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Micronutrients and biological patterns in Lake Mead

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MICRONUTRIENTS AND BIOLOGICAL PATTERNS IN LAKE MEAD

Final Report to Contract 14-06-300-2210, 1971
between
The United States Department of the Interior, Bureau of Reclamation and the University of Arizona

by

The Department of Hydrology and Water Resources of the College of Earth Sciences in cooperation with the Department of Biological Sciences
This report includes data which will be used in developing and validating a mathematical model for Lake Mead. Development and validation of the model will be part of a Ph.D. Dissertation at the University of Arizona by Mr. L. G. Everett.

Principal Investigators:

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Mr. Lome G. Everett

Dr. J. S. Carlson
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MICRONUTRIENTS AND BIOLOGICAL PATTERNS IN LAKE MEAD

INTRODUCTION

Progressive increases in concentration of dissolved solids in the Colorado River water from Lake Powell to Imperial Dam seem to alter plankton dynamics and biological productivity of the river. Also, changes in biological productivity and micronutrients concentrations occur within the same reservoir. Development of a digital simulation model to predict micronutrients concentrations and biological productivity is necessary for diagnosing changes in plankton population and effluent-carrying capacity of the system.

The objectives of the study are: (1) to determine trace metal balance at different locations in Lake Mead, (2) to measure biological productivity and conduct plankton population counts at each sampling location, (3) to derive functions relating biological productivity to trace metal concentrations, suspended sediments and some physical variables (temperature, light, solar radiation), and (4) to develop a mathematical model for predicting spatial and temporal changes in biological productivity, plankton dynamics and trace elements concentrations.

Data acquisition is limited to the identification of the principal parameters which relate to the biology and chemical properties of the aquatic system(s). The data is subjected to mathematical analysis to identify trends in spatial and temporal planktonic variabilities.

Extensive chemical and hydrodynamic studies have been attempted on Lake Mead. The United States Geological Survey publishes annually an extensive report containing water chemistry at Hoover Dam and Bright
Angel Creek. Additional chemical data are collected by the Bureau of Reclamation and is reported in the following publication series: CHE-46 (1965), CHE-70 (1970), REC-ERC-71-11 (1971).

The Environmental Protection Agency (FWQA) has completed minor investigations on Lake Mead in their report of January 1967 and of October 1968.

These studies were performed in the light of the monumentous efforts of Anderson and Pritchard (1951) and Smith et al (1954).

Hill (1965) draws a note of caution by his prediction of the quality of Colorado River water.

Outside of the limited work by the EPA and Moffett (1943), hydrobiology has been neglected.

This report constitutes the first integrated scheme of chemistry, hydrobiology and hydrodynamics. The original direction was to follow assumptions derived through our first zooplankton and chemical analyses of Lake Mead. At that time we felt that the chemistry data would indicate a sharp drop in primary productivity (PPR) from South Cove to Hoover Dam. Our zooplankton data, however, indicated that Boulder Basin was experiencing stress either chemically or biologically. The early chemistry study indicated the lack of certain required micronutrients across the system. We are satisfied that the PPR does drop from South Cove to Bonelli Landing; however, we did not expect the accelerated eutrophication covering the whole of Boulder Basin.

LAKE MEAD

Hoover Dam, proclaimed by the ASCE as one of the Seven Modern Civil Engineering Wonders, has resulted in the formation of Lake Mead.
Of the Colorado River's 1,400-mile descent (see Fig. 1), the canyon-type reservoir, when full, entails but 110 miles in length, making it this hemisphere's largest man-made reservoir. Covering 157,900 acres, this reservoir has a maximum depth of about 500 feet and an available capacity of 26.1 million acre-feet.

The lake is made up of four major sections: Boulder Basin, Virgin Basin, Overton Arm, and the upstream edge of Virgin Basin to Pierce's Ferry (see Fig. 2). Water in Lake Mead is derived from one major source, the Colorado River, and three minor sources, the Muddy and Virgin Rivers and Las Vegas Wash. The Colorado River introduces 98% of the total inflow while the Virgin River, Muddy River and Las Vegas Wash contribute 1.5, 0.3 and 0.2%, respectively. Quality of water flowing into the lake from all sources vary in time and from one source to another.

