WATER QUALITY MONITORING IN LAKE LAS VEGAS: LAKE LAS VEGAS PROJECT 1993

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I. PROJECT BACKGROUND

Lake Las Vegas was conceived in 1964 by J. Carlton Adair, then President of the Port Holiday Authority. The 2243 acre development project was known as Port Holiday, and the lake was called "Lake Adair." Project land was acquired from the federal government under a land exchange act (PL 88-639) authorized by Congress on October 8, 1964. Approximately 170 acres of privately owned land in the Lake Mead National Recreation Area (LMNRA) was exchanged for 2243 acres in Las Vegas Wash (LVW). That property was located along the western border of the LMNRA in Las Vegas Wash (Figure 1).

Carlton Adair halted the project in 1971, though a considerable amount of engineering and feasibility work had been done. The project remained idle until 1982 when it was reinitiated as the Lake at Las Vegas Project by Barry Silverton and the Pacific Malibu Development Corporation of Los Angeles, CA. Pacific Malibu and its prime consultant J.M. Montgomery (JMM) Consulting Engineers conducted extensive engineering and environmental studies during 1984-1987. Transcontinental Properties (TCP) of Scottsdale, AZ, acquired controlling interest in the project in 1988. TCP and its consultants completed the engineering and environmental studies and obtained the necessary local, state, and federal permits required to start construction of the project. Construction was started on April 1, 1989. The project is now called Lake Las Vegas Joint Venture.

II. PROJECT DESCRIPTION

Lake Las Vegas ultimately will consist of six hotels, five golf courses, 3,500-5,000 dwelling units, condominium developments, and commercial and civic developments. At full development, it will have an estimated permanent population of 12,500 people and a tourist population of 32,500.

The focal point of the project will be the 320 acre recreational lake. The lake is being filled behind a 4800 ft. zoned, S-shaped embankment dam, 1500 ft. upstream of North Shore Road. The 190 ft. high dam was constructed with 3.0 million cubic yards of locally available materials. The lake will be maintained at 1403 ft. above MSL. At that level, it will have a capacity of 10,000 acre feet, 320 surface acres, a two mile length, a one mile width, and 12.3 miles of shoreline.

The lake is being filled with water drawn from Lake Mead. About 7,000 acre feet will be required annually for project irrigation, seepage, and evaporative losses from the lake.

LVW wastewaters are by-passed under the lake through twin 84 inch diameter pipelines. The bypass system is 9,450 ft. in length and designed to pass flows up to 1760 CFS. Flows currently average about 220 CFS in LVW.

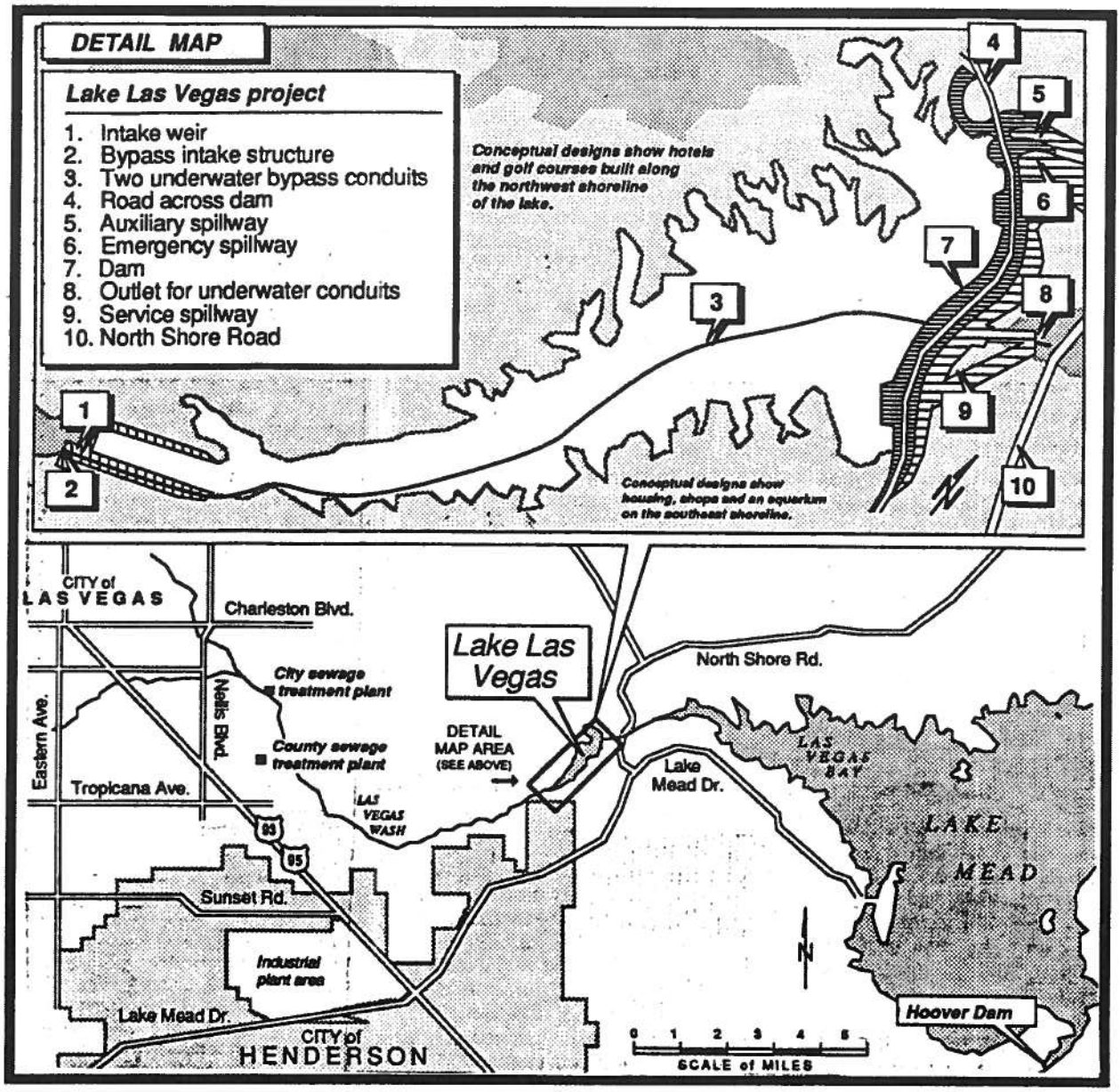

Figure 1. Location and description of the Lake Las Vegas Joint Venture (Las Vegas Review Journal map by Jim Day July 28, 1991).

III. WATER QUALITY HISTORY

Water quality in Lake Las Vegas itself and potential effects of the project on waters in LVW and Lake Mead have been major concerns since the project's inception in 1964. A water quality assessment was first made in 1968 as part of the engineering feasibility studies that were conducted by Tipton and Kalmback, Inc., Engineers of Denver, CO. Extensive water quality studies have been conducted since 1984 when the project was reintiated by Pacific Malibu Development Corporation, Los Angeles, CA. The following chronology is a summary of those studies and other water quality related activities.

A. Chronology of Lake Las Vegas Water Quality Activities

Date	Activities
Mar. 7, 1984	Pacific Malibu Development Corporation applies for a 404 permit (#8562) to the U.S. Army Corps of Engineers (USACE) to place fill material in LVW during construction of a dam and appurtenant works.
Mar. 16, 1984	James M. Montgomery (JMM) Consulting Engineers, consultant for Pacific Malibu, requests water quality certification for LLV from the Nevada Division of Environmental Protection (NDEP).
May 16, 1984	NDEP administrator, L.H. Dodgion recommends that a water quality assessment be done for LLV, including analysis of impacts in LVW and Lake Mead.
May 1984	JMM issues a 19 page report about general water quality impacts of LLV.
June 24, 1984	NDEP issues water quality certification for LLV under Section 404 of the Clean Water Act.
June 29, 1984	JMM prepares an Environmental Assessment for LLV.
Aug. 7, 1984	USACE holds a public hearing in Henderson, NV on the 404 permit (#8562) request from Pacific Malibu.
Sept. 19, 1984	U.S. Environmental Protection Agency (EPA) expresses written concern to USACE about potential water quality impacts of LLV on LVW and Lake Mead.
Nov. 1984	JMM issues a 9 page report entitled: "Water Quality Impact Analysis for Lake at Las Vegas."
Nov. 23, 1984	USACE issues a conditional 404 permit (#8562) for LLV. Special condition b.(4) requires that Pacific Malibu, ----"develop a detailed plan for water quality monitoring and operation and maintenance of the lake." Special condition c. requires that Pacific Malibu comply with the Clark County 208 Water Quality Management Plan.
April 1985	JMM prepares a draft, "Water Quality Criteria and Operations and Maintenance Plan for Lake at Las Vegas" report.
May 1985	JMM revises the draft, "Water Quality Criteria and Operations and Maintenance Plan for Lake at Las Vegas" report.
July 10, 1985	USACE accepts JMM water quality management plan and signs off on Special Condition b.(4) of permit application #8562.

Dec. 14, 1987	USACE extends permit application #8562 to December 31, 1989 provided the developer satisfies provisions of Clark County 208 Plan by June 30, 1988.
Feb. 25, 1988	JMM revises water quality plan to include an evaluation of impacts associated with urban and stormwater runoff.
Mar. 24, 1988	JMM issues a 18 page report entitled, "Lake at Las Vegas Project Water Quality Management Plan."
Mar. 28, 1988	City of Henderson and Transcontinental Properties (TCP), the new joint project owners, request an amendment to the Clark County 208 Plan for the LLV.
Apr. 4, 1988	JMM issues revised "Lake at Las Vegas Project Water Quality Management Plan."
Apr. 5, 1988	Board of Clark County Commissioners conditionally approves the Clark County 208 Plan amendment for LLV. One condition requires that a water quality monitoring and maintenance plan be enforced for LLV. Another requires that a variance be granted by the Clark County Regional Flood Control District (CCRFCD).
Aug. 11, 1988	USACE requests public comment on the amended 404 permit application #8562A for LLV.
Nov. 22, 1988	Dr. Larry J. Paulson develops a, "Water Quality Monitoring Program: Lake at Las Vegas Project" at the request of TCP.
Dec. 2, 1988	Harza Engineers completes its draft technical review of LLV for the CCRFCD.
Dec. 1988	TCP and its consultants respond to Harza Engineers' draft report.
Jan. 5, 1989	Harza Engineers issues its final technical review of LLV.
Jan. 12, 1989	CCRFCD denies the flood control variance for LLV.
Mar. 1, 1989	TCP contracts with Dr. Larry Paulson and the Lake Mead Limnological Research Center, UNLV, for a five month water quality monitoring program in LVW (March 1 - July 31, 1989).
Mar. 10, 1989	CCRFCD approves flood control variance for LLV.
Mar. 12, 1989	TCP and its contractor, Washington Construction Co. (WCC), begin construction on the dam abutment outside 100 year flood plain.
Mar. 13, 1989	Water quality sampling program begins in LVW.
Mar. 30, 1989	USACE issues 404 permit #8562A for LLV.
Apr. 1, 1989	TCP and WCC start construction on bypass pipeline and diversion inlet structure for LLV.
Aug. 9, 1989	Flood occurs in Las Vegas Wash.
Aug. 21, 1989	Saline spring surfaces in trench of bypass pipeline.
Jan. 1, 1990	TCP contracts with Dr. Larry J. Paulson and his firm West Lakes for water quality monitoring in Las Vegas Wash.
Jan. 19, 1990	Flood occurs in Las Vegas Wash.
Feb. 15, 1990	Bypass pipeline and diversion inlet structure completed.
Feb. 16, 1990	Las Vegas Wash flows diverted into bypass pipeline.
Feb. 17, 1990	WCC starts work on earthen dam.
March 7, 1990	Saline spring surfaces mid-way through reservoir site, forming a small lake upstream of coffer dam.

Apr. 1, 1990	Dr. Larry J. Paulson publishes technical report on results of water quality monitoring in Las Vegas Wash during 1989.
June 11, 1990	Large flood occurs in Las Vegas Wash. Flows were estimated at 3400 CFS and over-topped the intake structure, spilling about 700 acre feet of stormwaters into the LLV reservoir site.
July 16, 1990	Another large flood occurs in Las Vegas Wash.
Oct. 1990	WCC starts work on water inlet pipeline for LLV.
Dec. 26, 1990	Water inlet pipeline completed. TCP starts filling the LLV reservoir at about 800 GPM. Inlet waters combine with saline spring waters to increase size of lake above coffer dam.
Jan. 1, 1991	TCP contracts with Dr. Larry J. Paulson and his firm West Lakes for water quality monitoring in Las Vegas Wash and LLV reservoir.
Feb. 28, 1991	Moderate flood occurs in Las Vegas Wash.
March 1, 1991	Moderate flood occurs in Las Vegas Wash.
March 28, 1991	Large flood occurs in Las Vegas Wash. Stormwaters over-topped the intake structure and spilled into the LLV reservoir site.
May 25, 1991	Water inlet flows increased to 5600 GPM to accelerate filling of LLV reservoir.
June 24, 1991	Intensive water quality monitoring program started in LLV reservoir by Dr. Larry Paulson and his firm West Lakes.
June 27, 1991	WCC completes construction of sediment basin in Las Vegas Wash just upstream of intake structure.
July 1, 1991	Saline spring waters mix with inlet waters and flow into reservoir site.
August 20, 1991	WCC completes construction of LLV dam. Dam approved by Nevada State Engineer's office.
Aug.-Sept. 1991	Inflowing waters cause substantial erosion of alluvial deposits in the old Las Vegas Wash channel.
Aug.-Nov. 1991	Higher than expected algal growth occurs in LLV reservoir due to phosphorus inputs from spring waters and erosion of alluvial deposits.
Dec. 4, 1991	Water levels reach 1367 feet, 37 feet below the normal operating level of 1403 feet.
Dec. 31, 1991	Water levels reach 1370 feet, 33 feet below the normal operating level of 1403 feet.
Jan. 6, 1992	Flood occurs in Las Vegas Wash, over-tops the intake structure and spills 48 acre feet of stormwater into LLV.
Feb. 13, 1992	Flood occurs in Las Vegas Wash, over-tops the intake structure and spills 472 acre feet of stormwater into LLV.
Feb. 14, 1992	Water levels reach 1378 feet, 25 feet below the normal operating level of 1403 feet.
March 5, 1992	Dr. Larry J. Paulson publishes technical report on results of water quality monitoring in Las Vegas Wash during 1991.
March 8, 1992	Flood occurs in Las Vegas Wash, over-tops the intake structure and spills 569 acre feet of stormwater into LLV. Water levels reach 1381.3 feet in LLV.
March 23, 1992	Dr. Larry J. Paulson publishes technical report on results of water quality monitoring in LLV during 1991.
March 24, 1992	Moderate open water algae bloom occurs in LLV as a result of nutrient inputs from stormwater spills.

