TECHNICAL SERVICE CENTER
Denver, Colorado

Technical Memorandum No. 8220-04-06

Effects of Releases from Canyon Ferry Dam on the Limnology and Fisheries of Hauser Reservoir, MT.

Final Report Submitted to the
Bureau of Reclamation, Montana Area Office

Prepared by

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April 2004

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1. INTRODUCTION:

Hauser Reservoir is located 16 km north east of Helena, Montana and sits directly downstream of Canyon Ferry Dam. Hauser Reservoir is a 3,720 surface acre, 24km long reservoir on the Missouri River created by Hauser Dam. At full pool it contains 109,470 acre feet of water. Monitoring conducted below Canyon Ferry by Northwestern Power Company (formerly Montana Power Company) during late summer 1996 indicated dissolved oxygen (DO) levels in the Missouri River were significantly below the Montana State water quality standard of 6.5 mg/L for flowing waters. Pickett (1998) estimated that lowest DO levels occurred in mid-September and remained below 6.5 mg/L for 90 to 120 days each year depending on weather conditions. It is not known whether low DO levels are a recent or a long standing problem, as monitoring was only begun in the late 1990's. Historical water column data from Canyon Ferry though shows a pattern of dissolved oxygen decrease with depth that is very similar to what is observed today. This indicates water quality problems with respect to D.O. are likely not a recent development.

. From 1985 thru 1996 Hauser Reservoir was formerly one of the most important Kokanee salmon fisheries in Montana. In recent years, however, the species composition of this fishery has shown significant declines in Kokanee and rainbow trout (Dalbey, 2002). Whether this is a natural phenomena involving interaction between different species in the fishery (eg., predation), a climatically controlled event (eg., flushing losses), or a change as a result of dam operations in Canyon Ferry Reservoir is not well understood, and it is not known if this decline is related to changes in water quality or some other factor..

In a previous report (Horn and Boehmke, 1998) describing the physical, chemical, and, biological characteristics of Canyon Ferry Reservoir, low DO levels in the reservoir appeared to be relatively consistent from year to year. Water column profiles taken at the dam showed a similar pattern and magnitude of decreases in DO at deeper depths as reported in previous studies. The low DO water is entrained by the turbines, discharged at a lake depth of about 30 m below full pool, and then released downstream to Hauser Reservoir. For a description of limnological processes and DO dynamics influencing Canyon Ferry, see Horn and Boehmke (1998), Priscu (1977), Rada (1974), and Wright et al. (1974).

Anecdotal evidence suggests there is year to year variation in the magnitude of effects, particularly with respect to differences in primary productivity within Canyon Ferry reservoir and releases from the dam. During high runoff years there may be greater algal blooms within the reservoir due to higher nutrient availability (Figures 1 a,b, 2). For example, total phosphorus (TP) concentrations appeared are correlated to flows recorded at Townsend (Figure 3). Further, even at similar TP concentrations, higher flows resulted in higher net loads being delivered to the reservoir. Several authors have noted that phosphorus loading in the inflow was a principal factor driving blue-green algal blooms in Canyon Ferry (Priscu 1987, Rada 1974, Rada and Wright 1974). During four years of monitoring at Canyon Ferry Reservoir (1996 to 2000) the greatest algal densities coincided with the highest inflows during 1997 (Figure 4); Rotifers, which are indicative of eutrophic conditions, were at their highest densities during 1997 (Figure 5). During the years of study secchi transparency also appears related to inflow. During the higher flow years of this study, 1997 and 1999 secchi transparency were lower than compared to lower flow years (Figure 6). Patterns of nutrients within Canyon Ferry reservoir were more difficult to interpret (Figures 7 a,b,c,d). There may have been some subtle increases in orthophosphate and nitrate in surface waters during 1997, however, ammonia was lowest in 1997 and higher in 1998 and 1999. This could be related to changes in productivity, but such suppositions are outside the scope of this report.

The objectives of this study were to describe seasonality, duration, and extent of low dissolved oxygen releases from Canyon Ferry Dam downstream, as well as to provide a general description of the limnology of Hauser reservoir. During the course of this study two-test spills were conducted from Canyon Ferry Dam to measure potential beneficial effects of reoxygenation in Hauser Reservoir.

2. METHODS:

Limnology:

Monthly sampling was conducted at 10 sites from late spring through early fall during 1999 and 2000. Five sites were located longitudinally along the main body of the reservoir; beginning at the Riverside campground just below Canyon Ferry dam and ending in the forebay of Hauser Reservoir. Additionally, 3 sites were sampled in the Causway Arm and one site each at the Spokane Creek and Trout Creek inflows (Figure 8). Sampling sites at Canyon Ferry were the same ones previously used, see Horn and Boehmke (1998) (Figure 9). We do not specifically address data on Canyon Ferry in this report. However, these data, when combined with previously collected data (Horn and Boehmke, 1998) may be used to look at longer term trends in reservoir water quality.

Water column profiles were collected using a Hydrolab® Surveyor 4 connected to a Datasonde 4 probe for dissolved oxygen (DO), specific conductance (μS/cm), pH and temperature (^{0}C). Data were recorded from surface to bottom, with collection depths ranging from every meter to five meters, depending on uniformity of the water column. The sonde was calibrated according to Hydrolab specifications prior to the start of each sampling trip. The graphical package Surfer7 ® was used to provide two-dimensional mapping of water column profiles in the reservoir. It provides a reasonably accurate depiction of hydrodynamics and thermal structure. Surfer7 uses several smoothing functions (krieging) in processing data which may result in very extreme values being hidden, or in some cases spurious correlations introduced into the graph with the small number of data points collected in the 4-5 depth profiles each sampling trip. Most of these glitches were removed, but estimation of breakpoints between stations are an estimation only. For example, if DO levels were 1 mg/l at the bottom at one site and 4 mg/l at another site, then smoothing would blend the two values over the intervening distance between the stations. In reality, such a change in DO may occur faster or slower between stations. All other graphical data was presented using Sigmaplot7®.

Water samples were collected with a 3 L Van Dorn at each sampling site from the epilimnion and hypolimnion for ortho phosphorus (SRP), total phosphorus (TP), nitrate nitrogen, ammonia nitrogen. Water samples for SRP were kept on ice and not preserved. All other water samples were acidified using 1 ml of 10 % sulfuric acid. Samples were shipped on ice to Reclamation's Bismarck, North Dakota laboratory within 24 hrs following collection. Nutrients were analyzed according to EPA and Standard Methods (APHA, 1995).

A 0-5m composite water sample was collected for chlorophyll *a*. Integrated samples were collected using a 50 mm diameter pool hose lowered to a depth of 5 m. One-liter of sample was placed in an amber nalgene bottle and held on ice until processing at the end of the day. Replicate samples were randomly collected to insure adequacy of sampling and analyses. All samples were filtered within six hours of time of collection. Up to 1000 ml of sample, depending on water clarity, was vacuum filtered using a hand pump through a Whatman 47mm GF/C filter. Filters were individually placed in coin envelopes and frozen on dry ice until processing. Samples were extracted with 90 % acetone at the Technical Service Center (TSC) and analyzed spectrophotometrically for chlorophyll (μg/L) according to standard methods (APHA 1995).

A composite water sample (0-5 m) was also collected for phytoplankton at each site. One liter of sample was placed in an amber nalgene bottle and preserved with Lugols solution. Duplicate zooplankton samples were collected with a 80 μm birge-style net from 0 to 15 m at deeper stations and from surface to bottom at shallower sites. Samples were preserved with Lugols solution. Duplicate zooplankton samples were pooled prior to analysis. Phytoplankton and zooplankton were identified to species and enumerated to number per liter. Phytoplankton and zooplankton sample analyses were performed by Dr. John Beaver, BSA, Beachwood Ohio.

Fish Data:

A Biosonics DT-5000 combination dual-single beam echosounder with 6 degree transducers was used to collect data on fish distributions within Hauser Reservoir. Transducers were attached to a fixed pole on the side of the sampling boat. One transducer was aimed downward, the other out to the side at an angle just deep enough to avoid significant surface reflection. This angle could be adjusted to optimize data collection during each sampling trip to account for differences in boat state, such as loading, that may change the orientation of the hull. Sampling was accomplished by running the lake as one continuous transect, starting at Hauser dam moving up the Causway, then proceeding up the main arm of the reservoir to Riverside campground. Boat speed was maintained at a relatively constant 7km per hour. The boat path was stored as a GPS track within the echosounder data files to allow geo-referencing of individual fish. Fish data were presented graphically as locations of individual fish, size in decibels, and latitude and longitude. Based on volume of water sampled an estimated number of fish was also derived for the study area. Volumetric calculations were based on side-scan acoustic data. Down-looking data was not used to map spatial distributions, owing to the shallow nature of Hauser reservoir and small number of targets detected. Downward looking data were only used to obtain an estimate of vertical distribution of fish within the water column. Echoview v2.25 software package (Sonar Data) was used to analyze fishery data. Analyses were set to identify individual fish versus total counts of echoes (a fish could have more than one echo if it was detected in the beam for more than one ping interval). Identification of fish traces for single target counts reduced the number of spurious targets introduced by background noise and high plankton densities. Individual fish traces were identified using the Alpha-Beta tracking algorithm for two-dimensional data (range-time). Fish track output included size of fish, and longitude and latitude of fish.

Test Spills:

Test spills were conducted by releasing water from the spillways of Canyon Ferry to mix with low DO water from the turbine discharges during the second week of September 1999 and 2000. Tests were conducted for approximately 72 hrs (typically from Friday afternoon through Monday morning). Tests were done to coincide with lowest recorded DO levels in the discharge. During spill tests turbine discharge was decreased to 50 % of average to provide for water over the spillways, while still achieving desired downstream flows. Total discharge during the spill period averaged 3700 cfs and 3000 cfs during 1999 and 2000, respectively. During 2000, discharge was reduced to less than 2000 cfs at one point, when turbine releases were stopped for a period of time. Following start of the spill, upstream to downstream transects were run on Hauser every 12 hours to record how far downstream effects of the spill had progressed, and to record any changes in water quality. DO was recorded in the immediate vicinity of the discharge using a Hydrolab water quality probe suspended from a mid-channel buoy about 400 m downstream of the dam (no wake buoy at Riverside campground).

3. RESULTS AND DISCUSSION:

Limnology:

Typically, a reservoir consists of three zones: 1. a riverine zone where primarily river dominated processes of the inflows dominate, 2. transition zone which represents an intermediate area between river dominated processes and lake processes, and is often the most productive, 3. lacustrine zone. Each of these zones can be defined by currents, thermal stratification, relative productivity and sedimentation rates. Short retention times averaging 11.1 days can produce riverine-like conditions throughout Hauser Reservoir. During late spring and early summer releases, retention time can be less than two days during peak flow events. Flows start increasing in March or April, and reach a peak during June, resulting in a rapid flushing rate (Figure 4). Little in-reservoir productivity would have time to develop with the exception of the Causway Arm. The Causway Arm is relatively isolated from the rest of Hauser during high flow events and can be characterized primarily by inputs from Lake Helena. For the year 2000 in particular, flows were lower than normal, and may have allowed Hauser to become reservoir-like earlier in the season. For most years, during lower flows beginning in July and August and later, the riverine zone extends downstream to about Spokane Creek (Fig. 8).

Canyon Ferry Reservoir appeared to regulate the physical and biological processes upstream of Spokane Creek (station HA2) in Hauser Reservoir under all flow conditions. This reach was relatively shallow and narrow. Transit times of water were less than one day from Canyon Ferry. Typically, zooplankton, phytoplankton, chlorophyll, and physical variables such as dissolved oxygen, specific conductance, and secchi depth levels varied little in this reach (stations HA1, HA2), and were more similar to each other than to other sites (Figures 10-23). Seasonal shifts in parameters reflected seasonal differences in the water quality of releases from Canyon Ferry Reservoir. Only limited nutrient data was collected for this study and trends would be difficult to identify (Figure 23 a-d). In general ortho-phosphorus and nitrate were higher at upstream sites during late summer due to the deep release of nutrient rich water from canyon ferry. With progression downstream primary productivity would quickly sequester available nutrients resulting in the observed downstream decrease. Releases from Canyon Ferry were deep relative to the photic zone. Chlorophyll, phytoplankton, and zooplankton densities in downstream releases were similar to densities observed in the reservoir during those times when significant deep mixing occurred (Figures 1 a,b, 5, 6). For example, the spring-early summer peak of zooplankton densities in Canyon Ferry were reflected in similar densities downstream of the reservoir. However, later in the summer season, zooplankton densities from in-reservoir to downstream sites were not comparable due to weakly stratified waters from surface to 30 m. In addition, chlorophyll levels were reduced at deeper depths with on-set of stratification.

Near the Spokane Creek (Fig. 8) junction there was a shift from riverine to reservoir-like conditions the location of which was affected by flows and weather modifications. The physical and biological characteristics of Hauser change significantly from this point downstream.

Downstream of Spokane Creek, Hauser Reservoir opens into a large flat basin which heats quickly creating a stratified water column during summer months. Stratification forces the colder Canyon Ferry water to form a shallow underflow at a depth of about 4-6 m during July and August. The underflow was observed between stations HA2 and HA3 (the area from about Spokane Creek to the lower end of the basin downstream of Lakeside) (Figs. 14 and 15). Thermal stratification of Hauser Reservoir began in June and typically, the reservoir was stratified in July and August. Summer heating allowed surface waters to remain thermally isolated and resulted in greater productivity in the epilimnion. Development of thermal stratification as a result of seasonal warming and the perennially cold releases out of Canyon Ferry Reservoir were the principal reasons that water in the upper 4 m of Hauser Reservoir (below Spokane Creek) remained relatively unaffected by the seasonal decline in DO levels discharged from Canyon Ferry Dam. By September, cooling of the surface waters, along with seasonal highs in release temperatures from Canyon Ferry (Figure 22) caused waters to destratify in Hauser Reservoir. Stratification was not observed during this study upstream of Spokane Creek.

Reported differences between the years 1999 and 2000 in the physical and biological data of Hauser Reservoir were most likely driven by weather and flow conditions. Hauser Reservoir, although stratified during the summer and always on the verge of destratification. Thermal stratification only developed in the upper 4-6 m of the water column and temperatures in the small volume of water in the upper strata changed quickly with passing storms, resulting in temporary destratification. During late summer through fall of 1999, surface DO levels remained low, downstream to Trout Creek (Fig. 18, 20). Strong thermal stratification never developed in

1999 due to several possible reasons. Releases out of Canyon Ferry Dam were on average about 1 °C warmer during 1999 as compared to 2000 (Fig. 22). This resulted in a warmer hypolimnion in Hauser reservoir. In addition, a somewhat cooler summer (as evidenced by temperatures of the Lake Helena inflows which are governed closely by air temperatures (Fig. 22) meant surface waters did not warm as much to develop a strong thermal stratification. Finally, higher average releases (30-50 %, USGS stream flow data site 06065500 (below Hauser Dam)) in 1999 vs. 2000 may have contributed to changes in water temperature and increased mixing through reduced retention times allowing for less heating. Low flows in combination with warm summer temperatures appeared to result in the furthest reach upstream of acceptable DO levels. During the two years of study, however, DO levels upstream of Spokane Creek did not differ greatly.

Changes from reservoir to riverine conditions affected zooplankton and phytoplankton productivity in the system. The upper reaches of Hauser Reservoir had similar zooplankton composition as Canyon Ferry Reservoir due to low hydraulic residence time. Densities of major groups were similar at HA1 and HA2 with the exception of July during both years of this study when densities at HA2 were higher than anywhere else on the main stem of Hauser reservoir (Figure 10). This may be due to a combination of zooplankton released from Canyon Ferry Reservoir coinciding with on-set of thermal stratification and may represent higher production in this transition zone.

At all times of the year, chlorophyll a levels increased with greater distance downstream from Canyon Ferry Dam (Figure 11). Beginning immediately upstream of station HA3, greater stability in the water column and increased productivity was observed as the season progressed. There was a large spike in chlorophyll *a* concentration from station HA3 continuing downstream.

Much of the early summer contribution was from diatoms, while increases in productivity later in the summer and early fall were driven by blooms of blue-green algae (Fig. 12). A warm stable water column was conducive to formation of blue-green blooms. Temperatures and water column stability were both higher in the lower reaches of Hauser Reservoir. Typically, blue-green algal blooms were not common in upstream reaches due to lower water temperatures, and low water retention times. Some of the productivity at stations HA4 and HA5 may have also been from contributions via the Causway Arm (Figures 24, 25, 26).

Water quality of the Causway Arm was dictated by inflows from Lake Helena. Characteristics of flows entering from Lake Helena were very different than inflows from Canyon Ferry Reservoir. Lake Helena is shallow, warm, and almost hypereutrophic. Inflows from Lake Helena entering Hauser Reservoir were as much as 10 °C warmer than flows from Canyon Ferry (Figure 22). During the months of July and August, as Canyon Ferry releases formed an interflow through Hauser Reservoir, Lake Helena inflow formed an overflow (Figures 27-34) and could be tracked by the high specific conductance waters located on the surface (Figures 27, 28). Much of the productivity in the upper Causway Arm was a result of transport from Lake Helena. For example, chlorophyll, plankton, and nutrient levels were typically high in the inflow water from Lake Helena at Station C1 (Figures 24-26, 35 a-d). High productivity occurred in the surface waters as a result of warm inflow water overflowing the Causway Arm. From upstream to downstream, there was decreased productivity with distance. Year to year differences were significant. A late fall bloom of blue-green algae was observed in 2000 but not in 1999. Blue-green blooms typically develop at higher water temperatures. In 2000, an overflow condition from Lake Helena still existed in September. This may have helped to support algal blooms that extended down the Causway Arm to sites HA4 and HA5. In 1999, cooler water temperatures of Lake Helena resulted in the inflow plunging below the warmer surface waters of the Causway Arm in late August and early September. A decrease in algal productivity caused by cooler water temperatures and decreased nutrient availability occurred.

In September and October, a high conductance layer of water with very little oxygen was present in the lower part of Hauser Reservoir (Figures 16, 17). This volume of water represented inflow from Lake Helena that had formed an underflow in the reservoir. This region of low oxygen was relatively independent of Canyon Ferry dissolved oxygen levels and could be traced to Lake Helena inflow as a result of its high conductivity signature. Canyon Ferry releases depicted oxygen levels in the mid-layers of Hauser Reservoir below the thermocline and above the chemocline which was formed by Lake Helena flows.

Fishery Data:

Montana Fish Wildlife and Parks personnel have a series of acoustic transects that are run on the lower reaches of Hauser reservoir to provide an estimate of fish abundance. Our data was meant to compliment this data set, and to allow for increased temporal and spatial resolution of fish within the reservoir. Actual estimates in abundance were not directly comparable owing to different techniques, and equipment type used for data collection. Our principal objective was to determine broad scale distributions of fishes. The use of sidescan sonar allowed us to sample upstream reaches of Hauser Reservoir, whereas historically MFWP had only sampled downstream of Eldorado Bar. Our data collected were similar to MFWP, and showed greatest concentration of fish were in the lower reaches of the reservoir, with the highest densities occurring in the Causway Arm.

Observed pelagic fish numbers decreased dramatically from about Trout Creek upstream to Canyon Ferry dam for all fishes (Figures 36-44). Seasonally in the spring and summer, fish were concentrated near the lower reaches of Hauser and in the Causway Arm. There is some dispersal in the fall with more large and small fish being detected in upstream reaches of the reservoir in October than at other times of the year. Acoustically we describe smaller fishes as those smaller than -35 db in signal strength, or approximately a 22cm fish. Smaller fishes were always more predominant upstream than larger individuals. This is likely because the grouping of smaller fishes include many species that are more resistance to lower oxygen levels. Further, during much of the year degraded water quality precludes cold-water, oxygen sensitive species such as salmon and trout from these reaches. Further, as was shown with water quality data, conditions upstream of Trout Creek can change rapidly with short term climatic events, which could result in mixing, and subsequent water quality changes. While conditions, would not be considered lethal for salmonids, such changes may induce stress, and fish may move away (downstream) from the impacted zone. Fish may simply avoid this zone during the summer because of the unpredictability of water quality, until conditions improve in the fall.

Owing to the shallow nature of Hauser and the narrow beam-width of our transducers, numbers of fish detected using downward looking sonar were extremely low. Graphs showing vertical fish distribution have not been corrected for transducer beam angle. That is to say graphed observations represent individual fish uncorrected for the volume of water sampled. The sonar beam is cone shaped with a radius of 0.5 m at 10 m and 1.0 m at 20 m. The volume of the cone for the first 10m sampled is 7.75 m^3, the volume for the interval 10-20m is 55 m^3, or 7 times the volume of water. Thus if 8 fish were observed in the first 10 m this translates to about

1 fish/m3. If 8 were observed in the second 10m it translates to 0.15 fish/m3, or 1/7th the density.

Vertical distribution information was limited, but did match our expectations (Figures 45 a,b). When restricting observations to larger fish (greater than 22cm), vertical position in the water column did appear to be limited by dissolved oxygen. During spring and summer larger fish were detected in the upper portion of the water column. When low oxygen minima appear, most large fish apparently were avoiding areas of very low oxygen. Distribution of small fish is not as restricted and distributions were always wider. This is the same pattern we observed with upstream downstream distributions, where larger fish were fewer in number in reaches of the reservoir with lower dissolved oxygen levels. During October when stratification breaks down, we see larger fish moving deeper into the water column. During 2000, however, significant stratification still existed with a pool of high conductance, low oxygen, colder water from the Causway Arm preventing fish from utilizing the deepest portions of the reservoir. Canyon Ferry shows a similar vertical distribution of fish (Figure 46). During months of little stratification, hence higher deep water oxygen levels, fish were more widely dispersed in the water column. During late summer we see distribution become very surface oriented.

Temperatures may also act to limit distributions of fish within Hauser Reservoir. The lower reaches of the reservoir are quite a bit warmer, which during spring months may be an attractant. Later in the summer these temperatures near the surface may become too warm for salmonids, however, by that time the low DO zone is at a maxima in the upper end of the lake, which would now act to restrict upstream movements. It is possible susceptible species are being squeezed by a combination of warm surface temperatures, and low oxygen at deeper levels, which allows only a narrow band of conditions suitable for habitation. This is not so much the case at Canyon Ferry, where low oxygen minima do appear until about 30m of depth.

The Canyon Ferry fishery differed significantly from that observed in Hauser Reservoir. Overall vertical distributions followed similar patterns in that dissolved oxygen levels appeared to provide a lower limit to the depth fish were commonly found (Figure 46). This zone of acceptable water quality, however, is significantly thicker than observed at Hauser due to relatively constant mixing in the upper 30m of the water column. Like Hauser, vertical distribution of smaller fishes was broader than that of larger fishes. During summer and early fall fish were primarily surface oriented, with side-scan sonar providing the most effective means of detecting fish.

Spatially, however, observed fish distributions at Canyon Ferry were more uniform. Our study primarily focused on the reach from Canyon Ferry Dam upstream to near where Confederate Gulch enters the reservoir. Upstream of this point we typically had difficulty collecting good quality data due to presence of dense algal mats which tended to blind the hydroacoustics unit. High winds and waves severely limited the utility of side scan acoustics. Fish size on average was also much larger at Canyon Ferry. When restricted to fish of 22 cm or larger the proportion of these relative to smaller fish was about similar between the two reservoirs. Approximately 40 % of Hauser fish were greater than 22 cm whereas 50 % of Canyon Ferry fish were. Density estimates varied greatly between reservoirs, as a whole for Hauser Reservoir 0.00045 to 0.00075 fish per cubic meter of July and September 1999, and 0.00078 for September 2000. For Canyon Ferry these numbers were 0.00147, .0010 and 0.0032 and 0.0022 respectively. On average Canyon Ferry fish densities were several times higher than what was observed in Hauser Reservoir. This observation is consistent with netting observations made by Montana Fish Wildlife and Parks personnel.

Test spills:

Concern was voiced about water released from Canyon Ferry that was in violation of the state water quality standard of 6.5 mg/L DO in flowing water. It was unknown whether or not low DO releases from Canyon Ferry were a recent phenomena or whether they had occurred historically? It was also unknown whether or not the pattern of DO releases limited beneficial use of downstream water resources, primarily the fishery of Hauser Reservoir. For the five years we have monitored the tailrace DO patterns have been very predictable. DO is at or near saturation in the spring, and begins slowly decreasing by the middle of May (Figure 50). Minimum values usually occurred around the second week of September, with a gradual increase occurring until Canyon Ferry completely turns over, after which time DO is again near or at saturation. Spills were considered as an option to increase dissolved oxygen in the tailrace. However, from a management standpoint spills tend to be inefficient and wasteful due to lost hydropower revenues, potential limitations on the amount of available water to spill, potential for greater entrainment of fish from Canyon Ferry due to near surface releases, and potential increases in temperature downstream due to withdrawals of warm surface waters. Alternative methods of raising oxygen levels are being planned that will explore using direct injection of air into various portions of the turbine assembly either through existing valves or through modifications. The ultimate goal of these studies will be to determine the most cost effective methods for increasing DO levels in releases from Canyon Ferry Reservoir.

Two test spills were conducted on September 12, 1999 and September 15, 2000 (Figs. 48, 49). Observed results were very different during the two releases, owing to the amount of water being released, and conditions within Hauser reservoir at the time. Both spills, however, met the objective of bringing dissolved oxygen levels up to, or above the required standards. Temperatures of the releases however, were also increased, by about a degree for these two scenarios.

Data collection for the first spill began on August 25th and ended the evening of September 12th, 1990. Oxygen in the surface waters of Canyon Ferry at this time ranged from about 5.9 mg/L on the surface to 0.2 mg/L near the bottom at the buoy line (Figure 50). Thus, any increase in DO above 6 mg/L was a result of aeration in the spill. This is worthwhile to note as we observed low DO values in the reservoir surface waters previous years as well. What this means, is short of putting oxygen into the water using a spill or some other method, water released through the turbines even using a selective withdrawal would still be too low in oxygen to meet downstream requirements of 6.5 mg/L for flowing waters. High primary productivity is the principle reason for the low DO observed in Canyon Ferry at this time of the year. In 2000, data collection began August15th and ended September 19th. Dissolved oxygen levels at this time in Canyon Ferry were in the range of 6.5 to 7 near the surface and again approached zero below the thermocline. Differences in dissolved oxygen in Canyon Ferry in 2000 versus 1999 may have related to differences in operations, productivity, or other climatic influences.

During one time frame during the spill in 1999 when the observed DO was 6.44 mg/L immediately downstream dam, water temperature was 16.8 °C, giving an estimated saturation value of 76 % for oxygen. Nitrogen saturation was calculated as 114 % at this location indicating supersaturation, and potential gas-bubble diseases issues would not be much of problem during spill events. One note of interest was the lack of immediate mixing of water being released from the turbines, and that being released over the spillways. This was obvious near the release point, as DO in the river in front of the spillways was 9.1 mg/L or 109 % saturation. In front of the turbines it was 4.9 mg/L or 57 % of saturation. We also noted the lack of complete mixing by the time water reached the location of our anchored data sonde at Riverside during both years of the study. Water on the launch ramp side (Riverside campground) of the data sonde was consistently in the 5-6 mg/L range while water on the opposite bank was over 7 mg/L. The data sonde was near mid-point. Within the first few bends of the river water has completely mixed, and at Spokane creek there was little change in DO across a transect of the reservoir at that point, averaging about 6.5 mg/L on the surface and 6.2 mg/L at 5 m depth.

Spill data showed different results in terms of impact to Hauser reservoir each year of the study. These differences can be attributed to a combination of differences in the amount of water released from Canyon Ferry Dam and to differences in weather conditions each year. For either year it appears that the upper one-third to one-half of Hauser reservoir was most significantly affected be releases from Canyon Ferry Dam during the spill. Typically, severe degradation of water quality in terms of dissolved oxygen occurs during both years of this study in the reach extending from Canyon Ferry dam downstream to just past the point Spokane Creek enters Hauser reservoir. Hauser reservoir upstream of this point is narrow and riverine in nature. Travel time is short (typically 12-24 hrs) depending on releases from Canyon Ferry, with this reach essentially acting as a riverine zone. Below Spokane Creek Hauser reservoir opens into a broad basin where significant wind generated mixing and biological processes occur. Even through this stretch however, there was still significantly lower DO in 1999 versus 2000. This is probably a function of longer turnover times and differences in water temperatures, in both Hauser and of Canyon Ferry releases between the two years. Hauser never really stratifies very strongly, and with changes in temperatures of the releases using the spillways stratification was quickly destroyed in the upper reaches of the reservoir. From about Trout Creek downstream, however, surface water appeared little influenced by flows from Canyon Ferry during this study. Our limits to downstream detection may be related to the duration of the test spill. Dissolved oxygen levels in the upper water column in the lower reaches of Hauser were predominately dominated by more in reservoir processes such as biological production and mixing, than by flow effects from Canyon Ferry.

4. ACKNOWLEDGMENTS:

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Figure 1a,b. Phytoplankton density (total and by major groups) for samples collected from Canyon Ferry Reservoir.

