status located on the Rend Lake watershed. It is clear that most of the activity is on Rayse Creek and Big Muddy River.

NUTRIENT BUDGET

Nitrogen and phosphorus are generally considered to be the two main nutrients involved in the lake eutrophication process, even though these two are not the only nutrients required for algal growth. In spite of the controversy over the role of carbon as a limiting nutrient, a vast majority of researchers regard phosphorus as the most frequently limiting nutrient in lakes (Bartsch, 1972; U.S. Environmental Protection Agency, 1973; and Vollenweider, 1968).

Table 18. Land Use in the Rend Lake Drainage Area

(square miles)

	Big Muddy	*Rayse Creek*	*Casey Fork*	*Atchison Creek*	*Gun Creek*	*Bend Lake*	*Category total*
Cropland	52.52	67.72	55.82	15.16	19.20	44.45	254.96
Pasture	17.42	12.08	25.57	3.18	1.37	14.17	73.79
Woodland	21.98	20.60	27.35	3.07	4.58	29.31	106.89
Mineral resources	2.70	2.32	0.21	0.02	0.18	1.41	6.84
Urban	5.86	0.25	6.34		0.11	1.48	14.04
Water	0.22		0.10			31.88	32.20
Watershed total	100.70	102.97	115.39	21.43	25.44	122.79	488.72

Table 19. Estimated Status of Oil Well Activity*

	Number of producing wells	Number of abandoned wells	Number of water input wells	Number of salt water disposal wells
Above station 1	180	143	21	21
Below station 1	3	2	0	0
Above station 2	134	161	58	2
Below station 2	0	1	0	0
Above station 6	44	40	8	4
Below station 6	15	40	2	3
Above station 5	23	20	9	0
Below station 5	0	0	0	0
Above station 4	0	0	0	0
Below station 4	0	0	0	0
Non-trib. area	60	101	20	11
Inundated by Rend Lake	5	38	1	3
Totals	464	556	119	44

* From Oil and Gas Development Maps provided by Illinois State Geological Survey.

Several factors complicate the attempt to quantify the relationship between a lake's trophic status and measured nutrient concentrations of the lake's waters. A certain fraction of the nutrients, particularly phosphorus, become refractory while passing through successive biological cycles. Also, morphometric and chemical factors affect the availability of nutrients in lakes. Mean depth, basin shape, detention time, and other physical attributes affect the amount of nutrients a lake can absorb without developing nuisance conditions.

Potential sources of nitrogen and phosphorus for lakes are the watershed drainage areas which include agricultural runoff; urban runoff; swamp and forest runoff; domestic and industrial waste discharges; septic tank discharges from lakeshore developments, if any; precipitation on the lake surface; dry fallouts like leaves, dust, seeds, pollen, etc.; groundwater influxes; nitrogen fixation; sediment recycling; and aquatic bird and animal wastes. Potential sinks include outlet losses, fish catches, aquatic plant removal, denitrification, groundwater recharge, and sediment losses.

In a detailed evaluation of a nutrient budget for the Fox Chain of Lakes, tributaries to the lake system were found to account for about 90 to 95 percent of the nutrient influx to the lakes. As there are no significant residential developments with septic tank disposal systems around Rend Lake, which are a contributing factor to the Fox Chain of Lakes, nutrient influx from major tributary streams is the only source considered in developing the nutrient budget for Rend Lake. The instantaneous rates of nutrient transport, in pounds per day, for the Big Muddy River and other tributaries were evaluated by determining nutrient concentrations in samples collected on a weekly basis in conjunction with daily streamflow data. The long-term average nutrient transport values, in pounds per day, for ammonia, nitrate, total and dissolved phosphorus, and total and dissolved silica were computed with the use of the instantaneous rates and the long-term flow records for the tributaries. Because the tributary sampling sites were located close to the lake, nutrient transport values estimated for the tributaries combine the contributions of point and nonpoint sources.

The computations of long-term average nutrient transport were made by the flow-duration curve method discussed by Simmons (1976). This method has been used by the U.S. Geological Survey quite extensively in determining the long-term average suspended sediment transport in streams based on a very few sediment transport observations. In a test case, sediment yields at Yadkin River near Yadkin College Station (North Carolina) by the flow-duration curve method were compared with yields by the daily sediment sampling techniques for the period 1969-1973. The results differed by less than 2 percent. The computation of average sediment yield with daily values is widely accepted as the most accurate method.

The observed nutrient concentrations of a sample can be converted to instantaneous nutrient transport loads by the formula:

$$Qn = 5.394 \times c \times Q \qquad (1)$$

where

Qn = instantaneous nutrient discharge in pounds per day
c = concentration of nutrient in milligrams per liter
Q = instantaneous water discharge in cubic feet per second

Generally, a relationship exists between the chemical concentrations and water discharge in streams (Ledbetter and Gloyna, 1964; Steele and Jennings, 1972). Consequently, the instantaneous nutrient transport is a factor dependent on stream discharges. This relationship was examined for each of the nutrients considered in this report by the least squares curve fit technique using the following three mathematical expressions:

$$y = a + bx \qquad (2)$$

$$y = a \exp(bx) \qquad (3)$$

$$y = ax^b \qquad (4)$$

where

y = dependent variable (instantaneous nutrient transport in this case)

x = independent variable (instantaneous water discharge)

a and b = constants

The expression giving the highest coefficient of correlation was then chosen to define the relationship between nutrient transport and water discharge.

Figure 22 shows the relationship between nitrate-N transports and flow rates in the Big Muddy River. Equation 4 was found to define the relationship best with a correlation coefficient of 0.92 and the values of the constants a and b being 1.100 and 1.298, respectively. Figure 23 shows the flow-duration curve for the Big Muddy River. This information was developed from the flow data for the period 1966-1973 obtained from the St. Louis District of the Army Corps of Engineers.

Following the development of the above information, computations for the long-term average nutrient transport were made. As an example, table 20 shows such a computation for nitrate-N in the Big Muddy River. The flow-duration curve (figure 23) was used to determine water discharges for the corresponding percentages of time shown in column 1 of table 20. Then, with the relationship $y = 1.100\ x^{1.298}$ and the flow values in column 2, nitrate transport values were determined as shown in column 3. Average nitrate discharges were then computed from the values in column 3 by averaging the numbers at the limits of each time interval. Each average nitrate discharge was then multiplied by the corresponding time interval to give the nitrate discharge representative of that percentage of total time. The incremental nitrate transport values in column 6 were then totaled to give the average nitrate transport in pounds per day for the Big Muddy River upstream of the Rend Lake dam.

Similar computations for other nutrients and tributaries and the Big Muddy River below the dam were made and the results are shown in table 21. In developing these results, flow data for the period 1966-1973 were used for Casey Fork and Rayse Creek also. Only one-year weekly flow data developed by the Illinois State Water Survey for the Big Muddy River below the dam were used.

Flows in Gun Creek and Atchison Creek were found to be insignificant compared with the flows in the other three tributaries to the lake, and hence the impact of these two small creeks were not considered. In 32 out of 52 field trips to Rend Lake, flow was found to be zero in Atchison and Gun Creeks. Also, in developing the numerical values for column 3 of table 20, extrapolation of the relationship between instantaneous flow and instantaneous nutrient transport had to be made beyond the range of observations on which the relationship was derived. This was necessary because the extreme values of stream discharge found in the long-term flow records of the tributaries did not occur during this investigation.

For comparison of nutrient transports by the different streams, unit load factors expressed both as pounds per square mile per day (lbs/sq mi/day) and pounds per acre per year (lbs/ac/yr) were considered. These values are shown in table 22. The unit loads of nitrate transported by the Big Muddy River above the dam and by Rayse Creek are similar and higher than for Casey Fork. However, the ammonia and phosphorus values for Casey Fork are much

