NUTRIENT BUDGETS AND PHYTOPLANKTON TRENDS IN IRON GATE AND COPCO RESERVOIRS, CALIFORNIA, MAY 2005 - MAY 2006

PREPARED FOR THE
STATE WATER RESOURCES CONTROL BOARD

BY THE

KARUK TRIBE OF CALIFORNIA, DEPARTMENT OF NATURAL RESOURCES

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WITH

JACOB KANN, PH.D
AQUATIC ECOSYSTEM SCIENCES LLC
ASHLAND, OREGON

AND

ELI ASARIAN
KIER ASSOCIATES, FISHERIES AND WATERSHED PROFESSIONALS
ARCATA, CALIFORNIA

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EXECUTIVE SUMMARY

Copco and Iron Gate Reservoirs are mainstem reservoirs on the Klamath River in northern California, one of the major salmon rivers of the western United States. The Klamath River in California is listed as an impaired water body on the Clean Water Act (CWA) section 303(d) list for temperature, nutrients and dissolved oxygen. The North Coast Regional Water Quality Control Board (NCRWQCB) is in the process of developing a Total Maximum Daily Load (TMDL) for the Klamath River. PacifiCorp Energy, the owner and operator of the Klamath Hydroelectric Project (Project) is also in the process of relicensing the Project with the Federal Energy Regulatory Commission. Utilizing funds provided to the State Water Resources Control Board through a water quality cooperative agreement (CP 96941301-1) from the U.S. Environmental Protection Agency, as well as additional funding from the NCRWQCB and the Hydropower Reform Coalition, the Karuk Tribe of California initiated a sampling program to determine longitudinal, temporal, and depth trends in physical and chemical water quality in Copco and Iron Gate Reservoirs from May 2005 to May 2006. The overall goals of this study were to: 1) collect and analyze detailed nutrient and hydrologic data for Copco and Iron Gate Reservoirs, 2) construct mass-balance nutrient budgets to evaluate potential effects of the reservoirs on nutrient dynamics in the Klamath River, and 3) examine seasonal and longitudinal trends in phytoplankton dynamics.

Both reservoirs thermally stratified during the warm summer months, with the deeper waters (hypolimnion) in both reservoirs exhibiting low levels of dissolved oxygen as well as high concentrations of ammonia and soluble reactive phosphorus. The upper water column layers (epilimnion) in both reservoirs hosted large blooms of phytoplankton and had elevated pH. Concentrations of total nitrogen were consistently lower at Klamath River below Iron Gate than at Klamath River above Copco for the mid-June through September period, while total phosphorus concentrations were lower in the Klamath River below Iron Gate for the Mid-June through August period. This is likely due to 1) nutrient storage in the water column and sediments of the reservoirs, 2) penstock intakes that draw water from intermediate depths where concentrations are lower, and 3) possible atmospheric losses through denitrification (for nitrogen only).

Based on mass-balance nutrient budgets, Iron Gate and Copco Reservoirs combined retained 11.9% of the total phosphorus inflow over the entire study period (5/18/2005-5/11/2006). However, most of that retention occurred in the winter and spring high flow period when the majority of phosphorus was in particulate form. During the main reservoir phytoplankton growing season (5/18/2005-10/5/2005) combined total phosphorus retention was 3.7%, while for the period encompassing turnover (5/18/2005-12/14/2005) it was 2.4%. This relatively low retention during the growing season period is likely due to a combination of two factors: 1) A high percentage of the incoming phosphorus load was in dissolved form, which is less likely to settle than particulate phosphorus, and 2) in many reservoirs, internal phosphorus loading commonly occurs during the type of low and prolonged dissolved oxygen conditions observed in this study.

Over the entire study period, Iron Gate and Copco Reservoirs combined retained 18.1% of total nitrogen inflow. For the main reservoir phytoplankton growing season (5/18/2005-10/5/2005) combined total nitrogen retention was 29.8%, while for the period encompassing turnover (5/18/2005-12/14/2005) it was 16.8%.

When evaluated over shorter temporal scales (e.g. 14-day sampling periods to several months) the nutrient budgets showed the reservoirs acted as both sources and sinks for nitrogen and phosphorus, with substantial variability in retention occurring within and between seasons; however, when compared to a similar analysis using 2002 data (Kann and Asarian 2005) alternating source/sink periods were not as apparent in 2005-2006. During the algal growing season, total nitrogen retention was higher overall than total phosphorus retention, and showed more consistently positive retention, while total phosphorus oscillated between negative and positive retention. Negative retention values can denote a source from within a reservoir (nitrogen fixation or nutrient release from sediments), while positive retention reflects net losses from the water column resulting from sedimentation or denitrification.

Although periods of net negative retention were not as extreme in the 2005-2006 study compared to a previous analysis of 2002 data (Kann and Asarian 2005), overall net retention accounted for a relatively low (<20%) percentage of inflow on an annual basis (11.9% for total phosphorus, and 18.1% for total nitrogen). These observed values were generally within the range predicted using models developed from a broad range of lakes and reservoirs that incorporate inflow loading and other hydraulic characteristics.

Phytoplankton showed patterns that varied by site and sampling depth. Iron Gate and Copco Reservoirs hosted large blooms of blue-green algae, including toxigenic (*Microcystis aeruginosa*) and nitrogen-fixing (*Aphanizomenon flos-aquae*, *Anabaena sp.,* and *Gloeotrichia echinulata*) species. These blue-green algae were most concentrated in reservoir sites at upper water column depths, and though concentrations generally declined with increasing depth, they were present throughout the water column and were at times the most abundant taxonomic group even at depths of up to 10 meters. Similar to previous studies, longitudinal trends show the importance of the reservoirs for providing habitat conducive for growth of blue-green algae (relative to the upstream river, data showed increased blue green algae at surface and intermediate reservoir depths and in the river downstream). Increases in heterocyst abundance and the ratio of heterocysts to vegetative cells in the reservoirs indicate the potential for nitrogen fixation in the reservoirs.

In summary, results from the May 2005 to May 2006 sampling program provide an initial assessment of the complex set of interactions between hydrology, loading, and algal dynamics that drive water quality in the Klamath River system. Recommendations for further study are presented in the end of this report's conclusion section. The sampling will program will continue through fall 2007, and these additional data will provide opportunities for evaluation of inter-annual variability and further insights into the reservoirs' water quality dynamics.

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1. INTRODUCTION

1.1 DESCRIPTION OF STUDY AREA

The Klamath River is one of the major salmon rivers of the western United States. The Klamath River's uppermost tributaries originate in the mountains of southern Oregon. The tributaries then drain into large, shallow Upper Klamath Lake, and after a short stretch of river known as the Link River, followed by Lake Ewauna, the Klamath River proper begins. From this point the River continues through a series of impoundments, including Keno, J.C. Boyle, Copco, and Iron Gate Reservoirs. After Iron Gate Dam, the river flows 190 miles to the Pacific Ocean.

This study focuses specifically on Iron Gate and Copco Reservoirs (Fig. 1), located near the town of Yreka in northern California's Siskiyou County. PacifiCorp operates these reservoirs as part of the Klamath Hydroelectric Project (KHP) to regulate flows and generate electricity.

1.2 BACKGROUND

The Klamath River in California is listed as an impaired water body on the Clean Water Act (CWA) section 303(d) list for temperature, nutrients and dissolved oxygen. The North Coast Regional Water Quality Control Board (NCRWQCB) is in the process of developing a Total Maximum Daily Load (TMDL) for the Klamath River. PacifiCorp Energy, the owner and operator of the Klamath Hydroelectric Project (Project) is also in the process of relicensing the Project with the Federal Energy Regulatory Commission. The State Water Board has authority under section 401 of the Clean Water Act to issue water quality certification for the Project. The study was designed to provide critical information for the development of the technical TMDL, implementation plan, and for the water quality certification process.

The report was prepared using funds provided to the State Water Resources Control Board (State Water Board) through a water quality cooperative agreement (CP 96941301-1) from the U.S. Environmental Protection Agency, with additional funding provided by the NCRWQCB and the Hydropower Reform Coalition. The study was conducted under contract by the Karuk Tribe of California with the assistance of Aquatic System Sciences LLC. and Kier Associates. All samples were collected by the Karuk Tribe Department of Natural Resources.

1.3 PREVIOUS AND CURRENT NUTRIENT STUDIES

There have been several recent studies that included an examination of the effects of the KHP on Klamath River water quality. These include: 1) PacifiCorp's (2004) Final License Application, PacifiCorp's (2005b) water quality modeling effort, and other documents (PacifiCorp 2006), 2) ongoing Total Maximum Daily Loads (TMDLs) studies (St. John 2004), 3) nutrient budgets for the Iron Gate and Copco Reservoirs for calendar year 2002 (Kann and Asarian 2005), 4) a comparison of nitrogen retention between free-flowing river reaches and Iron Gate and Copco Reservoirs (Asarian and Kann 2006a), 5) a summary of phytoplankton data collected in the KHP area by PacifiCorp in the years 2001-2004 (Kann and Asarian 2006), and a comparison of PacifiCorp's water quality model and field data (Asarian and Kann 2006b). In addition, a previous study of nutrient

loading in Iron Gate Reservoir was conducted in 1978 (USEPA 1978).
However, these previous reservoir studies were primarily based on monthly data collection efforts, included only one sampling station in each reservoir, and generally did not span a full year. The intent of this study was to provide a more robust analysis of reservoir water quality dynamics through use of increased spatial and temporal data resolution.

1.4 STUDY GOALS

The overall goals of this study were to 1) collect and analyze detailed nutrient and hydrologic data for Copco and Iron Gate Reservoirs, 2) construct mass-balance nutrient budgets to evaluate potential effects of the reservoirs on nutrient dynamics in the Klamath River, and 3) examine seasonal and longitudinal trends in phytoplankton dynamics. This report includes analysis of data from May 17, 2005 to May 11, 2006

It is important to note that the goal of this report is not to comprehensively analyze and interpret all data collected as part of this study, but to focus on the calculation and interpretation of nutrient budgets as well as to document reservoir phytoplankton trends. The detailed dataset collected as part of this study is also intended to provide baseline data for future analyses and efforts to understand Klamath River nutrient and phytoplankton dynamics.

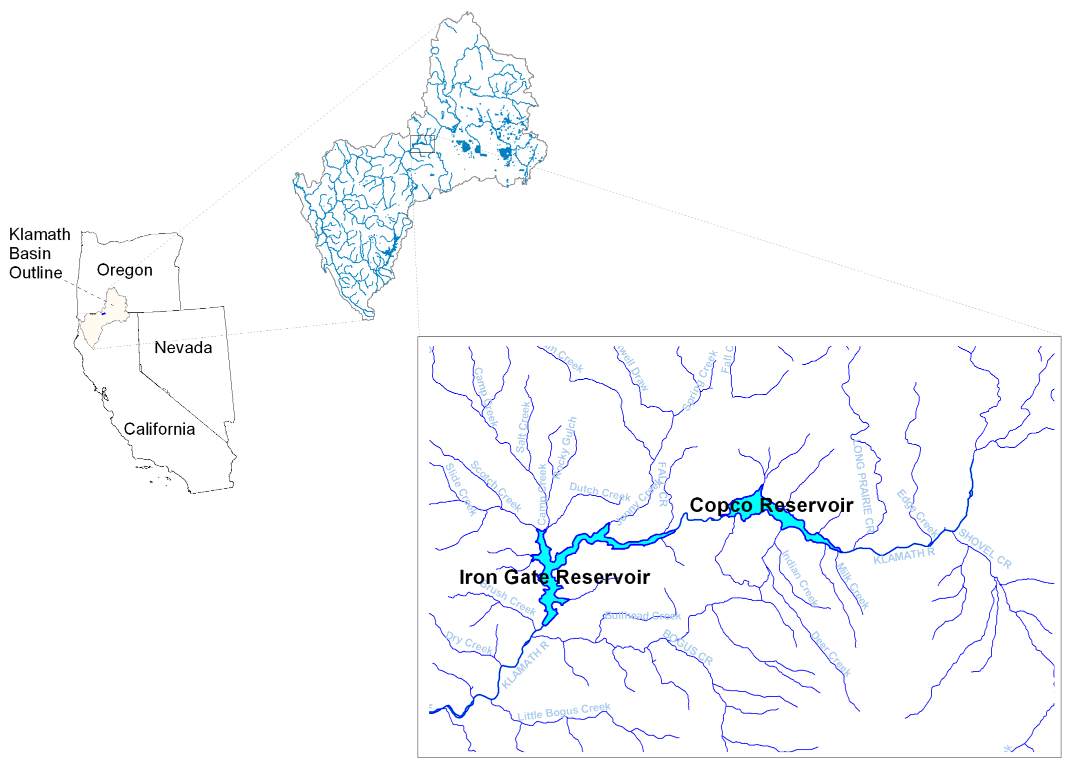


Fig. 1. Regional location of Iron Gate and Copco Reservoirs.

2. METHODS

2.1 DEVELOPMENT OF MASS-BALANCE ANALYSIS FOR WATER AND NUTRIENTS

As outlined in Kann and Asarian (2005), a crucial step in determining the effect of reservoirs on water quality is the development of hydrologic and nutrient budgets on a seasonal basis. Hydrologic (riverine discharge and reservoir volume data) and nutrient (riverine and in-reservoir concentrations of total nitrogen and total phosphorus) data were utilized. For this study these data were collected and/or assembled for inflow, outflow, and in-reservoir stations for both Copco and Iron Gate Reservoirs on a bi-weekly basis. Nutrient concentration data and hydrologic data were used to compute nutrient mass. Reservoir inflow, outflow, and in-reservoir change in mass on a bi-weekly basis were used to calculate nutrient budgets to determine temporal nutrient dynamics and the relative fate of nutrients in Project reservoirs.

2.1.1 Nutrient data

2.1.1.1 Sampling locations and parameters

2.1.1.1 Sampling Locations and Parameters

Samples were collected above, within, and below Copco and Iron Gate Reservoirs. Sampling stations and station codes used for this study are shown in Table 1 and Figure 2. The station codes will be used throughout this report.

Nutrient samples were collected approximately bi-weekly at one primary and one secondary station in both Copco and Iron Gate Reservoirs (Fig. 2, Table 1, Fig. 3). The primary sampling station in each reservoir (CR01 and IR01) was located near the deepest portion of the reservoir and at the same location established by PacifiCorp in previous monitoring efforts (e.g., PacifiCorp 2004). During the June through November period when the reservoirs tended to be less mixed both horizontally and vertically, a second station (CR02 and IR03) was sampled in each reservoir to represent central/upper portions that were somewhat shallower than the primary sampling stations located near the dams (Fig. 2).

Nutrient samples were collected in the Klamath River and tributaries to Iron Gate and Copco on the same (or adjacent) days that in-reservoir samples were collected (Fig. 3). Samples were collected approximately bi-weekly from May 17, 2005 to May 11, 2006. Mainstem sites included the Klamath River above Copco Reservoir, the outlet of Copco 2, and the Klamath River below Iron Gate Dam. Small tributary inputs (Fall Creek, Jenny Creek, and Shovel Creek), which are minor in comparison to mainstem inputs were periodically sampled, but less frequently (Fig. 2; Table 1, raw data contained in Appendix E2). Camp Creek nutrient concentrations were estimated by assuming concentrations to be the same as Jenny Creek (the nearest neighboring stream for which there were data).

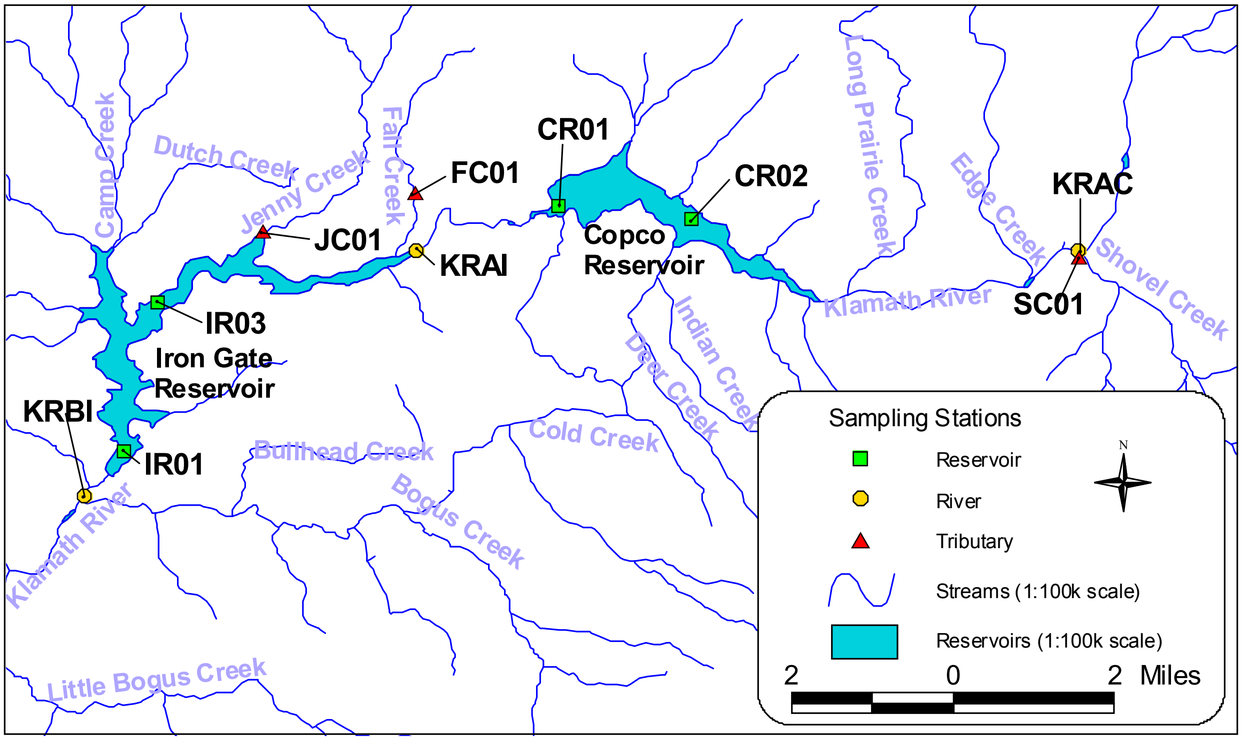


Fig. 2. Location of discharge measurements and nutrient sample sites for Copco and Iron Gate Reservoir inflows and outflows

Table 1. Key and description for sampling locations shown in Fig. 2.