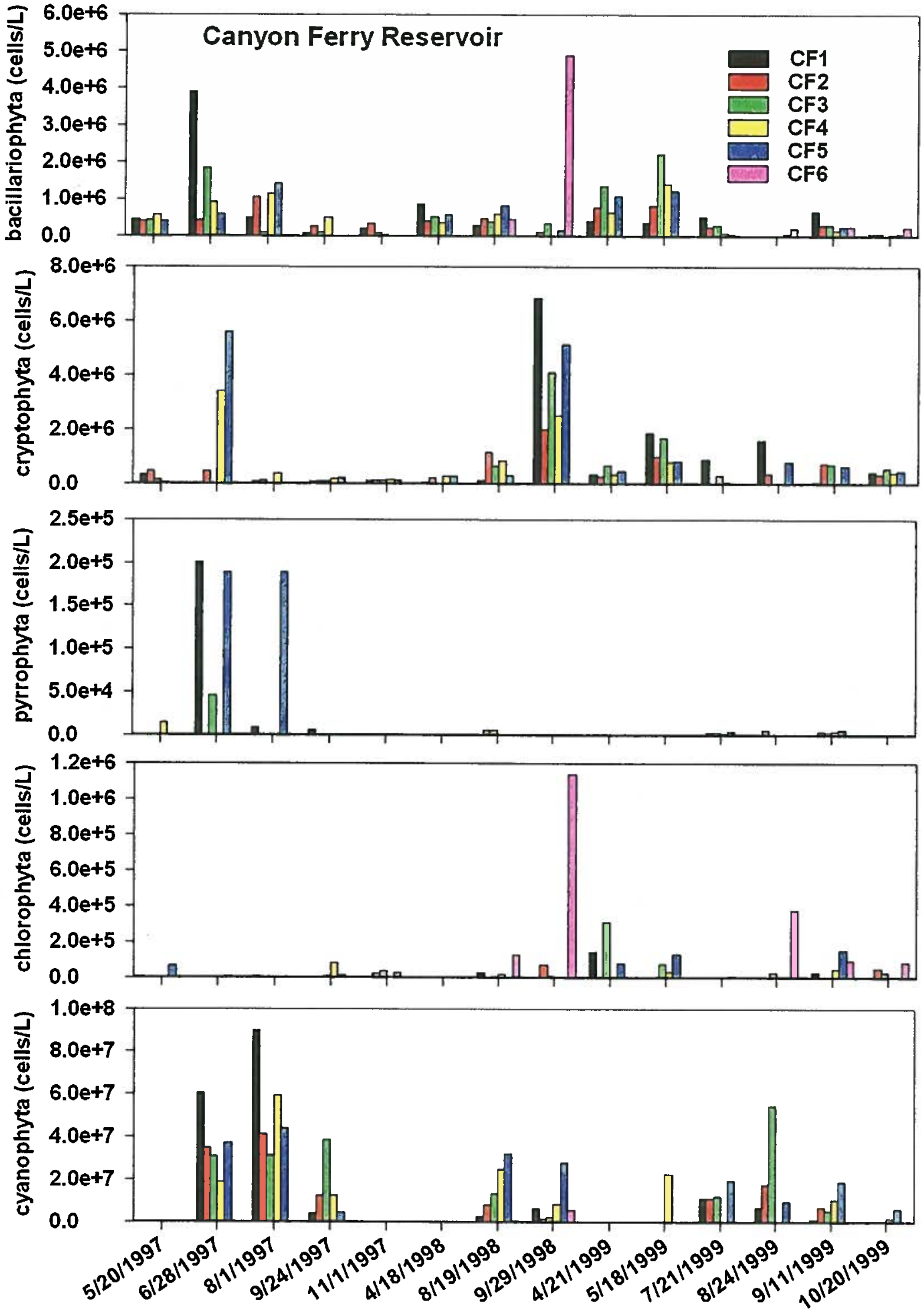
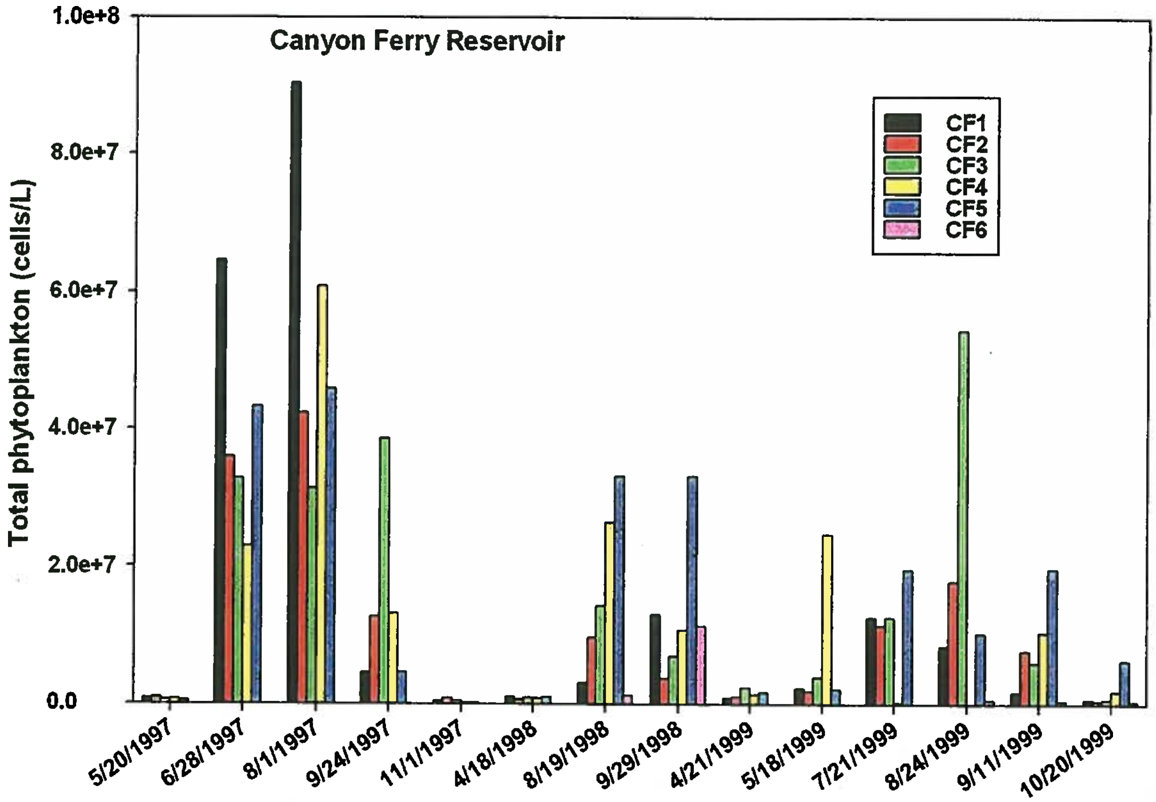


Figure 1b.



Canyon Ferry Reservoir
Total phytoplankton (cells/L)
1.0e+8
8.0e+7
6.0e+7
4.0e+7
2.0e+7
0.0
CF1
CF2
CF3
CF4
CF5
CF6
5/20/1997
6/28/1997
8/1/1997
9/24/1997
11/1/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/18/1999
7/21/1999
8/24/1999
9/11/1999
10/20/1999

Figure 2. Seasonal and spatial distribution of Chlorophyll *a* in Canyon Ferry Reservoir.

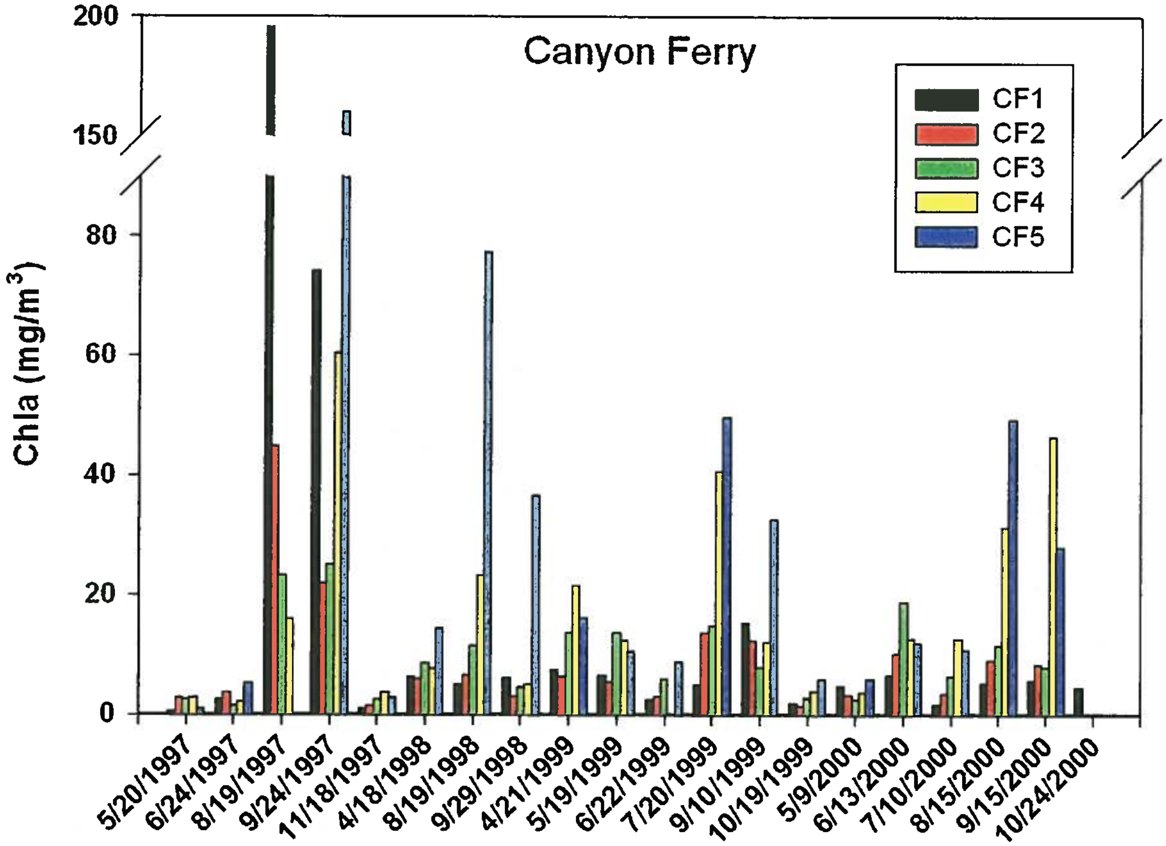


Figure 3. Total phosphorus (ug/L) measured in Missouri River inflows to Canyon Ferry.

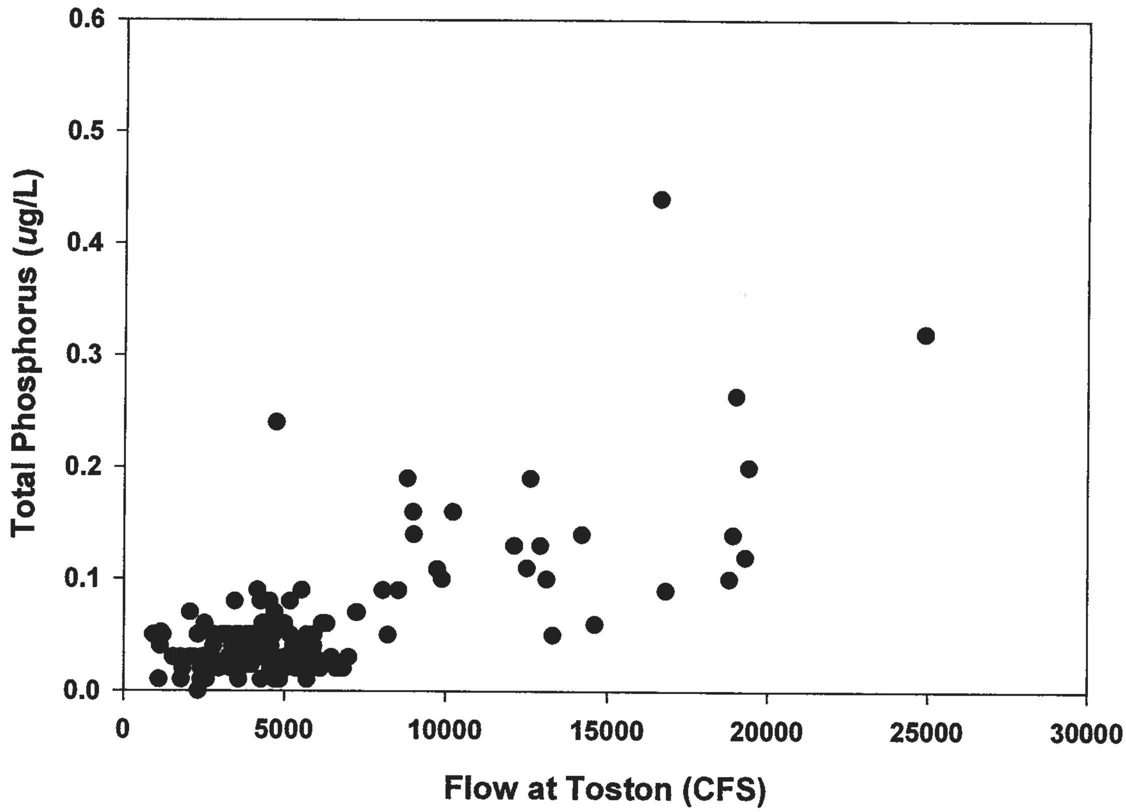


Figure 4. Mean monthly Missouri River inflows as measured at Toston to Canyon Ferry, MT for the period 1981 to 2000.

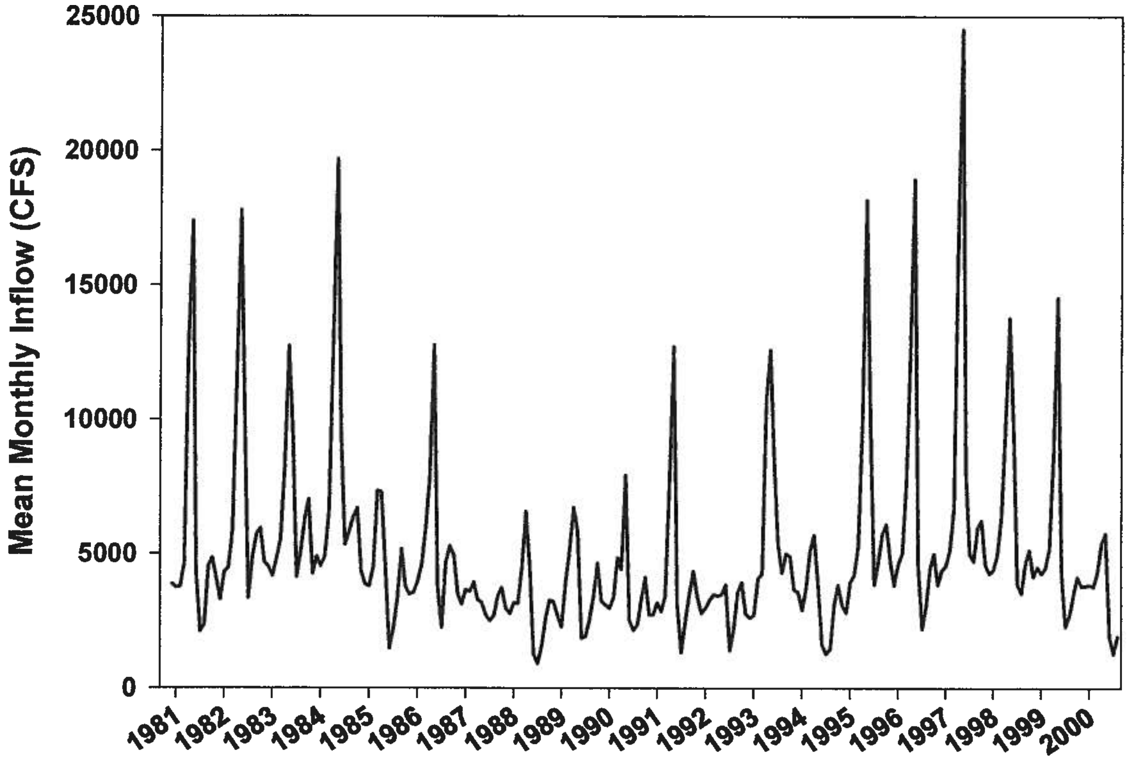


Figure 5. Seasonal patterns of zooplankton abundance in Canyon Ferry Reservoir with respect to Cladocera, Copepoda and Rotifera.

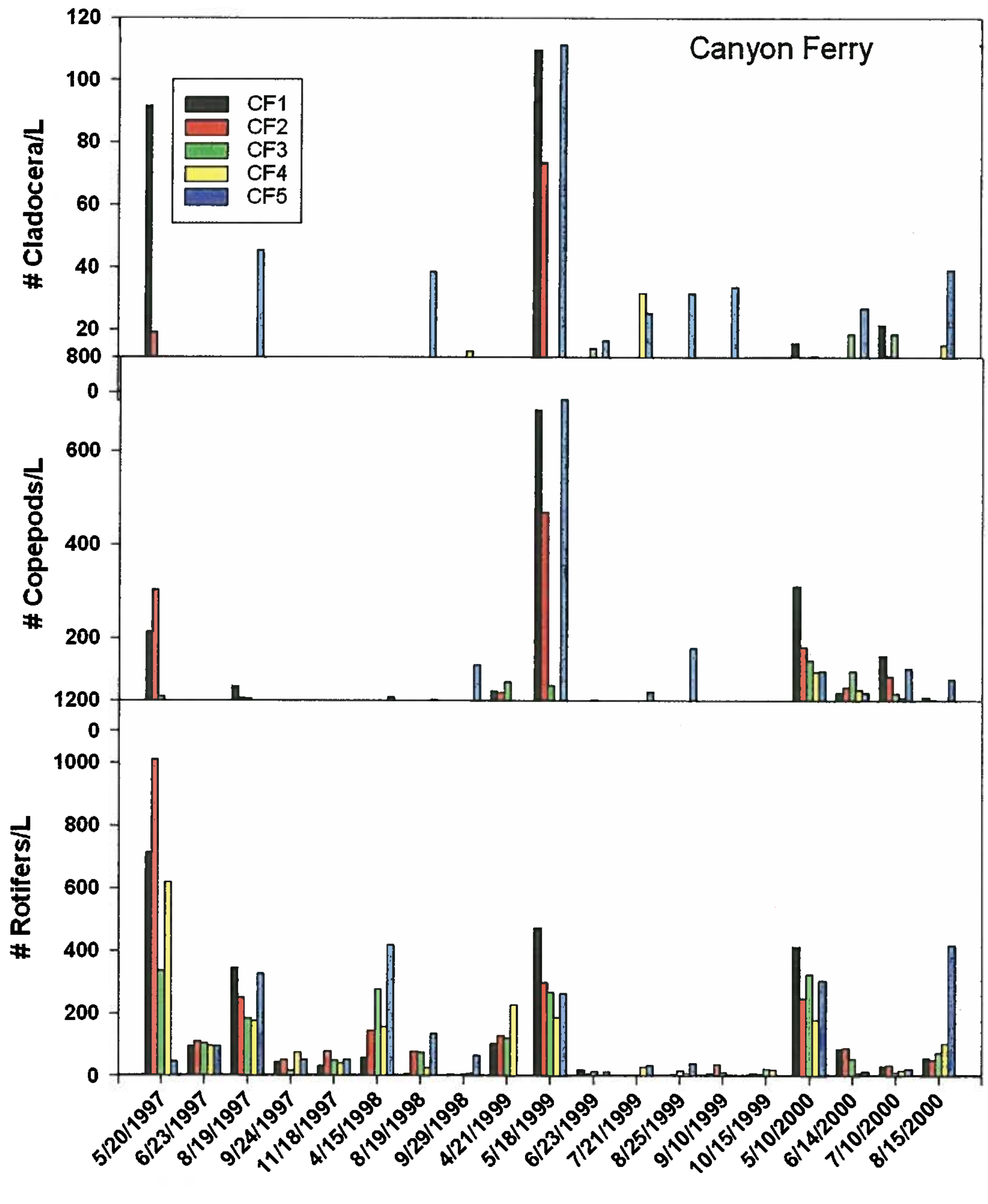


Figure 6. Distribution of secchi depth readings for 1997 to 2000 for Canyon Ferry, MT.

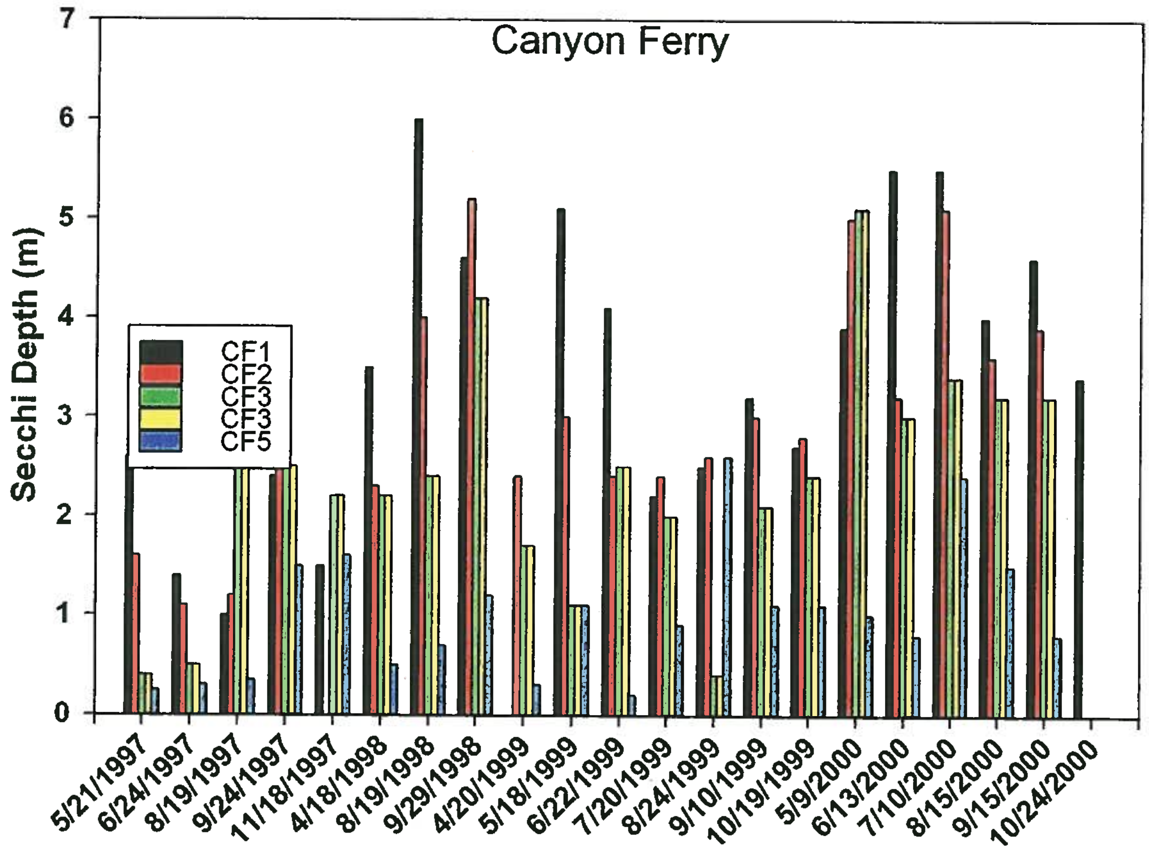


Figure 7 a,b,c,d. Ammonia, Nitrate, Ortho-phosphorus, and Total Phosphorus concentration in epilimnetic (top panel), and hypolimnetic waters for Canyon Ferry. Yellow bar represents detection limits.

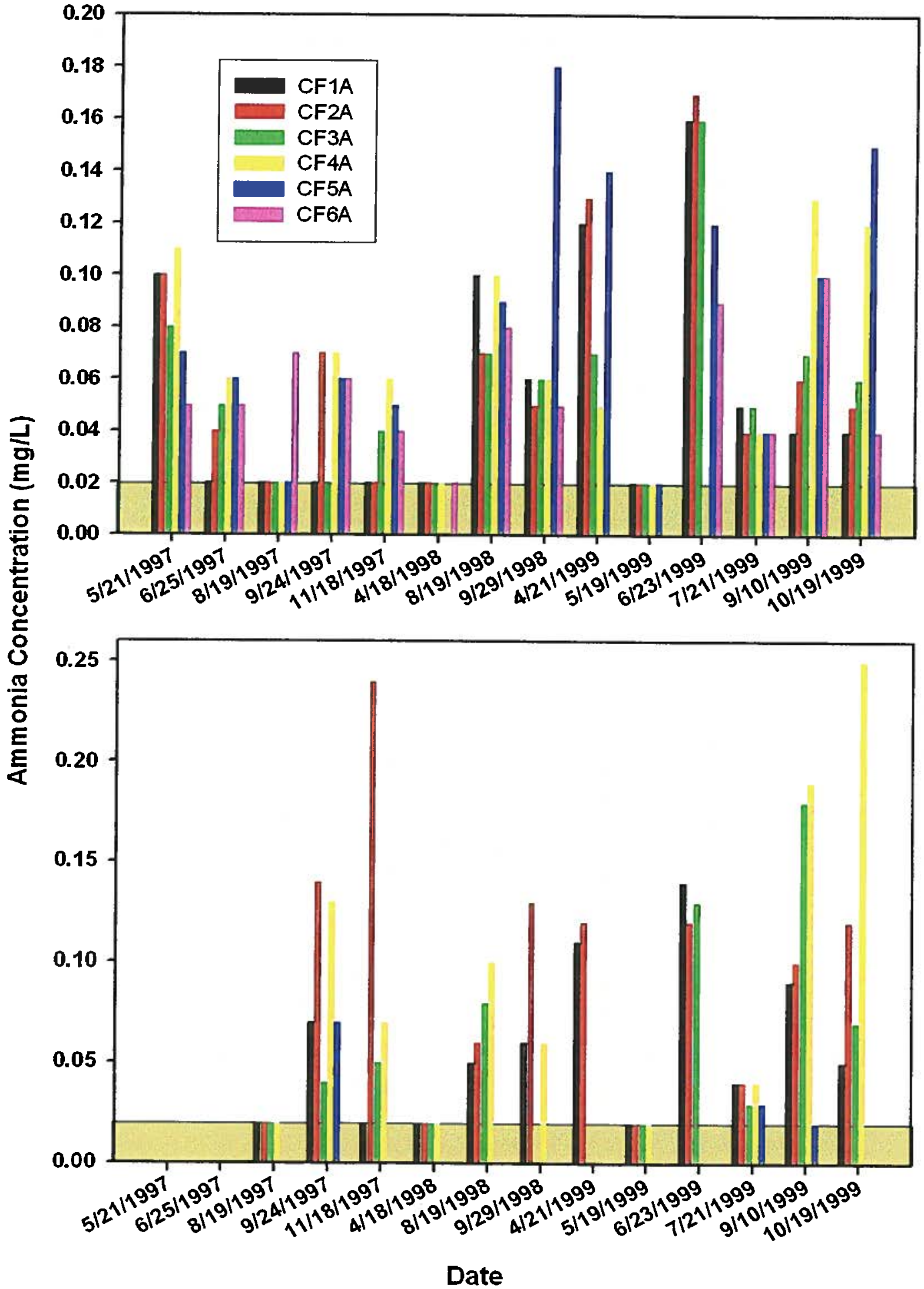


Figure 7b.

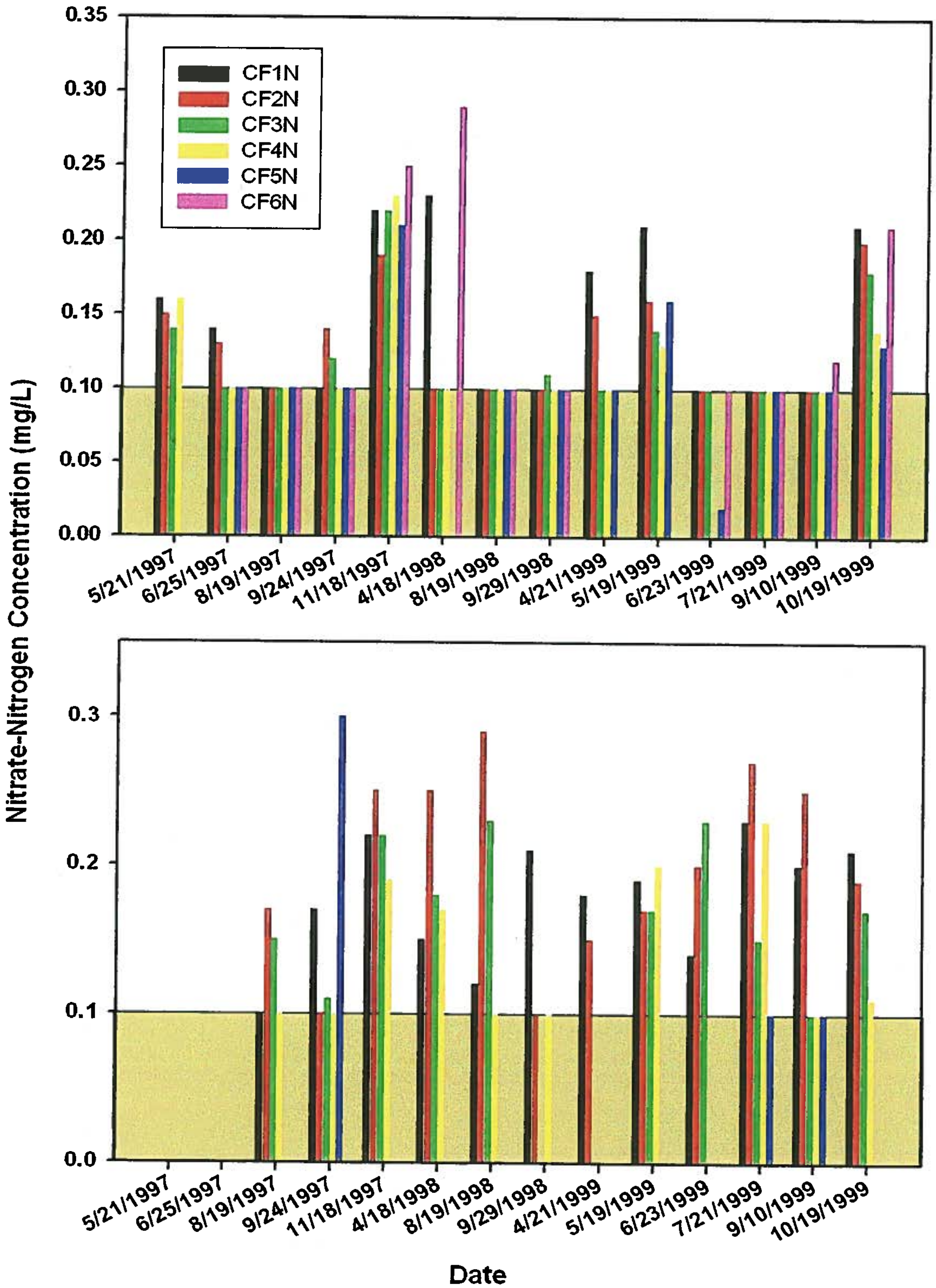

0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
CF1N
CF2N
CF3N
CF4N
CF5N
CF6N
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
Nitrate-Nitrogen Concentration (mg/L)
0.3
0.2
0.1
0.0
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
Date

Figure 7c.