**SAMPLING LOCATIONS**

A total of eight water-quality stations were used to quantify the biological, chemical and hydrodynamic parameters in Lake Mead. Their exact location is given in Figure 2. Three stations were placed in Boulder Basin as this section receives the major water use and represents the product of the natural flow of the system. The locations were chosen to be greater than 30 meters deep and far enough from shore not to receive any interference.

The sampling locations are:

- Boulder Basin
- I. Las Vegas Wash
- II. Bureau of Reclamation Raft
- III. Beacon Island
Figure 1. Map Showing the Colorado River Basin from Lake Powell to the Mexican Ranches.
Figure 2. Location Map of the Sampling Stations on Lake Mead.
Virgin Basin IV. Bonelli Landing
Overton Arm V. Miner's Cove
VI. Echo Bay
VII. Temple Bar
Gregg's Basin VIII. South Cove

SAMPLING AND MEASUREMENTS

Each of the eight water-quality stations was sampled identically. All water samples for analysis were collected using three- and six-liter, polyvinyl-chloride (PVC) Van Dorn samplers. The PVC sampler precludes any ion exchange. Methods of sampling and measurements are as follows:

1. Continuous temperature profiles to 54 meters were obtained using a Precision Scientific temperature probe.

2. The DO continuous readings were taken from a galvanic-cell oxygen analyzer manufactured by Precision Scientific. The meter was calibrated each day using the Azide-Modification of the Winkler technique as presented by Standard Methods for the Analysis of Water and Waste Water.

3. A portable Beckman Electromate pH meter was used to obtain the hydrogen ion levels. The pH meter was also used to obtain the alkaline values as described by Standard Methods.

4. Chlorophyll samples at five and 30 meters were taken. Two milligrams of magnesium sulphate were added to 1000 mls. of water and filtered through a 45-micron membrane filter. These samples will be analyzed and compared to the primary productivity (PPR) changes. Their value is academic in nature for this study since the $C_{14}$ technique is the best measure of PPR.
5. Complete chemical analysis was done on a 1-liter sample. The samples were kept in dark glass bottles which had been washed with a dilute acid solution. Since micro-elemental analysis was also done, no preservatives were added. Samples for chemical analysis were taken at five and 30 meters.

6. Phytoplankton and zooplankton samples were taken at zero, one, three, five, seven, ten, 15, 20, 25, 30 and 35 meters. The phytoplankton sample was placed in a six-dram vial and preserved with Lugol's reagent. The phytoplankton analysis is currently being done.

Each zooplankton sample was concentrated from six liters to six drams using a cloth mesh. A ten percent formalin solution was used to preserve the zooplankton.

7. Light transparency was measured with a photo-electric cell rather than a Secchi disc. The cell gives considerably more accurate results as it is corrected for changes in solar radiation. Also, the cell affords the opportunity to locate turbidity layers. Since this study was primarily concerned with the photic zone, we required an accurate light meter to determine the compensation depth. The compensation level is the depth at which one percent of the incoming solar radiation can be measured.

RESULTS

Temperature

The annual temperature regime in Lake Mead describes a warm monomictic cycle. These lakes have a water temperature which is never below 4 °C, and freely circulates during the winter at or above 4 °C (see Appendix A).
The temperature range was 10.1 to 28.4 °C, with November, January
and February temperature profiles showing the isothermous nature of the
lake during winter turnover. It is at this time that nutrients released
in the anaerobic hypolimnetic layers of summer are brought to the surface.
The homogeneous winter temperatures are 11 ± 1 °C. The June figures
indicate the beginning of the thermocline. In September we can
distinguish between the epilimnion, thermocline and hypolimnion at each
station. The thermocline in September is found between 18 and 28 meters
and has a temperature range of 17 to 26 °C.