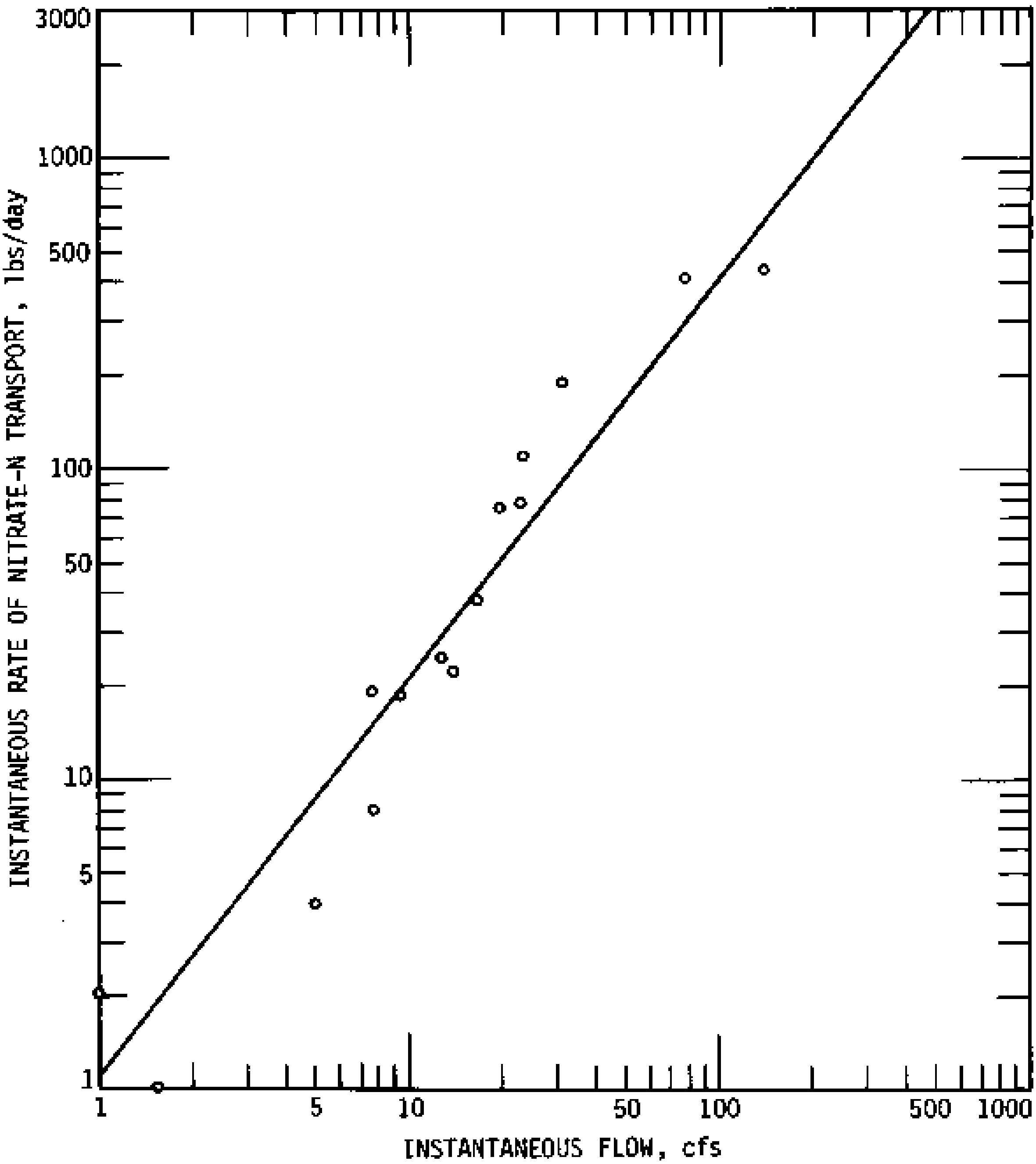

Figure 22. Nitrate transport curve for Big Muddy River above dam

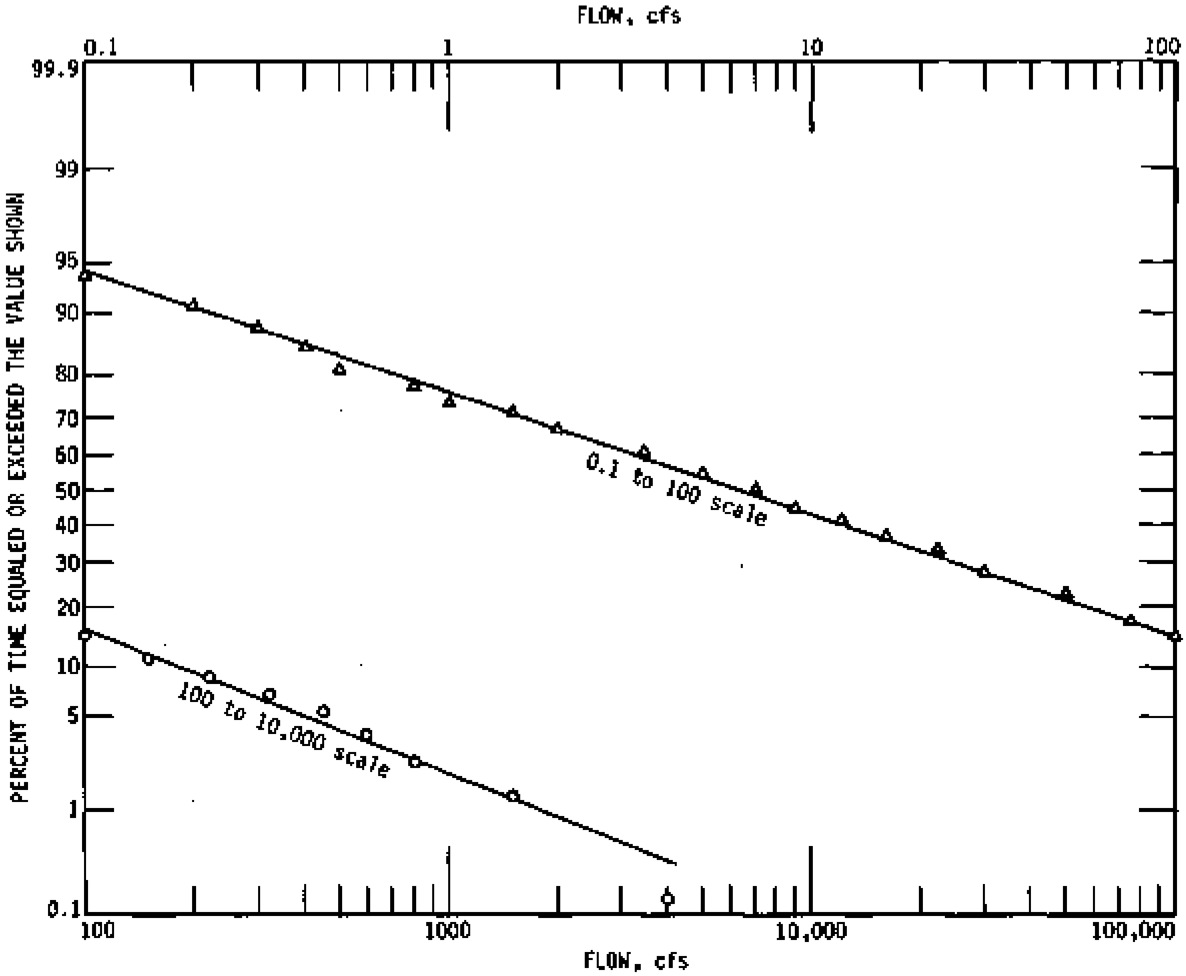

Figure 23. Duration curve of mean daily discharge, Big Muddy River near Mt. Vernon

Table 20. Computations of Long-Term Average Daily Nitrate Transport in Big Muddy River above Dam

Percent of time	*Flow equaled or exceeded*	*Nitrate load (lbs/day)*	*Interval between succeeding percent time*	*Average nitrate load for time interval (lbs/day)*	*Average nitrate load times interval*
0	1340	12,600	1.0	11,642	116
1.0	1180	10,683	1.0	9,651	97
2.0	1000	8,618	1.0	7,021	70
3.0	700	5,424	2.0	4,024	80
5.0	400	2,623	2.0	2,137	43
7.0	280	1,651	3.0	1,291	39
10.0	180	931	5.0	683	34
15.0	100	434	5.0	317	16
20.0	55	200	5.0	156	8
25.0	35	111	5.0	92	5
30.0	25	72	10.0	50	5
40.0	12	28	10.0	20	2
50.0	6	11	10.0	8	0.8
60.0	3.2	5	10.0	4	0.4
70.0	1.6	2	10.0	2	0.2
80.0	0.7	1	10.0	0.6	0.1
90.0	0.2	0.2	5.0	0.2	0
95.0	0.1	0.1	5.0	0.1	0
100.0	0	0			
				Total	516.5 lbs/day

Table 21. Long-Term Averages of Nutrients Transported by Tributaries to Rend Lake and Outlet Stream

(In pounds per day)

	Big Muddy above dam	*Rayse Creek*	*Casey Fork*	*Big Muddy below dam*
Nitrate-N	517	532	394	59
Amnionia-N	216	217	293	74
Inorganic-N	607	694	452	127
Total phosphorus	103	95	398	36
Total diss. P	7	21	215	3
Total silica	2843	5219	5094	523
Total diss. silica	2792	4524	4426	467

Table 22. Unit Load Factors of Nutrients Transported by Tributaries to Rend Lake and Outlet Stream

	Big Muddy above dam	Rayse Creek	Casey Fork	Big Muddy below dam
	In pounds per square mile per day			
Nitrate-N	6.16	6.08	4.53	0.12
Ammonia-N	2.57	0.88	3.37	0.15
Inorganic-N	7.23	7.93	5.19	0.26
Total phosphorus	1.23	1.09	4.57	0.07
Total diss. P	0.08	0.24	2.47	0.01
Total silica	33.87	59.65	58.54	1.07
Total diss, silica	33.26	51.70	50.86	0.96
	In pounds per acre per year			
Nitrate-N	3.51	3.47	2.58	0.07
Ammonia-N	1.47	0.50	1.92	0.09
Inorganic-N	4.12	4.52	2.96	0.15
Total phosphorus	0.70	0.62	2.61	0.04
Total diss. P	0.05	0.14	1.41	0.00
Total silica	19.31	34.02	33.38	0.61
Total diss. silica	18.97	29.50	29.00	0.55

higher than the corresponding values for the Big Muddy River and Rayse Creek, indicating the influence of the waste treatment plant discharges at Mt. Vernon. The values for the Big Muddy River below the dam show that the impoundment acts as an efficient nutrient trap.

