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Physical, Chemical, and Biological Characteristics of Cle Elum and Bumping Lakes in the Upper Yakima River Basin

Storage Dam Fish Passage Study
Yakima Project, Washington

Technical Series No. PN-YDFP-005

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Boise, Idaho

March 2007

U.S. Department of the Interior

Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

U.S. Bureau of Reclamation

Mission Statement

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Physical, Chemical, and Biological Characteristics of Cle Elum and Bumping Lakes in the Upper Yakima River Basin

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Introduction

As part of the Safety of Dams rehabilitation of Keechelus Dam on the Upper Yakima River in Washington State, the U.S. Bureau of Reclamation (Reclamation) entered into an agreement with the Washington Department of Fish and Wildlife to assess the feasibility of providing upstream adult and downstream juvenile passage for extirpated anadromous salmonids at its five water storage projects in the Yakima River Basin, to eventually restore anadromous salmonid runs to suitable habitats upstream from the dams. Fish passage was also desired to restore connectivity of the region's bull trout populations. The 2001 agreement was based on a need to correct some safety concerns at Keechelus Dam on the upper Yakima River. An interagency core team lead by Reclamation was established to assess the feasibility of providing fish passage at all five water storage projects. State and tribal fisheries co-managers are developing a plan for the eventual phased reintroduction of sockeye salmon (*Oncorhynchus nerka*), coho salmon (*O. kisutch*), Chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*) above the dams. Interim juvenile fish passage facilities completed at Cle Elum Lake in spring 2005 are testing the ability of juvenile fish to locate the passage facilitiy and exit the reservoir.

Cle Elum Dam was selected for the initial installation of interim downstream juvenile fish passage facilities, since the Phase 1 Assessment Report noted that substantial suitable habitat existed upstream from Cle Elum Lake in the Cle Elum River and some tributaries, compared to other projects, and authority for providing fish passage existed through the Yakima River Basin Water Enhancement Program (Reclamation 2003). Bumping Lake is also being considered for anadromous salmonid reintroduction. As part of this effort, Reclamation fisheries biologists, with cooperation and assistance from other agency fisheries biologists, assessed production potential for coho salmon and sockeye salmon in the Cle Elum and Bumping river basins upstream from the lakes. Since juvenile sockeye salmon rear in lakes, a comprehensive understanding of the physical, chemical, and biological conditions in Cle Elum and Bumping lakes was needed to supplement the sparse limnological information that was available for the lakes and to provide long-term seasonal characterization of the lakes to assess sockeye salmon production potential. The limnological study of Cle Elum and Bumping lakes was originally scheduled from September 2003 to October 2004, however, circumstances allowed an additional year of study on Cle Elum Lake to October 2005; Bumping Lake was not studied in 2005.

Anadromous salmonids historically occupied the watersheds in the upper Yakima River Basin but were extirpated as a result of construction of timber crib dams in the early 1900s. In addition, the upper Yakima River Basin (Figure 1) had viable bull trout (*Salvelinus confluentus*) populations that were able to migrate between smaller spawning/rearing streams and lakes. Mongillo and Faulconer (1982) explained that "…when dams were constructed at the lower end of these natural lakes, the sockeye salmon were eliminated and Chinook and coho salmon could no longer spawn above the reservoirs. The building of dams also had a significant impact on the productivity of these lakes. Historically, the carcasses of salmon spawning in streams running into the lakes contributed nutrients. After the reservoirs were built, this source of nutrients was removed. The present reservoirs are considerably larger than the original lakes and now receive fewer nutrients. The result is much lower productivity."

Cle Elum and Bumping lakes were originally natural glacial lakes that were dammed in their outflow area to increase water storage for irrigation and other uses in the Yakima Basin. Cle Elum Lake is the largest of the five irrigation storage reservoirs in the upper Yakima River Basin (Figure 2). The lake was first dammed by a timber crib dam in 1906, followed by a larger embankment dam in 1933. The 131-foot-high earthen dam increased the maximum surface area of the lake from about 2,990 acres to about 4,814 acres at full pool. The lake has an active storage volume of 436,950 ac-ft to provide irrigation water for the Yakima River Valley, and an estimated dead storage of 265,420 ac-ft, for a total volume of 702,370 ac-ft. Cle Elum Lake has a large and diverse watershed consisting of the main Cle Elum River above the lake and five major tributary streams. Much of the watershed lies in national forest or designated wilderness.

Bumping Lake is located in the Snoqualmie National Forest on the Bumping River in Yakima County about 25 miles northwest of Naches, Washington (Figure 3). The 61-foot-high earthfill dam was constructed in 1909 and 1910 to provide additional storage water. Bumping Lake has an active conservation capacity of 33,700 ac-ft, and a drainage area of 68 mi^2.

The limnological study of Cle Elum and Bumping lakes was conducted to describe in more detail the physical, chemical, and biological conditions in these two lakes, to assess primary and secondary production, to determine if the present conditions would support introduced anadromous salmonids, and ultimately to determine to what extent anadromous salmonid fisheries can be restored to the basin. Information obtained in this study was used extensively in assessing sockeye salmon production potential.

Methods

Cle Elum Lake was sampled monthly from September 2003 to October 2005 while Bumping Lake was only sampled from September 2003 to October 2004, except for the inaccessible winter months. Bumping Lake was not sampled in March 2004 due to snow conditions and inaccessibility to the lake. Fewer water quality parameters were collected in Cle Elum Lake during the 2005 survey.

Three sites were established in Cle Elum and Bumping lakes that included an uplake site (CLE1 and BMP1, respectively), a site at the deepest point at midlake (CLE2 and BMP2, respectively), and a site downlake near the dam (CLE3 and BMP3, respectively). In addition, one site was sampled in the inflow and outflow waters of Cle Elum Lake. Two sites were sampled in the inflow waters to Bumping Lake that included the Bumping River and Deep Creek; and one site in the outflow of Bumping Lake downstream from the dam. Sites were located and marked with GPS coordinates (Table 1).

Table 1. GPS coordinates for each sampling site within Cle Elum and Bumping Lakes.

Site	UTM Coordinates
CLE1	10 T 0642562
	5242257
CLE2	10 T 0644331
	5236452
CLE3	10 T 0645424
	5235013
BMP1	10 T 0625405
	5189444
BMP2	10 T 0626794
	5189177
BMP3	10 T 0629191
	5191903

Sample collections from lake sites included water column profiles recorded with a Hydrolab® (2003 to 2004) or YSI (2005) multiparameter probe. Physical data were collected from surface to bottom at 1-m increments through the thermocline (if present) and thereafter, at 5-m depth increments to the bottom for water temperature (°C), dissolved oxygen (DO) (mg/L), specific conductance (µS/cm), and pH (standard units). Secchi depth transparency measurements in meters were recorded using a 20-cm-diameter black and white round disk.

Composite water samples for chlorophyll *a* (chl *a*), an indicator of algal biomass, were collected at all lake sites in the 0 to 10 m depth stratum using a 10-m-long flexible pool hose. A Van Dorn water sampler was used to collect and composite 1 L of water from 12, 15, 18 and 20 m depths to represent the 10 to 20-m depth stratum; and from 22, 25, 28, and 30 m depths to represent the 20 to 30-m depth stratum at the midlake sites. Chl a samples were also collected from 1 m. Only one composite water sample was collected in each depth stratum. Composite water samples (1000 mL) for chl a from the three depth strata were filtered through Whatman GF/C filters (47 mm, particle retention 1.0 µm), folded, placed in separate small coin envelopes, stored on dry ice, and kept frozen until processed in the lab. Chlorophyll was extracted with 90 percent acetone and analyzed with a spectrophotometer for chlorophyll a (µg/L) (Strickland and Parsons, 1972) by Reclamation's Environmental Chemistry Laboratory at the Technical Service Center in Denver, Colorado.

Composite samples for phytoplankton were collected with the 10-m-long flexible pool hose and the Van Dorn water sampler (similar to the chlorophyll collection methods described above) to represent the individual depth strata of 0 to 10 m, 10 to 20 m, and 20 to 30 m. Samples were preserved with 5 percent Lugols iodine solution, later identified in the laboratory to species or lowest practical taxon, and reported as biovolume (μm^3/mL). Cell biovolumes of all taxa were quantified on a per milliliter basis by using formulae for solid geometric shapes that most closely matched the cell shape. Phytoplankton samples were not collected during the 2005 sampling season in Cle Elum Lake.

Single samples for zooplankton were collected with a 30-cm (opening of net) x 120-cm (length) x 64-µm (mesh size) simple closing net from the 0 to 10 m, 10 to 20 m, and 20 to 30 m depth strata. Zooplankton samples were preserved with 10 mL per 250 mL sample of 2 percent formaldehyde-8 percent ethanol-10 percent glycerol solution. Surface to bottom zooplankton hauls were also collected at midlake sites with a 50-cm (opening of net) x 300-cm (length) x 64-µm (mesh size) simple plankton net. Zooplankton were identified to genus or species and reported as number of individuals per liter.

Discrete water samples were collected at each station from a depth of 1 m below the surface to represent surface conditions and 0.5 m from the bottom with a Van Dorn water sampler for total phosphorus (TP), orthophosphorus (OP) (also referred to as soluble reactive phosphorus (SRP), dissolved nitrate-nitrite nitrogen, ammonia nitrogen, total Kjeldahl nitrogen (TKN), total organic carbon (TOC), and dissolved organic carbon (DOC). These samples were not intended to represent epilimnetic or hypolimnetic conditions since the lakes were seasonally well-mixed when some samples were collected. Separate water samples were collected for total nutrients (250 mL), dissolved nutrients (125 mL), TOC (40 mL), and DOC (40 mL). TOC and DOC were not collected during the 2005 sampling season in Cle Elum Lake. Water samples for ammonia-nitrogen, nitrite-nitrate nitrogen, and orthophosphorus were filtered through Gelman cellulose acetate filters (0.45 µm pore size), filtrate was decanted into sample bottles, and stored on ice. Water samples for total phosphorus and total Kjeldahl nitrogen were unfiltered. All nutrient samples were acidified with 1.0 mL of 10 percent sulfuric acid per 250 mL sample. Water samples for nutrients were analyzed with a Perstorp segmented flow analyzer. Detection limits were 3 µg/L for total phosphorus (TP), 1 µg/L for orthophosphate (OP), 3 µg/L for dissolved nitrate-nitrite nitrogen, 5 µg/L for ammonia nitrogen, 50 µg/L for total Kjeldahl nitrogen (TKN), 0.5 mg/L for total organic carbon (TOC) and dissolved organic carbon (DOC). TOC and DOC samples were acidified with 0.5 mL HCl and analyzed according to EPA method 415.1. Water samples collected in 2003-2004 were analyzed by Reclamation’s Environmental Chemistry Laboratory (DECL) at the Technical Service Center (TSC) in Denver, Colorado, while samples from 2005 were analyzed by Reclamation’s Chemistry Laboratory in Boulder City, Nevada.

Results and Discussion

Hydrodynamics

Cle Elum and Bumping lakes were natural glacial lakes that were enlarged by damming the outlets. Outlet works were constructed to control discharge water from the lakes. Historically, these once natural glacial lakes were characterized by their watershed size, simple shapes, surface outlets, a long hydraulic residence time, and a food web supported in part by marine-derived nutrients returned to the system by returning adult salmon. Today, these lakes have shorter hydraulic residence times, complex discharge operations, and fewer nutrients to support primary production. Cle Elum and Bumping lakes discharge water from the hypolimnion, which may cause some nutrients to be released downstream (Wright, 1967; Soltero et al., 1973).

Extreme fluctuations in reservoir elevation occur as a result of seasonal inflows and operations to store and release water for irrigation and other authorized purposes (Figure 4). These fluctuations affect the aquatic ecosystem of the Upper Yakima River Basin. River flows are unnaturally low in fall and winter, when releases are cut back to refill some of the reservoirs, and unnaturally high in the summer, when water must be released in large quantities to meet contractual obligations of downstream water users. Cle Elum Lake elevation reached its lowest level of 2120 ft. from late summer into early fall 2005 (Figure 5).

The average refill ratio for Cle Elum and Bumping lakes would be 1.5 times per year and 5.9 times per year, respectively. Hydraulic residence time or flushing rate is the average time required to completely renew a lake's water volume. During a normal water year, for the period May 1 to August 31, based on years 1998 and 2000, the residence time for Cle Elum Lake ranged from 73 to 74 days, and from 30 to 36 days for Bumping Lake. During a normal water year for the period September 1 to December 1, the residence time for Cle Elum Lake ranged from 164 to 178 days and from 36 to 44 days for Bumping Lake. Movement of riverine water through the reservoir is a function of release depth, volume of releases at the dam, amount of inflow entering the reservoir, and inflow density, primarily as a function of water temperature. Brook and Woodward (1956) found that the residence time had to be greater than 18 days for significant development of zooplankton. A combination of longer water residence times, adequate nutrients, and suitable foods may provide the most favorable conditions for maximal development of the zooplankton community (Gannon and Stemberger, 1978). Hayward and Van Den Avyle (1986) observed that residence times that were at least 50 to 250 days were sufficient to allow the establishment of plankton populations that reflected the productive potential as well as effects of species' interactions in the reservoir. Residence times for Cle Elum Lake are well above the range that is deemed adequate for establishing stable plankton communities. By contrast, during a wet water year, Bumping Lake may have a residence time of less than 20 days, releasing plankton downstream. However, nutrient availability, combined with reservoir operations, may play the greatest role in determining trophic levels in the Upper Yakima River Basin reservoirs.

Water Temperature

Cle Elum Lake is a temperate dimictic lake that turns over in the spring and fall. Surface water temperatures during the September 2003 to October 2004 sampling period were coolest in April and warmest in July (Figure 6). Surface temperature ranged from 6.87 to 18.28 °C at uplake site CLE1, from 6.58 to 21.05 °C at midlake site CLE2, from 6.33 to 21.16 °C at downlake site CLE3, from 5.18 to 18.26 °C at Cle Elum River inflow, and from 7.84 to 19.46 °C at Cle Elum River outflow. The lowest bottom temperature recorded was 4.24 °C at midlake (CLE2) during May. Temperatures gradually increased from nearly isothermal conditions in April to onset of thermal stratification between 16 to 18 m by June. Isothermal conditions probably occurred in March. Strong stratification persisted from July through September. During October, the surface water cooled, coinciding with cooler ambient air temperatures, and the thermocline began to drop in the water column, signaling a breakup of thermal stratification, and the initiation of the fall turnover, which probably occurred in November.

During the 2005 sampling period, Cle Elum Lake turned over in April and again towards the end of October. Overall surface temperatures recorded in Cle Elum Lake were slightly cooler than those observed in 2003-2004 (Figure 7). Maximum surface water temperatures peaked in August 2005, a month later and several degrees cooler than the maximum temperature recorded during the 2004 sampling season. Surface temperatures ranged from 6.15 to 16.90 °C at CLE1, from 5.37 to 18.20 °C at CLE2, from 5.21 to 18.35 °C at CLE3, from 7.08 to 17.92 °C at Cle Elum River inflow, and from 5.97 to 16.39 °C at Cle Elum River outflow. The minimum temperature of 4.31 °C (only slightly warmer than the 2004 value of 4.24 °C) was recorded at the bottom of the lake at CLE2 in April 2005. At this time, there was a slight thermal gradient in the lake (Figure 7) and the lake was strongly thermally stratified from June through the end of September. At this time, the thermocline was between 17 and 18 m. Cle Elum Lake remained stratified through September, and began to destratify in October. The physical processes of lake mixing, thermal stratification, and subsequent destratification were similar in both years.

Like Cle Elum Lake, Bumping Lake is a temperate dimictic lake that turns over in the early spring after ice-off, and again in the fall when decreasing air temperatures cool the lake's water. The coolest water temperatures occurred in May and the warmest temperatures occurred in July. Bumping Lake froze during winter 2003-2004, and we were not able to sample Bumping Lake like we did Cle Elum Lake in April 2004 due to heavy snow that limited access to the lake. Surface temperatures ranged from 7.20 to 19.85 °C at uplake site BMP1, from 8.27 to 20.38 °C at midlake site BMP2, from 10.2 to 19.82 °C at downlake site BMP3, from 2.7 to 16.9 °C at Bumping River inflow, from 3.66 to 8.75 °C at Deep Creek inflow, and from 9.8 to 18.6 °C in Bumping River outflow (Figure 8). The coldest bottom temperature of 4.74 °C was recorded in May at midlake (BMP2). Bumping Lake was weakly stratified in May at midlake (BMP2) (6 to 7 m) and downlake (BMP3) (8 to 10 m). By June, the thermocline at the upper site (BMP1) had developed. The lake was strongly stratified from July through September and at times, the thermocline encompassed over 5 m of vertical depth, particularly in the upper and mid-sections of the lake.

Temperate lakes and reservoirs generally stratify seasonally into three identifiable layers, the epilimnion, metalimnion, and hypolimnion. The epilimnion, the upper, warm layer is typically well mixed. Below the epilimnion is the metalimnion or thermocline, a layer of water in which the temperature declines rapidly (1 °C or greater per meter) with depth (Armantrout 1998). The hypolimnion is the bottom layer of colder water, isolated from the upper two layers. The density change in the metalimnion acts as a physical barrier that prevents mixing of the epilimnion and hypolimnion for several months during the summer stratification period. Thermal stratification begins gradually in the spring as air temperatures increase and warm the surface waters. Duration of stratification is influenced by ambient temperatures and intensity and amount of solar radiation, thus varying the length of time that thermal stratification persists from year to year. In late summer or fall, thermal stratification begins to weaken as increasing wind mixes cooler surface water with subsurface water. Eventually, the lake will mix entirely and undergo fall turnover and become isothermal. In addition, as the lake turns over, nutrients circulated from the hypolimnion are reintroduced into the water column, and brought up from the bottom of the lake to the epilimnion.

Dissolved Oxygen

During the 2003-2004 sampling season, DO profiles (Figure 9) at Cle Elum Lake exhibited orthograde oxygen curves that are usually indicative of unproductive or oligotrophic conditions (Wetzel, 1975). As summer stratification developed, the oxygen concentration in the circulating epilimnion decreased as the water temperature increased, and as temperatures decreased in the water column through the metalimnion and hypolimnion, the oxygen concentrations increased. Oxygen levels in the hypolimnion remained at or close to saturation from the period of spring turnover to just before the onset of summer stratification. An example of this phenomenon occurred at midlake site CLE2 beginning in June, when DO ranged from 10.01 mg/L (water temperature 9.82 °C) at 20 m to 11.21 mg/L (water temperature 4.83 °C) at 65 m (Figure 9), and continued through October, coinciding with thermal stratification. DO levels uplake (CLE1) and downlake (CLE3) were often at 100 percent or greater saturation (Figure 9). Bottom DO levels always remained above 6.5 mg/L.

DO levels in Cle Elum Lake during the 2005 sampling period were similar to those observed in 2003-2004 (Figure 10). Waters were well oxygenated at all times and often times supersaturated. Orthograde DO curves were predominant from July through October at CLE2 and were dependent on the water temperature, as described above during the 2003-2004 sampling season. DO concentrations were typically high and remained above 9 mg/L from surface to bottom throughout the sampling season.

Metalimnetic oxygen maxima (Figure 11) were observed from July to September 2004 in Bumping Lake at uplake site BMP1 and midlake site BMP2; and from July to August 2004 at downlake site BMP3, coinciding with strong thermal stratification. Metalimnetic oxygen maxima coinciding with subsurface algal growth and photosynthesis are common in lakes and may exhibit extreme supersaturated DO conditions (> 200 percent) caused by "oxygen produced by algal populations that develop more rapidly than they are lost by sinking from the zone of increased density (Wetzel, 1975). The algae are commonly stenothermal species, adapted to growing well at lower temperature and light intensities, but have access to nutrient concentrations that are usually higher in the lower metalimnion than in the epilimnion (Wetzel, 1975). Blue-green algae are often major contributors to this phenomenon and were reported in Bumping Lake, although the biovolume was low. DO levels at bottom depths at midlake site BMP2 were below 4 mg/L from August through October; lowest DO level was 2.26 mg/L in August 2004. During this same period, hypolimnetic DO was 1.82 mg/L near the dam (BMP3). Low DO levels in the hypolimnion of the lake may be attributed in part to the breakdown of organic matter in the bottom sediment layer. Sediment oxygen demand may be an important function in development of hypolimnetic minima at sampling sites when the lake is strongly thermally stratified. During our study, we did not detect low DO levels downstream in Bumping River outflow. DO levels at depth on Bumping Lake were substantially lower than those observed in Cle Elum Lake.

pH

During the 2003-2004 sampling period, pH in Cle Elum Lake ranged from 6.6 to 8.0, decreasing with depth at all sites. Higher pH values at the surface reflect more abundant algae and a higher photosynthetic rate in the upper layers of the water column. Decreases in pH levels in the water column were more pronounced when the lake was strongly stratified (Figure 12) and may be influenced by decompositional processes as well as photosynthesis and respiration (Wetzel, 1975).

During the 2005 sampling season, pH ranged from 6.20 to 8.38 at CLE2 (Figure 13). In April 2005 pH was 7.6 from surface to bottom (except at the very bottom), indicating that the lake was well mixed at this time. As the lake began to stratify, a pH gradient developed. By July, the pH gradient was pronounced as the lake became thermally stratified. pH data were not available for June 2005 due to a broken pH probe. Some of the pH profiles in Cle Elum Lake appeared to be erratic and we think that this pattern may have been caused by unbuffered waters rather than by an algal bloom (high pH) in the water column or an algal die-off (low pH). Lakes with lower pH tend to be less buffered and more susceptible to perturbations from environmental changes (Tolotti and Cantonati, 2000).

In Bumping Lake during 2003-2004 pH ranged from 5.9 to 7.7 at all sites (Figure 14).

Specific Conductance

There were no clear trends in specific conductance levels from uplake to downlake sites in Cle Elum Lake, but seasonal changes did occur. Specific conductance levels (Figure 15) ranged from 35 to 52.5 µS/cm (both values were recorded at uplake site CLE1). Highest specific conductance levels at the surface were recorded during September and October 2003, coinciding with diminishing inflows into the lake, and the fact that 2003 was a dry water year might have resulted in higher total dissolved solids. For example, at midlake site CLE2, surface specific conductance levels for September and October 2003 were 49.5 and 51.5 µS/cm, respectively, whereas surface levels for the same period in 2004 (a normal water year) were 48 and 45.5 µS/cm, respectively. Specific conductance levels tended to decrease in the metalimnion from June through September (Figure 15) apparently resulting from movement of interflows through the lake. Interflows are a function of release depth, volume of releases at the dam, amount of inflow entering the reservoir and inflow density, primarily as a function of water temperature. Inflowing waters that become interflows have much lower specific conductance than the relatively stagnant water in the hypolimnion, and inflow water temperatures are less than the surface water temperature and greater than the hypolimnetic water temperature (Thornton et al. 1990). The interflows were most pronounced in June and July after the lake thermally stratified and when inflow waters were at their peak. During June 2004 at midlake site CLE2, specific conductance at the surface was 45 µS/cm, decreased to about 40 µS/cm at 20 m, and increased to about 46 µS/cm at 50 m.

During the 2005 sampling season, specific conductance ranged from 41 to 56 µS/cm in Cle Elum Lake and from 36 to 55 µS/cm in the inflow and outflow waters (Figure 16). Highest levels were recorded in September and October similar to the 2003-2004 sampling season. Specific conductance values appear to be quite erratic at CLE2 and CLE3 during the late summer (from August to October). Drawdown of the lake may have resulted in specific conductance levels increasing due to concentration of total dissolved solids in the lake. Specific conductance levels tended to decrease from surface to bottom. Specific conductance levels were greater in 2005 than those reported in 2004 and these values indicated greater levels of total dissolved solids in the lake.

In Bumping Lake during 2003-2004, specific conductance ranged from 25 to 35 µS/cm. In the Bumping River inflow, specific conductance (Figure 17) ranged from 18.5 to 43 µS/cm, and in Deep Creek inflow it ranged from 34 to 55 µS/cm. Interflow waters were apparently

pulled through the lake by the bottom discharge at the dam. An example of this occurred during July and August 2004, when interflow waters were detected near the bottom of BMP3 at 7 and 10 m, respectively.

Nutrients

Nitrate-nitrite nitrogen levels at near surface reached a seasonal peak of 0.048 mg/L in Cle Elum Lake at all stations in April 2004, during the time of maximal reservoir mixing (Figure 18). Surface levels ranged from 0.003 to 0.048 mg/L for the entire sampling period. Once the lake stratified, nutrient levels at 1.0 m generally decreased, and remained below 0.030 mg/L, a level that Taylor et al. (1980) reported as critical for development of algal blooms and characteristic of mesotrophic and eutrophic water bodies. Nitrate-nitrite nitrogen levels for samples collected from just above the bottom at three sites ranged from 0.024 to 0.083 mg/L in October 2003. Levels of nitrate-nitrite nitrogen at the bottom were typically greater than levels at the surface at the deeper lake sites and reached slight peaks in August when the lake was thermally stratified, and again in October as the lake waters began to destratify and mix.

In 2005, spring runoff began about 3 weeks earlier than in 2004 and may have influenced the delay in springtime nitrate-nitrite nitrogen peaks by a month. Nitrate-nitrite nitrogen levels reached maximum seasonal peaks of 0.070 mg/L during spring runoff in May at upstream site CLE1. During this same period, Cle Elum River outflow levels peaked at 0.088 mg/L (Figure 19). At midlake site CLE2, nitrate-nitrite nitrogen levels peaked to 0.044 mg/L in May. Nitrate-nitrite levels in the Cle Elum River inflow peaked in August and decreased just slightly in September when inflows were at a minimum. These levels were comparable to those recorded during the 2003-2004 season. Following the springtime peak of 0.040 mg/L at the surface, nitrate-nitrite nitrogen levels remained below 0.030 mg/L. In general, these low levels are considered characteristic of oligotrophic waters (Taylor et al., 1980). Bottom nitrate-nitrite nitrogen levels were oftentimes greater than surface levels. Nutrients introduced into the upper depth strata would be used up relatively quickly by algae. Greater nitrate-nitrite nitrogen levels were present in the bottom in August at CLE2 when the reservoir was strongly stratified, while nutrient levels at the surface were reduced presumably as a result of algal production.

Surface nitrate-nitrite nitrogen levels in Bumping Lake ranged from 0.003 to 0.021 mg/L and bottom nitrate-nitrite nitrogen levels ranged from 0.003 to 0.041 mg/L at all sites over the entire sampling period (Figure 20). Surface and bottom levels showed similar seasonal trends with peaks coinciding with lake turnover and mixing in May.

Surface ammonia nitrogen levels at all sites in Cle Elum Lake ranged from 0.005 to 0.031 mg/L and bottom levels ranged from 0.005 to 0.059 mg/L in 2003-2004 (Figure 21). Ammonia nitrogen levels peaked following spring turnover and runoff in April and May 2004. Ammonia is a biologically active compound present in most waters as a normal biological degradation product of nitrogenous organic matter. Ammonia is used up quickly or converted to nitrate in well-oxygenated waters in the epilimnion, and the uptake by algae is usually rapid. As spring progressed, nutrient levels decreased as algal production increased. Periodic increases of ammonia occurred at all sites during the summer and may represent an algal crash where there is a small but measureable increase in ammonia due to algal decomposition. Other influences, such as weather and periodic mixing, may have also caused short-term increases in ammonia. During 2005, surface ammonia nitrogen levels at all sites in Cle Elum Lake ranged from 0.003 to 0.014 mg/L and bottom levels ranged from 0.003 to 0.014 mg/L (Figure 22). Surface ammonia nitrogen levels at CLE2 peaked in July 2005 to 0.014 mg/L when the reservoir was strongly stratified, and at the bottom peaked in October to 0.014 mg/L, coinciding with the breakdown of summer thermal stratification and subsequent mixing of the lake. Maximum ammonia nitrogen levels recorded in 2005 were lower than peak levels of 2004, both at surface and bottom. Ammonia nitrogen levels in the

Cle Elum River outflow peaked to 0.014 mg/L in May and August 2005. Levels of ammonia nitrogen were not elevated in the surface or bottom of the reservoir at downlake site CLE3 and remained below 0.008 mg/L. Ammonia nitrogen levels in the river were somewhat higher than surface or bottom levels that were reported from the lake, indicating that perhaps ammonia nitrogen levels may have been higher at the level where water was discharged from the lake. Ammonia nitrogen levels in 2004 were lower than those in 2005.

Surface ammonia-nitrogen levels in Bumping Lake ranged from 0.005 to 0.029 mg/L and bottom levels ranged from 0.005 to 0.028 mg/L over the entire sampling period in 2003-2004 (Figure 23). Surface increases occurred in May coinciding with runoff from Deep Creek (0.025 mg/L ammonia nitrogen) and lake mixing, in mid to late summer due to decomposition following a possible algal crash, and in October when thermal stratification began breaking down. A peak in ammonia nitrogen was observed near the bottom at midlake site BMP2 in September 2003 and 2004, which may have been due to low DO levels and decomposition of organic matter at the bottom of the lake.

Total Kjeldahl nitrogen (TKN) includes both total organic nitrogen and ammonia nitrogen, and is indicative of autochthonous organic matter present in the lake as well as the contribution from inflow. TKN levels in surface and bottom waters of Cle Elum Lake fluctuated throughout the 2003-2004 sampling period. Surface TKN levels ranged from 0.050 to 0.560 mg/L and bottom TKN levels ranged from 0.050 to 0.570 mg/L. TKN levels peaked in April at all sites in Cle Elum Lake during runoff and lake mixing (Figure 24). There were also periodic peaks during the summer months.

In 2005, surface TKN levels ranged from 0.027 to 0.372 mg/L, and bottom levels ranged from 0.036 to 0.351 mg/L (Figure 25). TKN levels in 2005 tended to be lower than TKN levels in 2004. Maximum surface and bottom levels in 2005 occurred in October, coinciding with the breakdown of thermal stratification and mixing of the water column. Peak TKN levels in the outflow waters were recorded in August as organic matter such as algal and zooplankton were released from the lake.

Surface TKN levels ranged from 0.050 to 0.490 mg/L and bottom TKN levels ranged from 0.050 to 0.350 mg/L at Bumping Lake (Figure 26) in 2003-2004.

Surface and bottom total phosphorus (TP) and orthophosphorus (OP) levels were very low at all Cle Elum Lake sites, and ranged from 0.003 to 0.008 mg/L and 0.001 to 0.007 mg/L, respectively (Figures 27 and 28). TP includes various soluble and insoluble organic and inorganic forms, but it is the orthophosphorus that is immediately available for algal uptake and growth (Cole, 1979). TP:OP ratios ranged from 5:1 to 4:1 for all sites in the lake, indicating much of the phosphorus pool contained low levels of orthophosphorus. Goodwin and Westley (1967) reported that the relatively low concentrations of phosphorus and nitrogen in Cle Elum Lake were typical of oligotrophic lakes and reported reduced values of orthophosphorus in the spring. They also reported that the concentrations of nitrates and phosphates were generally so low at any given time that they were “unimportant in explaining the increases and decreases in phytoplankton abundance." Mongillo and Faulconer (1982) found that phosphorus was limiting at various times of the year at Cle Elum Lake and concluded that a relatively high flushing rate was the most significant cause of poor phosphorus uptake by algae. In this study, we did not find evidence that low levels of TP and OP were a result of flushing rate of Cle Elum Lake. The residence time (as discussed in the Hydrodynamics Section) was not high enough to effect phytoplankton production negatively. Historically, carcasses of salmon spawning in streams tributary to the original lakes were thought to provide a substantial and reliable source of marine-derived nutrients. There was a significant difference between pre-1906 and post-1906 phosphorus levels in bottom core samples. Mongillo and Faulconer (1982) report that there was an average of 19 percent more phosphorus deposited in the sediment each year from approximately 1883 to 1906, which they attributed to marine-derived nutrients from salmon. Mongillo and Faulconer (1982) concluded that salmon runs were probably eliminated by the timber crib dam built in 1906 rather than by the existing concrete and earthen dam constructed in 1933, and that salmon carcasses once contributed appreciably to the phosphorus budget of the lake. During 2005, OP constituted a greater proportion of TP than in 2003-2004. TP levels ranged from 0.0023 to 0.004 mg/L and OP levels ranged from 0.001 to 0.004 mg/L (Figures 29 and 30). Surface and bottom TP and OP levels were very low and were similar to low levels of the 2003-2004 sampling season. Such low levels of TP and OP are typical of unproductive lakes. This additional year of data further confirms the oligotrophic classification of Cle Elum Lake (Vollenweider and Kerekes, 1982). In addition, Vollenweider and Kerekes' (1982) classification system considers lakes with <0.010 mg/L of TP as oligotrophic and lakes with 10 to 35 mg/L of TP as mesotrophic. Under this classification system, Cle Elum Lake would be classified as oligotrophic.