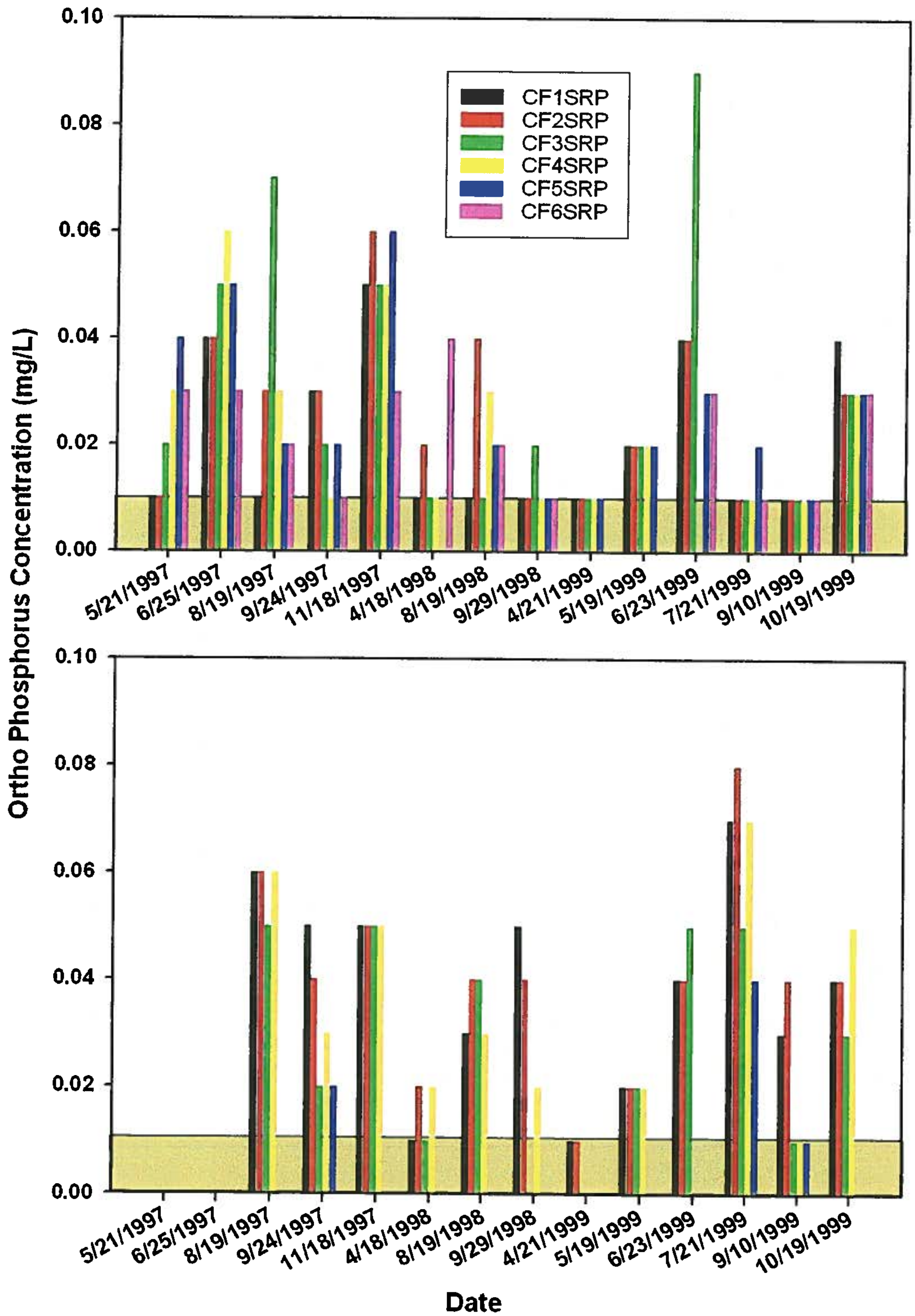
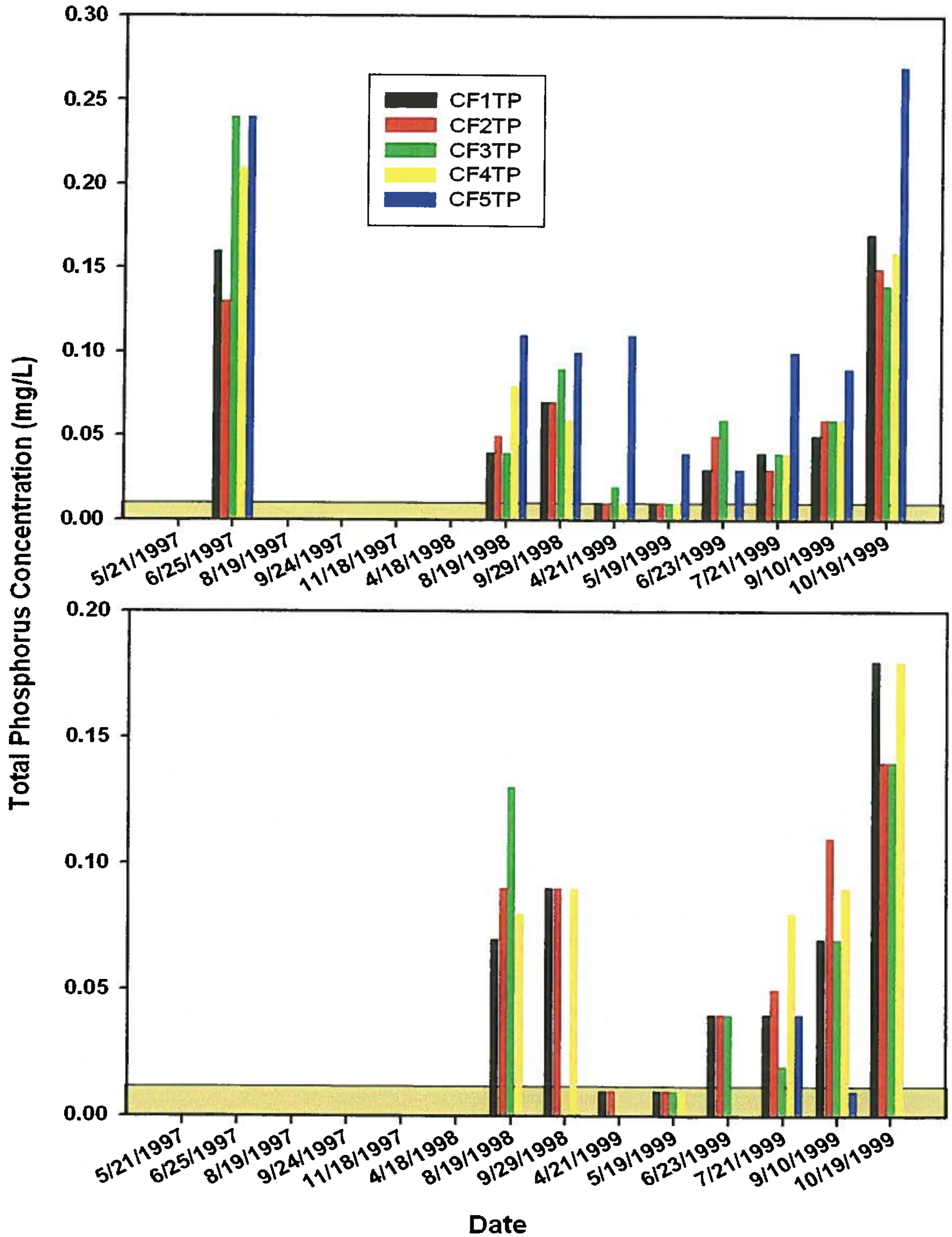

CF1SRP
CF2SRP
CF3SRP
CF4SRP
CF5SRP
CF6SRP
Ortho Phosphorus Concentration (mg/L)
0.10
0.08
0.06
0.04
0.02
0.00
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
Date

Figure 7d.



0.30
0.25
0.20
0.15
0.10
0.05
0.00
CF1TP
CF2TP
CF3TP
CF4TP
CF5TP
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
Total Phosphorus Concentration (mg/L)
0.20
0.15
0.10
0.05
0.00
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
Date

Figure 8. Site map of Hauser Reservoir showing sampling stations used for this study.

Figure 9. Site map of Canyon Ferry Reservoir showing sites sampled for this study.

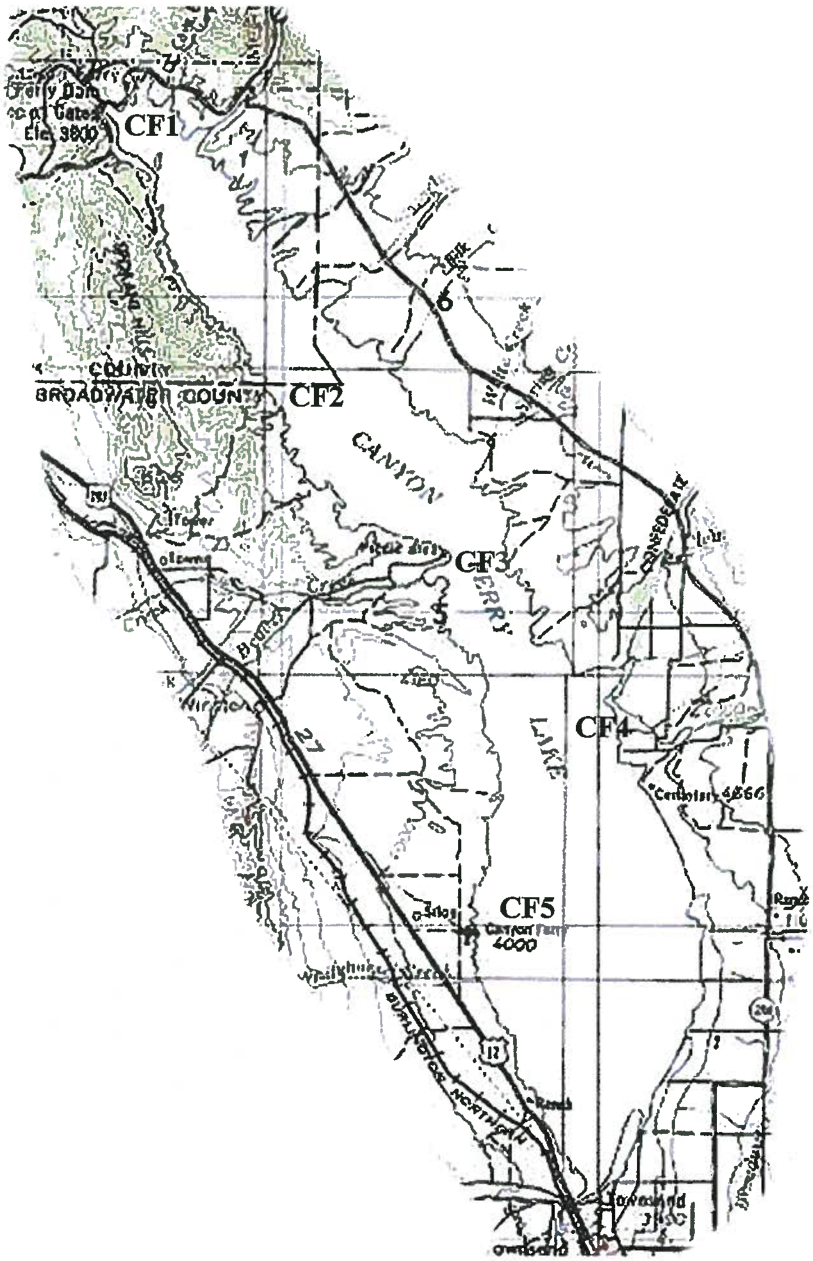


Figure 10. Seasonal patterns of zooplankton abundance in Hauser Reservoir with respect to Cladocera, Copepoda and Rotifera.

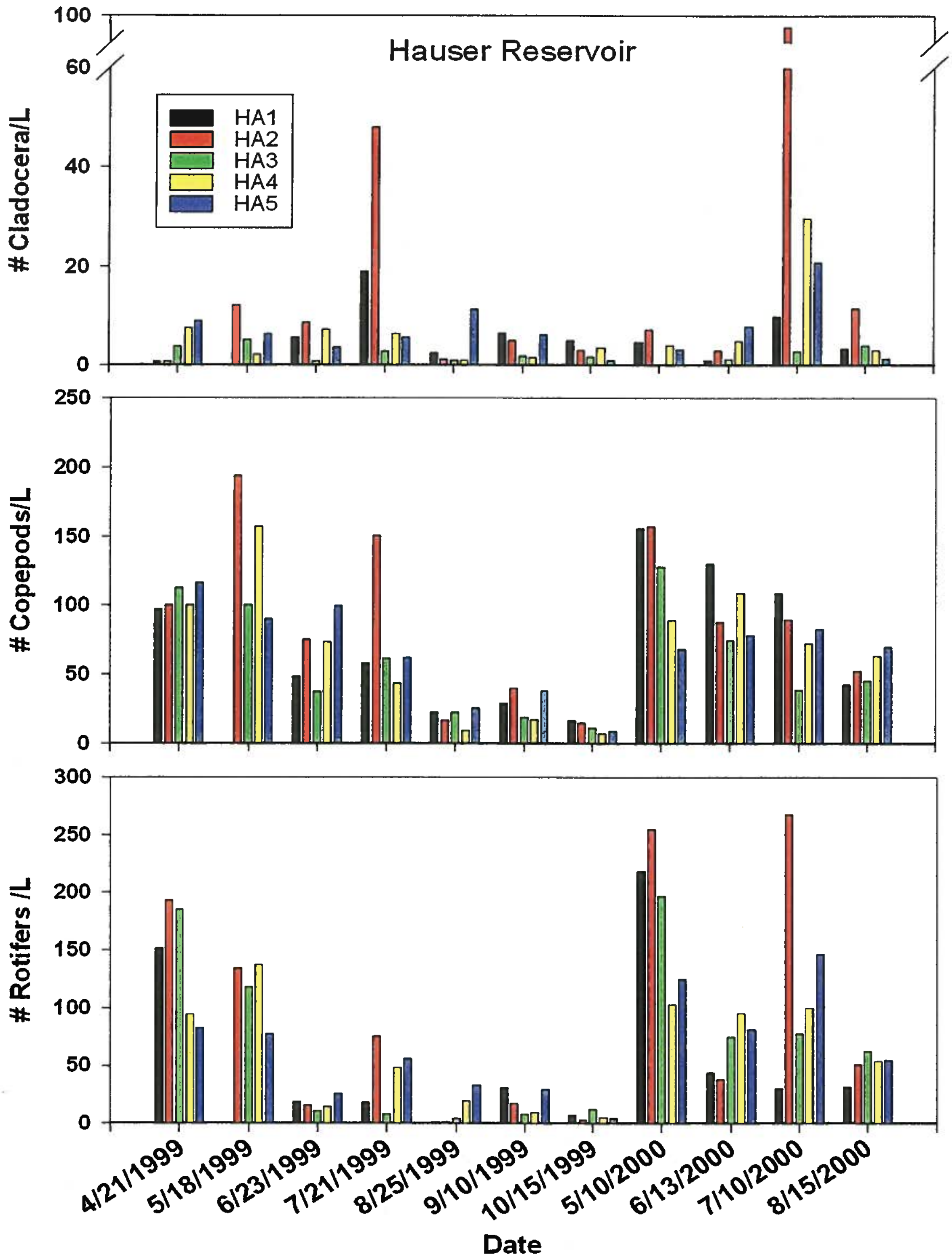


Figure 11. Spatial and seasonal distribution of Chlorophyll *a* in Hauser Reservoir.

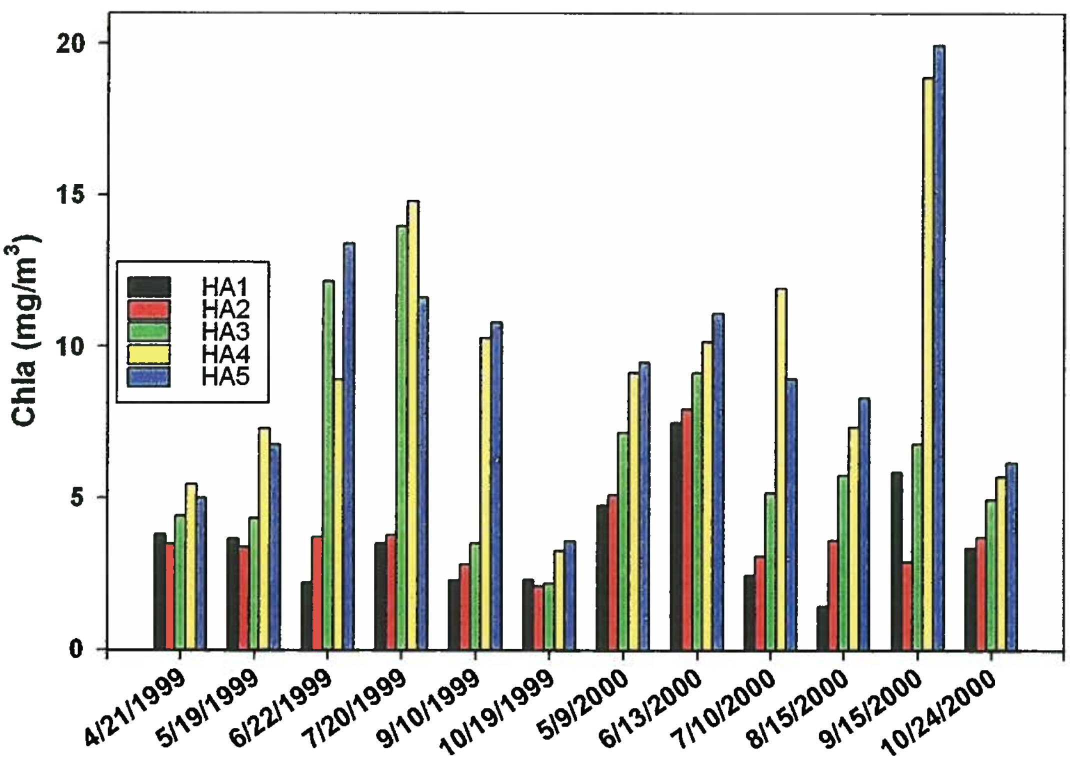


Figure 12 a,b. Seasonal changes in phytoplankton density by site for major divisions and as total numbers.

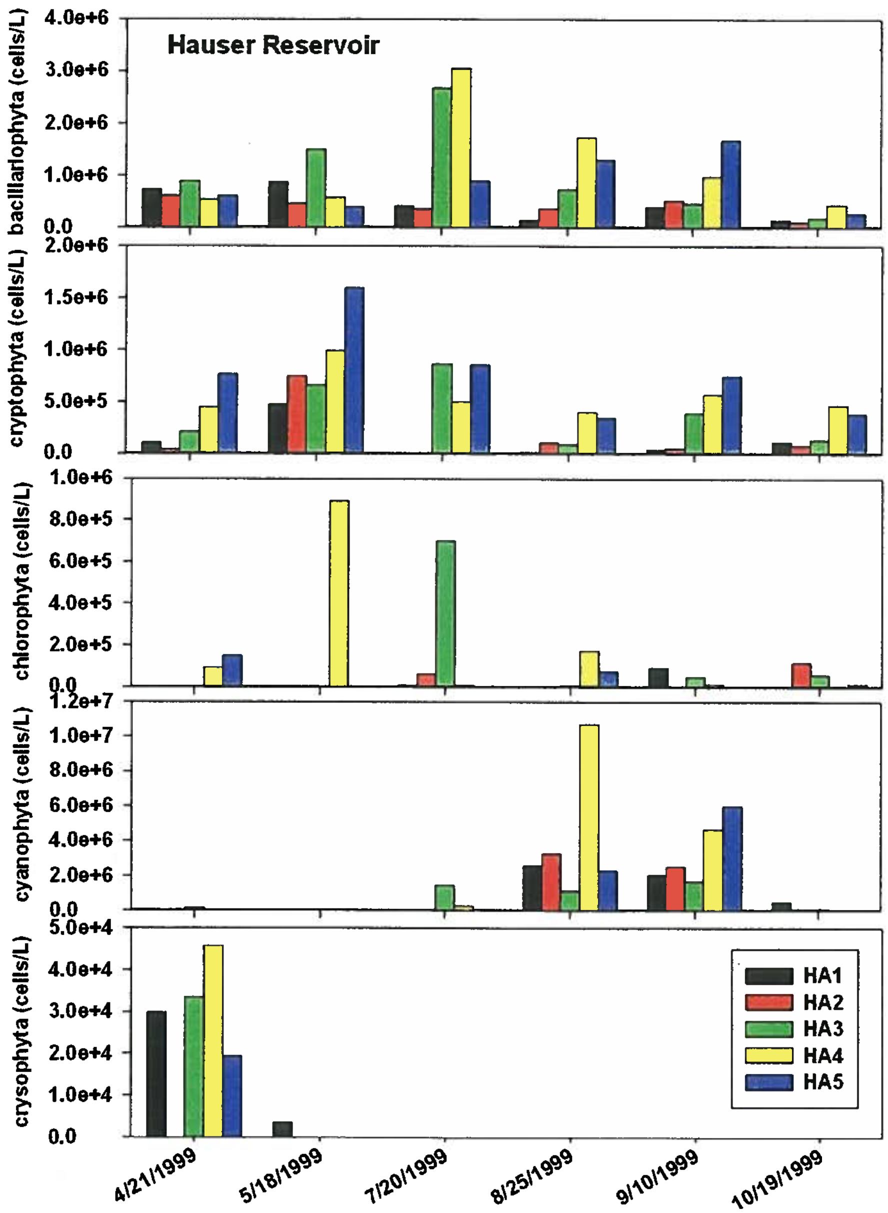
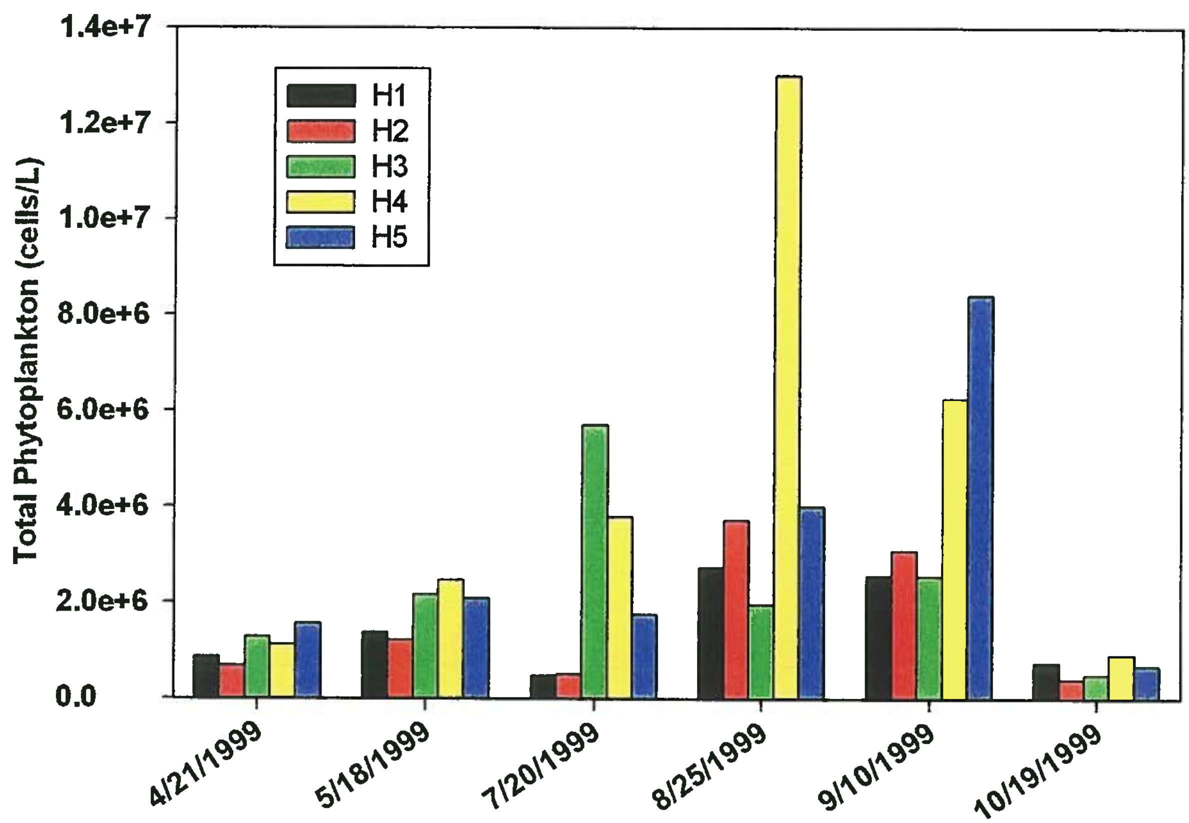


Figure 12b.



Total Phytoplankton (cells/L)
1.4e+7
1.2e+7
1.0e+7
8.0e+6
6.0e+6
4.0e+6
2.0e+6
0.0
H1
H2
H3
H4
H5
4/21/1999
5/18/1999
7/20/1999
8/25/1999
9/10/1999
10/19/1999

Figure 13. Distribution of secchi depth readings for 1999 and 2000 for Hauser Reservoir, MT.

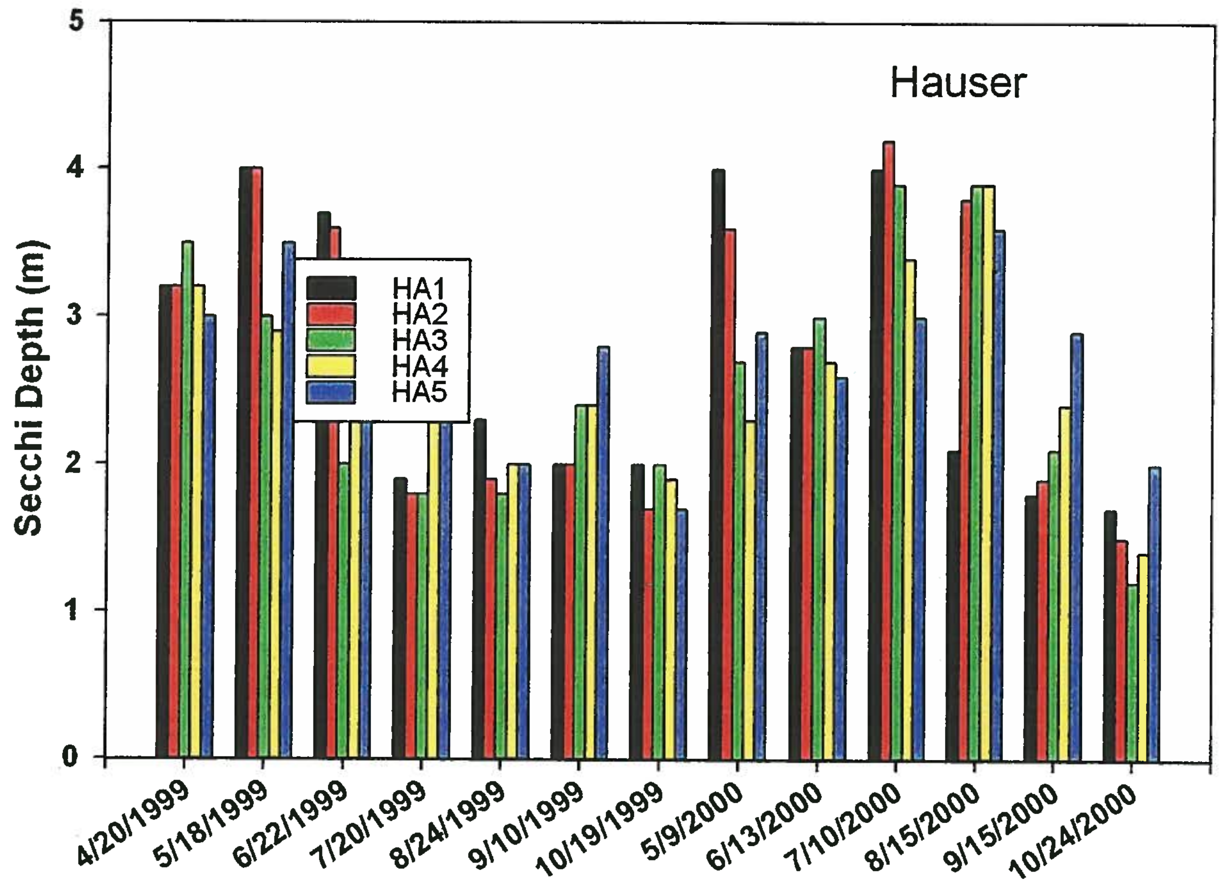


Figure 14. Longitudinal cross sections of temperature profiles for Hauser Reservoir, 1999.

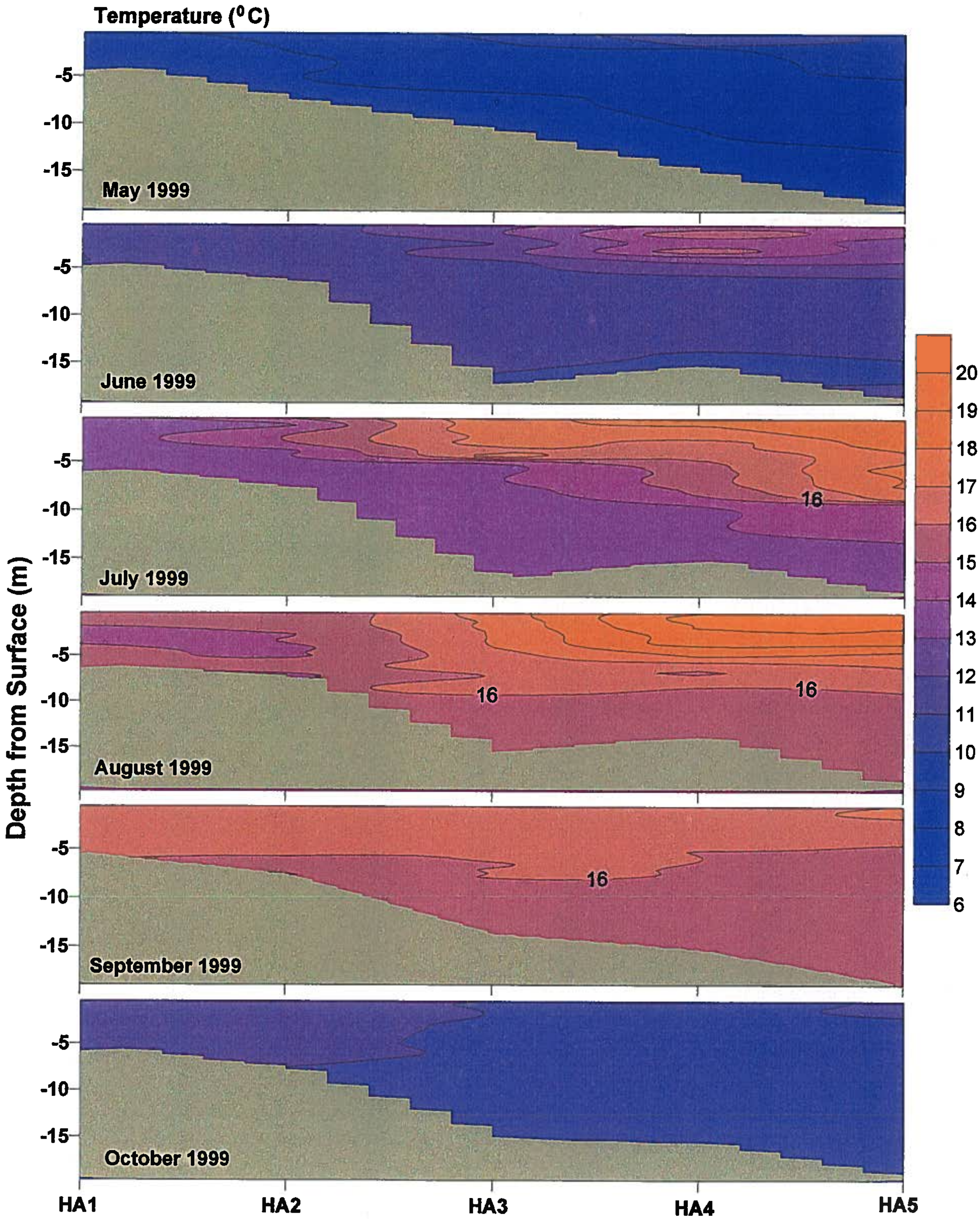


Figure 15. Longitudinal cross sections of temperature profiles for Hauser Reservoir, 2000.

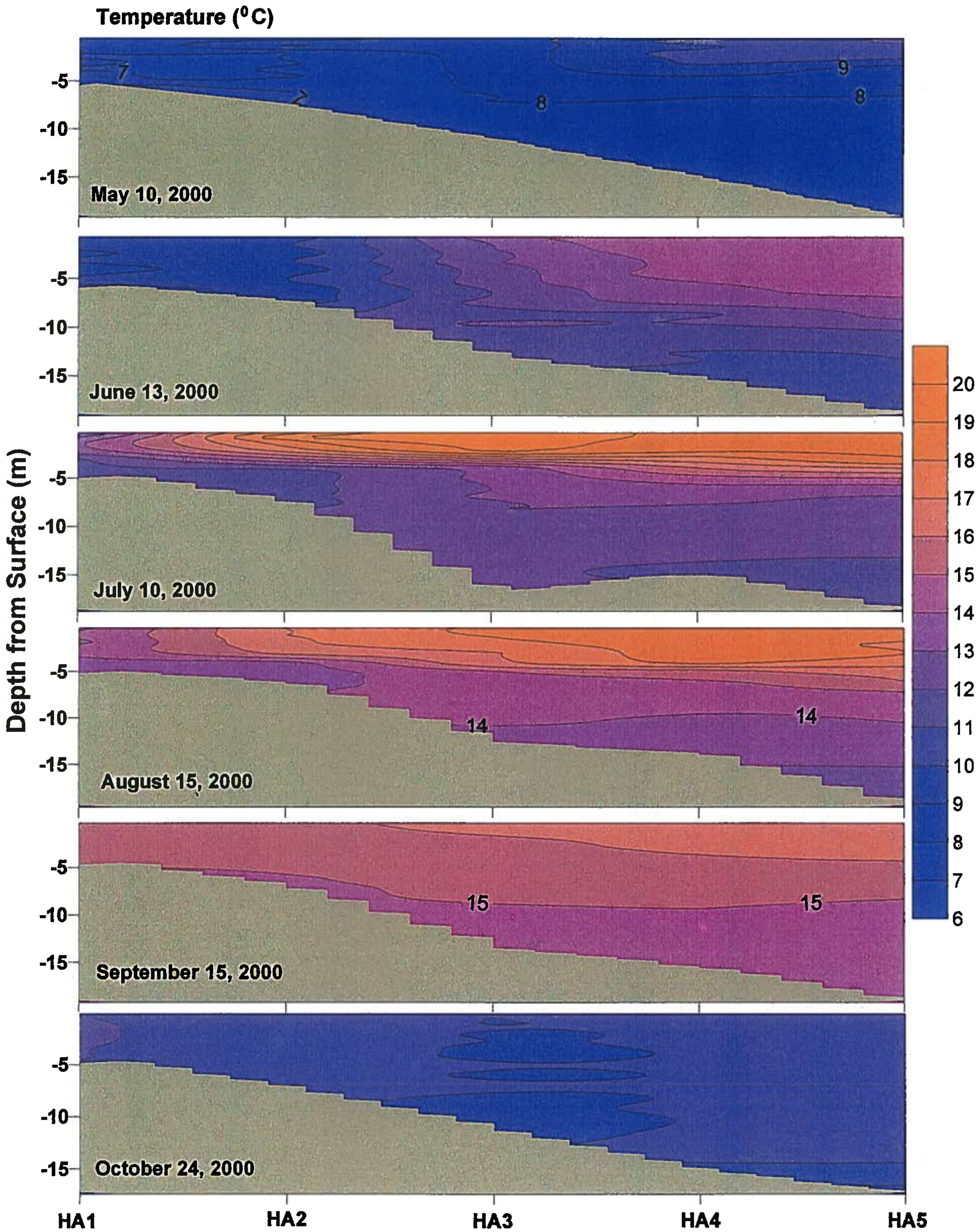


Figure 16. Longitudinal cross sections of Conductivity profiles for Hauser Reservoir, 1999.

