Characterization of Nutrients and Algal Blooms At Abiquiu and Cochiti Reservoirs

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LIST OF FIGURES

ABSTRACT

Key words: Cochiti Reservoir, Abiquiu Reservoir, algal blooms, blue-green algae, nutrient concentrations, primary productivity

A bloom of blue-green algae of nuisance proportions occurred at Cochiti Reservoir in the summer of 1976. The bloom was characterized as predominately *Aphanizomenon* with a smaller biomass of *Anabaena*. Bioassays of extracts prepared from this *Aphanizomenon* bloom indicated that the bloom was toxic to vertebrate organisms. In the summer of 1977 the surface bloom of *Aphanizomenon* was reduced by an order of magnitude and *Anabaena* was approximately equal in abundance to *Aphanizomenon*. Because of increased light penetration and enhanced photosynthetic activity at greater depths, phytoplankton primary productivity decreased only to about half the 1976 values. The decrease in blue-green algae in 1977 was associated with lower levels of total nitrogen and phosphorus in reservoir water. Cochiti Reservoir was characterized as eutrophic in the summer of 1976 and mesotrophic in 1977.

At Abiquiu Reservoir the blue-green algal population and primary productivity was considerably lower than at Cochiti Reservoir. In the summer of 1976 *Aphanizomenon* was abundant in algal samples while *Anabaena* was rarely observed. In 1977 smaller populations of *Aphanizomenon* occurred with an increased diversity of diatoms and green algae. Primary productivity and nutrient concentrations in Abiquiu Reservoir were characteristic of mesotrophic conditions in 1976-77.

LIST OF TABLES

Table of Contents

Introduction

Cochiti Reservoir was completed and partially filled in 1975. Considering its proximity to both Albuquerque and Santa Fe, it is subject to increasingly heavy recreational use. Cochiti receives Rio Grande water which in the past contained sewage treatment effluents which appeared to come from the cities of Espanola, Los Alamos, and White Rock. A moderate bloom of *Aphanizominon flos-aquae* was observed at Cochiti Reservoir in 1975.

In the past, Abiquiu Reservoir has been used for temporary storage of water; however, a permanent pool of about 40,000 acre-feet is planned for Abiquiu Reservoir and the City of Albuquerque is presently storing water in this reservoir. Storage at this reservoir may be increased in subsequent years and it is designated for recreational use. Algal blooms have frequently been observed at Abiquiu and a bloom in the late summer of 1975 was characterized by the New Mexico Environmental Improvement Agency as an extensive bloom of *Aphanizomenon flos-aquae*. Because of the magnitude of this bloom, concern over possible toxicity to livestock was expressed.

This investigation was initiated because of the blue-green algal blooms at Abiquiu and Cochiti Reservoirs. The predominant algal species, *Aphanozimenon flos-aquae*, is reported to be associated with production of toxins that may result in death of fish and other vertebrates. In view of the increasing recreational use of these waters and the future use of the water by the City of Albuquerque, these blooms should be regarded as potentially serious. This study provides data on the nutrient levels in the reservoirs and hopefully will contribute to the control of the algal blooms in the future. In addition, the study provides baseline information on chemical and biological conditions in these newly established reservoirs.

Project Objectives

The objective of this project was to characterize the proliferation of algae in Abiquiu and Cochiti Reservoirs by determining the chemical characteristics and the limnological conditions prior to, during, and following algal blooms as well as throughout the year. Microbial studies were employed to determine the possible health hazards due to contamination from human sewage. The specific aims of this investigation were as follows:

1. Algal Studies: Phytoplankton samples were collected at various times throughout the year for identification and enumeration. Samples were collected most frequently during the warmer months in order to characterize algal blooms. Primary productivity was measured at several sites throughout the year to provide an estimate of the annual level of primary productivity in the reservoirs. Animal toxicity studies were employed at the peak of the algal bloom at Cochiti Reservoir.

2. Water Chemistry and Limnological Conditions: The levels of the nutrients, nitrogen and phosphorus, were determined throughout the year. In addition, alkalinity, available inorganic carbon, pH, dissolved oxygen, transparency, and water temperature were measured when samples were collected for nutrient determinations.

3. Bacterial and Zooplankton Studies: Quantitative determinations of bacterial numbers were made periodically throughout the year to determine the capacity of organisms in the reservoir for nutrient cycling. The numbers of bacteria were compared to

the algal populations to determine the possible role of bacteria in controlling algal blooms. The extent of human and animal pollution was determined by quantitation of fecal coliforms and fecal streptococci. The presence of invertebrate organisms was noted in the water samples and abundance of invertebrates was determined although they were not identified.

Research Procedures

1. Algal Identification: Phytoplankton samples were collected when primary productivity and nutrient concentrations were determined. The phytoplankton samples were preserved in the field and returned to the laboratory where they were concentrated by the iodine settling method. The phytoplankton were enumerated using a counting chamber (Jackson and Williams) and identified by genus from the algal identification key by Prescott.

2. Primary Productivity Measurements: Primary productivity was determined using the C-14 method originally developed by Steemann Nielsen (Kidd and Johnson). Water samples were collected with a plastic Kemmerer water sampler and aliquots added to transparent bottles (light bottles) and an opaque bottle (dark bottle) each containing radioactive carbon as $NaH^{14}CO_3$. The dark bottle provided a correction factor for non-photosynthetic $^{14}CO_2$ fixation and exchange of C-14 which would not indicate primary productivity. These bottles were incubated *in situ* at the depth of collection; thus, primary productivity was measured under the conditions of temperature and light intensity prevailing in the environment of sample collection.

After four to six hours of incubation, bottles were removed from the lake and placed in a dark chamber until the aliquots were filtered using a membrane filter with a 0.45 micron pore size. The membrane filter retained both the phytoplankton and consumer organisms in the water sample. After drying, the C-14 retained on the filter was measured using a Beckman liquid scintillation counter. From the data for C-14 assimilation in the dark and in the light bottles and the bicarbonate content of the water, primary production was calculated and expressed as milligrams of carbon fixed per cubic meter per hour. Primary productivity was also computed on an area basis by integrating the productivity values for each depth using a planimeter.

3. Biological Nitrogen Fixation Measurements: Nitrogen fixation was measured by the acetylene reduction method described by Burris. Algae concentrated from a known volume of reservoir water was added to serum bottles and following the insertion of rubber stoppers, acetylene was injected and the bottles were incubated in situ for 30-60 min. At this time the sample was inactivated by the injection of acid and transported to the laboratory.

The amount of ethylene formed was determined by injecting samples of the gas from the serum bottle into a gas chromatography instrument fitted with a 9 ft x 1/8 inch diameter column containing Porapak R at 40 C with helium gas as a carrier.

4. Water Chemistry and Limnological Conditions: Water chemistry and selected limnological measurements were made in conjunction with all sample collections. Alkalinity, pH, and total inorganic carbon measurements were made using a glass electrode pH meter and titration with dilute H_2SO_4 (Golterman). Transparency was determined using a Secchi disk. The predominant forms of dissolved nitrogen (ammonium, nitrite, and nitrate) and the total nitrogen, were determined in initial samplings. The forms

present in significant concentrations were measured throughout the year. Nitrate*, ammonium, and orthophosphate were determined on membrane filtered water (0.45 microns) using a Technicon Autoanalyzer. Total nitrogen was determined on unfiltered water samples as ammonium using the Autoanalyzer following Kjeldahl digestion to convert nitrogen to ammonium. Unfiltered water samples for nitrogen and phosphorus analyses were preserved in the field by addition of H_2SO_4 as recommended by the EPA. Total phosphorus was determined on both membrane filtered and unfiltered water samples by the molybdenum blue procedure (APHA, 1971). Samples for chlorophyll analysis (usually a volume of 1 liter) were filtered through a glass fiber filter and the collected algae extracted with acetone. Chlorophyll and phaeophytin were measured spectrophotometrically (Golterman). Dissolved oxygen and water temperatures were determined _in situ_ at 1 meter intervals using a Yellow Springs Instrument Company dissolved oxygen meter.

Because the waters entering the Abiquiu and Cochiti Reservoirs drain from regions having complex geological formations, water was analyzed to determine the level of various inorganic ions in membrane filtered water. Sodium, potassium, calcium, magnesium, iron, manganese, copper, and zinc were measured by atomic absorption spectrophotometry. The anions chloride and sulfate were measured using a Technicon Autoanalyzer.

5. _Animal Toxicity Tests_: Following the procedure established by Sawyer et al., the presence of a toxin produced by _Aphanizomenon flos-aquae_ was assayed using white mice. Frozen algal cells concentrated from reservoir water were mascerated and

*includes nitrite.

mixed with distilled water for 4 hr at 5 C. This cell-free extract was injected intraperitoneally into several mice at various dose levels. Extracts from axenically grown Chlorella were used as controls. Since the toxin is fatal to mice, 100% mortality was used rather than LD_{50}.

6. Microbiological Studies: The Millipore membrane filter technique was used to determine the number of aerobic planktonic bacteria, fecal coliforms, and fecal streptococci using M-TGE broth, M-Coliform broth, and M-Enterococcus agar, respectively. The relative abundance of the bacteria was compared to the diversity of algal species and number of algae present.

Results and Discussion

Cochiti Reservoir

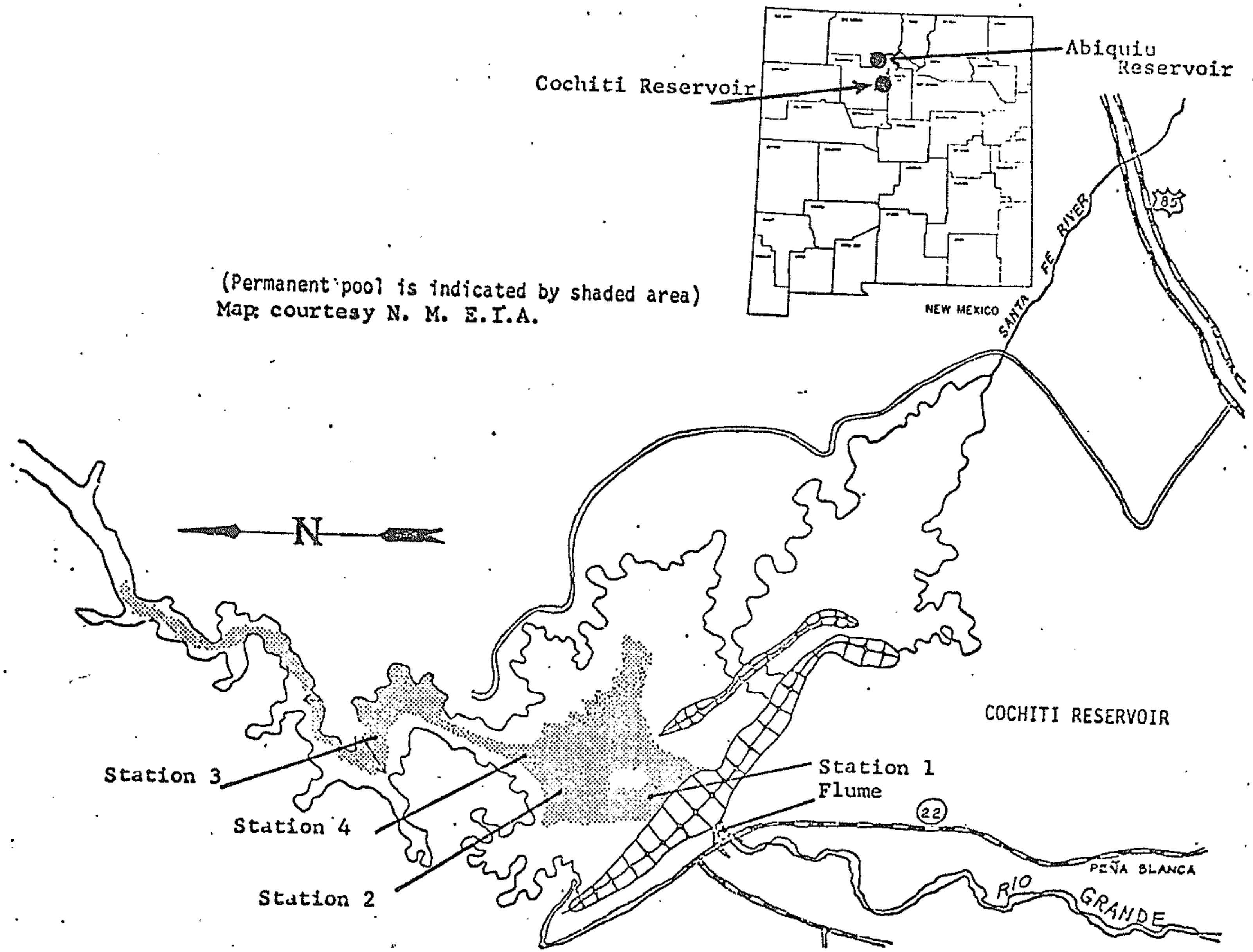
1. Location and Description

Cochiti Reservoir is located at an elevation of 5300 feet on the Rio Grande between Albuquerque and Santa Fe in Sandoval County, New Mexico (see Figure 1). The Santa Fe River also drains into Cochiti Reservoir near the dam; however, the Santa Fe River bed is usually dry throughout the year. Cochiti Dam, a large earth-fill dam, was completed and storage of a permanent pool of water began in 1975. The volume of water stored in Cochiti Reservoir varied from 47,052 to 49,190 acre-feet during this study.

Cochiti Lake, a small recreation and retirement oriented residental community, is being developed near the Reservoir. Well developed picnic and campsite facilities as well as a boat launching ramp and boat storage facilities are available. As the closest major body of water to Albuquerque and Santa Fe, Cochiti Reservoir is receiving increasingly heavy use for fishing, boating, and shoreline recreation.

2. Sampling Sites

The locations of the sampling stations for this investigation are shown in Figure 1. Station 1 was near the dam and outlet of the Reservoir. This is the deepest part of the Reservoir and was estimated to be 22 meters deep. Station 2 was located about 300 meters off the boat launching ramp. Station 4 was at the north end of the main body of the Reservoir



(Permanent pool is indicated by shaded area)
Map: courtesy N. M. E.I.A.

Figure 1. Cochiti Reservoir showing station location.

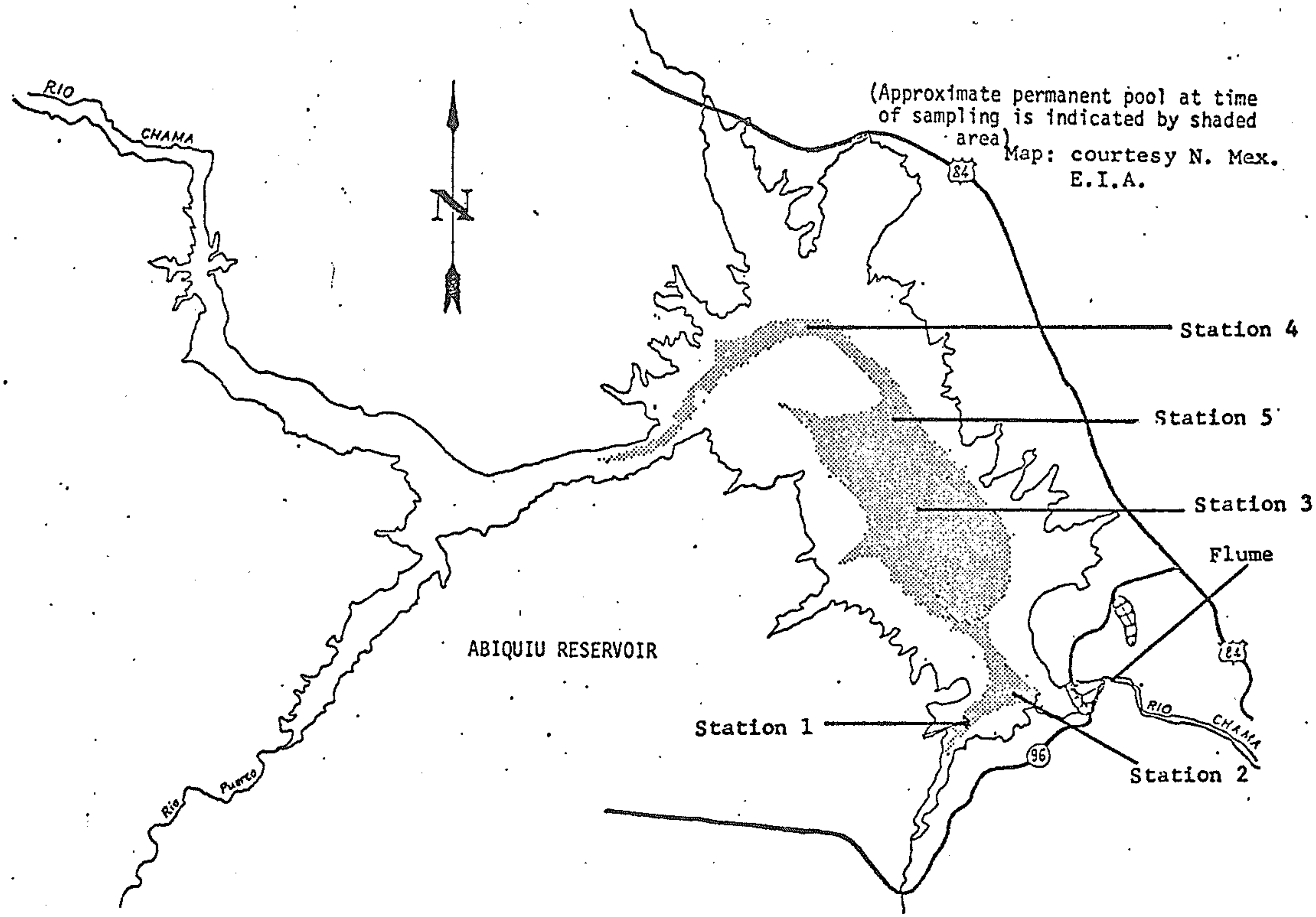


Figure 2. Abiquiu Reservoir showing station location.

near the proposed Tetilla Peak Recreation Area. Station 3 was located farther up the canyon, about 500 meters south of the confluence of Bland Canyon and the Rio Grande. Primary productivity measurements were made on the main body of the Reservoir (Stations 1, 2, and 4) and other chemical, physical, and microbiological measurements were made at all four stations. Samples for analysis were collected just below the surface (0.5m) and at 5 meters except that phytoplankton counts and chlorophyll measurements were made on samples from the surface and 2 meter depths. Samples were also taken from near the bottom of the Reservoir at Station 1 at a depth of 20 meters and from the Rio Grande about 200 meters below the dam ("Flume").

3. Water Temperature and Transparency

Surface water temperature usually ranged from 20-24.5 C during the months of June through early September although surface temperatures as high as 26 C were occasionally measured (Table 1). No significant thermal stratification was detected and temperatures at 15 m generally were no more than 3-4 C below surface water temperatures. The reservoir was covered with ice in January and February, 1977.

Secchi disc transparencies (Table 2) decreased from mid-July, 1976 through mid-August to values as low as 60 cm due to the occurrence of an extensive bloom of *Aphanizomenon*. By early September transparencies had increased at Stations 1, 2, and 4 as the bloom declined. At Station 3, located up

Table 1. Water temperature at Cochiti Reservoir in degrees Centigrade.

	Station 1				Station 2				Station 3				Station 4			
Date	Surface	5 m	10 m	15 m	Surface	5 m	10 m	15 m	Surface	5 m	10 m	12 m	Surface	5 m	10 m	15 m
7/14/76	23.5	22	21	19.5	24	22	21	20	24.5	22	21	20.5	-	-	-	-
7/29/76	26	22	21	20	25.5	22	21	20	23	21.5	21	20	-	-	-	-
8/11/76	22.5	21	21	20	22.5	21	21	20	23	21	20	19	22	21	21	20
9/7/76	19.5	19.5	19	18.5	20	20	19*	-	21.5	19	18.5	18	20	19	19	-
10/8/76	16	15.5	15.5	15.5	16	16	16	15.5	-	-	-	-	-	-	-	-
1/29/77**	0	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-
3/19/77	6	4	5	5	6	5	5	5	7	6	5	5	-	-	-	-
5/18/77	15.5	15	14.5	13.5	16	16	14	13.5	17	16	15	14	-	-	-	-
6/8/77	20	19	17	14.5	20	19	17	14.5	21	19.5	17	16.5	20	18.5	17	14.5
7/1/77	21	19	18	16.5	21	19.5	18.5	16.5	21	19.5	19.5	17.5	-	-	-	-
7/21/77	23	22.5	21	19	23.5	23	22+	-	24	21	20	19.5	-	-	-	-
8/12/77	21	21	21	20.5++	-	-	-	-	22.5	22	20	19.5	-	-	-	-
9/1/77	22	21	20.5	19.5	-	-	-	-	22.5	22	20	19.5	22	21	20.5	20

* Temperature at 9 m, bottom at 9.5 m.
** Ice cover, 28 cm thick at Station 1, 20 cm at Station 2.
\+ Temperature at 7 m, bottom at 8 m.
++ Temperature at 14 m, bottom at 15 m.

TABLE 2. Secchi disc transparency in centimeters

Cochiti Reservoir

Date	Station 1	Station 2	Station 3	Station 4
07/14/76	133	133	130	--
07/29/76	88	75	60	75
08/11/76	60	85	60	107
09/07/76	200	140	50	100
10/08/76	126	150	--	146
12/03/76	166	--	--	--
01/29/77	*	*	*	*
03/19/77	175	140	115	--
05/18/77	255	212	212	226
06/08/77	422	340	80	160
07/01/77	200	192	71	172
07/21/77	140	158	56	102
08/12/77	325	275	144	275
09/01/77	262	230	148	230

* Ice Cover

Abiquiu Reservoir

Date	Station 1	Station 2	Station 3	Station 4	Station 5
07/07/76	322	475	445	385	--
07/22/76	--	--	--	175	195
08/04/76	150	260	173	160	160
08/18/76	--	189	220	123	142
09/17/76	--	105	133	95	100
11/05/76	166	153	175	182	162
12/20/76	--	133	200	--	135
02/12/77	*	*	*	*	*
04/09/77	--	200	220	215	180
05/26/77	220	315	200	--	185
06/15/77	--	290	280	220	191
07/13/77	--	322	325	245	300
08/03/77	--	355	352	342	300
09/13/77	213	350	415	392	400

* Ice Cover

the river channel from the main body of the Reservoir, transparency remained low, influenced in part by continuation of bloom conditions in this area (see Chlorophyll a concentration in Table 14). Transparencies were considerably greater at Stations 1, 2, and 4 in the summer of 1977 than 1976 due to the decreased algal bloom. Even though the extent of the algal bloom was similarly reduced at Station 3 in the summer of 1977, transparencies were as low as 56 cm, probably due to a greater sediment load nearer the inlet than in the main body of the reservoir.

4. Chemical Characteristics

Results of analyses of Cochiti water for cations and anions are given in Table 3. Concentrations of Ca, Mg, Na, K, and Cl were somewhat higher in May, 1977 than in October, 1976, probably a result of the unusually dry winter and limited runoff in the spring of 1977; however, typical seasonal variation in the concentrations of these ions has not yet been characterized. The iron concentration in filtered surface water ranged from 7 to 30 μg/liter, low values compared to average values for many lakes given by Wetzel (1975). Manganese and copper were also much lower in most surface samples than average surface water values given by Wetzel.

pH values for surface and 5 m samples of Cochiti Reservoir water ranged from 7.0 to 7.6 during the fall and winter, and increased to 8.0 or higher during the spring and summer months (Table 4). pH values as high as 9.0 were measured during the

Table 3. Cation and anion concentrations in Cochiti Reservoir water samples in mg/ liter. Samples were filtered through 0.45μ membrane filters.

Date	Station	Depth	Ca	Mg	Na	K	Cl	SO_4	Fe	Mn	Cu	Zn
10/8/76	1	Surface	37.6	5.5	15.3	2.59	4.9	58.3	.01	nd*	nd	.010
		5 m	37.6	5.5	15.2	2.47	3.9	56.4	nd	nd	nd	.001
	2	Surface	37.7	5.5	15.3	2.50	3.8	57.7	.03	.02	nd	.011
		5 m	38.1	5.6	15.7	2.49	4.0	58.0	nd	nd	nd	.002
	Flume		37.7	5.5	16.7	2.56	4.5	60.2	0.06	0.02	nd	0.012
5/18/77**	1	Surface	41.1	7,6	23.6	3.00	7.2	-	0.010	0.0005	.0007	0
		5 m	41.0	7.5	23.4	3.00	13.8	-	-	-	-	-
		20 m	39.0	7.0	23.3	3.09	10.2	-	.003	.0185	.0012	0
	2	Surface	42.3	7.7	22.8	2.91	7.4	-	0	.0004	.0022	.015
		5 m	42.4	7.7	23.2	3.00	7.6	-	-	-	-	-
	3	Surface	43.7	7.8	21.6	2.77	7.4	-	.007	.0011	.0007	.002
		5 m	44.1	7.9	21.9	2.85	5.6	-	-	-	-	-
	Flume		41.5	7.6	23.8	3.06	7.4	-	-	-	-	-

* Below detectible limit of standard atomic absorption analysis (Fe, Mn, and Cu < 0.01)

** Fe, Mn, Cu, and Zn measured using carbon rod combustion.

Table 4. pH values at Cochiti Reservoir

Date	Station 1			Station 2		Station 3		Station 4		Flume
	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/14/76	7.8	8.1		8.1	7.8	7.9	7.6			7.5
7/29/76	8.6	8.8	7.6	8.9	8.7	8.7	8.3	8.9	8.5	
8/11/76	9.0	8.8		8.5	8.3	8.7	8.9	8.7	8.5	8.3
9/07/76	8.7	8.6		8.3	8.5	8.5	8.5	8.4	8.3	7.8
10/8/76	6.4	7.0		7.7	7.1			6.6	7.2	
12/03/76	7.5	7.5	7.6	7.6	7.6	7.5	7.3	7.6	7.0	
1/29/77	7.1	7.0		7.5	7.0			7.5	7.6	7.8
3/19/77	7.2	6.9		7.2	7.2	7.2	7.2			7.3
5/18/77	8.1	7.9	7.8	8.1	7.9	8.2	7.9	8.1	8.0	
6/08/77	8.3	8.2	8.0	8.2	8.0	8.2	7.9	7.3	8.0	
7/01/77	8.2	8.3	7.8	8.3	8.2	8.2	8.2	8.1	8.2	
7/21/77	8.7	8.4	7.7	8.5	8.3	8.1	7.9	8.3	8.1	
8/12/77	8.0	8.2	7.4	8.3	8.3	8.3	8.3	8.2	8.2	
9/01/77	8.2	8.2	7.5	8.3	8.3	8.2	8.0	8.3	7.9	

extensive algal bloom in the summer of 1976. The higher pH values in the spring and summer months correspond to increased phytoplankton photosynthetic use of CO_2.

