

LAKE MEAD PREFERTILIZATION STUDY

Preliminary Nutrient Enhancement  
Studies in Lake Mead

Technical Report No. 19

Lake Mead Limnological Research Center  
Environmental Research Center  
University of Nevada, Las Vegas

by

Richard P. Axler, Larry J. Paulson  
Patrick J. Sollberger and Donald H. Baepler

**GCES OFFICE COPY  
DO NOT REMOVE!**

September 1987

Final Report to the  
U.S. Bureau of Reclamation  
(Contract No. 6-CP-30-04770, Part B)  
Larry J. Paulson, Principal Investigator

Revised November 1987

124.01  
ENV-4.00  
6192  
-21-

AQU 0437-19

## Table of Contents

	<u>Page</u>
List of Figures .....	iii
List of Tables .....	iv
ACKNOWLEDGEMENTS.....	vi
1.0 INTRODUCTION.....	1
1.1 Background.....	1
1.2 Objectives.....	5
2.0 STUDY SITE - LAKE MEAD.....	5
3.0 METHODS.....	9
4.0 RESULTS OF LABORATORY STUDIES.....	10
4.1 Fertilizer Leaching Experiments.....	10
4.1.1 Background.....	10
4.1.2 Methods.....	12
4.1.3 Results.....	14
4.2 Nutrient Enrichment Algal Bioassays.....	21
4.2.1 Background.....	21
4.2.2 Methods.....	22
4.2.3 Results.....	25
4.3 River Injection/Phosphate-Sediment-Adsorption Studies.....	29
4.3.1 Background.....	29
4.3.2 Methods.....	30
4.3.3 Results.....	31
5.0 RESULTS OF FIELD STUDIES.....	43
5.1 Background.....	43
5.2 Fertilizer and Cove Selection .....	44
5.2.1 Fertilizer Formulations.....	44
5.2.2 Cove Description.....	46
5.3 Pilot-Scale Test Methodology.....	47
5.3.1 Monitoring Methods.....	47
5.3.2 Fertilization Procedures.....	52
5.4 Results-Cathedral Cove Studies (PF I and PF II).....	53
5.4.1 Algal Biomass.....	55
5.4.2 Algal Growth.....	61
5.4.3 Water Clarity.....	82
5.4.4 Salinity Effects/Major Anions and Cations.....	85
5.4.5 Nutrients.....	89
6.0 CONCLUSIONS AND RECOMMENDATIONS.....	101
7.0 REFERENCES.....	104
8.0 ADDENDUM - THE 1987 OVERTON ARM FERTILIZATION.....	110

## LIST OF FIGURES

	<u>Page</u>
1. The Lake Mead food chain.....	4
2. Map of Lake Mead.....	6
3. N and P release from granular fertilizers.....	19
4. Nutrient enrichment bioassay #1, 4 July 1986.....	26
5. Nutrient enrichment bioassay #2, 25 July 1986.....	27
6. Map of upper Overton Arm-Virgin River Inflow.....	32
7. Temperature isotherms for upper basins of Lake Mead, March-June 1987.....	40
8. Cathedral Cove sampling stations.....	48
9. DIN depletion in Cathedral Cove and Lower Overton, 1986.....	49
10. Regression of chlorophyll- <u>a</u> on fluorescence.....	51
11. Cathedral Cove, PF I, chlorophyll- <u>a</u> .....	56
12. Cathedral Cove, PF II, chlorophyll- <u>a</u> .....	57
13. Cathedral Cove, PF I, temperature profiles.....	58
14. Cathedral Cove, PF I and II, phytoplankton biomass.....	78
15. Cathedral Cove, PF I and II, phytoplankton %-composition.....	79
16. Cathedral Cove, PF I, <sup>14</sup> C-primary productivity.....	80
17. Cathedral Cove, PF II, <sup>14</sup> C-primary productivity.....	81
18. Cathedral Cove, PF II, profiles of T, EC, ortho-P, ammonia-N and (nitrate + nitrite)-N.....	96
19. Cathedral Cove, PF I and II, Dissolved Inorganic-N.....	99
20. Cathedral Cove, PF I and II, ortho-phosphorus-P.....	100

## LIST OF TABLES

	<u>Page</u>
1. Trophic state classifications.....	2
2. Morphometric characteristics of Lake Mead.....	8
3. Summary of analytical procedures.....	11
4. Chemical characteristics of fertilizers.....	13
5. Fertilizer solutions used.....	15
6. Fertilizer leaching experiments, 5 and 15 minutes.....	17
7. Fertilizer leaching experiments, 30 and 120 minutes.....	18
8. Preliminary fertilizer leaching experiment, 16-20-0.....	20
9. Nutrient enrichment bioassays #1 and #2, nutrient uptake.....	28
10. Phosphate adsorption to Virgin River sediment.....	34
11. Temperature, EC and D.O. in the upper Overton Arm, May 14, 1987.....	35
12. Temperature, EC and D.O. in the upper Overton Arm, June 12, 1987.....	37
13. Limnological comparison of Cathedral Cove, L. Overton, Virgin Basin, and Boulder Basin surface water, June/July 1986.....	23, 47a
14. Summary of Cathedral Cove studies, PF I and PF II.....	54
15. Mean daily algal growth rates in nutrient enrichment bioassays #1 and #2, and in Cathedral Cove during PF I and PF II.....	60
16. Cathedral Cove phytoplankton enumerations, PF I, pre-fertilization.....	62
17. Cathedral Cove phytoplankton enumerations, PF I, post-fertilization.....	65
18. Cathedral Cove phytoplankton enumerations, PF II, pre-fertilization.....	70
19. Cathedral Cove phytoplankton enumerations, PF II, post-fertilization.....	73
20. Cathedral Cove, PF I and PF II, secchi depth.....	83

LIST OF TABLES (continued)

	<u>Page</u>
21. Cathedral Cove, PF I and PF II, vertical light extinction coefficients.....	84
22. Cathedral Cove, PF I and PF II, specific electrical conductivity (EC).....	86
23. Cathedral Cove, PF I and PF II, post-fertilization salinity (major anions and cations) analyses performed by U.S.B.R.....	87
24. Cathedral Cove, PF I and PF II, nutrient concentrations.....	90

## ACKNOWLEDGEMENTS

We thank Gordon Mueller of the Lower Colorado Region, U.S. Bureau of Reclamation for his assistance with this investigation. Mike Coffey of the Lake Mead National Recreation Area (NPS) arranged for aerial photography of Cathedral Cove and obtained cost estimates for dispersing liquid fertilizer by aircraft. Bill Burke (NPS) helped with a barge at Cathedral Cove, and Bob Clark (formerly of the Echo Bay Resort) provided storage space and forklift help for loading fertilizer drums onto the barge. John Hutchings of the Nevada Department of Wildlife and Jennifer Stephens-Haley of the UNLV Limnology Research Center contributed valuable advice and discussion throughout this study. Gail Ackerman, Leanna Cody, Betsy Dickes, Lisa Heki, and Sherrell Paulson performed laboratory chemical analyses and Larry Shepard, Leanna Cody, and Suzanne Leavitt assisted with field aspects of the study. Bob Morris of the Nevada Cooperative Extension Service was extremely helpful during the early stages of the project by locating information and fertilizer expertise. We also acknowledge the administrative wizardry of Pattie Baldwin, the accounting skills of Shirley Blackburn, the good spirits of Carol Forsythe, the accurate typing and proofing of Michele Salas and Leslie Gorr, and the help of Gina Strebek and her staff for printing this report. Study funded by the Bureau of Reclamation, Boulder City, Nevada. Contract No. 6-CP-30-04770, Part B.

## 1.0 INTRODUCTION

### 1.1 Background

Studies conducted by the University of Nevada-Las Vegas (UNLV), the Nevada Department of Wildlife (NDOW), the Arizona Game and Fish Department (AGFD), The Nevada Division of Environmental Protection (NDEP), and the United States Bureau of Reclamation (USBR) have identified decreased algal production as a major factor involved in the decline of the Lake Mead sport fishery. Phosphorus-laden silt particles in the Colorado River have been sedimenting out in Lake Powell since the completion of Glen Canyon Dam 286 miles upstream in 1963. This sharp decrease in phosphorus loading to Lake Mead (>5000 tons per year) has resulted in decreased biomass and growth at all levels of the food chain (2,5,11,29,31,33,34). Phosphorus loading to the lower basin (Boulder Basin) has decreased even further since 1981 when Clark County and the City of Las Vegas began removing phosphorus from wastewaters discharged into Las Vegas Bay.

Most of Lake Mead is now oligotrophic according to almost all of the trophic status indices which have been developed (Table 1). Only the inner and middle regions of Las Vegas Bay (treated wastewater influent), the Overton Arm upstream of Fish Island (Muddy and Virgin River discharges), and the Iceberg Canyon/Grand Wash area (Colorado River influence) have been found to have phosphorus levels sufficient to sustain relatively higher productivity (30,31,32). Phytoplankton production becomes tightly regulated by the supply of phosphorus during most of the growing season.

Table 1. Trophic state of Lake Mead during 1981/1982 and during the 1986 growing season relative to classification criteria found in the literature. Data from 1981/1982 based on area weighted monthly surface composites (0-5m) from all lake stations. 1986 data are averages based on monthly surface composites from May-September from Virgin Basin, three Overton Arm stations, and Gregg Basin. O= oligotrophic, M=mesotrophic, E=eutrophic. Total-P (TP) and chlorophyll-*a* in ppb, and secchi depth (transparency) in meters.

SOURCE	TP			CHLOROPHYLL			SECCHI		
	O	M	E	O	M	E	O	M	E
<u>Criteria(cite):</u>									
(1)	<12	12-25	>25	-	-	-	-	-	-
(8)	<12	12-24	>24	<2.5	2.5-6.5	>6.5	>4.0	2.0-4.0	<2.0
(13)	<15	15-25	>25	<3.0	3.0-7.0	>7.0	>4.0	2.5-4.0	<2.5
(35)	<10	10-20	>20	<2.0	2.0-6.0	>6.0	>4.6	2.7-4.6	<2.7
(38)	<10	10-20	>20	<7.0	7.0-12	>12	3.7	2.0-3.7	<2.0
(39)	<10	10-30	>30	0.3-3.0	2-15	10-500	-	-	-
<u>Lake Mead:</u>									
1981-1982	9			1.5			9.5		
1986	9.2			<2			~5		

Zooplankton graze on planktonic algae, and threadfin shad feed primarily on these zooplankton and phytoplankton. Since game fish feed primarily on either zooplankton or shad at different stages of their life cycle, it is clear how a nutrient limitation of phytoplankton growth can cascade up the food chain (Figure 1). The declines in the sport fisheries, particularly largemouth bass, striped bass and trout, began in the early 1960's and have become much more dramatic since the mid to late 1970's as evidenced by declines in total yields of largemouth bass and trout, and striped bass condition factors, and increased angler effort (2,5,29,31). It is likely that as fish were increasingly stressed by food shortages, conditions were worsened by indirect factors such as lack of suitable cover for littoral populations and by fish predation (2,16).

The only way to restore the previous fertility of the lake water is to add nutrients. Large-scale fertilization programs in British Columbia and Alaska have been very successful at stimulating the productivity of all levels of the food chain, ultimately producing more salmon (19,22,24,36,37). Nevada and Arizona completed an intensive study of the black bass (largemouth bass) fishery in Lake Mead in 1982 which was funded by the U.S. Bureau of Reclamation (USBR). A major recommendation was that pilot fertilizations be conducted as a demonstration project for future large-scale nutrient enrichment (2). UNLV subsequently submitted a proposal to the Bureau of Reclamation in November 1984 to artificially fertilize about 30,000 acres in the Overton Arm and about 11,000 acres in Gregg Basin. Since that time a technical advisory panel (the Lake Mead Nutrient Enhancement Technical Committee) comprised of representatives from UNLV, NDOW, AGFD, USBR, NDEP, the National Park Service (NPS), and the U.S. Fish and Wildlife Service (USFWS), was formed to review the original proposal and develop a feasible plan for implementing an experimental program of large-scale fertilization.

# THE LAKE MEAD FOOD CHAIN

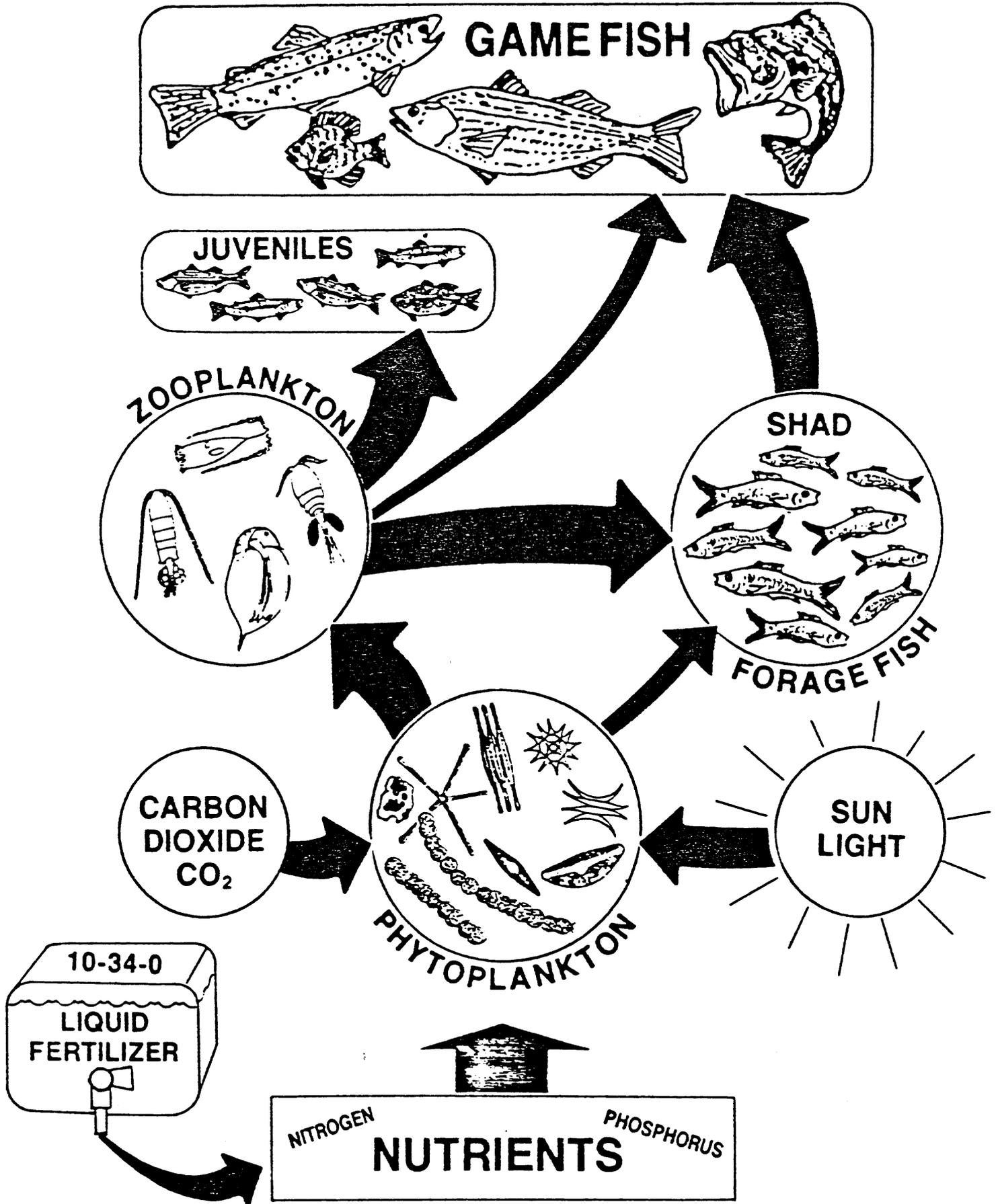


Figure 1.

Subsequently, the USBR funded the present study for 16 months (May 1986-August 1987) to conduct laboratory and pilot-scale field experiments designed to evaluate the potential for successfully stimulating algal growth on a large scale in Lake Mead using artificial fertilization.

## 1.2 Objectives

The principal goals were:

1. to determine the most suitable type(s) of fertilizer for large-scale additions to Lake Mead;
2. to evaluate methods of fertilizer application;
3. to make recommendations regarding the frequency of fertilizer applications.

## 2.0 STUDY SITE - LAKE MEAD

Lake Mead is located in the Mojave Desert of southeastern Nevada and northwestern Arizona 15 km northeast of Las Vegas, Nevada. The reservoir was formed in 1935 by construction of Hoover Dam. It extends 183 km from the mouth of the Grand Canyon (Pierce Ferry) to Black Canyon, the site of Hoover Dam (Figure 2). Lake Mead is comprised of four large basins: Boulder, Virgin, Temple, and Gregg Basins, interspersed with four narrow canyons: Black, Boulder, Virgin and Iceberg Canyons. The reservoir is bordered by the Muddy and Frenchman Mountains on the north and the Virgin and Black Mountains on the South.

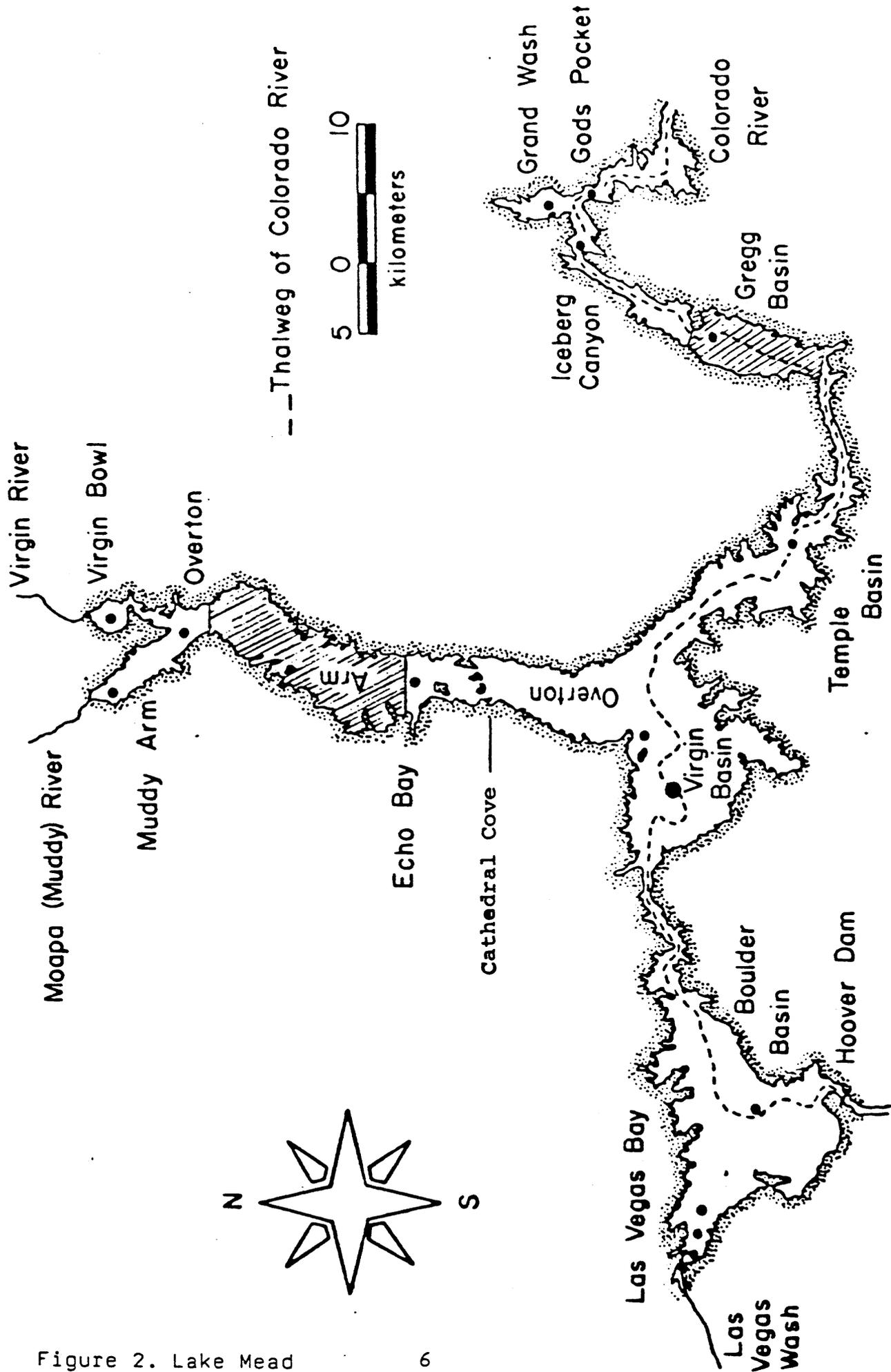


Figure 2. Lake Mead

In terms of volume, Lake Mead is the largest reservoir in the country and second only to Lake Powell in surface area. Shoreline development is irregular (SLD = 9.7) and includes several large bays (Las Vegas and Bonelli) and numerous coves. The reservoir has a short hydraulic retention rate (3-4 years) due to the great inflow from the Colorado River. The mean depth is 55 m (Table 2). The discharge from Hoover Dam is in the hypolimnion at 83 m depth (at operating level of 364 m).

The principal water inflow to Lake Mead is derived from the Colorado River (90%). The Virgin and Muddy Rivers, which discharge into the Overton Arm, and Las Vegas Wash, which discharges into Las Vegas Bay, also contribute year-round inflows. There is only one principal water diversion from Lake Mead. This is located at the Southern Nevada Water Project, Saddle Island, where municipal, irrigation, and industrial waters are diverted to the Las Vegas metropolitan area.

The water quality of the Colorado River and Lake Mead is alkaline (pH 7.6 - 8.3), and the TDS averages about 700 mg/l. The principal constituents of TDS are the anions sulfate > carbonate > chloride and cations sodium > calcium > magnesium > potassium. Total nitrogen concentrations are moderate (ca. < 0.2 - 0.5 mg/l), but total phosphorus is extremely low (ca. 0.010 mg/l) throughout the river. Silica is present in very high quantities (ca. 7-10 mg SiO<sub>2</sub> /l).

The predominant geological features of the Lake Mead floor and surrounding area are the sedimentary deposits of the Muddy Creek formation that were formed during the Paleozoic and Mesozoic eras (26). These deposits consist of moderately consolidated sand, silt and clay. There are also layers of shale, sandstone, and limestone interspersed with beds of gypsum, anhydrite, and rock salt (26). Deposition of fine silt material since formation of the reservoir has altered the original floor of Lake Mead. Up to

Table 2. Morphometric characteristics of Lake Mead (Paulson et. al. 1980)

Parameter	Lake Mead
Maximum operating level (m)	374.0
Maximum depth (m)	180.0
Mean depth (m)	55.0
Surface area (km <sup>2</sup> )	660.0
Volume (m <sup>3</sup> x 10 <sup>9</sup> )	36.0
Maximum length (km)	183.0
Maximum width (km)	28.0
Shoreline development*	9.7
Discharge depth (m)	83.0
Annual discharge (1977)(m <sup>3</sup> x 10 <sup>9</sup> )	9.3
Replacement time at maximum operating level (years)	3.9

\* Unitless parameter to measure regularity of shoreline, value of 1 is equivalent to a lake shaped in a perfect circle.

25 m of silt material was deposited in the upper reaches of the reservoir before Lake Powell was formed in 1963 (23).

The vegetation surrounding Lake Mead is comprised primarily of salt cedar (*Tamarix gallica*) and creosote bush (*Larrea tridentata*). Emergent macrophytes, such as cattails (*Typha sp*) and sedges (*Scirpus sp*), and submergent macrophytes, such as sago pondweed (*Potamogeton pectinatus*), curly leaf pondweed (*P. crispus*), and spiny naiad (*Najas marina*) were considered to be rare, and occur only in isolated coves prior to 1986. However, a project conducted by the UNLV Limnological Research Center in cooperation with the Nevada Department of Wildlife in 1986 and 1987 have indicated that aquatic plants are much more prevalent than previously believed. These intensive studies have censused shoreline terrestrial and aquatic communities seasonally, and evaluated factors controlling plant growth and their value as habitat for fish. The ultimate goal of the studies is to develop methodologies for enhancing these stands of vegetation to improve fish habitat (14,15,16).

The climate is arid with annual precipitation averaging about 8 cm. Mean annual temperature is about 19 degrees C with a range from 45 degrees C in the summer down to -1 degrees C in the winter. Winds are highly variable, but generally, southerly winds prevail in the summer compared to northeasterly winds in the winter.

### 3.0 METHODS

All nutrient analyses were performed according to the procedures outlined in the Lake Mead Limnological Research Center Methods Manual (21). Sampling protocols followed the routine field methods used for the Lake Mead/Lake Mohave/Lake Havasu Limnological Monitoring Program. Additional

details of each experiment will be described in the following individual results sections. Table 3 summarizes the routine methodologies used in this study.

#### 4.0 RESULTS OF LABORATORY STUDIES

##### 4.1 Fertilizer Leaching Experiments

###### 4.1.1 Background

These studies were conducted to determine the fertilizer(s) most suitable for use in a proposed large-scale test to be performed in the Overton Arm and Gregg Basin in Lake Mead. Although phosphorus levels have been shown to exert the greatest overall control of phytoplankton production in Lake Mead, levels of available nitrogen (dissolved inorganic nitrogen, DIN) in the euphotic zone typically are also depleted by late summer. At this time of year, it would be important to add nitrogen (N) as well as phosphorus (P) to stimulate algal growth (see Section 4.2).

A number of factors were considered prior to selecting fertilizer formulations, including: N and P content; potential to affect salinity, pH, or other chemical aspects of the lake water; solubility in water; public health aspects associated with direct or indirect contact; its chemical content aside from N and P; prior use in the environment; ease of handling, cost, availability, etc.

A total of eight commercial fertilizer formulations were tested for their nitrogen and phosphorus content and nutrient release characteristics. These included: two brands of diammonium phosphate (DAP or 18-46-0 in granular form); monoammonium phosphate (MAP or 11-53-0 in granular form); two

Table 3. Brief summary of analytical procedures used in the Pre-Fertilization Study. Full details and references can be found in the UNLV Lake Mead Limnological Research Center's methods manual (Kellar et al. 1981).

PARAMETER	METHOD
Nitrate + nitrite	hydrazine reduction / NED-sulfanilimide / colorimetry
Ammonia	phenol-hypochlorite / colorimetry
Total nitrogen	persulfate combustion (basic)
Orthophosphate	ascorbic acid- molybdenum blue / colorimetry
Total phosphorus	persulfate combustion (acidic)
Chlorophyll-a	trichromatic equations using 90% acetone extract ; <i>in vivo</i> fluorescence after correction for filtrate background fluorescence
Temperature, D.O., pH, EC	Hydrolab Water Quality Analyzer (calibrated daily )
Light intensity	Licor Quantum Sensor ( P.A.R. )
Phytoplankton primary productivity (PPr)	short-term radiotracer assays with $H^{14}CO_3$ at constant temperature and light
Alkalinity, DIC	titration with standardized acid
Phytoplankton identification and cell density	microscopy using <i>Utermohl</i> settling chambers

types of ammoniated phosphate/polyphosphate (LAP or APP or 10-34-0 in aqueous form); ammonium nitrate (AN or 34-0-0 in granular form); ammonium phosphate-sulfate (16-20-0); and monocalcium phosphate (triple superphosphate, 3\*-P, 0-46-0).

#### 4.1.2 Methods

The fertilizer chemical formulas and characteristics most relevant to this study are presented in Table 4. The triple designation refers to %N-%P<sub>2</sub>O<sub>5</sub>-%K. As an example, 18-46-0 contains 18% nitrogen, 46% phosphoric oxide and 0% potassium by weight. Note also that P<sub>2</sub>O<sub>5</sub> is only 44% phosphorus. All of the fertilizers were expected to be soluble in water in both the pure (reagent) and agriculture grades. Some of the formulations are acidic as 5% solutions, but these solutions are at least 7 orders of magnitude more concentrated than they would be after being mixed into the lake. The alkalinity of the lake water is also quite high (ca. 200 mg CaCO<sub>3</sub>/l) which would buffer pH changes unless enormous quantities of acid were added.

Two types of leaching experiments were performed. In the first, fertilizer granules were ground in a glass mortar and pestle to powder, and then "dissolved" in deionized water overnight using a magnetic stir plate. These stock solutions were then filtered and diluted for nutrient analyses and for use in nutrient enrichment bioassays (Section 4.2). Ammonium nitrate granules rapidly dissolved leaving no residue and so did not require powdering. The liquid formulations, 10-34-0, of course dissolved totally also. Both of the granular ammonium phosphate solutions contained a substantial particulate residue, even after a week of stirring and over a month on the shelf at room temperature.

The second set of leaching experiments was set up by adding whole granules to filtered lake water, shaking for specified time intervals, and

Table 4. Chemical characteristics of selected fertilizers, as pure reagents (from CRC Handbook of Chemistry and Physics) and as fertilizer formulations (from Farm Chemicals Handbook, 1986). Relative acidity data listed in reagent specifications in 1986 Fisher Scientific Company Catalogue.

FERTILIZER	CHEMICAL FORMULA	SOLUBILITY (grams/100 mL water)		RELATIVE ACIDITY (pH of a 5% solution)
		REAGENT GRADE	FORMULATION	
Diammonium phosphate (18-46-0, DAP)	$(\text{NH}_4)_2\text{HPO}_4$	57.5 @ 10°C	25 @ 0°C	7.7-8.1
Monoammonium phosphate (11-53-0, MAP)	$\text{NH}_4\text{H}_2\text{PO}_4$	22.7 @ 0°C	43 @ 0°C	3.8-4.4
Monocalcium phosphate (0-46-0, triple superphosphate)	$\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	1.8 @ 30°C	decomposes in water and is very soluble	neutral
Ammonium phosphate sulfate (16-20-0, 14% sulfate)	DAP + MAP + $(\text{NH}_4)_2\text{SO}_4$	above above 70.6 @ 0°C	above above 71 @ 0°C	above above 5-6
Ammonium nitrate (34-0-0, AN)	$\text{NH}_4\text{NO}_3$	118.3 @ 0°C	118 @ 0°C	4.5-6
Liquid ammonium polyphosphate (10-34-0, APP or LAP)	mixture	aqueous solution highly soluble		5.8-6.1 (undiluted)

then analyzing for N and P, pH and electrical conductivity (in order to estimate potential salinity effects). DAP, MAP and triple superphosphate (abbreviated as 3°-P) granules were added to 500 mls of filtered surface water collected from Boulder Basin in late June, 1986. Final concentrations were all set at 500 ppm of fertilizer by adding 10-20 granules to duplicate mason jars. Temperature was controlled at 25 degrees C (typical of the epilimnion in the late spring and summer) and the jars were shaken gently at 150 rpm for 5-120 minutes. This level of agitation is probably gentler than the turbulence created by being dragged in a porous bag behind a boat-a potential large-scale application procedure at this point in time.

Chemical analyses were performed on subsamples of the initial lake water and on 1:500 dilutions of the leachate filtrate. After processing the nutrient aliquots, an aliquot from each jar was removed for pH measurement and then the remaining solution was used for electrical conductivity (EC) measurements. The pH probe was standardized with pH 6.0 and 9.0 buffers and the EC probe (YSI 33 S-C-T meter) was checked against 100 and 1000 micromho/cm KCl solutions and compensated for temperature.

#### 4.1.3 Results

Table 5 summarizes the stock solutions and includes their predicted concentrations, based on the manufacturer's nominal formula, and the measured N and P concentrations. It can be seen that:

\* All of the nominal ammonia-N (NH<sub>3</sub>-N) and orthophosphorus-P (PO<sub>4</sub>-P) content of the two granular ammonium superphosphates (DAP and MAP) were solubilized from powdered samples.

\* All of the expected ammonia was recovered from the liquid ammonium polyphosphate (10-34-0) formulation but only about half of the phosphorus was present as orthophosphate. All of the "nominal" phosphorus was recovered, the balance being found in the dissolved pool apparently as biologically available

Table 5. Fertilizer solutions used in Pre-Fertilization Study. Granular formulations were ground to powder using a glass mortar and pestle and mixed with deionized water to prepare stock solutions for testing total nutrient content and algal growth potential. Solutions were filtered prior to use and diluted prior to nutrient analysis.

