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BLUE MESA RESERVOIR, COLORADO: A HISTORICAL REVIEW OF ITS LIMNOLOGY, 1965—1985

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16. ABSTRACT

Twenty years of biological, chemical, and physical data from Blue Mesa Reservoir, Colorado, were analyzed to elucidate the process of impoundment maturation in Bureau of Reclamation reservoirs. Blue Mesa Reservoir was chosen for two reasons: 1) the impoundment is 20 years old, and should have attained trophic equilibrium, and 2) there is a relatively large amount of data with which to assess the impoundment's biological, chemical, and physical structure and function over time.

Blue Mesa Reservoir's limnology has been studied since impoundment in 1965. Much of the initial work was performed by Colorado Division of Wildlife personnel; later work was conducted by the Environmental Protection Agency and National Park Service. The most recent work, contracted by the Bureau of Reclamation, culminates 20 years of study.

The data were analyzed for historical trends. Evidence of such trends was interpreted and used to assess present reservoir trophy, to predict future reservoir trends, and to indicate future management possibilities.

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FOREWORD

Phase 4 of research project DR-409, ''Limnology for the Ecological Management of Reclamation Projects,'' was an investigation of the process of impoundment maturation in USBR (Bureau of Reclamation) reservoirs. Blue Mesa Reservoir, on the Gunnison River, 30 miles below Gunnison, Colorado, was the site chosen for this investigation. This reservoir was formed in 1965, upon completion of the USBR's Blue Mesa Dam. Two major reasons for choosing Blue Mesa as a site for studying reservoir maturation processes were:

1. The impoundment is now 20 years old and should, therefore, have passed through its initial ''trophic disequilibrium'' phase and reached a relatively stable trophic level.

2. A large amount of fishery, water quality, and limnological data are available for Blue Mesa. These data include pre- and post-impoundment fishery studies by the CDOW (Colorado Division of Wildlife), several other CDOW fishery and water pollution studies, an EPA (Environmental Protection Agency) National Eutrophication Survey report, various NPS (National Park Service) water quality monitoring studies, and some recent USBR limnological studies.

The objectives of this study were to:

1. compile all available limnological, water quality, and fishery data on Blue Mesa Reservoir;

2. analyze these data for historical trends; and

3. interpret these trends to answer the following questions:

   a. Is Blue Mesa Reservoir currently in ''trophic equilibrium''?

   b. What changes in the reservoir's trophic status may be expected over the next 10 to 20 years?

   c. What are the reservoir management implications of these historical trends and possible future changes?

Because of personnel limitations in the Environmental Sciences Section, it was decided that phase 4 of DR-409 should be performed by a private contractor. Bio-Environs was selected for this job and awarded the contract in March 1986. This report is the final product of that contract.

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APPLICATION

Data compiled in this report and the statistical analyses of these data provide a summary of conditions in Blue Mesa Reservoir from its initial impoundment in 1965, through 1985. This summary and the conclusions noted in the report will be valuable to anyone concerned with future studies at Blue Mesa Reservoir or its management.

Information in this report will also be of interest to project planners, reservoir and fishery managers, and researchers studying the trophic dynamics of new reservoirs. The statistical methods used to analyze the Blue Mesa data base are generally useful to anyone attempting to discern historical trends in a lengthy and spotty data record.

INTRODUCTION

It is widely recognized in the literature on limnology and fisheries that often a newly impounded reservoir will pass through an initial phase of high biological productivity (Baxter 1977 [1]*; Lindstrom 1973 [2]; Goldman and Kimmel 1978 [3]). This highly productive period, which has been called the "trophic upsurge," is the result of a new biota colonizing an expanding aquatic environment with its abundance of plant nutrients, organic debris, and new habitats. When this habitat expansion ceases and readily available internal supplies of nutrients and food decline, the biological productivity of the young impoundment also decreases in what has been termed a "trophic depression." This entire initial "boom" and "bust" cycle is called the "trophic disequilibrium" phase. It is usually followed by a more stable phase of "trophic equilibrium" during which watershed hydrology, reservoir hydraulics, external nutrient loading, and internal cycling mechanisms control impoundment productivity.

On a management level, the trophic disequilibrium phase of a new reservoir can be a source of problems. Initial trophic upsurge may create expectations for a high level of fish production that cannot be sustained. The trophic depression is then perceived as a "crash" of the fishery, and even fishery managers sometimes wonder "what went wrong?" Reservoir operations may be blamed for the decline of sport fish populations and the appearance of larger populations of nongame species, when this may actually be the result of "habitat overshoot" and an approach to more sustainable conditions. A better understanding of reservoir maturation processes at the outset would help reservoir and fishery managers formulate long-term plans and adapt to changing conditions.

*Numbers in brackets refer to entries in the bibliography.

Phase 4 of research project DR-409, "Limnology for the Ecological Management of Reclamation Projects," is an investigation of reservoir maturation processes in Bureau of Reclamation impoundments. Blue Mesa Reservoir was chosen as the subject of this investigation for two reasons: 1) the impoundment is 20 years old and should have attained trophic equilibrium, and 2) there is a relatively large amount of data with which to assess the impoundment's biological, chemical, and physical structure and function over time.

Blue Mesa Reservoir's limnology has been studied since impoundment in 1965. Much of the initial work was performed by Colorado Division of Wildlife personnel; later work was conducted by the EPA (Environmental Protection Agency) and NPS (National Park Service). The most recent work, contracted by the USBR (Bureau of Reclamation) with Aquatic Environmental Services (1983, 1984) [4, 5] and Bio-Environs (1985) [6], culminates 20 years of study.

This report analyzes data for historical trends. Evidence of such trends was interpreted and used to assess present reservoir trophy, to predict future reservoir trends, and to indicate future management possibilities.

GENERAL DESCRIPTION

Blue Mesa Reservoir (El. 7519 ft (2292 m)) is Colorado's largest reservoir (approximate maximum storage is 940,800 acre-ft (1.1605×10^9 m^3); surface area is 8,895 acres (36 km^2)). It serves as a major storage site for irrigation purposes, as a hydroelectric facility, and as a national recreation area. Storage began October 26, 1965 as part of the Wayne N. Aspinall Unit of the Colorado River Storage Project. Reservoir water provides storage replacement to meet downstream requirements under the Colorado River Compact of 1922. Operation of Blue Mesa Reservoir is described as spring and early summer fills, late summer stabilization, and fall and winter drawdowns.

The reservoir, which is 26.1 miles (42 km) long, is located approximately 12 miles (19.3 km) west of Gunnison. Damming of the Gunnison River served as the major source of water for the three basins in Blue Mesa Reservoir. The shoreline perimeter measures 97.5 miles (157 km) (U.S. Dept. of the Interior 1984 [7]). Several campgrounds are situated along the reservoir shore. These campgrounds and some adjacent lands are administered as part of the Curecanti National Recreation Area by the National Park Service. Water related features of Blue Mesa Reservoir are operated by the Bureau of Reclamation. Figures 1, 2, and 3 depict the reservoir and the sites sampled in 1981-1985, 1983, and 1984-1985, respectively.

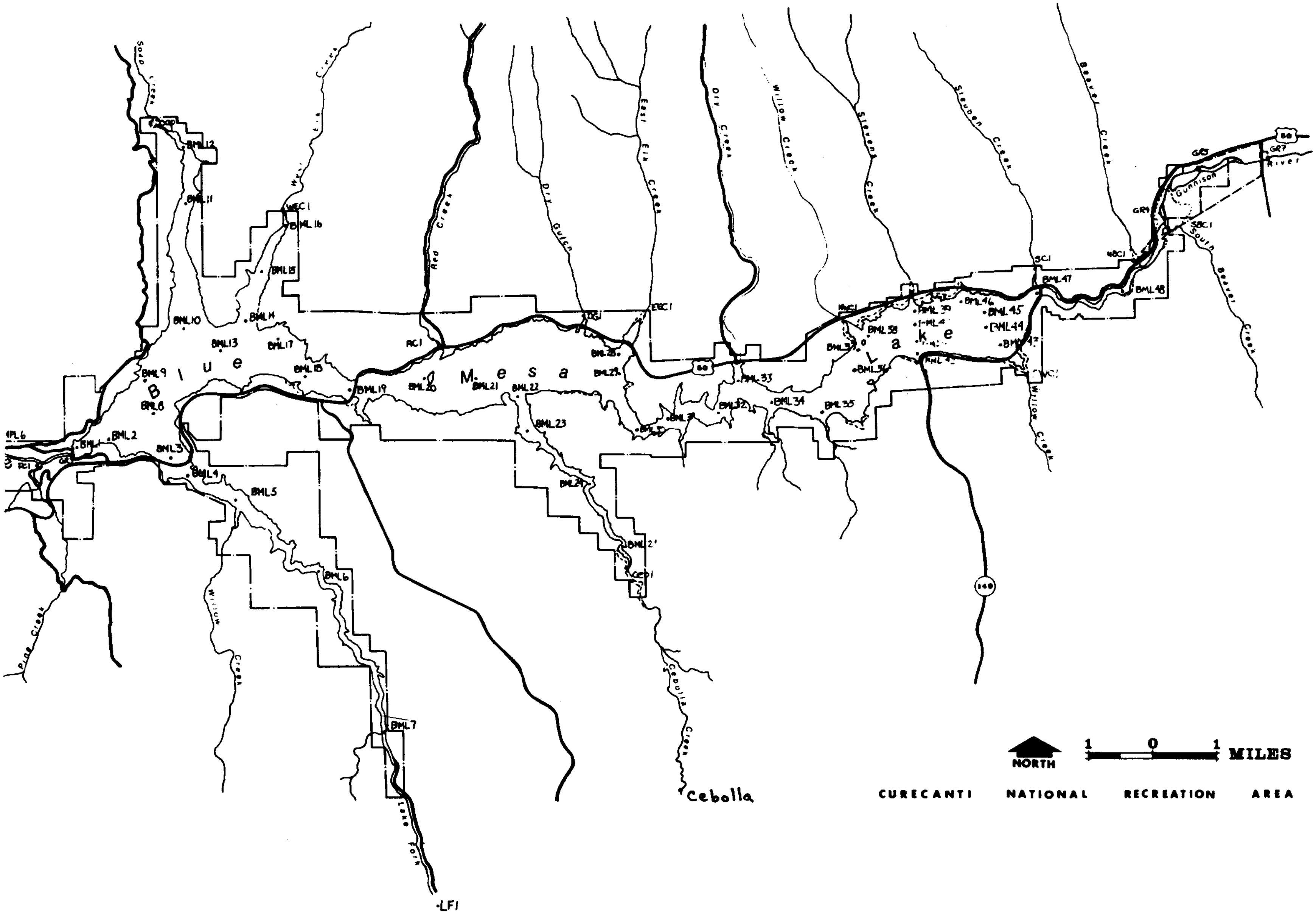

Figure 1. – National Park Service sampling sites, 1981-1985.

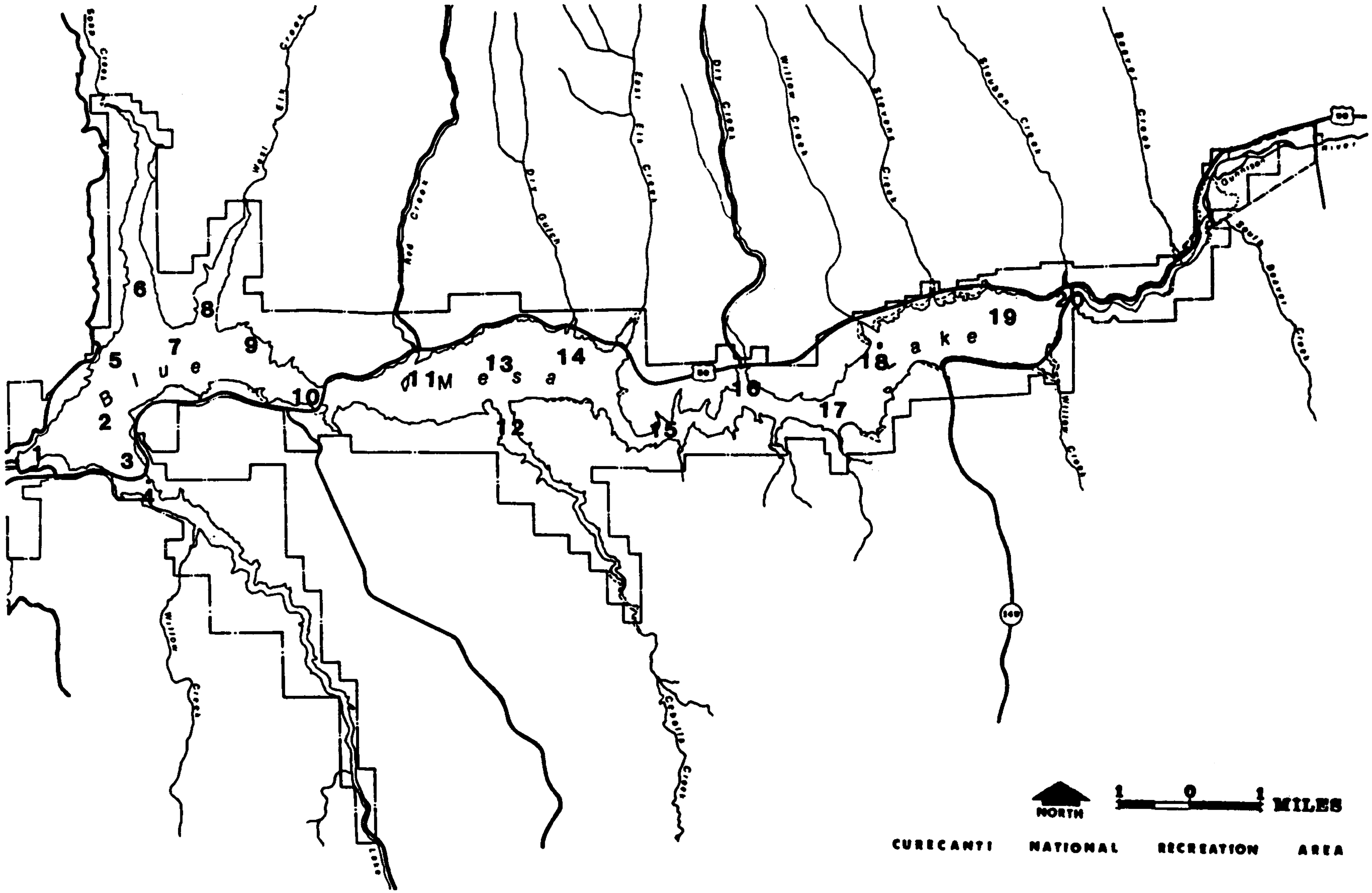

Figure 2. – Aquatic Environmental Services sampling sites, 1983.

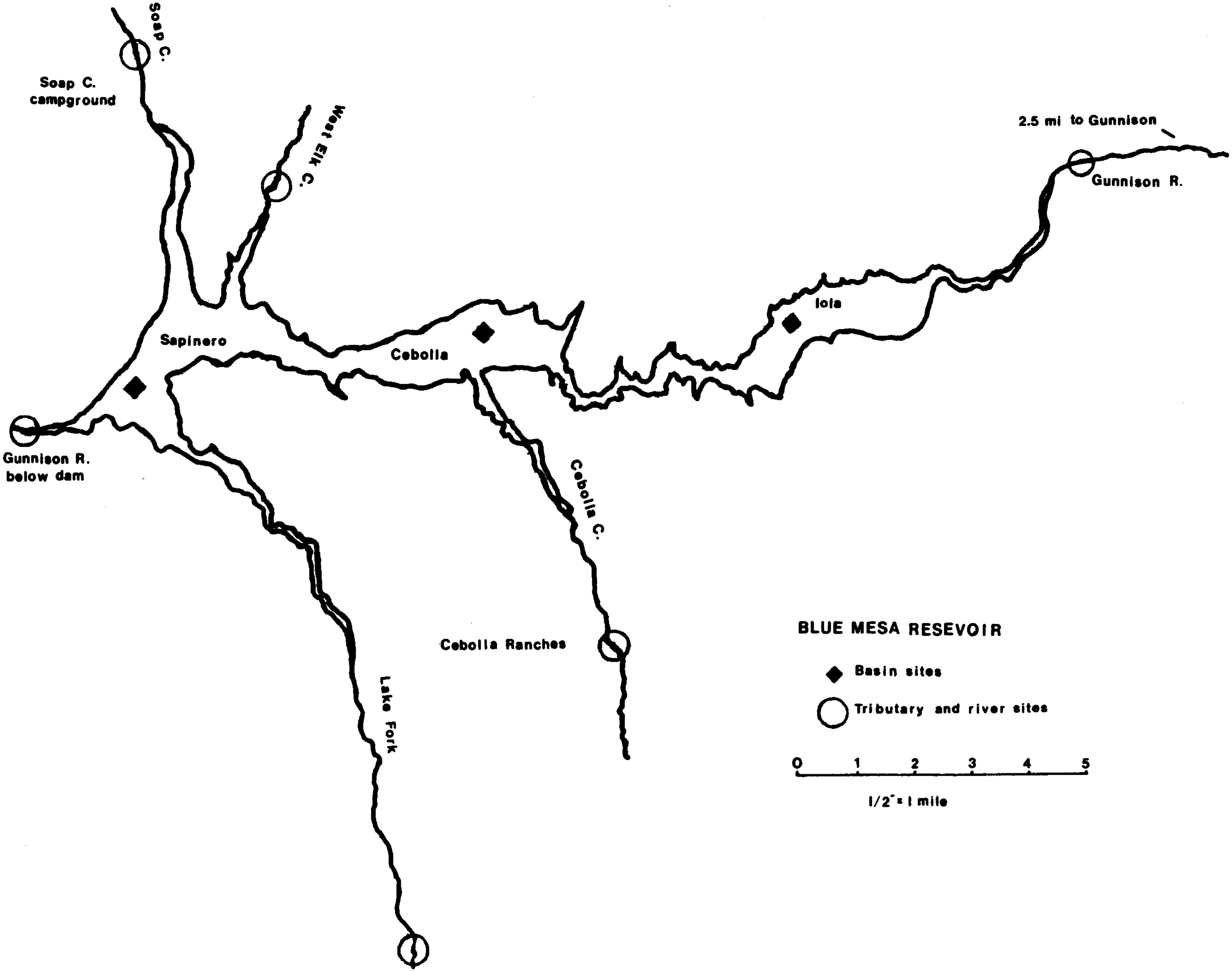

Figure 3. – Sampling sites of Aquatic Environmental Services and Bio-Environs, 1984-1985.

In addition to major inputs from the Gunnison River, the tributaries to Blue Mesa Reservoir are Soap Creek and West Elk Creek, which flow south into Sapinero Basin; Cebolla Creek, which flows north into Cebolla Basin; and Lake Fork of the Gunnison River, which flows north into Sapinero Basin. These streams and rivers drain high-elevation watersheds, and discharge is controlled largely by spring melt and localized rainstorms.

The surrounding vegetation consists of sagebrush and grassland communities set in varied and rolling topography. Oak-shrubland sites are also encountered. Conifers grow on the northern slopes, and aspens are predominant on the higher, moister sites. A summary vegetation description is found in Woodbury (1962) [8].

The reservoir inundates the Gunnison River, which flowed through less resistant rock of the Morrison Formation (Prather 1982) [9]. Underlying the Morrison Formation is the more resistant Precambrian rock. Blue Mesa Dam is situated in the Precambrian strata where the canyon narrows at the west end of the reservoir. Overlying the shale and sandstone of the Morrison Formation are Dakota Sandstone and Mancos Shale, which are highly visible along the north shore of the reservoir. Deposited above these Cretaceous formations are rocks of volcanic origin. The picturesque pinnacles north of Sapinero Basin were formed from erosion in the West Elk Breccia. Capping the mesas above Blue Mesa Reservoir are welded tuffs that originated from volcanic ash avalanches of the San Juan Mountains.

LITERATURE REVIEW

Articles edited by Woodbury (1962) [8] described the ecology of the Curecanti Reservoir Basins in western Colorado. Predictions made in these articles suggested that water level fluctuations would prevent establishment of submerged and emergent plant communities, and that cold water drawn from the upper basins would leave the reservoir system and flow as cold water through the Black Canyon. Wiltzius (1966-1976) [10, 11, 12] focused on pre- and post-impoundment fisheries and water quality measurements including temperature, pH, conductivity, dissolved oxygen, alkalinity, hardness, turbidity, and various ions. His work provides background data on the the pre- and post-impoundment environment, provides ranges for various chemical and physical parameters, and includes some local history. Reed (1968) [13] anticipated certain limnological developments in light of reservoir completion on the Gunnison River. He suggested that the Gunnison River had great capacity for biological productivity. Nutrient leaching and an availability of major ions after impoundment would certainly create a productive reservoir. He also noted that blue-green algal blooms had been encountered in the reservoir soon after inundation.

The numerous studies of the rivers and tributaries associated with the Blue Mesa Reservoir are summarized below. Water quality and supply were evaluated at six planned or existing recreation sites in the Curecanti Unit (Boettcher 1971) [14]. The Water Quality Control Division (1975) [15] discussed baseline water quality and potential problem sites within the upper Gunnison River drainage as follows. In the Gunnison River, dissolved solids were low, conductivity ranged from 167 to 257 µmhos/cm, and hardness was determined to be 140 mg/L as $CaCO_3$. Ammonia was detectable, and phosphorus levels were high after return flows of irrigation water in 1975. The largest increases in fecal coliform counts occurred in the river approximately 2 miles (3 km) north of Gunnison. The lowest benthic fauna diversity was encountered in channelized sections of the river.

Richards and Ferchau (1978) [16] and Apley (1981) [17] focused on studies of surface and ground water in the Powderhorn area. Chemical, physical, and biological data were summarized for Cebolla Creek, a main tributary to Blue Mesa Reservoir. A study of Blue Mesa's contributing tributaries and of other streams described biological, chemical, and physical properties to assess their stream classification (Rumberg et al. 1978) [18]. They note that waters were generally of "high quality"; 41 percent of the 32 sites studied met Colorado 1974 A1 standards developed by the Water Quality Control Commission 1974. Only fecal coliform, some metals, and ammonia levels exceeded standards at some sites. Effects of the Curecanti Unit impoundments on the physico-chemistry and biology of the downstream environment were discussed by Stanford and Ward (1981, 1982 unpublished) [19, 20]. Total dissolved solids and the organic carbon pool increased downstream. Winter water temperatures were elevated, but summer water temperatures were depressed below the last outlet. In addition, the invertebrate community structure apparently shifted downstream after impoundment development. The Water Quality Management Plan for District 10 (1980) [21] and the draft update (1983) [22] to that plan described the "high water quality" of the Gunnison River.

Colburn (1981) [23] studied levels of trace elements in aquatic insects in Gunnison area tributaries. Aquatic insects concentrated cadmium at 2 to 4 orders of magnitude; like cadmium, manganese in insects may reflect cumulative effects of past water quality. Aaronson (1981, 1982) [24, 25] tested for total dissolved solids, radiation, inorganics, heavy metals, and chlorinated hydrocarbon pesticides in the Gunnison River. Manganese levels exceeded the criteria (EPA 1976) [26] only in the Cimarron River, as reported by Aaronson (1982) [24].

A summary of fisheries and benthic studies in the Gunnison River were presented by Nehring and Anderson (1983) [27]. Excluding yearly creel surveys and salmonid stocking records, little research has been conducted on population structure and dynamics of the fisheries in Blue Mesa Reservoir. Early work on Wiltzius (1971-74) [11] focused on post-impoundment investigations of fish populations after initial stocking. Middleton's (1969) [28] research entailed studies on catostomid fishes in Blue Mesa Reservoir and associated tributaries. Wiltzius (1976) [12] prepared a report on the historical influences of irrigation diversions and reservoirs on temperature and fish distribution in the Gunnison River. Wiltzius and Smith (1976) [29] chronicled harvest trends and migration of salmonids in the Curecanti Unit. Recently, Weiler (1985) [30] conducted a trend analysis on rainbow trout and kokanee salmon versus catch per angler hour.

Additional efforts, including satellite imagery projects, have focused on the reservoir itself. A preliminary 1976 report on Blue Mesa Reservoir noted the waters were mesotrophic, and that they ranked sixth in overall trophic quality for Colorado's lakes and reservoirs (EPA 1976) [31]. High fecal coliform counts and recognition of certain problems such as high nutrient input and changed dissolved oxygen levels in Blue Mesa Reservoir were discussed by [21]. Blue Mesa Reservoir's water quality was surveyed as part of a selected lakes and reservoir study; Sapinero Basin was sampled and determined to be oligotrophic using several summary statistics (Britton and Wentz 1980) [32]. *Trophic Classification of Selected Colorado Lakes* by Blackwell and Boland (1979) [33] included Landsat imagery and a principal components technique to determine trophic status information on Blue Mesa Reservoir. The study aimed to elucidate the role of Landsat MSS (multispectral scanner) data with contact-sensed data. They suggested that MSS data can be used in regressions for predicting trophic indicators after some refinements to the process. Additional multispectral scanner information was obtained in 1983, and correlated to actual water samples. Lack of good relationships between surface and image data sets were attributed to a 24-hour delay between image acquisition and data collection. Water variability patterns were recognized and reported (Verdin 1984) [34].

Metal concentrations in fish at the Curecanti National Recreation Area were not found at levels harmful to humans (Kunkle et al. 1983) [35]. Extensive surveys (1983-1985) of chlorophyll *a* concentration were conducted during the open water season by Hickman (National Park Service, unpublished). Aquatic Environmental Services (1983, 1984) [4, 5] conducted additional surveys that focused primarily on reservoir biology. They noted that 1983 algal populations may have been influenced by the large flow of water into Blue Mesa Reservoir (see table 1a, b); the number of cells/L were lower than those for other years (see table 10). Limnological information from their 1985 survey of Blue Mesa Reservoir was summarized by Bio-Environs (1985) [6]. The three basins differed in their trophic status: Sapinero was considered oligotrophic, Iola mesotrophic, and Cebolla intermediate.

Table 1a. – Annual means of combined discharge from Gunnison River and Tomichi Creek, 1966-1985

Year	Discharge, ft^3/s
1966	693.00
1967	670.00
1968	894.00
1969	917.00
1970	1,231.00
1971	993.00
1972	759.00
1973	901.00
1974	702.00
1975	891.00
1976	697.00
1977	316.00
1978	872.00
1979	993.00
1980	1,089.00
1981	447.60
1982	874.00
1983	1,124.00
1984	1,724.00
1985	1,163.00

Table 1b. – Annual means of discharge from Lake Fork of the Gunnison River, 1966-1985

Year	Discharge, ft^3/s
1966	211.00
1967	142.00
1968	251.00
1969	200.00
1970	295.00
1971	223.00
1972	165.00
1973	261.00
1974	165.00
1975	294.00
1976	168.00
1977	88.70
1978	241.00
1979	260.00
1980	231.00
1981	128.00
1982	270.00
1983	302.00
1984	413.00
1985	334.00

METHODS

From 1982 through 1985, the National Park Service in conjunction with the Bureau of Reclamation monitored physical and chemical parameters and collected samples for chlorophyll, heavy metals, and ion analysis. Before that period, no formal water quality monitoring program had been instituted on Blue Mesa Reservoir. Thus, because of the inconsistent database, trend detection over the 20-year period was difficult; time series analysis of the data was considered invalid. Instead, monthly means for each basin or an entire basin are calculated and compared using the Student's t test, an analysis suggested by Lettenmaier (1977) [36] and by Montgomery and Reckhow (1984) [37]. This method of analysis (Lettenmaier 1977) [36] closely approximates the time series procedure, but was chosen instead because it permitted simpler corrections for seasonality. Time series analysis also requires a fixed number of sampling sites and a fixed time interval for sampling, conditions not met by the 1967 through 1985 data. Using the Student's t-test, differences detected at a *P* (probability) ≤ 0.05 are considered significant. The calculated *p* values are provided in most cases throughout the report.