Total alkalinity (Table 5) was somewhat lower in 1976 than in 1977 reflecting decreased phytoplankton photosynthesis in the summer of 1977. Phenolphtalein alkalinity (Table 6) was measureable only on three sampling dates in 1976 and one in 1977.

Dissolved oxygen in Cochiti Reservoir water (Table 7) was usually near saturation at the surface and on July 29, 1976 greatly exceeded saturation in surface water at Stations 1 and 2 during the intense algal bloom. Significant depletion of oxygen occasionally was detected at 5 m and 10 m depths, e.g. Station 1 in September, 1976 and March, 1977. These dissolved oxygen values were low enough to have adverse effects on such game fish as trout. Oxygen depletion was usually quite significant at a depth of 15 m at Station 1 although this depth was estimated to be 2-7 meters above the bottom of the Reservoir.

The concentrations of total phosphorus in unfiltered water, total phosphorus in membrane filtered water, and orthophosphate phosphorus in membrane filtered water are presented in Tables 8, 9, and 10 and depicted for surface samples from Station 1 in Figure 3. The total phosphorus concentration was higher in the surface and 5 m samples from the main body of the Reservoir in 1976 and the winter of 1977 (generally above 0.040 mg P/liter) than in May through September, 1977 (with

Table 5. Total Alkalinity as mg $CaCO_3$/liter

Cochiti Reservoir

Date	Station 1 Surf	Station 1 5 M	Station 1 20 M	Station 2 Surf	Station 2 5 M	Station 3 Surf	Station 3 5 M	Station 4 Surf	Station 4 5 M
07/14/76	70.0	75.0	-	72.6	71.0	70.6	69.0	-	-
07/29/76	75.0	77.0	56.0	78.0	75.0	76.0	64.0	80.0	67.0
08/11/76	81.0	75.0	-	78.0	72.0	80.0	80.0	78.0	76.0
09/07/76	89.4	87.0	-	78.0	84.8	85.0	84.4	83.6	77.6
10/08/76	80.0	84.0	-	87.0	85.0	-	-	78.0	82.0
12/03/76	67.0	69.0	71.6	72.6	72.2	68.0	66.2	73.0	65.6
01/29/77	82.0	81.0	-	85.0	80.0	-	-	84.0	84.4
03/19/77	87.0	84.0	-	86.0	83.6	86.2	88.0	-	-
05/18/77	96.0	92.0	94.0	92.0	90.0	91.0	88.0	90.0	89.0
06/08/77	122.9	125.4	116.8	117.0	110.0	104.6	92.1	101.4	109.6
07/01/77	92.0	91.8	93.0	94.5	94.3	90.1	91.8	93.7	94.3
07/21/77	97.7	97.4	95.1	95.8	96.2	93.7	93.0	96.8	92.8
08/12/77	95.55	96.0	95.0	95.3	97.4	102.1	99.1	96.6	97.9
09/01/77	96.0	95.3	102.7	94.9	96.6	103.7	105.4	98.7	99.8

Abiquiu Reservoir

Date	Station 1 Surf	Station 1 5 M	Station 2 Surf	Station 2 5 M	Station 2 20 M	Station 3 Surf	Station 3 5 M	Station 4 Surf	Station 4 5 M	Station 5 Surf	Station 5 5 M
07/07/76	53.0	57.0	57.0	54.0	-	55.0	57.0	56.0	-	-	-
07/22/76	-	-	68.0	66.0	-	67.0	67.0	67.0	-	66.0	66.0
08/04/76	82.0	-	77.0	76.0	76.0	77.0	74.0	80.0	73.0	74.0	72.0
08/18/76	-	-	64.0	66.0	62.0	65.0	62.0	65.0	62.0	64.0	61.0
09/17/76	-	-	65.0	60.0	-	66.0	66.0	-	65.0	66.0	65.0
11/05/76	60.0	64.0	68.0	70.0	68.0	69.0	69.0	66.0	70.0	66.0	70.0
12/20/76	-	-	60.0	64.0	-	70.0	66.0	-	-	68.0	70.0
02/12/77	-	-	77.0	78.0	-	82.0	75.0	-	-	79.0	76.0
04/09/77	-	-	83.4	83.4	-	84.6	84.6	84.0	84.0	85.2	87.0
05/26/77	77.7	76.65	77.3	77.7	76.7	76.0	75.6	76.2	76.7	70.5	78.1
06/16/77	-	-	87.2	85.9	77.5	88.0	83.0	87.1	85.3	88.8	81.7
07/13/77	-	-	84.4	83.2	72.45	81.5	81.1	82.7	82.5	83.0	80.2
08/03/77	-	-	85.5	82.5	78.1	82.95	81.7	83.6	77.5	83.8	79.4
09/13/77	89.25	90.93	89.25	86.73	88.62	83.16	80.43	83.58	81.9	85.68	84.0

Table 6. Phenolphtalein alkalinity as mg $CaCO_3$/liter

Cochiti Reservoir

Date	Station 1 Surf	Station 1 5 M	Station 1 20 M	Station 2 Surf	Station 2 5 M	Station 3 Surf	Station 3 5 M	Station 4 Surf	Station 4 5 M
07/14/76	0	0	0	0	0	0	0	0	0
07/29/76	9.0	10.0	-	10.0	9.0	9.0	-	11.0	2.0
08/11/76	10.0	8.0	-	6.0	-	6.0	8.0	6.0	3.0
09/17/76	6.4	6.0	-	-	5.8	6.0	6.0	5.6	-
10/08/76	0	0	0	0	0	0	0	0	0
12/03/76	0	0	0	0	0	0	0	0	0
01/29/77	0	0	0	0	0	0	0	0	0
03/19/77	0	0	0	0	0	0	0	0	0
05/18/77	0	0	0	0	0	0	0	0	0
06/08/77	0	0	0	0	0	0	0	0	0
07/21/77	5.25	1.89	0	2.52	0.84	0	0	0	0
08/12/77	0	0	0	0	0	0	0	0	0
09/01/77	0	0	0	0	0	0	0	0	0

Abiquiu Reservoir*

Date	Station 1 Surf	Station 1 5 M	Station 1 20 M	Station 2 Surf	Station 2 5 M	Station 3 Surf	Station 3 5 M	Station 4 Surf	Station 4 5 M
08/03/77	5.46	0	0	4.62	0	4.62	0	5.25	0

*Phenolphtalein alkalinity was 0 at all stations on all other dates for Abiquiu Reservoir.

Table 7. Dissolved oxygen at Cochiti Reservoir in mg O_2/ liter

Date	Station 1				Station 2				Station 3				Station 4			
	Surface	5 m	10 m	15 m	Surface	5 m	10 m	15 m	Surface	5 m	10 m	12 m	Sufrace	5 m	10 m	15 m
7/14/76	7.8	6.1	5.8	3.9	7.5	6.1	5.3	3.7	6.6	5.6	5.1	5.0	-	-	-	-
7/29/76	14.3	9.8	4.0	2.9	14.1	8.2	5.5	4.6	9.6	6.1	5.8	4.9	-	-	-	-
8/11/76	7.0	5.2	4.7	1.5	7.5	6.2	6.3	1.8	7.0	2.6	2.2	2.7	7.4	6.0	5.8	1.6
9/7/76	6.2	1.5	1.1	1.0	6.6	3.7	2.0*	-	8.4	6.7	3.5	3.0	9.7	5.9	5.0	-
10/8/76	7.5	6.9	6.8	6.5	7.6	7.3	7.0	6.8	-	-	-	-	-	-	-	-
3/19/77	9.0	2.7	2.2	2.0	10.2	2.9	2.5	2.4	9.5	3.8	3.0	2.9	-	-	-	-
5/18/77	8.4	8.1	8.0	6.4	8.0	7.9	7.3	6.1	8.1	7.8	7.0	0.5**	-	-	-	-
6/8/77	7.7	7.7	6.3	5.2	7.4	7.3	5.6	4.6	8.2	7.0	6.5	6.5	7.7	6.8	6.1	4.1
7/1/77	7.2	7.9	6.3	4.9	7.7	6.9	6.1	4.3	7.2	6.8	6.7	3.2	-	-	-	-
7/21/77	7.0	7.1	5.0	2.4	7.8	7.6	6.6+	-	6.6	5.1	3.8	1.8	-	-	-	-
8/12/77	7.5	6.9	4.5	2.6++	7.1	6.9	3.8	2.5	7.6	7.3	7.2	6.7	-	-	-	-
9/1/77	7.4	7.0	2.7	1.0					6.4	5.7	5.8	0.2***	7.4	6.9	2.6	1.7

* Oxygen concentration at 9 m, bottom at 9.5 m
** Near bottom, 6.5 mg/ liter at 11 m
*** Near bottom, 5.5 mg/ liter at 11 m.
\+ Oxygen at 7 m, bottom at 8 m.
\++ Oxygen at 14 m, bottom at 15 m.

Table 8. Total phosphorus concentration in unfiltered Cochiti Reservoir water as mg phosphorus/liter.

Date	Station 1 Surface	Station 1 5 m	Station 1 20 m	Station 2 Surface	Station 2 5 m	Station 3 Surface	Station 3 5 m	Station 4 Surface	Station 4 5 m	Flume
7/14/76	.052±.002* ab	.059±.004 ab	-	.052±.002 b	.058±.002 a	.075±.001 ab	.056±.002 ab	-	-	.070±.000 c
7/29/76	.042±.000 c	.039±.002 c	.108±.005 a	.059±.001 b	.056±.000 bc	.098±.002 a	.053±.004 bc	.049±.002 bc	.040±.002 c	.060±.002 b
8/11/76	.092±.003 a	.056±.001 b	-	.035±.002 b	.045±.002 b	.077±.004 a	.035±.002 b	.036±.003 b	.039±.000 b	.035±.002 b
9/7/76	.029±.000 d	.025±.001 d	-	.034±.004 cd	.047±.002 bd	.042±.005 a	.047±.018 a	.050±.007 bc	.053±.004 bd	.056±.011 b
10/8/76	.058±.004 ab	.060±.004 ab	.084±.000 a	.050±.012 b	.050±.007 b	-	-	-	-	.063±.014 ab
12/3/76	.055	.050	-	.060	.058	.047	.045	.042	.060	.063
1/29/77	.050	.043	-	.054	.049	.050	.061	.038	.044	.060
3/19/77	.053	.040	.075	.049	.047	.080	.077	.041	.050	.065
5/18/77	.023±.006 de	.021±.002 e	.137	.042±.000 ce	.049±.005 c	.045±.007 cd	.050±.002 c	.049±.002 c	.054±.004 b	.111±.007 a
6/8/77	.021±.002 d	.038±.007 bc	.048±.000 ab	.030±.001 cd	.034±.004 bd	.041±.002 bc	.057±.001 a	.039±.002 bc	.047±.001 ab	.060±.004 a
7/1/77	.018±.003 d	.026±.001 cd	.057±.000 a	.026±.004 cd	.024±.003 c	.044±.004 b	.046±.000 ab	.026±.003 cd	.029±.003 c	.051±.000 bc
7/21/77	.026±.002 e	.028±.001 e	.078±.002 b	.036±.001 de	.036±.001 de	.060±.004 c	.097±.003 a	.045±.002 cd	.052±.003 c	.074
8/12/77	.024±.001 f	.030±.001 de	.062±.001 a	.026±.000 ef	.036±.000 d	.044±.001 c	.036±.003 d	.025±.001 ef	.029±.002 ef	.051±.002 b
9/1/77	.012±.001 g	.010±.000 g	.066±.002 a	.014±.000 fg	.024±.002 e	.031±.002 d	.059±.001 b	.016±.000 fg	.019±.001 ef	.042±.002 c

* Standard error

Table 9. Total phosphorus concentration in filtered Cochiti Reservoir water as mg phosphorus/liter. Water samples were filtered through a 0.45µ membrane filter.

Date	Station 1			Station 2		Station 3		Station 4		
	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	Flume
7/14/76	0.031	0.025	-	0.035	0.025	0.021	0.023	-	-	0.021
7/29/76	0.014	.021	0.042	.025	.021	.021	.014	.014	.011	.014
8/11/76	.025	.017	-	.011	.014	.019	.015	.0.7	.016	-
9/7/76	.014	.013	-	.017	-	.036	.039	.017	,012	,017
10/8/76	.030	.017	-	.020	.018	.033	.022	.021	.017	.025
12/3/76	.028	.020	-	.022	.021	.031	.022	.019	.019	.026
1/29/77	.030	.022	-	.025	.018	.023	.021	.017	.017	.025
3/19/77	.027	.021	-	.025	.027	.021	.017	.019	.016	.020
5/18/77	-	-	-	-	-	-	-	-	-	-
6/8/77	.019	.020	.029	.021	.016	.018	.023	.021	.025	.037
7/1/77	.005	-	.016	-	.009	.003	.013	.007	-	.026
7/21/77	.012	.009	.060	.008	.007	.020	.014	.012	.017	.033
8/12/77	.014	.007	.041	.012	.009	.013	.015	.009	.010	.035
9/1/77	.005	.004	.046	.018	.002	.007	.019	.004	.009	.037

Table 10: Orthophosphate concentrations in Cochiti Reservoir water as mg phosphorus/ liter. Water samples were filtered through a 0.45μ membrane filter.

	Station 1			Station 2		Station 3		Station 4		Flume
Date	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/14/76	0.020	0.013	0.087	0.020	0.021	0.022	0.023	-	-	0.026
7/29/76	0.013	0.011	0.076	0.009	0.006	0.001	0.021	0.001	0.011	0.035
8/11/76	0	0	-	0	0	0	0.030	0.002	0.003	0.017
9/7/76	0.005	0.004	-	0	-	0.002	0.008	0.001	0.011	0.013
10/8/76	0.013	0.010	-	0.008	0.010	-	-	-	-	0.012
12/3/76	0.024	0.020	0.028	0.026	0.022	0.014	0.018	0.022	0.022	0.032
1/29/77	0.021	0.017	-	0.021	0.021	0.022	0.019	-	-	0.017
3/19/77	0.032	0.028	-	0.032	0.032	0.040	0.035	-	-	0.028
5/18/77	0	0.007	0.035	0	0	0	0	0	0	0.006
7/1/77	0.020	0.015	0.039	0.013	0.010	0.019	0.016	0.013	0.009	0.030
7/21/77	0.010	0.009	0.056	0.009	0.008	0.011	0.018	0.011	0.016	0.038
9/1/77	0.007	0.005	0.047	0.013	0.015	0.013	0.019	0.005	0.009	0.029

most samples ranging from 0.010 - 0.040 mg P/liter). The contribution of the soluble (filterable) total phosphorus to the total phosphorus in unfiltered samples was rather variable; however, the former appears to have decreased along with the unfiltered total phosphorus in the summer of 1977. The orthophosphate phosphorus ranged from zero to virtually all the filterable phosphorus. The high concentration of total phosphorus in unfiltered samples at the surface of Station 1 (see Figure 3) corresponds to a similar peak in total nitrogen and primary productivity and probably was mostly associated with phytoplankton cells.

When the total phosphorus in unfiltered water samples is compared at different stations it is apparent that values for Station 3, closer to the inlet, are somewhat higher than for the stations on the main body of the Reservoir. In addition, unfiltered samples from a depth of 20 m at Station 1 and the outlet (Flume) had higher concentrations of total phosphorus than the surface or 5 m samples from Stations 1, 2, and 4.

The total nitrogen concentrations and nitrate nitrogen concentrations are presented in Tables 11 and 12, and depicted for surface water from Station 1 in Figure 4. Total nitrogen in surface samples was extremely high during the Aphanizomenon bloom of the summer of 1976 (1.0-3.0 mg N/liter) and varied with indices of phytoplankton abundances measured as chlorophyll concentrations (Table 14), phytoplankton primary productivity (Table 15), and cell counts (Table 17). By early September the bloom of Aphanizomenon had decreased considerably

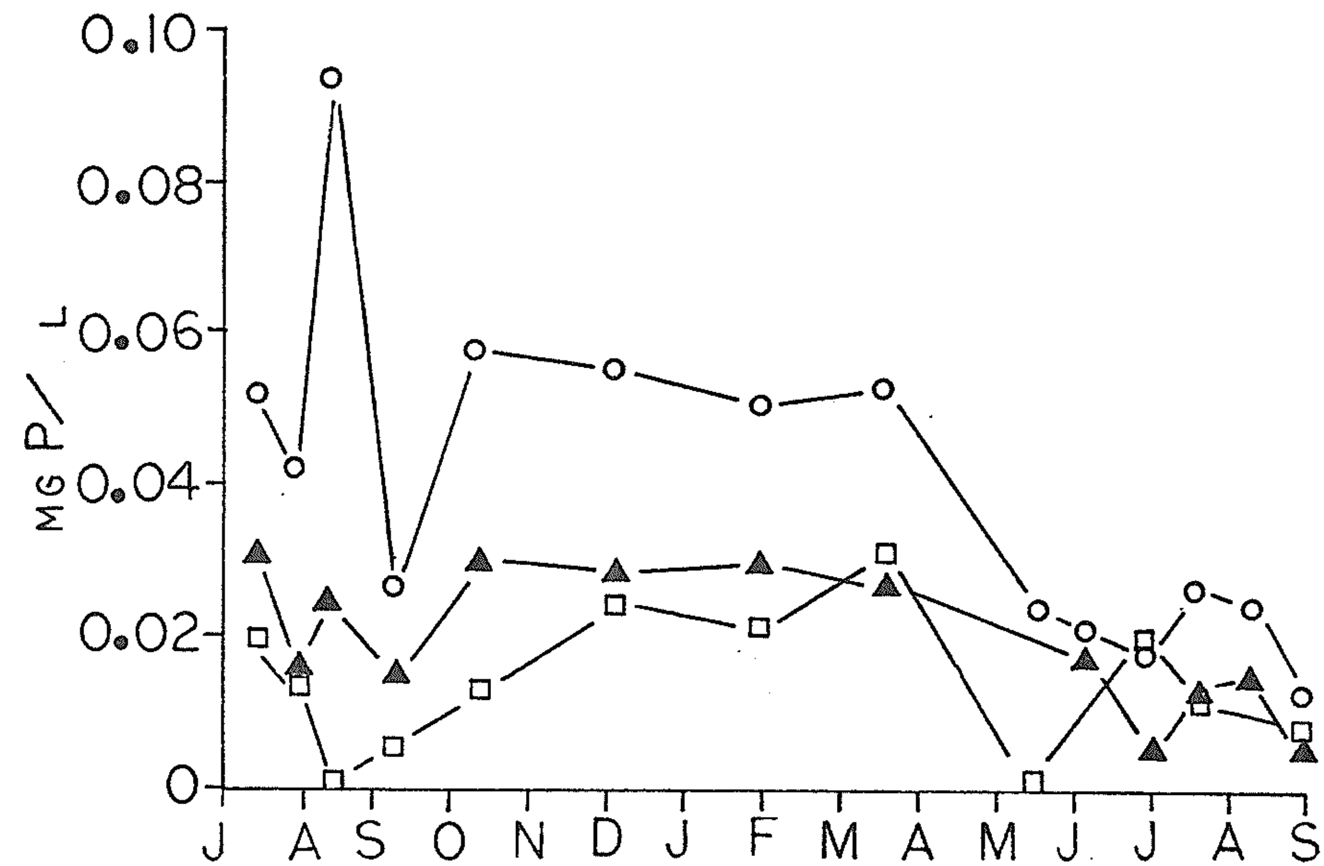


Figure 3. Phosphorus analysis of water from Cochiti Reservoir. Samples were filtered through 0.45µ membrane filters and analyzed for orthrophosphate (□—□) and total filtered phosphorus (▲–▲). Total phosphorus (O——O) was determined using unfiltered samples. Values are for the surface at station 1.

Table 11. Total nitrogen concentration in unfiltered Cochiti Reservoir water as mg nitrogen/ liter

	Station 1			Station 2		Station 3		Station 4		Flume
Date	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/14/76	.995±0.115* a**	.395±0.065 d	.485±0.015 cd	.765±.015 abc	.435±.135 d	.855±.125 ab	.600±.03 bcd	-	-	.600±.13 bcd
7/29/76	1.37	.910±.030 c	.440±.010 de	1.360±.050 b	.590±.030 d	1.37±.010 b	.465±.025 de	1.560±.110 a	.365±.075 e	.570±.030 d
8/11/76	2.120±.300 a	1.035±.075 cd	-	.845±.025 de	.750±.030 de	1.670±.090 ab	.410±.090 e	.935±.065 d	1.465±.325 bc	.810±.030 de
9/7/76	.820±.040 cd	.770±.040 cd	-	.875±.035 c	.735±.175 cd	2.965±.045 a	.660±.100 cd	1.175±.125 b	.545±.075 d	.760±.030 cd
10/8/76	.635±.035 ab	.585±.005 b	.690±.090 ab	.735±.005 a	.665±.015 ab	-	-	-	-	.580±.000 b
12/3/76	.725±.245 a	.490±.000 ab	.545±.005 ab	.445±.045 ab	.460±.030 ab	.385±.075 b	.405±.085 ab	.365±.025 b	.430±.010 ab	.500±.110 ab
1/29/77	.330±.035 b	.345±.060 bc	-	.640±.045 a	.205±.040 c	.285±.010 bc	.295±.010 bc	-	-	.250±.015 bc
3/19/77	.430±.020 abc	.475±.035 ab	-	.325±.005 cd	.325±.005 cd	.355±.005 cd	.300±.020 d	-	-	.480±.080 a
5/18/77	.700±.110 a	.590±.080 ab	.495±.005 bc	.450±.80 bc	.305±.025 c	.635±.065 ab	.330±.010 c	.650	.315±.035 c	.335±.015 c
6/8/77	.350±.020 abc	.340±.030 abc	.335±.035 bc	.290	.400±.030 abc	.385±.055 abc	.255±.055 c	.465±.055 ab	.410±.050 abc	.520±.080 a
7/1/77	.265±.055 b	.320±.000 ab	.190±.060 b	.305±.005 ab	.285±.005 ab	.260±.030 b	.230±.0. b	.445±.115 a	.315±.015 ab	.230±.050 b
7/21/77	.270±.020 a	.240±.050 a	.270±.120 a	.310±.030 a	.400±.140 a	.315±.125 a	.290±.100 a	.290±.030 a	.180±.020 a	.275±.095 a
8/12/77	.296±.005 a	.381±.050 a	.491±.140 a	.265±.005 a	.491±.221 a	.336±.025 a	.286±.005 a	.255±.005 a	.276±.005 a	.306±.005 a
9/1/77	.260±.020 b	.265±.045 b	.315±.035 ab	.320±.010 ab	.275±.025 b	.335±.015 ab	.330±.010 ab	.295±.005 ab	.285±.015 b	.370±.010 a

* Standard error

** Significant differences were determined by Duncan's new multiple range test. On each date values with differing letters are significantly different ($P = 0.05$).

Table 12. Nitrate nitrogen concentrations in Cochiti Reservoir water as mg nitrogen/ liter. Water samples were filtered through a 0.45μ membrane filter.