FERTILIZER	NOMINAL N,P	MEASURED (% NOMINAL)
18-46-0 (DAF) granular J. Brown, Inc.	10 ppm P, 9 ppm N	9.7 ppm PO <sub>4</sub> -P (97%) 8.9 ppm NH <sub>3</sub> -N (99%)
11-53-0 (MAP) granular J. Brown, Inc.	200 ppm P, 95 ppm N	186/193 ppm PO <sub>4</sub> -P (95%) 200/203 ppm DP (100%) 95 ppm NH <sub>3</sub> -N (103%)
10-34-0 (LAP, green) liquid J. Brown, Inc.	10.2 ppm P, 6.8 ppm N	4.3/4.8 ppm PO <sub>4</sub> -P (44%) 6.7 ppm NH <sub>3</sub> -N (98%)
10-34-0 (LAP, green) liquid J. Brown, Inc.	204 ppm P, 137 ppm N	99/104 ppm PO <sub>4</sub> -P (50%) 214 ppm DP (105%) 139 ppm NH <sub>3</sub> -N (102%)
10-34-0 (LAP, white) liquid Turf Equipment, Inc.	204 ppm P, 137 ppm N	120/127 ppm PO <sub>4</sub> -P (61%) 205 ppm DP (100%) 139 ppm NH <sub>3</sub> -N (102%)
34-0-0 (AN) unground granules Turf Equipment, Inc.	25 ppm NH <sub>3</sub> -N 25 ppm NO <sub>3</sub> -N	27.3 ppm NH <sub>3</sub> -N (109%) 25.4 ppm NO <sub>3</sub> -N (101%)
Ammonium Nitrate (Reagent grade)	25 ppm NH <sub>3</sub> -N 25 ppm NO <sub>3</sub> -N	26.1 ppm NH <sub>3</sub> -N (104%) 24.6 ppm NO <sub>3</sub> -N (98%)
Monopotassium phosphate (Reagent grade)	10 ppm PO <sub>4</sub> -P	10.2 ppm PO <sub>4</sub> -P (102%)

polyphosphates (7, discussions with several fertilizer companies). We have subsequently discovered that these polyphosphates are rapidly hydrolyzed to orthophosphate in the lake or even by exposure to well-oxygenated water in moderately concentrated stock solutions (~10 ppm P) sitting in the refrigerator for several weeks.

\* The yield of ortho-P in "white" liquid 10-34-0 was somewhat higher than in the less pure "green" form. The green color is due to metal impurities and so the white form was chosen for further field evaluations (see Section 5).

\* No significant difference in ammonium or nitrate concentration was found between the reagent and fertilizer grades of ammonium nitrate.

Tables 6 and 7 and Figure 3 summarize the granule-leaching experiments. Experiment FT-3 was also designed to compare the same nominal 18-46-0 (DAP) fertilizer from independent fertilizer companies. Table 8 summarizes a series of pilot experiments conducted from February-April, 1986, prior to the start of this study. Ammonium phosphate-sulfate (16-20-0) was added to 100 mls of distilled water or tap (derived from Lake Mead) water as powder or granules. Fertilizer concentrations ranged from 10-185 ppm.

Our principal conclusions from all of these leaching experiments are:

1. The phosphorus in all of the granular ammonium phosphate mixes was predominantly present as orthophosphate - the most biologically available form for phytoplankton growth.

2. Most of the orthophosphorus and ammonium release occurred within 15-30 minutes (~80% of nominal-P and ~90% of nominal-N) for all the experiments combined.

3. The DAP (18-46-0) available from Turf Equipment, Inc. (Las Vegas, NV) leached ortho-P and  $\text{NH}_3\text{-N}$  slightly faster than the fertilizer obtained from Jack Brown, Inc. (Alpaugh, CA).

Table 6. Fertilizer Leaching Experiments (N and P)

FT-3 (24 July 86) 500 ppm fertilizer				
	<u>5-6 minutes</u>		<u>15-16 minutes</u>	
	<u>ortho-P</u>	<u>NH<sub>3</sub>-N</u>	<u>ortho-P</u>	<u>NH<sub>3</sub>-N</u>
DAP - J. Brown, Inc. (18-46-0) P=100, N=90 ppm	53.0 ppm P <u>(53%)</u>	45.2 ppm N <u>(50%)</u>	72.1 ppm P <u>(72%)</u>	67.6 ppm N <u>(75%)</u>
DAP* - Turf Equipment (18-46-0) P=100, N=90 ppm	58.4 <u>(58%)</u>	55.4 <u>(62%)</u>	85.8 <u>(86%)</u>	91.8 <u>(102%)</u>

Table 7. Fertilizer Leaching Experiments (N and P)

	FT-1 (10 July 86) 500 ppm fertilizer		FT-2 (20 July 86) 500 ppm fertilizer					
	30 min		30 min			120 min		
	<u>ortho-P</u>	<u>NH<sub>3</sub>-N</u>	<u>OP</u>	<u>DP</u>	<u>NH<sub>3</sub>-N</u>	<u>OP</u>	<u>DP</u>	<u>NH<sub>3</sub>-N</u>
DAP (18-46-0) J. Brown, Inc. P,N=(100, 90 ppm)	83 ppm P (83%)	4-24 ppm N (4-27%)	80.9 (81%)	76.5 (76%)	79.6 (88%)	76.3 (76%)	72.5 (72%)	88.6 (98%)
MAP (11-53-0) J. Brown, Inc. P,N=(116, 55 ppm)	99 ppm P (85%)	18 ppm N (34%)	96.3 (83%)	92.1 (79%)	53.0 (96%)	100.8 (87%)	95.9 (83%)	56.5 (103%)
3 <sup>0</sup> -P (0-46-0) J. Brown, Inc. P=(100 ppm P)	75 ppm P (75%)	—	80.5 (80%)	77.5 (77%)	<0.1 (<1%)	83.4 (83%)	79.6 (80%)	<0.1 (<1%)

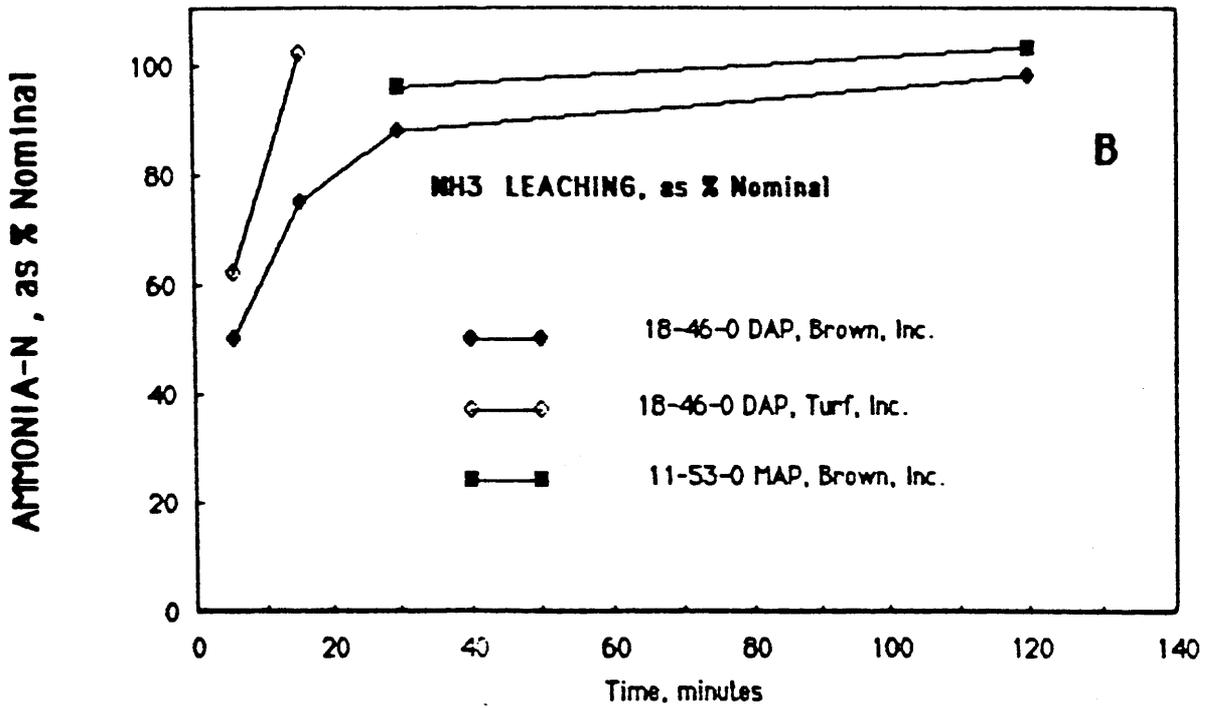
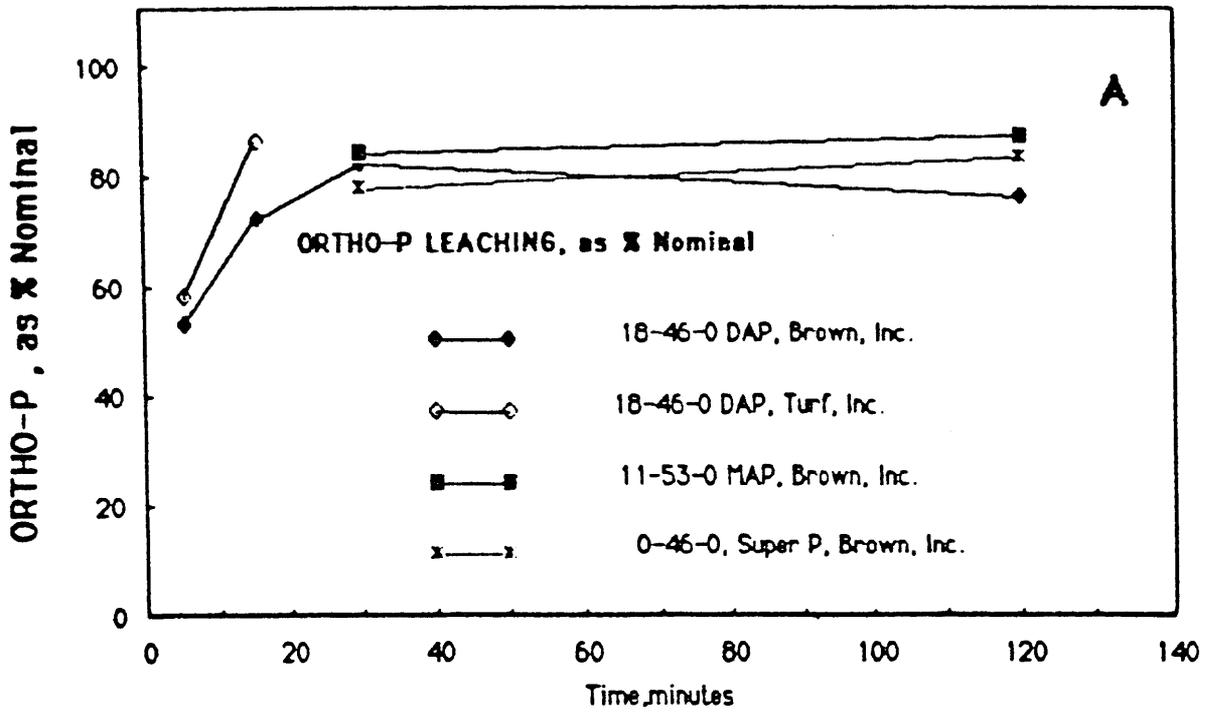


Figure 3. Time course of orthophosphate-P and ammonia-N release from fertilizer granules. Values expressed as % of nominal concentrations from Tables 6 and 7. Filtered Lake Mead surface water from Boulder Basin was used in these leaching experiments.

Table 8. Summary of preliminary fertilizer leaching experiments performed from February - April 1986 by L. Heki. Formulation was a 16-20-0 (ammonium phosphate-sulfate) mix in granular form. PWDR signifies that granules were ground to a coarse powder. The fertilizer was mixed on a shaker table at 150 rpm at 25°C for a set time period. %-Recovery is based on the manufacturers nominal formulation. DDW=double distilled water, TAP=tap (treated Lake Mead) water.

TREATMENT	FERTILIZER CONCENTRATION (ppm)	TIME (mins)	% - RECOVERY	
			ortho-P	ammonia-N
PWDR, DDW, pH5.5	10-50	30	85	---
PWDR, TAP, pH7.5	20-60	30 P; 2-6 N	87	85
PWDR, DDW, pH8-9.5	20-60	30 P; 6 N	83	96
PWDR, DDW, pH5.5	20-60	2-10	70%	93%
GRANULES, DDW, pH5.5	35-185	2	51	50
GRANULES, DDW, pH5.5	35-185	6	77	85

4. A residue was noted in all of the jars even after sitting for a week after the experiment with periodic vigorous shaking. This material is quite insoluble and is likely to be biologically inert and comprised of clay and calcium sulfate (gypsum) byproducts from the superphosphate production (7).

We also found that fertilizer additions to the lake to enrich the epilimnion by about 20 ppbP and up to 200 ppbN using combinations of the fertilizers tested, would not have a detectable effect on pH and salinity. No measurable change in pH or EC was found in 1:100 dilutions of the granule leachates, which are about 50 times more concentrated than the proposed large-scale lake fertilization.

#### 4.2 Nutrient Enrichment Algal Bioassays

##### 4.2.1 Background

These experiments were performed using natural phytoplankton communities from Lake Mead to test for algal growth responses as a function of various nutrient and fertilizer enrichments.

Previous limnological studies pointed to the importance of low levels of available phosphorus in regulating primary productivity (algal growth) in the main lake basins. However, phytoplankton algae also require available nitrogen (principally as nitrate or ammonium) in a ratio of ~5-15:1 (N:P, by weight) to maintain a balanced nutrition. This range of inorganic N:P ratio is typical of a wide variety of aquatic ecosystems (13,17,39). Nutrient enrichment bioassay experiments conducted in 1979-1980 as part of the Las Vegas Valley Water Quality Standards Study (6, Appendix C) demonstrated that an (inorganic-N):(inorganic-P) ratio of about 10:1 represented a balanced N and P nutrition for Lake Mead phytoplankton. Ratios much higher coincided

with periods of P-limited algal growth, and ratios much lower led to N-limitation.

The above discussion necessitates that decisions regarding the fertilization of the upper basins of Lake Mead must consider the inorganic nitrogen concentrations in addition to the phosphate level. An injection of phosphorus alone, in the absence of sufficient available nitrogen, might not produce the desired increase in algal biomass due to the ensuing N-limitation. Such an effect is less likely to occur in the spring when nitrate concentrations are maximal (150-200 ppbN), and more likely to occur as the summer progresses and phytoplankton uptake depletes the nitrate pool (levels were already < 25 ppbN by late July, 1986 in the lower basin, Paulson unpublished data submitted to USBR).

Two experiments were conducted in order to test for the algae growth potential of various fertilizer mixes relative to additions of reagent-grade N and P, and also to estimate the potential biomass yield likely to occur at Cathedral Cove (see Section 5) after fertilization. The assays were performed in early and late July using an epilimnetic composite collected from Boulder Basin (USBR station LM02). This water was collected because of its convenient location and because its characteristics were similar to those of Cathedral Cove. (Table 13).

#### 4.2.2 Methods

Experiments were conducted according to the same protocols as were used in the 1979-1980 bioassays conducted by UNLV and Ecological Research Associates (Davis, CA) for the Water Quality Standards Study in Las Vegas Bay (6). Briefly, the experiments involve enriching subsamples of water with nutrients and then estimating algae growth by measuring in-vivo fluorescence

Table 13. Limnological comparison of Cathedral Cove with Lower Overton Arm, Virgin Basin and Boulder Basin. Nutrient and chlorophyll data measured from 0-5 meter integrated composites and are expressed as  $\mu\text{g/l}$  (ppb). LM site numbers refer to designated stations from the 1986-1987 Lake Mead Monitoring Study funded by USBR.

PARAMETER LM (SITE #)	CATHEDRAL COVE		L. OVERTON	VIRGIN BASIN	BOULDER BASIN
	INNER (19a)	OUTER (19c)	(18)	(08)	(02)
JUNE 1986:					
chlorophyll-a	1.1	1.0	1.6	1.8	1.7
ortho-P	4	4	4	7	5
Total-P	6	6	10	16	7
$\text{NH}_3\text{-N}$	15	17	14	17	15
$\text{NO}_3\text{-N}$	114	107	98	108	131
Total-N	330	384	346	319	330
secchi (m)	5.5	5.3	5.7	5.5	5.0
temp (0-10m)	24.9 $\pm$ 0.9	24.6 $\pm$ 1.3	23.8 $\pm$ 0.8	23.5 $\pm$ 1.3	24.2 $\pm$ 1.0
thermocline	mixed	10-11m	11-12m	9-10m	11-12m
JULY 1986:					
chlorophyll-a	2.1	2.1	2.6	2.5	3.5
ortho-P	2	3	3	2	2
Total-P	9	5	6	5	6
$\text{NH}_3\text{-N}$	8	13	8	8	8
$\text{NO}_3\text{-N}$	42	43	46	50	50
Total-N	243	236	276	267	296
secchi (m)	5.5	6.0	6.7	6.5	5.2
temp (0-10m)	26.4 $\pm$ 0.1	26.3 $\pm$ 0.2	26.5 $\pm$ 0.1	26.1 $\pm$ 0.2	25.2 $\pm$ 0.1
thermocline	mixed	12-13m	11-12m	14-15m	12-14m

to estimate chlorophyll-a and algal biomass. We apportioned 1 liter aliquots of water from a 5 gallon carboy into 1 quart plastic containers and then added nutrients as small volumes (<5ml) of more concentrated stock solutions (see Table 5). Treatments were set up in duplicate and no-enrichment controls were triplicated. The samples were incubated outdoors in a small swimming pool where they floated just below the water surface. Two layers of fishing seines over the pool were used to prevent "light shock" and overheating. Temperatures ranged from about 25-29 degrees C and were typically 27 degrees C in mid-afternoon when fluorescence was measured. The light intensity at the same time inside the container at the water surface was estimated to be about 160 microeinsteins/m<sup>2</sup>/sec using a quantum photometer. This corresponds to about 15% of surface irradiance, or a depth of 5-6 meters (mid-epilimnion) in the lake at this time of year.

Chlorophyll fluorescence was estimated using a Turner-111 fluorometer set up with a red-sensitive photomultiplier, high sensitivity door, blue fluorescent lamp (F4T54B) emitting light through a blue primary filter (CS5-60) and receiving emissions through a red (CS2-64) secondary filter. The instrument was zeroed against deionized water before every treatment set and a treatment composite filtrate was measured to correct for non-chlorophyllous fluorescence (dissolved organic matter, primarily). Scale conversion factors were directly determined using filtered chlorophyll solutions extracted from grass in 90 % acetone. All values for an experiment were corrected for filtrate fluorescence and converted to arbitrary units from the same scale (10X for bioassay #1, and 3X for bioassay #2). Subsamples for nutrient concentrations and spectrophotometric determination of chlorophyll-a were taken at the beginning and end of each experiment.

#### 4.2.3 Results

Data are presented in Figures 4 and 5 and in Table 9. Chlorophyll was estimated using the regression equation for parallel sets of extracted chlorophyll-a and in-vivo fluorescence values measured during the Cathedral Cove pilot studies (see Section 5). Conclusions which were made based on these experiments include:

1. Algae growth was nutrient limited. The lack of growth or significant dissolved inorganic-N (DIN) uptake in the low phosphorus controls suggests severe P-deficiency.

2. Additions of orthophosphate stimulated algae growth and DIN uptake.

3. Enrichment with 20 ppbP and about 110 ppbN caused a 3X increase in algae biomass in Bioassay-1 (ambient OP was 2 ppbP and DIN was 98 ppbN) and a 4-5X fluorescence increase in Bioassay-2 (ambient OP was 1 ppbP and DIN was 86 ppbN) after 5 days. A 30 ppbP + 187 ppbN enrichment (includes DAP-N) in Bioassay-2 increased algal fluorescence by over 800% (9X).

4. Fertilizer phosphorus additions produced similar biomass yields to reagent-grade phosphate enrichments. Further, there was no significant difference between liquid fertilizer and solid fertilizer responses, despite the fact that about 50% of the liquid-P was in the form of polyphosphate (initially), not orthophosphate. This suggests that the polyphosphate fraction is readily available for microbial uptake.

5. A deficiency of nitrogen prevented some P-enriched samples from reaching their maximum algal yield. This occurred because accelerated algae growth and N-uptake depleted the pool of ambient DIN in the water. Greater yields were achieved when samples were also enriched with DIN. We expect that N-deficiency would be very unlikely in the spring when DIN levels are still high in the epilimnion, but that an N and P co-limitation would be probable in

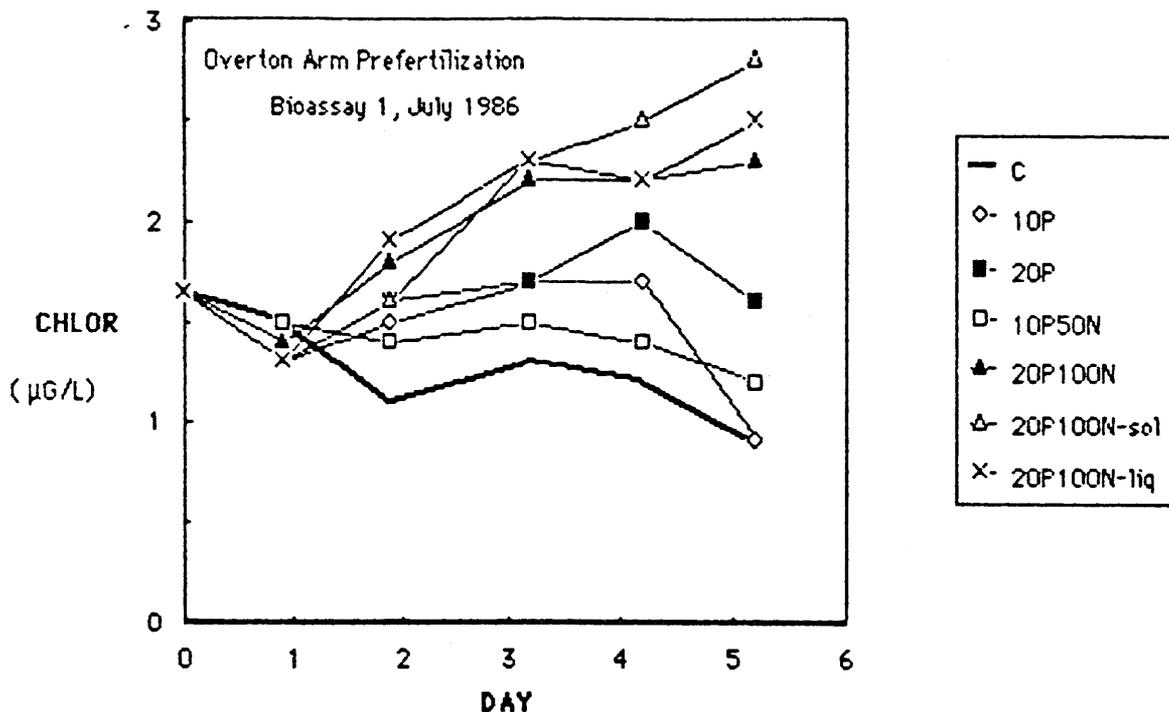


Figure 4. Nutrient enrichment algal bioassay #1, July 4, 1986. Potential phytoplankton responses to fertilization were determined using: 10 and 20 ppbP enrichments with reagent grade potassium phosphate; 10 ppbP + 50 ppbN with reagent grade potassium phosphate and ammonium nitrate; 20 ppbP + 100 ppbN with reagent grade potassium phosphate and ammonium nitrate; 20 ppbP + 100 ppbN with granular diammonium phosphate (18-46-0 formulation) and ammonium nitrate (34-0-0 formulation) fertilizers, labelled *sol*; and 20 ppbP + 100 ppbN with liquid ammonium polyphosphate (10-34-0, white) and granular ammonium nitrate (34-0-0) fertilizers, labelled *liq*. Daily chlorophyll fluorescence measurements were corrected for filtrate fluorescence and converted to chlorophyll estimates using the regression equation from Figure 9. Initial levels of P and N were 2 ppb ortho-P (6 ppb TP) and 98 ppb DIN.

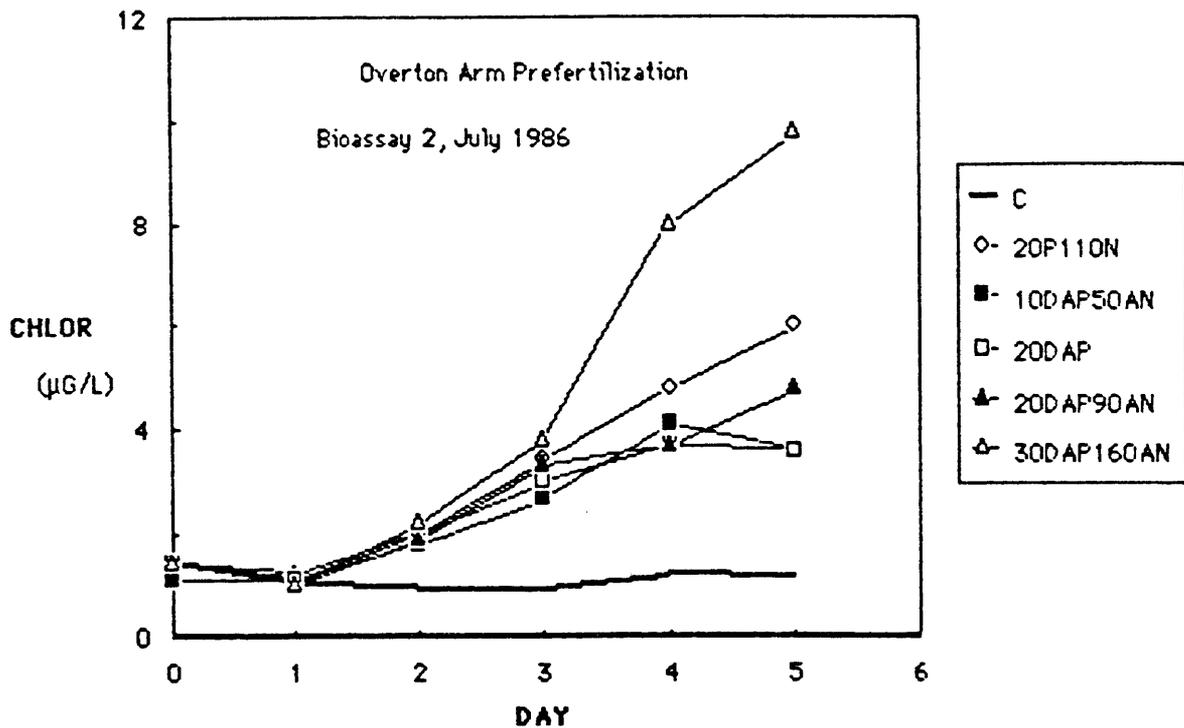


Figure 5. Nutrient enrichment algal bioassay # 2, July 25, 1986. Potential phytoplankton responses were determined using: 20 ppbP + 110 ppbN enrichments with reagent grade potassium phosphate and ammonium nitrate; and 10 ppbP + 50 ppbN, 20 ppbP, 20 ppbP + 90 ppbN, and 30 ppbP + 160 ppbN enrichments with mixtures of the granular fertilizers diammonium phosphate (DAP, 18-46-0) and ammonium nitrate (AN, 34-0-0). Daily chlorophyll fluorescence measurements were corrected for filtrate fluorescence and converted to chlorophyll estimates using the regression equation from Figure 9. Initial levels of P and N were 1 ppb ortho-P (8 ppb TP) and 86 ppb DIN.

Table 9. Nutrient levels ( in  $\mu\text{g/L}$  or ppb ) and calculated rates of P and N uptake ( $U_N$  and  $U_P$  , in  $\mu\text{g/L/day}$ ) in Lake Mead Bioassays 1 and 2. OP is orthophosphate and DIN is dissolved inorganic nitrogen (nitrate + nitrite + ammonium ). Water was collected as 0-5 meter vertical composites. Ambient concentrations were 2 ppb OP and 98 ppb DIN for Bioassay 1, and 1 ppb OP and 86 ppb DIN for Bioassay 2.

TREATMENT	INITIAL (Day 0)		FINAL (Day 5)		$U_P$	$U_N$
	OP	N	OP	N		
<u>Bioassay 1:</u>						
Control	2	95	2	82	0	2.6
10P	12	93	2	45	2.0	9.6
20 P	22	94	2	24	4.0	14.0
10P 50N	12	143	2	74	2.0	13.8
20P 100N	22	185	3	103	3.8	17.0
20DAP 100N	22	200	3	103	3.8	19.4
20LAP 100N	22	197	4	91	3.6	21.2
<u>Bioassay 2:</u>						
Control	1	52	1	63	0	~0
20P 110	18	139	1	20	3.4	23.8
10DAP 50AN	8	98	2	60	1.2	7.6
20DAP	17	66	3	9	2.8	11.4
20DAP 90AN	16	150	1	34	3.0	23.2
30DAP 160AN	24	226	3	13	4.2	42.6

mid-late summer when ambient levels of DIN are lowest (often near detection limits of  $\sim 10$  ppbN). Such an effect would be "hastened" by P-enrichment alone. The greatest biomass accumulations per unit of P-addition occurred when the cultures initially had a nutritionally balanced ratio of available N and P ( $\sim 10:1$ ).

#### 4.3 Phosphate Adsorption to Suspended Sediment and River Injection Studies

##### 4.3.1 Background

Direct addition of fertilizer to river inflows to Lake Mead has been suggested as a method for uniformly dispersing fertilizer nutrients into target areas. Only the Virgin and Colorado Rivers have sufficient late-spring and summer flows to be potentially useful. Consequently, a preliminary investigation was conducted to evaluate river injection as a means of fertilizer application.

The most important questions which needed to be addressed are :

- \* where do the river waters flow, once they enter Lake Mead, and
- \* how would interactions between the fertilizer and other constituents in the water affect the fertilizing potential of the application.

We attempted to provide at least preliminary answers to these questions in the following ways by:

- \* examining historical patterns of river flow during spring and summer using temperature and electrical conductivity (EC) profiles determined at Lake Mead monitoring stations,
- \* examining thermographs of Colorado and Virgin River water temperature set in place and maintained by USBR in 1987,
- \* collecting temperature, EC, and D.O. profiles in the Virgin River

inflow area, Virgin Bowl, mouth of Virgin Bowl, and up-lake at Columbine Falls and Iceberg Canyon where the Colorado River enters Lake Mead, and

\* conducting a series of adsorption experiments in the laboratory to help assess the potential for phosphate fertilizer adsorbing to river-borne silts and clays.

#### 4.3.2 Methods

The USBR installed Peabody-Ryan recording thermographs in the Virgin River 5.3 miles downstream from the Riverside Bridge, 0.5 m deep in swift water and in the Colorado River 1.5 miles upstream of the Bat Caves, 1.5 m deep in swift water. Both thermographs were in operation from February 1987 to mid-June 1987.

Sediment adsorption experiments were performed by measuring the disappearance of fertilizer orthophosphate from solution as a function of suspended sediment levels. A grab sample of surficial sediment was collected in ~1 meter depth water, approximately 200 meters from the Virgin River inflow to Lake Mead in mid-April 1987. The mud was reddish brown, was (qualitatively) a mixture of clay and silts with some fine sand, and had a dry residue of 73% @ 105 degrees C. The water in this region was extremely turbid and bottom sediment was easily resuspended by even gentle disturbances.

Experiments were initiated by resuspending known amounts of dried sediment (60 degrees C) into 50 ml volumes of GF/C-filtered surface water collected from the lower Overton Arm (USBR monitoring station LM18) in mid-April 1987. Pre-weighed, powdered, sediments were added to the water in 125 ml flasks. The assay was initiated by inoculating each flask with 0.5 ml of a 10 ppm P stock solution of liquid ammonium polyphosphate (10-34-0, white) fertilizer (see Table 5). Each sediment level was run in duplicate and the total range was 0-10,000 ppm total suspended sediment (TSS) in order to span a

wide range of possible field conditions. Samples were agitated gently at 150 rpm on a shaker table at room temperature (~25 degrees C) for 42-46 hours.