March 27, 1992	Flood occurs in Las Vegas Wash, over-tops the intake structure and spills 1087 acre feet of stormwater into LLV. Water levels reach 1387.9 feet in LLV.
March 28, 1992	Flood occurs in Las Vegas Wash, over-tops the intake structure and spills 109 acre feet of stormwater into LLV.
March 30, 1992	Flood occurs in Las Vegas Wash, over-tops the intake structure and spills 470 acre feet of stormwater into LLV.
March 31, 1992	Flood occurs in Las Vegas Wash, over-tops the intake structure and spills 603 acre feet of stormwater into LLV. Water levels reach 1391.5 feet in LLV.
April 7, 1992	Another moderate open water algae bloom occurs in LLV as a result of nutrient inputs from late March stormwater spills.
April-May 1992	Zooplankton explode in LLV and graze open water algae. Transparency increases to nearly 30 feet in lower end of the lake. Attached algae bloom occurs on rip-rap and underwater debris.
May-June 1992	Crayfish population in LLV augmented by stocking in an effort to control growth of attached algae.
July 7, 1992	Bluegreen algae bloom occurs in upper LLV due to nutrient inputs from springs.
Oct. 25, 1992	Flood occurs in Las Vegas Wash, over-tops the intake structure and spills 330 acre feet of stormwater into LLV.
Jan. 19, 1993	Moderate flood occurs in Las Vegas Wash.
Feb 8-9, 1993	Flood occurs in Las Vegas Wash, over-tops the intake structure and spills 1785 acre feet of stormwater into LLV. Water levels reach 1399.5 feet in LLV.

IV. WATER QUALITY MONITORING PROGRAM

The revised Clark County 208 Water Management Plan approved by the Clark County Board of County Commissioners on April 5, 1988 and certified by the State of Nevada on August 8, 1988 required that a water quality monitoring program be developed for Lake Las Vegas. The monitoring is required to insure that water quality standards are not being violated by construction activities and operations of the reservoir. The water quality monitoring program was started on Lake Las Vegas in June 1991. Results of water quality monitoring during 1991 were presented in Paulson et al. (1992b), those for 1992 were presented in Paulson et al. (1993b).

A. Lake Las Vegas Sampling Stations

Water quality sampling was conducted in Lake Las Vegas monthly in January, February, November, and December during 1993. Sampling was done biweekly during March and October and weekly during April through September. Sampling was also conducted during, or after, major stormwater spills into the reservoir.

Water quality sampling was conducted at stations shown in Figure (2). Primary monitoring stations in the reservoir were located at fixed points along the center

channel in the deepest part of the reservoir (Figure 2). Physical measurements and limited sampling also were conducted periodically in select coves and sites near spring inflows (Figure 2).

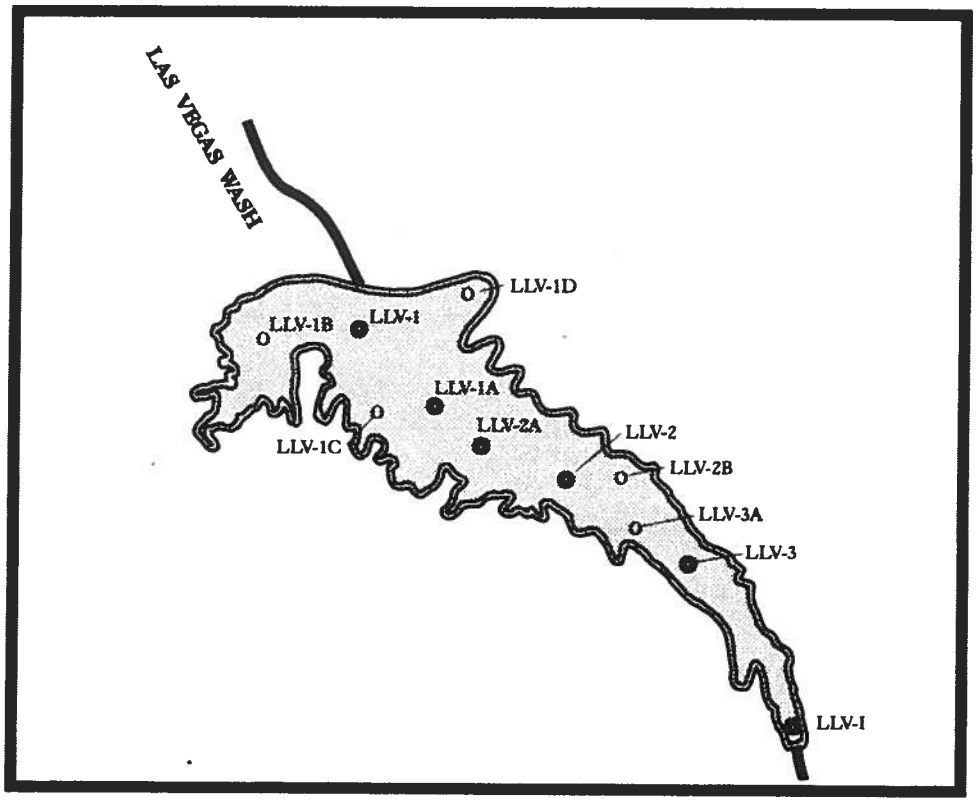

Figure 2. Locations of water quality monitoring stations in Lake Las Vegas.

B. Field Measurements

Temperature, pH, dissolved oxygen, and specific conductance were measured by 1m intervals, surface to bottom at all stations with a Hydrolab Surveyor Model III Water Quality Analyzer (Table 1). Duplicate measurements were made on about 10% of the measurements. Transparency was measured at each lake station with a Secchi disc. Wind speed and direction and air temperature also were measured at each station.

C. Chemical and Biological Analyses

Depth integrated water samples were collected from 0-2.5 m at main-lake sampling stations (Table 1). Samples also were collected quarterly at 5 m, 10 m, and 20 m at Station LLV-1A with a Van Dorn sampler. Samples requiring filtration were filtered through 0.45 µm Millipore filters.

Table 1. Physical, chemical, and biological measurements for Lake Las Vegas.

	Sampling Program		
Measurements	Depth(s)	Frequency	Method(s)
Physical			
Temperature (°C)	1.0 m Intervals Surface to Bottom	Variable[1]	Leavitt et al. (1990)
Dissolved Oxygen (mg/l)	"	"	"
pH (Std. Units)	"	"	"
Conductivity (µmhos/cm)	"	"	"
Secchi Depth (m)	Surface	"	"
Turbidity (NTU)	0-2.5 m Int.	"	"
Chemical			
Total Nitrogen (µg/l)	0-2.5 m Int.	"	Leavitt et al.
Ammonia-N (µg/l)	"	"	(1990)
Nitrite+Nitrate-N (µg/l)	"	"	"
Total Phosphorus (µg/l)	"	"	"
Ortho-Phosphorus (µg/l)	"	"	"
Total Suspended Solids (mg/l)	"	"	APHA (1989)
Total Dissolved Solids (mg/l)	"	"	"
Major Anions/Cations (mg/l)	"	"	"
Biological			
Chlorophyll-a (µg/l)	"	"	Leavitt et al.
Phytoplankton Counts (mg/m^3)	"	"	(1990)
Zooplankton Counts (No./l)	"	"	"

Field duplicates and spike recoveries were run on about 10% of the samples. The chemical and biological analyses were run with low level methods described in Leavitt et al. 1990.

Additional samples were collected quarterly at 0-2.5 m, 5 m, 10 m, and 20 m at station LLV-1A and shipped to American Analytical Laboratory in Tucson, AZ for analyses of major anions and cations.

Zooplankton samples were collected at LLV-1 in a vertical tow from 0-15 m with an 80 µ Wisconsin plankton net. Phytoplankton (algae) were collected monthly at 0-2.5 m from LLV-1. Phytoplankton identifications were made by Dr. Jeff Janick (with the California Department of Water Resources). Zooplankton identifications and counts were made by Mr. Gene R. Wilde (with the Texas Department of Wildlife).

Extensive gill netting was conducted throughout the reservoir over a two day period on September 9-10, 1993. Experimental (variable mesh) nylon nets, 100 to 300 ft. in length and 4 ft. wide were set in coves and open waters at depths ranging from surface sets to bottom sets as deep as 30 ft. Total length was measured on all captured fish.

D. Water Quality Guidelines

Water quality standards have not been established for Lake Las Vegas. However, the water quality guidelines presented in Table 2 are patterned after standards for open waters of Lake Mead (NAC 445.1351). These guidelines were established to protect and enhance the following beneficial uses in Lake Las Vegas:

1). Irrigation;
2). Recreation not involving contact with the water (boating, sailing, canoeing) ;
3). Recreation involving contact with the water (swimming, bathing, diving, wading);
4). Propagation of wildlife; and
5). Propagation of aquatic life, including a warmwater fishery.

V. WATER QUALITY MONITORING RESULTS

A. Reservoir Water Levels

Water is being pumped from the hypolimnion in Lake Mead through either the Southern Nevada Water System or the Basic Management Incorporated (BMI) pipelines to fill Lake Las Vegas. The inflow was first started on December 26, 1990 at a rate of about 800 GPM. The inflow was increased to 5600 GPM on May 25, 1991 and held at that rate during most of 1991.

Surface elevations in Lake Las Vegas increased steadily in 1991. The water level increased from 1320 ft. on May 30, 1991 to 1370 ft. in December 1991 (Figure 3). Major flooding in Las Vegas Wash resulted in several spills of stormwater into Lake Las Vegas during winter and early spring of 1992 (Table 3). The stormwater spills from Las Vegas Wash quickly filled Lake Las Vegas. In a three month period between January

Table 2. Water quality guidelines for Lake Las Vegas (Revised from: NAC 445.1351, Water Quality Standards for Lake Mead).

1. The lake waters should be free of:
    a. Visible floating, suspended, or settleable solids,
    b. Sludge banks, lime infestations, heavy growths of attached plants (periphyton) and animals, or of floating algae mats,
    c. Discoloration or excessive turbidity,
    d. Visible oil or slicks,
    e. Surfactant concentrations that will produce foam when water is agitated or aerated,
    f. Toxicants in toxic amounts;

2. The pH as measured in standard units should range between 7.0-9.0 in 90% of the measurements;

3. Dissolved oxygen concentrations should be 5 mg/l in the epilimnion during stratification, and 5 mg/l throughout the water column the rest of the year;

4. The average chlorophyll-a concentration in the epilimnion (0-2.5 m) should not exceed 0.005 mg/l during April through September. The average must include at least two samples per month. The single value must not exceed .010 mg/l in10% of the samples;

5. In all lake areas, the log mean of not less than five samples taken over a 30 day period during the recreational season (May-September) should not exceed 200 MPN/100 ml and not over 10% of such samples should exceed 400 MPN/100 ml;

6. Average temperature in the epilimnion should not exceed 2°C above ambient temperature (eg. temperature in epilimnion in Lake Mead);

7. Total dissolved solids concentrations should not exceed an annual average of 2000 mg/l throughout the water column;

8. Turbidity must not exceed that characteristic of natural conditions by more than 10 NTU.

and March 1992, the water level increased by nearly 22 ft. (Figure 3). The sharpest rise occurred between March 27-31, 1992 when the lake level increased by 10 ft., bringing the level to 1391 ft. (Figure 3). The lake level increased to about 1393 ft. by the end of 1992.

Another large flood occurred in Las Vegas Wash on February 8-9, 1993. This flood spilled 1785 acre feet of stormwater into Lake Las Vegas. The water level increased by about 6 ft. overnight, and the lake reached its highest level of 1399.5 ft. on February 10, 1993. That is 3.5 ft. from its normal operating level of 1403 ft. Inflows from Lake Mead were shut off for the rest of 1993. Water levels decreased through evaporation to year-end levels of about 1391 ft. (Figure 4).

Table 3. Volumes of stormwater spills into Lake Las Vegas from floods in Las Vegas Wash during 1992 and 1993.

Date	Stormwater Volumes (acre feet)
January 6, 1992	48
February 13, 1992	472
March 8, 1992	569
March 27, 1992	1087
March 28, 1992	109
March 30, 1992	470
March 31, 1992	603
October 25, 1992	330
February 8, 1993	1785
Total	5473

B. **Quality Control**

There was less than 5% difference between field duplicate measurements for temperature, dissolved oxygen, pH, conductance, and transparency (Table 4). Differences between duplicates were less than 20% for TDS, turbidity, nitrite+nitrate-N, total phosphorus, and total nitrogen (Table 4). Variability was higher for TSS, chlorophyll-a, ammonia-N, and ortho phosphorus.

Ammonia, ortho phosphorus and TSS were quite low in Lake Las Vegas and near the limits of detection. A 30% variation between duplicates seems high but only represents a concentration difference of a few parts per billion. Chlorophyll-a, like most biological analyses, tend to have higher variation than chemical analyses. The methods used for chemical analyses have an accuracy within 10% of the true values (Paulson et al. 1992b).

Table 4. Precision estimates for physical, chemical, and biological constituents based on analyses of field duplicate samples collected in Lake Las Vegas during 1993.

Statistics	Temperature (°C)	Oxygen (mg/l)	Conductance (µM/cm)	pH (Std. Units)	TDS (mg/l)	TSS (mg/l)	Turbidity (NTU)	Transparency (m)
Average % Difference	1.1	5.0	0.4	0.4	1.7	43.5	9.9	4.3
Standard Deviation	1.5	4.4	0.6	0.9	3.0	37.5	17.6	4.4
Number of Observations	175	169	172	168	33	33	35	14

Table 4. continued.

Statistics	Ammonia-N (µg/l)	Nitrite+Nitrate-N (µg/l)	Total-N (µg/l)	Ortho-P (µg/l)	Total-P (µg/l)	Chlorophyll-a (µg/l)
Average % Difference	36.9	13.5	19.6	32.3	14.9	34.4
Standard Deviation	54.7	29.3	19.7	38.3	19.5	29.1
Number of Observations	33	33	28	33	32	31

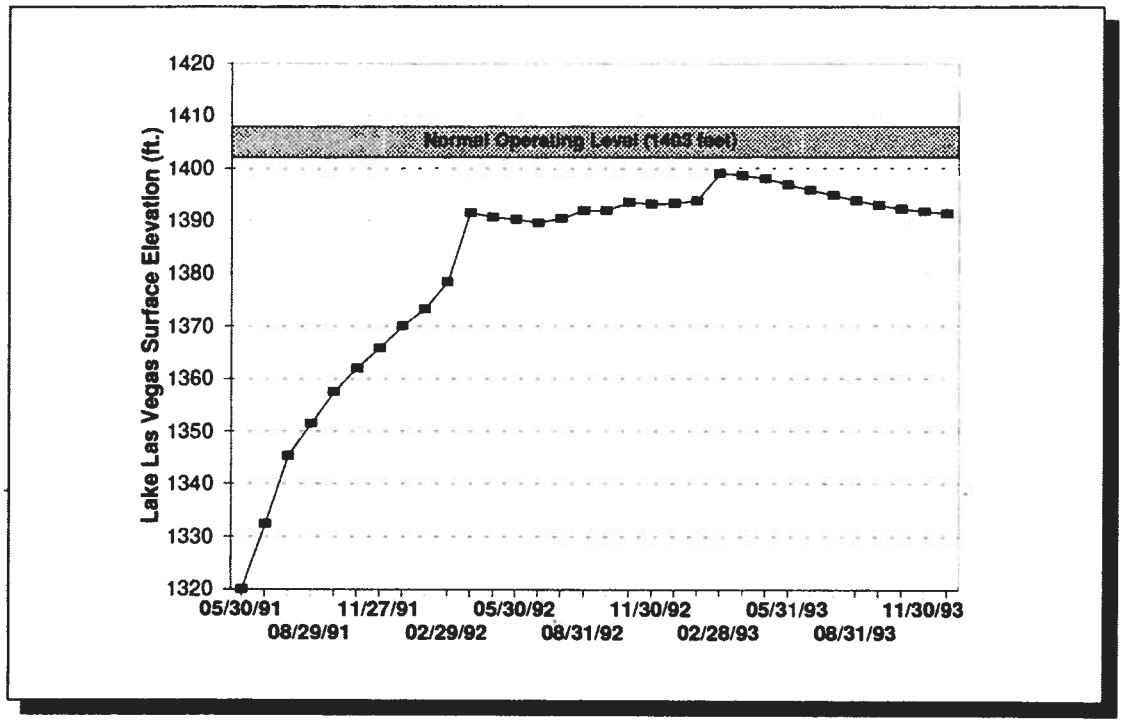

Figure 3. Surface water elevations in Lake Las Vegas during June 1991 - December 1993.