	Station 1			Station 2		Station 3		Station 4		Flume
Date	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/14/76	0.002	0.001	0.250	0.007	0.005	0.005	0	-	-	0.018
7/29/76	0	0	0.130	0	0.006	0.011	0.012	0	0.010	0.056
8/11/76	0	0	-	0	0.003	0.031	0.119	0	0.024	0.048
9/7/76	0	0	-	0	-	0	0.013	0	0.032	0.041
10/8/76	0.062	0.060	-	0.048	0.048	-	-	-	-	0.066
12/3/76	0.023	0.022	0.024	0.025	0.022	0.024	0.026	0.025	0.031	0.031
1/29/77	0.237	0.168	-	0.223	0.187	0.216	0.197	-	-	0.144
3/19/77	0.091	0.095	-	0.135	0.135	0.172	0.169	-	-	0.144
5/18/77	0.004	0.004	0.074	0.005	0.005	0.002	0.002	0.005	0.005	0.025
6/8/77	0	0.003	0.011	0.002	0	0.001	0.033	0.004	0.007	0.020
7/1/77	0.009	0.004	0.084	0.002	0.005	0.002	0	0	0	0.032
7/21/77	0.001	0.002	0.117	0.006	0.008	0.018	0.047	0.022	0.026	0.054
8/12/77	0.026	0.019	0.144	0.016	0.018	0.007	0.006	0.011	0.013	0.071
9/1/77	0	0	0.166	0	0.007	0	0.019	0	0.059	0.110

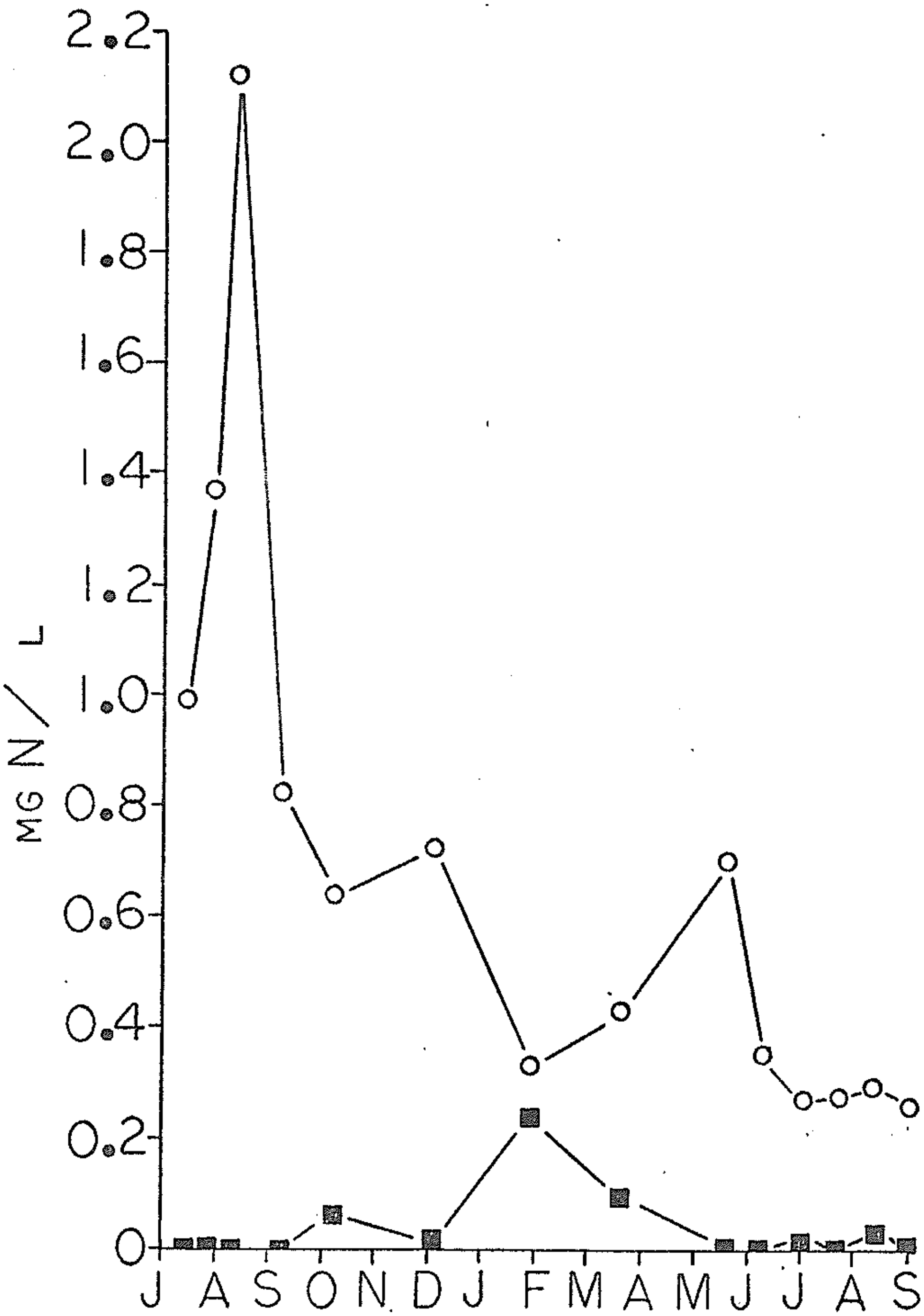


Figure 4. Nitrogen analysis of water from Cochiti Reservoir. Nitrate (■——■) measurements were made on water filtered through 0.45 µ membrane filters. Total nitrogen (O——O) was determined using unfiltered samples. Values are the surface at sample station 1.

at Stations 1, 2, and 4 and the total nitrogen concentration also decreased. At Station 3, bloom conditions continued (based on the chlorophyll concentration) and the highest total nitrogen concentration observed in this investigation (2.96 mg N/liter) was measured. During the fall and winter total nitrogen concentrations decreased; however, they increased in March and May, 1977. The highest surface values measured in 1977 were in May (0.45-0.7 mg N/liter) and this was followed by a decrease to a stable level of 0.2-0.45 mg N/liter during the summer. The lower concentrations of total nitrogen in the summer of 1977 are associated with the greatly reduced population of phytoplankton compared to the summer of 1976 (c.f. chlorophyll concentrations, primary productivity, and phytoplankton cell counts). The highest total nitrogen concentrations in 1977 occurred on May 18, when phytoplankton abundance and productivity was quite low and blue-green algae were not detected in preserved algal samples. Thus the relatively high concentration of total nitrogen on this date cannot be attributed to nitrogen fixation by blue-green algae.

During the summer of 1976 due to the decreasing biomass of phytoplankton at greater depths significantly higher total nitrogen concentrations were observed in surface samples than in 5 m samples. After the conclusion of this bloom total nitrogen concentrations in surface and 5 m depth samples were essentially the same even during the smaller algal bloom in the summer of 1977. The total nitrogen concentration of water released from the reservoir (Flume sample) was usually not significantly different from the 5 m or 20 m samples obtained from Station 1 which is near the dam. The total nitrogen concentration released from the reservoir gradually decreased from the summer of 1976 through the summer of 1977.

Nitrate nitrogen concentrations were very low in surface and 5 m samples until January, 1977 when a large increase in the nitrate concentration occurred at all stations and at the outlet. Nitrate concentrations decreased in March and then decreased again to negligible levels in May and subsequent months. Rapid biological utilization of inorganic nitrogen probably is responsible for maintaining the nitrate concentration at a barely detectible level except during the coolest months.

The ammonium concentration in membrane filtered water from surface and 5 m depths was usually <0.1 mg nitrogen/liter and often was negated by variable blank values on membrane filtered redistilled water (Table 13). Ammonium nitrogen concentrations, however, usually exceeded nitrate nitrogen concentrations in the euphotic zone during the seasons of most active phytoplankton growth when nitrate concentrations approached zero. Ammonium concentrations were occasionally as high as 0.2-0.3 mg N/liter at Station 1 at a depth of 20 m and in the sample from the outlet (Flume).

The ratio of total nitrogen: total phosphorus in unfiltered samples was computed and is tabulated in Table 13a.

Table 13. Ammonium nitrogen concentration in Cochiti Reservoir water as mg nitrogen/liter. Water samples were filtered through a 0.45 μ membrane filter.

	Station 1			Station 2		Station 3		Station 4		Flume
Date	Surface	5 m	≥20 m	Surface	5 m	Surface	5 m	Surface	5 m	Flume
7/29/76	.05	0	.03	0	.04	.01	.02	0	0	.02
8/11/76*	0	0	–	.01	0	0	0	.01	0	0
9/7/76*	0	0	–	0	–	.10	0	0	0	0
10/8/76*	0	0	–	0	0	–	–	–	–	.26
12/3/76	.02	.03	.07	.20	.02	.01	.07	.08	.05	.08
1/29/77	.05	.06	–	.07	.04	.12	.08	–	–	.05
3/19/77	0	0	–	.02	0	0	0	–	–	.01
5/18/77	.01	.09	.28	.08	.01	0	.07	.01	.07	.09
6/8/77	.04	.03	.03	.03	.04	.04	.03	.05	.04	.05
7/1/77	.07	.08	.01	.20	.01	.05	0	.02	0	.03
7/21/77	.03	.05	.03	.04	.05	.03	.05	.03	.05	.04
8/12/77	0	.15	.22	.02	.01	.02	.05	.04	.04	.04
9/1/77	.02	.01	.02	0	.02	0	0	0	.03	.02

* Most values were negated due to high blank concentrations of ammonium.

Table 13a. Total nitrogen:total phosphorus ratio computed for unfiltered Cochiti Reservoir water

	Station 1			Station 2		Station 3		Station 4		
Date	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	Flume
7/14/76	19.1	6.7	-	14.7	7.5	11.4	10.7	-	-	8.6
7/29/76	32.6	23.3	4.1	23.1	10.5	13.9	8.8	31.8	9.1	9.5
8/11/76	23.0	18.5	-	24.1	16.7	21.7	11.7	25.9	37.6	23.1
9/7/76	28.3	30.8	-	25.7	15.6	70.6	14.0	23.5	10.3	13.6
10/8/76	10.9	9.75	8.2	14.7	13.3	-	-	-	-	9.2
12/3/76	13.2	9.8	-	7.4	7.9	8.2	9	8.7	7.2	7.9
1/29/77	6.6	8.0	-	11.9	4.2	5.7	4.8	-	-	4.2
3/19/77	8.1	11.9	-	6.6	6.9	4.4	3.9	-	-	7.4
5/18/77	30.4	28.1	3.6	10.7	6.2	14.1	6.6	13.3	5.8	3.0
6/8/77	16.7	8.9	6.9	9.6	11.8	9.4	4.5	11.9	8.7	8.7
7/1/77	14.7	12.3	3.3	11.7	11.9	5.9	6.0	17.1	10.9	4.5
7/21/77	10.4	8.6	3.5	8.6	11.1	5.25	2.9	6.4	3.5	3.7
8/12/77	12.3	12.7	7.9	10.2	13.6	7.6	7.9	10.2	9.5	6.0
9/1/77	21.7	26.5	4.8	22.9	11.5	10.8	5.6	18.4	15	8.8

The N:P ratios were highest in surface samples on the main body of the Reservoir (Stations 1, 2, and 4) in the summer of 1976. After the decline of the 1976 summer bloom, N:P ratios were generally much lower. This indicates a decreased supply of nitrogen relative to phosphorus and occurred as the population of blue-green algae decreased. Bachmann and Jones cite a ratio of about 7:1 given by Vallentyne as the typical N:P ratio of aquatic plant materials. Thus considering nitrogen and phosphorus as potentially limiting nutrients, a ratio >7 would imply adequate nitrogen relative to phosphorus. In Table 13a the highest ratios are associated with surface samples and abundant blue-green algae. Low ratios, indicative of nitrogen limitations, commonly occurred at a depth of 20 m at Station 1 and at Station 3, after the conclusion of the summer bloom in 1976. Higher nitrogen concentrations relative to phosphorus clearly occur with the greatest populations of phytoplankton, suggesting that nitrogen fixation by the blue-green algae, when abundant, may contribute significantly to the nitrogen budget of Cochiti Reservoir.

5. Phytoplankton and Microbiological Studies

Chlorophyll a concentrations in surface samples and at a depth of 2 m are tabulated in Table 14. The difference in the magnitude of algal blooms in the two summers is clearly indicated by the ranges in chlorophyll a concentrations. In July to September, 1976 the average chlorophyll a concentration was 42.0 mg/m^3 with a range of 22.1-118.4 mg/m^3. During the

Table 14. Chlorophyll a concentrations in Cochiti Reservoir water as mg/ m^3

Date	Station 1		Station 2		Station 3		Station 4	
	Surface	2 m	Surface	2 m	Surface	2 m	Surface	2 m
7/29/76	38.8	36.1	46.4	34.7	40.4	26.2	50.8	41.0
8/11/76	52.1	72.9	72.0	24.8	22.7	31.6	34.6	37.6
9/7/76	30.0	40.4	36.6	35.8	118.4	54.6	28.6	22.1
10/8/76	0	0	0	0	0	0	0	0
3/19/77	-	-	20.22	-	6.4	-	-	-
5/18/77	0	0	0	0	0	0	0	0
6/8/77	0	0	0	0	0	0	0	0
7/1/77	1.1 (0.4)*	3.9±1.6** b	4.4±1.4 ab	4.9±0.1 ab	6.2±0.9 ab	7.2±1.0 ab	7.6±0.2 a	4.9±0.7 ab
7/21/77	11.7±1.9 a	10.5±0.1 ab	1.9±0.1 c	6.2±0.6 bc	4.4±1.5 c	2.4±2.3 c	2.9	0
8/12/77	4.6±1.5 c	4.2±0.2 c	3.9±1.1 c	3.6±0.3 c	8.5±0.5 ab	9.8±0.1 a	7.4±0.5 b	4.6±0.1 c
9/1/77	8.2±1.8 ab	3.3±0.2 c	3.9±0.5 c	2.4±1.3 (0.8) c	2.2 (1.2)	9.1±0.4 a	4.2±1.3 (0.4) c	5.3±1.0 bc

* Phaeophytin concentration in mg/ m^3. Phaeophytin was dectectible only in indicated samples.

** Standard error

*** Significant differences were determined by Duncan's new multiple range test. On each date values with differing letters are significantly different (P=0.05).

Table 15. Primary productivity of Cochiti Reservoir in mg carbon/ m^3/hr.

Date	Station 1 Surface	Station 1 1 m	Station 1 2 m	Station 1 3 m	Station 2 Surface	Station 2 1 m	Station 2 2 m	Station 2 3 m	Station 4 Surface	Station 4 1 m	Station 4 2 m	Station 4 3 m
7/29/76	76.96±4.93*	62.40±0.31	13.62±7.17	4.34±0.31	143.87±12.94	47.37±3.02	11.48±0.49	4.98±1.79	194.49±0.70	50.25±7.01	14.66±1.72	2.32±0.69
8/11/76	245.56±0.25	46.47±12.89	12.42±1.12	2.34±2.15	212.06±23.87	104.41±0.33	14.94±0.24	3.04±0.63	127.57±33.73	102.33±1.12	21.65±2.26	5.90±0.28
9/7/76	60.69±6.13	50.07±8.40	15.63±2.91	5.82±0.30	65.94±4.88	57.36±2.48	22.95±3.66	6.10±0.05	89.79±36.74	92.97±18.50	18.04±2.04	-
10/8/76	13.87±1.21	18.39±2.78	10.35±0.25	4.41±0.23	27.21±5.31	22.40±3.59	14.65±1.68	7.95±3.30	20.60±0.70	25.79±2.62	12.55±0.34	2.87±1.19
12/3/76	0.17±0.05	1.05±0.32	0.79±0.09	0.90±0.16	0.14±0.07	0.38±0.08	0.89±0.02	1.34±0.07	1.60±0.13	1.65±0.37	1.59±0.29	2.32±0.59
3/19/77	6.64±1.45	26.50±4.15	39.29±1.71	24.45±0.73	8.76±3.05	23.31±0.81	23.96±3.47	18.82±0.31	14.77±6.79	15.51±0.61	18.06±2.74	16.79±11.79
5/18/77	9.10±0.30	3.96±1.99	9.57±0.68	7.44±1.41	-	-	-	-	13.05±0.30	10.46±4.34	8.17±0.01	9.86+2.31
6/8/77	24.99±1.74	13.56±2.43	13.79±0.60	11.66±1.11	11.33±0.09	13.40±0.76	13.25±4.43	7.14±1.20	21.08±0.32	17.59±0.80	14.33±1.02	21.62±4.56
7/1/77	16.68±0.64	21.87±0.01	15.67±0.50	20.59±8.56	31.14±0.14	28.98±3.37	25.39±7.02	14.69±1.16	26.19±3.31	26.40±1.23	29.85+1.52	19.18±1.85
7/21/77	31.77±4.01	38.21±5.41	37.98±2.78	15.62±1.58	41.83±1.90	41.60±1.90	23.91±1.61	10.46±0.26	28.96±2.34	25.04±0.74	15.27±0.94	5.22+0.16
8/12/77	19.22±0.03	13.65±1.38	11.33±1.51	8.56±0.20	23.22±0.52	23.77±1.44	19.05±1.68	14.48±0.35	35.21±1.32	39.37±2.00	27.64±5.26	23.71±0.01
9/1/77	23.08±0.42	25.10±4.59	19.29±0.91	11.46±0.25	18.98±6.24	18.13±2.53	17.20±2.90	8.53±1.79	37.51±13.02	32.00±1.15	28.35	13.95

* Standard error

Table 16. Primary productivity of Cochiti Reservoir on an area basis as mg carbon/m^2/hr

Date	Station 1	Station 2	Station 4
7/29/76	117.74	133.87	155.48
8/11/76	180.32	223.23	193.55
9/7/76	97.10	117.10	149.03
10/8/76	38.39	55.48	50.65
12/3/76	2.58	2.26	5.81
3/19/77	83.23	60.97	36.45
5/18/77	20.97	-	32.26
6/8/77	44.52	36.45	53.55
7/1/77	55.48	77.10	79.03
7/21/77	100.00	92.90	59.34
8/12/77	38.71	62.90	96.77
9/1/77	61.29	48.39	86.13

period of July to September, 1977 the average concentration was 5.2 mg/m^3 with a range of 0-11.7 mg/m^3. Generally similar chlorophyll concentrations were measured in the surface and 2 m samples except during the summer of 1976 when very high surface concentrations of chlorophyll were associated with a reduction in concentration by a factor of 2-3 at 2 m. A suprisingly high chlorophyll concentration was measured in the two samples analyzed in March, 1977. The phytoplankton present apparently did not remain intact during the preservation procedure and very few phytoplankton were identified in preserved samples (Table 17).

Phytoplankton productivity is tabulated on a volume basis for the surface to 3 m depths in Table 15 and the data for the surface samples at the three primary productivity stations are plotted in Figure 5. Primary productivity was estimated on an area basis by integrating the volume rate at each depth using a planimeter (see Table 16 and Figure 6). Primary productivity was indicative of eutrophic conditions in the summer of 1976. The great decrease in the extent of the algal bloom in the summer of 1977 as compared to 1976 is quite evident in Figure 5. Primary productivity of surface samples was lower by factors of 3-10 during the second summer. With the reduced magnitude of the surface bloom in 1977, transparency increased (Table 2) and primary productivity (Table 15) also increased at greater depths. Some examples of the depth distributions of primary productivity are shown for selected dates in Figure 7. As a consequence of the increased depth of the euphotic zone in

Table 17. Identification and enumeration of phytoplankton collected from Cochiti Reservoir (cont.)

DATE	STATION-DEPTH(m)	GENUS	TOTAL CELLS/ml	CYANOPHYTES Heterocysts/ml	CYANOPHYTES Cells/heterocyst (range)	CYANOPHYTES Filaments/ml w/o heterocysts	CYANOPHYTES Filaments/ml w/heterocysts
07/21/77	1-2	Aphanizomenon	40,005	1,111	5-25	1,556	1,111
		Anabaena	36,104	1,333	15	1,111	1,333
		Diatoma	222				
	2-S	Anabaena	14,465		~20	789	526
		Aphanizomenon	2,630			526	
	2-2	Anabaena	25,920	789	16-20	536	789
		Aphanizomenon	3,156			526	
	3-S	Aphanizomenon	1,602			267	
	3-2	Schroederia	256				
		Aphanizomenon	1,024			256	
	4-S	Anabaena	5,300			530	
	4-2	Schroederia	256				
		Anabaena	2,560			256	
		Aphanizomenon	1,024			256	
08/12/77	1-S	Diatoma	506				
	1-2	Aphanizomenon	1,265			253	
		Diatoma	263				
		Aphanizomenon	1,184			263	
	2-S	Diatoma	263				
	2-2	Diatoma	261				
		Aphanizomenon	2,088			261	
	3-S	Diatoma	205				
		Schroederia	205				
		Aphanizomenon	1,230			205	
	3-2	Diatoma	259				
		Aphanizomenon	2,331			260	
	4-S	Diatoma	265				
	4-2	Diatoma	260				
		Ceratium	265				
09/01/77	1-S	Diatoma	260				
	1-2	Diatoma	260				
		Staurastrum paradoxum	519				
	2-S	Diatoma	465				
		Staurastrum paradoxum	233				
	2-2	Diatoma	260				
	3-S	Diatoma	421				
		Staurastrum paradoxum	211				
	3-2	Diatoma	516				
	4-S	Diatoma	260				
	4-2	Staurastrum paradoxum	267				
		Diatoma	533				

Table 17. Identification and enumeration of phytoplankton collected from Cochiti Reservoir (cont.)

DATE	STATION-DEPTH (m)	GENUS	TOTAL CELLS/ml	CYANOPHYTES Heterocysts/ml	CYANOPHYTES Cells/heterocyst (range)	CYANOPHYTES Filaments/ml w/o heterocysts	CYANOPHYTES Filaments/ml w/heterocysts
05/18/77	1-S	nd					
	1-2	nd					
	2-S	Schroederia	265				
	2-2	nd					
	3-S	nd					
	3-2	Schroederia	526				
	4-S	nd					
	4-2	nd					
06/08/77	1-S	nd					
	1-2	Aphanizomenon				206	
	2-S	Aphanizomenon				263	
		Schroederia	263				
	2-2	nd					
	3-S	nd					
	3-2	nd					
	4-S	Schroederia	519				
	4-2	Schroederia	519				
07/01/77	1-S	Anabaena	13,680	759	16-20		759
		Ceratium	253				
	1-2	Ceratium	258				
		Diatoma	258				
		Aphanizomenon		258	5-20	516	258
		Anabaena	9,159	258	31-40		258
	2-S	Aphanizomenon	18,816	784	19-29		784
		Anabaena	3,263	261	10-15		261
	2-2	Schroederia	261				
		Gurosigma	261				
		Aphanizomenon	129,000	800	~15	800	800
		Anabaena	2,800			400	
	3-S	Actinastrum	250				
		Aphanizomenon				500	
	3-2						
		Schroederia	506				
		Aphanizomenon	7,590	253	23-37		253
	4-S	Anabaena	22,435	1,282	15-20		1,282
		Aphanizomenon		769	5-10	769	769
	4-2	Ceratium	253				
		Aphanizomenon				506	
07/21/77	1-S	Aphanizomenon		533	20	1,333	533
		Anabaena		800	20-30	1,067	800
		Ceratium	267				

Table 17. Identification and enumeration of phytoplankton collected from Cochiti Reservoir (cont.)

DATE	STATION-DEPTH (m)	GENUS	TOTAL CELLS/ml	CYANOPHYTES Heterocysts/ml	Cells/heterocyst (range)	Filaments/ml w/o heterocysts	Filaments/ml w/heterocysts
08/11/76	1-S	Aphanizomenon	306,000	8,000	8-31	12,000	8,000
		Diatoma	500				
		Anabaena	21,000	750	19-37		750
	1-2	Aphanizomenon	264,125	4,250	20-35	7,750	4,250
		Anabaena	120,125	7,750	11-20		7,750
		Diatoma	1,250				
	2-S	Aphanizomenon	243,500	3,250	16-30	6,750	3,250
		Anabaena	1,400			250	
	2-2	Diatoma	1,013				
		Aphanizomenon	150,491	3,797	14-41	6,582	3,797
		Anabaena	15,625	1,250	10-15		1,250
		unknown	500				
	3-S	Aphanizomenon	682,814	11,168	19-46	13,506	11,168
		Anabaena	20,907	1,818	9-14		1,818
	3-2	Anabaena	10,440	870	6-18		870
		Diatoma	652				
		Aphanizomenon	71,854	1,739	14-35	2,174	1,739
	4-S	Diatoma	769				
		Aphanizomenon	100,657	2,821	25-30	2,308	2,821
		Anabaena	25,130			1,795	
		Amphithrix	256				
	4-2	Aphanizomenon	62,510	2,051	15-25	3,070	2,051
		Diatoma	513				
09/07/76	1-S	Aphanizomenon	51,872	1,867	20-31	533	1,867
	1-2	Aphanizomenon	50,646	1,299	21-37	1,038	1,299
		Diatoma	259				
	2-S	Aphanizomenon	31,162	779	7-23	2,597	779
		Diatoma	519				
	2-2	Aphanizomenon	53,814	1,842	10-33	1,579	1,842
		Diatoma	263				

Table 17. Identification and enumeration of phytoplankton collected from Cochiti Reservoir (cont.)