The ratio of N:P often is a good indicator of the limiting nutrient in aquatic systems (Reynolds, 1986). A TN (total Kjeldahl nitrogen + nitrate-nitrogen+ nitrite-nitrogen):TP ratio of greater than 7 indicates that algal growth will be limited by the amount of phosphorus present and a TN:TP ratio less than 7 indicates nitrogen limiting conditions (Reynolds, 1986). TN:TP ratios of Cle Elum Lake in 2004 were always greater than 7:1 at all surface and bottom sampling sites, indicating phosphorus limitation. The greatest TN:TP ratios coincided with runoff in April (169:1 at midlake site CLE2); ratios decreased during strong stratification in July (18:1 at midlake site CLE2 as nutrients were quickly used up by algal uptake, and ratios increased somewhat in September coinciding with late summer algal blooms (25:1 at midlake site CLE2. As was seen in 2004, TN:TP ratios of Cle Elum Lake during 2005 were always greater than 7:1 at all near-surface and near-bottom sampling sites, again indicating phosphorus limitation.

Ratios of TIN (ammonia-nitrogen + nitrate-nitrogen + nitrite-nitrogen) to OP often provide a better indication of nutrient limitation than TN:TP ratios because these inorganic nutrient forms are more readily available for algal uptake and growth. Ratios of TIN:OP suggested that P-limiting and N-limiting conditions were present at different times in the surface of Cle Elum Lake. The greatest TIN:OP ratio of 34.5:1 occurred in April 2004 at midlake site CLE2, coincident with the greatest TN:TP ratio. Nitrogen-limiting conditions existed at

CLE2 during June (5.7:1), August (2:1), and September (2.8:1). The TIN:OP ratios for the 2005 sampling season were almost always greater than 7:1, indicating phosphorus-limiting conditions. Occasionally at site CLE2, the ratios dipped below 7:1, indicating nitrogen-limiting conditions during September in the surface and bottom in May and October 2005.

In Bumping Lake, TP and OP levels were greater at times than levels in Cle Elum Lake. Surface TP levels ranged from 0.003 to 0.019 mg/L and bottom levels ranged from 0.003 to 0.028 mg/L (Figure 31); surface OP levels ranged from 0.001 to 0.005 mg/L and bottom levels ranged from 0.001 to 0.008 mg/L (Figure 32). The most dramatic TP peaks occurred in late spring during June, uplake in the epilimnion and midlake in the hypolimnion, as the lake began to stratify strongly. TP:OP ratios ranged from 1:1 to 9.5:1. The higher ratios occurred only occasionally since most of the TP was composed of OP. TN:TP ratios that ranged from 12.6:1 (October 2003) to 73:1 (June 2004) at midlake site BMP2 suggested phosphorus-limiting conditions within the lake. TIN:OP ratios that ranged from 4.0 (October 2003) to 17:1 (April 2004) suggested either nitrogen-limiting or phosphorus-limiting conditions during different times of the year. Phosphorus-limiting conditions occurred during July, when Bumping Lake was strongly stratified.

Secchi Depth Transparency and Chlorophyll *a* Concentrations

Secchi depths in Cle Elum Lake at midlake site CLE2 ranged from 6.9 to 10.2 m and averaged 8.35 m in 2004 (Figure 33). Secchi depths were similar at downlake site CLE3 near the dam. Lowest secchi depths were typically recorded during spring runoff in May and in September perhaps from increased algal abundance. Secchi depths in Cle Elum Lake at midlake site (CLE2) ranged from 5.55 to 8.4 m and averaged 6.79 m and at downlake site CLE3 ranged from 5.02 to 8.72 m and averaged 6.98 m during the 2005 sampling season (Figure 34). Water clarity was reduced somewhat from 2004, as the secchi depths were not as deep, indicating lowered transparency. Greatest secchi depths occurred in May, at the onset of thermal stratification and as lake mixing decreased, resulting from diminishing flows from spring run-off, in contrast to lowest secchi depths in 2004 were recorded during spring runoff in May. Lowest secchi depths occurred in October 2005 caused by the drawdown of the lake, resulting in increased turbidity. Particulates may have been drawn into the water from the shoreline and from upreservoir as the lake was drawn down, increasing suspended material and decreasing water clarity. During 2004, greatest secchi depth of 10.2 m occurred in July when the lake was strongly stratified and nutrients were not readily available for algal uptake. By contrast, during July 2005, secchi depth at CLE2 was only 6.88 m. The disparity in water transparency between years was not due to increases in chlorophyll concentration (algal biomass) (Figure 34) but rather due in part to the drawdown in the reservoir and the introduction of suspended sediment into the water column. Secchi depth transparency is a function of light absorption characteristics of water due to dissolved and particulate matter, either organic material such as plankton, or inorganic material such as suspended sediments. Secchi depth transparency reflects both the seasonal thermal structure and plankton productivity in the reservoir, if the waters are free from sediment and other particulates.

Chlorophyll *a* (chl *a*) concentrations, an estimate of total algal biomass, typically used to estimate productivity, and to compare with other aquatic systems to assess trophic status (Likens, 1975) appeared to be highest at midlake site CLE2 and downlake site CLE3 in September. During these times, inflow waters and algal material contributed to a decrease in water clarity. Greatest secchi depths occurred during July when the lake was strongly stratified, algal production was reduced in the upper depth strata of the euphotic zone, and increased production occurred in the metalimnion. Oftentimes, chl *a* correlates with secchi depth transparency; shallower secchi depths may coincide with greater chl *a* concentrations. Chl *a* concentrations were low at all sites in the lake (Figure 33) and there appears to be a weak relationship between secchi depth and chl *a* concentrations, although no statistical analysis was conducted. Greatest concentrations of chl *a* occurred in May and in September, when secchi depths were shallow. Chl *a* ranged from 0.43 to 1.9 µg/L. Mean chl *a* at midlake site CLE2 was 0.9 µg/L at 1.0 m, 1.07 µg/L in the 0 to 10 m depth stratum, 1.16 µg/L in the 10 to 20 m depth stratum, 0.8 µg/L in the 20 to 30 m depth stratum; mean chl *a* at the downlake site CLE3 was 1.0 µg/L at 1 m and 1.10 µg/L in the 0 to 10 m depth stratum. Chl *a* concentrations appeared to be somewhat greater deeper in the water column at midlake site CLE2. The uplake site was too shallow to collect chl *a* samples during each sampling date.

Chlorophyll *a* concentrations were very low (Table 2) indicating oligotrophic conditions in the lake (Likens, 1975). Chlorophyll levels peaked at all stations in September 2004 and again in September 2005 except for the 0 to 10 m depth stratum where it peaked on October at CLE2 (Figures 33 and 34). Greatest chlorophyll *a* levels (1.6 µg/L) tended to be present in the 10 to 20 m depth stratum during the period when the reservoir was strongly stratified. At these low chlorophyll *a* levels, the reservoir would be classified as oligotrophic (Likens, 1975) or unproductive and were actually somewhat lower than the levels reported for 2003-2004.

Table 2. Ranges of chlorophyll *a* concentrations (n = 7) in the Cle Elum River inflow, Cle Elum River outflow, and at mid lake station, CLE2 from May to October 2005.

Station	Chlorophyll *a* (µg/L)
Cle Elum Inflow	0.2 - 0.4
Cle Elum Outflow	0.5 – 1.2
CLE2 (1m)	0.5 – 1.4
CLE2 (0 to 10m)	0.6 – 1.5
CLE2 (10 to 20m)	0.5 – 1.6
CLE2 (20 to 30 m)	0.5 – 0.9

During 2003-2004, Bumping Lake secchi depths ranged from 5.9 to 11.2 m and averaged 8.85 m (Figure 35). Secchi depth was lowest (5.9 m) in October 2003 during a dry water year when the lake was drawn down to minimum pool and had begun to destratify. During 2004, secchi depths were lowest coinciding with May runoff, and again in August or September at peak of algal production.

At uplake site BMP1, mean chl *a* concentration was 1.3 µg/L at 1.0 m and 1.95 µg/L in the 0 to 10 m depth stratum (Figure 35); at midlake site BMP2, mean chl *a* concentration was 1.0 µg/L at 1m, 1.55 µg/L in the 0 to 10 m depth stratum, 1.38 µg/L in the 10 to 20 m depth stratum, and 0.93 µg/L in the 20 to 30 m depth stratum; at downlake site BMP3, mean chl *a* concentration was 1.09 µg/L at 1 m and 1.22 µg/L in the 0 to 10 m depth stratum. The lake supported phytoplankton production to 30 m, perhaps even deeper, as measured by chl *a* concentration, but chl *a* levels indicated relatively low productivity throughout the spring/summer/fall months. Chl *a* concentrations range from 0.3 to 3.0 µg/L in oligotrophic lakes and from 2 to 15 µg/L in mesotrophic lakes (Likens, 1975). According to this classification system, Cle Elum and Bumping lakes would be classified as oligotrophic.

Total Organic Carbon (TOC)

TOC values were low throughout Cle Elum Lake and ranged from 0.8 to 1.6 mg/L at Cle Elum River inflow, from 1.4 to 1.5 mg/L at uplake site CLE1, from 0.7 to 1.4 mg/L at midlake site CLE2, from 0.9 to 1.3 mg/L at downlake site CLE3, and from 0.9 to 1.4 mg/L at Cle Elum River outflow during the 2003-2004 sampling season.

TOC levels were also low in Bumping Lake and ranged from <0.5 to 1.4 mg/L at Bumping River inflow and Deep Creek inflow, from 0.6 to 1.2 mg/L uplake site BMP1, from 0.8 to 1.2 mg/L at midlake site BMP2, and from 1.2 to 1.3 mg/L at downlake site BMP3, and from 1.4 to 1.6 mg/L at Bumping River outflow.

Much of the TOC in a lake is of allochthonous origin and may contribute to biological oxygen demand (BOD), resulting in low DO in the water column (Jassby and Goldman, 2003). Compared to other lakes and reservoirs, reported mean TOC levels were 40 mg/L in hypereutrophic Salton Sea, California (Holdren and Montano, 2002); TOC levels ranged from 2.6 to 11.4 mg/L in mesotrophic Horsetooth Reservoir, Colorado (Lieberman, 2005); and mean TOC levels were 3.5 mg/L in oligotrophic Lake Powell, Utah (Chris Holdren, USBR, Technical Service Center, Denver, CO, pers. comm.). Based on TOC levels alone, Cle Elum and Bumping lakes would again be classified as oligotrophic. Samples for TOC analysis were not collected during the 2005 sampling season.

Phytoplankton

A total of 37 phytoplankton species were identified from all sampling sites in Cle Elum Lake (Table 3). Algal biovolume was dominated by the Division Chrysophyta, which includes the many diatoms and golden-brown algae such as Dinobryon spp. Many of these forms are cosmopolitan in nature and occur commonly in oligotrophic lakes. Other algal groups were present but less abundant. There were occasional blue-green algae detected at very low levels in the lake. The dominant diatom species included *Asterionella formosa*, *Tabellaria fenestrata*, *Melosira italica*, *Cyclotella comta*; the dominant golden-brown species were *Dinobryon bavaricum* and *Dinobryon sertularia*. Biovolume peaked at 900,000 μm^3/mL in September 2003 (Figure 36) in the 10 to 20 m depth stratum at midlake site CLE2. According to Vollenweider's (1968) classification system, a lake with < 1,000,000 μm^3/mL of algal biovolume would be classified ultraoligotrophic. Algal biovolume peaked at 300,000 μm^3/mL in August 2004 again in the 10 to 20 m depth stratum at CLE2, coinciding with strong thermal stratification at 6 to 11 m. Water clarity was high with a secchi depth of about 10 m and a great proportion of the algal biovolume below the 0 to 10 m depth stratum.

Table 3. Phytoplankton species identified from all sites in Cle Elum Lake from samples collected monthly from September 2003 to October 2004.

Cyanophyta	*Dinobryon sertularia*	*Synedra ulna*
Oscillatoria sp**.**	*Fragilaria crotonensis*	*Tabellaria fenestrata*
Chrysophyta	*Fragilaria vaucheria*	**Chlorophyta**
Achnanthes flexella	*Gomphonema angustatum*	*Ankistrodesmus falcatus*
Achnanthes minutissima	*Gomphonema tenellum*	*Chlamydomonas* sp.
Anomoeoneis vitrea	*Kephyrion littorale*	*Chrysochromulina* sp.
Asterionella formosa	*Kephyrion* sp.	*Cocconeis placentula*
Cyclotella comta	*Melosira italica*	*Oocystis pusilla*
Cyclotella stelligera	*Navicula cryptocephala veneta*	**Cryptophyta**
Cymbella minuta	*Nitzschia acicularis*	*Cryptomonas erosa*
Cymbella sinuata	*Synedra acus*	*Rhodomonas minuta*
Denticula elegans	*Synedra radians*	**Pyrrhophyta**
Diatoma tenue elongatum	*Synedra rumpens*	*Ceratium hirundinella*
Dinobryon bavaricum	*Synedra tenera*	*Glenodinium* sp.

A total of 42 phytoplankton species were identified from all sites in Bumping Lake (Table 4). The great majority of species collected were dinoflagellates (Division Pyrrhophyta) and diatoms (Division Chrysophyta). Some blue-green algae (Division Cyanophyta) were collected in September and October 2003. *Anabaena flos-aquae* and *Aphanocapsa* sp. were present in low levels. Low nutrient concentrations such as those observed in Bumping Lake do not typically result in abundant blue-green algae assemblages. Possibly the small size of Bumping Lake influenced the development of blue-green algae since the lake is weakly buffered and may be more susceptible to external disturbances such as anthropogenic activity in the area. In addition, a dry water year such as 2003 may have been responsible for the presence of these more eutrophic forms in the lake. The algae assemblage changed from dinoflagellates in 2003 to diatoms and golden-brown algal dominance (Division Chrysophyta) during 2004. Dominant diatoms collected were *Melosira italica*, *Synedra radians*, and *Asterionella formosa*, all cosmopolitan forms. Melosira is one of the most ubiquitous of algal genera, and is widely distributed in all types of water bodies. Golden-brown algae was dominated by *Dinobryon bavaricum* and *Dinobryon sertularia*. Algal biovolume reached a maximum of 500,000 μm^3/mL in September 2003 at the upper end of the lake (BMP1) in the 0 to 10 m depth stratum (Fig. 37). A metalimnetic DO maxima occurred below the 0 to 10 m depth stratum at about 11-12 m, indicating active algal growth within this layer. A metalimnetic DO maximum was present at midlake site BMP2 beginning in July 2004 (biovolume ranged from 75,000 to 100,000 μm^3/mL) and became more pronounced in August and September (Figure 11). The greatest proportion of algal biovolume occurred within the 0 to 10 m depth stratum, and DO maxima occurred from 7 to 14 m. Greater biovolume of Cryptophyta (*Cryptomonas* spp. and *Rhodomonas* spp.) and Pyrrhophyta (*Glenodinium neglectum* and *Gymnodinium* sp.) were present deeper in the water column (20 to 30 m) at the midlake site BMP2 and tended to increase later in the summer season. This lake would also be classified oligotrophic (Vollenweider, 1968), similar to Cle Elum Lake; it may possibly be even less productive

Phytoplankton samples were not collected in Cle Elum Lake during the 2005 sampling season.

Table 4. Phytoplankton species identified from all sites in Bumping Lake from samples collected monthly except for winter months from September 2003 to October 2004.

Cyanophyta	*Eunotia pectinalis*	Cryptophyta
Anabaena flos-aquae	*Fragilaria construens*	*Cryptomonas ovata*
Aphanocapsa sp.	*Gomphonema angustatum*	*Rhodomonas minuta*
Chrysophyta	*Gomphonema* sp.	**Chlorophyta**
Achnanthes lanceolata	*Kephyrion* sp.	*Ankistrodesmus falcatus*
Achnanthes minutissima	*Melosira distans alpigena*	*Chroomonas* sp.
Amphipleura pellucida	*Melosira granulata*	*Cocconeis placentula*
Amphora ovalis	*Melosira* sp.	*Cosmarium*
Asterionella formosa	*Navicula cryptocephala*	*Pediastrum tetras*
Chrysochromulina sp.	*Navicula* sp.	*Pinnularia* sp.
Cymbella microcephala	*Nitzschia linearis*	*Sphaerocystis schroeteri*
Cymbella minuta	*Staurastrum* sp.	**Pyrrhophyta**
Diatoma hiemale mesodon	*Synedra radians*	*Glenodinium* sp.
Dinobryon bavaricum	*Synedra rumpens*	*Gymnodinium* sp.
Dinobryon sertularia	*Synedra tenera*	**Euglenophyta**
Diploneis elliptica	*Synedra ulna*	Unidentified flagellate

Zooplankton

Zooplankton play an important role in a lake's ecosystem; they are an integral part of the lake's food web, as prey for other zooplankton and fish. The food web interaction is influenced by both predation and availability of food, as well as the physical and chemical components of the lake. There were 32 zooplankton species collected from all sites at Cle

Elum Lake during the 2003-2005 sampling period (Table 5). The dominant cladocerans were *Bosmina longirostris* and *Daphnia rosea*; the large cladoceran, *Leptodora kindtii* was present in the lake although not collected very often since it tends to migrate vertically within the water column. It is extremely transparent and may not be visible to fish, although fish are known to feed on this large predator. *Leptodora* spp. have been observed to prey on other cladocerans and may be responsible for the low densities present in the lake. Dominant copepods were *Acanthocyclops vernalis* and *Leptodiaptomus ashlandi*, and dominant rotifers were *Collotheca mutabilis*, *Kellicottia longispina*, *Keratella cochlearis*, and *Synchaeta pectinata*. Seasonally, total zooplankton densities peaked in late summer/fall. Densities peaked at 100 individuals/L and 140 individuals/L at Cle Elum midlake site CLE2, in the 0 to 10 m depth stratum in August and September 2004, respectively (Figure 38) as a result of rotifer blooms. Greater densities occurred at uplake and midlake sites CLE1 and CLE2 than near the dam (CLE3). Typically, zooplankton densities were below 30 individuals/L from spring through mid-summer when rotifers were not in bloom.

Copepod nauplii and copepod densities exhibited bimodal peaks in late spring and again in late summer/fall, whereas rotifers and cladocerans peaked in late summer/fall 2004 (Figures 39 and 40). Copepod nauplii densities of 20 individuals/L peaked in fall 2003 in the 10 to 20 m depth stratum at the midlake site. During 2004, densities peaked at only about 8 individuals/L for the same time period. Copepod nauplii appeared to be evenly distributed throughout the water column, from surface to 30 m at the midlake site CLE2, with greater densities in spring and fall. Adult copepod densities peaked at about 13 individuals/L in early spring in the 0 to 10 m depth stratum at midlake and were relatively abundant in all three depth strata; similar low copepod densities were observed in oligotrophic Twin Lakes, Colorado (Lieberman, 1993). Rotifer densities peaked at 122 individuals/L in late summer 2004 in the 0 to 10 m depth stratum at CLE2 (Figure 40), coinciding at times with copepod and nauplii peaks, and cladoceran blooms. Rotifers were most concentrated in the upper depths of the water column, and relatively few were collected from 20 to 30 m at midlake (CLE2). For comparison, the greatest rotifer densities reported for oligotrophic Twin Lakes, Colorado were 35 individuals/L during early summer. Cladoceran densities peaked in August and September in Cle Elum Lake, and tended to occur in greater concentration uplake in the 0 to 10 m depth stratum (Figure 41). They were relatively sparse during other months and in deeper depth strata. Cladoceran densities reached 18 individuals/L at uplake site CLE1 in August, considerably higher than maximum densities of 4.0 individuals/L reported for oligotrophic Twin Lakes, Colorado during the summer months. Seasonally, total zooplankton densities peaked in late summer/fall.

Total zooplankton densities peaked at 93.02 individuals/L in May 2005 and again in October 2005 at 104.48 individuals/L in the 0 to 10 m depth stratum at CLE2 (Figure 42). Densities reached 122.42 individuals/L in May in the 10 to 20 m depth stratum. The seasonal peaks for total zooplankton are similar to those from the 2003-2004 sampling season when densities peaked in August and September 2004 but were low in May 2004. Maximum density peaks were the result of increased rotifer abundance in the lake. Ranges and means of total zooplankton densities are reported in Table 6. Greatest zooplankton densities occurred in the

0 to 10 m depth stratum, with substantially lower densities in the 20 to 30 m depth stratum. Oftentimes, zooplankton will migrate throughout the water column during daylight hours and migrate up to the surface waters at night (Horne and Goldman, 1994). In Cle Elum Lake, zooplankton are only migrating to about 30 m depth. We conducted some surface to bottom vertical zooplankton tows that showed that few zooplankton were present deeper than 30 m. In addition, total zooplankton densities were consistently lower in the 20 to 30 m depth stratum compared to the 0 to 10 m and 10 to 20 m depth strata (Figure 42). Greater average densities were observed at uplake site CLE1 and at midlake site CLE2 than near the dam (CLE3) in 2004, whereas during the 2005 sampling season zooplankton densities were quite similar at midlake and downlake sites CLE2 and CLE3, respectively. However, in 2005, uplake site CLE1 was dry due to lake drawdown.

Figures 43 and 44 show seasonal cycles of cladoceran and copepod densities, and rotifer densities, respectively. During the 2005 sampling season, copepod densities peaked in May at midlake site CLE2 to downlake site CLE3, and in June at uplake site CLE1 where they were the dominant zooplankton group. Rotifer densities peaked in May as copepod densities decreased. During June, densities of cladocerans increased. Copepods were collected to 30 meters depth, whereas cladocerans and rotifers were prevalent in the upper 20 meters of the water column (Figs. 43, 44). The observed alternating peaks in the three major zooplankton taxa can be explained in part by avoidance of competition for food and habitat in this relatively unproductive lake (Orcutt and Pace, 1984).

Table 7 shows range and mean of copepod and cladoceran densities at each depth stratum at midlake (CLE2) and downlake (CLE3) sites. There were greater mean copepod densities in the 0 to 10 m depth stratum at midlake site CLE2 than at the downlake site CLE3, but greater mean cladoceran densities in the 0 to 10 m depth stratum downlake (CLE3) than at midlake site CLE2. Maximum densities for both copepods (13.84 individuals/L) and cladocerans (14.40 individuals/L) occurred at downlake site CLE3 (Figures 45 and 46). These copepod and cladoceran maximum densities are very similar to the low levels reported for 2004. Nauplii were well distributed throughout the lake and peaked at various times throughout the sampling period (Figure 45). Greatest nauplii densities of 19.02 individuals/L occurred in October 2005 at CLE2 at the 10 to 20 m depth stratum. No zooplankton sampling occurred at uplake site CLE1 from August through October because the lake was drawn down.

Maximum rotifer densities peaked at 104.79 individuals/L in May 2005 in the 0 to 10 m depth stratum at CLE3 and peaked at 101.79 individuals/L in May 2005 in the 10 to 20 m depth stratum at CLE2 (Figure 44). Mean rotifer densities were 44.85 individuals /L in the 0 to 10 m depth stratum, 33.70 individuals /L in the 10 to 20 m depth stratum, 6.71 individuals /L in the 20 to 30 m depth stratum at CLE2; and 35.42 individuals/L at CLE3. Rotifers were most concentrated in the upper depth strata of the water column, and relatively few were collected from the 20 to 30 m depth stratum at midlake site CLE2.

Table 5. Zooplankton species collected monthly from September 2003 to October 2005 except for the winter months from all sites at Cle Elum Lake.

Cladocera	*Cyclopoid copepodid*	*Gastropus hypotus*
Bosmina longirostis	*Diacyclops thomasi*	*Gastropus stylifer*
Chydorus sphaericus	*Leptodiaptomus ashlandi*	*Hexarthra mira*
Daphnia rosea	*Mesocyclops edax*	*Kellicottia longispina*
Daphnia juveniles	**Rotifera**	*Keratella cochlearis*
Daphnia pulex	*Aplanchna* spp.	*Keratella quadrata*
Holopedium gibberum	*Aplanchna priodonta*	*Lecane* spp.
Leptodora kindtii	*Brachionus caudatus*	*Notholca striata*
Pleuroxus striatus	*Brachionus quadradentatus*	*Ploesoma* spp.
Immature cladocerans	*Collotheca mutabilis*	*Polyarthra vulgaris*
Copepoda	*Conochiloides dossuarius*	*Synchaeta pectinata*
Acanthocyclops vernalis	*Conochiloides unicornis*	unidentified rotifers
Calanoid copepodid	*Filinia longiseta*	

Table 6. Range and mean of zooplankton densities (n = 7) at sites CLE2 and CLE3 in Cle Elum Lake during the May 2005 to October 2005 sampling period.

Site	Zooplankton Densities (individuals/L) range	Zooplankton Densities (individuals/L) mean
CLE2 (0 to 10m)	22.95 – 104.48	55.57
CLE2 (10 to 20m)	15.86 – 122.42	46.53
CLE2 (20 to 30m)	1.97 – 31.97	17.25
CLE3 (0 to 10m)	14.44 - 112.16 .	44.17

Table 7. Range and mean of copepod and cladoceran densities (n = 7) at sites CLE2 and CLE3 in Cle Elum Lake during the May 2005 to October 2005 sampling period.

Site	Copepod Densities (individuals/L) range	Copepod Densities (individuals/L) mean	Cladoceran Densities (individuals/L) range	Cladoceran Densities (individuals/L) mean
CLE2 (0 to 10m)	0.69-10.32	4.24	0.00-5.79	2.82
CLE2 (10 to 20m)	1.21 – 5.98	3.54	0.00-2.73	1.37
CLE2 (20 to 30m)	0.12-4.52	2.48	0.00-0.378	0.14
CLE3 (0 to 10m)	0.18-13.84	3.05	0.21-14.40	3.37

Twenty-seven zooplankton species were collected from Bumping Lake (Table 8). The dominant cladoceran species were *Daphnia rosea*, Bosmina longirostris, and *Holopedium gibberum*; the large cladoceran, *Leptodora kindtii* was collected infrequently. Dominant copepod species were *Diacyclops thomasi*, *Hesperodiaptomus franciscanus*, and dominant rotifer species were *Conochilus unicornis*, *Filinia longiseta*, *Kellicottia longispina*, and *Synchaeta pectinata*. *Holopedium gibberum* is also a large omnivorous cladoceran that mainly filters phytoplankton, and in some cases it has been found to consume mostly nannoplankton (very small phytoplankton). *Holopedium gibberum* seems to be adapted to areas where food is scarce. The organism undergoes a diel migration and moves toward the surface near sunset and returns to deeper waters during the daylight hours.

Rotifers dominated total zooplankton densities in Bumping Lake throughout the sampling period (Figure 47). Maximum zooplankton densities reached about 70 individuals/L in July and again in August at midlake site BMP2 in the 10 to 20 m depth stratum. A total of about 130 individuals/L were collected in the 0 to 30 m depth stratum for this same sampling period. This is comparable to the greatest zooplankton densities of 110 individuals/L reported for oligotrophic high montane Twin Lakes in Colorado (Lieberman, 1993).

Table 8. Zooplankton species collected from September 2003 to October 2004 except during the winter months from all sites in Bumping Lake.

Cladocerans	*Hesperodiaptomus franciscanus*	*Gastropus hypotus*
Bosmina longirostis	*Mesocyclops edax*	*Gastropus stylifer*
Daphnia rosea	**Rotifers**	*Hexarthra mira*
Daphnia juv	*Aplanchna spp.*	*Kellicottia longispina*
Daphnia pulex	*Aplanchna priodonta*	*Keratella cochlearis*
Holopedium gibberum	*Brachionus caudatus*	*Keratella quadrata*
cladocerans immature	*Brachionus quadradentatus*	*Lecane spp.*
Copepods	*Chromogaster spp.*	*Notholca striata*
Calanoid copepodid	*Collotheca mutabilis*	*Ploesoma spp.*
copepodid	*Conochiloides dossuarius*	*Polyarthra vulgaris*
Cyclopoid copepodid	*Conochiloides unicornis*	*Synchaeta pectinata*
Diacyclops thomasi	*Filinia longiseta*	unknown rotifers

Typically, densities were below 40 individuals/L and densities were low in the deeper stratum (20 to 30 m). Zooplankton were most abundant at BMP2 in the 10 to 20 m depth stratum, particularly during July, August, and September.

Copepod densities in Bumping Lake were substantially lower than in Cle Elum Lake (Figure 48). Maximum copepod nauplii densities were 2.5 individuals/L and adult copepod densities were 1.8 individuals/L. Nauplii seasonal peaks occurred in May at uplake site BMP1 and in July at the midlake site BMP2. Nauplii were more abundant and for a longer period of time in the 0 to 10 m depth stratum at all 3 sites. They were less abundant and occurred less frequently in deeper strata. Adult copepods were more abundant during July and August at BMP1 and in the 10 to 20 m depth stratum at BMP2 in July.

Rotifers comprised the greatest proportion of total zooplankton in Bumping Lake and were abundant throughout the sampling period (Figure 47). Maximum rotifer densities reached about 70 individuals/L in August in the 10 to 20 m depth stratum at midlake site BMP2 (Figure 49). Rotifers were more abundant in the 0 to 10 m depth stratum at uplake than downlake sites and tended to occur at greater densities in the upper 20 m of the water column.

Cladocerans were more abundant than copepods in Bumping Lake. Cladocerans peaked in July at 17 individuals/L in the 10 to 20 m and 20 to 30 m depth strata at midlake site BMP2 and at 11 individuals/L at downlake site (BMP1) sites; the density increased later in the season to 21 individuals/L in September at uplake site BMP1 (Figure 50). The Bumping Lake zooplankton community consisted predominantly of cladocerans and rotifers, with few copepods. This zooplankton species composition may be an indication of predation on copepods by resident fish. Cropping by fish dictate to some extent the composition of the zooplankton community in a lake, if top-down control of the food base occurs (Frank et al., 2005).

Conclusions

This study revealed that Cle Elum and Bumping lakes in the upper Yakima River basin are relatively unproductive oligotrophic lakes with low nutrient levels, chlorophyll *a* concentrations, phytoplankton biovolume, zooplankton densities, and TOC concentrations. The very low densities of zooplankton may limit the lakes' capacity to support resident fish as well as introduced salmonids such as sockeye salmon. Nutrient enrichment of the lakes may be one method to increase both algal and zooplankton production to sustain a viable fishery. A detailed study on the potential enhancement of productivity by nutrient enrichment of these relatively unproductive lakes and perhaps tributaries would provide Reclamation managers an opportunity to assess the likelihood of successful reintroductions of anadromous salmonids based on whether or not the reservoir has the food base sufficient to support reintroduction or restoration of anadromous fish populations.

Data from the second year of this study in 2005 indicated that Cle Elum appeared even less productive in terms of nutrients, chlorophyll, and zooplankton than was found during the 2003-2004 sampling season. Secchi depths were lower and decreased in 2005, which may have been due to the lake drawdown and an increased amount of inorganic material in the lake. This in turn may have caused decreased water clarity resulting in lower algal densities (as measured by chlorophyll *a*), and in turn lower zooplankton densities. Conditions during the drawdown of the lake in 2005 may be illustrative of what might occur to water quality conditions during a severe drought year. It appears that under such a scenario, Cle Elum Lake would remain oligotrophic and the food base might be affected somewhat from the lake being drawn down to historic lows.

Acknowledgements

Funding for this study was provided by Bureau of Reclamation, Pacific Northwest Region Reclamation, Boise, Idaho. Many thanks to Andrew Montano for assisting in the limnological surveys and to numerous others from both Reclamation and elsewhere for support and guidance in this study.