The range of values of nitrate unit load factors observed for Rend Lake tributaries seems to be comparable to the values for the Fox Chain of Lakes tributaries (Kothandaraman et al., 1977). However, the nitrate loads transported by all these streams are considerably less than the average nitrate contribution of 21 lbs/ac/yr observed on the 1030-square-mile drainage area for the Kaskaskia River upstream of Lake Shelbyville (Harmeson and Larson, 1974). Again in the case of phosphorus the unit load factor values for the Rend Lake tributaries are comparable with the Fox Chain of Lakes tributaries. All these values are much higher than the 0.17 lbs/ac/yr of phosphorus estimated for the Kaskaskia River at Shelbyville (Engelbrecht and Morgan, 1959).

The total nitrate-N flux to Rend Lake through its tributaries is estimated to be above 1443 lbs/day of which 96 percent or 1384 lbs/day is retained in the lake. The total inorganic nitrogen loading rate is 1753 lbs/day. Of the 596 lbs/day of total phosphorus transported by the tributaries, 94 percent or 560 lbs/day is retained in the lake. With a total surface area of 18,900 acres for Rend Lake, the loading rates for total phosphorus and total inorganic nitrogen to the lake surface amount to 11.51 lbs/ac/yr (1.29 $g/m^2/yr$) and 33.85 lbs/ac/yr (3.79 $g/m^2/yr$). Considering only the dissolved phosphorus, which is a more readily available form of phosphorus for algal uptake, the loading rate amounts to 4.69 lbs/ac/yr (0.53 $g/m^2/yr$).

The best available guidelines for relating the nutrient flux to water quality in lakes were first proposed by Vollenweider (1968). According to Vollenweider, for lakes with mean depths of 5 meters (16.4 feet) or less, permissible loading levels of biochemically active nitrogen and phosphorus are, respectively, 1.0 and 0.07 $g/m^2/yr$. For the same average depth, loading rates greater than 2.0 $g/m^2/yr$ for nitrogen and 0.13 $g/m^2/yr$ for phosphorus are considered excessive from a eutrophic viewpoint. These guidelines pertain to lake surface areas.

It is apparent that the nitrogen and phosphorus loading rates to Rend Lake are much higher than the excessive rates suggested by Wollenweider. Nutrient loading rates for the Fox Chain of Lakes, which are highly eutrophic, were found to be 54.0 $g/m^2/yr$ for total inorganic nitrogen and 4.5 $g/m^2/yr$ for dissolved orthophosphorus (Kothandaraman et al., 1977). Because Casey Fork transports 67 percent of the total phosphorus coming into Rend Lake, efforts to abate phosphorus emission from its watershed could prove to be worthwhile. Considering only the dissolved phosphorus, any abatement program in the Casey Fork basin could drastically reduce the impact of phosphorus that is readily available for biosynthesis.

Even though the algal counts in Rend Lake are not of bloom proportions, if the present nutrient loading conditions are allowed to persist, the eutrophic process in the lake could be greatly accelerated. Controlling either nitrogen or phosphorus within the waters of the Fox Chain of Lakes was found to be effective in curbing algal blooms in the lakes (Kothandaraman et al., 1977). However, controlling phosphorus input is technically and economically feasible in the case of Rend Lake.

LIMNOLOGY OF REND LAKE

In order to assess the physical, chemical, and biological characteristics of the lake system, field trips were undertaken on a biweekly basis from April 7, 1976, to December 7, 1976. As shown in figure 1, sampling locations were established for the deep portion above the dam (station 9), and for the Big Muddy, Casey Fork, and Gun Creek branches (stations 7, 8, and 10) of Rend Lake. Also, water samples were collected on a weekly basis from August 11, 1976, to January 19, 1977, at the sampling sites for the Casey Fork and Big Muddy sub-impoundments (stations 13 and 14).

In situ observations of temperature, dissolved oxygen, and water transparency were made at stations 7-10. Only temperature and DO measurements were taken at stations 13 and 14. Surface samples were collected from all the stations for chemical and biological analyses. In addition, water samples were collected at a depth 1 foot from the bottom at station 12 which is in the deepest portion of the lake.

Chemical determinations were made on water samples for alkalinity, hardness, pH, nitrate and ammonia nitrogen, total silica, total and total dissolved phosphorus, and algal growth potential (AGP). The methods and procedures involved are described in the section on Materials and Methods. The water quality characteristics of Rend Lake are summarized here. Raw data are in the Open File Data Supplement.

Physical Characteristics

Temperature and Dissolved Oxygen

Lakes in the temperate zone generally undergo seasonal variations in temperature through the water column. The temperature of a deep lake in the temperate zone is about 4°C during early spring. As the air temperatures rise, the upper layers of water warm up and mix with the lower layers by wind action. By late spring, the differences in thermal resistance cause mixing to cease and the lake approaches the thermal stratification of the summer season. Following closely the temperature variations in water is the physical phenomenon of increasing density with decreasing temperature up to a certain point. These two interrelated forces are capable of creating widely differing characteristics within the lake strata of water.

During thermal stratification the upper layer (the epilimnion) is isolated from the lower layer of water (the hypolimnion) by a temperature gradient (the thermocline). Temperatures in the epilimnion and hypolimnion are essentially uniform. The thermocline will typically have a sharp temperature drop per unit depth between these two zones of thermal regimes. When the thermal stratification is established, the lake enters the summer stagnation period, so named because the hypolimnion becomes stagnated.

With cooler air temperatures during the fall season, the temperature of the epilimnion decreases. This decrease in temperature continues until the epilimnion is the same temperature as the upper margin of the thermocline. Successive cooling through the thermocline to the hypolimnion results in a uniform temperature through the water column. The lake then enters the fall circulation period, called 'fall turnover' and is again subjected to a complete mixing by the wind.

Isothermal plots for the deep sampling stations (9 and 12) in Rend Lake are shown in figure 24. Temperatures in the water column are uniform or nearly so for most of the investigation except for a brief period of 3 to 4 weeks in July. The highest surface water temperature of 29.5°C was observed on July 13, 1976. On this day the lake exhibited a temperature gradient of 6.5°C in 28 feet which again happens to be the maximum temperature gradient experienced by the lake. There was no well defined thermal stratification in Rend Lake. This is in contrast to the lakes of comparable depths in the northern half of the state (Kothandaraman and Evans, 1970; Kothandaraman et al. , 1977).

Figure 25 shows the temperature profiles for the Gun Creek, Casey Fork, and Big Muddy branches of Rend Lake. These sampling stations were relatively