Station Code	Station Description	Station Type	Latitude (decimal degrees)	Longitude (decimal degrees)
KRAC	Klamath River Above Copco Reservoir	River	41.97242	-122.20168
CR02	Copco Res. Upper Half (east)	Reservoir	41.97993	-122.29660
CR01	Copco Res. Near Dam (west)	Reservoir	41.98220	-122.32823
KRAI	Klamath River Above Iron Gate Reservoir	River	41.97289	-122.98106
IR03	Iron Gate Res. Upper Half (east)	Reservoir	41.96460	-122.42315
IR01	Iron Gate Res. Near Dam (west)	Reservoir	41.93883	-122.43217
KRBI	Klamath River Below Iron Gate Reservoir	River	41.93108	-122.44220
SC01	Shovel Creek	Tributary	41.97150	-122.20180
JC01	Jenny Creek	Tributary	41.97710	-122.39760
FC01	Fall Creek	Tributary	41.98400	-122.36100

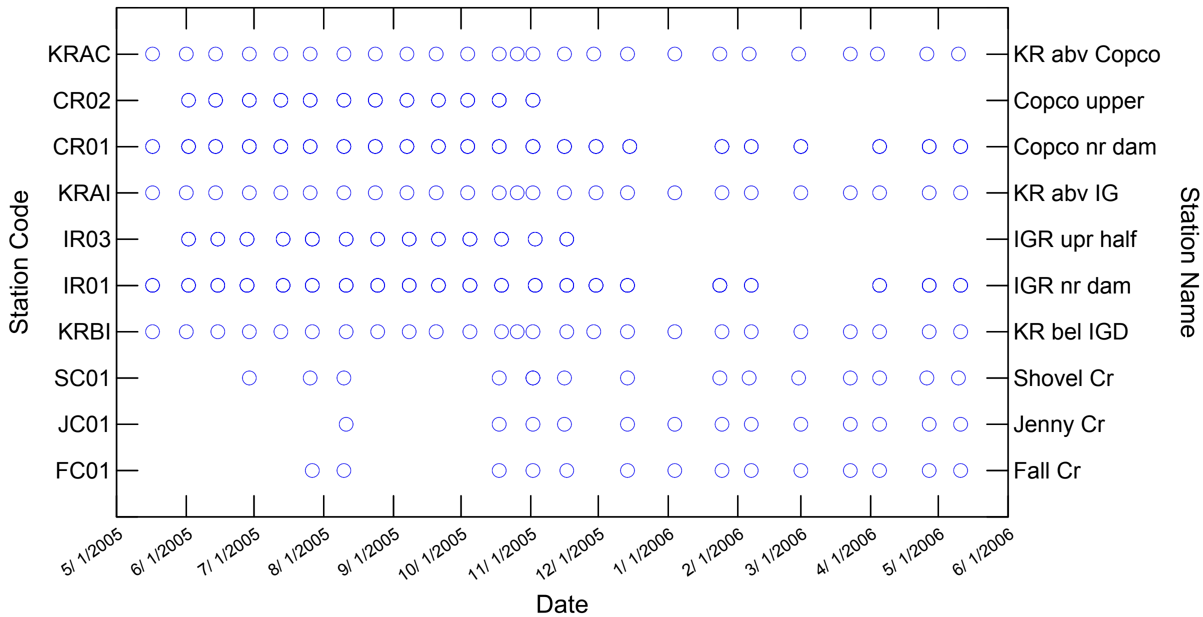


Fig. 3. Timing of May 2005 – May 2006 nutrient samples collected in Copco and Iron Gate Reservoirs, the Klamath River, and tributaries.

Details of the standard operating procedures, analytical methods, and detection limits are described in detail in the project's Quality Assurance Plan, but are summarized briefly here. All sampling trips included at least one duplicate sample with a minimum of 10% duplicate samples collected. These were analyzed with respect to their relative percent difference to determine laboratory reproducibility (these analyses are available upon request). Samples were analyzed by Aquatic Research Incorporated in Seattle, Washington. Parameters analyzed included ammonia (NH3), nitrate-plus-nitrite (NO_3-NO_2), total nitrogen (TN), soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll-a (CHLA), and phaeophytin (PHEO); laboratory reporting limits are shown in Table 2. Total inorganic nitrogen (TIN) was computed as NH3 plus NO3, organic nitrogen (ORGN) was computed as TN minus NH3 minus NO_3-NO_2, particulate phosphorus (PP) was calculated as TP minus SRP. Total organic carbon (TOC) was collected only at mainstem river stations, not at in-reservoir stations. Chlorophyll-a (CHLA) and phaeophytin (PHEO) were not collected at Shovel, Fall, or Jenny Creeks

Table 2. Reporting limits for nutrient samples used in the nutrient budgets.

Parameter Code	Parameter	Reporting Limit (mg/L)
NH3	Ammonia Nitrogen	0.010
NO_3-NO_2	Nitrate (as Nitrogen)	0.010
TN	Total Nitrogen	0.100
SRP	Soluble Reactive Phosphorus	0.001
TP	Total Phosphate Phosphorus	0.002
TOC	Total organic carbon	0.250
CHLA	Chlorophyll *a*	0.100
PHEO	Phaeophytin *a*	0.100

2.1.1.2 In-Reservoir data

To encompass vertical variability due to consistent thermal stratification, samples were taken at multiple depths intended to correspond with the epilimnetic (surface), metalimnetic (middle), and hypolimnetic (bottom) layers. Aside from the initial Copco sample dates in 2005 when two vertical samples were taken, the number of depths sampled varied from three to five, depending on the water depth and degree of thermal stratification. Depth profiles of physical parameters were measured using a Quanta® multi-parameter probe, with measurements generally taken every five meters. Parameters included temperature, pH, dissolved oxygen, and conductivity. The depth profiles of the physical parameters were used to delineate stratification layers so that nutrient samples could be collected at representative depths for each layer.

Poor weather limited access and prevented sampling for two sample dates in Copco and three in Iron Gate between January and March 2006. Given the absence of thermal stratification, higher inflow during this period, and the proximity of the in-reservoir and outflow stations we substituted reservoir outflow concentrations for in-reservoir nutrient concentrations on these dates.[1].

As noted above, a second sampling station was established in each reservoir (Fig. 2; CR02 in Copco and IR03 in Iron Gate) during periods of thermal stratification. These stations were established to evaluate and incorporate potential spatial variability in nutrient concentration that may influence the computation of respective volume-weighted means for the reservoirs. Following are the steps utilized to compute volume-weighted concentrations used in construction of the nutrient budgets, as well as to assess spatial sensitivity to using one vs. two sampling stations.

1) Bathymetry data were obtained from PacifiCorp as an ArcInfo Digital Elevation Model (DEM) grid (Scott, 2005) based on surveys by Eilers and Gubala (2003)(Figs. 4 and 5). To account for the bathymetric surveys being conducted when the reservoirs were not at full pool, volumes were extrapolated to the maximum observed elevations using methods described in Kann and Asarian (2005).

2) Using ArcInfo and the bathymetry grid, reservoir elevation-volume and elevation-surface area curves were then constructed (Fig. 6). For those dates when two stations were sampled, each reservoir was split into an eastern and western portion, with each portion corresponding to a respective sampling station (Figs. 4 and 5). Separate elevation-volume curves were then constructed for each of the eastern and western segments of the reservoirs (Fig. 6: Table 3).

[1] Comparisons of TN and TP at other times during the isothermal period showed that outflow concentrations and in-reservoir concentrations were generally within a few percent

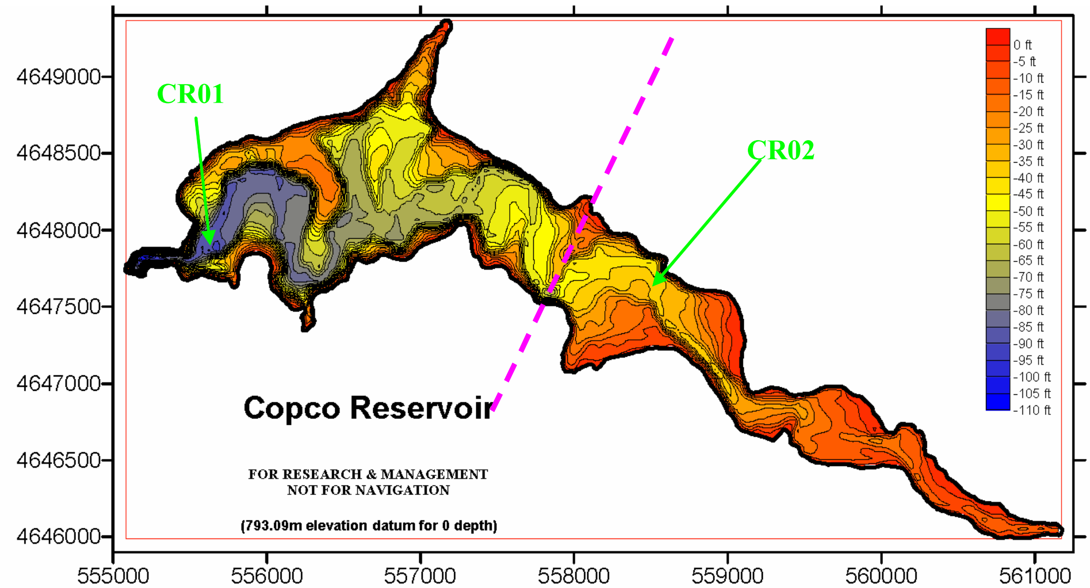


Fig. 4. Bathymetry of Copco Reservoir with reservoir sampling stations shown in green. The pink line represents the break used in calculating water-columns means for nutrient concentration in the eastern and western portions of the reservoir, with water volumes east of the line assigned to CR02, and water volumes west of the line assigned to CR01. Figure Adapted from Eilers and Gubala (2003).

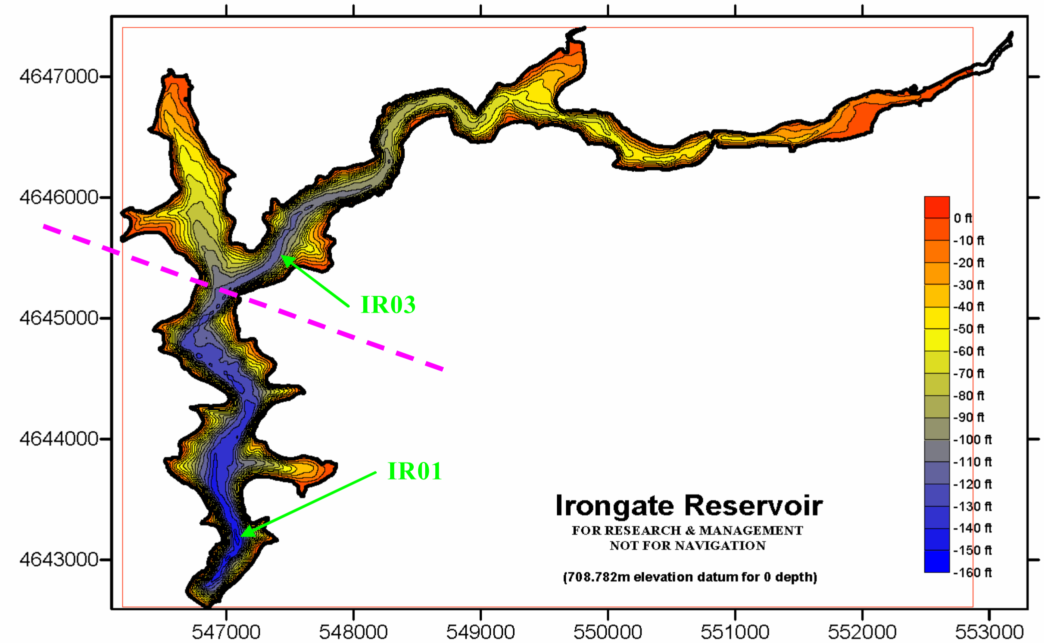
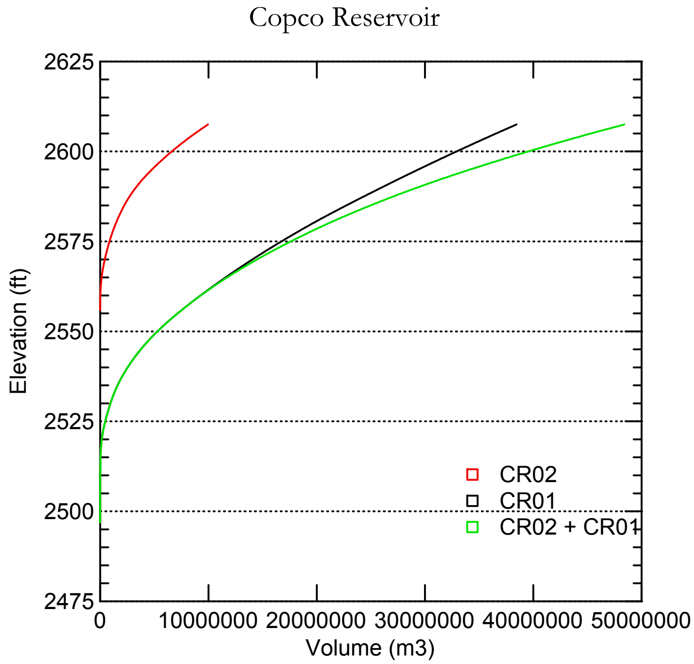


Fig. 5. Bathymetry of Iron Gate Reservoir, with reservoir sampling stations shown in green. The pink line represents the break used in calculating water-columns means for nutrient concentration in the eastern and western portions of the reservoir, with water volumes east of the line assigned to IR03, and water volumes west of the line assigned to IR01. Figure Adapted from Eilers and Gubala (2003).



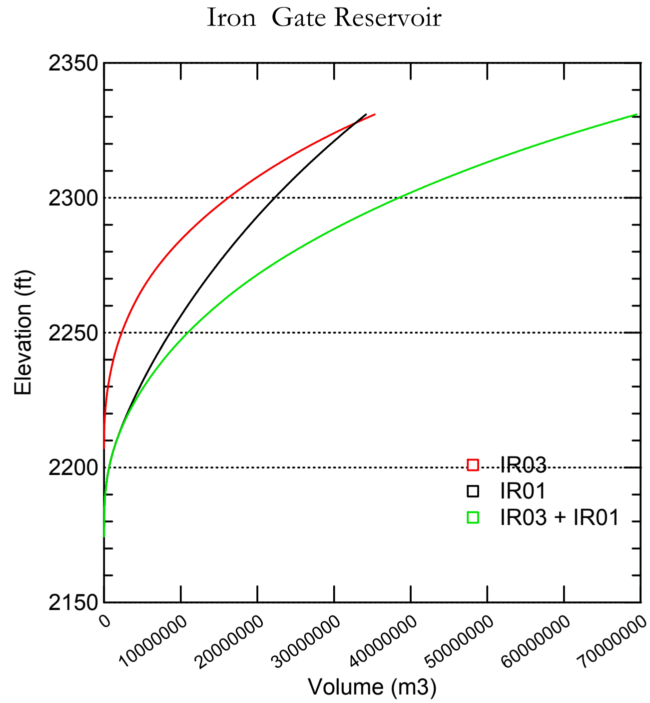


Fig. 6. Water surface elevation-volume curves for Copco and Iron Gate Reservoirs as a whole, and for the eastern and western portion of each reservoir separately.

Table 3. Comparison of elevation, surface area, and volume of the east and west half of Iron Gate and Copco Reservoirs.

Site	Maximum Elevation (ft)	Maximum Surface Area (ft^2)	Maximum Surface Area (% of combined)	Maximum Volume (ft^3)	Maximum Volume (% of combined)
CR01 (west Copco)	2607.5	26915938	60.3%	1357577266	79.4%
CR02 (east Copco)	2607.5	17730783	39.7%	351758524	20.6%*
CR01 + CR02	2607.5	44646721	100.0%	1709335790	100.0%
IR01 (west Iron Gate)	2330.9	15494682	35.0%	1206600570	49.2%
IR03 (east Iron Gate)	2330.9	28801551	65.0%	1246512293	50.8%
IR01 + IR03	2330.9	44296234	100.0%	2453112863	100.0%

*Note: unlike Iron Gate which maintains deeper depths towards the upper portion of the reservoir, the upper portion of Copco becomes shallower resulting in substantially lower volume relative to the lower portion.

3) Reservoir-wide mean nutrient concentration was then computed for each sample date by a) examining temperature and dissolved oxygen profiles to delineate reservoir layers represented by each sample (profiles graphs are contained in Appendix A1 and a stratification table showing the layer assigned to each sample is contained in Electronic Appendix E1), b) utilizing the appropriate reservoir water surface elevation–volume curve (see Fig. 6 above) to assign a volume to this layer, c) multiplying layer volume by nutrient concentration to determine nutrient mass (kg) for each layer, and d) summing the mass in each of the layers and dividing total mass by total reservoir volume on each sample date. Reservoir-wide mean nutrient concentrations are contained in Appendix E2. On days when two sites were sampled in each reservoir, the reservoir-wide mass was calculated as the sum of the nutrient mass in both portions. The final volume-weighted average for each reservoir was calculated by dividing the total reservoir-wide mass by total reservoir volume.

2.1.1.3 Inflow/Outflow data

Both reservoir and tributary concentration data were interpolated between adjacent sample dates to generate a daily record for input to the mass-balance model and to pair with daily hydrologic data. In this fashion the midpoint concentration of each interval represents the interval mean. Although these interpolated daily concentrations and subsequently calculated daily loads are shown below to illustrate budget accounting, it is not the intent to imply that daily values represent specific daily fluctuations. Rather, these daily values were summarized to represent both sample period and whole season or annual dynamics and to account for travel time through the reservoir complex.

Tributary sampling began later in the year than reservoir and mainstem sampling, thus concentrations from the initial samples (6/29/2005 at Shovel Creek, 7/27/2005 at Fall Creek, and 8/11/2005 at Jenny Creek) were substituted for the period May 17 through the first sample at each tributary. An examination of late spring and early summer tributary nutrient concentration data for the year 2002 from PacifiCorp, as well as Karuk data from 2006, showed an inconsistent temporal pattern that precluded further seasonal adjustment. Although estimating these missing concentration values has the potential to be a source of error, these tributaries typically provide a minor contribution relative to total inflow load.

