WATER CHEMISTRY AND ZOOPLANKTON IN THE LAKE POWELL FORBAY AND THE GLEN CANYON DAM TAILWATER

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INTRODUCTION

Background

The Glen Canyon Environmental Studies (GCES) were initiated in 1982 in response to potential changes in the Bureau of Reclamation management of water flowing in the Colorado River through Glen Canyon Dam and environmental concerns relating in part to dam operations. Research under Phase I (GCES I) extended from 1982-1988 and provided the basis for implementation in 1988 of further investigations under Phase II (GCES II). Phase II studies were designed to incorporate testable hypotheses and develop an information base necessary to evaluate operations of Glen Canyon Dam. Patten (1991) provided a broad perspective of the history of GCES I and of GCES II projected studies and objectives.

On January 4, 1994, a draft Environmental Impact Statement concerning operation of Glen Canyon Dam was filed with the Environmental Protection Agency, based upon information and data gathered during GCES I and GCES II studies. A previous report by the Arizona Game and Fish Department (Angradi et al. 1992) addressed the scope and background of GCES I investigations, emphasizing research conducted during controlled flows from June 1990 through July 1991. Since August 1, 1991, releases from Glen Canyon Dam have followed interim flow criteria mandated by the Secretary of the Interior. As reviewed by Kubly (Angradi et al. 1992), the interim flow regime has restricted minimum and maximum releases from the dam to 5,000 cfs and 20,000 cfs, respectively. Daily ranges vary dependent upon total monthly flows but may not exceed 8,000 cfs, while hourly increases and decreases are limited to 2,500 cfs and 1,500 cfs, respectively. Errors not to exceed 10% are permitted, recognizing difficulty in controlling releases.

Purpose

Purpose of the present report is to provide information relevant to and results of investigations carried out during the interim flow regime from August 1991 to December 1994 within the Lake Powell forebay and tailwaters of Glen Canyon Dam to Lee's Ferry (25 km downstream). Particularly, these studies have emphasized driving variables (flow components as related to dam discharge) in relation to response variables (ecosystem processes and lower trophic levels). Our use of the terms ecosystem and trophic level incorporate descriptions provided by Poole (1974). Ecosystem processes and trophic levels addressed are those which affect and/or represent directly the provisioning of food resources to the fishes for which the Arizona Game and Fish Department and other resource management agencies have legislatively mandated responsibilities.

The circulation pattern in the Lake Powell forebay has been reported prior to interim flows, with general descriptive agreement (Gloss et al. 1980; Merritt and Johnson 1977; Stanford and Ward 1991). Physical and chemical profiles of Lake Powell forebay and Glen Canyon Dam tailwater during 1990-1991 were presented by Angradi et al. (1992). Physical and chemical profiles of the lake forebay and tailwater during 1993-1994 and zooplankton populations in the lake forebay and tailwater from 1990 - 1994 are the focus of the present report

Dam operations, through daily fluctuation in tailwater flow, current withdrawal regimes, and possibly through selective depth withdrawal systems, may influence tailwater epilithon, periphyton and zooplankton communities and transport of particulate organic matter (Angradi and Kubly 1993; Angradi et al. 1992; Blinn et al. 1989; Gloss et al. 1980; Usher and Blinn 1990; Petts 1984). Lake plankton entering lotic systems may be affected both quantitatively and qualitatively during passage through tailwater systems (Petts 1984). Phytoplankton and zooplankton in tailwater of Glen Canyon Dam appear to derive primarily from lentic populations in Lake Powell (Angradi 1994; Haury 1986). In addition, Haury (1986) stated that reproduction by zooplankton may occur in the river. Seston, including zooplankton, provides an important food source for microfauna and benthic invertebrates (Kondratieff and Simmons 1984).

Zooplankton in Lake Powell and the Glen Canyon Dam tailwaters were investigated prior to the interim flow regime (reviewed by Blinn and Cole 1991; Stanford and Ward 1991), but little is known regarding seasonal density, distribution and community composition of zooplankton in the Lake Powell forebay or entering and within the dam tailwaters during interim flows. Present studies were conducted to examine these parameters and provide a basis for long term monitoring. Specifically, present studies examined seasonal variations during interim flows in Lake Powell forebay and the dam tailwaters for: 1) physicochemical parameters and 2) zooplankton density and composition. Other aspects of water chemistry and effects of dam operations on macroinvertebrates and transport of particulate organic matter are reported elsewhere (Ayers and McKinney 1995).

METHODS

Temperature, dissolved oxygen (DO), pH and specific conductance were measured monthly beginning April 1993 in the Lake Powell forebay 200 m from the dam using a Hydrolab Datasonde III datalogger and Surveyor III logging system. Instrument pH and conductivity were calibrated against commercial pH standards and conductivity standards provided by the USGS Ocala laboratory. The dissolved oxygen sensor was calibrated using air calibration at 100% saturation and the current barometric pressure. Beginning August 1993, single measurements were taken every 1.5 m from the water surface to 60 m and then every 3 m to 91 m. Prior to July 1993, measurement depth varied. Beginning July 1993, single, monthly measurements from Glen Canyon Dam draft tube ports were taken immediately following collection of water samples into a five gallon bucket. This procedure was changed in April 1994 to a method using a section of hose with the end of the hose placed in the bottom of a five gallon bucket. Water continually overflowed the bucket while measurements were recorded. Single surface measurements were taken monthly beginning July 1993 from the approximate midpoint of the river at Lee's Ferry and -14 mile bar.

From March 1990 through March 1992, single zooplankton samples were collected intermittently at the forebay of Lake Powell 200 m in front of the dam from the surface to 62m in depth. From October 1989 - December 1991, zooplankton samples were collected intermittently from draft tubes in Glen Canyon Dam and from Lee's Ferry. Zooplankton were collected by pumping 10 L - 200 L of water through an 80 μm plankton net and preserving in 10% formalin. In the laboratory, the sample was poured into a 80μm sieve, rinsed, transferred into a 50ml graduated cylinder and the volume brought to 50ml with water. Three 1 ml subsamples were counted from each sample bottle, and a mean density was calculated.

Beginning April 1993, single zooplankton samples were collected at the forebay of Lake Powell 200 m in front of the dam from surface and penstock depths, from #5 or #6 draft tube in Glen Canyon Dam, and from -14 mile and Lee's Ferry on the Colorado River. Zooplankton were collected by pumping 100L of water through an 80μm plankton net and preserving in 70% ethanol. In the laboratory, the sample was poured into a 53 micron sieve, rinsed, transferred into a 50 ml graduated cylinder and the volume brought to 50 ml with water. Five 1 ml subsamples were counted from each sample, and a mean density was calculated.

RESULTS

Chemical and Physical Parameters

From March 1, 1993 to August 1, 1993, the elevation of Lake Powell rose from 3612 ft to 3667 ft, which is a rise of 55 ft or 16.8 m, resulting from a large spring runoff into Lake Powell from the watershed (full pool = 3700 ft).

Conductivity values in the upper 75 m of Lake Powell decreased from an average of 0.876μS/cm in July 1993 to an average of 0.761μS/cm in August 1993, indicating an influx of water with lower conductivity (Figure 2.1.1). The lowest conductivity water was at 15 - 35 m in depth. By November 1993, conductivity was relatively constant at 0.755 μS/cm to a depth of 50 m and increased to 1.022 μS/cm at 91 m. Conductivity continued to decrease in the lake to an average of 0.689 μS/cm in the upper 55 m and to 0.955 μS/cm at 91m by January 1994, forming a chemocline at 55 - 65 m. The chemocline had dissipated by May of 1994, leaving a gradual increase in conductivity with depth from 0.770 μS/cm at the surface to 1.111 μS/cm at 91 m (Figure 2.1.2). Conductivity decreased from May 1994 to June 1994, then gradually increased over the summer to 0.748 μS/cm at the surface and 1.036μS/cm at 91 m. By November 1994, conductivity was relatively constant at 0.806 μS/cm to a depth of 55 m and climbed to 1.053μS/cm at 91 m (Figure 2.1.2).

During the spring and summer of 1993, the lake was warmed to a depth of 59 m where temperature reached ca. 9.7°C. The water at 59 m remained near this temperature until the first part of February 1994 (Figure 2.1.3). The maximum surface temperature recorded during the summer of 1993 was 24.72°C. By the first part of February 1994, the temperature was uniform at 9.2 ± 0.5°C from the surface to 60 m. Surface warming began again by the first part of March. During the spring and summer, the lake was warmed to a depth of 47 m where temperature reached 9.7°C. The maximum surface temperature recorded during the summer of 1994 was 27.87°C (Figure 2.1.3.).

A pocket of low DO (4.4 mg/l) was recorded at 17 m in September 1993. This pocket dropped to 27 m and decreased to 3.3 mg/l by October. A similar pocket of low DO was recorded in October 1994 at 37 m. DO values of 10.0 ±0.2 mg/l extended from the surface to 55 m in January 1994. A maximum DO level of 12.23 mg/l was recorded at a depth of 5 m in April 1994 (Figure 2.1.4.).

A pocket of low pH water was recorded at ca.30 m during August, September and October 1993; a value of pH 6.5 was recorded in August and this rose to pH 7.5 by September.

With winter mixing, values were uniform at pH 8.1 from the surface to 55m from mid November 1993 through January 1994. Values were highest (>pH 8.2) at the surface to ca. 15 m during June - September (Figure 2.1.5).

Patterns in the temperature and DO profiles recorded from the draft tubes in Glen Canyon Dam reflect changes in the temperature and DO values in the lake at penstock depth over time (Table 2.1.1; Figures 2.1.3, 2.1.4, 2.1.6). DO and pH values were slightly higher from the draft tubes as compared to the corresponding penstock level values.