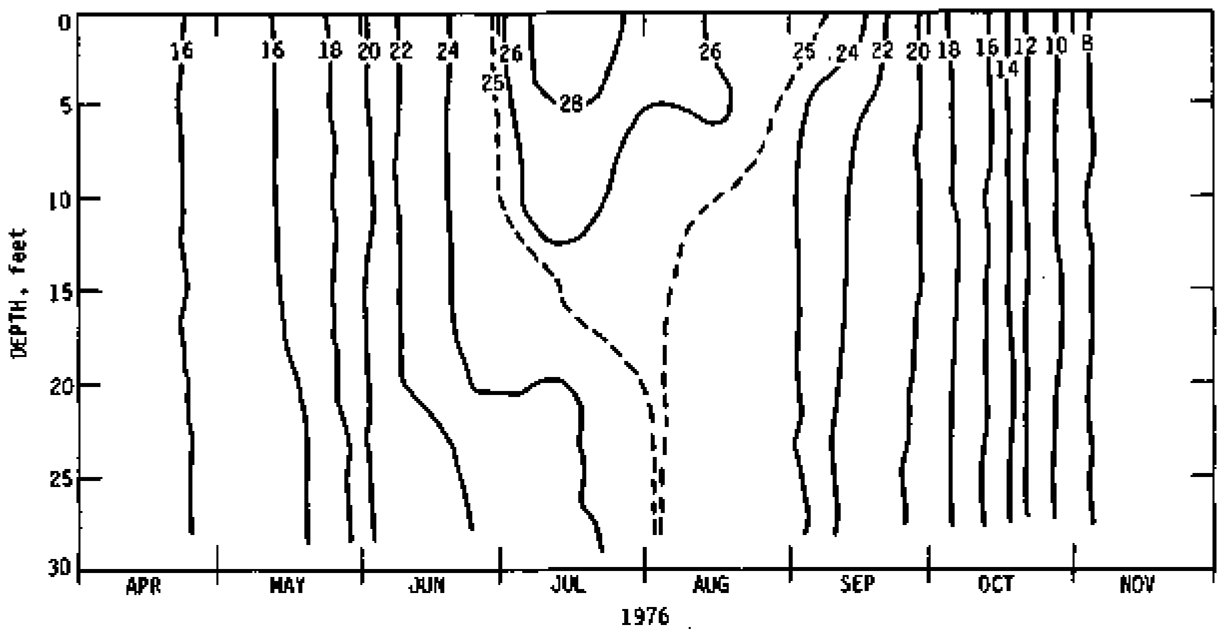

Figure 24. Isothermal plots for Rend Lake, stations 9 and 12

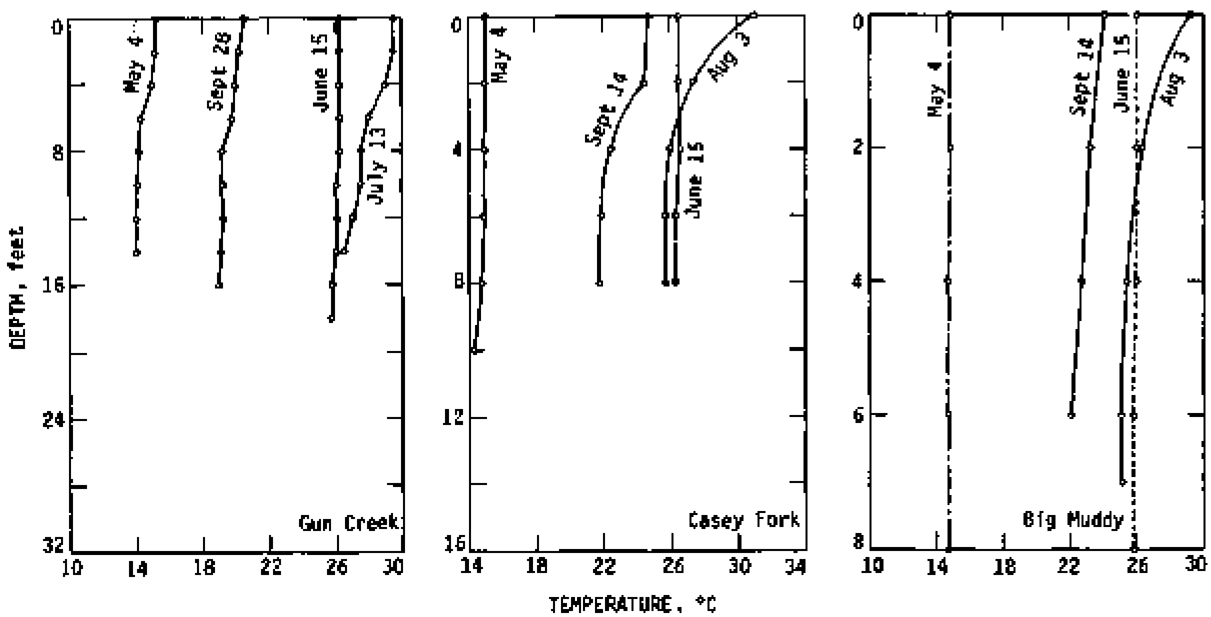

Figure 25. Temperature profiles in Gun Creek, Casey Fork, and Big Muddy branches of Rend Lake

shallow. The temperature profiles are plotted for four different dates. The surface water temperatures reached a maximum of about 30°C in midsummer at these locations. Because these lake areas are shallow, they are completely mixed by wind action and the thermal gradients at these observation stations are insignificant. In general, the lake does not appear to thermally stratify to any significant degree. The observed mean and range of temperatures, along with information on other physical and chemical characteristics of Rend Lake water quality, are shown in table 23.

Impoundment of water, natural or man-made, alters its physical, chemical, and biological characteristics. The physical changes in the configuration of the water mass following impoundment reduce reaeration rates to a small fraction of those of free flowing streams. Where the impoundment is deep, the thermal stratification acts as an effective barrier for the wind-induced mixing of the hypolimnetic zone. The oxygen transfer to the deep waters is essentially confined to the molecular diffusion transport mechanism.

During the summer months with increasing water temperatures, bacterial decomposition of the bottom organic muck exerts a high rate of oxygen demand on the overlying waters. When this rate of oxygen demand exceeds the oxygen replenishment, and sustains for a long period, anaerobic conditions begin to prevail in the zones adjacent to the lake bottom.

The isopleth plots of dissolved oxygen for the deep station in Rend Lake (stations 9 and 12) are shown in figure 26. Dissolved oxygen concentrations at the deep station were found to be satisfactory for the entire depth of the lake except perhaps for 2 or 3 weeks in July when the water temperature attained its maximum value. The bottom 10 feet of the lake at this location was found to be very nearly anoxic. Except for this one brief period, dissolved oxygen concentrations in the deep waters of the lake were at satisfactory levels. All of the lakes in the Fox Chain with depths comparable to Rend Lake experienced anoxic conditions in the hypolimnion for a period of nearly 4 1/2 months extending from mid-May (Kothandaraman et al., 1977)•

Dissolved oxygen profiles for the shallow portions of the lake are shown in figure 27. These figures pertain to the Gun Creek, Casey Fork, and Big Muddy branches of Rend Lake. Even though these areas of the lake are thermally uniform or nearly so (figure 25), during peak summer periods the oxygen demands exerted by the lake bottom sediments on the overlying waters appear to be in excess of the oxygen replenishment from the atmosphere and algal activity. This phenomenon is much pronounced for the observations made in midsummer when the observed DO concentrations at 2 to 4 feet from the bottom were much less than the DO concentrations in the upper layers. However, unlike the shallow lakes of the Fox Chain, oxygen levels near the lake bottom did not go below 4 mg/l in most cases.

The saturation concentrations for dissolved oxygen were computed from the following expression (Butts et al., 1973):

$$DO = 14.652 - 0.41022T + 0.007991T^2 - 0.000077774T^3$$

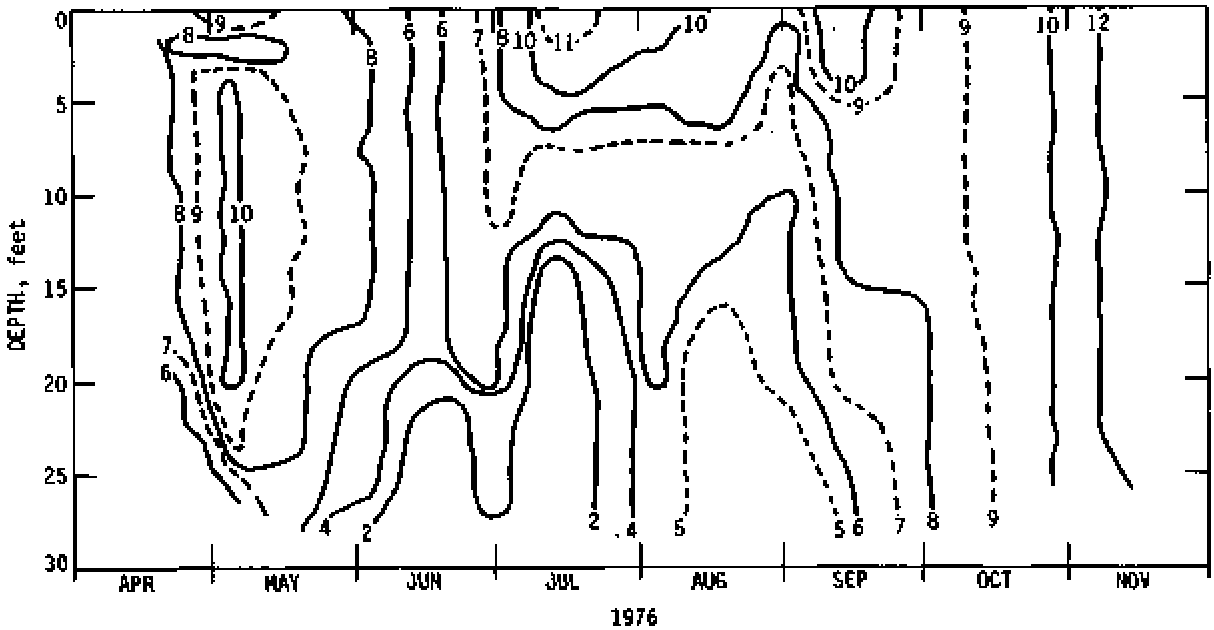

Figure 26. Isopleths of dissolved oxygen in Rend Lake, stations 9 and 12

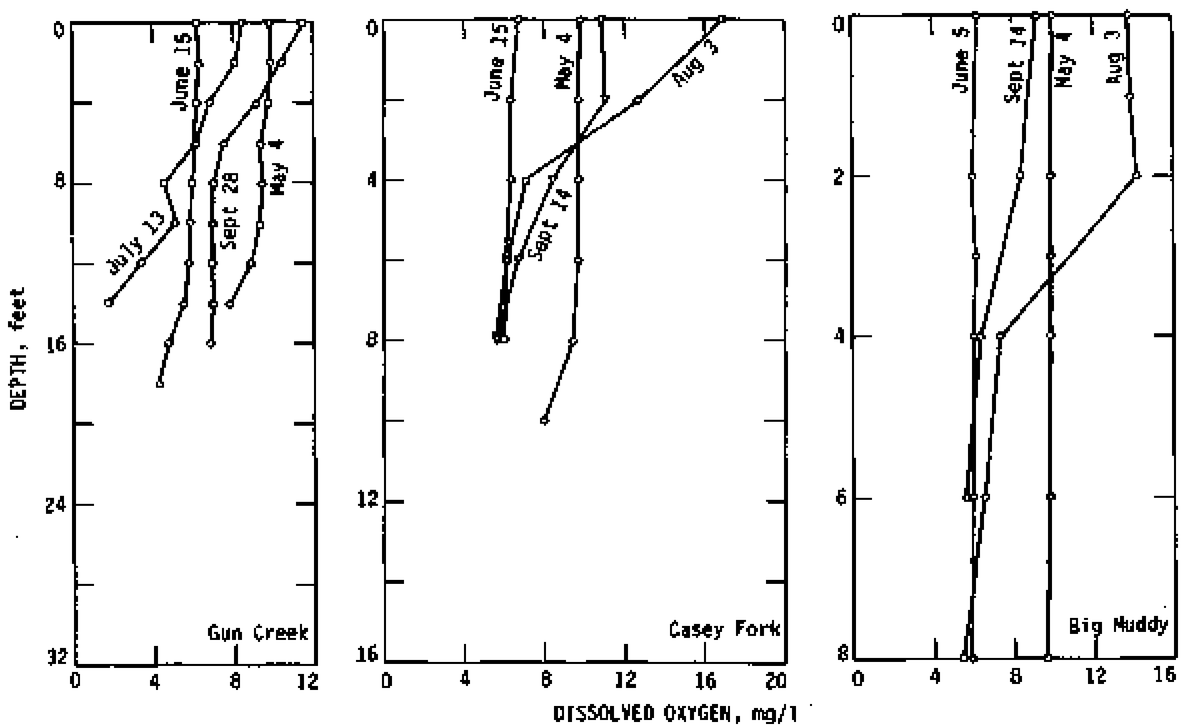

Figure 27. Dissolved oxygen profiles in Gun Creek, Casey Fork, and Big Muddy branches of Rend Lake