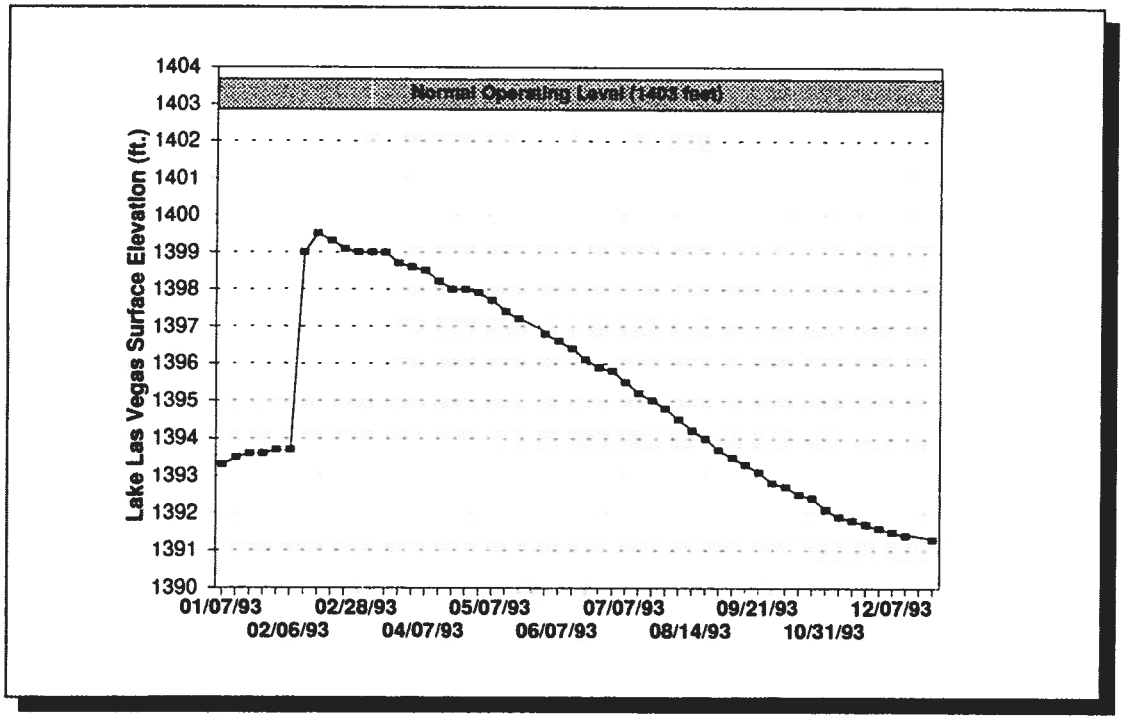

Figure 4. Surface water elevations in Lake Las Vegas during January 1 - December 31, 1993.

C. Seasonal Variations in Water Quality

Physical Measurements

Surface temperatures in Lake Las Vegas ranged from 8-10°C at all stations during January and February 1993 (Figure 5). Temperatures increased steadily during March and April. Thermal stratification began to develop in late March with the thermocline located between 5 and 10m (Figure 6). Bottom temperatures were at 12°C in late March. Surface temperatures continued to increase in May and June (Figure 5). The lake was well stratified by June with the thermocline located between 15 and 20 m (Figure 6). The maximum temperatures of 25-27°C occurred during July. Temperatures gradually decreased during August and September (Figure 5). The lake began mixing in late September as the thermocline dropped to between 20 and 25 m (Figure 6). Bottom temperatures were about 15°C. Surface temperatures dropped sharply in October and November. Temperatures were back to about 9°C, throughout the water column by December (Figure 6).

Dissolved oxygen (DO) concentrations in surface waters ranged from highs of 10-12 mg/l during winter months to lows of 7-8 mg/l during the summer (Figure 7). There were minor differences in DO at the main-lake stations. Oxygen depletion began to develop in the hypolimnion by late March (Figure 8). DO concentrations in the hypolimnion were less than 1 mg/l during summer and early fall. Hypolimnetic DO concentrations were replenished in the fall when the lake mixed. DO concentrations ranged from 11.0 - 11.5 mg/l throughout the water column in December (Figure 8).

There were minor seasonal or spatial variations in pH of surface waters in Lake Las Vegas (Figure 9). The lowest pH of about 7.7 occurred during winter months and the highest pH of about 8.2 occurred during summer. There were some vertical variations in pH during thermal stratification (Figure 10). pH dropped from about 7.9 in the epilimnion to about 7.3 in the hypolimnion in late June and from 8.2 in the epilimnion to 7.1 in the hypolimnion during late September (Figure 10). pH was nearly uniform throughout the water column during December.

Conductance was about 2200 µmho/cm in surface waters of Lake Las Vegas during January 1993 (Figure 11). There was a slight decrease in surface conductance after the February 8-9 stormwater spill. Conductance increased considerably during the spring, summer, and fall. Conductance in surface waters was 2900 µmho/cm by December. There were some vertical differences in conductance during thermal stratification (Figure 12). Conductance dropped from 2520 µmho/cm in the epilimnion to 2330 µmho/cm in the hypolimnion in late June. In late September, it dropped from 2750 µmho/cm in the epilimnion to about 2400 µmho/cm in the hypolimnion.

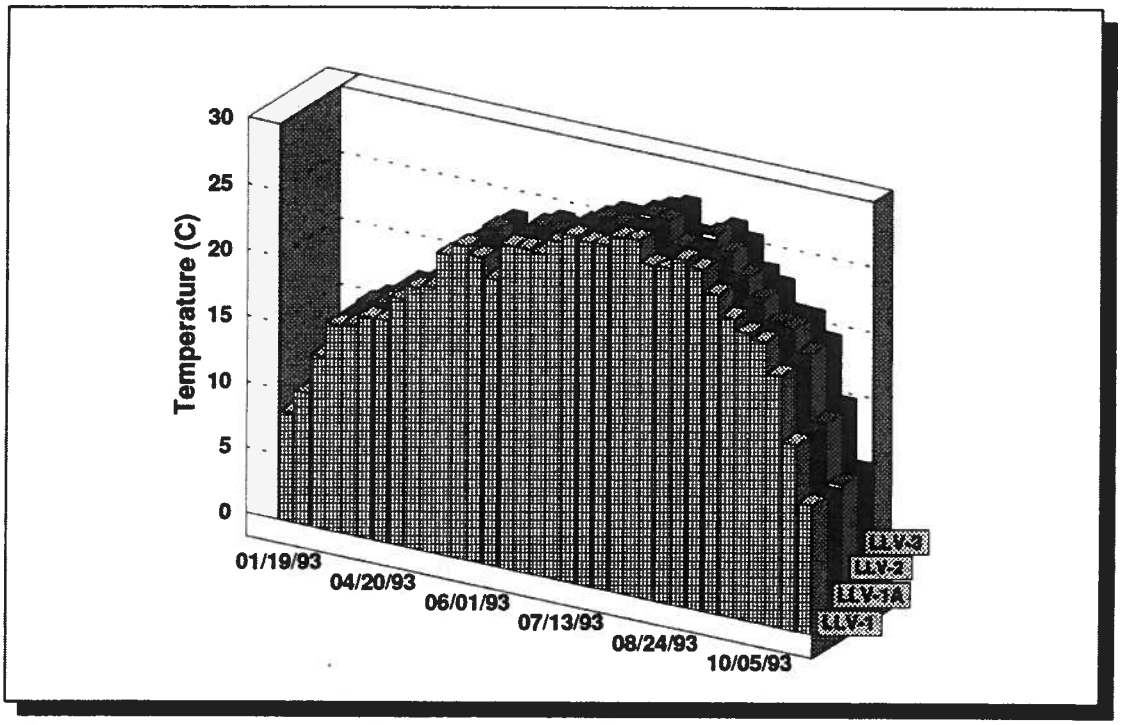

Figure 5. Temperatures in surface waters (0 m) at main-lake stations in Lake Las Vegas during January - December 1993.

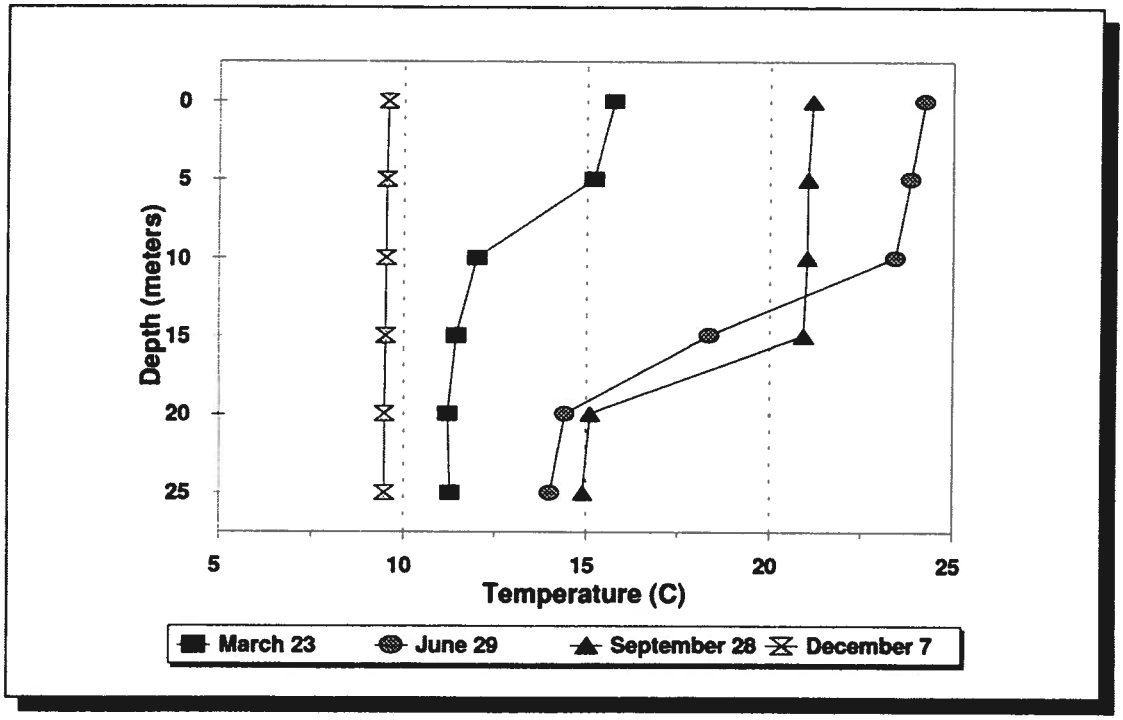

Figure 6. Temperature profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

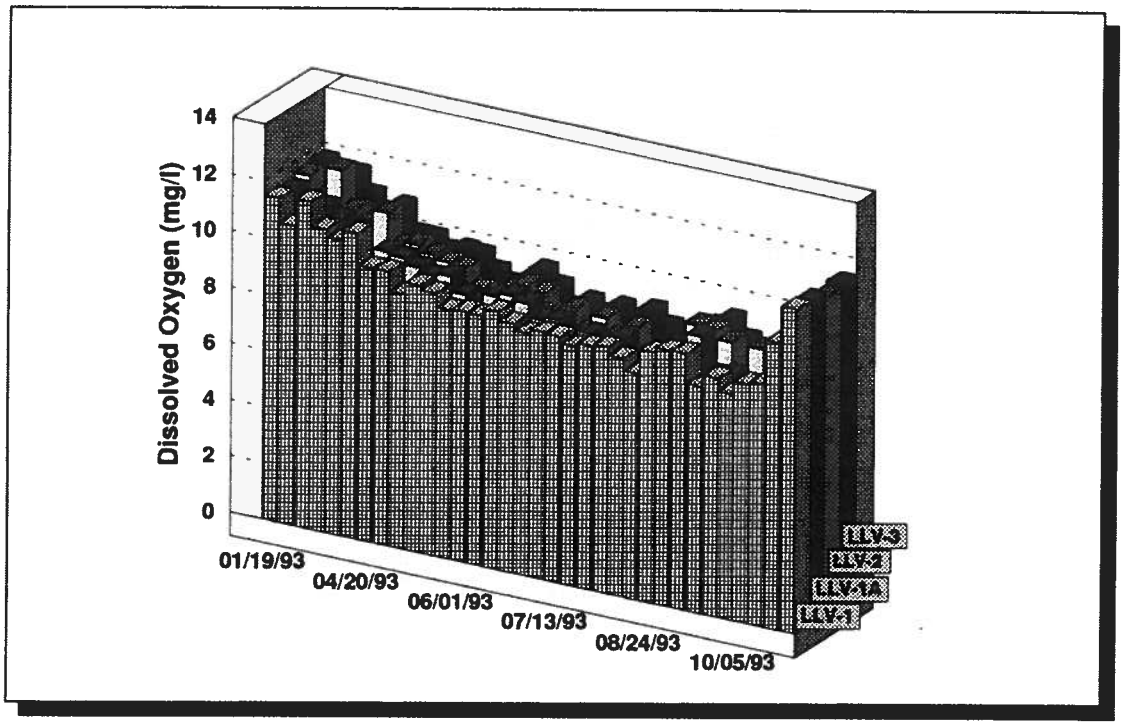

Figure 7. Dissolved oxygen in surface waters (0 m) at main-lake stations in Lake Las Vegas during January - December 1993.