Physical/chemical data (pH, dissolved oxygen, conductivity, temperature, and transparency) were analyzed by basin on a monthly basis. Differences in the data for different basins and months made pooling the data invalid for trend analysis. Heavy metal and ion data were analyzed for the entire reservoir on a seasonal (sampling period usually extends from June to September) instead of on a monthly basis because of the limited number of data points. Sampling period means were compared with EPA criteria (1976) [26] and with standards from the WQCC (Water Quality Control Commission) of the Colorado Department of Health (1984) [38] using the Student's t-tests. All values that exceeded the criteria or standards were noted by date and site to identify trends over time and to pinpoint problem areas.

Limits of detection were encountered, particularly for nutrient and heavy metal data. These minimum limits of detection vary by year because different laboratories undertook the analysis. To give an environmentally conservative interpretation, values measured as "less than or equal to" were assumed to be the maximum possible value for the analysis. The laboratories that performed the 1982-1985 analyses and the methods used are outlined in Hickman (1986) [39].

The pH values were considered intrinsically valid as indicators of water quality. Therefore, means were derived by summing the values and dividing by the number of observations. Values were not converted to hydrogen ion concentration and averaged in that manner. All statistical analyses were performed using SPSS-11 and BMDP statistical programs at Western State College in Gunnison, Colorado.

With the exception of the chlorophyll data, all biological data were graphed and qualitatively interpreted for trends. The chlorophyll data was treated in the same manner as the physical/chemical data. Quantitative analysis of the data was precluded by the lack of data from several years.

SUMMARY

Data available for Blue Mesa Reservoir are numerous, but concentrated within the later years, 1983-1985. Few data comparable with these later data are available for 1967-1982. Therefore, the analysis focused on the later years.

Significant historical trends were detected using the Student's t-test, a method suggested by Lettenmaier (1977) [36] and by Montgomery and Reckhow (1985) [37] for use when time series analysis is considered invalid or not applicable. Trends that were not significantly different but recognizable through visual inspection of graphs and statistically significant are discussed below.

Physical/Chemical

1. Although no significant differences ($p > 0.05$) were detected between the same months for successive years, graphic depiction of conductivity versus time indicates a gradual decrease from 1981 to 1985. Mean levels in 1967 were 242 and 200 µmhos/cm for Cebolla and Sapinero basins, respectively. After a high of 200 µmhos/cm in 1974, mean levels decreased to the 120 to 170 µmhos/cm range in August and September 1975. From 1967 to 1985, a trend towards lower conductivity is visible, but not statistically significant.

2. From 1982 to 1985, pH decreased significantly in July between successive years ($p < 0.002$) in Iola Basin. However, this indication of decreasing pH may merely reflect the small level of variability despite the logarithmic basis of pH values. The 1967 mean level ranged from 8.27 to 8.35, and is apparently no different from that in later years.

3. Graphically (fig. 4c), it appears that dissolved oxygen levels increased with time. However, it must be noted that a sensitive membrane was used in 1985, when the highest levels of dissolved oxygen were detected in Cebolla and Sapinero Basins. June levels increased significantly ($p < 0.001$) from 1982 to 1985, in Sapinero Basin, but decreased in Cebolla Basin.

Major Ions and Nutrients

1. Calcium levels significantly decreased from 1983 to 1985, on a reservoir-wide basis. The 1967 levels were within the range of data from later years. No overall trend is detectable.

2. Alkalinity/bicarbonate levels tended to decrease over time. Bicarbonate means from 1983 through 1985 significantly differed from 1975 levels ($p < 0.001$). A trend towards lower alkalinity and bicarbonate levels over the years may reflect reduction of carbonate rock leaching, chemical precipitation (Bolke 1979) [50], and dilution of waters from recent wet years (see table 3).

3. Chlorides appear to decrease from 1983 to 1985; this decrease may reflect changes in laboratory analytical techniques. The 1985 technique was verified using EPA quality control samples.

4. Nutrient levels were measured from 1983 to 1985. Inconsistent sampling and the measuring of nutrient levels at their limits of detection prevented diagnosis of historical trends. Within-season cycles were noted. Elevated levels of inorganic nutrients (nitrates and orthophosphates) were detected in early-summer samples.

Heavy Metals

1. No detectable trends for heavy metals are presented because of a limited database. Levels of aluminum, iron, manganese, mercury, selenium, silver, thorium, uranium, and zinc exceeded criteria or standards established by EPA (1976) [26] and WQCC (1984) [38].

Biological Parameters

1. No detectable trends were observed with the chlorophyll *a* data. The available data included determinations made in 1975, and from 1983 to 1985. Chlorophyll *a* levels varied widely from May to September, but comparisons between successive years for this period revealed little change from 1975 to 1985. Chlorophyll *a* levels indicate overall persisting oligotrophic to mesotrophic conditions in Blue Mesa Reservoir.

2. Biological data including phytoplankton (1975, 1983-1985), zooplankton (1984-1985), benthos (1984-1985), and the fishery (1966-1985) were qualitatively examined. Phytoplankton density apparently increased from 1983 to 1985. A 1975 count (0-5 m column) exceeds the 1985 level. The number of zooplankton per liter in all three basins increased from 1984 to 1985. With regard to benthic organisms, numbers per liter during 1984, exceeded those of 1985, and did not differ by taxon. Catch per unit effort for rainbow trout decreased from 1971 to 1976, and increased from 1977 to 1984 (Weiler 1985) [30]. The Colorado Division of Wildlife, which controls the Blue Mesa fishery, has not quantified fish population structure within the reservoir other than to determine how its stocking efforts meet fishing demands.

RESULTS AND DISCUSSION

Hydrology

Flows in the Gunnison River and Tomichi Creek are available for the period of interest – 1966 to the present. Combined flows from the two stations approximate the total flow entering Blue Mesa Reservoir from the Gunnison River (the Gunnison River gauging station is above Tomichi Creek). The only other gauged tributary associated with the reservoir is the Lake Fork of the Gunnison. The Gunnison and Lake Fork rivers generate the largest flow of water into the reservoir system. Discharge for both rivers is summarized in tables 1a and 1b. Flows were variable, and mean annual discharge ranged from 316 ft^3/s in 1977, to 1724 ft^3/s in 1984 in the Gunnison River.

Physical/Chemical

Physical/chemical data including measurements of conductivity, pH, dissolved oxygen, temperature, and transparency are available for most years (1967, 1974-1975, and 1981-1985). Data collected during 1967, and other early data had no specific months assigned to them, nor were the data obtained from the reservoir surface at all times. Because of the sparse early database and the difficulties in applying time series analysis, trend analysis was performed by t-test between the same months of successive years.

Significant differences within a sampling period (usually May through September) were detected between basins for several physical/chemical parameters. Iola and Sapinero basins exhibit the greatest differences. Conductivity and pH were significantly greater in Iola than in Sapinero basin for 1982-1985 ($p \leq 0.06$ for all sample period comparisons). Conductivity in Cebolla and Iola basins differs significantly for all years except 1985. Iola consistently expressed higher conductivity levels than Cebolla ($p < 0.005$). Differences were less pronounced between Cebolla and Sapinero basins. BioEnvirons (1985) [6] noted basin differences and suggested that Cebolla expressed limnological characteristics between those of Iola and Sapinero basins. In light of these basin differences and to detect trends, the basins were tested separately.

Sample period means by basin for physical/chemical parameters are summarized in tables 2a-c. Monthly summaries of the basin physical/chemical parameters are depicted on figures 4a-e.

Temperature. – Blue Mesa Reservoir is dimitic; i.e., the reservoir undergoes spring and autumn overturn. Surface warming occurs quickly after ice-out and, thereafter, thermal stratification takes place. Seasonal means ranged from 15.74 to 17.91 °C in Iola Basin, 16.83 to 18.05 °C in Cebolla, and 16.23 to 17.29 °C in Sapinero Basin. These sample period means include different months from one year to the next and do not reflect the extent of each basin's variability. Tables 2a-c summarize seasonal means by basin, and figure 4d depicts monthly means by basin for the years sampled.

In July, August, and September, no trends are detectable for years with available data in each of the three basins. Water temperature, as a measure of solar radiation input and of the climatic environment, can drastically change from year to year. Therefore, without a much larger database, it is difficult to interpret any variation over the years. Temperature and its effect on the reservoir biological parameters cannot be underestimated. Temperature variability and its effects on the chemical and physical properties of the water will in turn regulate seasonal variation of biological function and structure.

Transparency. – Transparency, as measured by Secchi disk depth, changes seasonally (Wetzel 1975 [40]; Lewis et al. 1984 [41]; Pennak 1949 [42]). These monthly trends are depicted on figure 4e. On

Table 2a. – Mean seasonal physical/chemical parameters for Iola Basin, 1982-1985 (s.d. = standard deviation)

	1982		1983		1984		1985	
Parameter	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Specific conductance (µmhos/cm)	272	33	236	25	135	17	144	31
Temperature (°C)	17.91	3.70	17.59	2.67	17.54	2.20	15.74	2.65
pH	8.06	0.23	8.15	0.44	8.08	0.42	7.75	0.33
Dissolved oxygen (mg/L)	5.52	0.53	7.08	1.04	7.50	1.27	9.29	2.30
Transparency (m)			3.20	0.72	2.71	1.44	2.77	1.27
Chlorophyll *a* (mg/m³)			7.33	6.14	5.15	2.04	8.19	8.30
Chlorophyll *b* (mg/m³)			0.11	0.12	0.17	0.23	0.33	0.39
Chlorophyll *c* (mg/m³)			.86	.44	.59	.79	.76	.50

Table 2b. – Mean seasonal physical/chemical parameters for Cebolla Basin, 1982-1985 (s.d. = standard deviation)

	1982		1983		1984		1985	
Parameter	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Specific conductance (µmhos/cm)	243	43	223	26	127	19	139	38
Temperature (°C)	17.19	4.70	18.05	2.93	17.67	3.14	16.83	2.90
pH	7.88	0.31	7.00	0.43	7.49	0.41	7.86	0.25
Dissolved oxygen (mg/L)	5.71	0.92	7.08	1.04	7.45	1.66	9.75	2.83
Transparency (m)			3.08	1.09	2.62	1.47	3.04	1.20
Chlorophyll *a* (mg/m³)			6.86	7.86	3.27	1.29	6.57	7.60
Chlorophyll *b* (mg/m³)			0.56	1.05	0.11	0.03	0.35	0.51
Chlorophyll *c* (mg/m³)			2.11	2.61	.40	.37	.99	.66

Table 2c. – Mean seasonal physical/chemical parameters for Sapinero Basin, 1982-1985 (s.d. = standard deviation)

	1982		1983		1984		1985	
Parameter	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Specific conductance (µmhos/cm)	235	28	217	27	128	12	141	41
Temperature (°C)	16,23	4.99	17.29	2.98	17.23	3.99	16.38	4.09
pH	7.94	0.34	7.98	0.38	7.97	0.35	7.67	0.26
Dissolved oxygen (mg/L)	6.22	0.90	6.75	0.77	7.45	1.78	9.00	2.45
Transparency (m)			3.65	0.93	2.58	1.24	2.76	1.21
Chlorophyll *a* (mg/m³)			4.06	5.31	2.61	0.85	5.04	5.65
Chlorophyll *b* (mg/m³)			0.80	1.39	0.14	.18	0.40	0.45
Chlorophyll *c* (mg/m³)			2.53	4.09	.40	.29	.88	.48

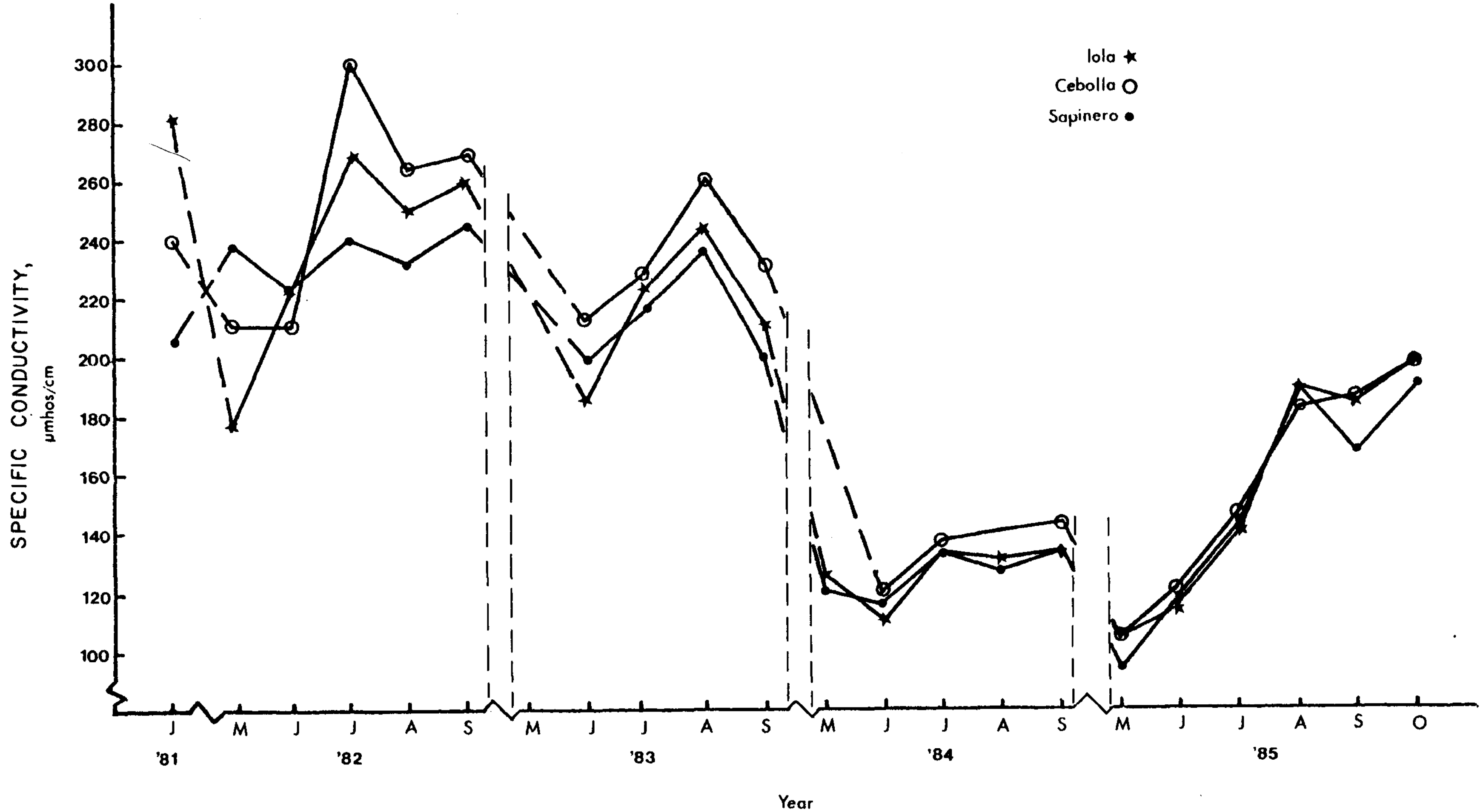

Figure 4a. – Mean monthly specific conductivity (µmhos/cm) in three basins, 1981-1985.

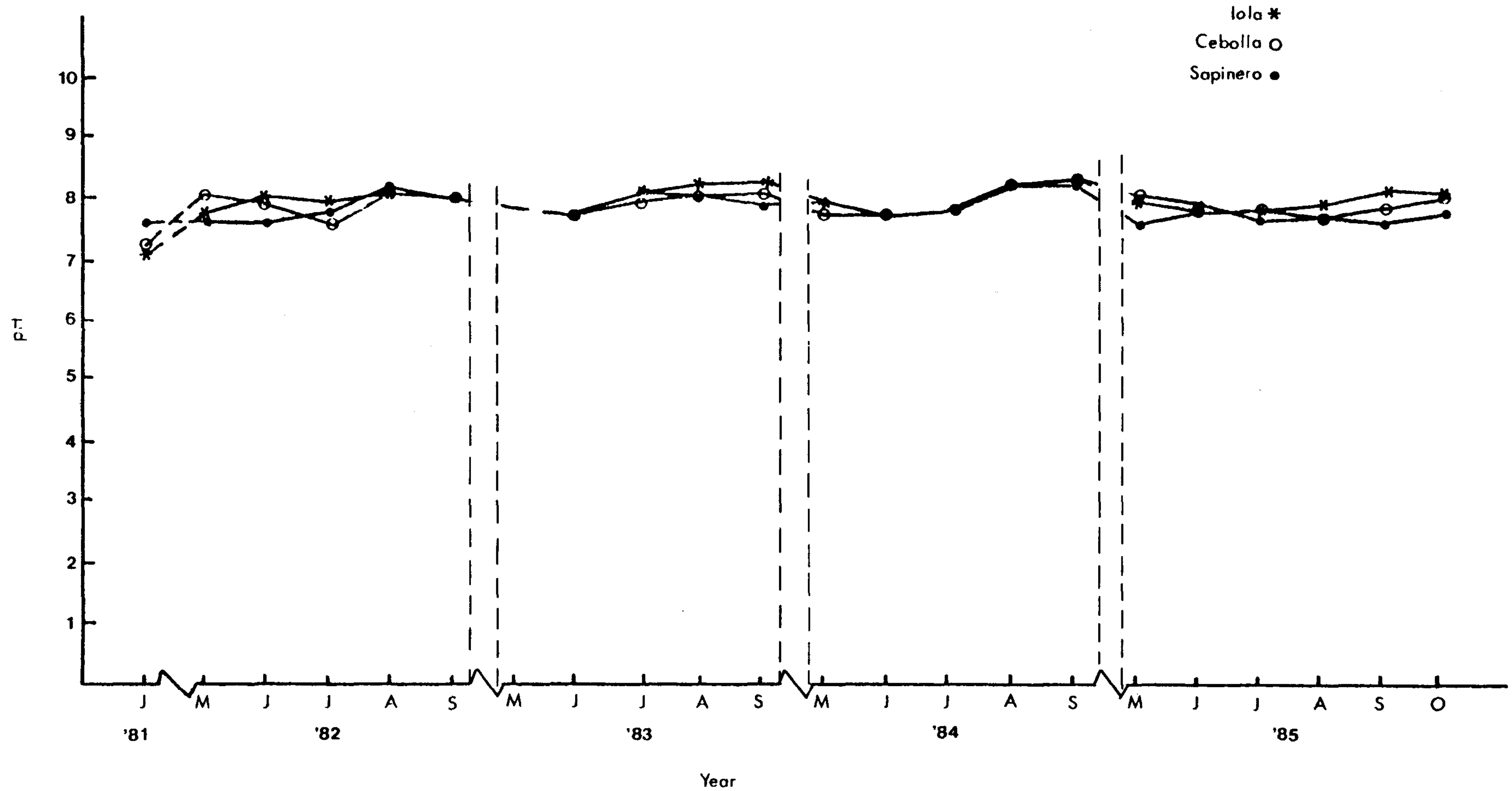

Figure 4b. – Mean monthly pH in three basins, 1981-1985.

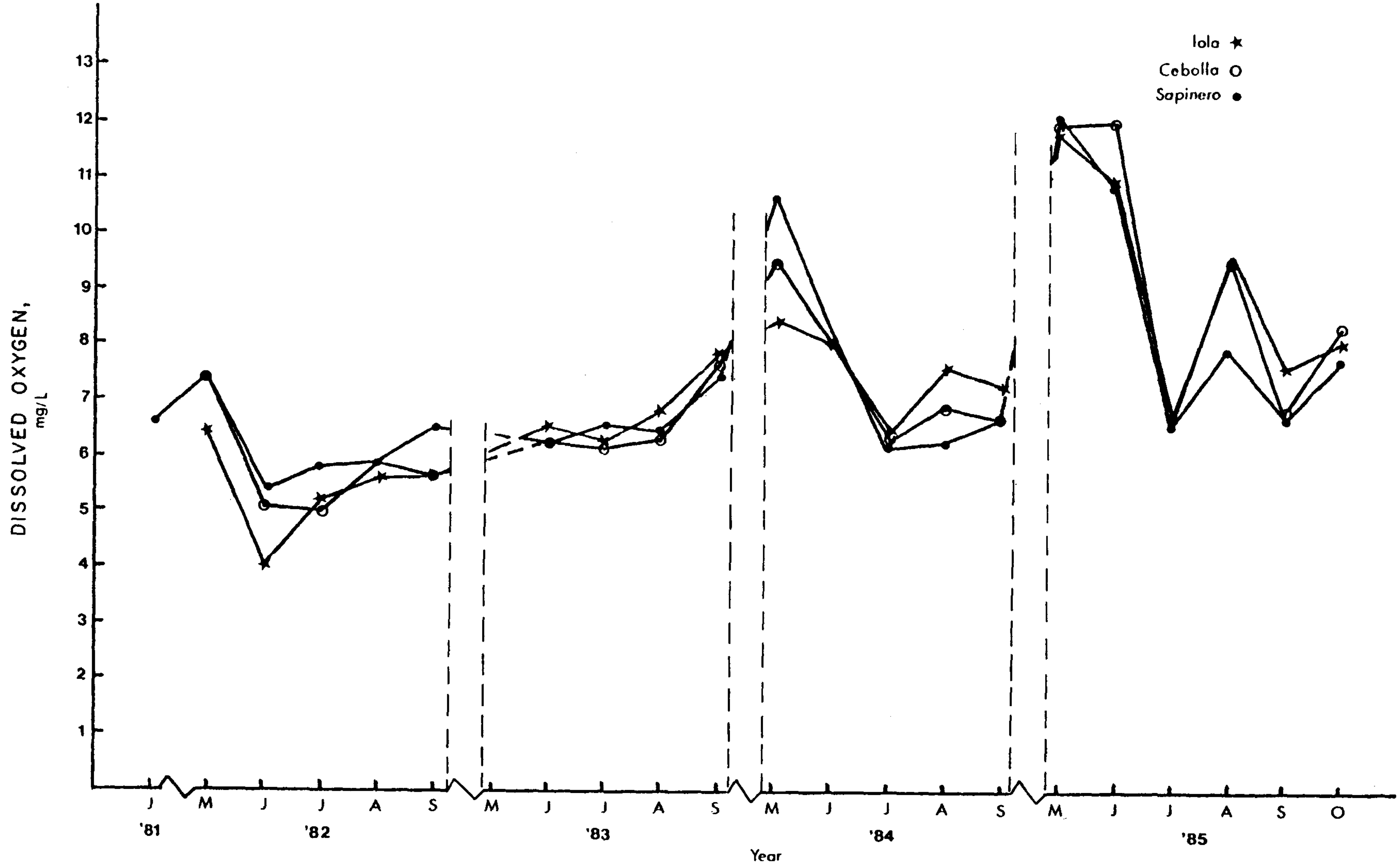

Figure 4c. – Mean monthly dissolved oxygen (mg/L) in three basins, 1981-1985.

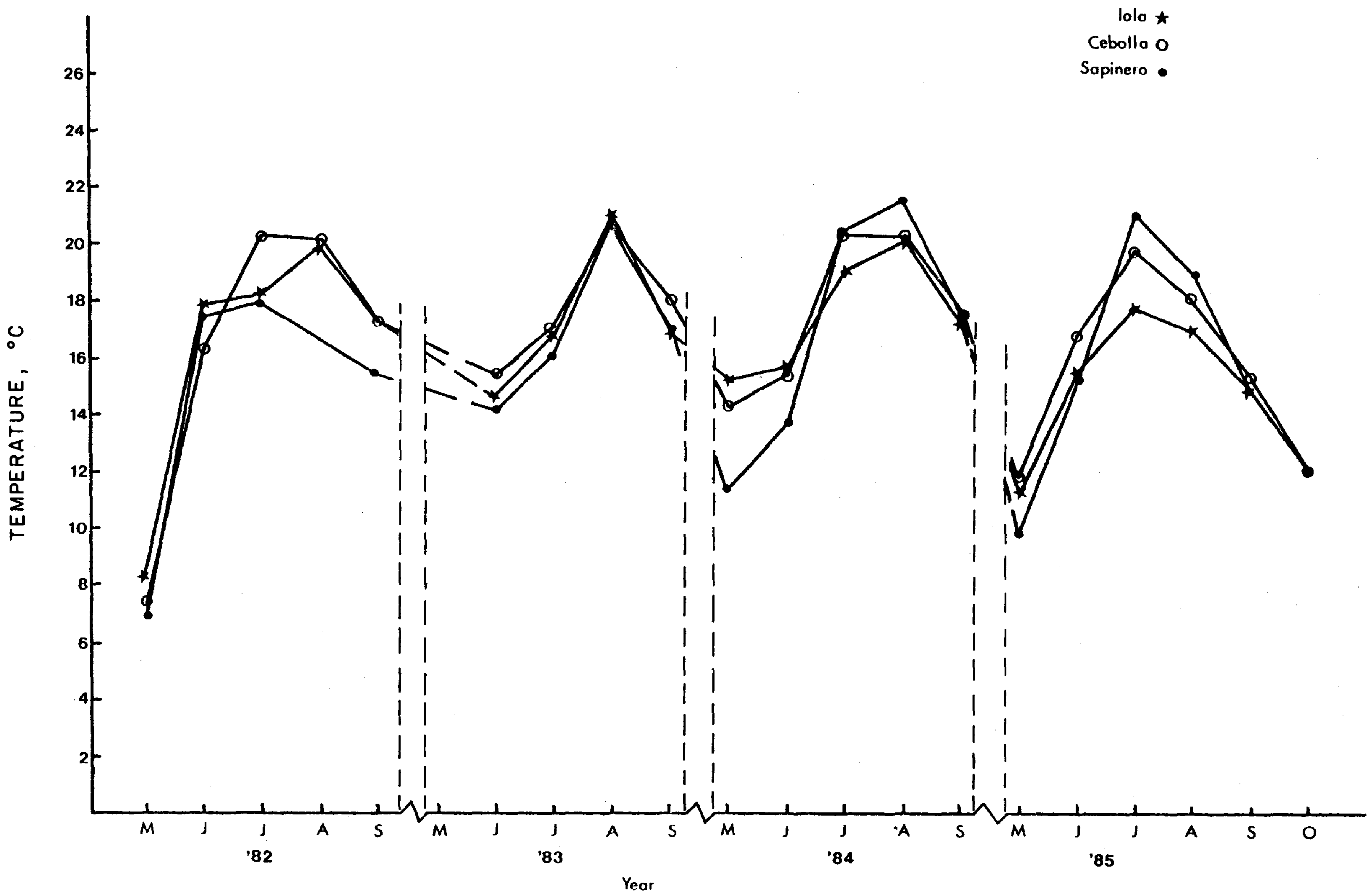

Figure 4d. – Mean monthly temperature (°C) in three basins, 1982-1985.