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Appendix A

Figures

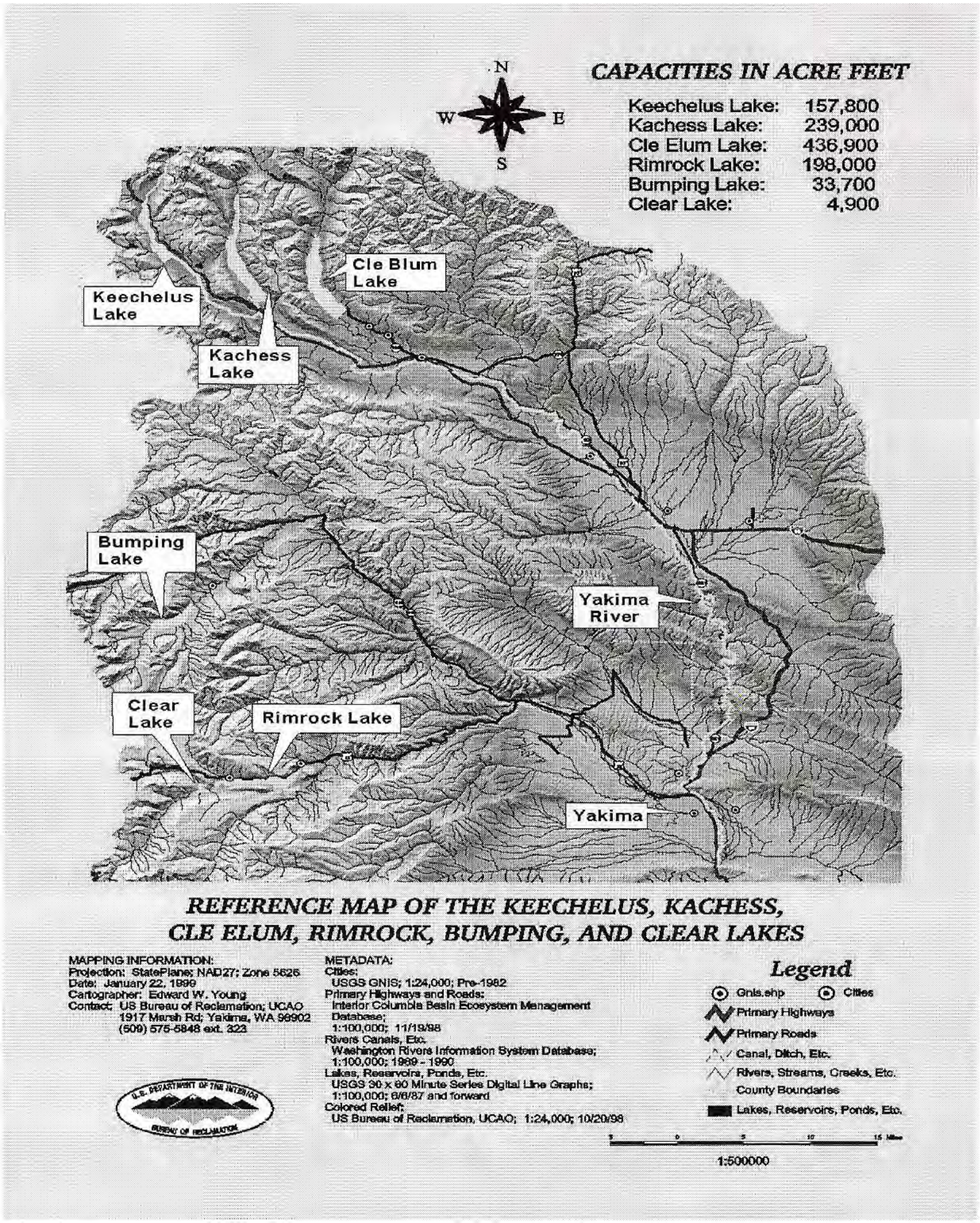


Fig. 1. Map of the Upper Yakima Basin lakes in Washington State.

Fig. 2. Contour map of Cle Elum Lake, Washington.

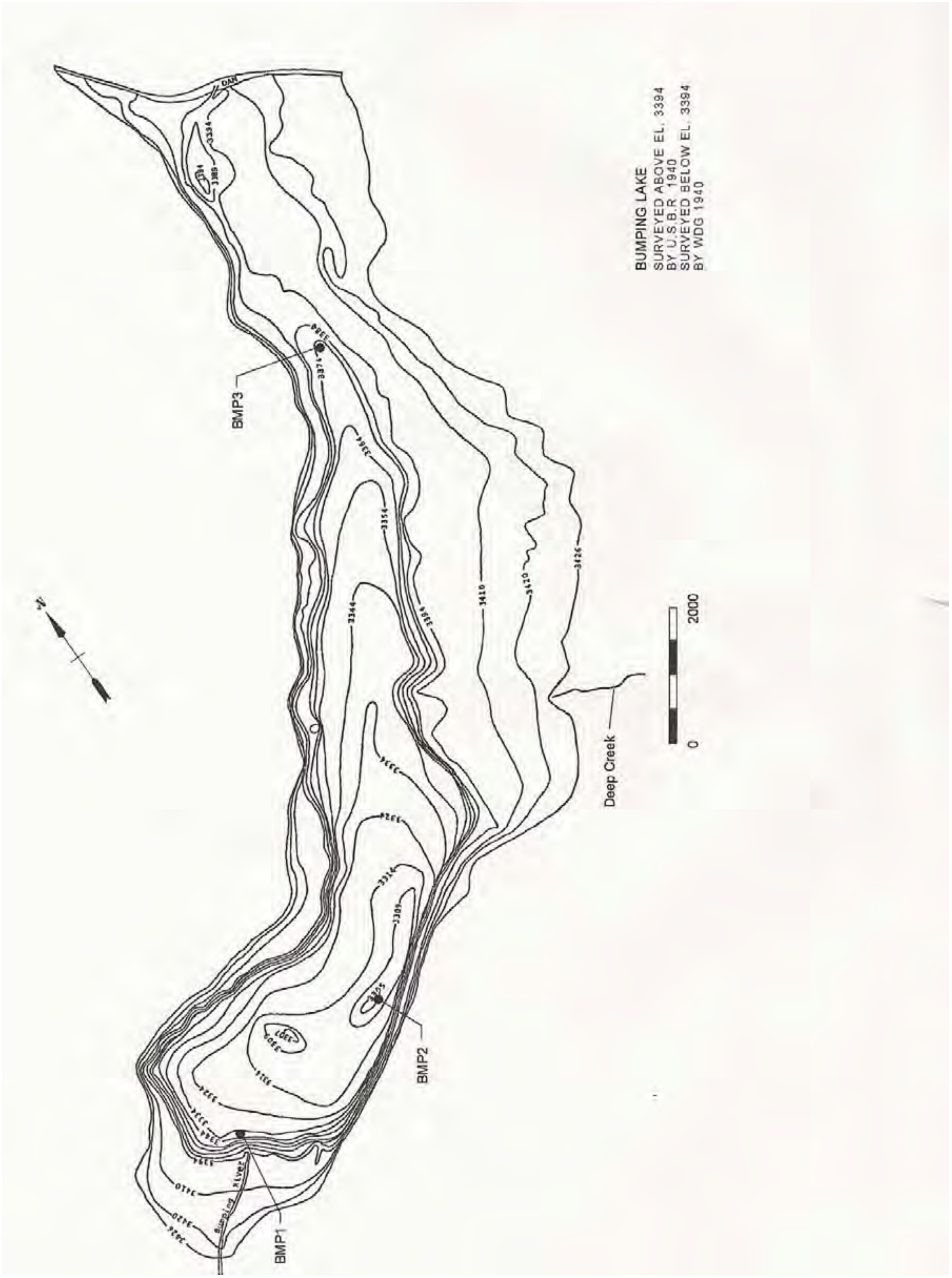
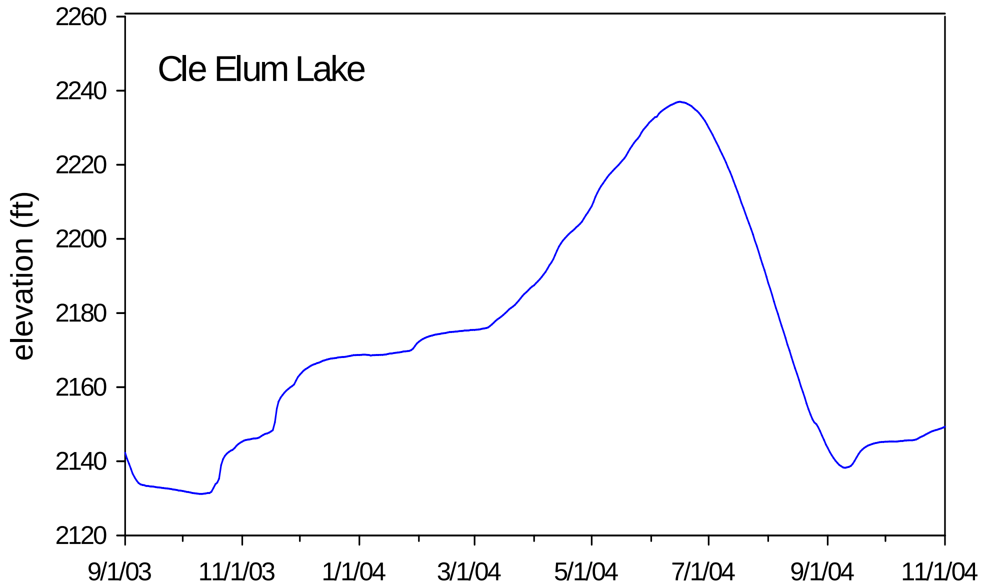


Fig. 3. Contour map of Bumping Lake, Washington.

a



b

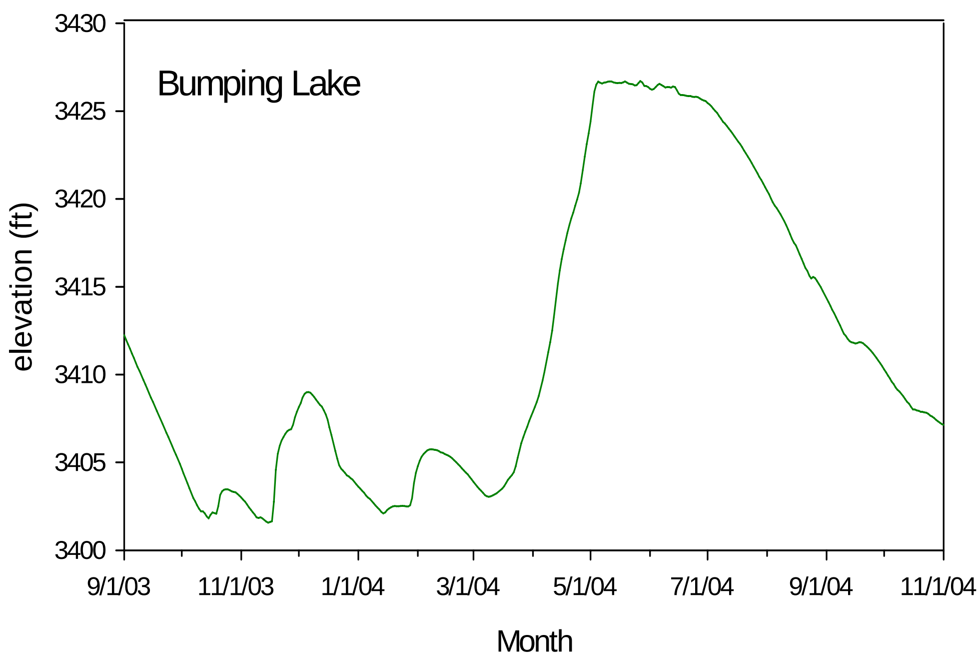


Fig. 4. Lake elevation of a) Cle Elum Lake, and b) Bumping Lake from September 2003 to November 2004.

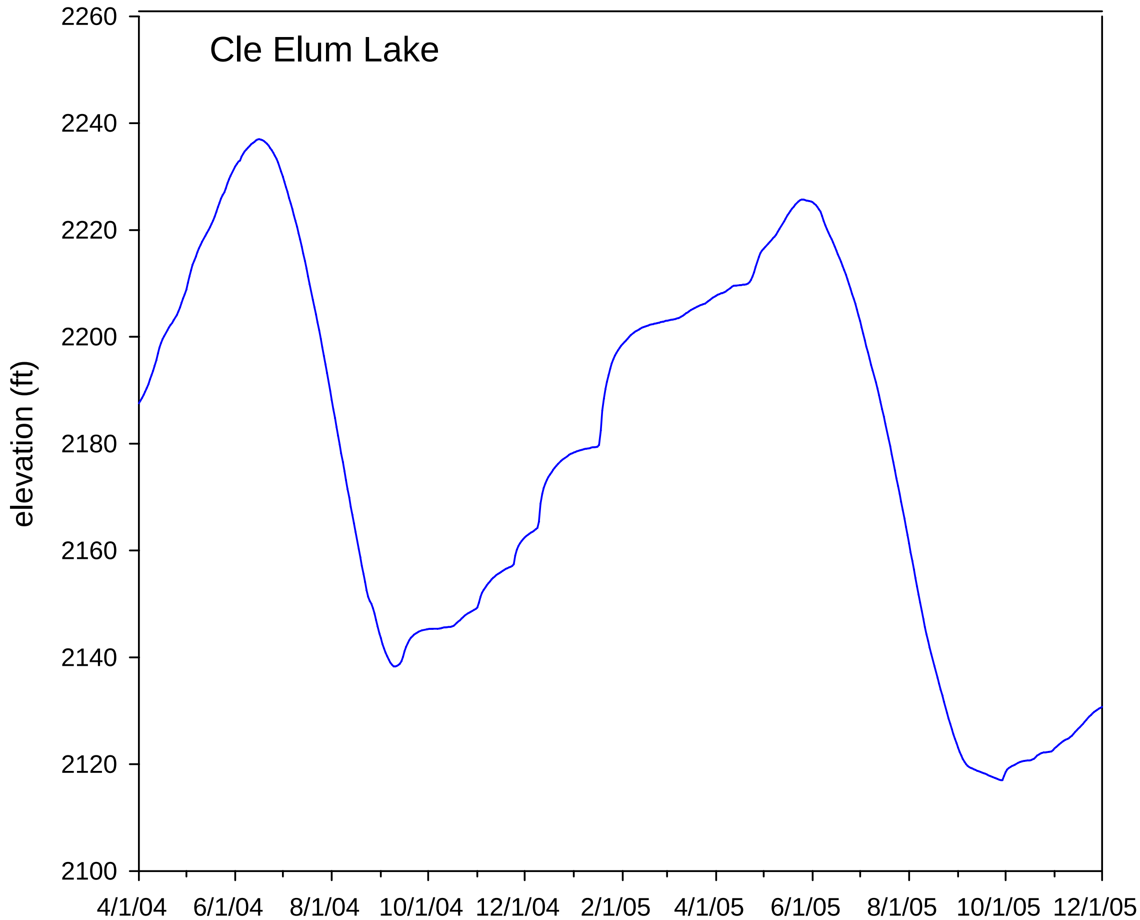


Fig. 5. Lake elevation of Cle Elum Lake from April 2004 to December 2005.

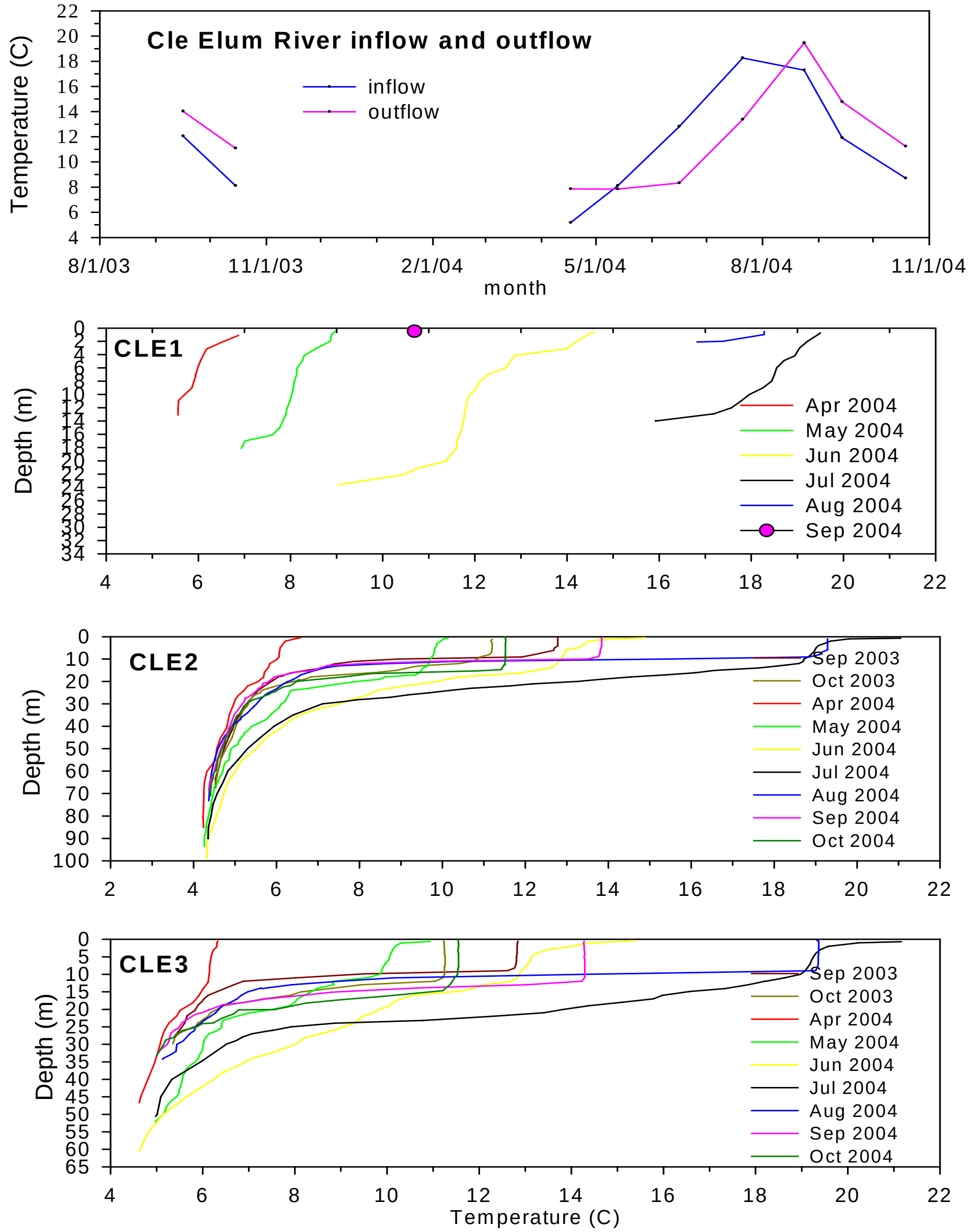


Figure 6. Water temperatures at inflow and outflow sites. Water temperature profiles at Cle Elum Lake site CLE1, CLE2, and CLE3. Site CLE1 was too shallow to sample during September and October 2003, and October 2004.

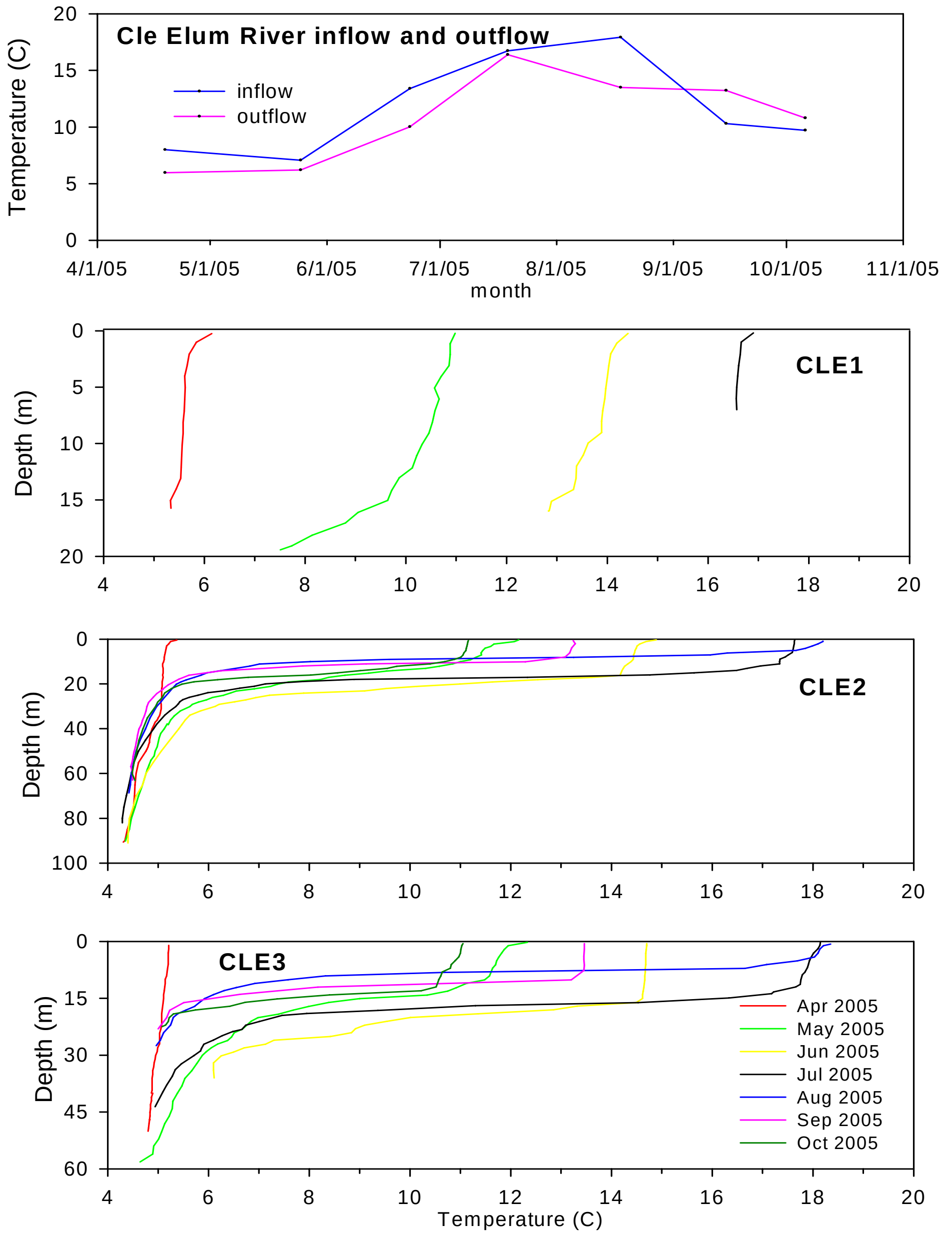


Figure 7. Water temperatures at Cle Elum River inflow and outflow sites. Water temperature profiles at Cle Elum Lake sites CLE1, CLE2, and CLE3. CLE1 site was too shallow to sample from August through October 2005.

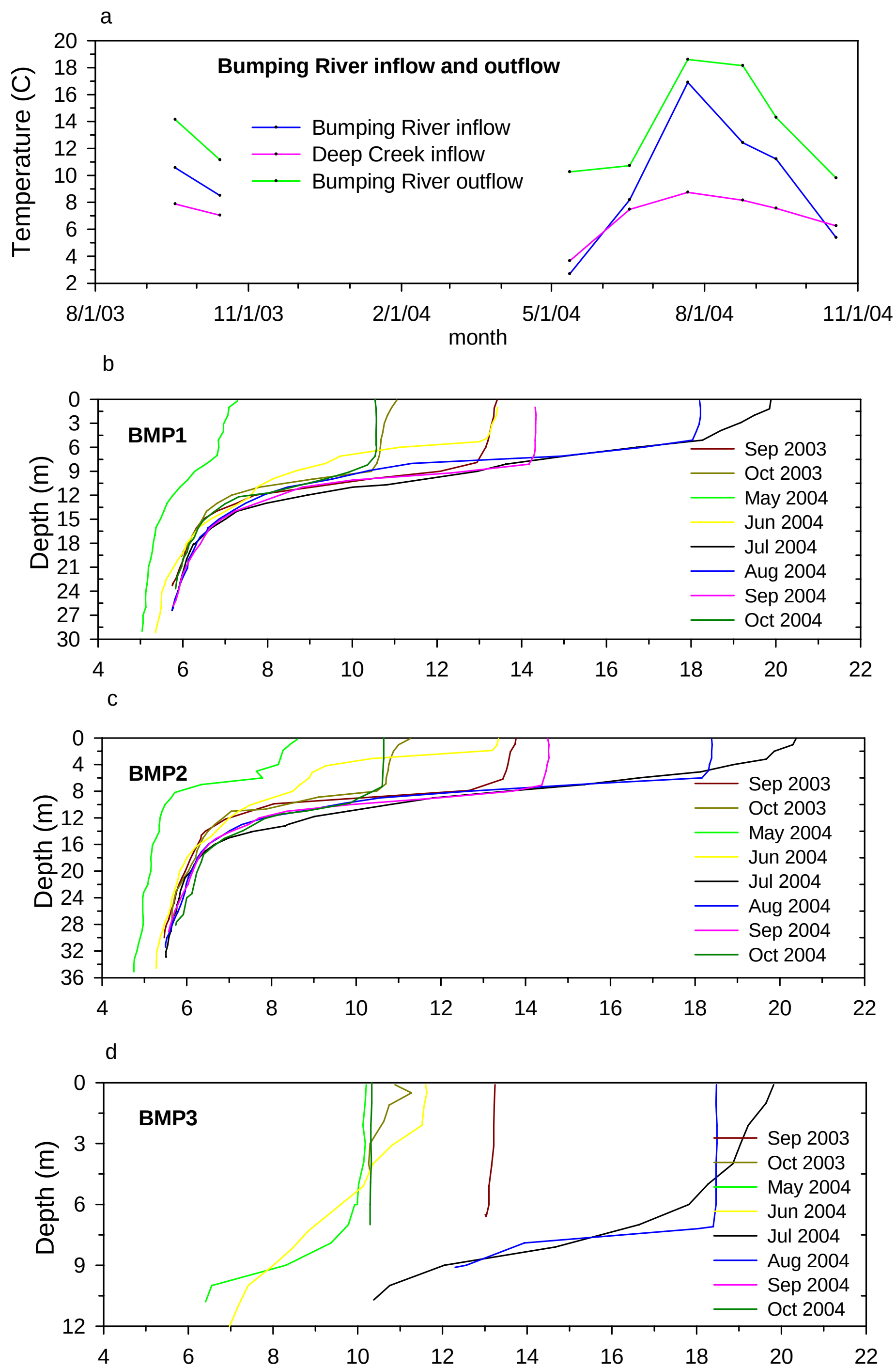


Figure 8. Water temperatures at Bumping River inflow and outflow sites (a). Water temperature profiles at BMP1 site (b), BMP2 site (c), and BMP3 site (d). Sites were not sampled in April 2004.

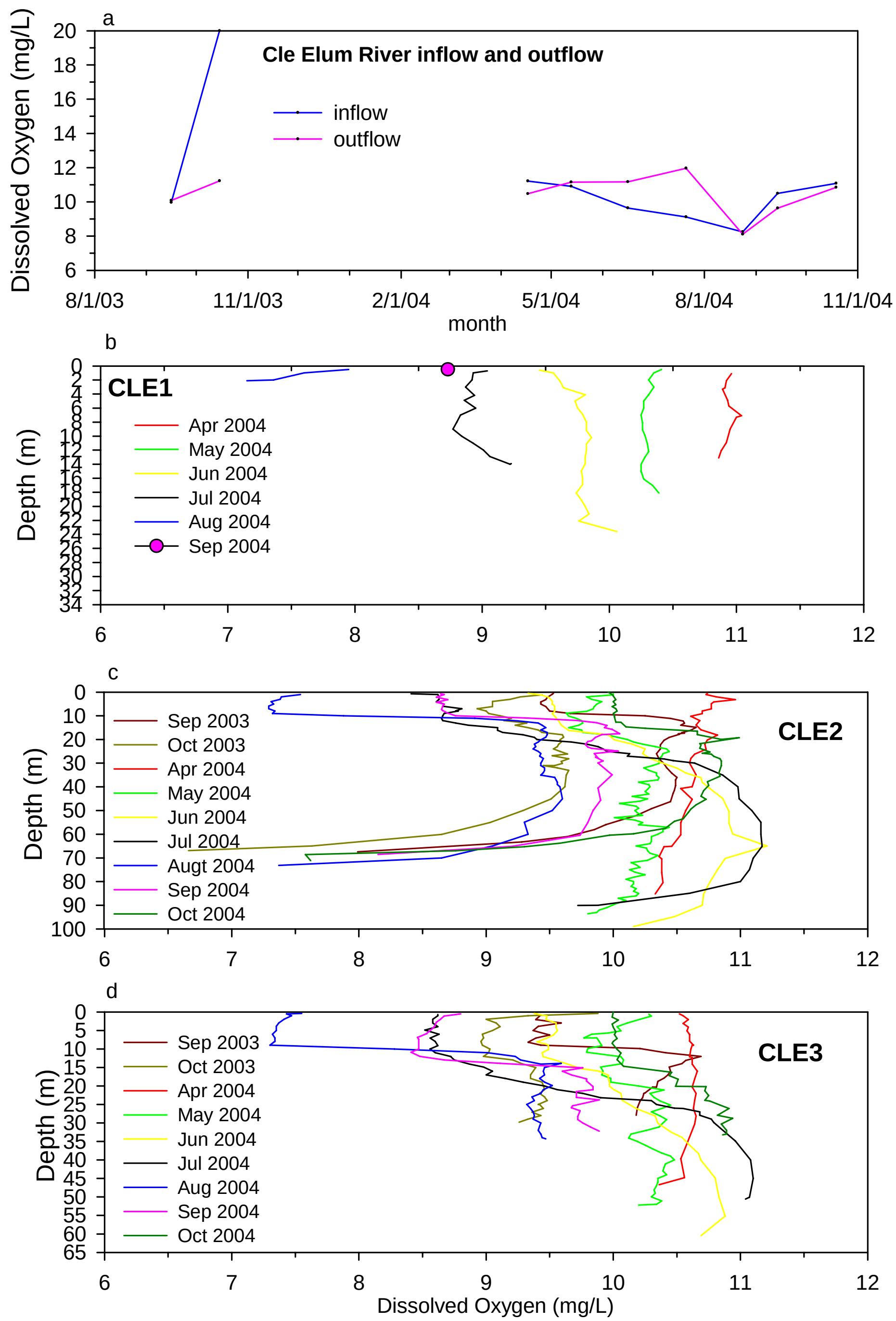


Figure 9. Dissolved oxygen at Cle Elum River inflow and outflow sites (a). Dissolved oxygen profiles at CLE1 site (b), CLE2 site (c), and CLE3 site (d). CLE1 site was too shallow to sample during September to October 2003, and October 2004.