Nutrient data collected at KRAC is impacted by hydropower peaking operations. However, a review of available diel concentration information suggests that nearly all KRAC samples were collected at a time that approximates the flow-weighted daily average concentration (see Appendix A2 for details). To account for concentration uncertainty at this station, an additional sensitivity analysis was performed by varying the inflow concentration by ±10% (the range indicated by observed diel data (see section 3.4.4). One sample (June 1, 2005) was collected during a period of prolonged bypass flows, and thus was corrected by increasing its TN and TP concentrations. Note: the original non-corrected value appears in all plots of nutrient concentration in this report; the corrected value was used in the nutrient budgets. Details are provided in Appendix A2.

2.1.2 Hydrologic Data

2.1.2.1 In-Reservoir data

Daily 8 a.m. reservoir elevation data for the years 2005-2006 were obtained from PacifiCorp[2]. Daily lake volume was then computed from the reported 8 a.m. elevation by applying the elevation-volume relationship developed from bathymetric surveys by Eilers and Gubala (2003).

Daily precipitation records were obtained for the Montague Airport[3], and daily precipitation volume was computed as a product of precipitation and lake surface area as derived from elevation–surface area curves (Eilers and Gubala (2003).

Because daily pan evaporation measurements utilized for construction of the hydrologic budget for 2002 (Kann and Asarian 2005) were discontinued, long-term mean monthly pan evaporation values (WRCC 2005)[4] were divided by the number of days in each month to yield daily average pan evaporation. Data were corrected to approximate open-water evaporation by multiplying by 0.7 (Farnsworth et al. 1982), and daily estimated evaporative loss from the lake surface was computed as the product of open-water evaporation and lake surface area. No data were available for November, so evaporation was assumed to be zero for all days in that month. . Because evaporation is an extremely small component (<1%) of the hydrologic budget, overall results would not be sensitive to errors in estimated evaporation.

2.1.2.2 Inflow/outflow data

Streamflow data for the Klamath River below J.C. Boyle Powerhouse (USGS gage 11510700; 16 miles upstream from Copco Reservoir) were obtained from U.S. Geological Survey[5] and data from this site were used as the mainstem hydrologic inflow to Copco Reservoir. PacifiCorp (2004a) modeling results indicate that typical travel time from the gage to Copco Reservoir varies depending upon flow, but is approximately 8 to 12 hours. Although the travel time issue could introduce error at an hourly time scale, mean daily flow used to compute inflow mass is generally similar on adjacent days; thus, for the purposes of calculating mean daily inflow Boyle gage data were not adjusted.

Shovel Creek is the only significant tributary flowing into the Klamath River between Copco Reservoir and USGS site 11510700. The Karuk Tribe DNR used a hand-held meter to measure discharge in Shovel Creek on four occasions in 2005. In addition, when nutrient samples were collected at Shovel Creek, stage was also recorded from a staff gage located in Shovel Creek. The

[2] PacifiCorp provided the following disclaimer with the data: "The source of this information is from an operations database and not necessarily a database specifically designed and QA/QC'd for water management purposes. That is, the database was not designed nor is it routinely used to create a meaningful hydrologic record, instead its purpose is to predict operational relationships between the measured parameters such as river flows, reservoir elevations, and penstock flows."

[3] Available online at:
http://www.wunderground.com/history/airport/KSIY/2006/1/11/DailyHistory.html?req_city=NA&req_state=NA&r eq_statename=NA

[4] Available online at http://oregonstate.edu/dept/kes/

[5] Available online at http://waterdata.usgs.gov/usa/nwis/uv?site_no=11510700

discharge measurements and staff gage were used to construct a stage-discharge curve, which allowed the estimation of discharge based on staff gage readings from days when flow measurements were not taken. Stage data after 12/14/2005 were not used, due to high-flow events that caused the Creek to overtop the staff gage and flow through two channels. The bi-weekly stage readings did not capture shorter-term fluctuation in discharge caused by rain events.

For dates prior to the first staff gage measurement on 6/29/2005 and after 11/5/2005 (the first major precipitation event was on 11/6/2005), Shovel Creek flows were estimated based on using a watershed area accretion method. The total watershed area contributing to the ungaged accretions between Iron Gate and Seiad Valley, including the Scott Canyon downstream of the Scott River gage, was determined using ArcView GIS. The watershed area of Shovel Creek, Camp Creek, and Bogus Creek were also determined, and the ratio of those areas to the total accretion area were calculated (Table 4). The discharge for each of these creeks then was calculated as the daily accretion multiplied by that ratio[6]. It should be noted that because Shovel Creek, Camp Creek, and Bogus Creek are not located within the Iron Gate to Seiad Valley reach; resulting discharge values are intended to provide basic estimates only. However, as noted above, these small tributaries provide a low overall contribution relative to mainstem flows.

Table 4. Details regarding method for developing discharge estimates for Shovel Creek, Camp Creek, and Bogus Creek.

	Area	
Watershed	**(km²)**	**(%)**
Area contributing to Iron Gate to Seiad ungaged accretion (including lower Scott canyon)	2227.7	100.0%
Shovel Creek	130.5	5.86%
Camp Creek	54.0	2.42%
Bogus Creek	133.3	5.99%

Daily lake outflow volume for Copco Reservoir (station KRAI Table 1; also the inflow to Iron Gate) was obtained from PacifiCorp (2005); however, data appear to be inaccurate, especially during high flows when the Copco spillway is operating. Thus, a record of daily average flow was derived by treating the KRAI flow as an unknown and solving the hydrologic budget for it. We did this using both the Iron Gate and Copco hydrologic budgets, and both resulted in an estimate of KRAI flows lower than reported by PacifiCorp (Fig. 7). Thus, for the purposes of the hydrologic and nutrient budgets, we used the average of the two hydrologic budget-based estimates for KRAI flows.

[6] Daily accretion calculated by subtracting daily average flow at Iron Gate (gage number 11516530), Scott River (11519500), and Shasta River (11517500) from the Seiad Valley (gage number 11520500).

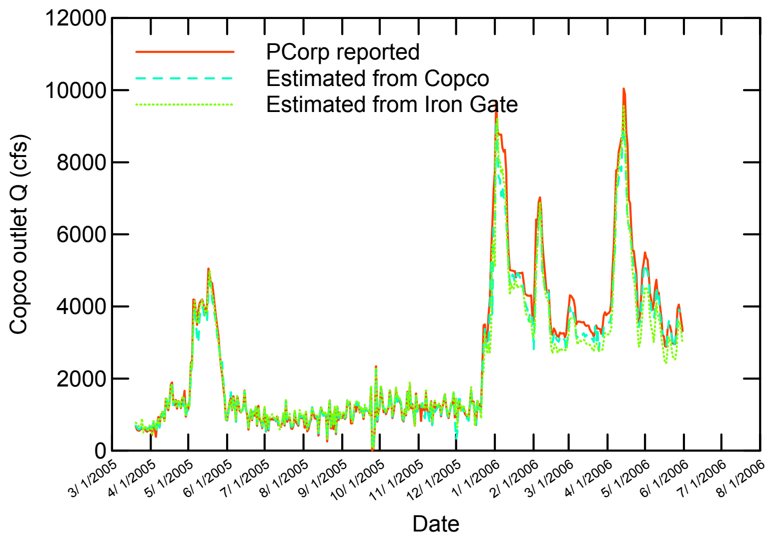


Fig. 7. A comparison of three methods for determining daily average flows for the outlet of Copco Reservoir (KRAI). PacifiCorp data are from lookup tables based on performance testing, engineering specifications and/or engineering equations. Estimated data were derived using water balances for Copco and Iron Gate Reservoirs (see above for details).

Daily outflow from Iron Gate Reservoir was computed by subtracting estimated flow for Bogus Creek (which is located below Iron Gate Dam but upstream of the USGS gage) from the USGS Iron Gate gage (11516530). Bogus Creek discharge data measured using a hand-held flow meter were obtained for three days from late June to late September in 2004, with values ranging from 7.2 to 11.9 cubic feet per second (cfs)[7]. In contrast, the accretion-based estimates of flows were as low as 1-2 cfs on many days during the end of that period. Hence, when accretion-based flow estimates were less than 10 cfs, we adjusted them upwards to 10 cfs.

Flow data for Jenny Creek were obtained from the BLM (2006) station located approximately 1 mile below the confluence of Spring Creek and Jenny Creek. It is unlikely that there are any significant water diversions in the approximately 4 miles of Jenny Creek between the gage and Iron Gate Reservoir (Montfort, pers. comm.). Flows over ~ 80 cfs are extrapolated because no measurements were taken during high flow events that prevent wading (Montfort, pers. comm.). Such flows occurred frequently in the winter and spring: 5/11/2005-5/2/2005, 11/14/2005, 12/1/2005-12/3/2005, and 12/19/2005-5/17/2006. A comparison of these data with estimates of discharge using the accretion-based estimate describe above showed that they were relatively similar.

A hand-held meter was used to measure discharge in Fall Creek on three occasions in 2005. Flows were interpolated between these dates. For periods outside the measured data, monthly average Fall Creek flow values were calculated from a flow gage operated by USGS from 1933 to 1959. These monthly average values were then adjusted downward to incorporate the City of Yreka's diversion for municipal use. Monthly total diversion records were obtained from the City of Yreka (Taylor, pers. comm.) and these were subtracted from average 1933-1959 monthly flows. This method of

[7] Excel spreadsheet "Mid-Klamath and Salmon Rivers Streamflow Data for 1996 - 2004 collected by the Karuk Tribe of California, and the Klamath and Six Rivers National Forests" obtained from the U.S. Forest Service.

estimating Fall Creek flows does not attempt to estimate increased flows during storm events. Fall Creek is largely spring-fed and hence seasonal fluctuations should be less than in other nearby creeks, although flow likely increases during storm events such as occurred in December 2005 and January 2006. Additional sources of error include a potential increase in PacifiCorp diversions beginning in 1989 (in a letter to FERC (Taylor 2004) states that beginning in 1989 PacifiCorp began diverting up to 16.5 cfs from Spring Creek, whereas its previous diversion had been no more than 4 cfs). Although uncertainly exists in estimates of tributary inflow, with the exception of sporadic high flow events in the winter and spring, tributary inputs are generally small relative to mainstem inflows.

2.1.2.3 Hydrologic Residual

Information on groundwater inputs was not available and was assumed to be negligible for both reservoirs. However, as a check of both groundwater and all other error in measured discharge and lake hydrologic characteristics, the residual of the reservoir water balance (hydrologic residual) was computed as:

Hydrologic Residual = outflow + evaporation + Δ lake storage – inflow [tributary + mainstem] – precipitation

where Δ lake storage is the change in lake storage for the time step analyzed

2.1.3 Nutrient budget construction

The above estimates of nutrient concentration and water volume were used in all subsequent determinations of nutrient mass. The nutrient mass from each surface inflow and outflow was computed as the product of daily estimated nutrient concentration and daily mean discharge. The nutrient mass contained in each reservoir was computed as the product of daily reservoir volume and daily estimated reservoir-wide volume-weighted mean nutrient concentration (described above).

Atmospheric nutrient inputs (the sum of wetfall and dryfall, but excluding N input via nitrogen fixation by phytoplankton) were estimated at fixed areal rates of 18 $kg/km^2\ yr^{-1}$ for phosphorus, and 1080 $kg/km^2\ yr^{-1}$ for nitrogen (U.S. EPA, 1975).

2.1.3.1 Nutrient retention

Net nutrient retention was calculated as the residual of the nutrient mass-balance equation as follows:

Net Retention = inflow mass [mainstem + tributary + atmospheric] – outflow mass - Δ reservoir storage

Net retention reflects 1) net losses from the water column resulting from sedimentation, 2) atmospheric fixation (for nitrogen only), 3) nutrient releases from bottom sediments, and 4) the cumulative effects of errors in the other mass-balance terms. Negative retention values denote a source from within a reservoir.

Although separate budgets were calculated for Copco and Iron Gate, the net effect of both reservoirs in tandem was also evaluated. As noted above, to account for actual sample period resolution, as well as travel time (reservoir residence time ranges between 10-30 days), budgets were summarized on a sample period (~biweekly) basis, approximate main river periphyton growing season (~July-September), approximate reservoir growing season (end of May-September), study start through turnover (end of May-early December), and annually (May 2005-May 2006).

2.2 PHYTOPLANKTON

2.2.1 Introduction to Phytoplankton Analysis

While previous Klamath River analyses based both on monthly sampling intervals for longitudinal phytoplankton trends (Kann and Asarian 2006) and biweekly intervals for specific toxic algal (e.g., *Microcystis aeruginosa*) trends (Kann and Corum 2006; Kann 2006) have been performed for the Copco/Iron Gate Reservoir system, the analyses below provide a detailed analysis of biweekly-based phytoplankton biomass and community structure.

This section of the report provides a summary and analysis of phytoplankton data collected biweekly from May 2005 through December 2005, including a description of seasonal and longitudinal patterns in algal species composition and biovolume.

2.2.2 Phytoplankton Sample Collection and Laboratory Methods

Phytoplankton and chlorophyll samples were collected in a similar fashion to the nutrient samples described above. However, depths varied from the nutrient samples in order to characterize the photic zone of the reservoirs.

Samples for microscopic determination of phytoplankton density and biovolume were preserved in Lugol's Iodine and sent to Aquatic Analysts in White Salmon, WA where enumeration and biovolume measurements are determined according to APHA Standard Methods (1992). Chlorophyll samples were shipped with the nutrient samples to Aquatic Research as described above.

2.2.3 Phytoplankton Data Analysis Approach

2.2.3.1 Longitudinal Analyses

Longitudinal trends in the biovolume of total phytoplankton (including separate measurements of chlorophyll *a*), nitrogen fixing phytoplankton, and major algal taxonomic groups (Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, Diatoms, Euglenophyta, and Pyrrophyta) were evaluated for all available 2005 data. Because river station samples were collected 0.5 meters below the surface, longitudinal plots that include reservoir stations consist of samples taken between the surface and 1 m to facilitate comparison of similar water column depths.

In addition, because the nitrogen fixing blue-green alga, *Aphanizomenon flos-aquae*, as well as other species such as *Anabaena* and *Gloeotrichia* can play an important role in introducing nitrogen into aquatic systems, specific analyses for total and percent biovolume of nitrogen fixing phytoplankton were evaluated to assess their distribution and relative magnitude. Longitudinal data were evaluated both for all dates, and for the June-September algal season when major blue-green blooms are typically observed in the reservoirs (Kann and Asarian 2006).

Although much is known about the phytoplankton dynamics upstream in Upper Klamath Lake, for purposes of this report the station KRAC serves as the boundary (i.e., it represents inflow conditions) reference with respect to evaluating longitudinal patterns.

2.2.3.2 Time-Series Analyses

Seasonal trends of major taxonomic groups and dominant phytoplankton species for the May 2005 to December 2005 period were evaluated for both reservoir stations (including depth-distribution) and river stations. In addition, because heterocysts are specialized blue-green algal cells that can indicate nitrogen fixation, the seasonal and longitudinal trends in relative heterocyst abundance were also evaluated.

3. RESULTS AND DISCUSSION

3.1 DEPTH PROFILES FOR TEMPERATURE, DISSOLVED OXYGEN, PH, AND NUTRIENTS

Depth distribution of temperature, dissolved oxygen (DO), and pH is an important aspect of water quality dynamics and fish habitat, and depth-time plots of isotherms and isopleths for these parameters allows both seasonal and depth distribution to be evaluated simultaneously (Figs. 8-11). For the purposes of this report they were mainly utilized to determine (along with the profile plots in Appendix A1) stratification and mixing patterns with respect to understanding nutrient dynamics. Temperature isotherms show that for 2005 stratification began during late May to early June for the Copco stations, but that seasonal stratification had already developed by this time at the Iron Gate stations (Fig. 8). Copco stations also showed earlier fall mixing than did Iron Gate, with complete mixing occurring nearly a month later in Iron Gate (early December) than it did in Copco (early November). Likewise, low dissolved oxygen (< 3mg/L) extended further up in the water column and longer in the season in the Iron Gate system (Fig. 9 and 10). Coinciding with the period of elevated upper water column temperatures during summer months, pH and dissolved oxygen also showed elevated levels during this same period (Fig. 9-11). Supersaturated dissolved oxygen and high pH near the surface during the stratified period are the likely reflection of higher algal biomass and productivity from buoyant cyanobacteria concentrating near the reservoir surface (see below for description of chlorophyll and phytoplankton dynamics)

Figures12-15 illustrates differences in nitrogen and phosphorus concentrations at various depths over time in Copco and Iron Gate Reservoirs. Beginning in mid May and continuing through mid July TN values tended to be lower at the 1-20 meters (m) depths than they were at the 20-40 m depths in Iron Gate (Fig. 12). A similar trend was observed in Copco, but only thorough mid-June (Fig. 14). This TN difference appears to be driven by lower NO_3-NO_2 in the upper water column layers compared to lower water column layers. Coincident with the period of maximum stratification and low dissolved oxygen (Figs. 9 and 10), lower layer NO_3-NO_2 then declined while upper layer concentrations increased. During this period of deeper reservoir anoxia, NH_3 increased in the bottom layer, reaching a seasonal maximum in early November in Iron Gate (Fig. 12) and in late September in Copco (Fig. 14). The trend of increasing NH_3 and decreasing NO_3-NO_2 is particularly evident in the deepest layer of each reservoir.

Organic N began to increase in mid July in both reservoirs at the 1 m depth, and coincided with low total inorganic nitrogen (NO_3-NO_2 + NH_3) in the surface layer that extended until early September in Iron Gate (Fig. 12), but only until the end of June for Copco (Fig. 14). For both reservoirs NO_3-NO_2 and TIN tended to increase with increasing depth. These trends are likely the result of phytoplankton growth in the upper reservoir layers (see phytoplankton section below). The concentration of all forms of nitrogen at specific depths then tended to converge during water column mixing in the fall months.

TP and SRP were similar at all depths from late May through late July in Iron Gate, and for late May through late June in Copco (Figs. 13 and 15). Values then diverged, particularly for SRP, where a seasonal increase in bottom layer SRP continued through early November in Iron Gate and through early October in Copco. Similar to ammonia increases, SRP increases generally coincided with the development of an anoxic hypolimnion, and are possibly reflective of internal P loading due to release of iron-bound P. SRP in the surface layer of Iron Gate decreased until the end of July and then increased again before declining in October (Fig. 13). There was also a seasonal increase in particulate P (PP; particularly for the 1 m layer in Iron Gate) that likely stems from phytoplankton concentrating near the surface during the stratified period. This trend was consistent with the trend in organic nitrogen. As with nitrogen, the concentration of all forms of phosphorus at specific depths then tended to converge during water column mixing in the fall months.