DATE	STATION-DEPTH(m)	GENUS	TOTAL CELLS/ml	CYANOPHYTES			
				Heterocysts/ml	Cells/heterocyst (range)	Filaments/ml	
						w/o heterocysts	w/heterocysts
09/07/76	3-S	Aphanizomenon	33,107	779	8-29	1,558	779
	4-S	Aphanizomenon	260,041	8,846	11-41	3,076	8,846
	4-2	Aphanizomenon	27,563	1,282	9-32	1,282	1,282
		Diatoma	256				
	3-2	Aphanizomenon	18,733	4,303	10-38	1,519	4,303
		Diatoma	253				
		Ceratium	253				
10/08/76	1-S	Aphanizomenon	20,519	789	8-11	2,368	789
	1-2	Aphanizomenon	12,812	256	10-15	769	256
	2-S	Aphanizomenon	25,377			2,307	
	2-2	Aphanizomenon	33,887			2,711	
	4-S	Aphanizomenon	38,101	760	10-17	2,531	760
	4-2	Aphanizomenon	17,574	286	8-10	2,000	286
12/03/76	1-S	nd*					
	1-2	nd					
	2-S	nd					
	2-2	nd					
	3-S	nd					
	4-S	nd					
	4-2	nd					
01/29/77	1-S	nd					
	1-2	nd					
	2-S	nd					
	2-2	nd					
	3-S	nd					
	3-2	nd					
03/19/77	1-S	nd					
	1-2	Asterionella	256				
	2-S	nd					
	2-2	Diatoma	1,489				
		Gomphonies	213				
	3-S	nd					
	3-2	nd					

* no discernible phytoplankton

Table 17. Identification and enumeration of phytoplankton collected from Cochiti Reservoir

DATE	STATION-DEPTH (m)	GENUS	TOTAL CELLS/ml	CYANOPHYTES Heterocysts/ml	Cells/heterocyst (range)	Filaments/ml w/o heterocysts	Filaments/ml w/heterocysts
07/14/76	1-S*	Anabaena	71,120	4,064	12-23		4,064
		Aphanizomenon	94,311	4,491	17-25		4,491
		Diatoma	427				
	1-5	Diatoma	1,250				
	2-S	Frustulia	422				
		Aphanizomenon	121,312			9,705	
		Diatoma	422				
	2-5	Diatoma	606				
		Frustulia	202				
		Aphanizomenon	5,252			808	
	3-S	Aphanizomenon	54,475			4,737	
	3-5	Aphanizomenon	40,904			2,821	
07/29/76	1-S	Anabaena	17,970	1,797	7-13		1,797
		Aphanizomenon	205,264	4,269	18-31	7,191	4,269
	1-2	Aphanizomenon	129,567	2,609	15-40	4,130	2,609
		Anabaena	21,740	1,087	14-26		1,087
	2-S	Aphanizomenon	154,557	5,455	11-35	4,156	5,455
		Anabaena	24,543	1,818	9-18		1,818
		Diatoma	779				
	2-2	Diatoma	506				
		Ceratium	759				
		Anabaena	34,800	2,784	11-14		2,784
		Aphanizomenon	81,256	2,025	14-37	3,291	2,025
	3-S	Anabaena	32,732	2,338	12-16		2,338
		Aphanizomenon	152,843	3,636	21-45	2,857	3,636
		Ceratium	519				
07/29/76	3-2	Diatoma	1,266				
		Aphanizomenon	24,822	2,532	23-28	4,304	2,532
	4-S	Anabaena	34,554	1,772	16-23		1,772
		Diatoma	513				
		Aphanizomenon	144,618	5,128	14-20	4,103	5,128
		Ceratium	256				
		Anabaena	53,850	3,590	12-18		3,590
	4-2	Anabaena	47,175	3,145	14-16		3,415
		Aphanizomenon	121,411	2,359	20-25	6,029	2,359

*Surface

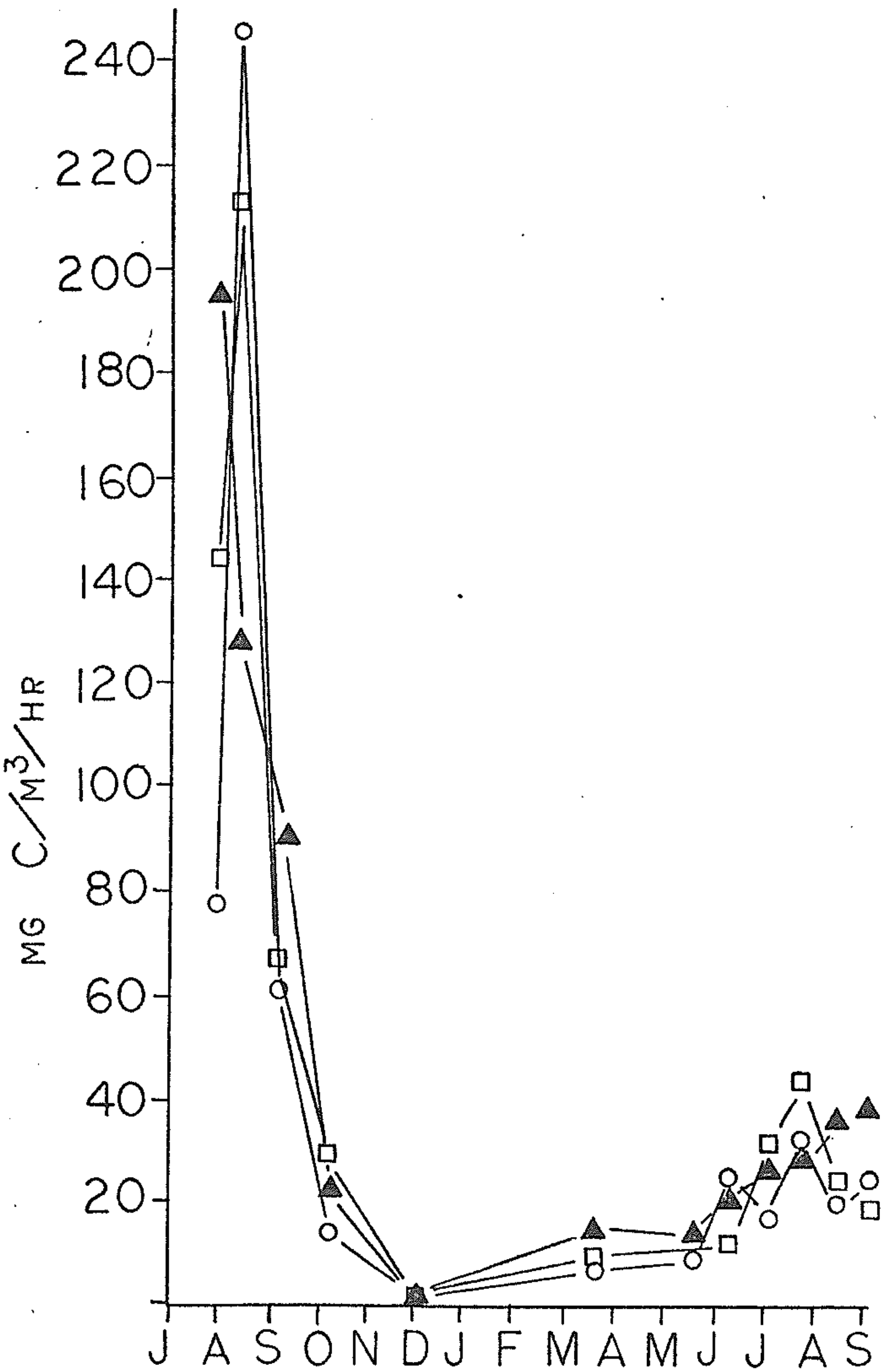


Figure 5. Primary productivity measurements on the surface of the Cochiti Reservoir. Values indicate CO_2 fixation at stations 1(O—O), 2 (□—□) and 4 (▲—▲).

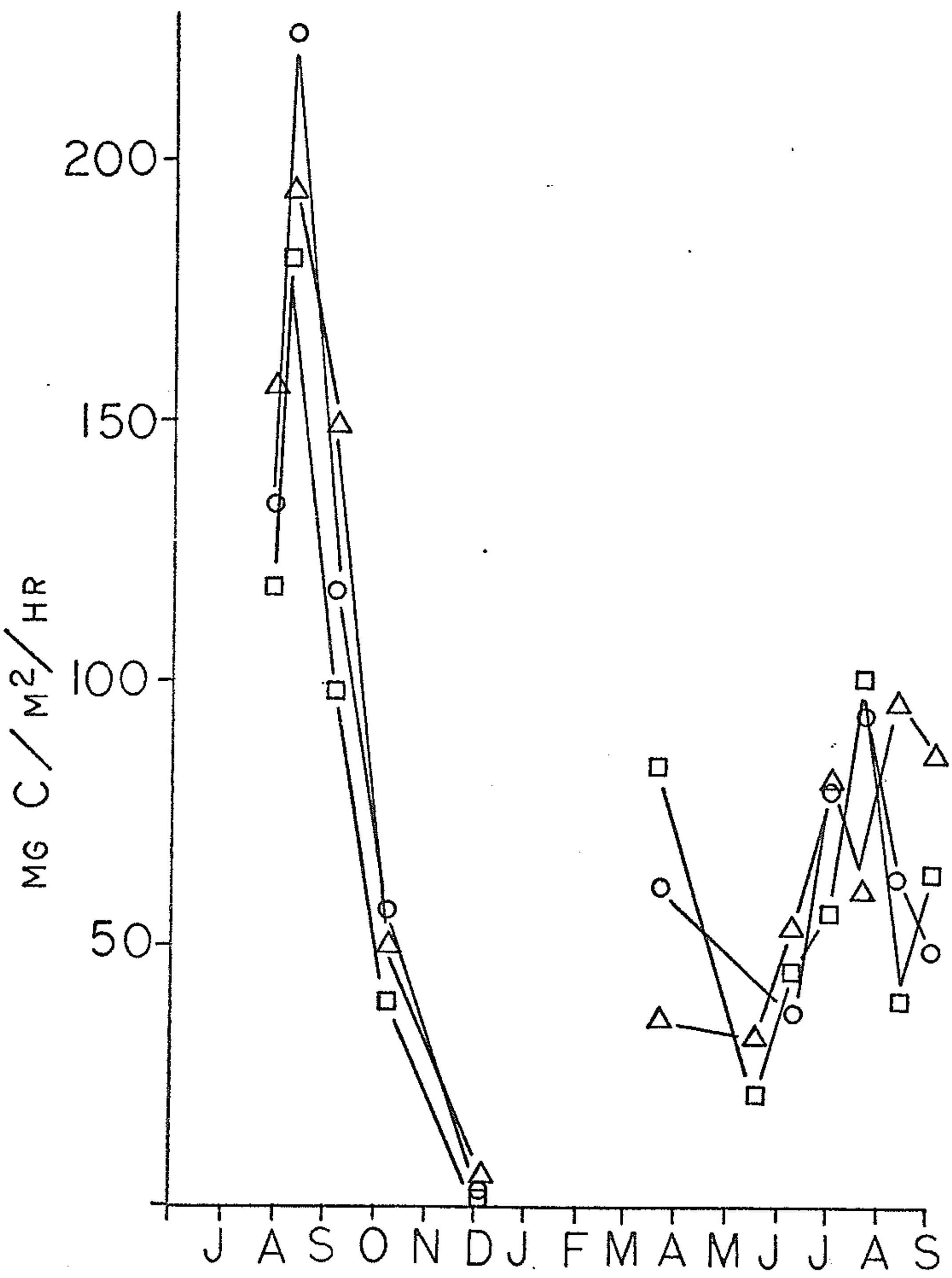


Figure 6. Primary productivity values for each station at Cochiti Reservoir. Values include CO_2 fixation at surface and deep levels at stations 1 (□—□), 2 (○—○) and 4 (△—△).

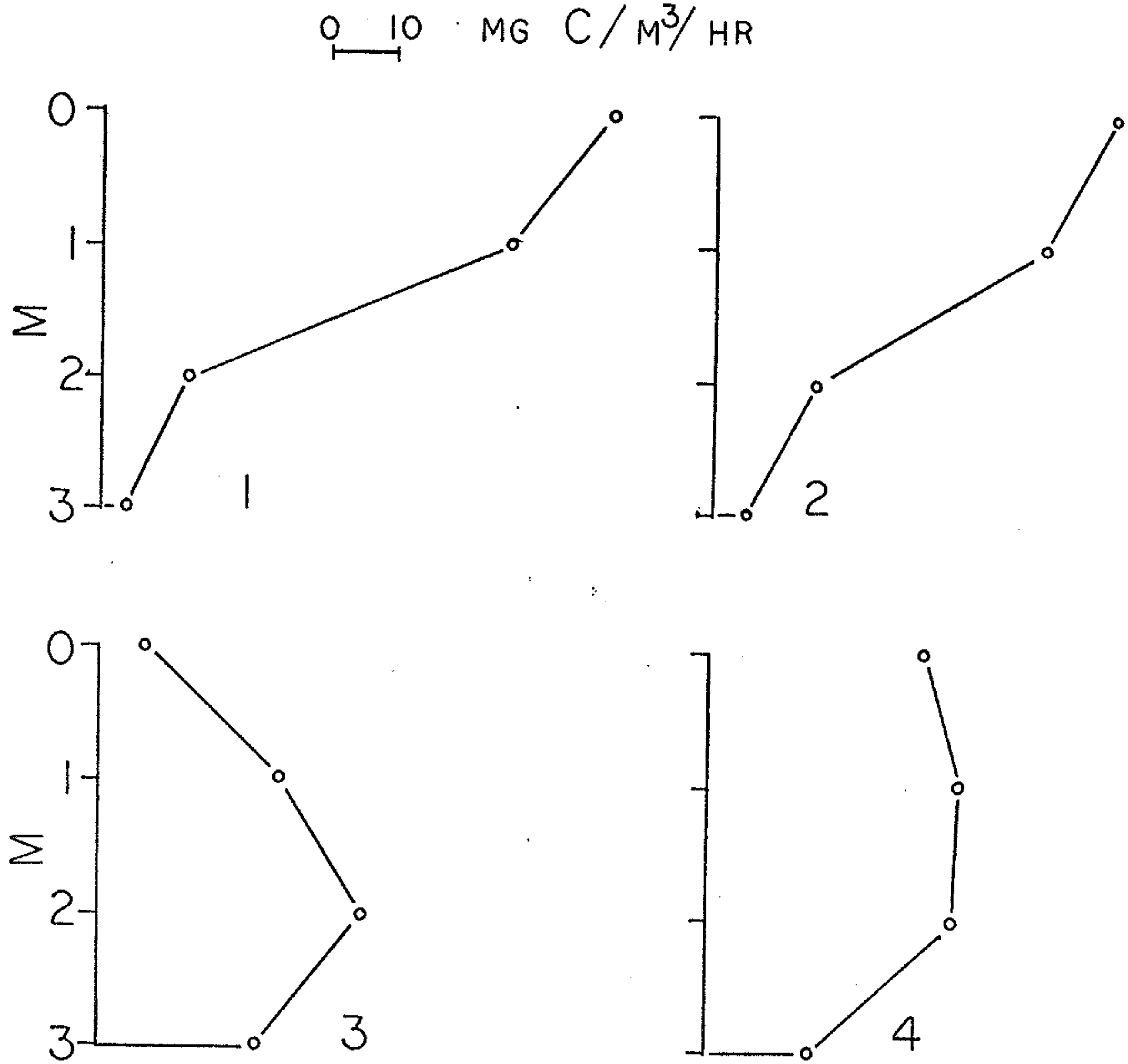


Figure 7. Primary Productivity at various depths at Cochiti Reservoir. Values are for station 1 with the dates indicated as follows:
1, 7/29/76; 2, 9/7/76;
3, 3/19/77; 4, 7/21/77.

1977, while primary productivity on an area basis decreased, it did not decrease as greatly as primary productivity of the surface samples (compare Figures 15 and 16). While the primary productivity on an area basis was accurately estimated by samples from the surface, 1, 2, and 3 m in 1976, samples from the same depths resulted in an underestimate of primary productivity in 1977 because of increased productivity at greater depths.

No consistent differences in primary productivity were apparent at the three stations sampled and when primary productivity is computed on an area basis rather than on the basis of the surface sample alone, differences between the three stations are further decreased. This suggests some variations in the depth distribution of phytoplankton at each station but little difference in the activity of the phytoplankton on an area basis at the stations in the main body of the Reservoir.

An attempt was made to measure nitrogen fixation by the acetylene reduction method on September 1, 1977 at Station 4. While some characteristic filaments of *Aphanizomenon* were present at Station 4, they were not abundant and blue-green algae were not observed in the preserved sample (Table 17). While phytoplankton was concentrated 250 fold, nitrogen fixation was not detected in these assays. It seems very probable that nitrogen fixation would have been readily measureable earlier in the summer and in the summer of 1976 when an extensive bloom of *Aphanizomenon* occurred and *Anabaena* was also abundant.

The genera of phytoplankton identified and enumerated in preserved samples from Cochiti Reservoir are tabulated for each sampling date in Table 17. It should be noted that some phytoplankton genera were not stable in the preservative used and hence were not detected. The total number of phytoplankton cells, heterocysts, *Aphanizomenon* cells and *Anabaena* cells in preserved samples from the surface of Station 1 are shown in Figures 9, 10, and 11. During the summer of 1976, *Aphanizomenon flos-aquae* was by far the most abundant phytoplankton with maximum cell numbers occurring in late July and August. At these dates most surface and 2 m samples had 100,000-300,000 cells/ml of *Aphanizomenon*. The only other abundant phytoplankton during July and August, 1976 was *Anabaena* sp. which usually did not exceed 35,000 cells/ml. Virtually all *Anabaena* filaments included a heterocyst while less than half the *Aphanizomenon* filaments included a heterocyst. This is evidence that both phytoplankton were at least partially dependent on fixation of nitrogen gas. In September, *Anabaena* was no longer observed in samples and the abundance of *Aphanizomenon* decreased in September and October. During the summer months small numbers of *Diatoma* were the only other phytoplankton genus frequently observed in samples.

Very few phytoplankton were observed in samples collected during the winter and spring. Small numbers of *Schroederia* occurred in May and June, 1977 and a small number of *Aphanizomenon* were observed in June. In samples collected July 1, 1977, *Aphanizomenon* had increased to as many as 24,000 cells/ml and

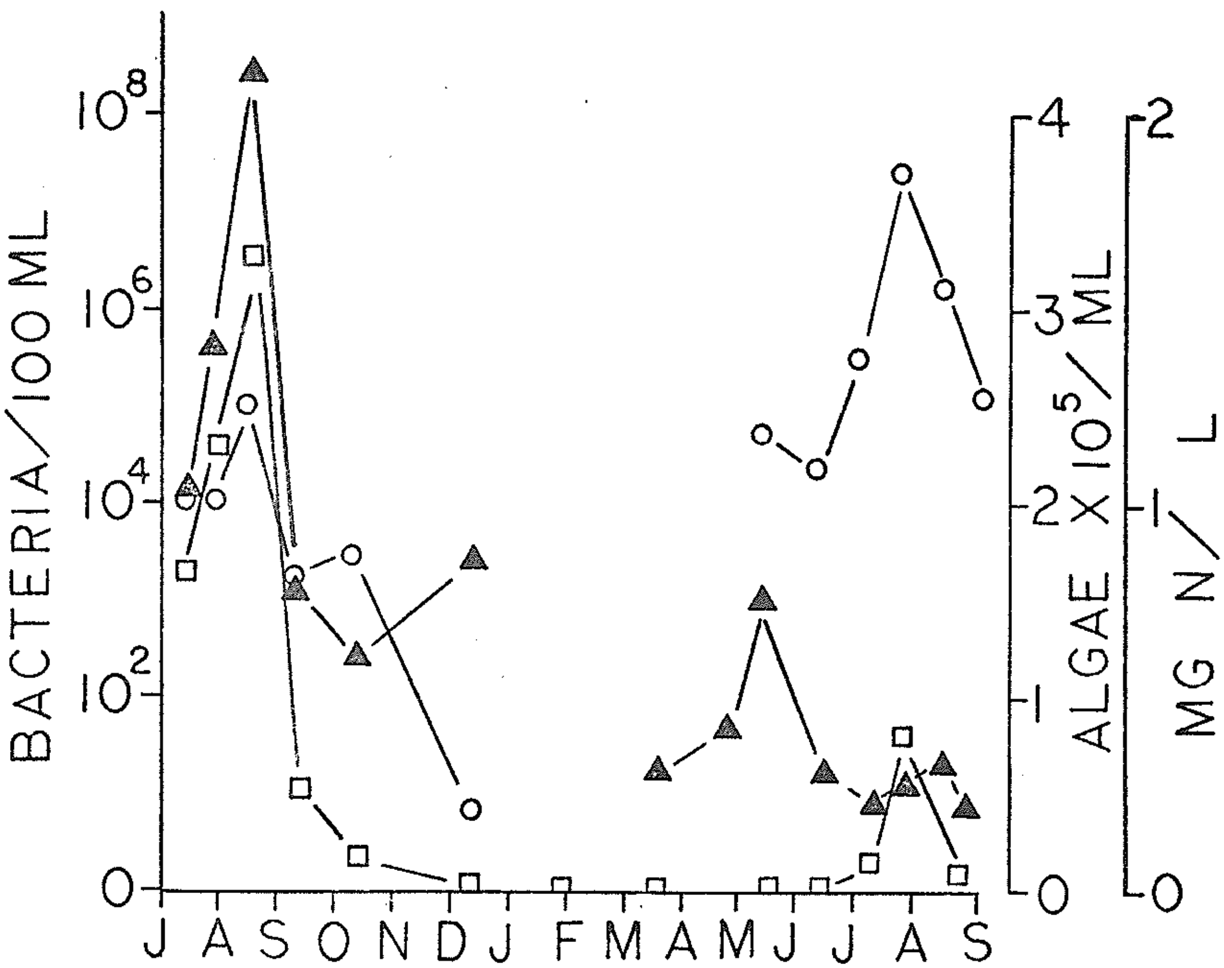


Figure 8. Comparison of nitrogen content to bacteria and phytoplankton. The values are total nitrogen (▲—▲), heterotophic bacteria (○—○) and phytoplankton (□—□) in the surface water at Cochiti Reservoir.

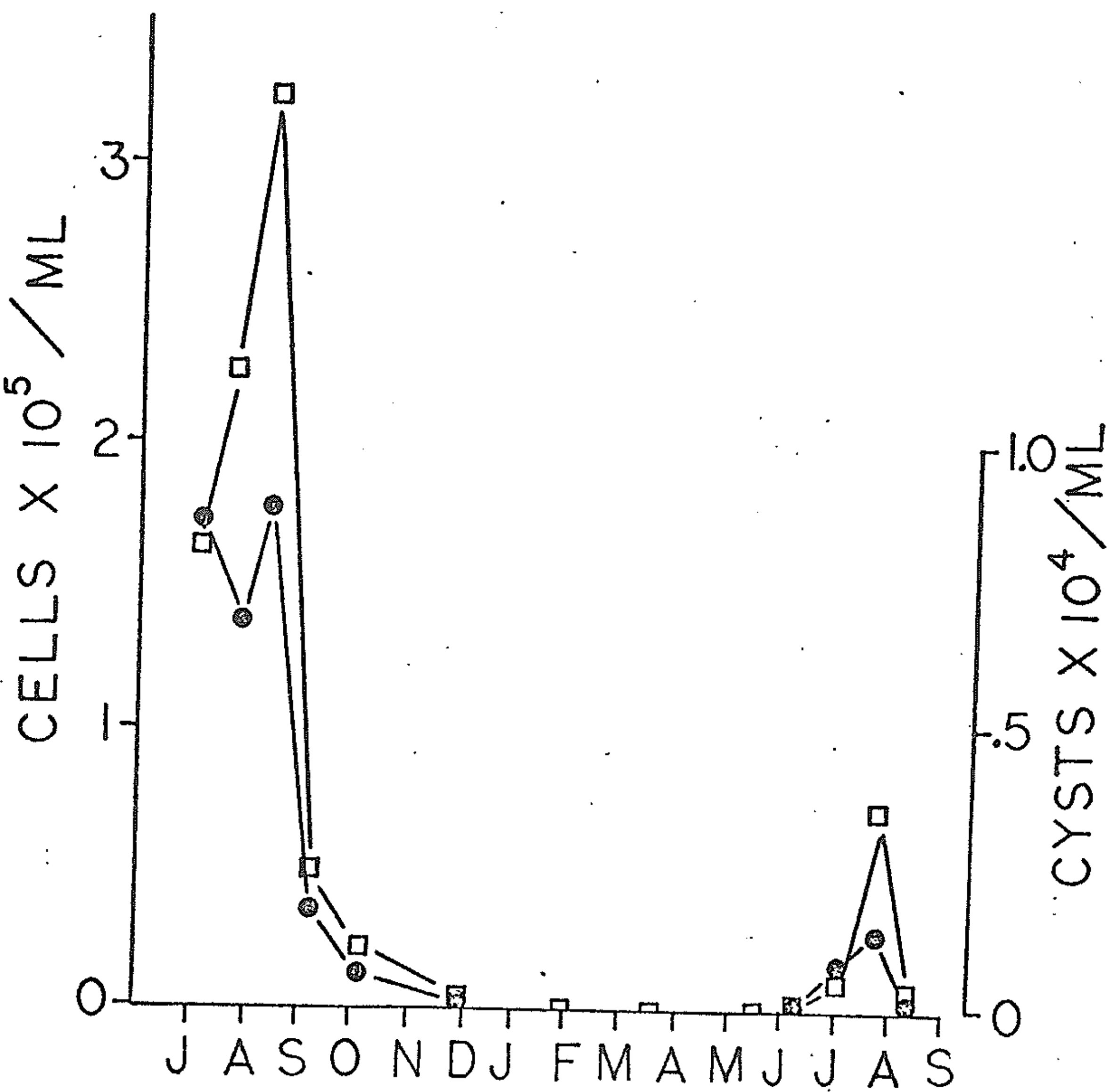


Figure 9. Abundance of phytoplankton cells and heterocysts in Cochiti Reservoir. The values represent the total number of cells (□—□) and heterocysts (●—●) at the surface of station 1.

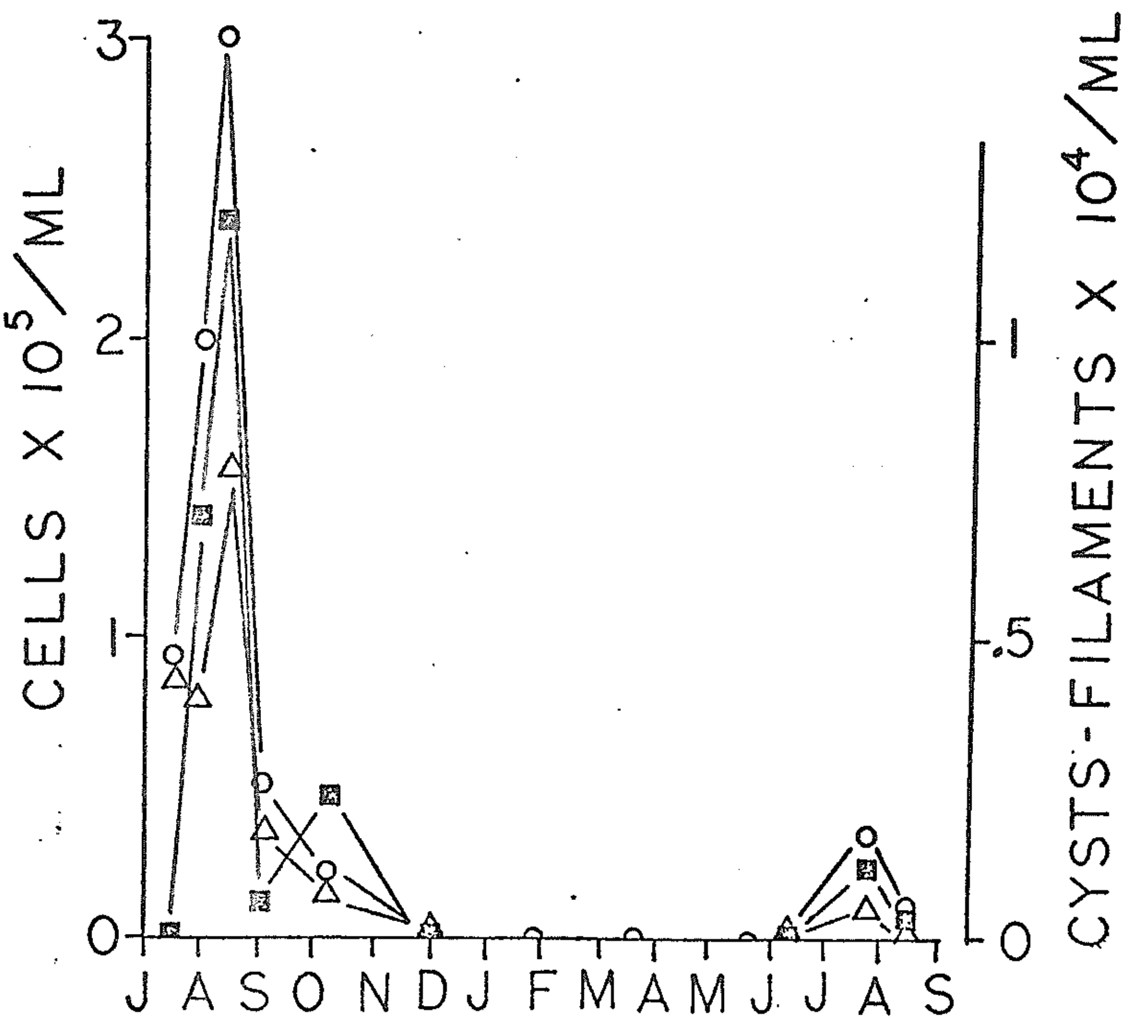


Figure 10. Abundance of Aphanizomenon at Cochiti Reservoir. The values represent the total number of cells (O——O), heterocysts (△— △) and filaments (■—■) at the surface of station 1.