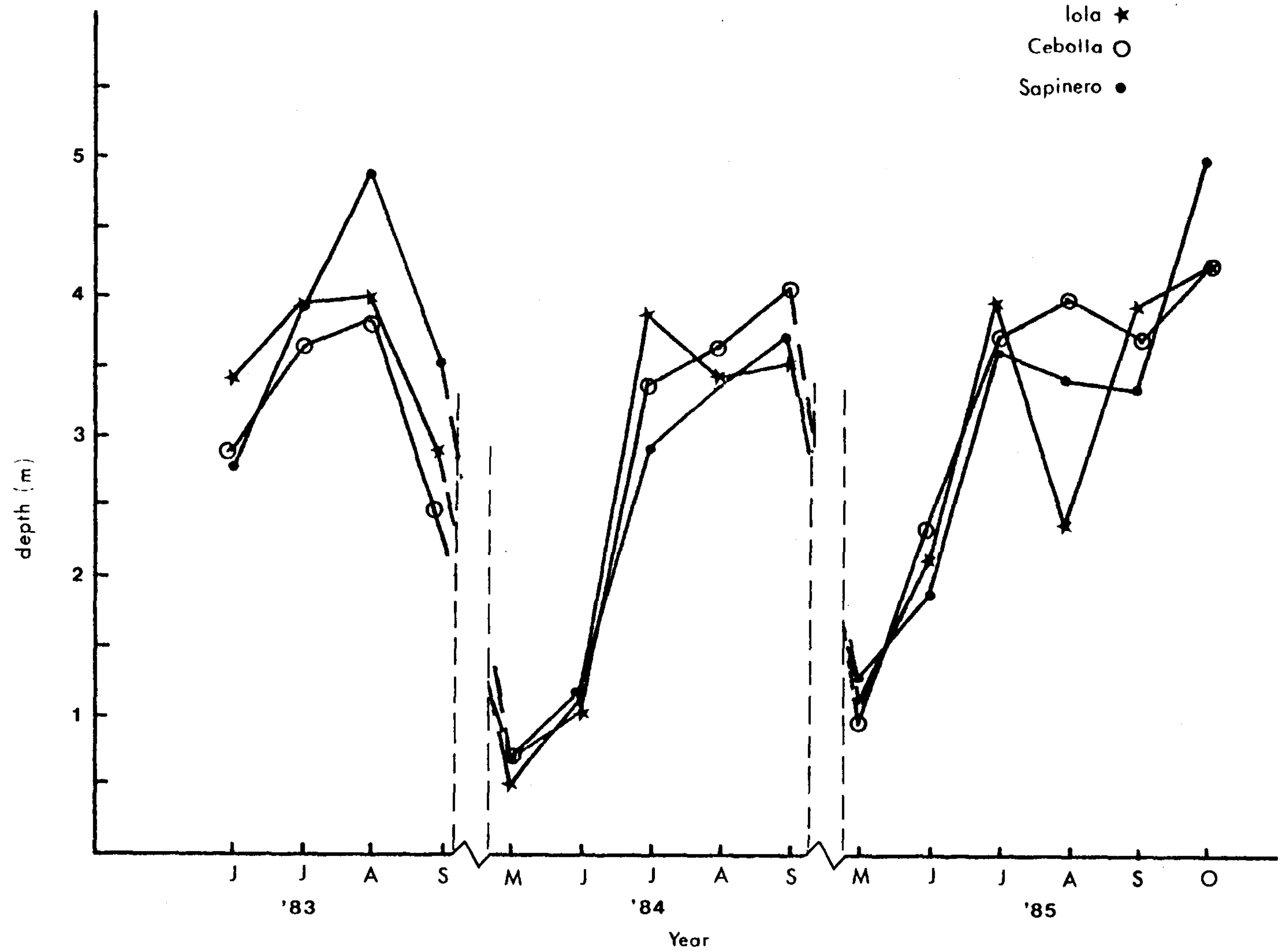

Figure 4e. – Mean monthly Secchi disk depth (m) in three basins, 1983-1985.

a seasonal basis, Secchi depth was typically greatest in Iola Basin. Greater transparency in this basin is counterintuitive and does not reflect larger phytoplankton densities (see figs. 7a, b and table 7a, b), resultant higher chlorophyll *a* levels (fig. 6), and larger inputs of suspended materials to Iola Basin.

In July, August, and September (1982-1985), no transparency trends are detectable in any basin. A trophic index using Secchi depth, developed by Carlson (1977) [43] is an effective tool in determining the trophic status of a body of water. However, with only 3 years of data, no conclusions are drawn with regard to transparency and its capacity to reflect trophic status changes over the life of Blue Mesa Reservoir.

Conductivity. – Mean seasonal conductivity levels over the years ranged from 135 to 272 µmhos/cm in Iola, 127 to 243 µmhos/cm in Cebolla, and 128 to 235 µmhos/cm in Sapinero Basin. These values, except for 1967, 1974, and 1975 data, are depicted on figure 4a. Mean levels in 1967, were 243 and 200 µmhos/cm in Cebolla and Sapinero basins, respectively. A 1974 Sapinero Basin conductivity was measured at 200 µmhos/cm. The 1975 August and September levels ranged from 123 to 172 µmhos/cm. Same month comparisons between successive years show no significant differences, and therefore no significant trends are detectable basin by basin. However, graphically, conductivity has decreased over time. This suggests that less material and associated ions have entered the reservoir by leaching or other mechanisms and that recent high-water years have probably had diluting effects (see tables 1a and 1b).

Seasonal variability predominates. Typically, higher conductivity values are associated with late summer and early autumn. Lewis et al. (1984) [41] also noted seasonal variation, but between-year levels differed only slightly.

pH. – July Iola Basin comparisons reveal the only detectable trend for pH levels: pH decreased from 1982 to 1985. Mean monthly pH levels ranged from 6.50 to 8.77. Figure 4b shows that little variation occurs over time. Because there is so little variability, any change becomes pronounced, particularly in light of the logarithmic basis of pH.

The decline in Iola Basin pH over time is difficult to interpret. A mean pH level was measured at 8.27 in 1967, 8.3 in 1968, 8.1 in 1974, and 8.15 and 8.43 in August and September 1975, respectively. In later years, monthly pH levels approached 8. Normally, pH levels are closely associated with photosynthetic activity. Golterman (1969) [44] suggested that during photosynthesis, water tends to be more alkaline as a result of CO_2 uptake by algae. Because July pH levels show a decreasing tendency over time, a corresponding decrease in chlorophyll *a* levels was expected. Nevertheless, this relationship was not detected.

Dissolved Oxygen. – The 1974 level of dissolved oxygen was 6.3 mg/L in Sapinero Basin. The mean August and September 1975 levels ranged from 6.80 to 7.73 mg/L in all three basins. Other monthly means by year are summarized on figure 4c. No trends between the same months over successive years are detectable except for an increase in June levels from 1982 to 1985 in Sapinero Basin, and a decrease in June levels from 1982 to 1985 in Cebolla Basin. These opposite results for the same time period support the idea that Sapinero and Cebolla basins function differently.

Surface levels of dissolved oxygen are within the standards developed by WQCC (1984) [38] for freshwater organisms. The apparent surface changes in dissolved oxygen levels pose no threat to aquatic life. At greater depths, decreasing oxygen levels may restrict aquatic organisms from flourishing. A 1985 survey (Bio-Environs 1985) [6] measured low levels of dissolved oxygen near the sediment surface, indicating that decaying organic material may contribute to depletion of oxygen. Few species other than *Tubifex tubifex* were encountered in sediment samples. This species, as explained in the benthic section of this report, is typical of waters that are low in dissolved oxygen and that exhibit polluted conditions (Brinkhurst and Cook 1974) [45].

Major Ions and Nutrients

A major portion of ion data for Blue Mesa Reservoir covers the 1983-1985 period. The reservoir was sampled ($n = 1$) in September 1974 (Sapinero Basin, a site located above the deepest point), and in August and September 1975 (Britton and Wentz 1980 [32]; EPA 1976 [33]), for several ions including calcium, magnesium, sodium, and potassium, for various nutrients, and for alkalinity. Early surveys of the reservoir performed by Wiltzius (1974) [11] included sampling for many ions. However, his samples were obtained at a 5-meter depth, and it is believed these values should not be statistically compared with samples from the surface or from a 1-meter depth. Values for Wiltzius's effort are not included in the analysis, but are discussed below. Analytical techniques at various laboratories used to measure ion concentrations presumably differed. Limits of detection were approached for much of the nutrient data. Nevertheless, comparisons (Student's t-test) using all data (except Wiltzius's and the 1974 data), including limit of detection values, were made by year. Because many years of data (essentially from 1966 to 1982) were unavailable, time-series regression was not considered applicable.

Basin differences were recognized by Bio-Environs (1985) [6] and Verdin (1984) [34] with respect to chlorophyll *a* and phytoplankton standing crop. However, for dominant ions and nutrients (Ca, Mg, SO_4, HCO_3, NO_3, total phosphorous, and orthophosphate) within a season, basin differences were not detectable. Hence, seasonal comparisons of ion concentrations are based on means for the entire reservoir.

Seasonal and monthly means for the entire reservoir are presented in tables 3 and 4. Figures 5a-k show monthly changes in ion concentration from 1974 to 1985.

Major Ions. – Typically for freshwater systems in this region, calcium dominates the family of cations present (Cole 1979 [46]; Wetzel 1975 [40]; Hutchinson 1957 [47]). Calcium concentrations are highest in Blue Mesa Reservoir, followed by magnesium, sodium, and potassium (see figs. 5a-d). Samples from Wiltzius's efforts contained calcium levels ranging from 26 to 32 p/m. The 1974 level of 28 mg/L approaches values determined for the 1983-1985 samples. The 1983 yearly calcium mean is significantly higher than the 1984 mean ($p < 0.001$). Both 1983 and 1984 means ($p < 0.001$ and $p < 0.053$, respectively) are significantly greater than the 1985 mean. Low concentrations detected in May and June 1985 tend to reduce the overall mean. Highest calcium concentrations dominated the later summer months for the years sampled. May to October 1985 concentrations steadily increased, and may reflect early season dilution from snowmelt and later accumulation in the reservoir. Interestingly, the highest mean levels (1983 and 1984) occurred in relatively "wet years" where runoff levels peaked for the 20-year study period. It is possible that calcium is released from the watershed in large amounts when runoff is great (Likens et al. 1977) [48].

Mean seasonal levels of magnesium, sodium, and potassium were variable (table 3). The 1983 magnesium mean is significantly greater than the 1985 mean level ($p < 0.016$). Like calcium concentrations, 1985 magnesium levels are low compared with those of 1984. The highest concentration of magnesium was detected in July 1985 ($\bar{x} = 6.7$, s.d. = 2.0). No sampling for sodium and potassium was done in 1984, and sodium means differ significantly between 1983 and 1985 ($p < 0.027$, the 1983 mean is higher than that for 1985). Wiltzius's analyses reveal magnesium levels ranging from 4.4 to 6.3 p/m

Table 3. – Mean ion concentrations in Blue Mesa Reservoir by year, 1974, 1975, and 1983-1985

Parameter	1974 Mean (n = 1)	1975 Mean	1975 s.d.[1]	1983 Mean	1983 s.d.	1984 Mean	1984 s.d.	1985 Mean	1985 s.d.
Acidity (mg/L)	*	*		7.8	6.2	6.8	4.7	*	
Alkalinity (mg/L)	76	91.4	10.5	74.8	6.4	72.2	9.8	68.9	2.1
HCO_3 (mg/L)	93	*		74.8	6.4	*		68.9	2.1
CO_3 (mg/L)	*	*		0	0	*		0	0
Calcium (mg/L)	28	*		46.8	20.4	20.7	2.4	15.0	8.2
Magnesium (mg/L)	4.8	*		5.7	0.9	5.2	1.2	4.4	1.6
Sodium (mg/L)	4.9	*		3.9	1.8	*		4.0	1.4
Potassium (mg/L)	1.2	*		1.6	0.5	*		1.8	0.6
Chloride (mg/L)	1.3	*		5.6	2.2	11.6	5.1	0.8	.9
Sulfate (mg/L)	16	*		18.0	3.2	18.1	5.0	13.6	3.3
Boron (µg/L)	*	*		157	129	*		*	
Cyanide (µg/L)	*	*		5.7	3.0	3.0	4.0	*	
Fluoride (mg/L)	0.2	*		0.23	0.13	0.13	0.07	*	
Organic N (mg/L)	*	*		.8	.2	.1	0	*	
TKN (mg/L)	*	0.30	0.18	.92	.21	*		0.40	0.29
NO_2-N (mg/L)	*	*		.5	0	*		.04	.04
NH_3 (mg/L)	*	0.02	0.01	.12	0.09	0.10	0	.07	.02
NO_3-N (mg/L)	*	*		.04	.04	.18	0.27	1.08	1.06
NO_2NO_3-N (mg/L)	0	0.02	0.02	.44	.16	*		*	
Ortho-P (mg/L)	0.01	*		.04	.04	0.03	0.02	0.14	0.24
Total P (mg/L)	*	0.04	0.10	.24	.21	.08	0.06	.09	0.14
Nutrient[2] index	*	*		48.3	64.8	15.4	15.0	17.8	

* Not measured.
[1] s.d. = standard deviation.
[2] Nutrient index equals inorganic nitrogen/orthophosphate phosphorus.

Table 4. – Mean ion concentrations in Blue Mesa Reservoir by months sampled, 1974, 1975, and 1983-1985[1]

	1974	1975		1983		1984					1985					
Parameter	S	A	S	J	A	M	J	J	A	S	M	J	J	A	S	O
Acidity (mg/L)	*	*	*	13.5 (2.2)	2.0 (0)	10.0 0	*	0.5 0	*	10.0 0	*	*	*	*	*	*
Alkalinity (mg/L)	76	90.0 (10.8)	92.8 (11.0)	70.1 (4.5)	79.4 (4.1)	84.0 (4.0)	*	65.3 (4.2)	*	67.3 (6.1)	64.5 (8.4)	59.3 (3.1)	65.9 (5.0)	68.3 (6.7)	78.1 (9.0)	77.2 (3.2)
HCO_3 (mg/L)	93	*	*	70.1 (4.5)	79.4 (4.1)	84.0 (4.0)	*	65.3 (4.2)	*	67.3 (6.1)	64.5 (8.4)	59.3 (3.1)	65.9 (5.0)	68.3 (6.7)	78.1 (9.0)	77.2 (3.2)
CO_3 (mg/L)	*	*	*	0	0	*	*	*	*	*	0	0	0	0	0	0
Calcium (mg/L)	28	*	*	26.0 (0)	64.6 (5.0)	22.4 (1.6)	*	18.4 (0.6)	*	21.4 (2.7)	5.0 (2.5)	6.2 (0.6)	16.5 (3.8)	19.9 (6.7)	17.9 (7.9)	24.3 (0.6)
Magnesium (mg/L)	4.8	*	*	5.07 (0.26)	6.24 (0.98)	6.36 (1.13)	*	4.46 (0.08)	*	4.84 (1.33)	3.59 (1.42)	4.44 (0.11)	6.70 (1.95)	4.39 (0.44)	3.73 (2.17)	3.73 (1.00)
Sodium (mg/L)	4.9	*	*	2.3 (0.1)	5.4 (1.1)	*	*	*	*	*	4.4 (0.7)	4.1 (0.2)	4.5 (1.9)	4.1 (1.2)	1.6 (0.2)	5.0 (0.5)
Potassium (mg/L)	1.2	*	*	1.2 (0.4)	2.0 (0)	*	*	*	*	*	1.5 (0.3)	1.6 (0.2)	1.7 (1.4)	1.9 (0.4)	1.7 (0.6)	2.5 (1.1)
Chloride (mg/L)	1.3	*	*	6.2 (3.1)	5.0 (0)	14.0 (2.0)	*	6.3 (1.4)	*	14.3 (5.9)	2.5 (0.5)	0.2 (0.1)	0.9 (0.4)	0.2 (0.1)	0.5 (0.3)	0.4 (0.1)
Sulfate (mg/L)	16	*	*	20.6 (1.3)	15.3 (1.7)	23.2 (3.7)	*	13.8 (4.0)	*	17.3 (1.8)	18.9 (0.9)	12.7 (1.1)	8.4 (0.5)	12.5 (0.2)	14.6 (1.1)	14.2 (1.1)
Boron (µg/L)	*	*	*	257 (42)	57 (19)	*	*	*	*	*	*	*	*	*	*	*
Cyanide (µg/L)	*	*	*	1.5 (0.9)	10.0 (0)	1.0 (0)	*	4.0 5.2	*	4.0 5.2	*	*	*	*	*	*
Fluoride (mg/L)	0.2	*	*	0.4 (0.1)	0.1 (0.0)	0.2 (0.1)	*	0.1 (0)	*	0.1 (0)	*	*	*	*	*	*
Organic N (mg/L)	*	*	*	0.9 (0.6)	0.1 (0)	0.1 (0)	0.1 (0)	0.1 (0)	0.1 (0)	0.1 (0)	*	*	*	*	*	*
TKN (mg/L)	*	0.35 (0.24)	0.25 (0.08)	*	1.00 (0)	*	*	*	*	*	0.58 (0.13)	0.65 (0.11)	0.32 (0.34)	0.40 (0.50)	ND	0.14 (0.04)
NO_2-N (mg/L)	*	*	*	*	0.50 (0)	*	*	*	*	*	0.03 (0.01)	0.06 (0.06)	ND	ND	ND	ND
NH_3-N (mg/L)	*	0.02 (0)	0.02 (0.01)	0.14 (0.13)	0.10 (0.00)	0.10 (0)	0.10 (0)	0.10 (0)	0.10 (0)	0.10 (0)	0.07 (0.2)	ND	ND	ND	ND	ND
NO_3-N (mg/L)	*	*	*	0.04 (0.04)	*	0.27 (0.17)	0.34 (0.57)	0.14 (0.09)	0.10 (0)	0.10 (0)	1.74 (0.17)	3.00 (0.81)	0.64 (0.12)	0.18 (0.03)	0.30 (0.03)	0.65 (0.02)
NO_2NO_3-N (mg/L)	0	0.03 (0)	0.01 (0.01)	0.5 (0)	0.44 (0.17)	*	*	*	*	*	*	*	*	*	*	*
Ortho-P (mg/L)	0.01	0.01	0.02	0.07 (0.03)	0.01 (0.01)	0.04 (0.03)	0.02 (0.01)	0.04 (0.03)	0.02 (0.02)	0.01 (0.00)	0.02 (0.01)	0.17 (0.23)	0.04 (0.03)	0.03 (0.01)	ND	ND
Total-P (mg/L)	*	*	*	0.43 (0.01)	0.05 (0)	0.12 (0.08)	0.07 (0.02)	0.08 (0.06)	0.07 (0.07)	0.04 (0.04)	0.03 (0.02)	0.24 (0.28)	0.05 (0.03)	0.03 (0.01)	0.14 (0.14)	0.02 (0)
Nutrient index	*	*	*	4.15 (4.02)	92.47 (67.3)	13.60 (9.95)	25.42 (30.2)	7.75 (5.34)	12.45 (5.77)	19.38 (2.50)	30.60	17.65	18.29	4.68	*	*

* Not measured.
ND = Not detectable.
[1]Numbers in parentheses are standard deviations.

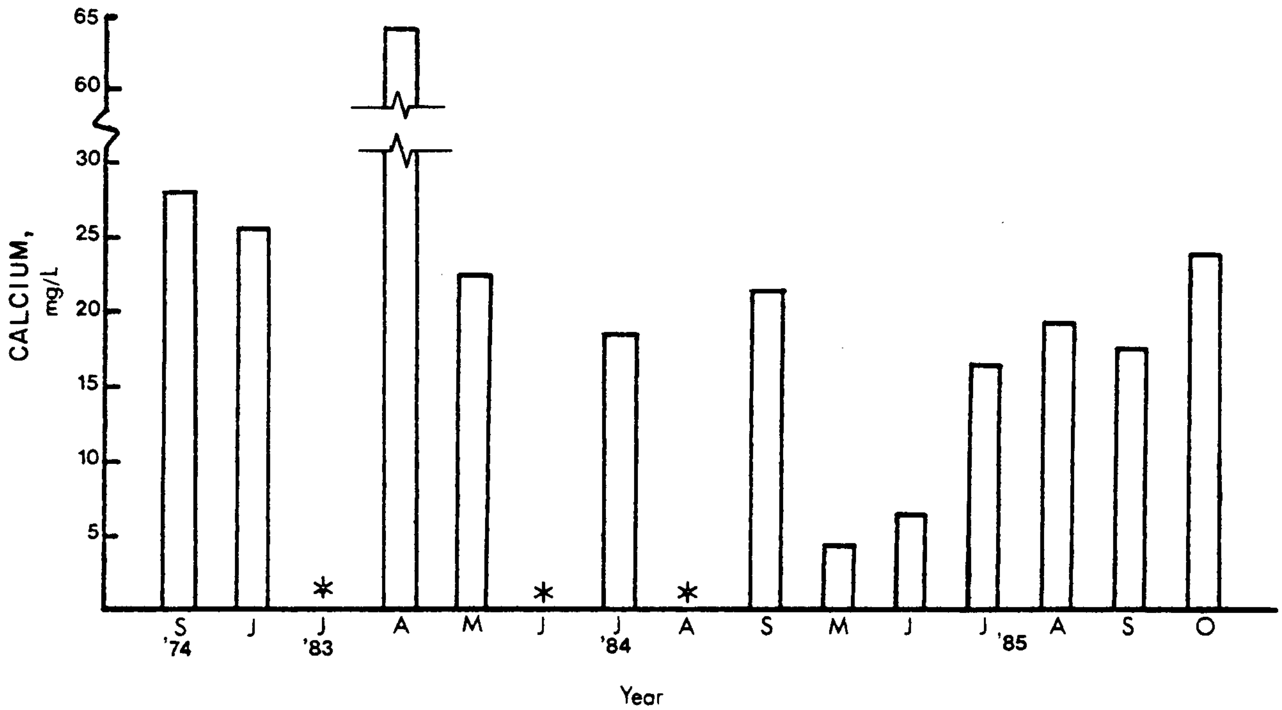

Figure 5a. – Mean monthly calcium (mg/L) in entire reservoir. Asterisks indicate months not sampled.

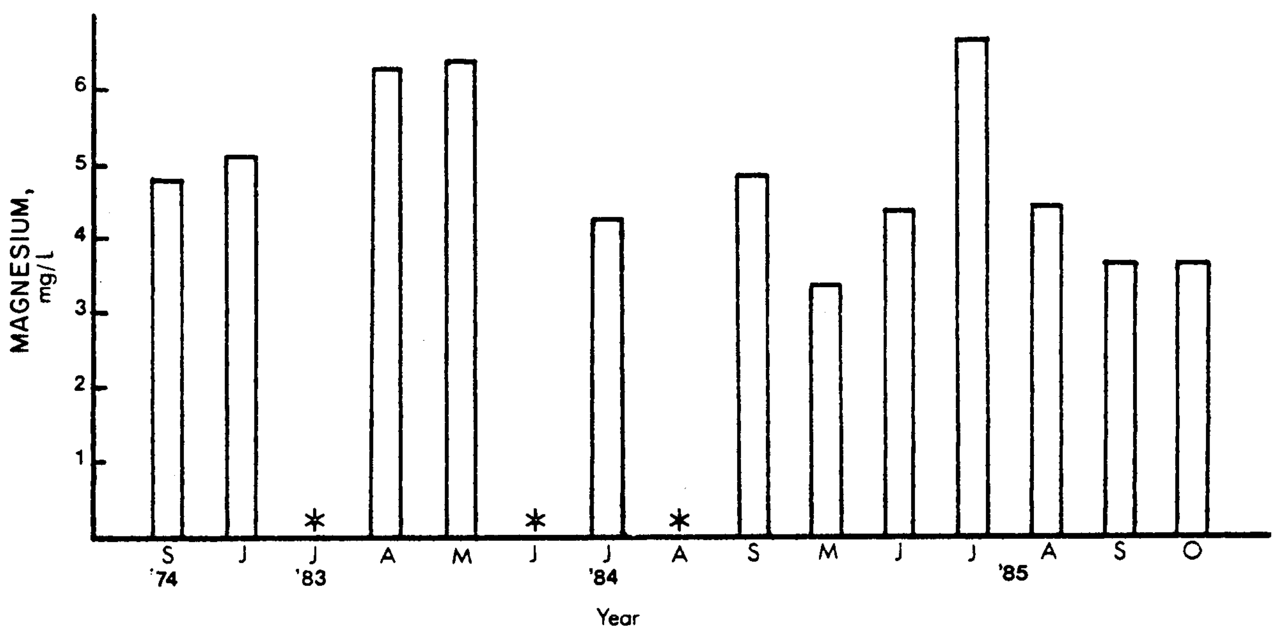

Figure 5b. – Mean monthly magnesium (mg/L) in entire reservoir. Asterisks indicate months not sampled.

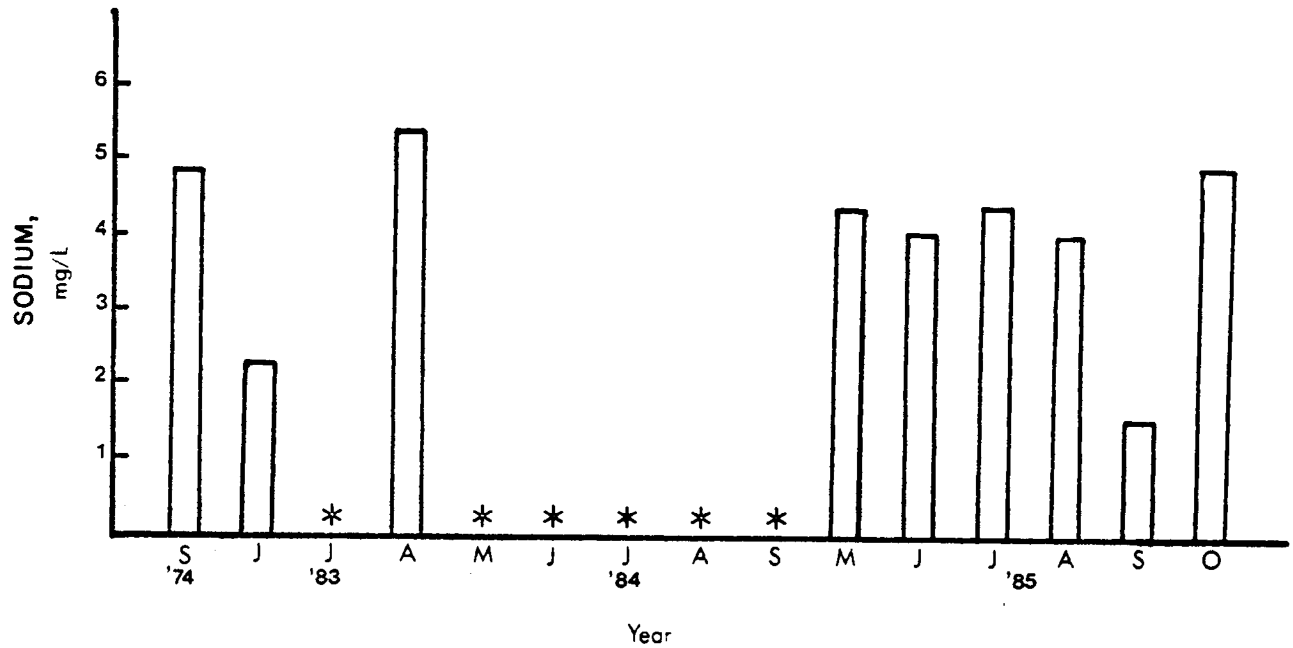

Figure 5c. – Mean monthly sodium (mg/L) in entire reservoir. Asterisks indicate months not sampled.