Dissolved Oxygen (DO)

The dissolved oxygen cycle in Lake Mead can be described as a
negative heterograde scheme. In this case we observe a minimum DO in the
thermocline with higher saturations in the epilimnion and hypolimnion.
The DO pattern is similar at all stations during the seasonal changes.
The range of DO is 1.8 to 13.0 ppm. The November, January and February
DO isopleths indicate that the winter turnover is reaerating the system.
The September charts, however, show that the lake goes into stress in the
hypolimnion during summer stratification. DO values of two ppm at the
thermocline depth indicate a high Biochemical Oxygen Demand (BOD). Since
the DO level recovers from this zone of high oxygen demand we postulate
that high levels of organic matter are oxidized at the thermocline level.
As the algae sink under gravity they meet the denser cold waters capped
by the thermocline. Here bacteria break the algae down, releasing ions,
and using up DO through respiration. The DO levels in the hypolimnion in
September are considerably below the recommended level for cold-water
fish regeneration.
Soluble Salts

The September data indicates across all the stations that with a well-developed thermocline we observe the highest values for soluble salts at 30 meters in the hypolimnion. There is approximately a 100 ppm increase in soluble salts from South Cove to the Bureau Raft at all seasons of the year. During winter turnover the 5- and 30-meter values are very close. The range of soluble salts is from 600 to 840 ppm. The soluble salts in Vegas Bay do not appear to seriously increase the level at the Raft. Higher jumps in soluble salts are noted between South Cove and Temple Bar.

Electrical Conductivity (EC)

EC does not appear to be affected by thermal stratification. There is a conductivity increase of about $0.30 \times 10^3$ at each station throughout the year. The EC ranges between 0.95 and $1.25 \times 10^3$ over the eight stations. The specific conductance of an oligotrophic lake is <200 micro mhas at 18 °C. The specific conductance of a eutrophic lake is >200 micro mhas at 18 °C. These levels place Lake Mead deep into the range of a eutrophic lake.

Hydrogen Ion Concentration (pH)

The pH generally decreases slightly across the basins. During summer stratification the lower pH values were consistently found in the hypolimnion. The pH ranged between 7.8 and 8.4 (see Appendix B). The Las Vegas Wash station does not appear to be affecting the pH levels in Boulder Basin.
Chloride, Magnesium, Potassium, Sodium, Calcium

Each of these elements appear to increase across the basins. This is primarily a result of salt loading and salt concentration. All of these elements except Mg appear to have much lower September values in South Cove. However, the levels of these elements nutrients are very high. The level of chloride is five times as high as found in Lake Erie.

Phosphate

The ortho-phosphate levels found in Lake Mead fall in the range of an oligotrophic lake (0.1 to 0.3 ppm). Boulder Basin appeared to be richer in PO₄ than Virgin Basin. The PO₄ levels at South Cove drop across Gregg's Basin. This could be a result of complexing and sedimentation or increased primary productivity. The minimum ortho-phosphate level for excessive crops of algae is equal to or greater than 0.01 ppm.

Nitrate

The nitrate values are much higher in September and November. There is no increase or decrease across the system; therefore, the Colorado River is responsible for introducing these high levels. The minimum content of nitrogen for excessive algae bloom must be equal to or greater than 0.3 ppm. Excessive nitrogen is available at all times of the year. Boulder Basin does not contribute excessive nitrate values.

Bicarbonate

The bicarbonate (HCO₃⁻) values show excellent response to thermal stratification in September. The higher values are found 30 m beneath the surface. There is a trend to reduced HCO₃⁻ across the lake. The
summer levels are 10-15 ppm less than the cool winter turnover values. Excessive HCO$_3$ is available throughout the year.

Iron, Manganese, Zinc

These three elements do not show a consistent trend across the system. Manganese is available in the optimal range. The iron and zinc levels do not appear to be limiting.

Copper

The copper levels do not appear to follow any trend. Copper is toxic to algae at concentrations greater than 0.05 ppm. This level is exceeded many times in Lake Mead. However, the Cu level goes into stress at certain times of the year.

Sulphate

The sulphate levels consistently increase by more than 60 ppm across Lake Mead. This is a result of extensive chemical action in the reservoir. The sulphate begins to increase at South Cove. Part of the increase can be attributed to salt concentration. Part is a result of the hydrobiology. In Gregg's Basin we get high productivity resulting in a high Biochemical Oxygen Demand (BOD) in the bottom of the basin. This creates low dissolved oxygen conditions and low electropotential (EH). Under these conditions hydrogen sulphide (H$_2$S) is released and iron is precipitated out. Some of the available H$_2$S goes into solution as sulphates. The sulphate level in Boulder Basin is 15 times as high as it is in Lake Erie.
Carbonate

The carbonate levels read zero at all times of the year and at all stations.