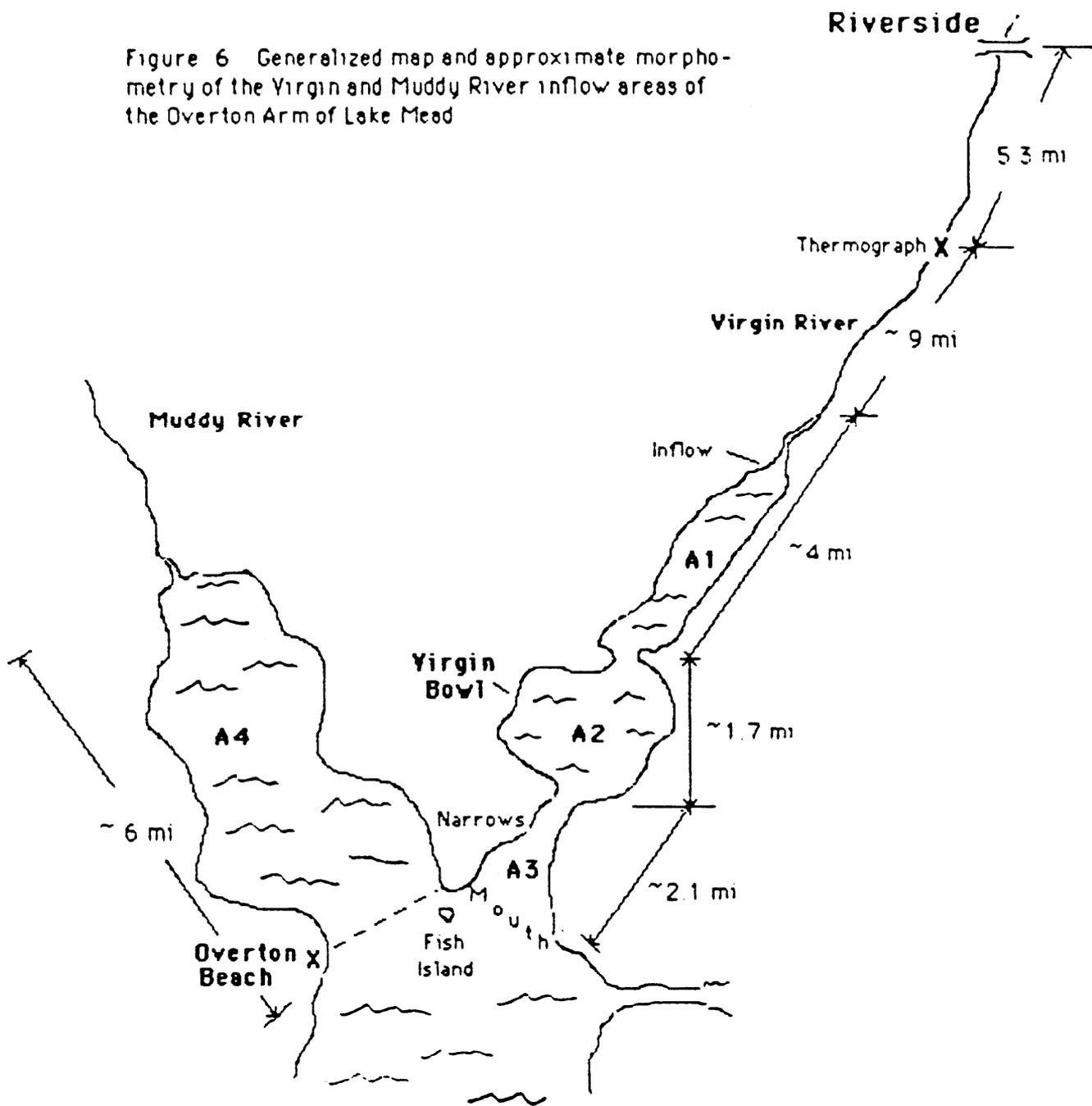
### 4.3.3 Results

#### 4.3.3.1 Virgin River

The Virgin River channel is schematically shown in Figure 6. Flows are quite variable in the spring, ranging from a mean daily value of 85 cfs to almost 2000 cfs in the previous 10 year period (USGS data). Discharge depends on mountain snowmelt runoff and rainstorms in addition to agricultural diversions upstream from the USGS gauging station at Riverside. The river is typically quite turbid during this time of year. Bottom sediments are very fine and easily resuspended in the area where the river broadens and slows as it enters the lake.

Therefore, it is reasonable to expect that there would be a relatively high degree of contact between the river water and suspended or bottom sediments. When flows are low, there is higher bottom sediment contact per unit volume in the inflow and Virgin Bowl areas (A1 and A2 in Figure 6). Estimated residence times in this "high turbidity" zone were about four days in May and 14 days in June for Area 1 assuming median 10-year flows for these months (USGS data for station 09415230, Halfway Wash near Riverside, NV and station 09415000 at Littlefield, AZ). The turnover times for median May and June flows for the Virgin Bowl and Narrows (connecting the bowl and lake) are considerably longer (several weeks to months). Although higher river flows would result in a shorter transit time for this water to reach the lake

Figure 6 Generalized map and approximate morphometry of the Virgin and Muddy River inflow areas of the Overton Arm of Lake Mead



**APPROXIMATE MORPHOMETRIC FEATURES**

	<b>AREA (acres)</b>	<b>DEPTH (max, feet)</b>	<b>VOLUME (max, acre-feet)</b>
<b>A1</b>	1400	2	2800
<b>A2</b>	1700	34	57,800
<b>A3</b>	750	43	32,250
<b>A4</b>	4800	40	192,000

proper, (and less contact time with bottom sediments), suspended sediment concentrations would probably be much higher.

Table 10 presents the results of the sediment-phosphate adsorption experiments conducted using Area #1 bottom sediments. It can be seen that TSS levels of about 1000 ppm, which are probably not exceptionally high for the inflow region, can potentially scavenge approximately 10 ppb of orthophosphate. This is about 50% of the target P-concentration for large-scale fertilization. We realize that these experiments only provide first order estimates of the actual chemical exchange processes that would actually occur. The exchange chemistry of aquatic sediments is extremely complicated and relatively poorly understood (27). Sediment types are likely to vary seasonally with flow as will the major ionic composition of the river water. Mayer and Gloss (1980) found that phosphate adsorption/desorption kinetics were in part regulated by absolute values of phosphate and silicate in addition to their molar ratio in the Colorado River and in Lake Powell. A more thorough evaluation of these processes may be warranted in the future, but is beyond the scope of the current study.

We attempted to trace the passage of Virgin River water through the inflow, Virgin Bowl and Narrows areas by examining the vertical profiles of data collected using a Hydrolab Water Quality Analyzer in the period March - June 1987. A density current associated with the river was not identifiable until the mid-May sampling (Table 11). At this time, a plume of higher density water, presumably due to high levels of suspended sediment, was apparent just off the bottom at 10 m depth in the Virgin Bowl. It was clearly evident at the Narrows station as a stratum of relatively high conductivity, low dissolved oxygen water between 10 m and the bottom at 12.5 meters depth. The data from station LM19a, at Fish Island suggest the presence of the plume

Table 10. Adsorption of fertilizer phosphate to muddy surficial sediment near the Virgin River inflow to Lake Mead.  $\Delta$ OP is the measured change in orthophosphate during the assay after 42-46 hours of exposure to different concentrations of suspended sediment (TSS). Phosphate was added as liquid ammonium polyphosphate, 10-34-0 white, the formulation recommended for large scale fertilization.

TSS (ppmD.W.)	Initial OP (ppbP)	Final OP (ppbP)	$\Delta$ OP (ppbP)	$\Delta$ OP / TSS (ppbP / ppm D.W.)
0	99.8	99.8	0 (assumed)	--
200	96.0	92.5	3.5	$17.5 \times 10^{-3}$
500	99.8	95.1	4.7	9.4 "
1000	99.8	90.5	9.3	9.3 "
1000	96.0	82.5	13.5	13.5 "
3000	99.8	83.4	16.4	5.5 "
10000	99.8	55.0	44.8	4.5 "

Regression Equation:  $\Delta$ OP = a [ TSS ] + b , where n=7 ,  $r^2 = 0.96$  ,

$$a = 4.16 \times 10^{-3} \text{ ppbP/ppm TSS} , b = 3.85 \text{ ppbP}$$

Table 11. Vertical profiles of temperature (°C) , dissolved oxygen (ppm D.O.) , and electrical conductivity (µmho/cm) in the upper Overton area of Lake Mead (see also Figure 6 ) , May 14, 1987.

SITE	Depth (m)	T	D.O.	EC
Virgin River Inflow:	0.3	29.1	8.3	1974
Virgin Bowl- Middle:	0	24.9	9.0	972
	2	24.6	9.1	967
	4	23.9	9.1	982
	6	23.2	9.2	979
	7	22.9	9.4	998
	8	22.2	9.1	1033
	9	21.7	9.1	997
	10	20.9	8.0	1103
	10.5 (bottom)	20.1	6.7	1107
Virgin Narrows: (main lake mouth)	0	24.9	8.5	940
	2	24.1	8.9	952
	4	24.0	9.2	971
	6	23.1	9.2	948
	7	22.1	9.6	922
	8	21.8	9.6	923
	9	21.5	9.1	988
	10	20.5	8.4	1087
	11	19.5	7.2	1265
	12	19.0	5.6	1454
	12.5 (bottom)	18.8	4.6	1471
Overton Beach: (Fish Island)	0	25.1	9.0	852
	2	23.9	9.2	855
	4	22.5	9.4	838
	6	22.1	9.7	835
	8	21.1	9.8	829
	9	20.3	9.6	875
	10	18.6	9.5	879
	11	18.3	9.6	881
	12	17.3	9.3	888
	13	17.0	9.3	889
	14	16.3	9.4	839
	16	15.8	9.6	838
	18	15.1	9.6	844
	20	14.7	9.3	846
	22	14.6	9.5	848
24	14.2	9.3	845	
26	14.0	8.9	843	
28	13.7	8.8	843	
	(bottom at 29 m)			

between about 9 and 13 m based on EC. D.O. changes were less dramatic than in the Narrows, decreasing by about 0.3 ppm D.O. above and below these depths.

In mid-June, the river plume was more easily identifiable as a stratum of water with elevated EC and relatively low dissolved oxygen (Table 12). D.O. values were apparently reduced by the relatively long exposure of inflowing water with shallow sediments in the uppermost region of the Virgin River bay since the actual river water had higher D.O. values, as did the rest of the lake. The plume flowed from about 7-10 meters depth just off bottom in the Virgin Bowl. As it reached deeper water where the Narrows area opens up into the lake proper, it lifted off the bottom while still maintaining its integrity as a 5 m band from about 7-12 meters in depth. Below 12 meters depth, electrical conductivity decreased sharply and D.O. increased. Above and below this stratum, the water chemistry was more characteristic of Lake Mead.

We were also able to delineate the plume quite far into the main lake in mid-June. At the Fish Island site it was evident as a sharp drop in D.O. below 11 meters, extending to about 16 meters depth. Electrical conductivity was also elevated by about 4% in this region.

The temperature regime in the Overton Arm is extremely complex in the spring and early summer. In May and June of 1987 there were often three distinct thermoclines where temperature gradients exceeded 1 degrees C/meter. These patterns varied from station to station and resulted from very variable spring weather conditions (it was unusually windy and cool in May 1987), together with north-south seiching in the Overton Arm, and high Colorado River runoff intruding from Virgin Basin into the metalimnion. The June data suggest that Virgin River water may also have a small effect on the temperature and density gradients in the upper Overton Arm. The overall conclusion from these field data is that Virgin River water cannot be reliably

Table 12. Vertical profiles of temperature, D.O., and EC in the Upper Overton Arm area of Lake Mead, June 12, 1987. As per Table 11.

SITE	Depth (m)	T	D.O.	EC
Virgin River Inflow:	0.3	29.5	8.7	1450
Virgin Bowl- Middle	0	26.8	9.6	896
	2	26.1	9.5	960
	4	26.0	9.4	991
	6	25.5	9.0	1021
	8	24.7	8.3	1097
	9	23.6	8.9	1018
	10	22.9	8.0	1032
	10.3(bottom)			
Virgin Narrows. (main lake mouth)	0	27.7	9.6	843
	2	26.9	10.0	835
	4	26.5	9.9	850
	5	26.4	9.9	849
	6	25.6	9.3	988
	7	25.0	9.1	1021
	8	24.7	9.0	1022
	9	23.5	8.4	1024
	10	22.7	7.3	1060
	11	22.0	5.9	1094
	12	20.9	4.9	1119
	13	19.7	5.9	976
	14	18.8	6.4	901
		14.2 (bottom)		
Overton Beach: (Fish Island)	0	27.2	10.0	836
	2	26.4	10.2	835
	4	26.2	10.2	839
	6	25.6	10.0	852
	7	24.7	10.0	861
	8	23.5	10.5	908
	9	23.3	10.5	908
	10	22.7	9.9	897
	11	22.1	9.7	887
	12	21.2	7.4	955
	13	19.8	7.7	876
	14	18.8	7.8	867
	15	18.2	7.8	859
	16	17.5	7.9	855
	18	16.5	8.2	834
20	15.9	8.2	839	
22.5	15.2	7.3	845	
25	14.8	7.3	842	
27.5	14.5	7.2	843	
	(bottom at 28m)			

expected to form a surface overflow into the main lake, where algal production needs to be stimulated, at this time of year.

Our basic conclusion drawn from the field and laboratory studies presented above is that the Virgin River should not be considered for use as a medium to transport fertilizer downstream into Lake Mead. Reasons include:

1. There is a great potential for a significant fraction of the phosphate in the added fertilizer to adsorb to suspended or bottom sediments in the shallow areas above the Virgin Bowl. Most of this material would settle out and become largely unavailable to P-deficient phytoplankton in the main lake.

2. Much of the nutrients dissolved in the river water in spring and summer would not disperse into the upper layer of the lake 0-5 meters, where most of the phytoplankton production occurs, but would be "trapped" in the metalimnion and upper hypolimnion.

3. The morphometry of the Virgin River inflow area is such that even if conclusions 1 and 2 above were not true, the added phosphate would be rapidly taken up by phytoplankton in the Narrows and Virgin Bowl areas. The potential would exist for creating too large a bloom in these regions without affecting the much larger target area (Echo Bay to Overton Beach) in the main lake.

#### 4.3.3.2 Colorado River

The Colorado River historically provided most of the nitrogen and phosphorus loading to Lake Mead. This occurred primarily during the spring runoff season (April-July) when warm river waters formed a turbid overflow across the upper basin of Lake Mead. The construction of Glen Canyon Dam in 1963 drastically reduced phosphorus loading, temperatures and spring runoff in the Colorado River inflow to Lake Mead (11,30,32,34). Phytoplankton

productivity in the upper basin decreased by about 80% as a result of these changes in the Colorado River (34).

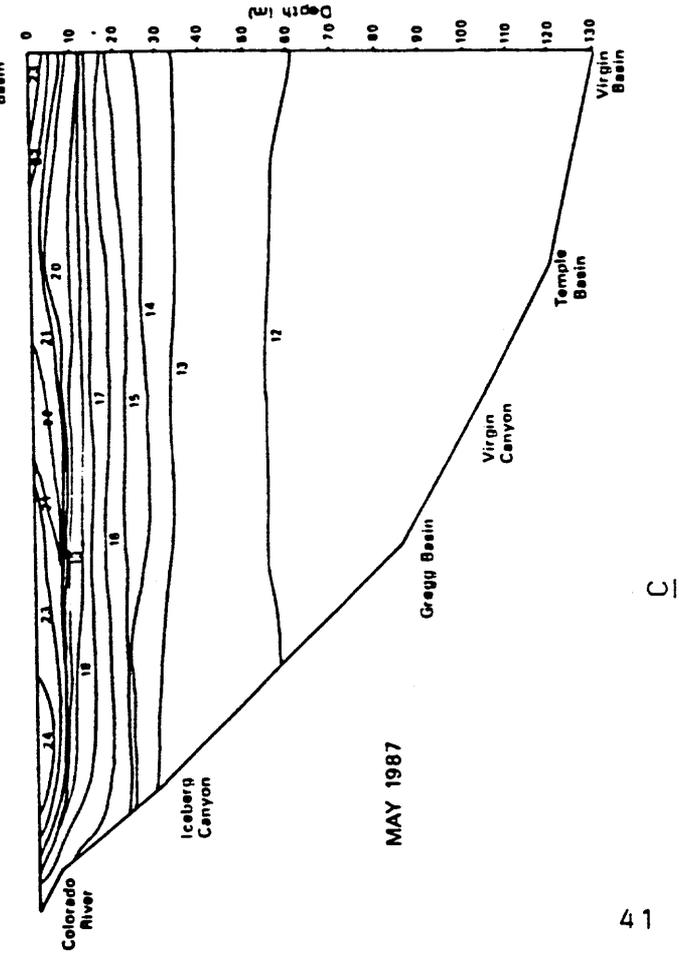
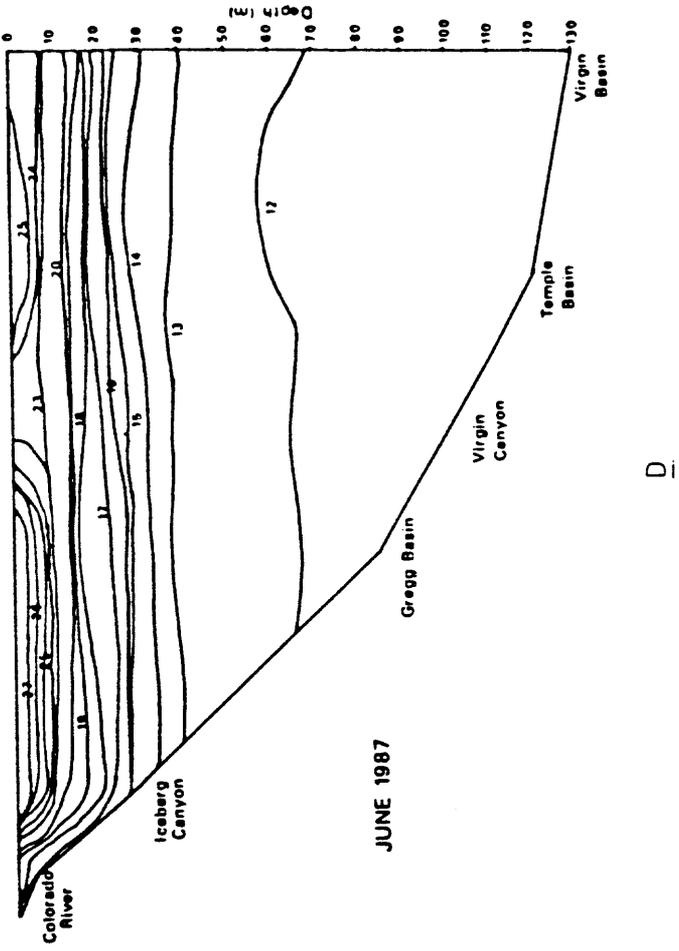
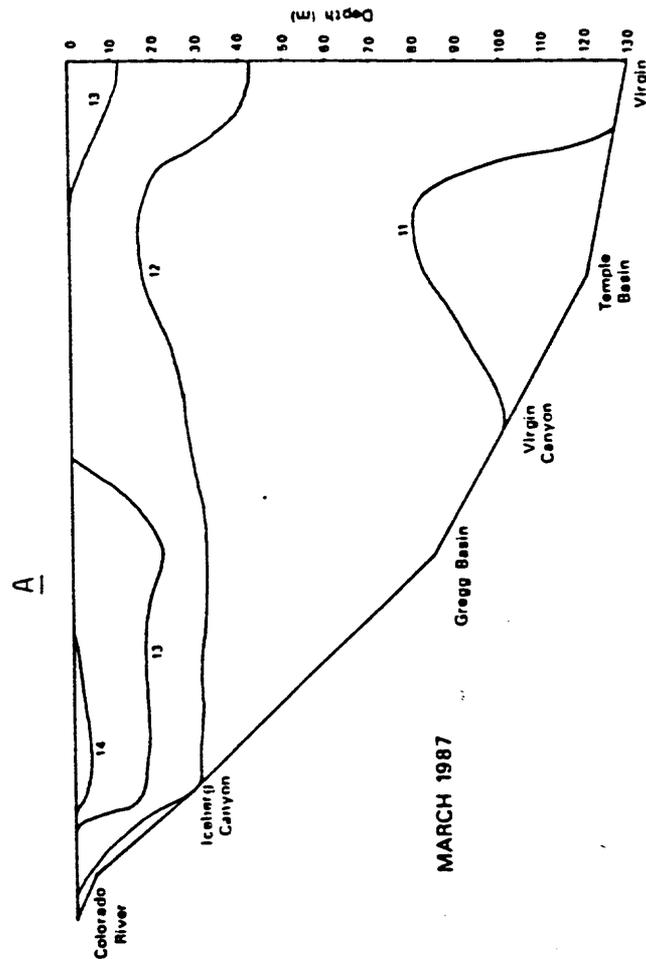
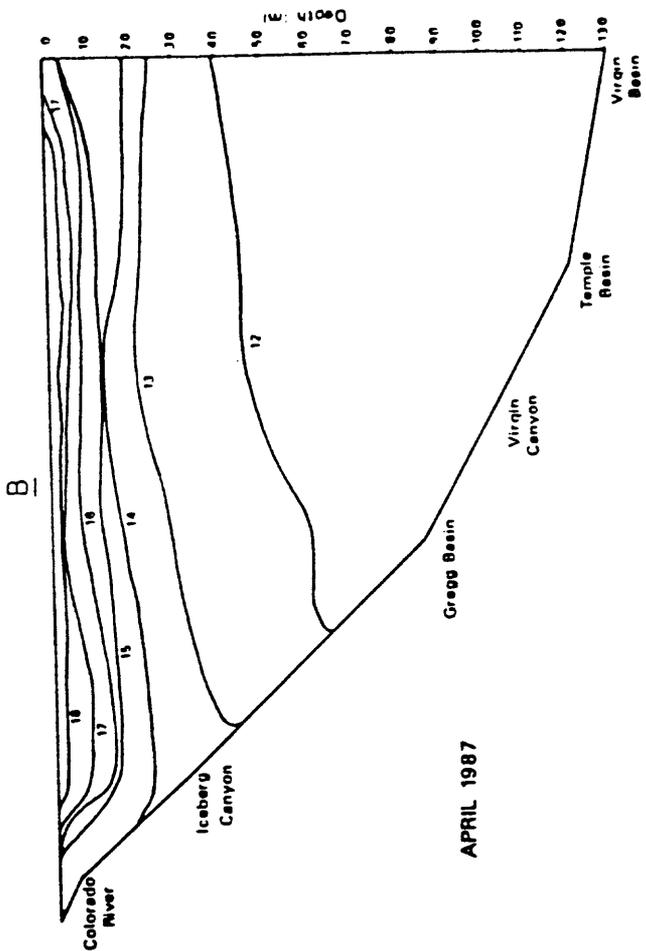
Injection of fertilizer directly into the Colorado River may represent a method of restoring phosphorus concentrations and productivity in the upper basin, provided it can be dispersed into the epilimnetic waters where most of the primary production occurs. Cold-water discharges from Glen Canyon Dam cause the Colorado River to form an underflow or deep interflow in Lake Mead for most of the year (30). However, a brief overflow was noted in Iceberg Canyon during March of 1978 (30). Since overflows load directly into the epilimnion, they could provide a natural mechanism for dispersing fertilizer in upper Lake Mead.

Flows in the Colorado River have changed considerably in recent years with above normal runoff and filling of Lake Powell. This has also affected present-day circulation patterns in the upper end of Lake Mead. Temperature profiles determined in upper Lake Mead during spring 1987 revealed that the Colorado River formed an underflow in Iceberg Canyon and a deep interflow in Gregg Basin in March (Figure 7a). However, cooler surface temperatures in Virgin Canyon and Temple Basin indicate that considerable mixing of river and lake waters occurred in those areas during March (Figure 7a).

Similar circulation patterns were also evident in April. River waters entered the lake at about 14 degrees C and again formed an underflow in Iceberg Canyon where surface temperatures were over 18 degrees C (Figure 7b). Surface temperatures in Virgin Canyon and Temple Basin were similar to Iceberg Canyon, but upwarping in the 14-17 degrees C isotherms indicates that considerable mixing of river and lake waters once again occurred in those areas.

River temperatures were about 17-18 degrees C during May and June (Figures 7c and 7d). Surface temperatures in Virgin Canyon and Temple Basin

Figure 7. Temperature isotherms for the upper basins of Lake Mead,  
March-June 1987.



were 1-2 degrees C colder than uplake areas in May (Figure 7c). In June, surface temperatures in Virgin Canyon were nearly 4 degrees C cooler than Iceberg Canyon and Gregg Basin (Figure 7d).

Although it is difficult to determine the cause(s) for these variations in surface temperature, they most likely reflect upwelling of river waters in Virgin Canyon and at times in Temple Basin. During peak discharges from Glen Canyon Dam, large volumes of cold water are forced under relatively warm lake waters in Iceberg Canyon. This lifts the epilimnion which results in upwarping of the isotherms in that area. River waters then spread out along the thermocline as an interflow and essentially flow under the epilimnion in Gregg Basin. The lake narrows again at Virgin Canyon. This apparently constricts the flow of river waters and causes an upwelling and considerable mixing in that area. The degree of upwelling and mixing would vary considerably in relation to discharges from Glen Canyon Dam. More upwelling could be expected during periods of high discharges.

It does not appear that river injection of fertilizer would significantly improve fertility in the Iceberg Canyon or Gregg Basin since river waters flow under the epilimnion. However, it seems that injection of fertilizer in the interflow below Gregg Basin could improve fertility in areas downstream, particularly in Virgin Canyon and Temple Basin where considerable mixing of lake and river waters occur.

This possibility should be carefully evaluated as part of the Spring Canyon Pump Storage Project. If discharges from the Spring Canyon Reservoir can be enriched with fertilizer and released into the river interflow, it seems nutrients could be efficiently dispersed to downstream areas.

The Spring Canyon Pump Storage Project offers numerous possibilities for nutrient management in the upper end of Lake Mead. In order to maximize its environmental benefits, more detailed studies are required on the relationship

between river discharges and temporal variations in lake temperature. The hydrologic regime is extremely dynamic in those areas and cannot be adequately evaluated without frequent monitoring. Serious consideration should be given to installing a vertical string of thermistors in Iceberg Canyon, Gregg Basin, Virgin Canyon, and Temple Basin so temperatures can be continuously monitored. Results of these measurements could then be used to design dye experiments to directly measure dispersal and mixing characteristics of nutrients injected into the interflow.

## 5.0 RESULTS OF FIELD STUDIES

### 5.1 Background

Two pilot-scale field tests in which fertilizer was directly applied to the lake surface were conducted in August and September 1986. The tests had several major purposes, including:

- \* Develop relatively simple and inexpensive methods for dispersing either liquid or granular fertilizers uniformly over large areas. When the present study was designed, it was believed that a flotilla of volunteer boats might be an excellent way to inexpensively apply fertilizer. Other procedures, such as aerial dispersal and barge spraying were also evaluated with help from M. Coffey of the NPS at Lake Mead.

- \* Determine if differences existed between algal responses to liquid as opposed to granular formulations of fertilizer.

- \* Verify the results of laboratory studies. It was important to demonstrate on a larger scale that the proposed large-scale (Overton Arm) fertilization would not significantly affect salinity and would not produce a eutrophication problem or in any other way significantly degrade water quality for its other beneficial uses. The pilot-scale response of phytoplankton would also provide important information regarding potential large-scale

responses at these times of year, and allow us to better assess the accuracy of routine algal nutrient enrichment bioassays (Section 4.2).

## 5.2 Fertilizer and Cove Selection

### 5.2.1 Fertilizer Formulations

Based on the results of the laboratory studies (Section 4) we scheduled two tests, the first with a mix of granular ammonium phosphate (DAP, 18-46-0) and granular ammonium nitrate (AN, 34-0-0) and the second with liquid ammonium polyphosphate (LAP, 10-34-0, "white") and liquid ammonium nitrate (20-0-0). The first test was scheduled for late August and the second for late September 1986.

DAP was the granular formulation chosen because it offered the best balance between high phosphate content and ammonium content per unit weight. Since a large DIN supplement was needed by late summer to maintain a balanced (re algae nutrition) N:P ratio, the higher N content favored DAP over monoammonium phosphate (MAP, 11-53-0) which has a slightly higher P-content. Other grades of fertilizer contained either lower N and P, or contained relatively high percentages of calcium, potassium, or sulfate, ions which were unnecessary for algal growth and which would therefore, contribute unnecessarily to the salinity of the water (albeit a trivial and immeasurable addition). Ammonium nitrate is a high-N supplement which is extremely soluble, relatively inexpensive, and comprised entirely of  $\text{NH}_3\text{-N}$  and  $\text{NO}_3\text{-N}$  with no "extra" salts present. We also noted that neither DAP nor AN presented any special handling problems such as being caustic or toxic if touched.

Liquid ammonium polyphosphate (10-34-0) was selected for further evaluation because of:

- \* its ease of handling (7,12; confirmed by numerous personal communications of R. Axler and L. Paulson (UNLV) and M. Coffey (NPS-Lake Mead NRA) with fertilizer distributors and manufacturers, research biologists with direct experience with 10-34-0, and with National Forest Service fire-fighting units who use the chemical for fighting forest fires). It is not caustic, nor is special handling care required. This formulation was previously approved for aerial dispersal into Karluk Lake at Kodiak National Wildlife Refuge in Alaska in 1986 by the U.S. Fish and Wildlife Service after reviewing an Environmental Assessment for the project (U.S.FWS, Finding of No Significant Impact, FONSI RS/0196R, May 6, 1986, Anchorage, Alaska; Dr. J. Koenings, Alaska Dept. of Fish and Game (FRED), pers. Comm.);

- \* its commercial availability and moderate cost. A number of regional manufacturers and distributors were found to be available to supply the amounts proposed for large-scale tests.

- \* its proven effectiveness in other studies designed to stimulate fish production (e.g. Alaska Department of Fish and Game, Division of Fisheries Rehabilitation, Enhancement and Development Sockeye Salmon Fertilization Program; 9,22,28).

Liquid ammonium nitrate (20-0-0) in aqueous solution was chosen as the N-supplement for the second test because it has relatively high nitrogen content, is entirely in the inorganic (readily available to algae) form, and is non-caustic and requires no special handling precautions. It is routinely mixed with liquid ammonium polyphosphate to produce formulations with varying N:P ratios.

### 5.2.2 Cove Description

The primary criteria for a test cove were that it be representative of the Overton Arm of the lake and that its size and location be convenient for the fertilization and for monitoring subsequent biological responses. The first choices were Stewarts Bay and Salt Cove on the west shore of the Overton Arm north of Echo Bay. However, site surveys in May and June of 1986 ruled these out because of excessive turbidity during windy periods (nearly every afternoon). Apparently a fine clay fraction is easily eroded from the shoreline. Adsorption of orthophosphate to these suspended sediments could have confounded interpretations of the pilot fertilization experiments (see Section 4.3).

Cathedral Cove, along the west shore of the Overton Arm approximately 5 km south of Echo Bay was a better choice for these field tests. The cove was selected for a number of reasons relating to size, depth, sheltering from the wind, convenience of location, similarity of its water quality to the main lake, and its rocky shore which minimized the production of phosphorus adsorbing silts from shoreline wave-action. The area of the cove was estimated from the 1983 USGS 7.5 minute topographic map, from aerial photographs taken from an overflight arranged by Michael Coffey of the National Park Service, and from calculations based on depth profiles of nitrate, ammonium, and orthophosphate concentrations immediately after the second fertilization. Bottom depths were determined using a Furuno echosounder. The surface area was approximately 13 hectares (~32 acres) and assuming a mean mixed layer depth of ~15 m the volume of the fertilized region was  $-2 \times 10^6 \text{ m}^3$  during both experiments.