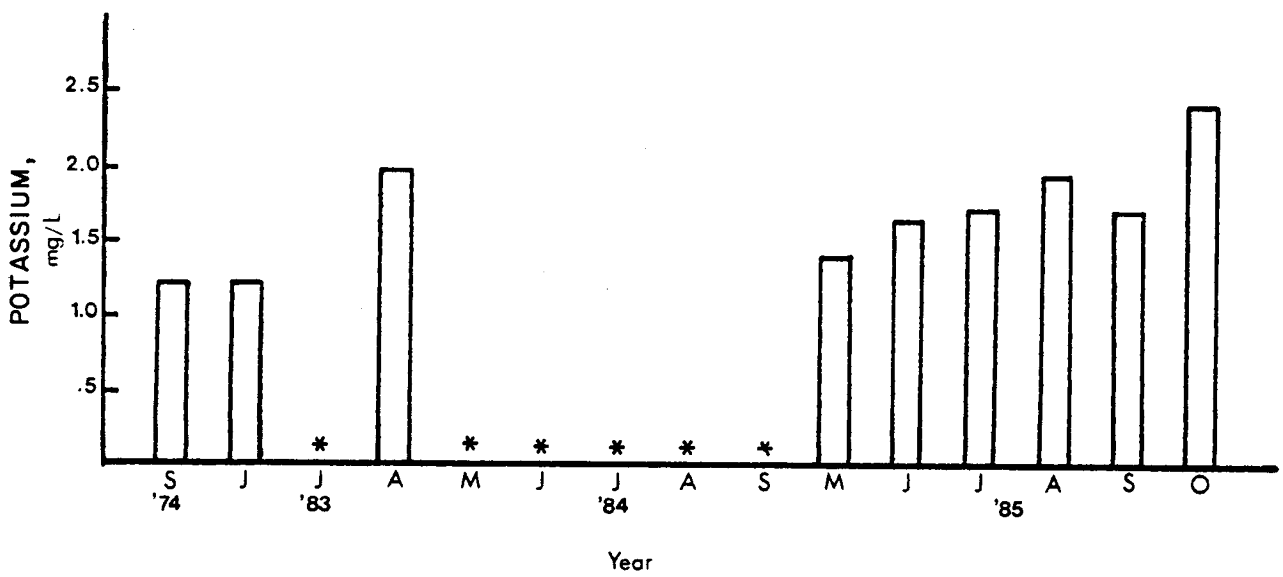

Figure 5d. – Mean monthly potassium (mg/L) in entire reservoir. Asterisks indicate months not sampled.

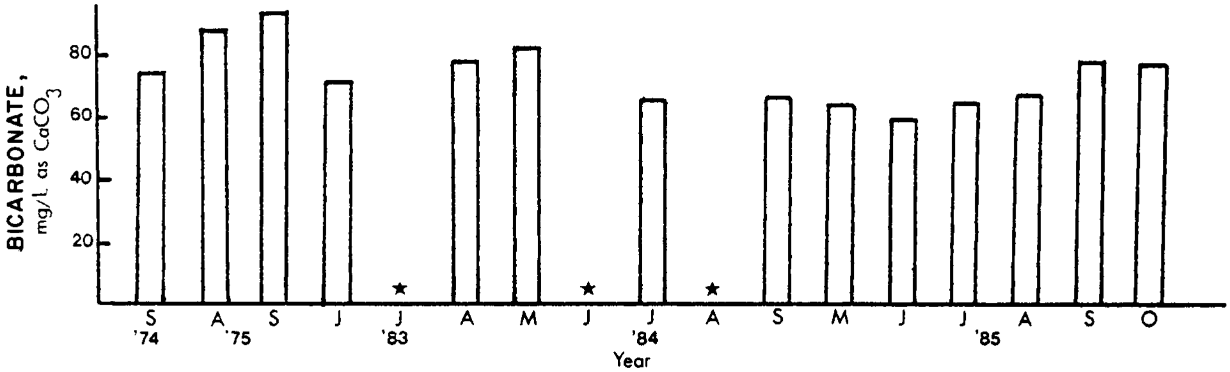

Figure 5e. – Mean monthly bicarbonate (mg/L) in the reservoir. Asterisks indicate months not sampled.

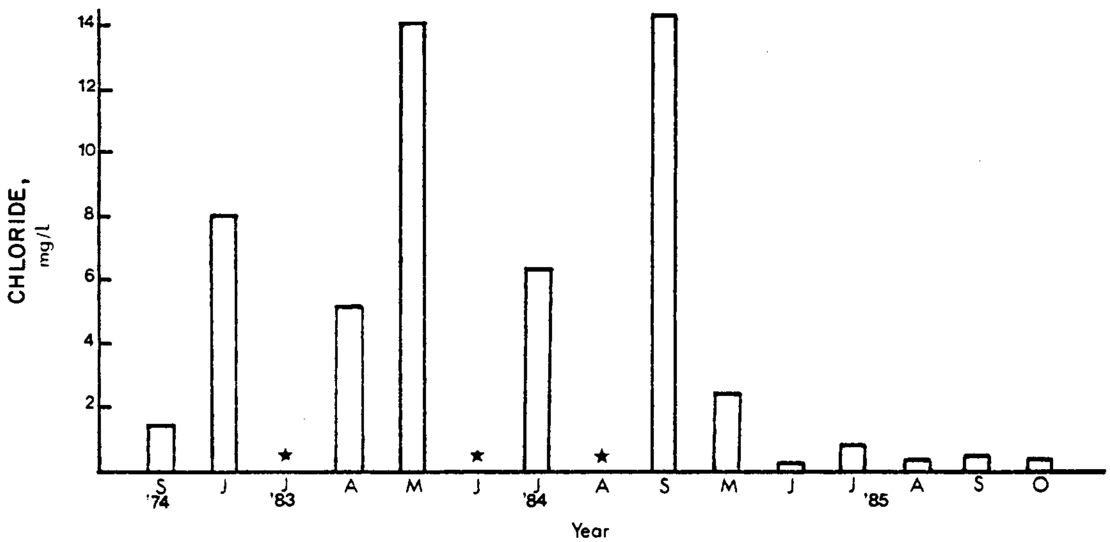

Figure 5f. – Mean monthly chloride in the reservoir. Asterisks indicate months not sampled.

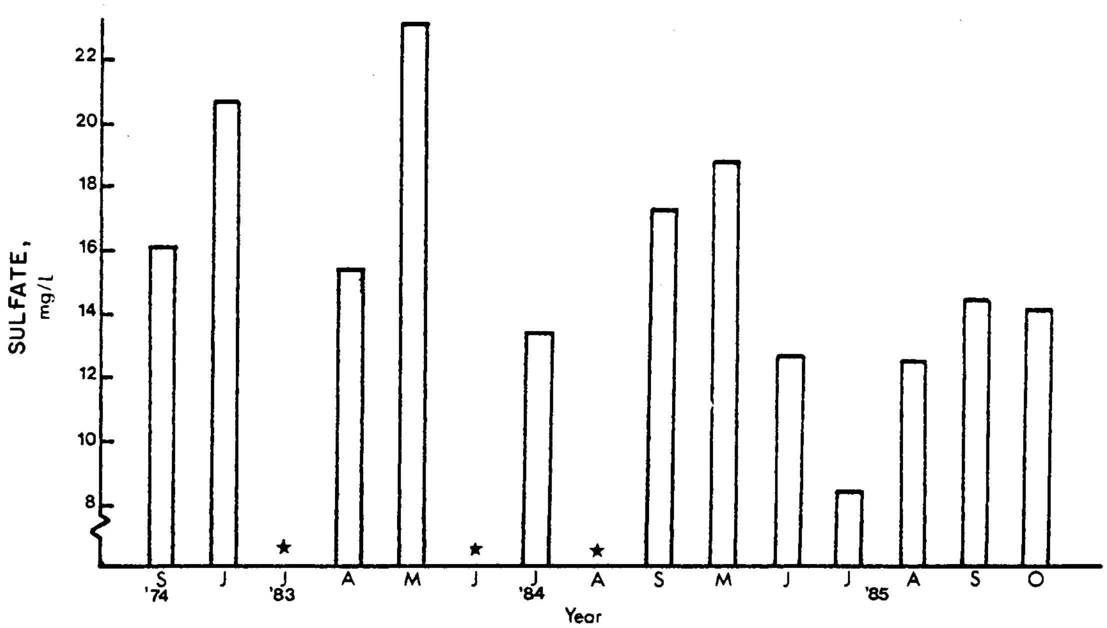

Figure 5g. – Mean monthly sulfate (mg/L) in the reservoir. Asterisks indicate months not sampled.

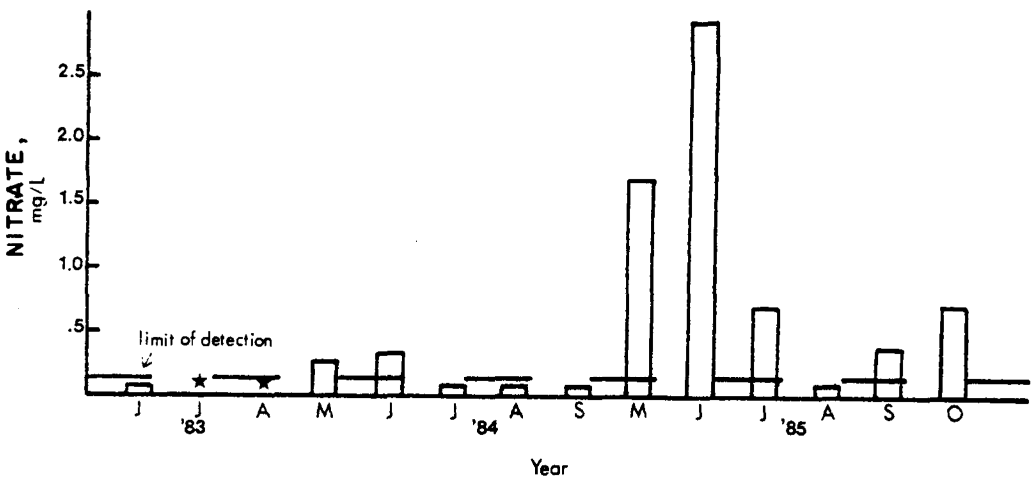

Figure 5h. – Mean monthly nitrate (mg/L) in the reservoir. Asterisks indicate months not sampled.

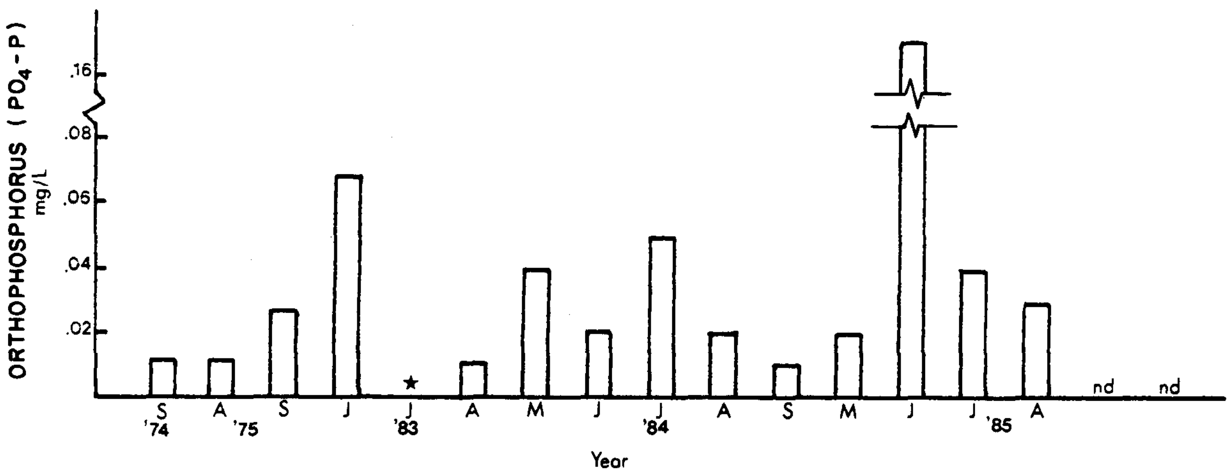

Figure 5i. – Mean monthly orthophosphorus (mg/L) in the reservoir. Asterisks indicate months not sampled.

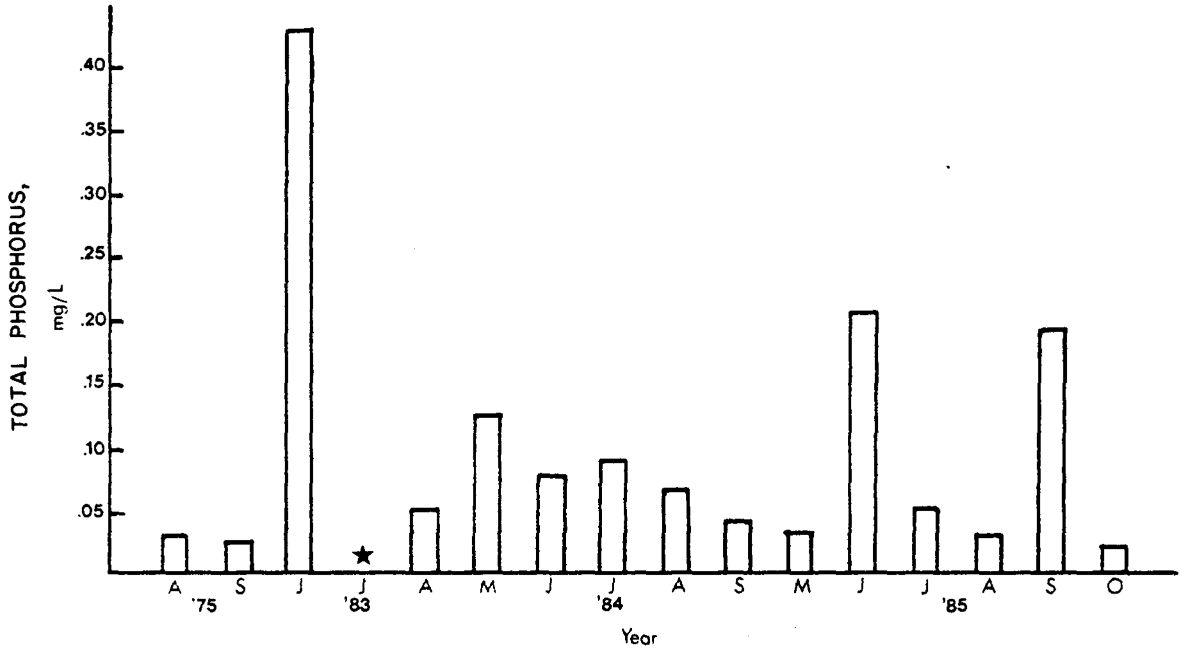

Figure 5j. – Mean monthly total phosphorus (mg/L) in the reservoir. Asterisk indicates month not sampled.

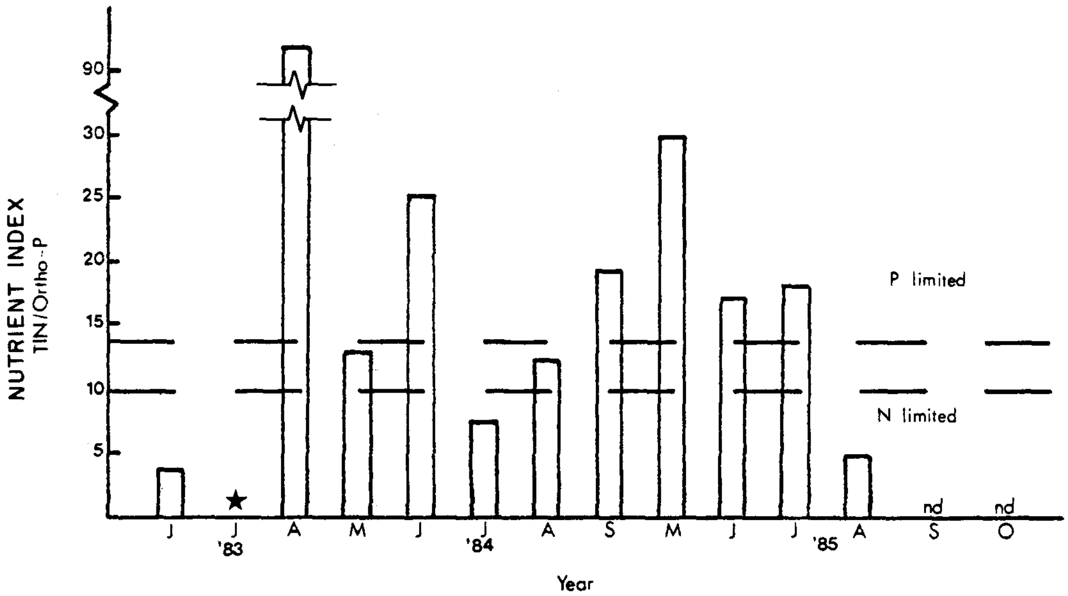

Figure 5k. – Mean monthly nutrient index (TIN/ortho-P) in the reservoir. Asterisk indicates month not sampled.

(sodium and potassium were not measured). The 1974 values for sodium, magnesium, and potassium are within the range of the 1983 and 1985 data.

Bicarbonates, sulfates, and chlorides, are the predominant anions in the reservoir system. From 1983 to 1985, total alkalinity was attributable to bicarbonates because no carbonate concentrations were detected. At pH levels exceeding 8.4 (which did occur from 1966 to 1969) carbonates dominate the bicarbonate-carbonate equilibrium system (Hutchinson 1975 [47]). However, mean pH levels rarely exceeded 8.3 in Blue Mesa Reservoir (see fig. 4b); therefore, where no bicarbonate values are available (1984), total alkalinity was substituted for graphed values.

Wiltzius measured methyl orange alkalinity from 1966 to 1969; levels ranged from 77 to 124 p/m. Yearly means ranged from 68.9 in 1985, to 91.4 mg/L as $CaCO_3$ in 1975 (table 3). From 1983 to 1985, little change occurred over the months sampled; however, there was a slight decrease in bicarbonate concentration from 1975 to 1985 (see fig. 5c). Bicarbonate means of 1983, 1984, and 1985, differ significantly from the 1975 mean ($p < 0.001$). The carbon dioxide gas fraction of the atmosphere is the principal source of CO_2 responsible for producing alkalinity (Hem 1985 [49]). Another source is the metamorphism of carbonate rocks. A trend towards lower alkalinity and bicarbonate levels over the years may reflect reduction of carbonate rock leaching, chemical precipitation in the reservoir (Bolke 1979 [50]) and dilution of waters by the recent "wet year."

Sulfates and chlorides are significant anions in the system. They vary monthly and seasonally (see tables 3 and 4). The mean high for sulfates ($\bar{x}$ = 23.2, s.d. = 3.7) occurred in May 1984, the low in July 1985 ($\bar{x}$ = 8.4, s.d. = 0.5). Significant differences were detected between sulfate means in 1983 and 1985 ($p < 0.001$), and between 1984 and 1985 ($p < 0.010$). The 1974 level (1.3 mg/L) is low compared with the 1983-1984 data. Chloride values for 1985 are considerably lower than data from previous years and other data for the region's streams (Rumberg et al. 1978 [18]; Apley 1982 [17]). Analytical techniques may be questionable, resulting in somewhat anomalous values. The 1984 mean is significantly greater than the 1983 mean ($p < 0.001$). Both 1983 and 1984 chloride levels are significantly greater than the 1985 mean ($p < 0.001$). The highest level was detected in September 1984 ($\bar{x}$ = 14.3, s.d. = 5.9). The 1966-1969 Wiltzius data revealed chloride levels ranging from 5.0 to 7.5 p/m.

These cations and anions are ubiquitous in freshwater systems, and no criteria limits have been set, except that alkalinity should exceed 20 mg/L (as $CaCO_3$) in freshwater systems. Often snowmelt dilutes concentrations of these ions in streams, but large absolute amounts are often brought into the receiving system as may be the case for Blue Mesa Reservoir. These essential ions are used with increased production of plankton as the season progresses. Apparently, in Blue Mesa Reservoir, no extreme reduction of ion content occurs from biological use. Though there may be significant differences between years for some constituents, no overall trend in ion concentrations is recognized with the exception of decreasing total alkalinity levels from 1966 to 1985.

Other ionic constituents (boron, cyanide, fluoride, and uranium) were sampled, but inconsistently. Mean seasonal and monthly levels are summarized in tables 3 and 4. No significant differences exist between years for cyanide and fluoride levels. No comparison of boron is made because of the lack of data.

The mean cyanide level in 1983 exceeded the 5.0-µg/L criterion established by EPA 1976 [26]. Some samples from 1984 also exceeded this criterion. However, in neither year did the yearly mean significantly differ from the criterion. It is important to note that cyanide is reported at its limit of detection, which can lead to misrepresentation of actual concentration. As a toxic ion, cyanide can form hydrocyanic acid, and may complex with heavy metal ions if not associated in highly unstable complexes with zinc and cadmium in neutral and acidic environments. Alkalinity and hardness of dilution waters apparently have little relationship with cyanide toxicity to fish (EPA 1976) [26]. Cyanide has not been reported to have direct effects on recreational uses of water, but further monitoring of cyanide is warranted considering the levels detected in 1983.

Nutrients. – From 1975 to 1985, many nutrient compounds were measured. In each of these years, one or more forms of phosphorus or nitrogen were detected. Inconsistencies in measuring the same types of nutrient compounds over the years presents some difficulty in interpreting seasonal or monthly trends. In addition, nitrates, ammonia, nitrites, and sometimes Kjeldahl nitrogen were measured at their limit of detection in 1983 and 1984. These limits were used in the analysis, representing a conservative approach to interpreting data with regard to the trophic status of Blue Mesa Reservoir. Describing the trophic status by using lower limits would tend to neglect gross ongoing eutrophication.

The following focuses to a large extent on the inorganic forms of phosphorus and nitrogen because these are the nutrients biologically available to organisms (Hutchinson 1975 [47]). The inorganic forms include nitrates, ammonia, nitrites, and orthophosphates. In Blue Mesa Reservoir, nitrate-nitrogen dominated the inorganic forms of nitrogen. In well-oxygenated waters, nitrites are readily oxidized to the more stable nitrate form. Nondetectable or very low levels of nitrites in Blue Mesa Reservoir are attributed to oxidation processes. Ammonia concentrations were relatively low or barely detectable from 1975 to 1985. Ammonia levels were reported as ammonium in 1985. At pH levels less than 9.24, ammonia nitrogen is typically in the ammonium ion form (Hem 1985) [49]; therefore, the 1985 values are compared with ammonia nitrogen measurements of earlier years. Ammonium is readily oxidized by microbes in decomposition processes and taken up by phytoplankton (Hutchinson 1975 [47]; Lewis et al. 1984 [41]). These processes most likely reduce ammonium levels in Blue Mesa Reservoir.

Nitrates were measured from 1983 to 1985. Most of the 1983 and 1984 samples were measured at their limits of detection (0.1 mg/L). The monthly mean levels are depicted on figure 5h. It may be expected that spring and late autumn levels would differ from late summer levels. May and June 1985 nitrate-nitrogen levels are elevated compared with July through September concentrations. Although significantly lower than 1985 values ($p < 0.001$), the 1984 monthly means reflect similar increased late spring values compared with late summer means. Reduction of nitrates during late summer is attributed to uptake by phytoplankton. Increased levels of chlorophyll *a* and density of phytoplankton in August and September (see figs. 9a-c) correspond to these depressed nitrate levels. Nitrate levels of 1983 do not differ significantly from 1984 levels ($p < 0.189$). The significant differences between 1985, and 1983-1984 ($p < 0.026$ and $p < 0.001$, respectively) may be a reflection of the ability to detect nitrate concentrations and of laboratory techniques. Nitrate-nitrogen levels were much higher in 1985.

Other forms of nitrogen include Kjeldahl nitrogen, nitrites plus nitrates, total nitrogen, organic nitrogen, and total inorganic nitrogen (see tables 3 and 4). Kjeldahl nitrogen was measured in 1975, 1983, and 1985. The 1983 level was measured at its limit of detection (1 mg/L). The 1985 mean of 0.40 mg/L is not significantly different ($p < 0.323$) from the 1975 level of 0.3 mg/L. Ammonia levels (from 1975 to 1985) ranged from 0.02 to 0.12 mg/L. The t-test suggests a significant difference exists between 1983 and 1984 ammonia means ($p < 0.030$), but this is perhaps due to the limit of detection and the different sample sizes ($n = 14$ in 1983, $n = 87$ in 1984). Levels in 1975 and 1985 were lower than the 1983 and 1984 levels (see table 3).

Phosphorus concentrations were measured in 1974, 1975, and 1983-1985. Tables 3 and 4 and figures 5i and 5j summarize the seasonal and monthly means. Orthophosphate phosphorus concentrations varied with regard to season. Levels are normally higher in June and July than in other months sampled. A high of 0.17 mg/L (s.d. = 0.27) was detected in June 1985; the low occurred in September 1984 ($\bar{x} = 0.01$, s.d. = 0.00). No significant difference exists between 1983 and 1984 levels ($p < 0.187$), or between 1985 and 1983-1984 levels ($p > 0.05$). A seasonal trend similar to nitrate-nitrogen levels is noticeable for orthophosphate phosphorus. Levels are depressed in late summer; September and August means are lower than other monthly means except for those of June 1984 and May 1985. As a biologically available form, orthophosphate is used by phytoplankton throughout the growing season. Corresponding to increased algal standing crop in late summer, low levels of orthophosphate reflect uptake by these living organisms.