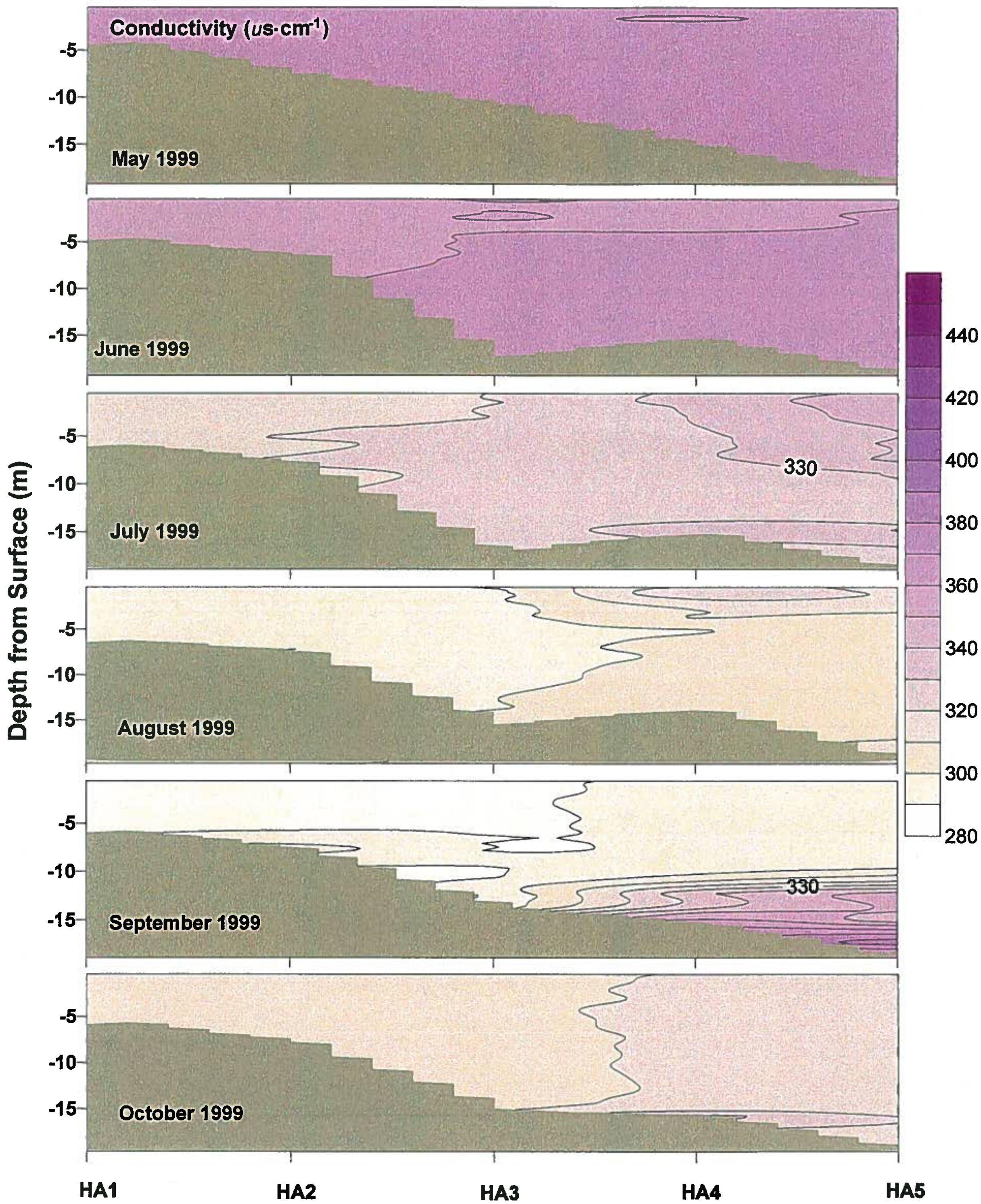


Figure 17. Longitudinal cross sections of Conductivity profiles for Hauser Reservoir, 2000.

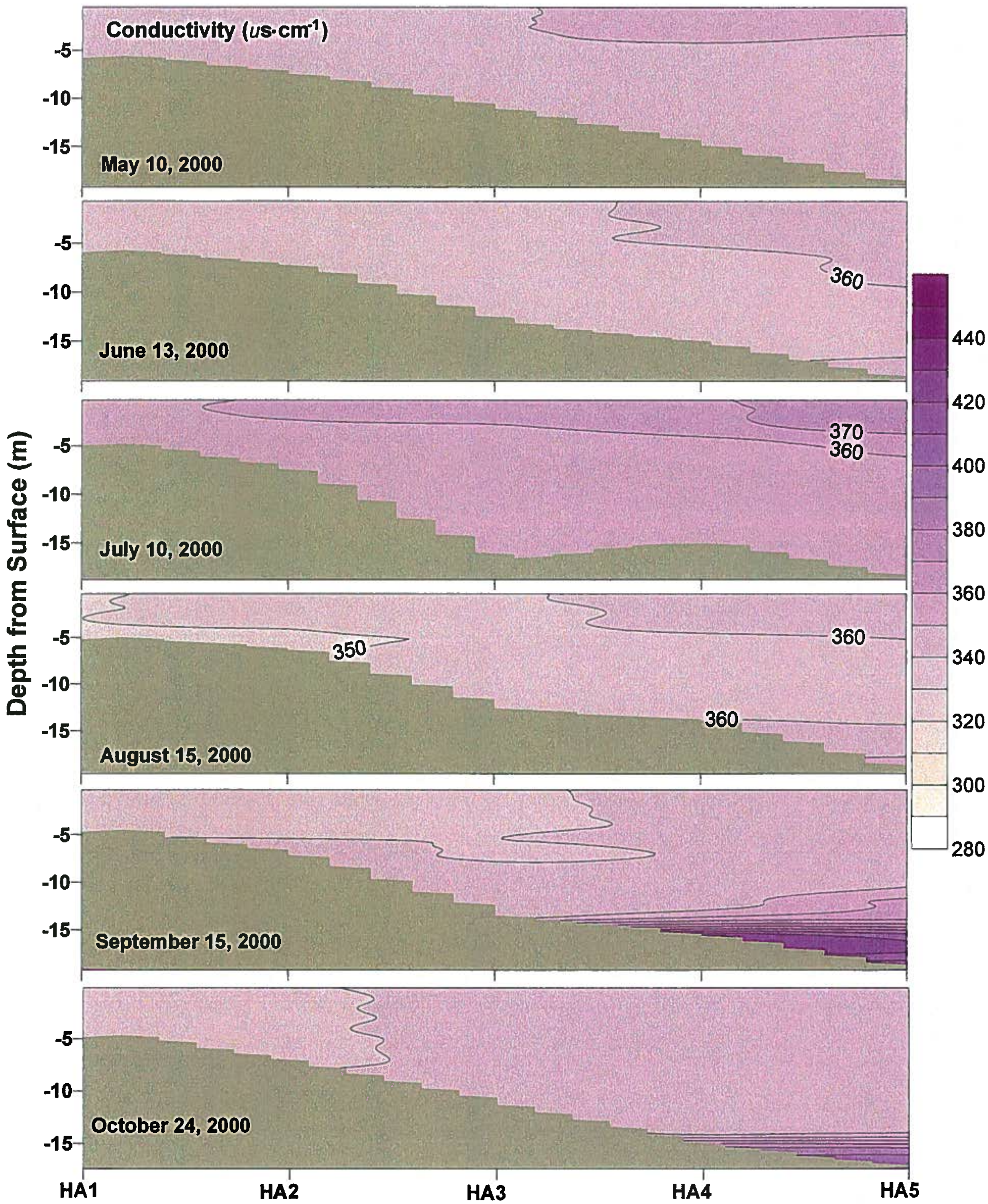


Figure 18. Longitudinal cross sections of dissolved oxygen saturation profiles for Hauser Reservoir, 1999.

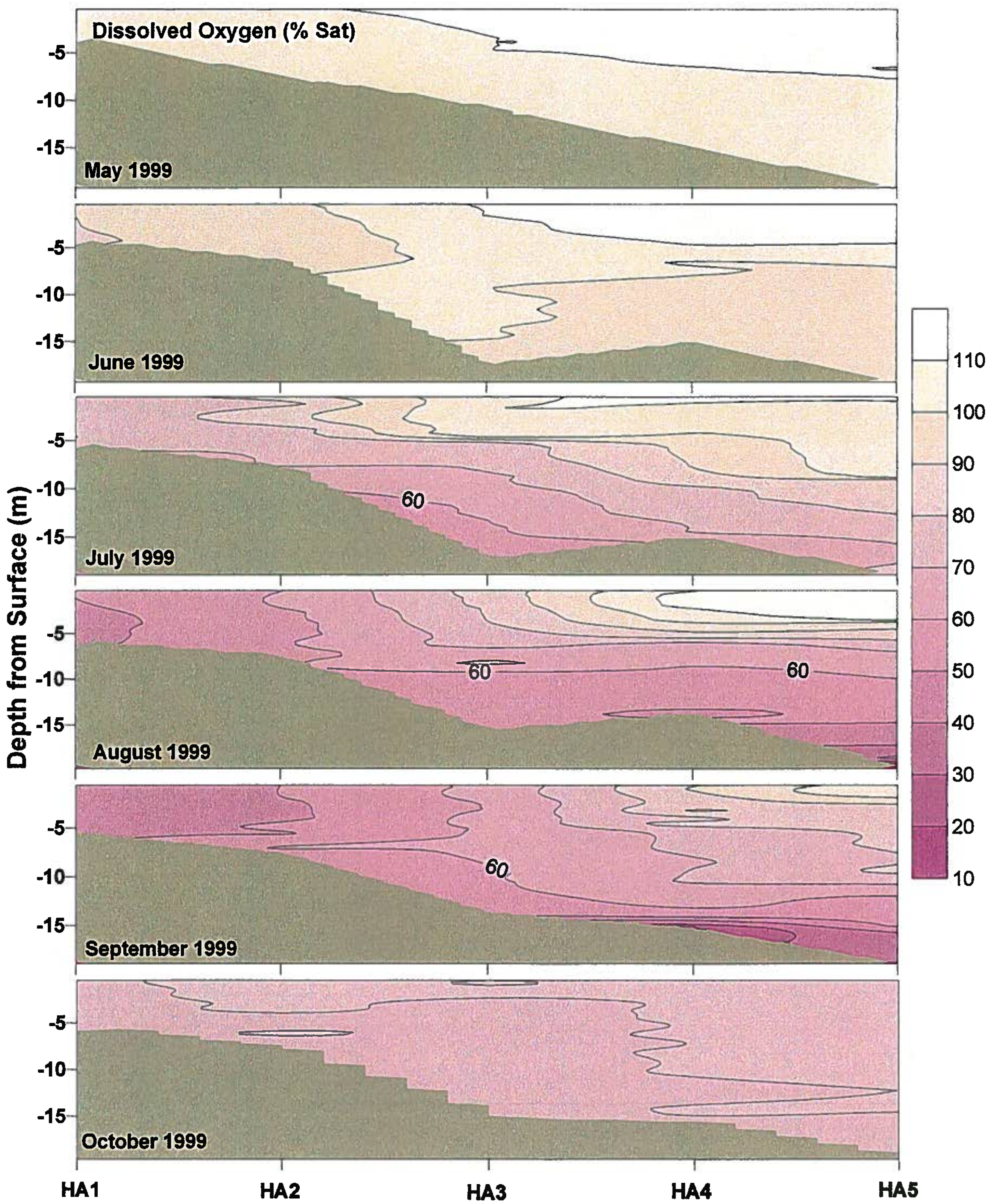


Figure 19. Longitudinal cross sections of dissolved oxygen saturation profiles for Hauser Reservoir, 2000.

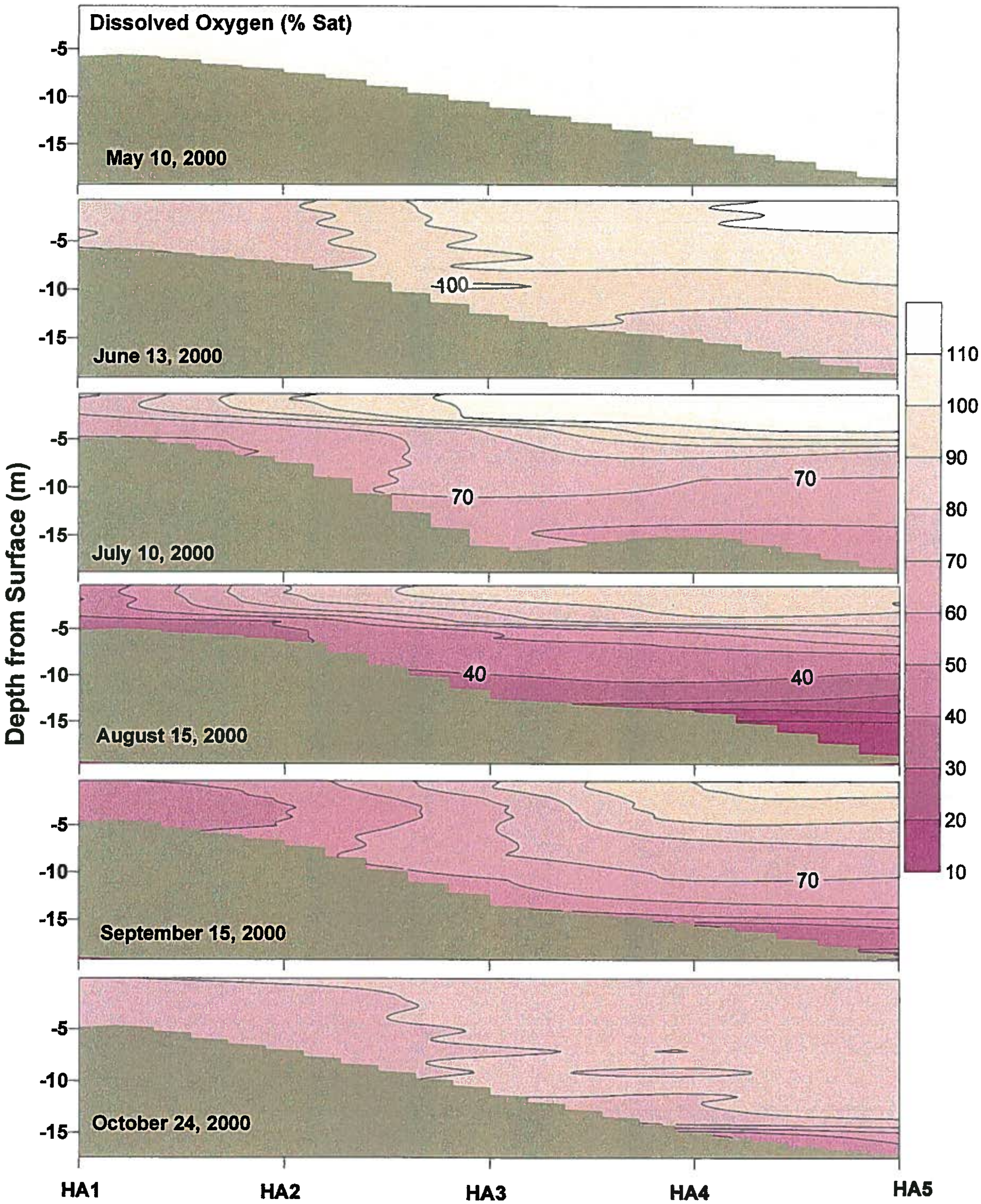


Figure 20. Longitudinal cross sections of dissolved oxygen concentration profiles for Hauser Reservoir, 1999.

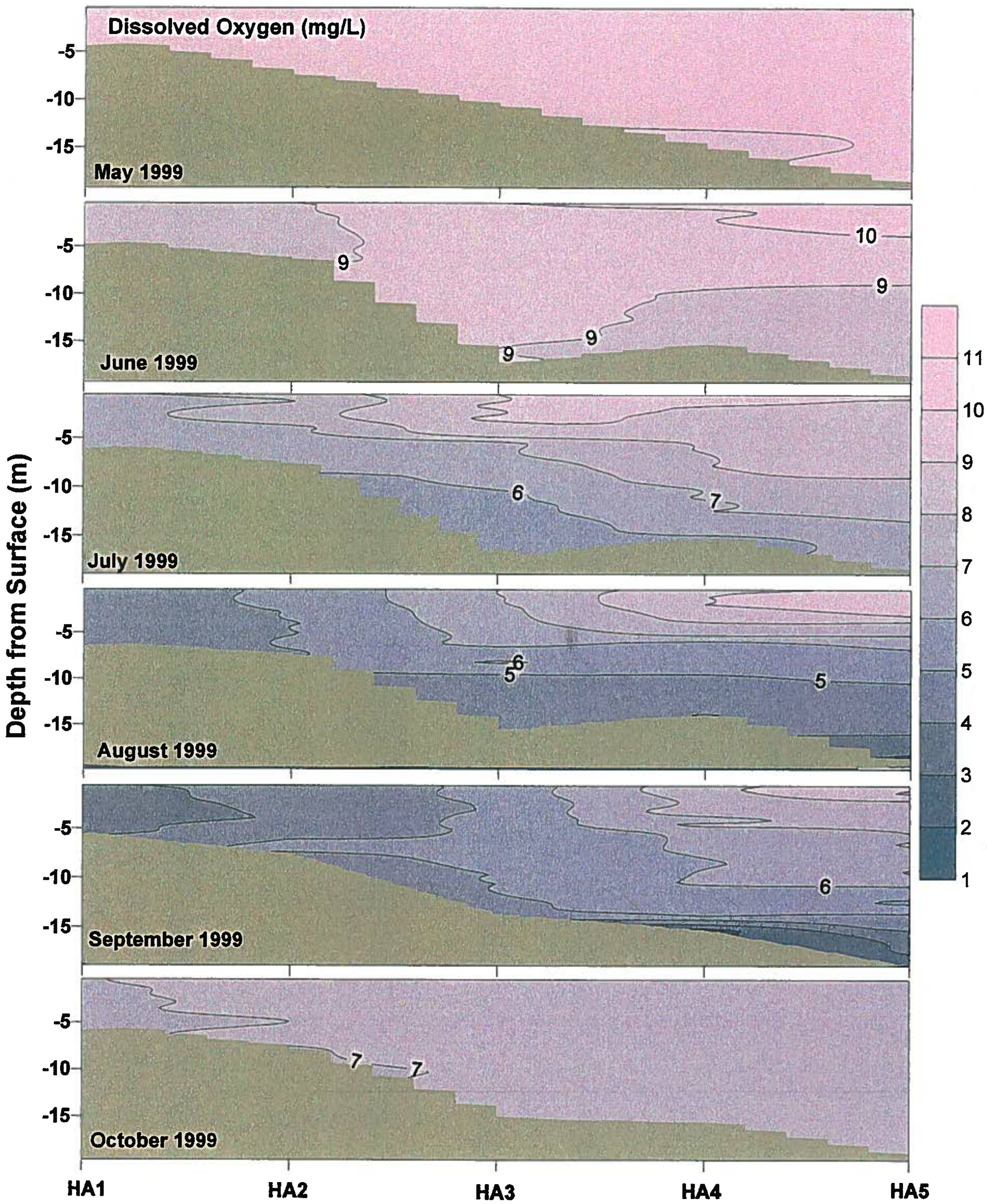


Figure 21. Longitudinal cross sections of dissolved oxygen concentration profiles for Hauser Reservoir, 2000.

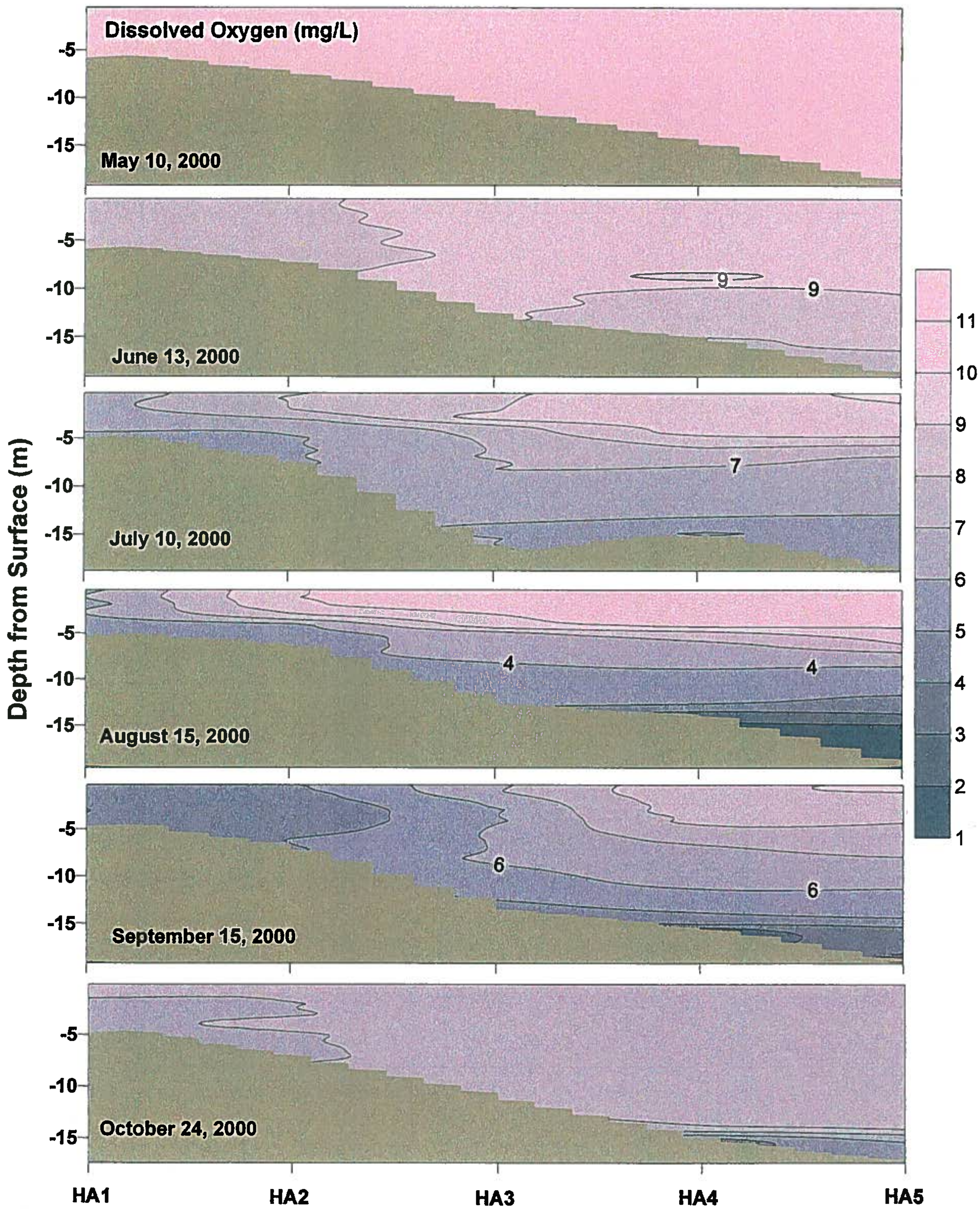


Figure 22. Water temperatures of inflows to Hauser reservoir from Canyon Ferry and Lake Helena 1999 and 2000.

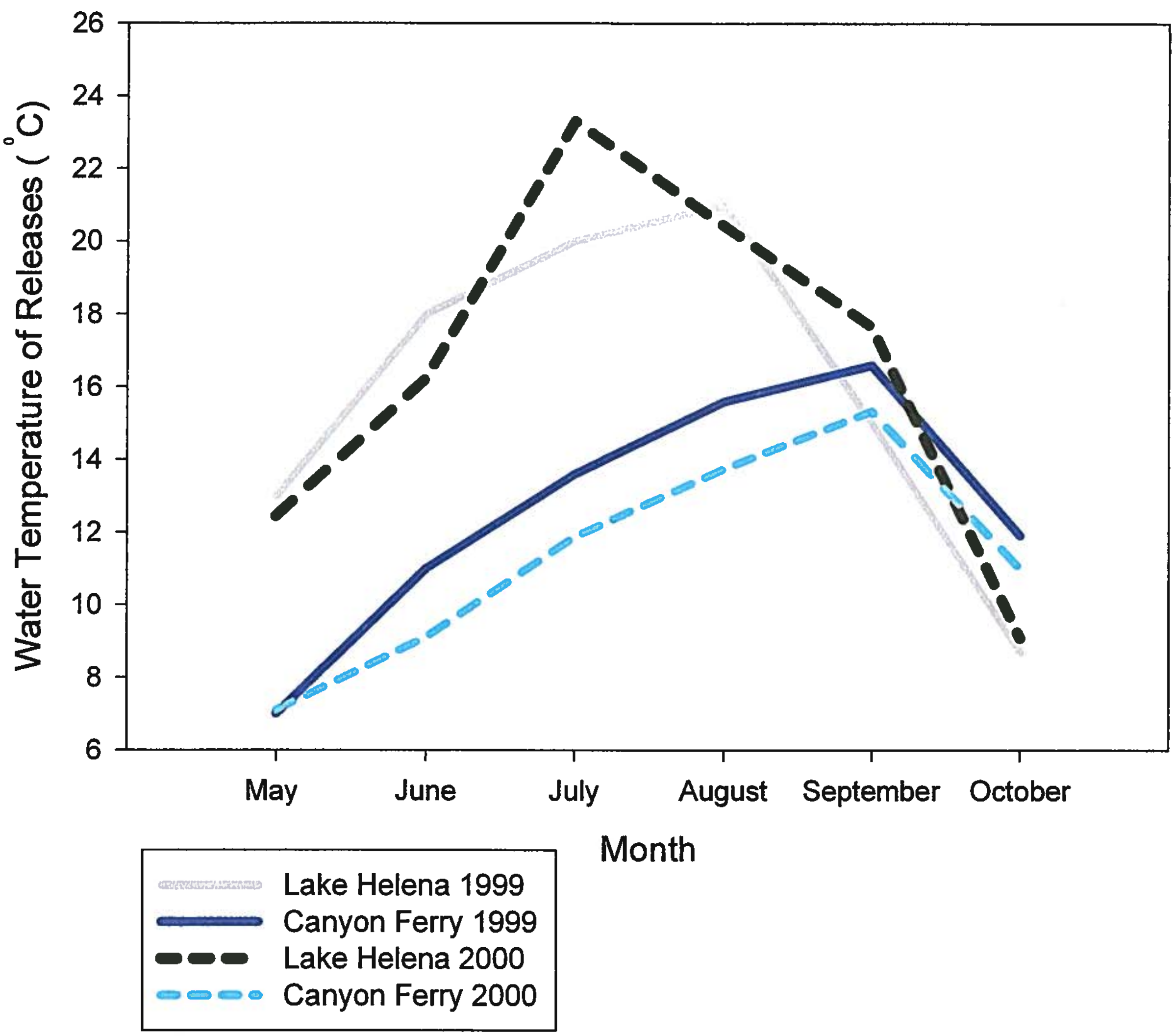


Figure 23 a,b,c,d. Ammonia, Nitrate, Ortho-phosphorus, and Total Phosphorus concentration in epilimnetic (top panel), and hypolimnetic waters for Hauser Reservoir. Yellow bar represents detection limits.