During the stratified period TIN:SRP ratios tended to be lower in the upper water column layers and showed an increasing trend with depth; although the trend was more pronounced in Iron Gate than it was in Copco (Figs. 13 and 15). For both reservoirs the TIN:SRP ratio is relatively low in the upper layers (<5 in Iron Gate and <7 in Copco) during the stratified period.

Although the observed trends in the depth distribution of nutrients are consistent with the observed stratification and algal production data (see phytoplankton section below); as mentioned above, it is not the intent of this report to provide a detailed analysis of the nutrient dynamics relative to physical and biological processes occurring in the reservoirs. However, these data will provide the base for future analyses that analyze nutrient, physical, and biological dynamics in the reservoirs.

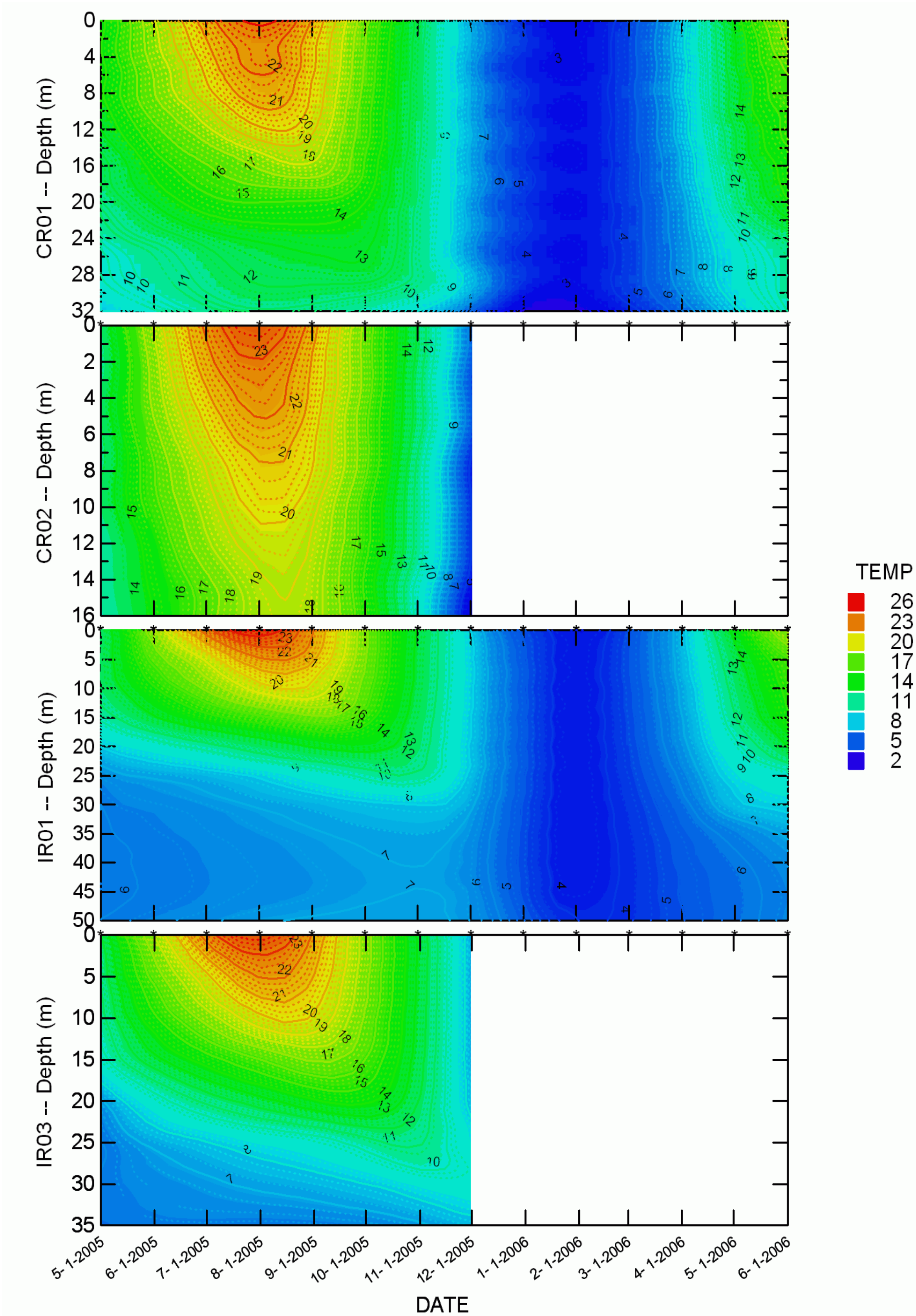


Fig. 8. Depth-time distributions of isotherms of temperature (°C) at stations in Copco and Iron Gate Reservoir, May 2005-May 2006.

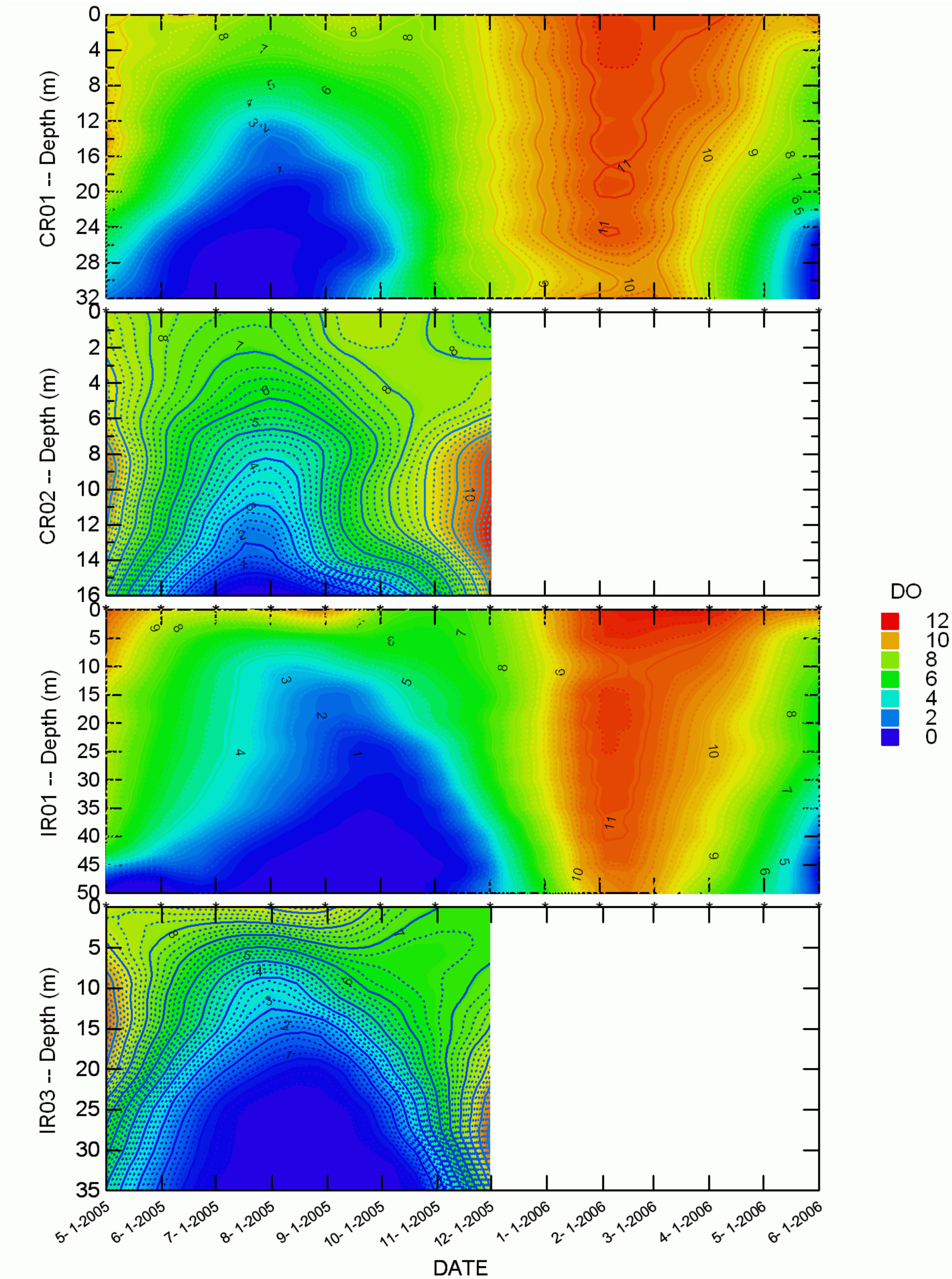


Fig. 9. Depth-time distributions of isopleths of dissolved oxygen (mg/L) at station in Copco and Iron Gate Reservoir, May 2005-May 2006.

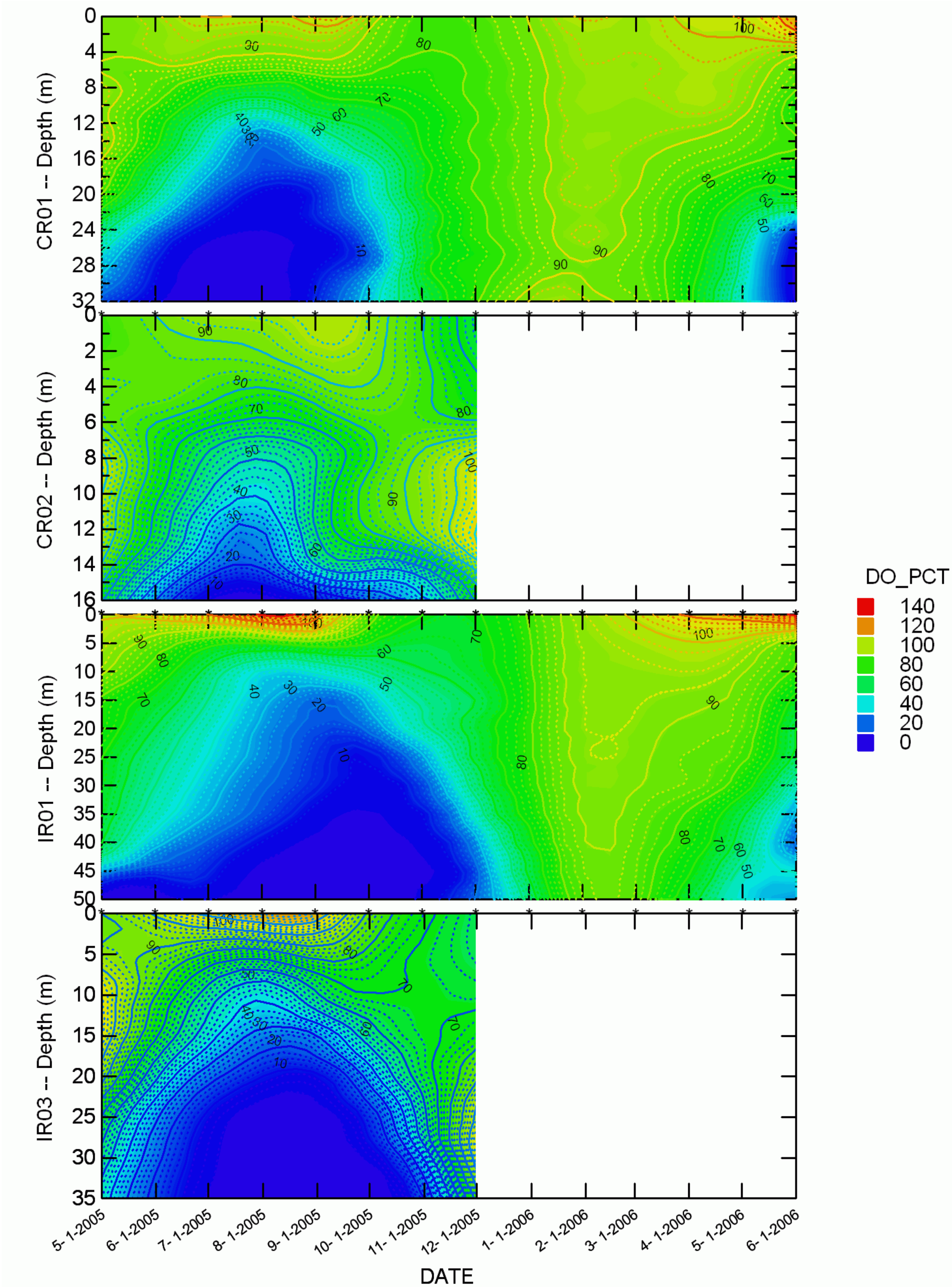


Fig. 10. Depth-time distributions of isopleths of dissolved oxygen (percent saturation) at stations in Copco and Iron Gate Reservoir, May 2005-May 2006.

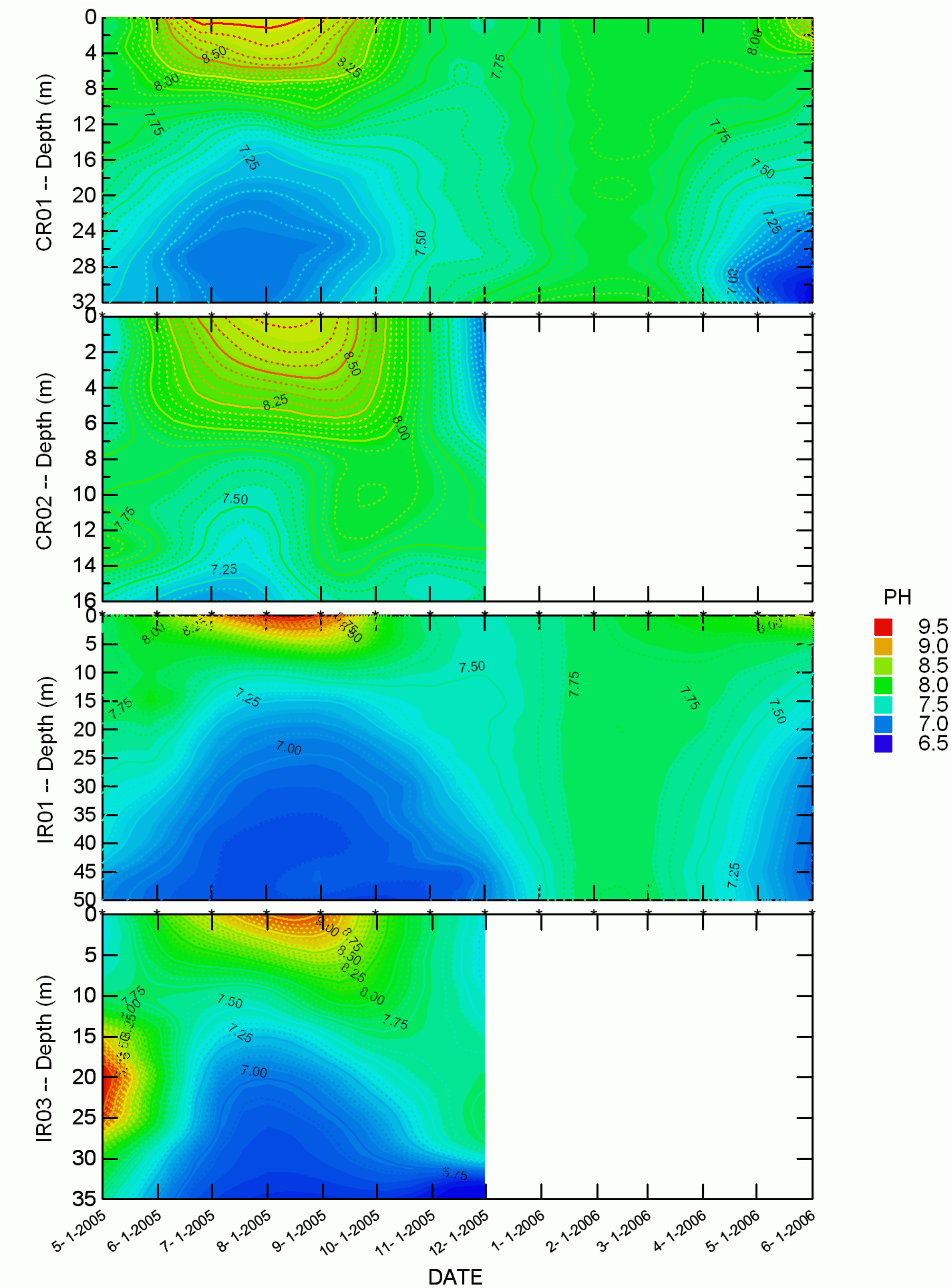


Fig. 11. Depth-time distributions of isopleths of pH at stations in Copco and Iron Gate Reservoir, May 2005-May 2006 (note that high pH showing at mid depths for IR03 in May 2005 is an artifact of extrapolating beyond the sample date).