Limnological data collected from Cathedral Cove during the June and July 1986 upper basin monitoring surveys were very similar to data from Lower

Overton, Virgin Basin and Boulder Basin (see Table 13 and Figure 9). Therefore, the assumption that the cove was limnologically representative of the Overton Arm was reasonable.

### 5.3 Pilot-Scale Test Methodology

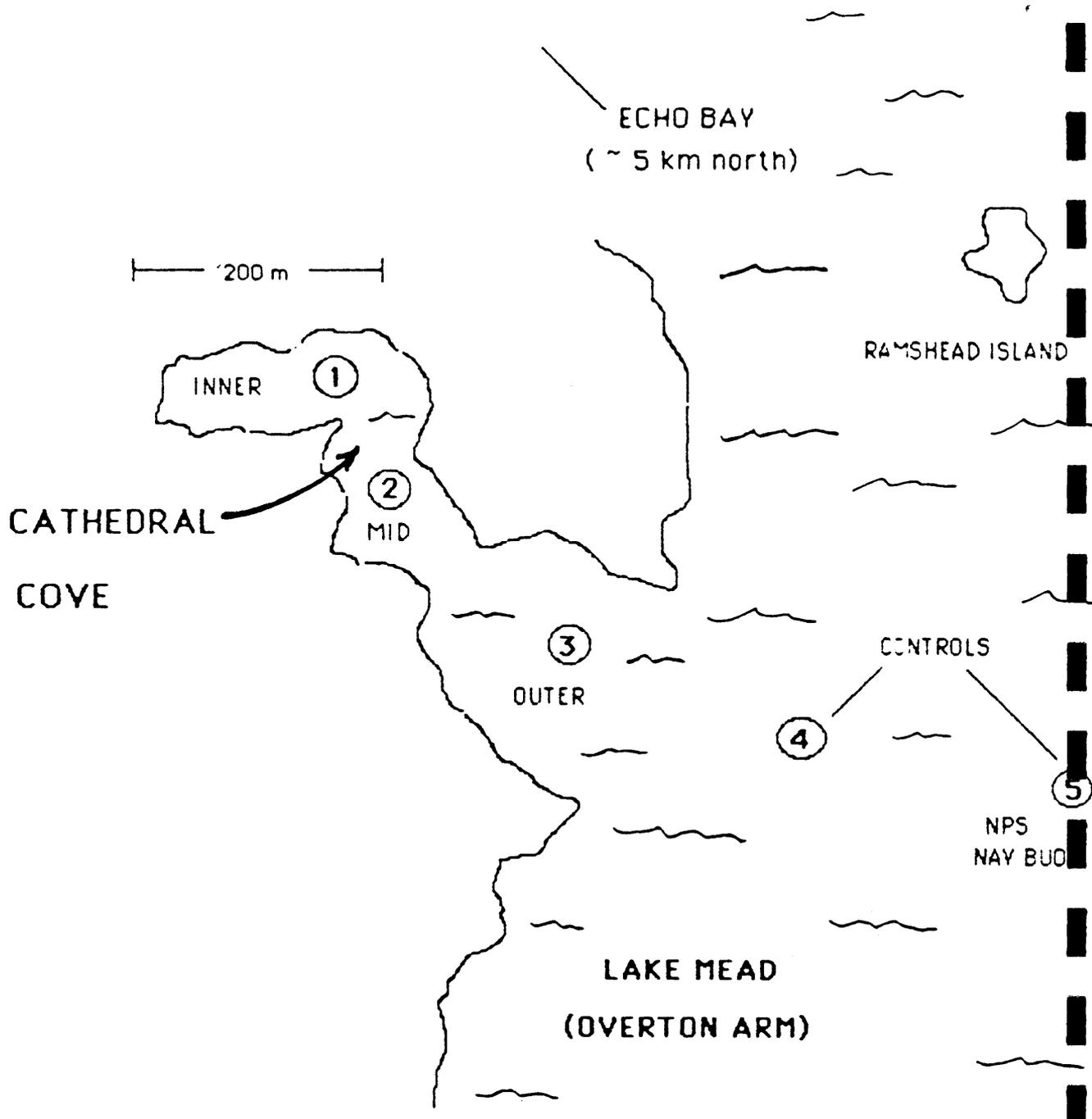
#### 5.3.1 Monitoring Methods

Figure 8 depicts the cove and the location of our five sampling stations along a transect from the inner cove (#1) to the outer mouth (#3) to the main body of the Overton Arm (#5). Stations 4 and 5 were used as "control" stations during the experiments. Depths were ~3-16 m in the inner cove (west-east), >25 m in the middle, >50 m in the mouth, and ~100 m at the control sites. Station 1 was designated LM19b and Station 3 as LM19c during the June, July, August, September, and October monthly USBR monitoring program performed by UNLV. Sampling was intensified to include all 5 sites the day before each of the fertilizations.

Water for nutrient, salinity (major anions/cations), algal biomass, and algal productivity (PPr) determinations was collected as an integrated composite from 0-5 m using a tube sampler for ease of comparison to historical Lake Mead data. Additional water column discrete-depth nutrient profiles were periodically determined using a Van Dorn bottle at depths of 0, 3, 5, 7, 10, 12.5, 15, 17.5, and 20 m. All chemical methods were those routinely used for the Lakes Mead, Mohave, Havasu Limnological Monitoring Program. Additional physical (temperature, electrical conductivity, light intensity, secchi depth/clarity) and chemical (pH, dissolved oxygen) measurements were made using field instruments. Salinity samples were sent to the USBR laboratory in Boulder City, NV for analysis.

Table 13. Limnological comparison of Cathedral Cove with Lower Overton Arm, Virgin Basin and Boulder Basin. Nutrient and chlorophyll data measured from 0-5 meter integrated composites and are expressed as  $\mu\text{g/l}$  (ppb). LM site numbers refer to designated stations from the 1986-1987 Lake Mead Monitoring Study funded by USBR.

PARAMETER LM (SITE #)	CATHEDRAL COVE		L. OVERTON (18)	VIRGIN BASIN (08)	BOULDER BASIN (02)
	INNER (19b)	OUTER (19c)			
JUNE 1986:					
chlorophyll-a	1.1	1.0	1.6	1.8	1.7
ortho-P	4	4	4	7	5
Total-P	6	6	10	16	7
NH <sub>3</sub> -N	15	17	14	17	15
NO <sub>3</sub> -N	114	107	98	108	131
Total-N	330	384	346	319	330
secchi (m)	5.5	5.3	5.7	5.5	5.0
temp (0-10m)	24.9±0.9	24.6±1.3	23.8±0.8	23.5±1.3	24.2±1.0
thermocline	mixed	10-11m	11-12m	9-10m	11-12m
JULY 1986:					
chlorophyll-a	2.1	2.1	2.6	2.5	3.5
ortho-P	2	3	3	2	2
Total-P	9	5	6	5	6
NH <sub>3</sub> -N	8	13	8	8	8
NO <sub>3</sub> -N	42	43	46	50	50
Total-N	243	236	276	267	298
secchi (m)	5.5	6.0	6.7	6.5	5.2
temp (0-10m)	26.4±0.1	26.3±0.2	26.5±0.1	26.1±0.2	25.2±0.1
thermocline	mixed	12-13m	11-12m	14-15m	12-14m



Note: Station LM 18 (Lower Overton) is located ~ 10 km south from station 5 in the main channel

Figure 8. Cathedral Cove, Lake Mead Sampling Stations. See also Figure 2 for relation to the entire lake.

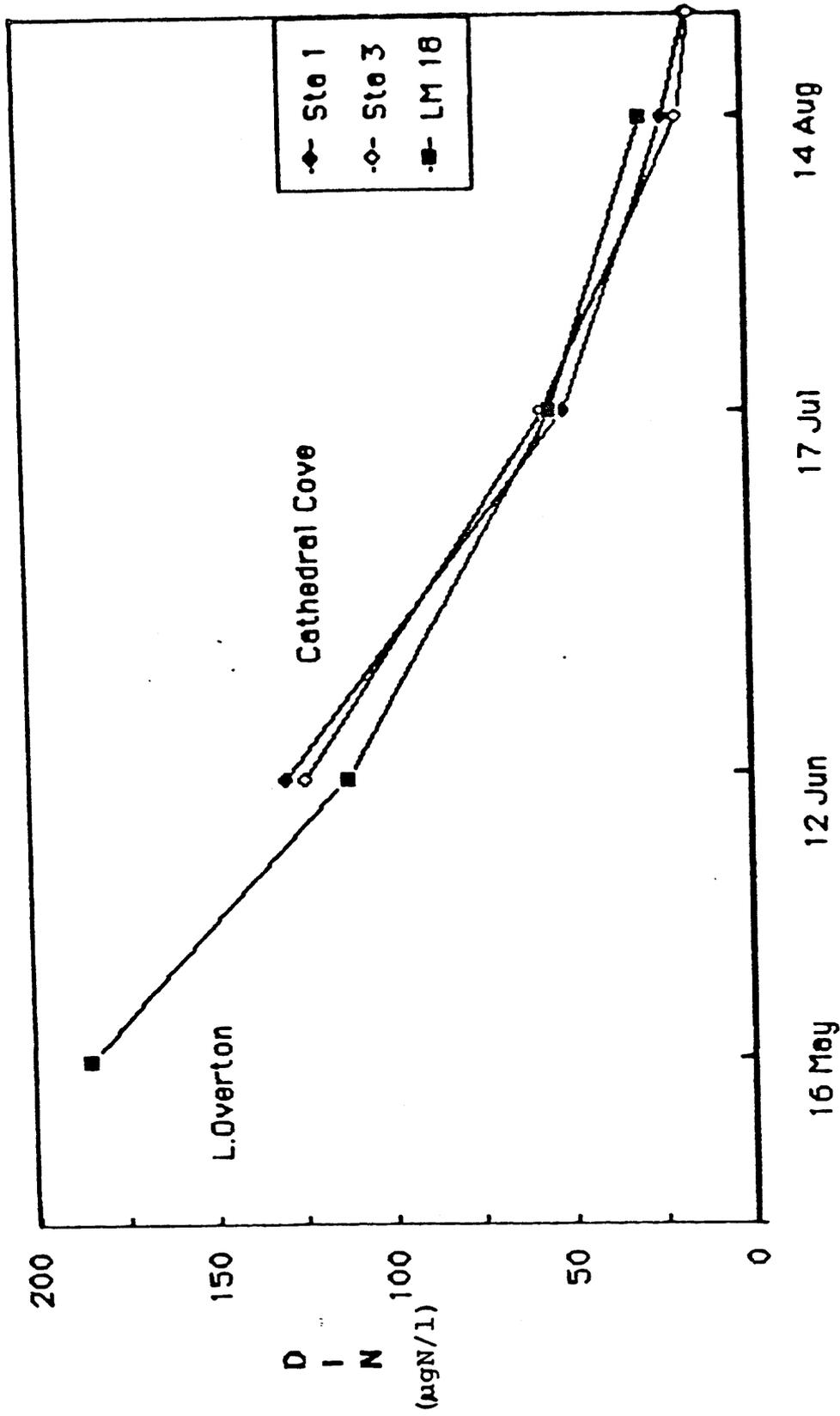


Figure 9. Dissolved Inorganic Nitrogen (DIN) depletion in Cathedral Cove and Lower Overton Bay (UNLV station LM18) during summer 1986

Algal biomass was estimated by chlorophyll-a concentrations calculated using the trichromatic equations for acetone-extracted pigments. "Real time" estimates of chlorophyll were made by measuring the in vivo fluorescence of raw water samples immediately after returning to the field laboratory at Stewarts Point. These data were corrected for non-chlorophyllous fluorescence by subtracting out the values obtained for glass fiber (GF/C) filtrates. Figure 10 shows the strong correlation between the two chlorophyll estimates ( $r=0.93$ )

Additional estimates of phytoplankton abundance and taxonomic identifications were made by microscopy. Phytoplankton samples were collected from the 0-5 meter integrated composite water samples at each station and preserved with acid-Lugol's solution. Samples were taken from stations 1, 3, and 5 from 24 August 1986 and 21 September 1986 (one day prior to the Cathedral Cove fertilizations) and from stations 1, 2, 3, 4, and 5 from 28 August and 24 September (4 days and 3 days respectively, after the applications). They were sent to Dr. Jeff Janik, of the Castle-Tahoe Research Group at the University of California-Davis, who is an aquatic biologist with particular expertise in the areas of phytoplankton and zooplankton taxonomy. His master's thesis research focused on the Lake Mead phytoplankton community (20). The 16 samples were settled for 24 hours using standard Untermyhl sedimentation cylinders. A Wild M40 inverted microscope was used to count 2 strips at 600x for smaller algae, 2 strips at 150x for intermediate sized algae, and a full scan of the chamber at 45x for the net plankton (e.g. *Lyngbya* and *Ceratium*). Abundance estimates were converted to biomass by assuming a density of 1.0 and using cell volumes developed from previous studies of Lake Mead phytoplankton after rechecking some of the major species found in the Cathedral Cove samples.

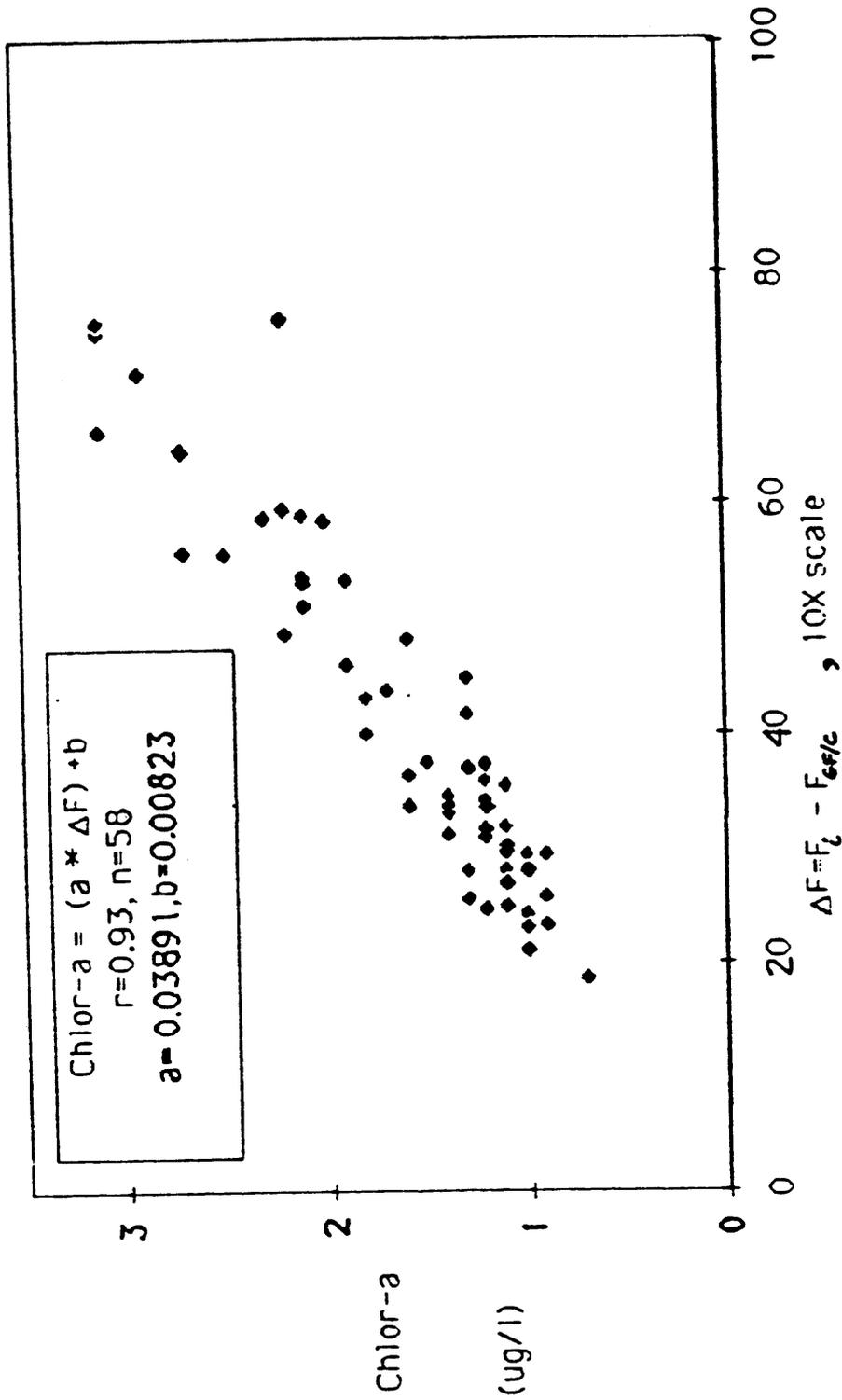


Figure 10. Chlorophyll-a vs. Fluorescence (PF I & PF II)  
 Data from 24-31 Aug 86 and 21-29 Sep 86

Algal rates of primary productivity (PPr) were estimated using the radiotracer  $^{14}\text{C}$ . One-hundred milliliter aliquots of lake water were apportioned into standard 125ml glass "PPr" bottles, inoculated with  $\sim 2$  uCi of  $^{14}\text{C}$ -labelled  $\text{Na}_2\text{CO}_3$  and incubated for 2 hours under a bank of cool white fluorescent bulbs. The light intensity at "mid-bottle" approximated mid-morning values in the middle epilimnion of the lake during late summer. The bottles were placed in a shallow water bath set to ambient surface water temperature. Bottle positions were rotated every 15-20 minutes to control for a potentially inhomogeneous light field. Radioactive algae were concentrated onto 0.45u millipore filters and counted by liquid scintillation. Dissolved inorganic carbon concentrations estimated from alkalinity titrations performed immediately after sampling were then used to calculate rates of photosynthetically fixed carbon (PPr).

### 5.3.2 Fertilization Procedures

PF I: A total of 486 lbs of granular diammonium phosphate (DAP, 18-46-0) and 1475 lbs of granular ammonium nitrate (AN, 34-0-0) fertilizer were added to Cathedral Cove on 25 August 1986. The N:P ratio of the spike was 6.1:1. The total load was divided into three portions corresponding to the relative volumes of the inner, middle, and outer cove regions. The fertilizer was dispersed by adding it to 50 lb polypropylene sand bags which were towed behind a boat at a depth of 1-2 m. The two fertilizers were mixed in a ratio of  $\sim 3:1$  (AN:DAP). We dragged 8 bags at a time, each with about 10 lbs of mix, for 10-15 minutes before "reloading". Relatively small loads were used so that we could distribute the fertilizer as uniformly as possible. Although important for the pilot experiment, this need not be as stringent a requirement for large-scale fertilizations. Four transects were run in the inner bay, 12 in the middle, and 16 in the outer cove. On each load-transect

we criss-crossed the cove at a speed of several knots to obtain maximum coverage. The actual fertilization operation took about 7 hours. It would not be difficult to expand a single boat's coverage of the lake to ~100 acres in a day as part of a large scale scheme.

PF II: A total of 135 gallons (1540 lbs) of liquid ammonium polyphosphate (10-34-0, "white" grade), 300 gallons (3150 lbs) of liquid ammonium nitrate (20-0-0), and 1250 lbs of granular ammonium nitrate (34-0-0) was added to Cathedral Cove on 22 September 1986. The N:P ratio of the spike was 5.3:1. The loading rates were increased to x2.4 for P and 2.0 for N, relative to PF I, in order to stimulate greater algal production than was observed during PF I. The granular AN was only used in the outer cove and was used in addition to liquid AN because it was easier to handle.

The fertilizers were mixed together in a ratio of ~1 part LAP:3 parts LAN:3 parts lake water in a 100 gallon water tank on the UNLV boat. The mixture was then pumped into the water at a rate of ~5 gpm with a portable pump. The solution was dispersed by pumping through a 10 foot wide spray boom made from 1" PVC pipe with 1/16" holes drilled every 1-2" which was towed about 1m deep. As with the granular addition in PF I, we divided the cove into 3 regions and criss-crossed each about a dozen times to obtain a more uniform distribution of nutrients. The actual application took only 4-5 hours.

#### 5.4 Results - Cathedral Cove Studies (PF I and PF II)

Overall, the Cathedral Cove pilot scale fertilizations were quite successful. We approximately tripled algal growth and biomass within a few days, despite significant interchanges of water from inside the cove with epilimnetic water from the main lake. A summary of the two experiments is presented in Table 14 and in the sections which follow.

Table 14. Summary

**LAKE MEAD PREFERTILIZATION STUDY  
CATHEDRAL COVE PILOT STUDIES - 1986**

	<u>PF I-Aug '86</u>	<u>PF II-Sep '86</u>
1. Fertilizer:	granular ammonium phosphate (18-46-0)	liquid ammonium phosphate (10-34-0)
	granular ammonium nitrate (34-0-0)	liquid ammonium nitrate (20-0-0) + granular ammonium nitrate
2. Enrichment:	+22 ppbP +140 ppbN (NH <sub>3</sub> /NO <sub>3</sub> =80/60)	+53 ppbP +280 ppbN (NH <sub>3</sub> /NO <sub>3</sub> =157/123)
3. Loading Rate:	~3.4 kgP/ha (3.0 lbP/acre) ~20.4 kgN/ha(18.2 lbN/acre)	7.9 kgP/ha (7.1 lbP/acre) 41.8 kgN/ha (37.3lbN/acre)
4. Algal Response: (comparison of inner cove to control stations)		
-chlorophyll-a (biomass)	+230 % (Days 3,4) 1.3-3.1 ug/l	+270% (Day 3) 1.1-3.1 ug/l
- <sup>14</sup> C-PPr (growth rate)	+300% (Day 3)	+570% (Day 3)
- secchi depth (clarity)	-0.5 to -0.7m (Day 2-4) ( out of ~5m)	-1.5 to -2m (Day1-3) (out of ~10m)
5. Salinity effects:		
- conductivity(EC)	not significant (P<0.05)	not significant (P<0.05)
- major ions	" "	" "

#### 5.4.1 Algal Biomass

Figures 11 and 12 show the rapid increase in chlorophyll concentrations in the cove immediately following fertilization. Chlorophyll-a during both experiments increased from initial levels of about 1 ug/L to over 3 ug/L in the inner cove within three days. The control stations (4 and 5) exhibited little change during this period, although there was a slight increase at station 4 on Day 2 of PF II which was probably due to advective flushing of the cove during a wind storm (see discussion below).

It appears that the final yield of phytoplankton in the cove was severely limited by exchange of surface waters with the main lake. Both fertilizations were followed by relatively windy days with the wind direction primarily from the southeast. This would tend to "pile" surface water into the cove, forcing a return flow of deeper (but still epilimnetic) water out of the cove. This effect was particularly dramatic two days after the second fertilization (24 September) when winds of 25-40 knots blew continuously for about 2 days. The waves outside the cove ranged from 4-8 feet from trough to crest. It can be seen in Figure 13 that the epilimnion was radically cooled (~3 degrees C) and that the thermocline in the cove appeared to drop by more than 10 meters. After the wind subsided, however, the thermocline was reestablished near its original depth. This suggests that although the steep canyon walls in Cathedral Cove prevented large waves and their resultant vertical mixing from occurring inside the cove, horizontally advected water effectively flushed the cove for at least two days.

Although we cannot estimate the magnitude of this dilution in order to correct for it, we can make some interesting comparisons of the Cathedral data with nutrient enrichment bioassays conducted in early and late July 1986. These experiments utilized natural phytoplankton assemblages from Boulder Basin when nutrient levels were similar to those in the upper basin and growth

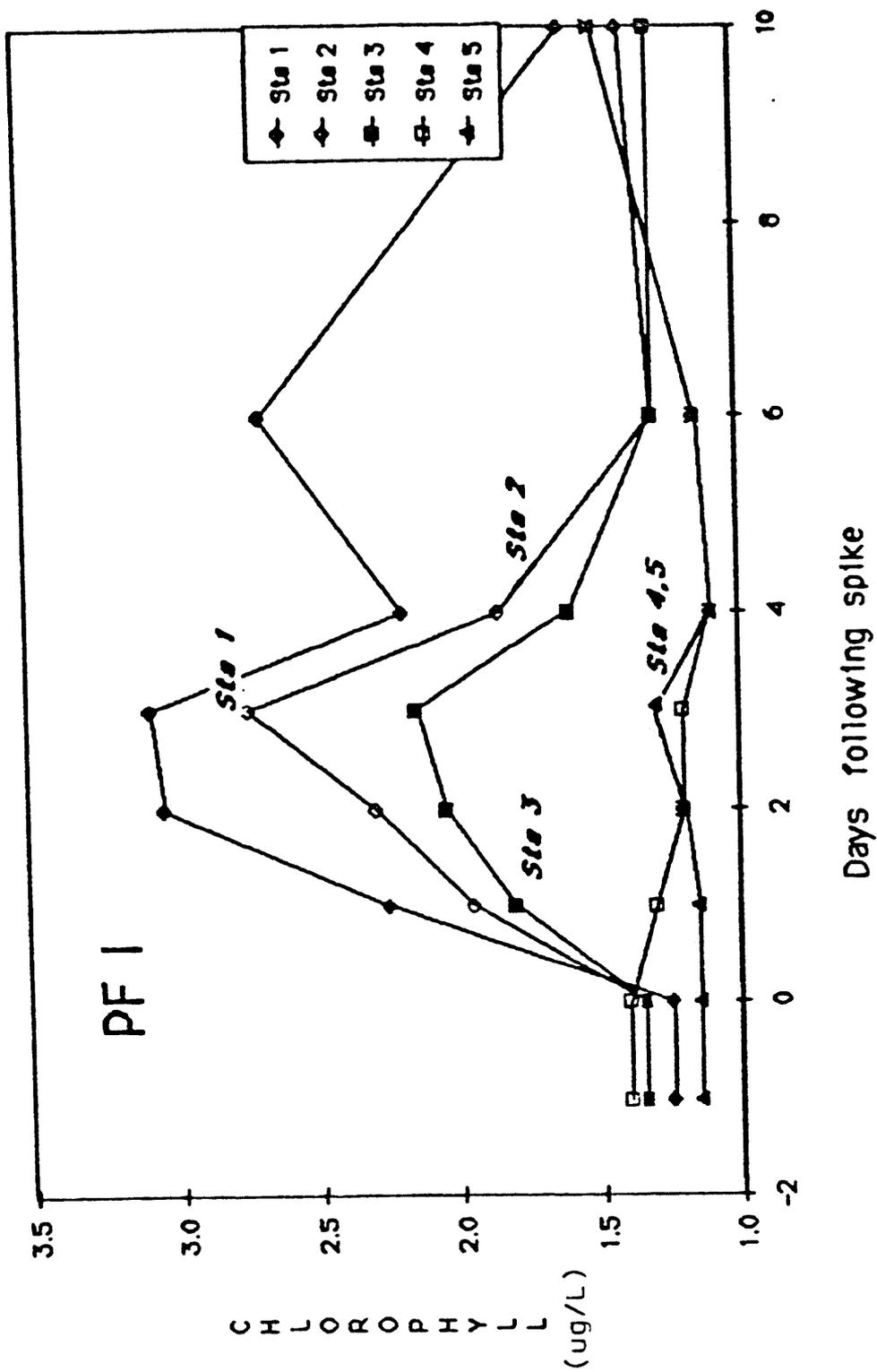


Figure 11. Cathedral Cove chlorophyll concentration-Preferential Iron Study I. Spike was added on 25 August 1986 (Day 0)

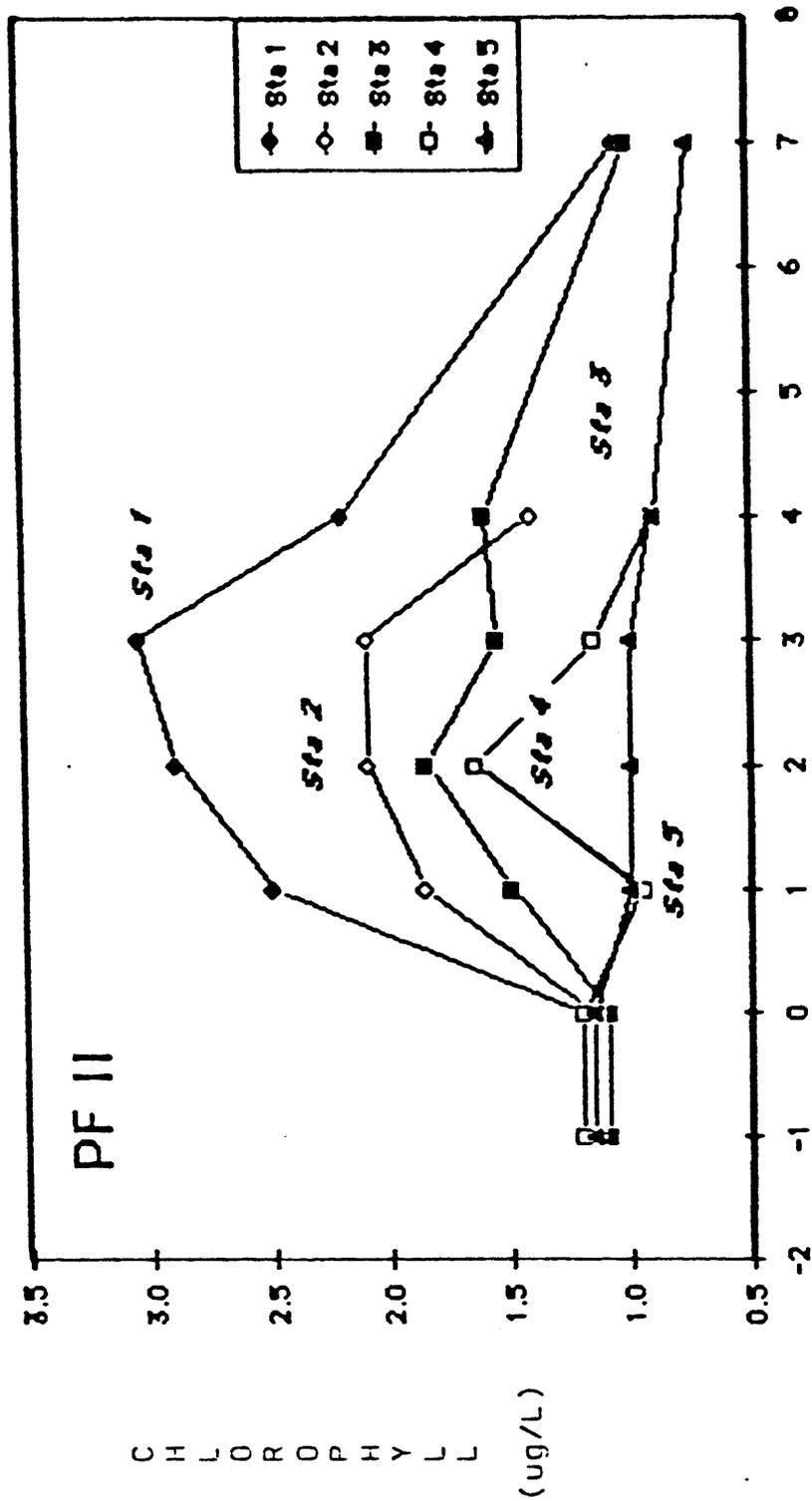


Figure 12. Cathedral Cove chlorophyll concentrations--Fertilization Study II. Spike was added on 22 September 1986 (Day 0)