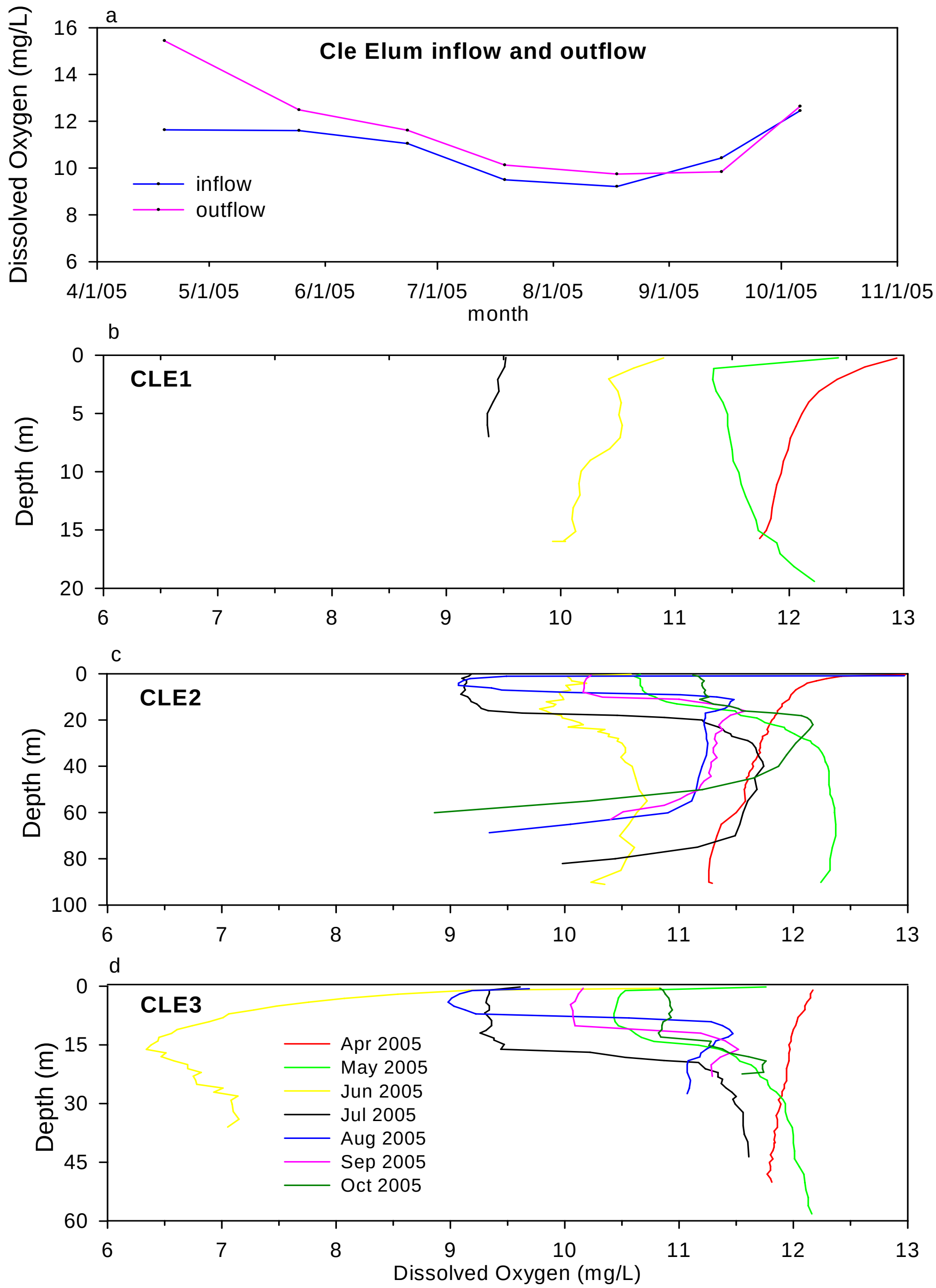


Figure 10. Dissolved oxygen at Cle Elum River inflow and outflow sites (a). Dissolved oxygen profiles at CLE1 site (b), CLE2 site (c), and CLE3 site (d). CLE1 site was too shallow to sample from August through October 2005.

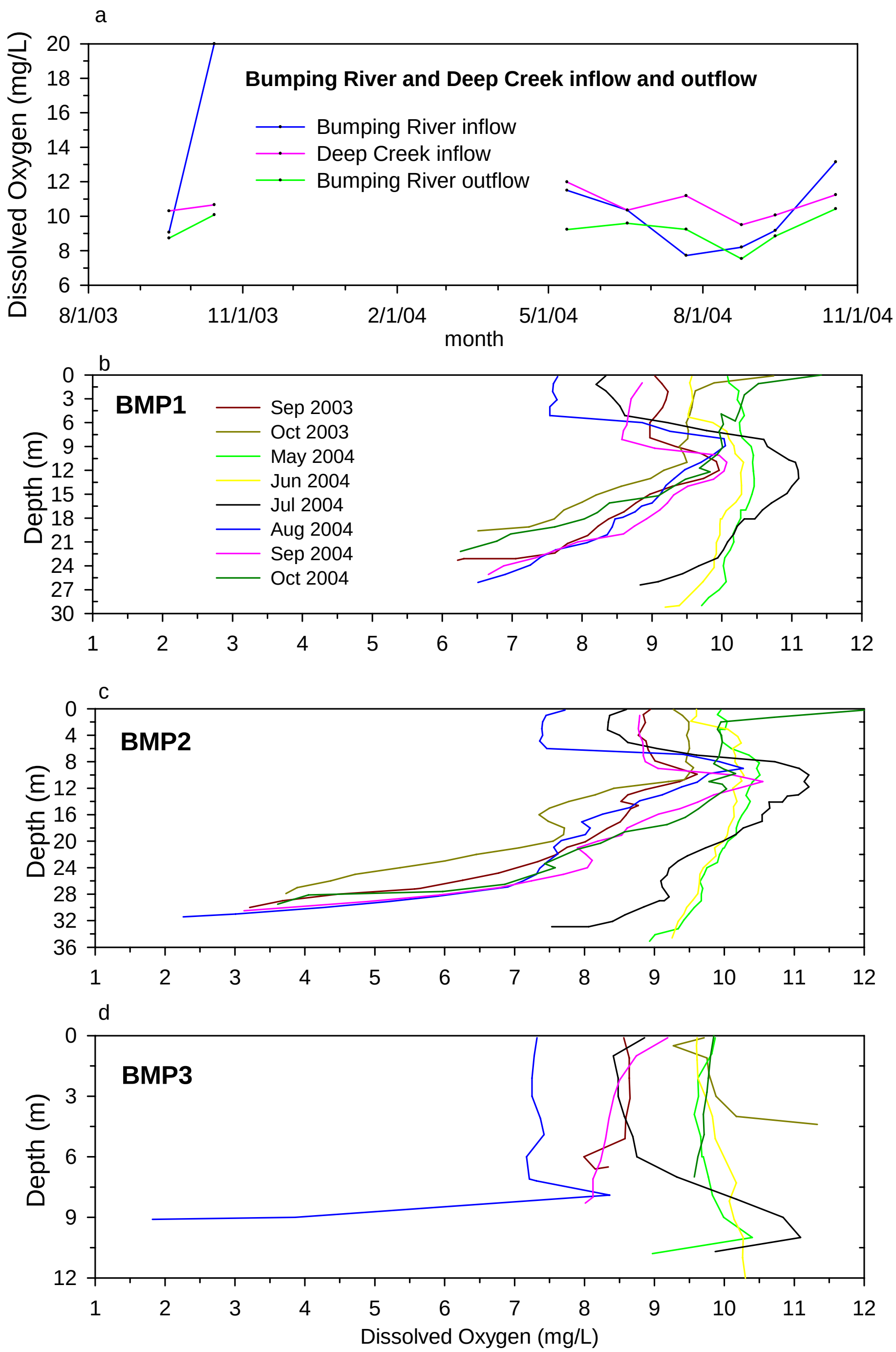


Figure 11. Dissolved oxygen at Bumping River and Deep Creek inflow and outflow sites (a). Dissolved oxygen profiles at BMP1 site (b), BMP2 site (c), and BMP3 site (d). Sites were not sampled in April 2004.

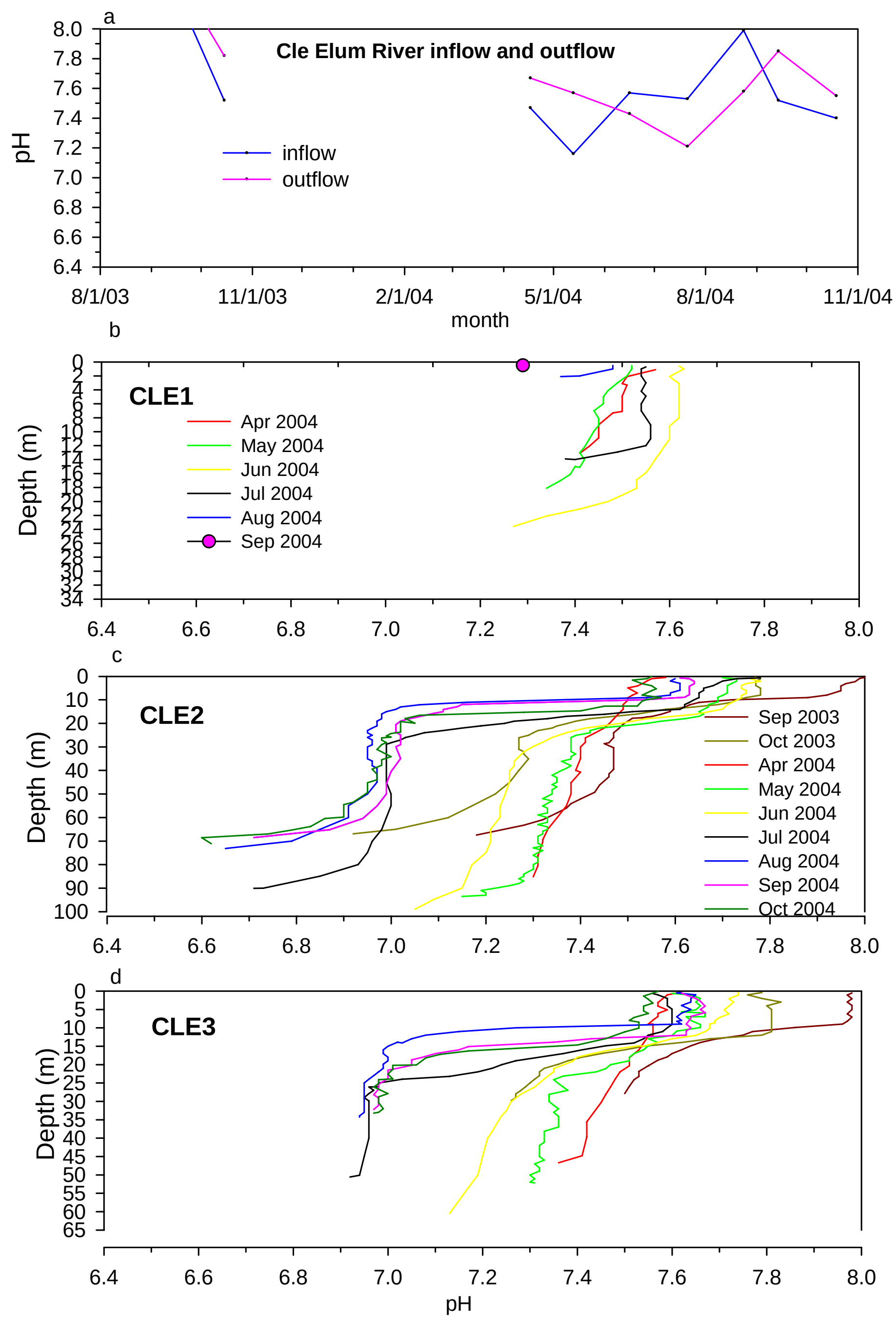


Figure 12. pH at Cle Elum River inflow and outflow sites (a). The pH profiles at CLE1 site (b), CLE2 site (c), and CLE3 site (d). Site CLE1 was too shallow to sample during September and October 2003, and October 2004.

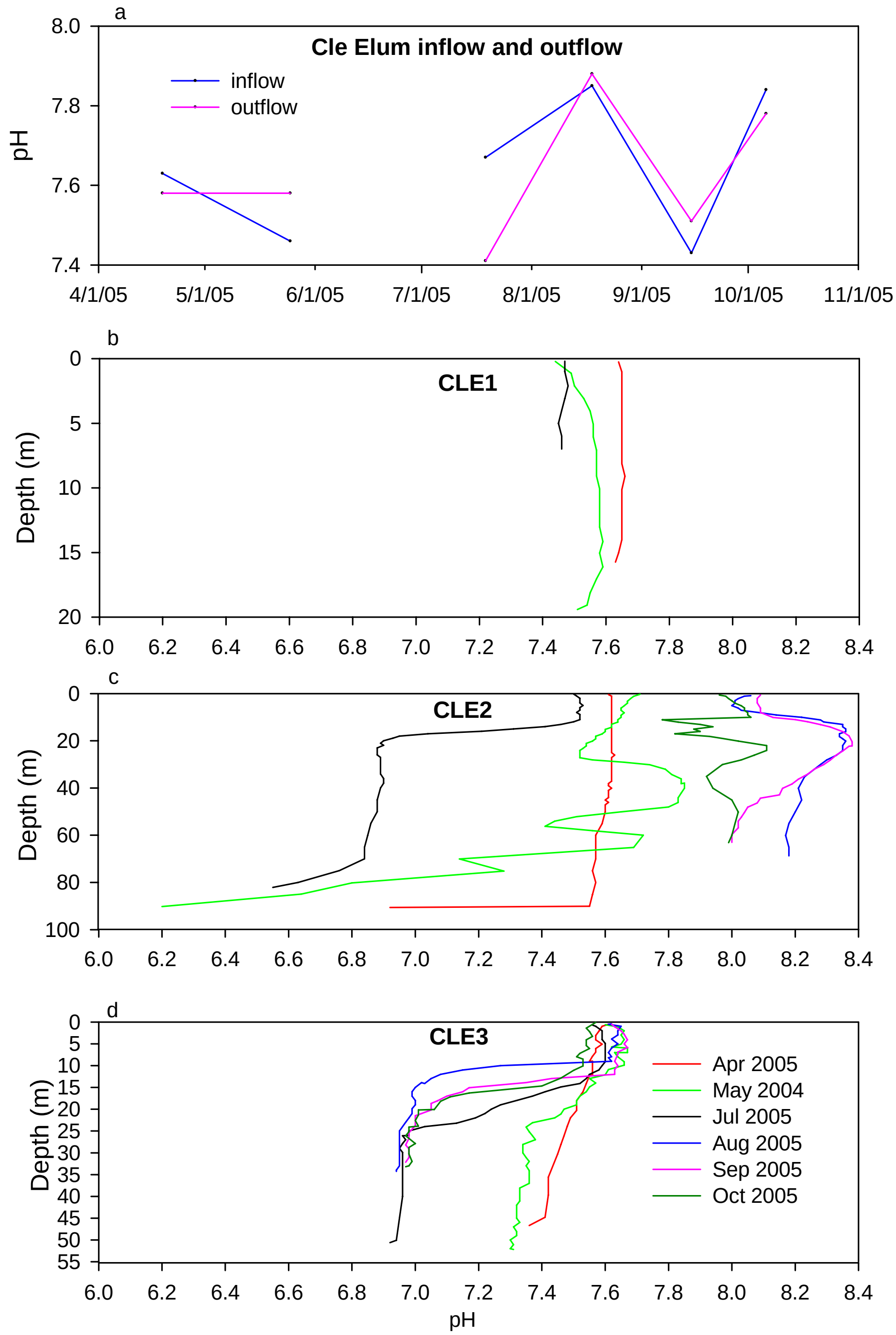


Figure 13. The pH at Cle Elum River inflow and outflow sites (a). The pH profiles at CLE1 site (b), CLE2 site (c), and CLE3 site (d). Site CLE1 was too shallow to sample from August through October 2005. Data for June 2005 are not reported due to a broken pH probe.

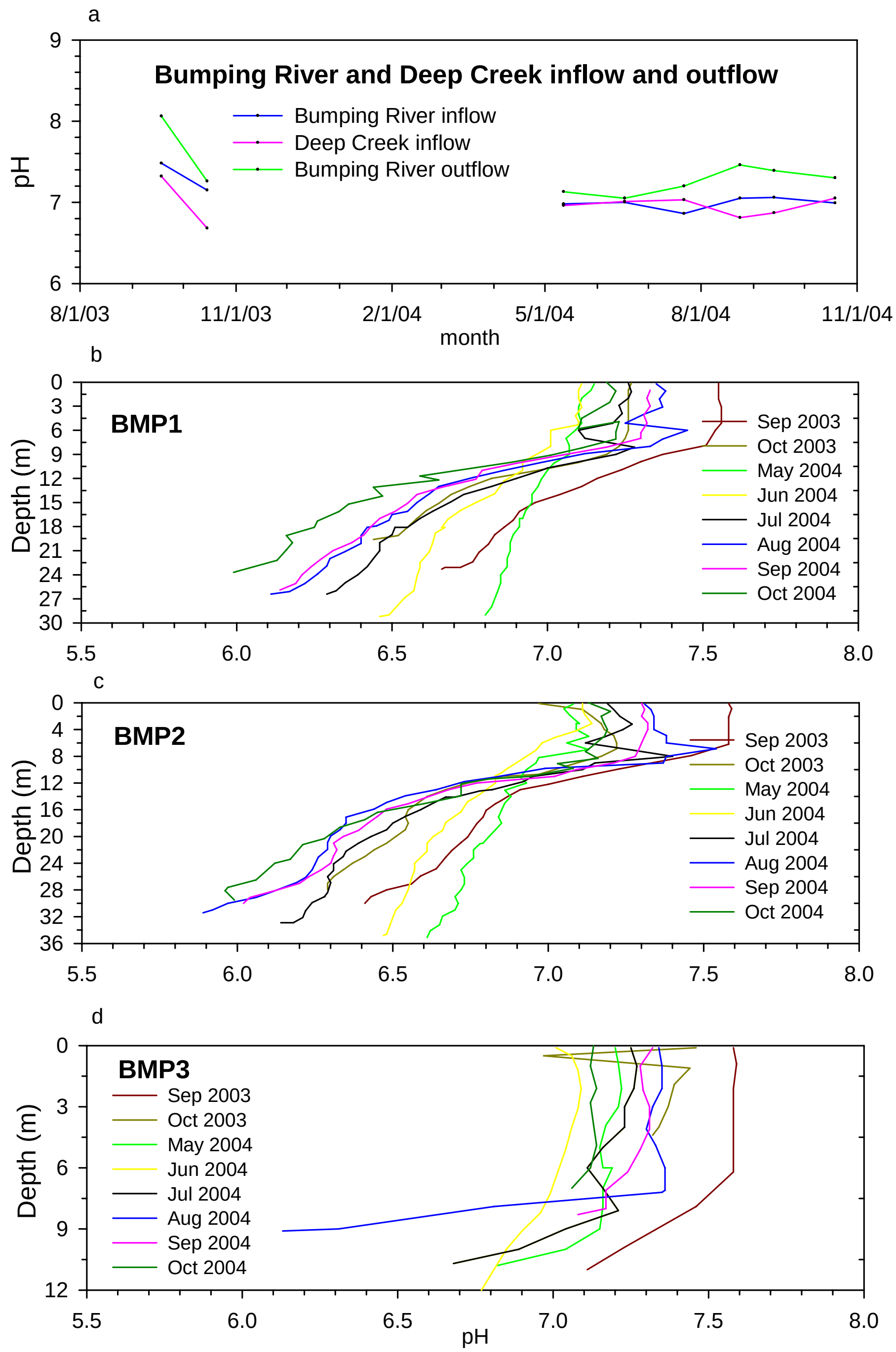


Figure 14. The pH levels at Bumping River and Deep Creek inflow and outflow sites (a). The pH profiles at BMP1 site (b), BMP2 site (c), and BMP3 site (d). Sites were not sampled in April 2004.

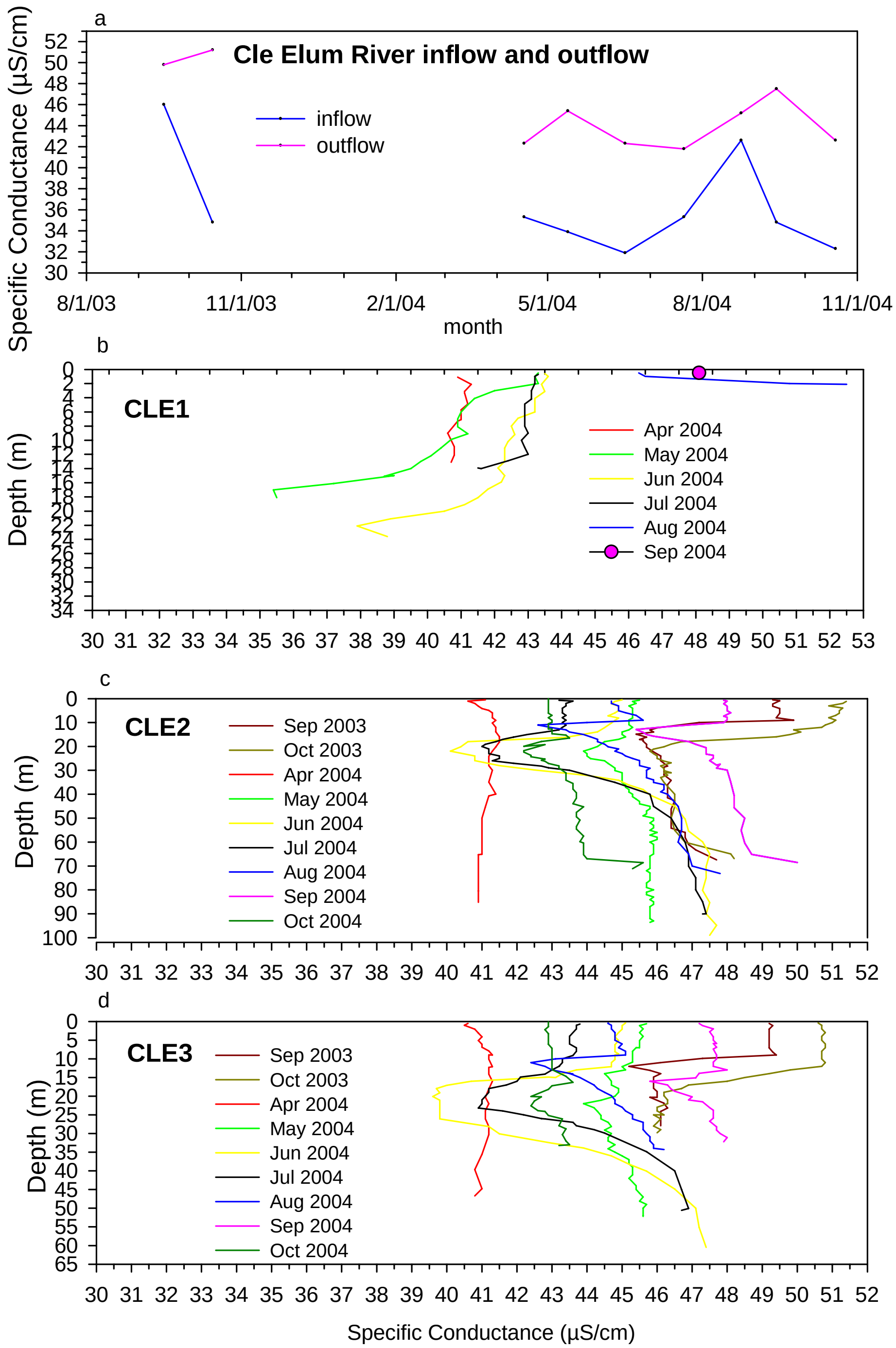


Figure 15. Specific conductance at Cle Elum River inflow and outflow sites (a). Specific conductance profiles at CLE1 site (b), CLE2 site (c), and CLE3 site (d). CLE1 site was too shallow to sample during September to October 2003, and October 2004.

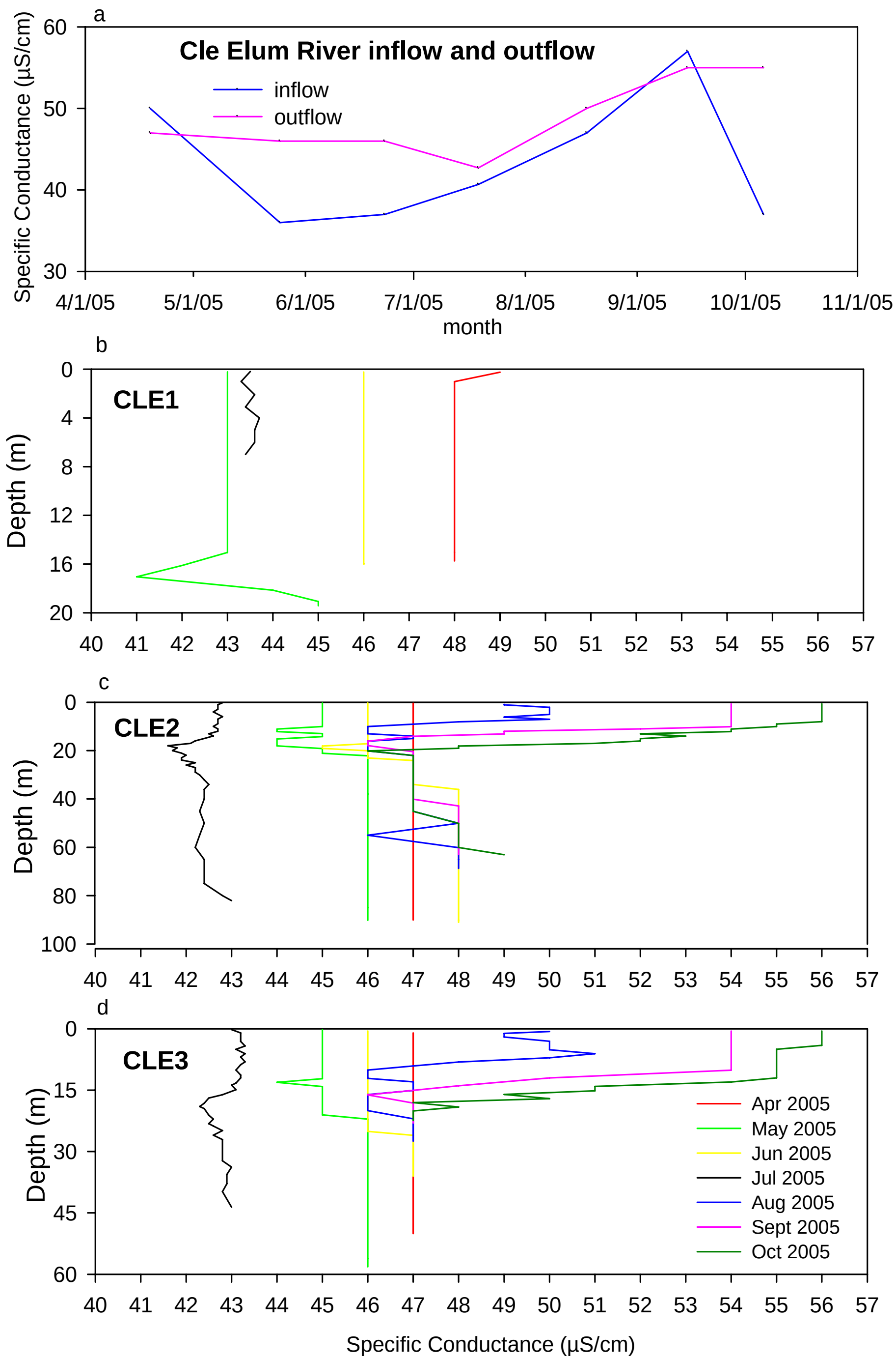


Figure 16. Specific conductance at Cle Elum River inflow and outflow sites (a). Specific conductance profiles at CLE1 site (b), CLE2 site (c), and CLE3 site (d). CLE1 site was too shallow to sample from August through October 2005.

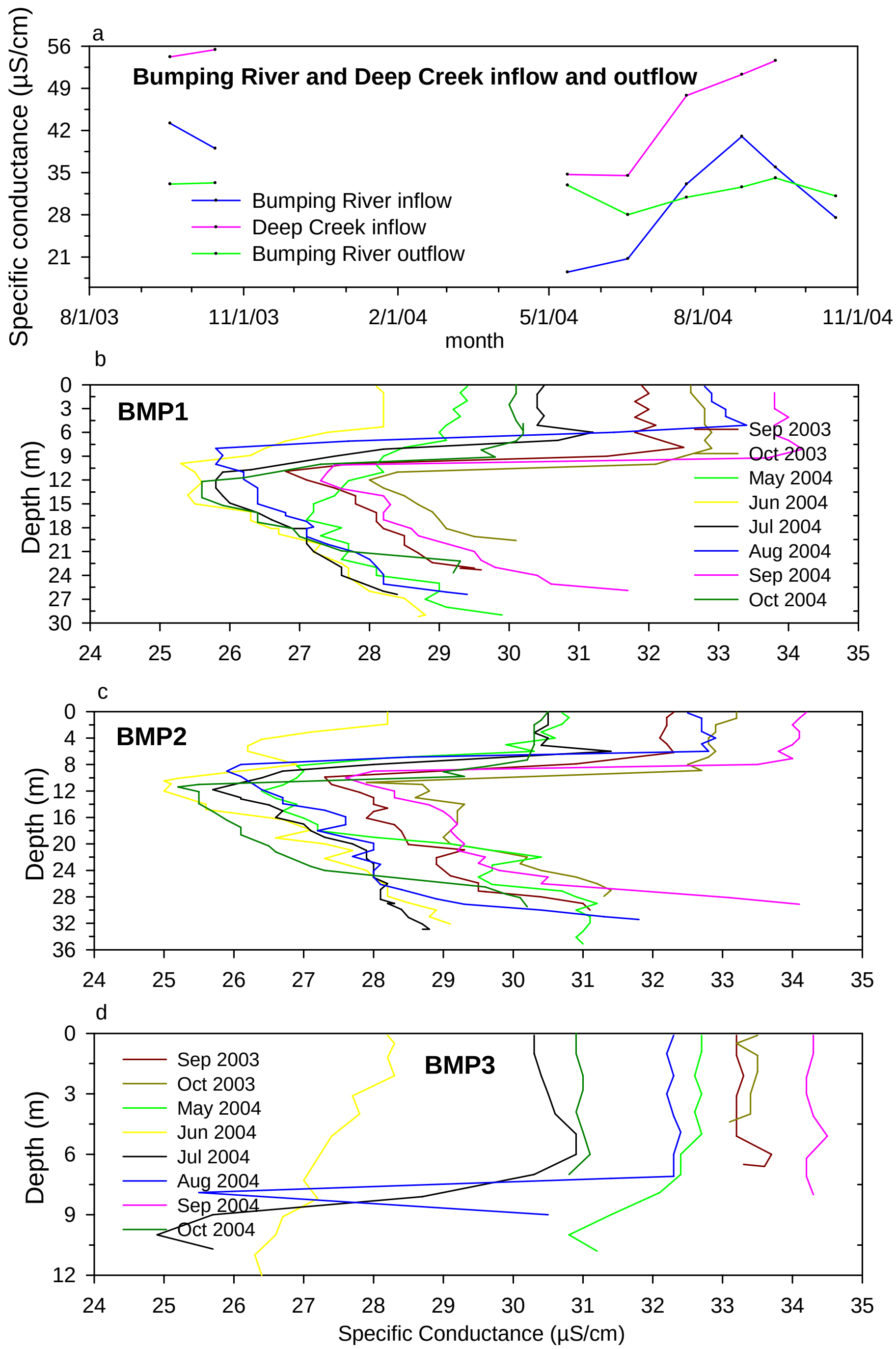


Figure 17. Specific conductance levels at Bumping River and Deep Creek inflow and outflow sites (a). Specific conductance profiles at BMP1 site (b), BMP2 site (c), and BMP3 site (d). Sites were not sampled in April 2004.

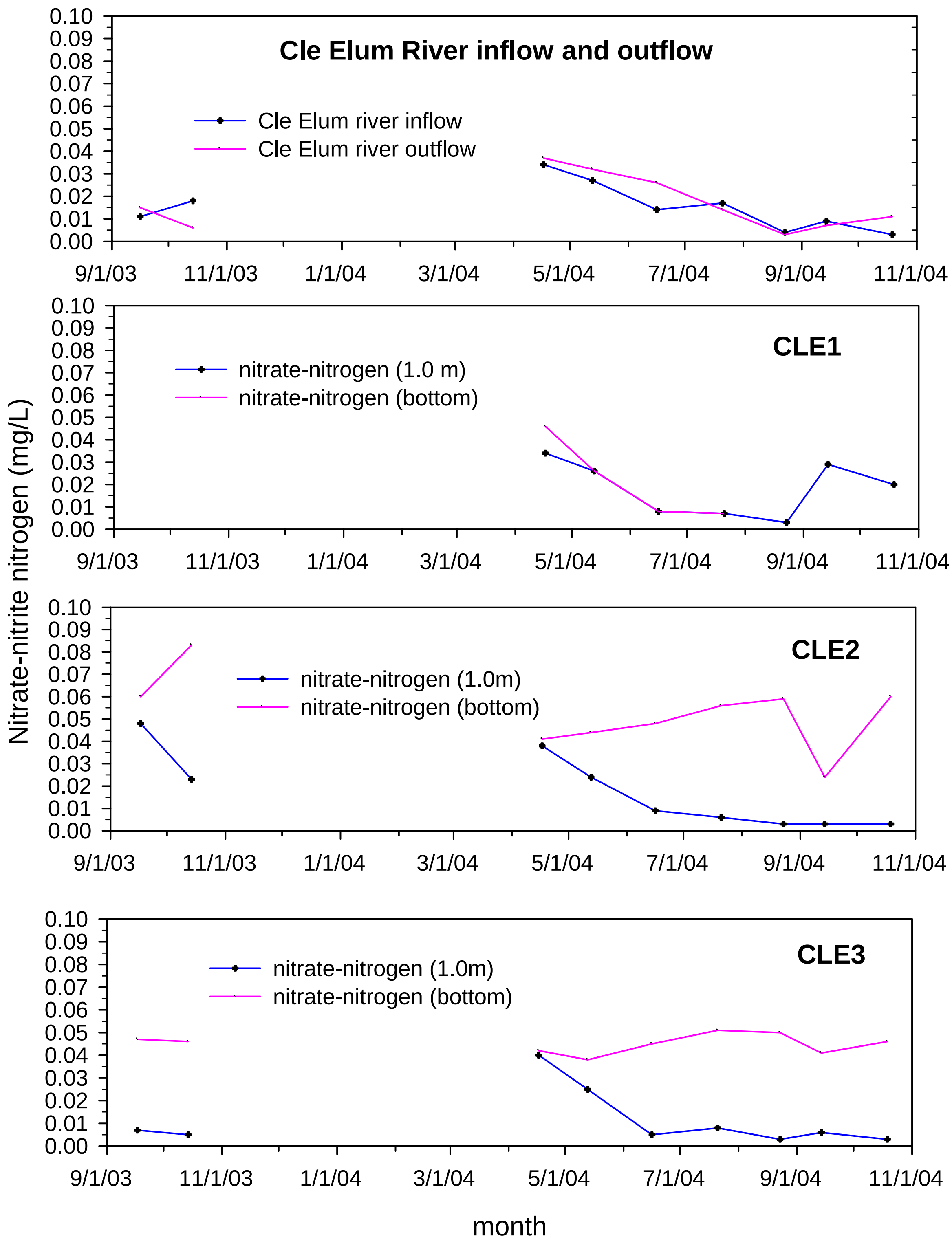


Figure 18. Nitrate-nitrite nitrogen levels at Cle Elum River inflow and outflow (a); and from 1.0 m and bottom depths at lake sites CLE1 (b), CLE2 (c), and CLE3 (d) from September and October 2003 and April to October 2004. Missing data denotes sampling sites were not sampled during those date.