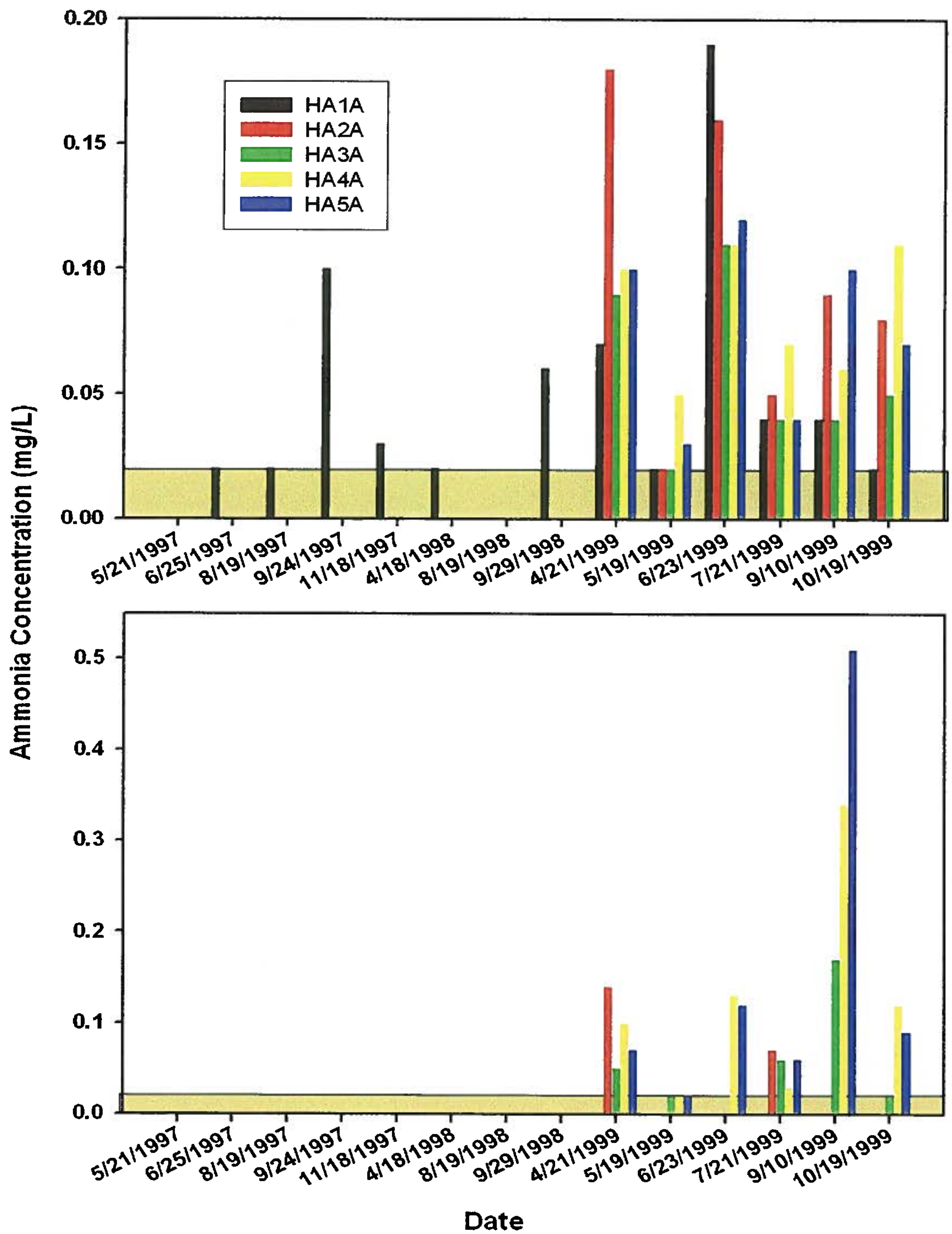
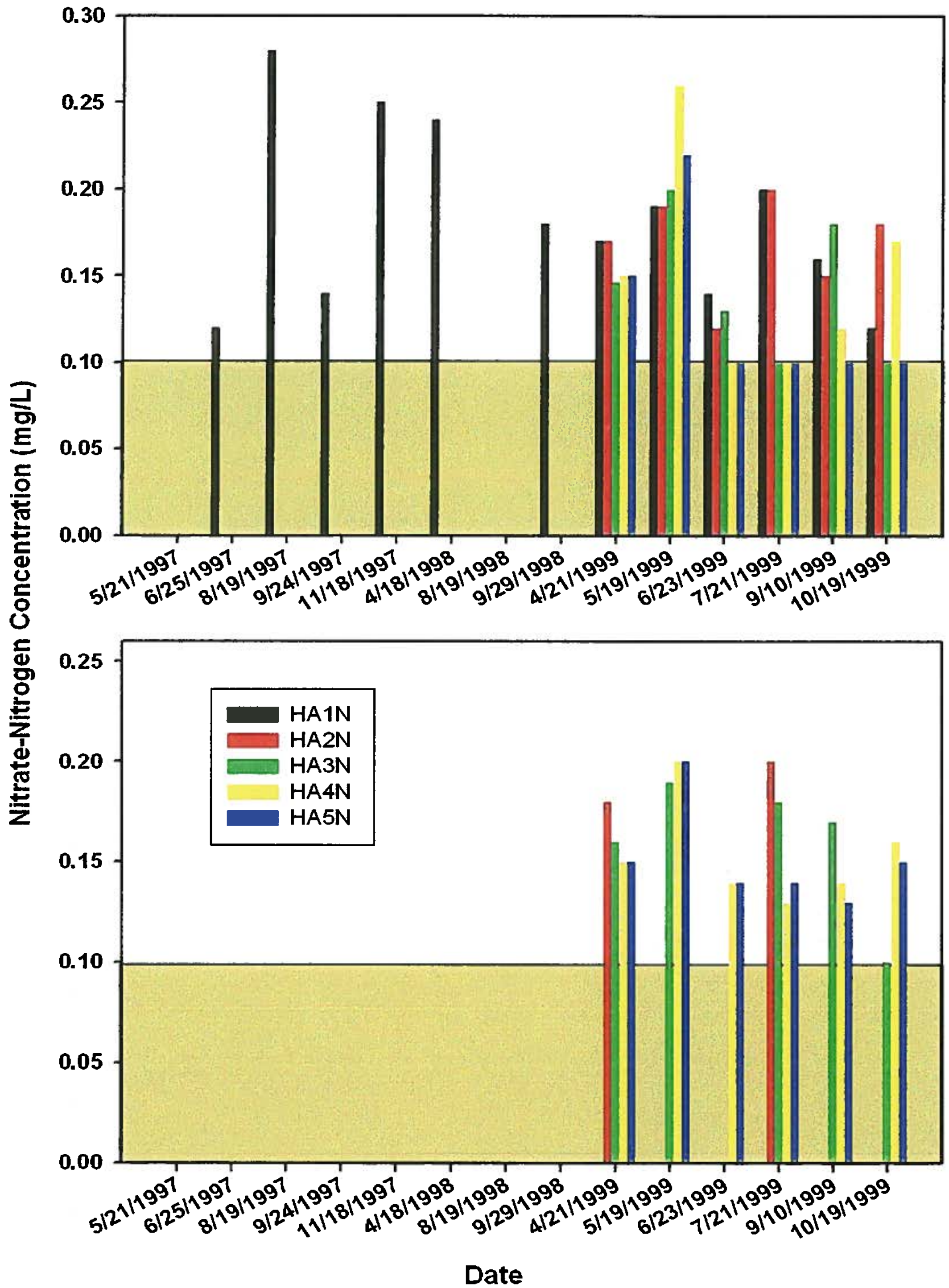
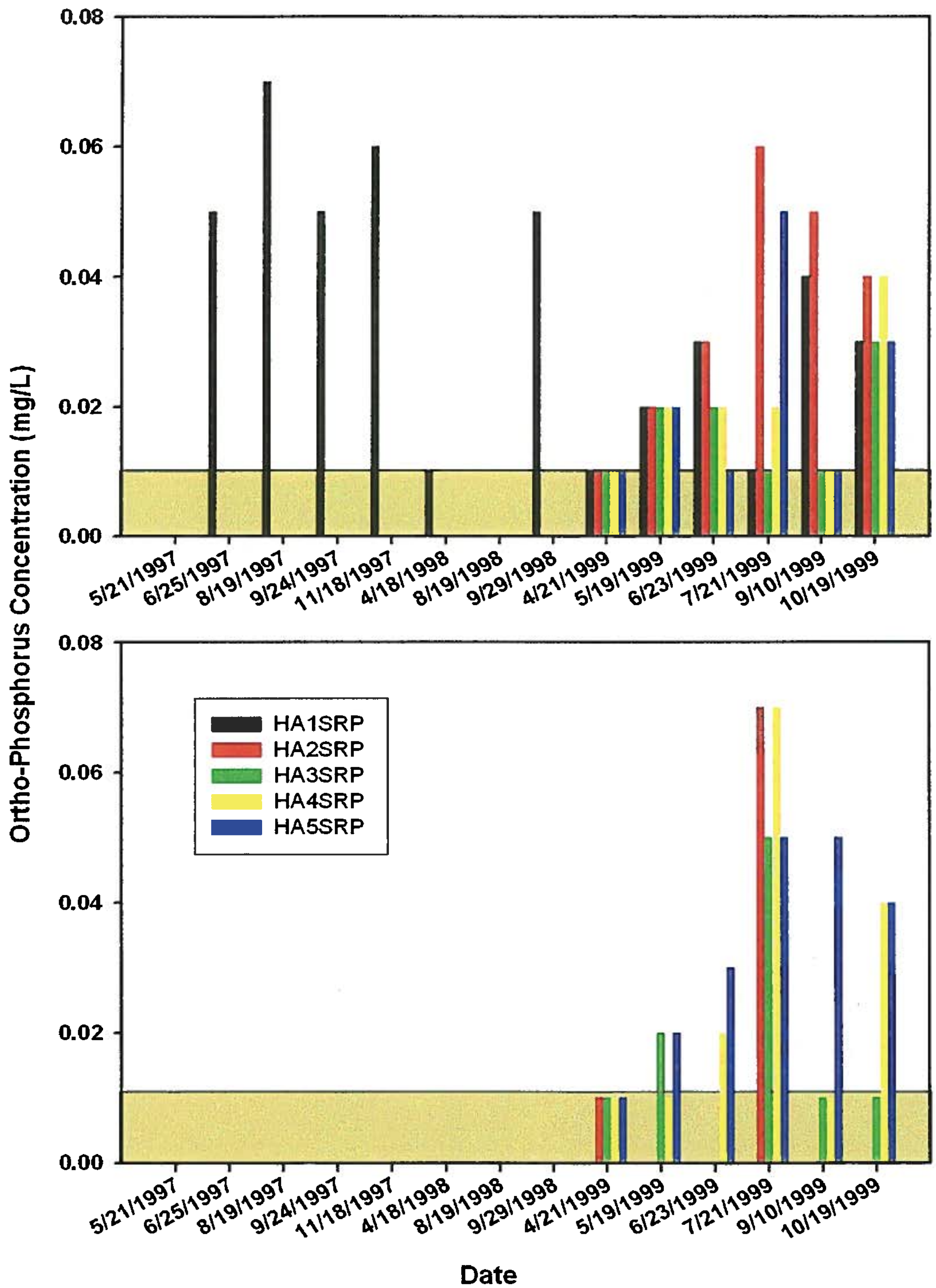


Figure 23 b.



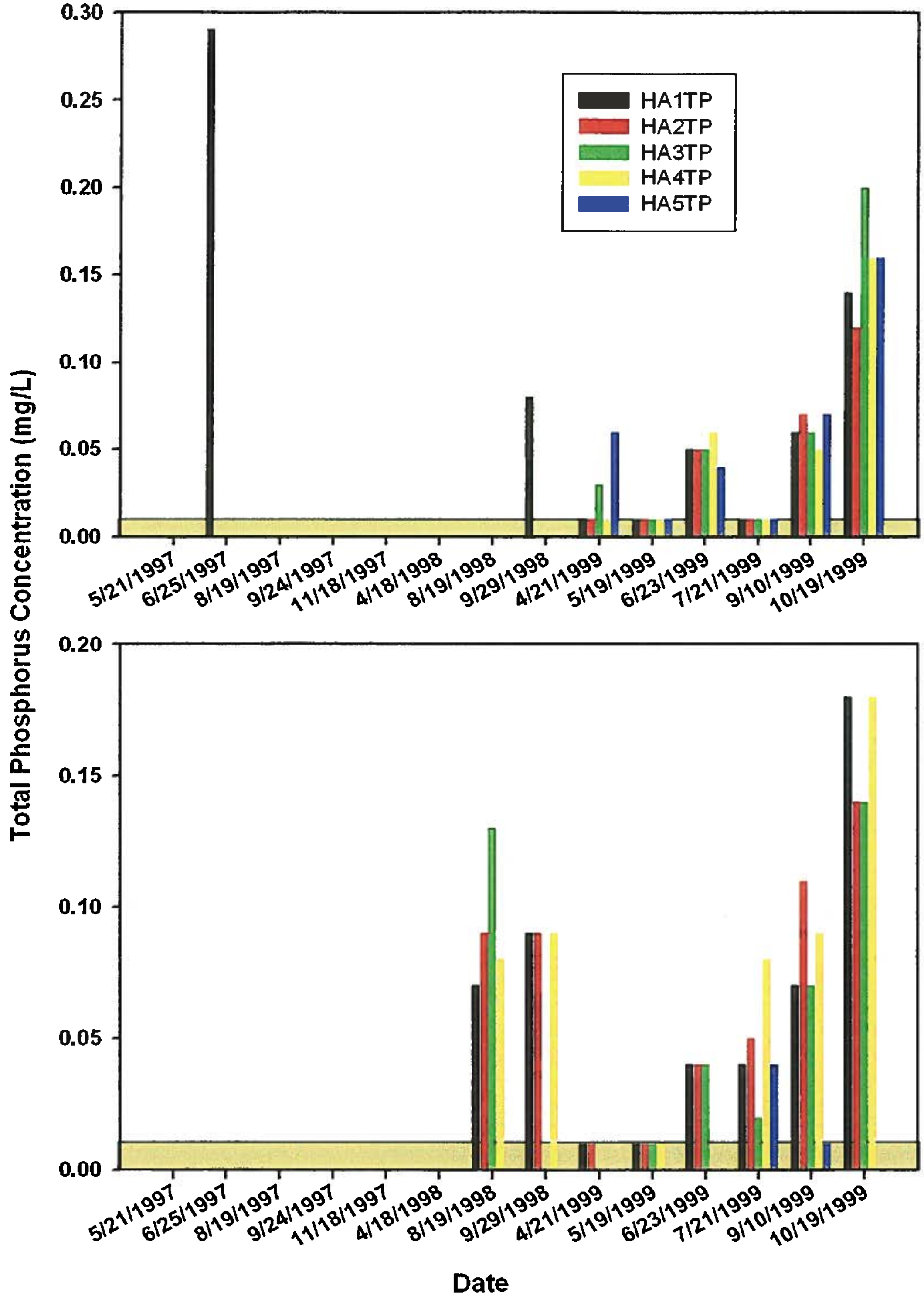
Nitrate-Nitrogen Concentration (mg/L)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
HA1N
HA2N
HA3N
HA4N
HA5N
Date

Figure 23 c.



0.08
0.06
0.04
0.02
0.00
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
Ortho-Phosphorus Concentration (mg/L)
HA1SRP
HA2SRP
HA3SRP
HA4SRP
HA5SRP
Date

Figure 23 d.



HA1TP
HA2TP
HA3TP
HA4TP
HA5TP
Total Phosphorus Concentration (mg/L)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
Date

Figure 24. Seasonal and spatial distribution of Chlorophyll a. in the Causway Arm of Hauser Reservoir 1999 and 2000.

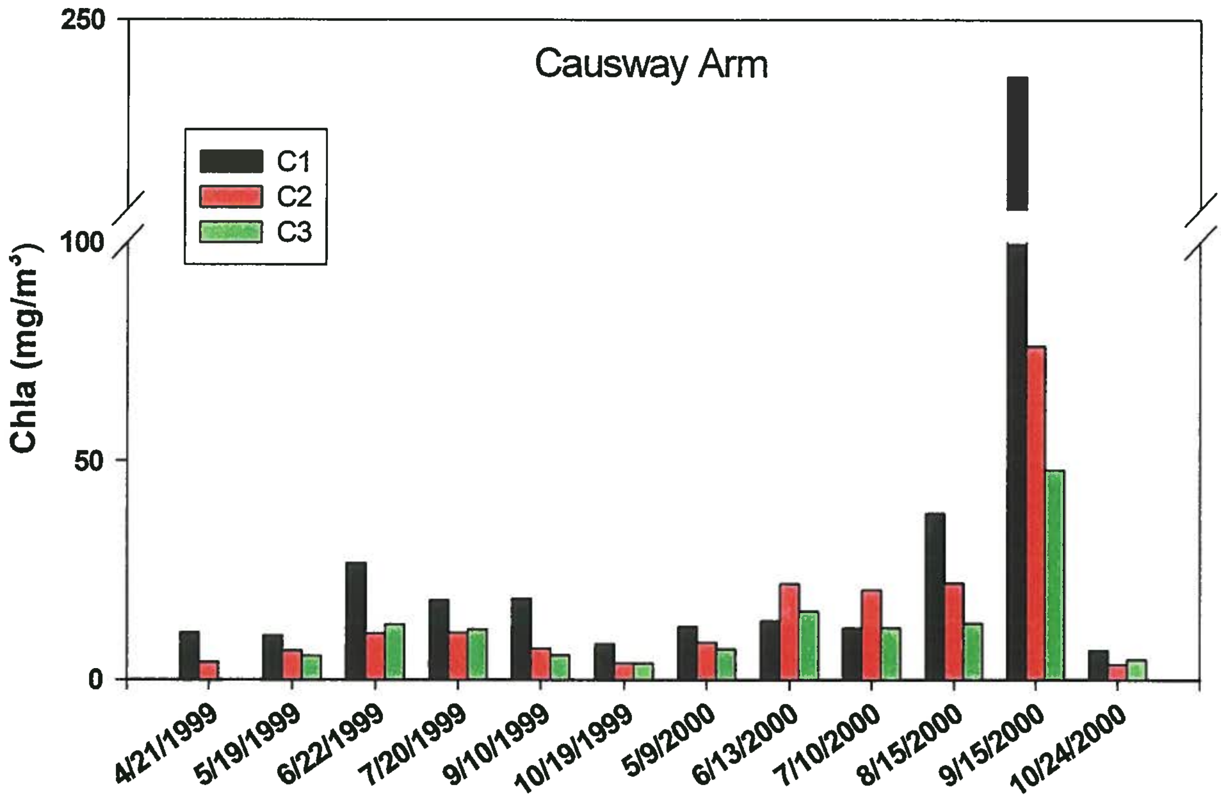


Figure 25. Spatial and seasonal distribution of phytoplankton groups and total cell density of the Causway Arm of Hauser for 1999.

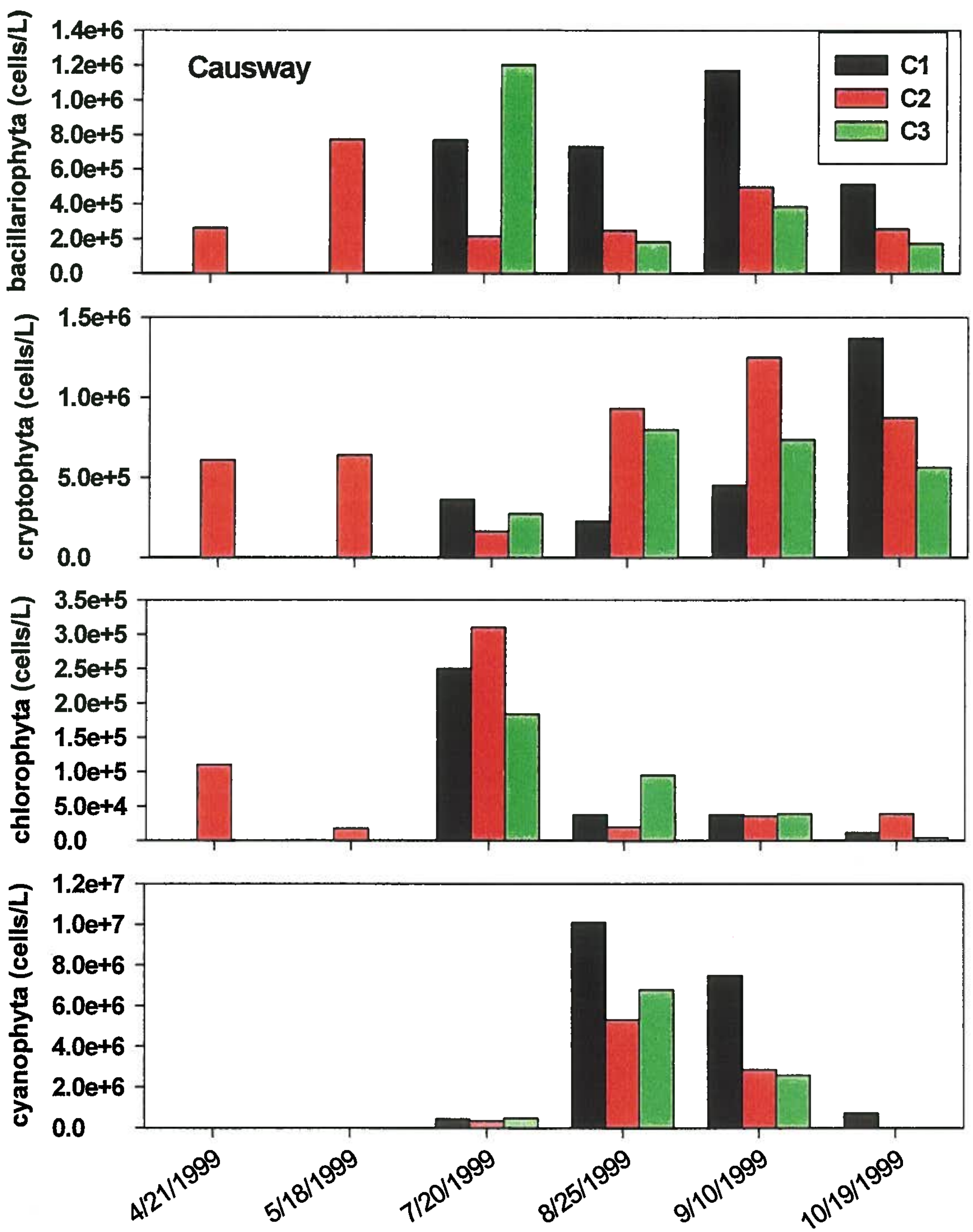


Figure 26. Seasonal and spatial distribution of major zooplankton groups in the Causway Arm of Hauser Reservoir 1999 and 2000.

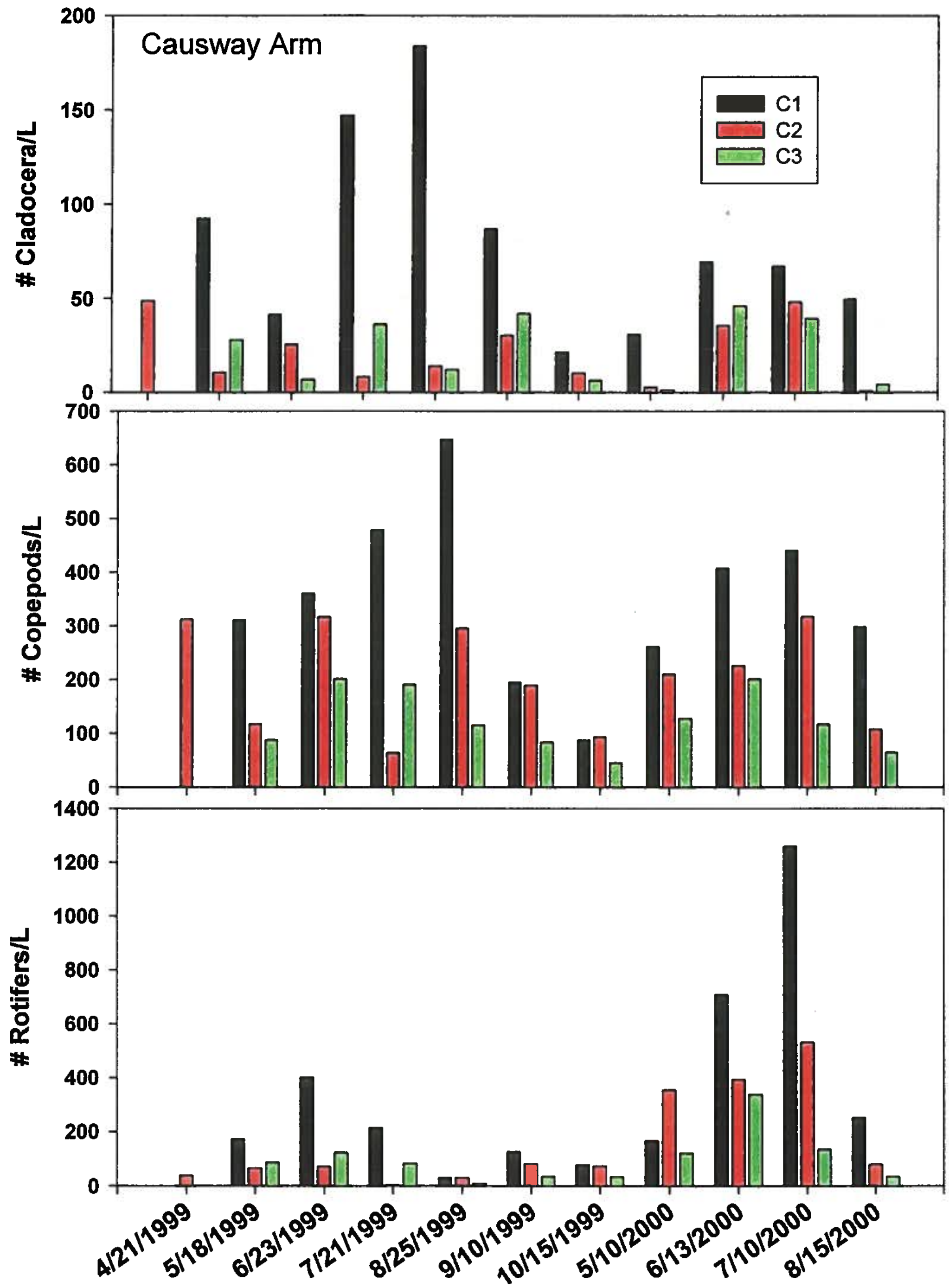


Figure 27. Longitudinal cross sections of Conductivity profiles for the Causway Arm, 1999.

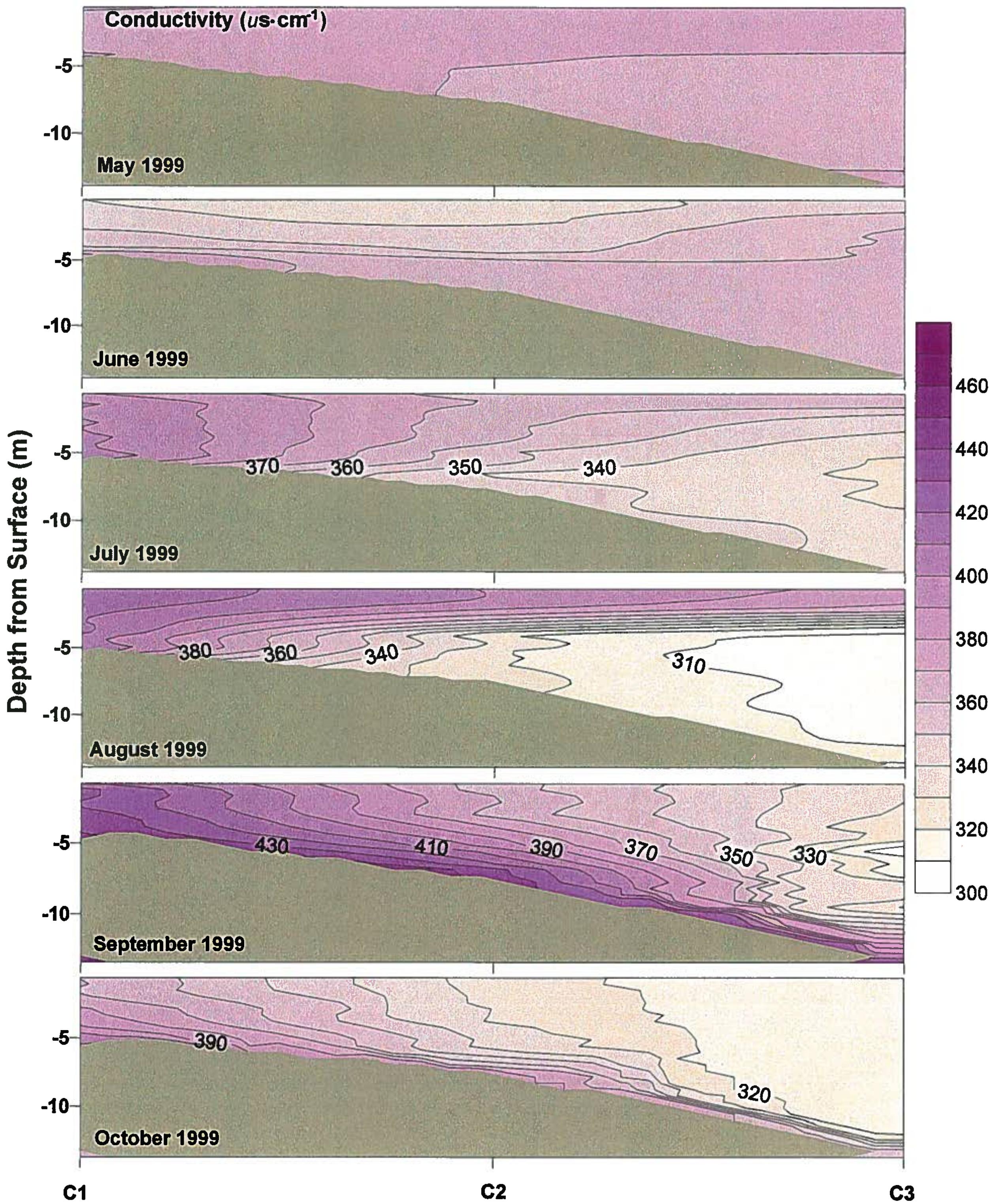


Figure 28. Longitudinal cross sections of conductivity profiles for the Causway Arm, 2000.

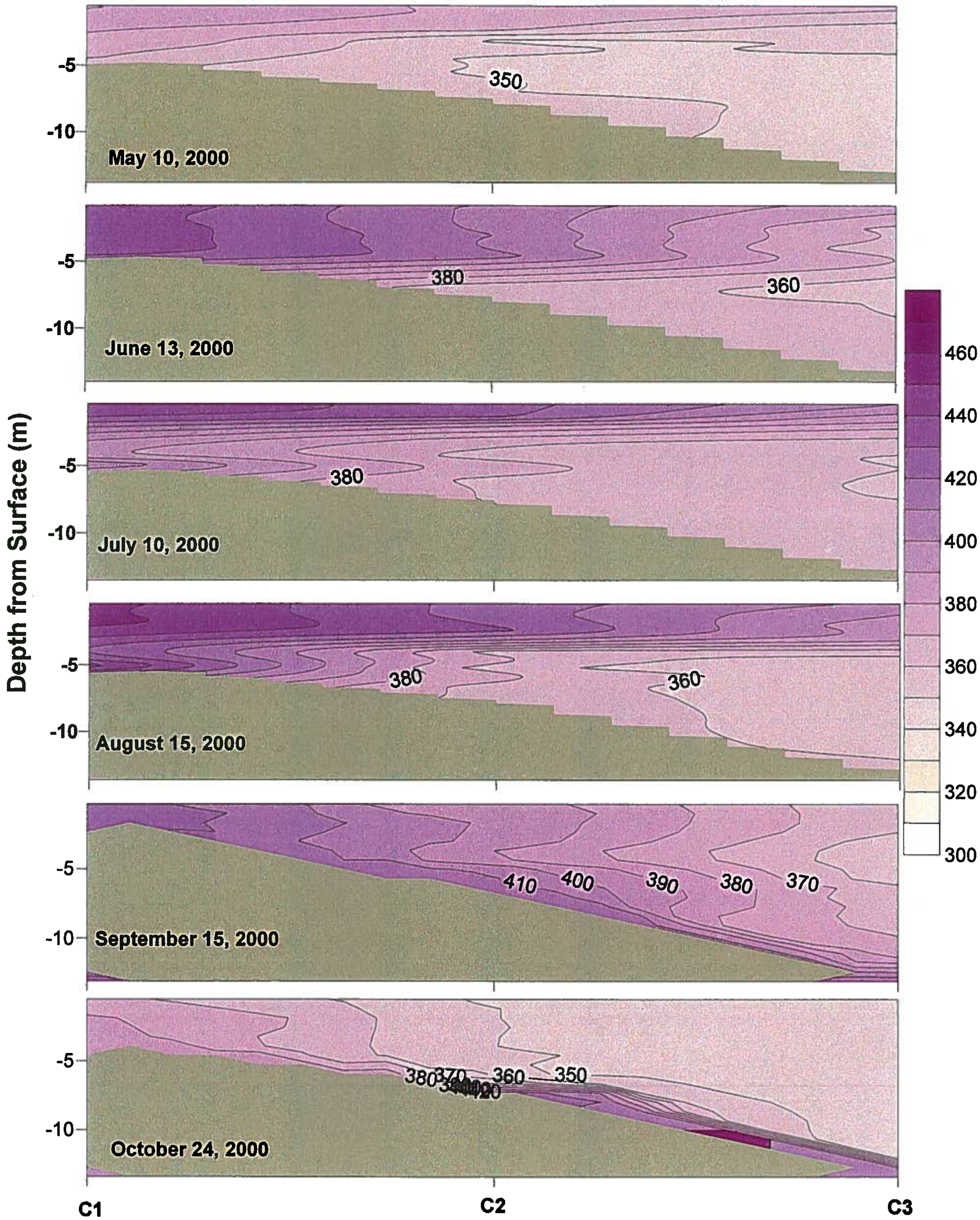


Figure 29. Longitudinal cross sections of temperature profiles for the Causway Arm, 1999.