Table 23. Summary of Water Quality Characteristics of Rend Lake (Chemical constituents in mg/l)

	Temperature, °C Mean	Range	Diss. oxygen Mean	Range	Transparency (inches) Mean	Range
7 Big Muddy branch	18.66	0.50-29.30	9.35	6.00-14.20	21	12-40
8 Casey Fork branch	18.68	0.60-31.00	9.14	6.20-12.70	19	12-32
9 Rend Lake (surface)	17.81	0.10-29.50	9.39	5.60-12.30	31	22-40
12 Rend Lake (deep)	18.6	6.50-25.00	4.68	0.10-11.10		
10 Gun Creek branch	18.59	0.25-29.50	9.30	6.30-12.40	22	15-36
13 Casey Fork sub-imp.	10.36	0.00-25.50	8.57	1.20-16.20		
14 Big Muddy sub-imp.	11.52	0.50-27.80	7.21	1.60-14.20		

	pH Range	Alkalinity Mean	Range	Hardness Mean	Range
7 Big Muddy branch	6.98-8.07	62	36-80	152	122-199
8 Casey Fork branch	7.03-8.17	59	48-84	141	122-185
9 Rend Lake (surface)	7.39-8.26	61	41-76	135	109-166
12 Rend Lake (deep)	7.09-7.99	59	49-76	136	109-166
10 Gun Creek branch	7.16-8.25	60	41-87	138	102-172
13 Casey Fork sub-imp.	6.68-7.95	69	30-94	142	108-205
14 Big Muddy sub-imp.	6.12-7.94	74	15-122	149	99-211

	Nitrate Mean	Range	Ammonia Mean	Range	Total silica Mean	Range
7 Big Muddy branch	0.10	0.03-0.19	0.13	0.03-0.34	1.70	0.18-3.05
8 Casey Fork branch	0.10	0.03-0.27	0.12	0.00-0.39	0.88	0.11-1.89
9 Rend Lake (surface)	0.09	0.05-0.22	0.13	0.00-0.28	0.69	0.07-1.73
12 Rend Lake (deep)	0.10	0.05-0.23	0.13	0.00-0.30	1.13	0.00-6.84
10 Gun Creek branch	0.09	0.03-0.18	0.11	0.00-0.24	0.76	0.08-1.73
13 Casey Fork sub-imp.	0.23	0.11-0.50	0.59	0.00-4.56	3.16	1.03-7.35
14 Big Muddy sub-imp.	0.13	0.05-0.20	0.15	0.00-0.56	3.26	0.00-8.93

	AGP Mean	Range	Total phosphorus Mean	Range	Total diss. P Mean	Range
7 Big Muddy branch	14	3-35	0.17	0.09-0.30	0.08	0.00-0.23
8 Casey Fork branch	15	3-47	0.10	0.00-0.17	0.02	0.00-0.06
9 Rend Lake (surface)	12	4-36	0.08	0.00-0.46	0.03	0.00-0.38
12 Rend Lake (deep)	10	2-20	0.16	0.00-0.90	0.02	0.00-0.10
10 Gun Creek branch	10	0-23	0.07	0.00-0.17	0.01	0.00-0.04
13 Casey Fork sub-imp.	25	3-53	0.46	0.13-1.27	0.22	0.00-1.12
14 Big Muddy sub-imp.	18	0-77	0.15	0.02-0.33	0.05	0.00-0.23

where

DO = the dissolved oxygen, mg/l

T = water temperature, °C

At the beginning of the field investigation, the percent saturation of DO was less than 100 at all the sampling locations. Even though the algal growth in the lake has not reached a bloom or nuisance proportions, supersaturated conditions were observed in the main bodies of the lake except in the two sub-impoundments. In all cases highest supersaturated conditions were concomitant with maximum water temperatures. This indicates increased algal activities at elevated water temperatures along with abundant sunlight during July and August. The DO levels in the sub-impoundments were found to be almost always undersaturated during the period of observation.

Lake Water Transparency

Secchi disc visibility is a measure of the lake water transparency or its ability to allow light transmission. The Secchi disc transparency serves as an index and a means of comparison of similar bodies of water or the same body of water at different times. Greeson (1971) reported that in Oneida Lake in New York, the 1 percent penetration depth averaged 13.1 feet, and a concurrent Secchi disc transparency reading averaged 5.6 feet which equalled the 10.5 percent penetration depth. The 1 percent light penetration depth is generally defined as the lower limit of the euphotic zone.

The maximum, minimum, and mean values of Secchi disc transparency observations are shown in table 23. The mean Secchi disc observation was the highest at station 9 near the dam with a value of 31 inches. The Secchi disc mean values for the shallower portions of the lake were about 20 inches. These values indicate that they are somewhat related to lake depth, suggesting that boating activities and wind and wave actions, which could stir up the bottom sediments in shallow areas, affect significantly the depth of light penetration.

Chemical Characteristics

Values of pH

Values of pH above 8.0 in natural waters are generally considered to be produced by a photosynthetic rate that demands more carbon dioxide than that furnished by respiration, decomposition, and diffusion from the atmosphere. Photosynthesis by aquatic plants utilizes carbon dioxide, removing it from bicarbonate and producing carbonate when no free carbon dioxide exists in the water column. Carbonates of calcium and magnesium, which are weakly soluble, tend to precipitate out. Decomposition of organic matter tends to reduce pH and increase bicarbonates, whereas the tendency of photosynthesis is to raise pH and reduce bicarbonates.

The pH values in Rend Lake were generally in the range of 7 to 8. In the main body and the three branches of the lake, pH of the surface water samples was slightly above 8.0 during July and August. This was the period when supersaturated conditions were observed in the lake, thus corroborating the evidence for increased algal activity. The pH value dipped to 6.12 in the Big Muddy sub-impoundment only on one occasion. At that time the alkalinity was severely depressed suggesting an uncommon influx of acidic material.

Alkalinity and Hardness

These factors are governed to a large extent by the geochemistry of the watershed of the lakes. The alkalinity of a water is its capacity to accept proton and is generally imparted by the bicarbonate, carbonate, and hydroxide components. The species composition of alkalinity is a function of pH and mineral composition. The carbonate equilibria, in which carbonate and bicarbonate ions and carbonic acid are in equilibrium, are the predominant chemical system present in natural waters.

Any substance in water that will form an insoluble precipitate with soap causes hardness. Hardness is attributable principally to calcium and magnesium as other polyvalent cations are seldom present in appreciable concentrations in natural waters. Hard waters have no demonstrable harmful effects upon the health of consumers. The detrimental effects of hardness include excessive soap consumption, formation of scales in boilers, hot water heaters, pipes, and utensils. The major detrimental effect of hardness is economic.

The mean and range of values for alkalinity and hardness pertaining to all the lake observations are given in table 23. The waters of Rend Lake are only moderately hard. The hardness and alkalinity values at all sampling locations are comparable, particularly for the deep water samples at station 12. Because the dissolved oxygen concentrations in the deepest areas of the lake were adequate (figure 26), precluding anaerobic conditions, decomposition of organic matter in the lake bottom is insignificant. Alkalinity and other products of decomposition like ammonia, phosphorus, etc. are comparable in magnitude in both stations 9 and 12.

Nitrogen

Nitrogen is present in water as dissolved organic nitrogen, or as inorganic nitrogen such as ammonium, nitrate or nitrite, or as elemental nitrogen. These various forms cannot be used to the same extent by different groups of aquatic plants and algae. Nitrogen is one of the principal elemental constituents of amino acids, peptides, proteins, urea, and other organic matter.

Vollenweider (1968) reports that in laboratory tests, the two inorganic forms of ammonia and nitrate are as a general rule used by planktonic algae roughly to the same extent. However, Wang et al. (1973) reported that during periods of maximum algal growth under laboratory conditions, ammonium nitrogen was the source of nitrogen preferred by planktons.