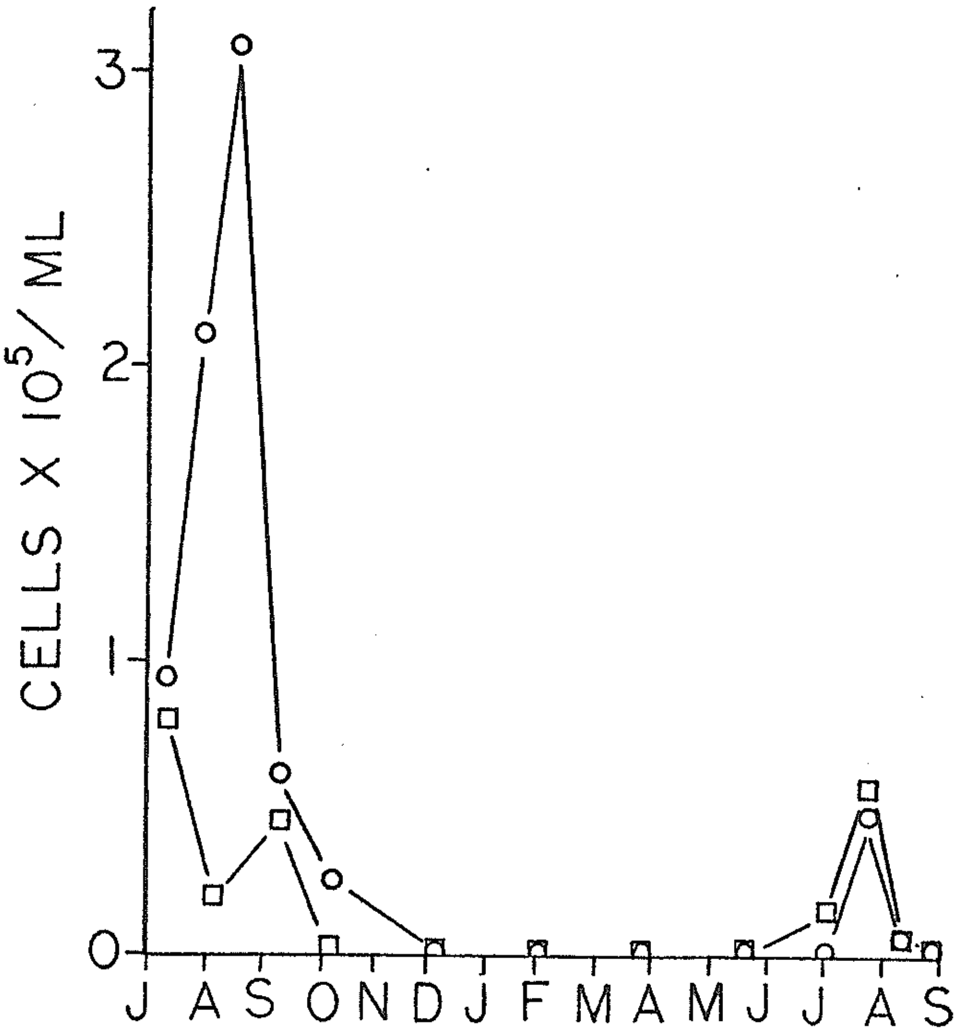


Figure 11. Abundance of Anabaena and Aphanizomenon in Cochiti Reservoir. Values reflect phytoplankton at the surface of station 1. Aphanizomenon (O—O) and Anabaena (□—□).

roughly similar numbers of Anabaena were observed. By July 21 Aphanizomenon and Anabaena had increased to 30,000-40,000 cells/ml at Station 1, the greatest abundance of blue-green algae observed during this year. Anabaena was more numerous than Aphanizomenon at Station 2 and were observed in numbers of less than 5,300 and 1,600 cells/ml respectively at both Stations 3 and 4. Anabaena was not present in th August samples and Aphanizomenon was observed in small numbers. Blue-geen algae were not present in samples collected September 1, 1977. The much greater number of blue-green algae in the summer of 1976 than 1977 as well as the relatively greater importance of Anabaena in 1977 is shown in Figure 11. In the summer of 1977, most Anabaena filaments included a heterocyst until July 21 when numerous filaments without heterocysts were observed. Heterocysts were noted in about one-third of the Aphanizomenon filaments. Small numbers of several genera of green-algae were noted in samples collected in the summer of 1977.

Aquatic higher plants are of very limited occurrence in Cochiti Reservoir; however, small populations of Myriophyllum sp. were observed along the shoreline of the channel between Stations 3 and 4.

From a public health standpoint, fecal pollution of Cochiti Reservoir appears to be low. Fecal coliforms and fecal streptococci were most numerous nearer the inlet (Station 3), and near the boatdock (Station 2), where recreational activity was greatest (Tables 20 and 21). The number of fecal bacteria at Station 3 were substantially fewer than had been observed in

Table 18. Aerobic heterotrophic bacteria/ 100 ml in Cochiti Reservoir

Date	Station 1			Station 2		Station 3		Station 4		Flume
	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/14/76	$1x10^4$	$1x10^5$	-	$1x10^4$	$1x10^5$	$1x10^5$	$5x10^3$	$1x10^5$	$1.8x10^4$	-
7/29/76	$1x10^4$	$7.5x10^4$	$1.5x10^2$	$1x10^5$	$1x10^5$	$1x10^5$	$6x10^3$	$1x10^4$	$1.4x10^4$	$1x10^4$
8/11/76	$1x10^5$	$1x10^5$	-	$3.4x10^3$	$2x10^4$	-	-	$3.5x10^3$	$1.1x10^4$	$1x10^5$
9/7/76	$2.5x10^3$	$1x10^3$	-	$2x10^4$	$1.3x10^4$	$1x10^4$	$1.8x10^4$	$1x10^5$	$1x10^5$	$1.2x10^4$
10/8/76	$3.4x10^3$	$1x10^4$	-	$3x10^3$	$1.5x10^4$	-	-	-	-	$1x10^4$
12/3/76	$5x10^2$	$8.3x10^2$	-	$8x10^2$	$1.1x10^4$	$8x10^3$	$2x10^3$	-	-	$1.2x10^4$
5/18/77	$8.1x10^4$	$1.4x10^5$	$7x10^4$	$2x10^5$	$2x10^5$	$1.3x10^5$	$1.5x10^5$	-	-	$1.4x10^5$
6/8/77	$7.5x10^4$	$1.5x10^5$	$1.7x10^5$	$1.6x10^5$	$1.8x10^5$	$1.5x10^5$	$3.2x10^5$	$2.6x10^5$	$1.35x10^5$	$2.5x10^5$
6/30/77	$4.2x10^5$	$6x10^5$	$3.6x10^5$	$6x10^5$	$3.4x10^5$	$4.2x10^5$	$3.8x10^5$	-	-	$1x10^6$
7/20/77	$2.1x10^7$	$7.2x10^7$	$4.2x10^7$	$1.5x10^7$	$5x10^7$	$2.3x10^7$	$2.7x10^7$	-	-	$3.2x10^7$
8/12/77	$1.8x10^6$	$1.2x10^5$	$6x10^4$	$5.8x10^3$	$1.5x10^4$	$1x10^4$	$4.1x10^5$	-	-	$2.6x10^5$
9/1/77	$2.6x10^5$	$3.5x10^5$	$4.9x10^6$	$1.5x10^8$	$3.9x10^6$	$2.6x10^5$	$4.1x10^6$	-	-	$5.3x10^6$

Table 19. Anaerobic bacteria/ 100 ml water sample.

Cochiti Reservoir

	Station 1			Station 2		Station 3		Flume
Date	Surface	5 m	20 m	Surface	5 m	Surface	5 m	
5/18/77	$1.6x10^2$	$3.8x10^4$	$6.4x10^2$	$1x10^3$	$1.7x10^4$	$7.5x10^3$	$2.2x10^3$	$3.2x10^3$
9/1/77	$1x10^3$	$5x10^3$	$1.7x10^4$	$1.5x10^4$	$4.5x10^4$	$1.5x10^5$	$1.4x10^5$	$1.6x10^5$

Abiquiu Reservoir

	Station 1		Station 2			Station 3		Station 4		Station 5		Flume
Date	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
5/26/77	$6.2x10^2$	$1.6x10^2$	$1x10^2$	$1.4x10^2$	$4.4x10^2$	$5x10^2$	$4x10^2$	$1.1x10^3$	$4.6x10^2$	$4.6x10^2$	$4x10^2$	$6x10^2$
6/16/77	-	-	$1.8x10^3$	$4.5x10^2$	$2.1x10^3$	$4.8x10^2$	$1.1x10^3$	$5.1x10^2$	$3.5x10^3$	-	-	$2.1x10^3$
9/13/77	$5x10^3$	$1.3x10^3$	$6x10^3$	$2.4x10^4$	-	$6x10^3$	$1.5x10^4$	$4x10^3$	$2.1x10^4$	-	-	$2.7x10^4$

Table 20. Fecal Coliforms/ 100 ml

Cochiti Reservoir

Date	Station 1 Surface	Station 1 5 m	Station 1 20 m	Station 2 Surface	Station 2 5 m	Station 3 Surface	Station 3 5 m	Station 4 Surface	Station 4 5 m	Flume
7/14/76	0	0	0	0	0	0	0	0	0	0
7/29/76	0	0	0	3	1	2	0	0	0	0
8/11/76	1	0	14	0	-	0	0	0	0	0
9/7/76	0	0	12	0	0	3	9	0	0	0
10/8/76	0	0	-	0	0	-	-	-	-	0
12/3/76	0	0	5	0	0	0	0	0	0	0
5/18/77	0	0	0	3	3	1	3	-	-	2
6/8/77	0	0	0	3	0	0	0	0	0	0
6/30/77	0	0	1	0	26	12	-	-	9	1
7/20/77	0	0	0	0	0	2	0	-	-	0
8/12/77	0	0	0	0	0	0	0	-	-	0
9/177	0	0	0	0	0	0	2	-	-	0

Abiquiu Reservoir

Date	Station 1 Surface	Station 1 5 m	Station 2 Surface	Station 2 5 m	Station 2 20 m	Station 3 Surface	Station 3 5 m	Station 4 Surface	Station 4 5 m	Station 5 Surface	Station 5 5 m	Flume
7/7/76	0	0	0	0	-	0	0	0	0	-	-	0
7/22/76	-	-	0	0	0	0	0	0	0	-	-	0
8/4/76	0	0	0	0	0	0	0	1	2	-	-	0
8/18/76	-	-	5	8	-	8	11	6	3	-	-	-
9/17/76	-	-	0	0	0	0	0	0	0	-	-	0
11/5/76	0	0	0	0	0	0	0	0	0	-	-	0
5/26/77	0	0	0	0	0	0	0	0	0	0	0	0
6/16/77	-	-	3	0	0	0	0	0	0	-	-	0
7/13/77	-	-	0	0	0	0	0	0	0	-	-	0
8/3/77	-	-	0	0	0	0	0	0	2	-	-	0
9/13/77	0	0	0	0	0	0	0	0	0	0	0	0

Table 21. Fecal Streptococci/ 100 ml

Cochiti Reservoir

Date	Station 1			Station 2		Station 3		Station 4		Flume
	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/14/76	0	3	0	0	0	0	32	-	1	0
7/29/76	6	7	0	0	3	0	30	0	2	15
8/11/76	9	0	119	1	0	4	0	1	3	0
9/7/76	0	-	26	0	0	0	43	10	4	0
10/8/76	3	0	2	0	2	-	-	-	-	3
12/3/76	0	0	5	0	1	0	0	0	0	0
5/18/77	0	0	0	0	2	0	0	-	-	3
6/8/77	1	0	0	0	0	2	45	0	3	11
6/30/77	0	1	0	0	1	2	7	-	-	4
7/20/77	0	0	0	0	0	0	2	-	-	0
8/12/77	4	3	5	2	0	7	6	-	-	248
9/1/77	1	0	11	0	1	1	4	-	-	0

Abiquiu Reservoir

Date	Station 1		Station 2			Station 3		Station 4		Station 5		Flume
	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/7/76	1	7	0	0	-	0	0	0	-	-	-	5
7/22/76	-	-	3	0	75	3	2	0	0	-	-	172
8/4/76	0	18	0	0	0	0	0	0	0	-	-	-
8/18/76	-	-	0	0	-	3	-	1	16	-	-	78
9/17/76	-	-	0	0	16	10	0	3	5	-	-	0
11/5/76	0	0	30	30	0	0	0	0	0	-	-	0
12/20/76	-	-	0	1	-	1	2	0	0	-	-	0
4/19/77	-	-	3	2	-	1	0	0	0	-	-	0
5/26/77	0	0	0	0	1	0	0	0	0	5	0	3
6/16/77	-	-	0	0	30	3	0	0	64	-	-	46
7/13/77	-	-	0	0	1	0	0	0	0	-	-	10
8/3/77	-	-	0	0	3	1	0	0	2	-	-	20
9/13/77	8	12	4	3	1	0	1	0	6	-	-	4

Table 22. Invertebrates/ 200 ml water sample

Cochiti Reservoir

Date	Station 1 Surface	Station 1 5 m	Station 1 20 m	Station 2 Surface	Station 2 5 m	Station 3 Surface	Station 3 5 m	Station 4 Surface	Station 4 5 m	Flume
7/14/76	0	0	-	1	0	0	3	0	0	-
7/29/76	0	2	0	1	0	1	0	2	1	3
8/1176	0	0	-	2	0	0	0	5	4	2
9/7/76	0	4	-	3	2	0	2	2	2	6
10/8/76	8	10	-	13	20	-	-	-	-	15
12/3/76	1	3	-	1	0	4	10	-	-	2
5/18/77	1	6	2	0	3	0	4	-	-	0
6/8/77	0	4	2	0	30	0	0	2	2	-
7/01/77	0	1	0	0	2	0	0	-	-	-
8/12/77	0	1	0	0	0	0	0	-	-	-
9/02/77	0	0	0	0	0	0	0	-	-	-

Abiquiu Reservoir

Date	Station 1 Surface	Station 1 5 m	Station 2 Surface	Station 2 5 m	Station 2 20 m	Station 3 Surface	Station 3 5 m	Station 4 Surface	Station 4 5 m	Station 5 Surface	Station 5 5 m	Flume
7/7/76	3	9	4	2	-	10	5	4	-	-	-	12
7/22/76	-	-	0	6	-	0	0	0	5	-	-	-
8/4/76	4	2	1	4	0	2	3	0	1	-	-	0
9/17/76	-	-	1	2	-	3	2	2	0	-	-	4
11/5/76	5	10	3	2	-	0	3	0	1	-	-	-
12/20/76	-	-	0	0	-	0	3	-	-	-	-	2
2/12/77	-	-	1	0	-	2	0	-	-	-	-	0
4/9/77	0	0	0	0	-	0	0	0	0	-	-	0
5/26/77	3	5	6	8	0	0	4	0	0	0	4	0
6/16/77	-	-	0	0	0	0	0	0	0	-	-	0
7/13/77	-	-	0	1	0	0	0	0	0	-	-	0
8/3/77	-	-	0	0	0	0	1	0	0	-	-	0
9/13/77	0	1	0	0	0	0	0	0	0	-	-	0

1974 (EIA, 1975).

The abundance of aerobic heterotrophic bacteria in 1976 generally coincided with the increase of algae populations, see Figure 8 and Tables 17 and 18. In 1977, a significantly greater proliferation of bacteria was observed than the previous year and this growth followed an increase in phosphorus level in the reservoir. This bacterial growth preceeded the algae bloom and perhaps played an important role in reducing the magnitude of the algal bloom. Bacteria have often been considered significant in controlling blue-green algal populations (Shilo; Wu et al.).

The phytoplankton collected from Cochiti Reservoir in August, 1977 were found to be highly toxic to laboratory white mice. When the test vertebrates were injected with a few mg of phytoplankton extract, the mice died within 24 hours. At lower concentrations of the extract, normal activities of the mice were impaired suggesting a neural toxic effect. To ensure that toxicity was in fact due to the phytoplankton, controls were employed where mice were injected with extracts of Chlorella and with extracts from large quantities of aquatic bacteria. The toxic activity of the phytoplankton from Cochiti Reservoir was comparable to that produced from phytoplankton taken from Eagle Nest Lake in New Mexico. In both cases, the organisms associated with the toxic activity is Aphanizomenon which is the predominate algal type in Cochiti Reservoir as well as in Eagle Nest Lake (Johnson and Barton).

Abiquiu Reservoir

1. Location and Description

Abiquiu Reservoir is located at an elevation of 6,150 feet on the Rio Chama in Rio Arriba County in north-central New Mexico (Figures 1 and 2). Abiquiu Dam, a high earthfill dam is located about 30 miles above the confluence of the Rio Chama and Rio Grande. Abiquiu Dam was completed in 1963. The reservoir has been used for flood control and until recently only a small permanent pool was stored throughout the year. Since early 1976, the City of Albuquerque has been storing water in Abiquiu Reservoir and the storage volume during this investigation ranged from 22,780-26,845 acre-feet.

There are no residential communities located upstream along the Rio Chama between El Vado Dam and Abiquiu Reservoir and only a few very small communities are located near the Rio Chama above El Vado Reservoir. The U.S. Army Corp of Engineers has constructed picnic facilities near the reservoir as well as a boat launching area. People using the reservoir for boating and fishing often camp on the shoreline in the boat launching area although only restroom facilities are provided.

2. Sampling Sites

The sampling stations are shown in Figure 2. Station 2 is located near the dam and outlet in the deepest part of the reservoir (26 m). Station 3 is located near the boat launching area, Station 5 at the northern end of the main body of the reservoir, and Station 4 in the Rio Chama channel above the main body of the reservoir. Water from the outlet was sampled just below the dam ("Flume"). Station 1, in narrow Canones Creek at the southern end of the Reservoir, was occassionally sampled. Primary productivity measurements were made at Stations 2, 3, and 5 while limnological measurements, chemical determinations, and phytoplankton and microbiological determinations were made on samples from all five stations on the reservoir.

Water samples were collected at the surface (0.5 m) and 5 m for chemical and microbiological determinations and also at a depth of 20 m at Station 2. Chlorophyll determinations and phytoplankton counts were obtained on samples from the surface and 2 m depths.

3. Water Temperature and Transparency

Surface water temperatures during the summer months usually ranged from 20-23 C and occasionally were as high as 25 C (Table 23). During the summer, temperatures at 15 m were frequently 7 to 8 C below the surface water temperatures. Abiquiu Reservoir was frozen over before December 20, 1976 and the ice cover remained through February, 1977.

Secchi disc values are given in Table 2. Abiquiu Reservoir was quite clear in early July, 1976 (Secchi disc readings of 322-475 cm). Transparencies were lower later in July and through November with most measurements falling between 95-220 cm. Transparencies were considerably greater during the period July-September, 1977 with most values ranging from 300-415 cm. While primary productivity was not decreased in the summer of 1977

Table 23, Water temperature at Abiquiu Reservoir in degrees Centigrade.

Date	Station 1		Station 2				Station 3				Station 4			Station 5		
	Surface	5 m	Surface	5 m	10 m	15 m	Surface	5 m	10 m	15 m	Surface	5 m	10 m	Surface	5 m	10 m
7/7/76	25	20	23.5	19.5	17.5	16.5	23	20	18	17	23	20		-	-	-
7/22/76	-	-	-	-	-	-	20	15	13	12.5*	22	20.5	16.5	-	-	-
8/4/76	21	20	22	20	17	16.5	22	20	19**	-	21	20.5	17	-	-	-
8/18/76	-	-	20	20	17	15	21	20	17	14***	20	20	14	20	20	14.5
9/17/76	-	-	17.5	17	15.5	15	17	17	16.5	15	19	17	15	-	-	-
11/5/76	10	8	10	8	7.5	7	9.5	7.5	-	-	11	10	8	-	-	-
12/20/76+	-	-	2	2	2	4	3	3	3**	-	-	-	-	3	3.5	3
2/12/77++	-	-	1.5	4	4.5	-	1	-	-	-	-	-	-	1	4	-
4/9/77	-	-	10.5	6	5	4.5	10	7.5	5	5*	10	7.5	5.5	-	-	-
5/26/77	14.5	13	14.5	14	13	12.5	14	13	13	12.5*	14.	13	13.5	14	13.5	12
6/6/77	-	-	20	16	14	12.5	20	15	13	-	21	16.5	12	-	-	-
7/13/77	-	-	21	19.5	17.5	16.5	21.5	19.5	17.5	17*	20	19	16.5	20	19.5	17
8/3/77	-	-	25	19	17	17	23.5	19	17	-	24	19.5	17.5+++	-	-	-
9/13/77	21.5	19	21	19	18	17.5	20.5	19	19**	-	21	19	18.5+++	-	-	-

* Measured at 11 m.
** Measured at 8 m.
*** Measured at 12 m.
\+ Ice cover, 7.5 cm at Stations 2 and 3, 12 cm at Station 5
\++ Ice cover 37 cm at Station 2
\+++ Measured at 9 m.

(Tables 34 and 35, Figures 15 and 16) the abundance of *Aphanizomenon* in phytoplankton samples was greatly reduced in 1977 (Table 36) and may have in part been responsible for the increased transparencies in the second summer. During July and August of both years transparencies were considerably greater in Abiquiu than Cochiti Reservoir.

4. Chemical Characteristics

Cation and anion concentrations in membrane filtered water from Abiquiu Reservoir are tabulated in Table 24 for September, 1976 and May, 1977. Calcium, magnesium, sodium and chloride concentrations in Abiquiu Reservoir were somewhat higher in May, 1977 than in September, 1976 as was also noted for Cochiti Reservoir. Sulfate also increased in Abiquiu Reservoir; however, the sulfate data were not available for Cochiti in 1977. The potassium concentrations remained essentially constant in Abiquiu Reservoir.

Calcium, magnesium, and sulfate concentrations in Abiquiu Reservoir were similar to concentrations measured at the same time of the year at Cochiti Reservoir while sodium, potassium, and chloride concentrations were somewhat higher in Cochiti Reservoir.

Concentrations of iron, manganese, copper and zinc, in Abiquiu water were very low. In May, 1977, transition metals were determined by atomic absorption spectrophotometery following carbon rod combustion, thus increasing the sensitivity; however, iron was below detectible limits in these samples and manganese was found to be present at 1 μg/liter or less. The lowest iron

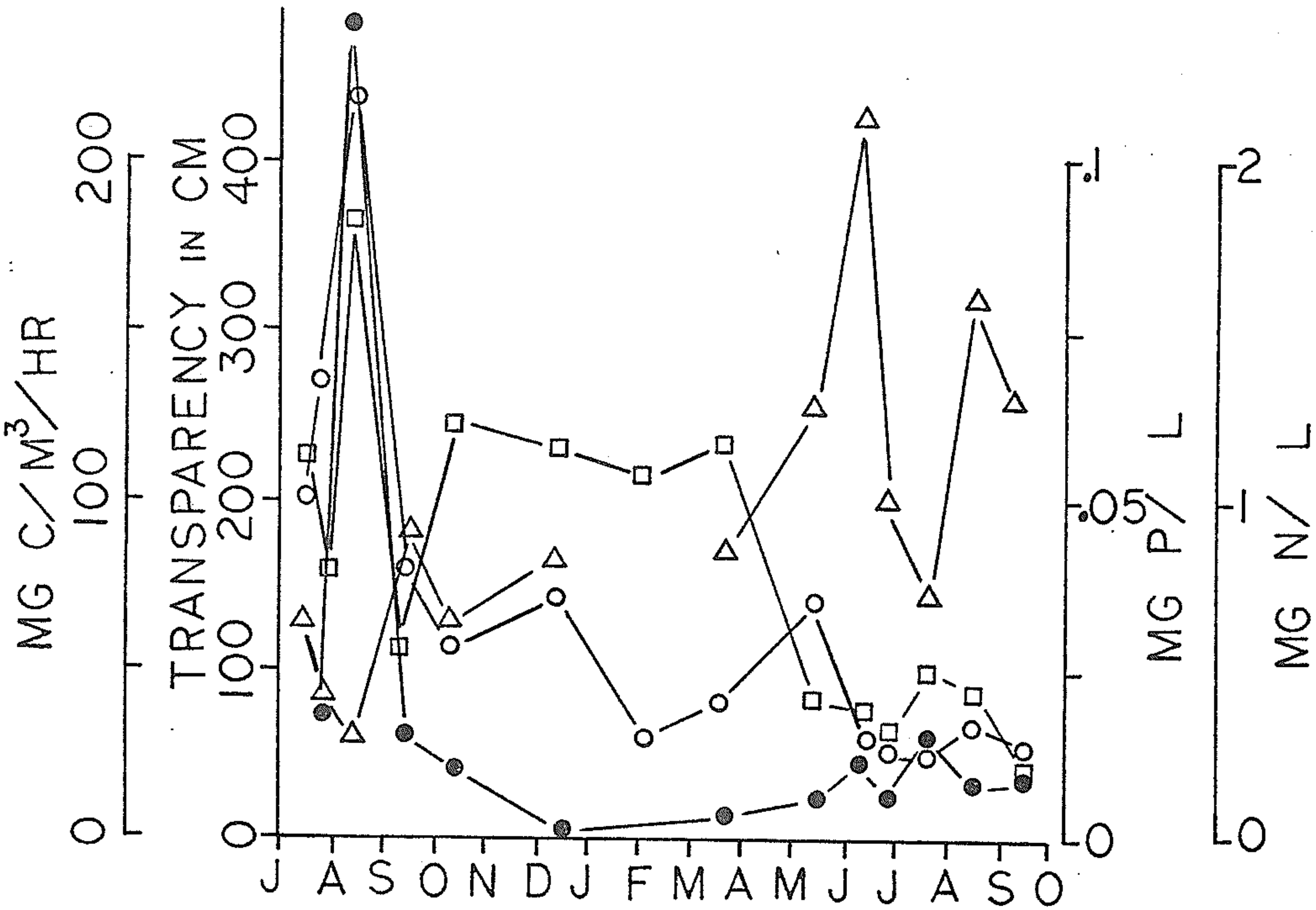


Figure 12. Comparison of primary productivity to transparency, nitrogen and phosphorus levels at Cochiti Reservoir. The values of transparency (△—△), fixation of CO_2 (●—●), Nitrogen content (○—○) and Phosphorus (□—□) were determined on the surface at station 1.