Iron Gate (IR01)

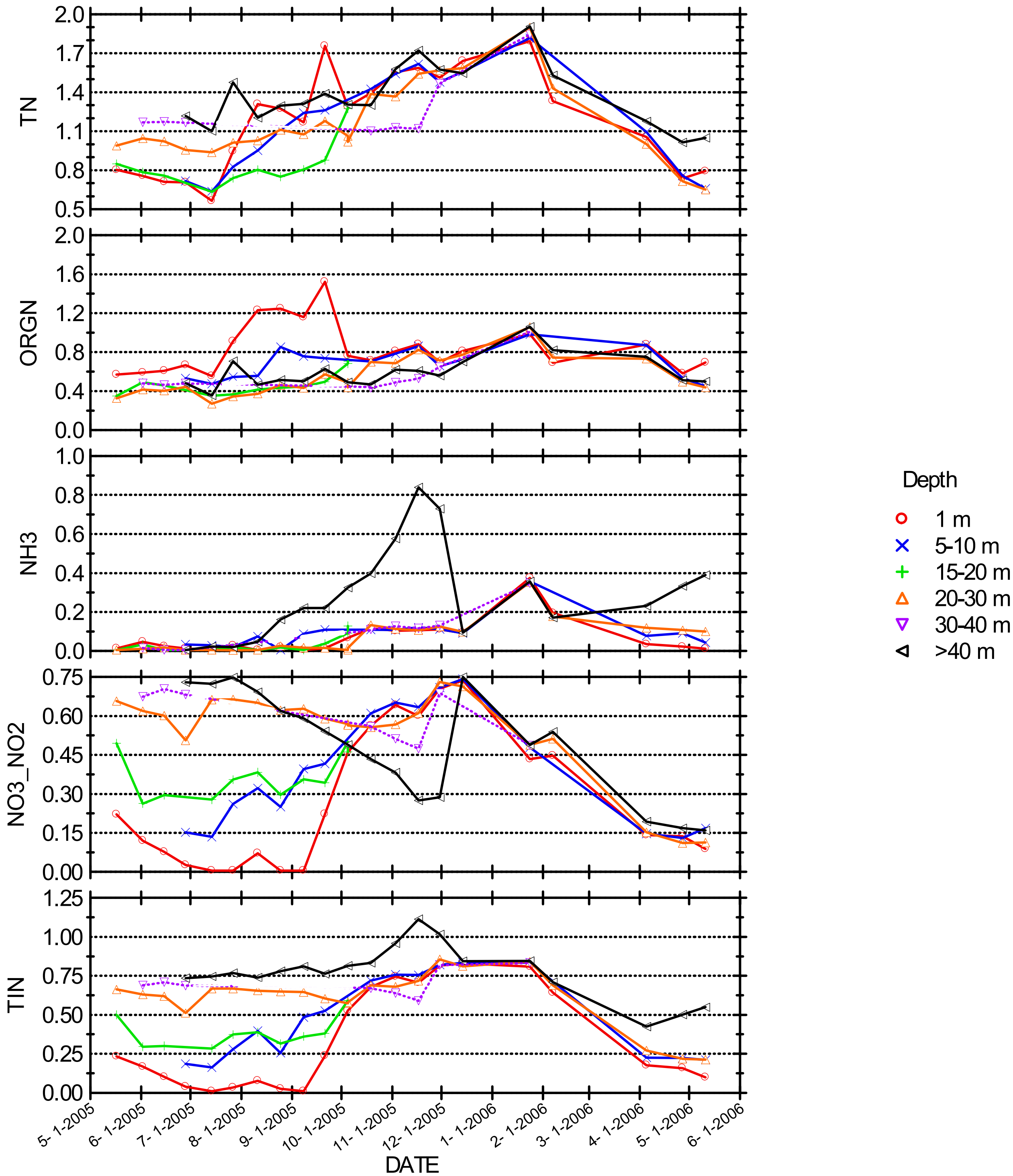


Fig. 12. Depth-profiles of nitrogen concentrations at Iron Gate Reservoir sampling station IR01, May 2005 – May 2006.

Iron Gate (IR01)

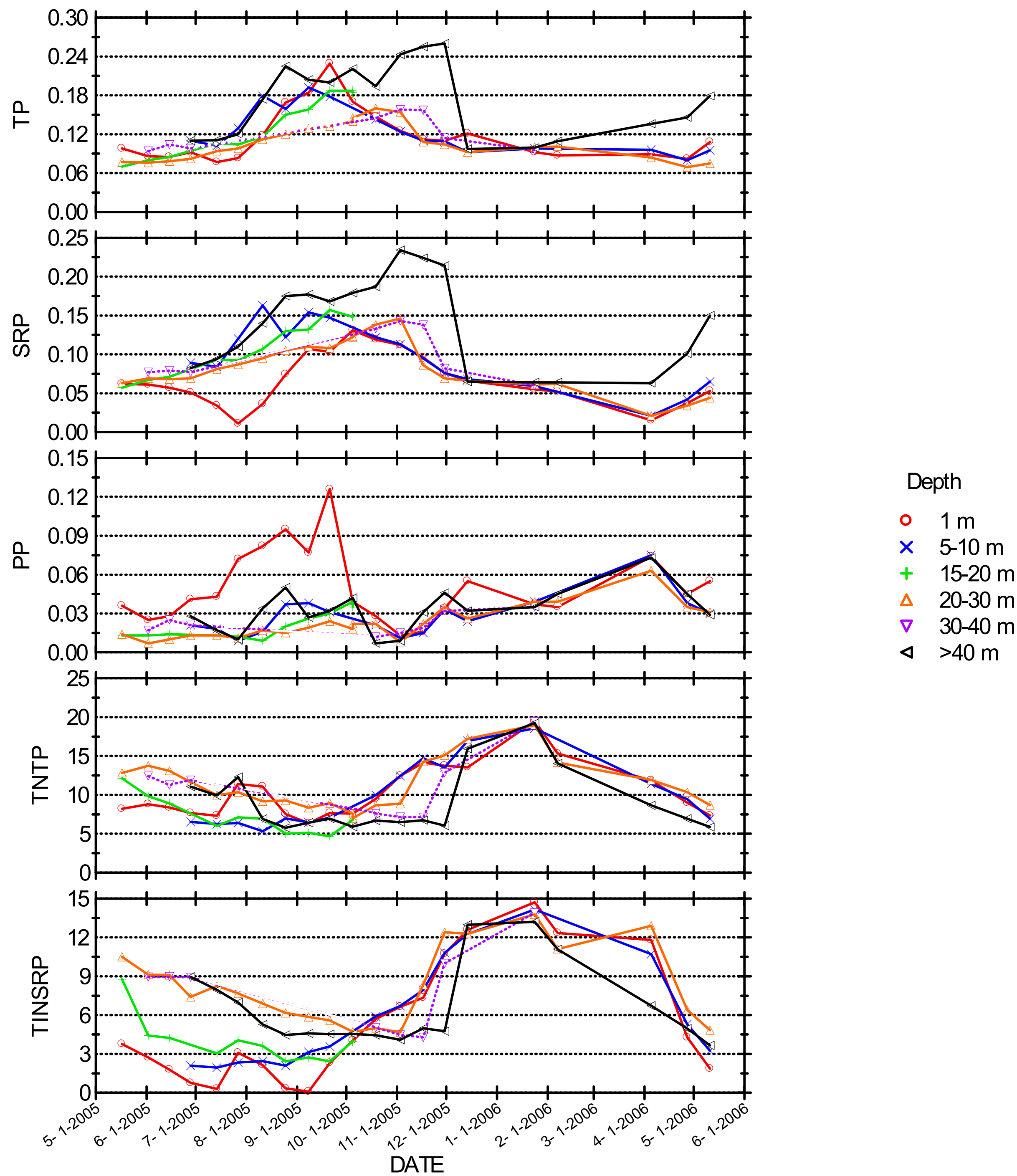


Fig. 13. Depth-profiles of phosphorus concentrations and nitrogen:phosphorus ratios at Iron Gate Reservoir sampling station IR01, May 2005 – May 2006. TNTP is ratio of TN to TP, and TINSRP is ratio of TIN to SRP.

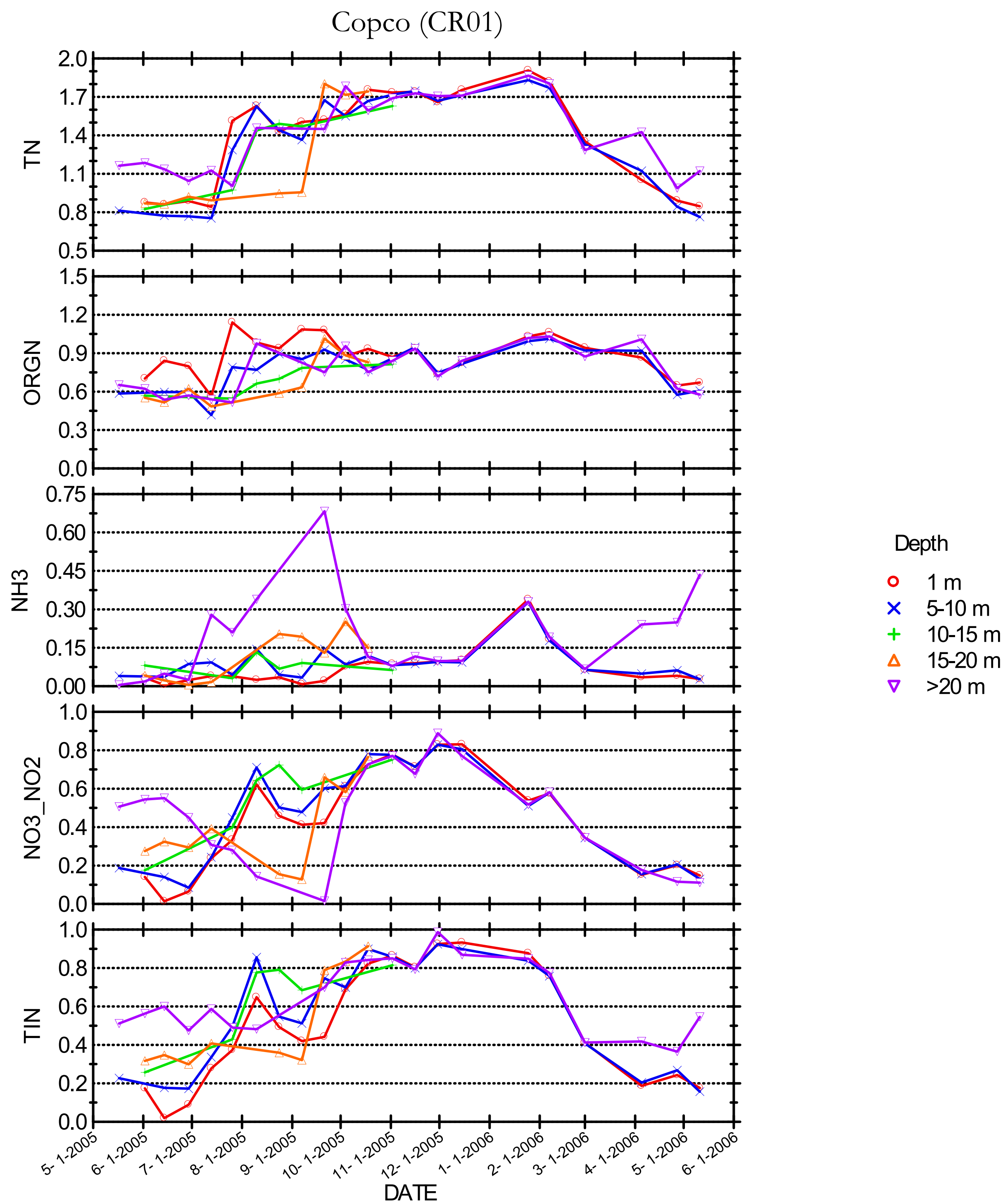


Fig. 14. Depth-profiles of nitrogen concentrations at Copco Reservoir sampling station CR01, May 2005 – May 2006.

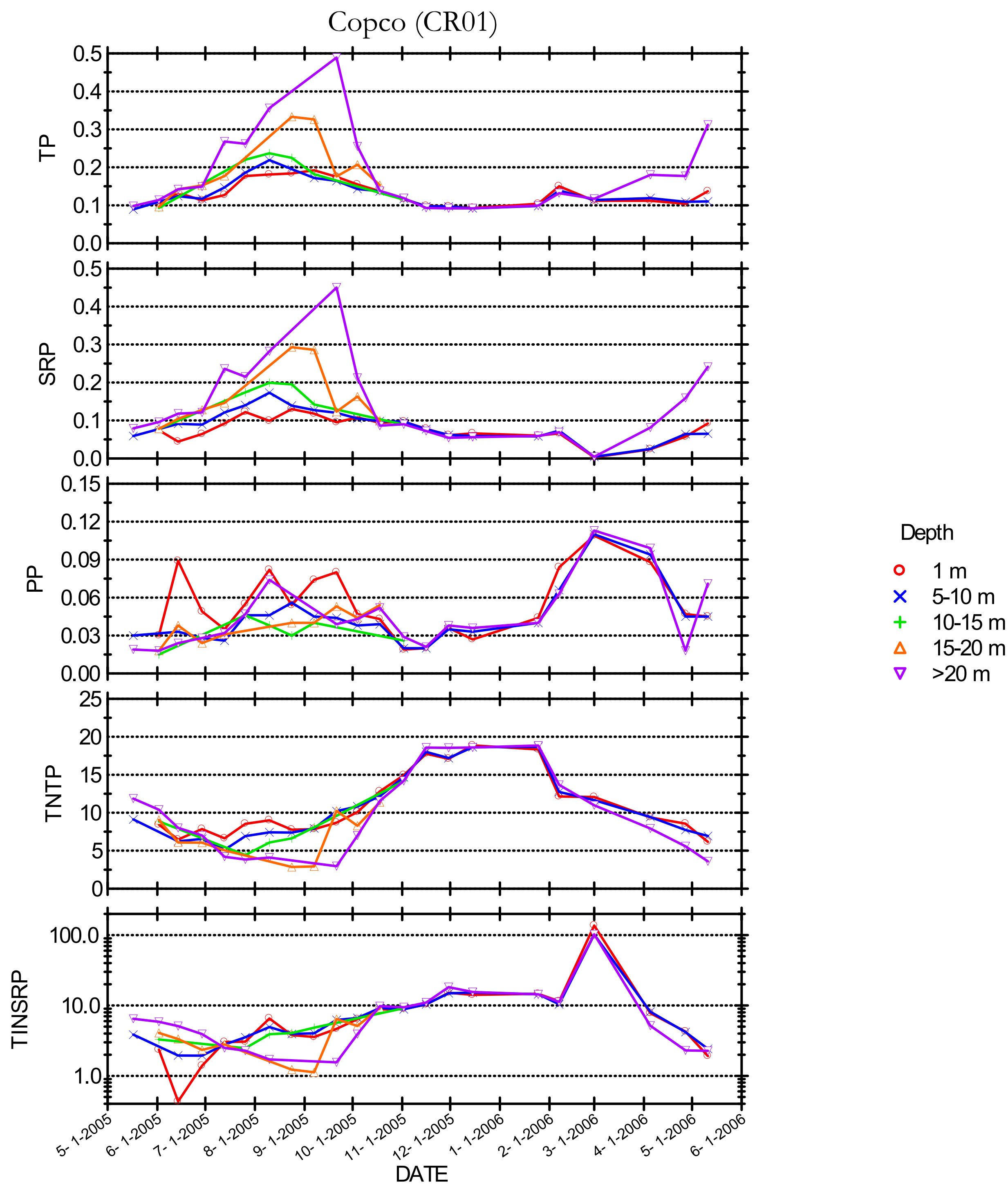


Fig. 15. Depth-profiles of phosphorus concentrations and nitrogen:phosphorus ratios at Copco Reservoir sampling station CR01, May 2005 – May 2006. TNTP is ratio of TN to TP, and TINSRP is ratio of TIN to SRP.

3.2 LONGITUDINAL NUTRIENT CONCENTRATIONS

3.2.1 Copco Reservoir

Nitrogen

Time series of all Copco nutrient parameters for inflow[8], in-reservoir and outflow terms are shown in Figures 16 and 17. From late June through September, NH3 concentrations were higher in Copco Reservoir than in inflow or outflow (Fig. 16). From mid-September through mid-December, ammonia concentrations in the outflow increased to levels similar to those in-reservoir, and diverged from inflow concentrations that generally remained low. The highest ammonia concentrations of the season were observed during the peak flows in early January, subsiding to more commonly observed levels by the end of February.

During the thermally stratified period from June through October, inflow NO_3-NO_2 concentrations were substantially higher than in-reservoir and outflow concentrations (Fig. 16). During isothermal periods, inflow NO_3-NO_2 concentrations were equal or lower compared to outflow and in-reservoir concentrations. With the exception of January and February 2006, NO_3-NO_2 comprised the greatest portion of the TIN.

In-reservoir and outflow ORGN concentrations were generally similar, and with some exceptions were either similar or slightly lower than in inflow (Fig. 16). TN concentrations were typically very similar in outflow and in-reservoir, and generally lower than in inflow except during/after turnover in mid-October through mid-December and in May, when inflow concentrations were generally similar or lower than outflow and in-reservoir concentrations.

Phosphorus

In Copco inflow, TP and SRP were highest during July, while the highest in-reservoir and reservoir outflow concentrations were observed in August (Fig. 17). Peaks in TP concentration were also observed during high flows in January and February 2006, consisting largely of PP, not SRP. The ratios of total nitrogen to total phosphorus (TN:TP) and total inorganic nitrogen to SRP (TIN:SRP) were generally higher in Copco inflow than in Copco Reservoir and its outflow, indicating that conditions are more nitrogen-limiting below Copco than above (Fig. 17), but in mid-January through May TN:TP and TIN:SRP ratios sometimes showed an opposite pattern.

[8] Inflows values shown in these figures are not flow-weighted averages that take into account dilution by small tributaries; they are the directly measured concentrations. Flow-weighted biweekly summaries for total inflow are shown in Table A3-1 of Appendix A3.