The concerns for nitrogen as a contaminant in water bodies are twofold. First, because of adverse physiological effects on infants and because the traditional water treatment processes have no effect on the removal of nitrate, concentrations of nitrate plus nitrite as nitrogen are limited to 10 mg/l in public water supplies. Second, a concentration in excess of 0.3 mg/l is considered sufficient to stimulate nuisance algal blooms (Sawyer, 1947). The Illinois Pollution Control Board stipulates that the ammonia nitrogen and nitrate plus nitrite as nitrogen should not exceed 1.5 and 10.0 mg/1, respectively.

The mean nitrate concentrations at various locations in the lake were comparable (table 23) and the temporal variations were moderate with the exception of the Casey Fork sub-impoundment. The average nitrate concentration in the Casey Fork sub-impoundment is nearly twice the values observed for other locations. Likewise, ammonia concentrations were comparable at all locations except for the Casey Fork sub-impoundment. The average concentration in this sub-impoundment is about four times higher than the values for other areas. The most likely reason for the higher nitrate and ammonia values is the discharge from the Mt. Vernon wastewater treatment plant. Except in the case of the average value for ammonia in the Casey Fork sub-impoundment, nitrate and ammonia concentrations in Rend Lake were found to be at acceptable levels.

Silica

The element silicon is not found free in nature, but it occurs as silica (silicon dioxide) in the form of finely divided or colloidal matter. An abundance of silica in water, along with other necessary nutrients, favors the growth of diatoms. Since diatoms contain significant amounts of silica in their frustules, they can be expected to alter the silica concentrations in water bodies.

The silica concentrations observed in Rend Lake (main lake and branches) are not excessive (table 23). With the exception of a single observation of 6.84 mg/1 for the deep water samples at station 12, the temporal variations were moderate. The variations in the sub-impoundments were much more pronounced. The higher concentrations are probably associated with higher suspended solids and turbidity because of the shallowness of these sub-impoundments. A high degree of association among these parameters has been reported in the literature.

Algal Growth Potential and Phosphorus

Because of the strong association of phosphorus and algal growth potential, these two parameters are treated together here. Phosphorus has been implicated as being primarily responsible for algal blooms in lakes. Gakstatter et al. (1975) reported that out of 623 lakes surveyed in the states east of the Rocky Mountains, under the National Eutrophication Survey Program, 67 percent were phosphorus limited.

Phosphorus is an active element which does not occur free in nature. It is found in the form of phosphates in several minerals and it is a constituent of fertile soils, plants, protoplasm, and tissues and bones of animal life. It is an essential nutrient for plant and animal growth, and like nitrogen, it passes through cycles of photosynthesis and decomposition.

Sawyer (1952), from experimental work with Wisconsin lakes, concluded that aquatic blooms are likely to develop in lakes during summer months when concentrations of inorganic nitrogen and inorganic phosphorus are in excess of 0.3 mg/l and 0.01 mg/l respectively. These critical levels for nitrogen and phosphorus concentrations have been accepted and widely quoted in scientific literature. Numerous published reports indicate that productivity is largely determined by two factors, i.e., phosphorus and nitrogen. Vollenweider (1968) concluded after extensive analysis of data pertaining to the lakes of central Europe that the critical levels for phosphorus and nitrogen concentrations suggested by Sawyer were also valid for those lakes. He further observed that phosphorus was the more critical of the two nutrients.

Total phosphorus and total dissolved phosphorus were the only two forms of phosphorus considered in this investigation. The means and ranges of algal growth potential (AGP) and phosphorus values are given in table 23.

In the deepest portion of the lake (station 12), the total dissolved phosphorus, with the exception of one observation, was less than 0.03 mg/1 and often times zero. The phosphorus levels for deep water samples at station 12 were comparable or less than surface water samples at station 9. This suggests strongly that the bacterial decomposition of organic matter in the lake bottom is absent or extremely low.

Total dissolved phosphorus, which is considered a readily available form of phosphorus for biosynthesis will be much less than 0.03 mg/1. The total dissolved phosphorus fraction was found in the past to vary from about 90 to 35 percent of the total phosphorus in water samples depending on their sources. Waste treatment plant effluents carry a high percentage of dissolved phosphorus loads, and stream samples far removed from any domestic wastewater discharges have a low percentage of dissolved phosphates. The highest levels of phosphorus were observed in the Casey Fork sub-impoundment, and again this is most likely due to the municipal waste discharge at Mt. Vernon.

The AGP values observed in the lake water samples were much less than the AGP values observed in water samples of the Fox Chain of Lakes (Kothandaraman et al., 1977). The mean AGP value for the Casey Fork sub-impoundment was the highest among all the sampling sites in the lake. This observation is coupled with the fact that at this location, the mean concentrations of nitrogen and phosphorus were the highest. In general, the lake does not experience algal growth problems. This aspect is discussed in greater detail in the section on Biological Characteristics.

Metals in Sediments

Four sediment samples were collected from each of the four lake stations for heavy metal analyses. Analyses were performed for lead, copper, zinc, iron, and mercury. The average values detected (in mg/l) are shown as follows along with average values determined in the sediments of two other lakes in southern Illinois.

	7	*8*	*9*	*10*	*Dolan L.*	*Cedar L.*
Lead	19	26	30	24	23	23
Copper	15	21	30	16	7	15
Zinc	44	57	79	48	60	49
Iron	13000	17800	28000	18000	5400	16700
Mercury	0.05	0.05	0.05	0.05	0.12	0.03

Except for mercury concentrations, the deep station in Rend Lake, station 9, shows the highest values. It is probable that this is due to the smaller size particles and older sediments than obtained in the shallower areas of Rend Lake. The range of mercury concentrations in the lake sediments was from 0.02 to 0.09 mg/l. Although there were no significant variations between stations, there were significant differences between sampling dates.

Summary of Physical and Chemical Characteristics

Rend Lake does not experience any significant thermal stratification even in the deepest portion of the lake. Except for a brief period of near zero dissolved oxygen levels in the bottom 10 feet of the lake at its deepest station, DO concentrations are at satisfactory levels. Decomposition of organic matter in the lake is insignificant. The nitrogen and phosphorus levels in the lake are at acceptable levels with the exception of the Casey Fork sub-impoundment. The algal growth potential values of the lake samples are not excessive.

Biological Characteristics

Phytoplankton

The locations and frequency of phytoplankton collections were the same as those previously described for chemical analyses. The number of algal collections varied from 11 to 47 per station. With the exception of station 12 (Rend Lake - deep), the samples were collected at the surface for all stations. Methods and procedures were described in the section on Materials and Methods.

Algal Composition

A great number of algal species were found in the Rend Lake system. During the 12 months study period, 110 algal species were recovered from 322 samples. The species included 6 blue-green algae, 26 green algae, 68 diatoms, 9 flagellates, and 1 desmid. During the Fox Chain of Lakes study (Kothandaraman et al., 1977), 64 algal species were recovered from 414 samples for the period from June to October 1974.

The number of species per sampling location ranged from 36 to 52 for the six stream samples (stations 1 through 6) and from 31 to 34 for the Rend Lake surface samples (stations 7 through 10). As expected, the Rend Lake deep station (station 12) had the lowest number of algal species recovered. This is probably due to the limited light available and small sample size. Thirty-seven and 41 algal species were detected in the two sub-impoundments (stations 13 and 14). It is difficult to compare the productiveness of all sampling locations because of the difference in sample size.

Occurrences of blue-green algae and desmid were trifling, and diatoms were clearly the dominant type of algae in the Rend Lake system. This is common for other surface waters in Illinois (Lin et al., 1972, 1973, 1975; Evans and Schnepper, 1974; Butts et al., 1977), except for the waters of the Fox Chain of Lakes. The most common diatoms observed were *Caloneis amphisbaena*, *Synedra acus*, and *Surivella ovata.* These three species were not, however, the most numerous diatoms in other surface waters in Illinois. The diatoms, *Cyclotella meneghiniana₃ Melosiva granulata*, and *Navioula gastvum* . also occurred at most of the sampling locations. Although the recovery rates were low for *Navioula* sp., 12 species were detected. The predominant genera in the Rend Lake system were *Navioula*, *Caloneis*, and *Synedra*, in that order.

The green algae *Soenedesmus dimorphus* and *Pediastrum simplex* occurred at most of the stations. *Euglena viridis* and *Tvachelomonas crebea* were the important flagellates.

The recovery rates (above 20 percent) of the 17 most frequently observed algae at 13 sampling stations are depicted on figure 28. This figure is a partial summary of the full data tabulated in the Open File Data Supplement. The recovery rates of all species observed were generally very low. Only in two cases were rates of recovery above 40 percent. In several instances, some species were detected 30 to 40 percent of the time. In Grass Lake in the Fox Chain (Kothandaraman et al., 1977), *Cyalotella meneghiniana* were detected more than 90 percent of the time.