Light Intensity

The depth of penetration as seen in Figure 3 appears to increase in the warmer months. The 1% level appears to be consistently deeper at Bonelli Landing and Temple Bar with the former being the clearest water in the lake. Light penetration does not consistently improve across the system as sediment is lost. The transparency in Boulder Basin is often as poor as South Cove.

Zooplankton

Among the limnetic zooplankton of temperate lakes the three dominant planktonic groups are the cladocerans, copepods and rotifers. All three of these are well represented in Lake Mead. The zooplanktonic organisms that were studied in this investigation include somewhat of a heterogeneous grouping from a systematic standpoint. Ceratium has been classified as both a plant and an animal by some taxonomists. Barnes (1969) has classified this organism as a protozoan in the class phytomastigophorea, order dinoflagellida. Keratella, a small rotifer is placed in the class monogonota and order ploima. Among the planktonic orthopoda studied were copepods and cladocerans. The copepods were separated at the ordinal level and counts were made of the calanoida, cyclopoida and the young copepods or nauplii. There were two genera of cladocerans investigated, *Bosmina* and *Daphnia*. Another planktonic form that was very common at times was that of radiolaria, a protozoan group.
Figure: 3

LIGHT METER DATA

A - BUREAU RAFT  E - MINER'S COVE
B - VEGAS BAY  F - ECHO BAY
C - BEACON ISLAND  G - TEMPLE BAR
D - BONELLI LANDING  H - SOUTH COVE
The zooplankton distribution in space and time has been tabulated. The relative totals of each of the zooplanktonic species have been plotted in Appendix C. Since the samples were added over the 35-meter column they are relative in number. A digital program is now available and the values will be integrated over the column of water.

When one examines Lake Mead planktonic samples, the following patterns can be seen. *Daphnia*, a common cladoceran, reaches its maximum number of organisms between April and June with a minimum occurring between September and January. The collecting sites with the number of organisms found at each site for the month of June is shown in Table 1. The maximum number of *Daphnia* for the month of June occurred between three and ten meters, indicating a somewhat euryoecious range for pressure. The above findings seem to agree well with work done by Kuntze (1938) for *Daphnia* in the Schleinsee. This range of population for this organism seems to indicate that each basin of the lake acts independently of the others in as much as the numbers of organisms differ significantly from station to station.