Table 2.1.1. Penstock depths In Lake Powell 3/29/90 - 12/14/94

Date	Penstock depth	Date	Penstock depth
3/29/90	55.2 m	6/21/93	58.5 m
5/15/90	54.6 m	7/14/93	60.7 m
6/15/90	54.9 m	8/19/93	59.4 m
7/25/90	54.3 m	9/15/93	58.5 m
9/25/90	51.2 m	10/14/93	58.2 m
10/15/90	50.9 m	11/15/93	58.2 m
12/17/90	50.3 m	12/15/93	58.2 m
1/15/91	49.4 m	1/19/94	57.3 m
2/4/91	48.8 m	2/16/94	56.7 m
3/11/91	48.5 m	3/15/94	56.4 m
4/23/91	47.8 m	4/19/94	56.1 m
5/28/91	49.1 m	5/23/94	57.3 m
6/24/91	51.2 m	6/23/94	59.7 m
8/16/91	50.0 m	7/13/94	59.1 m
9/24/91	48.5 m	8/16/94	57.6 m
10/30/91	47.8 m	9/14/94	56.6 m
1/1/92	46.9 m	10/18/94	55.8 m
1/26/92	46.0 m	11/15/94	55.5 m
3/24/92	45.4 m	12/14/94	54.9 m

DO values were higher from the draft tubes than at -14 mile from July 1993 - March 1994 and lower than at -14 mile from April - December 1994. DO values were higher at Lee's Ferry than at -14 mile, except for May 1994. Temperature, conductivity and pH profiles and values were similar at all three locations (Figure 2.1.6 & 2.1.7).

Zooplankton

March and June - July 1990 zooplankton densities ranged from 140,868/m^3 to 688,906/m^3 from the surface to 62 m in depth. Copepods (adults and copepodids) comprised 44% - 50%, cladocerans 28% - 58%, copepod nauplii 10% - 18% and rotifers 1% - 5% of the total zooplankton. Copepod density peaked at 9 - 15m, cladoceran density peaked at 6 - 15m, and nauplius density peaked at 18 - 37m (Figure 2.1.8).

December 1990, April and August 1991 zooplankton densities averaged from 53,153/m^3 to 522,779/m^3 from the surface to 62m. Copepods comprised 23% - 47%, cladocerans 18% - 62%, nauplii 5% - 24% and rotifers <1% - 3% of total zooplankton. Cladoceran and copepod densities peaked at 6 - 12m and nauplius density peaked at 36 - 52 m (Figure 2.1.9).

November 1991 and January and March 1992 zooplankton densities averaged from 56,875/m^3 to 118,291/m^3 from the surface to 62m. Copepods comprised 14% - 57%, cladocerans 17% - 40%, nauplii 9% - 26% and rotifers <1% - 2% of total zooplankton. Cladoceran density peaked from the surface to 12m, copepod density peaked at 6 - 36m, and nauplius density peaked at 6 - 46m (Figure 2.1.10).

Zooplankton at the surface of Lake Powell from April 1994 - January 1995 peaked in January 1994 at 39,240/m^3. Lowest totals were found in May and July - August in 1993 and 1994. Unusually high numbers of rotifers were found in March 1994, when they reached 29,100/m^3. Nauplii comprised the largest fraction of the zooplankton at 49%. Copepods were the second most abundant zooplankter at 29%. Rotifers comprised 17%, and cladocerans comprised 5% of the total (Figure 2.1.11). Zooplankton density at penstock depth from April 1994 - January 1995 was much lower than surface values, with a mean total of 4776/m^3. Nauplii comprised 73%, followed by copepods at 18%, then by rotifers at 5% and cladocerans at 4% of the total. Highest numbers were found in December 1993 at 13,200/m^3 and lowest numbers in February at 1,400/m^3 (Figure 2.1.11).

Glen Canyon Dam draft tube zooplankton collections from October 1989 - December 1991 had a mean total number of 22,508/m^3. The total was composed of 55% copepods, 27% nauplii, 17% cladocerans and 0.5% rotifers. Totals ranged from a low of 1000/m^3 in March 1990 to a high of 50,652/m^3 in June 1991(Figure 2.1.12).

Glen Canyon Dam draft tube zooplankton collections from December 1993 - January 1995 averaged 11,700/m³ total zooplankton. Nauplii comprised 74%, copepods 24%, rotifers 1% and cladocerans 1% of total zooplankton. Total values ranged from a high of 11,700/m³ in May and August 1994 to a low of 2,200 in April 1994 (Figure 2.1.13).

Lee's Ferry zooplankton collections from October 1989 - December 1991 had a mean total number of 23,151/m³. Copepods comprised 50%, nauplii 39%, cladocerans 10% and rotifers 1% of total zooplankton. Totals ranged from a low of 6,382/m³ in March 1990 to a high of 23,151/m³ in May 1991 (Figure 2.1.12).

Lee's Ferry zooplankton collections from June 1993 - January 1995 averaged 4,290/m³ total zooplankton. Nauplii comprised 73%, copepods 20%, rotifers 5% and cladocerans 3% of total zooplankton. Totals ranged from a high of 9,200/m³ in December 1993 to a low of 200/m³ in March 1994 (Figure 2.1.13).

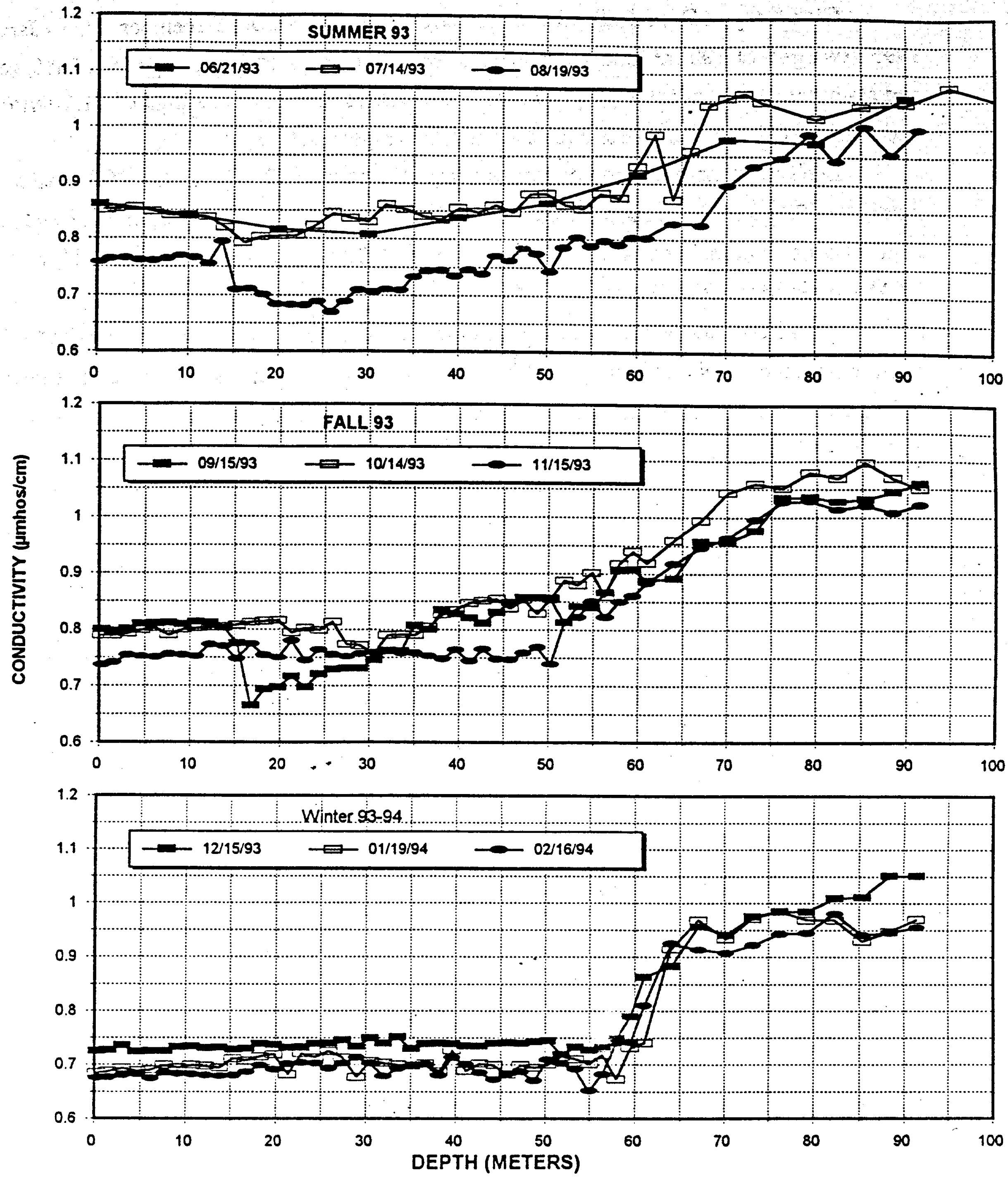

Figure 2.1.1. Conductivity profiles from Lake Powell forebay June 1993 - February 1994.