Algal Density

A summary of the average composition for each algal type at each station, based on algal density, is given in table 24. Also shown is the maximum pel—centage composition of all types except diatoms for all sampling locations. The maximum for diatoms was 100 percent at each location, i.e., at one time or another all algae in a water sample for each location consisted solely

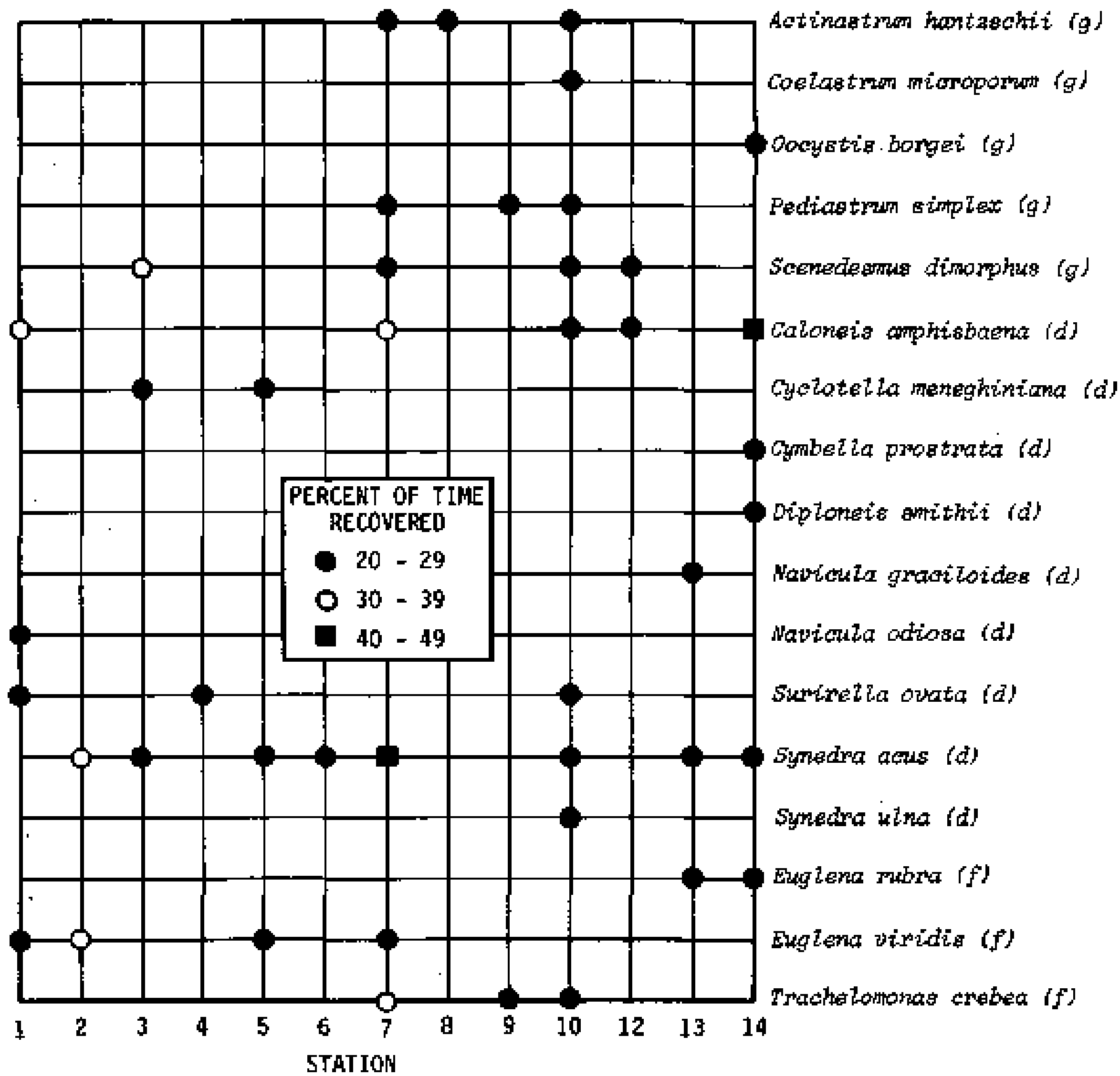

Figure 28. Occurrence of the most abundant algae in Rend Lake system

Table 24. Summary of Composition of the Algal Types

(In percent of time recovered)

	Average					Maximum *			
	B-g	*G*	*Dia*	*F*	*Des*	*B-g*	*G*	*F*	*Des*
Rayse Creek (1)		19.2	67.3		13.5		86.4	100.0	
Big Muddy (2)	0.4	15.2	72.1	12.3		13.8	81.3	72.2	
Lake outlet (3)	0.7	34.4	53.4	7.5		18.4	100.0	100.0	
Gun Creek	6.4	14.0	71.8	7.8		74.5	83.6	62.5	
Atchison Creek (5)		16.7	66.5	16.8			"100.0	100.0	
Casey Fork (6)	0.8	25.3	63.2	10.7		5.1	100.0	55.2	
Lake-Big Muddy branch (7)	0.7	43.8	39.5	16.0		10.9	83.1	78.6	
Lake-Casey Fork branch (8)	3.9	33.2	50.6	16.2			90.6	79.3	
Lake above dam (surface) (9)	3.7	25.7	51.7	18.9		59.1	100.0	59.3	
Lake-Gun Creek branch (10)		35.2	43.9	12.0		50.0	100.0	100.0	
Lake above dam (deep) (12)		34.8	59.3	5.9			100.0	58.8	
Casey Fork sub-imp. (13)		19.8	65.1	15.1			51.9	79.6	
Big Muddy sub-imp. (14)	0.9	22.3	68.5	7.7	0.6		68.8	51.2	11.2

* Maximum value for diatoms was 100 percent for all 13 stations.

Note: B-g = blue-green; G = green; Dia = diatom; F = flagellate; Des = desmid.

of diatoms. The samples at many locations consisted solely of green algae and of flagellates.

As shown in table 24, diatoms accounted for 40 to 72 percent of the total algal density at all stations. About 14 to 44 percent of the total algal population were green algae, and flagellates made up 8 to 19 percent of all algal counts. The relatively high occurrence of green algae at station 3, compared with other streams, is the influence of Rend Lake.

The algal densities expressed as cell counts per milliliter (cts/ml) along with some statistical results are tabulated in table 25. The observed total algal densities ranged from a low of none at Rend Lake-surface (station 9) and Rend Lake-deep (station 12) both on May 18, 1976, to a high of only 650 cts/ml in the Big Muddy sub-impoundment (station 14) on September 15, 1976. The algal densities at all sampling stations were found to be very low in comparison with those of other Illinois surface waters (Lin et al., 1972, 1973, 1975; Evans and Schnepper, 1974; Butts et al., 1977).

An examination of the algal density data for each location showed them to be generally distributed in a log-normal pattern. Therefore the central tendency and dispersion of the data were expressed in geometric terms. The geometric means for all stations varied narrowly from 54 to 120 cts/ml.

Since low algal densities occurred at all sampling locations, no attempt was made to derive algal succession or population dynamics. The maximum densities for the dominant species were poorly developed.

Table 25. Statistical Summary of Algal Densities and Algal Species Diversity Indexes

	Algal density			
	Number of samples	Range (cts/ml)	Geometric mean (cts/ml)	Geometric standard deviation
Rayse Creek (1)	36	6-180	71	1.96
Big Muddy (2)	33	16-180	71	1.64
Lake outlet (3)	47	13-300	79	2.08
. Gun Creek	29	12-160	65	1.84
Atchison Creek (5)	24	22-160	65	1.67
Casey Fork (6)	43	29-260	75	1.61
Lake-Big Muddy branch (7)	15	25-220	84	1.60
Lake-Casey Fork branch (8)	16	22-130	71	1.64
Lake above dam (surface) (9)	15	ND-150*	63	3.17
Lake-Gun Creek branch (10)	15	13-270	76	2.02
Lake above dam (deep) (12)	9	ND-200	54	4.33
Casey Fork sub-imp. (13)	17	61-440	120	1.88
Big Muddy sub-imp. (14)	19	42-650	110	2.07

	Diversity index		
	Range	Average	Standard deviation
Rayse Creek (1)	0-2.40	1.40	0.62
Big Muddy (2)	0-2.66	1.30	0.56
Lake outlet (3)	0-3.03	1.56	0.89
Gun Creek	0-1.98	0.96	0.60
Atchison Creek (5)	0-2.19	1.19	0.57
Casey Fork (6)	0-2.29	1.29	0.60
Lake-Big Muddy branch (7)	1.26-2.76	1.76	0.40
Lake-Casey Fork branch (8)	0-2.44	1.50	0.61
Lake above dam (surface) (9)	0-2.08	1.30	0.63
Lake-Gun Creek branch (10)	0-2.76	1.42	0.76
Lake above dam (deep) (12)	0-1.96	1.19	0.72
Casey Fork sub-imp. (13)	0.75-2.86	1.72	0.57
Big Muddy sub-imp. (14)	0.87-3.03	1.84	0.60

* ND - alga was not detected

Diversity Index

There have been many methods suggested for defining the structure of a biological community. The most widely used procedure is the diversity index and the one most commonly used is Shannon's index (Shannon and Weaver, 1949). For this report the index for each sampling location on each day of collection was determined as follows (Hutchinson, 1967):

$$D = - \sum_{i=1}^{m} P_i \log_2 P_i$$

where $P_i = N_i/N$ is the probability of the occurrence of the *ith* species, M. is the density of the *ith* species, N is the total algal density of the sample, and m is the number of species per sample. For convenience $\log_2 P_i$ may be expressed as 1.44 In P_i. The index D has a minimum value (zero) when m equals 1 and a maximum value when $m = N_s$.