The other cladoceran, *Bosmina*, behaved somewhat differently from *Daphnia* in that the maximum number of organisms occurred between February and April, with a minimum occurring between June and September. Table 1 has a ranking of the collecting sites with the numbers of *Bosmina* found during April. The maximum number of organisms for the month of February occurred between one and 25 meters, while the maximum for April was between five and 20 meters, suggesting a euryoecious range. As with *Daphnia* one would expect that each basin is acting somewhat independent of the other. The work of Kuntze (1938), Wesenberg and Lund (1904) also indicates a prevernal maximum for *Bosmina*. 
<table>
<thead>
<tr>
<th></th>
<th>Las Vegas Wash</th>
<th>Bureau Raft</th>
<th>Beacon Island</th>
<th>Bonelli Landing</th>
<th>Lower Overton Arm</th>
<th>Echo Bay</th>
<th>Temple Bar</th>
<th>South Cove</th>
<th>max occurred during</th>
</tr>
</thead>
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<tr>
<td>Daphnia</td>
<td>2 (674)</td>
<td>1 (1475)</td>
<td>6 (315)</td>
<td>8 (191)</td>
<td>4 (361)</td>
<td>3 (384)</td>
<td>5 (321)</td>
<td>7 (235)</td>
<td>[June]</td>
</tr>
<tr>
<td>Bosmina</td>
<td>1 (1749)</td>
<td>4 (153)</td>
<td>2 (1338)</td>
<td>3 (406)</td>
<td>5 (248)</td>
<td>8 (152)</td>
<td>6 (185)</td>
<td>7 (185)</td>
<td>[April]</td>
</tr>
<tr>
<td>Cyclopoida</td>
<td>1 (1801)</td>
<td>3 (690)</td>
<td>2 (705)</td>
<td>5 (366)</td>
<td>4 (550)</td>
<td>7 (257)</td>
<td>6 (296)</td>
<td>8 (172)</td>
<td>[June]</td>
</tr>
<tr>
<td>Calanoida</td>
<td>4 (54)</td>
<td>3 (162)</td>
<td>5 (51)</td>
<td>6 (32)</td>
<td>1 (385)</td>
<td>2 (285)</td>
<td>7 (25)</td>
<td>8 (15)</td>
<td>[January]</td>
</tr>
<tr>
<td>Keratella</td>
<td>1 (750)</td>
<td>3 (564)</td>
<td>2 (623)</td>
<td>6 (118)</td>
<td>7 (39)</td>
<td>8 (32)</td>
<td>4 (143)</td>
<td>5 (128)</td>
<td>[April]</td>
</tr>
<tr>
<td>Ceratium</td>
<td>1 (750)</td>
<td>3 (564)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 (10640)</td>
<td>6 (18195)</td>
<td>7 (15695)</td>
<td>2 (30890)</td>
<td>3 (29972)</td>
<td>5 (23293)</td>
<td>4 (25821)</td>
<td>1 (32746)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. A ranking of the collecting sites indicating number of organisms per site. The number in parentheses represents the number of organisms sampled at that site during the month indicated.
The Cyclopoida showed a peak between April and June, with a minimum between November and January. This maximum for the month of April occurred between one and 20 meters while the one for June between one and 25 meters. The order Calanoida, the other copepod order studied, had maxima for the different collecting sites over three collecting times, namely February, April and June. Thus one can say that the maximum for Calanoida occurred between February and June. The maximum for February occurred between one and 25 meters, for April between three and ten meters and for June between one and 15 meters, suggesting a trend toward a sternoecious range with respect to pressure. In other investigations, Wesenberg-Lund (1904) and Elster (1954), using the calanoid *Eudiaptomus gracilis* in Danish lakes and the Obersee, lakes that are more boreal than Lake Mead, found peaks in late winter and early spring (January-March). The range of organisms found (numbers) does not vary as much as those for the cladocerans, with some of the sites registering similar counts (see Table 1). This seems to suggest that calanoids are more evenly distributed throughout the lake system and perhaps are not good indicators of water quality.

*Keratella* is a rotifer that is sometimes very abundant in Lake Mead, especially during February, April and September. The data points toward two maxima in this rotifer, a spring maximum occurring between February and April and a fall maximum occurring in September. The maximum for February counts occurred between zero and 30 meters; for April between one and 15 meters; and for September between zero and ten meters. Hutchinson (1967) indicates that rotifers in general have maxima in the spring. He also points out that *Keratella* is an indicator of eutrophic lakes.
The flagellate Ceratium at times was the most abundant organism in the lake system (see Table 1). This organism is capable of rapid multiplication and may develop in large numbers and even surface blooms if conditions are favorable. According to Palmer (1962), Ceratium is a flagellate that is involved with taste and odor of water supplies. In Lake Mead there appears to be but one maximum and that occurs during June with a November minimum. The maximum in June occurs between three and seven meters, and thus appears to be somewhat sternoecious in this respect. This might be due to the fact that Ceratium contains chromoplasts and is capable of photosynthesis and thus is limited by the upper photic zone. Birge and Juday (1922) found that Ceratium in Lake Mendota peaked during July and August.

Primary Productivity

Primary productivity (PPR) refers to the rate at which phytoplankton will produce organic matter from CO₂ and water or, in other words, it is the photosynthesis rate. The PPR is a function of solar radiation, nutrients and light.

PPR's were estimated using the method described by Nielsen (1952). Values were determined at each of the eight stations during five surveys (see Fig. 4). C¹⁴ activity on discs was read on a Nuclear Chicago (NC) planchet model D-47. An NC model 8700 scaler was used for inputting data to the NC model C11B printer. The data was then analyzed using a digital program developed by Goldman, University of California at Davis.

Although PPR data was taken at zero, one, three, five, seven, ten, 15 and 20 meters, the computer output was in grams of carbon fixed per m² per day. The output was corrected for weather conditions. The PPR change
Figure 4. Space-Time Distribution of Primary Productivity

The graph shows the distribution of primary productivity over time at various locations:

- BR - Bureau Raft
- LVB - Las Vegas Bay
- BI - Beacon Island
- BL - Bonelli Landing
- MC - Miner's Cove
- EB - Echo Bay
- TB - Temple Bar
- SC - South Cove

The data points are labeled with specific dates:
- 9/4-11/70
- 1/23-29/71
- 6/4-9/71
- 11/24-29/71
- 4/3-9/71

The y-axis represents the grams of carbon fixed per m²/day.
with depth as a function of the various other parameters will be the subject of the following report.