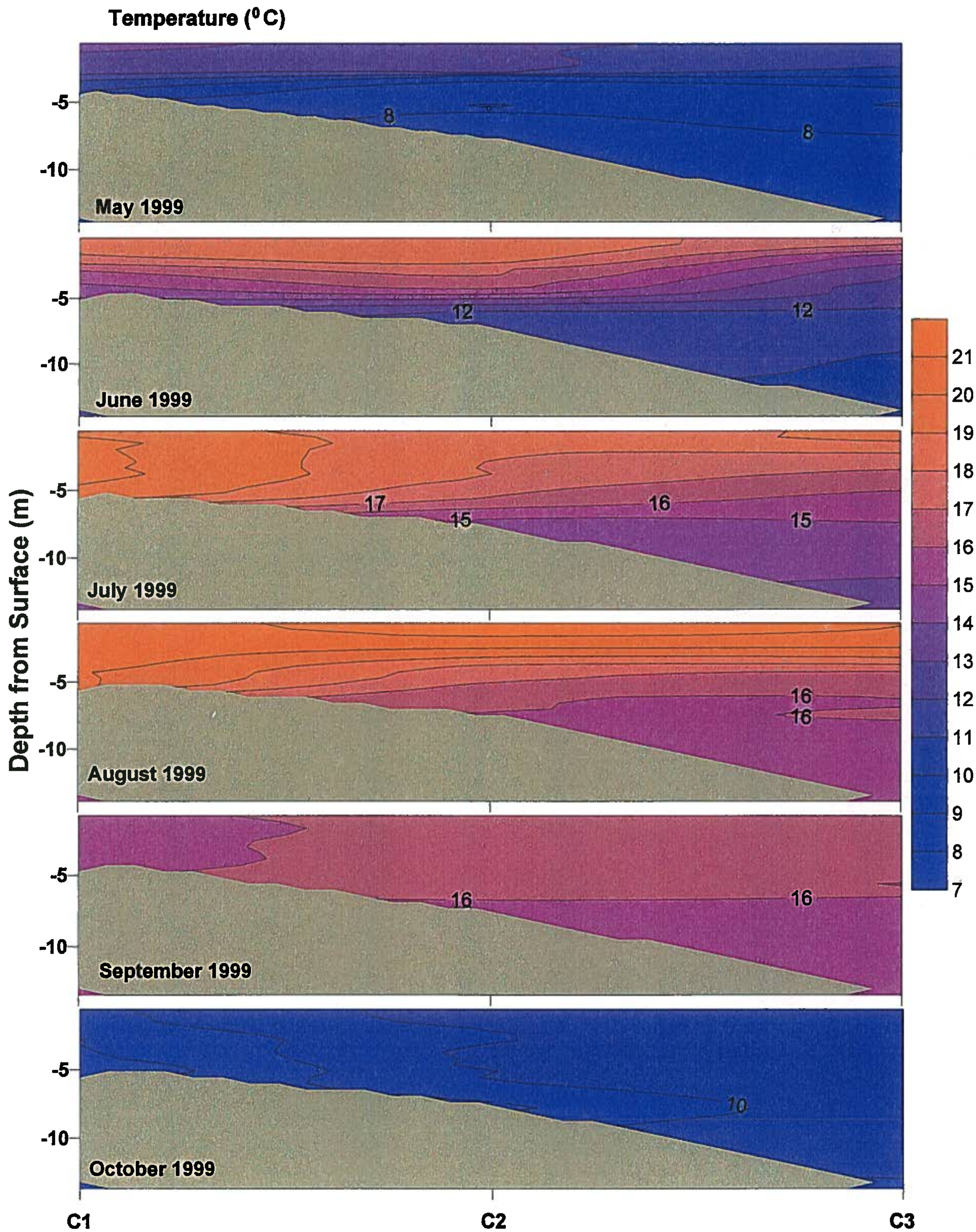


Figure 30. Longitudinal cross sections of temperature profiles for the Causway Arm, 2000.

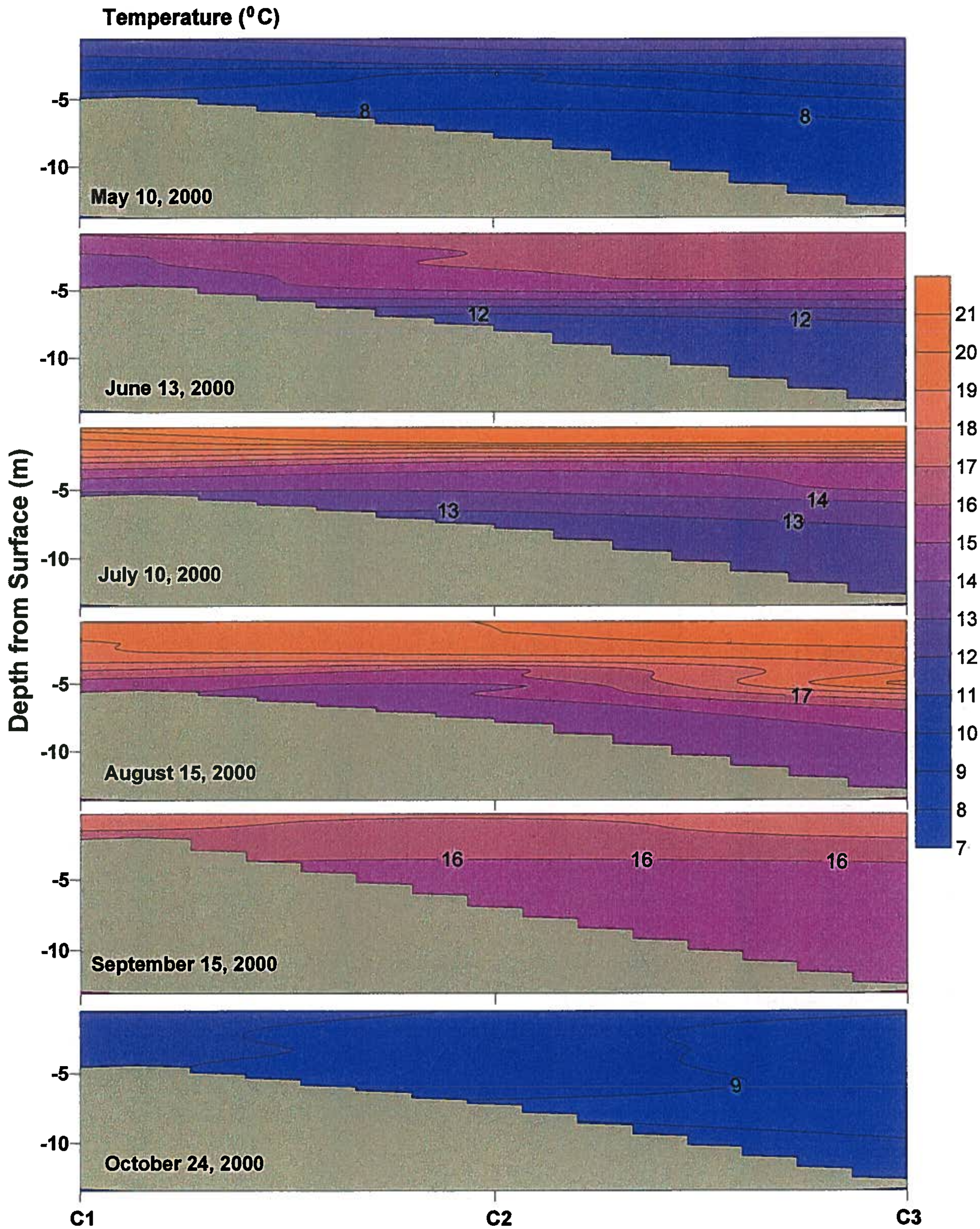


Figure 31. Longitudinal cross sections of dissolves oxygen concentration profiles for the Causway Arm, 1999.

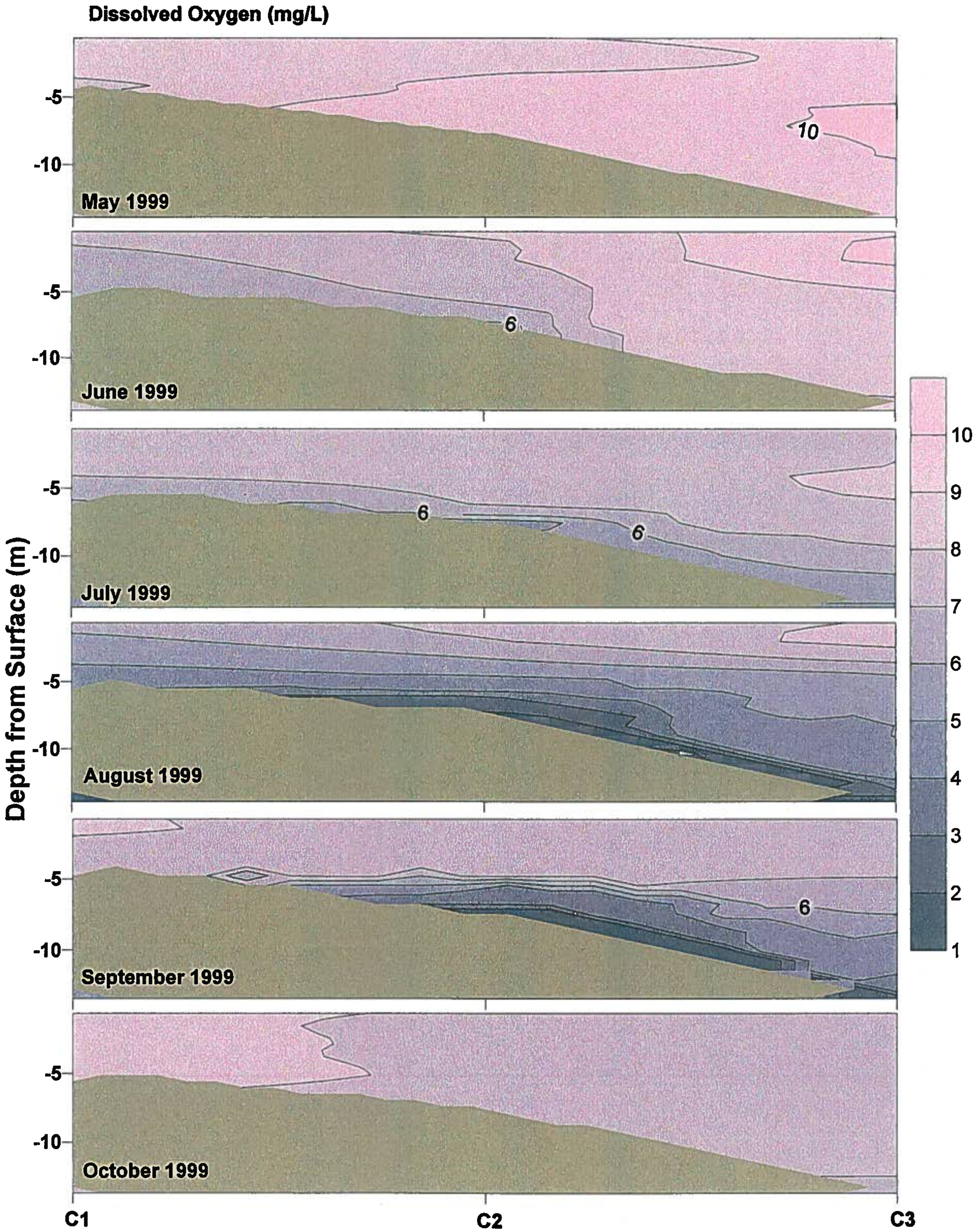


Figure 32. Longitudinal cross sections of dissolves oxygen concentration profiles for the Causway Arm, 2000.

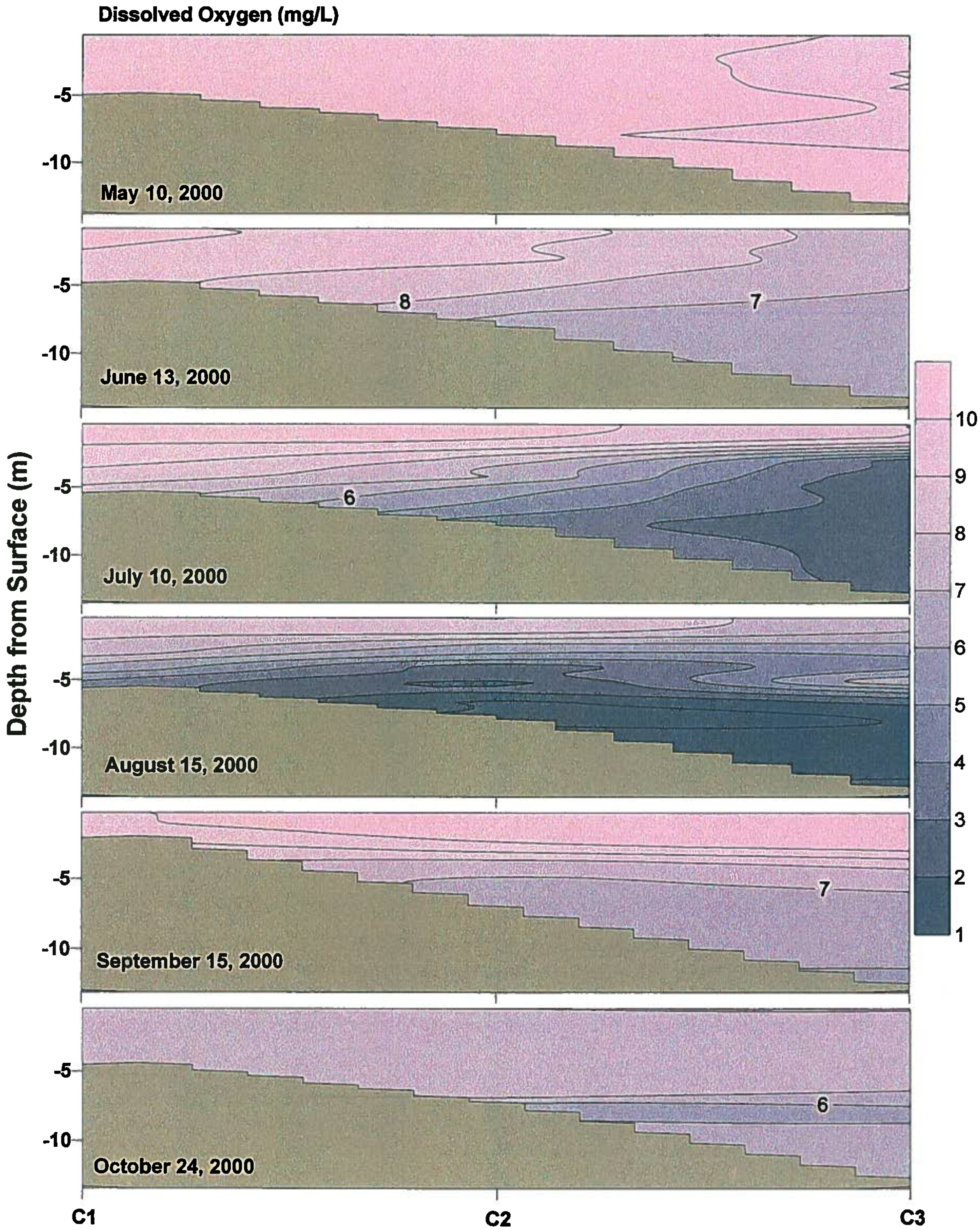


Figure 33. Longitudinal cross sections of dissolves oxygen saturation profiles for the Causway Arm, 1999.

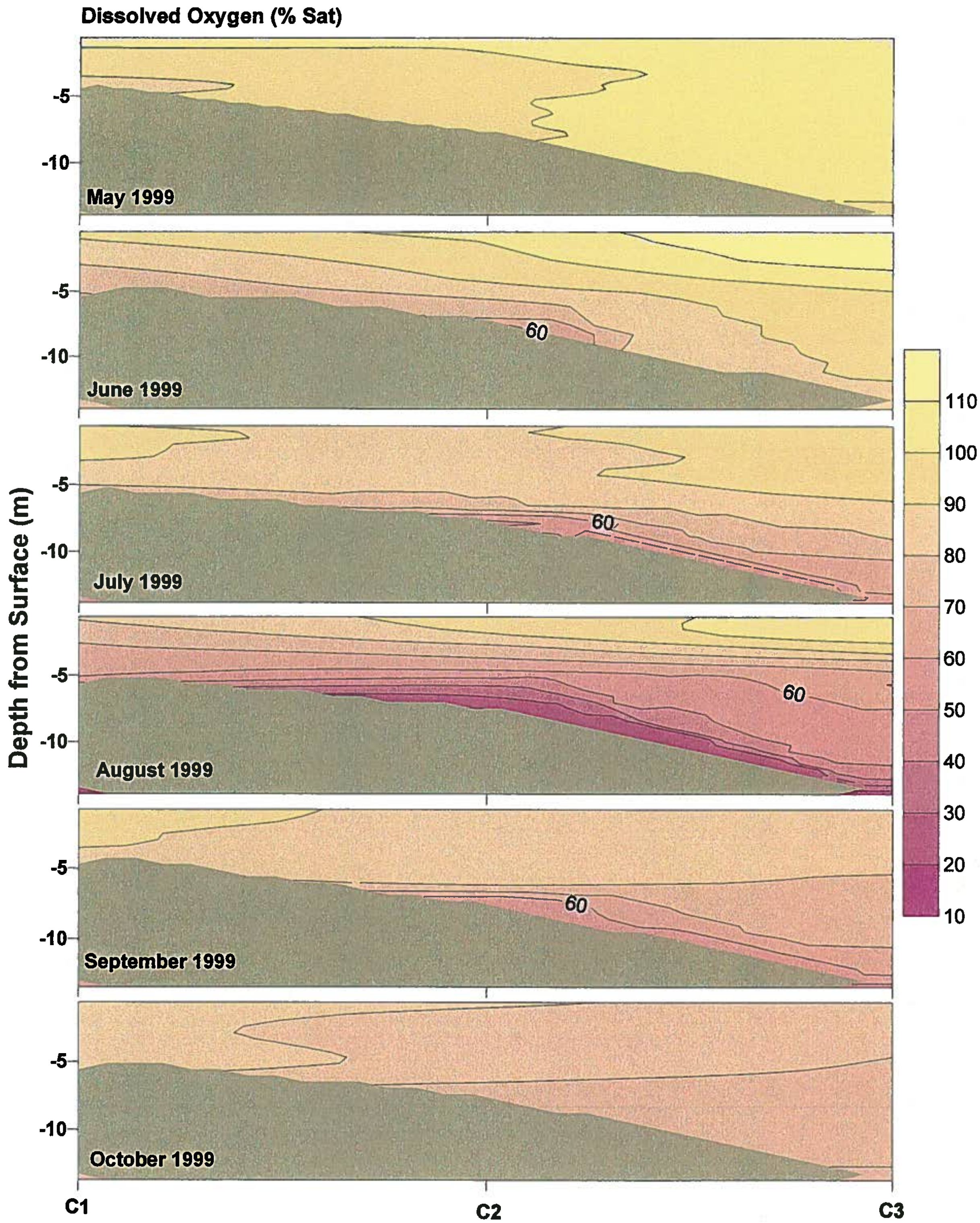


Figure 34. Longitudinal cross sections of dissolves oxygen saturation profiles for the Causway Arm, 2000.

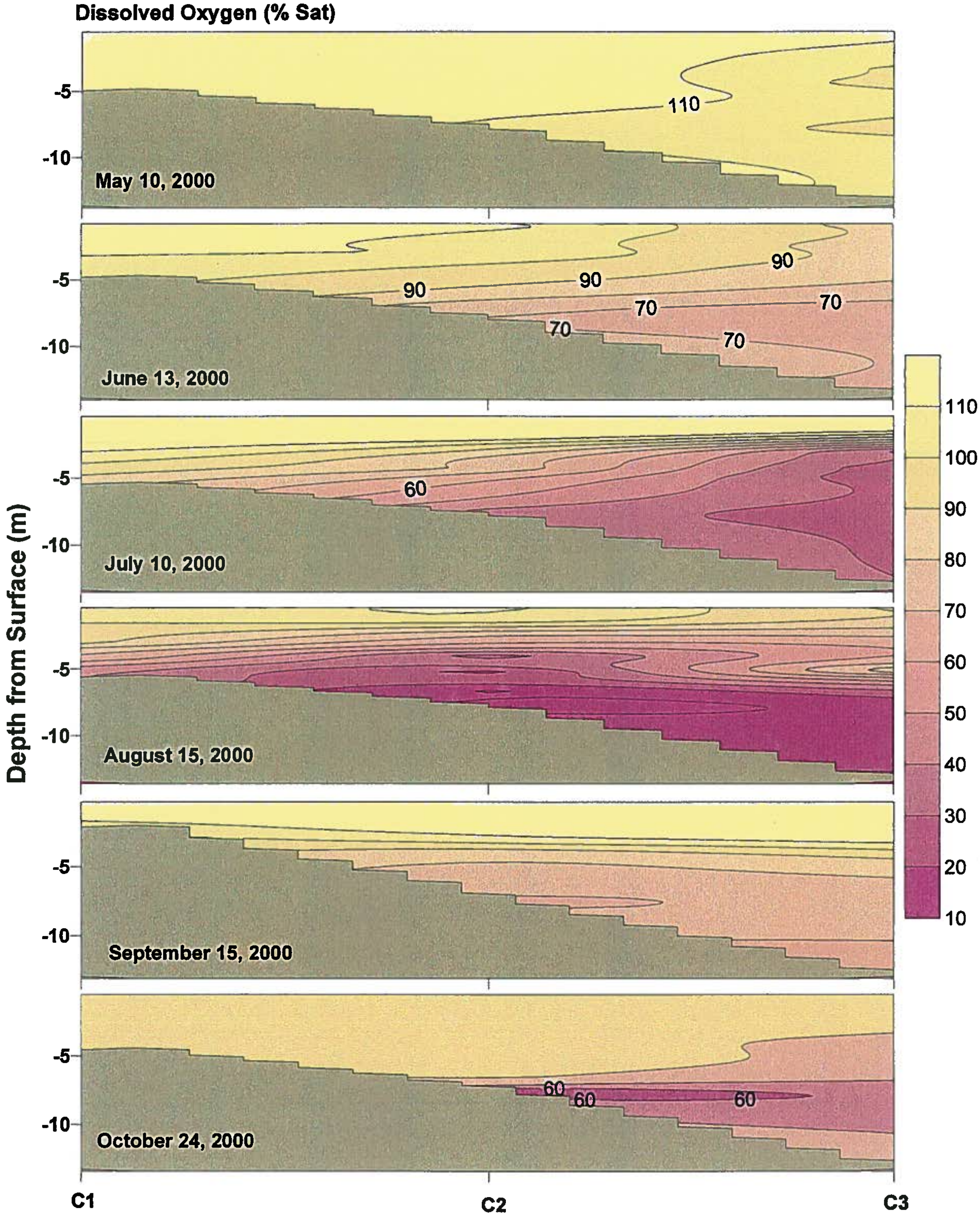


Figure 35 a,b,c,d. Ammonia, Nitrate, Ortho-phosphorus, and Total Phosphorus concentration in epilimnetic (top panel), and hypolimnetic waters for Canyon Ferry. Yellow bar represents detection limits.

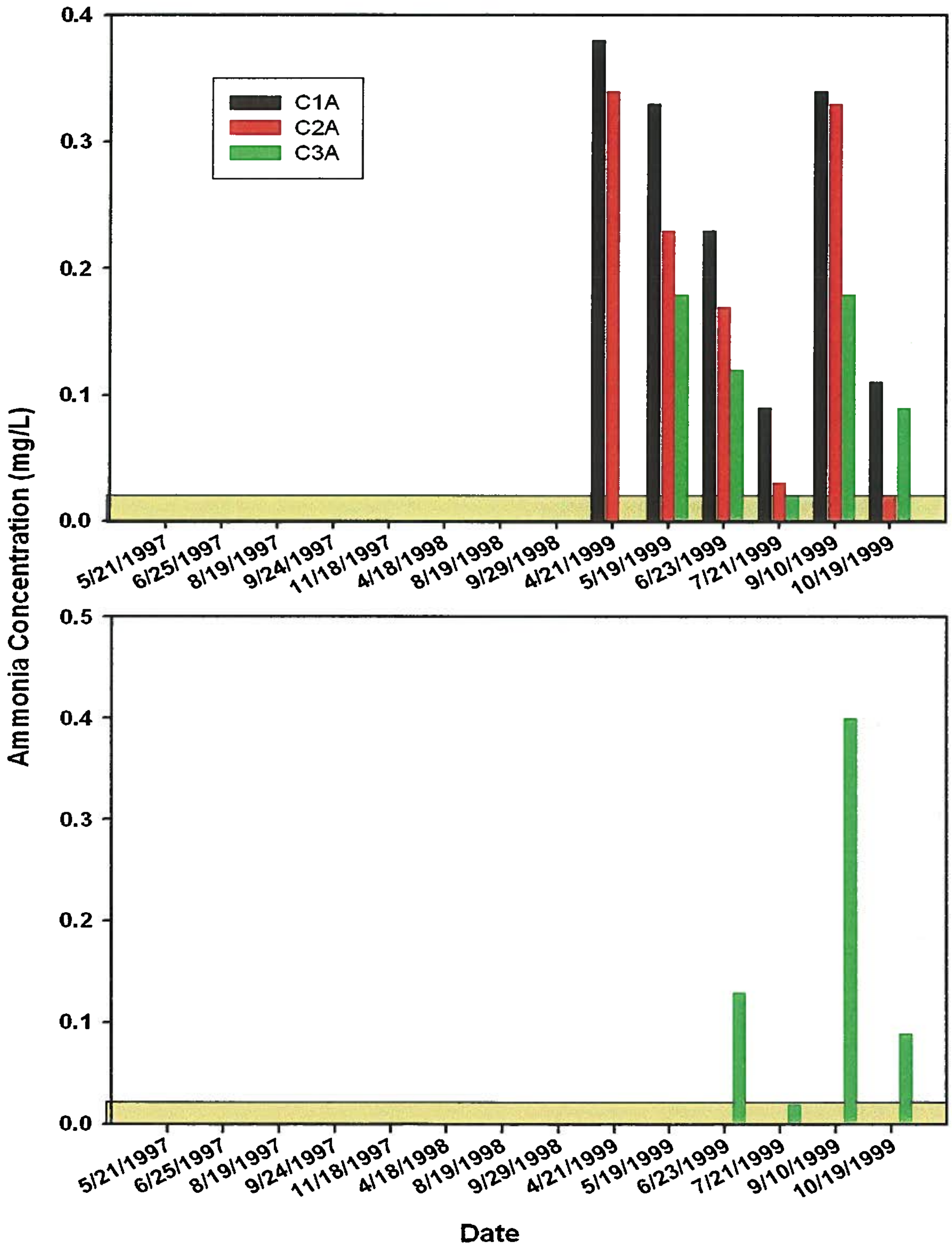


Figure 36 b..

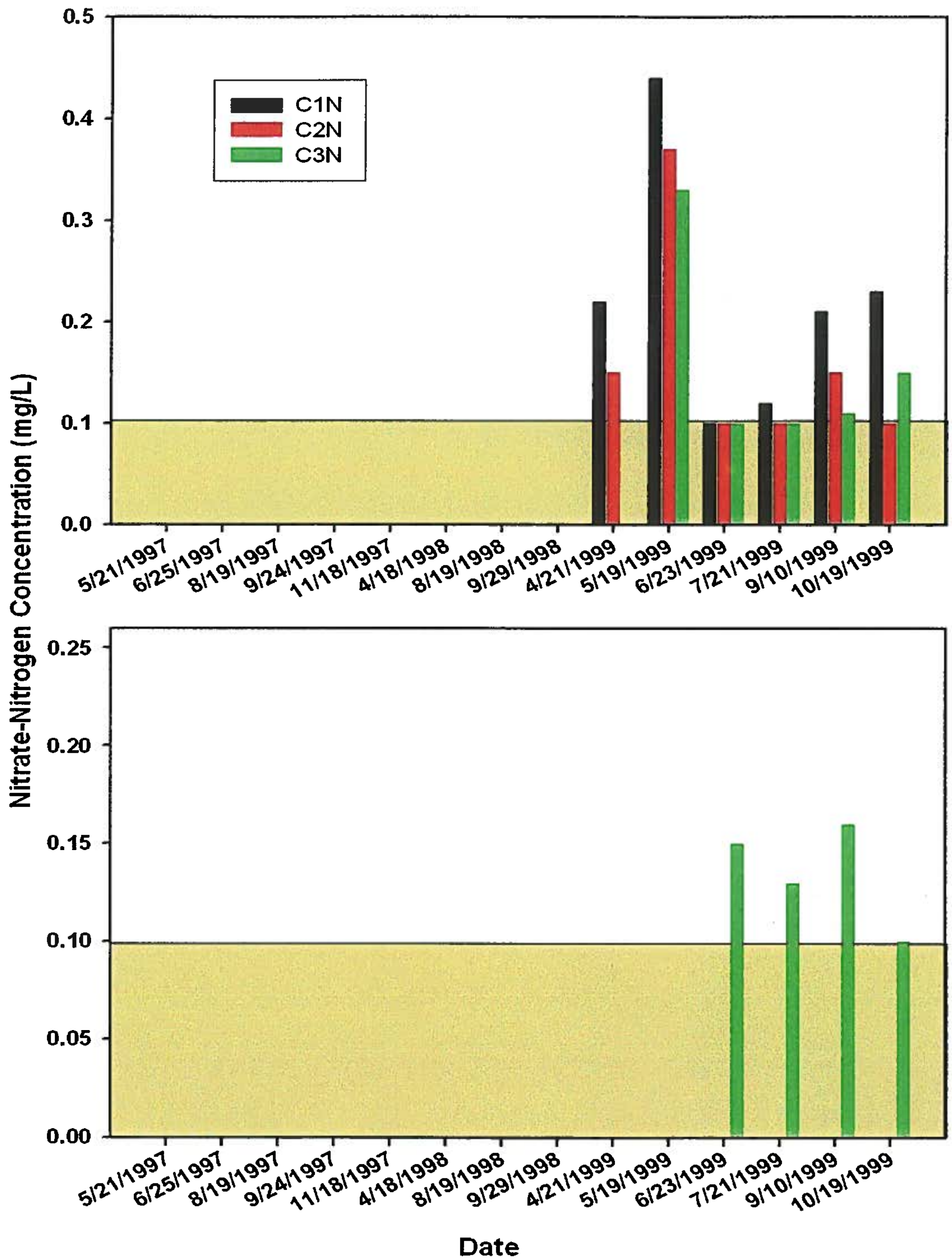

C1N
C2N
C3N
Nitrate-Nitrogen Concentration (mg/L)
0.5
0.4
0.3
0.2
0.1
0.0
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
0.25
0.20
0.15
0.10
0.05
0.00
Date

Figure 36 c..

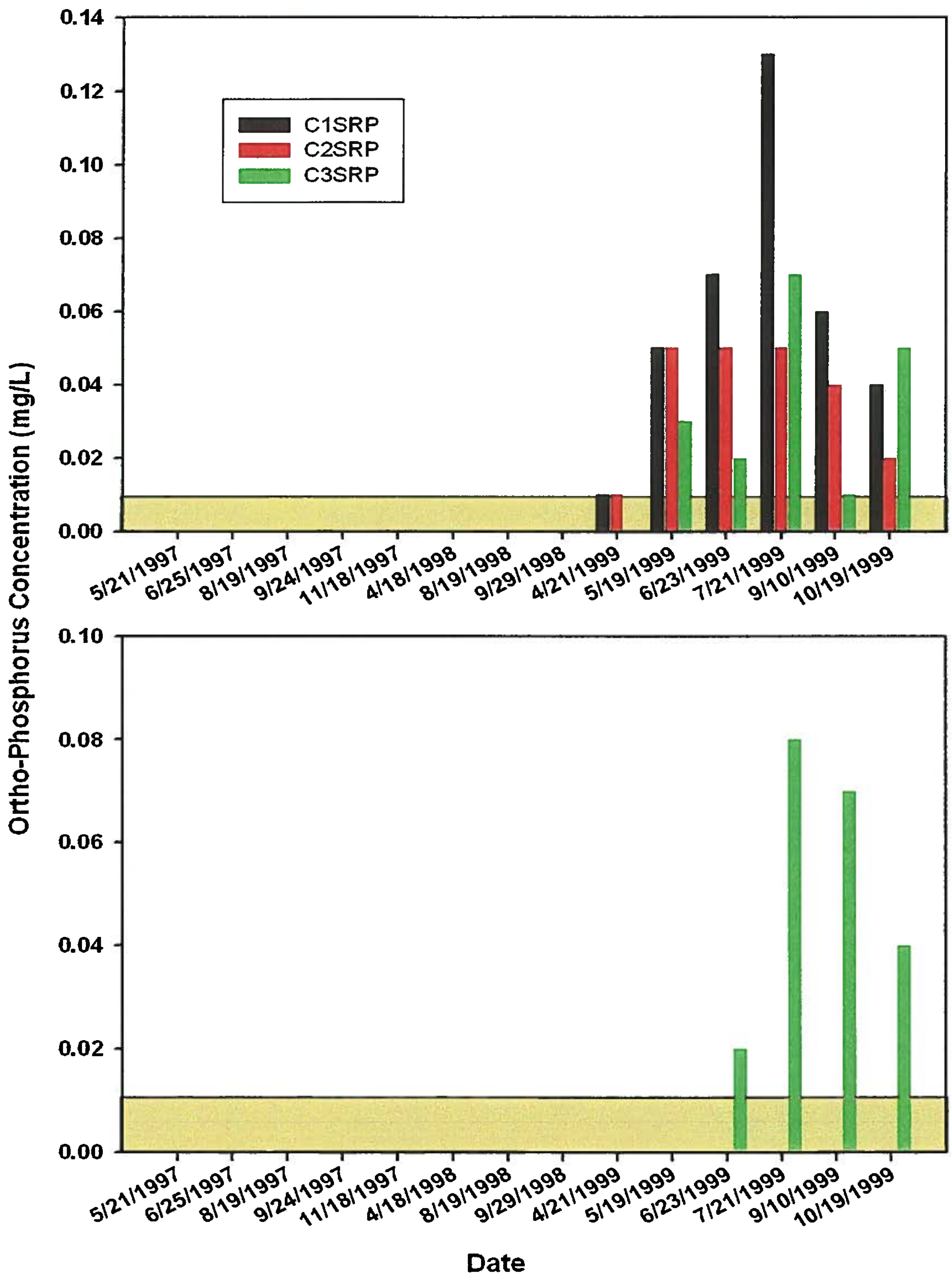

Ortho-Phosphorus Concentration (mg/L)
C1SRP
C2SRP
C3SRP
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
Date

Figure 36 d..