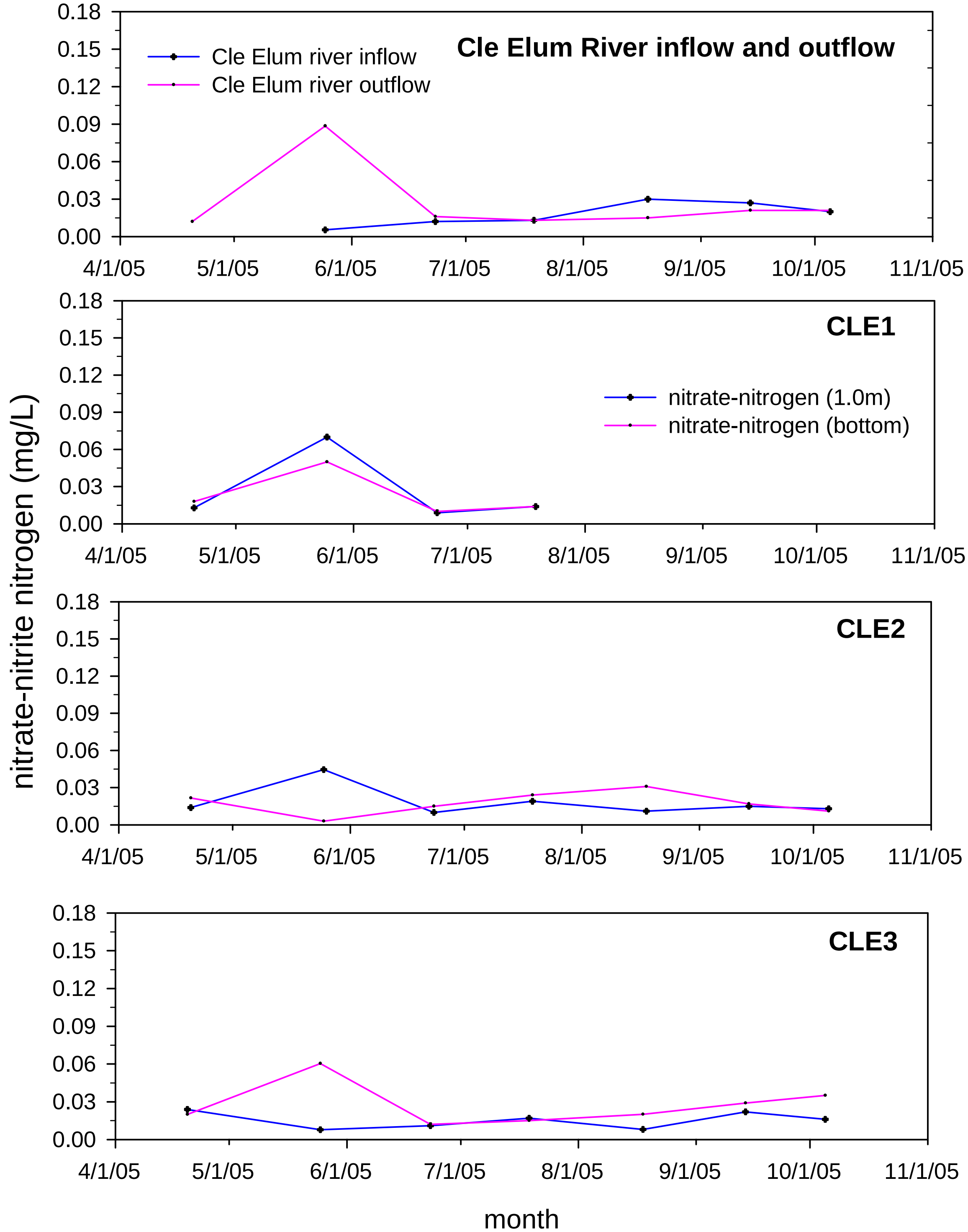


Fig. 19. Nitrate-nitrite nitrogen levels at Cle Elum River inflow and outflow (a); and from 1.0 m and bottom depths at lake sites CLE1 (b), CLE2 (c), and CLE3 (d) from April through October 2005. Missing data denote sampling sites were not sampled during those dates.

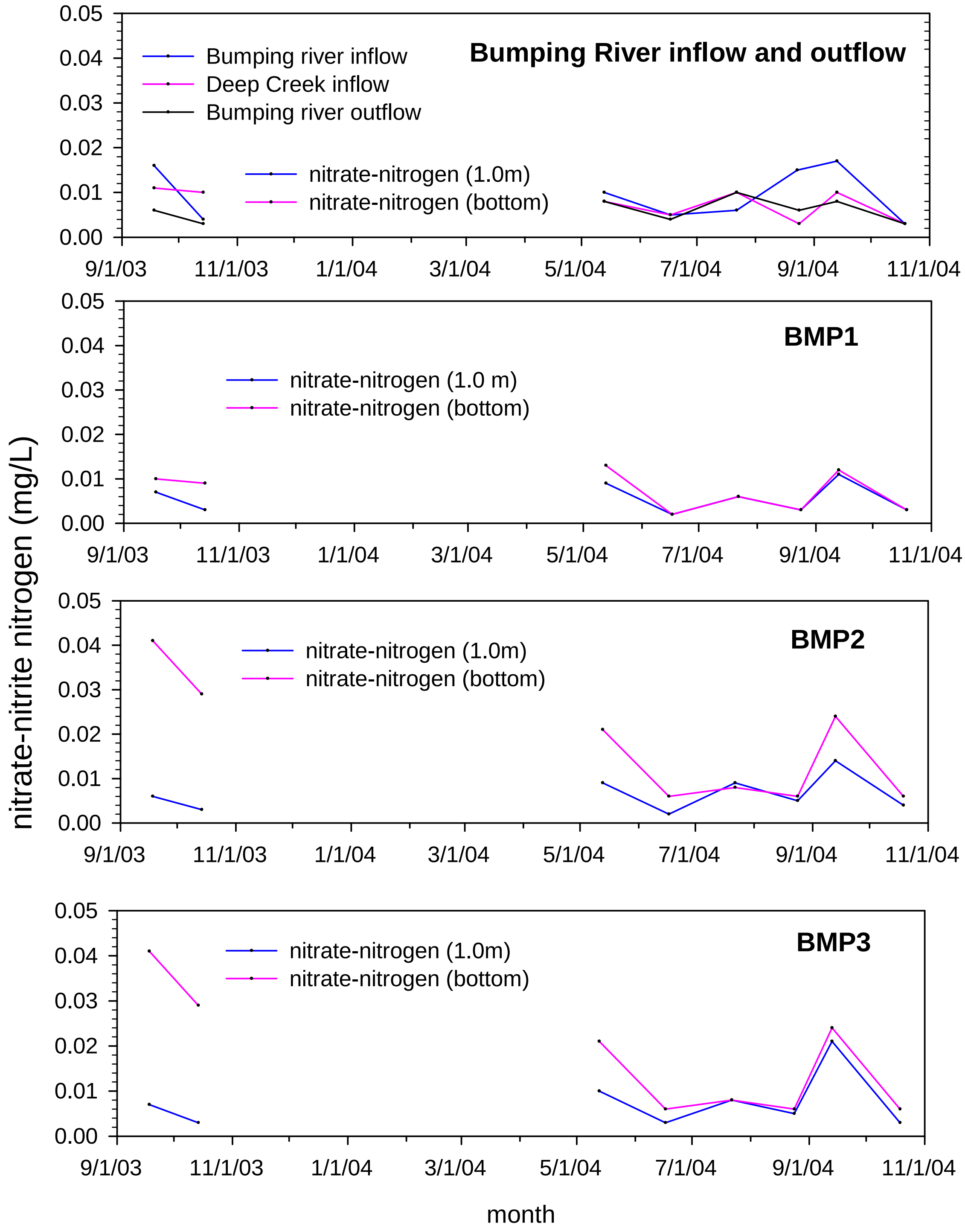


Fig. 20. Nitrate-nitrite nitrogen levels (mg/L) at Bumping River and Deep Creek inflow and outflow (a); and from 1.0 m and bottom depths at lake sites BMP1(b), BMP2 (c), and d) BMP3 (d) fromSeptember and October 2003 and May to October 2004. Missing data denotes sampling sites were not sampled during those dates.

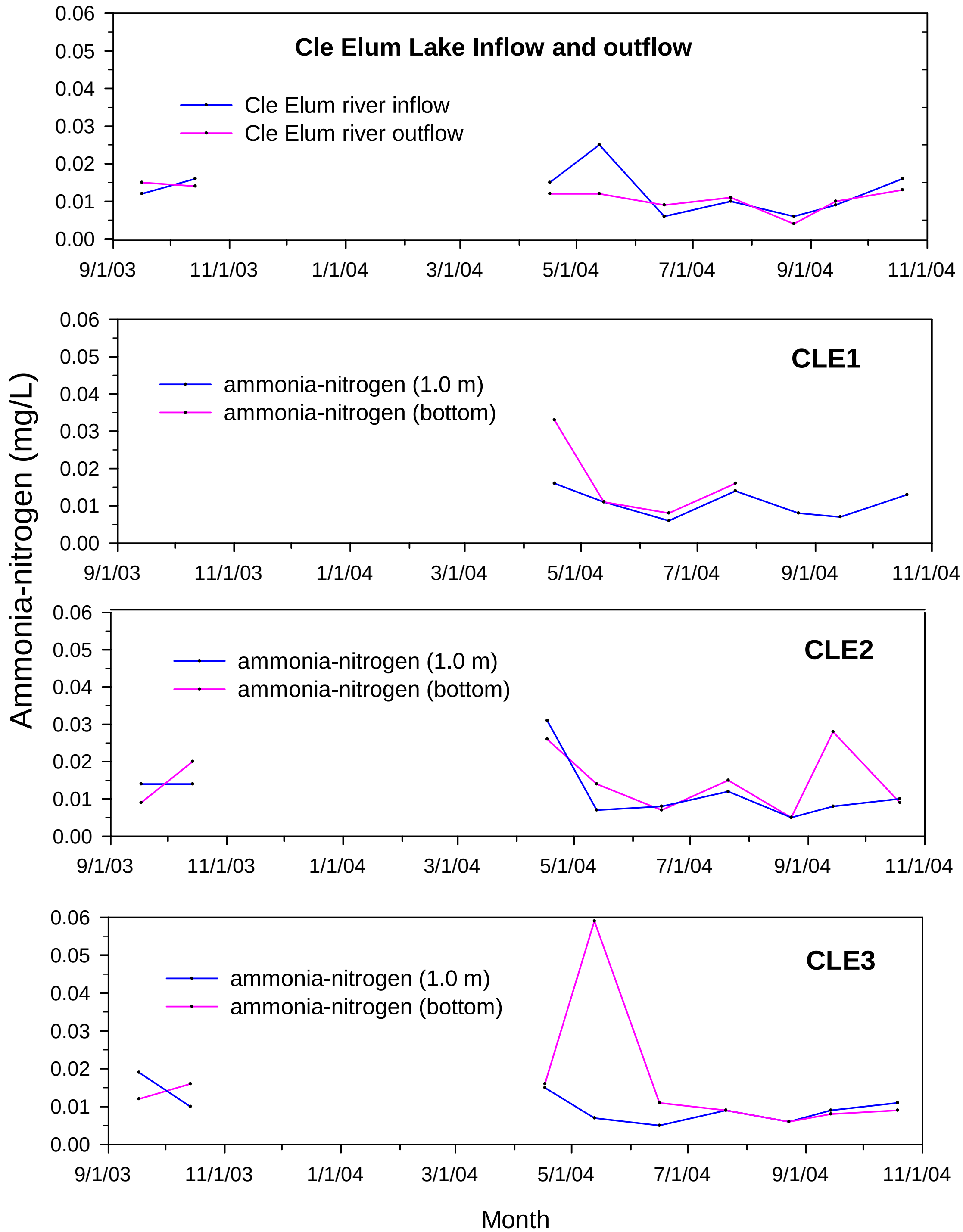


Figure 21. Ammonia-nitrogen levels at Cle Elum River inflow and outflow (a); and from1.0 m and bottom depths at lake sites CLE1 (b), CLE2 (c), and CLE3 (d) from September and October 2003 and April to October 2004. Some sites, indicated by missing data, were not sampled during those dates.

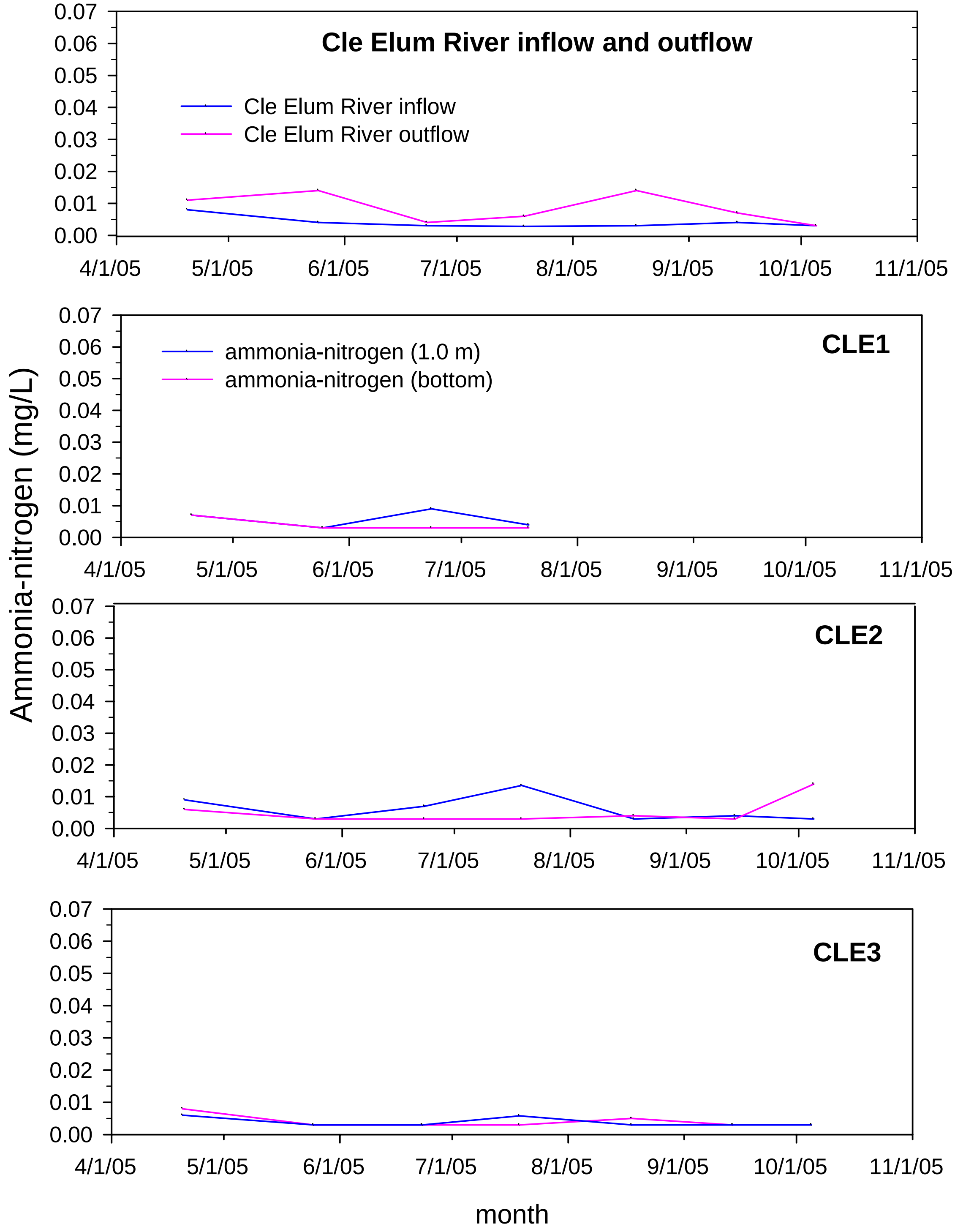


Figure 22. Ammonia-nitrogen levels at a) Cle Elum River inflow and outflow (a); and from 1.0 m and bottom depths at lake sites CLE1 (b), CLE2 (c), and CLE3 (d) from April through October 2005. Missing data denotes sampling sites were not sampled during those dates.

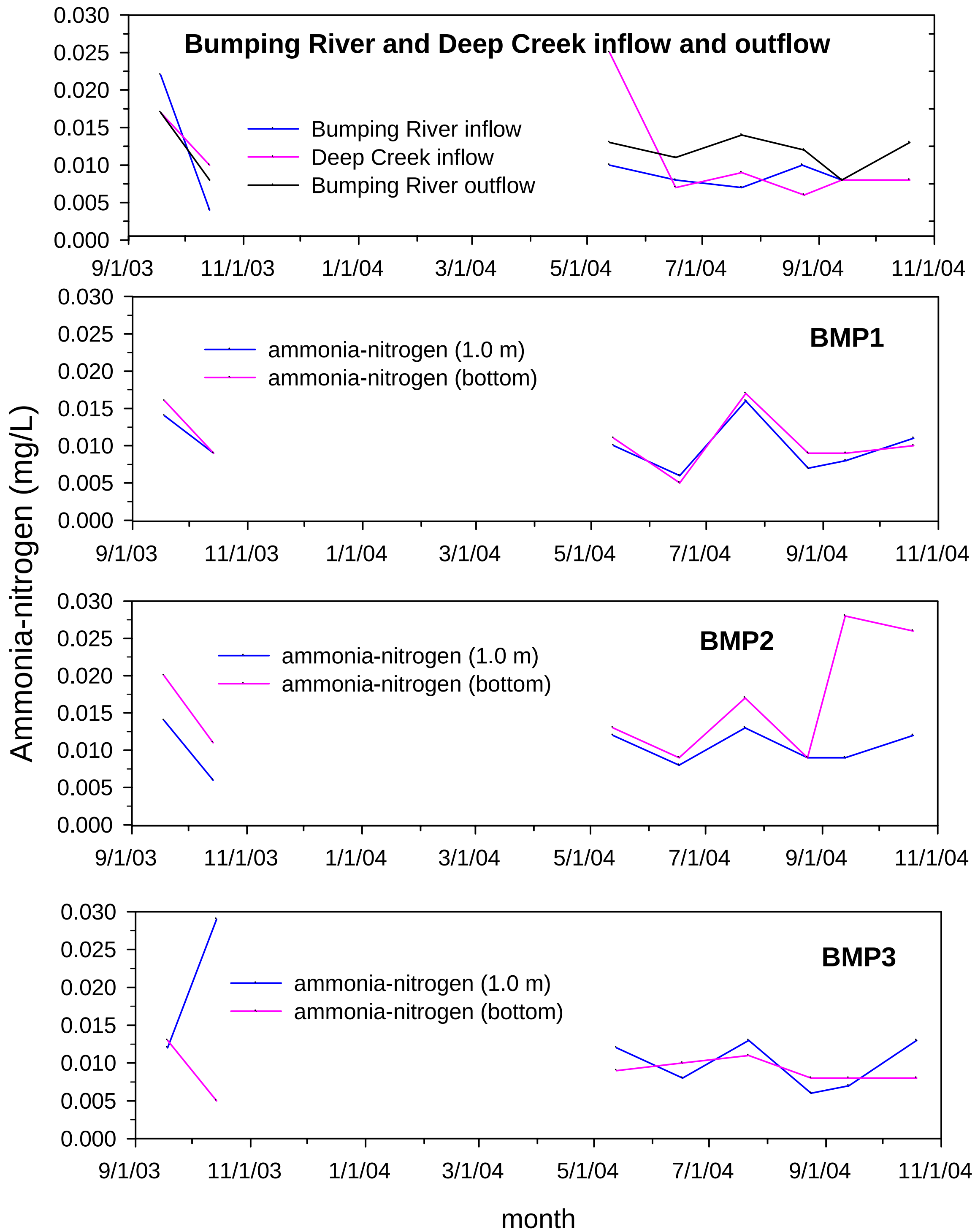


Figure 23. Ammonia-nitrogen levels at Bumping river inflow and outflow (a); and from 1.0 m and bottom depths at lake sites BMP1 (b), BMP2 (c), and BMP3 (d) from September and October 2003 and from May to October 2004. Missing data denote that sampling sites were not sampled during those dates.

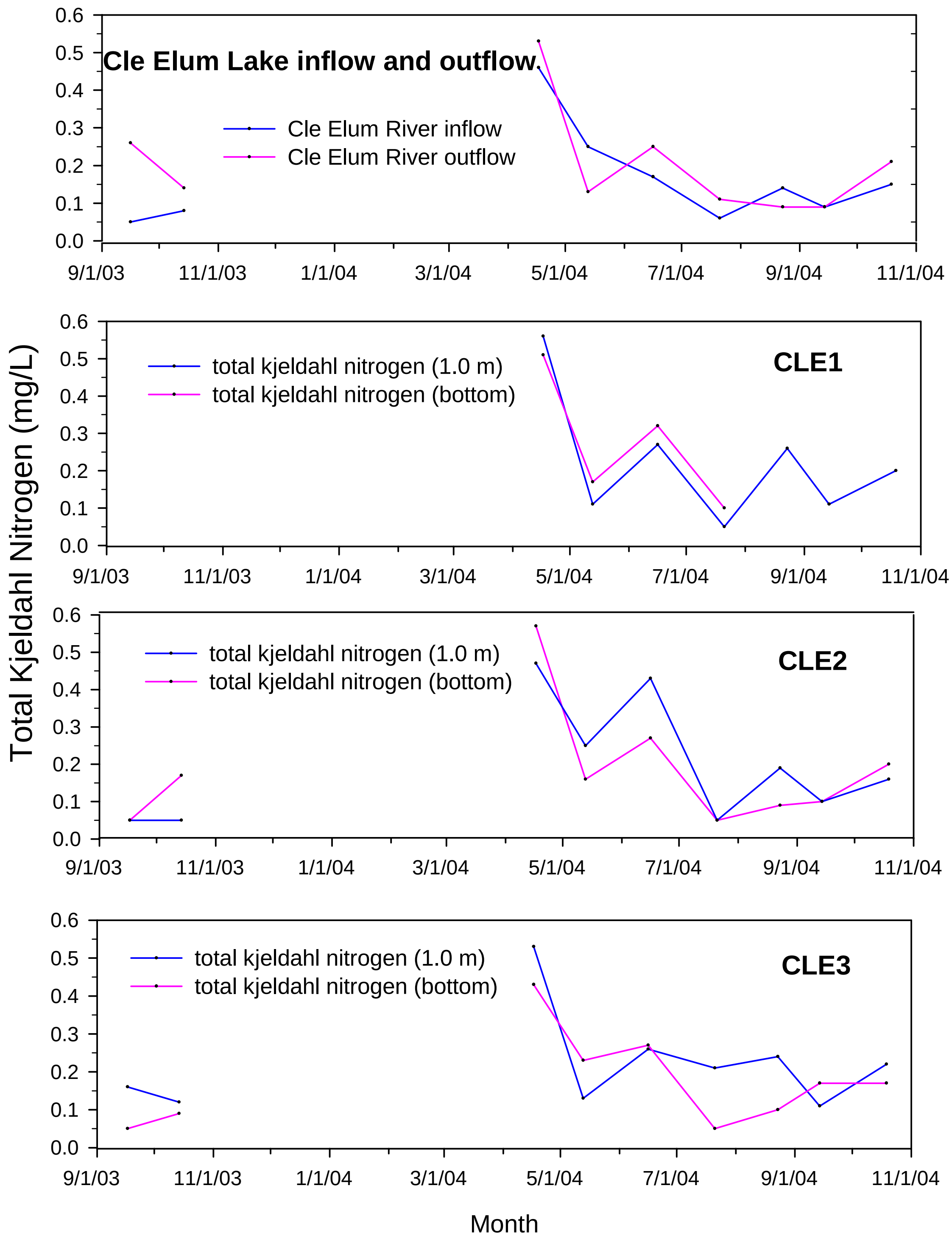


Figure 24. Total kjeldahl nitrogen levels at Cle Elum River inflow and outflow; and from 1.0 m and bottom depths at Cle Elum Lake sites CLE1, CLE2, and CLE3 from September and October 2003 and April to October 2004. Some sites, indicated by missing data, were not sampled during those dates.

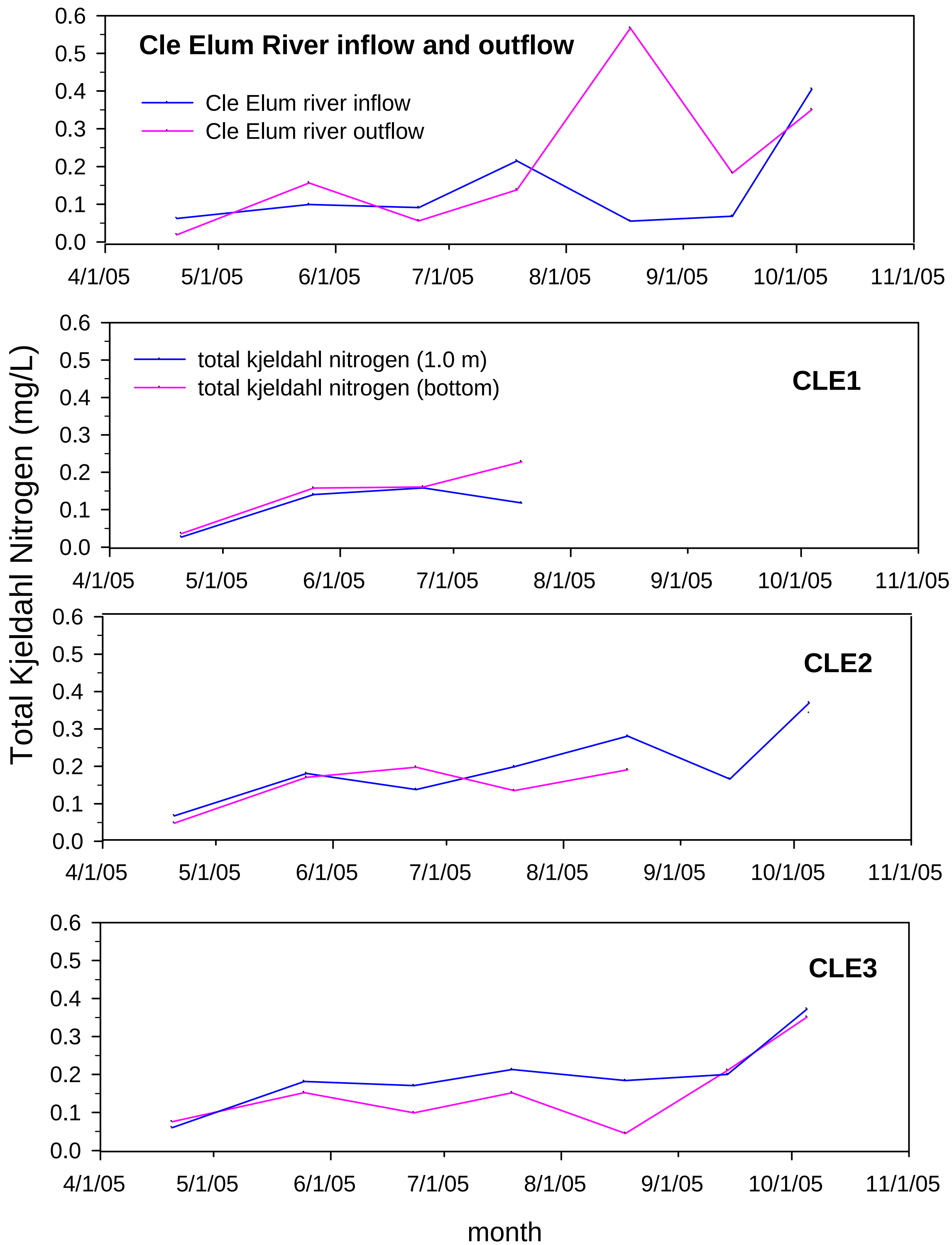


Figure 25. Total kjeldahl nitrogen levels at Cle Elum River inflow and outflow (a); and from 1.0 m and bottom depths at lake sites CLE1 (b), CLE2 (c), and CLE3 (d) from April to October 2005. Missing data denotes sampling sites were not sampled during those dates.

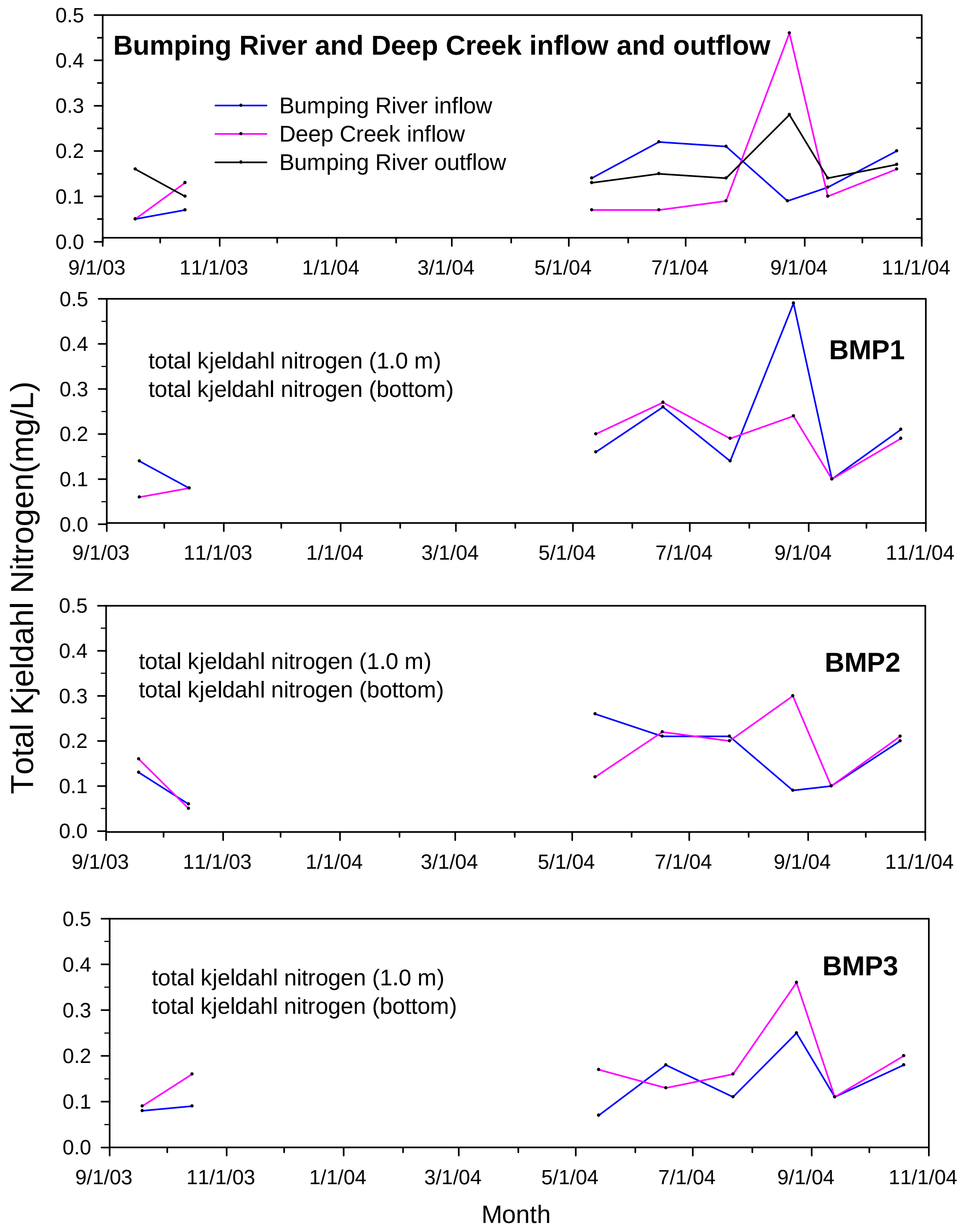


Figure 26. Total kjeldahl nitrogen levels at Bumping River and Deep Creek inflow and outflow (a); and from1.0 m and bottom depths at lake sites BMP1 (b), BMP2 (c), and BMP3 (d) from September and October 2003 and May to October 2004. Some sites, indicated by missing data, were not sampled during those dates.