The accepted ranges for autotrophy in a lake (see Table 2) were described by Rodbe (1969).

Although the rates given in Table 2 are for the growing season, we can compare our seasonal data at each of the eight stations.

The PPR in Lake Mead is greater than an oligotrophic lake at all times and all locations. In the winter months the lake behaves as a natural eutrophic lake. This implies that artificial enrichment is not responsible for the PPR. In June, Gregg's and Virgin Basin act as natural eutrophic lakes, however, Boulder Basin, at all three locations, is in the polluted range. In September, when the water temperature is relatively high, the entire system falls into the polluted range with the Boulder Basin resulting in the most severe conditions.

Although the PPR data has been corrected for weather conditions each of the five surveys provide consistent plots. It appears that in all cases there is a trend to reduced PPR from South Cove to Temple Bar. In all cases the PPR data at Echo Bay is comparable to the low values at Temple Bar. However, in Miner's Cove we observe increased PPR in each of the surveys. At all times the Bonelli Landing station recovers and indicates a leveling of the PPR. In Boulder Basin we observe the highest PPR values. It is very interesting to note that the highest PPR values are at the Bureau of Reclamation Raft and not in the Las Vegas Bay station.

In so many eutrophic waters the most abundant algae are Cyanophyta (blue-green algae) which are also among the most troublesome. A quantitative study of the number of blue-green algae has begun. In
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<td>75-250</td>
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<tr>
<td></td>
<td></td>
<td>350-700</td>
</tr>
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<td></td>
<td>mg of C/m$^2$/day</td>
<td>g of C/m$^2$/day</td>
</tr>
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</table>

Table 2. Autotrophy (phytoplankton).
reservoir practice, however, diatoms are usually the first algae that becomes troublesome when enrichment of the drainage area takes place. The diatom *Asterionella* is one of the worst pests of British reservoirs (Lund, 1955). Spot checks of *Asterionella* indicate that this diatom has not reached problem levels.

**CONCLUSIONS**

The original hypothesis of a limiting nutrient across Lake Mead has not been solved. PPR from South Cove to Bonelli Landing behaves as predicted. However, a much more serious problem has been discovered. Because of enrichment which can only be a result of the accumulated effluent from Las Vegas Bay, the whole of Boulder Basin behaves like a polluted lake. This will soon result in a species shift of phytoplankton to as much more serious problem. The fact that basins act as nutrient traps has created the problem in Boulder Basin. Without flushing, these nutrients are accumulating on the basin floor.

The redox conditions in the mud-water interface largely regulate the flux of dissolved phosphate and other solutes from the mud to the free water, and vice versa. In the oxidized mud surface layer, precipitates of ferric iron and associated colloidal complexes constitute an effective trap for many substances, in particular phosphate ions, and form a barrier for the exchange of nutrients between mud and water. If the mud surface becomes anaerobic, as it does during summer stratification, the ferric iron is reduced to ferrous iron and the absorbing colloids are broken down, resulting in the liberation of nutrients from the vast reserves stored in the bottom muds to the supernatant water. Thus, we get the common expression, "spring bloom." All of the nutrients released in
the hypolimnion in summer are allowed to enrich the surface waters in the winter turnover. When the temperature is optimal the available nutrient produces high PPR.

The potential for a severe eutrophication problem exists in Boulder Basin. The saving factor to date is the species composition in the algae population. When we get a species shift as is the case in all eutrophic lakes, this high rate of PPR will become very obvious.

Extensive macro-chemical analysis is not required in Lake Mead. The macro elements should be monitored but not as rigorously as in the past year. Micro-elemental studies should be expanded further. The drop in PPR from South Cove to Bonelli Landing could be a result of a limiting element. Since water transparency and water temperature improve towards Bonelli Landing, the drop in PPR must be the result of nutrient limitation.

The nutrient problem in Boulder Basin makes the Lake Eries situation appear trivial. The reason we have not had a species shift to a problem organism is not known. However, our existing data is an excellent avenue to answer these questions.