Total phosphorus follows a different seasonal pattern. Total phosphorus includes various forms of phosphorus – soluble, insoluble, organic, and inorganic (USGS 1982 [51]). A mean high for all years sampled occurred in June 1983 ($\bar{x} = 0.43$, s.d. = 0.10). Total phosphorus decreased from May to September 1984. High levels occurred in June and September 1985. Apparently the September 1985 level corresponds to increased surface chlorophyll *a* levels and to extremely large phytoplankton populations of the alga *Aphanizomenon flos-aquae*. Significant differences occurred between 1983 and all other years sampled for total phosphorus. The differences reflect the very high levels of phosphorus measured in June 1983. Trends over the years for all forms of nutrients and, specifically, for inorganic forms are not identifiable given the sample population size and years studied.

A nutrient index was developed based on inorganic nitrogen to orthophosphate phosphorus for Blue Mesa Reservoir. Understanding the interaction between these two nutrients may clarify the seasonal shifts in phytoplankton communities (Smith 1982) [52]. For example, the nitrogen-fixing alga *Aphanizomenon flos-aquae* (Gentile and Maloney 1969) [53] tolerates nitrogen-poor environments, whereas diatoms may flourish in waters lacking adequate sources of phosphorus (Cole 1979) [46]. According to Lambou et al. (1976) [54], the ratio of nitrogen to phosphorus indicates to which either nutrient would be limiting to phytoplankton productivity based on yearly mean chlorophyll *a* levels. A ratio greater than 14 indicates phosphorus deficiencies, less than 10 indicates nitrogen limitation, and intermediate levels are indicative of a transition between nitrogen and phosphorus limitation over the seasons. Applied to Blue Mesa Reservoir, seasonal means indicate that phosphorus deficiencies prevail (see table 3), contrary to other findings (EPA 1976) [31]. Monthly means (fig. 5k) reveal variability with regard to nitrogen or phosphorus deficiencies. It was expected that nitrogen deficiencies would correspond to blooms of blue-green algae. To the contrary, no consistent pattern between years for August and September (when blooms usually appeared) is detectable. These variable monthly values may be associated with inputs from tributaries. For example, elevated levels of nitrates were measured in each tributary in June 1985 (Bio-Environs 1985) [6]. Figure 5k and table 4 values are presented to depict the variability within seasons. The seasonal means describe the overall tendency toward one type of nutrient limitation or another.

Caution is again advised when interpreting the nutrient index. Much of the inorganic nitrogen forms were reported at their limits of detection, and not all forms were measured at any one time. However, as a rough indication of nutrient limitations, the index may provide managers with insight into problems associated with future loading of either nitrates or phosphates.

Heavy Metals

Few years of heavy metal data are available, and no values for metals, except copper, were determined from 1966 to 1982. Table 5 depicts the reservoir mean values, standard deviations, and the standard or criterion values for each metal by season (usually June through September). Twenty-four metals were detected in 1983 and 1984. Samples were taken at the surface and represent total metal concentration. Alkaline waters, as represented by Blue Mesa Reservoir, normally exhibit precipitated or complex forms of these metals; therefore, heavy metals in the ionic form are unlikely (Hem 1985) [49]. Several metals were measured near their limit of detection. These values, used in calculating reservoir means, are identified in the following discussion of results.

Criteria and standard levels established by the EPA (1976) [26] and WQCC (Water Quality Control Commission of Colorado) (1984) [38] are compared with the Blue Mesa Reservoir data. When State standards are more stringent, WQCC values are included in table 5. Mean values for aluminum, iron, manganese, mercury, selenium, silver, thorium, uranium, and zinc exceed criteria or standards established by either EPA (1976) or WQCC (1984). These metals and cadmium, copper, and lead, are discussed below.

Aluminum. – All values for 1983 and 1984 exceed the standard of 0.1 mg/L established by the Colorado Department of Health 1984. Table 5 reveals a mean of 349 µg/L (the range was 250 to 820 µg/L) in 1983. In 1984, values were again high with a mean of 448 µg/L and a range of 146 to 1100 µg/L. No significant difference exists between these years ($p > 0.05$). Samples were taken at several sites on one date in 1983 ($n = 7$), whereas samples were taken at several sites on various dates in 1984 ($n = 9$). Highest values were determined for the dam, Lake City Bridge, and Red Creek sites on September 25, 1984. High levels of dissolved aluminum have recently been associated with the "acid precipition" phenomenon, whereby low pH levels correspond to higher dissolved aluminum levels (Robinson and Deano 1986) [55]. High aluminum levels in Blue Mesa's more alkaline waters represent total aluminum.

Cadmium. – Levels for cadmium do not exceed the EPA 1976 criterion of 1.2 µg/L. The greatest amount, 0.9 µg/L, was measured in 1983. Most 1984 values are at their limit of detection, and the 1984 mean is significantly lower than the 1983 mean ($p < 0.014$).

Cadmium exhibits high toxic potential to aquatic organisms, and in this region is usually associated with lead and zinc from mining operations. Though this element has been detected at higher levels in Gunnison area rivers and streams, it is apparently not of considerable concern in Blue Mesa Reservoir.

Copper. – Levels of copper were determined in 1966 (at the dam, $\bar{x} = 10$ µg/L, $n = 1$), in 1967 ($\bar{x} = 40$ µg/L, $n = 5$), in 1983, and in 1984. Although levels are below the EPA 1976 domestic water supply criterion (1.0 mg/L), a relatively high mean value was reported in 1983 (see table 5) at Elk Creek Marina. Potentially high levels of copper may be detrimental to rainbow trout in water with an alkalinity of 17-26 mg/L (as $CaCO_3$); the 96-hour LC50 is 0.02 mg/L, as determined by Chapman (EPA 1976) [56]. High copper levels detected in Blue Mesa Reservoir (1983) should present little problem because the toxicity of copper decreases in more alkaline or hard waters.

The 1966, 1967, 1983, and 1984 yearly mean levels of copper were 10, 40, 289, and 10 µg/L, respectively. The 1984 mean is significantly different from the 1983 mean ($p < 0.001$) and, apparently, there are considerable differences among the 1966, 1967, and 1983 levels. A yearly trend is not detectable.

Iron. – Levels of iron do not differ significantly between 1983 and 1984, nor do they exceed the 1-mg/L EPA criterion. However, individual determinations, did exceed the criterion on four occasions between 1983 and 1984. In the Gunnison River Basin, iron and manganese levels were unusually high compared with other regions; this may result from ambient geologic conditions and the effects of mining. Although an EPA (1976) [57] citation reported that levels greater than 1 mg/L were associated with an absence of fish in a Colorado stream, this is not the case for Blue Mesa Reservoir tributaries. No reports were found that suggest measured levels of iron in Blue Mesa Reservoir are detrimental to invertebrates or to fish.

Table 5. – Mean levels of metals in Blue Mesa Reservoir, 1983 and 1984

Metal	1983		1984		Criterion value	
	Mean, µg/L	s.d.	Mean, µg/L	s.d.	EPA, µg/L	WQCC, µg/L
Aluminum	349	194	448	105		100
Arsenic	10	8	*		50	
Barium	27	2	*		1000	
Beryllium	ND		*		1100	
Boron	157	129	*		750	
Cadmium	0.5	0.3	0.1	0.1	1.2	
Cobalt	2.9	1.6	1	0		
Chromium	10	7	1	0	100	
Copper	289	214	10	8	20-1000	
Cyanide	5.7	4.5	3.0	4.0	5.0	
Iron	537	342	667	670	1000	
Lead	4	2	1	1	50	
Manganese	33	30	174	200	50	
Mercury	0.06	0.2	0.2	0	0.05	
Molybdenum	5	0	1	0	*	
Nickel	8	1	30	15		50
Niobium	27	11	*			
Selenium	51	34			10	
Silica	10	2	*			
Silver	1.4	1.5	*		50	0.1
Thorium	32	18				15
Titanium	77	51	*			
Uranium	44	38	2	1		30
Zinc	69	32	19	18	500	50

* Not measured.
ND = Not detectable.

Lead. – A study of surface waters determined that concentrations were normally below 1 µg/L in the Western States (Durum et al. 1971, in Hem 1985) [58]. To the contrary, yearly means and standard deviations for Blue Mesa Reservoir samples in 1983 and 1984, were 4 µg/L (s.d. = 2) and 1 µg/L (s.d. = 1), respectively. Of the 32 samples taken in 1983, the highest values were 8 µg/L and 7 µg/L, detected at the Lake Ford Marina site on June 19, and the Narrows site on August 12, respectively. The high in 1984, 3 µg/L, was collected at Stevens Gulch in September. The 1984 mean is significantly lower than the 1983 mean ($p < 0.05$).

Interestingly, the highest values were not detected at Elk Creek Marina where most of the boat traffic and refueling occurs. Lead has no beneficial use physiologically to living organisms and is toxic. The 96-hour LC50 times 0.01 is the criterion established for sensitive freshwater resident species (EPA 1976) [26]. In relatively soft waters (hardness equal to 43 to 45 mg/L as $CaCO_3$) the 24-hour LC50 lead concentration is 3.75 mg/L for rainbow trout (Benoit and Holcombe in EPA 1976) [59]. Currently, little risk to freshwater organisms in Blue Mesa Reservoir exists.

Manganese. – Manganese is present in Gunnison area waters (Rumberg et al. 1978 [18]; Aaronson 1981 [24]). The 1984 mean is 174 µg/L (n = 9, s.d. = 200). The 1983 mean of 33 µg/L is below the EPA 1976 domestic water supply criterion of 50 µg/l; however, a high of 88 µg/L occurred in 1983, at Deep Creek in Cebolla Basin. The means for 1983 and 1984 differ significantly ($p < 0.05$).

Manganese is a common metal, but is still less than one fiftieth as abundant as iron in the earth's crust. The divalent form is found in igneous and metamorphic rocks, and in dolomites and limestones. In Blue Mesa Reservoir, where thermal stratification occurs, the bottom may become anoxic, thus releasing the formerly oxidized species. As the dissolved manganese encounters oxygenated waters, it is again oxidized and returned to the sediments.

Mercury. – The 1983 mean level of mercury does not exceed the EPA 1976 criterion value of 0.05 µg/L; however, individual levels, 4.0 µg/L at Lake City Bridge, 0.06 at West Elk/Soap Creek and Elk Creek Marina in 1983 exceed this criterion. Limits of detection for 1984 data were 0.2 µg/L. No comparison to the criterion value is possible. Regardless, further study of mercury levels is required because of its potentially toxic characteristics.

Selenium. – Although selenium is an essential trace element, it is toxic at levels from 0.1 to 1 mg/kg with respect to living organisms. The 1983 mean level, 51 µg/L, is significantly greater than the 10-µg/L domestic water supply EPA 1976 criterion. The highest values occurred on June 19, at Elk Creek Marina, Lake City Bridge, and the damsite.

Natural levels of selenium in water are proportional to soil levels. In this region, selenium is reportedly high. Anderson et al. (1961 in Hem 1985) [60] reported 80 µg/L in a sample from the Gunnison River near Grand Junction, Colorado. Continued monitoring of selenium in this area is warranted.

Silver. – The mean level of 1.4 µg/L (n = 7) exceeds the WQCC standard of 0.1 µg/L for silver. The highest value (40 µg/L) was detected at Middle Bridge on June 19, 1983.

Silver has wide commercial and industrial use, little of which occurs near Blue Mesa Reservoir. Natural sources may emanate from mining in associated drainage areas or as ambient background levels.

Thorium. – The WQCC 1984 standard of 15 µg/L was exceeded at every site sampled in 1983. The mean level was 32 µg/L, and the high, as suggested by Hem (1985) [49], compared with the tenths or hundredths of micrograms usually detected. Thorium is associated with uranium, but is less soluble. Thorium-232 decay products include isotopes of radium, radon, and lead, but little else is known about the aqueous geochemistry of the element (Hem 1985) [49]. Langmuir and Herman (1980, in Hem 1985) [61] indicated that complexing phenomenon with organic and inorganic ligands tend to enhance the mobility of thorium. Nevertheless, natural freshwater levels are expected to range from 0.01 to 1 µg/L. By comparison, uranium levels do not exceed the WQCC 1984 standard. Further study of thorium levels in Blue Mesa Reservoir is suggested.

Uranium. – Uranium levels were significantly greater in 1983 ($\bar{x}$ = 44 µg/L, s.d. = 38) than in 1984 ($\bar{x}$ = 2 µg/L, s.d. = 1) ($p < 0.004$); this may be due to the limits of detection. No significant difference was detected between the 1983 level and the WQCC 1984 standard of 30 µg/L. Monitoring uranium concentrations should continue because of the tailings in the immediate area and the need to record natural background levels.

Zinc. – Zinc is as common as copper and nickel, but more soluble in most types of water. Skidmore (1964 in EPA 1976) [62] noted that an increase in temperature and reduction in oxygen levels tended to increase the toxicity of zinc to fish. He also reported synergistic effects of zinc with heavy metals in soft water.

The 1983 and 1984 mean zinc levels did not exceed the 500-µg/L domestic water supply EPA criterion. However, the 1983 mean of 69 µg/L exceeds the WQCC 1984 standard of 50 µg/L. Five of seven sites sampled in 1983, and one of nine sites sampled in 1984, exceeded the standard. The 1983 mean (69 µg/L) is significantly greater ($p < 0.001$) than the 1984 mean (19 µg/L).

BIOLOGY

Chlorophyll a. – Mean monthly chlorophyll *a* levels are summarized on figure 6, and mean seasonal levels (usually June through September) in tables 6a-c. Three years of consistent chlorophyll *a* data were collected from 1983 to 1985. Levels were also measured in 1975. Iola Basin levels were 4.93 and 10.47 mg/m³ in August and September 1975, respectively. Cebolla Basin attained levels of 4.60 and 6.60 mg/m³ in August and September 1975. Sapinero Basin levels were intermediate between Iola and Cebolla: 5.05 and 7.15 mg/m³ in August and September 1975. Over the years, Iola tended to exhibit higher chlorophyll *a* levels (see tables 6a-c). Chlorophyll *b* and *c* were also monitored from 1983 to 1985. These data are presented in tables 6a-c.

No trends were detected between the same months in successive years using the Student's t-test. The overall monthly chlorophyll *a* lows occurred in August 1983, for both Cebolla and Sapinero Basins: 1.20 and 1.03 mg/m³, respectively. The low in Iola Basin, 1.43 mg/m³, occurred in June 1983. An overall mean monthly high, 16.53 mg/m³, occurred in August 1985 in Iola Basin. Cebolla and Sapinero basin highs, 15.56 and 14.05 mg/m³, respectively, occurred in May 1985. Seasonal fluctuations are evident. In 1983, chlorophyll *a* levels approached a low in August then rose sharply in September. Conversely, corresponding plankton data reveal increasing levels through August 1983, for both Iola and Sapinero basin (see fig. 9c). Chlorophyll *a* levels that increased from July to September 1984, correspond to phytoplankton density increases for the same period (see figs. 9a-c.). In May 1985, high chlorophyll *a* levels in all basins were detected (see fig. 6). A corresponding high density of phytoplankton was encountered in all basins (see fig. 9c). Nitrate concentrations were high in May (Bio-Environs 1985) [6] and possibly contributed to the production of phytoplankton after iceout. Lower chlorophyll *a* levels and phytoplankton densities correspond to high levels of nitrates in June 1985, an apparent anomaly, perhaps caused by a lag period between nitrate inputs during

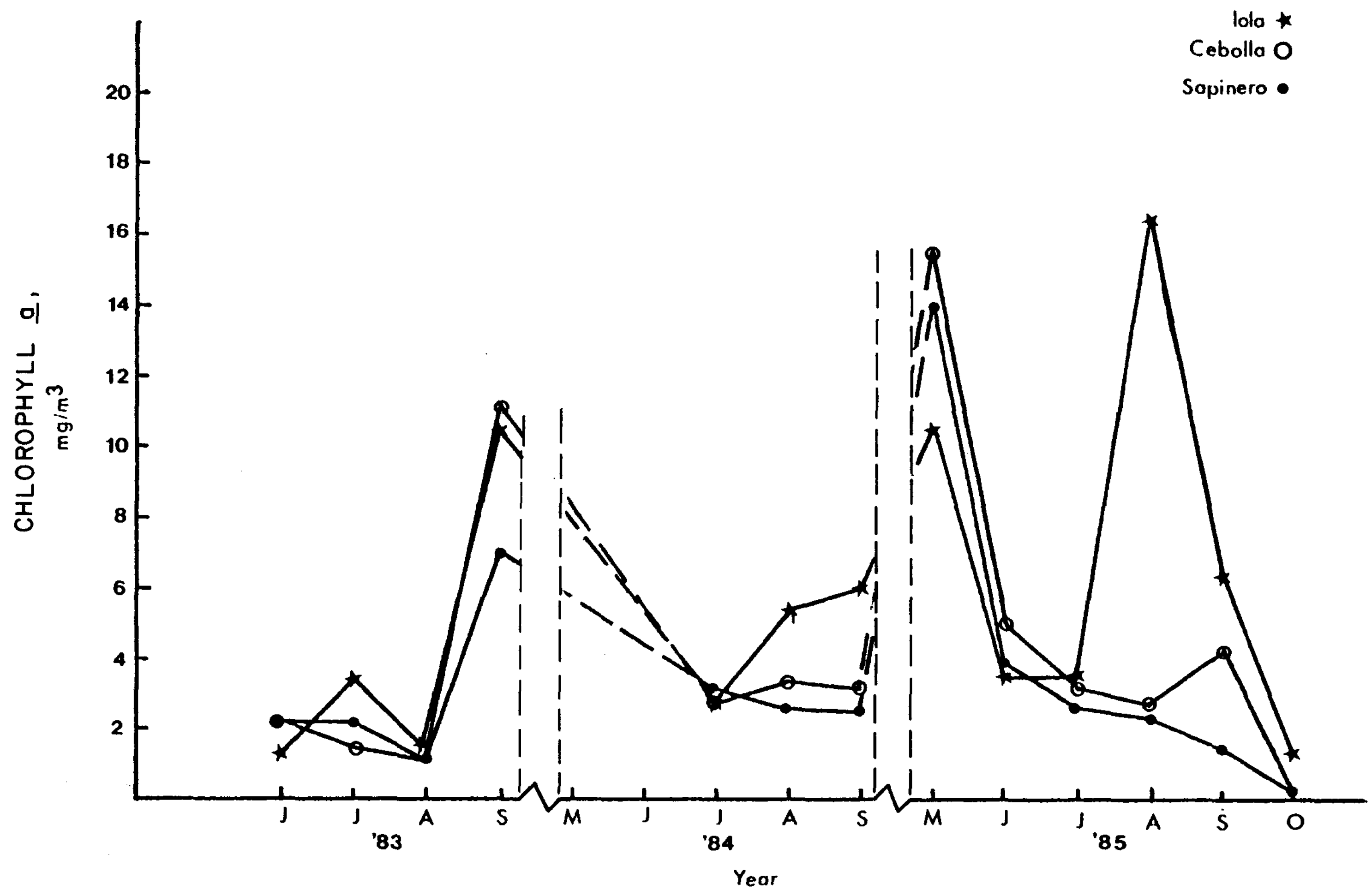

Figure 6. – Mean monthly chlorophyll *a* (mg/m³) levels at the surface in three basins, 1983-1985.

Table 6a. – Mean seasonal chlorophyll levels for Iola Basin, 1983-1985

Parameter	1983 Mean, mg/m³	1983 s.d.	1984 Mean, mg/m³	1984 s.d.	1985 Mean, mg/m³	1985 s.d.
Chlorophyll *a*	7.33	6.14	5.15	2.04	8.19	8.30
Chlorophyll *b*	0.11	0.12	0.17	0.23	0.33	0.39
Chlorophyll *c*	.86	.44	.59	.79	.76	.50

Table 6b. – Mean seasonal chlorophyll levels for Cebolla Basin, 1983-1985

Parameter	1983 Mean, mg/m³	1983 s.d.	1984 Mean, mg/m³	1984 s.d.	1985 Mean, mg/m³	1985 s.d.
Chlorophyll *a*	6.86	7.86	3.27	1.29	6.57	7.60
Chlorophyll *b*	0.56	1.05	0.11	0.03	0.35	0.51
Chlorophyll *c*	2.11	2.61	.40	.37	.99	.66

Table 6c. – Mean seasonal chlorophyll levels for Sapinero Basin, 1983-1985

Parameter	1983 Mean, mg/m³	1983 s.d.	1984 Mean, mg/m³	1984 s.d.	1985 Mean, mg/m³	1985 s.d.
Chlorophyll *a*	4.06	5.31	2.61	0.85	5.04	5.65
Chlorophyll *b*	0.80	1.39	0.14	.18	0.40	0.45
Chlorophyll *c*	2.53	4.09	.40	.29	.88	.48

runoff and phytoplankton uptake and production. The 1985 chlorophyll *a* levels declined through June, then increased through August.

Chlorophyll *a* levels varied within a season for the three years sampled (tables 6a-c), but consistently remained within the 3- to 8-mg/m³ range. According to Likens (1975) [63], 0 to 3 mg/m³ of chlorophyll *a* indicates oligotrophic conditions, 2 to 15 mg/m³ is associated with mesotrophic conditions, and 10 to 500 mg/m³ indicates eutrophic conditions. Based on Likens ratings, Blue Mesa Reservoir is mesotrophic over the 1983 to 1985 period. As reported earlier, 1975 chlorophyll *a* levels indicate mesotrophic conditions. Levels from 1967-1974 were not measured; therefore, little can be said about the 20-year trend. Color-coded enhancement images acquired with MSS (multi-spectral scanning) equipment in 1983 (Verdin 1984) [34] revealed bloom conditions in Sapinero Basin and the lowest concentrations in Iola Basin. Although a 1-day delay between MSS data acquisition and water sampling prevented development of strong relationships between MSS and ground data, the ability to detect extreme basin and site variability is still of interest. Reservoir arms exhibited high levels of chlorophyll *a*.

A 1976 preliminary report (EPA 1976) [31] on Blue Mesa Reservoir pointed out that phosphorus loading to the reservoir was excessive, and recommended that point source contributions be studied in more detail. Apparently from 1975 to 1985, chlorophyll *a* levels have changed little, an indication that trophic equilibrium has been attained despite high nutrient inputs determined in the 1976 EPA report [31].

Phytoplankton. – Tables 7a, b, and 8 and figures 7a, b and 8 (data from Morris et al. 1979 [65]; Aquatic Environmental Services 1983, 1984 [4, 5]; Bio-Environs 1985 [6]) summarize phytoplankton results for the summer season (July to September) from 1975, and 1983-1985. Sampling techniques varied between years and within 1985. The results and graphic depiction of the data are therefore subject to scrutiny, and little information regarding population trends can be obtained without careful observation.

Wiltzius (1974) [11] noted that plankton and bottom samples were collected in 1967. He further stated that in August 1967, *Aphanizomenon flos-aquae* reached bloom proportions in the main Gunnison inlet and tended to decrease towards the dam. These findings correspond to more recent studies performed from 1983 to 1985. Little information was found concerning phytoplankton sampling from 1967 to 1982. Apparently, algal blooms encountered in recent years were present in the earliest years of the reservoir.

Data for 1983, in tables 7a, b, and 8 and on figures 7a, b, and 8 represent mean values for several sites within a basin. The map on figure 2 denotes those sites sampled in 1983, by Kugrens of Aquatic Environmental Services [4]. Mean phytoplankton densities are represented by averages of the number of cells per liter for sites 1, 2, 5, 7, 9 in Sapinero Basin, sites 10, 11, 13, 14 in Cebolla Basin, and sites 17, 18, 19, 20 in Iola Basin. Sites sampled in 1984 and 1985 are marked on figure 3. The 1975 data (Morris et al. 1979) [64] are a composite of six sites in Blue Mesa Reservoir. Figure 8 depicts total phytoplankton density for Blue Mesa Reservoir for the years 1975, and 1983-1985. Basin phytoplankton numbers are summed to obtain approximate total reservoir density for the summer sampling period.

Table 7a and figure 7a, which depicts 1983 to 1985 data, are based on the means of summer season samples (July-August 1983; July-September 1984 and 1985). The 1985 data are adjusted to a 0-5 meter interval from a 0-15 meter composite haul. Numbers of phytoplankton in the 0-5 meter interval were estimated to be approximately 75 percent of the 0-15 meter haul. Vertical distribution of phytoplankton as determined by measured levels of productivity and chlorophyll *a* change seasonally,

Table 7a. – Mean number (No./L, 0-5 m composite) of phytoplankton over the sampling season for each basin, 1983-1985

Year	Iola	Cebolla	Sapinero
1983	165,000	126,000	180,000
1984	4,808,000	593,000	250,000
1985	6,363,000	3,634,000	12,000

Table 7b. – Mean number (No./L, 0-15 m composite) of phytoplankton over the sampling season for each basin, 1983-1985

Year	Iola	Cebolla	Sapinero
1983	86,000	66,000	69,000
1984	3,290,000	386,000	239,000
1985	8,484,000	4,846,000	16,000

Table 8. – Mean number (No./L, 0-5 m composite) of phytoplankton over the sampling season for Blue Mesa Reservoir, 1975 and 1983-1985

Year	No./L
1975	3,644,000
1983	157,000
1984	1,883,000
1985	3,336,000

approach maximum levels below the surface, and decrease exponentially in most cases to the compensation point (Wetzel 1975 [40]; Fogg 1980 [65]; Moss 1980 [66]). No references were found to actual percentages of production at various depths, number of cells, or chlorophyll levels. Therefore, based on 0-5 meter and 5-15 meter cell counts in 1984, 75 percent of the phytoplankton population was estimated to be in the top (0-5 m) interval.

Table 7b and figure 7b summarize 0-15 meter composite hauls from 1983 to 1985. Values from 1984 were adjusted by weighting the 0-5 meter and 5-15 meter data with water volumes in those intervals (determined by storage capacity calculations by the Bureau of Reclamation 1969 [67]). Calculations by basin were based on an approximate percentage of total reservoir volume (37.5% for Sapinero, 37.5% for Cebolla, and 25% for Iola). Estimates of 1983 phytoplankton numbers in the 0-15 meter interval were based on the 0-5 meter data of Aquatic Environmental Services (1983) [4], and adjusted by 1.33 (75% within the 0-5 meter interval, thus 1.33 times total number within the 0-5 meter interval equals the number within the 0-15 meter interval).

Figures 7a, b show large increases in the number of phytoplankton cells per liter for Iola and Cebolla basins over the 1983-1985 period. A 1975 study (Morris et al. 1979) [64] reveals high counts of phytoplankton in August and September: 2,476,000 and 4,811,000 total cells/L, respectively. *Aphanizomenon flos-aquae* dominated both monthly samples. Figure 8 shows 0-5 meter summer season phytoplankton densities for the reservoir from 1975, and 1983-1985. Apparently, the highest densities occurred in 1985. Figures 9a-c summarize 0-5 meter monthly phytoplankton densities from 1983-1985. Densities in Sapinero Basin decreased from 1983 to 1985, but increases are apparent in Cebolla and Iola basins. The results do not imply increasing numbers of phytoplankton over time, but may merely reflect yearly fluctuations. Several years of data and consistancy in sampling method and site selection are the only means of recognizing trends. Interestingly, Wiltzius (1974) [11] notes an algal bloom of *Aphanizomenon flos-aquae* in the early years. Today those conditions still prevail.