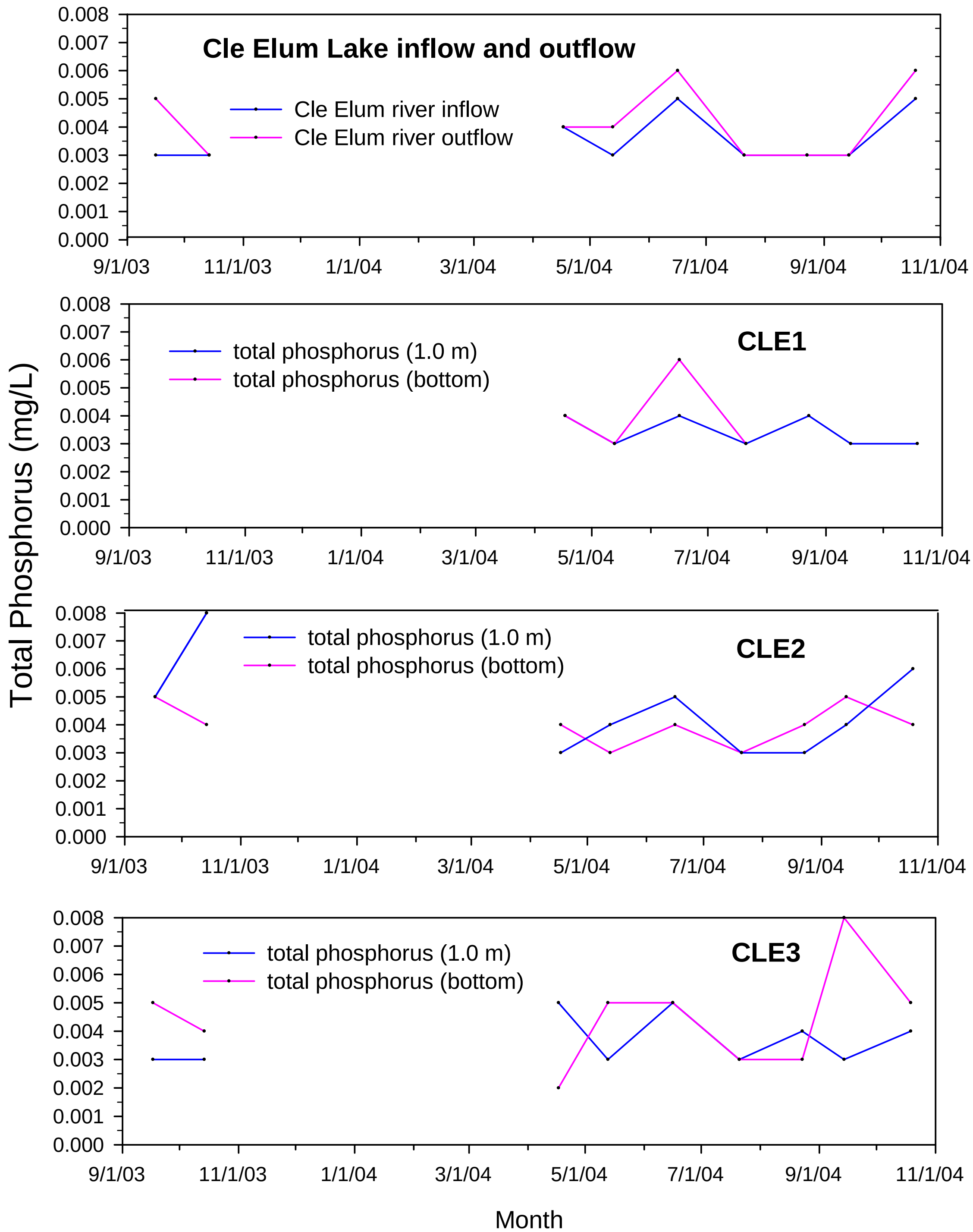


Figure 27. Total phosphorus levels at Cle Elum River inflow and outflow; and from 1.0 m and bottom depths at Cle Elum Lake sites CLE1, CLE2, and CLE3 from September and October 2003 and April to October 2004. Some sites, indicated by missing data, were not sampled during those dates.

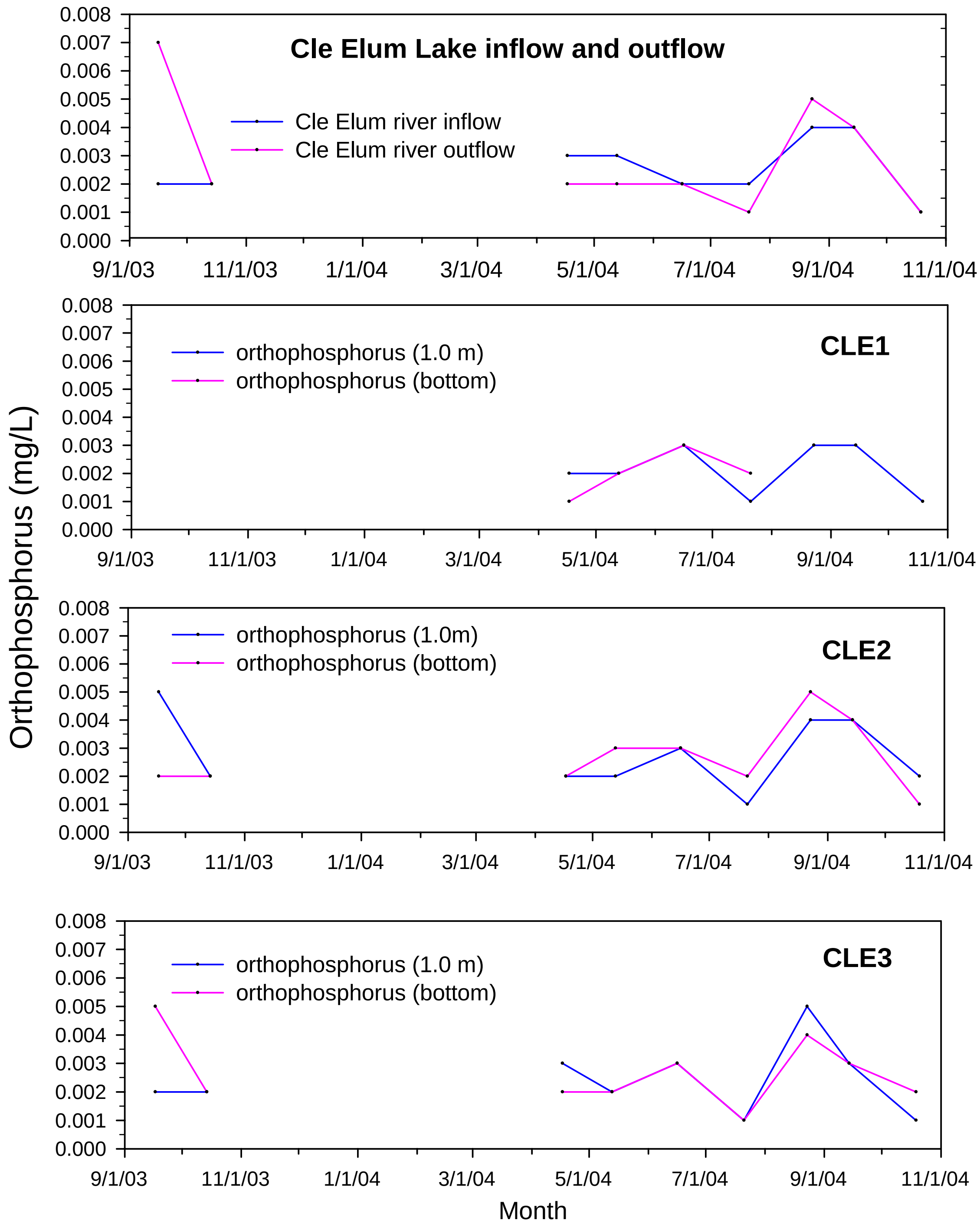


Figure 28. Orthophosphorus levels at Cle Elum River inflow and outflow; and from1.0 m and bottom depths at Cle Elum Lake sites CLE1, CLE2, and CLE3 from September and October 2003 and April to October 2004. Some sites, indicated by missing data, were not sampled during those dates.

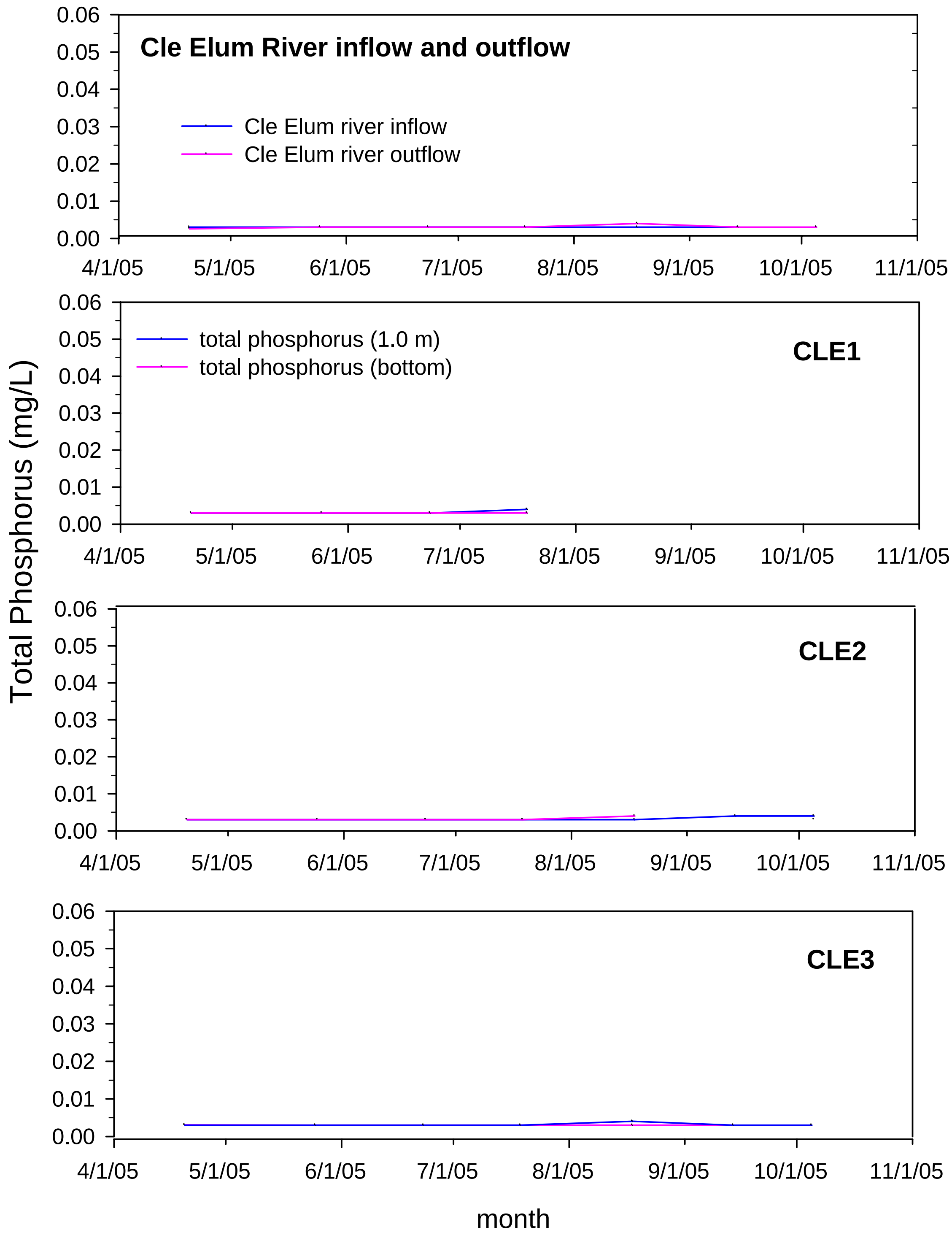


Figure 29. Total phosphorus levels at Cle Elum River inflow and outflow; and from 1.0 m and bottom depths at Cle Elum Lake sites CLE1, CLE2, and CLE3 from April to September 2005. Missing data denotes sampling sites were not sampled during those dates.

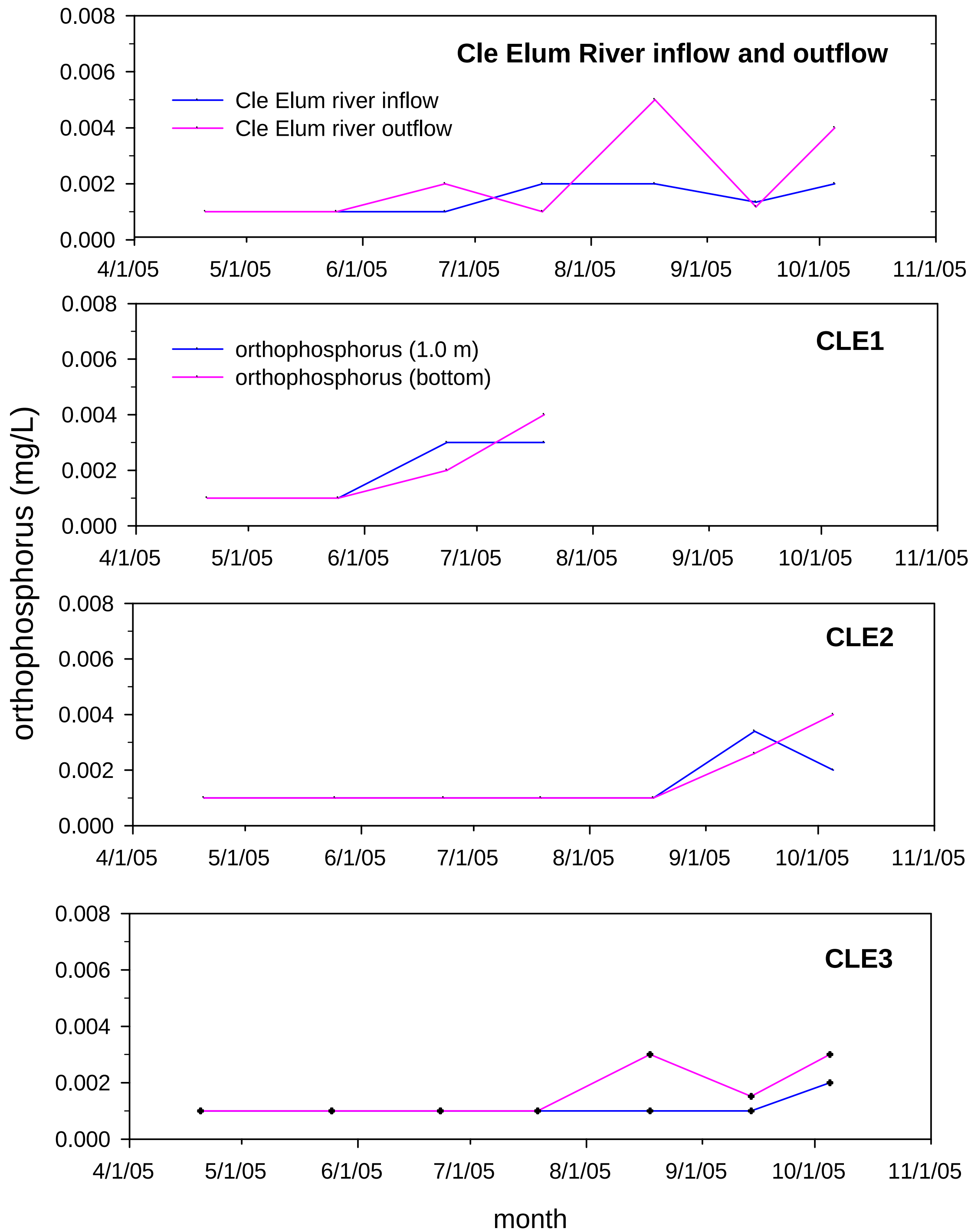


Figure 30. Orthophosphorus levels at Cle Elum River inflow and outflow; and from 1.0 m and bottom depths at Cle Elum Lake sites CLE1, CLE2, and CLE3 from April through October 2005. Missing data denotes sampling sites were not sampled during those dates.

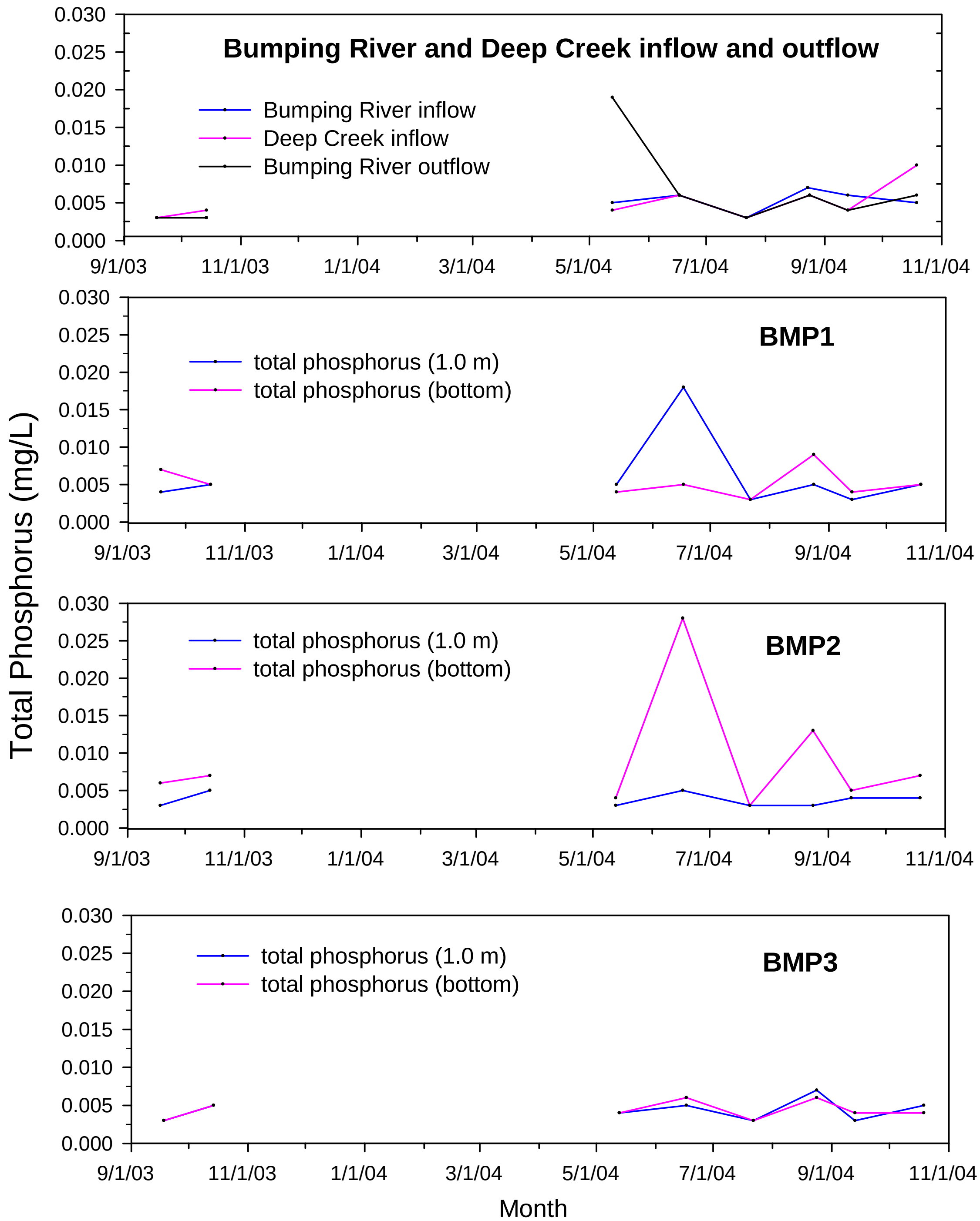


Figure 31. Total phosphorus levels at Bumping River and Deep Creek inflow and outflow; and from 1.0 m and bottom depths at Bumping Lake sites BMP1, BMP2, and BMP3 sites from September to October 2003 and May to October 2004. Some sites, indicated by missing data, were not sampled during those dates.

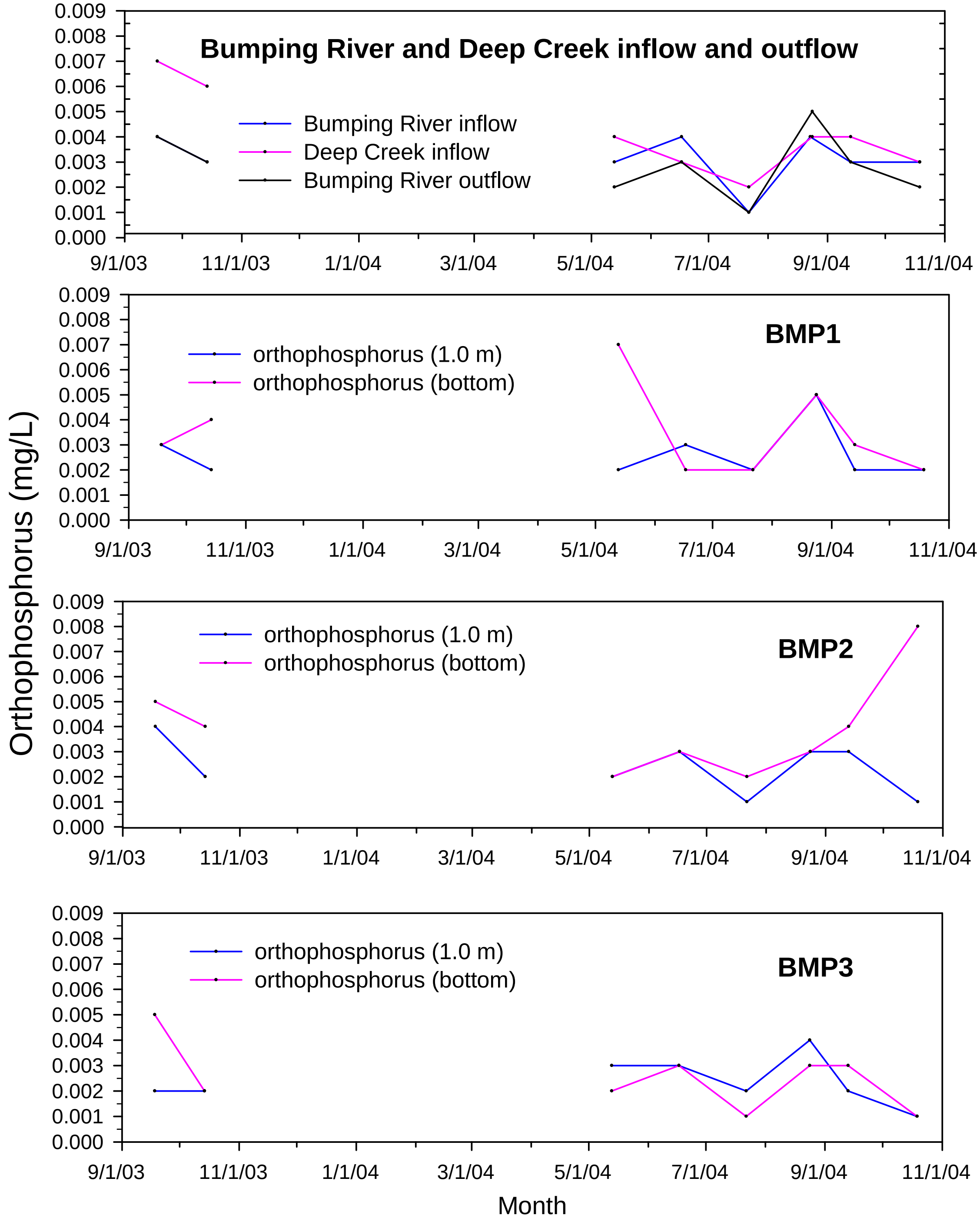


Figure 32. Orthophosphorus levels at Bumping River and Deep Creek inflow and outflow; and from 1.0 m and bottom depths at Bumping Lake sites BMP1, BMP2, and BMP3 from September to October 2003 and May to October 2004. Some sites, indicated by missing data, were not sampled during those dates.

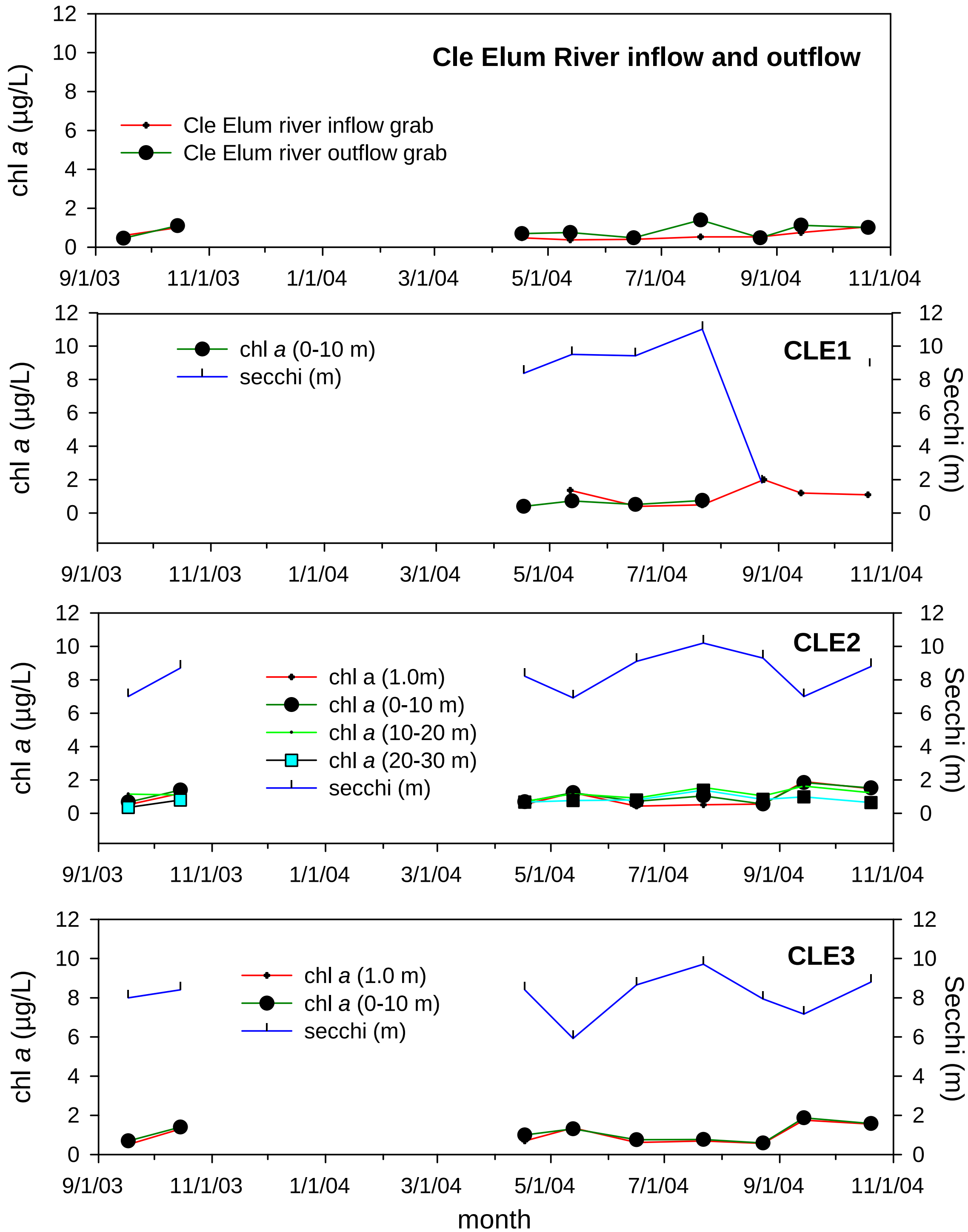


Figure 33. Chl *a* concentrations at Cle Elum River inflow and outflow. Chl *a* concentrations and secchi depth transparencies at Cle Elum Lake sites CLE1 (0-10 m) CLE2 (0-10 m, 10-20 m, 20-30 m), and CLE3 (0-10 m) from September and October 2003, and April to October 2004.

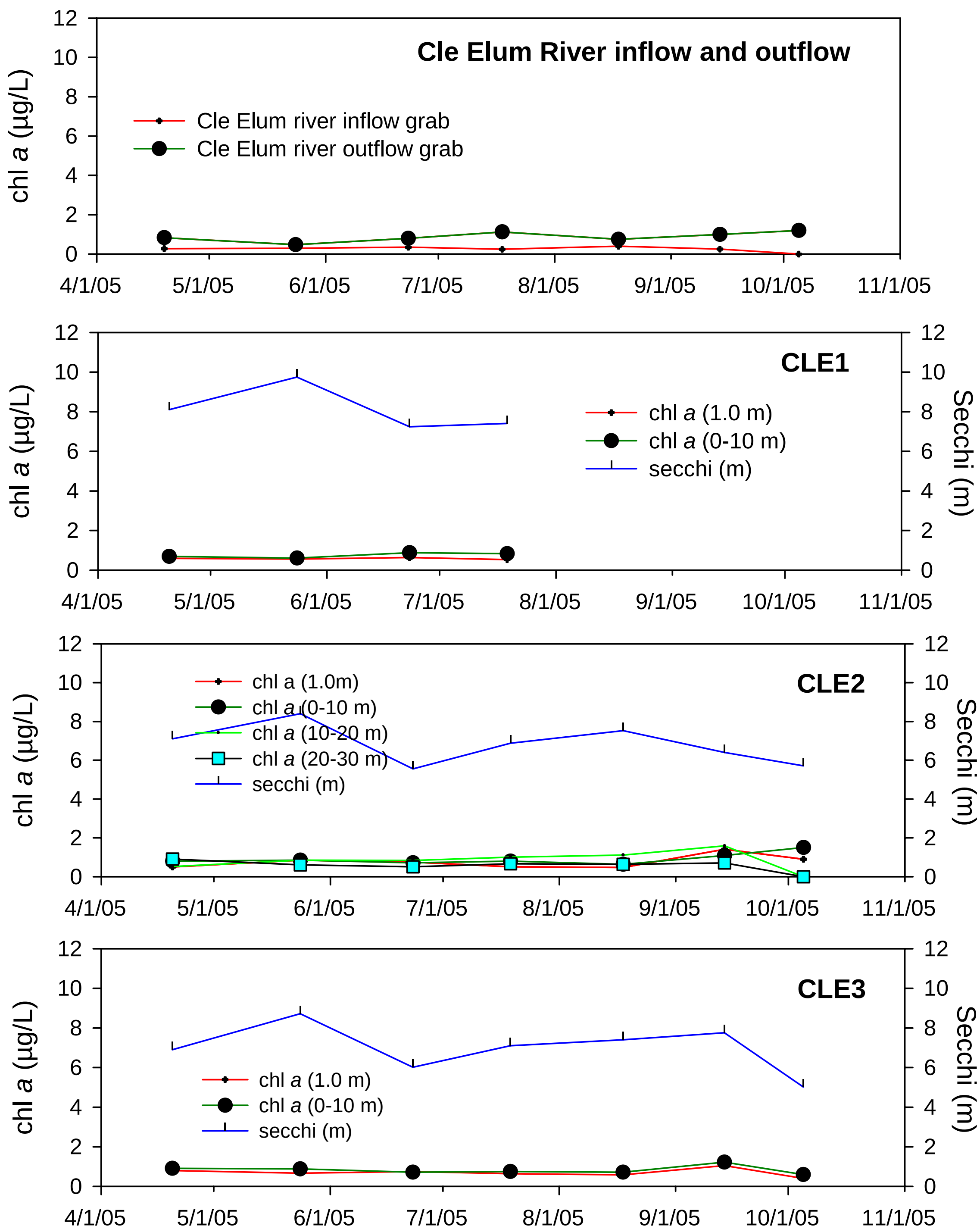


Figure 34. Chl *a* concentrations at Cle Elum River inflow and outflow. Chl *a* concentrations and secchi depth transparencies at Cle Elum Lake sites CLE1 (1 m, 0-10 m), CLE2 (1 m, 0-10 m, 10-20 m, 20-30 m), and CLE3 (1 m, 0-10 m) from April to October 2005. Water samples were collected at CLE1 from April through July only since the lake was drawndown beyond this point after this time.