FUTURE STUDIES

While studies have been made in Boulder Basin the extent of the areal problem had not been diagnosed. We have shown quantitatively the scope of the problem. This study has been monumentous in its data collection. This has only been possible through the free help of graduate students. A continued interpretation of the data available to explain the causes of these patterns is highly desirable. Computerized phytoplankton and zooplankton analysis programs are available and will be used to determine relationships.
A minimal number of surveys in the following year will be required to determine if a species shift is developing.

Phytoplankton cell counts have limited value. The C\textsuperscript{14} technique is the only quantitative tool available to give us the rate of organism development. This technique should be used further on the developing problem in Boulder Basin.

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REFERENCES


APPENDIX A*

Lake Temperature
Location: Las Vegas Wash
Figure: A-1
Location: Bureau Raft

Figure: A-2
Location: Beacon Island

Figure: A-3
Location: Bonelli Landing
Figure: A-4
Location: Miner's Cove
Figure: A-5
Location: Echo Bay
Figure: A-6
Location: Temple Bar
Figure: A-7
Location: South Cove
Figure: A-8
APPENDIX B

Chemical Analysis Data
Soluble Salts

9/4-11/70

11/24-29/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

RELATIVE DISTANCE (in %)
Depth: 5m.: ---
30m.: X --- X

A - BUREAU RAFT  E - MINER'S COVE
B - VEGAS BAY    F - ECHO BAY
C - BEACON ISLAND G - TEMPLE BAR
D - BONELLI LANDING H - SOUTH COVE

Figure: B-1
RELATIVE DISTANCE (in %)
Depth: 5m.: O
30m.: x

A - BUREAU RAFT
B - VEGAS BAY
C - BEACON ISLAND
D - BONELLI LANDING
E - MIXER'S COVE
F - ECHO BAY
G - TEMPLE BAR
H - SOUTH COVE

Figure: B-2
RELATIVE DISTANCE (in %)

Depth: 5m.: A - BUREAU RAFT
30m.: x - - x
A - BUREAU RAFT  E - MINER'S COVE
B - VEGAS BAY   F - ECHO BAY
C - BEACON ISLAND  G - TEMPLE BAR
D - BONELLI LANDING   H - SOUTH COVE

Figure: B-3
Chemical: Chloride

RELATIVE DISTANCE (in %)
Depth: 5m.: o
30m.: x

A - BUREAU RAFT  B - VEGAS BAY  C - BEACON ISLAND  D - BONELLI LANDING
E - MINER'S COVE  F - ECHO BAY  G - TEMPLE BAR  H - SOUTH COVE

Figure: B-4
Chemical: Magnesium

9/4-11/70

1/23-29/71

4/3-9/71

6/4-9/71

11/24-29/70

2/25-28/71

RELATIVE DISTANCE (in %)

Depth: 5m.:

30m.: x-x x

A - BUREAU RAFT
B - VEGAS BAY
C - BEACON ISLAND
D - BONELLI LANDING
E - MINER'S COVE
F - ECHO BAY
G - TEMPLE BAR
H - SOUTH COVE

Figure: B-5
Chemical: Potassium

9/4-11/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

RELATIVE DISTANCE (in %)
Depth: 5m.: o o
30m.: x - - x

A - BUREAU RAFT
B - VEGAS BAY
C - BEACON ISLAND
D - BONELLI LANDING
E - MINER'S COVE
F - ECHO BAY
G - TEMPLE BAR
H - SOUTH COVE

Figure: B-6
Figure: B-7
Chemical: Calcium

9/4-11/70

1/23-29/71

4/3-9/71

11/24-29/70

2/25-28/71

6/4-9/71

RELATIVE DISTANCE (in %)

Depth: 5m.: o — o
30m.: x — x

A - BUREAU RAFT
B - VEGAS BAY
C - BEACON ISLAND
D - BONELLI LANDING
E - MINER'S COVE
F - ECHO BAY
G - TEMPLE BAR
H - SOUTH COVE

Figure: B-8
Chemical: Nitrate

9/4-11/70

11/24-29/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

RELATIVE DISTANCE (in %)
Depth: 5m.: — — —
30m.: ----- —

A - BUREAU RAFT
B - VEGAS BAY
C - BEACON ISLAND
D - BONELLI LANDING
E - MINER'S COVE
F - ECHO BAY
G - TEMPLE BAR
H - SOUTH COVE