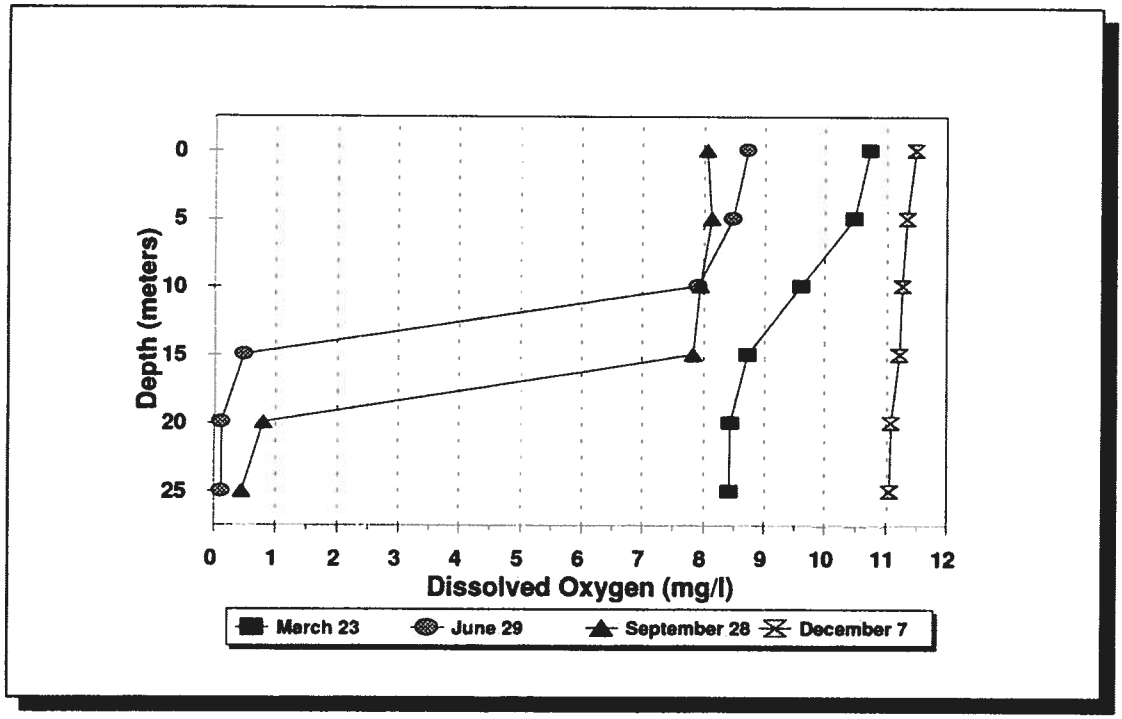

Figure 8. Dissolved oxygen profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

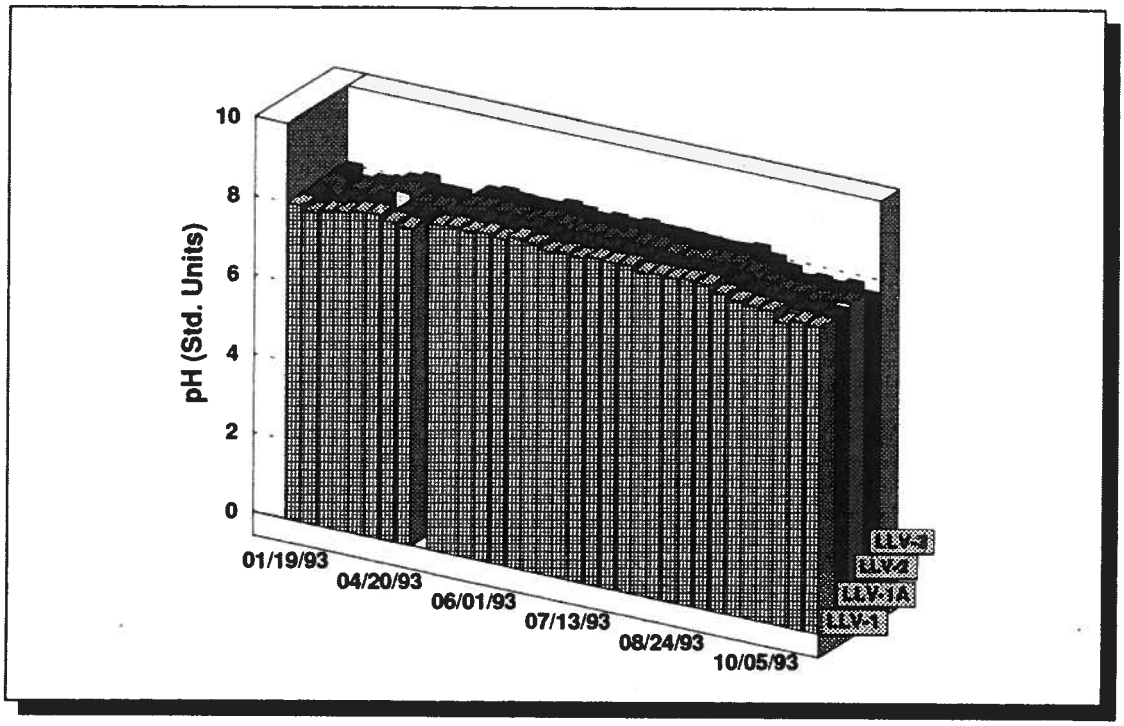

Figure 9. pH in surface waters (0 m) at main-lake stations in Lake Las Vegas during January - December 1993.

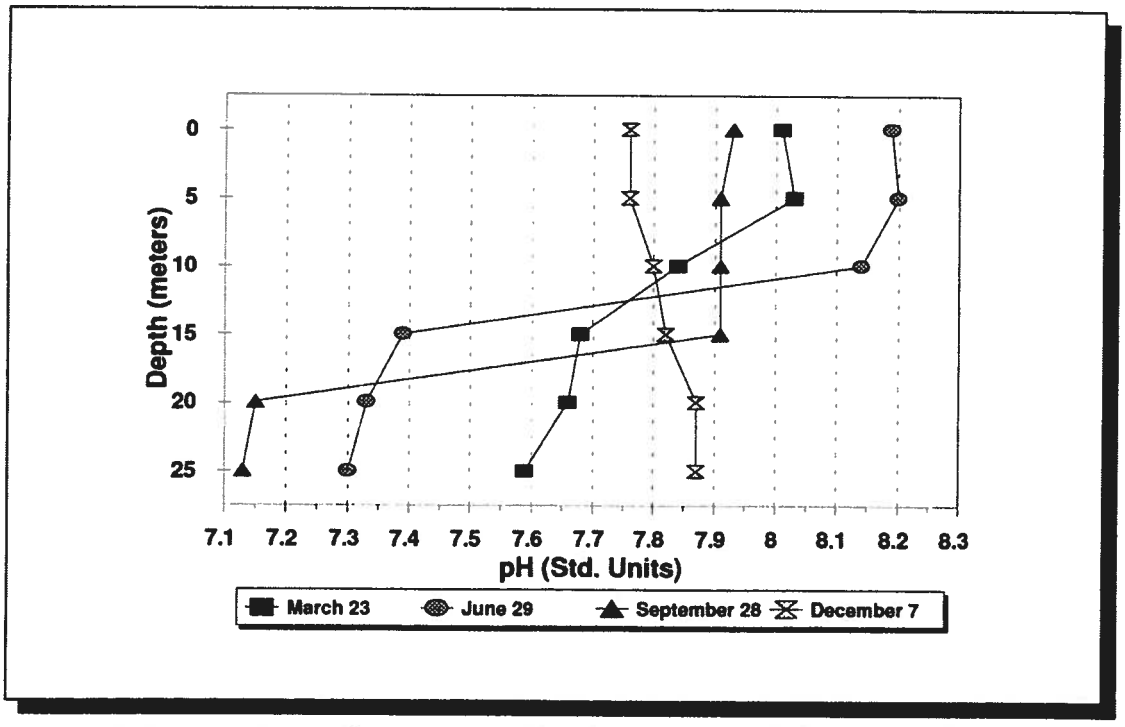

Figure 10. pH profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

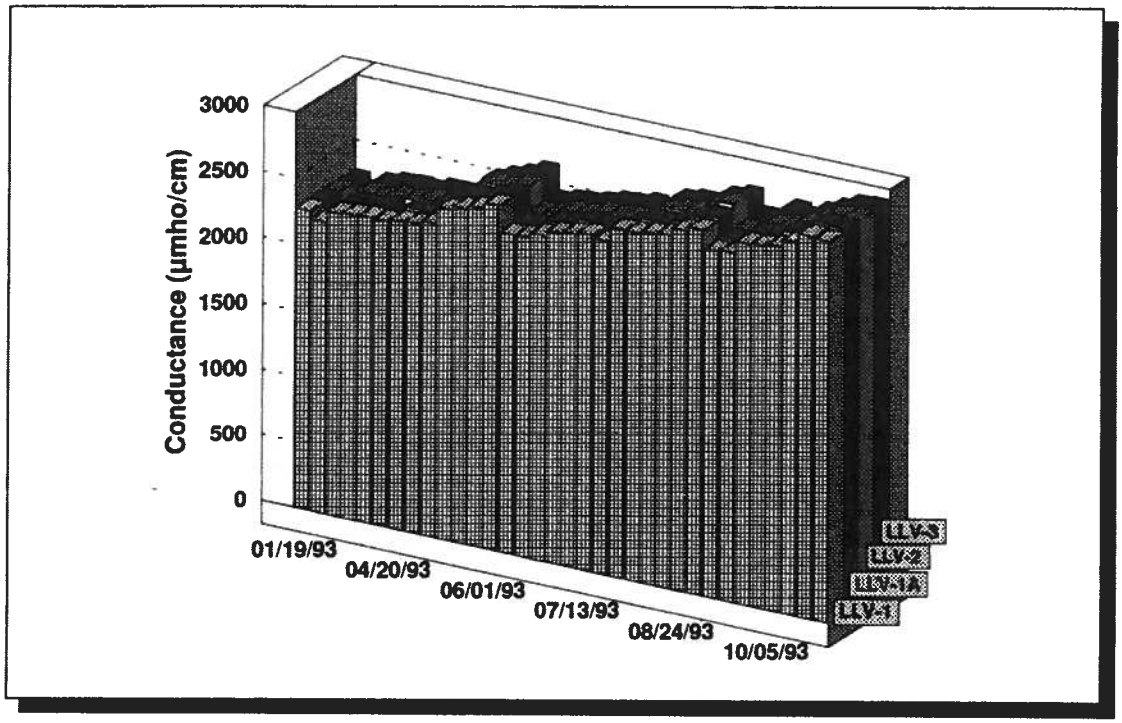

Figure 11. Conductance in surface waters (0 m) at main-lake stations in Lake Las Vegas during January - December 1993.

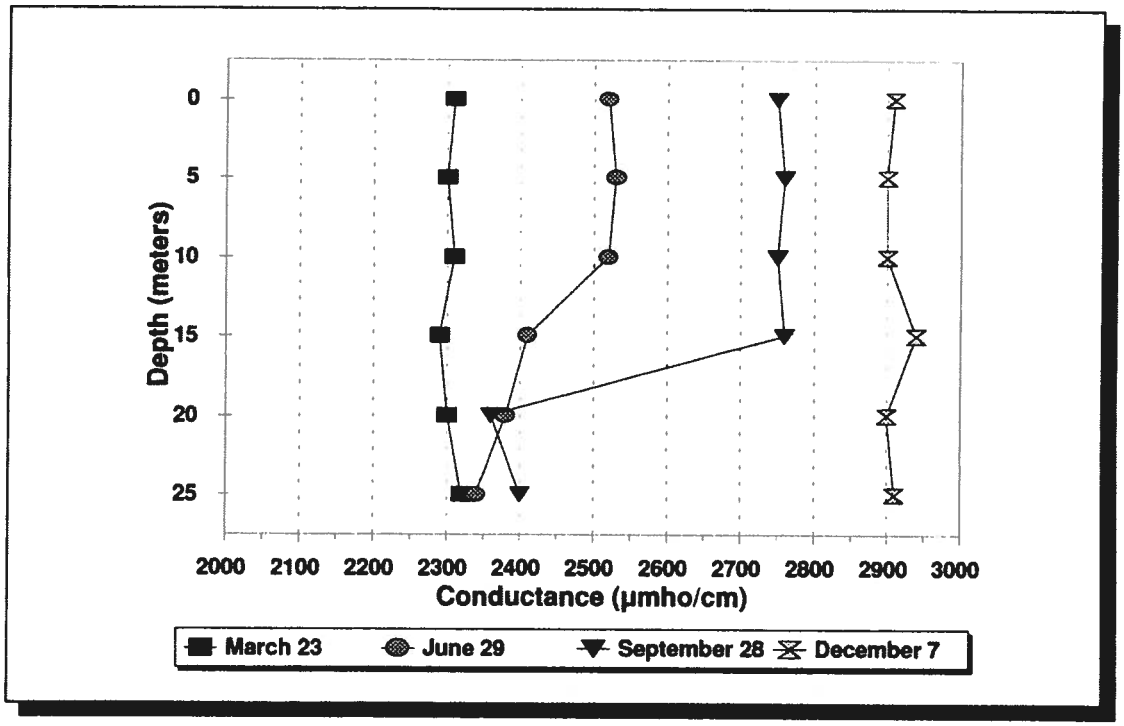

Figure 12. Conductance profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

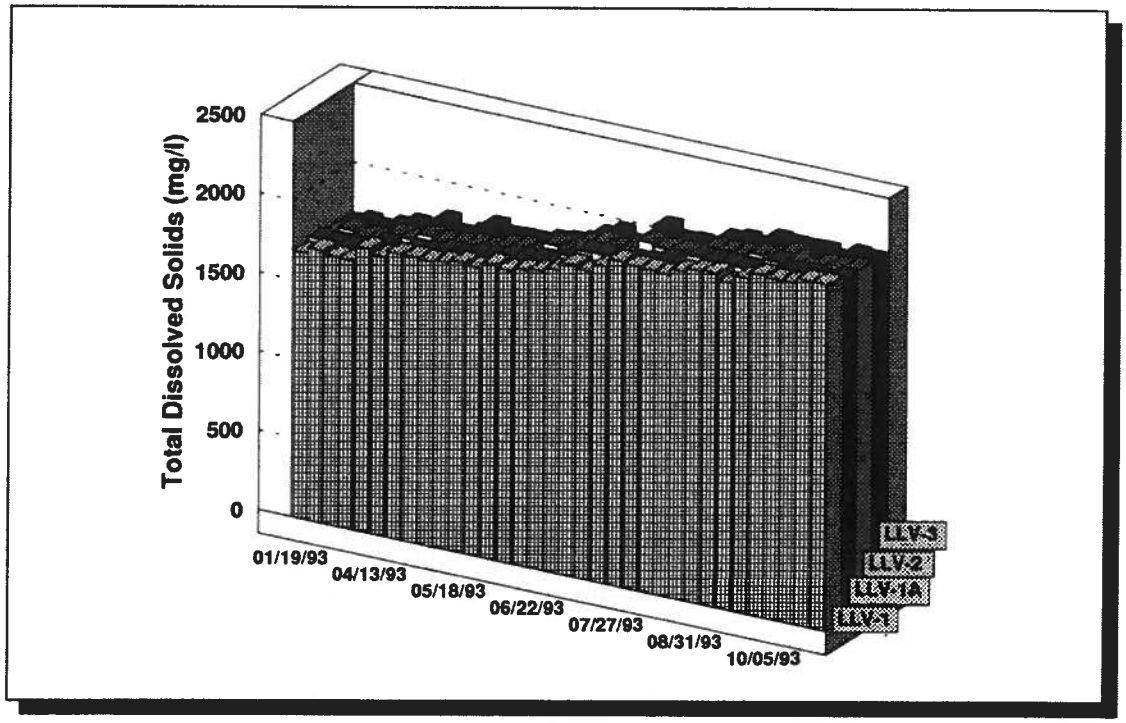

Figure 13. TDS in surface waters (0 m) at main-lake stations in Lake Las Vegas during January - December 1993.