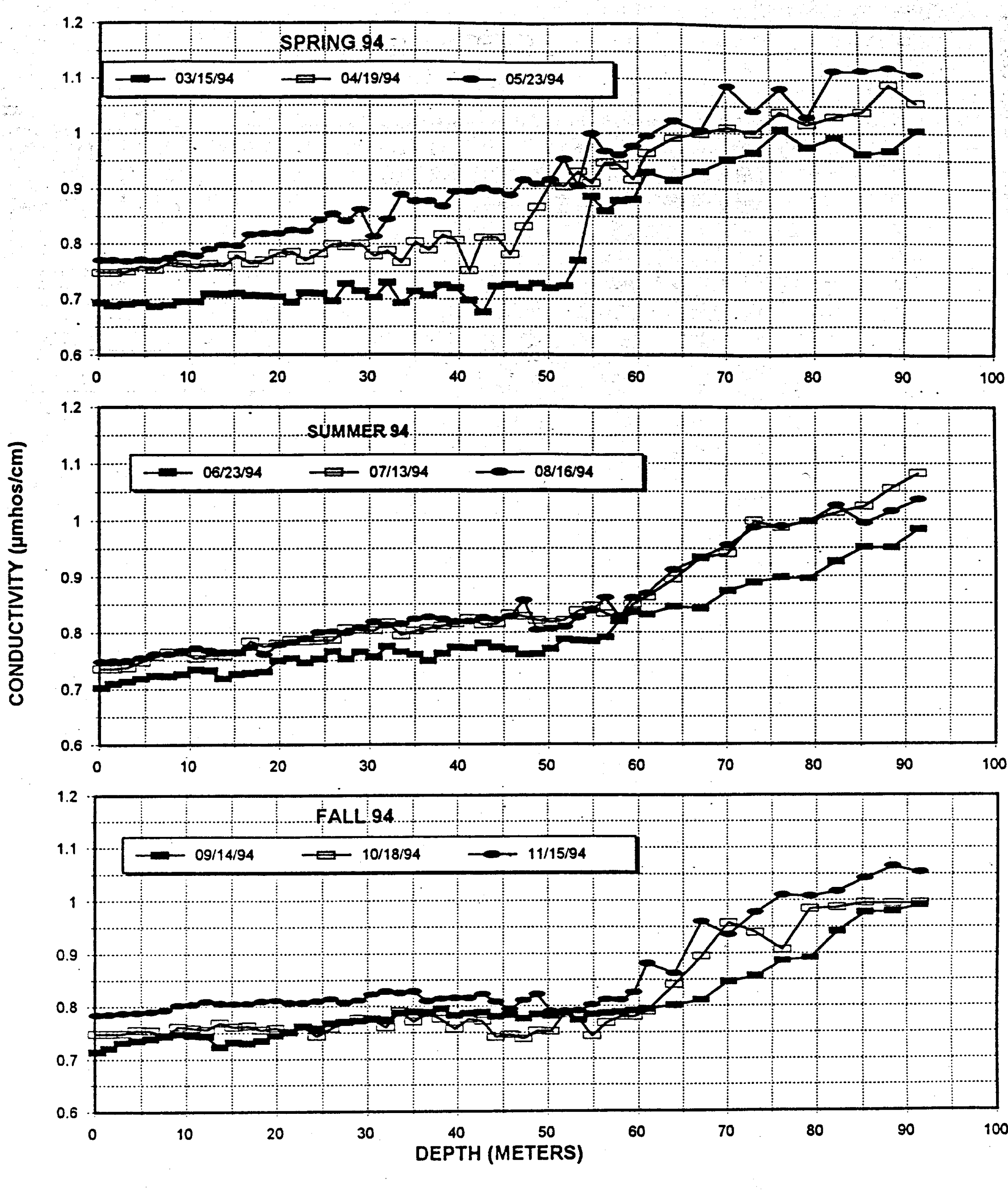

Figure 2.1.2. Conductivity profiles from Lake Powell forebay, March 1994 - November 1994.

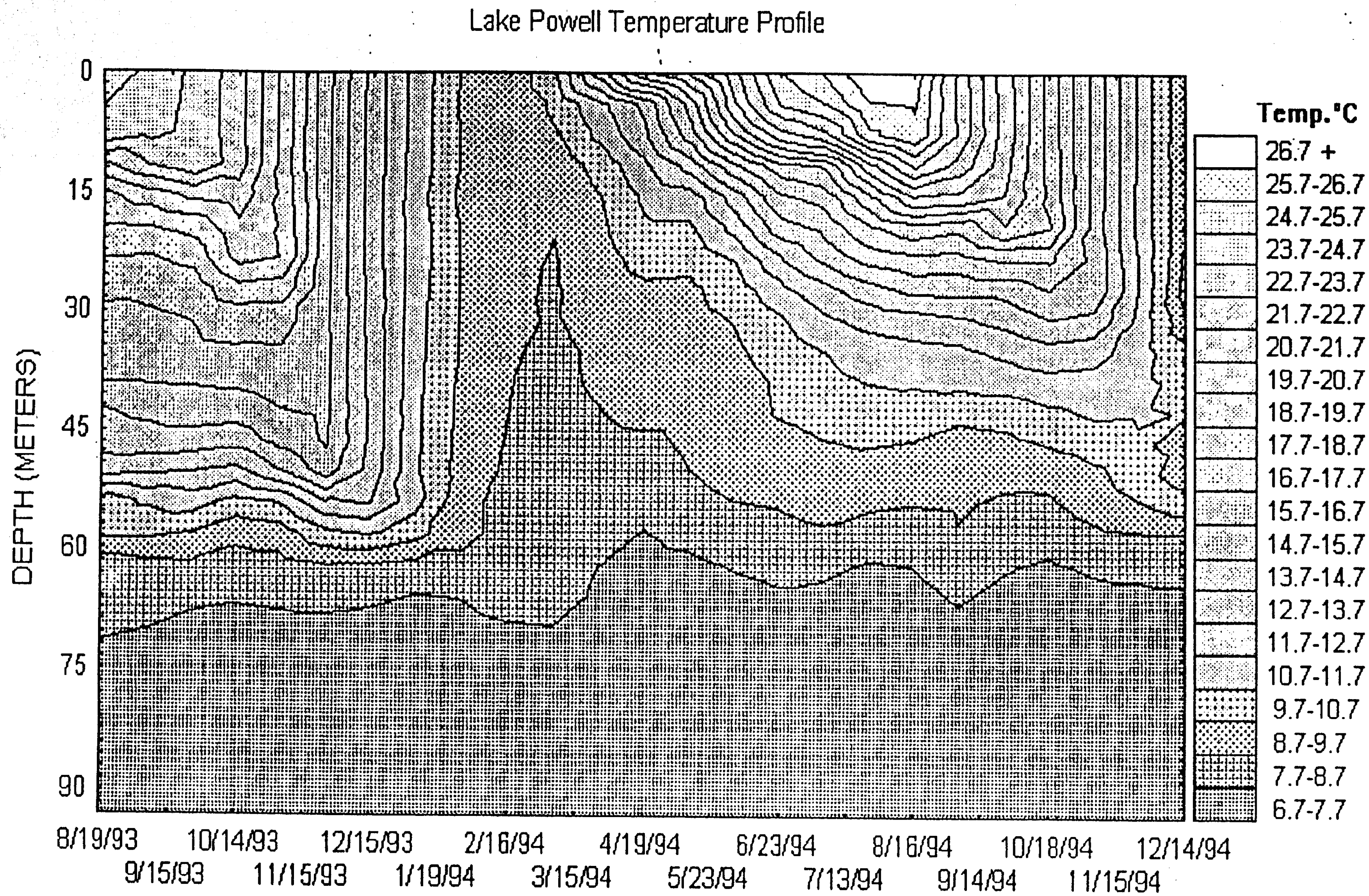

Figure 2.1.3. Lake Powell forebay temperature profiles, August 1993 - December 1994.

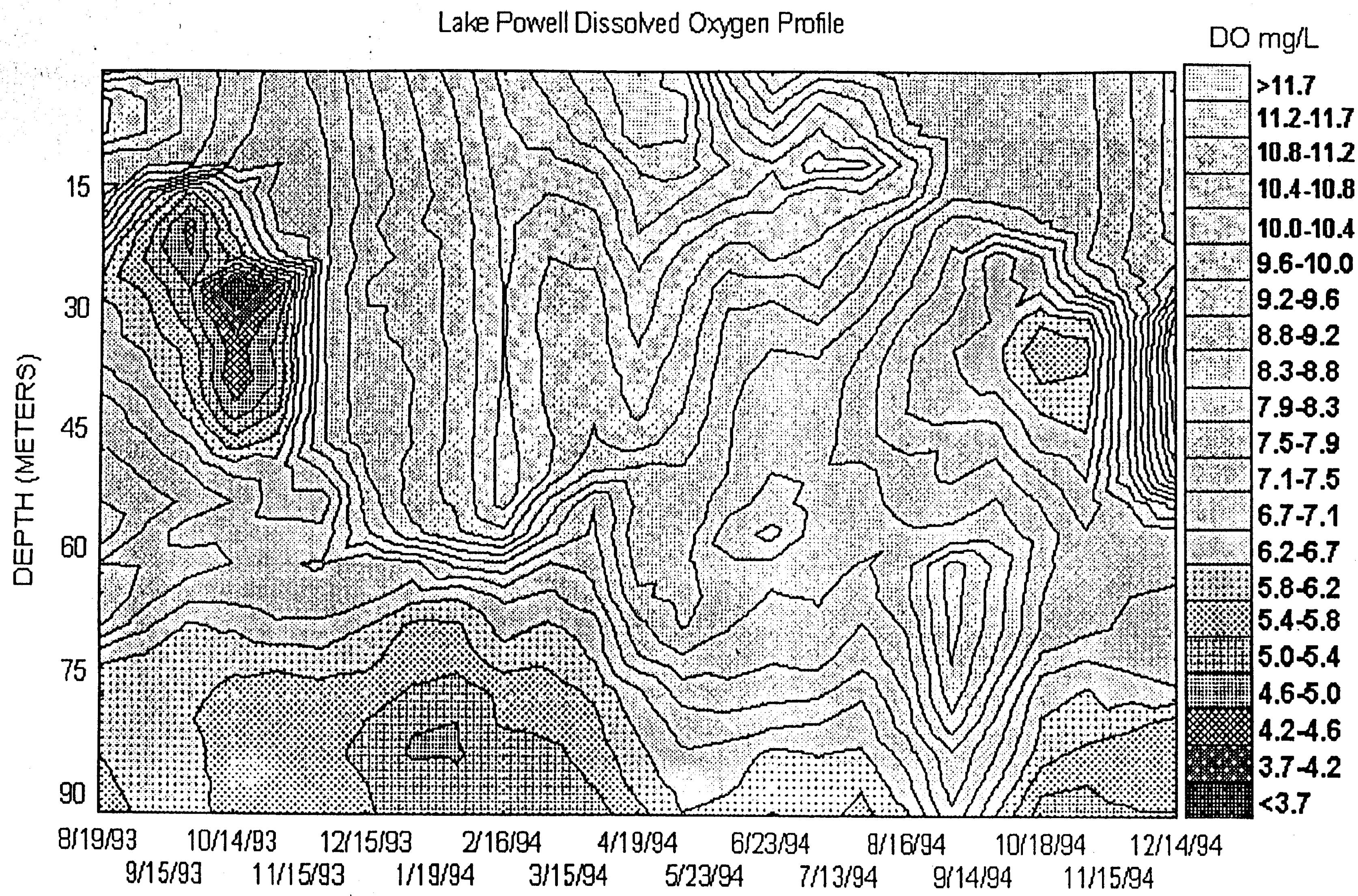

Figure 2.1.4 Lake Powell forebay dissolved oxygen profiles, August 1993 - December 1994.