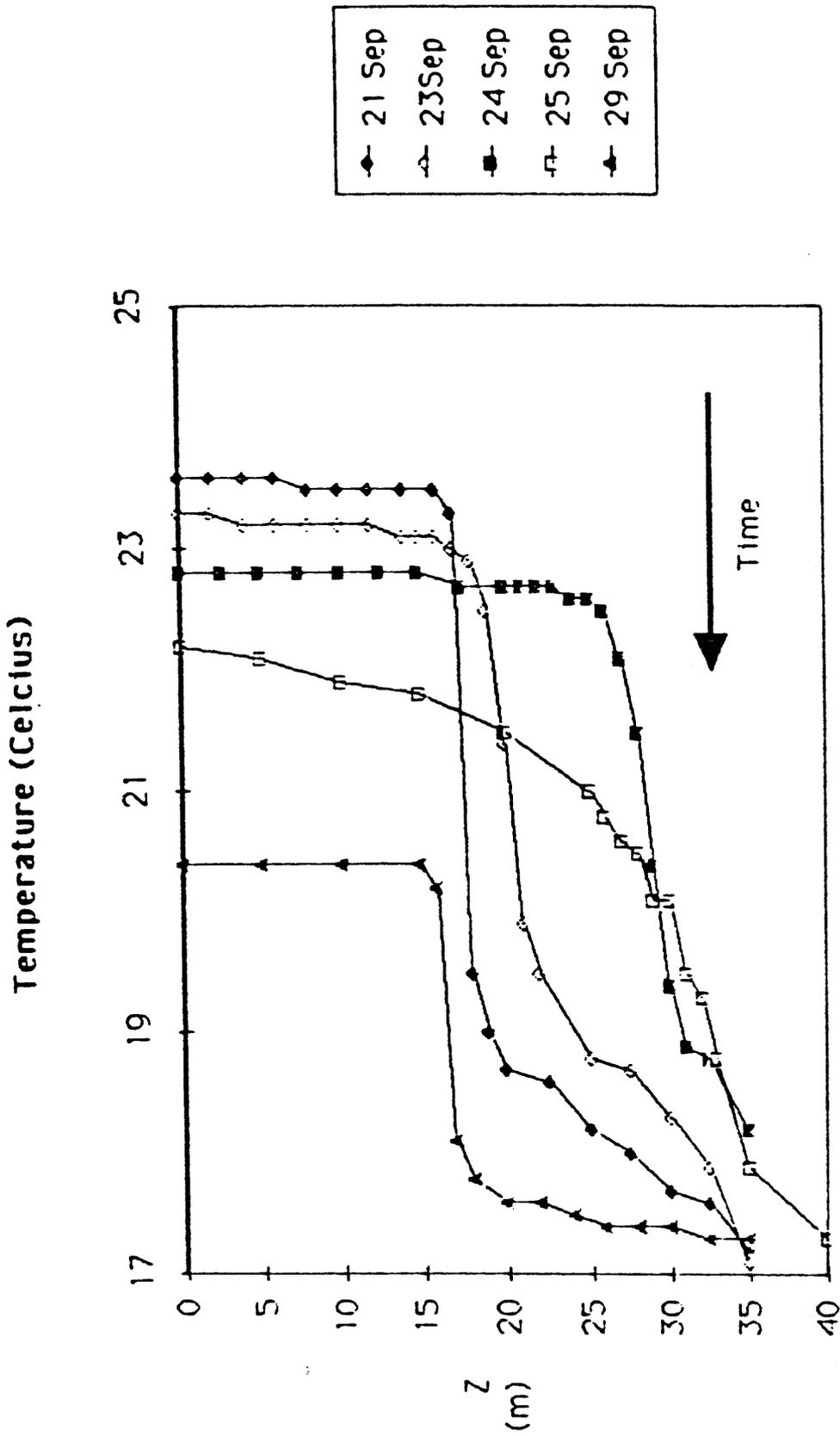


Figure 13. Vertical profiles of temperature in Cathedral Cove (Station 4) during Pt 11. Note the dramatic decrease in the thermocline depth on 24 and 25 September during a severe wind storm

was strongly nutrient limited (see Section 4.2). Mean daily growth rates were calculated from the chlorophyll fluorescence data for Bioassays 1 and 2 and for both field experiments. Those values for bioassay treatments in which the initial inorganic-N and ortho-P levels (after spiking with nutrients) most closely approximated the conditions in Cathedral Cove after fertilization are compiled in Table 15. Several conclusions can be drawn from these data:

1. The two bioassays both demonstrated that nutrient enhancement to levels proposed for large-scale fertilization would increase algal growth. However, the magnitude of this effect in Bioassay 1 was about half of that in Bioassay 2. Daily growth rates were much lower in the early-July experiment and we cannot offer a good explanation for this;

2. The growth rates measured for the first day after fertilization in inner Cathedral Cove in both field experiments were relatively high (~100%) and similar to that measured for the first day of Bioassay 2. However, algal growth decreased dramatically after this initial burst of activity, presumably due to the advective flushing of nutrients and algae;

3. If growth had continued in the cove as in Bioassay 2, the final yield of chlorophyll-a would have been similar - approximately 8 ug/L, which is the target value for the proposed large-scale fertilization. In fact, preliminary analyses of the results of the 1987 Overton Arm Fertilization (conducted on May 30, 1987) indicate that chlorophyll-a concentrations peaked in the range of 5-10 ug/L between four and seven days after the application (4; see section 8.0). Further, additional bioassays performed in July and August 1987 with similar N and P enrichments also produced chlorophyll-a yields of about 8 ug/L (Axler and Vaux, unpublished data). Therefore, it is clear that the natural phytoplankton community in Cathedral Cove was dramatically stimulated by nutrient enrichment and that higher levels of biomass were limited by "cove effects" and weather patterns.

Table 15. Mean daily growth rates estimated from fluorescence measurements in Bioassays 1 and 2 (early and late July 1986) and from the pilot fertilizations of Cathedral Cove in August and September 1986 (see Prefertilization Study Quarterly Report, August 1986). The treatments used were those most closely approximating the Cathedral Cove experiments. N=nitrate + ammonium; P= ortho-P immediately after spike.

TREATMENT	N,P (ug/L)	% GROWTH ON DAY				CHLOROPHYLL YIELD
		1	2	3	4	
<b>Bioassay 1:</b>						
+20P 100N	21P 185N	33%	19%	2%	4%	3.0 µg/L
+20DAP 100N	22P 200N	25%	40%	10%	11%	3.5
+20LAP 100N	22P 197N	<u>46%</u>	<u>23%</u>	<u>-7%</u>	<u>13%</u>	2.9
	X±s.d	35±11	27±11	2±8	9±5	
<b>Bioassay 2:</b>						
+20P 110N	21P 139N	74%	73%	37%	25%	5.0
+20DAP 90AN	21P 150N	88%	69%	13%	31%	5.6
+30DAP 160AN	31P 226N	<u>134%</u>	<u>71%</u>	<u>109%</u>	<u>23%</u>	8.2
	X±s.d.	99±31	71±2	53±50	26±4	
<b>Cathedral PF I (Aug):</b>						
Station I:						
+22DAP 140AN	~24P 155N	113%	26%	-11%	14%	3.1
<b>Cathedral PF II (Sep):</b>						
Station I:						
+53LAP 280AN	~56P 504N	89%	28%	6%	-36%	3.1

Phytoplankton species lists, enumerations of cell density, and calculated biomass concentrations from microscopic examination are presented in Tables 16-19 and Figures 14 and 15. The response patterns were generally similar to those measured for chlorophyll-a, chlorophyll fluorescence, and <sup>14</sup>C- primary productivity during the fertilization experiments. Biomass increased by factors of about 2-3x due to the nutrient additions. Further, the most dramatic increases occurred for smaller species <50u in size, which are collectively referred to as nanoplankton. Some of these species, such as *Chrysochromulina parva*, *Rhodomonas minuta*, and *Cryptomonas marsonii* are easily eaten by zooplankton and were stimulated by factors of 3-6x in the inner cove relative to the main channel control stations. These results indicate a great potential for stimulating phytoplankton growth and channeling this "new" production into zooplankton biomass. There were no indications of potential problems arising from scum-forming blue-green algae (Cyanophyta), either.

#### 5.4.2 Algal Growth

Figures 16 and 17 show the time course of <sup>14</sup>C- primary productivity (PPr) following enrichment of the cove. These data estimate the photosynthetic rate of the natural phytoplankton community which generally approximates their growth rate. The patterns are basically similar to those for chlorophyll (Figures 11 and 12) which show the greatest stimulation in the inner cove for both experiments. In fact growth rate at Station 1 in PF II was increased by 570% relative to the control stations on Day 2, despite the fact that a lot of flushing had no doubt already occurred.

These results are particularly exciting because it is the growth rate of the algae which we most wanted to increase by nutrient enrichment. The ideal situation would be to increase algal growth, producing biomass which is in turn immediately grazed by zooplankton. The result would be to increase

24 Aug 1986 Sta. 1				
Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Anabaena sp.	0.04	0.00	0.02	0.01
Aphanocapsa sp.	1792.00	22.01	15.77	9.84
Chroococcus sp.	6016.00	73.89	3.13	1.95
Lynghya birgeii	0.24	0.00	24.00	14.97
	<b>7808.28</b>	<b>95.91</b>	<b>42.92</b>	<b>26.77</b>
<b>Chrysophyta</b>				
Mallomonas pseudocoronata	0.04	0.00	0.06	0.04
	<b>0.04</b>	<b>0.00</b>	<b>0.06</b>	<b>0.04</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	4.00	0.05	0.36	0.23
Rhodomonas minuta	52.00	0.64	4.16	2.59
	<b>56.00</b>	<b>0.69</b>	<b>4.52</b>	<b>2.82</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.16	0.00	14.13	8.81
Glenodinium pulviscus	5.00	0.06	18.19	11.35
Peridinium villei	0.16	0.00	9.86	6.15
	<b>5.32</b>	<b>0.07</b>	<b>42.18</b>	<b>26.31</b>
<b>Bacillariophyceae</b>				
Anomooneis vitrea	39.00	0.48	9.52	5.94
Asterionella formosa	1.00	0.01	0.58	0.36
Cyclotella spp.	60.00	0.74	18.00	11.23
Synedra ulna	0.04	0.00	0.88	0.55
	<b>100.04</b>	<b>1.23</b>	<b>28.98</b>	<b>18.08</b>
<b>Chlorophyta</b>				
Elakatothrix gelatinosa	11.00	0.14	0.60	0.37
Oocystis gigas v. incrass.	4.00	0.05	34.02	21.22
Oocystis pusilla	6.00	0.07	0.76	0.48
Planctonema lauterbornii	55.00	0.68	1.67	1.04
Tetraedron muticum	4.00	0.05	0.22	0.13
	<b>80.00</b>	<b>0.98</b>	<b>37.26</b>	<b>23.24</b>
<b>MISC Monads</b>				
Monads 2.5-5	68.00	0.84	0.55	0.34
Monads 5.1-10	8.00	0.10	0.64	0.40
Monads <2.5	16.00	0.20	3.20	2.00
	<b>92.00</b>	<b>1.13</b>	<b>4.39</b>	<b>2.74</b>
<b>TOTAL</b>	<b>8141.68</b>	<b>100.00</b>	<b>160.31</b>	<b>100.00</b>

Table 16a. Phytoplankton composition

24 Aug 1986 Sta. 3				
Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Anabaena sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	1344	14.21	11.83	8.11
Chroococcus sp.	7520	79.48	3.91	2.68
Chroococcus limneticus	4	0.04	0.97	0.67
Lyngbya birgeii	0.04	0.00	8.62	5.91
Microcystis aeruginosa	10	0.11	0.65	0.45
Merismopedia minima	128	1.35	0.01	0.01
	<b>9006.04</b>	<b>95.1876</b>	<b>26.00</b>	<b>17.82</b>
<b>Chrysophyta</b>				
Mallomonas pseudocoronata	1	0.01	1.50	1.03
	<b>1.00</b>	<b>0.01</b>	<b>1.50</b>	<b>1.03</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	4	0.04	0.36	0.25
Rhodomonas lens	48	0.51	18.34	12.57
Rhodomonas minuta	76	0.80	6.08	4.17
	<b>128.00</b>	<b>1.35</b>	<b>24.78</b>	<b>16.99</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.12	0.00	10.60	7.26
Glenodinium pulviscus	2	0.02	7.28	4.99
Peridinium villei	0.2	0.00	12.33	8.45
	<b>2.32</b>	<b>0.02</b>	<b>30.20</b>	<b>20.70</b>
<b>Bacillariophyceae</b>				
Anomooneis vitrea	30	0.32	7.32	5.02
Asterionella formosa	0	0.00	0.00	0.00
Cyclotella spp.	100	1.06	30.00	20.56
Synedra ulna	0	0.00	0.00	0.00
	<b>130.00</b>	<b>1.37</b>	<b>37.32</b>	<b>25.58</b>
<b>Chlorophyta</b>				
Elakatothrix gelatinosa	9	0.10	0.49	0.33
Oocystis gigas v. incrass.	2	0.02	17.01	11.66
Oocystis pusilla	16	0.17	2.03	1.39
Planctonema lauterbornii	48	0.51	1.46	1.00
Scenedesmus bijuga	11	0.12	0.69	0.48
Tetraedron muticum	12	0.13	0.65	0.44
	<b>98.00</b>	<b>1.04</b>	<b>22.33</b>	<b>15.31</b>
<b>MISC Monads</b>				
Monads 2.5-5	68	0.72	0.55	0.38
Monads 5.1-10	20	0.21	1.60	1.10
Monads <2.5	8	0.08	1.60	1.10
	<b>96.00</b>	<b>1.01</b>	<b>3.75</b>	<b>2.57</b>
<b>TOTAL</b>	<b>9461.36</b>	<b>100.00</b>	<b>145.88</b>	<b>100.00</b>

Table 16b. Phytoplankton composition

24 Aug 1986 Sta. 5				
Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Anabaena sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	2240	18.04	19.71	11.68
Chroococcus sp.	9664	77.81	5.03	2.98
Lyngbya birgei	0.12	0.00	12.00	7.11
Microcystis aeruginosa	0	0.00	0.00	0.00
Merismopedia minima	0	0.00	0.00	0.00
	<b>11904.1</b>	<b>95.85</b>	<b>36.74</b>	<b>21.77</b>
<b>Chrysophyta</b>				
Dinobryon divergens	1.00	0.01	0.24	0.14
Chrysochromulina parva	4.00	0.03	0.10	0.06
Mallomonas pseudocoronata	1	0.01	1.50	0.89
	<b>6.00</b>	<b>0.05</b>	<b>1.84</b>	<b>1.09</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	0	0.00	0.00	0.00
Cryptomonas erosa	1	0.01	1.00	0.59
Rhodomonas lens	28	0.23	10.70	6.34
Rhodomonas minuta	92	0.74	7.36	4.36
	<b>121.00</b>	<b>0.97</b>	<b>19.06</b>	<b>11.29</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.04	0.00	3.53	2.09
Glenodinium pulviscus	6	0.05	21.83	12.93
Poridinium willoi	0	0.00	0.00	0.00
	<b>6.04</b>	<b>0.05</b>	<b>25.36</b>	<b>15.02</b>
<b>Bacillariophyceae</b>				
Anomooneis vitrea	56	0.45	13.66	8.10
Asterionella formosa	1	0.01	0.58	0.34
Cyclotella spp.	88	0.71	26.40	15.64
Synedra ulna	0	0.00	0.00	0.00
	<b>145.00</b>	<b>1.17</b>	<b>40.65</b>	<b>24.08</b>
<b>Chlorophyta</b>				
Elakatothrix gelatinosa	8	0.06	0.43	0.26
Oocystis gigas v. incrass.	4	0.03	34.02	20.15
Oocystis pusilla	0	0.00	0.00	0.00
Planctonema lauterbornii	70	0.56	2.13	1.26
Scenedesmus bijuga	4	0.03	0.25	0.15
Tetraedron muticum	4	0.03	0.22	0.13
	<b>90.00</b>	<b>0.72</b>	<b>37.05</b>	<b>21.95</b>
<b>MISC Monads</b>				
Monads 2.5-5	92	0.74	0.75	0.44
Monads 5.1-10	32	0.26	2.56	1.52
Monads <2.5	24	0.19	4.80	2.84
	<b>148.00</b>	<b>1.19</b>	<b>8.11</b>	<b>4.80</b>
<b>TOTAL</b>	<b>12420.16</b>	<b>100.00</b>	<b>168.79</b>	<b>100.00</b>

Table 16c. Phytoplankton composition

28 Aug 1986 Sta. 1				
Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Anabaena sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	1024	8.42	9.01	2.33
Chroococcus sp.	8480	69.75	4.41	1.14
Chroococcus limneticus	4	0.03	0.97	0.25
Lyngbya birgeii	0.04	0.00	8.62	2.23
Microcystis aeruginosa	20	0.16	1.31	0.34
Merismopedia minima	1216	10.00	0.14	0.04
	<b>10744</b>	<b>88.38</b>	<b>24.46</b>	<b>6.34</b>
<b>Chrysophyta</b>				
Dinobryon divergens	2.00	0.02	0.49	0.13
Chrysochromulina parva	240.00	1.97	5.81	1.50
Mallomonas pseudocoronata	2	0.02	3.00	0.78
	<b>244.00</b>	<b>2.01</b>	<b>9.29</b>	<b>2.41</b>
<b>Cryptophyta</b>				
Katablepheris ovalis	0	0.00	0.00	0.00
Cryptomonas marssonii	136	1.12	59.30	15.36
Cryptomonas erosa	14	0.12	14.00	3.63
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minuta	524	4.31	41.92	10.86
	<b>674.00</b>	<b>5.54</b>	<b>115.22</b>	<b>29.85</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0	0.00	0.00	0.00
Glenodinium pulviscus	18	0.15	65.48	16.96
Gymnodinium sp.	24	0.20	6.72	1.74
Gymnodinium sp.	24	0.20	36.10	9.35
Peridinium quadridens	4	0.03	40.94	10.60
Peridinium villei	0	0.00	0.00	0.00
	<b>70.00</b>	<b>0.58</b>	<b>149.24</b>	<b>38.66</b>
<b>Bacillariophyceae</b>				
Anomooneis vitrea	54	0.44	13.18	3.41
Asterionella formosa	2	0.02	1.16	0.30
Cyclotella spp.	64	0.53	19.20	4.97
Synedra ulna	0	0.00	0.00	0.00
	<b>120.00</b>	<b>0.99</b>	<b>33.54</b>	<b>8.69</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	92.00	0.76	17.94	4.65
Elakatothrix gelatinosa	12	0.10	0.65	0.17
Oocystis gigas v. incrass.	1	0.01	8.50	2.20
Oocystis pusilla	0	0.00	0.00	0.00
Phacotus sp.	4	0.03	0.92	0.24
Planctonema lauterbornii	24	0.20	0.73	0.19
Platymonas elliptica	16	0.13	16.64	4.31
Scenedesmus bijuga	8	0.07	0.50	0.13
Tetraedron muticum	8	0.07	0.43	0.11
	<b>165.00</b>	<b>1.36</b>	<b>46.32</b>	<b>12.00</b>
<b>MISC Monads</b>				
Monads 2.5-5	92	0.76	0.75	0.19
Monads 5.1-10	20	0.16	1.60	0.41
Monads <2.5	28	0.23	5.60	1.45
	<b>140.00</b>	<b>1.15</b>	<b>7.95</b>	<b>2.06</b>
<b>TOTAL</b>	<b>12157.04</b>	<b>100.00</b>	<b>386.01</b>	<b>100.00</b>

Taxo	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Aphanocapsa sp.	160	1.39	1.41	0.49
Aphanocapsa sp.	0	0.00	0.00	0.00
Chroococcus sp.	9792	85.08	5.09	1.77
Gomphosphaeria lacustris	0	0.00	0.00	0.00
Lunghya birgei	0.12	0.00	12.00	4.17
Microcystis aeruginosa	0	0.00	0.00	0.00
Single cells	128	1.11	0.07	0.02
Merismopedia minima	384	3.34	0.04	0.02
	<b>10464.1</b>	<b>90.919</b>	<b>18.6098</b>	<b>6.4613</b>
<b>Chrysophyta</b>				
Dinobryon divergens	0.00	0.00	0.00	0.00
Chrysochromulina parva	72.00	0.63	1.74	0.60
Pseudopedinella erkenis	0.00	0.00	0.00	0.00
Mallomonas pseudocoronata	0	0.00	0.00	0.00
	<b>72.00</b>	<b>0.63</b>	<b>1.74</b>	<b>0.60</b>
<b>Cryptophyta</b>				
Katableptaris ovalis	0	0.00	0.00	0.00
Cryptomonas marssonii	64	0.56	27.90	9.69
Cryptomonas erosa	7	0.06	7.00	2.43
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minuta	384	3.34	30.72	10.67
	<b>455.00</b>	<b>3.95</b>	<b>65.62</b>	<b>22.78</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.16	0.00	14.13	4.91
Glenodinium pulviscus	8	0.07	29.10	10.10
Glenodinium gumnodinium	1	0.01	29.75	10.33
Peridinium willei	0	0.00	0.00	0.00
	<b>9.16</b>	<b>0.08</b>	<b>72.98</b>	<b>25.34</b>
<b>Bacillariophyceae</b>				
Ammoniaea vitrea	69	0.60	16.84	5.85
Asterionella formosa	0	0.00	0.00	0.00
Cyclotella spp.	104	0.90	31.20	10.83
Cyclotella bocanica	2	0.02	23.72	8.23
	<b>175.00</b>	<b>1.52</b>	<b>71.75</b>	<b>24.91</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	40.00	0.35	7.80	2.71
Elakstothrix gelatinosa	0	0.00	0.00	0.00
Oocystis gigas v. incrass.	4	0.03	34.02	11.81
Oocystis pusilla	0	0.00	0.00	0.00
Oocystis borgeri	0	0.00	0.00	0.00
Planctonema lauterbornii	65	0.56	1.98	0.69
Platymonas elliptica	1	0.01	1.04	0.36
Scenedesmus bijuga	16	0.14	1.01	0.35
Tetraedron muticum	0	0.00	0.00	0.00
	<b>126.00</b>	<b>1.09</b>	<b>45.84</b>	<b>15.92</b>
<b>MISC Monads</b>				
Monads 2.5-5	112	0.97	0.91	0.31
Monads 5.1-10	72	0.63	5.76	2.00
Monads <2.5	24	0.21	4.80	1.67
	<b>208.00</b>	<b>1.81</b>	<b>11.47</b>	<b>3.98</b>
<b>TOTAL</b>	<b>11509.28</b>	<b>100.00</b>	<b>288.02</b>	<b>100.00</b>

Table 17b. Phytoplankton composition

28 Aug 1986 Sta. 3				
Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Anabaena sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	1216	16.22	10.70	5.15
Chroococcus sp.	5440	72.55	2.83	1.36
Lynbya birgeii	0	0.00	0.00	0.00
Microcystis aeruginosa	16	0.21	1.05	0.50
Merismopedia minima	0	0.00	0.00	0.00
	<b>6672</b>	<b>88.98</b>	<b>14.58</b>	<b>7.01</b>
<b>Chrysophyta</b>				
Dinobryon divergens	0	0.00	0.00	0.00
Chrysochromulina parva	112	1.49	2.71	1.30
Mellomonas pseudocoronata	1	0.01	1.50	0.72
	<b>113.00</b>	<b>1.51</b>	<b>4.21</b>	<b>2.03</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	0	0.00	0.00	0.00
Cryptomonas marssonii	88	1.17	38.37	18.45
Cryptomonas erosa	6	0.08	6.00	2.89
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minuta	304	4.05	24.32	11.70
	<b>398.00</b>	<b>5.31</b>	<b>68.69</b>	<b>33.04</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.08	0.00	7.06	3.40
Gymnodinium sp.	12	0.16	3.36	1.62
Gymnodinium sp.	0	0.00	0.00	0.00
Glenodinium pulviscus	6	0.08	21.83	10.50
Peridinium willei	0	0.00	0.00	0.00
	<b>18.08</b>	<b>0.24</b>	<b>32.25</b>	<b>15.51</b>
<b>Bacillariophyceae</b>				
Anomoconeis vitrea	50	0.67	12.20	5.87
Asterionella formosa	3	0.04	1.74	0.84
Cyclotella spp.	40	0.53	12.00	5.77
Synedra ulna	1	0.01	22.05	10.60
	<b>94.00</b>	<b>1.25</b>	<b>47.99</b>	<b>23.08</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	16.00	0.21	3.12	1.50
Elakathrix gelatinosa	4	0.05	0.22	0.10
Oocystis gigas v. incrass.	2	0.03	17.01	8.18
Oocystis pusilla	0	0.00	0.00	0.00
Planctonema lauterbornii	13	0.17	0.40	0.19
Platymonas elliptica	12	0.16	12.48	6.00
Scenedesmus bijuga	20	0.27	1.26	0.61
Sphaerocystis Schroeteri	16	0.21	1.39	0.67
Tetradron muticum	0	0.00	0.00	0.00
	<b>83.00</b>	<b>1.11</b>	<b>35.87</b>	<b>17.25</b>
<b>MISC Monads</b>				
Monads 2.5-5	100	1.33	0.81	0.39
Monads 5.1-10	4	0.05	0.32	0.15
Monads <2.5	16	0.21	3.20	1.54
	<b>120.00</b>	<b>1.60</b>	<b>4.33</b>	<b>2.08</b>
<b>TOTAL</b>	<b>7498.08</b>	<b>100.00</b>	<b>207.92</b>	<b>100.00</b>

Table 17c. Phytoplankton composition

Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Aphanocapsa sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	0	0.00	0.00	0.00
Chroococcus sp.	5312	82.78	2.76	2.03
Gomphosphaeria lacustris	256	3.99	2.10	1.54
Lyngbya birgei	0.04	0.00	4.00	2.94
Microcystis aeruginosa	0	0.00	0.00	0.00
Single cells	152	2.37	0.08	0.06
Merismopedia minima	0	0.00	0.00	0.00
	<b>5720.04</b>	<b>89.1372</b>	<b>8.94</b>	<b>6.57</b>
<b>Chrysophyta</b>				
Dinobryon divergens	7.00	0.11	1.70	1.25
Chrysochromulina parva	72.00	1.12	1.74	1.28
Pseudopedinella erkenis	16.00	0.25	3.26	2.40
Mallomonas pseudocoronata	0	0.00	0.00	0.00
	<b>95.00</b>	<b>1.48</b>	<b>6.71</b>	<b>4.93</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	0	0.00	0.00	0.00
Cryptomonas marsonii	10	0.16	4.36	3.20
Cryptomonas erosa	7	0.11	7.00	5.14
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minuta	272	4.24	21.76	15.99
	<b>289.00</b>	<b>4.50</b>	<b>33.12</b>	<b>24.33</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.08	0.00	7.06	5.19
Glenodinium pulviscus	2	0.03	7.28	5.35
Peridinium willei	0	0.00	0.00	0.00
	<b>2.08</b>	<b>0.03</b>	<b>14.34</b>	<b>10.54</b>
<b>Bacillariophyceae</b>				
Anomoeoneis vitrea	35	0.55	8.54	6.27
Asterionella formosa	2	0.03	1.16	0.85
Cyclotella spp.	48	0.75	14.40	10.58
Cyclotella bodanica	1	0.02	11.86	8.71
Synedra ulna	0	0.00	0.00	0.00
	<b>86.00</b>	<b>1.34</b>	<b>35.96</b>	<b>26.42</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	16.00	0.25	5.12	2.29
Elakatothrix gelatinosa	16	0.25	0.87	0.64
Cocystis gigas v. increas.	2	0.03	17.01	12.50
Cocystis puella	16	0.25	2.03	1.49
Cocystis borgeri	0	0.00	0.00	0.00
Planctonema lauterbornii	10	0.16	0.30	0.22
Platomonas elliptica	1	0.02	1.04	0.76
Scenedesmus bijuga	4	0.06	0.25	0.19
Tetraedron muticum	0	0.00	0.00	0.00
	<b>65.00</b>	<b>1.01</b>	<b>24.62</b>	<b>18.09</b>
<b>MISC Monads</b>				
Monads 2.5-5	72	1.12	0.58	0.43
Monads 5.1-10	48	0.75	3.84	2.82
Monads <2.5	40	0.62	8.00	5.88
	<b>160.00</b>	<b>2.49</b>	<b>12.42</b>	<b>9.13</b>
<b>TOTAL</b>	<b>6417.12</b>	<b>100.00</b>	<b>136.12</b>	<b>100.00</b>

Table 17d. Phytoplankton composition

28 Aug 1986 Sta. 5		Cells	Cells	Biomass	Biomass
Taxa	per/ml	%	mg/m3	%	
<b>Cyanophyta</b>					
Anabaena sp.	0	0.00	0.00	0.00	0.00
Aphanocapsa sp.	1408	19.35	12.39	7.79	
Chroococcus sp.	5376	73.87	2.80	1.76	
Lyngbya birgeii	0.12	0.00	12.00	7.54	
Microcystis aeruginosa	0	0.00	0.00	0.00	0.00
Merismopedia minima	0	0.00	0.00	0.00	0.00
	<b>6784.12</b>	<b>93.22</b>	<b>27.19</b>	<b>17.08</b>	
<b>Chrysophyta</b>					
Dinobryon divergens	4.00	0.05	0.97	0.61	
Chrysochromulina parva	44.00	0.60	1.06	0.67	
Mallomonas pseudocoronata	8	0.11	12.00	7.54	
	<b>56.00</b>	<b>0.77</b>	<b>14.04</b>	<b>8.82</b>	
<b>Cryptophyta</b>					
Katablepharis ovalis	0	0.00	0.00	0.00	0.00
Cryptomonas marssonii	23	0.32	10.03	6.30	
Cryptomonas erosa	2	0.03	2.00	1.26	
Rhodomonas lens	0	0.00	0.00	0.00	0.00
Rhodomonas minuta	132	1.81	10.56	6.64	
	<b>157.00</b>	<b>2.16</b>	<b>22.59</b>	<b>14.19</b>	
<b>Dinophyceae</b>					
Ceratium hirundinella	0.08	0.00	7.06	4.44	
Gymnodinium sp.	16	0.22	4.48	2.82	
Gymnodinium sp.	4	0.05	4.00	2.51	
Glenodinium pulviscus	1	0.01	3.64	2.29	
Peridinium willei	0.2	0.00	12.33	7.75	
	<b>21.28</b>	<b>0.29</b>	<b>31.51</b>	<b>19.80</b>	
<b>Bacillariophyceae</b>					
Anomoeoneis vitrea	48	0.66	11.71	7.36	
Asterionella formosa	1	0.01	0.58	0.37	
Cyclotella spp.	60	0.82	18.00	11.31	
Synedra ulna	0	0.00	0.00	0.00	0.00
	<b>109.00</b>	<b>1.50</b>	<b>30.29</b>	<b>19.04</b>	
<b>Chlorophyta</b>					
Chlamydomonas spp.	36.00	0.49	7.02	4.41	
Elakatothrix gelatinosa	13	0.18	0.70	0.44	
Oocystis gigas v. incrass.	2	0.03	17.01	10.69	
Oocystis pusilla	0	0.00	0.00	0.00	0.00
Planctonema lauterbornii	23	0.32	0.70	0.44	
Platymonas elliptica	0	0.00	0.00	0.00	0.00
Scenedesmus bijuga	0	0.00	0.00	0.00	0.00
Tetradron muticum	4	0.05	0.22	0.14	
	<b>78.00</b>	<b>1.07</b>	<b>25.65</b>	<b>16.12</b>	
<b>MISC Monads</b>					
Monads 2.5-5	24	0.33	0.19	0.12	
Monads 5.1-10	16	0.22	1.28	0.80	
Monads <2.5	32	0.44	6.40	4.02	
	<b>72.00</b>	<b>0.99</b>	<b>7.87</b>	<b>4.95</b>	
<b>TOTAL</b>	<b>7277.40</b>	<b>100.00</b>	<b>159.14</b>	<b>100.00</b>	