Figure: B-10
Chemical: Bicarbonate

9/4-11/70

11/24-29/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

RELATIVE DISTANCE (in %)
Depth: 5m.: O
30m.: x

A - BUREAU RAFT
B - VEGAS BAY
C - BEACON ISLAND
D - BONELLI LANDING
E - MINER'S COVE
F - ECHO BAY
G - TEMPLE BAR
H - SOUTH COVE

Figure: B-11
Figure: B-12
Chemical: Manganese

9/4-11/70

11/24-29/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

RELATIVE DISTANCE (in %)
Depth: 5m.: — — —
30m.: × × ×

A - BUREAU RAFT
B - VEGAS BAY
C - BEACON ISLAND
D - BONELLI LANDING
E - MINER'S COVE
F - ECHO BAY
G - TEMPLE BAR
H - SOUTH COVE

Figure: B-13
RELATIVE DISTANCE (in %)
Depth: 5m.: o-- o
30m.: x-- x

A - BUREAU RAFT  E - MINER'S COVE
B - VEGAS BAY    F - ECHO BAY
C - BEACON ISLAND G - TEMPLE BAR
D - BONELLI LANDING H - SOUTH COVE

Figure: B-14
Chemical: Copper

9/4-11/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

RELATIVE DISTANCE (in %)
Depth: 5m.: o---o
30m.: x---x

A - BUREAU RAFT
B - VEGAS BAY
C - BEACON ISLAND
D - BONELLI LANDING
E - MINER'S COVE
F - ECHO BAY
G - TEMPLE BAR
H - SOUTH COVE

Figure: B-15
Chemical: Sulphate

9/4-11/70

11/24-29/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

RELATIVE DISTANCE (in %)
Depth: 5m.: O-O
30m.: x-x-x

A - BUREAU RAFT  E - MINER'S COVE
B - VEGAS BAY   F - ECHO BAY
C - BEACON ISLAND  G - TEMPLE BAR
D - BONELLI LANDING  H - SOUTH COVE

Figure: B-16
APPENDIX C

Zooplankton Data
Relative Number of Zooplankton (in 35M Column)

Location: Las Vegas Wash
9/4-11/70

1/23-29/71

4/3-9/71

6/4-9/71

11/24-29/70

2/25-28/71

B - Bosmina
D - Daphnia
N - Nauplii
Ca - Calanoida
Cy - Cyclopoidea
K - Keratilla
R - Radiolaria
Ce - Ceratium

Figure: C-1
Location: Bureau Raft
9/4-11/70

1/23-29/71

4/3-9/71

B - Bosmina
D - Daphnia
N - Nauplii
Ca - Calanoida

Figure: C-2
Location: Beacon Island 9/4-11/70

11/24-29/70

B - Bosmina
D - Daphnia
N - Nauplii
Ca - Calanoida
Cy - Cyclopoida
K - Keratilla
R - Radiolaria
Ce - Ceratium

Figure: C-3
Location: Miner's Cove
9/4-11/70

B - Bosmina
D - Daphnia
N - Nauplii
Ca - Calanoida
Cy - Cyclopoida
K - Keratilla
R - Radiolaria
Ce - Ceratium

Figure: C-5
Relative Number of Zooplankton (in 35M Column)

Location: Echo Bay
9/4-11/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

B - Bosmina
D - Daphnia
N - Nauplii
Ca - Calanoida

Cy - Cyclopoida
K - Keratilla
R - Radiolaria
Ce - Ceratium

Figure: C-6
Relative Number of Zooplankton (in 35M Column)

Location: Temple Bar
9/4-11/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

B - Bosmina
D - Daphnia
N - Nauplii
Ca - Calanoida
Cy - Cyclopoida
K - Keratilla
R - Radiolaria
Ce - Ceratium

Figure: C-7
Location: South Cove
9/4-11/70

11/24-29/70

1/23-29/71

2/25-28/71

4/3-9/71

6/4-9/71

B - Bosmina
D - Daphnia
N - Nauplii
Ca - Calanoida
Cy - Cyclopoida
K - Keratilla
R - Radiolaria
Ce - Ceratium

Figure: C-8