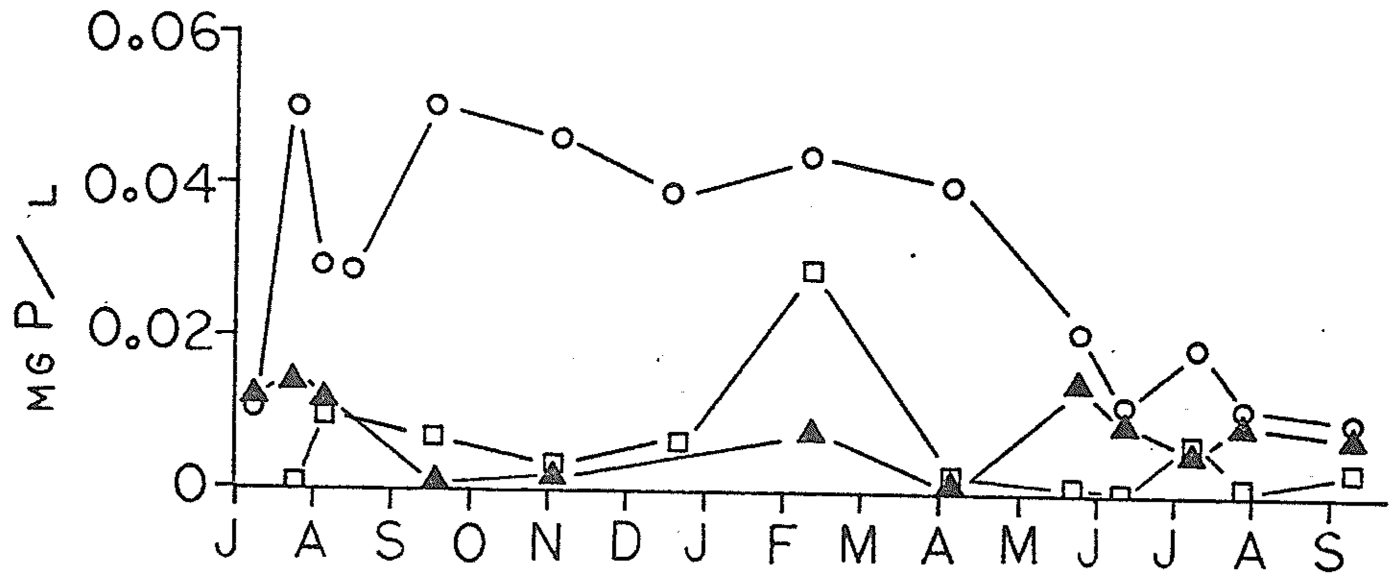


Figure 13. Phosphorus analysis of water from Abiquiu Reservoir. Samples were filtered through 0.45μ membrane filters and analyzed for orthrophosphate (□—□) and total filtered phosphorus (▲—▲). Total phosphorus (O—O) was determined using unfiltered samples. Values are for the surface of station 2.

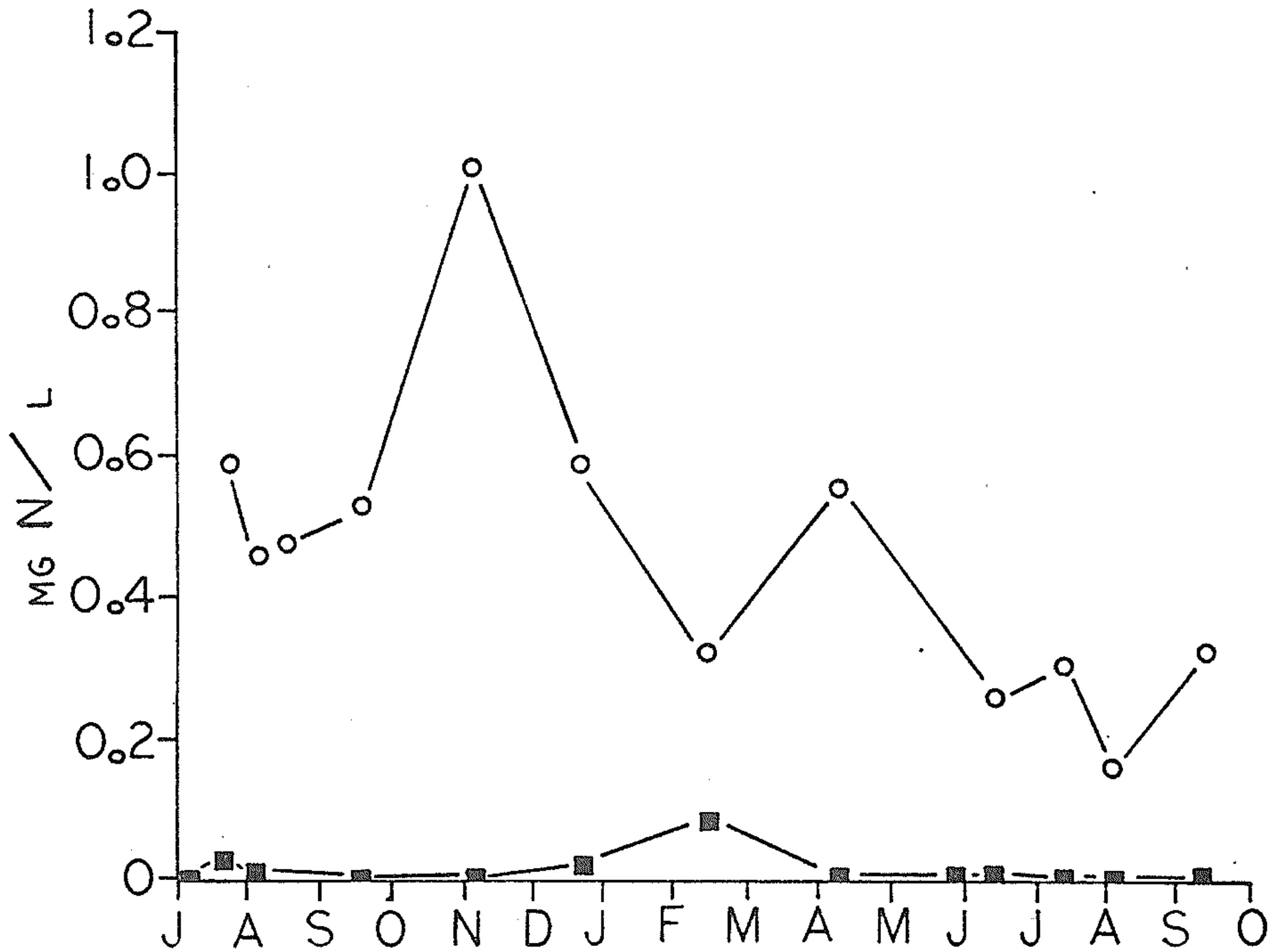


Figure 14. Nitrogen analysis of water from Abiquiu Reservoir. Nitrate (■—■) measurements were made on water filtered through 0.45μ membrane filters. Total nitrogen (O—O) was determined using unfiltered samples. Values are for the surface at station 2.

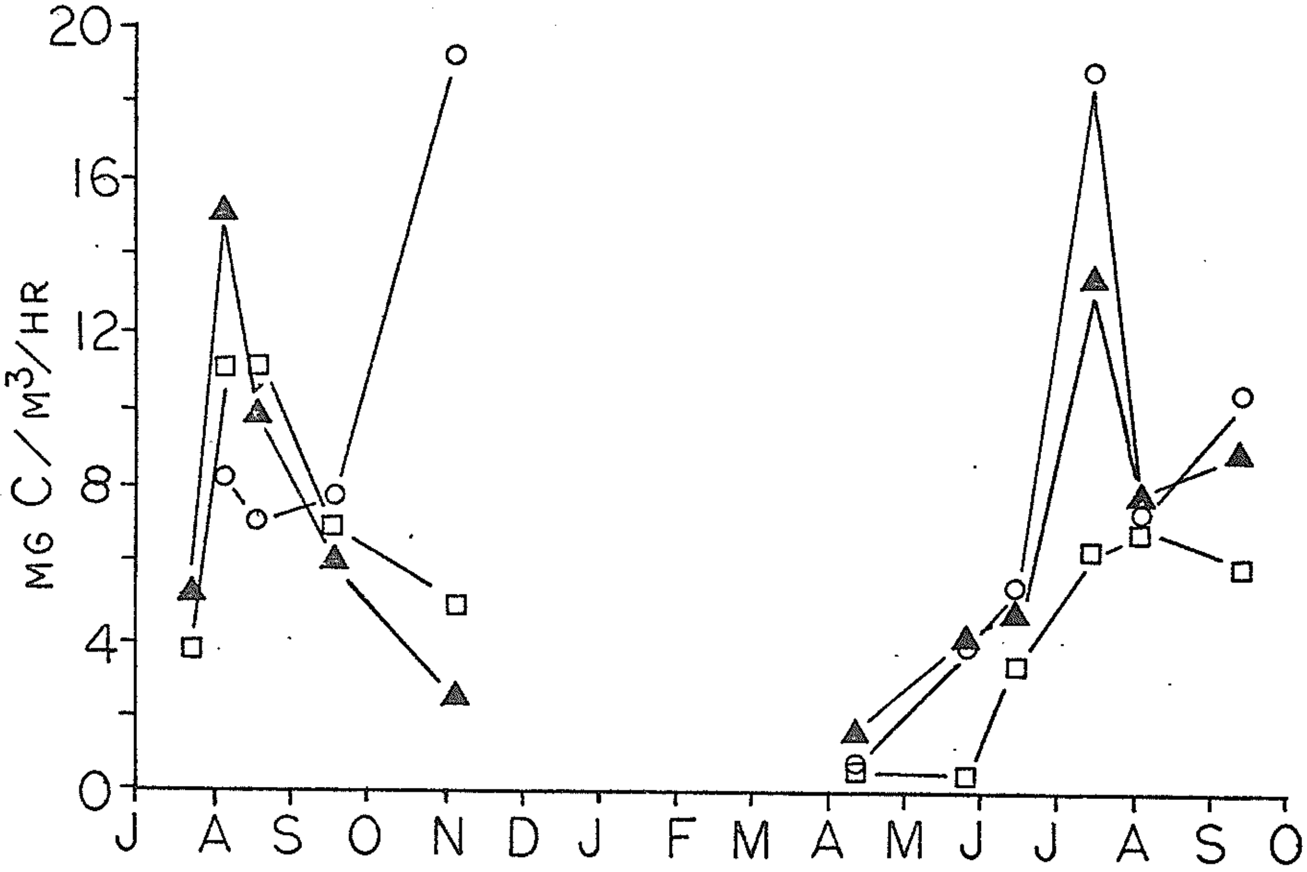


Figure 15. Primary Productivity measurements on the surface of the Abiquiu Reservoir. Values indicate CO_2 fixation at stations 2 (○—○), 3 (□—□) and 5 (▲—▲).

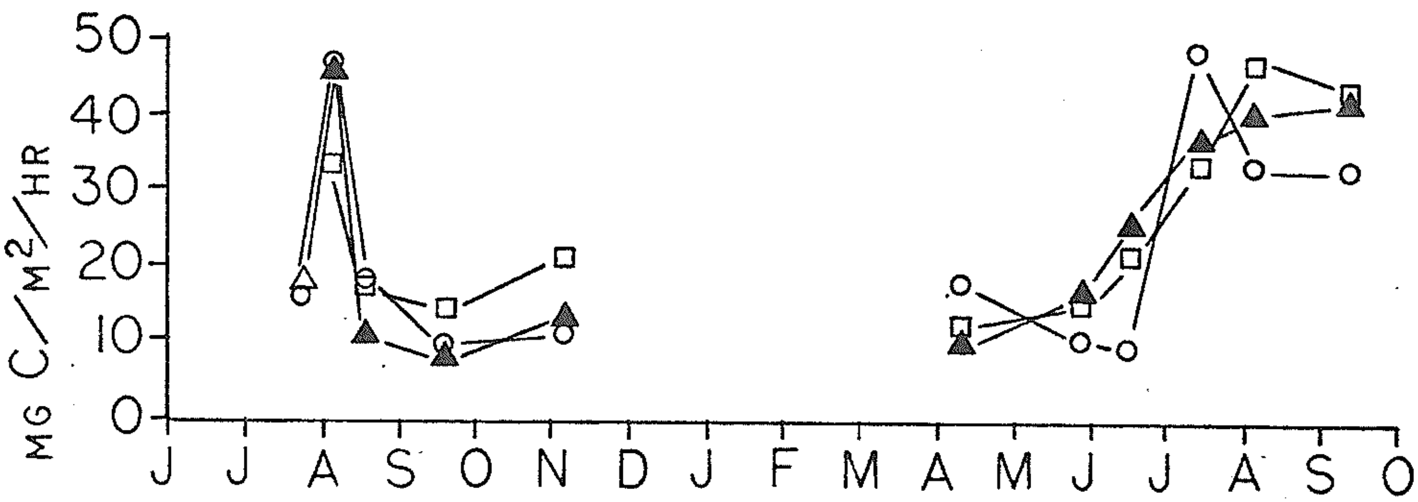


Figure 16. Primary Productivity values for each station at Abiquiu Reservoir. Values include CO_2 fixation at surface and deep levels at stations 2 (□—□), 3 (○—○) and 5 (▲—▲).

Table 24. Cation and anion concentrations in Abiquiu Reservoir water samples in mg/ liter. Samples were filtered through 0.45μ membrane filters.

Date	Station	Depth	Ca	Mg	Na	K	Cl	SO_4	Fe	Mn	Cu	Zn
9/17/76	2	Surface	33.3	5.3	11.1	-	2.83	57.5	0.02	nd*	nd	nd
		5 m	35.4	5.4	11.3	2.20	2.27	57.6	0.02	nd	nd	0.003
		20 m	28.5	4.6	8.1	2.24	1.91	39.1	0.01	0.01	nd	0.001
	3	Surface	34.7	5.3	11.3	2.11	2.77	59.1	0.02	nd	nd	nd
		5 m	35.1	5.3	11.5	2.06	2.49	58.1	0.02	nd	.01	0.003
	4	Surface	32.6	5.3	11.0	1.86	2.29	63.6	0.04	nd	0.01	nd
		5 m	31.7	5.1	10.1	1.97	2.31	51.6	0.05	nd	0.01	0.001
	Flume		28.7	4.5	8.3	1.73	1.75	39.1	0.01	nd	nd	0.005
5/26/77	1	Surface	42.1	7.3	16.6	2.21	3.2	88.4	-	-	-	-
		5 m	42.0	7.3	16.6	2.12	3.2	98.4	-	-	-	-
	2	Surface	42.6	7.3	15.9	2.20	3.1	83.4	0	0.001	0.004	0.004
		5 m	-	-	-	-	-	-	0	0	0.001	0
		20 m	41.9	7.3	15.8	2.17	2.9	68.4	-	-	-	-
	3	Surface	42.3	7.3	16.2	2.16	3.0	68.4	-	-	-	-
		5 m	42.0	7.2	15.9	2.11	3.0	63.4	-	-	-	-
	4	Surface	42.6	7.3	16.3	2.14	2.8	68.4	-	-	-	-
		5 m	39.1	6.7	14.9	1.98	2.6	68.4	-	-	-	-
	5	Surface	42.1	7.3	16.3	2.15	2.9	63.4	-	-	-	-
		5 m	43.5	7.5	16.1	2.21	3.0	68.4	-	-	-	-
	Flume		40.1	7.0	14.8	2.06	1.8	78.4	-	-	-	-

* Below detectable limits of standard atomic absorption analysis (Mn and Cu < 0.01 and Zn < 0.001)

concentration for 49 lakes investigated throughout the United States by the EPA (Miller et al., 1974) was 4 μg/liter. It appears that the concentration of iron and possibly manganese as well might have been limiting for phytoplankton growth in May, 1977.

pH values for Abiquiu Reservoir water are tabulated in Table 25. During the summer of 1976 pH values at the surface and 5 m depth ranged from 7.7 - 8.0 except on August 18 when values of 6.7 - 7.1 were measured. During the fall, winter and early spring pH values were somewhat lower (5.9 - 7.4). From late May through September, 1977, pH values were higher, ranging from 7.8 - 8.7. The higher pH values are associated with periods of increased phytoplankton photosynthesis.

Total alkalinities for Abiquiu Reservoir, are listed in Table 5. The total alkalinities were noted to be slightly higher in the summer of 1977 than 1976. Total alkalinities of Abiquiu water samples are slightly lower than those measured in samples from Cochiti Reservoir. Phenolphtalein alkalinity was measureable only in surfaces samples collected on August 3, 1977 (Table 6).

Dissolved oxygen concentrations for Abiquiu Reservoir water are presented in Table 26. Oxygen depletion occurred at depths of 5 m and greater when the reservoir was frozen over (December, 1976). Significant oxygen depletion occurred at Station 2 at depths of 5 m or more and at Stations 3 and 4 at 10 m in April, 1977. Oxygen depletion was noted occasionally in August and September of bothyears (e.g. Station 2 at 10 m in September, 1977).

Table 25. pH values at Abiquiu Reservoir

Date	Station 1		Station 2			Station 3		Station 4		Station 5	
	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m
7/7/76	7.2	7.3	7.4	7.2		7.4	7.5	7.8	-		
7/22/76	-	-	7.8	7.5		7.7	7.8	7.8	7.7	7.8	
8/4/76	8.3	-	7.8	7.8	7.8	7.9	7.7	8.0	7.6	7.7	7.7
8/18/76	-	-	6.9	7.1	6.9	6.8	6.8	6.8	6.7	6.8	6.7
9/17/76	-	-	7.7	7.8	-	8.0	8.1	-	7.7	8.0	7.8
11/5/76	6.5	6.5	6.8	6.6	6.9	6.6	6.7	6.4	6.6	6.5	6.6
12/20/76	-	-	6.7	7.1	-	7.4	7.2	-	-	7.3	7.4
4/9/77	-	-	6.9	6.7	-	7.0	6.0	6.0	5.9	7.1	7.2
5/26/77	8.2	8.1	8.2	8.0	7.9	8.1	8.1	8.2	8.2	7.8	8.2
6/15/77	-	-	8.4	8.2	8.0	8.4	8.2	8.4	8.3	8.4	8.2
7/13/77	-	-	8.4	8.2	7.0	8.2	8.1	8.4	8.4	8.5	8.0
8/3/77	-	-	8.7	7.8	7.6	8.6	8.0	8.6	7.8	8.6	8.0
9/13/77	8.3	8.3	8.3	8.2	7.6	8.3	8.2	8.3	8.3	8.2	8.2

Table 26. Dissolved oxygen at Abiquiu Reservoir in mg O_2/ liter

Date	Station 1		Station 2				Station 3				Station 4			Station 5		
	Surface	5 m	Surface	5 m	10 m	15 m	Surface	5 m	10 m	15 m	Surface	5 m	10 m	Surface	5 m	10 m
7/7/76	10.2	8.4	10.1	5.0	4.6	5.3	11.4	7.2	5.2	4.6	10.8	10.2	-	-	-	-
7/22/76	-	-	-	-	-	-	7.5	7.2	7.4	-	6.5	6.3	6.2	-	-	-
8/4/76	7.2	6.8	6.7	6.6	5.0	5.2	6.9	6.9	4.9*	-	7.1	6.8	5.6	-	-	-
8/18/76	-	-	7.4	7.1	5.5	6.5	7.2	7.0	5.4	-	7.1	6.7	7.0	7.4	7.2	6.9
9/17/76	-	-	7.0	6.7	6.6	6.7	7.4	6.8	6.8	6.9	8.2	2.0	1.5	-	-	-
11/5/76	7.7	8.3	9.0	8.8	8.4	8.4	8.6	8.3	-	-	8.5	8.3	8.3	-	-	-
12/20/76	-	-	7.0	2.3	2.2	2.3	9.0	3.2	2.5*	-	-	-	-	5.8	2.5	2.3
4/9/77	-	-	12.0	3.0	2.8	2.9	8.0	5.2	3.6	3.4**	10.5	5.8	3.4	-	-	-
5/26/77	9.5	9.5	9.0	9.0	8.8	8.3	9.8	9.0	8.6	8.5**	9.3	9.1	8.7	9.1	9.2	8.4
6/16/77	-	-	7.2	6.9	6.7	7.0	7.5	7.2	7.4	7.8**	7.6	8.1	8.5	-	-	-
7/13/77	-	-	7.0	6.7	5.2	4.9	7.5	7.7	6.5	6.3**	7.3	6.8	5.8	7.1	7.0	6.1
8/3/77	-	-	8.0	5.1	4.1	4.5	8.0	5.3	1.4	-	8.0	5.8	4.2+	-	-	-
9/13/77	6.9	5.5	6.7	6.6	2.6	3.8	7.2	7.1	6.0*	-	8.0	6.7	3.1+	-	-	-

* Measured at 8 m.
** Measured at 11 m.
\+ Measured at 9 m.

The total phosphorus concentrations in unfiltered water, total phosphorus concentrations in membrane filtered water, and orthophosphate-phosphorus concentrations in membrane filtered water are given for Abiquiu Reservoir in Tables 27, 28 and 29. The concentration of the three phosphorus classes are depicted in Figure 13 for surface samples at Station 2 during the course of the study. The total phosphorus concentrations in unfiltered samples from the surface and 5 m depths did not vary in any consistent pattern among the various sampling stations on the reservoir (Table 27). The total phosphorus concentrations at a depth of 20 m at Station 2 and from the outlet (flume) were significantly higher than most surface and 5 m samples on the same sampling dates and similarly the highest concentrations of total phosphorus in membrane filtered water were generally at Station 2 at 20 m and the flume sample (Table 28). Usually only a small proportion of the total phosphorus was present as orthophosphate and on a number of sampling dates in 1977 it was below detectable limits. Concentrations of total phosphorus in unfiltered water from surface and 5 m depths from May through September, 1977 were considerably lower than samples collected during the period of July 22, 1976 to May 9, 1977 (Table 27 and Figure 13). Total phosphorus concentrations in Abiquiu Reservoir were below those measured in Cochiti Reservoir.

Total nitrogen concentrations in unfiltered water and nitrate- and ammonium-nitrogen concentrations in membrane filtered water from Abiquiu Reservoir are tabulated in Tables 30, 31 and 32. The total nitrogen concentration and nitrate-nitrogen concentrations are shown graphically for surface samples from Station 2 in Figure 14.

Table 27. Total phosphorus concentration in unfiltered Abiquiu Reservoir water as mg phosphorus/liter.

	Station 1		Station 2			Station 3		Station 4		Station 5		Flume
Date	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/7/76	0.010	0.010	0.010	-	-	0.005	-	-	-	-	-	0.075
7/22/76	-	-	0.05±.000* a	0.039±.000 abc	-	0.035±.000 bc	0.028±.000 c	0.028±.000 c	0.032±.002 bc	0.032±.002 bc	0.035±.004 abc	0.046±.002 ab
8/4/76	0.032±.001 ef	-	.029±.001 f	.028±.002 f	.057±.001 b	.042±.000 de	.046±.001 cd	.052±.002 bc	.046±.002 cd	.042±.000 de	.048±.003 cd	.070±.001 a
8/18/76	-	-	.028±.000 b	.030±.002 b	.058±.002 a	.035±.004 b	.035±.004 b	.044±.003 ab	.038±.002 b	.042±.000 ab	.029±.003 b	.057±.001 a
9/17/76	-	-	.050	.047	.030	.030	.030	.030	.047	.027	.047	.050
11/5/76	.031±.014 abc	.034±.000 bf	.046±.011 a	.034±.002 bd	.046±.002 ab	.018±.000 cdef	.031±.004 abc	.018±.000 cdef	.034±.005 abc	-	-	.084±.004 ab
12/20/76	-	-	.039	.030	-	.028	.025	-	-	.020	.038	.063
2/12/77	-	-	.044	.032	-	.031	.028	-	-	.032	.035	.051
4/9/77	-	-	.040	.030	-	.035	.025	-	-	.031	.040	.055
5/26/77	.020±.001 cd	.018±.000 d	.021±.001 cd	.023±.004 cd	.038±.002 a	.018±.001 d	.019±.002 cd	.026±.000 bcd	.026 .002 bcd	.020±.000 cd	.029±.000 abc	.036±.004 ab
6/15/77	-	-	.012±.001 d	.022+.002 bc	.050±.001 a	.013±.000 cd	.025±.000 b	.018±.002 bcd	.036±.003 e	.015±.001 cd	.026±.003 b	.057±.002 a
7/13/77	-	-	.019±.001 c	.010±.001 d	.032±.002 b	.012±.002 d	.004±.000 e	.008±.001 de	.012±.001 d	.021±.001 c	.013±.001 d	.059±.001 a
8/3/77	-	-	.012±.000 de	.023±.001 c	.045±.000 b	.009±.000 e	.021±.000 c	.014±.001 d	.021±.001 c	.011±.001 de	.021±.001 c	.087±.001 a
9/13/77	.021±.002 b	.021±.001 b	.009±.000 c	.013±.002 c	.021±.001 b	.008±.000 c	.012±.001 c	.009±.000 c	.009±.002 c	.008±.001 c	.009±.001 c	.054±.000 a

* Standard Error

Table 28. Total phosphorus concentration in filtered Abiquiu Reservoir water as mg phosphorus/liter. Water samples were filtered through a 0.45 membrane filter.