Table 17e. Phytoplankton composition

Sta 1 21 Sept 86					
Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %	
<b>Cyanophyta</b>					
Anabaena sp.	0	0.00	0.00	0.00	
Aphanocapsa sp.	1024	17.66	9.01	8.37	
Chroococcus sp.	3520	60.71	1.83	1.70	
Lyngbya birgei	0	0.00	0.00	0.00	
Microcystis aeruginosa	0	0.00	0.00	0.00	
Single Cells	144	2.48	0.07	0.07	
Merismopedia minima	440	7.59	0.05	0.05	
	5128	88.448	10.97	10.19	
<b>Chrysophyta</b>					
Dinobryon divergens	21	0.36	5.10	4.74	
Chrysochromulina parva	132	2.28	3.19	2.97	
Pseudopepinella erkerensis	16.00	0.28	3.26	3.03	
Mallomonas pseudocoronata	0	0.00	0.00	0.00	
	169	2.91	11.56	10.74	
<b>Cryptophyta</b>					
Katablepharis ovalis	0	0.00	0.00	0.00	
Cryptomonas marssonii	6	0.10	2.62	2.43	
Cryptomonas erosa	1	0.02	1.00	0.93	
Rhodomonas lens	0	0.00	0.00	0.00	
Rhodomonas minuta	112	1.93	8.96	8.32	
	119.00	2.05	12.58	11.68	
<b>Dinophyceae</b>					
Ceratium hirundinella	0.04	0.00	3.53	3.28	
Glenodinium pulviscus	0	0.00	0.00	0.00	
Peridinium willet	0	0.00	0.00	0.00	
	0.04	0.00	3.53	3.28	
<b>Bacillariophyceae</b>					
Anomoeoneis vitrea	24	0.41	5.86	5.44	
Asterionella formosa	0	0.00	0.00	0.00	
Cyclotella spp.	129	2.21	38.40	35.68	
Synedra ulna	0	0.00	0.00	0.00	
	152.00	2.62	44.26	41.12	
<b>Chlorophyta</b>					
Chlamydomonas spp.	0.00	0.00	0.00	0.00	
Elakatothrix gelatinosa	6	0.14	0.43	0.40	
Oocystis gigas v. incrass.	0.72	0.01	6.12	5.69	
Oocystis pusilla	16	0.28	2.03	1.89	
Oocystis borget	3	0.05	2.60	2.41	
Planctonema leuterbornii	10	0.17	0.30	0.28	
Platymonas elliptica	0	0.00	0.00	0.00	
Scenedesmus brugga	0	0.00	0.00	0.00	
Tetraedron muticum	4	0.07	0.22	0.20	
	41.72	0.72	11.70	10.87	
<b>MISC Monads</b>					
Monads 2.5-5	88	1.52	0.71	0.66	
Monads 5.1-10	64	1.10	5.12	4.76	
Monads <2.5	36	0.62	7.20	6.69	
	188.00	3.24	13.03	12.11	
<b>TOTAL</b>	<b>5797.76</b>	<b>100.00</b>	<b>107.63</b>	<b>100.00</b>	

Table 18 a. Phytoplankton composition

Sta 3 21 Sept 86

Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Anabaena sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	96	1.63	0.84	0.64
Aphanocapsa sp.	0	0.00	0.00	0.00
Chroococcus sp.	4544	77.09	2.36	1.79
Lyngbya birgei	0.04	0.00	4.00	3.03
Microcystis aeruginosa	0	0.00	0.00	0.00
Merismopedia minima	608	10.31	0.07	0.05
Single Cells	148	2.51	0.08	0.06
	<b>5248.04</b>	<b>89.0304</b>	<b>7.28</b>	<b>5.52</b>
<b>Chrysophyta</b>				
Dinobryon divergens	18.00	0.31	4.37	3.32
Chrysochromulina parva	120.00	2.04	2.90	2.20
Pseudopedinella erkenis	0.00	0.00	0.00	0.00
Mallomonas pseudocoronata	1	0.02	1.50	1.14
	<b>139.00</b>	<b>2.36</b>	<b>8.78</b>	<b>6.66</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	0	0.00	0.00	0.00
Cryptomonas marssonii	12	0.20	5.23	3.97
Cryptomonas erosa	2	0.03	2.00	1.52
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minuta	168	2.85	13.44	10.20
	<b>182.00</b>	<b>3.09</b>	<b>20.67</b>	<b>15.68</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.12	0.00	10.60	8.04
Glenodinium pulviscus	0	0.00	0.00	0.00
Peridinium willei	0.5	0.01	5.00	3.79
	<b>0.62</b>	<b>0.01</b>	<b>15.60</b>	<b>11.83</b>
<b>Bacillariophyceae</b>				
Anomoeoneis vitrea	31	0.53	7.56	5.74
Asterionella formosa	0	0.00	0.00	0.00
Cyclotella spp.	148	2.51	44.40	33.68
Synedra ulna	0	0.00	0.00	0.00
	<b>179.00</b>	<b>3.04</b>	<b>51.96</b>	<b>39.42</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	0.00	0.00	0.00	0.00
Elakatothrix gelatinosa	8	0.14	0.43	0.33
Coccytis gigas v. increase	2	0.03	17.01	12.90
Coccytis pusilla	0	0.00	0.00	0.00
Coccytis borgeri	0	0.00	0.00	0.00
Flanctonema leuterbornii	12	0.20	0.36	0.28
Pistimonas elliptica	4	0.07	4.16	3.16
Scenedesmus bijuga	0	0.00	0.00	0.00
Tetraedron muticum	4	0.07	0.22	0.16
	<b>30.00</b>	<b>0.51</b>	<b>22.18</b>	<b>16.83</b>
<b>MISC Monads</b>				
Monads 2.5-5	68	1.15	0.55	0.42
Monads 5.1-10	40	0.68	3.20	2.43
Monads <2.5	5	0.14	1.50	1.21
	<b>116.00</b>	<b>1.97</b>	<b>5.35</b>	<b>4.06</b>
<b>TOTAL</b>	<b>5894.66</b>	<b>100.00</b>	<b>131.82</b>	<b>100.00</b>

Table 18b. Phytoplankton composition

Sta 5 21 Sept 86				
Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Aphanocapsa sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	0	0.00	0.00	0.00
Chroococcus sp.	2976	67.66	1.55	0.94
Gomphosphaera lacustris	400	9.09	3.28	2.00
Lyngbya birgei	0.16	0.00	16.00	9.77
Microcystis aeruginosa	22	0.50	1.44	0.88
Single, cells	96	2.18	0.05	0.03
Merismopedia minima	384	8.73	0.04	0.03
	<b>3878.16</b>	<b>88.1761</b>	<b>22.36</b>	<b>13.65</b>
<b>Chrysophyta</b>				
Dinobryon divergens	9.00	0.20	2.19	1.33
Chrysochromulina parva	88.00	2.00	2.13	1.30
Pseudopedinella erkensis	0.00	0.00	0.00	0.00
Mallomonas pseudocoronata	0	0.00	0.00	0.00
	<b>97.00</b>	<b>2.21</b>	<b>4.32</b>	<b>2.63</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	0	0.00	0.00	0.00
Cryptomonas merissonii	5	0.11	2.18	1.33
Cryptomonas erosa	3	0.07	3.00	1.83
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minuta	112	2.55	8.96	5.47
	<b>120.00</b>	<b>2.73</b>	<b>14.14</b>	<b>8.63</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.04	0.00	3.53	2.16
Glennodinium pulvicaus	0	0.00	0.00	0.00
Peridinium wiliei	0	0.00	0.00	0.00
	<b>0.04</b>	<b>0.00</b>	<b>3.53</b>	<b>2.16</b>
<b>Bacillariophyceae</b>				
Anomooneis vitrea	24	0.55	5.86	3.57
Asterionella formosa	0	0.00	0.00	0.00
Cyclotella spp.	104	2.36	31.20	19.04
Cyclotella bodanica	0	0.00	0.00	0.00
Synedra ulra	0	0.00	0.00	0.00
	<b>128.00</b>	<b>2.91</b>	<b>37.06</b>	<b>22.62</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	0.00	0.00	0.00	0.00
Elakatothrix gelatinosa	8	0.18	0.43	0.26
Oocystis gigas v. incrass.	8	0.18	68.03	41.52
Oocystis pusilla	0	0.00	0.00	0.00
Oocystis birgei	4	0.09	3.46	2.11
Planctonema lauterbornii	7	0.16	0.21	0.13
Platymonas elliptica	0	0.00	0.00	0.00
Scenedesmus bifuga	40	0.91	2.52	1.54
Tetraedron muticum	0	0.00	0.00	0.00
	<b>67.00</b>	<b>1.52</b>	<b>74.66</b>	<b>45.57</b>
<b>MISC Monads</b>				
Monads 2.5-5	52	1.18	0.42	0.26
Monads 5.1-10	32	0.73	2.56	1.56
Monads <2.5	24	0.55	4.80	2.93
	<b>108.00</b>	<b>2.46</b>	<b>7.78</b>	<b>4.75</b>
<b>TOTAL</b>	<b>4398.20</b>	<b>100.00</b>	<b>163.84</b>	<b>100.00</b>

Table 18c. Phytoplankton composition

Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
<i>Anabaena</i> sp.	0	0.00	0.00	0.00
<i>Aphanocapsa</i> sp.	64	1.22	0.56	0.28
<i>Aphanocapsa</i> sp.	0	0.00	0.00	0.00
<i>Chroococcus</i> sp.	3936	75.30	2.05	1.02
<i>Lyngbya birgei</i>	0.04	0.00	4.00	1.99
<i>Microcystis aeruginosa</i>	32	0.61	2.99	1.04
<i>Merismopedia minima</i>	128	2.45	0.01	0.01
Single Cells	304	5.82	0.16	0.08
	<b>4160.04</b>	<b>79.5869</b>	<b>8.72</b>	<b>4.33</b>
<b>Chrysophyta</b>				
<i>Dinobryon divergens</i>	10.00	0.19	2.43	1.21
<i>Chrysochromulina parva</i>	140.00	2.68	3.39	1.68
<i>Pseudopedinella erkenis</i>	28.00	0.54	5.71	2.84
<i>Mallomonas pseudocoronata</i>	1	0.02	1.50	0.75
	<b>179.00</b>	<b>3.42</b>	<b>13.03</b>	<b>6.48</b>
<b>Cryptophyta</b>				
<i>Katsblepharis ovalis</i>	0	0.00	0.00	0.00
<i>Cryptomonas maresonii</i>	30	0.57	13.08	6.50
<i>Cryptomonas erose</i>	10	0.19	10.00	4.97
<i>Rhodomonas lens</i>	0	0.00	0.00	0.00
<i>Rhodomonas minuta</i>	424	8.11	33.92	16.87
	<b>464.00</b>	<b>8.88</b>	<b>57.00</b>	<b>28.35</b>
<b>Dinophyceae</b>				
<i>Ceratium hirundinella</i>	0	0.00	0.00	0.00
<i>Glenodinium pulviscus</i>	0	0.00	0.00	0.00
<i>Peridinium willei</i>	0	0.00	0.00	0.00
	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
<b>Bacillariophyceae</b>				
<i>Anomoeoneis vitrea</i>	23	0.44	5.61	2.79
<i>Asterionella formosa</i>	0	0.00	0.00	0.00
<i>Cyclotella</i> spp.	216	4.13	64.80	32.22
<i>Synedra ulna</i>	0	0.00	0.00	0.00
	<b>239.00</b>	<b>4.57</b>	<b>70.41</b>	<b>35.02</b>
<b>Chlorophyta</b>				
<i>Chlamydomonas</i> spp.	0.00	0.00	0.00	0.00
<i>Elatolithrix gelatinosa</i>	4	0.08	0.22	0.11
<i>Cocystis gigas</i> v. <i>incrass.</i>	4	0.08	34.02	16.92
<i>Cocystis pusilla</i>	0	0.00	0.00	0.00
<i>Cocystis borgeri</i>	0	0.00	0.00	0.00
<i>Planctonema lauterbornii</i>	5	0.10	0.15	0.08
<i>Platymonas elliptica</i>	4	0.08	4.16	2.07
<i>Scenedesmus bijuga</i>	20	0.38	1.26	0.63
<i>Tetraedron muticum</i>	4	0.08	0.22	0.11
	<b>41.00</b>	<b>0.78</b>	<b>40.02</b>	<b>19.90</b>
<b>MISC Monads</b>				
Monads 2.5-5	68	1.30	0.55	0.27
Monads 5.1-10	32	0.61	2.56	1.27
Monads >2.5	44	0.84	8.80	4.38
	<b>144.00</b>	<b>2.75</b>	<b>11.91</b>	<b>5.92</b>
<b>TOTAL</b>	<b>5227.04</b>	<b>100.00</b>	<b>201.09</b>	<b>100.00</b>

Table 19a. Phytoplankton composition

Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Anatsera sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	0	0.00	0.00	0.00
Chroococcus sp.	4672	77.41	2.43	1.28
Gomphosphaeria lacustris	96	1.59	0.79	0.42
Lunghia birgei	0.04	0.00	4.00	2.11
Microcystis aeruginosa	8	0.13	0.52	0.26
Single cells	216	3.58	0.11	0.06
Merismopedia minima	0	0.00	0.00	0.00
	<b>4992.04</b>	<b>82.716</b>	<b>7.85</b>	<b>4.14</b>
<b>Chrysophyta</b>				
Dinobryon divergens	26.00	0.43	6.32	3.33
Chrysochromulina parva	176.00	2.92	4.26	2.25
Pseudopedinella erkenis	16.00	0.27	3.26	1.72
Mallomonas pseudocoronata	2	0.03	3.00	1.58
	<b>220.00</b>	<b>3.65</b>	<b>16.84</b>	<b>8.89</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	0	0.00	0.00	0.00
Cryptomonas marssonii	24	0.40	10.46	5.52
Cryptomonas erosa	6	0.10	8.00	3.17
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minute	352	5.83	28.16	14.86
	<b>382.00</b>	<b>6.33</b>	<b>44.62</b>	<b>23.54</b>
<b>Dinophyceae</b>				
Cerastium hirundinella	0.12	0.00	10.60	5.59
Glenodinium pulviscus	0	0.00	0.00	0.00
Peridinium willei	0	0.00	0.00	0.00
	<b>0.12</b>	<b>0.00</b>	<b>10.60</b>	<b>5.59</b>
<b>Bacillariophyceae</b>				
Anomooneis vitrea	30	0.50	7.32	3.86
Asterionella formosa	0	0.00	0.00	0.00
Cyclotella spp.	216	3.58	64.80	34.19
Cyclotella bodanica	2	0.03	23.72	12.51
Synedra ulna	0	0.00	0.00	0.00
	<b>248.00</b>	<b>4.11</b>	<b>95.84</b>	<b>50.56</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	0.00	0.00	0.00	0.00
Elakatothrix gelatinosa	0	0.00	0.00	0.00
Cocystis gigas v. incrass.	1	0.02	8.50	4.49
Cocystis borgeri	0	0.00	0.00	0.00
Planctonema lauterbornii	8	0.13	0.24	0.13
Platymonas elliptica	0	0.00	0.00	0.00
Scenedesmus bijuga	16	0.27	1.01	0.53
Tetraedron muticum	3	0.13	0.43	0.23
	<b>33.00</b>	<b>0.55</b>	<b>10.19</b>	<b>5.37</b>
<b>MISC Monads</b>				
Monads 2.5-5	128	2.12	1.04	0.55
Monads 5.1-10	32	0.53	2.56	1.35
Monads <2.5	0	0.00	0.00	0.00
	<b>160.00</b>	<b>2.65</b>	<b>3.60</b>	<b>1.90</b>
<b>TOTAL</b>	<b>6035.16</b>	<b>100.00</b>	<b>189.53</b>	<b>100.00</b>

Table 19b. Phytoplankton composition

Sta 3 24Sept86

Taxa	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Anabaena sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	0	0.00	0.00	0.00
Chroococcus sp.	4576	80.04	2.38	1.35
Lyngbya birgei	0.08	0.00	8.00	4.54
Microcystis seruginosa	0	0.00	0.00	0.00
Single, cells	232	4.06	0.12	0.07
Merismopedia minima	0	0.00	0.00	0.00
	<b>4808.08</b>	<b>84.0997</b>	<b>10.50</b>	<b>5.96</b>
<b>Chrysophyta</b>				
Dinobryon divergens	2.00	0.03	0.49	0.28
Chrysochromulina parva	208.00	3.64	5.03	2.85
Pseudopedinella erkersis	0.00	0.00	0.00	0.00
Mallomonas pseudocoronata	0	0.00	0.00	0.00
	<b>210.00</b>	<b>3.67</b>	<b>5.52</b>	<b>3.13</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	0	0.00	0.00	0.00
Cryptomonas marssonii	32	0.56	13.95	7.91
Cryptomonas erosa	3	0.05	3.00	1.70
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minuta	308	5.39	24.64	13.93
	<b>343.00</b>	<b>6.00</b>	<b>41.59</b>	<b>23.59</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.04	0.00	3.53	2.00
Glenodinium pulviscus	0	0.00	0.00	0.00
Peridinium willei	0	0.00	0.00	0.00
	<b>0.04</b>	<b>0.00</b>	<b>3.53</b>	<b>2.00</b>
<b>Bacillariophyceae</b>				
Anomoeoneis vitrea	24	0.42	5.86	3.32
Asterionella formosa	2	0.03	1.16	0.66
Cyclotella spp.	220	3.85	66.00	37.43
Synedra ulna	0	0.00	0.00	0.00
	<b>246.00</b>	<b>4.30</b>	<b>73.02</b>	<b>41.41</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	0.00	0.00	0.00	0.00
Eleakothrix gelatinosa	16	0.28	0.87	0.49
Docystis gigas v. increas.	4	0.07	34.02	19.29
Docystis pusilla	0	0.00	0.00	0.00
Docystis borgeri	2	0.03	1.73	0.98
Planctonema leuterbornii	0	0.00	0.00	0.00
Piatomonas elliptica	0	0.00	0.00	0.00
Scenedesmus biluca	4	0.07	0.25	0.14
Tetraedron muticum	0	0.00	0.00	0.00
	<b>26.00</b>	<b>0.45</b>	<b>36.87</b>	<b>20.91</b>
<b>MISC Monads</b>				
Monads 2.5-5	40	0.70	0.32	0.18
Monads 5.1-10	32	0.56	2.56	1.45
Monads <2.5	12	0.21	2.40	1.36
	<b>84.00</b>	<b>1.47</b>	<b>5.28</b>	<b>3.00</b>
<b>TOTAL</b>	<b>5717.12</b>	<b>100.00</b>	<b>176.31</b>	<b>100.00</b>

Table 19c. Phytoplankton composition

Sta 4 24 Sept 86

Taxo	Cells per/ml	Cells %	Biomass mg/m <sup>3</sup>	Biomass %
<b>Cyanophyta</b>				
Aphanocapsa sp.	128	2.63	1.13	0.72
Aphanocapsa sp.	0	0.00	0.00	0.00
Chroococcus sp.	3584	73.73	1.86	1.20
Gomphosphaeria lacustris	160	3.29	1.31	0.84
Lyngbya birgei	0.04	0.00	4.00	2.57
Microcystis aeruginosa	0	0.00	0.00	0.00
Single cells	160	3.29	0.08	0.05
Mormonopoda minima	0	0.00	0.00	0.00
	<b>4032.04</b>	<b>82.9454</b>	<b>8.39</b>	<b>5.38</b>
<b>Chrysophyta</b>				
Dinobryon divergens	7.00	0.14	1.70	1.09
Chrysochromulina parva	192.00	3.95	4.65	2.98
Pseudopedinella erkensis	8.00	0.16	1.63	1.05
Mallomonas pseudocoronata	1	0.02	1.50	0.96
	<b>208.00</b>	<b>4.28</b>	<b>9.48</b>	<b>6.08</b>
<b>Cryptophyta</b>				
Katablepharis ovalis	0	0.00	0.00	0.00
Cryptomonas marssonii	13	0.27	5.67	3.64
Cryptomonas erosa	5	0.10	5.00	3.21
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minuta	320	6.58	25.60	16.43
	<b>338.00</b>	<b>6.95</b>	<b>36.27</b>	<b>23.28</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.04	0.00	3.53	2.27
Glenodinium pulviscus	0	0.00	0.00	0.00
Peridinium willet	0	0.00	0.00	0.00
	<b>0.04</b>	<b>0.00</b>	<b>3.53</b>	<b>2.27</b>
<b>Bacillariophyceae</b>				
Achnanthes vitrea	17	0.35	4.15	2.66
Asterionella formosa	1	0.02	0.58	0.37
Cyclotella spp.	140	2.88	42.00	26.96
Cyclotella bodanica	3	0.06	35.57	22.83
	<b>161.00</b>	<b>3.31</b>	<b>82.30</b>	<b>52.83</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	0.00	0.00	0.00	0.00
Elakatothrix gelatinosa	0	0.00	0.00	0.00
Cocystis gigas v. incress.	1	0.02	8.50	5.46
Cocystis puella	0	0.00	0.00	0.00
Cocystis borgeri	0	0.00	0.00	0.00
Planctonema lauterbornii	4	0.08	0.12	0.08
Platomonas elliptica	1	0.02	1.04	0.67
Scenedesmus bijuga	8	0.16	0.50	0.32
Tetraedron muticum	4	0.08	0.22	0.14
	<b>18.00</b>	<b>0.37</b>	<b>10.39</b>	<b>6.67</b>
<b>MISC Monads</b>				
Monads 2.5-5	60	1.23	0.49	0.31
Monads 5.1-10	32	0.66	2.56	1.64
Monads <2.5	12	0.25	2.40	1.54
	<b>104.00</b>	<b>2.14</b>	<b>5.45</b>	<b>3.50</b>
<b>TOTAL</b>	<b>4861.08</b>	<b>100.00</b>	<b>155.80</b>	<b>100.00</b>

Table 19d. Phytoplankton composition

Taxa	Cells	Cells	Biomass	Biomass
	per/ml	%	mg/m <sup>3</sup>	%
<b>Cyanophyta</b>				
Aphanocapsa sp.	0	0.00	0.00	0.00
Aphanocapsa sp.	0	0.00	0.00	0.00
Chroococcus sp.	2363	74.68	1.23	1.24
Gomphosphaeria lacustris	64	2.02	0.52	0.53
Lynghya birgei	0.04	0.00	4.00	4.04
Microcystis aeruginosa	25	0.79	1.64	1.65
Single cells	120	3.78	0.06	0.06
Merismopedia minima	64	2.02	0.01	0.01
	<b>2641.04</b>	<b>83.2936</b>	<b>7.46</b>	<b>7.53</b>
<b>Chrysophyta</b>				
Dinobryon divergens	6.00	0.19	1.46	1.47
Chrysochromulina parva	88.00	2.78	2.13	2.15
Pseudopedinella erkerensis	12.00	0.38	2.45	2.47
Mallomonas pseudocoronata	1	0.03	1.50	1.51
	<b>107.00</b>	<b>3.37</b>	<b>7.54</b>	<b>7.61</b>
<b>Cryptophyta</b>				
Ketoblepharis ovalis	0	0.00	0.00	0.00
Cryptomonas marsonii	11	0.35	4.80	4.84
Cryptomonas erosa	4	0.13	4.00	4.04
Rhodomonas lens	0	0.00	0.00	0.00
Rhodomonas minuta	176	5.55	14.08	14.21
	<b>191.00</b>	<b>6.02</b>	<b>22.88</b>	<b>23.09</b>
<b>Dinophyceae</b>				
Ceratium hirundinella	0.16	0.01	14.13	14.26
Glenodinium pulviscus	0	0.00	0.00	0.00
Peridinium willet	0	0.00	0.00	0.00
	<b>0.16</b>	<b>0.01</b>	<b>14.13</b>	<b>14.26</b>
<b>Bacillariophyceae</b>				
Anomoeoneis vitrea	9	0.28	2.20	2.22
Asterionella formosa	0	0.00	0.00	0.00
Cyclotella spp.	104	3.28	31.20	31.49
Cyclotella bodanica		0.00	0.00	0.00
Synedra ulna	0	0.00	0.00	0.00
	<b>113.00</b>	<b>3.56</b>	<b>33.40</b>	<b>33.71</b>
<b>Chlorophyta</b>				
Chlamydomonas spp.	0.00	0.00	0.00	0.00
Elakatothrix gelatinosa	0	0.00	0.00	0.00
Cocystis gigas v. incrass.	0.56	0.02	4.76	4.81
Cocystis pusilla	0	0.00	0.00	0.00
Cocystis borgeri	0	0.00	0.00	0.00
Planctonema lauterbornii	14	0.44	0.43	0.43
Platymonas elliptica	0	0.00	0.00	0.00
Scenedesmus bijuga	24	0.76	1.51	1.53
Tetraedron muticum	0	0.00	0.00	0.00
	<b>38.56</b>	<b>1.22</b>	<b>6.70</b>	<b>6.76</b>
<b>MISC Monads</b>				
Monads 2.5-5	32	1.01	0.26	0.26
Monads 5.1-10	24	0.76	1.92	1.94
Monads <2.5	24	0.76	4.80	4.84
	<b>80.00</b>	<b>2.52</b>	<b>6.98</b>	<b>7.04</b>
<b>TOTAL</b>	<b>3170.76</b>	<b>100.00</b>	<b>99.08</b>	<b>100.00</b>

Table 19e. Phytoplankton composition

### Lake Mead Pre-Fertilization Study

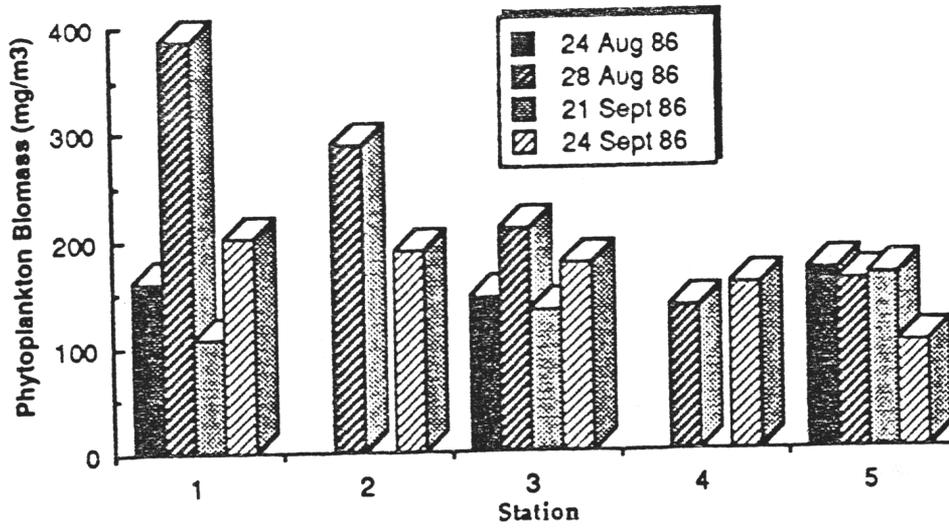


Figure 14. Summary of phytoplankton biomass

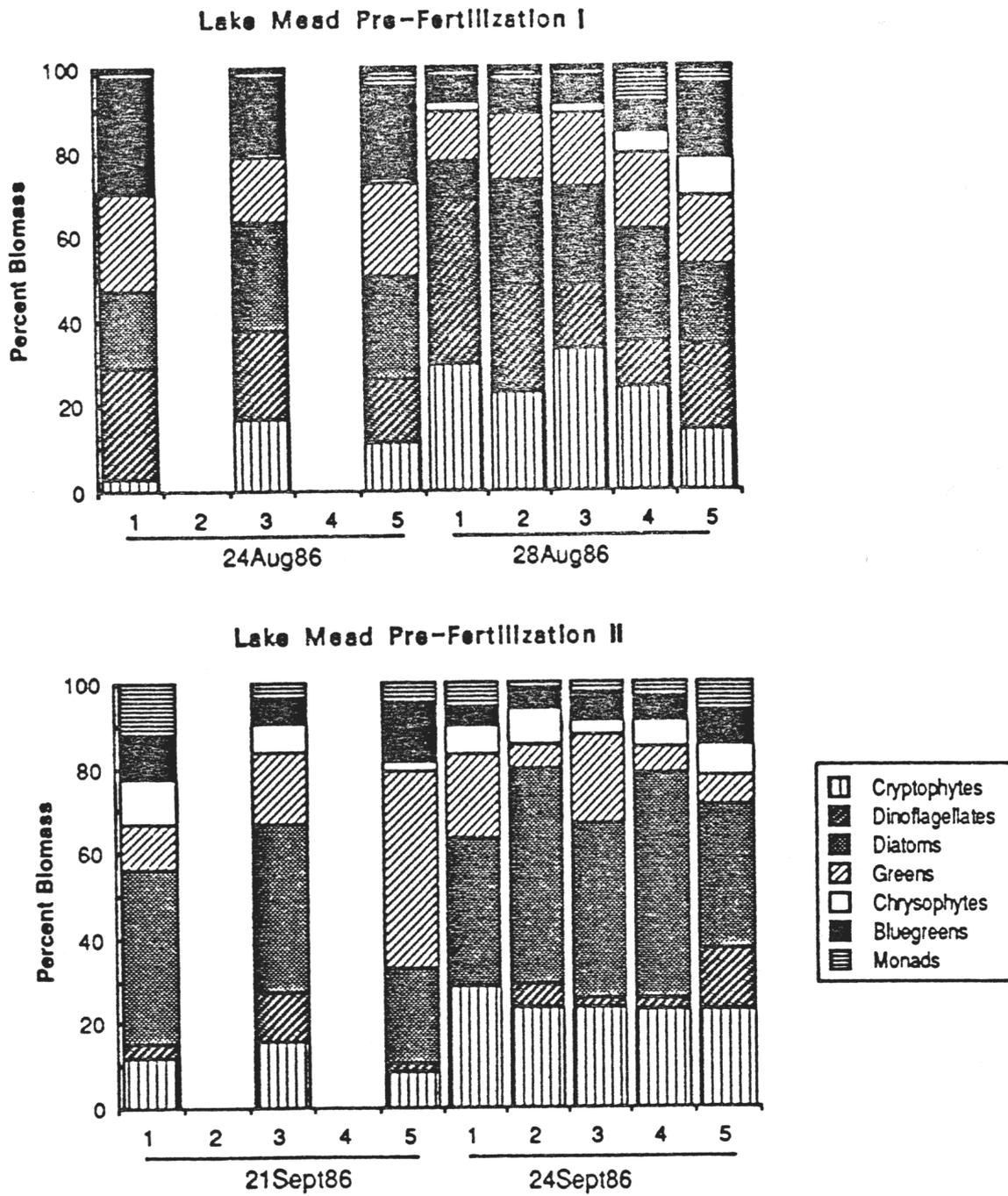


Figure 15. Cathedral Cove, PF I and PF II, phytoplankton %-composition

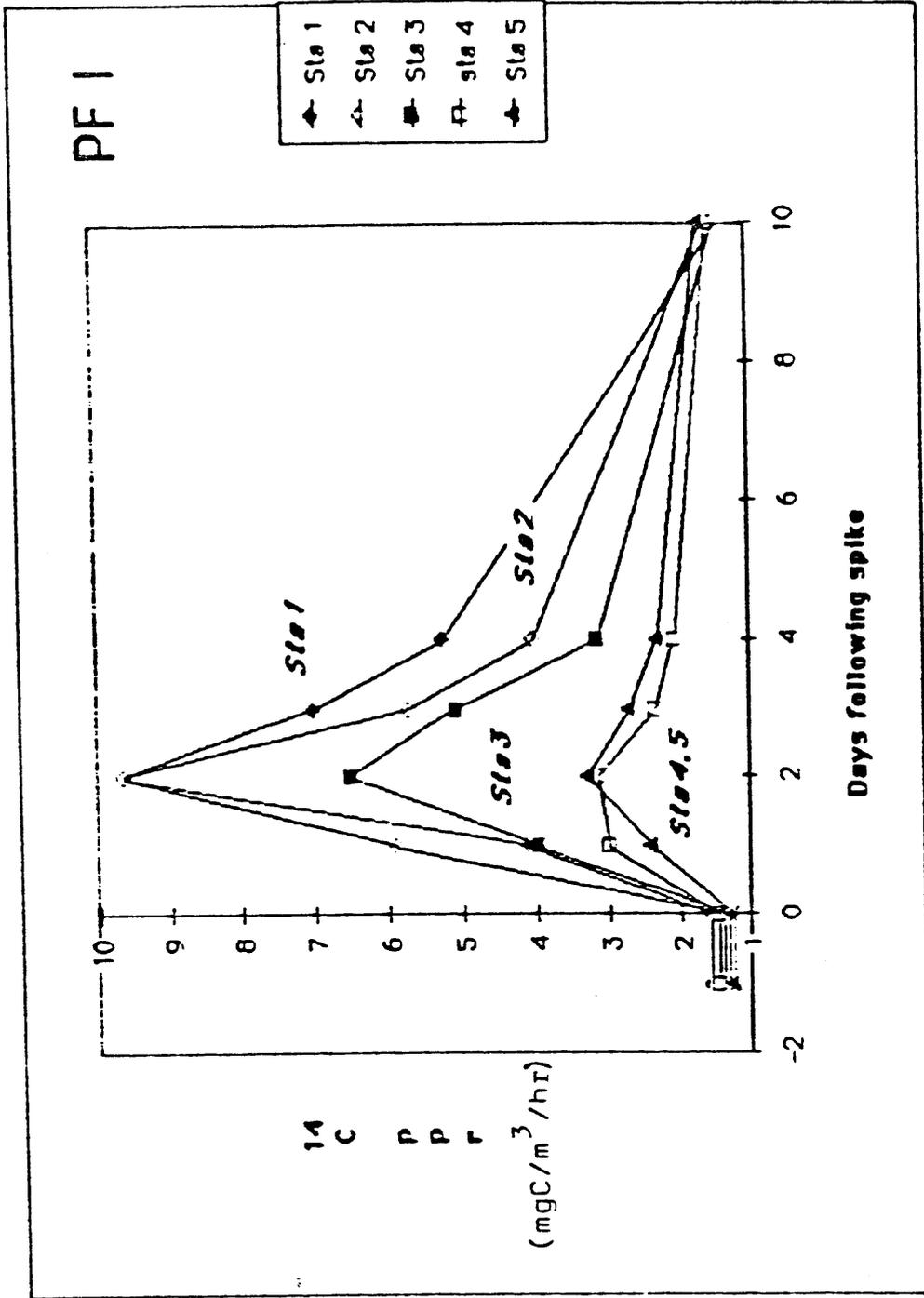


Figure 16. Cathedral Cove  $^{14}\text{C}$ - Primary Productivity rates-Preferential-  
 tion I. Spike added on 25 August 1986 (Day 0)