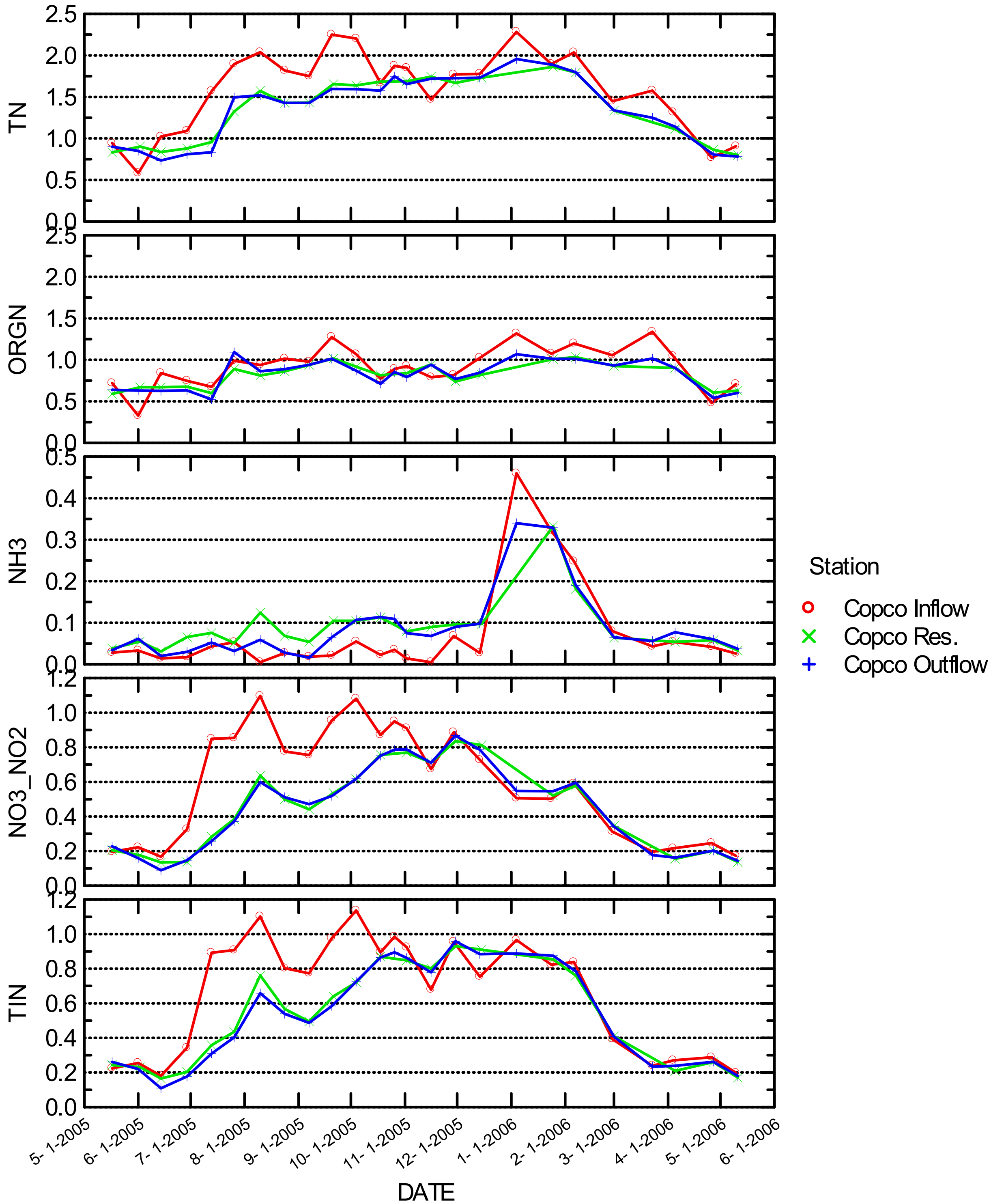


Fig. 16. Biweekly time series of Copco Reservoir nitrogen concentrations, Apr-Nov May 2005 - May 2006.

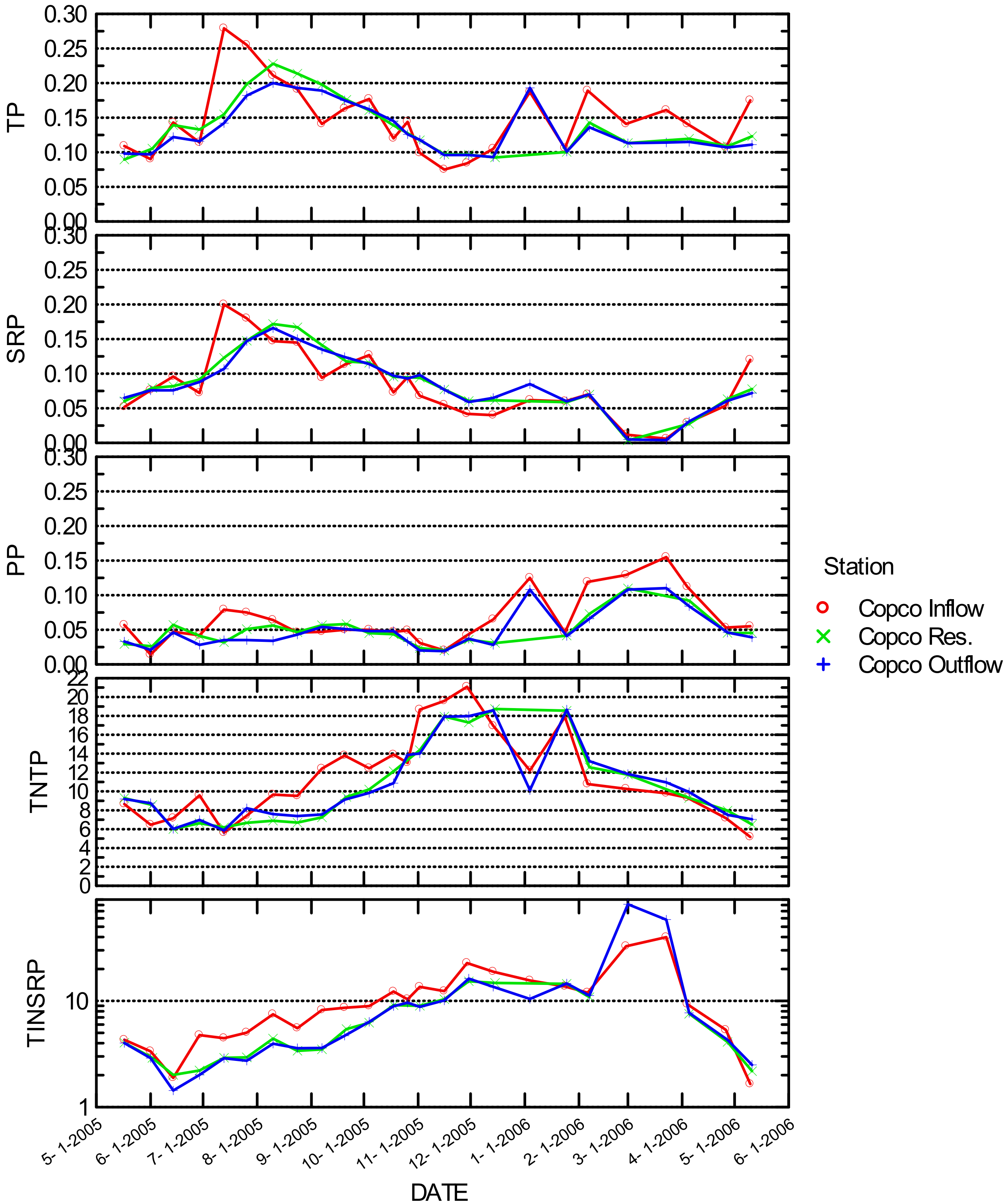


Fig. 17. Biweekly time series of Copco Reservoir phosphorus concentrations and nitrogen-phosphorus ratios, May 2005 - May 2006.

3.2.2 Iron Gate Reservoir

Time series of all nutrient parameters for inflow, in-reservoir and outflow terms are shown in Figures 18 and 19. Volume weighted bi-weekly summaries are shown in Table A3-2 of Appendix A3. As noted above, inflow values in these figures are not flow-weighted averages that take into account dilution by small tributaries; they are the directly measured concentrations.

Nitrogen
Some longitudinal and temporal patterns in nutrient concentrations in Iron Gate inflow, in-reservoir, and outflow were similar to patterns observed in Copco, but others are different. Because ammonia concentrations were already elevated in Copco Reservoir outflows, ammonia concentrations do not show the consistent longitudinal patterns observed in Copco Reservoir (Fig. 18). In May and June in Iron Gate, NO_3-NO_2 concentrations were highest in-reservoir, a different pattern than was observed in Copco where inflow concentrations were higher or equal to in-reservoir and outflow concentrations. From mid-July to early February, NO_3-NO_2 concentrations were typically higher in inflow than in-reservoir and outflow concentrations, yet the difference is not as large as it was in the Copco Reservoir system. Similar to Copco, most of the TIN in Iron Gate was NO_3-NO_2, so the trend of TIN closely follows that of NO_3-NO_2.

With the exception of one data point in late July, Iron Gate inflow ORGN concentrations were typically close to or slightly higher than outflow concentrations. This trend was also observed in Copco; however, there were a few days in Copco when outflow concentrations exceeded inflow, which did not occur in Iron Gate. Iron Gate inflow TN concentrations were typically higher or equal to in-reservoir and outflow concentrations, although differences were less than those observed for Copco Reservoir.

Phosphorus
Iron Gate inflow TP and SRP concentrations were higher than in-reservoir and outflows for June through August, while September through November TP and SRP concentrations were generally higher in-reservoir (and to a lesser extent, outflow) than in inflow (Fig.19). Longitudinal trends in Iron Gate TN:TP and TIN:SRP ratios were generally similar to trends observed in Copco, except that in mid-May through mid-July, TN:TP and TIN:SRP were higher in-reservoir in Iron Gate compared to inflow and outflow

In general, with a few exceptions, the lack of large changes in TN and TP from one sampling period to the next indicates that a biweekly sampling frequency is generally adequate for the Iron Gate and Copco Reservoir complex. Exceptions to this were a mid-July spike in TP in Copco inflow, a late-July spike in TN at Copco outflow, and January/February TP at all stations (some sampling frequencies in this winter period were actually closer to 21 days than biweekly).

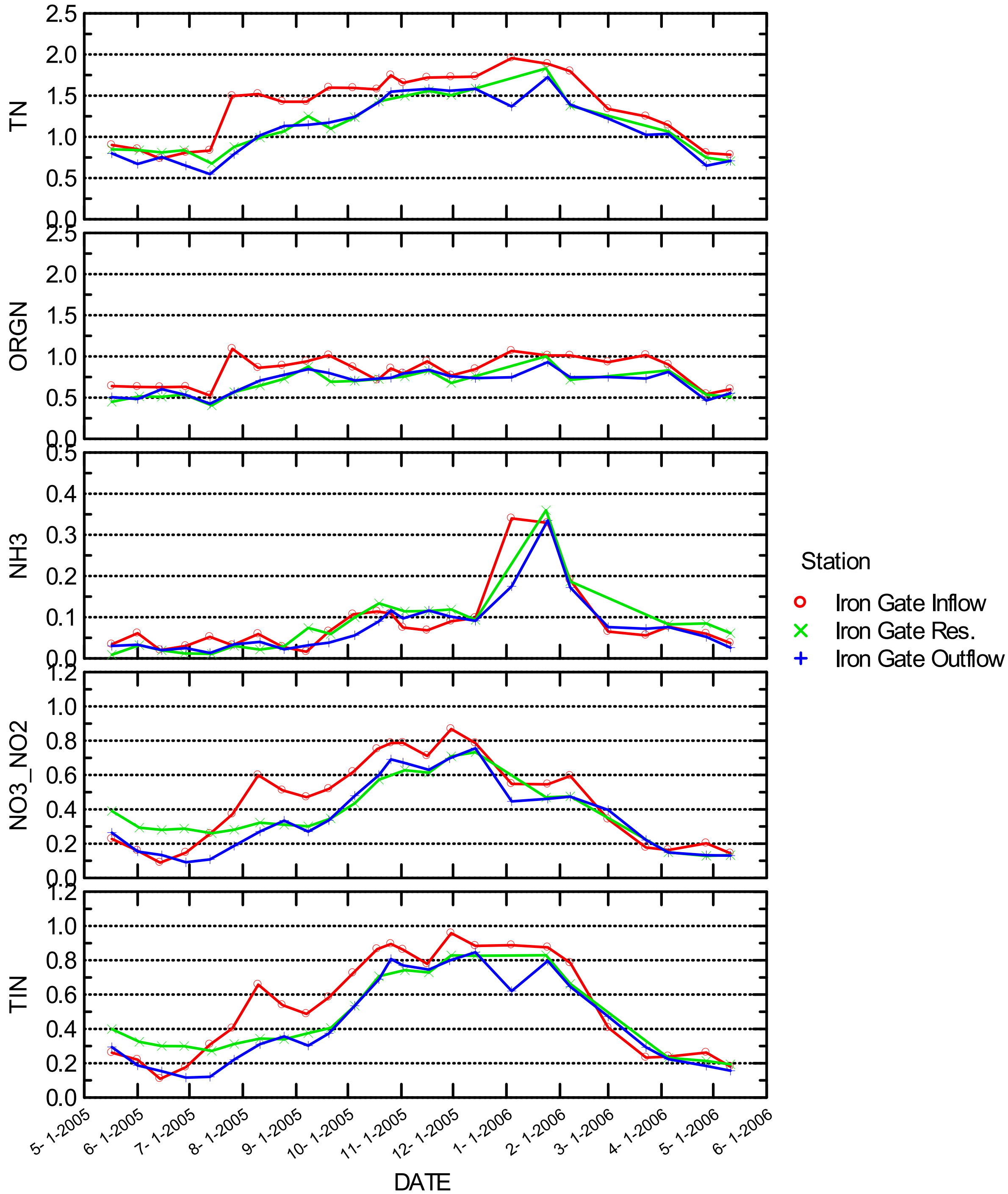


Fig. 18. Biweekly time series of Iron Gate Reservoir nitrogen concentrations, May 2005 - May 2006.

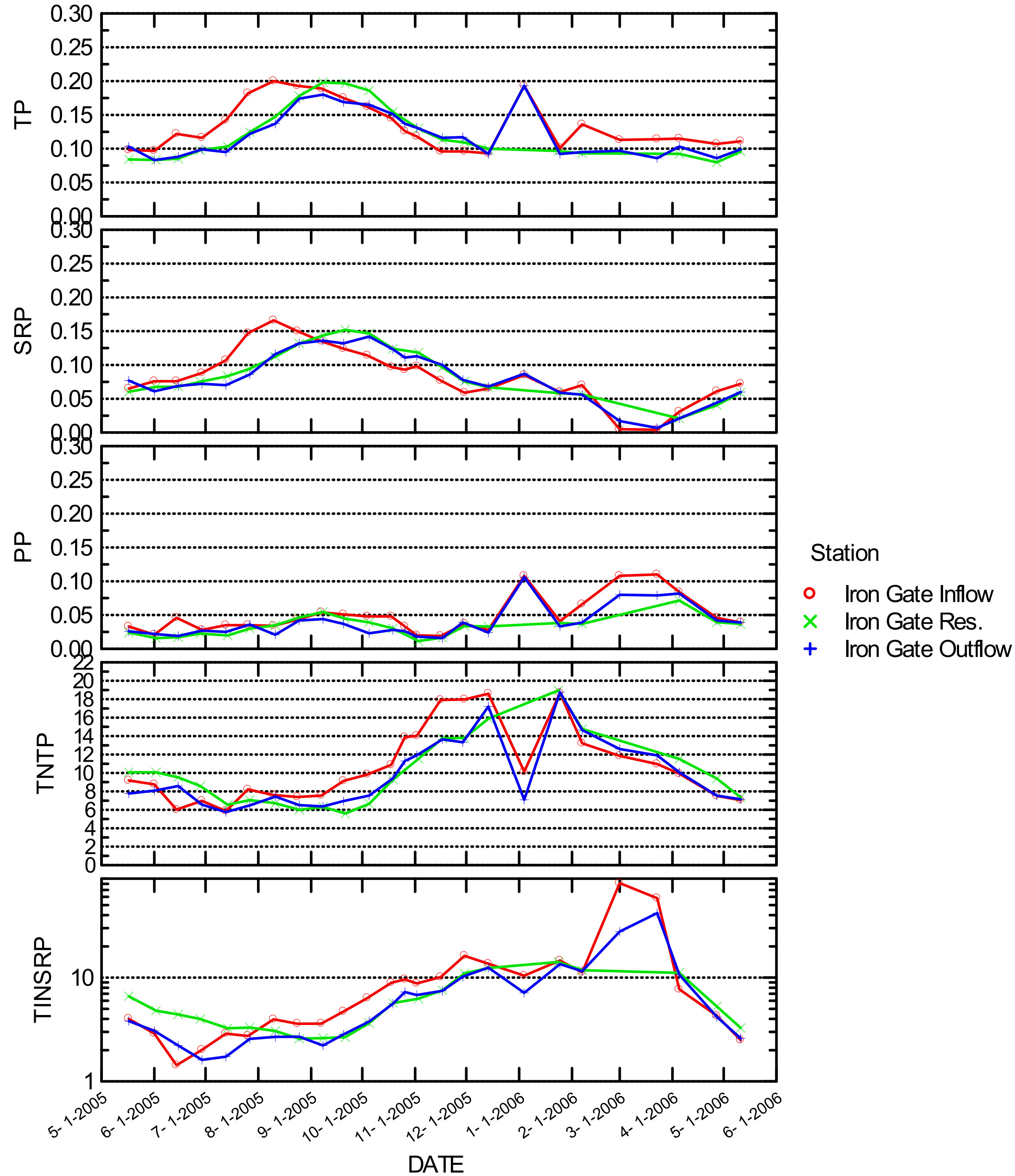


Fig. 19. Biweekly time series of Iron Gate Reservoir phosphorus concentrations, May 2005 - May 2006.

3.2.3 Reservoir and River Concentrations

Biweekly time series of TN and TP concentrations for all Klamath River and reservoir stations show several trends (Figure 20). First, volume-weighted TP and TN concentrations are typically higher at CR02 than at CR01. Similarly, TP concentrations are higher at IR03 than at IR01, although this is generally not the case for TN. Second, the peak TP concentration at KRAC occurs in July, at CR01 and CR02 in August, and at IR01 and IR03 in September. A similar lag is not clearly evident for TN. Third, concentrations of TN were consistently lower at KRBI (by a maximum of ~50%) than KRAC for the mid-June through September period, while TP concentration was lower at KRBI (again by a maximum of ~50%) for the Mid-June through August period. This is likely due to 1) nutrient storage in the water column and sediments of the reservoirs, 2) penstock intakes that draw water from intermediate depths where concentrations are lower, and 3) possible atmospheric losses through denitrification (for nitrogen only).