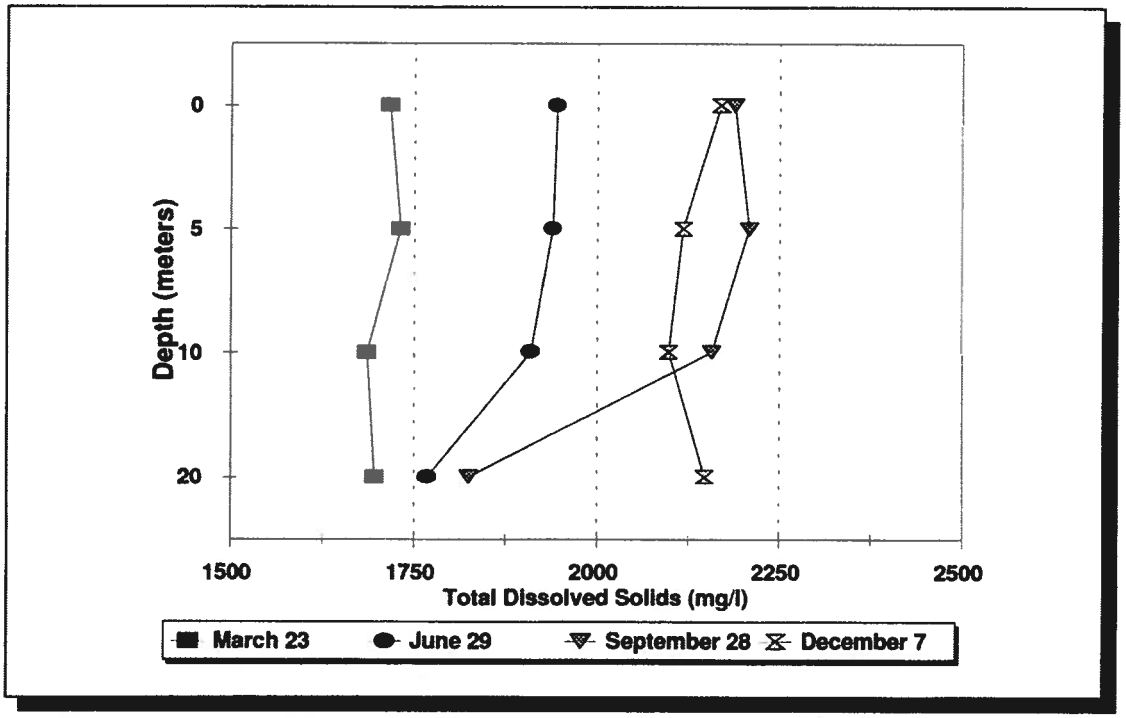

Figure 14. TDS profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

The same trends were evident in total dissolved solids (TDS). TDS in surface waters increased from about 1700 mg/l in January to 2250 mg/l by December (Figure 13). TDS concentrations in the hypolimnion, like conductance, also were lower than in the epilminion during periods of thermal stratification (Figure 14).

Nutrient Concentrations

Nutrient concentrations in Lake Las Vegas varied considerably with depth and season. The stormwater spill that occurred on February 8-9 caused marked increases in concentrations of nutrients throughout the lake (Figures 15-24). It increased ortho phosphorus in surface waters (0-2.5 m) from about 5 µg/l to 25 µg/l; total phosphorus from 12 µg/l to nearly 50 µg/l; ammonia-N from 30 µg/l to nearly 250 µg/l; nitrite+nitrate-N from 300 µg/l to nearly 600 µg/l; and total nitrogen from 700 µg/l to 1400 µg/l (Figures 17,17,19,21,23).

Ortho phosphorus in surface waters (0-2.5 m) decreased back to pre-flood levels of 5 µg/l by early March and remained at about 2.5 µg/l for the rest of the year (Figure 15). Ortho phosphorus concentrations remained high in the hypolimnion throughout summer and fall (Figure 16). By December, ortho phosphorus concentrations were 2-3 µg/l throughout the water column (Figure 16).

Total phosphorus concentrations in surface waters decreased back to pre-flood levels of 10-15 µg/l by mid-April and remained near those levels through summer months (Figure 17). Total phosphorus remained high in the hypolimnion through summer, reaching levels of about 65 µg/l by late September (Figure 18). Total phosphorus increased to about 20 µg/l in surface waters during fall when the lake was mixing and then dropped back to 10-15 µg/l during winter (Figures 17,18).

Ammonia-N concentrations in surface waters decreased back to about 25 µg/l by early April and remained near that level through the summer (Figure 19). Ammonia-N increased to nearly 800 µg/l in the hypolimnion by late September (Figure 20). Fall mixing increased ammonia-N concentrations in surface waters to about 60 µg/l (Figure 20). Nitrite+nitrate-N concentrations in surface waters decreased steadily from post flood levels of 600 µg/l to less than 10 µg/l by late summer (Figure 21). Nitrite+nitrate-N concentrations increased slightly during fall mixing but remained below 50 µg/l for the rest of the year. Nitrite+nitrate-N concentrations were slightly higher in the hypolimnion than epilimnion during late March and June (Figure 22). Hypolimnetic nitrite+nitrate-N concentrations dropped from 700 µg/l in late March to about 50 µg/l by late September (Figure 22).

Total nitrogen concentrations reached a maximum of about 1500 µg/l after the February 8-9 flood (Figure 23). Total nitrogen concentrations decreased during spring and summer and reached a minimum of 200-300 µg/l during late summer (Figure 23). This decrease in total nitrogen also occurred in the hypolimnion where concentrations dropped from about 1400 µg/l in late March to about 250 µg/l in late September (Figure 24).

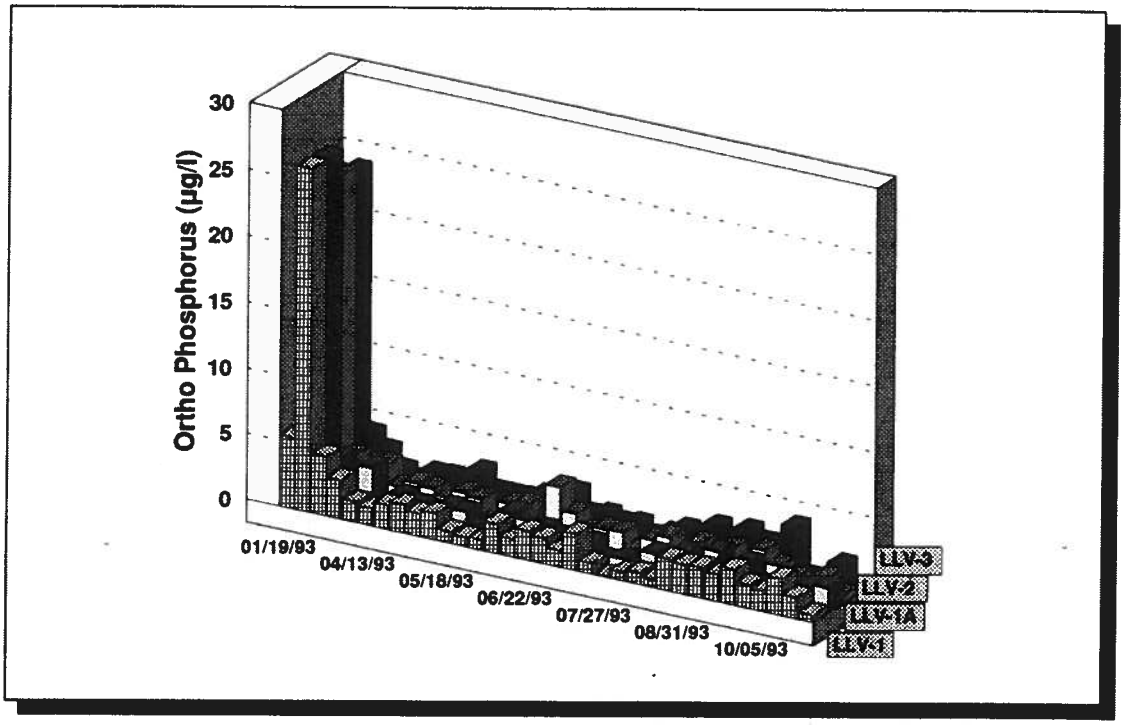

Figure 15. Ortho phosphorus in surface waters (0-2.5 m) at main-lake stations in Lake Las Vegas during January - December 1993

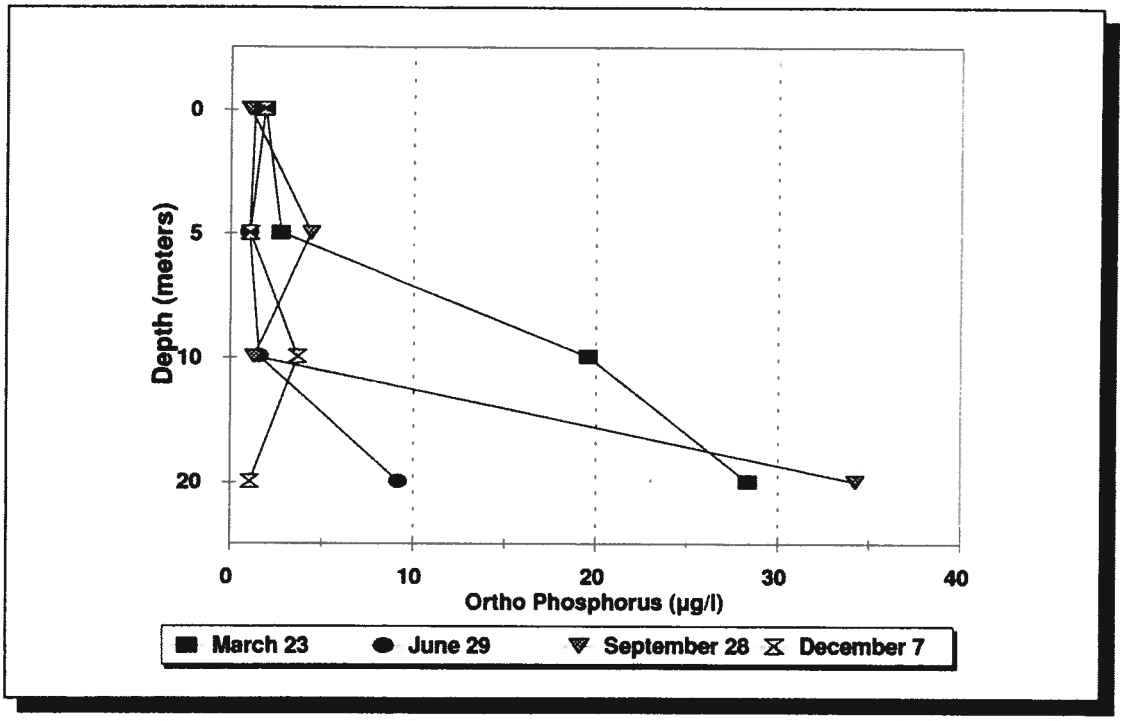

Figure 16. Ortho phosphorus profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

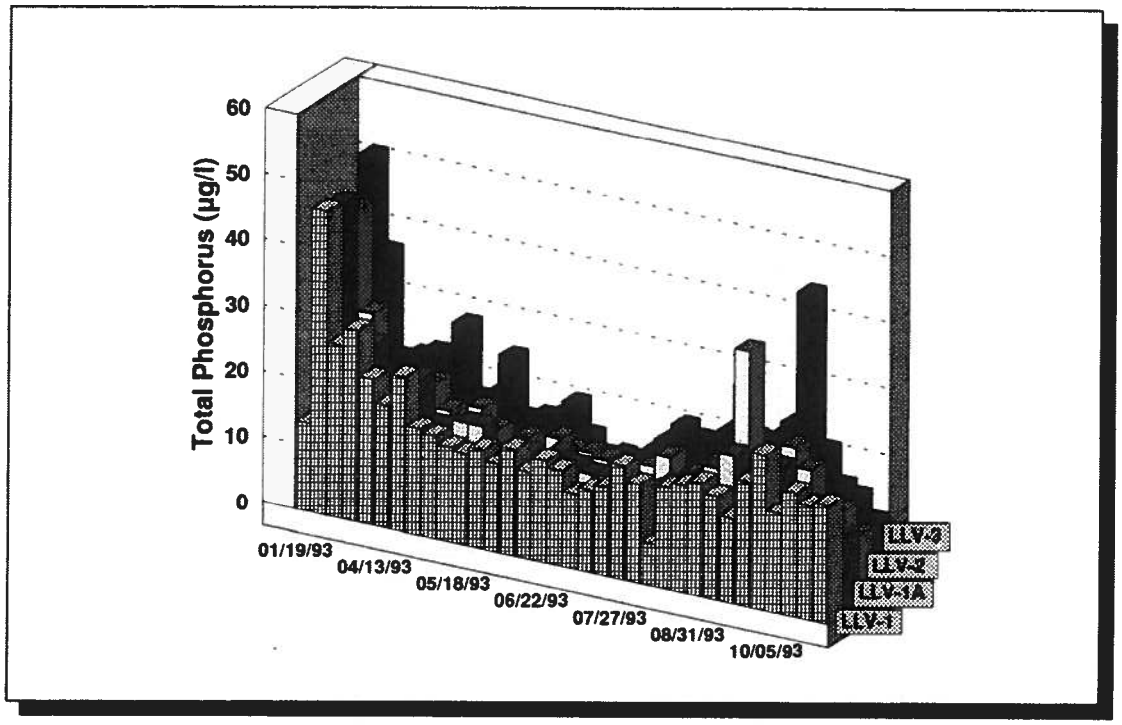

Figure 17. Total phosphorus in surface waters (0-2.5 m) at main-lake stations in Lake Las Vegas during January - December 1993

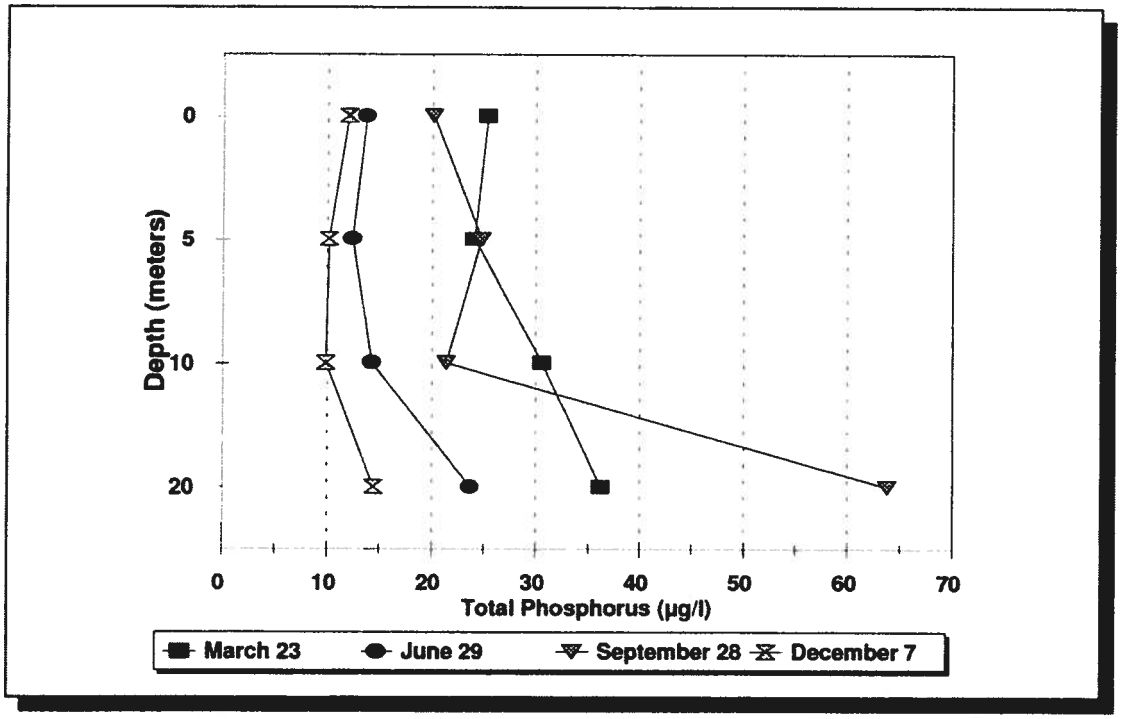

Figure 18. Total phosphorus profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