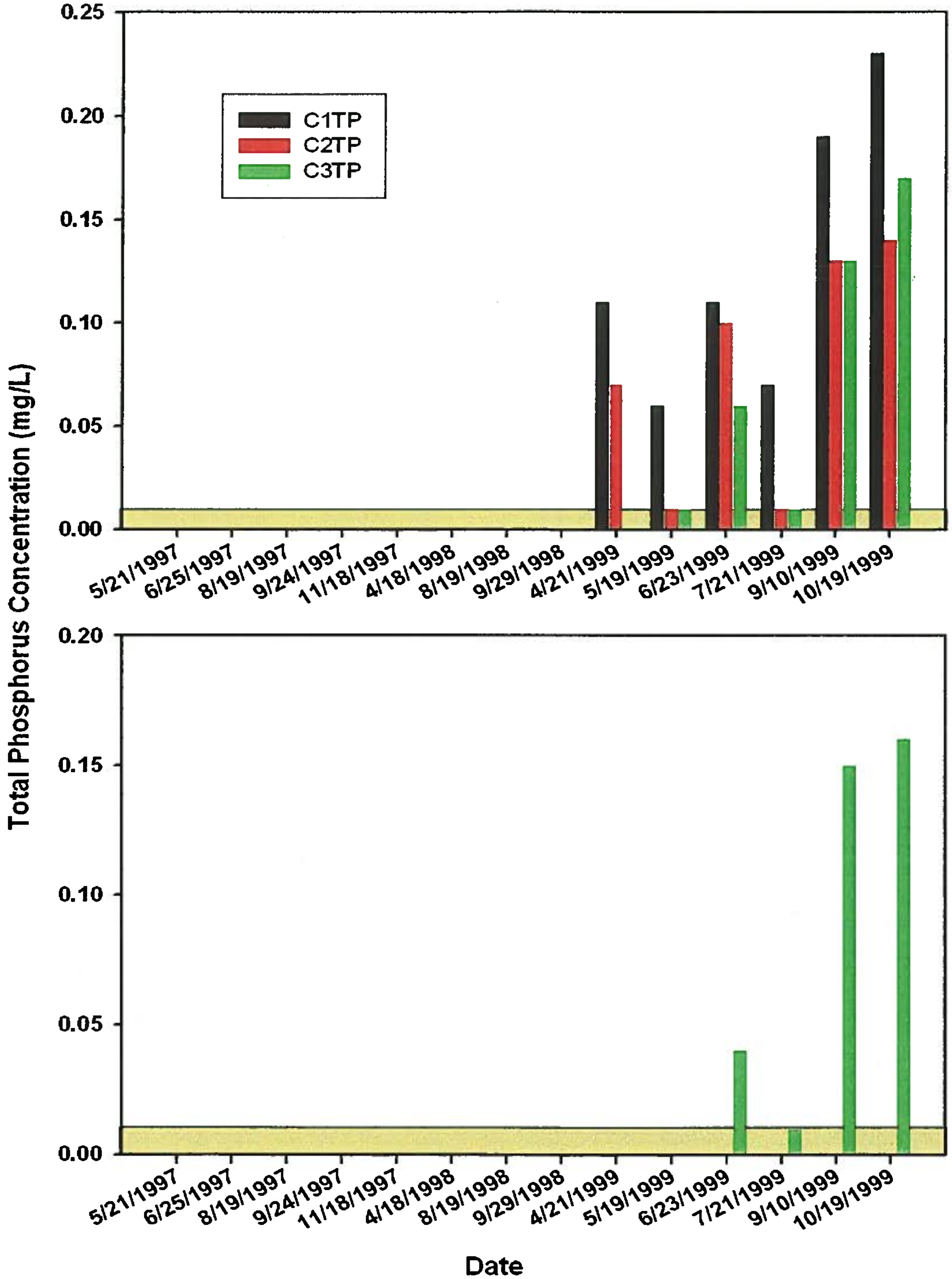

C1TP
C2TP
C3TP
Total Phosphorus Concentration (mg/L)
0.25
0.20
0.15
0.10
0.05
0.00
5/21/1997
6/25/1997
8/19/1997
9/24/1997
11/18/1997
4/18/1998
8/19/1998
9/29/1998
4/21/1999
5/19/1999
6/23/1999
7/21/1999
9/10/1999
10/19/1999
Date

Figure 36. Spatial distribution of fish detected hydro acoustically in Hauser Reservoir June 1999. Fish are overlaid over dissolved oxygen (mg/L) measured in surface waters. Pink dots represent fish greater than 22cm in length, black dots those less than 22cm.

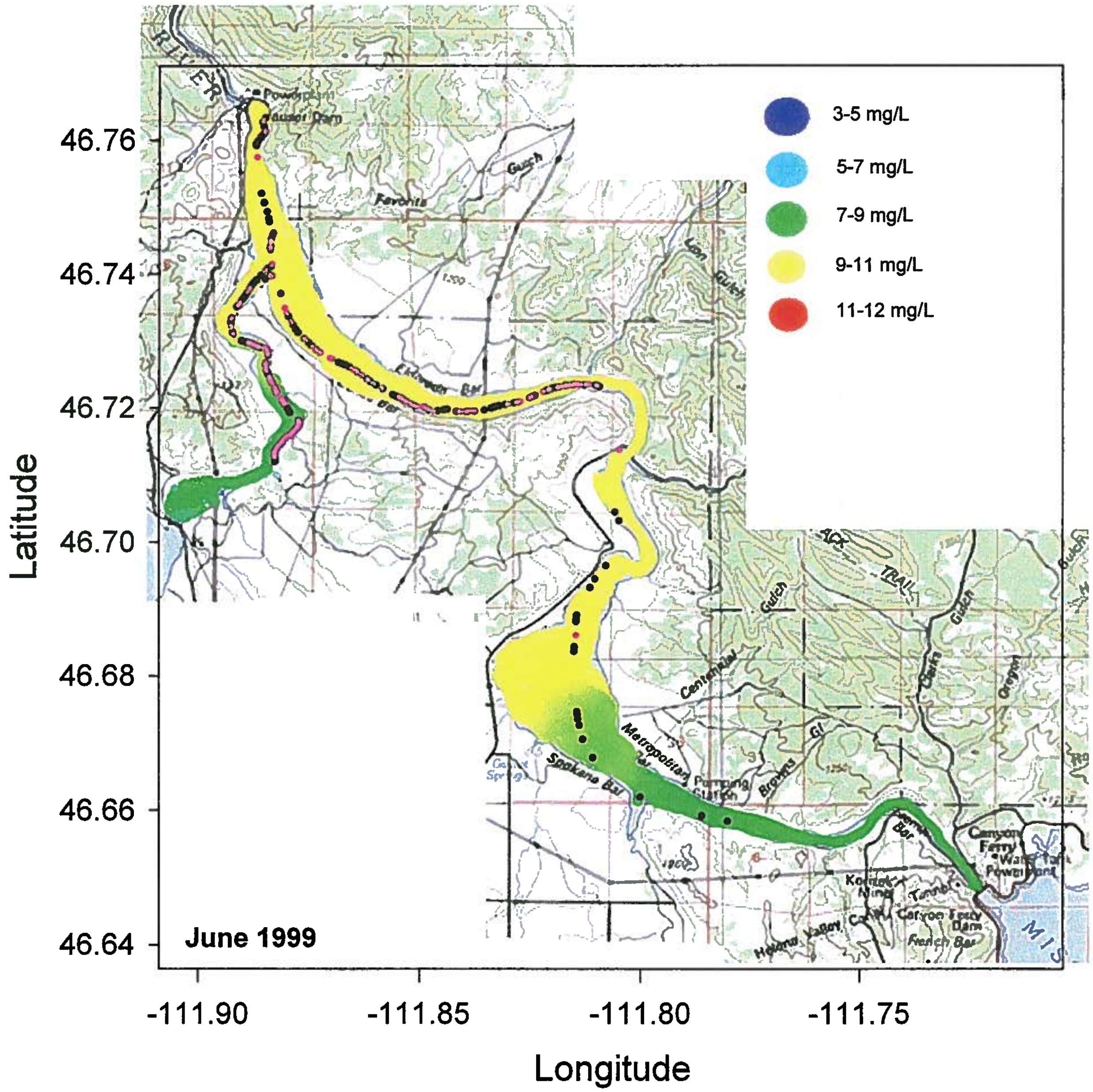


Figure 37. Spatial distribution of fish detected hydro acoustically in Hauser Reservoir July 1999. Fish are overlaid over dissolved oxygen (mg/L) measured in surface waters. Pink dots represent fish greater than 22cm in length, black dots those less than 22cm.

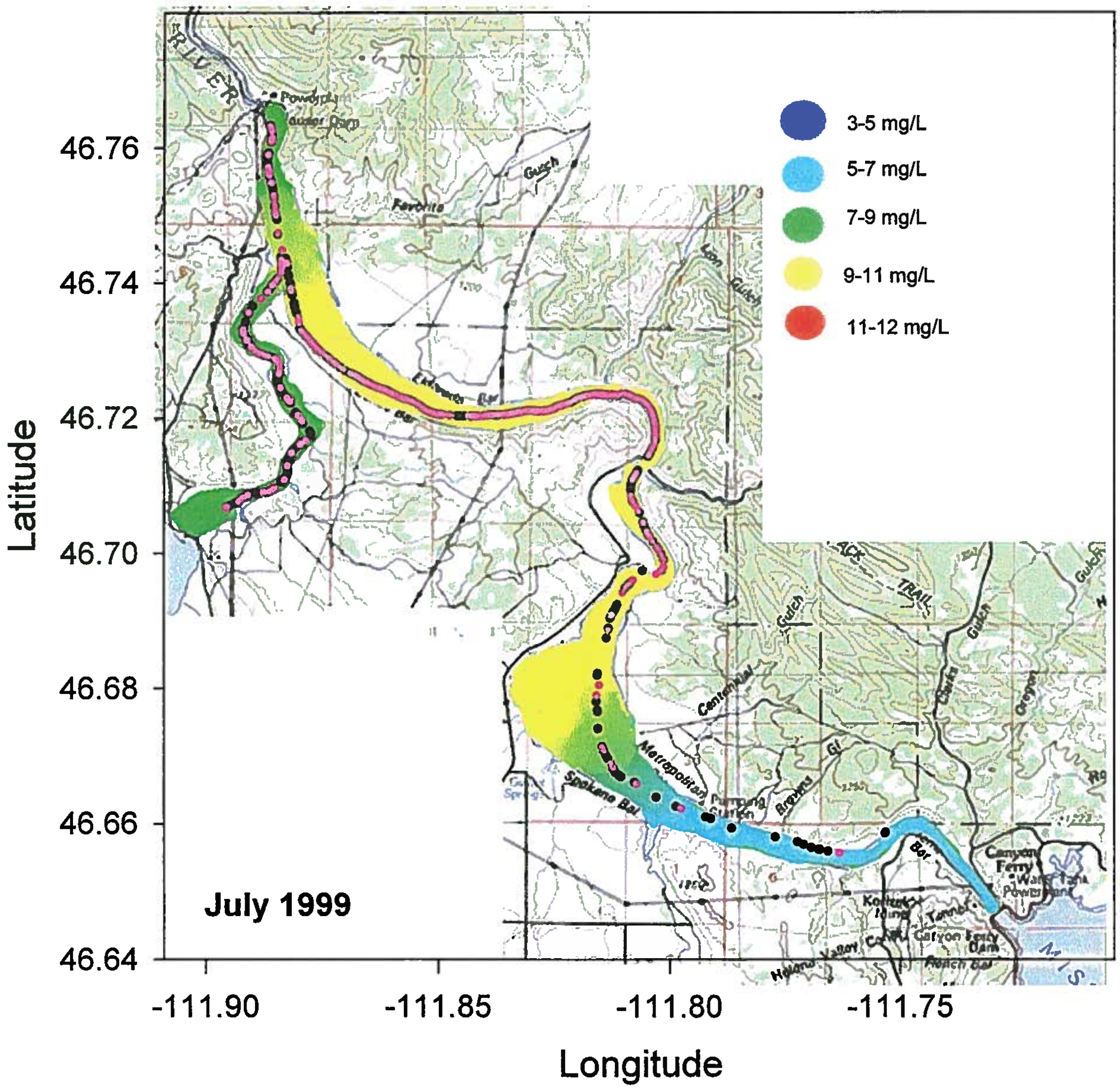


Figure 38. Spatial distribution of fish detected hydro acoustically in Hauser Reservoir August 1999. Fish are overlaid over dissolved oxygen (mg/L) measured in surface waters. Pink dots represent fish greater than 22cm in length, black dots those less than 22cm.

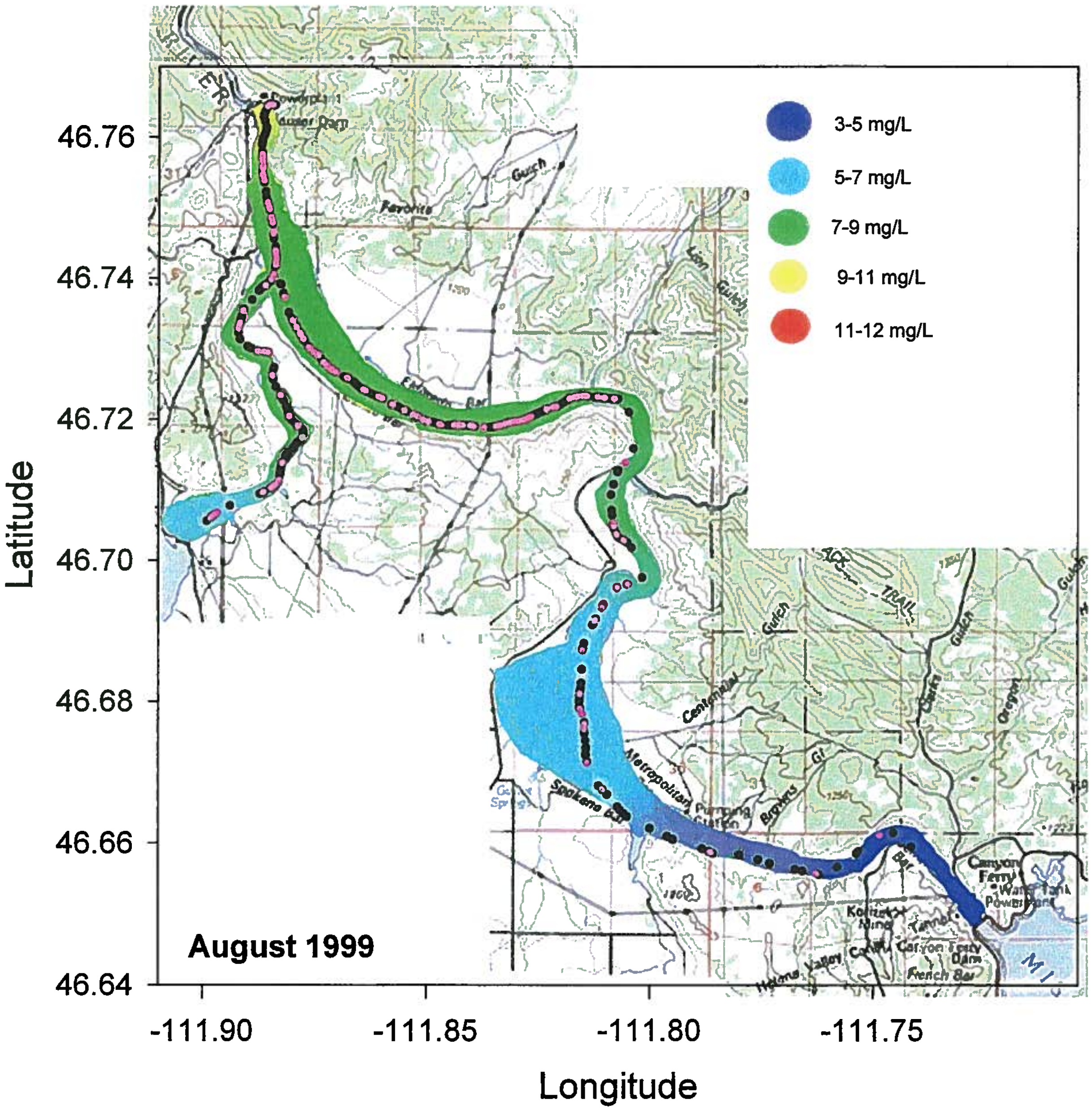


Figure 39. Spatial distribution of fish detected hydro acoustically in Hauser Reservoir September 1999. Fish are overlaid over dissolved oxygen (mg/L) measured in surface waters. Pink dots represent fish greater than 22cm in length, black dots those less than 22cm.

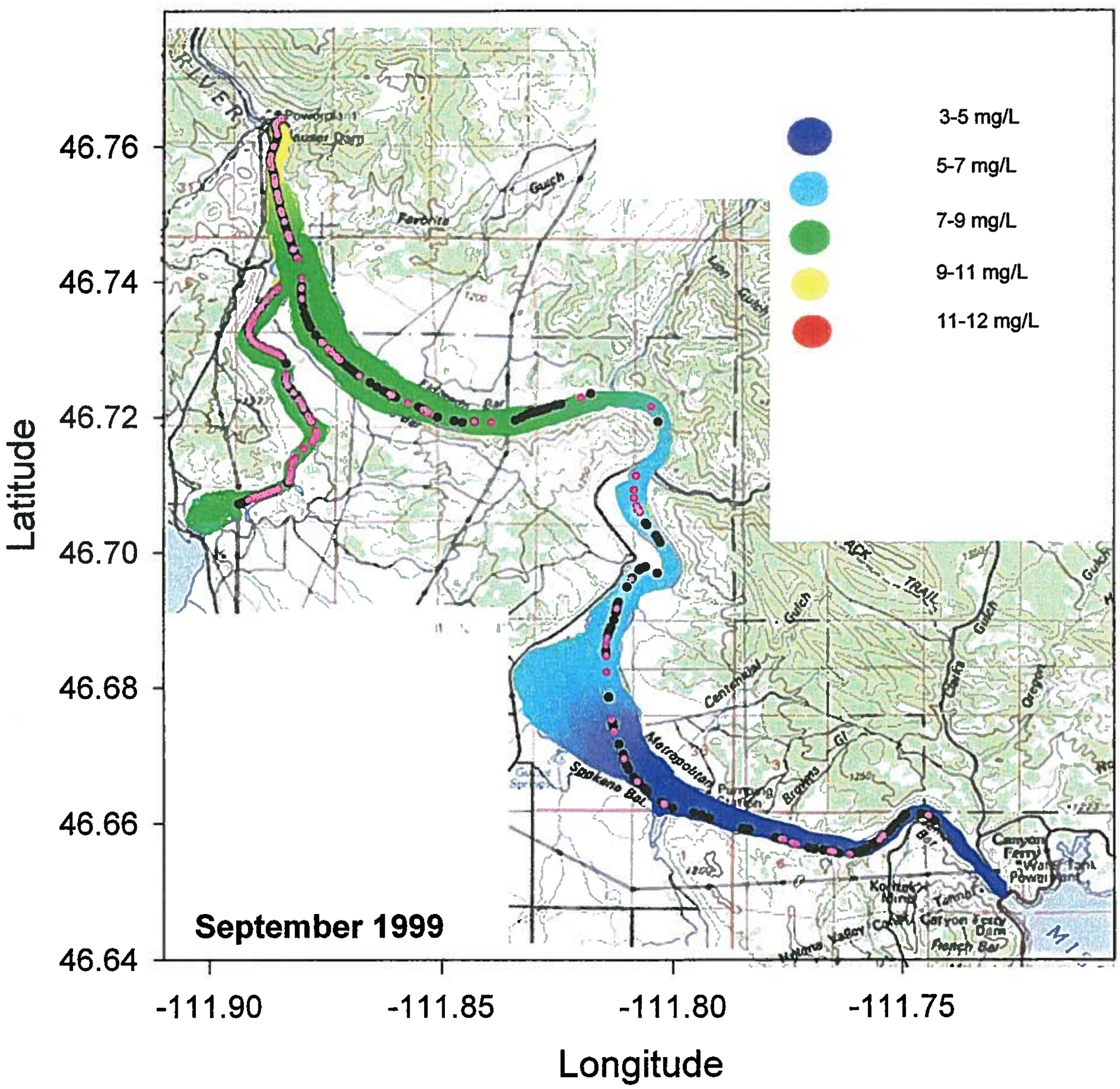


Figure 40. Spatial distribution of fish detected hydro acoustically in Hauser Reservoir October 1999. Fish are overlaid over dissolved oxygen (mg/L) measured in surface waters. Pink dots represent fish greater than 22cm in length, black dots those less than 22cm.

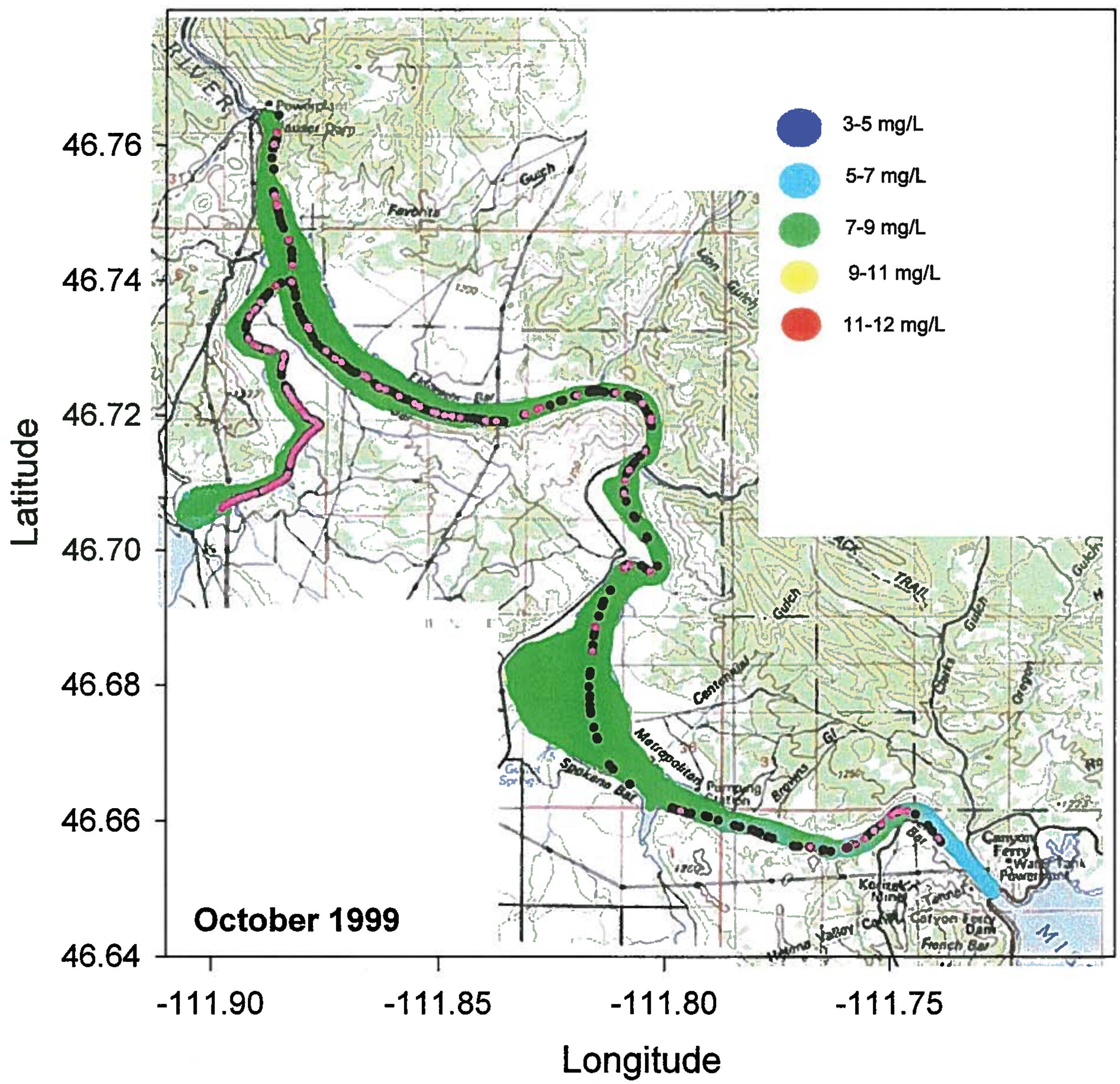


Figure 41. Spatial distribution of fish detected hydro acoustically in Hauser Reservoir May 2000. Fish are overlaid over dissolved oxygen (mg/L) measured in surface waters. Pink dots represent fish greater than 22cm in length, black dots those less than 22cm.

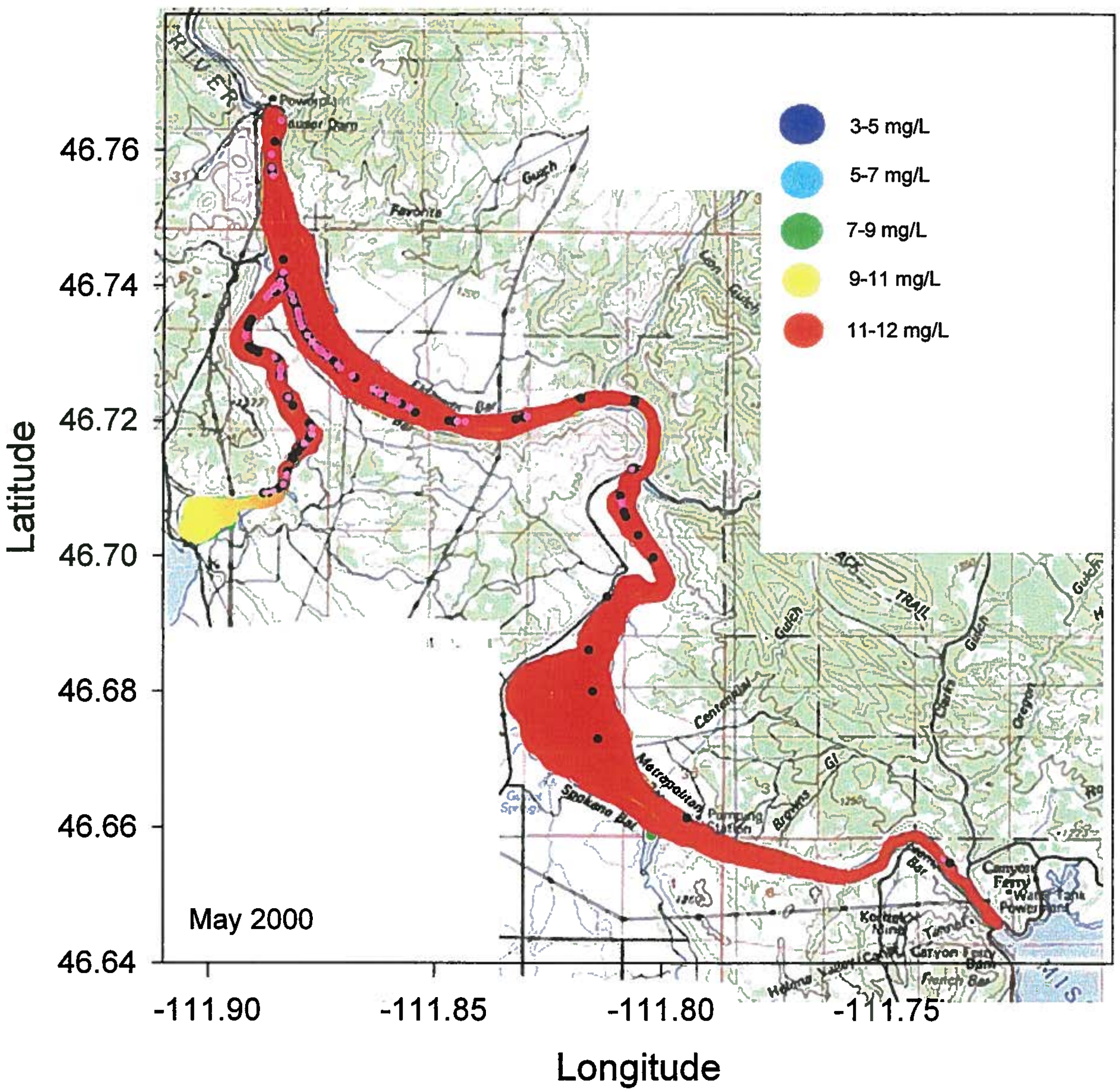


Figure 42. Spatial distribution of fish detected hydro acoustically in Hauser Reservoir July 2000. Fish are overlaid over dissolved oxygen (mg/L) measured in surface waters. Pink dots represent fish greater than 22cm in length, black dots those less than 22cm.

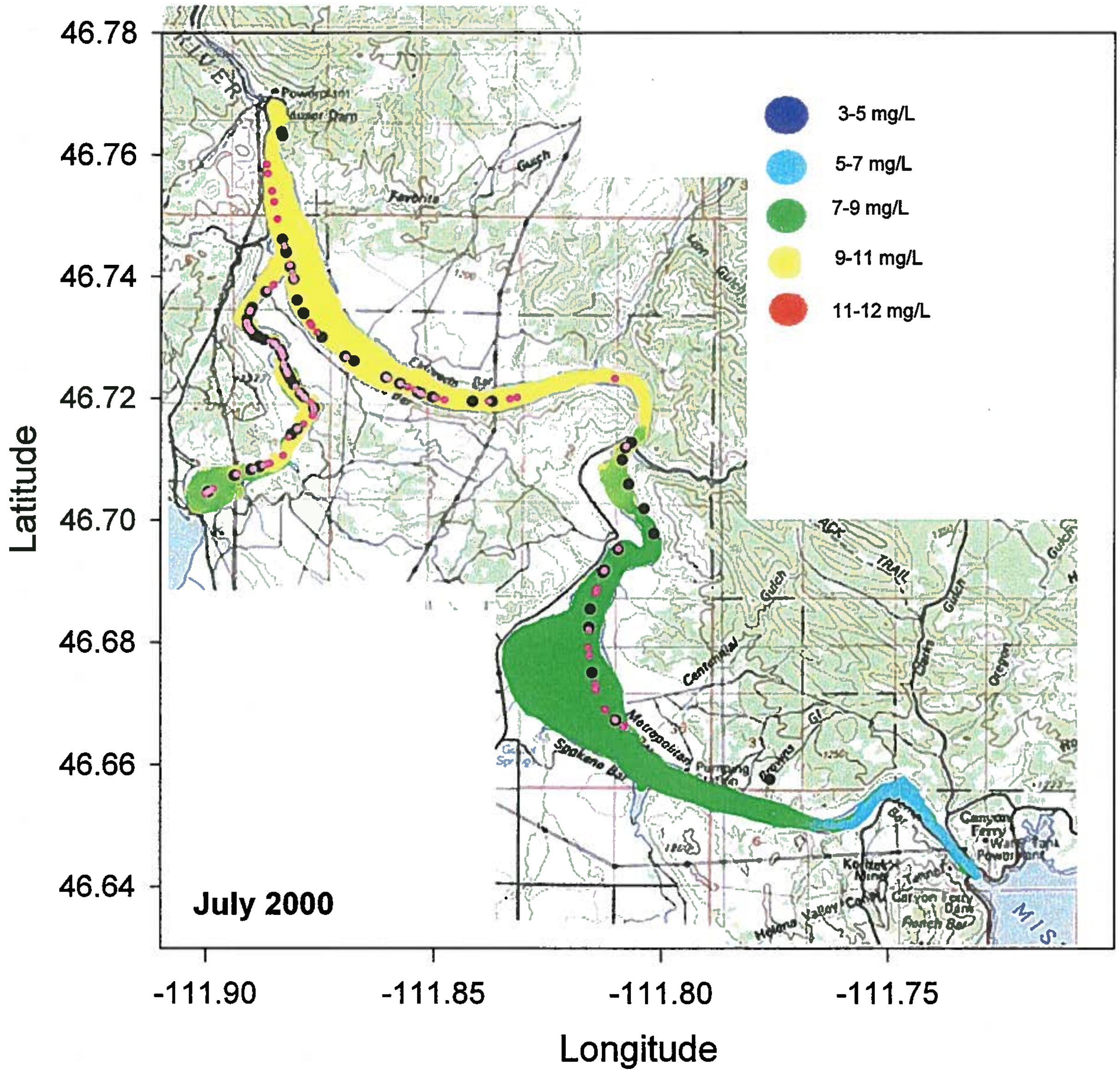


Figure 43. Spatial distribution of fish detected hydro acoustically in Hauser Reservoir September 2000. Fish are overlaid over dissolved oxygen (mg/L) measured in surface waters. Pink dots represent fish greater than 22cm in length, black dots those less than 22cm.