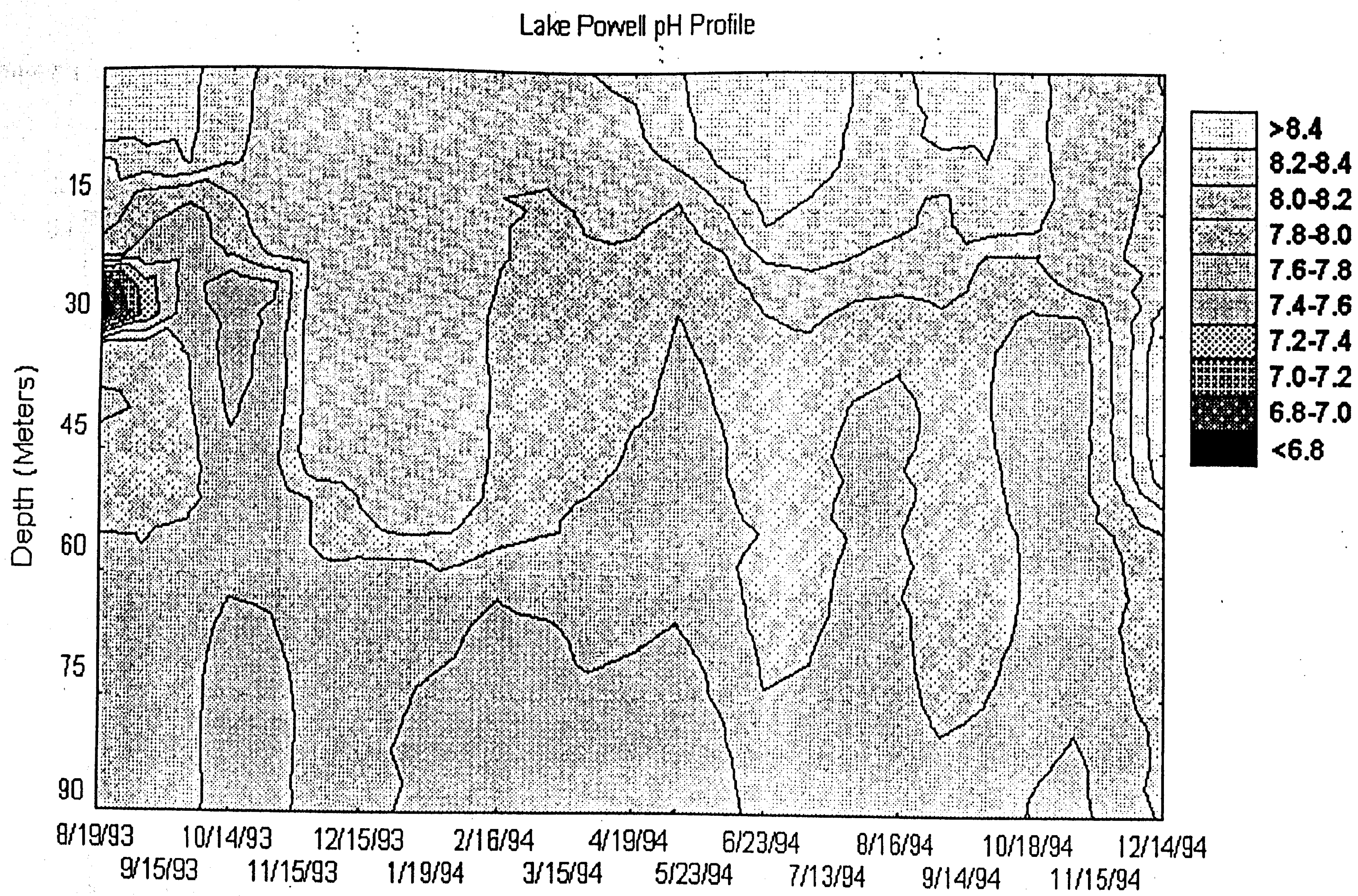

Figure 2.1.5. Lake Powell forebay pH profiles, August 1993 - December 1994.

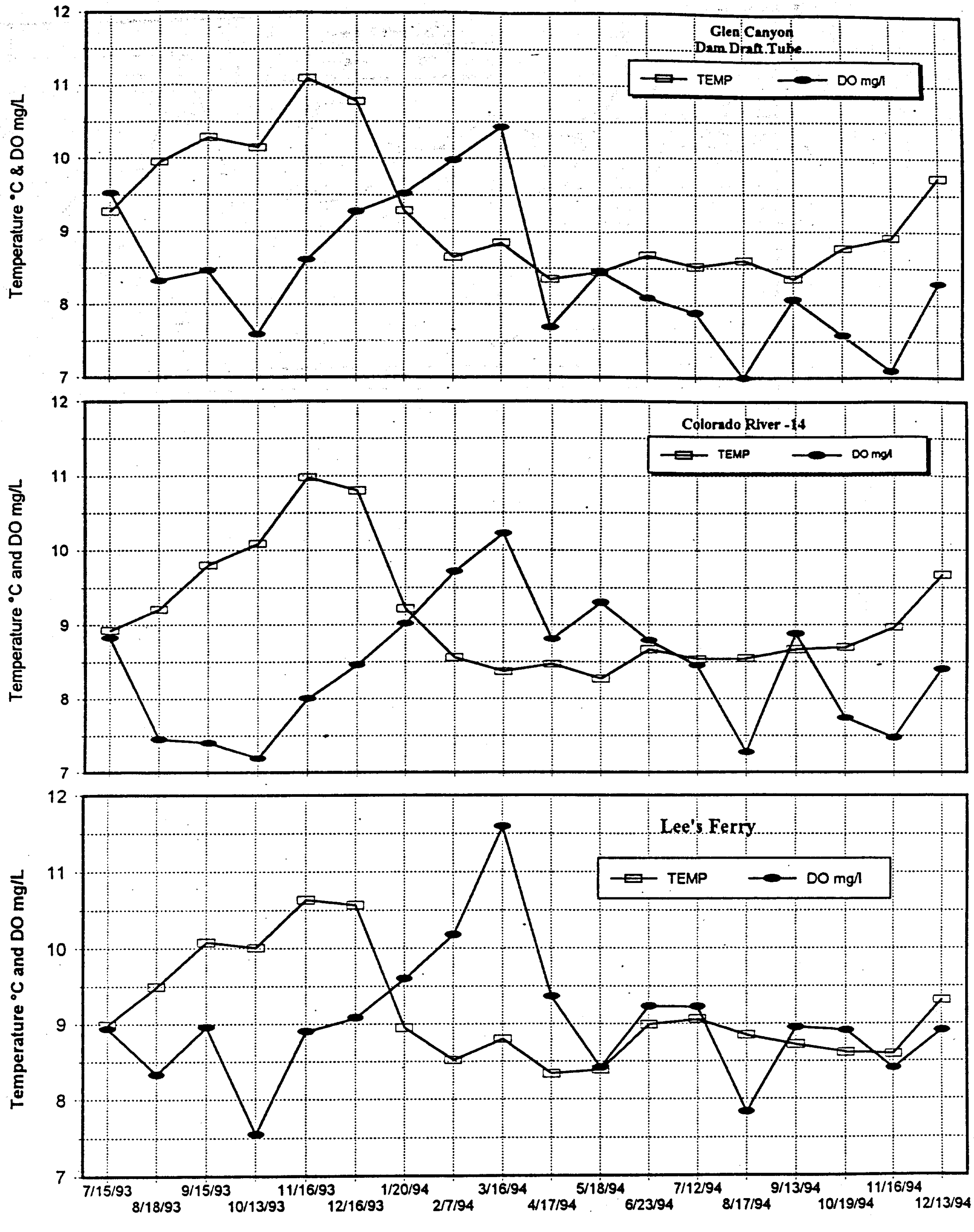

Figure 2.1.6 Temperature and dissolved oxygen (DO) values from Glen Canyon Dam to Lee's Ferry, July 1993 - December 1994.