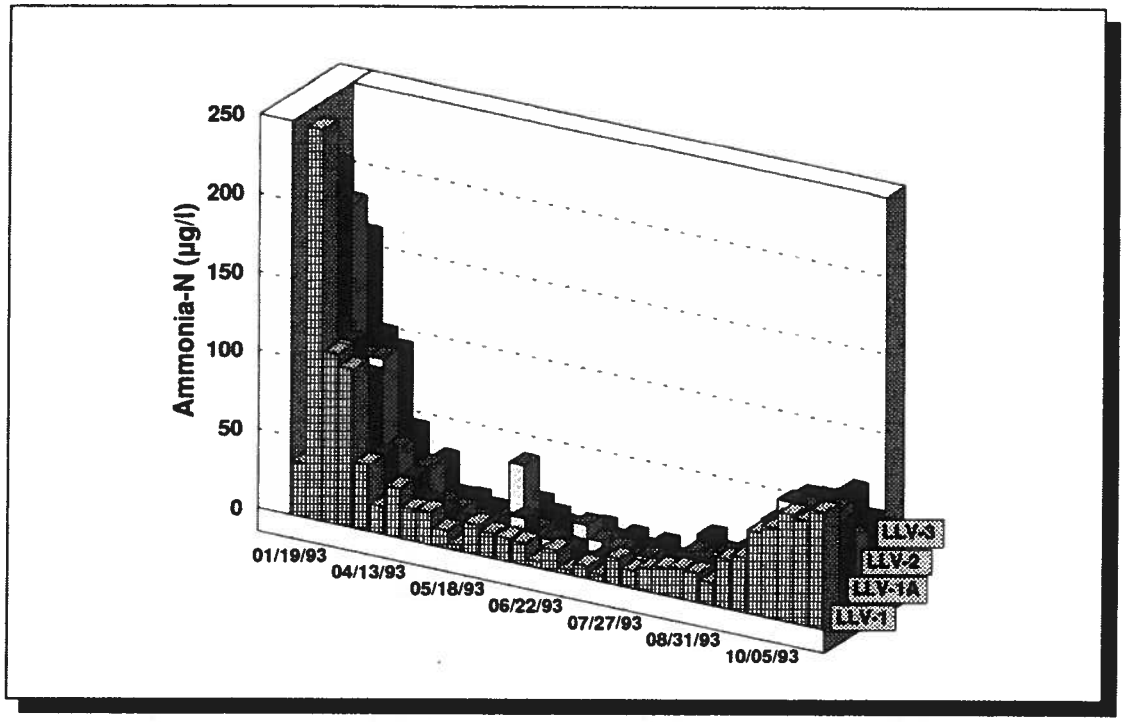

Figure 19. Ammonia-N in surface waters (0-2.5 m) at main-lake stations in Lake Las Vegas during January - December 1993

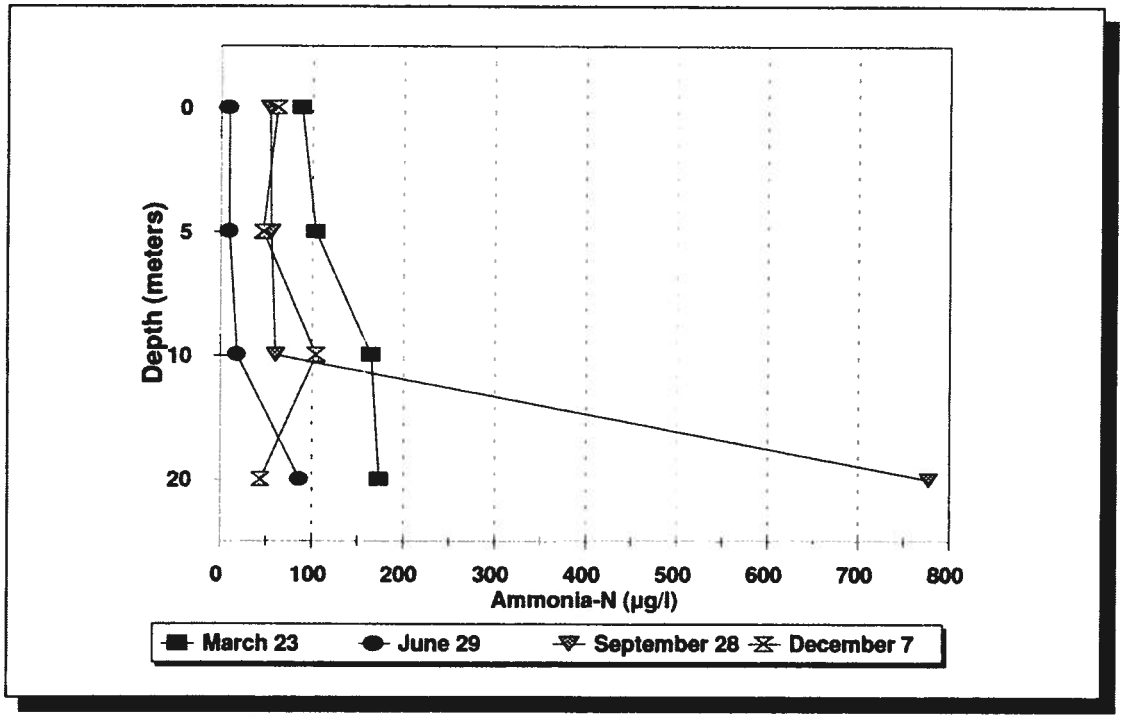

Figure 20. Ammonia-N profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

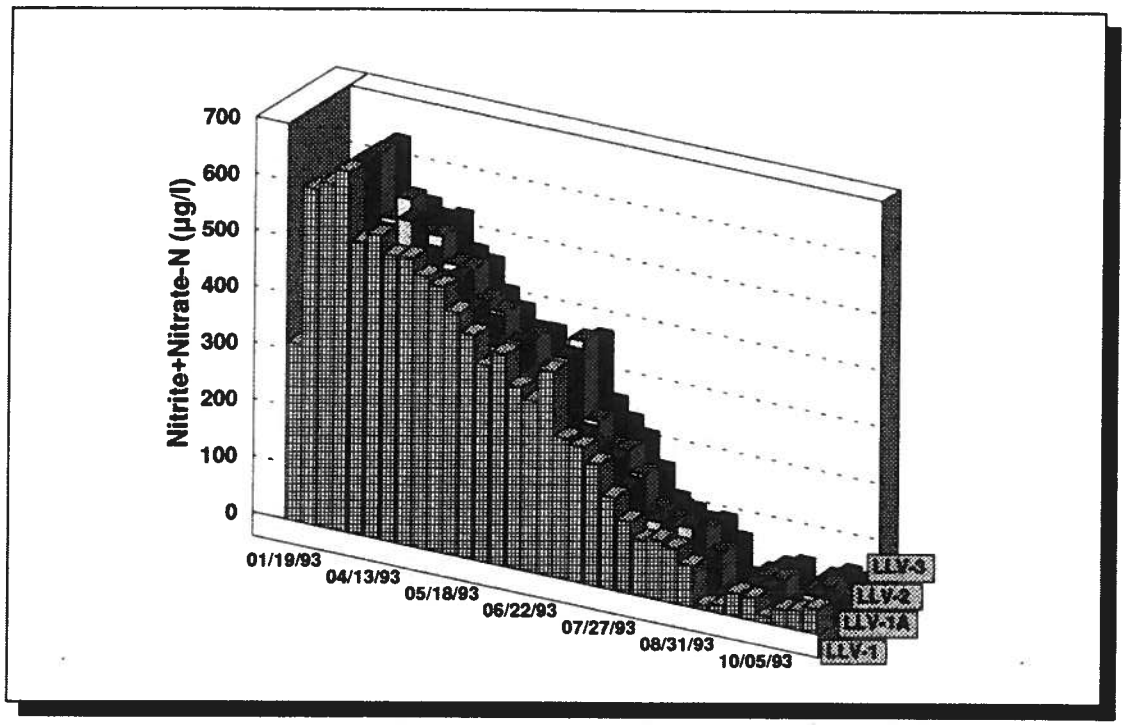

Figure 21. Nitrite+nitrate-N in surface waters (0-2.5 m) at main-lake stations in Lake Las Vegas during January - December 1993

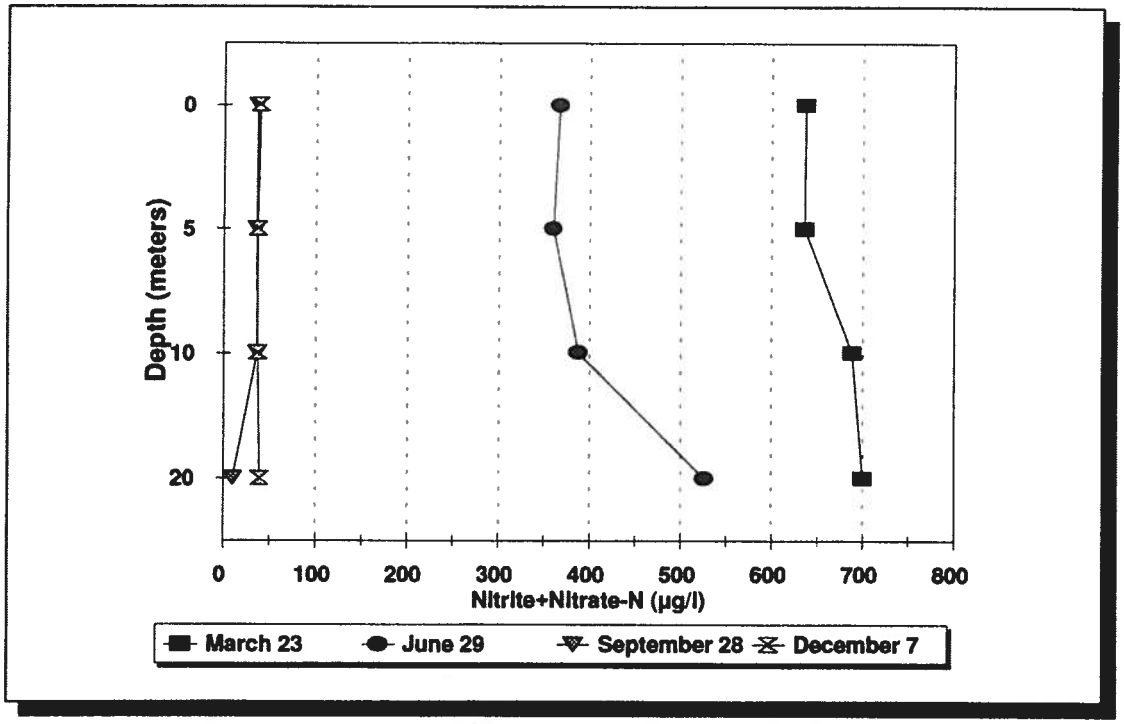

Figure 22. Nitrite+nitrate-N profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

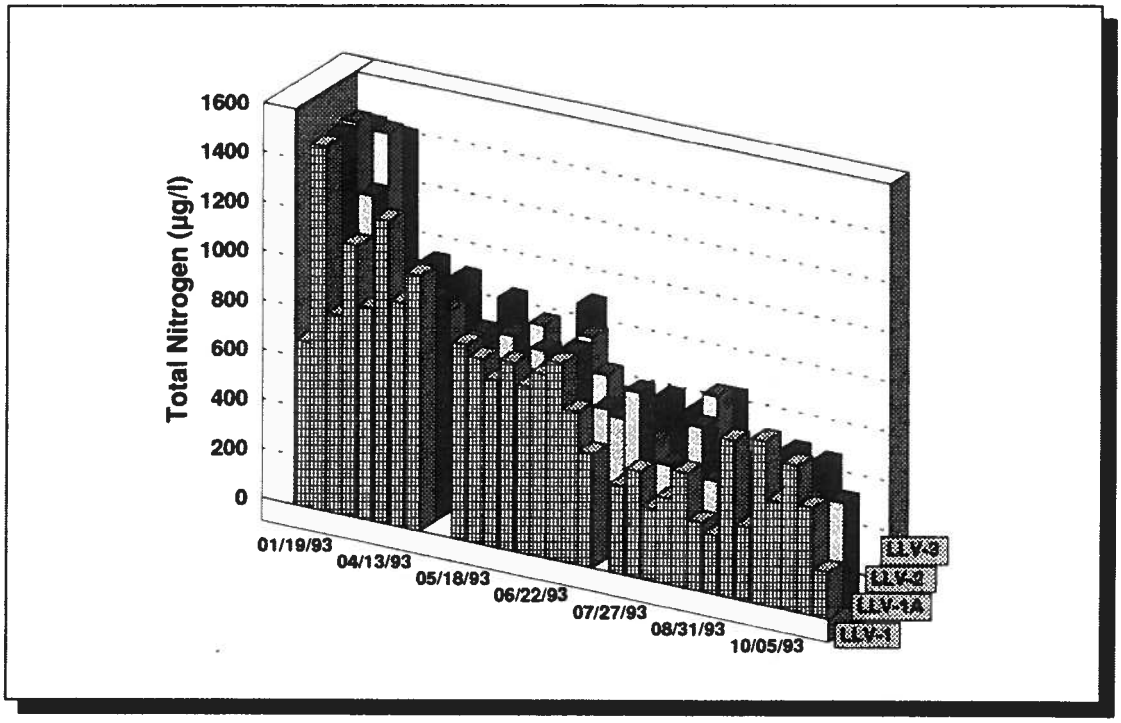

Figure 23. Total nitrogen in surface waters (0-2.5 m) at main-lake stations in Lake Las Vegas during January - December 1993

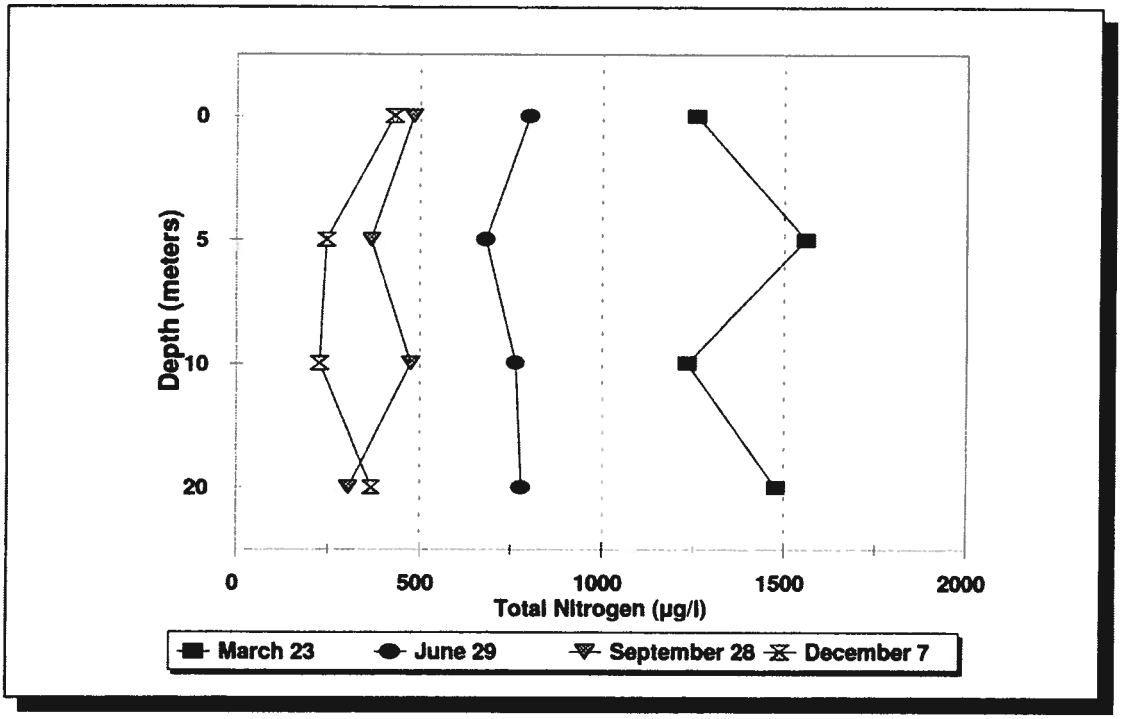

Figure 24. Total nitrogen profiles at station LLV-1A in Lake Las Vegas during March, June, September, and December 1993.