Phytoplankton species lists for 1975, 1983, and 1985, and a genera list for 1984, are presented in the appendix. Aquatic Environmental Services (1983) [4] identified more genera in the 1983 study than in 1984. Phytoplankton were identified to genus in the 1984 study. Similar species were found in 1984 and 1985. The diversity of species identified in 1983, may reflect laboratory enrichment studies of collected samples. In addition, a nannoplankton (10-µm mesh) net was used; in 1985, a 76-µm mesh net was used. Eighty-four species were identified in 1983,

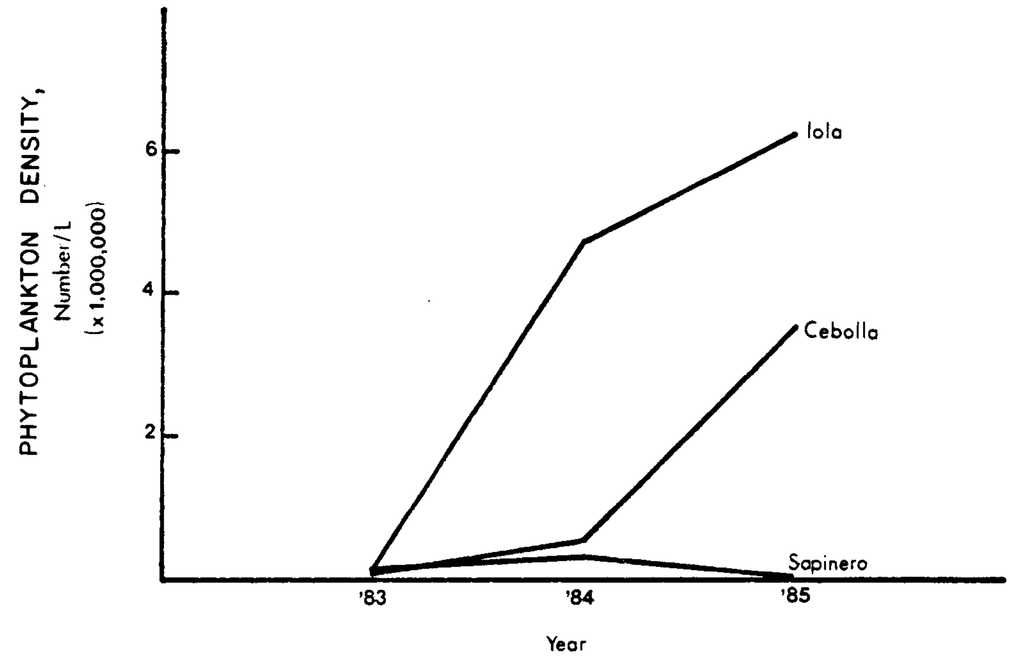

Figure 7a. – Mean density of phytoplankton (0-5 m column) in three basins, 1983-1985.

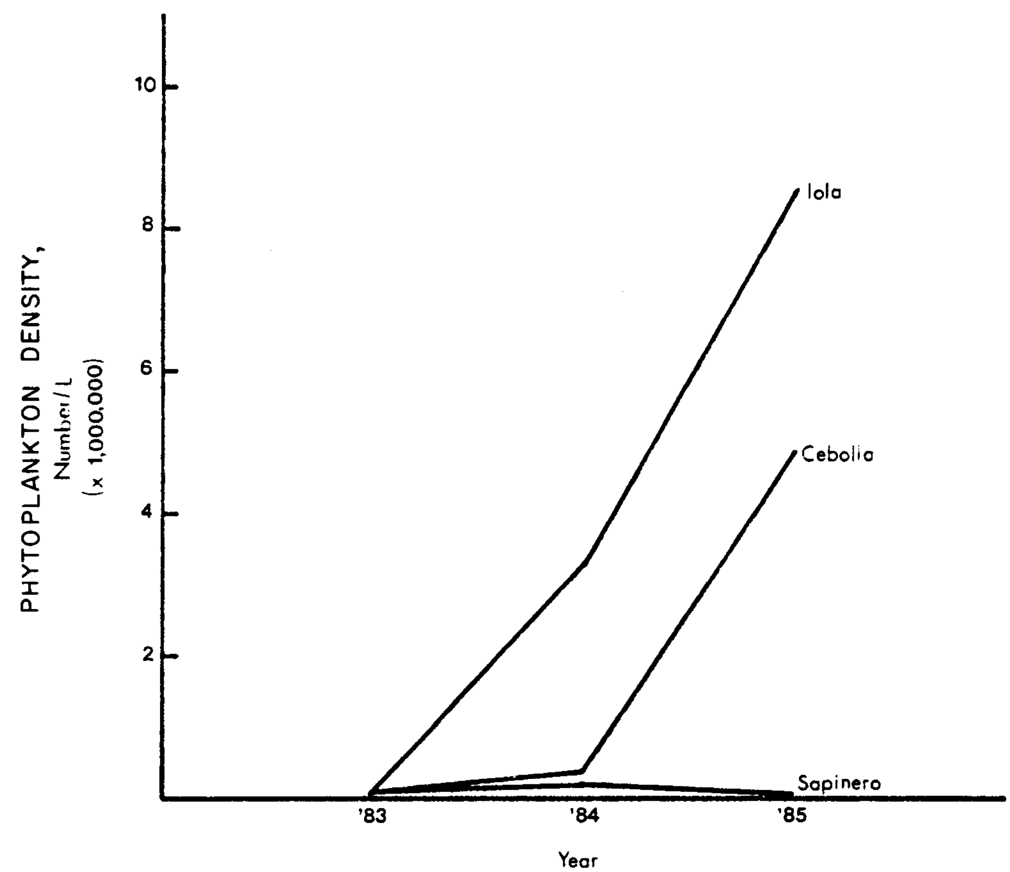

Figure 7b. – Mean density of phytoplankton (0-15 m column) in three basins, 1983-1985.

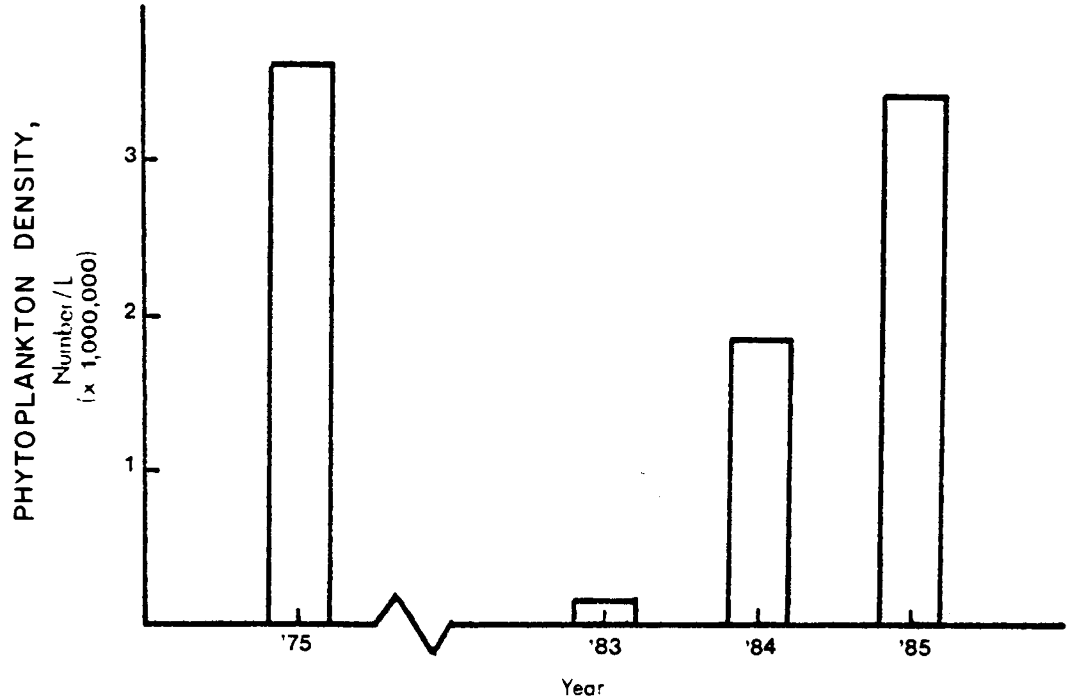

Figure 8. – Mean density of phytoplankton in Blue Mesa Reservoir, 1975, 1983-1985.

forty-three genera in 1984, and fifty-one in 1985. Two of the genera identified in 1985 may be considered protists (*Difflugia* and *Tetrahymena*) and are not listed in the appendix. Of the 43 species found in 1984, 18 were also identified in the 1985 survey. Of the 84 genera found in 1983, 33 were also found in 1984.

The most common species from 1983 to 1985 were *Aphanizomenon flos-aquae, Asterionella formosa, Fragilaria* sp., and *Melosira* sp. *Aphanizomenon flos-aquae* and *Chroomonas* sp. were predominant in 1975. Several of these species (*Aphanizomenon flos-aquae, Fragilaria crotonensis,* and *Asterionella* spp.) are associated with eutrophic waters (Wetzel 1975) [40]. Species presence varied throughout the sampling season. Samples from May and June (1983 and 1985) were dominated by *Asterionella formosa, Chlamydomonas* sp., *Cryptomonas* sp., and *Ankistrodesmus* sp. *Fragilaria* sp. predominated in July for all three years. *Aphanizomenon flos-aquae,* numbering in the millions in 1975, 1984, and 1985, was predominant in the later months of the summer (primarily September). Such numbers are indicative of bloom conditions. Aquatic Environmental Services (1983) [4] noted that blue-green algae populations did not constitute a nuisance in 1983 (*Aphanizomenon* populations numbered in the hundreds of thousands per liter). Aquatic Environmental Services (1983) [4] also stated that 1983 may have been an anomalous year, considering the large inflow of water to the reservoir.

Aphanizomenon flos-aquae, a blue-green alga, characteristically forms flakes that float on the water. Wind and wave action can move these particles shoreward, concentrating the total number of cells in certain areas. Blue-green algae, considered a nuisance, form a surface scum by means described above and produce a toxin that may influence growth and reproduction of other plankton species (Carr and Whitten 1973) [68]. In addition, feeding apparatus of zooplankton may clog from ingestion of large filamentous *Aphanizomenon flos-aquae* cells (Gentile and Maloney 1969) [53]. Although algal blooms are associated with fish kills, no such kills have been documented in Blue Mesa Reservoir. Currently, the Colorado Division of Wildlife (Dave Langlois, personal communication) does not consider this blue-green algae to be a nuisance.

Zooplankton. – Figures 10 and 11 a-c and table 9 (data from Aquatic Environmental Services 1984 [5]; Bio-Environs 1985 [6]) denote zooplankton numbers and types in 0-15 meter intervals for Iola, Cebolla, and Sapinero Basins from July to September. May and June 1985 results are included in table 9, but are not included on the figures, because no May and June 1984 data are available, and May and June 1985 techniques differed from the remainder of 1985 sampling. Figure 10 summarizes the types of zooplankton encountered in 1984 and 1985. Figure 11 includes a summary of *Daphnia* and *Cyclops* densities for 1984 and 1985. May and June data in table 9 represent mean densities for the discrete sampling

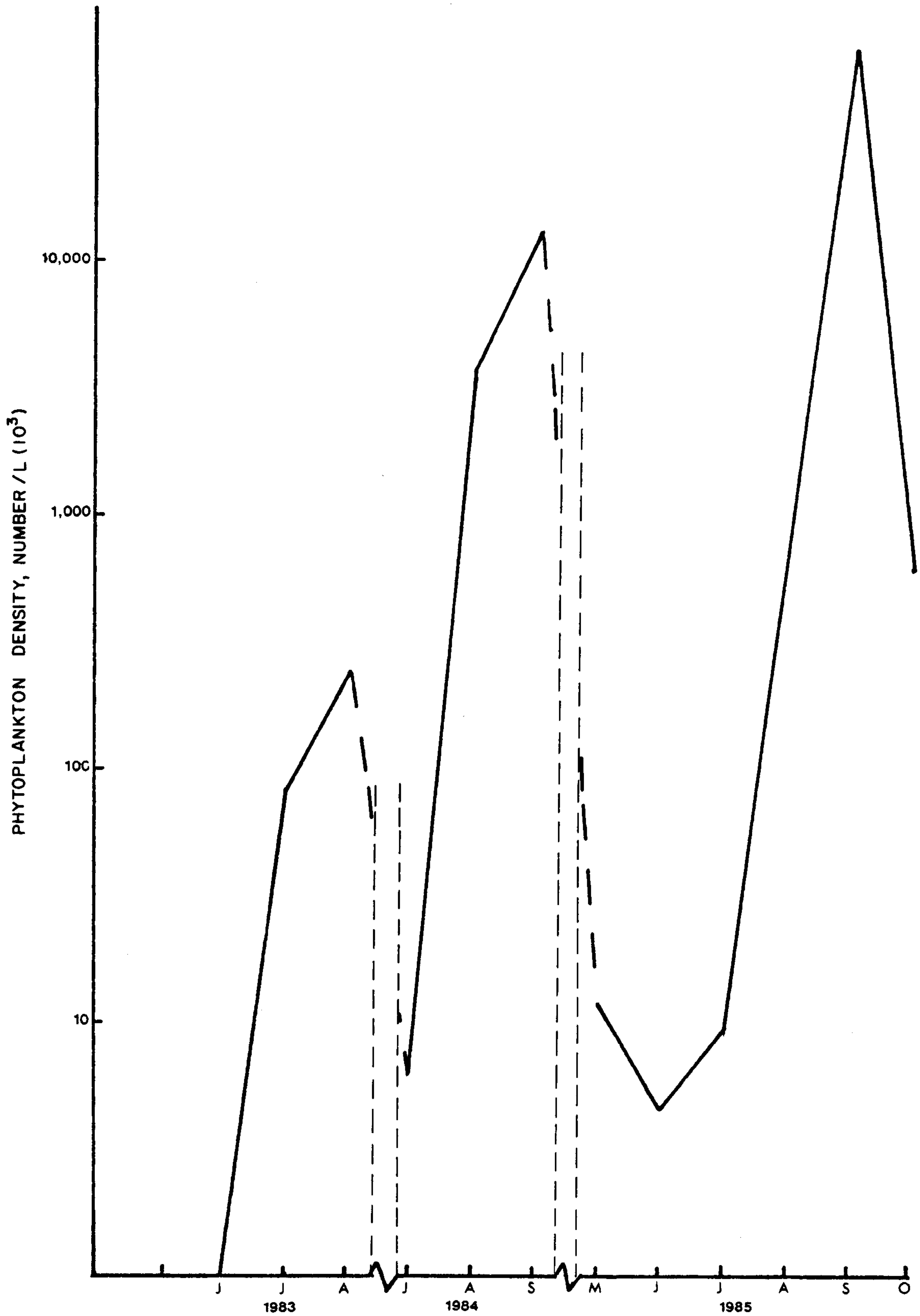

Figure 9a. – Mean monthly densities of phytoplankton in Iola Basin, 1983-1985.

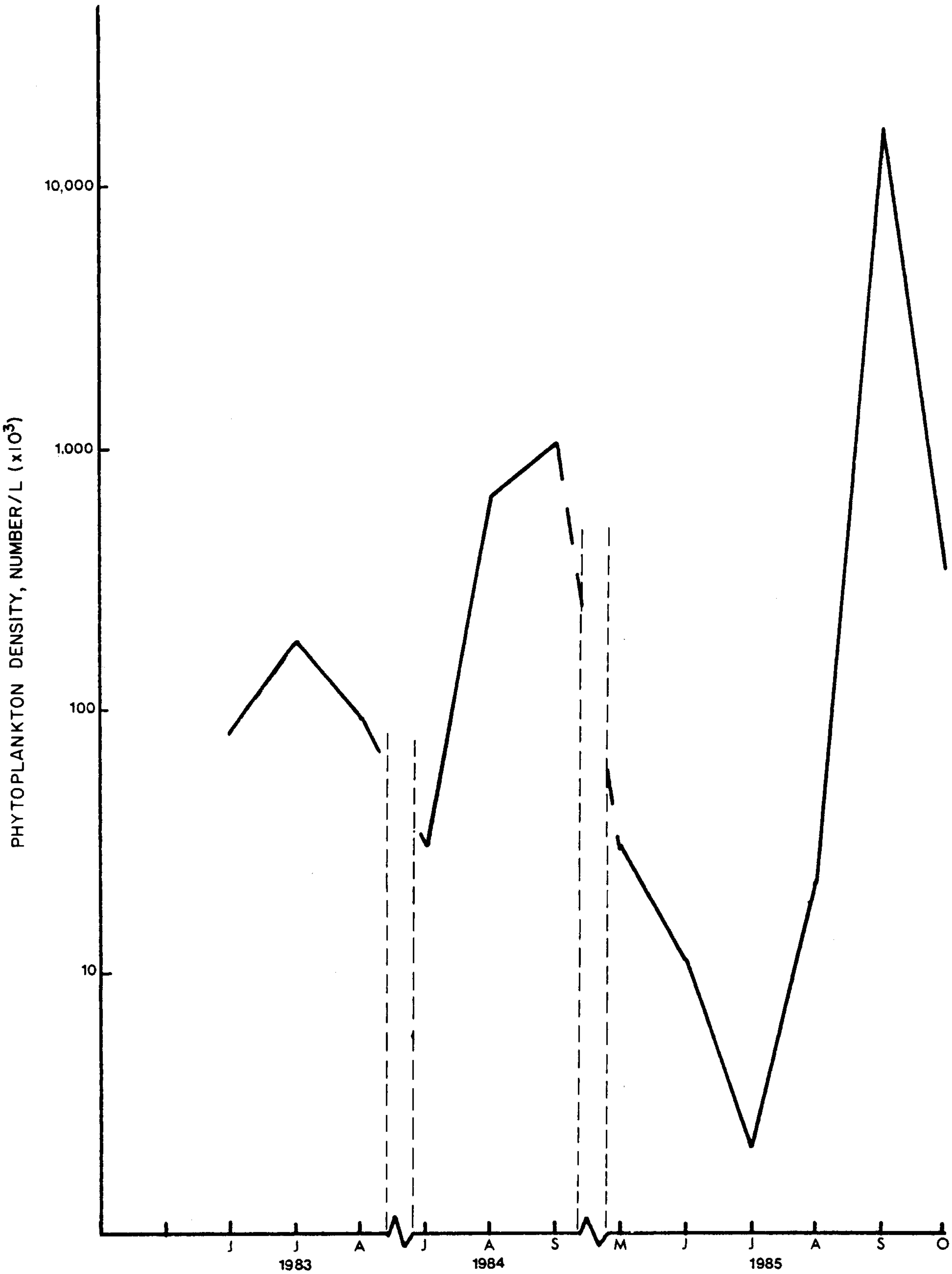

Figure 9b. – Mean monthly densities of phytoplankton in Cebolla Basin, 1983-1985.

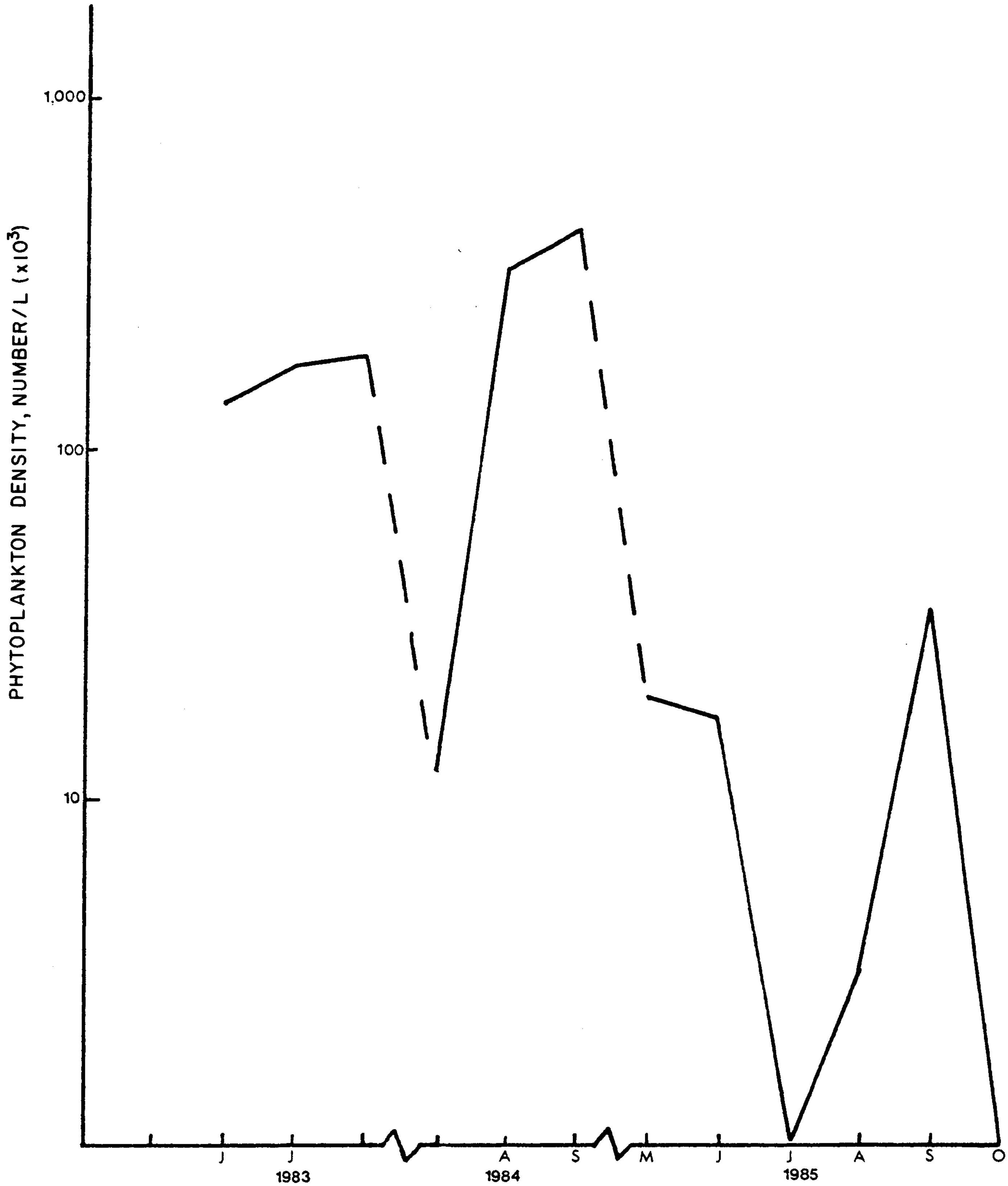

Figure 9c. – Mean monthly densities of phytoplankton in Sapinero Basin, 1983-1985.

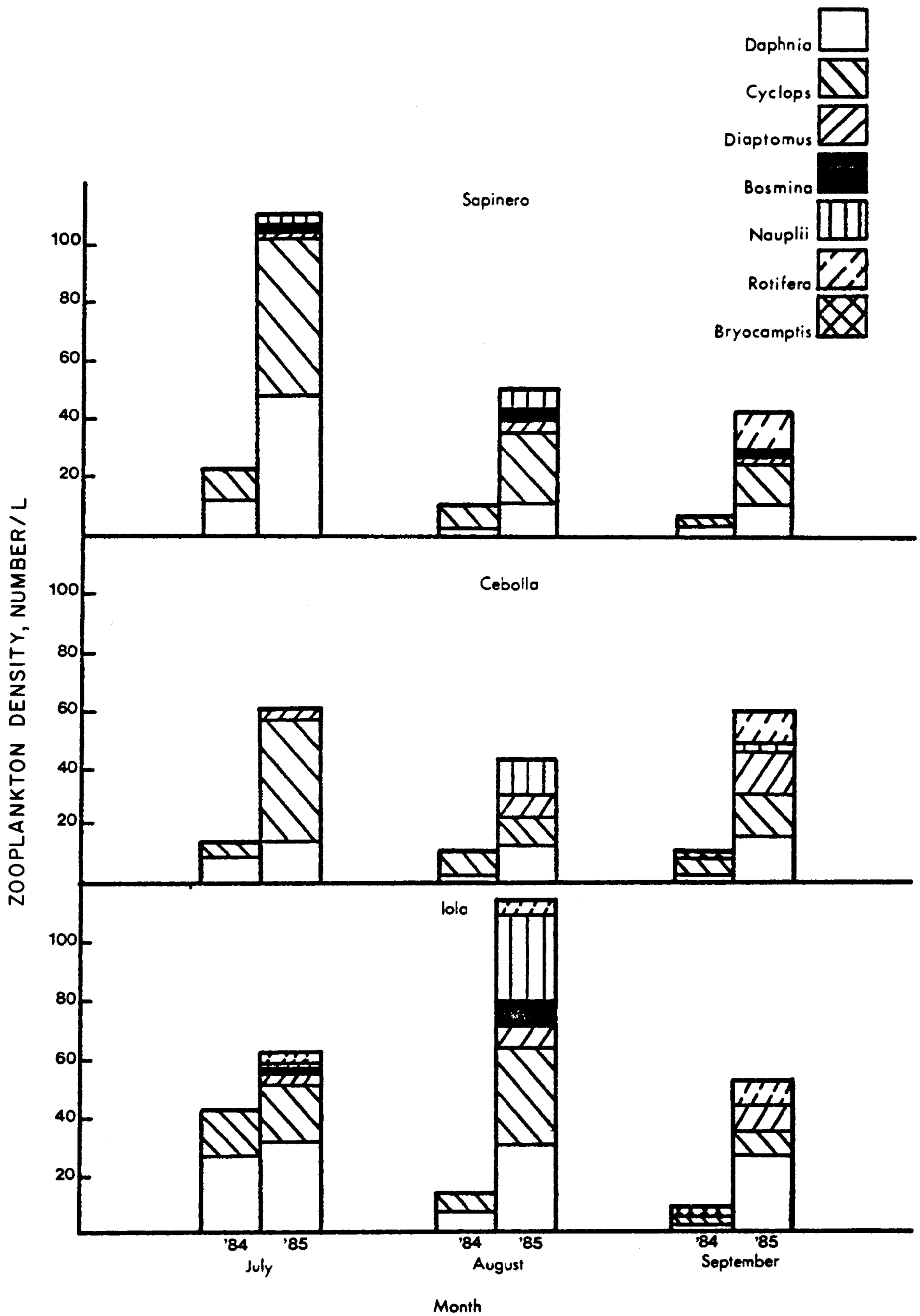

Figure 10. – Zooplankton density (No./L) in three basins, July through September 1984-1985.