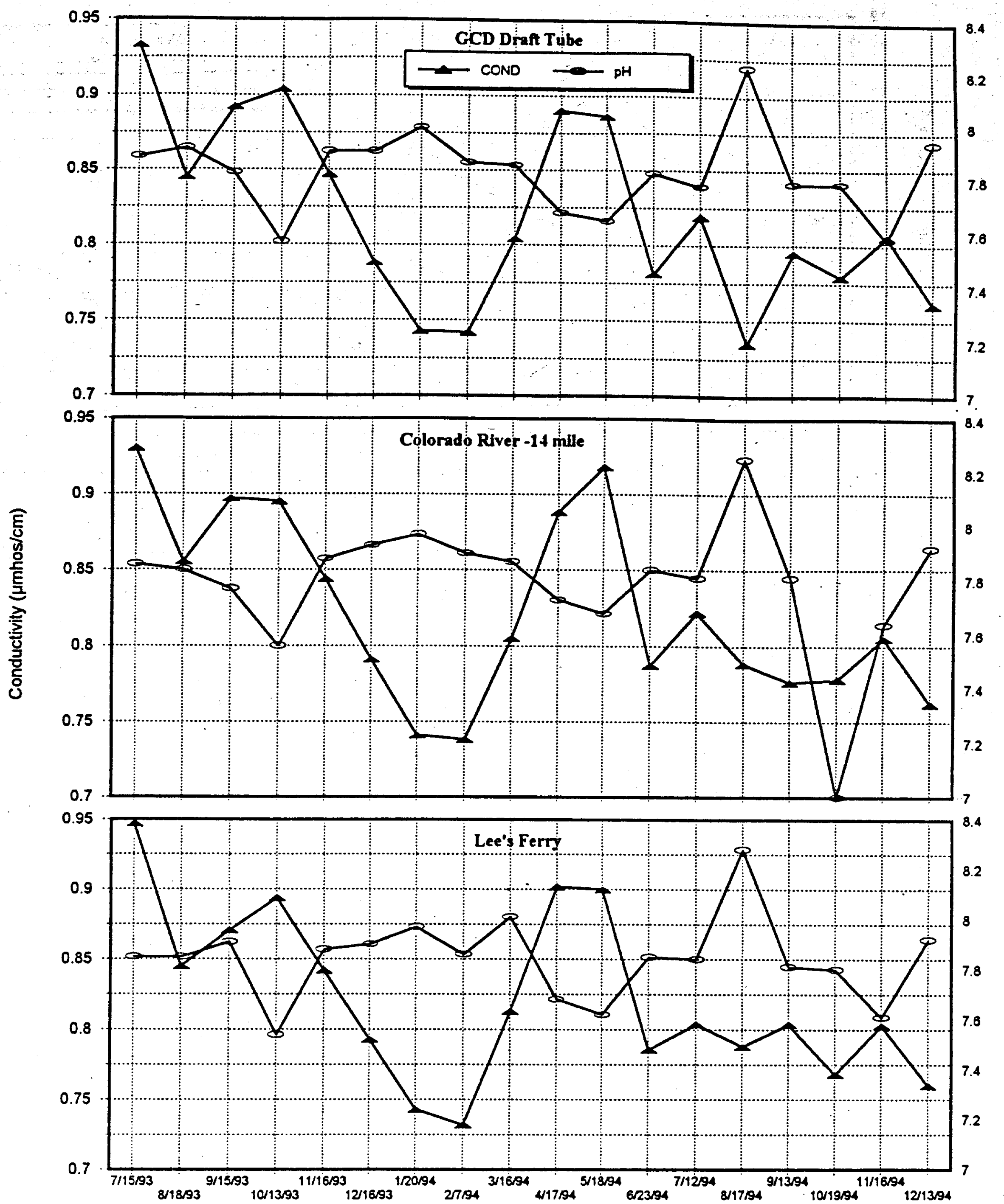

Figure 2.1.7. Conductivity and pH values for Glen Canyon Dam draft tubes, Colorado River -14 mile and Lee's Ferry, July 1993 - December 1994.

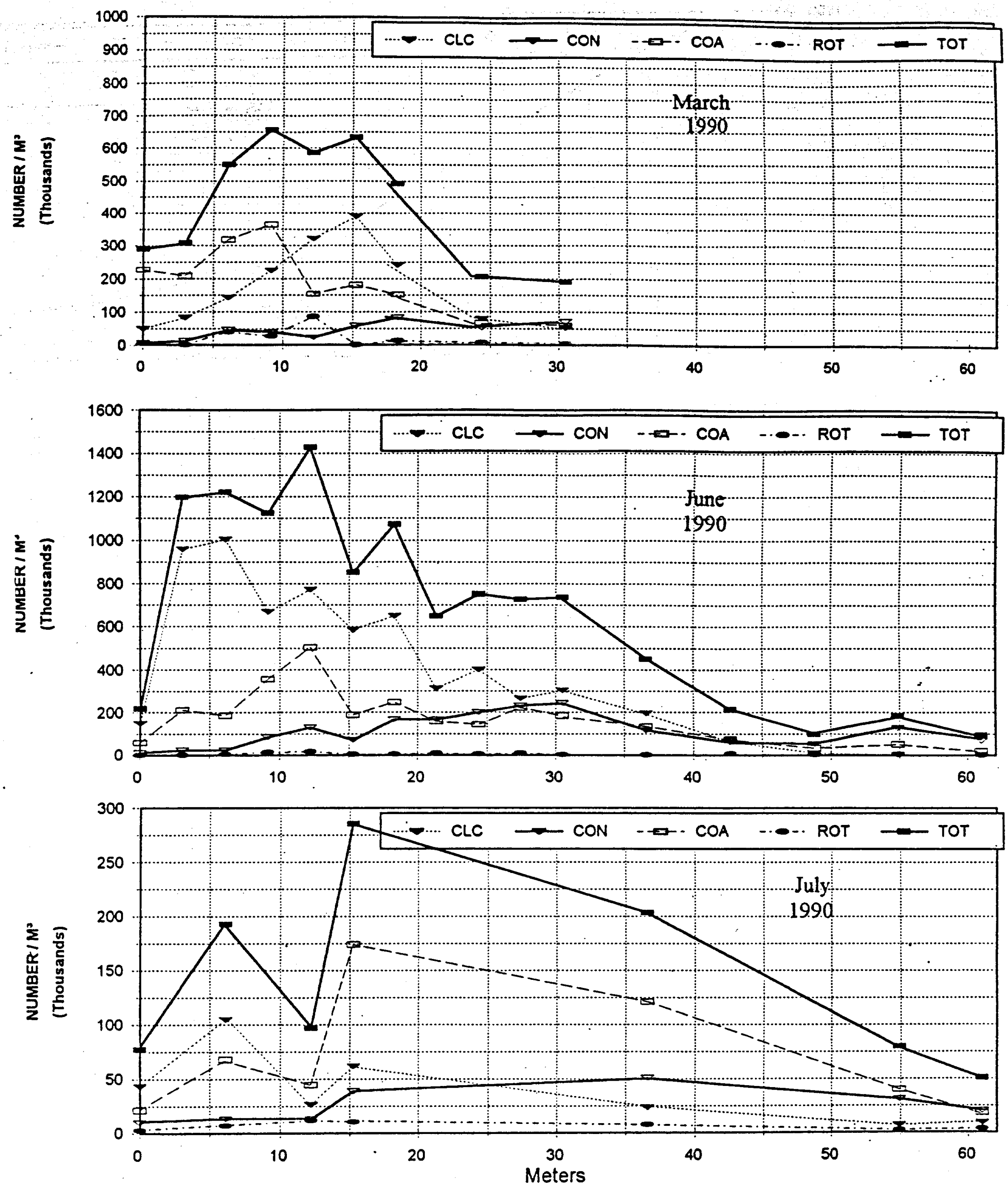

Figure 2.1.8 Zooplankton density by depth March, June-July 1990. CLC = Cladoceran, CON = Copepod nauplii, COA = Copepod adults and copepodids, ROT = Rotifers, TOT = Total zooplankton.

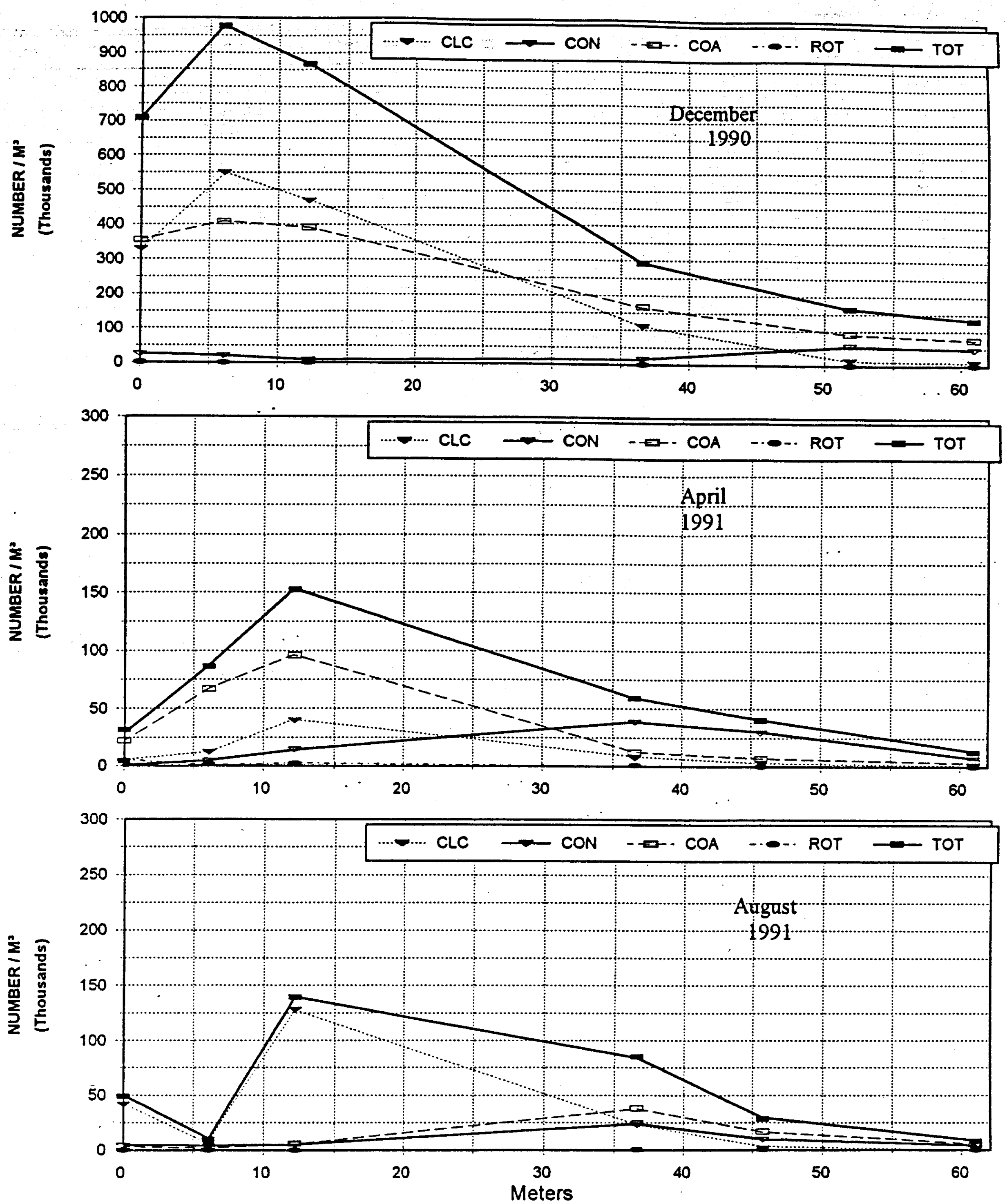

Figure 2.1.9. Zooplankton density by depth December 1990, April , August 1991. CLC = Cladoceran, CON = Copepod nauplii, COA = Copepod adults and copepodids, ROT = Rotifers, TOT = Total zooplankton