Transparency/Turbidity

There were considerable seasonal and spatial variations in transparency in Lake Las Vegas during 1993. Transparency typically was highest at the down lake stations, LLV-1 and LLV-1A, where it often ranged in excess of 8 m (Figure 25). Transparency at station LLV-3 in the upper end of the lake rarely exceeded 4 m (Figure 25).

Transparency varied considerably at all stations throughout the year (Figure 25). The February 8-9 stormwater spill reduced transparency to 1-3 m throughout the lake. Transparency increased back to about 8 m at LLV-1, and 7 m at stations LLV-1A and LLV-2 during March. Transparency then decreased again to 2-3 m at all stations in April, followed by another increase in May and June (Figure 25). Transparency was about 6-8 m at station LLV-1 during summer, compared to about 2-4 m at station LLV-3. Transparency decreased back to about 1-2 m at all stations again in late summer and early fall when the lake began mixing. Transparency steadily increased again in the late fall and winter, reaching levels of 11-12 m at stations LLV-1 and LLV-1A in November and December.

Transparency varied inversely with changes in turbidity and total suspended solids (TSS). TSS in surface waters (0-2.5 m) reached levels near 10 mg/l (Figure 26) and turbidity ranged as high as 7.5 NTU (Figure 27) at the up lake station, LLV-3, after the February stormwater spill. Turbidity was about 2-3 NTU and TSS 2-4 mg/l at the down lake stations during summer. Turbidity and TSS increased at all stations again in late summer and early fall, followed by another decrease in late fall and winter. Turbidity was about 2.5 NTU and TSS about 2.5 mg/l at all stations in November and December.

Major Ion Concentrations

Salinity in Lake Las Vegas was dominated by calcium and sulfate (Table 5). Sulfate concentrations averaged about 940 mg/l at station LLV-1A on March 23. Calcium averaged about 260 mg/l on that date. Collectively, these two ions comprised about 70% of the TDS. Concentrations of sodium, chloride, and bicarbonate also are quite high in Lake Las Vegas. Sodium was about 175 mg/l, chloride about 170 mg/l, and bicarbonate about 112 mg/l on March 23.

Concentrations of all major ions except bicarbonate increased during the year. Bicarbonate concentrations decreased from an average of about 112 mg/l on March 23 to about 94 mg/l by December 7. Bicarbonate also was the only ion where concentrations were lower in the epilimnion than hypolimnion during periods of thermal stratification. Concentrations of the other ions, and TDS, were significantly lower in the hypolimnion than epilimnion.

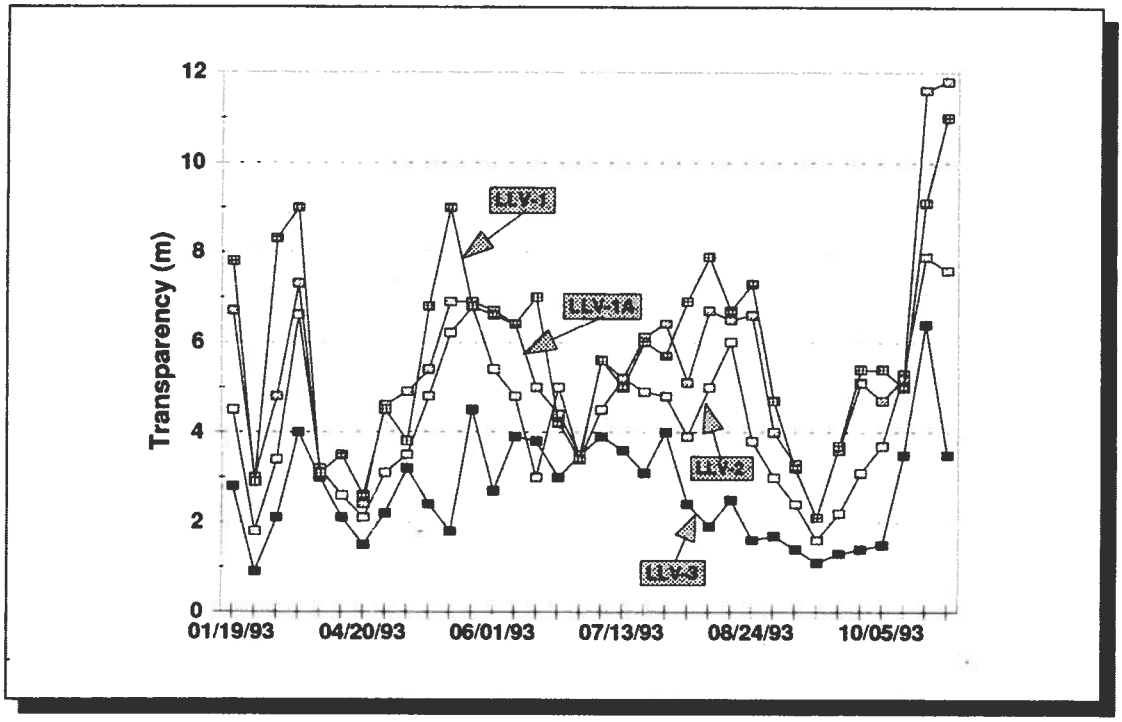

Figure 25. Transparency in surface waters at main-lake stations in Lake Las Vegas during January - December 1993.

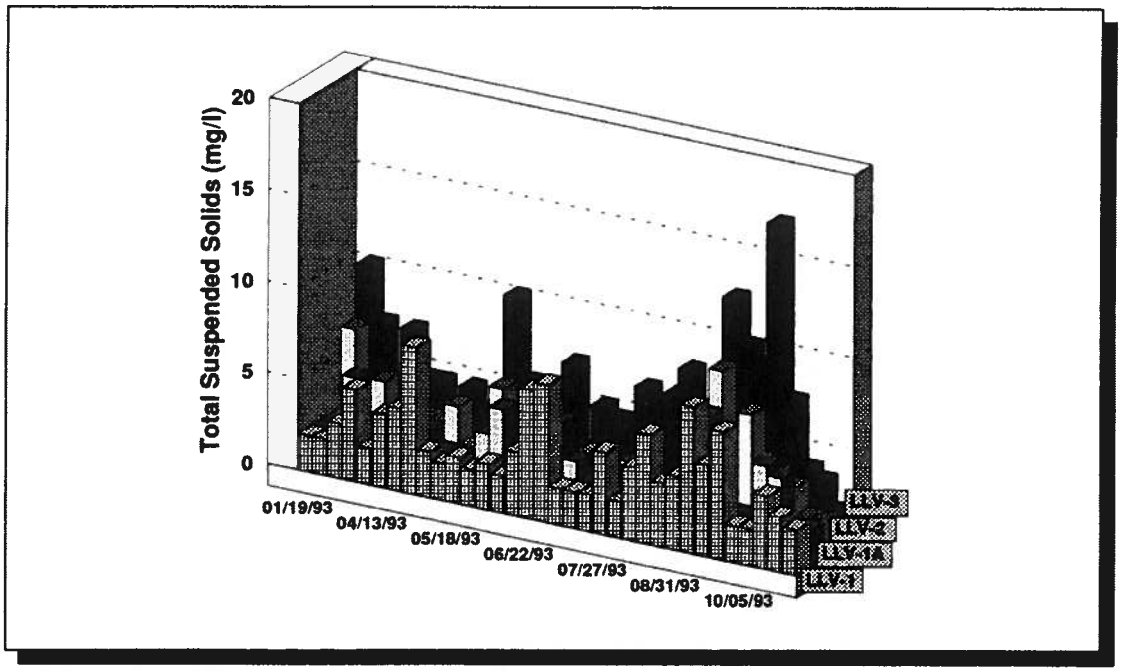

Figure 26. TSS in surface waters (0-2.5 m) at main-lake stations in Lake Las Vegas during January - December 1993.

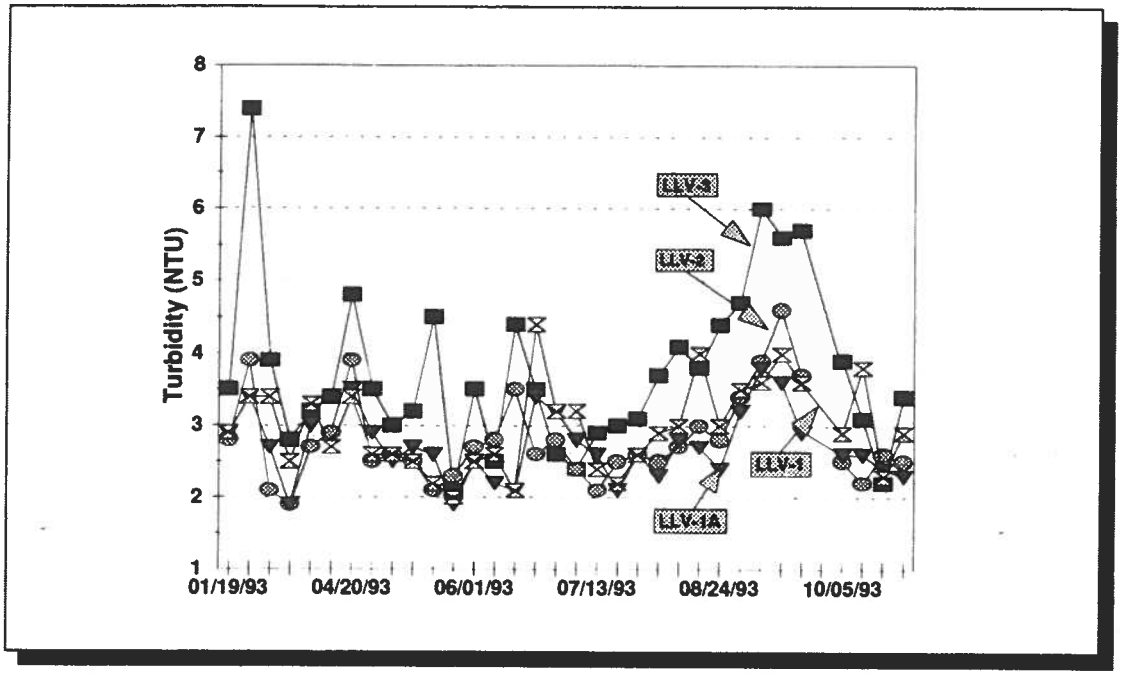

Figure 27. Turbidity in surface waters (0-2.5 m) at main-lake stations in Lake Las Vegas during January - December 1993.

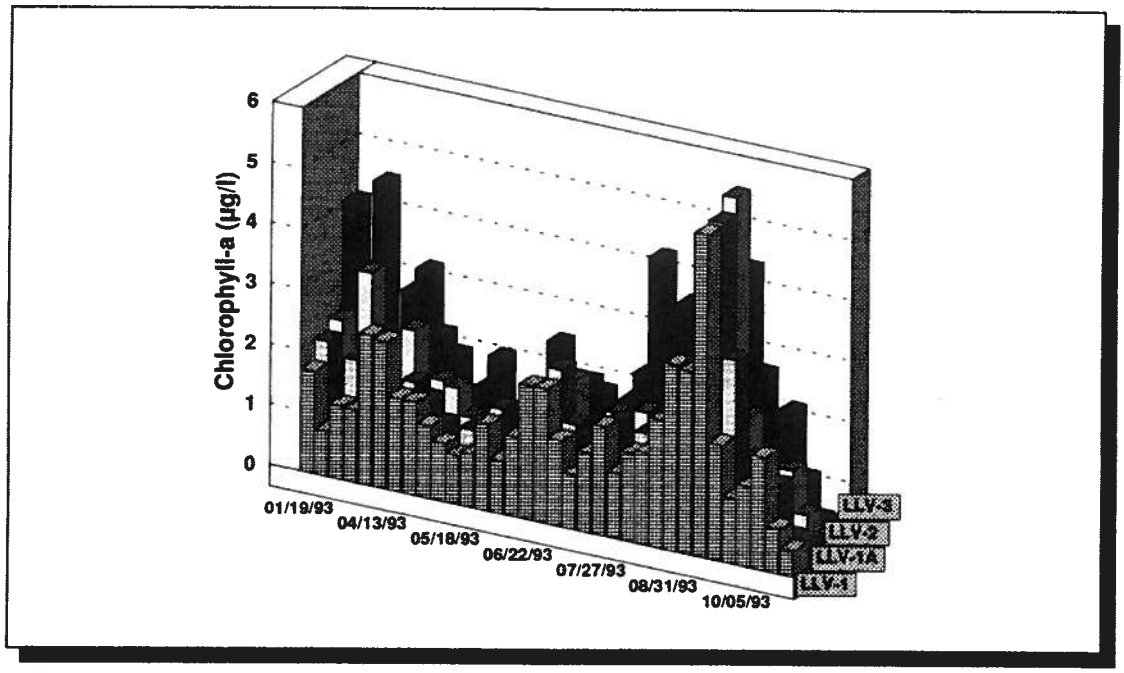

Figure 28. Chlorophyll-a in surface waters (0-2.5 m) at main-lake stations in Lake Las Vegas during January - December 1993.

Table 5. Major ion concentrations at various depths in Lake Las Vegas during March, June, September, and December 1993.

Date	Depth	TDS	Ca^{++}	Na^{+}	Mg^{+}	K^{+}	HCO_3^{-}	CL^{-}	$SO4^{-}$
03/23/93	0-2.5 m	1717	261	177	60.0	17.7	112	177	934
03/23/93	5m	1732	281	175	62.6	18.4	112	180	945
03/23/93	10m	1686	241	161	57.7	17.8	112	179	952
03/23/93	20m	1697	251	167	56.7	18.8	117	177	939
06/29/93	0-2.5 m	1945	274	140	58.9	17.7	95	234	1100
06/29/93	5m	1939	255	163	59.7	17.2	95	233	1070
06/29/93	10m	1909	244	137	57.6	17.2	105	240	1090
06/29/93	20m	1768	216	115	50.2	18.8	119	211	960
09/28/93	0-2.5 m	2188	319	194	76.6	25.0	92	272	1250
09/28/93	5m	2208	312	194	72.2	27.0	87	276	1220
09/28/93	10m	2157	327	193	74.4	27.0	92	281	1230
09/28/93	20m	1825	260	158	59.1	18.0	131	227	1020
12/07/93	0-2.5 m	2169	288	223	60.4	27.0	96	290	1220
12/07/93	5m	2118	310	216	87.4	25.6	92	289	1120
12/07/93	10m	2098	311	224	66.3	26.9	96	292	1130
12/07/93	20m	2147	241	212	39.7	26.9	92	286	1110

Chlorophyll-a and Phytoplankton Species

Chlorophyll-a concentrations in surface waters (0-2.5 m) were low at the main-lake stations throughout most of 1993 (Figure 28). However, some seasonal and spatial trends were still evident in the data. Chlorophyll-a concentrations were bimodal with a pulse in the spring, followed by another in late summer and early fall. The late summer-early fall pulse was the highest with chlorophyll-a reaching levels of 5-6 µg/l throughout the lake (Figure 28). During the spring pulse, chlorophyll-a reached levels of about 2-3 µg/l at the downlake stations. Chlorophyll-a typically was slightly higher at the uplake station, LLV-3. Chlorophyll-a concentrations were only 1-2 µg/l at all stations during the summer, and dropped below 1 µg/l during the late fall and winter.