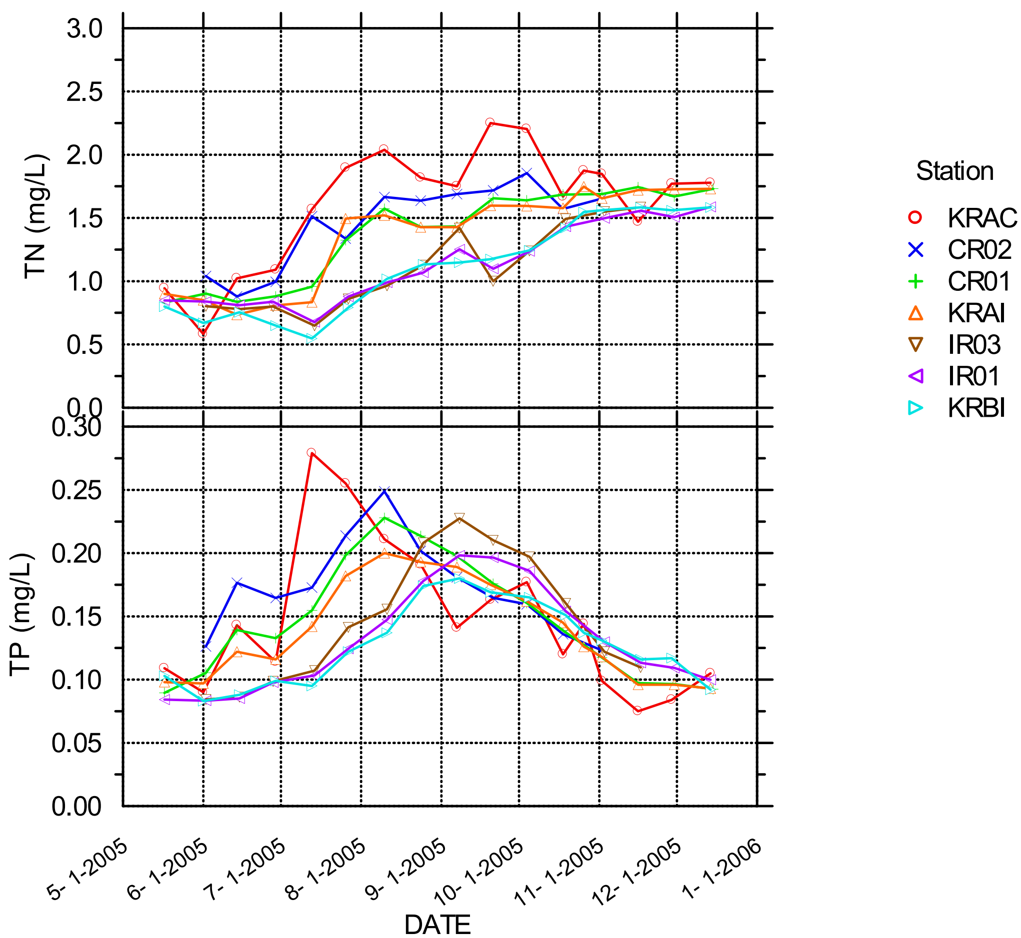


Fig. 20. Biweekly time series of TN and TP concentrations at all Klamath River and Reservoir stations, May 2005 – mid-December 2006.

From mid-May through October, TOC concentrations are higher at KRAC than KRAI or KRBI, although on other dates the pattern is reversed (Fig. 21).

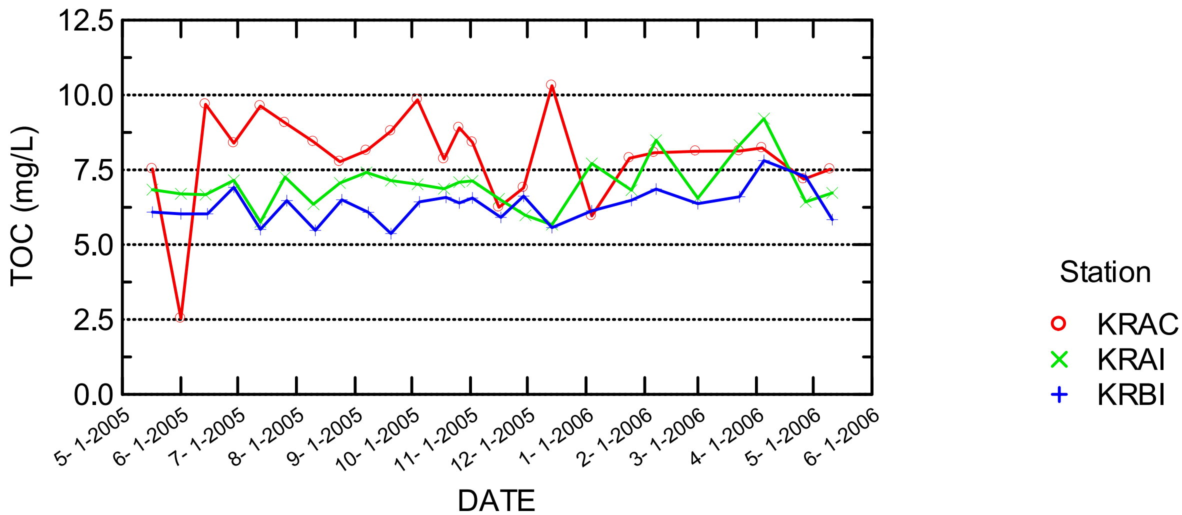


Fig. 21. Biweekly time series of total organic carbon (TOC) concentrations at Klamath River above Copco (KRAC), Klamath River above Iron Gate (KRAI), and Klamath River below Iron Gate (KRBI), the only stations where TOC was measured, May 2005 - May 2006.

3.3 HYDROLOGIC BUDGET

Hydrologic data were assembled for the same dates as nutrient data: May 17, 2005 though May 11, 2006. While the budgets were constructed using metric units, river and tributary flows are graphically shown in cfs because these are the units most commonly discussed in the Klamath Basin management area.

3.3.1 Copco Reservoir

Daily time series for major water balance terms for Copco Reservoir are presented in Figs. 22-25 and Appendix E3, and a bi-weekly summary table is included in Appendix A3. As expected for a mainstem reservoir, inflow to Copco was dominated by the Klamath River, which showed a spring runoff peak in May 2005, and then declined to summer minimum flows that are influenced by upstream irrigation withdrawal (Fig 22c). Inflows then rose dramatically starting in mid-December 2005, reaching a peak of 8160 cfs on 1/2/2006, and generally remaining above 3000 cfs through May 2006 with several high peaks (Fig. 22c). Shovel Creek represented only a small portion (0.5 to 3.5%) of the total inflow during May-November 2005 and March-May 2006, but ranged from 4.2 to 11.8% of the total inflow from December 2005 through February 2006. (see Table A3-1 in Appendix A3).

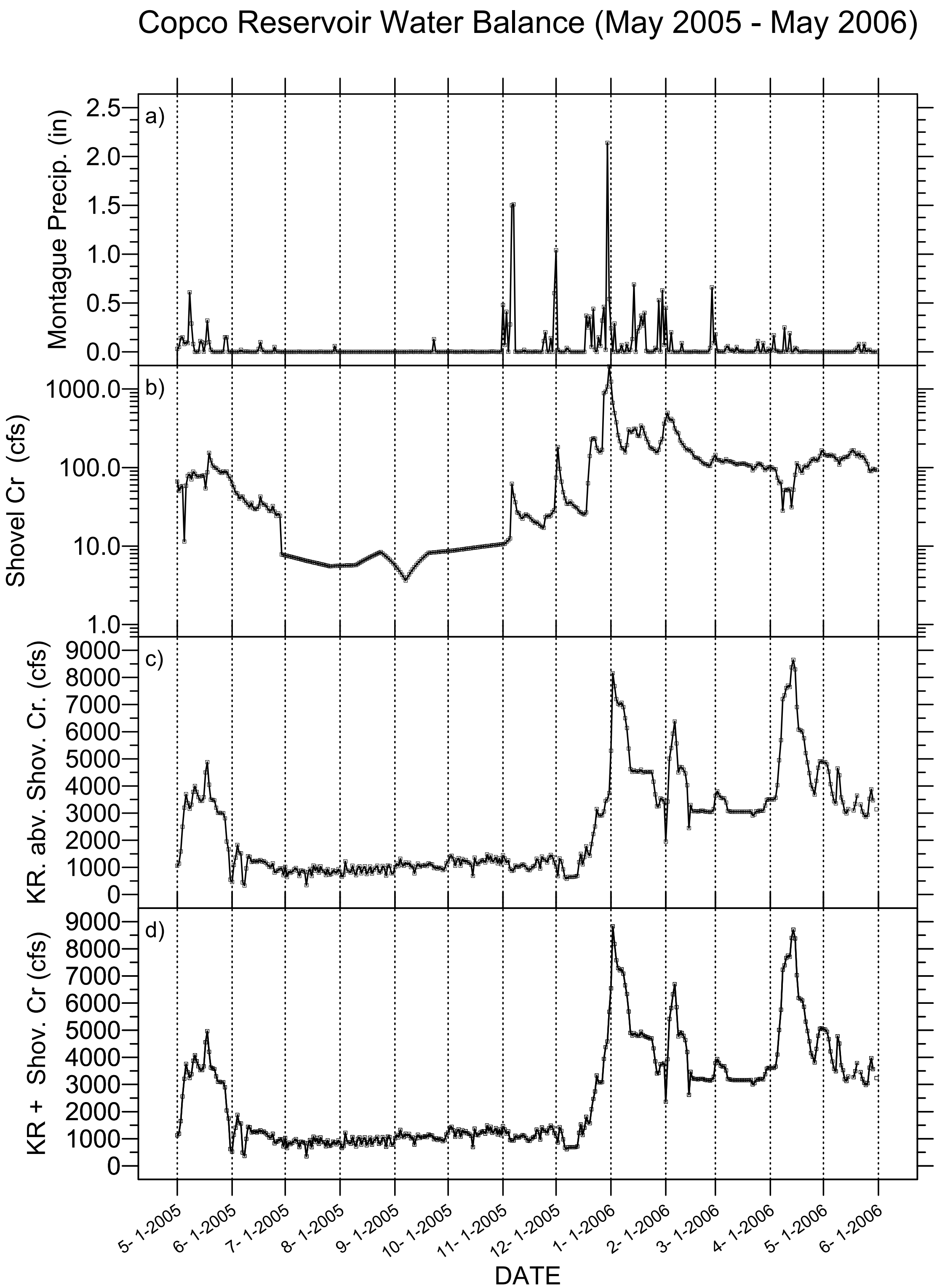


Fig. 22. Daily time series of Copco Reservoir water balance input terms, May 2005 - May 2006.

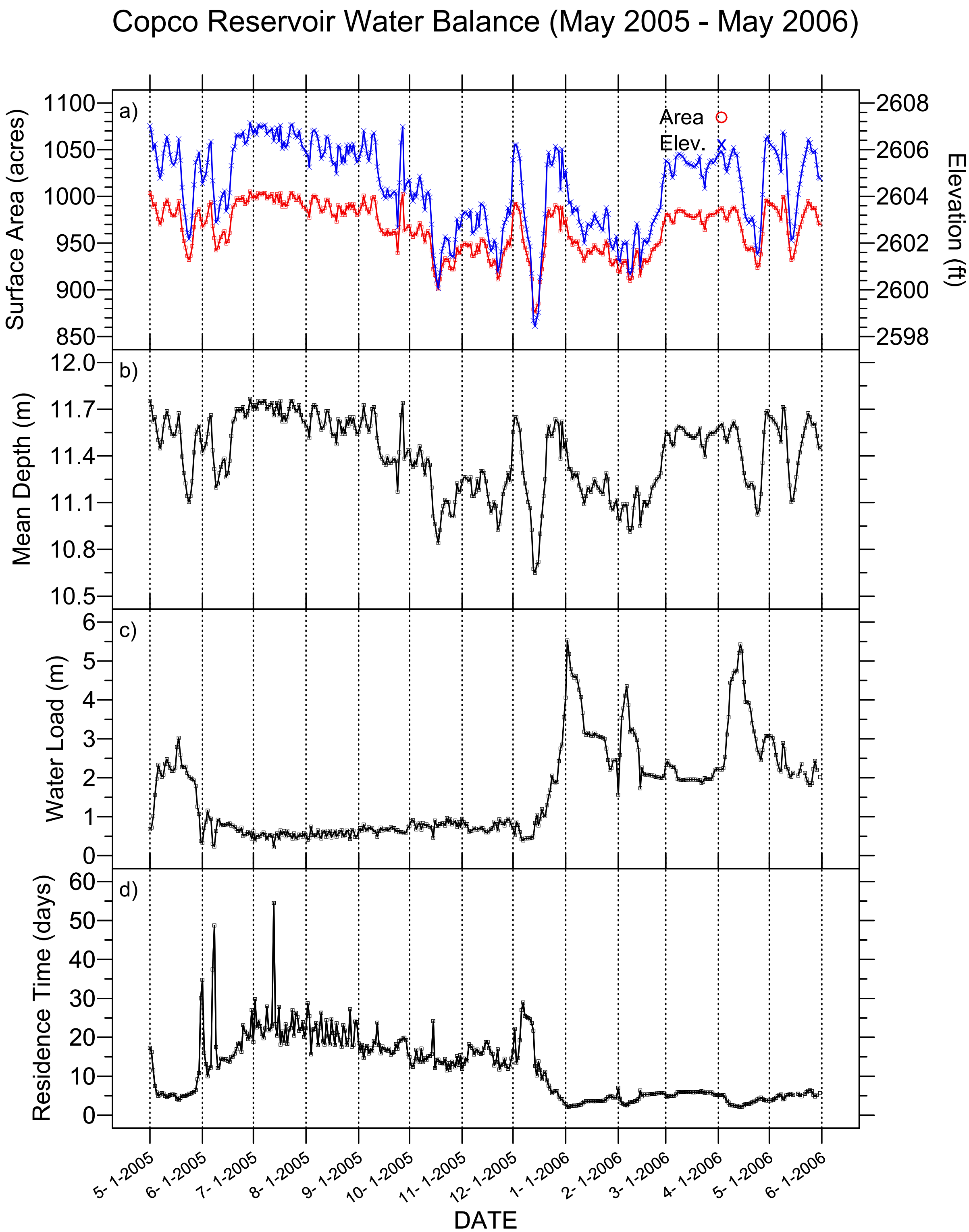


Fig. 23. Daily time series of Copco Reservoir water balance reservoir terms, May 2005 - May 2006.

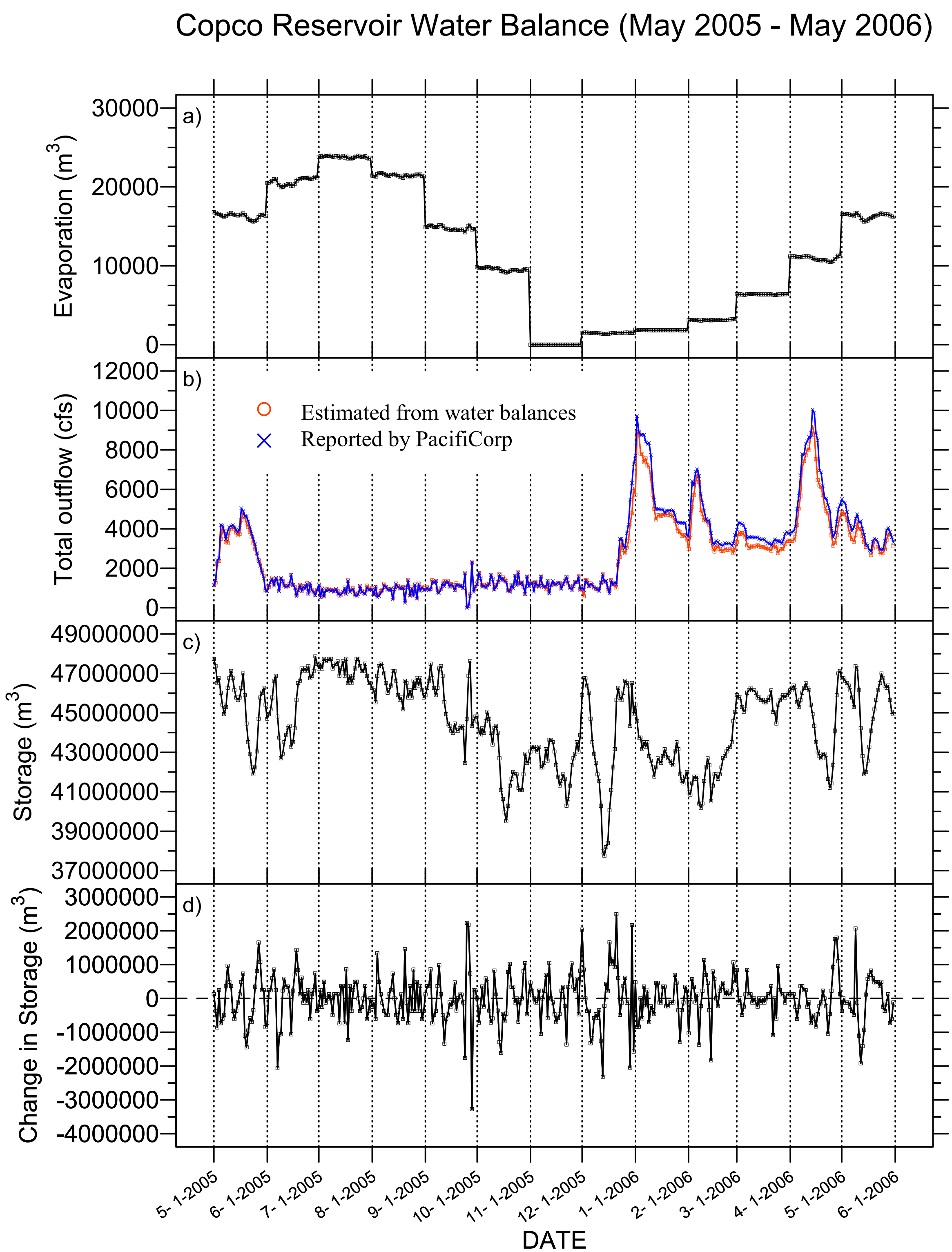


Fig. 24. Daily time series of Copco Reservoir water balance reservoir terms and outflow, May 2005 - May 2006.