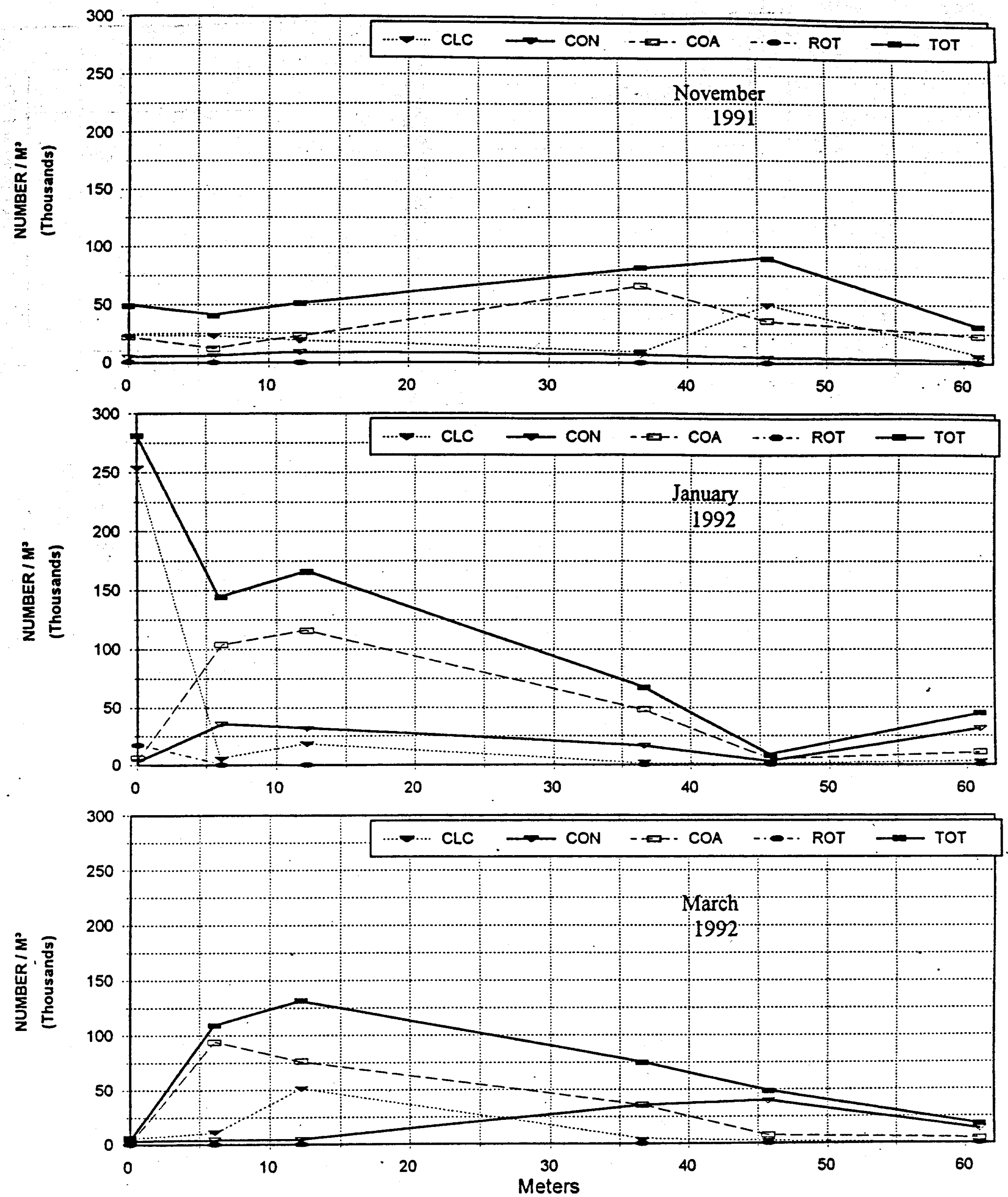

Figure 2.1.10 Zooplankton density by depth November 1991, January and March 1992. CLC = Cladoceran, CON = Copepod nauplii, COA = Copepod adults and copepodids, ROT = Rotifers, TOT = Total zooplankton

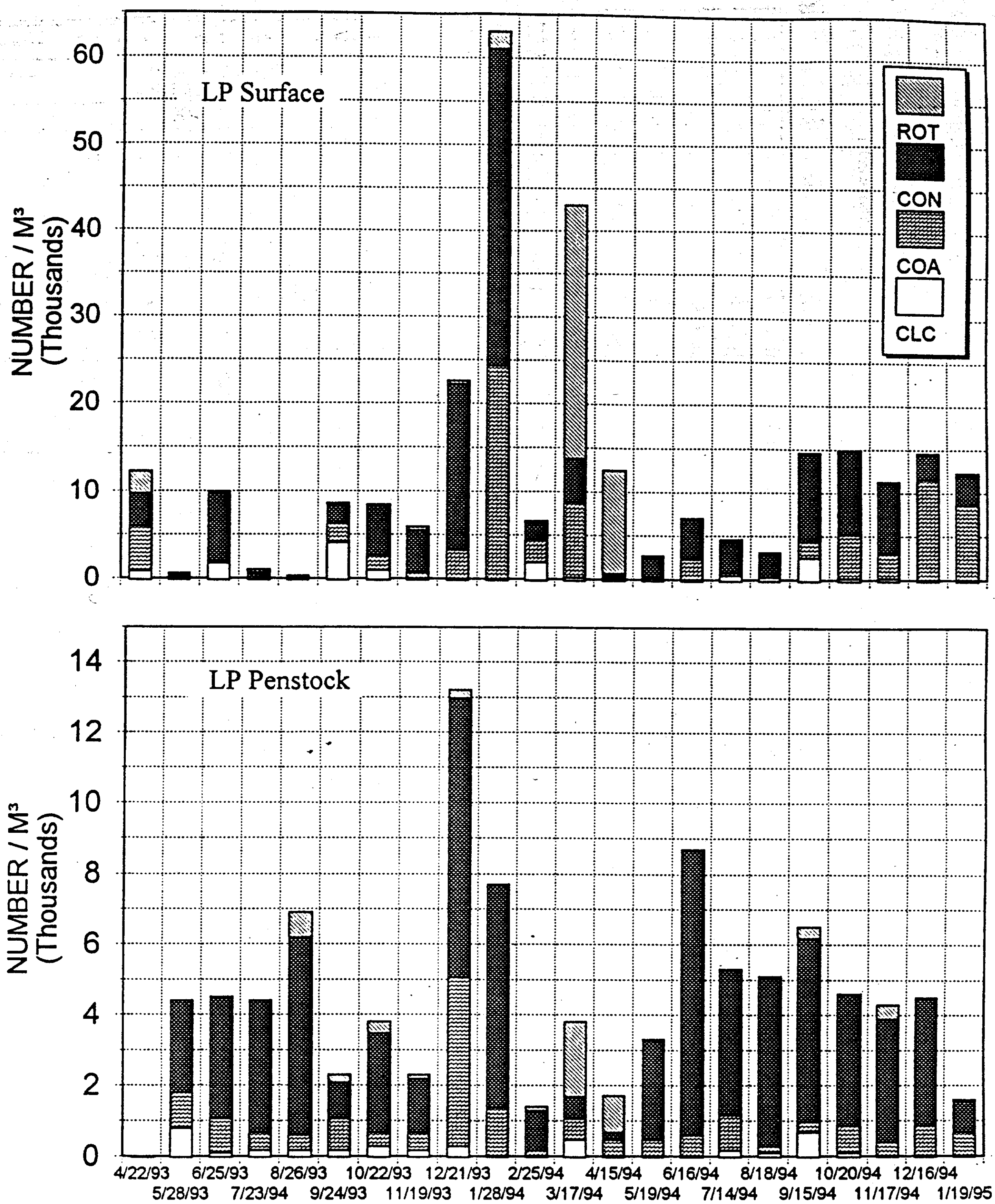

Figure 2.1.11. Zooplankton (number / m³) at Lake Powell surface and penstock depth. ROT = Rotifer, COA = Copepod adults and copepodids, CON = Copepod Nauplii, CLC = Cladoceran.