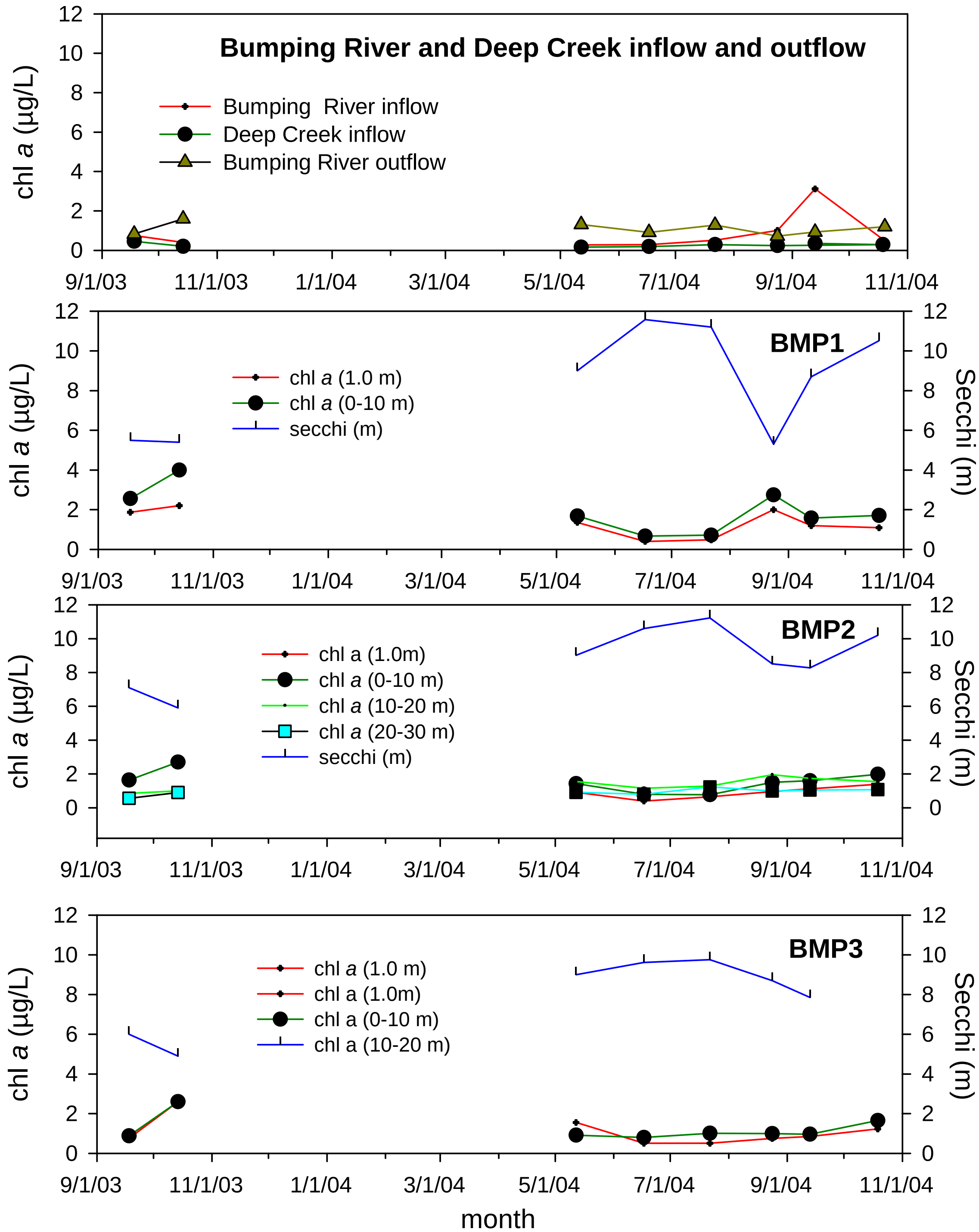


Figure 35. Chl *a* concentrations at Bumping River and Deep Creek inflow and Bumping River outflow. Chl *a* concentrations and secchi depth transparencies at Bumping Lake sites BMP1 (0-10 m), BMP2 (0-10 m, 10-20 m, 20-30 m), and BMP3 (0-10 m) from September and October 2003 and May to October 2004.

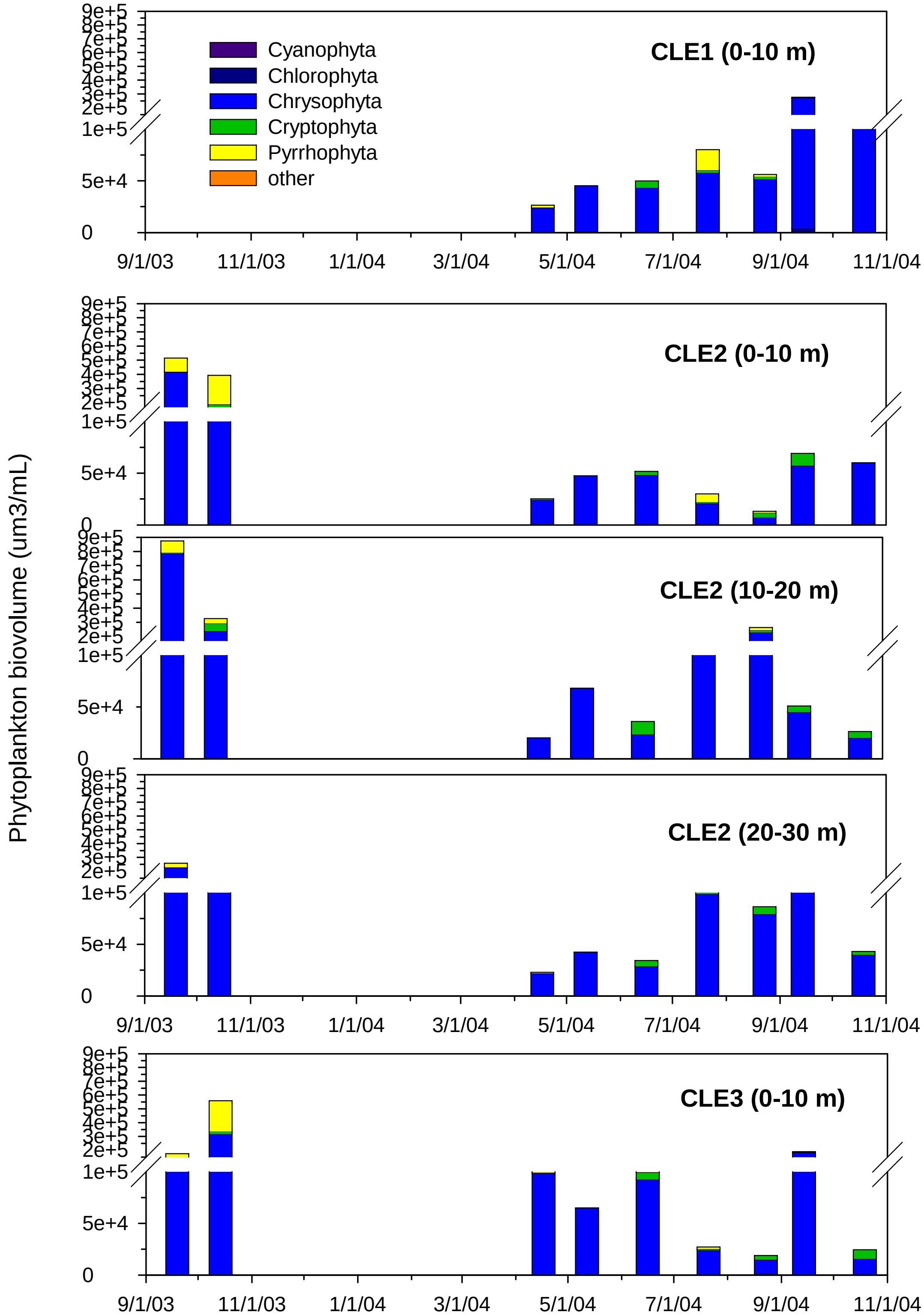


Figure 36. Biovolumes for phytoplankton collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2; and from 0-10 m at CLE3.

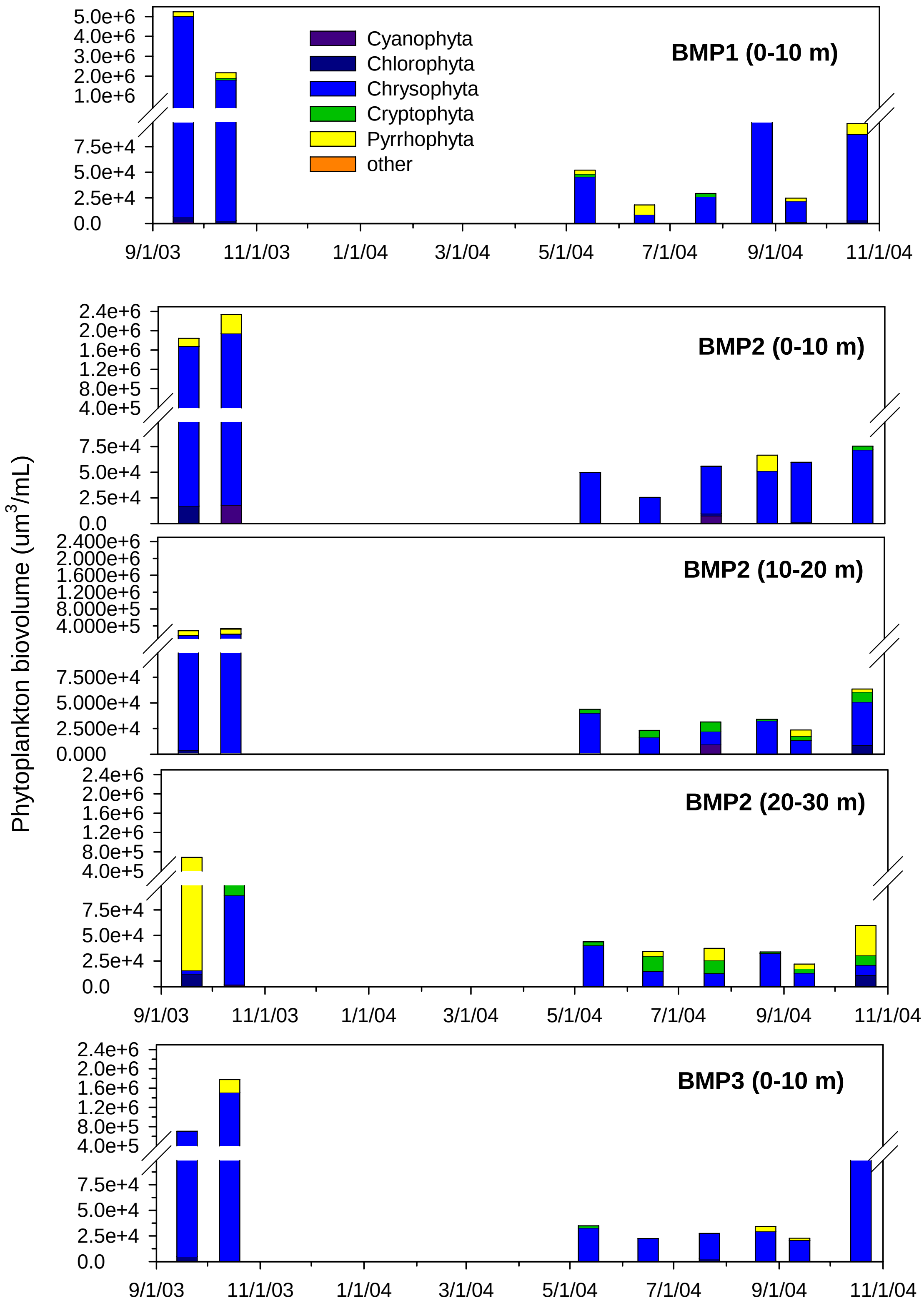


Figure 37. Biovolume of phytoplankton collected from the 0-10 m depth stratum at Bumping Lake site BMP1, from the 0-10 m, 10-20 m, and 20-30 m depth strata at BMP2, and in the 0-10 m depth stratum at BMP3.

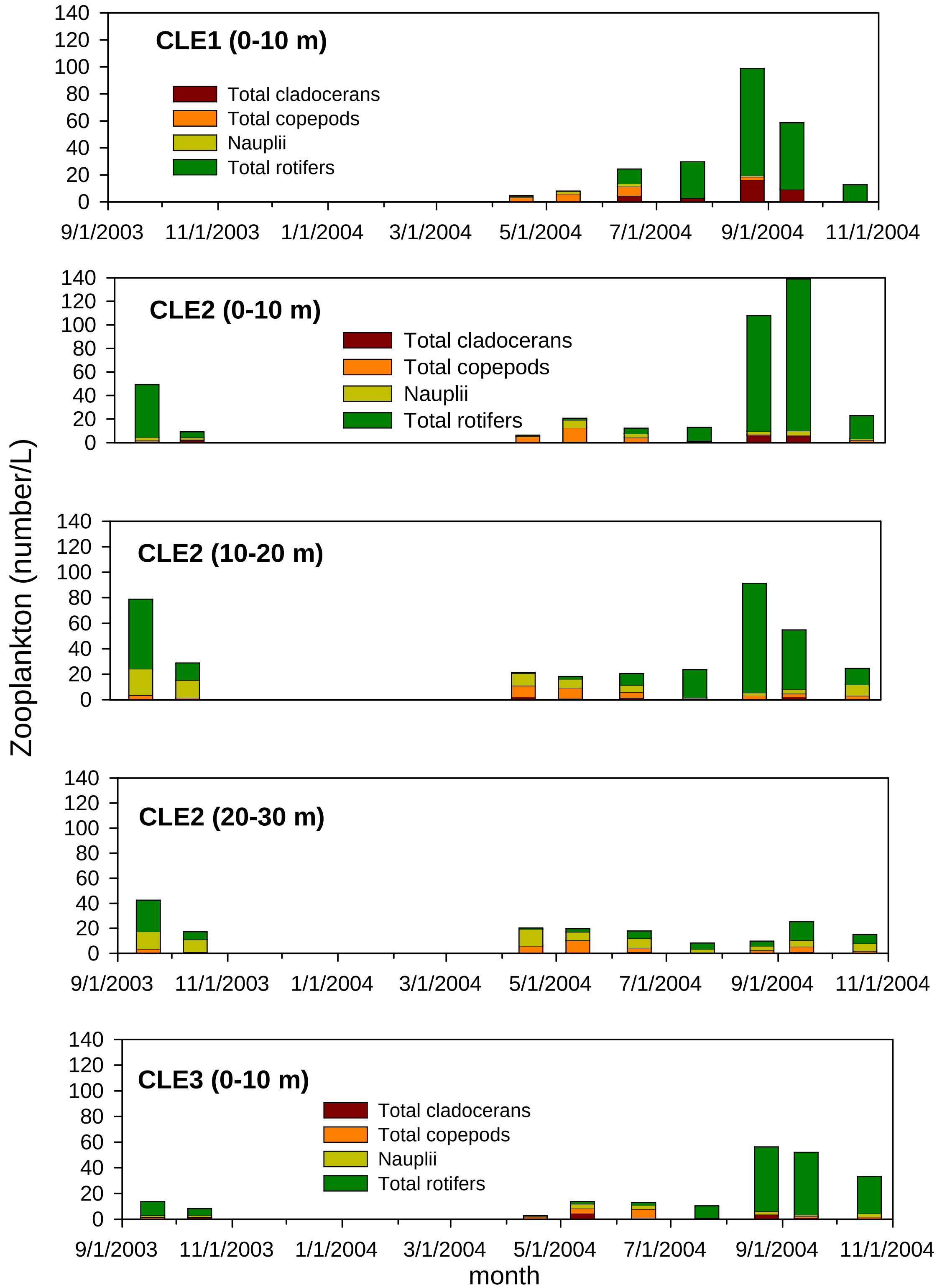


Figure 38. Zooplankton densities collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1, from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2, and from the 0-10 m depth stratum at CLE3 during September and October 2003 and April to October 2004.

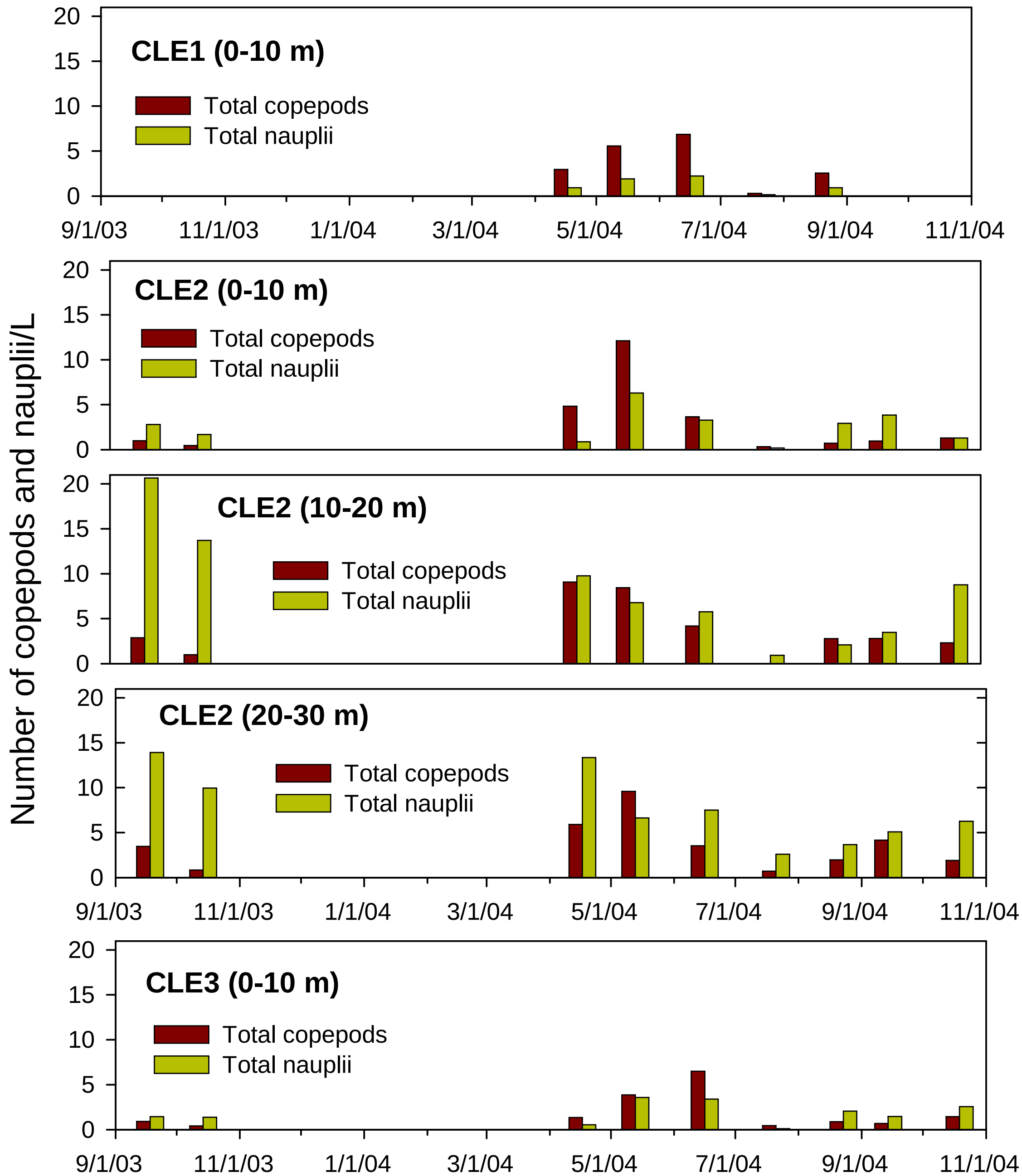


Figure 39. Densities of copepods and nauplii collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2; and from the 0-10 m depth stratum at CLE3.

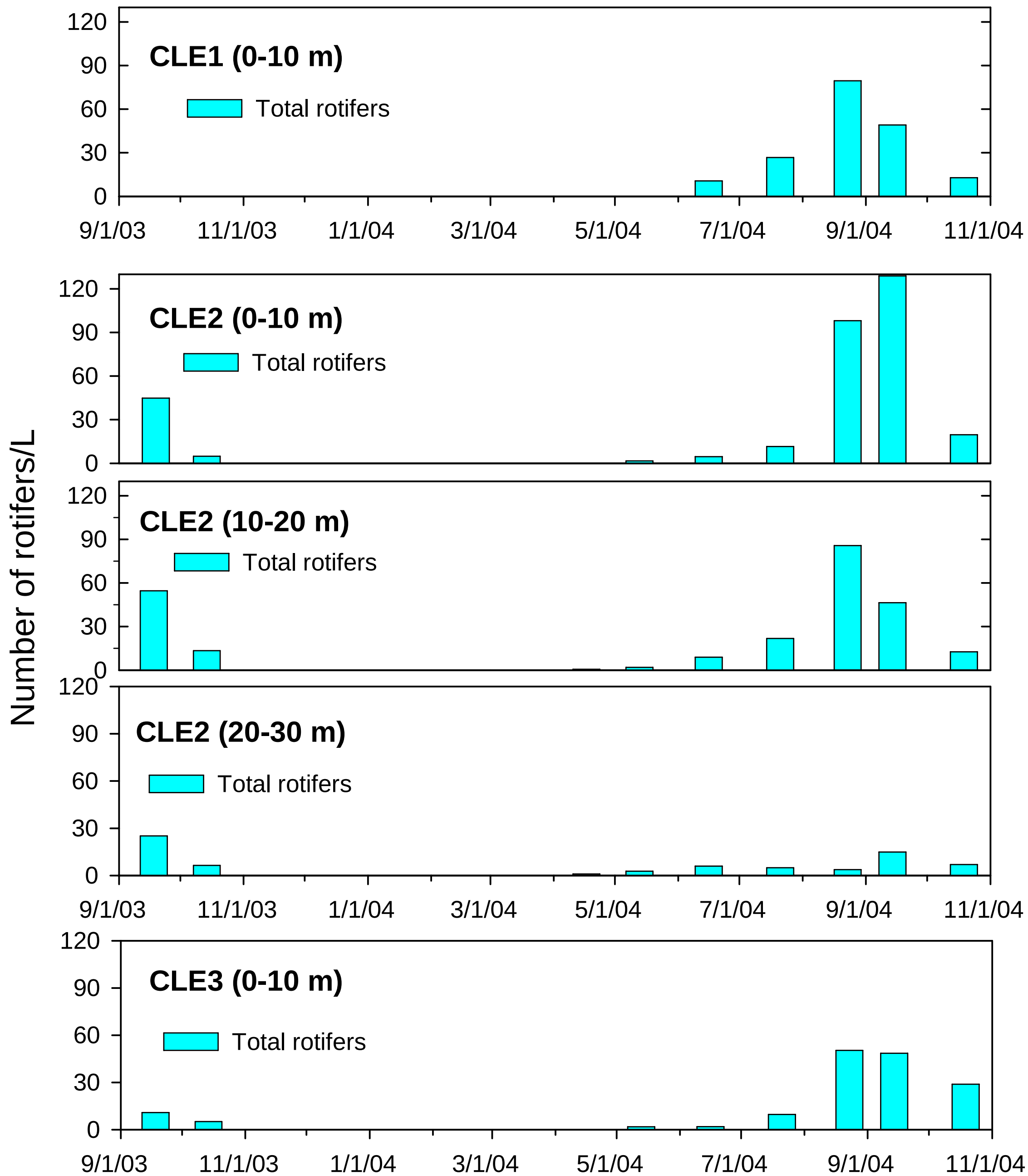


Figure 40. Densities of rotifer collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2; and from the 0-10 m depth stratum at CLE3 during September and October 2003 and from April to October 2004.

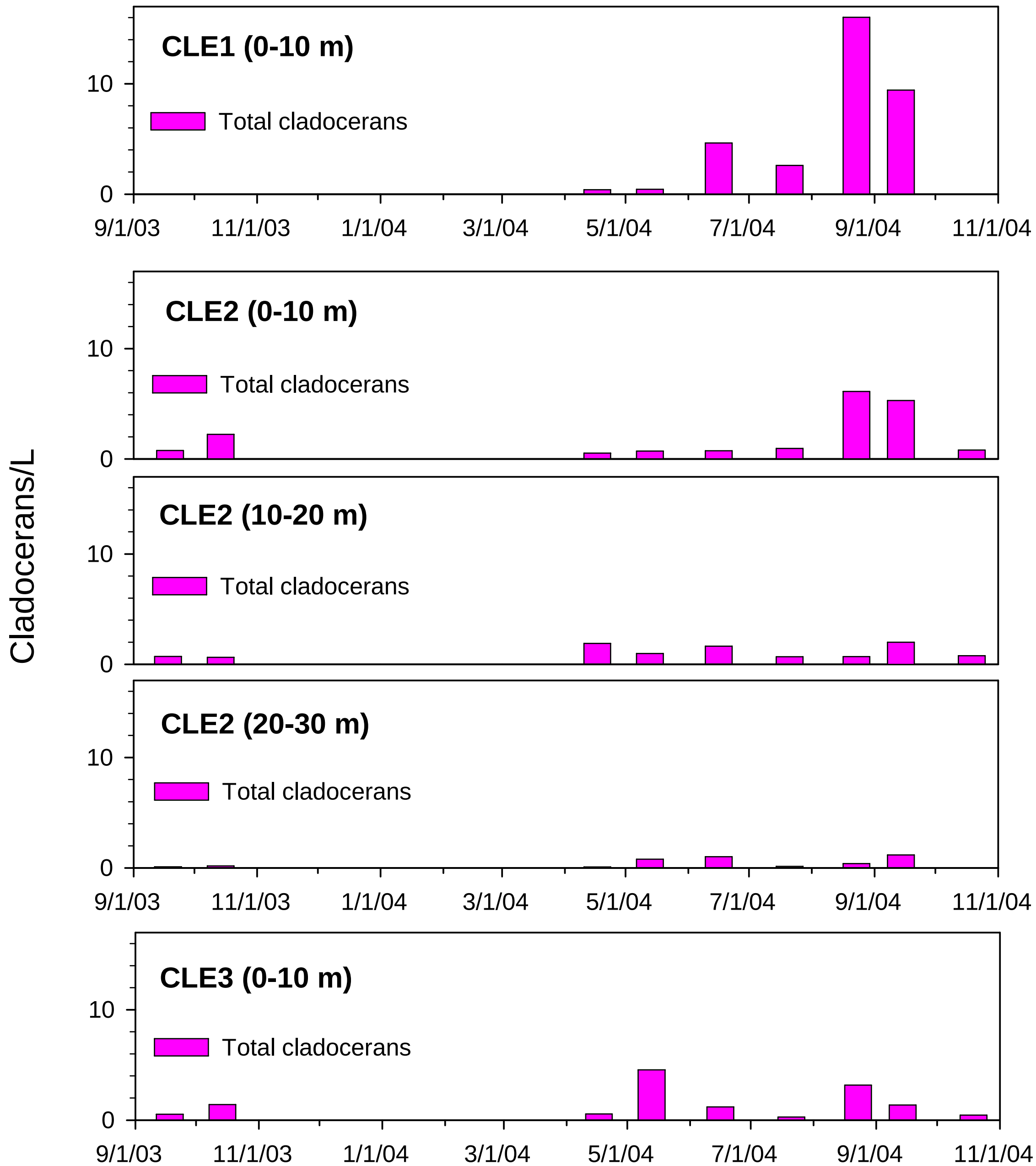


Figure 41. Densities of cladoceran collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2; and from the 0-10 m depth stratum at CLE3 during September and October 2003 and from April to October 2004.

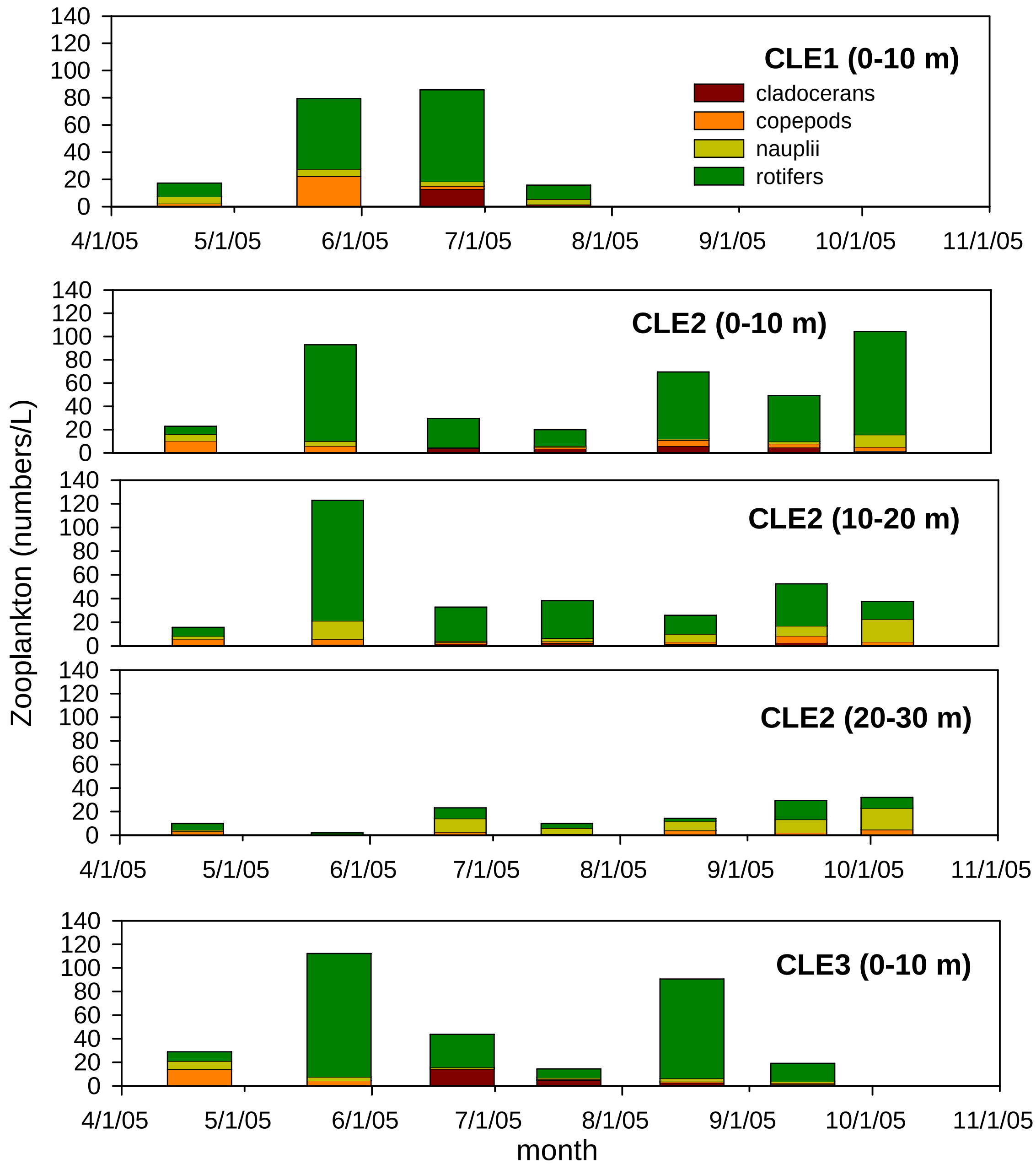


Figure 42. Zooplankton densities collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2; and from the 0-10 m at CLE3 from April to October 2005. Zooplankton were not reportedfrom August through October at CLE1; and in October at CLE3.