Only one species of alga was observed in many samples collected from most of the locations. This gives a diversity index of zero (table 25). The greatest algal species diversity index developed was 3.03 for both the Big Muddy River-below dam (station 3) on April 14, 1976, and the Big Muddy River sub-impoundment (station 14) on September 15, 1976. The mean index ranged from 0.96 for Gun Creek (station 4) to 1.84 for the Big Muddy River sub-impoundment. The standard deviation of index varied from 0.40 for the Rend Lake-Big Muddy branch (station 7) to 0.76 for the Rend Lake-Gun Creek branch (station 10). No attempt was made to correlate total algal density and species diversity index.

Summary

Diatoms were the dominate algae in the stream and Rend Lake waters. The most frequently occurring diatoms were *Caloneis amphisbaena*, *Synedra acus*, and *Surirella ovata.* Twelve species of *Navicula* were recovered. Algal densities and the frequency of occurrence for all samples were very low. The largest density was 650 cts/ml. The maximum of dominant algae was poorly developed. The maximum diversity index was 3.03. The types and densities of algae observed during the study period do not appear to be a significant governing factor on the water quality of the lake system.

Macroinvertebrates

Aquatic macroinvertebrates are defined as animals which are visible to the unaided eye, and capable of being retained by a U.S. Standard 30-mesh sieve. Benthic macroinvertebrates, being relatively stationary, tend to reflect the minimum water quality conditions at a given point in a stream. Fish, plankton, and water samples tend to reflect water quality at a station for only that moment. The macroinvertebrate community indicates the summation of the physical and chemical environment. Disturbance of this community by poor water quality may be detected by benthic sampling but may not be readily detected by water sampling techniques.

The cumulative knowledge and experience of aquatic biologists have made possible the rating of aquatic organisms as to their pollution tolerance. Similarly, the rating of a benthic community's ecological balance has been formulated. In this study, the Illinois Environmental Protection Agency's rating system was used (Schacht and Matsunaga, 1975). Methods and procedures are described in the section on Materials and Methods. The raw data are available in the Open File Data Supplement.

Macroinvertebrate Composition

Sixty-one taxa were found in the 103 samples analyzed. Of the 124 artificial substrates put out 87 were recovered.

Stream Artificial Substrates. Station 3 had the most (272) and the least (2) number of individuals found on an artificial substrate, in the October and December collections, respectively. The most taxa (12) in a sample were found at stations 4 and 5 in the August and June collections, respectively. Only one taxon was found at stations 3 and 5 in March. Both numbers of individuals and diversity of taxa are limited on artificial substrates for November through March.

Averaging the IEPA aquatic classification of the samples, station 2 indicated the most ecologically balanced community (1.4 average) and station 3 the least balanced (2.9 average). The low ranking for community balance at station 3 may be due to the relatively uninhabitable hardpan clay bottom at that lake outlet station.

Lake Artificial Substrates. Of the two samplers used at each lake station, the one at 2 feet from the surface was identified by t (top) and the one at 2 feet from the bottom by b (bottom). The highest number of individuals found on a substrate was in August (324) at station 8t. The most taxa (5) were found at station 10b and 7t in May and June, respectively.

No organisms were found at station 8b in November, and in December none was found at stations 7b, 8t, 8b, 9t, and 10b. The least taxa (0) were found on those same dates and stations since no individuals were found. As with the tributaries, winter severely limits the populations in the lake.

Stations 7t and 8t showed the greatest ecological balance and station 9b the worst. Station 9 cannot be adequately evaluated because of the low rate of recovery of substrates (4 of 16 recovered) at that station. The top substrates showed a slightly higher balance (2.4) than the lower substrates (2.9), probably because of higher dissolved oxygen concentrations in the surface waters of the lake.

Lake Benthos

The benthos in descending order of average individuals per square meter were: November 1248, March 1144, May 326, and August 247. Generally, the populations of benthic aquatic insects decrease in spring and summer as a result of the emergence of adults, increase in autumn because of the hatching of eggs, and decline in winter because of predation.

The benthic community was composed mainly of Chironomidae (49%), Tubificidae (31%), and *Chaoborus* (20%). The presence of these organisms, plus the occasional occurrence of other taxa *(Caenis, Cheumatopsyehe)* and the lack of domination by *Chaoborus,* Indicates a less harsh environment than is found in a eutrophic hypolimnion.

Rend Lake had a lower benthic dry weight per square meter (138.3 mg/m^2) than Cedar Lake (265.3 mg/m^2) when three similar dates were averaged.

Summary

The IEPA rating system was used in the summary of classification for all stations sampled, as given in table 26. There were no obviously degraded macroinvertebrate communities due to poor water quality at any of the stations sampled.

CONCLUSIONS AND RECOMMENDATIONS

1) The waters of Rend Lake do not show measurable signs of significant degradation. Algal densities are sparse. A maximum density of 270 cell counts per milliliter was recovered from the water surface of the lake. Significant numbers of nuisance blue-green algae do not exist. Except for brief periods of near zero in the lower 10 feet of the deep portion of the lake, dissolved oxygen concentrations are satisfactory. However, nutrient loadings in terms of nitrogen and phosphorus are excessive and eutrophic conditions may accelerate with time.

2) Nutrient budget computations show that Rend Lake retains 94 percent of the 560 pounds per day of phosphorus transported to it by its tributary streams. Casey Fork contributes 67 percent of the total phosphorus load applied to the lake. The major source of the phosphorus is the sewage treatment works serving the city of Mt. Vernon. Phosphorus removal facilities should be provided as part of the municipal treatment plant, to lower phosphorus content in the effluent to the lowest concentration practicable. Such measures will minimize the rate of inevitable eutrophication of the lake waters.

3) The relationship of land use to water quality is difficult to access during periods of low stream flow. Under such conditions, as experienced during this study, the effects of non-point sources are minimized and those of point sources are maximized.

4) The only identifiable non-point source producing a measurable change in water quality in the streams of the watershed was oil fields. The waters of Rayse Creek and the Big Muddy River showed elevated chloride concentrations, but these did not exceed the water quality standard of 500 mg/l. However, the potential exists for higher concentrations of the substance during times of more runoff than occurred during 1976. A management program should be developed leading to effective chloride disposal procedures on the Rayse Creek and Big Muddy River watersheds.

5) The waters of Casey Fork are seriously degraded by frequent episodes of dissolved oxygen depression and high concentrations of ammonia-nitrogen.

Table 26. Summary of the IEPA Aquatic Classifications

Date	Stream stations 1	2	3	4	5	6	Lake stations 7t	7b	8t	8b	9t	9b	10t	10b	Averages Stream	Lake t	Lake b
3/30/76	X	X	4	3	4	1									3.0		
4/20/76	3	X	3	1	2	X									2.3		
5/19/76	X	1	3	3	2	X	4	3	X	X	X	X	X	2	2.3	4.0	2.5
6/16/76	2	2	2	3	2	3	2	3	3	3	X	X	3	3	2.3	2.7	3.0
7/13/76	3	1	X	3	3	2	2	3	1	X	X	X	X	2	2.4	1.5	2.5
8/18/76	2	1	3	2	3	3	1	1	1	X	3	X	1	1	2.3	1.5	1.0
9/15/76	3	1	X	3	3	2	1	X	X	2	X	X	X	X	2.4	1.0	2.0
10/12/76	2	1	3	X	2	3	X	3	2	3	X	X	X	X	2.2	2.0	3.0
11/10/76	3	2	2	3	3	3	2	4	2	5	2	4	2	4	2.9	2.0	4.3
12/18/76	X	2	3	X	X	3	4	5	5	5	5	X	4	5	4.1	4.5	5.0
Averages	2.6	1.4	2.9	2.6	2.7	2.5	2.3	3.1	2.3	3.5	3.3	4.0	2.5	2.8	2.5	2.4	2.9

X-Substrate not recovered
t-Top substrate
b-Bottom substrate

Aquatic class	Point value
Balanced (B)	1
Unbalanced (UB)	2
Semi-polluted (SP)	3
Polluted (P)	4
Barren areas (BA)	5

The source of these conditions is the waste discharge within the city of Mt. Vernon. In all fairness, it should be emphasized that measurements for water quality assessment on Casey Fork were performed, generally, during periods when dilution was not available. Nevertheless, the sources causing dissolved oxygen depression and excessive NH_3-N concentrations (average 4.16 mg/l) in Casey Fork should be identified and corrective measures implemented. The waters of Casey Fork will not support a fishery under the conditions observed.

6) The significance of frequent occasions when total iron and copper exceeded water quality standards in all tributary streams is not clear. The ranking order of prevalence, i.e., iron, zinc, mercury, copper, and lead, in the stream waters, though illuminating, is a condition not readily compared with other fllinois streams. It will be useful if future water quality assessments of other Illinois streams include similar examinations of particulate heavy metals for comparative purposes.

7) Fecal coliform bacteria generally exceeded water quality standards in all tributary streams during the period May to September. This suggests that the application of bacterial standards is a questionable practice for Illinois streams. When applying the rule governing bacterial quality, that portion of the requirement stipulating that no more than 10 percent of the samples shall exceed 400 FC/100 ml is most applicable.

8) As the study of Rend Lake and its watershed streams progressed, it was learned that the public water system is plagued with frequent occurrences of taste and odor problems. The techniques employed by this study did not reveal likely causes. However, the operations of the two sub-impoundments are suspect. A wel1-conceived investigation should be undertaken to assess the influence, if any, of the management of the two impoundments on taste and odor occurrences in the water system.

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