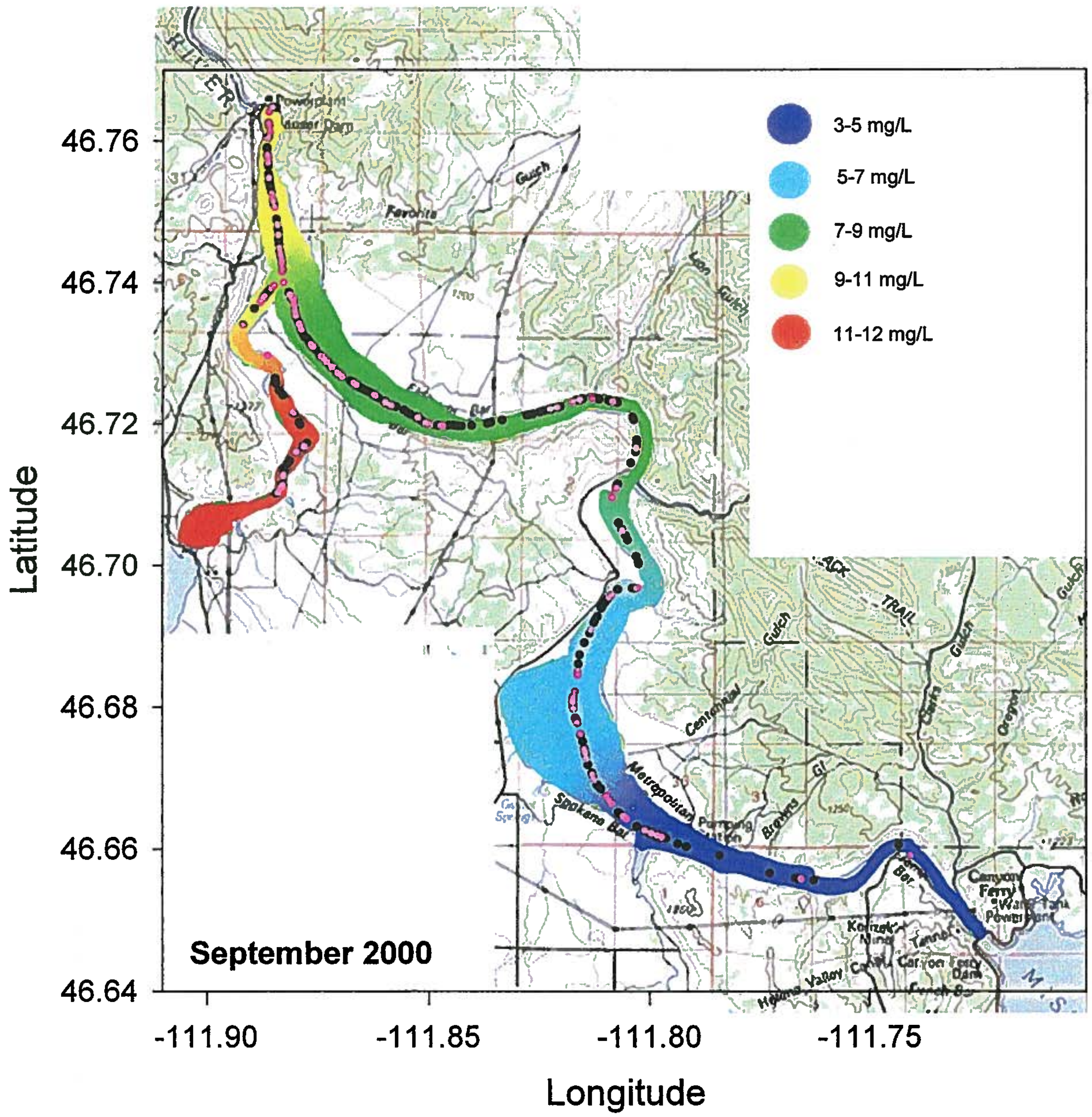


Figure 44. Spatial distribution of fish detected hydro acoustically in Hauser Reservoir October 2000. Fish are overlaid over dissolved oxygen (mg/L) measured in surface waters. Pink dots represent fish greater than 22cm in length, black dots those less than 22cm.

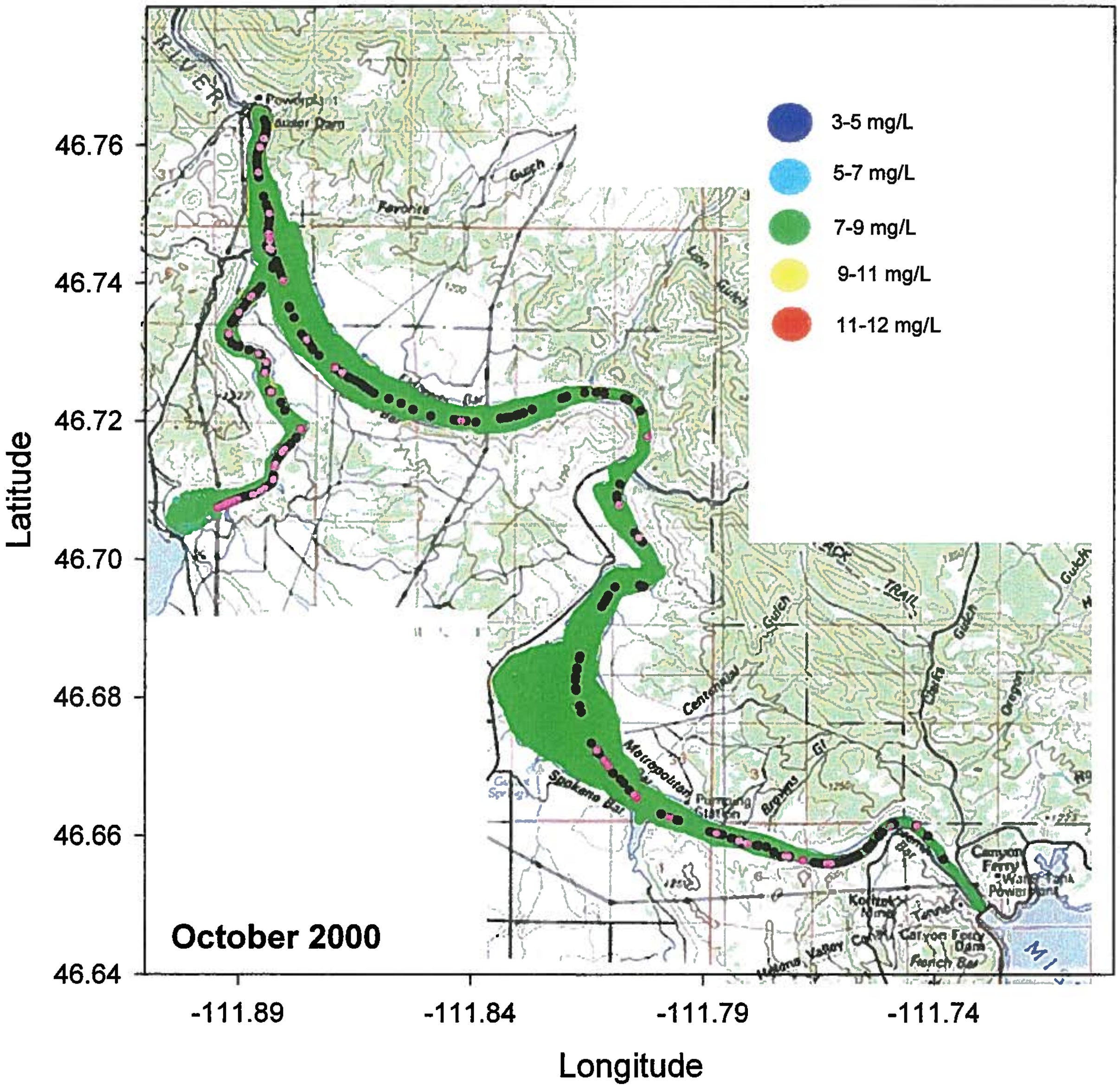


Figure 45 a, b. Seasonal depth distribution of fish detected using hydro acoustics in Hauser Reservoir 1999 and 2000.

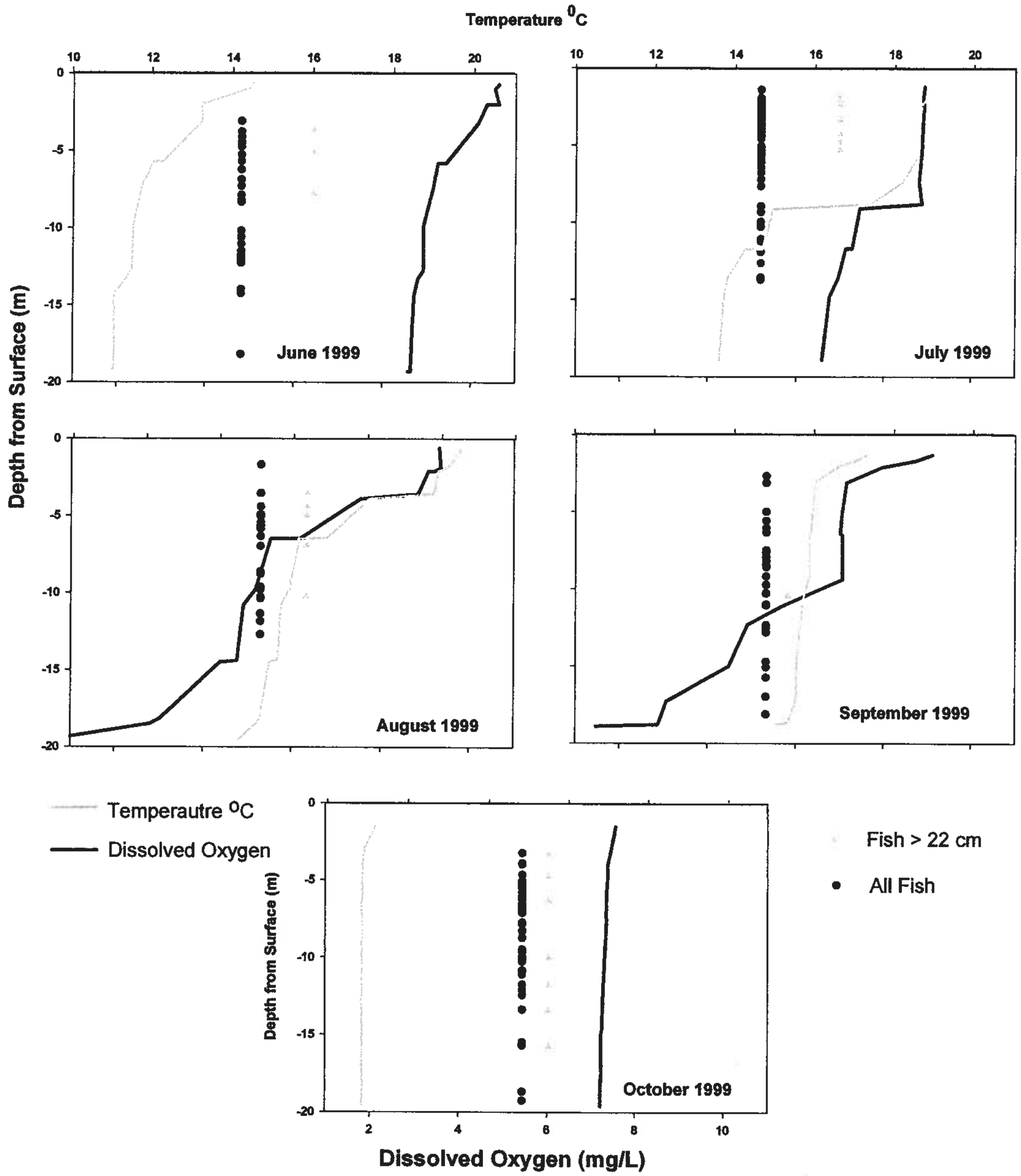


Figure 45 b.

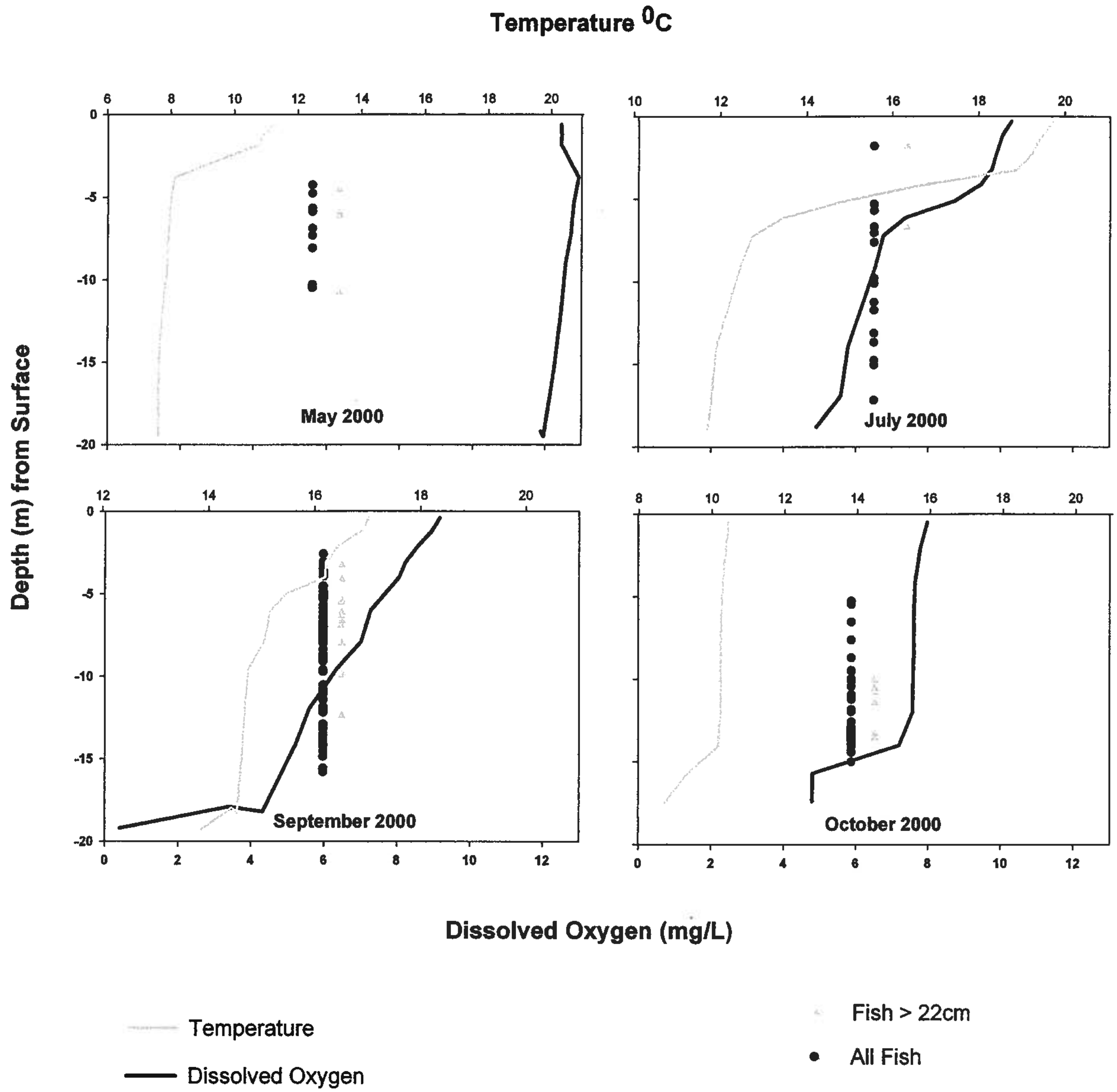

Temperature ^{0}C
Depth (m) from Surface
May 2000
July 2000
September 2000
October 2000
Dissolved Oxygen (mg/L)
Temperature
Dissolved Oxygen
Fish > 22cm
All Fish

Figure 46. Seasonal depth distribution of fish detected using hydro acoustics in Canyon Ferry Reservoir1999.

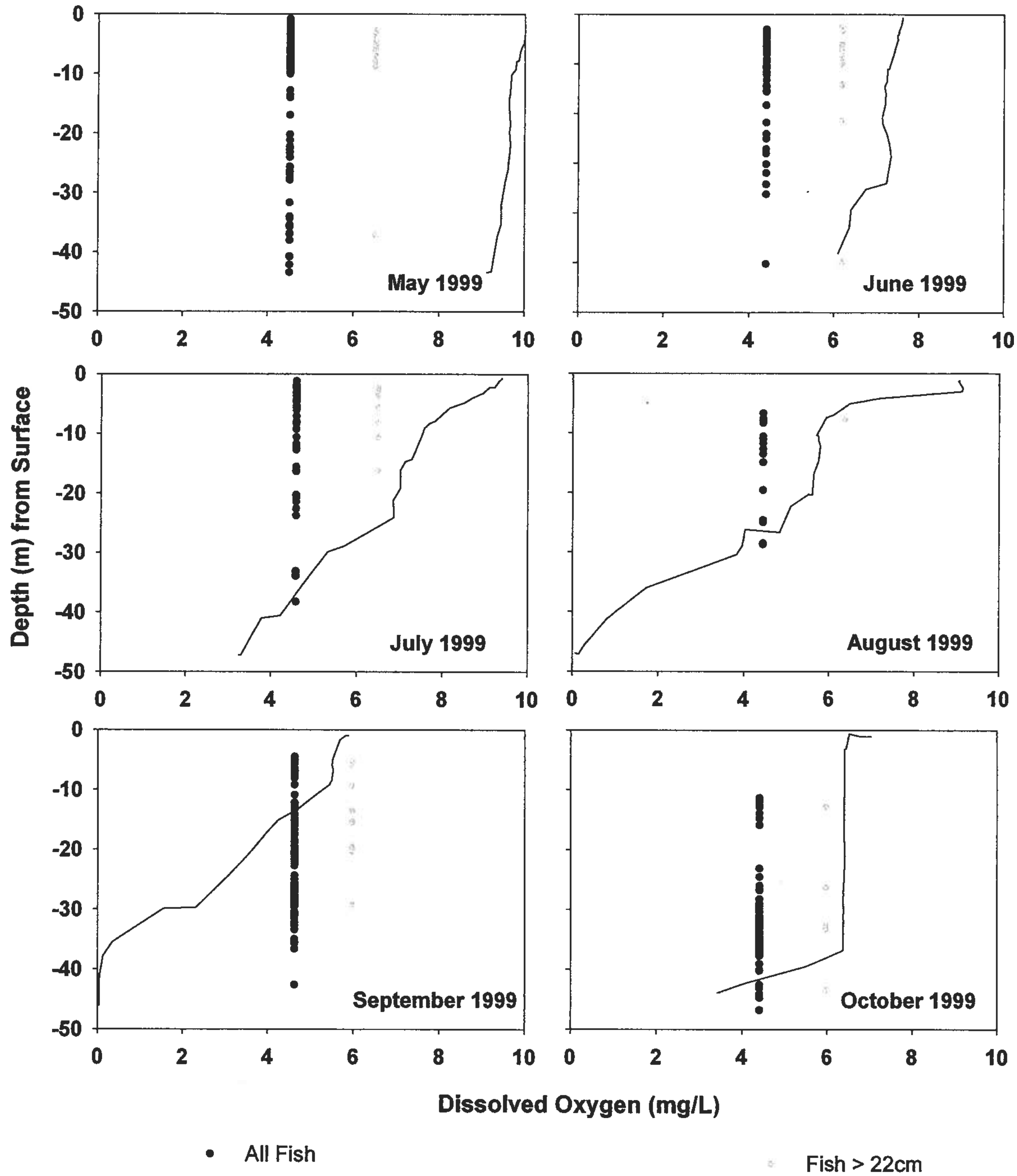


Figure 47. Seasonal patterns of decline in dissolved oxygen in the Canyon Ferry tailrace as measured at Riverside Campground. The gray area represents levels below the Montana standard for flowing waters of 6.5 mg/L.

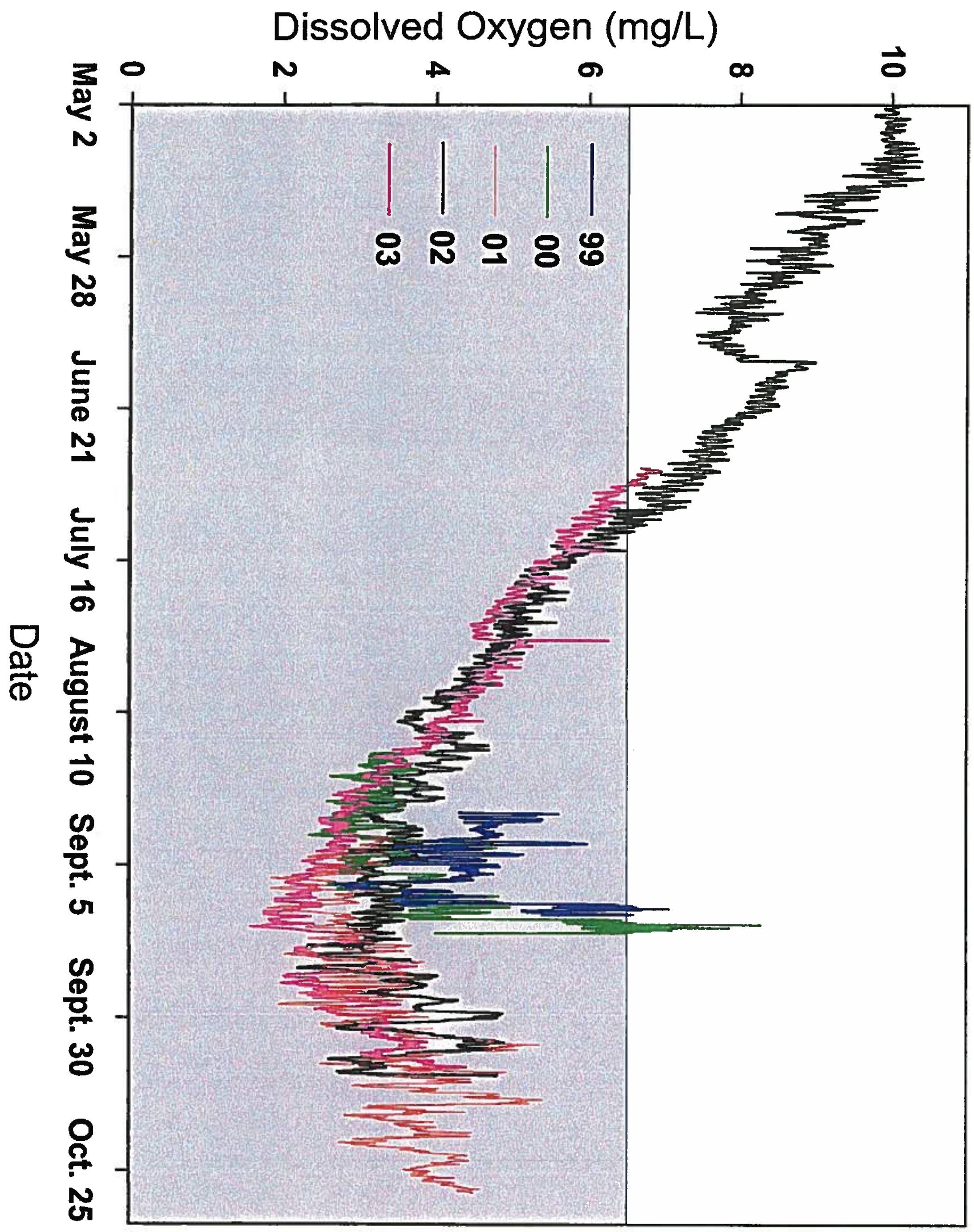


Figure 48. Pattern of releases from Canyon Ferry Dam for late summer 1999 showing discharge and dissolved oxygen levels.

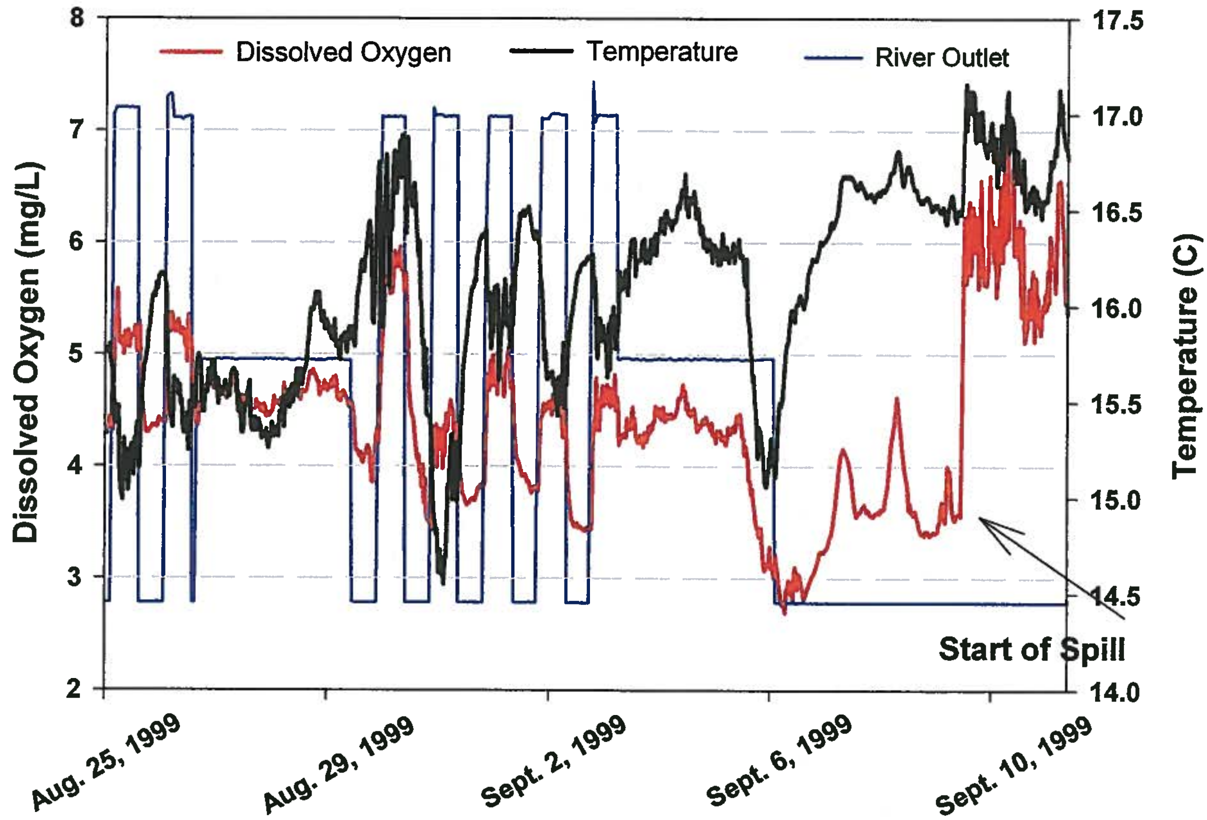


Figure 49. Pattern of releases from Canyon Ferry Dam for late summer 2000 showing discharge and dissolved oxygen levels.

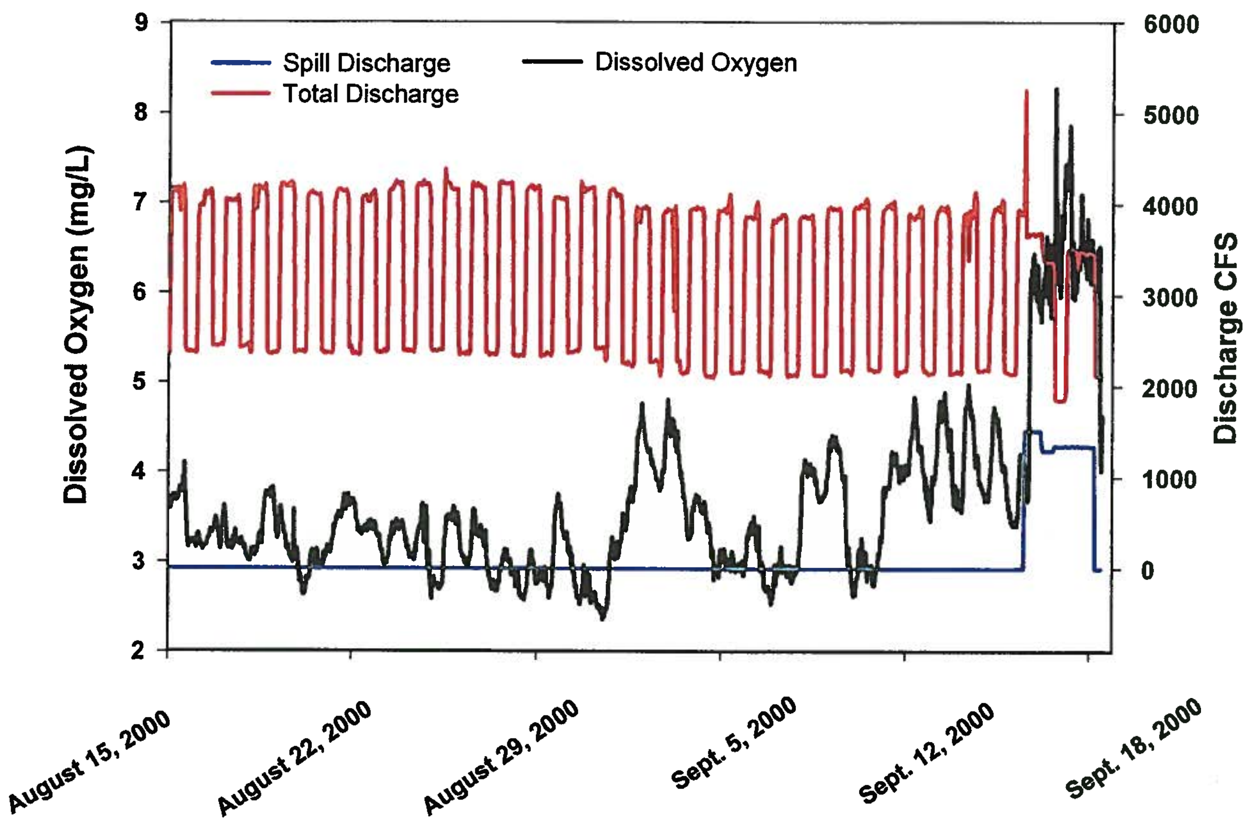


Figure 50. Dissolved oxygen, conductivity and temperature profiles in the forebay of Canyon Ferry Dam for September 1999 and 2000.