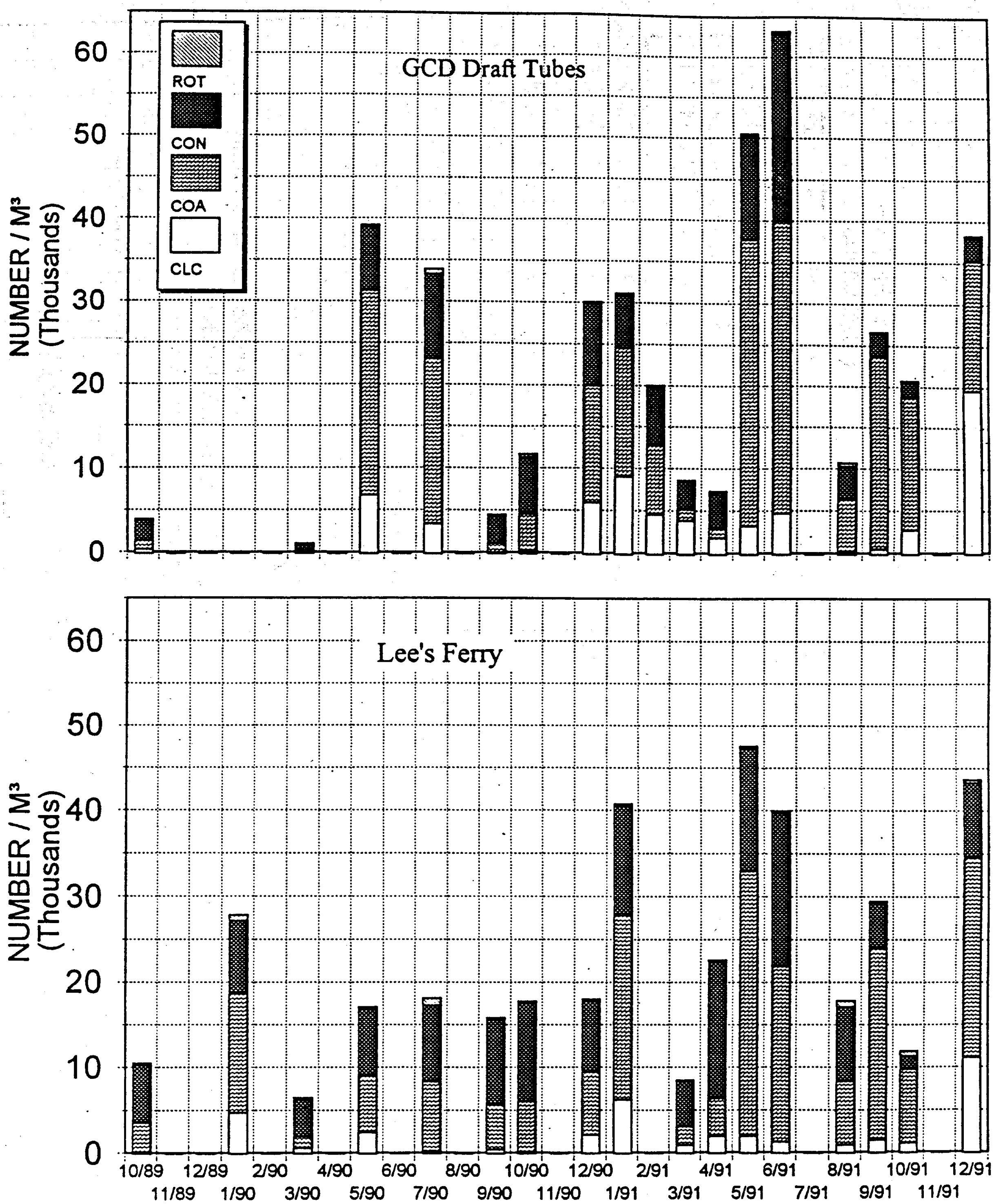

Figure 2.1.12. Glen Canyon Dam draft tubes and Lee's Ferry zooplankton densities, October 1989 - December 1991. ROT = Rotifer, COA =Copepod adults and copepodids, CON = Copepod nauplii, CLC = Cladoceran.

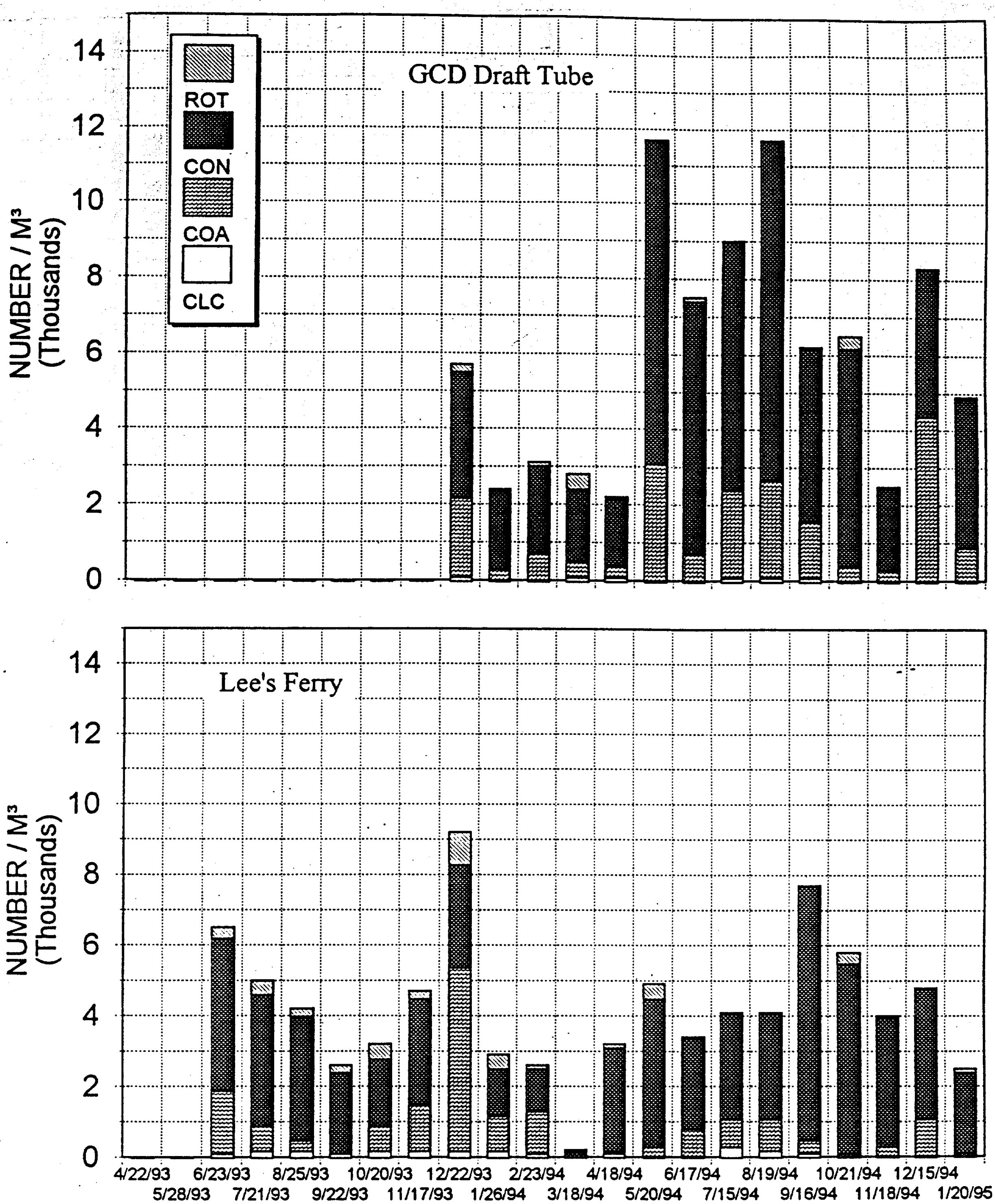

Figure 2.1.13. Glen Canyon Dam draft tube and Lee's Ferry zooplankton densities. ROT = Rotifer, COA = Copepod adult and copepodids, CON = Copepod nauplii, CLC = Cladoceran.

DISCUSSION

Chemical and Physical Parameters

The seasonal pattern of current distribution in Lake Powell is characterized by strong advective overflow during late spring and early summer, interflow during late summer-early fall and underflow during late fall and winter, with convective mixing occurring during winter to ca. 60m (Merritt and Johnson 1977). The hypolimnion in southern parts of the lake is close to isothermal and isohaline. Waters above the hypolimnion become well-mixed during winter and extremely stratified during summer, tending to develop a well-defined epilimnion 30 to 50 feet thick (Merritt and Johnson 1977). Results of the present study agree generally with the circulation pattern for Lake Powell as summarized by Gloss et al. (1980), Merritt and Johnson (1977) and Stanford and Ward (1991).

The large 1993 spring runoff created an advective overflow in Lake Powell which reached the dam by August 1993. A drop in conductivity in the upper 70 m in August and September 1993 shows the arrival of this mass of water at the dam (Figure 2.1.1). This overflow of low conductivity water continued to arrive at the dam, and by late fall and winter of 1993 - 1994, conductivity in the upper 60 m was at its lowest value for the year. Autumnal convective mixing in the upper 55m resulted in a strong halocline at 55-65m depth by December-January (Fig. 2.1.1), similar to observations reported by Mayer (1977). By January 1994, conductivity began to rise as summer inflow water arrived at the dam and was mixed with the lower conductivity water. The 1994 spring runoff was significantly less than in 1993, resulting in a small decrease in conductivity in the upper 50m by September 1994, when this water mass reached the dam (Figure 2.1.2).

During summer 1993, warming extended to maximum levels as a result of the large warm spring overflow, with reservoir surface elevation rising 16.8m by August 1993. This large overflow precluded the development of a strong thermocline (Merritt and Johnson 1977)(Figure 2.1.3). Water remained warm through December-January, at the time of winter turnover. Minimal temperatures at the surface occurred during January-March and extended uniformly during February to a depth of about 50 M (Fig. 2.1.3). Surface waters were warmer during summer 1994 than 1993, but warming extended to shallower depth, due probably to a lower inflow volume in 1994 as compared to 1993, rather than any effect of lower ambient temperatures. In addition, a strong thermocline formed at 10m - 20m in July and August 1994.. From August 1993 to January 1994, water passing through dam penstocks (ca. 59m in depth) was warmer than at any time during 1994 (Figure 2.1.3). This is reflected in the values recorded from the draft tubes in the dam, from -14 mile and Lee's Ferry (Figure 2.1.6). If the warming of Lake Powell is more dependent on the amount of spring runoff than it is on summer ambient air temperature, the use of a multilevel intake structure should be integrated with both anticipated yearly runoff and warming of the lake due to convective summer heating.

Oxygen minima were recorded at 15-45m depth during the fall 1993, and pH minima were recorded at 25-35m in August 1993, possibly reflecting bacterial digestion of organic matter carried in the spring overflow (Fig. 2.1.4, 2.1.5). Convective mixing during the winter 1993-94 occurred to 60 M and was associated with higher dissolved oxygen (DO) and pH levels (Figs. 2.1.1, 2.1.3, 2.1.4, 2.1.5). Zones of low DO and pH occurred during fall in both 1993 and 1994, but less oxygen depletion was apparent during 1994. These zones of low DO were associated with slight drops in conductivity (Figure 2.1.1). Differences between 1993 and 1994 DO and pH profiles were probably due to greater water inflow to the lake during 1993 which carried a heavier organic load. A phytoplankton bloom in the warmer 1994 waters (increased FPOM chlorophyll a and biomass; Ayers and McKinney 1995) coincided with maximum DO at the lake surface and the onset of spring warming of surface waters (Figs. 2.1.4, 2.1.3). However, plankton blooms may occur irregularly throughout the year (Stone and Rathbun 1969b). Strong underflow from the previous winter may tend to flush through dam penstocks, reducing salinity and increasing DO during spring-fall (Mayer 1977). Evidence of this may be found in the higher DO and a lower conductivity recorded at 60-90m in September 1994 (Figure 2.1.2, 2.1.4).