	Station 1		Station 2			Station 3		Station 4		Station 5		Flume
Date	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/7/76	0.005	-	0.010	-	-	0.005	-	-	-	--	-	0.025
7/22/76	-	-	.014	0.14	-	.014	.011	.007	.014	.011	.014	.021
8/4/76	.007	-	.011	.014	.021	.007	.014	.014	.014	0.[illegible]	.014	.014
8/18/76	-	-	-	.007	-	.009	-	.007	0	0	-	-
9/17/76	-	-	0	0	.004	0	0	0	0	0	0	.005
11/5/76	0	-	.001	0	.003	0	0	0	0	-	-	.004
2/12/77	-	-	.006	.004	-	.007	.004	-	-	.004	.009	.008
4/9/77	-	-	.001	0	-	.011	.006	.001	.001	.004	.009	.008
5/26/77	.016	.017	.014	.015	.014	.029	.017	.014	.015	.007	.007	.017
6/15/77	-	-	.009	.013	.013	.008	.013	.006	.018	.015	.009	.025
7/13/77	-	-	.005	.005	.019	.003	.005	.012	.007	.014	.008	.019
8/3/77	-	-	.009	.015	.014	.012	.010	.019	.013	.008	.009	.015
9/13/77	0	0	.008	.004	.013	0	0	0	.001	.004	.003	.013

Table 29. Orthophosphate concentrations in Abiquiu Reservoir water as mg phosphorus/liter. Water samples were filtered through a 0.45 membrane filter.

	Station 1		Station 2			Station 3		Station 4		Station 5		Flume
Date	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/7/76	.006	.009	.010	.007	-	.009	.008	.021	-	-	-	.013
7/22/76	-	-	0	.006	-	0	0	0	0	0	0	0
8/4/76	.019	-	.009	-	.020	.009	.007	.014	.010	.009	.010	.023
8/18/76	-	-	-	.001	-	0	-	.008	.008	.004	-	-
9/17/76	-	-	.006	.006	.016	.006	.006	.007	.008	.007	.009	.015
11/5/76	.008	.006	.003	.003	.009	.006	.014	.002	.012	-	-	.008
12/20/76	-	-	.008	.008	-	-	-	-	-	-	.020	-
2/12/77	-	-	.028	.008	-	.008	.008	-	-	.009	.015	.006
4/9/77	-	-	0	0	0	0	0	.001	0	0	0	0
5/26/77	0	0	0	0	0	0	.03	0	0	0	0	0
6/15/77	-	-	0	0	0	0	0	0	0	0	0	0
7/13/77	-	-	.004	.004	.010	.002	.002	.002	.004	.002	.002	.002
8/3/77	-	-	0	0	0	0	0	.004	.002	0	0	.006
9/13/77	.006	.006	.003	.008	0	.003	.008	.003	.003	.003	.012	.007

Table 30. Total nitrogen concentration in unfiltered Abiquiu Reservoir water as mg nitrogen/liter.

Date	Station 1		Station 2			Station 3		Station 4		Station 5		Flume
	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/22/76	-	-	.575±.045* a**	.500±.060 a	-	.395±.025 a	.735±.305 a	.310±.230 a	.480±.030 a	.500±.070 a	.410±.110 a	.570±.040 a
8/4/76	.450±.040 abc	-	.455±.075 ab	.355±.025 abc	-	.380±.060 abc	.275±.025 bc	.300±.030 abc	.275±.005 bc	.215±.045 c	.280	.520±.160 a
8/18/76	-	-	.470±.190 ab	.380±.100 ab	.495±.005 ab	.370±.140 ab	.510±.060 ab	.450±.050 ab	.380±.100 ab	.310±.020 b	.400±.050 ab	.680±.170 a
9/17/76	-	-	.525±.035 ab	.415±.005 b	.710±.090 a	.545±.035 ab	.535±.135 ab	.580±.050 ab	.595±.045 ab	.510±.050 ab	.470±.050 b	.525±.045 ab
11/5/76	.445±.035 b	.545±.075 b	1.070±.270 a	.375±.005 b	.440±.030 b	.420	.390±.020 b	.425±.015 b	.435±.035 b	-	-	.640±.110 b
12/20/76	-	-	.585±.045 a	.570±.000 a	-	.755±.105 a	.555±.105 a	-	-	.465±.015 a	.590±.150 a	.725±.025 a
2/12/77	-	-	.305±.035 c	.385±.005 bc	-	.350±.040 bc	.535±.025 a	-	-	.605±.015 a	.315±.025 c	.430±.020 b
4/9/77	-	-	.550±.030 a	.340±.120 bc	.550±.030 a	.255±.005 bc	.210±.020 c	.260±.020 bc	.285±.025 bc	.270±.000 bc	.270±.020 bc	.380±.010 b
5/26/77	.310±.010 bc	.375±.035 ab	-	-	.305±.025 bc	.245±.005 c	.320±.010 bc	.400±.060 ab	.310±.040 bc	.315±.015 bc	.435±.035 a	.460±.010 a
6/15/77	-	-	.250±.070 ab	.260±.020 ab	.225±.005 ab	.195±.005 b	.260±.000 ab	.225±.005 ab	.285±.005 ab	.245±.005 ab	.210±.010 ab	.290±.040 a
7/13/77	-	-	.300±.020 b	.330±.050 b	.305±.015 b	.290±.020 b	.330±.050 b	.295±.035 b	.350±.040 b	.320±.030 b	.370±.030 b	.530±.010 a
8/3/77	-	-	.155±.005 bc	.210±.020 bc	.175±.005 bc	.125±.015 c	.195±.035 bc	.130±.010 c	.530±.030 a	.220±.080 bc	.315±.125 abc	.410±.180 ab
9/13/77	.375±.065 cd	.275±.005 d	.320±.020 cd	.295±.005 d	.665±.115 b	.320±.020 cd	.420±.020 cd	.385±.035 cd	.395±.045 cd	.315±.015 cd	.470±.060 c	.855±.055 a

* Standard error

** Significant differences were determined by Duncan's new multiple range test. On each date values with differing letters are significantly different ($P = 0.05$).

Table 31. Nitrate nitrogen concentrations in Abiquiu Reservoir water as mg nitrogen/liter. Water samples were filtered through a 0.45 μ membrane filter.

	Station 1		Station 2			Station 3		Station 4		Station 5		Flume
Date	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/7/76	0.005	0.007	0.003	0.005	-	0.005	0.008	0.003	-	-	-	0.022
7/22/76	-	-	0.022	0.018	-	0.010	0.010	0.014	0.016	0.004	0.002	0.062
8/4/76	0.010	-	0.007	-	0.145	0.014	0.013	0.040	0.012	0	0.039	0.129
8/18/76	-	-	-	0	-	0	-	0	0	0	-	-
9/17/76	-	-	0	0.014	0.116	0.001	0.009	0.005	0.038	0	0.030	0.107
11/5/76	0	0	0	0	0.011	0.005	0.003	0	0	-	-	0.005
12/20/76	-	-	0.016	0.012	-	-	-	-	-	-	0.005	-
2/12/77	-	-	0.073	0.021	-	0.005	0.010	-	-	0.005	0.021	0.035
4/9/77	-	-	0.002	0.001	0.005	0.001	0.001	0.002	0.001	0	0.001	0.003
5/26/77	0.001	0.002	0.002	-	0.004	0.002	0.001	0	0.003	0.001	0.002	0.004
6/15/77	-	-	0.004	0.004	0.012	0.002	0.002	0	0.003	0	0	0.014
7/13/77	-	-	0.001	0	0.105	0	0.005	0.002	0.029	0.002	0.015	0.108
8/3/77	-	-	0	0.002	0.012	0.001	0	0	0.002	0	0	0.011
9/13/77	0.006	0.005	0.008	0	0.002	0	0.012	0.010	0.008	0.008	0.006	0.169

Table 32. Ammonium nitrogen concentration in Abiquiu Reservoir water as mg nitrogen/liter. Water samples were filtered through a 0.45 μ membrane filter.

	Station 1		Station 2			Station 3		Station 4		Station 5		Flume
Date	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/7/76*	.01	.01	.02	.01	–	.01	.01	.03	–	–	–	.02
7/22/76	–	–	.05	.03	–	.07	.05	.05	.11	0	0	–
8/4/76	0	–	0	–	.01	0	0	.02	0	.01	.02	.01
8/18/76	–	–	–	.02	.07	–	–	–	–	–	–	.09
9/17/76	–	–	.03	.02	–	.07	.03	.03	–	–	–	.06
11/5/76	.20	.27	.18	.04	.02	.12	.04	.34	.20	–	–	.08
12/20/76	–	–	.08	.56	–	–	–	–	–	–	.19	.05
2/12/77	–	–	0	.05	–	.07	.11	–	–	.08	.09	.08
4/9/77	–	–	0	0	0	0	0	0	0	0	0	0
5/26/77	0	.01	.09	0	.02	.03	.06	.30	0	0	0	0.12
6/15/77	–	–	.02	.02	.03	.01	.03	.04	.03	.01	.01	.02
7/13/77	–	–	.02	.01	.03	.02	.01	.01	.03	0	.03	.04
8/3/77	–	–	.02	.01	.03	0	.02	.02	.04	0	.20	.14
9/13/77	.02	.03	.01	.01	0	.02	–	.02	0	.02	.01	.08

* On this date only samples were acidified but not filtered

On the various sampling dates total nitrogen concentrations did not generally vary significantly between surface and 5 m depths at each station or between reservoir stations. The total nitrogen concentration at the outlet (flume) usually did not differ significantly from concentrations at the surface, 5 m, or 20 m depths, at Station 2 which is near the dam. However, on three of the five sampling dates between May and September, 1977, significantly higher concentrations of total nitrogen occurred in the outlet than at Station 2. The unusually high total nitrogen concentration in the surface sample at Station 2 on November 5, 1976, was associated with an extremely large population of Aphanizomenon (Table 36) in the surface sample. Based on phytoplankton cell counts and primary productivity (Table 34), the abundance of phytoplankton decreased sharply with increasing depth and the total nitrogen concentration was also considerably lower at the 5 m depth. It is probable that nitrogen fixation could readily have been measured at the surface at Station 2 on this date. The total nitrogen concentrations in surface and 5 m samples were lower in the summer of 1977 with a mean of 0.30 mg/liter compared to the period of July-September, 1976 with a mean of 0.44 mg/liter. Total nitrogen concentrations were considerably lower in Abiquiu Reservoir than Cochiti Reservoir in the summer of 1976; however, total nitrogen concentrations were similar in the two reservoirs in the summer of 1977.

Nitrate-nitrogen concentrations in membrane filtered water were generally very low in samples from the surface and 5 m depths compared to the total nitrogen concentration (Table 31, Figure 14).

Table 32a. Total nitrogen:total phosphorus ratio computed for unfiltered Abiquiu Reservoir water

	Station 1		Station 2			Station 3		Station 4		Station 5		
Date	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	Flume
7/22/76	-	-	11.5	12.8	-	11.3	26.3	11.1	15.0	15.6	11.7	12.39
8/4/76	14.1	-	15.7	12.7	-	9.0	5.9	5.8	5.9	5.1	8.0	7.4
8/18/76	-	-	16.8	12.7	8.5	10.6	14.6	10.2	10.0	7.4	13.8	11.9
9/17/76	-	-	10.5	8.8	23.7	18.2	17.8	19.3	12.7	18.9	10	10.5
11/5/76	14.4	16.0	23.3	11.0	9.6	23.3	12.6	23.6	12.8	-	-	7.6
12/20/76	-	-	15	19	-	26.9	22.2	-	-	23.3	15.5	11.5
2/12/77	-	-	6.9	12.0	-	11.3	19.1	-	-	18.9	9.0	8.4
4/9/77	-	-	13.8	11.3	-	7.3	8.4	-	-	8.7	6.75	6.9
5/26/77	15.5	20.8	-	-	8.0	13.6	16.8	15.4	11.9	15.8	15	12.8
6/15/77	-	-	20.8	11.8	4.5	15.0	10.4	12.5	7.9	16.3	8.1	5.1
7/13/77	-	-	15.8	33.0	9.5	24.2	82.5	36.9	29.2	15.2	28.5	8.9
8/3/77	-	-	12.9	9.1	3.9	13.9	9.3	9.3	25.2	20	15	4.7
9/13/77	17.9	13.1	35.6	22.7	31.7	40	35	42.8	43.9	39.4	52.2	15.8

Table 33. Chlorophyll a concentrations in Abiquiu Reservoir water as mg/ m^3.

	Station 1		Station 2		Station 3		Station 4		Station 5	
Date	Surface	2 m	Surface	2 m	Surface	2 m	Surface	2 m	Surface	2 m
7/22/76	-	-	1.9	2.6	4.9	4.1	-	-	11.7	3.5
8/4/76	-	-	1.1	0	0	0	0	0	0	0
8/18/76	-	-	2.8	2.1 (0.4)*	3.9 (0.9)	2.0 (1.4)	4.2 (0.6)	-	1.6 (3.4)	6.1
9/17/76	-	-	0	0	0	0	0	0	0	0
11/5/76	143.8(4.1)	0	0	0		-	0	-	-	0
5/26/77	-	-	0	0	0	0	0	0	0	0
6/15/77	-	-	0	0	0	0	0	0	0	0
7/13/77	-	-	8.9	4.7	3.5	0	5.3	3.8	0	4.5
8/3/77			2.6	2.2	1.9	1.5	0	0	2.3	2.8
9/13/77	4.8 (0.3)	4.2	1.8(0.9)	4.6	0.6 (0.3)	0	-	-	-	-

* Phaeophytin concentration in mg/ m^3. Phaeophytin was detectible only in indicated samples.

Table 34. Primary productivity of Abiquiu Reservoir in mg carbon/ m^3/ hr.

Date	Station 2 Surface	1 m	2 m	3 m	4 m	Station 3 Surface	1 m	2 m	3 m	4 m	Station 5 Surface	1 m	2 m	3 m	4 m
7/22/76	-	-	-	-	-	3.71±0.84*	6.60±0.93	3.59±0.62	3.01±0.67	2.02±0.04	5.21±1.77	6.25±0.20	7.74±1.76	3.27±0.40	-
8/4/76	8.01±2.63	6.02±1.71	11.18±0.42	8.33±0.11	7.14±1.08	10.78±2.74	13.81±0.12	14.05±2.55	11.54±1.77	6.78±0.33	15.07±0.63	11.74±4.12	13.84±0.93	9.93±0.67	7.26±0.35
8/18/76	7.02±0.78	6.54±0.88	4.64±0.03	3.72±1.61	1.77±0.15	10.79±0.52	7.77±0.01	3.56±0.87	2.05±0.11	0.92±0.0	9.74±0.92	4.23±1.80	1.69±0.66	0.98±0.52	1.21±0.30
9/17/76	7.61±0.65	5.16±0.05	2.21±0.30	0.75±0.04	0.08±0.02	6.54±0.01	4.55±0.92	2.44±0.15	0.83±0.06	0.57±0.12	5.84±3.32	3.57±0.93	1.25±0.25	0.315±0.06	0.07
11/5/76	19.13±3.33	5.16±0.28	4.07±0.42	1.08±0.41	0.61	4.66±1.48	2.50±1.48	2.37±0.48	2.96±0.18	1.18±0.11	2.36±0.94	3.16±1.68	5.12±1.04	1.33±0.37	0.81±0.52
4/9/77	0.55	3.025±0.19	3.85±0.83	3.11±0.09	4.66±0.74	0.64±0.10	10.42±8.7	1.41±1.05	3.30±0.54	2.76±0.42	1.20±0.45	3.67±1.72	1.46±0.36	1.33±1.19	1.06±0.27
5/26/77	3.91	3.22±0.22	3.46±0.29	3.45±0.74	2.71±0.32	0.31±0.02	2.66±0.69	2.42±0.55	2.66±0.58	2.91±0.25	3.80±0.59	4.18±0.34	2.84±0.64	2.26±0.09	4.83±3.01
6/15/77	5.00±0.16	5.00±0.52	6.16±0.04	6.20±0.96	2.06±0.03	3.09±0.14	3.00±0.05	0.73±0.05	3.30±0.27	4.09±0.24	4.48±1.86	2.82±0.14	3.80±0.33	4.46±0.79	4.95±0.14
7/13/77	18.74±1.05	8.18±0.25	5.89±1.37	5.47±0.30	5.61±0.59	6.20±0.17	7.03±0.19	6.49±0.0	5.18±0.75	6.78±1.28	13.36±1.56	10.17±0.99	10.20±0.08	7.47±0.74	3.93±0.20
8/3/77	7.35±1.40	10.41±0.88	10.16±0.05	13.82±0.86	15.61±0.45	6.75±0.14	7.10±0.31	10.36±0.41	7.29±0.70	8.69±0.26	7.82±0.04	10.41±0.99	10.23±0.32	8.76±0.86	13.63±1.06
9/13/77	10.24±0.52	10.86±0.74	10.66±0.09	11.24±0.66	8.87±1.38	5.80±1.60	10.69±0.07	9.63±0.24	7.21±1.10	6.71±0.07	8.63±0.55	13.43±0.48	10.73±0.11	10.15±0.41	7.70±1.72

* Standard error

Table 35. Primary productivity of Abiquiu Reservoir on an area basis as mg carbon/m^2/hr

Date	Station 2	Station 3	Station 5
7/22/76	-	16.13	18.39
8/4/76	33.87	47.42	46.45
8/18/76	18.39	18.71	11.94
9/17/76	13.55	10.97	9.68
11/5/76	20.97	10.65	12.26
4/9/77	12.58	17.10	9.68
5/26/77	14.84	10.32	13.87
6/15/77	21.61	10.00	25.81
7/13/77	32.26	48.39	35.48
8/3/77	46.77	33.22	40.00
9/13/77	42.58	33.22	42.26

During the summer months the nitrate concentration at a depth of 20 m at Station 2 and the flume were much higher than surface and 5 m concentrations but never accounted for more than 20 - 25% of the total nitrogen concentration.

The ammonium-nitrogen concentrations in membrane filtered water (Table 32) were frequently considerably higher than nitrate-nitrogen concentrations (Table 31) at the surface and 5 m depths. Usually less than 5-10% of the total nitrogen (Table 30) was in the form of ammonium; however, in the November, 1976 surface and 5 m samples ammonium comprised 36% of the total nitrogen on the average. Ammonium-nitrogen concentrations at the outlet were usually slightly higher than in surface and 5 m samples; however, nitrate was occasionally a more abundant form of inorganic nitrogen than ammonium in the outflow.

The ratios of total nitrogen: total phosphorus in unfiltered water are given for Abiquiu Reservoir in Table 32a. In almost all surface or 5 m samples the ratio was >7:1, implying, according to Bachmann and Jones, that nitrogen was adequate for aquatic plant growth while phosphorus was limiting in relation to the supply of nitrogen. While the ratio of total nitrogen: total phosphorus was high in surface samples when the greatest number of Aphanizomenon cells were present (November, 1976 according to Table 36), high ratios of nitrogen: phosphorus occurred in July-September, 1977 when blue-green algae were infrequently observed. If another nutrient were limiting, phytoplankton populations would fail to respond to increases in either nitorgen or phosphorus.

5. Phytoplankton and Microbiological Studies

Chlorophyll a concentrations are relatively low in most samples from Abiquiu Reservoir (less than 5 mg/m^3) and did not differ greatly during the two summers included in this study (Table 33). Some inconsistencies in the chlorophyll a concentrations compared to the abundance of phytoplankton (Table 36) are apparent. For example on November 5, 1976, chlorophyll a was not detectible in samples from Stations 2 through 5 while Aphanizomenon was very numerous in some samples and primary productivity was appreciable at the three primary productivity stations (Tables 34, 35). Possibly the failure to detect chlorophyll may be attributed to horizontal and vertical movements of the Aphanizomenon occurring between the time of collection of samples for primary productivity measurements and phytoplankton counts and samples for chlorophyll measurements. Primary productivity samples were always collected in the morning while sometimes chlorophyll samples were collected later in the day when surface blooms often were much less apparent. The occurrence of an extremely large population of Aphanizomenon at the surface of Station 1 is indicated by the chlorophyll a concentration on November 5, 1976. The sample was collected at the same time the sample for phytoplankton cell counts was obtained and suggests that even higher chlorophyll a concentrations should have been measured at Station 2. Station 1, in a narrow canyon at the lower end of the reservoir, appears to collect much of the algal bloom that drifts into the lower end of the reservoir.

Primary productivity is tabulated for each depth sampled in Table 34 and on an area basis in Table 35. Primary productivity is shown graphically for surface samples and on an area basis for the period of investigation in Figures 15 and 16. The depth distribution of primary productivity is depicted for each date of measurement at Station 2 in Figure 17. No consistent differences in primary productivity were noted between the three stations sampled. Primary productivity was low from late August, 1976 through June, 1977 and then increased in the period of July through September, 1977. While more values in the range of 30-50 mg C/m^2/hr were measured in the summer of 1977 than 1976, primary productivity did not differ greatly between the two summers. The lower values for primary productivity at Abiquiu Reservoir are typical of average values for oligotrophic lakes while the higher values (above $\sim$30 mg C/m^2 /hr) are in the mesotrophic range according to Wetzel.

The depth distribution of primary productivity (Table 34 and Figure 17) indicate that on some dates significant phytoplankton photosynthesis probably occurred at depths below 4 m and hence primary productivity was sometimes underestimated when computed on an area basis. This was most significant during July-September, 1977 when Secchi disc transparencies increased to values of 300-415 cm.

The phytoplankton genera identified and enumerated at Abiquiu Reservior are reported in Table 36. *Aphanizomenon flos-aquae* was the only phytoplankton genera identified in preserved samples in the early summer of 1976. *Aphanizomenon* was the most abundant phytoplankton during the summer and increased to very large

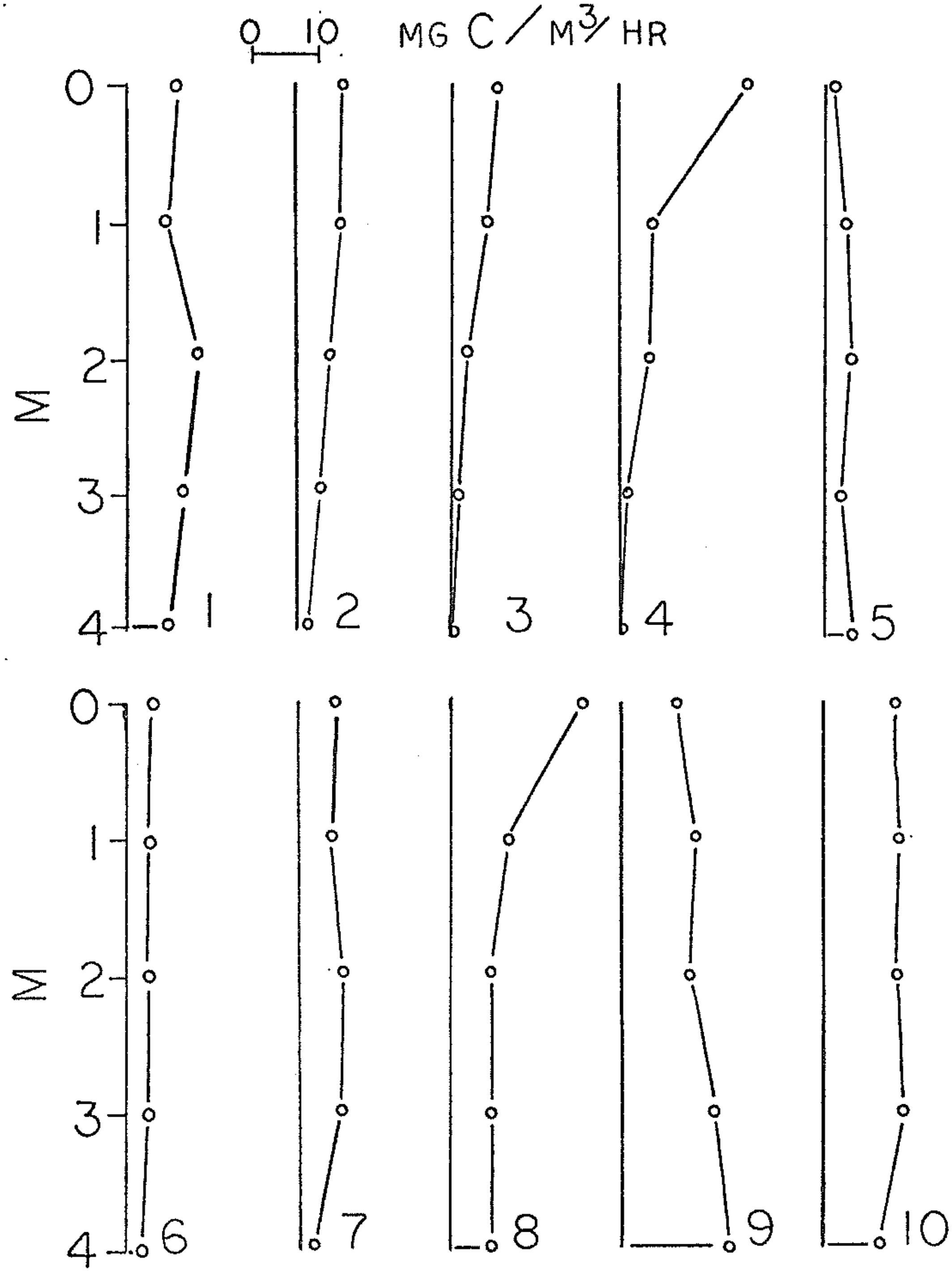


Figure 17. Primary Productivity at various depths at Abiquiu Reservoir. Values are for station 2 with the dates indicated as follows: 1, 8/4/76; 2, 8/18/76; 3, 9/17/76; 4, 11/5/76 5, 4/9/77; 6, 5/25/77; 7, 6/15/77; 8, 7/13/77; 9, 8/3/77; 10, 9/13/77.