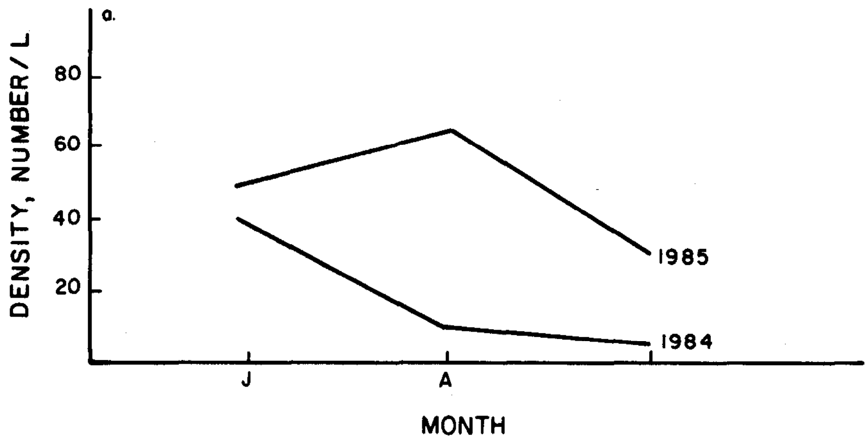

Figure 11a. – Density (No./L) of *Daphnia* and *Cyclops* in Iola Basin, 1984-1985 (0-5 m column).

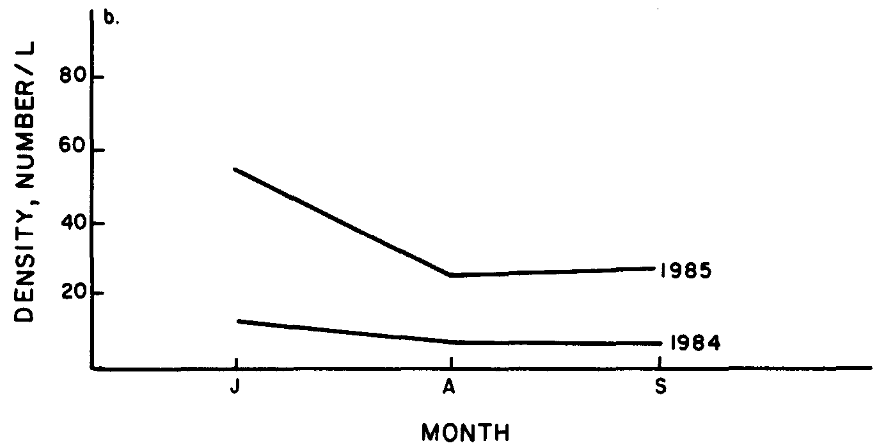

Figure 11b. – Density (No./L) of *Daphnia* and *Cyclops* in Cebolla Basin, 1984-1985 (0-5 m column).

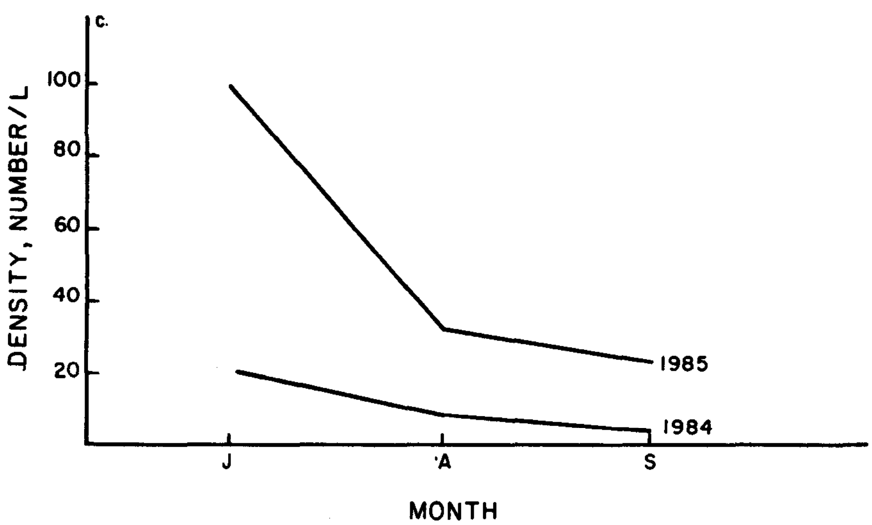

Figure 11c. – Density (No./L) of *Daphnia* and *Cyclops* in Sapinero Basin, 1984-1985 (0-5 m column).

Table 9. – Densities (No./L, 0-15 m composite) of zooplankton in each basin, 1984 and 1985

Month	Daphnia	Cyclops	Diaptomus	Bosmina	Nauplii	Rotifera	Bryocamptis
				Iola Basin			
1984							
July	26	15	–	–	–	–	–
Aug	6	6	–	–	–	–	–
Sept	1	5	–	–	–	–	2
1985							
May	–	76	–	–	18	–	–
June	491	236	29	35	23	23	–
July	30	21	5	2	2	2	–
Aug	30	33	9	9	70	9	–
Sept	9	26	9	–	–	9	–
Oct	14	29	8	–	–	157	–
				Cebolla Basin			
1984							
July	8	7	–	–	–	–	–
Aug	2	6	–	–	–	–	–
Sept	3	6	–	–	–	–	–
1985							
May	57	151	–	–	–	–	–
June	154	69	–	46	23	–	–
July	16	41	2	–	–	–	–
Aug	11	15	4	–	11	–	–
Sept	17	12	15	3	–	13	–
Oct	9	9	1	3	6	49	–
				Sapinero Basin			
1984							
July	12	10	–	–	–	–	–
Aug	1	7	–	–	–	–	–
Sept	1	3	–	–	–	–	–
1985							
May	–	23	–	–	34	–	–
June	97	114	–	–	45	11	–
July	46	55	2	2	5	–	–
Aug	9	26	3	3	6	–	–
Sept	8	17	2	2	–	12	–
Oct	2	5	3	–	6	24	–

method. In May and June for Iola Basin, counts from 1, 5, 10, and 15 meters were averaged. For the other two basins, the 1-, 10-, 20- and 30-meter counts were averaged.

More genera were identified in 1985 than in 1984 (table 9 and fig. 10). The total number of zooplankton encountered were greater in 1985 than in 1984, based on a 0-15 meter composite of 1985, and volume-weighted adjustments of 1984 data (adjustments similar to those performed for phytoplankton results). Actual zooplankton populations were low during the July through September period. Population estimates were larger for May and June, but may reflect effects of weight-volume adjustments for discrete sampling techniques. Both *Cyclops* and *Daphnia* species dominated the 1984 and 1985 samples.

Populations and types changed over the season in 1984 and in 1985. In 1984, a steady decline occurred from July to September (fig. 10). No trends are detectable in 1985, except for *Daphnia* and *Cyclops* populations in Sapinero Basin; densities of both genera decreased from July to September (fig. 11c). The most apparent change in zooplankton populations over a season was an increase of rotifers in September and October 1985 (fig. 10). Their increase corresponded to the peak and later decline of phytoplankton populations discussed in Wetzel (1975) [40]. The density of the rotifers *Polyartha* and *Keratella* increased after thickening of the September thermocline in Lake Dillon (Lewis et al. 1984) [41]. Apparently, the rise in the Lake Dillon zooplankton population corresponded with increases in phytoplankton; this same phenomenon was noted by Bio-Environs (1985) [6] in the Blue Mesa Reservoir study.

Wiltzius (1974) [11] noted that *Daphnia pulex* was dominant in a 1967 sampling. He stated that since inundation, entomostracan zooplankton had increased in numbers of species and in density. However, the effects of preferential cropping of larger zooplankton by rainbow trout reduced the total volume in the upper 10 meters. May and June 1985 observations corroborate the findings of Wiltzius (1974) [11] that zooplankton show some preference for the 10-20 meter depth in Blue Mesa Reservoir. Pennak (1978) [69] mentioned that zooplankton, particularly *Asplanchia, Filinia, Polyartha,* and *Keratella,* were present over a range of depths, even down to 100 meters. Shifts in population numbers through the water column on a seasonal basis are not unusual, especially in temperate climates (Parsons 1980) [70]. In addition, diurnal migration of zooplankton has been documented, but few reasons for such migration are offered (Orcutt and Porter 1983) [71]. Nesler (1981) [72] suggested that knowledge of vertical movement in zooplankton such as opossum shrimp is important. Zooplankton population dynamics and fish predation may be further elucidated by quantifying zooplankton community distribution over a 24-hour period.

High zooplankton densities may limit phytoplankton populations by depleting the nutrients (Lewis et al. 1984) [41]. In addition, Wetzel (1975) [40] noted that zooplankton predation may affect algal populations. However, Tilman et al. (1982) [73] offered that differential nutrient regeneration and patchiness caused by zooplankton may affect phytoplankton more than mere predation. High zooplankton densities and concomitant low nutrient levels may have exerted pressure on phytoplankton populations in Blue Mesa Reservoir during July 1984 and 1985.

Benthos. – Table 10 and figures 12a-c show numbers of benthic invertebrates encountered per square meter in Blue Mesa Reservoir for 1984 and 1985. No samples were taken in May and June 1984 or in June 1985 in Sapinero and Iola basins. Aquatic worms (Class Oligochaeta) of the subfamily Tubificidae dominated all samples. The oligochaetes burrow in soft sediments and feed on bacteria (Brinkhurst and Cook 1974) [45]. Present to a lesser degree were midge larvae of the family Chironomidae. Like the tubificids, chironomids play an important role in the exchange of substances between the sediments and water column (Sartoris et al. 1981) [74].

One other reference to bottom fauna was found: Wiltzius (1974) [11] encountered small tendipedid (chironomid) larvae and oligochaetes, and noted that they were not abundant. He estimated a population of approximately 140 organisms per square meter over the entire reservoir bottom in 1967. Apparently, population numbers and type have changed over the years. Baxter (1977) [1] noted that in areas of large flooding, chironomids were first to colonize, followed by oligochaetes.

Tendipedid (chironomid) larvae are associated with fairly neutral waters, and some species can tolerate

Table 10. – Benthic organisms (No./m^2) in each basin, 1984 and 1985

			Month					
Basin	Year	Taxon	May	June	July	Aug	Sept	Oct
Iola	1984	Tubificidae			25,473	91,115	50,811	
		Chironominae			43			
	1985	Tubificidae	19,770	*	9,848	27,957	24,739	43,086
		Chironominae	29					
Cebolla	1984	Tubificidae			29,473	10,076	37,678	
	1985	Tubificidae	14,834	7,202	11,543	25,217	21,607	7,782
		Chironominae				21		
Sapinero	1984	Tubificidae			25,489	16,643	17,009	
	1985	Tubificidae	2,023	*	10,587	4,174	9,130	11,608
		Chironominae				43		

* Samples not collected.

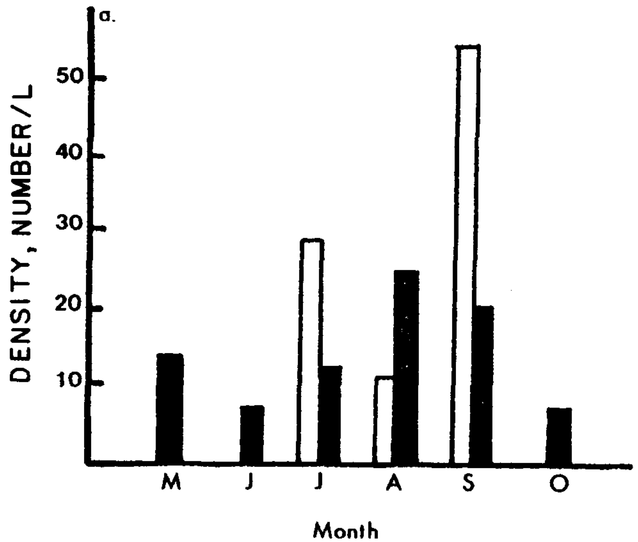

Figure 12a. – Monthly densities (No./L) of benthic organisms in Cebolla Basin, 1984-1985.

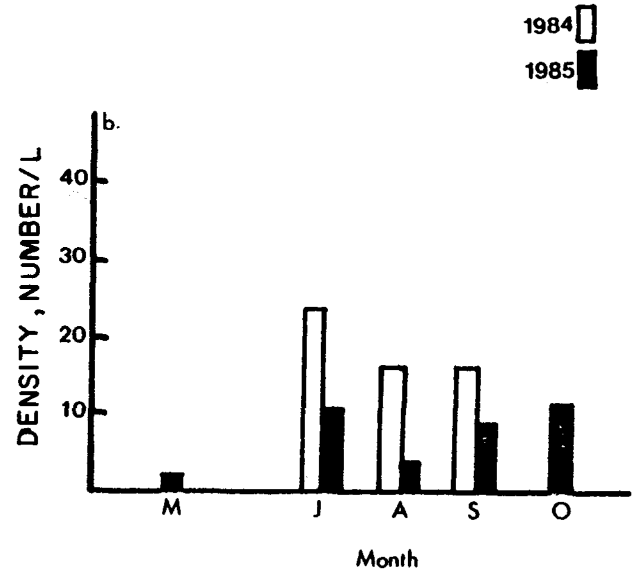

Figure 12b. – Monthly densities (No./L) of benthic organisms in Sapinero Basin, 1984-1985.

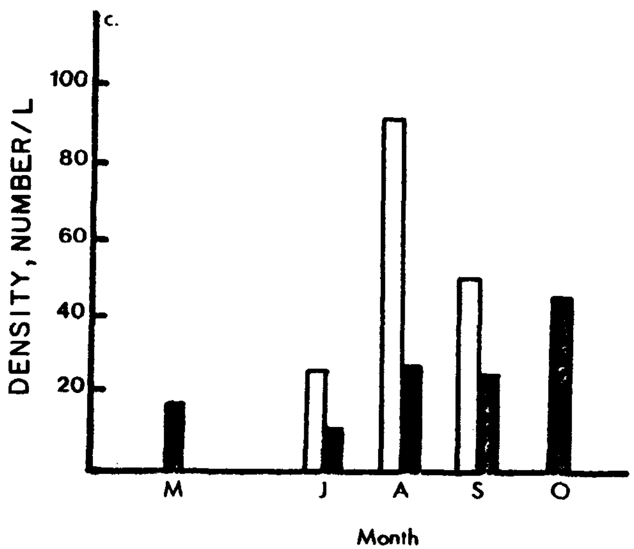

Figure 12c. – Monthly densities (No./L) of benthic organisms in Iola Basin, 1984-1985.

poorly oxygenated water (Pinder 1986) [75]. Few tendipedid larvae were encountered in 1984 or in 1985 (see table 10, data from Aquatic Environmental Services 1984 [5] and Bio-Environs 1985 [6]); 29 to 43 Chironominae per square meter were collected within these two years. Much larger populations of oligochaetes were found from 1984 to 1985. Numbers ranged from 2,030/m^2 to 91,115/m^2. Oligochaetes in the 1985 samples were identified as *Tubifex tubifex*. Investigators of the 1984 samples identified the aquatic worms to the subfamily level Tubificidae.

Lack of greater diversity for 1967, 1984, and 1985, may indicate polluted or unbalanced conditions (Wiederholm 1984) [76]. Such low populations and lack of diversity in 1967, can be attributed to creation of a new reservoir. Destruction of riverine habitat by impoundment led to the death of the original benthic fauna in Gorkii and Volga Reservoirs (Baxter 1977) [1]. Increased numbers and the same lack of diversity in 1984 and 1985, are indicative of stratification processes and, perhaps, unbalanced conditions. Conditions supportive of such large tubificid populations may stem from three phenomenon: 1) temperature stratification resulting in low hypolimnetic dissolved oxygen levels, 2) sewage input from point and from nonpoint sources, or 3) significant amounts of natural organic debris. Once distributed or deposited in the system, both types of inputs require oxygen for decomposition. Hypolimnetic dissolved oxygen levels were low, and showed a seasonal decrease from early to late summer (Bio-Environs 1985 [6]). Colonization by tubificids, particularly by *Tubifex tubifex*, is likely under low oxygen levels (Brinkhurst and Cook 1974) [45].

Lack of sampling coverage and frequency diminishes the ability to quantify species and population trends. However, the increase in oligochaete numbers from 1967 to 1985, indicates that the bottom conditions cannot support organisms requiring higher oxygen levels and that organic inputs and internal cycling of organic matter may continue to play an important role in benthic population and sediment dynamics.

Fishery. – Game species within Blue Mesa Reservoir are represented by rainbow trout (*Salmo gairdneri* Richardson), brown trout (*Salmo trutta* Linnaeus), cutthroat trout (*Salmo clarki* Richardson), brook trout (*Salvelinus fontinalis* Mitchell), lake trout (*Salvelinus namaycush* Walbaum) and kokanee salmon (*Oncorhynchus nerka* Walbaum). Nongame species found in the reservoir are western white sucker (*Catostomus commersoni* Lacepede) and longnose sucker (*Catostomus catostomus* Forster).

Wiltzius (1967) [10] reported that 90 percent of all fishing within the Curecanti Unit occurs on Blue Mesa Reservoir. A later report (Colorado Division of Wildlife 1982) [77] determined that 84 percent of fishing hours is spent on boat. Because of the inconsistency in creel surveys, quantifiable data for fishery resources in Blue Mesa Reservoir is limited. Creel survey results presented herein are data gathered by the Colorado Division of Wildlife (1965-1985). Harvest success is measured as CPUE (catch per unit of fishing effort). Harvest information is collected through roving creel surveys in which anglers are contacted while they are fishing. CPUE estimates are obtained by dividing total fish harvested by angler hours (hours from the time fishing began to the time of contact).

Figure 13 depicts CPUE for rainbow trout over a 20-year period, and figure 14 depicts the total number of rainbow trout stocked from 1965 to 1985. Weiler (1985) [30] reported a downward trend in CPUE for rainbow trout from 1971 to 1976, and an upward trend from 1977 to 1984. He attributed this upward trend to the production of better quality fish (5-inch or more) in the reservoir. A linear regression was used to determine whether there was a correlation between the CPUE for one year and the number of rainbow trout stocked the previous year. Figure 15 indicates that no correlation (r = 0.07) exists between these two variables. CPUE for kokanee salmon increased from 1972 to 1981, but the harvest decreased in 1982 and 1983 (fig. 16). Recent creel surveys (fig. 15) show an increase in harvest for kokanee salmon.

Table 11 reflects the number of salmonids stocked in Blue Mesa Reservoir from 1965 to 1985. Rainbow trout constituted 85 percent of all salmonids stocked, followed by kokanee salmon (11%) and mackinaw trout (3 %); native trout, brown trout, and brook trout made up less than 1 percent of the stocked salmonids. Harvest data reveal that rainbow trout constituted 79 percent of the harvest, kokanee salmon 10 percent, brown trout 5 percent, and the other salmonids 6 percent of the total harvest (fig. 17). Angler use and harvest at Blue Mesa Reservoir is shown in table 12. Rainbow trout in the 4- to 6-inch class constituted 52.5 percent of the total rainbow trout stocked over the 20-year period (table 13).

Without a second statistical sampling program it is difficult to accurately document the change in fishery over the past 20 years. The effort and catch information provides managers with a means to evaluate the progress of stocking efforts and the degree to which angler demands are met. It is not possible to assess the effects of reservoir maturation processes on fishery management because the available data do not lend themself well to this type of consideration.

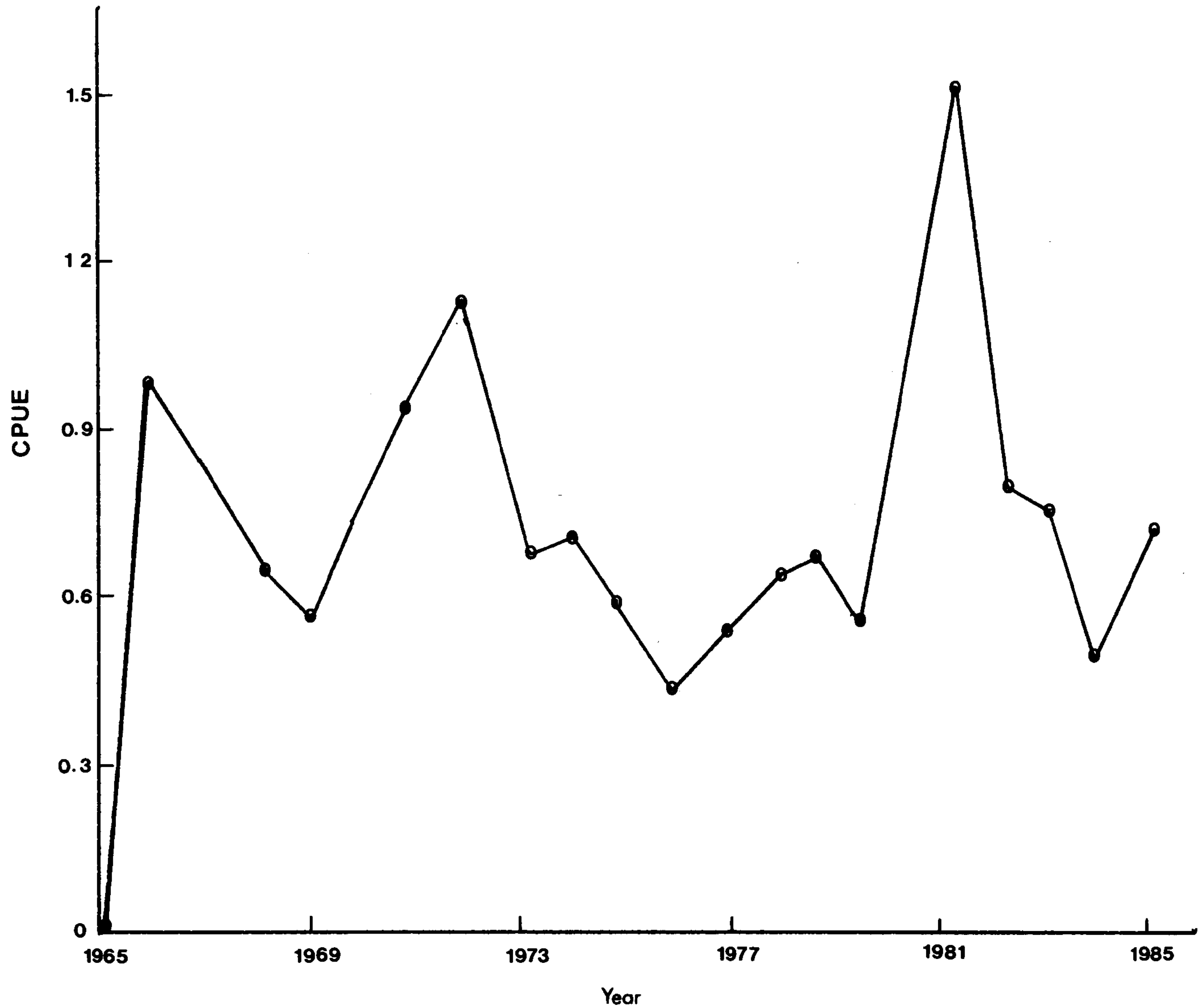

Figure 13. – CPUE (catch per unit effort) for rainbow trout in Blue Mesa Reservoir.

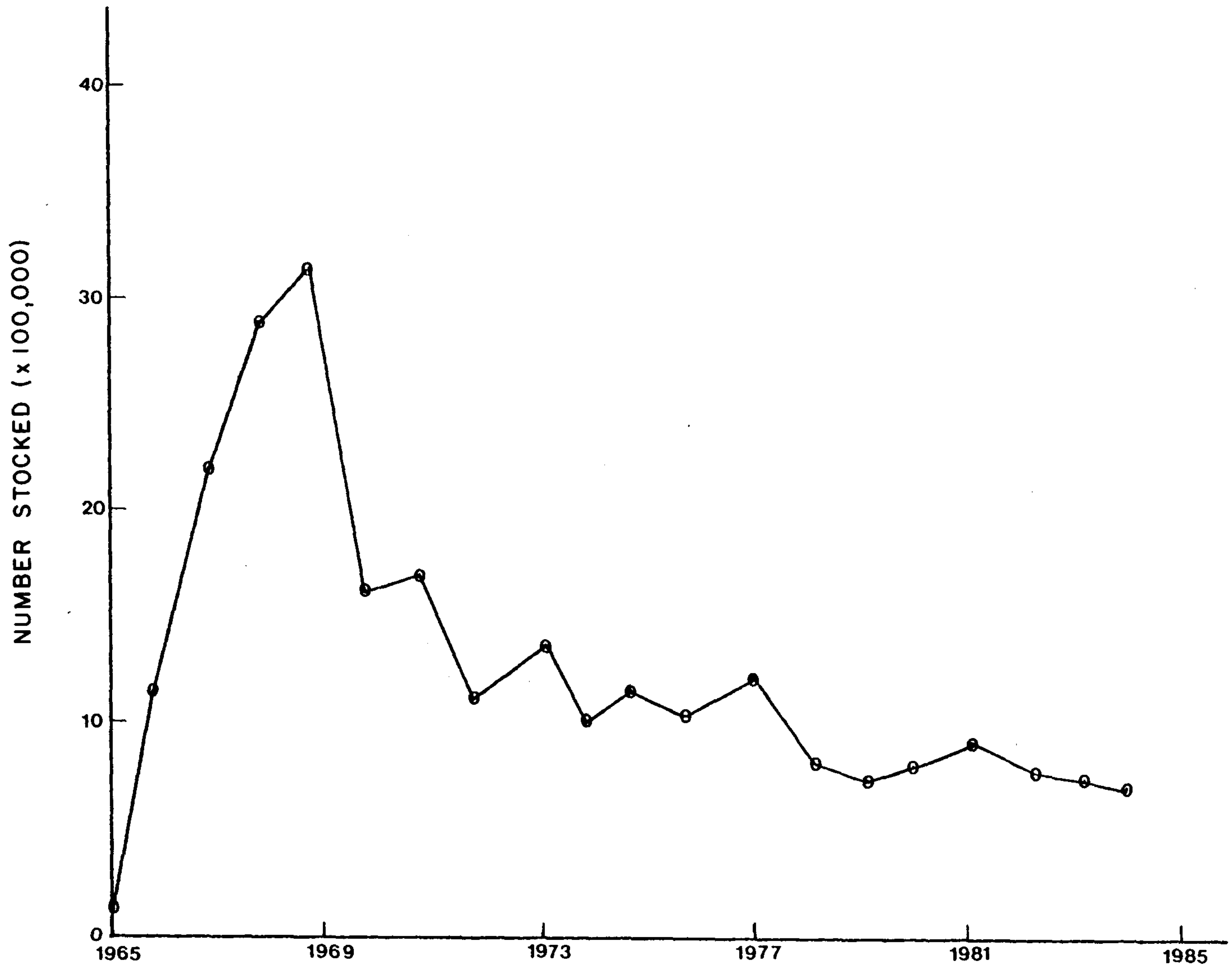

Figure 14. – Total number of rainbow trout stocked in Blue Mesa Reservoir.