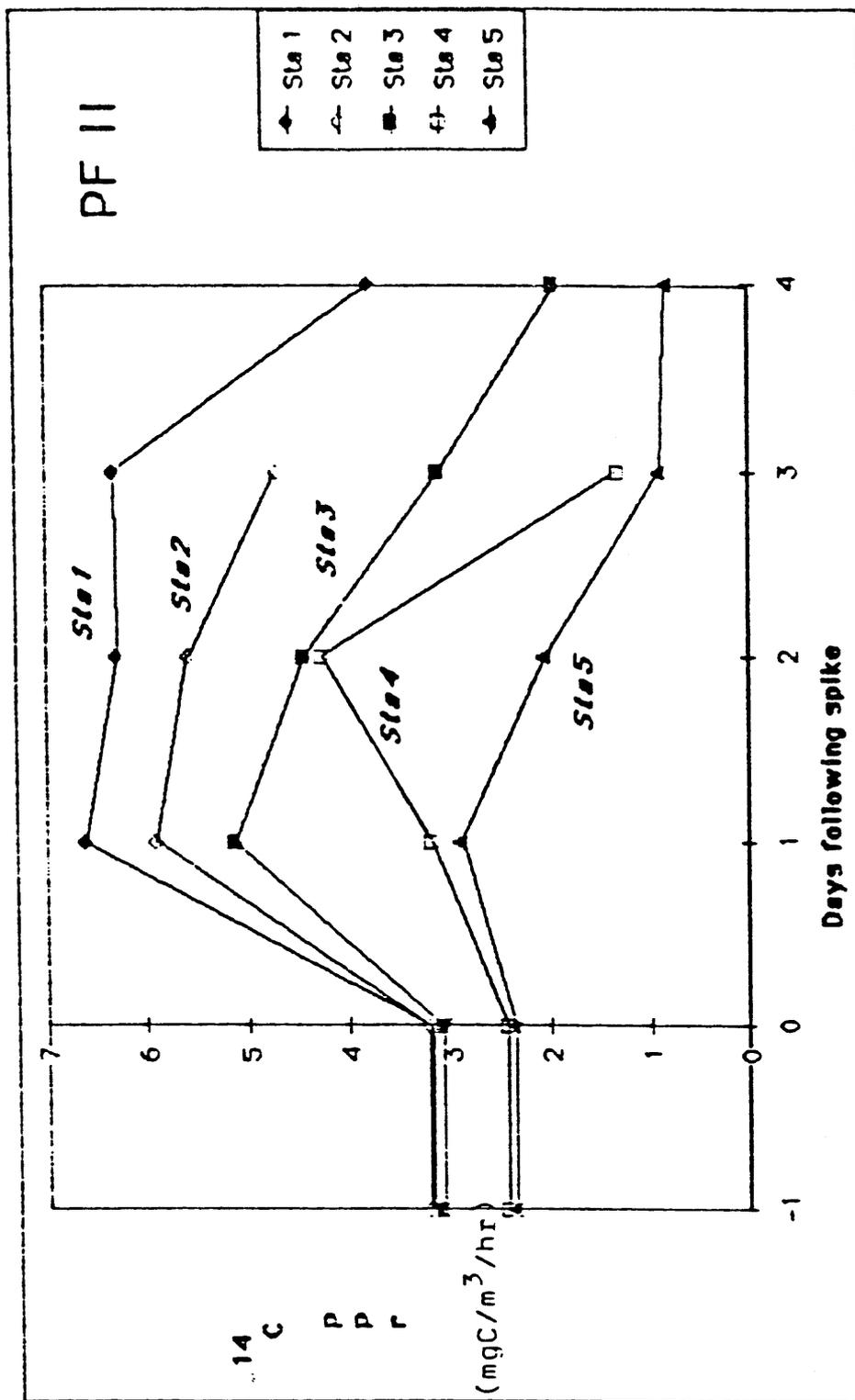


Figure 17. Cathedral Cove  $^{14}\text{C}$ - Primary Productivity rates- Prefertilization II  
Spike added on 22 September 1986 (Day 0)

zooplankton biomass (utilizable by forage fish and juvenile predators) without dramatically increasing the standing stock of algae, thus minimizing changes in water clarity.

#### 5.4.3 Water Clarity

Secchi depth measurements are presented in Table 20. The maximum difference between the cove and the controls was only -0.7 m in PF I and occurred two days after peak algal biomass was observed. No visual differences were seen from the boat or from an overflight about 3000 feet above the cove on Day 3 of PF I.

A much more dramatic effect was seen during PF II. The water in the inner cove was noticeably greener on the day following fertilization than at the outer stations and secchi depth was reduced more than 2 meters (out of about 10m). This "greenness" persisted for at least two more days (and is evident from Table 20) despite the flushing and relatively poor viewing conditions due to wave action. However, water clarity was still excellent in the inner cove and actually exceeded the clarity measured two weeks earlier, prior to fertilization.

Table 21 summarizes values of vertical extinction coefficients calculated by linear regressions of the quantum photometer (light meter) vertical profiles. Data are presented for the day prior to each fertilization and then at maximum chlorophyll for PF I and near-maximum chlorophyll for PF II (it was too rough on the lake on day 2 when chlorophyll reached its maximum value). It can be seen that there was little difference between pre and post fertilization values during PF I, either inside or outside the cove. During PF II, the extinction coefficient increased in the inner cove but actually decreased in the middle and outer cove.

Table 20.

CATHEDRAL COVE PREFERTILIZATION STUDY-SECCHI DEPTH (m)

DATE (1986)	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	NOTES
8/14	5.5	5.2	5.2	5.2	5.0	Spike Day
8/24	5.5	4.7	4.5	4.5	4.7	
8/25	5.2	5.2	5.3	5.3	5.2	
8/26	5.1	4.5	5.0	5.0	5.0	
8/27 (AM)	4.5	5.3	5.5	5.5	5.6	
8/27 (PM)	5.2	5.3	5.3	5.6	5.8	Max Δ ~ 0.7m
8/28	5.0	5.2	5.0	5.0	5.0	
8/29	5.0	5.7	6.2	6.2	6.0	
8/31	6.1	5.5			5.5	
9/4	5.2					
9/10						
9/21	8.8	8.7	7.7	7.7	8.6	Spike Day
9/22	6.9	8.5	8.9	8.9	9.4	Max Δ ~ 2.3m
9/23	7.4	8.5	~9	~9	~8-9	4-6' waves
9/24	7.5	10.5	~9-10	~9-10	~8-10	4-8' waves
9/25	8.7	9.7	10.5	10.5	10.2	oalm
9/26	11.2	10.6	9.7	10.2	~10-11	3' waves
9/29	12.5	11.2	10.6	11.2	10.5	
10/15						

Table 21. Cathedral Cove vertical light extinction coefficients ( $k$ , in  $m^{-1}$ ), PF I and PF II. Values determined by linear regression of  $\ln I(z)$  versus depth.  $r > 0.97$  for all values. A depth range of 8 meters was used for Station 1 on 24 August, 9 meters for Station 1 on 27 August, and 10 meters for all other data sets. Peak chlorophyll levels occurred on 27 August for PF I and 24 September for PF II. Light attenuation data were not collected on 24 September because of rough weather.

STATION	1	2	3	4	5	$\bar{X} \pm S.D.$
24 August 1986 ( <u>PF I, Pre</u> ):						
	0.31	0.29	0.29	0.30	0.28	0.29 $\pm$ 0.01
27 August 1986 ( <u>PF I, Post</u> ):						
	0.29	0.30	0.30	0.28	0.25	0.28 $\pm$ 0.02
21 September 1986 ( <u>PF II, Pre</u> ):						
	0.30	0.27	0.28	0.27	0.28	0.28 $\pm$ 0.01
23 September 1986 ( <u>PF II, Post</u> ):						
	0.35	0.21	0.23	0.25	0.26	0.26 $\pm$ 0.05

It is also interesting to note that even though clarity improved markedly, as measured by secchi depth, between the two experiments, the extinction coefficients showed only a small change. Although a complete analysis of this phenomenon is beyond the scope of this study, it is clear that because of differences in the relative influence of suspended sediment, phytoplankton, and light absorbing solutes on light attenuation in the lake, extinction coefficients and secchi depth may not always correlate well. These observations have been noted by other researchers for natural lakes and reservoirs (10,25,39).

#### 5.4.4 Salinity Effects/Major Anions and Cations

All available evidence has shown that fertilization of the Overton Arm of Lake Mead, at the proposed levels, will not significantly increase the salinity of the lakewater. This conclusion is based on calculations, laboratory studies (Section 4.1), and the results of the Cathedral Cove pilot-scale experiments in August and September 1986 (Tables 22 and 23).

Field measurements of specific electrical conductivity (EC) before, during, and after the fertilizations showed that salinity was not significantly increased. Even in the inner portion of Cathedral Cove, where almost 3x the proposed dose for the Overton Arm was supplied in September 1986, we did not measure a significant increase in EC. During PF 1, within 2 hours of the actual fertilization, we conducted an intensive survey of the inner cove. Eight Hydrolab profiles of temperature, pH, conductivity, and D.O. were measured along an east-west transect of the inner cove and no significant differences were found.

The field EC data were further corroborated by complete analyses for TDS, Na, K, Ca, Mg,  $\text{HCO}_3$ ,  $\text{CO}_3$ , Cl,  $\text{SO}_4$ , and  $\text{SiO}_2$  performed by the U.S. Bureau of

Table 22. Specific electrical conductivity (EC, in umhos/cm) in the epilimnion of Cathedral Cove, Lake Mead during fertilization pilot studies in 1986. Data are from the inner cove (\*1), mid-cove (\*2), outer-cove (\*3), and control stations \*4 and \*5 in the Overton Arm outside the cove. Data expressed as mean  $\pm$ s.d. for n depths within the mixed layer,  $Z_e$ , before and after the fertilizations on 25 August and 22 September. The data for stations 1 and 2 for August 25 were collected immediately fertilizing these regions. Stations 3, 4, and 5 were sampled just prior to fertilization.

		STA 1	STA 2	STA 3	STA 4	STA 5
8/24:	$Z_e$	>9m	13m	13m	14m	14m
	$EC_e$	807 $\pm$ 1	806 $\pm$ 2	806 $\pm$ 1	805 $\pm$ 1	804 $\pm$ 1
	n	10	13	14	15	15
8/25:	$Z_e$	10m	12m	11-12m	12m	12m
	$EC_e$	824 $\pm$ 9	830 $\pm$ 10	827 $\pm$ 13	822 $\pm$ 9	819 $\pm$ 9
	n	11	13	12	13	13
8/26:	$Z_e$	11-12m	11-12m	11-12m	12m	12m
	$EC_e$	835 $\pm$ 7	840 $\pm$ 3	836 $\pm$ 5	836 $\pm$ 5	839 $\pm$ 4
	n	12	12	12	13	13
9/21:	$Z_e$	>15m	16m	17m	17m	16.5m
	$EC_e$	802 $\pm$ 1	801 $\pm$ 1	801 $\pm$ 1	802 $\pm$ 1	800 $\pm$ 2
	n	16	17	18	18	18
9/23:	$Z_e$	>15m	19m	18 <sup>*</sup> m	19m	18 <sup>*</sup> m
	$EC_e$	802 $\pm$ 0	800 $\pm$ 3	801 $\pm$ 2	801 $\pm$ 2	801 $\pm$ 2
	n	9	11	9	12	13

TABLE 23. Summary of the results of salinity analyses performed by the U.S. Bureau of Reclamation on water samples collected during the Cathedral Cove, Lake Mead pilot-scale fertilizations in 1986. The sampling dates are two days following enrichment with granular fertilizer in August and with liquid fertilizer in September 1986, respectively. Stations 1, 2 and 3 were located within the fertilized area, and stations 4 and 5 were control areas outside of the cove. Field pH and electrical conductivity (EC) are averages taken from vertical profiles throughout the epilimnion by UNLY. All other data were determined in the USBR, Lower Colorado Region, Soil and Water Laboratory on 0-5 m depth-integrated composite water samples. EC in  $\mu\text{mho/cm}$ , all other data in  $\text{mg/l}$ .

DATE	STATION	pH		EC		TDS	Na	K	Ca	Mg
		Field	Lab	Field	Lab					
27 Aug 1986	1	8.0	7.4	840	848	584	66	4	68	26
	2	8.5	7.6	839	846	587	66	4	68	26
	3	8.4	7.6	840	846	589	66	4	69	26
	4	8.4	7.6	844	843	583	66	4	68	26
	5	8.3	7.8	843	845	562	66	4	68	26
24 Sep 1986	1	8.4	7.4	802	834	560	64	4	68	26
	2	8.4	7.4	802	829	553	63	4	68	26
	3	8.4	7.4	802	832	558	63	4	68	26
	4	-	7.5	-	830	555	63	4	68	26
	5	8.3	7.7	801	828	552	63	4	67	25

DATE	STATION	$\text{HCO}_3$	Cl	$\text{SO}_4$	$\text{SiO}_2$	USBR
						Lab. #
27 Aug 1986	1	149	60	228	9	86-3748.
	2	151	59	230	9	86-3749
	3	144	57	230	8	86-3750
	4	142	64	226	9	86-3751
	5	156	53	223	9	86-3752
24 Sep 1986	1	146	57	223	8	86-3753
	2	151	53	216	8	86-3754
	3	156	53	216	9	86-3755
	4	142	57	223	8	86-3756
	5	154	59	218	8	86-3757

Reclamation (Table 23). EC was also determined independently in this laboratory. The analyses were performed on two sets of 0-5 meter integrated composite water samples, one from each fertilization experiment. They were sampled approximately 48 hours after the initial application to allow the wind to vertically mix the fertilizer throughout the epilimnion. The five samples corresponded to the five station transect used for all limnological monitoring in the study. Stations 1, 2, and 3 were inside the cove, and stations 4 and 5 were the designated control sites outside the fertilized cove.

The data clearly show that neither salinity, as estimated by TDS and EC, nor any of the major anions and cations were significantly increased by fertilization with either granular (diammonium phosphate plus ammonium nitrate) or liquid (ammonium phosphate/polyphosphate plus ammonium nitrate) formulations. This finding is consistent with the field measurements of EC reported earlier (<4% relative percent difference between the field and lab values). Only if extremely high doses of these fertilizers were applied, orders of magnitude higher than those proposed for the Overton Arm and Gregg Basin experiments, could one reasonably expect to see an effect on the salinity of Lake Mead water.

It should also be noted that neither ammonium nor phosphate are routinely considered to contribute to the salinity of water bodies. They are nutrients which, even immediately after fertilization, will be present at levels thousands of times lower than the major components of the salt load of Lake Mead water. This fact is either explicitly stated or inferred in virtually every limnology and water quality textbook. Dr. Wetzel states on p. 143 of his textbook Limnology (39, one of the most widely used texts in North America), "The concentrations of four major cations, Ca, Mg, Na, K, and four major anions,  $\text{HCO}_3$ ,  $\text{CO}_3$ ,  $\text{SO}_4$ , and Cl, usually constitute the total ionic "salinity" of the water for all practical purposes. The concentrations of

ionized components of other elements such as nitrogen (N), phosphorus (P), and iron (Fe), and numerous minor elements are of immense biological importance, but from the standpoint of the composition of water they are small."

Similarly, Dr. G.E. Hutchinson, who is generally considered to be the "father" of modern limnology, writes on p. 553 of Volume I-Limnology (18):

"...it would be more satisfactory to define salinity as the concentration of the Na, K, Mg, Ca, CO<sub>3</sub>, SO<sub>4</sub>, and halide (Cl) present, all bicarbonate being converted to carbonate."

#### 5.4.5 Nutrients

Concentrations of ammonium-N, nitrate (+nitrite)-N, total-N, ortho-P, dissolved-P, and total-P in surface water composites (0-5m depth) are summarized in Tables 24 a-f. Values measured on the fertilization days (25 August and 22 September) are not representative of the entire epilimnion because the fertilizer had not yet mixed completely. For PF II, we collected a separate set of discrete depth samples the day before, immediately after the fertilization was complete, and the following morning from Station 2 in the middle of the cove (Figure 18). The results indicate that most of the spike was concentrated in the upper 5 meters on the first afternoon but that by the following morning, the nitrogen and phosphorus were well mixed throughout most of the epilimnion. Further, the mean concentrations on Day 1 (23 September) were significantly lower than the predicted values which were calculated as the actual fertilizer load divided by the estimated volume of the mixed layer in the cove (listed in Table 14). This was probably due to a combination of horizontal patchiness in the original distribution of fertilizer, exchange with the main lake, phytoplankton uptake (especially luxury uptake of ortho-P), and adsorption of phosphate onto suspended silt particles.

Table 24a .

CATHEDRAL COVE PREFERTILIZATION STUDY- NH<sub>3</sub>-N (ug/L,  $\bar{X} \pm S$ ), 0-3m INT

DATE (1986)	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	NOTES
8/14	10	-	8	-	-	
8/24	6±1	7±0	4±1	6±0	6±0	
8/25	173	295	254	20	9	
8/26	36±2	36±8	32±7	8	0	
8/27	5±1	12±3	14±1	14±1	13±1	
8/28	4±1	3±1	3±0	5±1	3±1	
8/29	4±2	4±1	5±1	6±1	7±0	
8/31	2	2	2	0	0	
9/4	1	0	0	0	1	
9/10	5±1	-	5±0	-	12±1	
Spike: incomplete mixing						
9/21	7±1	7±1	8±0	8±1	13±4	
9/22	491±3	572±3	564±18	24±8	46±17	
9/23	229±2	120±3	59±6	7±1	13±2	
9/24	96±7	65±2	37±2	26±1	7±1	
9/25	43	32	28	12	10	
9/26	11	5	9	8	10	
9/29	5	-	9	-	8	
10/15	4	-	4	-	-	
Spike: incomplete mixing						

Table 2/4b.

CATHEDRAL COVE PREFERTILIZATION STUDY- NO3-N (ug/L), 0-5m INT X1R/2

DATE (1986)	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	NOTES
8/14	12	-	.10	-	-	-
8/24	9±0	9±1	10±1	20±9	8±1	Spike Day
8/25	-	-	-	-	-	-
8/26	43±4	47±0	56±2	28±4	12±2	-
8/27	24±0	37±1	23±1	13±1	5±0	-
8/28	25±0	12±1	13±1	26±14	7±1	-
8/29	3±1	5±0	5±0	8±1	7±1	-
8/31	7±0	7±0	26±5	9±1	15±5	-
9/4	8	7	7	7	8	-
9/10	3±0	-	6±0	-	10±2	-
9/21	53±1	57±4	60±2	51±12	75±3	Spike : Incomp
9/22	380±10	437±2	460±7	80±0	102±2	-
9/23	212±7	127±1	81±6	61±1	64±3	-
9/24	171±26	100±4	96±2	78±4	49±2	-
9/25	117±1	99±1	98±3	86±1	84±2	-
9/26	50±5	44±6	95	88	92	-
9/29	107	-	121	-	73	-
10/15	114	-	118	-	-	-

Table 24c.

CATHEDRAL COVE PREFERTILIZATION STUDY- ORTHO-P ( $\mu\text{g/L}$ ,  $\bar{X} \pm \text{SE}$ ), 0-5m INT

DATE (1986)	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	NOTES
8/14	2.0	-	2.0	-	-	
8/24	2.3	1.9	2.5	3.9	2.1	
8/25	25	44	64	7	6	Spike: incomplete mixing
8/26	3.2	2.3	2.5	2.5	2.5	
8/27	2.5	3.0	3.2	2.5	2.8	
8/28	3.7	3.4	2.3	2.3	2.8	
8/29	5.9	3.2	3.2	2.8	4.6	
8/31	2.3	2.5	2.3	3.2	2.5	
9/4	2.1	-	1.9	-	2.3	
9/10	3.7	-	3.5	-	5.3	
9/21	3.2	1.0	1.2	1.2	1.2	
9/22	182	128	214	1.9	2.8	
9/23	40	20	13	2.8	2.6	
9/24	11	6.4	3.0	7.8	2.6	
9/25	6.9	6.4	3.5	2.3	2.1	
9/26	3.0	4.1	6.4	4.4	3.7	
9/29	3.5	-	2.8	-	3.5	Spike: incomplete mixing
10/15	2.0	-	2.0	-	-	

Table 24d.

CATHEDRAL COVE PREFERTILIZATION STUDY- DP ( $\mu\text{g/L}$ ,  $\bar{X} \pm \frac{B}{2}$ ) 0-5m INT

DATE (1986)	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	NOTES
8/14	-	-	-	-	-	
8/24	4.3	4.7	5.4	8.6±0.3	4.5	Spike Day
8/25	-	-	-	-	-	
8/26	4.2	4.7	4.2	5.0	4.5	
8/27	2.4	3.1	1.2	3.3	1.0	
8/28	-	-	-	-	-	
8/29	-	-	-	-	-	
8/31	-	-	-	-	-	
9/4	-	-	-	-	-	
9/10	1.4	-	2.3	-	3.0	
9/21	3.3	0.4	1.1	2.1	1.4	Spike: incomplete mixing
9/22	178	134	221	1.4	3.3	
9/23	46	31	17	3.0	3.7	
9/24	14	7.3	3.3	13±1	5.0±0.8	
9/25	13	16	3.7	3.3	4.7	
9/26	3.5	3.5	3.0	2.8	4.9	
9/29	4.7	-	2.8	-	8.5	
10/15	-	-	-	-	-	

Table 24e.

CATHEDRAL COVE PREFERTILIZATION STUDY- TOTAL-P ( $\mu\text{g/L}$ ,  $\bar{X} \pm \text{SE}$ ) 0-5m INT

DATE (1986)	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	NOTES
8/14	10	-	6	-	-	Spike Day
8/24	6.6±0.8	8.7±0.3	6.0±1.6	4.1±0.1	3.9±0.1	
8/25	-	-	-	-	-	
8/26	18.2±1.6	16.3±0.2	14.9±0.0	9.6±0.0	6.1±0.2	
8/27	10.3±0.3	9.1±0.1	8.8±0.4	6.5±0.2	8.7±1.1	
8/28	6.1	5.9	5.4	2.4	1.9	
8/29	6.8	5.2	15±1	3.8	6.6	
8/31	9.4	4.3	3.3	4.0	4.0	
9/4	4.3	2.6	3.3	3.6	3.8	
9/10	3.4±0.2	-	4.7±0.0	-	6.1±0.0	
9/21	4	3	3	3	3	Spike: incomplete mixing
9/22	192±11	156±16	245±24	4±3	6±2	
9/23	88	47	28	3	6	
9/24	39	31	17	16	14	
9/25	21	17	11	6	4	
9/26	10±1	34	28	8	6	
9/29	5	-	4	-	4	
10/15	4	-	11	-	-	

Table 24f.

CATHEDRAL COVE PREFERTILIZATION STUDY- TN ( $\mu\text{g/L}$ ), 0-5m INT  $X \pm R/2$ 

DATE (1986)	STATION 1	STATION 2	STATION 3	STATION 4	STATION 5	NOTES
8/14	269	-	372	-	-	
8/24	93	119	112	80	135	
8/25	-	-	-	-	-	Spike Day
8/26	223 $\pm$ 24	298 $\pm$ 22	340 $\pm$ 65	231	203	
8/27	192	148 $\pm$ 10	286 $\pm$ 2	192	280 $\pm$ 15	
8/28	-	-	-	-	-	
8/29	109 $\pm$ 19	177 $\pm$ 2	159 $\pm$ 5	202	245 $\pm$ 27	
8/31	-	-	-	-	-	
9/4	173	112	lost	103	176 $\pm$ 1	
9/10	240 $\pm$ 1	-	324	-	337 $\pm$ 1	
9/21	272 $\pm$ 12	190 $\pm$ 15	256 $\pm$ 4	300 $\pm$ 38	195 $\pm$ 38	
9/22	-	-	-	-	-	
9/23	459 $\pm$ 45	494 $\pm$ 35	341 $\pm$ 8	266	221	
9/24	-	-	-	-	-	
9/25	404 $\pm$ 42	334 $\pm$ 44	250 $\pm$ 22	256 $\pm$ 20	292 $\pm$ 40	
9/26	-	-	-	-	-	
9/29	286 $\pm$ 46	-	195 $\pm$ 4	-	206 $\pm$ 23	
10/15	449	-	416	-	-	

Spike: Incomplete mixing

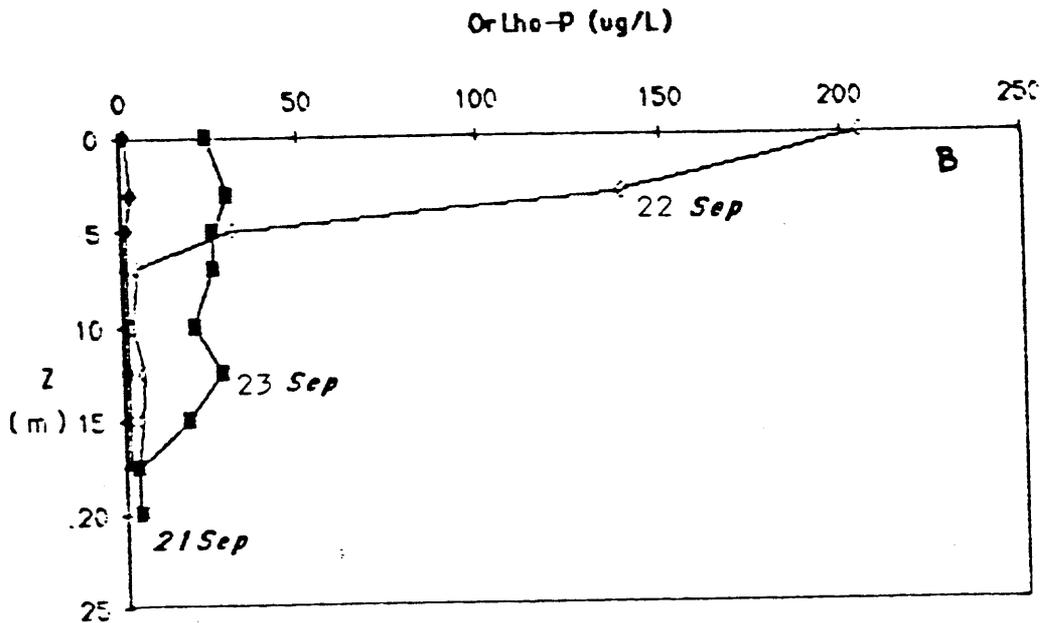
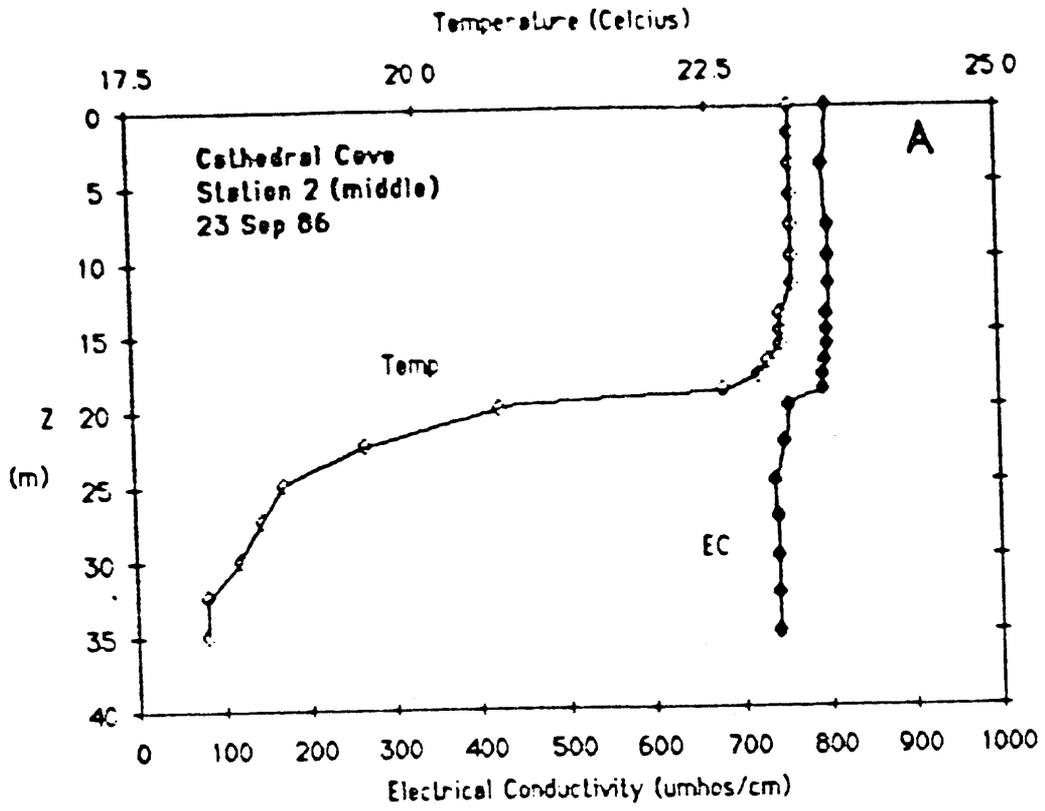
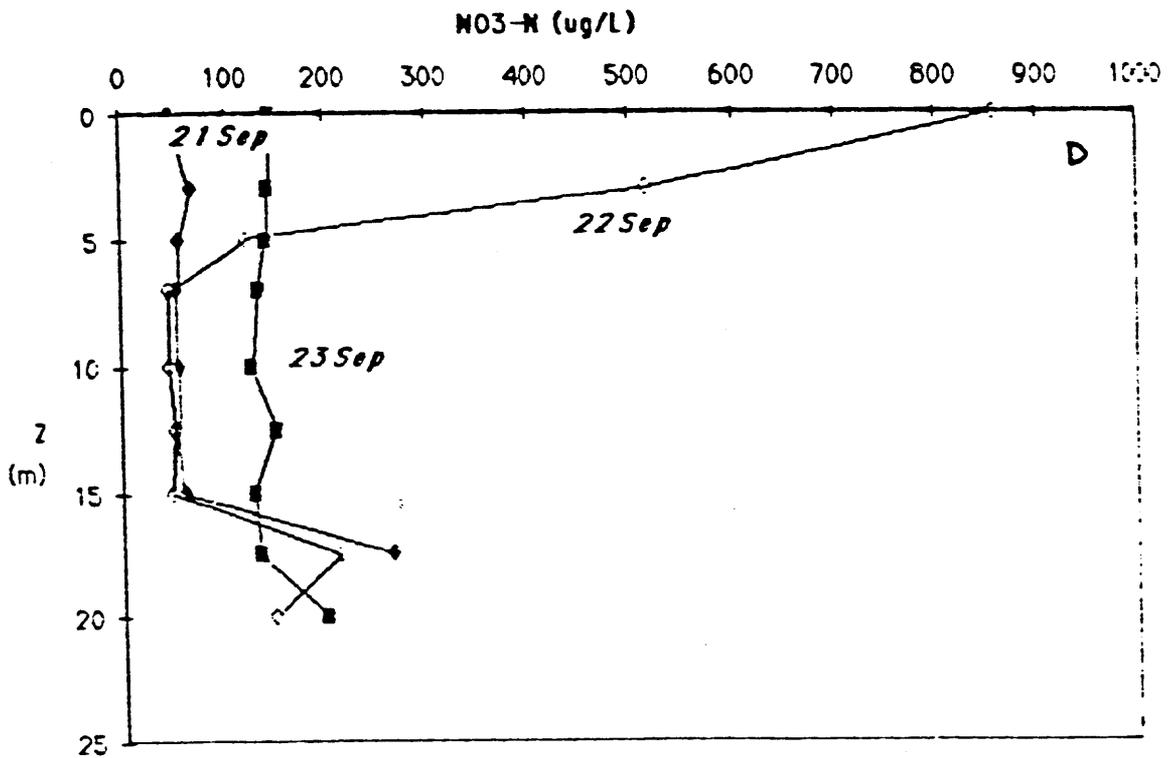
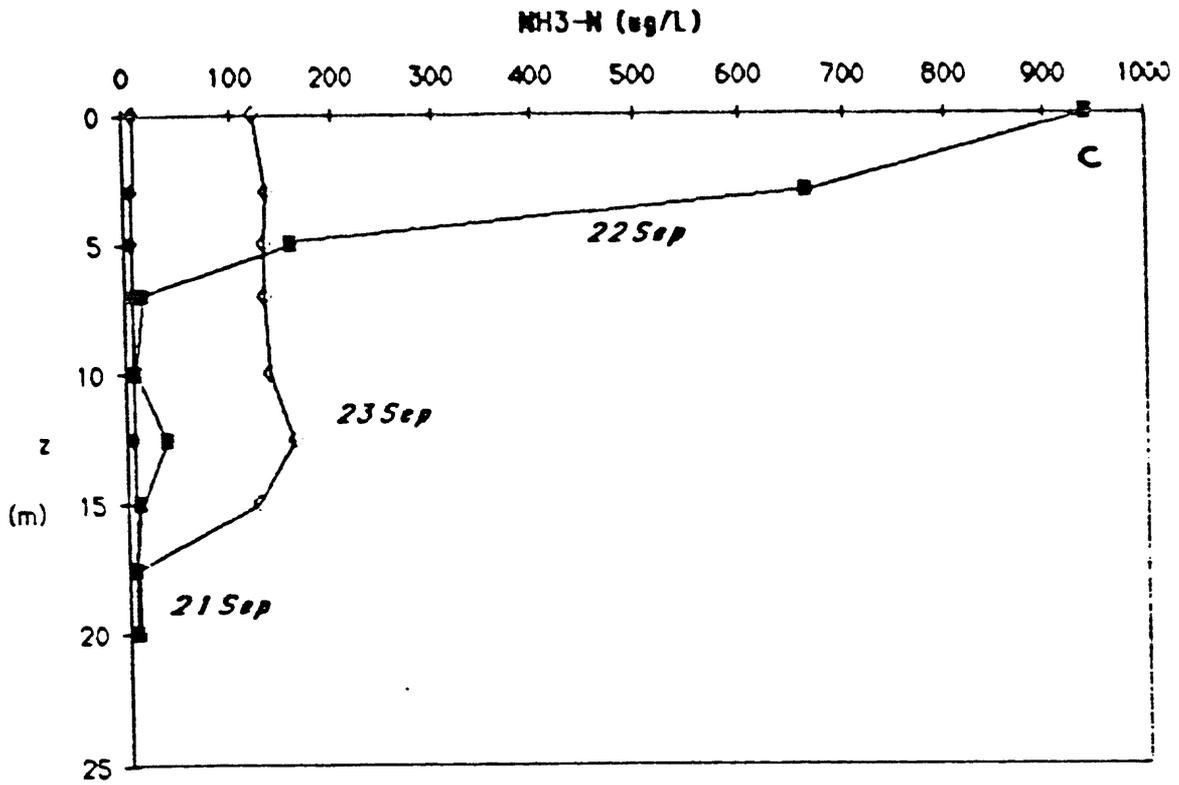