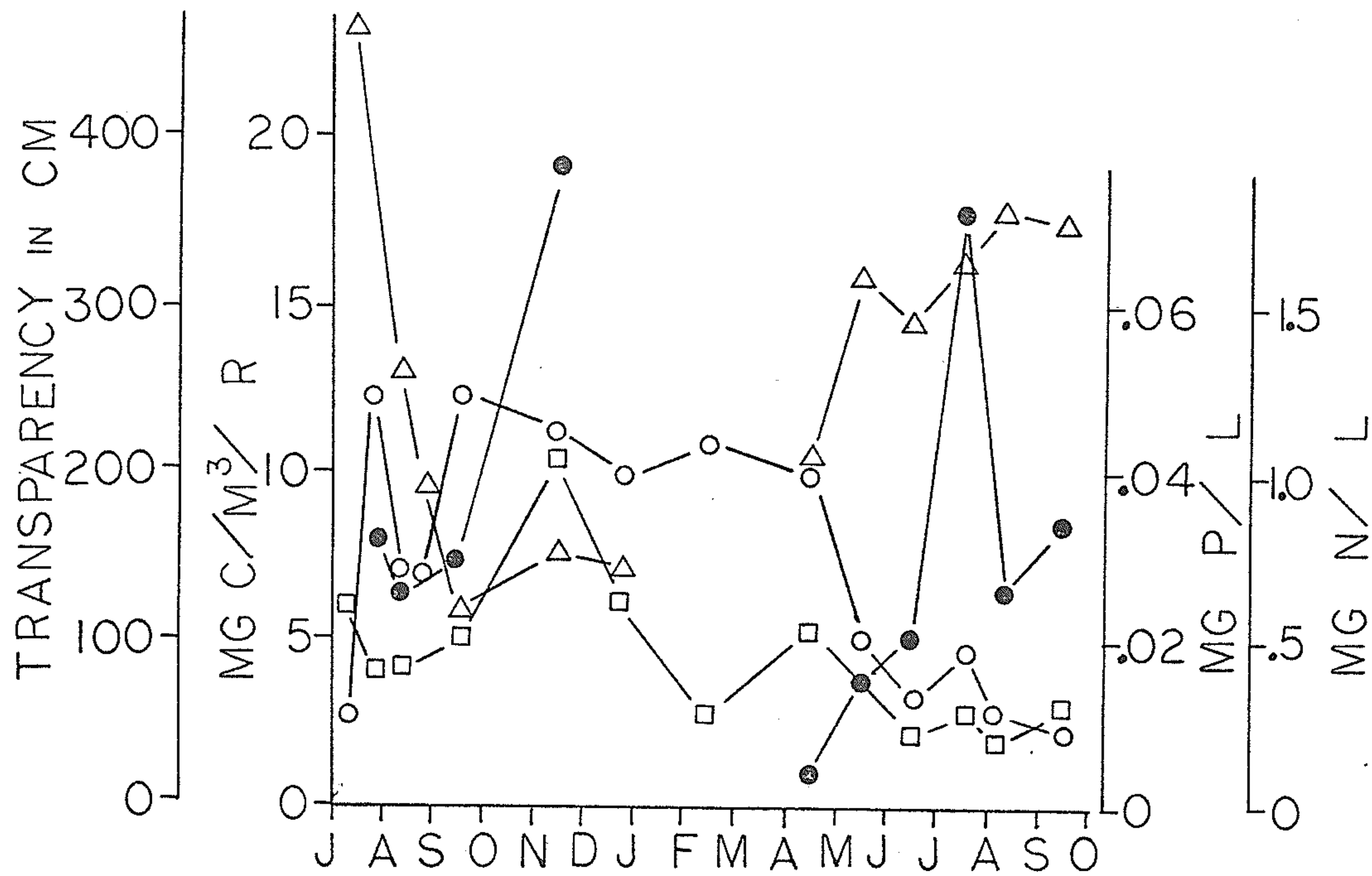


Figure 18. Comparison of primary productivity, transparency, nitrogen and phosphorus levels at Abiquiu Reservoir. The values of transparency (△—△), fixation of CO_2 (●—●), nitrogen (□—□) and phosphorus (○——○) were determined at the surface of station 2.

Table 36. Identification and enumeration of phytoplankton collected from Abiquiu Reservoir

DATE	STATION-DEPTH(m)	GENUS	TOTAL CELLS/ml	CYANOPHYTES			
				Heterocysts/ml	Cells/heterocyst	Filaments/ml	
						w/o heterocysts	w/heterocysts
07/07/76	1-S*	nd**					
	1-5	Aphanizomenon	1,556			257	
	2-S	nd					
	3-S	nd					
	3-5	nd					
	4-S	Aphanizomenon	7,272			909	
	4-5	nd					
07/22/76	2-2	nd					
	2-5	nd					
	3-2	nd					
	3-5	nd					
	4-S	Aphanizomenon	8,144	519	~16		519
	5-S	nd					
	5-2	nd					
08/04/76	2-S	nd					
	2-2	nd					
	3-S	Anabaena	15,390				
	3-2	Aphanizomenon	26,802	755	30-41	513	755
	4-S	Calothrix	253				
	5-S	Anabaena	15,384			1,282	
		Aphanizomenon	15,014	512	18-23	512	512
	5-2	Aphanizomenon	2,816	256	~11		256
08/18/76	2-S	Ceratium	779				
		Aphanizomenon	14,791	519	16-41		519
	2-2	Ceratium	833				
	3-S	nd					
	3-2	Ceratium	800				
	5-2	nd					
09/17/76	2-S	Aphanizomenon	4,608		~18	256	
	2-2	Aphanizomenon	7,101		6-21	526	
	3-S	Aphanizomenon	5,940	270	11-31		270
	3-2	nd					
	4-S	nd					
	4-2	Ceratium	270				
	5-S	nd					
	5-2	nd					
11/05/76	1-S	Aphanizomenon	92,209	3,117	8-15	8,052	3,117
	2-S	Aphanizomenon	219,094	3,333	6-17	12,051	3,333
	2-2	Aphanizomenon	16,211	540	~9	1,081	540
	3-S	Actinastrum	270				
		Aphanizomenon	1,723	533	13-25	266	533
		Actinastrum	266				

* Surface
** No discernable phytoplankton

DATE	STATION-DEPTH (m)	GENUS	TOTAL CELLS/ml	CYANOPHYTES heterocysts/ml	CYANOPHYTES cells/heterocyst	CYANOPHYTES filaments/ml w/o heterocysts	CYANOPHYTES filaments/ml w/heterocysts
	3-2	Aphanizomenon	3,367	259	~13		259
	4-S	Aphanizomenon	9,316	548	~17		548
	4-2	nd					
	5-S	nd					
	5-S	unknown	555				
	5-2	nd					
12/20/76	2-S	Asterionella	267				
	2-2	Asterionella	274				
	3-S	Asterionella	253				
	5-S	nd					
02/12/77	2-S	nd					
	2-2	nd					
	3-S	nd					
	3-2	Asterionella	200				
	4-S	nd					
	5-2	nd					
04/09/77	2-S	Asterionella	1,000				
	2-2	nd					
	3-S	nd					
	4-S	nd					
	4-2	nd					
	5-S	nd					
	5-2	nd					
05/26/77	1-S	Schroederia	1,143				
	2-S	nd					
	2-2	nd					
	3-S	nd					
	3-2	nd					
	4-S	Schroederia	256				
	4-2	Schroederia	769				
		Aphanizomenon	897			256	
	5-S	nd					
	5-2	nd					
06/15/77	2-S	Schroederia	250				
	2-2	nd					
	3-S	Diatoma	253				
		unknown	253				
	3-2	nd					
	4-S	unknown	256				
	4-2	nd					
	5-S	Schroederia	204				
		Aphanizomenon				204	
	5-2	Schroederia	263				

DATE	STATION-DEPTH (m)	GENUS	TOTAL CELLS/ml	CYANOPHYTES			
				heterocysts/ml	cells/heterocyst	filaments/ml	
						w/o heterocysts	w/heterocysts
07/13/77	2-S	Schroederia	205				
	2-2	nd					
	3-S	nd					
	3-2	Ceratium	253				
	4-S	Ceratium	250				
	4-2	nd					
	5-S	Aphanizomenon				216	
	5-2	Ceratium	250				
08/03/77	2-S	nd					
	2-2	Diatoma	256				
	3-S	Ceratium	207				
	3-2	nd					
	4-S	Diatoma	261				
		Ceratium	261				
	4-2	nd					
	5-S	Ceratium	268				
		Diatoma	268				
	5-2	Diatoma	274				
09/13/77	1-S	Diatoma	258				
	1-2	nd					
	2-S						
		Staurastrum paradoxum	533				
	2-2	Cosmarium punctalatum	222				
		Staurastrum paradoxum	222				
	3-S	Staurastrum paradoxum	220				
	3-2	Ceratium	294				
	4-S						
		Staurastrum paradoxum	217				
	4-2						
		Staurastrum paradoxum	267				
	5-S						
		Ceratium	244				
	5-2						
		Staurastrum paradoxum	253				

numbers at Stations 1 and 2 in November, 1976. Aphanizomenon filaments with heterocepts occurred in about equal numbers to those without heterocysts except in the November, 1976 samples when filaments without heterocysts were about twice as abundant as those with heterocysts. Another blue-green alga, Anabaena sp. was abundant in some samples collected in early August, 1976. The Anabaena filaments did not include heterocysts hence they can be presumed not to be fixing nitrogen gas. Small numbers of green algae, Calothrix, Ceratium, and Actinastrum were also observed in preserved samples in 1976.

Green algae (Asterionella and Schroederia) were present in the winter and spring of 1977. In late May through July small numbers of Aphanizomenon were present, however, no heterocysts were observed in preserved samples in 1977. In the second summer of the study other algae (Schroederia, Ceratium, Diatoma, Staurastrum paradoxum and Cosmarium punctulatum) were more abundant than Aphanizomenon, the only blue-green genus observed.

While a small population of Potamagetem sp. was observed near the boat launching area, aquatic macrophytes are of very limited abundance in Abiquiu Reservoir and probably do not contribute significantly to the productivity of the reservoir.

The level of fecal contamination in Abiquiu Reservoir is lower than at Cochiti Reservoir. Highest levels of bacteria indicating fecal pollution were on August 18, 1977, see Tables 20 and 21. The number of heterotrophic aerobic bacteria in Abiquiu Reservoir was low and remained relatively unchanged throughout the study (Table 37). The nutrient loading of Cochiti Reservoir, due to fecal pollution, has decreased considerably

Table 37. Aerobic heterotrophic bacteria/ 100 ml in Abiquiu Reservoir.

Date	Station 1		Station 2			Station 3		Station 4		Station 5		Flume
	Surface	5 m	Surface	5 m	20 m	Surface	5 m	Surface	5 m	Surface	5 m	
7/7/76	2550	$>10^4$	130	$>10^4$	–	450	2250	150	–	–	–	200
7/22/76	–	–	10^4	$>10^4$	10^6	$>10^3$	$>10^5$	10^5	10^5	–	–	10^5
8/4/76	10^5	10^4	10^4	$>10^5$	10^3	$>10^5$	$>10^4$	$>10^5$	$>10^5$	–	–	10^4
8/18/76	–	–	$>10^5$	$>10^4$	–	$>10^3$	$>10^3$	$>10^3$	$>10^3$	–	–	$>10^3$
9/17/76	–	–	$>10^4$	$>10^5$	–	$>10^4$	$>10^4$	$>10^3$	$>10^4$	–	–	–
11/5/76	$>10^7$	$>10^3$	10^4	10^3	10^5	800	–	400	10^3	–	–	–
12/20/76	–	–	800	$>10^3$	–	500	800	–	–	–	–	–
2/12/77	–	–	$8x10^3$	660	–	800	740	–	–	–	–	800
4/9/77	–	–	10^3	10^3	–	10^3	10^3	10^3	10^3	–	–	10^4
5/26/77	$3x10^2$	$6x10^2$	$3x10^2$	$1.2x10^3$	$1.6x10^3$	$3.6x10^4$	$8.5x10^3$	$6.5x10^3$	$1.3x10^4$	$4.2x10^4$	$2.9x10^4$	$1.5x10^4$
6/16/77	–	–	$1.7x10^4$	$1.7x10^4$	$2x10^4$	$9x10^3$	$2.4x10^4$	$1.3x10^4$	$5.3x10^4$	–	–	$3.8x10^4$
9/13/77	$8.6x10^4$	$5.1x10^4$	$5.7x10^4$	$6.0x10^4$	$2.8x10^4$	$3.3x10^4$	$4.6x10^4$	$8.7x10^4$	$5.8x10^4$	–	–	$6.6x10^4$

from 1975 to 1977.

Conclusions

Nutrient concentrations are important in characterizing the productivity potential of standing bodies of water, such as reservoirs. Using the concentration of phosphorus and nitrogen, primary productivity, and chlorophyll a measurements, Wetzel has suggested values which would be typical for the various trophic conditions. The pertinent characteristics and ranges, as given by Wetzel, are listed in Table 38.

Another system for determining trophic status of lakes has been employed by Rawson. This classification relies heavily on the parameters promoting or associated with algal activity and is summarized in Table 39. There is an inherent difficulty in declaring the trophic level for reservoirs because many of the chemical and limnological values change with the season as well as the quality of water entering the reservoir. Even though the character of the reservoirs are subject to change with time it is important to assess the potential which these reservoirs have for algal proliferation and nuisance blooms.

The results of our research, summarized in Table 40, can be compared to the trophic types characterized in Tables 38 and 39. The values listed in Table 40 were computed separately as averages for the months of July - September for 1976 and 1977, since nutrient concentrations and biological activities were quite different in Cochiti Reservoir during the two summers of the study. In July - September, 1976, Cochiti Reservoir would probably be classed, overall, as eutrophic based on primary productivity,

Table 38. Characteristics of trophic levels as established by Wetzel.

	Characteristic and Level				
Trophic Type	Mean Primary Productivity (mg C/m /day)	Chlorophyll a (mg/m^3)	Total Phosphorus (mg/liter)	Total Nitrogen (mg/liter)	Sub Phylum of Dominant Phytoplankton
Ultra-oligotrophic	<50	0.01-0.5	<.001-.005	<.001-.250	
Oligotrophic	50-300	0.3-3			Chrysophyceae, Cryptophyceae
Oligo-mesotrophic			<.005-.010	<.250-.600	Dinophyceae, Bacillariophyceae
Mesotrophic	250-1000	2-15			(Diatomaceae)
Meso-eutrophic			.010-.030	.500-1.100	
Eutrophic	>1000	10-500			Bacillariophyceae Cyanophyceae
Hypereutrophic			.030->5.0	.500->15.0	(Blue-green algae) Chlorophyceae Euglenophyceae

Table 39. Algae as indication of trophic status as reported by Rawson

Character or Parameter	Trophic Level	
	Oligotrophic	Eutrophic
Nutrient concentrations	Poor	Rich
Variety of algae	Many species	Few species
Distribution of algae in water	To great depths	Trophogenic layer
Diurnal migration of algae	Extensive	Limited
Development of algal blooms	Very rare	Frequent
Characteristic algal groups	Chlorophyceae (green algae) Desmids *Staurastrum* Diatomaceae (diatoms) *Tabellaria* *Cyclotella* Chrysophyceae *Dinobryon*	Cyanophyceae (blue-green algae) *Anabaena* *Aphanizomenon* *Microcystis* Diatomaceae (diatoms) *Melosira* *Fragilaria* *Stephanodiscus* *Asterionella*

Table 40. Summary of nutrient levels and biological activities at Cochiti and Abiquiu Reservoirs computed for July-September in 1976 and 1977*

Characteristic	Cochiti Reservoir 1976	Cochiti Reservoir 1977	Abiquiu Reservoir 1976	Abiquiu Reservoir 1977
Total Phosphorus (mg/liter)	0.052	0.033	0.032	0.013
Total Nitrogen (mg/liter)	0.974	0.310	0.434	0.355
Inorganic Carbon (mg/liter)	17.9	23.1	18.1	19.8
Transparency (cm)	102.	186.	217.	341.
Biological Activities				
Primary Productivity (mg C/m^2/day)	1,519.	715.	219.	394.
Chlorophyll a (mg/m^3)	42.9	5.2	2.0	2.4
Algal Genera	few	few	few	several
Most Abundant Types	*Aphanizomenon* *Anabaena*	*Aphanizomenon* *Anabaena* diatoms green algae	*Aphanizomenon*	*Aphanizomenon* green algae diatoms
Bacterial Density	highly variable		low, relatively stable	
Fecal Bacteria Density	low	low	low	low
Toxicity of Phytoplankton (mouse bioassay)	toxic		not tested	

*Total phosphorus and total nitrogen concentrations are average values for surface and 5 m samples. Inorganic carbon was computed from the alkalinity measurements for surface and 5 m samples. Transparency is an average for Seechi disc readings. Primary productivity was estimated on a daily basis by multiplying average hourly rates by 10. Chlorophyll a concentrations are averages for surface and 2 m samples. Stations 1-4 at Cochiti Reservoir and Stations 2-5 at Abiquiu Reservoir were used in the computation of these average values.

chlorophyll concentrations, total nitrogen concentrations and total phosphorus concentrations. It should be noted that primary productivity values given by Wetzel are average daily values for the year while values reported in Table 40 are averages for the summer alone and yearly averages would be considerably lower. The dominance of the blue-green algae also are indicative of eutrophic conditions. In the same period in 1977 primary productivity, chlorophyll concentrations, total nitrogen, and total phosphorus all decreased to levels approximating a mesotrophic condition. Blue-green algae, characteristic of eutrophic conditions, continued to be the dominant phytoplankton although they were less abundant in the summer of 1977. While the bases for the differences in nutrient levels and phytoplankton activities in 1976-77 are uncertain, two possibilities are suggested: 1) Differences in nutrient input during the two years may possibly have been related to reduced runoff in 1977 following an unusually dry winter; 2) Possibly the decline from enriched nutrient levels and high productivity which typically occurs over several years following the filling of a new reservoir may already be apparent in the second year of water storage in Cochiti Reservoir. A better indication of future trophic conditions at Cochiti Reservoir will be obtained following our studies in 1978-79.

Comparison of measurements at Abiquiu Reservoir (Table 40) with those in Tables 38 and 39 suggest classifications of this reservoir ranging from oligiotrophic to mesoeutrophic based on criteria of primary productivity, chlorophyll concentrations, and total nutrient concentrations. The dominant phytoplankton in the summer of 1976 was Aphanizomenon with a smaller number of Anabaena while in the summer of 1977 only a small number of Aphanizomenon was observed with an increased abundance of diatoms, green algae, and desmids, indicating a shift from phytoplankton genera charactistic of eutrophic to mesotrophic or oligiotrophic conditions. Based on the several criteria available, Abiquiu Reservoir is probably best characterized as mesotrophic. The extensive bloom of Aphanizomenon reported by the E.I.A. in 1975, did not occur with equal intensity in 1976, although a bloom was observed in November, 1976. The abundance of Aphanizomenon in 1977 was greatly reduced. It is probable that storage of water from the San Juan River in Abiquiu Reservoir has improved water quality in the reservoir. In addition, an increase in storage volume in Abiquiu Reservoir may have contributed to the reduction of problem blue-green blooms since 1975. The low concentrations of iron and manganese measured in May, 1977 (Table 24) may also have limited phytoplankton growth. Nitrogen fixing blue-green algae would be expected to be especially sensitive to limited concentrations of iron since the nitrogen fixing enzyme system contains iron.

The dominance of blue-green algae in both reservoirs suggests that these organisms may have inhibited the growth of other algae. Blue-green algae have been reported to produce allelopathic substances which inhibit the growth of diatoms and phytoplankton (Keating, 1977 and 1978). The rapid progression of these new reservoirs to the stage of dominant blue-green algae would indicate that either the successional changes in community structure may have occurred quickly, or the reservoirs supported blue-green algae from the onset. The reversion of the reservoirs from the dominant blue-green algal populations may require the dilution of the toxic metabolite, establishment of algal strains resistant to the metabolite, or proliferation of microorganisms such as bacteria which could metabolize the inhibitory substances. Control of allelopthic effects could be by appropriate bacteria since the blue-green algae are relatively unstable and lyse readily following death. The release of nutrients from the blue-green algae does support bacteria as evidenced from our results where bacterial growth follows blue-green algae proliferation.

The presence of toxin producing blue-green algae in Cochiti Reservoir is of some concern. Although the chemical structures are available for some of the blue-green algal toxins (Moore), little is known concerning the persistence of these toxins or the resistance of these toxins to bacterial decomposition. Since the water from Cochiti Reservoir is used for both recreational and agricultural purposes, including supplying water to domestic and wild animals, algal toxins will become a major problem if massive blue-green algal blooms continue to occur.

The level of fecal contamination in Abiquiu Reservoir is lower than at Cochiti Reservoir. The levels of fecal *Streptococci* and fecal coliforms suggest periodic fecal pollution (Tables 20 and 21). The nutrient loading of Cochiti Reservoir, due to fecal pollution, has decreased considerably from that reported in 1975 (EIA, 1975). The number of heterotrophic aerobic bacteria in

Abiquiu Reservoir was low and remained relatively unchanged throughout the study.

Our results concerning the physical characteristics of the reservoirs were similar in some respects to those obtained by the New Mexico Environmental Improvement Agency (EIA, 1975). Neither Abiquiu Reservoir or Cochiti Reservoir exhibit appreciable thermostratification and although seasonal turnover would be expected there is no documentation of this event. Both reservoirs have a basic pH with adequate carbon to support algal growth. Transparency of the water decreases from the dam toward the inlet in both reservoirs and the maximum euphotic zone is about 4 meters.

Considerable year to year variation is evident in the magnitude of blue-green algal blooms and also nutrient concentrations in Cochiti and Abiquiu Reservoirs between 1975-77. Accurate predictions of future trends in the trophic status and the potential for algal blooms in these recently established reservoirs will require data on nutrients and phytoplankton populations collected over several years.

LITERATURE CITED

APHA. 1971. Standard methods for the examination of water and wastewater. American Public Health Assocation, Inc. New York. 874 p.

Bachman, R.W. and J.R. Jones. 1976. Nutrient inputs and algal blooms in Iowa lakes. Completion Report on Project A-0490IA, Iowa State Water Resources Research Institute, Iowa State University, Ames. 31 p.

Burris, R.H. 1974. Methodology, pp. 13-33. In A. Quispel (ed.). The biology of nitrogen fixation. American Elsevier Publishing Co., New York.

E.I.A. 1975. Algae bloom in Abiquiu Reservoir. Memeograph Report. New Mexico Environmental Improvement Agency.

EPA. 1974. Methods for chemical analysis of water and wastes. U.S. Environmental Protection Agency (EPA-625/74-003). Washington, D.C.

Golterman, H.L. 1969. Methods for chemical analysis of fresh water. IBP Handbook No. 8. Blackwell Scientific Publications. Oxford. 172 p.

Jackson, H.W. and L. Williams. 1962. Calibration and use of certain plankton-counting equipment. Trans. Amer. Mic. Soc. 81:96.

Johnson, G.V. and L.L. Barton. 1976. Trophic status of selected Northern New Mexico lakes. Technical Completion Report Project No. A-530NMEX. New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces, NM. 178 p.

Keating, K.I. 1977. Allelopathic influence on blue-green bloom sequence in a eutrophic lake. Science 196:885.

Keating, K.I. 1978. Blue-green algal inhibition of diatom growth: Transition from mesotrophic to eutrophic community structure. Science 199:971.

Kidd, D.E. and G.V. Johnson. 1971. An investigation of primary productivity using the carbon-14 method and analysis of nutrients in Elephant Butte Reservoir. Completion Report on Project A-021-NMEX-3109-32, New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces, NM. 106 p.

Miller, W.E., T.E. Maloney, and J.C. Greene. 1974. Algal productivity in 49 lake waters as determined by algal assays. Water Res. 8:667.

Moore, R.E. 1977. Toxins from blue-green algae. Bioscience 27:797.

Prescott, G.W. 1970. How to know the freshwater algae. Wm.C.Brown Publishers, Dubuque, Iowa. 348 p.

Rawson, D.S. 1956. Algal indicators of trophic lake types. Limnol. and Oceanog. 1:18.

Sawyer, P.J., J.H. Gentile, and J.J. Sasner, Jr. 1968. Demonstration of a toxin from Aphanizomenon flos-aquae (L.) Ralfs. Can. J. Microbiol. 14:1199.

Shilo, M. 1966. Predatory bacteria. Science J. 33.

Wetzel, R.G. 1975. Limnology. W.B. Saunders. Philadelphia. 743 p.

Wu, B., M.K. Handy, and H.B. Howe. 1968. Antimicrobial activity of a myxobacterium against blue-green algae. Bact. Proc. 48 p.