Changes in relative levels of conductivity, DO, pH and temperature in draft tubes corresponded to those at Lee's Ferry (Figs. 2.1.6, 2.1.7), confirming that outflow from Lake Powell is the primary determinant of limnology within the Glen Canyon Dam tailwater (Stanford and Ward 1991). However, DO levels at dam draft tubes tended to be slightly higher than those at lake penstock depth (Figure 2.1.4, 2.1.6). This was probably due to the injection of air into the water as it passes through the dam. DO was somewhat higher (July 1993-March 1994) or lower (April-December 1994) in draft tubes than at -14 mi. The higher readings from the draft tubes are due to our sampling technique prior to April 1994, which allowed aeration of the water before DO readings were taken. However DO readings at Lee's Ferry tended to be higher than at the draft tubes and -14 mile, probably due to aeration of the water and additions of oxygen due to photosynthetic activity as the water passed through Glen Canyon (Figure 2.1.6). Conductivity, temperature and pH were unaffected by passage of water through Glen Canyon (Figure 2.1.7).

Zooplankton

1989-1992

During March 1990-March 1992, total zooplankton densities in the Lake Powell forebay exhibited no seasonal pattern in depth-integrated samples (Figs. 2.1.8, 2.1.9, 2.1.10). Zooplankton consistently were most abundant within the upper 10-20m of the water column. Greatest numbers of copepods(adult and copepodid) and cladocerans were found in the upper 20m of the water column. In contrast, copepod nauplii density peaked at greater depth. Others (Stone 1966; Stone and Rathbun 1969b) recorded greatest density within surface to less than 20m depth in Lake Powell at Wahweap. In contrast to recent (April 1993 to January 1995) observations, copepods and cladocerans were most prevalent during 1990-1992, and nauplii numbers were low. However, relative predominance of copepods, nauplii and cladocerans varied with sampling depth and month; rotifers remained uniformly low.

Further, total zooplankton densities at the surface of Lake Powell during 1990-1992 greatly exceeded those during 1993-1995 (Figs. 2.1.9, 2.1.10, 2.1.11). This was particularly apparent during March - December 1990. In all months where comparison was possible, densities of copepod and cladocerans exceeded 1993-1995 levels. During most months, zooplankton density at the surface exceeded that near penstock depth.

Copepods and nauplii predominated in Glen Canyon dam draft tubes and dam tailwater. However, cladocerans were more prevalent during 1989-1992 than 1993-1994, rotifers were less abundant, and total zooplankton densities were greater (Fig. 2.1.12). Little correspondence was apparent between total zooplankton density at penstock depth in Lake Powell forebay (1990-1992) and at dam draft tubes (1989-1992), but relative changes in densities at dam draft tubes tended to correspond with those at Lee's Ferry (Figs. 2.1.8, 2.1.9, 2.1.12). Density and composition varied monthly at all sampling locations.

Total zooplankton and copepod densities in dam draft tubes exceeded those at Lee's Ferry during six of seventeen months. Conversely, nauplii at Lee's Ferry exceeded draft tube levels during ten of sixteen months. Average total zooplankton density for the two sites was similar (draft tubes averaged 22,508/m^3, Lee's Ferry 23,151/m^3). These results differed from those obtained during 1993-1994, but they are concordant in indicating possible copepod reproduction within the dam tailwater. Cladoceran numbers in dam draft tubes and at Lee's Ferry during 1990-1992 exceeded those during 1993-1994, but no differences were apparent between the two sites during 1990-1994.

1993-1994

Density of zooplankton at the surface of Lake Powell forebay exceeded that from penstock depth (Fig. 2.1.11). Zooplankton at surface and penstock depths showed no clear seasonal pattern in density or composition, confirming other findings indicating irregular monthly variation (Haury 1986; Stone 1966; Stone and Rathbun 1969b). Haury (1986), however, suggested peak total zooplankton density may occur during summer. Allan (1976) and Allan and Goulden (1980) reported that seasonal pattern for copepods is variable but may tend to exhibit late winter-early spring peaks, and rotifers tend to peak during winter. Rotifer density was generally low during 1993 - 1994, in agreement with earlier observations (Stone and Rathbun 1969b).

Copepods dominated all samples at surface and penstock depths in Lake Powell forebay during the present study, while cladoceran numbers were low (Fig. 2.1.11). These results contrast with findings of Haury (1986) and Stone and Rathbun (1969b), who reported abundant cladocerans. The present study incorporated sampling using a diaphragm pump, while Haury (1986) and Stone and Rathbun (1969b) used nets within the water column. Cladocerans may be susceptible to destruction by sampling procedure and passage through dam draft tubes and therefore underestimated in the present study; body parts were observed frequently during counting.. Destructive effects of our sampling procedure would appear at worst to be slight in present studies (1989-1994), since cladocerans comprised approximately 1%-62% of total zooplankton in various samples. Also, sampling at the lake surface may not accurately represent total densities or relative abundance of taxa at depths below surface depth (Figs. 2.1.8, 2.1.9, 2.1.10; Stone and Rathbun 1969b).

Nauplii were present during all months at forebay surface and penstock depths and during most months were prevalent over other stages (Fig. 2.1.11). At penstock depth, nauplii exceeded copepod density in all but two months and often approached or exceeded surface densities, indicating major potential contribution of this form to withdrawal and inflow to the tailwater below the dam.

Copepods predominated in the Glen Canyon Dam draft tubes and tailwater, and nauplii were more abundant than other stages (Fig. 2.1.13). In general, total zooplankton, copepods and nauplii from draft tubes exceeded export at Lee's Ferry; average total zooplankton from draft tubes was 11,700/m^3; from Lee's Ferry, it was 4,290/m^3. Contrary to Haury's (1986) results, this indicates a tendency toward downstream decrease in zooplankton density. Densities in draft tubes exceeded those at Lee's Ferry during eight of fourteen months (Fig. 2.1.13). Copepods were equal to or more abundant from draft tubes than from Lee's Ferry during all months except December 1993 to February 1994. Nauplii and copepods were equal to or more abundant at

Lee's Ferry only during December 1993, April 1994 and September to December 1994 (Fig. 2.1.13).

General

Monthly changes in zooplankton densities tended in general to correspond among Lake Powell forebay surface and penstock depths, draft tubes and Lee's Ferry. Notable exception occurred at Lake Powell forebay surface during January - March 1994, when zooplankton numbers increased substantially (Fig. 2.1.11, 2.1.12). The increase in density in Lake Powell followed autumnal convective mixing and coincided with maximal cooling and higher DO levels in lake water (Figs. 2.1.2, 2.1.3, 2.1.4). Along with similarities in composition, particularly between Lee's Ferry and dam draft tubes, present findings support Haury's (1986) contention that zooplankton in the Glen Canyon reach derive primarily from Lake Powell. However, net recruitment of zooplankton may occur during some months within the tailwater, net loss during other months. Interestingly, rotifers tended to be more abundant in Glen Canyon than in dam draft tubes or lake sampling points during June 1993 to May 1994. During March 1994, however, rotifers predominated at Lake Powell forebay surface and penstock depths, increased in the dam draft tubes, but were absent at Lee's Ferry (Figs. 2.1.11, 2.1.13), further reflecting perhaps the high intrinsic variability of zooplankton communities.

Several considerations are relevant to interpreting zooplankton results presented herein. At the surface and penstock depths of Lake Powell forebay during 1990-1992, very high numbers of zooplankton were found, generally exceeding by a wide margin the levels subsequently observed. Differences in density were greater for data collected during 1990 than 1991-1992, as well. Similarly, zooplankton densities from dam draft tube and at Lee's Ferry were greater during 1990-1992 than 1993-1994. Importantly, zooplankton densities during 1993-1994 are in general agreement with densities reported previously in Lake Powell and dam tailwater (Haury 1986; Stanford and Ward 1991; Stone 1966; Stone and Rathbun 1969b). However, differences in density and composition occurred throughout present studies with respect to sampling site, lake depth, month and year.

Lake Powell sampling protocol was changed in the present study beginning April 1991 (sampling volume was standardized at 100 L), coincident with a reduction in zooplankton density, but densities did not drop during 1991-1992 to 1993-1994 levels. Also, Lake Powell surface elevation averaged much lower during 1990-1991 than 1993-1994 (Table 2.1.1), perhaps contributing to elevated zooplankton densities during 1990-1991. However, no relationship is apparent between lake penstock depth and zooplankton density (at either surface or penstock depth) monthly between 1990-1994 (Figs. 2.1.8, 2.1.9, 2.1.10, 2.1.11; Table 2.1.1), nor was zooplankton density affected by warmer surface water (1994) or colder water at penstock depth (1993) (Figs. 2.1.3, 2.1.11, 2.1.13).

While reasons for disparities in zooplankton density and composition remain unclear, it has long been recognized that zooplankton in freshwater lakes may vary greatly in number and taxa. They are not necessarily distributed uniformly horizontally, vertically or temporally (including diel movement), and populations can fluctuate wildly. Cladocerans and rotifers are highly opportunistic and have high reproductive potential; copepods are less opportunistic and have lower reproductive potential (Allan 1976). Densities during 1990, particularly, in the Lake Powell forebay appear disproportionately high. One can argue, however, that disparities in numbers and composition such as discussed above may reflect inherent variability in zooplankton communities, temporal and spatial fluctuations that characterize these organisms. Indeed, Whittaker and Fairbanks (1958) observed that population irregularity and instability is the most formidable problem and challenge presented in synecological studies of zooplankton.

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