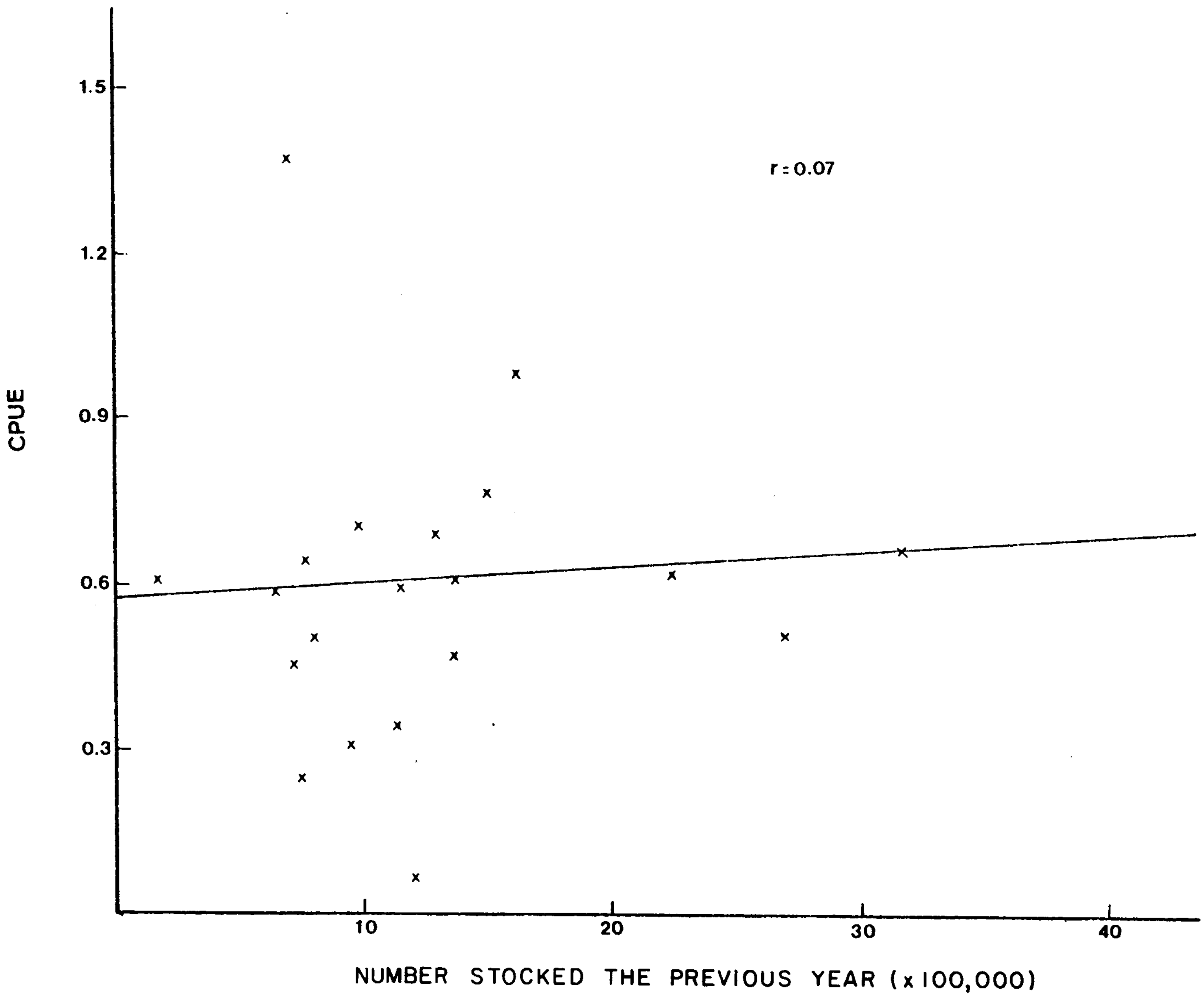

Figure 15. – Scatter Plot of CPUE versus total number of rainbow trout stocked the previous year in Blue Mesa Reservoir, 1965-1985.

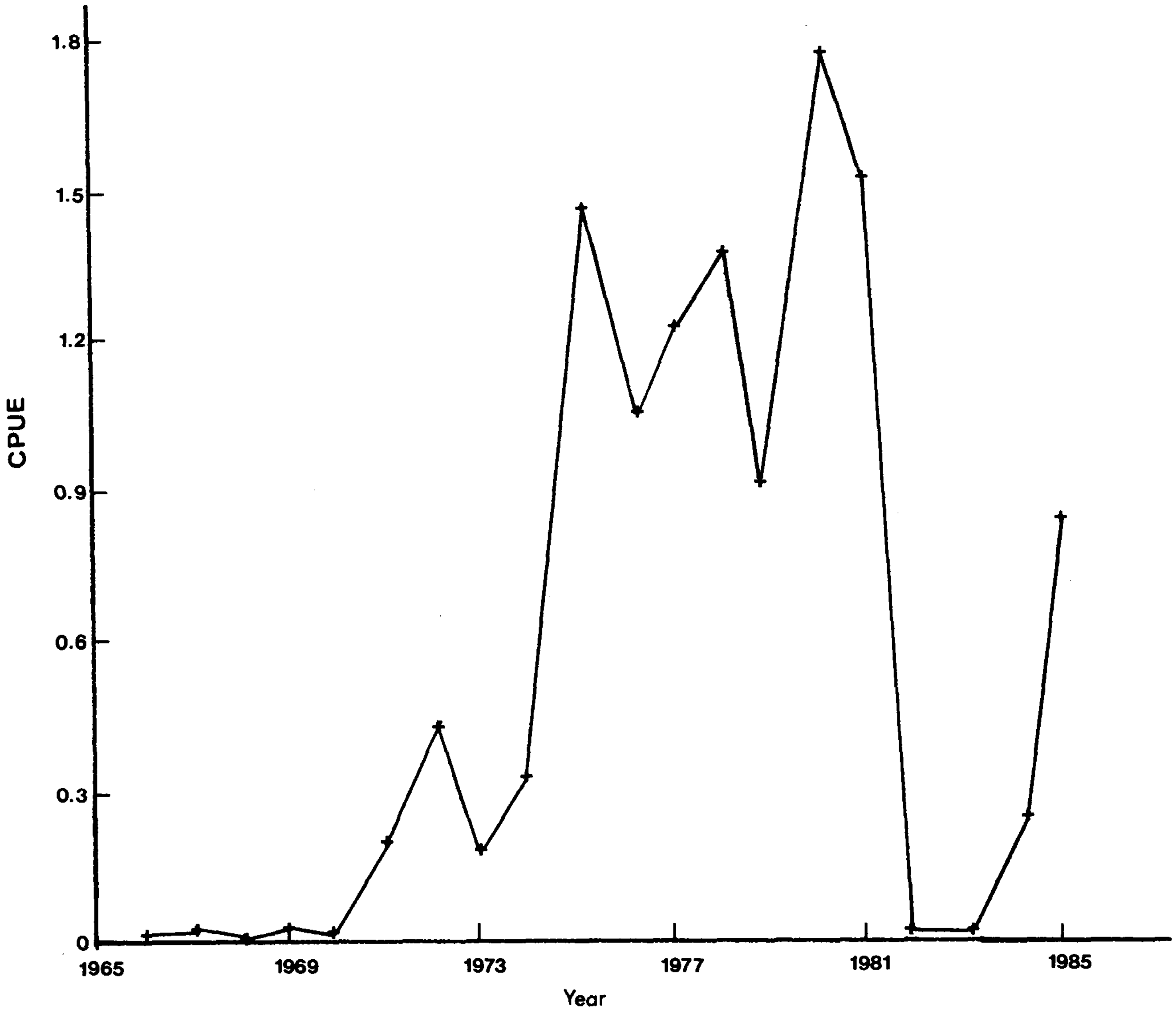

Figure 16. – CPUE (catch per unit effort) for kokanee salmon versus year in Blue Mesa Reservoir, 1965-1985.

Table 11. – Total number of salmonids stocked in Blue Mesa Reservoir, 1965-1985

Year	Salmonid species				
	Rainbow	Native	Lake	Brown	Kokanee
1965	186,350	0	0	0	0
1966	1,291,670	0	0	0	201,000
1967	2,320,791	0	0	0	375,000
1968	2,778,335	0	28,000	0	0
1969	3,117,524	0	0	18,000	0
1970	1,567,710	0	0	0	0
1971	1,634,345	0	0	0	845,000
1972	1,113,205	0	35,200	0	0
1973	1,373,198	0	24,960	0	0
1974	969,919	0	18,060	0	870,000
1975	1,198,892	0	0	0	0
1976	1,104,023	0	0	0	0
1977	1,322,092	0	0	0	0
1978	791,425	0	0	0	250,666
1979	763,101	4,875	760,401	0	0
1980	827,597	0	0	0	0
1981	999,044	0	0	0	0
1982	801,113	36,800	0	0	624,752
1983	741,531	0	0	0	250,000
1984	716,092	0	0	0	0
1985	1,084,093	0	0	0	83,432
Total	26,702,050	41,675	866,621	18,000	3,499,850

CONCLUSIONS

Difficulties identifying and interpreting historical trends in Blue Mesa Reservoir over its 20-year existence stem from a spotty, and haphazard sampling regime. Lettenmaier (1977) [36] noted that trend detection is limited unless a specific sampling program is adhered to. The disparate sampling pattern from 1966 through 1982 offsets the intensive sampling accomplished from 1983 to 1985. Nevertheless, conclusions are proffered with regard to Blue Mesa's trophic status.

The Wiltzius (1974) [11] noted algal blooms soon after the Gunnison river was inundated supports general theories of accelerated productivity and nutrient availability after impoundment (Baxter 1977[1]; Lindstrom 1973[2]; Goldman and Kimmel 1978[3]). High conductivity and alkalinity levels during this early period attest to sufficient levels of nutrients and ions to support large colonizing zooplankton and phytoplankton populations.

Later data (1974 and 1975) apparently do not corroborate the reservoir-aging theory that productivity decreases after an initial "boom cycle." Phytoplankton populations in 1975, attained densities of approximately 4.0×10^6 cells/L, similar to levels 10 years later (see fig. 8). No data are available from the early years. Chlorophyll *a* levels were of the same magnitude between 1975 and 1983-1985. Again earlier data is unavailable. The 1975 and 1983-1985 data suggest that the reservoir has attained a steady-state, or trophic equilibrium, without passing through a depressed stage of production.

Hutchinson (1969) [78] discussed eutrophication processes in light of the morphoedaphic characteristics of a body of water, nutrient inputs to the system and their internal cycling, and anthropogenic inputs. Trophic equilibrium is attained naturally depending upon types, amounts, balance of nutrient and ion inputs and outputs, and the general water body morphometry. The best estimate of Blue Mesa's overall trophic status is based on chlorophyll *a* levels measured in studies of 1974, 1975, and 1983-1985. All points to oligotrophic to mestrophic conditions. However, and more importantly, basin differences recognized by Bio-Environs (1985) [6] indicate that basin geometry and influx of nutrients tend to control the dynamics of a particular basin. For example, Iola Basin's relative shallowness and the direct influence of the Gunnison River (which contributes approximately 52 percent of total flow in the Iola Basin) regulated the basin's biological, chemical, and physical dynamics. These regulating mechanisms were manifested as higher phytoplankton densities and higher associated chlorophyll *a* levels than those of Cebolla and Sapinero basins.

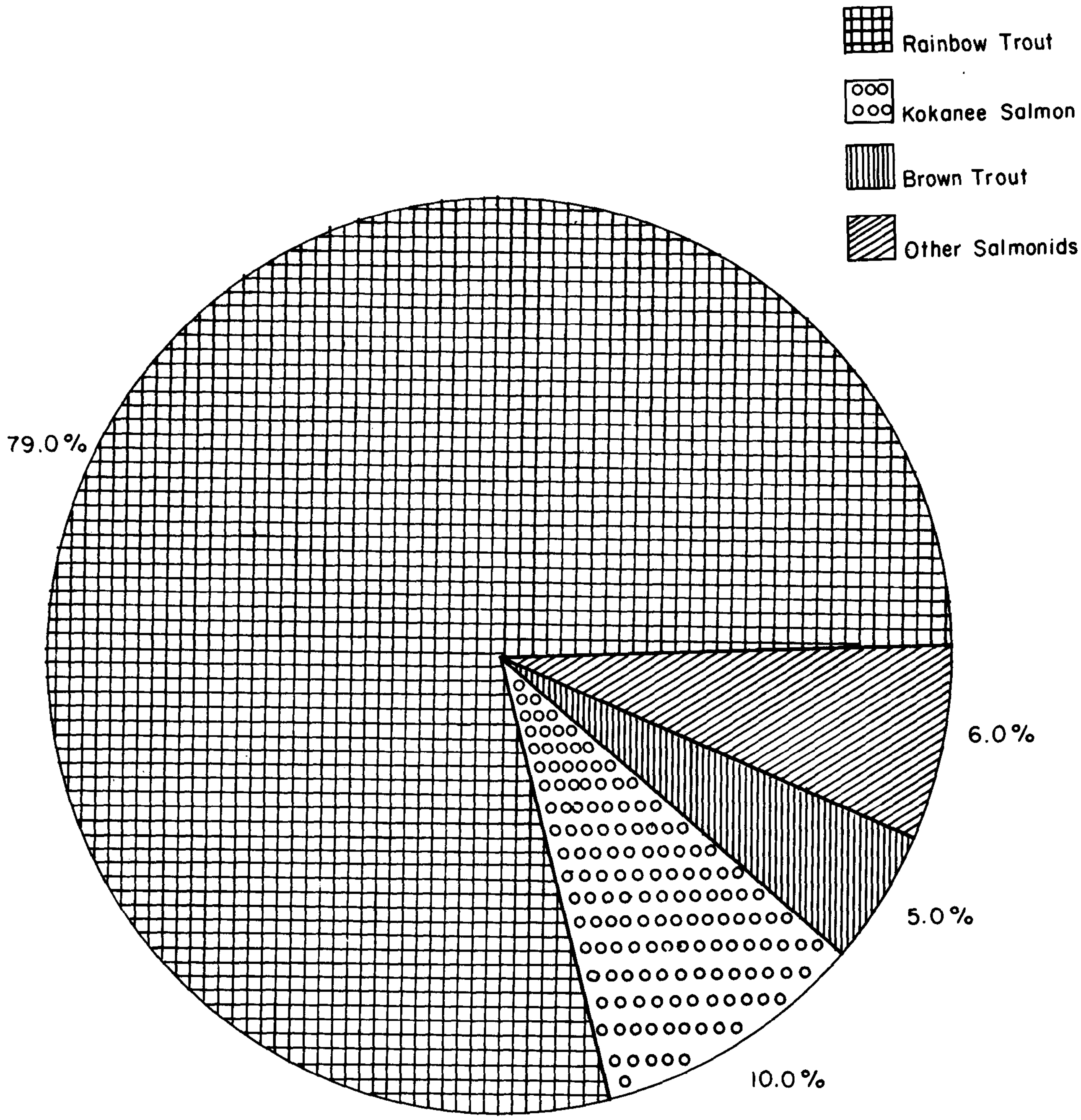

Figure 17. – Percent harvest of salmonids in Blue Mesa Reservoir, 1966-1985.

Because historical trend evaluation was limited, extrapolation to future reservoir dynamics is even more limited, and speculative at best. If it is agreed that Blue Mesa has attained steady state, variation of any parameter about its mean is probable, but long-term trend detectability is negligible. Therefore, Blue Mesa's trophic status is unlikely to change naturally without critical changes in climatic conditions or anthropogenic inputs. An EPA preliminary report on Blue Mesa stated that it was mesotrophic, and that phosphorus loading exceeded rates noted by Vollenweider and Dillon (1974 in EPA 1976) [31] as leading to eutrophication. Interestingly, 10 years later, in 1985, Blue Mesa Reservoir can be still classified as mesotrophic based on Likens (1975) [63] criteria. Bio-Environs (1985) [6] estimated that the mean 6-month loading rates of total phosphorus to the reservoir from major tributaries was 2.38 g/m^2. Mean yearly phosphorus loading may still equal that measured in 1975, because all point sources discussed in the 1975 study are still functioning. In addition, not all known municipal discharge levels were included in that report. Apparently, over this 10-year period, eutrophication as a result of phosphorus loading was

Table 12. – Angler use and percent harvest of stocked salmonids at Blue Mesa Reservoir, 1965-1985

Year	No. of anglers checked	Total fish harvested	Rainbow trout No.	Rainbow trout Percent	Kokanee salmon No.	Kokanee salmon Percent	Other species No.	Other species Percent
1966	185	421	257	62.0	0	0	164	38.0
1967	1,405	5,075	4,669	92.0	0	0	406	8.0
1968	578	1,066	1,044	98.0	10	1.0	12	1.0
1969	446	750	652	87.0	60	8.0	38	5.0
1970	609	1,597	1,469	92.0	16	1.0	112	7.0
1971	1,779	5,351	4,548	85.0	107	2.0	696	13.0
1972	678	1,960	1,803	92.0	98	5.0	59	3.0
1973	2,947	6,403	5,635	88.0	193	3.0	575	9.0
1974	2,671	5,758	5,093	88.0	347	6.0	348	6.0
1975	4,942	8,583	5,236	61.0	2,489	29.0	858	10.0
1976	4,148	5,288	1,269	24.0	1,322	25.0	2,697	51.0
1977	3,799	5,404	3,729	69.0	1,351	25.0	324	6.0
1978	1,419	1,970	1,399	71.0	473	24.0	98	5.0
1979	1,591	2,510	1,983	79.0	376	15.0	151	6.0
1980	3,405	6,318	3,601	57.0	2,274	36.0	443	7.0
1981	703	2,026	1,783	88.0	208	10.3	35	1.7
1982	685	1,516	1,439	94.9	6	0.4	71	4.7
1983	1,206	2,354	323	98.7	15	.6	16	0.7
1984	364	462	429	92.8	22	4.8	11	2.4
1985	349	753	651	86.4	84	11.1	18	2.5

Table 13. – Number of rainbow trout in selected size classes stocked in Blue Mesa Reservoir, 1965-1985

Year	0 to 2 inch	2 to 4 inch	4 to 6 inch	6+ inch
1965	0	153,000	33,350	0
1966	541,980	860,000	87,690	3,000
1967	0	2,320,791	0	0
1968	390,000	2,344,335	44,000	0
1969	0	3,135,524	0	0
1970	0	1,541,806	17,804	8,100
1971	0	450,500	1,049,309	134,537
1972	0	187,258	925,947	0
1973	0	471,500	898,698	3,000
1974	0	0	969,919	0
1975	0	0	1,198,892	0
1976	0	0	1,104,023	0
1977	0	0	1,322,580	0
1978	0	0	725,580	0
1979	2,700	0	760,401	0
1980	0	0	827,597	0
1981	0	0	999,044	0
1982	0	0	801,113	0
1983	0	0	741,531	0
1984	0	0	571,989	144,104
1985	0	0	1,033,996	50,050
Total	934,680	11,464,714	14,140,462	342,791
Percent	3.5	42.7	52.5	1.3

not corroborated. Nitrogen loading demands greater consideration, because possible nitrogen limitation has been noted in the reservoir (EPA 1976) [31], and nitrogen producing alga, *Aphanizomenon flos-aquae,* represents the bloom species in late summer. With increased use of the reservoir, increased development of reservoir recreational sites, their accompanying septic systems, and continued upstream inputs, eutrophication, particularly in Iola Basin, is likely. The anthropogenic sources of ions and nutrients may force the steady-state dynamics of Blue Mesa Reservoir to change, and thus lead to overall problems with water quality and fisheries.

Management implications from such limited identification of trends are the need for communication efforts between water resource managers and fishery specialists. Rigler (1982) [79] summarized the dissimilar approaches fish biologists and limnologists use to study and manage lakes and reservoirs. The fish biologists concentrates on fish stocking and angler demands, whereas the limnologist concentrates on the depletion of oxygen from the hypolimnion in their study of methods to sustain fish populations. Larson (1980) [80] discussed the necessity of adequately sampling annual variations of resource to clarify system dynamics. More than one trophic level must be studied in depth to determine what changes may emanate from trophic level interaction.

In light of these ideas, future management emphases may center upon 1) well-focused sampling designs, 2) specific attention to heavy metal levels, nutrient inputs and outputs, and sediment chemistry, and 3) interpretation of relationships between fish populations and their food source and availability.

By focusing future sampling programs to fulfill the requirements of time series analysis (e.g., fixed sites and sampling dates), trend analysis will be valid, and changes in the trophic status of reservoirs will be better recognized. The need for a focused sampling design stems from the goal of maintaining Blue Mesa Reservoir's water quality. Several concerns emanating from this review, and actual threats to Blue Mesa's water quality are presented: 1) Several heavy metals were detected at levels exceeding Federal criteria or State standards. For example, a uranium tailings pile located near the confluence of Tomichi Creek and the Gunnison River may have contributed to elevated levels measured in 1983 and 1984. Planned movement of the uranium pile may eliminate cumulative problems. 2) The Bay of Chickens area is used intensively for swimming. Fecal coliform counts in August 1984 exceeded the 500 colony-forming units per 500 mL allowed by the State. This public threat to recreation and water quality should be addressed. 3) Nutrient inputs from increased recreational use, accelerated recreational site development, and the possibility of new point source discharges on associated tributaries warrant monitoring. In addition, by measuring nutrient and ion output from Blue Mesa Reservoir, managers will be able to understand reservoir dynamics in terms of input versus output, and thus, actually determine whether Blue Mesa has attained steady state. 4) Depleted hypolimnion oxygen levels and benthic populations lacking diversity were encountered in 1984 and 1985. Reservoir sediments act as a respository and indirect gauge of inputs to the reservoir; sediment study is necessary to understand the basis for the low species diversity, low oxygen levels, and possible flux of phosphorus from sediments associated with anaerobic conditions (Mawson et al. 1983) [81]. 5) Alkalinity and pH levels should continue to be monitored. Decreasing bicarbonate levels over the years may result from leaching of ions and chemical precipitation. However, the effects of acid precipitation may promote lowering of the water's buffering capacity in the future.

Finally, if reservoir aging processes and their effects are to be identified, adequate fish population data must be available. Because this sort of data is lacking for Blue Mesa Reservoir, no relationships between reservoir maturation and fishery production are offered. Instead, these relationships might be pursued in other reservoirs where fish population studies (including electrofishing, gill netting, and seining) have been instituted to a greater degree. Ultimately, a larger emphasis might be placed on studying the dymnamics between fish populations and their food sources in an effort to model sustaining conditions of Blue Mesa Reservoir.

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APPENDIX

PHYTOPLANKTON TAXA LISTS FOR 1975 AND 1983-1985

1975 Phytoplankton Species Listed in their Respective Divisions

Division Bacillariophyta

Asterionella formosa
Cymbella sp.
Fragilaria crotonensis
Stepahnodiscus sp.

Division Chlorophyta

Oocystis sp.
Schroederia setigera
Staurastrum sp.
Tetraedron muticum

Division Cryptophyta

Chroomonas sp.
Cryptomonas erosa

Division Cyanophyta

Aphanizomenon flos-aquae
Microcystis incerta

1983 Phytoplankton Species Listed in their Respective Divisions

Division Bacillariophyta

Amphora ovalis
Asterionella formosa
Cocconeis placentula
Fragilaria construens
Fragilaria crotonensis
Fragilaria vaucheriae
Hannea arcus
Melosira granulata
Melosira italica
Navicula cuspidata
Nitzschia acicularis
Nitzschia hungarica
Nitzschia palea
Stephanodiscus asterae
Stephanodiscus niagarae
Synedra ulna

Division Chlorophyta

Ankistrodesmus falcatus
Ankistrodesmus gelatiniformis
Asterococcus limneticus
Botryococcus braunii
Chaetophora sp.
Characium limneticum
Chlamydomonas sp.
Chlamydomonas alpinum
Chlorogonium carefooti
Closteriopsis longissima
Closterium sp.
Closterium lunula
Coelastrum microporum
Eudorina elegans
Gloecoccus tetrasporus
Gloeocystis sp.
Gongrosira sp.
Gonium sociale
Kirchneriella obesa
Mougeotia sp.
Nannochloris sp.
Octocystis reidii
Otosporiella coloradensis
Oedogonium sp.
Oocystis lacustris
Oocystis parva
Palemellopsis sp.
Pandorina morum
Pediastrum duplex
Pediastrum tetras
Quadrigula lacustris
Scenedesmus quadricauda
Schroederia setigera
Sphaerocystis schroederi
Spriogyra sp.
Spondylosium planum
Staurastrum sp.
Staurastrum leptocladum
Stigleoclonium tenue
Ulothrix sp.
Ulothrix fimbriata
Volvox aureaus
Volvulina steinii

Division Chrysophyta

Chromulina sp.
Chrysamoeba sp.
Mallomonas sp.

Division Cryptophyta

Cryptomonas sp.
Cryptomonas erosa
Cryptomonas marsonii
Cryptomonas ovata
Cryptomonas platyuris
Cryptomonas rostratiformis

Division Cyanophyta

Anabaena sp.
Anabaena circinalis
Anabaena spirulinoides
Aphanizomenon flos-aquae
Aphanothece sp.
Microcystis aeruginosa
Oscillatoria sp.
Pseudoanabaena catenata

Division Euglenophyta

Colacium vesiculosum
Euglena sp.

Division Pyrrophyta

Ceratium hirundinella
Massartia - like

Division Xantophyta

Tribonema sp.

1984 Phytoplankton Genera Listed in their Respective Divisions

Division Bacillariophyta

Asterionella
Cyclotella
Fragilaria
Gomphonema
Hannea
Melosira
Navicula
Nitzschia
Rhopalodia
Stephanodiscus
Synedra

Division Chlorophyta

Ankistrodesmus
Botryococcus
Chlamydomonas
Eudorina
Mougeotia
Octocystis
Octosporiella
Oedogonium
Oocystis
Pediastrum
Sphaerocystis
Schroederia
Spirogyra
Staurastrum
Ulothrix
Volvox
Volvulina

Division Chrysophyta

Chrysamoeba
Chrysochromulina
Dinobryon
Synura

Division Cryptophyta

Cryptomonas

Divisions Cyanophyta

Anabaena
Aphanothece
Aphanizomenon
Dactylococopsis
Gomphosphaeria
Mycrocystis

Division Euglenophyta

Colacium
Euglena

Division Pyrrophyta

Ceratium

Division Xanthophyta

Tribonema

1985 Phytoplankton Species Listed in their Respective Divisions

Division Bacillariophyta

Achnanthes affinis
A. lanceolata
Achnanthes sp.
Amphipleura pellucida
Asterionella formosa
Biddulphia sp.
Cocconeis placentula
Cyclotella sp.
Cymatopleura sp.
Cymbella minuta
Diatoma sp.
Epithemia sorex
Epithemia sp. or *Denticula*
Fragilaria crotonensis
F. contruens
F. vaucheriae
Gomphonema sp.
Hannea arcus
Mastigloia sp.
Melosira granulata
M. granulata var. *angustissima*
M. italica
Navicula cuspidata
N. crytocephala var. *venata*
N. graciloides
N. pupila
Nitzschia acicularis
N. linearis
N. sigmoidea
Nitzschia sp.
Pinnularia sp.
Rhoicosphenia sp.
Stephanodiscus asterae
S. niagarae
Stephanodiscus sp.
Surirella sp.
Synedra ulna

Division Chlorophyta

Botryococcus loraunii
Chlamydomonas sp.
Gloeocystis sp.
Schroederia setigera
Sphaerocystis sp.
Staurastrum sp.

Division Cryptophyta

Cryptomonas sp.

Division Cyanophyta

Anabaena circinalis
A. spirulinioides
Anabaena sp.
Aphanizomenon flos-aquae

Division Euglenophyta

Euglena sp.

GPO 854-036

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-822A, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.