Numerous species of phytoplankton (open water algae) were identified in 0-2.5 m samples collected at station LLV-1 during 1993 (Table 6). The phytoplankton community was comprised of species from five taxonomic divisions. The most diverse groups were the Chlorophyta and Cryptophyta. None of the phytoplankton species identified in Lake Las Vegas were of the noxious or "scum" forming types. There was only one species of bluegreen algae identified in the samples, and it was only observed in low numbers during late summer.

Table 6. Phytoplankton species identified at 0-2.5 m at station LLV-1 during March - December 1993.

CHLOROPHYTA (Green Algae)	
	Platymonas elliptica
	Oocystis gigas v. incrassata
	Planktonema lauterbornii
PYRRHOPHYTA (Dinoflagellates)	
	Peridinuim sp.
CRYPTOPHYTA (Cryptomonads)	
	Cryptomonas erosa
	Katablepharis ovalis
	Rhodomonas minuta
CHRYSOPHYTA (Golden Algae)	
	Chrysochromulina parva
CYANOPHYTA (Bluegreen Algae)	
	Chroococcus dispersus

Zooplankton Species Composition and Abundance

Numerous species of zooplankton were identified in 0-15 m vertical plankton tows at station LLV-1 during 1993 (Table 7). Rotifers comprised the most diverse group with 11 species, followed by the copepods with 8 species, and cladocerans with 5 species.

Copepods, mainly the juvenile stages, dominated the population in terms of numbers (Figure 29). They reached levels of 140/liter during April and May. Their abundance gradually decreased during the rest of the year, but they still remained the dominate zooplankton group in the lake.

Table 7. Zooplankton species identified in 0-15 m vertical plankton tows at station LLV-1 during February - December 1993.

COPEPODA (Copepod Zooplankton)

Cyclops sp.
Cyclops vernalis
Diacyclops biscupidatus
Diaptomus siciloides
Eurythemora sp.
Eurythemora affinis
Mesocyclops edax
Onychocamptus sp.

CLADOCERA (Cladoceran Zooplankton)

Alona guttata.
Daphnia pulex
Daphnia galeata mendotae
Bosmina longirostris
Chydorus sphaericus

ROTIFERA (Rotifer Zooplankton)

Asplanchna priodonta
Brachionus havanensis
Hexarthra sp.
Keretella cochlearis
Keretella quadrata
Lecane (Monostyla) lunaris
Lecane (Lecane) luna
Notholca sp.
Polyarthra sp.
Syncheata sp.
Testudinella sp.

Cladocerans were the second most abundant zooplankton group, followed by the rotifers. Rotifers were present in low numbers throughout the year. They showed slight peaks in abundance during March and August. Cladocerans were most abundant during February and March, but they also remained numerous throughout the summer and fall.

The cladocerans were comprised mainly of the large ***Daphnia*** species. (Figure 30). These species comprise a large percentage of the zooplankton biomass because of their large size. ***D. pulex*** abundance was highest during February, but it dropped off sharply in March. ***D. pulex*** was absent from the population through early May. ***D. galeata mendotae*** was also most abundant in February, and its numbers remained high until early April. ***D. galeata mendotae*** became less numerous as ***D. pulex*** increased in May and June. ***D. galeata mendotae*** disappeared from the cladoceran population after mid-June.

Fish Abundance in Lake Las Vegas

Experimental (variable mesh) gill nets were set at various depths ranging from the surface to about 30 ft. in select coves throughout the lake on September 9-10, 1993. A total of 315 green sunfish (***Lepomis cyanellus***), ranging in size from 50-190 mm, was captured during the netting (Figure 31). The population was dominated by individuals from the 1993 spawn, which ranged in size from 50-80 mm (Figure 31).

Carp (***Cyprinus carpio***) are also known to occur in Lake Las Vegas. No carp were captured during this year's netting, but several large adults were frequently observed in the upper end of the lake during summer months.

VI. SUMMARY

The large flood in Las Vegas Wash on February 8-9, 1993 spilled 1785 acre feet of stormwater into Lake Las Vegas. Water levels in the lake increased by about 6 ft. overnight, raising surface elevations to an all-time high of 1399.5 ft. That is only 3.5 ft. from the normal operating level of 1403 ft. The lake volume at elevation 1399.5 ft. is 9334 acre feet. Stormwater spills in 1992 and 1993 totaled 5473 acre feet, or about 60% of the lake's volume.

The February 8-9 stormwater spill significantly increased TSS, turbidity, and nutrient concentrations throughout the lake. Transparency decreased to 1-3 m. Nutrient concentrations remained quite high during late winter and early spring, but then steadily decreased during summer. There was only a slight increase in chlorophyll-a concentrations during the spring.

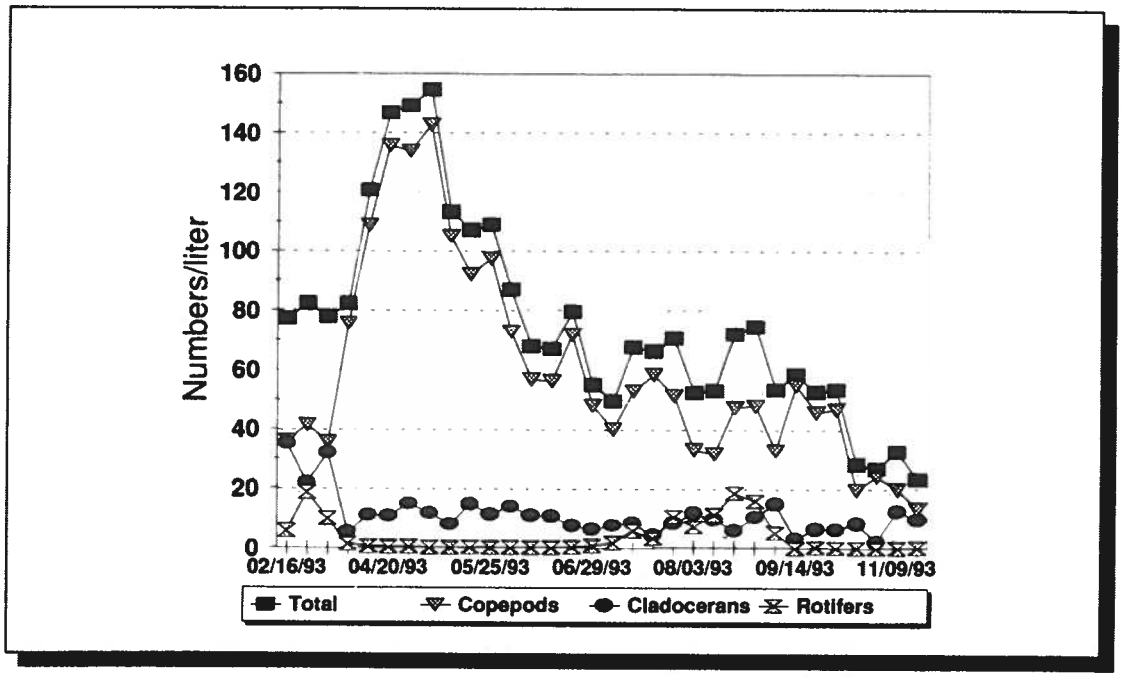

Figure 29. Seasonal changes in abundance of major zooplankton groups in 0-15 m plankton tows collected at station LLV-1 during February - December 1993.

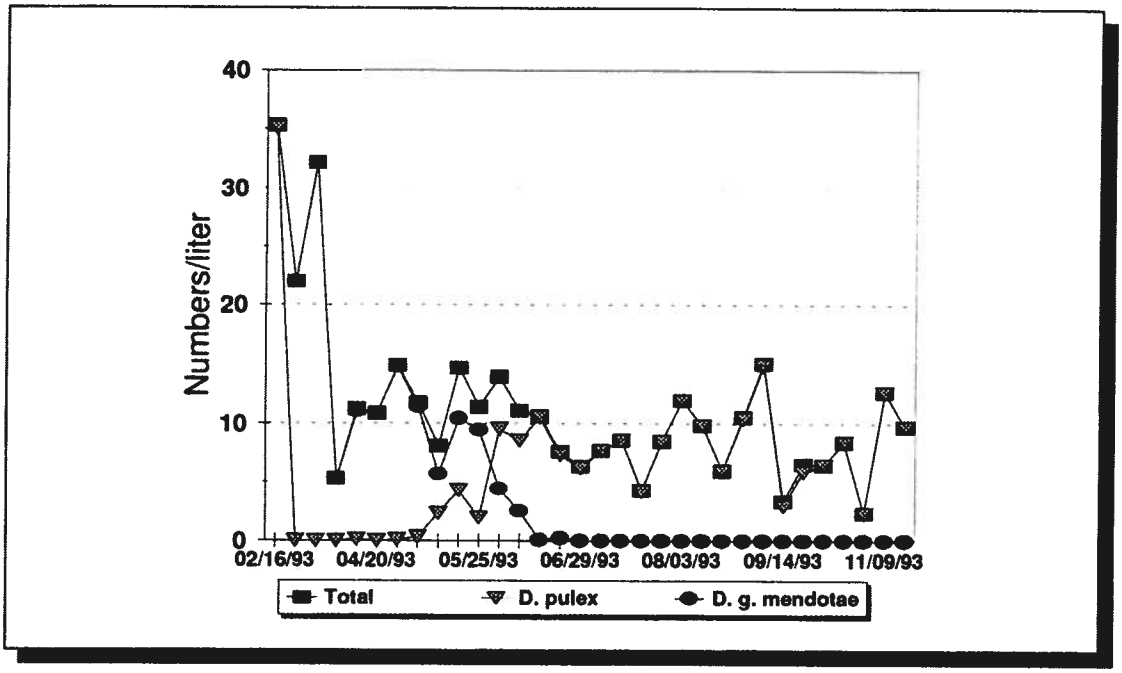

Figure 30. Seasonal changes in abundance of ***Daphnia*** species in 0-15 m plankton tows collected at station LLV-1 during February - December 1993.

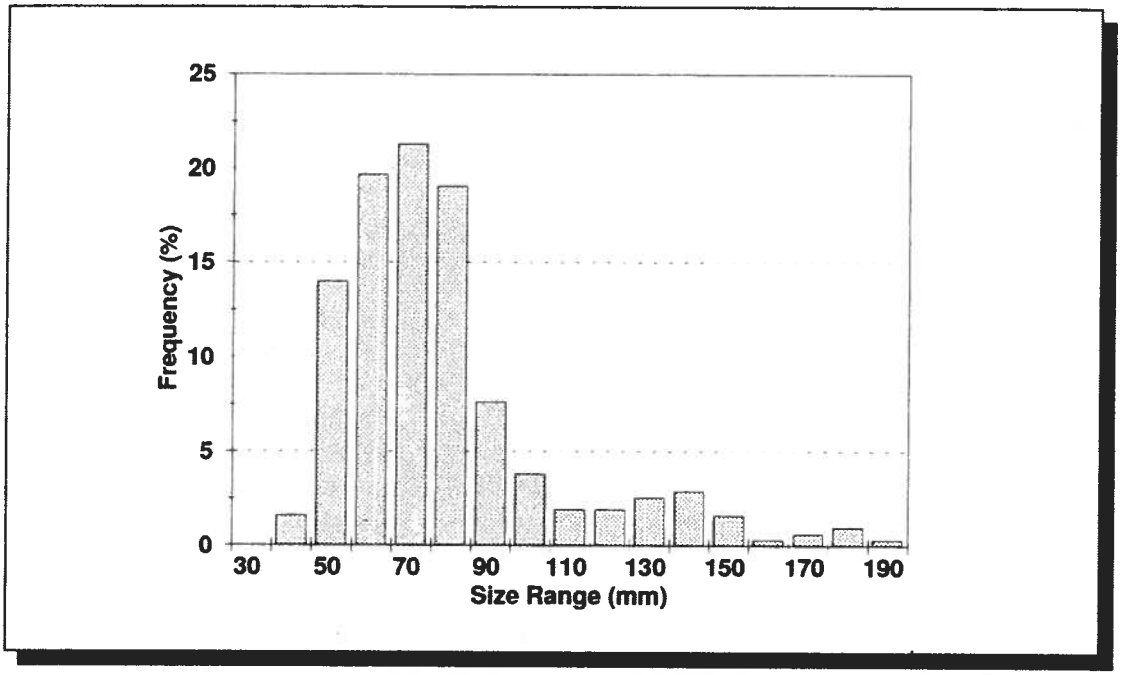

Figure 31. Length (total) frequency distribution of green sunfish captured in experimental gill nets set at various depths and locations in Lake Las Vegas during September 9-10, 1993.

Zooplankton grazers, particularly the ***Daphnia*** species, were abundant prior to, and during the spill. Juvenile copepods increased dramatically in the weeks after the spill. Chlorophyll-a concentrations were held to about 2-3 µg/l at the main-lake stations during spring. The large cladoceran, ***Daphnia pulex***, remained abundant throughout the summer and fall months. Chlorophyll-a rarely exceeded 1-2 µg/l during the summer.

The lake began mixing in late summer and early fall. Nutrients accumlated in the hypolimnion during summer were brought back to surface waters by the mixing. Chlorophyll-a increased to about 5-6 µg/l during that period but then decreased back to < 1 µg/l again by fall. ***D. pulex*** showed a slight increase in abundance during the fall bloom.

The inflow from Lake Mead was shut off after the February 8-9 stormwater spill. TDS concentrations in Lake Las Vegas increased from about 1750 mg/l to 2200 mg/l during 1993. That increase in TDS was largely due to evaporation. Water levels in Lake Las Vegas decreased by 8 ft. during 1993. Calcium and sulfate comprised about 60% of the TDS. All ions except bicarbonate increased in concentration during the year. Bicarbonate decreased by an average of about 10 mg/l during 1993. That is most likely due to uptake of carbon by phytoplankton during photosynthesis.

TDS in Lake Las Vegas exceeded the proposed guideline of 2000 mg/l after June. The TDS guideline was established to keep salinity in the lake at levels acceptable for irrigation. The project was designed so lake waters can be withdrawn for on-site irrigation. The lake currently has no outflow and evaporation will continue to increase TDS until ions reach saturation and precipitate, or are diluted by inflows from Lake Mead. It will take several years for development to reach the point where irrigation demands are sufficient to keep TDS in the lake at acceptable levels. Initially, water drawn from the lake for irrigation may have to be blended with Lake Mead water to dilute the TDS.

Except for TDS, water quality in Lake Las Vegas was well within the proposed water quality guidelines, even though it received 1785 acre feet of stormwater in February. Chlorophyll-a was less than the proposed guideline of 5 µg/l during the April - September growing season. The chlorophyll-a guideline is applied at that time of year to protect water quality during the peak recreation period.

Attached algae problems, which were so troublesome in Lake Las Vegas last year, were not serious in 1993. The crayfish (***Procambaris clarkii***) population in Lake Las Vegas was augmented by stocking in May 1992 to increase grazing pressure on the attached algae. Lake maintenance personnel frequently sighted crayfish along shorelines in 1993, indicating that the population is expanding. Crayfish may be reaching numbers where they are able to keep attached algae under control. Another factor may be low phosphorus concentrations. Ortho phosphorus was rapidly depleted by phytoplankton during early spring of 1993, thus reducing that available for growth of attached algae.

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