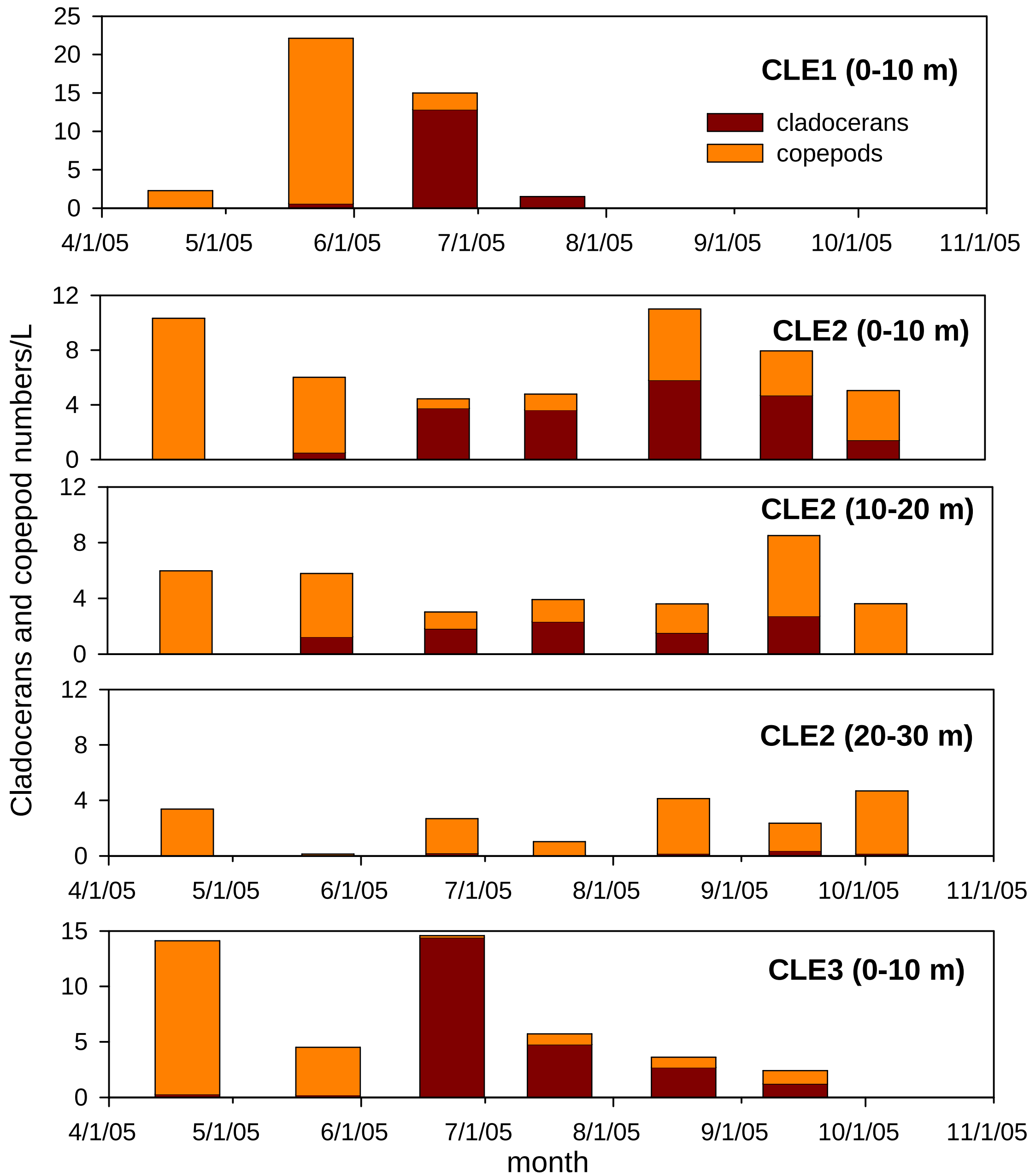


Figure 43. Cladoceran and copepod densities collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2; and from the 0-10 m depth stratum at CLE3 from April to October 2005. Zooplankton were not reported from August through October at CLE1; and in October at CLE3.

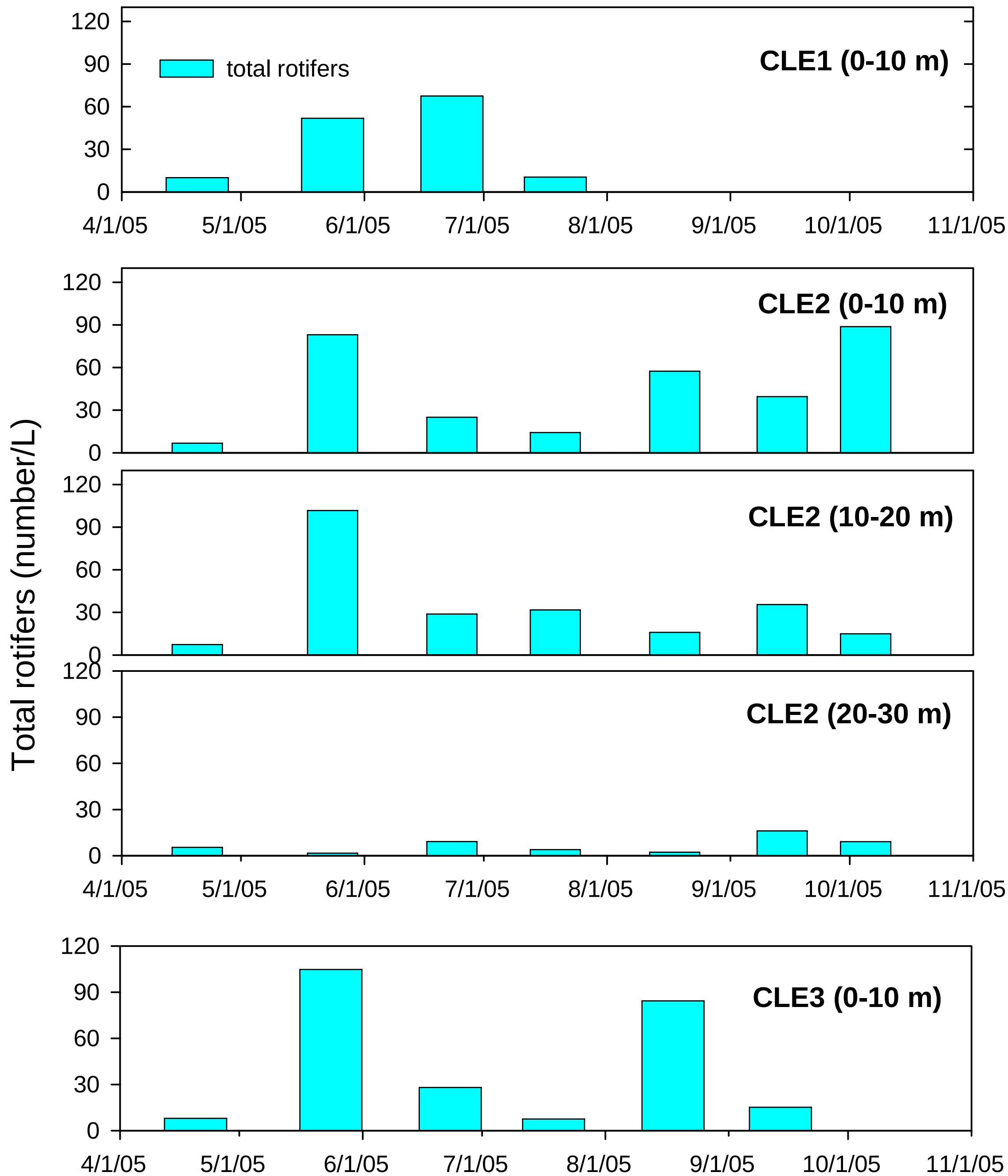


Figure 44. Densities of rotifers collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2; and from the 0-10 m depth stratum at CLE3 from April to October 2005. Zooplankton were not reported from August through October at CLE1; and in October at CLE3.

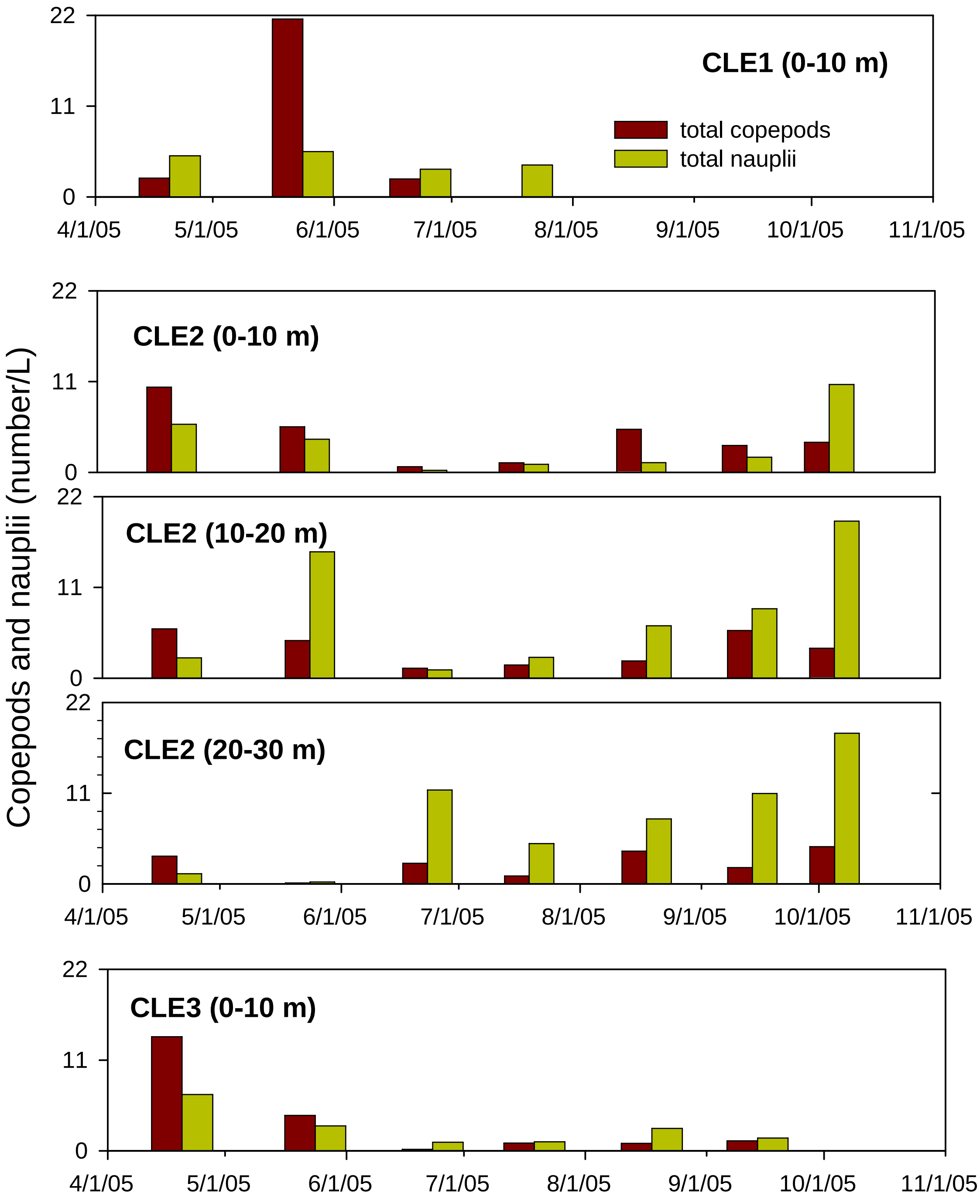


Figure 45. Densities of copepods and nauplii collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2; and from the 0-10 m depth stratum at CLE3 from April to October 2005. Zooplankton were not reported from August through October at CLE1; and in October at CLE3.

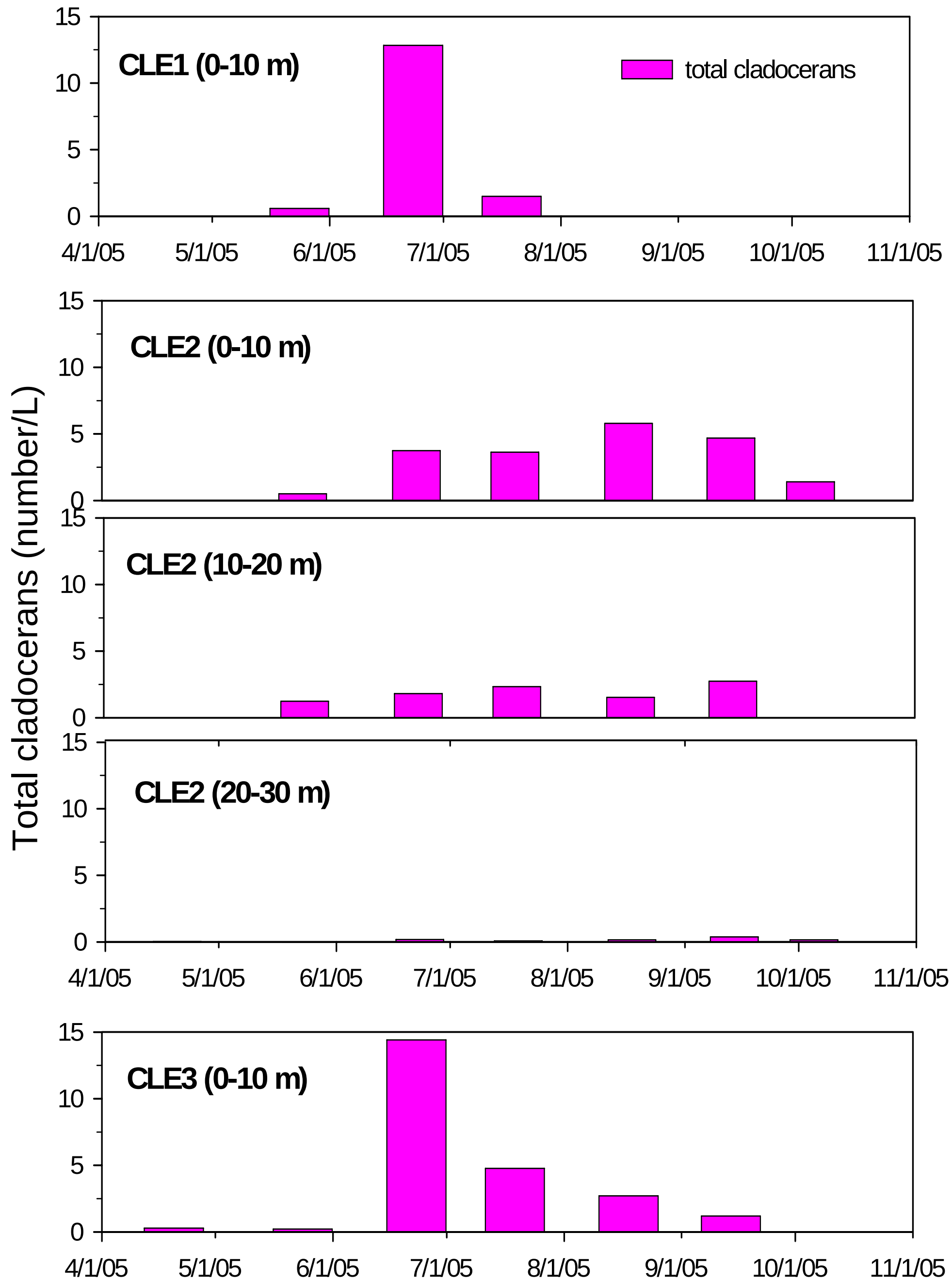


Figure 46. Densities of total cladoceran collected from the 0-10 m depth stratum at Cle Elum Lake site CLE1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at CLE2; and from the 0-10 m depth stratum at CLE3. Zooplankton were not reported from August through October at CLE1; and in October at CLE3.

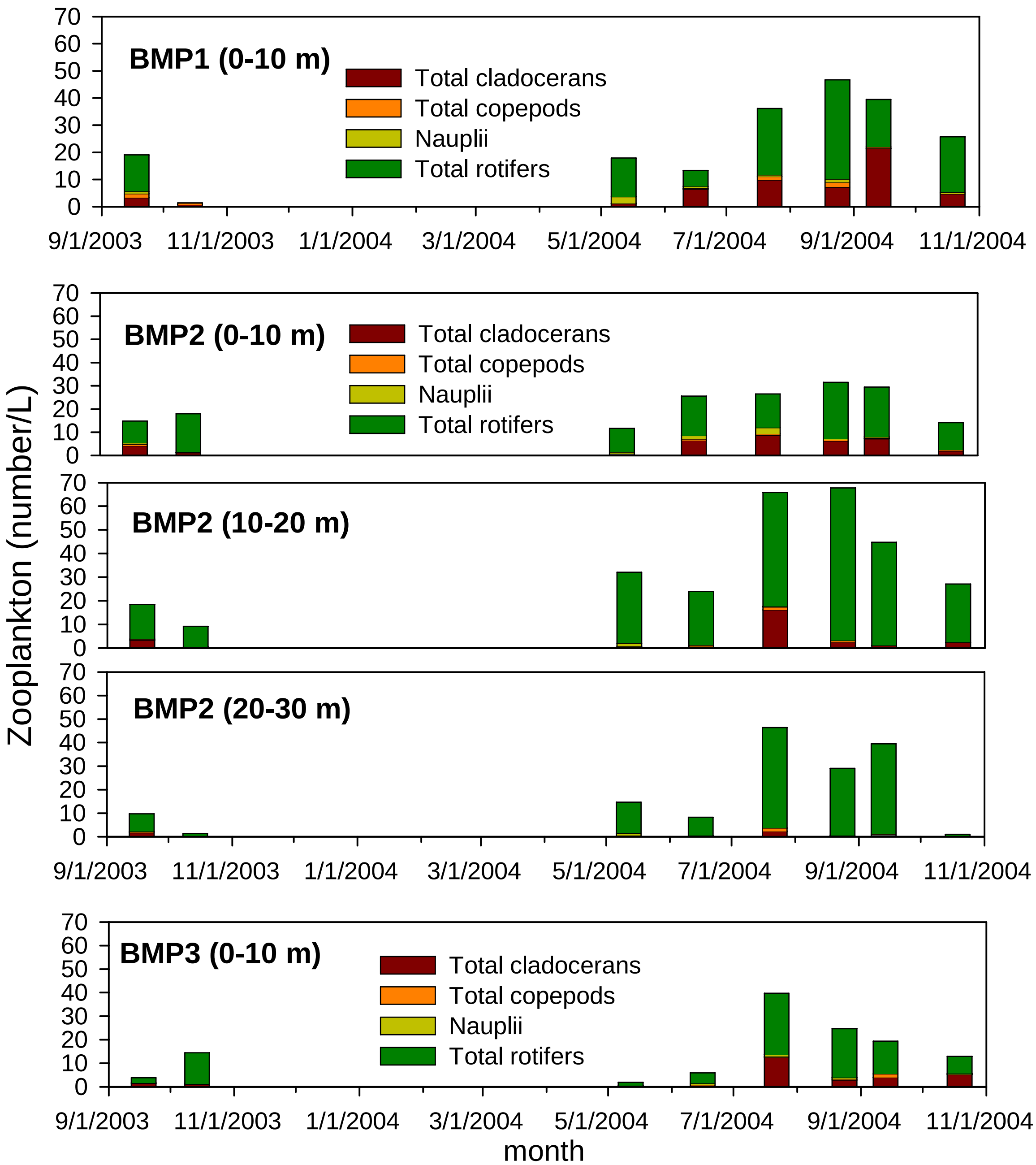


Figure 47. Densities of zooplankton collected from the 0-10 m depth stratum at Bumping Lake site BMP1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at BMP2; and from the 0-10 m depth stratum at BMP3 from September and October 2003 and from May to October 2004.

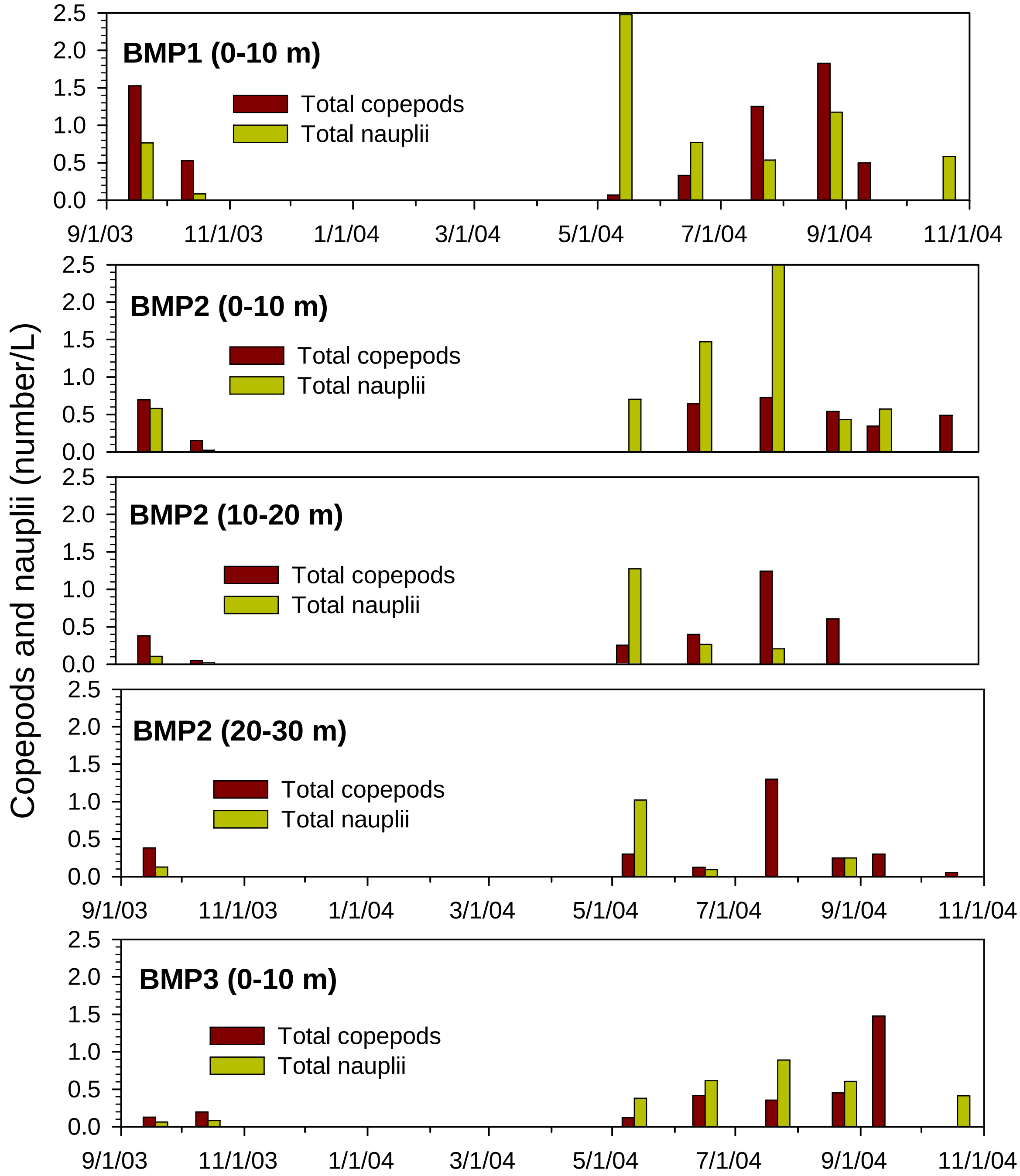


Figure 48. Densities of copepods and nauplii collected from the 0-10 m depth stratum at Bumping Lake site BMP1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at BMP2; and from the 0-10 m depth stratum at BMP3 from September and October 2003 and from May to October 2004.

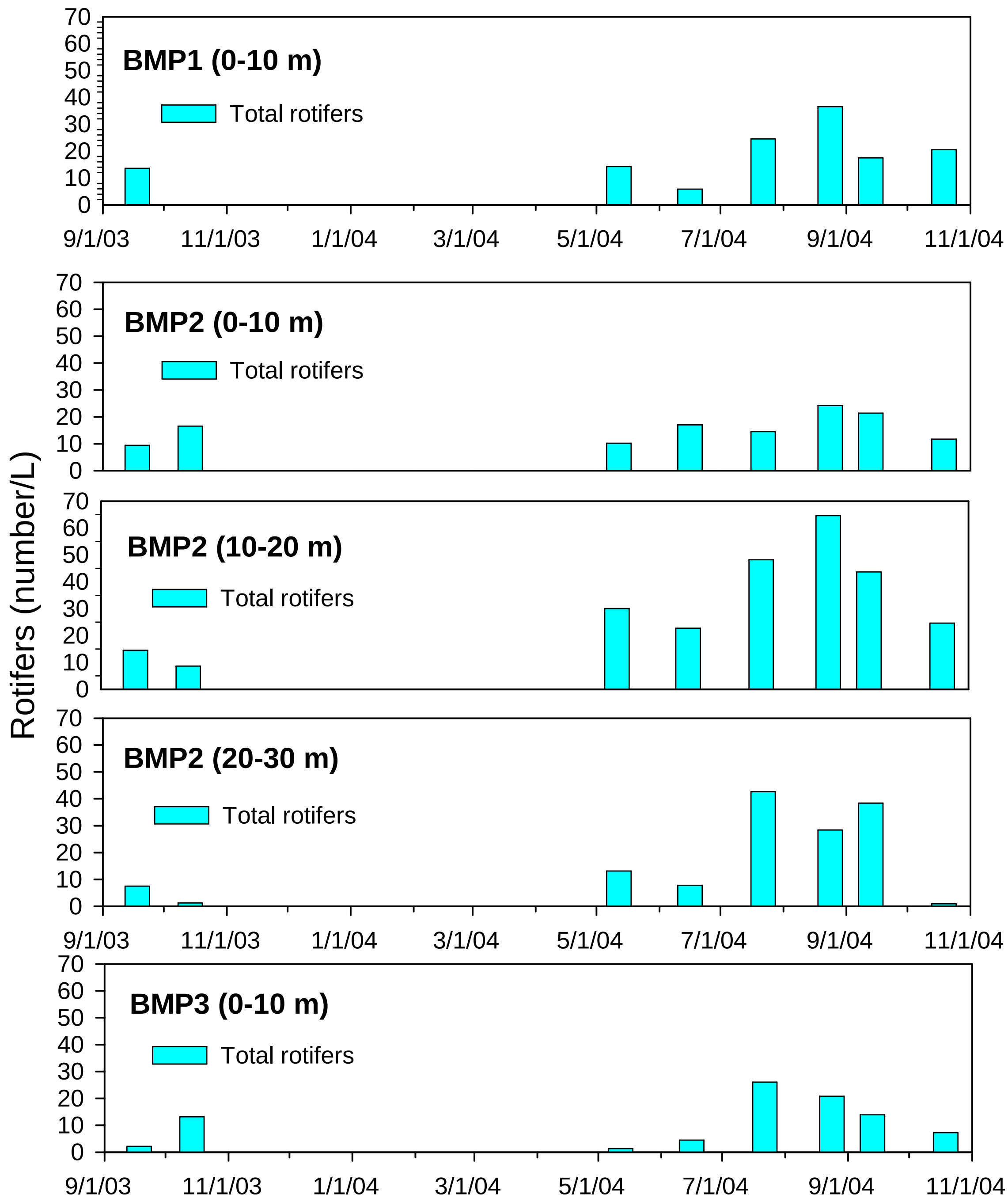


Figure 49. Densities of rotifer collected from the 0-10 m depth stratum at Bumping Lake site BMP1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at BMP2; and from the 0-10 m depth stratum at BMP3 from September and October 2003 and from May to October 2004.

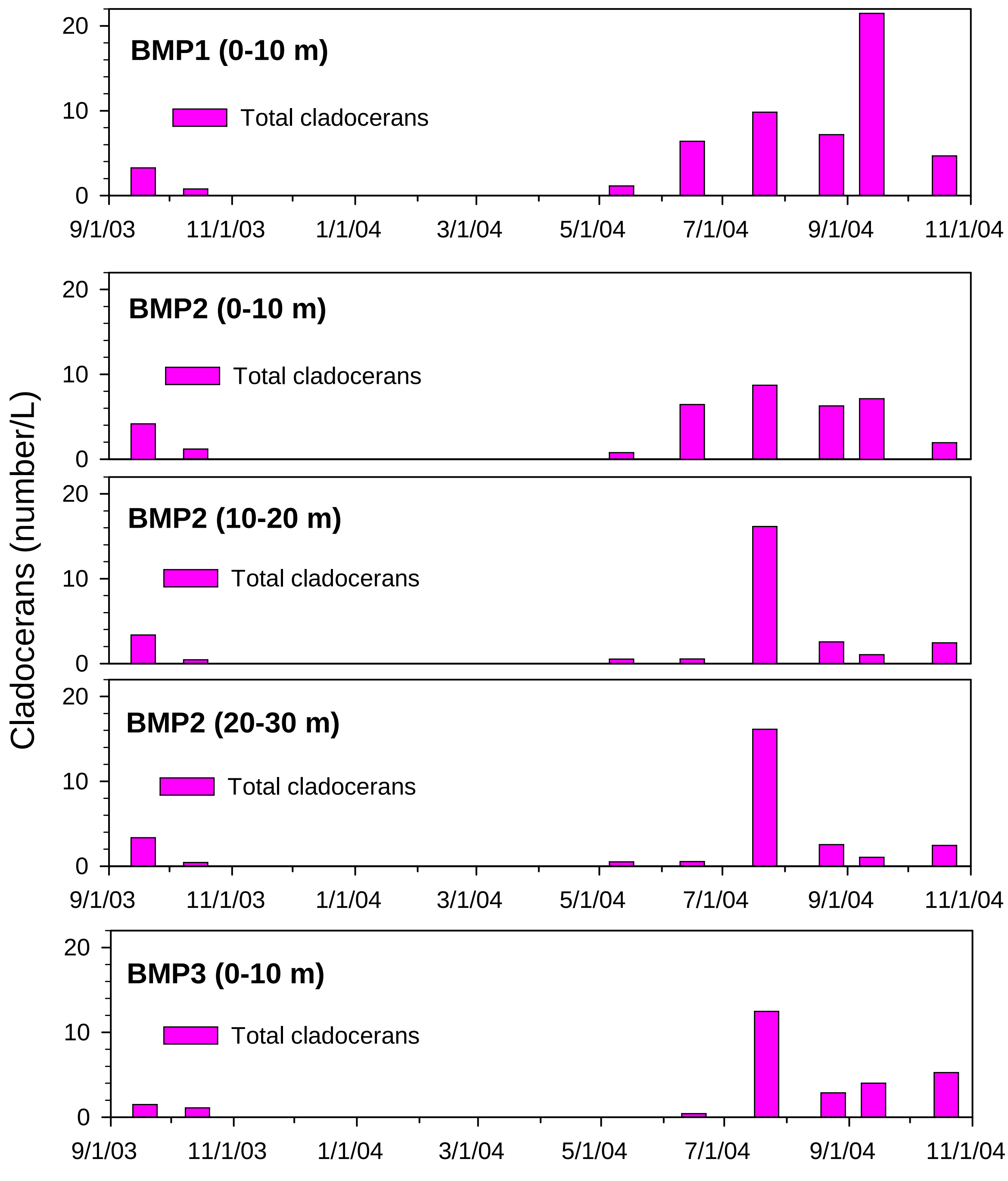


Figure 50. Densities of cladoceran collected from the 0-10 m depth stratum at Bumping Lake site BMP1; from the 0-10 m, 10-20 m, and 20-30 m depth strata at BMP2; and from the 0-10 m depth stratum at BMP3 from September and October 2003 and from May to October 2004.