Figure 18 a,b. Cathedral Cove: Vertical profiles, PF II

Figure 18 c,d. Cathedral Cove: Vertical profiles, PF 11



The time courses of dissolved inorganic-N (DIN=ammonium-N + nitrate-N + nitrite-N) and ortho-P depletion from the cove are plotted in Figures 19 and 20. Conclusions which can be drawn from the nutrient data include:

1. Fertilizer additions near the lake surface were rapidly dispersed (~24 hours) throughout the mixed layer (epilimnion) by moderate winds;

2. Orthophosphate was rapidly transformed into particulate-P due to algal assimilation and to a lesser extent adsorption to silt. It disappeared overnight in PF I (>75% in particulate form). More than 75% of the (larger) PF II spike was associated with particles after only 2 days;

3. Depletion of ammonium-N was faster than for nitrate. Preferential  $\text{NH}_3$ -uptake is typical of phytoplankton communities, particularly when inorganic nitrogen is deficient (3). Both forms of nitrogen are readily available for algal uptake;

4. The liquid 10-34-0 phosphorus fertilizer was recovered almost entirely in the ortho-P fraction immediately after addition to the lake. Previous laboratory analyses (and the manufacturer's formulation) had indicated it was comprised of equal amounts of ortho-P and polyphosphates. This rapid hydrolysis of polyphosphates could be due to extracellular alkaline phosphatases, released by P-deficient algae. This hypothesis is consistent with previous studies of phosphatase activity by the UNLV Limnological Research Center in the period 1979-1981 (6). In any event, this formulation is readily available to algae;

5. The elevated concentrations of inorganic nitrogen and phosphorus which resulted from fertilization were rapidly assimilated by nutrient deficient algae and returned to normal (pre-fertilization) levels within several days. Even though this process was hastened by dilutional flushing from the main lake, the field data we collected, together with the nutrient enrichment bioassay experiments, strongly indicate that a relatively rapid

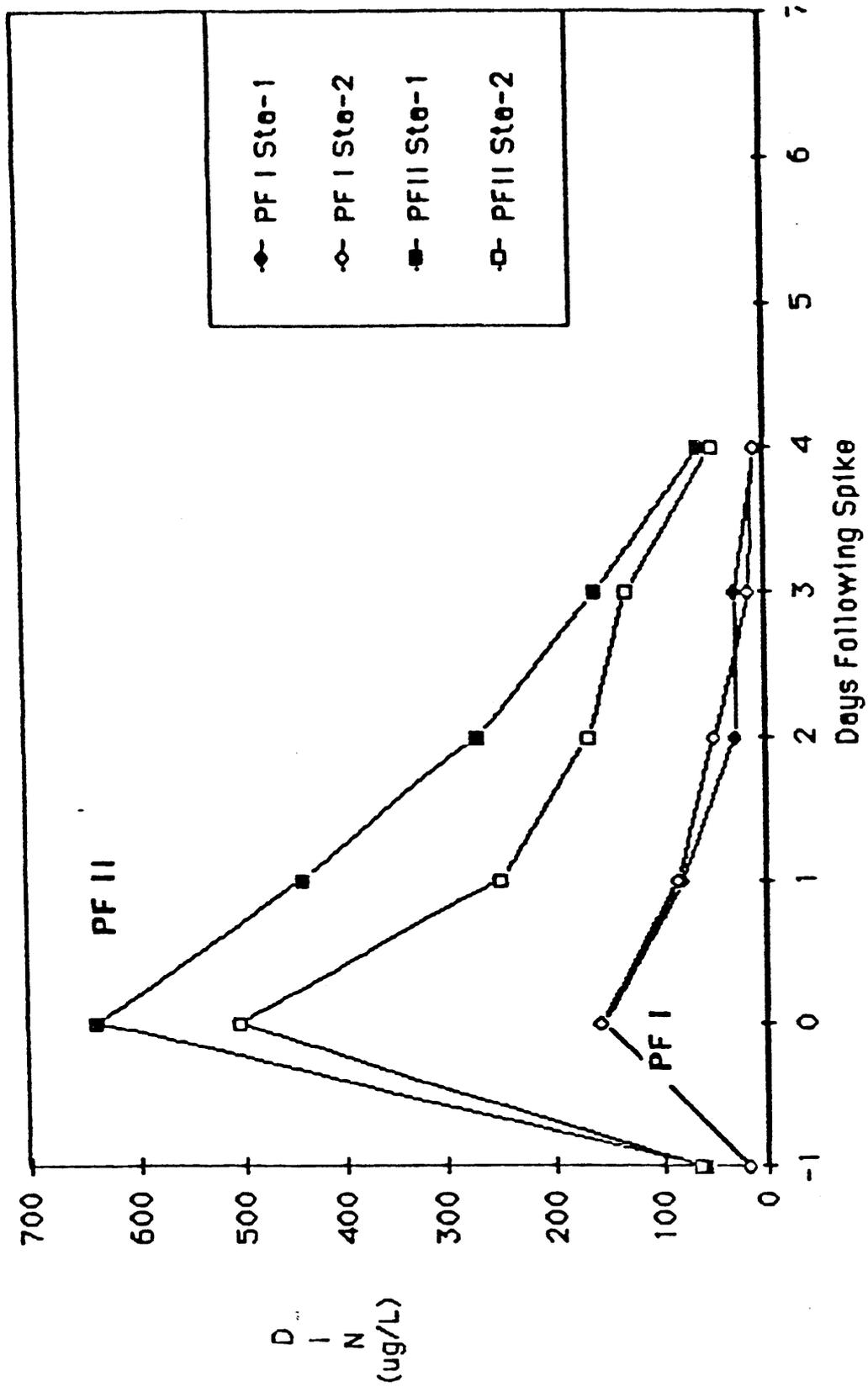


Figure 19. Dissolved Inorganic-N (ammonium-N + nitrate-N + nitrite-N) concentrations in 0-5m composites in Cathedral Cove following fertilizations. DIN at Station 2-PF II is the average throughout the mixed layer (using data from Fig 17). Day 0 values for Station 1-PF II and both stations during PF I are calculated load and volume estimates since water column values were not determined.

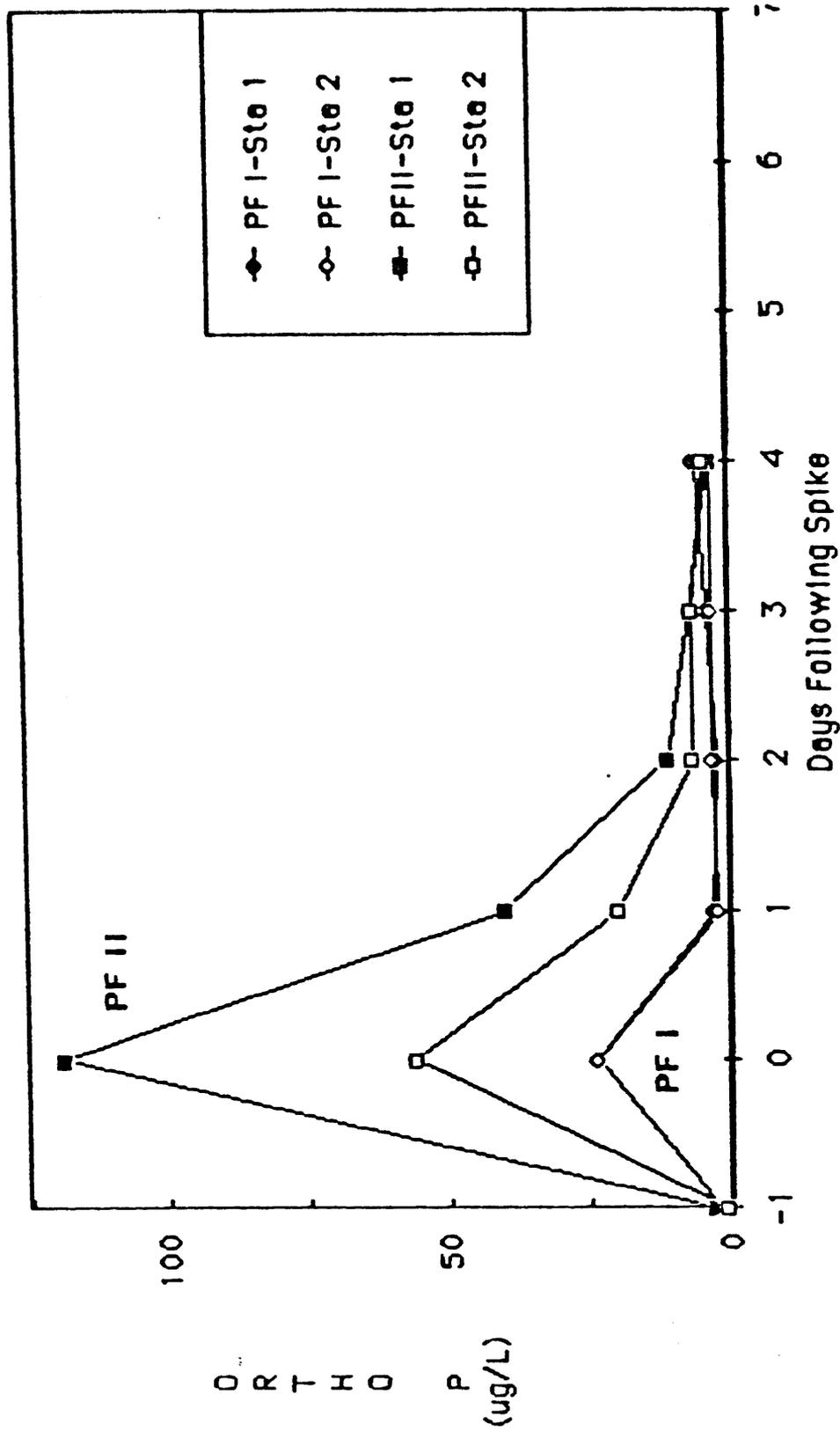


Figure 20. Ortho-P concentrations in the 0-1m stratum of Cathedral Cove following fertilizations. Ortho-P at Station 2- PF II is the average throughout the mixed layer( from Fig.17). Day 0 values for Station 1-PF II and both stations during PF I are calculated from load and volume estimates since complete water column values were not determined.

(-1-2 weeks) return to pre-fertilization conditions would occur following a large-scale fertilization of the Overton Arm or Gregg Basin.

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

Principal goals of the Prefertilization Study were:

- \* to determine the most suitable type(s) of fertilizer for large-scale additions to Lake Mead;
- \* to evaluate methods of fertilizer applications;
- \* to make recommendations regarding the frequency of fertilizer additions.

The conclusions and recommendations which follow are based upon the results of the present study. However, it is important to note that this information was used to design and implement the first large-scale fertilization of Lake Mead which was conducted in the Overton Arm on May 30, 1987. Consequently, some of the following conclusions from the Prefertilization Study have been substantiated by the preliminary results of this large-scale test. An overview of the 1987 Overton Arm Fertilization has been appended as Section 8.0.

### Conclusions and Recommendations:

1. Liquid ammonium polyphosphate (10-34-0) is currently the most suitable formulation of phosphorus fertilizer for use in Lake Mead.
2. Either liquid ammonium nitrate (20-0-0) or granular ammonium nitrate (34-0-0) are most suitable for use as a nitrogen supplement in Lake Mead during mid or late summer when low levels of inorganic-N could necessitate N-enrichment, in addition to P-enrichment.

3. Dispersing liquid fertilizer(s) from slowly moving boats appears to be the most cost-effective method of uniformly applying fertilizer to surface water at a rate of about one gallon per acre. Over 1000 volunteers and about 300 boats effectively applied fertilizer to about 19,000 acres on May 30, 1987. Effective planning prevented major mishaps and the event was very successfully carried out (see section 8.0).

4. Alternative application methods which could be used are:

\* spraying from a barge with a storage tank of about 2000 gallons. This would require a one-time capital investment in the barge, tank(s), and pumps. This arrangement would allow for uniform fertilizer dispersal over a period of several days to about a week (assuming a 20,000 gallon enrichment in the Overton Arm).

\* spraying from a large aircraft with a capacity of 1000-2000 gallons. This method has been successfully used in British Columbia and Alaska, but we estimated its cost to be at least \$12,000-\$15,000 for the Overton Arm, which is substantial. Another consideration would be ownership of the aircraft; that is, how much control, and at what cost, would the Committee have over the timing of the spraying. Delays of any sort, particularly as related to weather, could cause major cost overruns unless the aircraft was local.

5. It does not appear that river injection of fertilizer would significantly improve fertility in the Overton Arm (via the Virgin or Muddy Rivers) or in the Iceberg Canyon/Gregg Basin areas (via the Colorado River). However, there is the potential for improving fertility in Virgin Canyon and Temple Basin by using the proposed Spring Canyon Reservoir discharge to disperse fertilizer. More detailed studies of the Spring Canyon Pump Storage Project, as related to improving the fertility of this region of Lake Mead, are recommended.

6. Weekly enrichments of several parts-per-billion phosphorus throughout the spring would probably best simulate the higher P-loading which occurred historically. However, this type of program would be relatively difficult to evaluate experimentally. The following are recommended:

- \* A first-year large-scale enrichment of ~20 ppbP in spring when the lake is thermally stratified, ample inorganic-N is present in the epilimnion, and threadfin shad and bass are spawning.

- \* Multiple (smaller) fertilizations to prolong the period of enhanced primary production in the spring should be tested. The exact frequency and intensity of these fertilizations will depend upon the results of the first year test, in addition to considerations of cost and potential effects on other beneficial uses of the lake.

- \* A test fertilization of coves in the fall when inorganic-N is reintroduced into the euphotic zone by wind mixing of the upper hypolimnion (containing relatively high nitrate) should be conducted. Increased phytoplankton and zooplankton production at this time could enhance over-winter survival of forage and game fish populations.

## 7.0 REFERENCES

1. Ahl, T. and T. Wiederholm. 1977. Swedish water quality criteria. Eutrophication elements. Nat. Swed. Environ. Protect. Bd. PM 918.
2. Arizona Game and Fish Department and Nevada Department of Wildlife. 1982. The status of the black bass fishery in Lake Mead and a program toward restoration and enhancement. Final Report to U.S. Bureau of Reclamation. Contract No. 7-07-30-X0028.
3. Axler, R.P., R.M. Gersberg, and C.R. Goldman. 1982. Inorganic nitrogen assimilation in a subalpine lake. *Limnol. Oceanogr.* 27:53-65.
4. Axler, R., L. Paulson, P. Vaux, P. Sollberger and D. Baepler. In press. Fish Aid-The Lake Mead Fertilization Project. In Lake and Reservoir Management: Pro. 7th Ann. Int. Symp. N. Amer. Lake Manage. Soc., Nov. 3-7, 1987, Orlando, FLA. N. Am. Lake Manage. Soc., Washington, D.C.
5. Baker, J.R. and L.J. Paulson. 1983. The effects of limited food availability on the striped bass fishery in Lake Mead. In: V.D. Adams and V.A. Lemarra (eds.), Aquatic Resources Management of the Colorado River Ecosystem. Ann Arbor Sci. Publ. p. 551-561.
6. Brown and Caldwell. 1982. Water quality standards study. Report submitted to Las Vegas Valley Water Quality Program by Brown and Caldwell Consulting Engineers, Inc. Sacramento, CA.

7. California Fertilizer Association. 1975. Western Fertilizer Handbook. California Fert. Assoc., Sacramento, CA. 250 p.
8. Carlson, R.E. 1977. A trophic state index for lakes. J. Fish. Res. Bd. Can. 29:673-682.
9. Davidson, R.G. and C.E. Boyd. 1981. Phytoplankton response to liquid fertilizers. Prog. Fish-Cult. 43:126-129.
10. Edmondson, W.T. 1980. Secchi disk and chlorophyll. Limnol. and Oceanogr. 25:371-372.
11. Evans, T.D. and L.J. Paulson. 1983. The influence of Lake Powell on the suspended sediment-phosphorus dynamics of the Colorado River inflow to Lake Mead. In: V.D. Adams and V.A. Lemarra (eds.), Aquatic Resources Management of the Colorado River Ecosystem. Ann Arbor Sci. Publ., p. 57-68.
12. Farm Chemicals Handbook. 1986. R.T. Meister (ed.). Meister Publ. Co., Willoughby, OH.
13. Forsberg, C., S. Rydeny, A. Claesson, and A. Forsberg. 1978. Water chemical analyses and/or algal assay? Sewage effluent and polluted lakewater studies. Mitt. Internat. Verein. Limnol. 21:352-363.
14. Haley, J.S., S. Leavitt, L. Paulson, and D.H. Baeppler. 1987. Wildlife agency efforts to improve fish habitat by introducing artificial and

- natural cover. Lake Mead Limnological Research Center Technical Report No. 15, University of Nevada-Las Vegas. 34 p.
15. Haley, J.S., S. Leavitt, L. Heki, L. Paulson, and D.H. Baepler. 1987. Annotated bibliography to largemouth bass habitat requirements, artificial cover, and terrestrial and aquatic plant introduction. Lake Mead Limnological Research Center Technical Report No. 17, University of Nevada-Las Vegas. 36 p.
  16. Haley, J.S., S. Leavitt, L. Paulson, and D.H. Baepler. 1987. Lake Mead Cover Enhancement Project. Lake Mead Limnological Research Center Technical Report No. 18, University of Nevada-Las Vegas. 117 p.
  17. Healey, F.P. 1975. Physiological indicators of nutrient deficiency in algae. Fish. Mar. Serv. Res. Dev. Tech. Rep. 585.
  18. Hutchinson, G.E. 1975. A treatise on limnology. Volume 1 (Part 2)-Chemistry of lakes. John-Wiley and Sons, New York. 1015 p.
  19. Hyatt, K.D. and J.G. Stockner. 1985. Responses of sockeye salmon to fertilization of British Columbia coastal lakes. Can. J. Fish. Aquat. Sci. 42:320-331.
  20. Janik, J.J. 1984. The role of nanoplankton in the phytoplankton dynamics of four Colorado River reservoirs (Lakes Powell, Mead, Mohave and Havasu). M.S. Thesis. University of Nevada-Las Vegas.

21. Kellar, P.E., S.A. Paulson, and L.J. Paulson. 1981. Methods for biological, chemical, and physical analyses in reservoirs. Lake Mead Limnological Research Center Technical Report No. 5, University of Nevada-Las Vegas. 234 p.
22. Koenings, J.P. and R.D. Burkett. In press. The population characteristics of sockeye salmon smolts relative to temperature regimes, euphotic volume, fry density and forage base within Alaskan lakes. Can. J. Fish. Aquat. Sci. Spec. Publ. 1986.
23. Lara, J.M. and J.I. Sanders. 1970. The 1963-64 Lake Mead survey. U.S. Bureau of Reclamation Report No. REC-OCE-20-21. 169 p.
24. LeBrasseur, R.J., C.D. McAllister, W.E. Barraclough, O.D. Kennedy, JManzer, D. Robinson, and K. Stephens. 1978. Enhancement of sockeye salmon (Oncorhynchus nerka) by lake fertilization in Great Central Lake: Summary Report. J. Fish. Res. Bd. Can. 35:1580-1596.
25. Lind, O.T. 1986. The effect of non-algal turbidity on the relationship of secchi depth to chlorophyll-a. Hydrobiologia 140:27-35.
26. Longwell, C.R. 1936. Geology of the Boulder Reservoir floor. Geol. Soc. Amer. Bull. 47:1393-1476.
27. Mayer, L.M. and S.P. Gloss. 1980. Buffering of silica and phosphate in a turbid river. Limnol. Oceanogr. 25:12-22.

28. Metzger, R.J. and C.E. Boyd. 1980. Liquid ammonium polyphosphate as a fish pond fertilizer. *Trans. Amer. Fish. Soc.* 109:563-570.
29. Morgensen, S.A. 1983. Factors affecting the production and recruitment of largemouth bass, *Micropterus salmoides* in Lake Mead. M.S. Thesis, University of Nevada-Las Vegas.
30. Paulson, L.J., J.R. Baker, and J.E. Deacon. 1980. The limnological status of Lake Mead and Lake Mohave under present and future powerplant operations of Hoover Dam. Lake Mead Limnological Research Center Technical Report No. 1, University of Nevada-Las Vegas. 229 p.
31. Paulson, L.J. and J.R. Baker. 1983. Interrelationships among nutrients, plankton, and striped bass in Lake Mead. Lake Mead Limnological Research Center Technical Report No. 10, University of Nevada-Las Vegas. 94 p.
32. Paulson, L.J. and J.R. Baker. 1984. The limnology in reservoirs on the Colorado River. Lake Mead Limnological Research Center Technical Report No. 11, University of Nevada-Las Vegas. 275 p.
33. Prentki, R.T. and L.J. Paulson. 1983. Historical patterns of phytoplankton productivity in Lake Mead. In: V.D. Adams and V.A. Lemarra (eds.), *Aquatic Resources Management of the Colorado River Ecosystem*. Ann Arbor Sci. Publ. Ann Arbor, MI. p. 105-123.
34. Prentki, R.T. , L.J. Paulson, and J.R. Baker. 1981. Chemical and biological structure of Lake Mead sediments. Lake Mead Limnological

Research Center Technical Report No. 6, University of Nevada-Las Vegas.  
89 p.

35. Rast, W. and G.F. Lee. 1978. Survey analysis of the northern American (U.S.) OECD eutrophication project: Nutrient loading-lake response relationships and trophic state indices. EPA-600/3-78-008.
36. Stockner, J.G. 1981. Whole-lake fertilization for the enhancement of sockeye salmon (*Oncorhynchus nerka*) in British Columbia, Canada. Verh. Internat. Verein. Limnol. 21:293-299.
37. Stockner, J.G., K.S. Shortreed, and K. Stephens. 1980. The British Columbia lake fertilization program: Limnological results from the first two years of nutrient enrichment. Can. Tech. Rep. of Fish. and Aq. Sci. No. 924, Dept. of Fisheries and Oceans, Resource Serv. Branch, W. Vancouver, B.C. 91 p.
38. U.S.E.P.A. 1974. The relationship of phosphorus and nitrogen to the trophic state of northeast and northcentral lakes and reservoirs. National Eutrophication Survey, U.S. Environmental Protection Agency, Working Paper No. 23.
39. Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Philadelphia, PA. 743 p.

## 8.0 ADDENDUM - THE 1987 OVERTON ARM FERTILIZATION

As the Prefertilization Study progressed, a secondary set of goals were developed because the first large-scale fertilization of the Overton Arm of Lake Mead was scheduled for May 30, 1987, prior to the formal completion of this Final Report. The planning process for this experiment was developed by the Lake Mead Nutrient Enhancement Technical Committee, a technical advisory panel formed in January 1985 and comprised of representatives of the Lake Mead Limnological Research Center (Environmental Research Center, UNLV), the Nevada Department of Wildlife, the Arizona Game and Fish Department, the Nevada Division of Environmental Protection, the U.S. Bureau of Reclamation, the National Park Service at the Lake Mead National Recreation Area, and the U.S. Fish and Wildlife Service. Numerous meetings have been held in the period June 1986 to the present to review and evaluate the experimental work and to determine short and long-range plans for implementing an experimental program of fertilization in both the Overton Arm and in Gregg Basin. The proposals developed from this process, of course, were largely based upon the results of the Prefertilization Study. The major accomplishments of this process were:

- \* A formal proposal was submitted to the committee by the Limnological Research Center at UNLV to fertilize the Overton Arm and Gregg Basin once each, in May or June 1987 using volunteer help with a surface application in the Overton Arm and aerial spraying in Gregg Basin (Paulson, Axler and Baepler, January 20, 1987). The Gregg Basin element of the proposal was subsequently postponed indefinitely because of inadequate funding;

- \* A determination was made by the National Park Service that an Environmental Assessment for the proposed fertilizations would be required to comply with the Council of Environmental Quality regulations implementing the procedural provisions of the National Environmental Policy Act (NEPA). In

response, the Lake Mead Nutrient Enhancement Technical Committee submitted the Lake Mead Fertilization Project Environmental Assessment to NPS at Lake Mead National Recreation Area on March 11, 1987. The document was open for public review for 30 days and a Finding of No Significant Impact (FONSI) was authorized and announced on May 21, 1987. Permission to proceed with the test was made contingent upon issuance of a National Pollutant Discharge Elimination System (NPDES) permit from the Nevada Division of Environmental Protection;

- \* Following a 30 day comment period and a public hearing, the NPDES permit was issued (May 27, 1987, #NV0021393) by the State of Nevada;

- \* A volunteer force of approximately 300 boats and 1000 people assisted in applying 20,000 gallons of liquid ammonium polyphosphate (10-34-0, "white" formulation) on May 30, 1987. An intensive monitoring program was implemented by UNLV in early May 1987 which has continued to the present time. The program was designed to evaluate the beneficial effects of fertilization on the Lake Mead food chain in addition to assessing potential impacts on down-lake and downstream beneficial uses of Lake Mead and the Colorado River;

- \* Provisional data from the May 30, 1987 test was presented by UNLV to the Lake Mead Nutrient Enhancement Technical Committee on July 20, 1987. A data report was submitted to NDEP in late October 1987 to satisfy the reporting requirements of the NPDES permit. To date, we note that no substantiative negative impacts of the fertilization have been reported and that the experiment appears to have successfully stimulated short-term algal growth, and improved the nutritional status and reproductive potential of cladoceran zooplankton. We also collected a limited amount of data which suggested that the survival of shad may have been enhanced and their range extended. The expanded distribution of threadfin shad from Overton Beach south to Echo Bay appears to have resulted in increased surface feeding

activity by striped bass ("boils") and improved condition factors (see reference 4).

\* Based on the apparent success of the 1987 test, plans are currently being developed for a continuation of the program in 1988 and 1989. It now appears that the single, relatively large (-20 ppbP) enrichment which we used in 1987 in the Overton Arm was very successful in terms of providing food for shad. Therefore, we have recommended repeating the exact same experiment in the Overton Arm in May 1988.

\* A single, late spring addition is recommended for Gregg Basin as originally proposed in the Lake Mead Fertilization Project Environmental Assessment (March, 1987) if funding is available.

\* Fertilization in the fall when inorganic-N is reintroduced into the euphotic zone by wind mixing of the upper hypolimnion (containing relatively high nitrate) should be considered in either the second or third year of the experimental test program. Increased algal and zooplankton production at this time of year would be likely to improve over-winter survival of shad and juvenile game fish.

Our major conclusions based on the results of the 1987 Overton Arm Fertilization are:

1. Controlled fertilization of Lake Mead, as proposed and implemented in 1987 for the Overton Arm, and as proposed for 1988 will temporarily increase phytoplankton production to moderate levels, improve the nutritional status and productivity of zooplankton populations, and improve the survival, growth, and range of threadfin shad. The expanded distribution of shad will be likely to increase striped bass surface feeding activity in the fertilized regions of the lake. Striped bass, largemouth bass, and other game fish will be likely to have increased growth rates and improved condition factors due to nutrient enrichment.

2. Fertilization at the proposed (approximately + 20 ppbP) levels will not degrade water quality in the fertilized region(s), down-lake, or downstream. More specifically,

\* fertilization of the Overton Arm north of Echo Bay and of Gregg Basin will not produce demonstrable changes in any water quality parameters in Virgin Basin, far uplake from Hoover Dam discharges to Lake Mohave.

\* The fertilizations conducted in 1987 and proposed for 1988 pose no threat to local (Las Vegas) or downstream (Arizona and California) beneficial uses of Colorado River water. This includes: domestic (drinking water), agricultural (irrigation and livestock watering), wildlife, industrial, contact and non-water contact recreation uses, and aesthetic values.