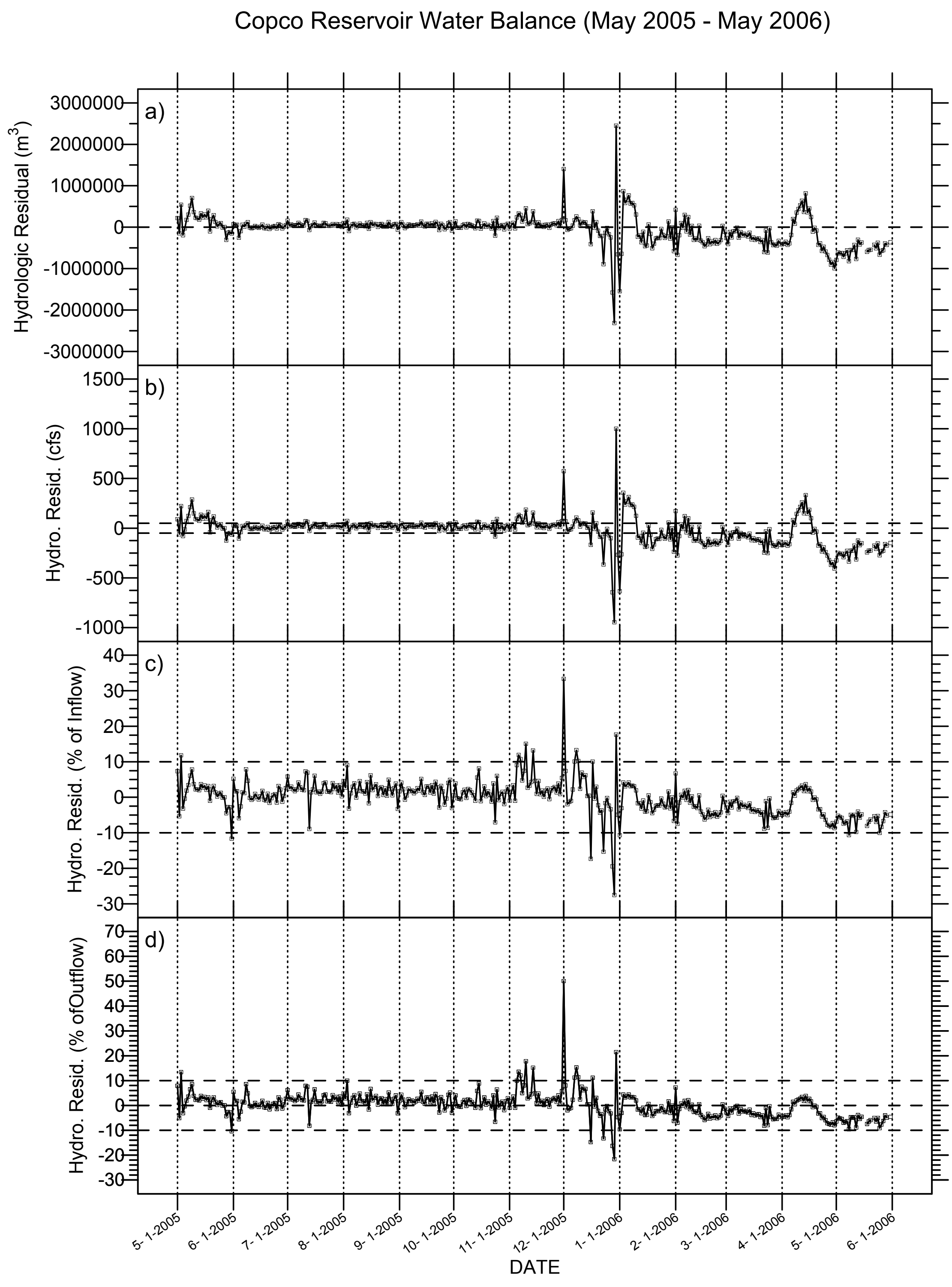


Fig. 25. Daily time series of Copco Reservoir water balance; hydrologic residual, May 2005 - May 2006.

Mean depth (volume/surface area), water load (total inflow/surface area), and residence time (outflow/volume) were computed as a check on other water balance terms (Fig. 23). These computations show mean depth to fluctuate a maximum of 1.1 m, with less variation occurring from late June to early September 2005 (Fig. 23b). Water load and residence time are inversely proportional, and residence time is on the order of ~5 days during high winter and spring flows, increasing to 20-25 days during the summer (Fig. 23d).

Given small surface area relative to total reservoir volume, evaporation represented only 0.2% of the outflow volume over the entire study period, peaking in July at a cfs equivalent of 10 (Fig. 24a; Table A3-1 in Appendix A3). The general trend of total outflow mirrors that of total inflow, and reservoir storage and change in storage fluctuate on a seasonal and daily basis according to PacifiCorp hydroelectric operations and minimum in-stream flows for fish (Figs. 24b,c,d).

As noted earlier, the hydrologic residual is a term that includes measurement error in all budget terms, as well as unmeasured groundwater or diffuse overland flow. During the low-flow portions of 2005, from June through October, the residual term was generally within ±50 cfs, or about 5% of inflow (Fig. 25b). On both a relative (percent) and absolute (cfs) basis, residuals were larger during the higher-flow months. Various spikes exceeding the ±5 % or 50 cfs level for the residual could be due to measurement error in any of the terms, including daily stage or inflow/outflow measurements. However, such daily spikes are expected to have little influence on the hydrologic budget as a whole. Spikes most often occurred surrounding precipitation events, indicating that during such events, errors (apparently under-estimation) in measurements of tributary flows are the cause of the residual spikes. Some directional bias was evident; after fluctuating around zero (+2.4% of inflow) from June through mid-December 2005, residuals were then increasingly negative from January-May 2006, but still did not exceed -10% of inflow.

3.3.2 Iron Gate Reservoir

Daily time series for major water balance terms for Iron Gate Reservoir are presented in Figs. 26-29 and Appendix E3, and a bi-weekly summary table is included in Appendix A3. Again, as expected for a mainstem reservoir, inflow to Iron Gate was dominated by the Klamath River, in this case the outflow from Copco, which also showed a May 2005 spring runoff peak, then declined to summer low flows (Fig. 26c), with flows increasing again in mid-December and remaining high through the rest of the study period. Tributaries were more important than they were for Copco Reservoir, contributing ~11% for the entire May 2005 – May 2006 period, and as much as ~23% during the early January storms, and ~16% in the May 2006 snowmelt period (see Table A3-2 in Appendix A3). Copco outflow contributed 94-96% of the inflow for the majority of the growing season.

Mean depth (volume/surface area), water load (total inflow/surface area) and residence time (outflow/volume) were computed as a check on other water balance terms (Fig. 27). These computations show mean depth to fluctuate a maximum of 0.4 m, with less variation occurring during the June to mid-December period (Fig. 27b). Mean depth typically ranged from ~16.5 to ~16.7 m in the lower-flow period of June through mid-December, and was slightly higher at ~16.8 m during the higher flow mid-December through May period. There was two-day spike with residence time of up to 238 days in late September 2005, apparently driven by sharply reduced water load as regulated by Copco outflow (Fig. 27c,d). However, aside from this and other spikes, residence time is on the order of about 3-10 days during the winter and spring, increasing to 25-35 days during the summer (Fig. 27d).

As with Copco, evaporation represented only a small portion of the total outflow volume (0.2% over the entire study period), peaking in July at a cfs equivalent of 9 (Fig. 28a; Table A3-1 in Appendix A3). However, unlike Copco Reservoir, Iron Gate outflow fluctuation is muted relative to inflow (Fig. 28b). Reservoir storage and change in storage fluctuates on a seasonal and daily basis according to PacifiCorp hydroelectric operations and minimum in-stream flows for fish (Figs. 28b,c,d).

Similar to Copco, low-flow period residuals were generally less than ±50 cfs, or about 5% of inflow (Fig. 29b). During higher-flow months, relative and absolute residuals increased, particularly during precipitation events. While residuals for the low-flow season were centered around zero, in winter and spring 2006, residuals were mostly negative, indicating a consistent bias in one or more terms.

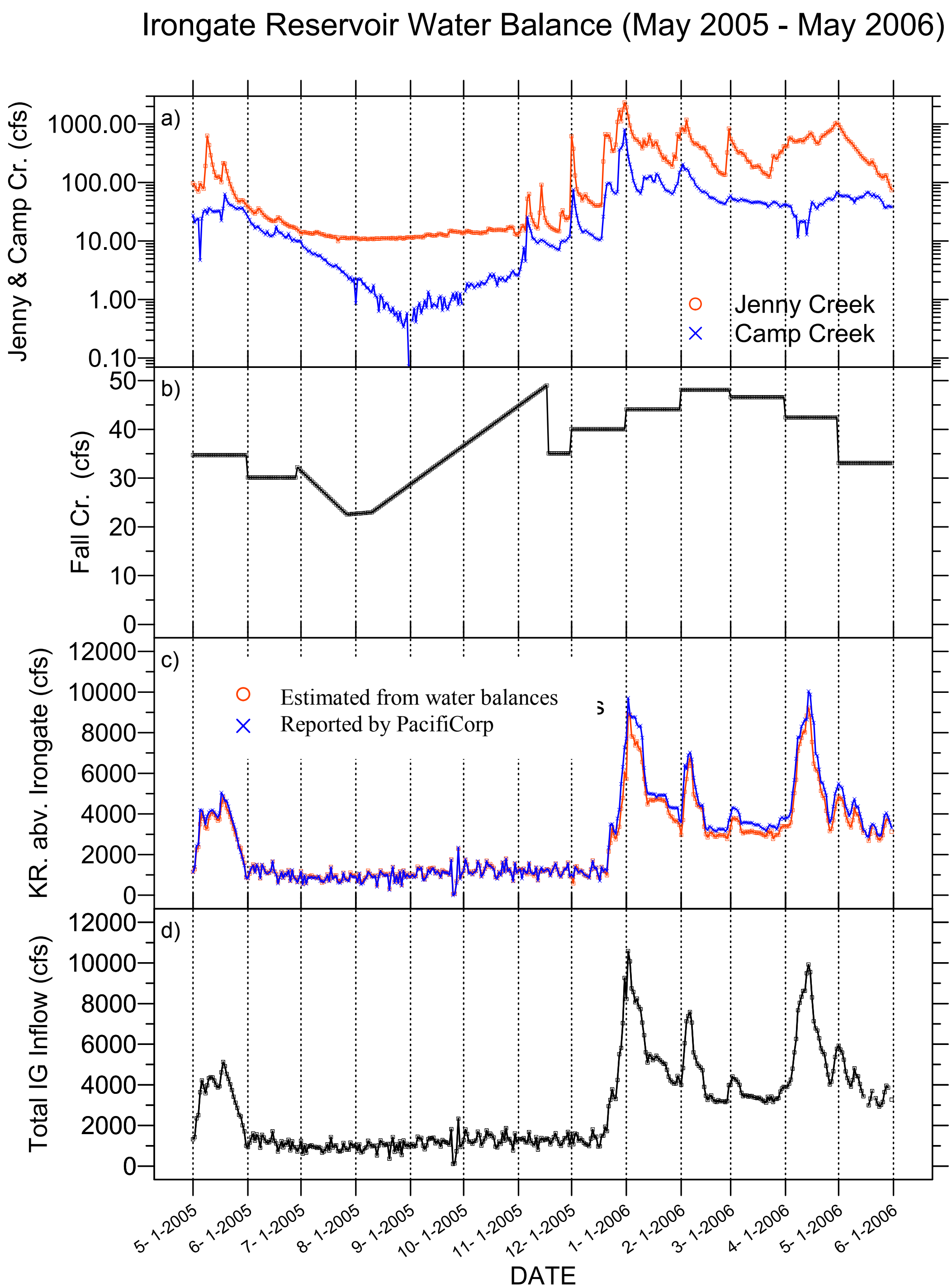


Fig. 26. Daily time series of Iron Gate Reservoir water balance input terms, May 2005 - May 2006.

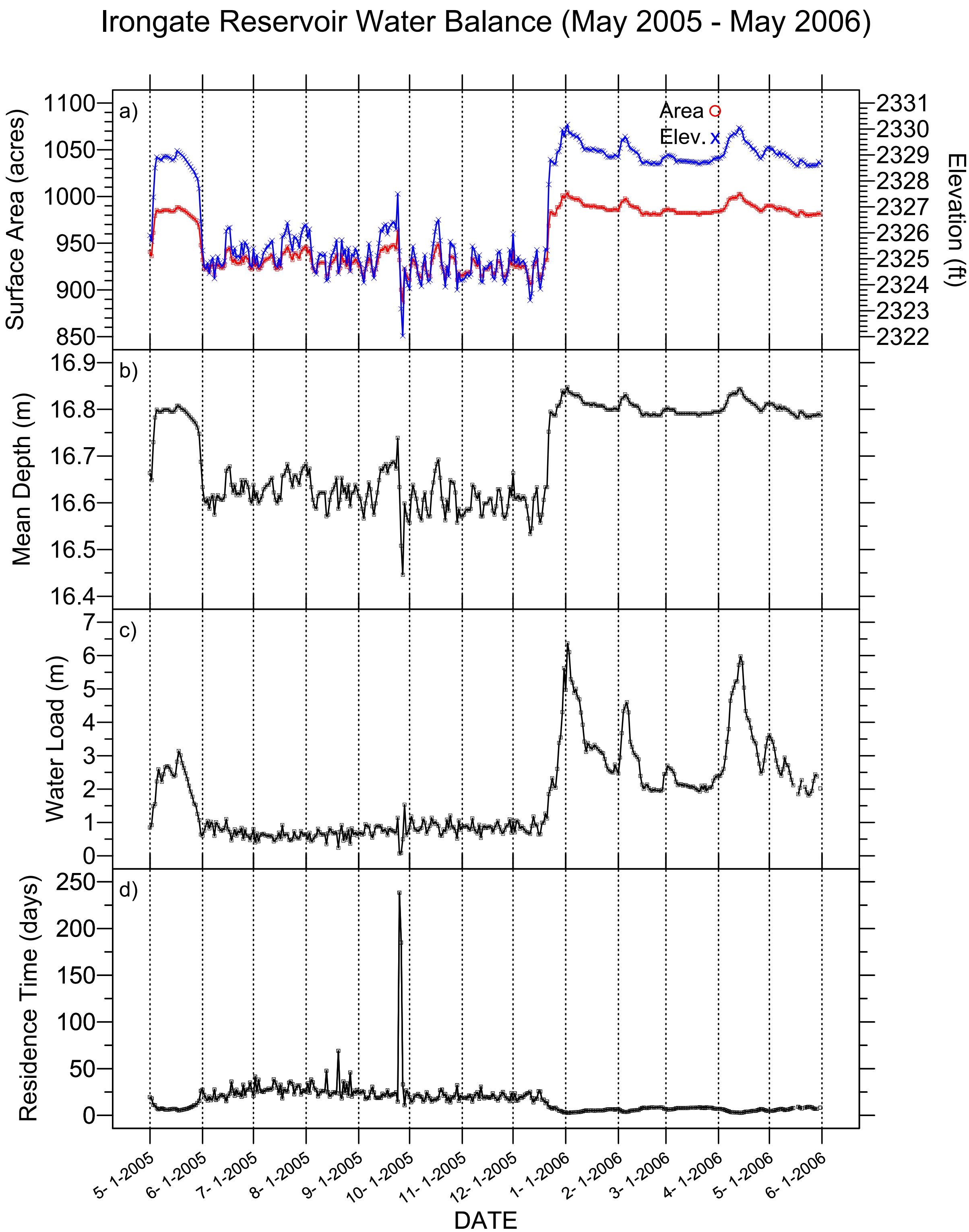


Fig. 27. Daily time series of Iron Gate Reservoir water balance reservoir terms, May 2005 - May 2006.

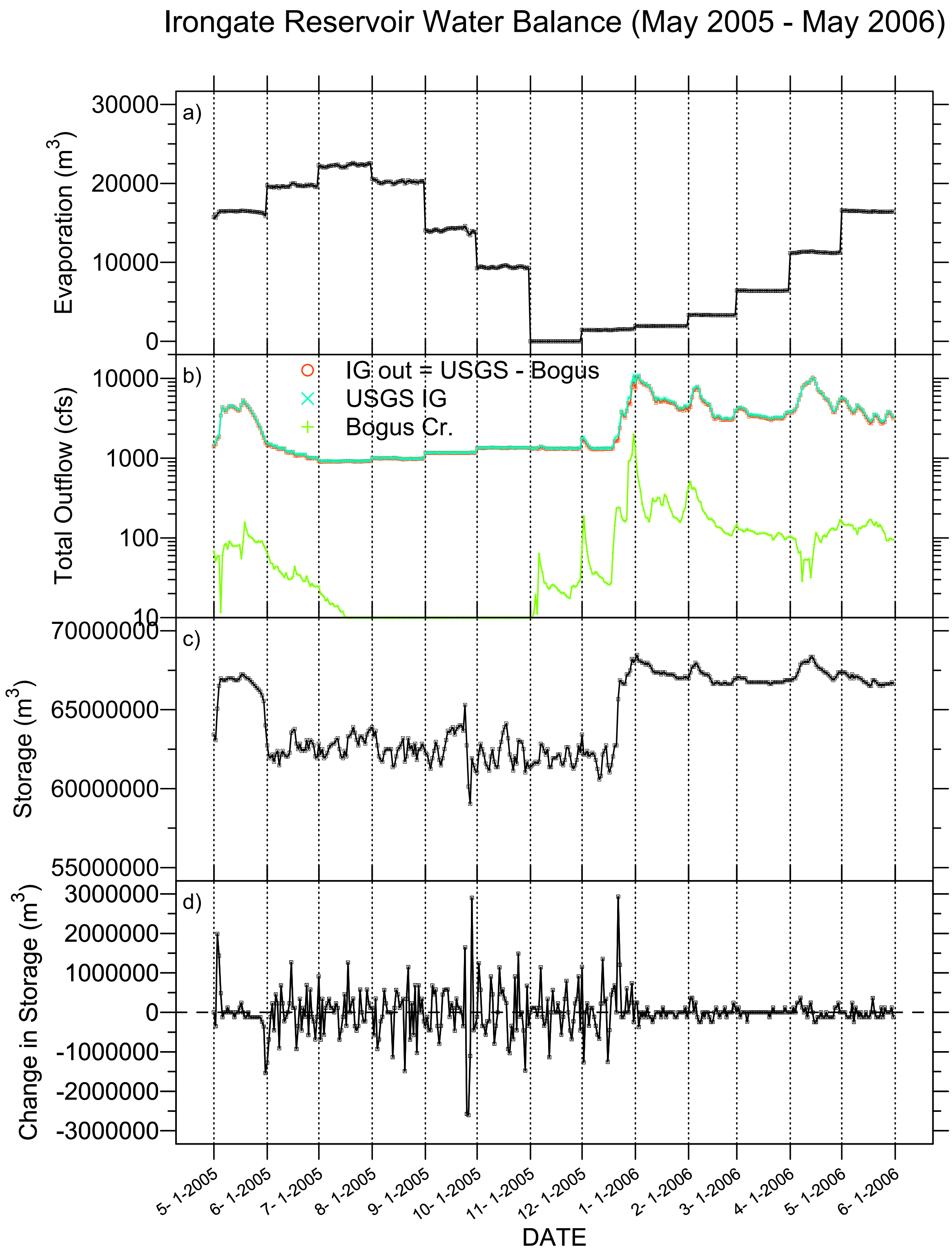


Fig. 28. Daily time series of Iron Gate Reservoir water balance reservoir terms and outflow, May 2005 - May 2006.

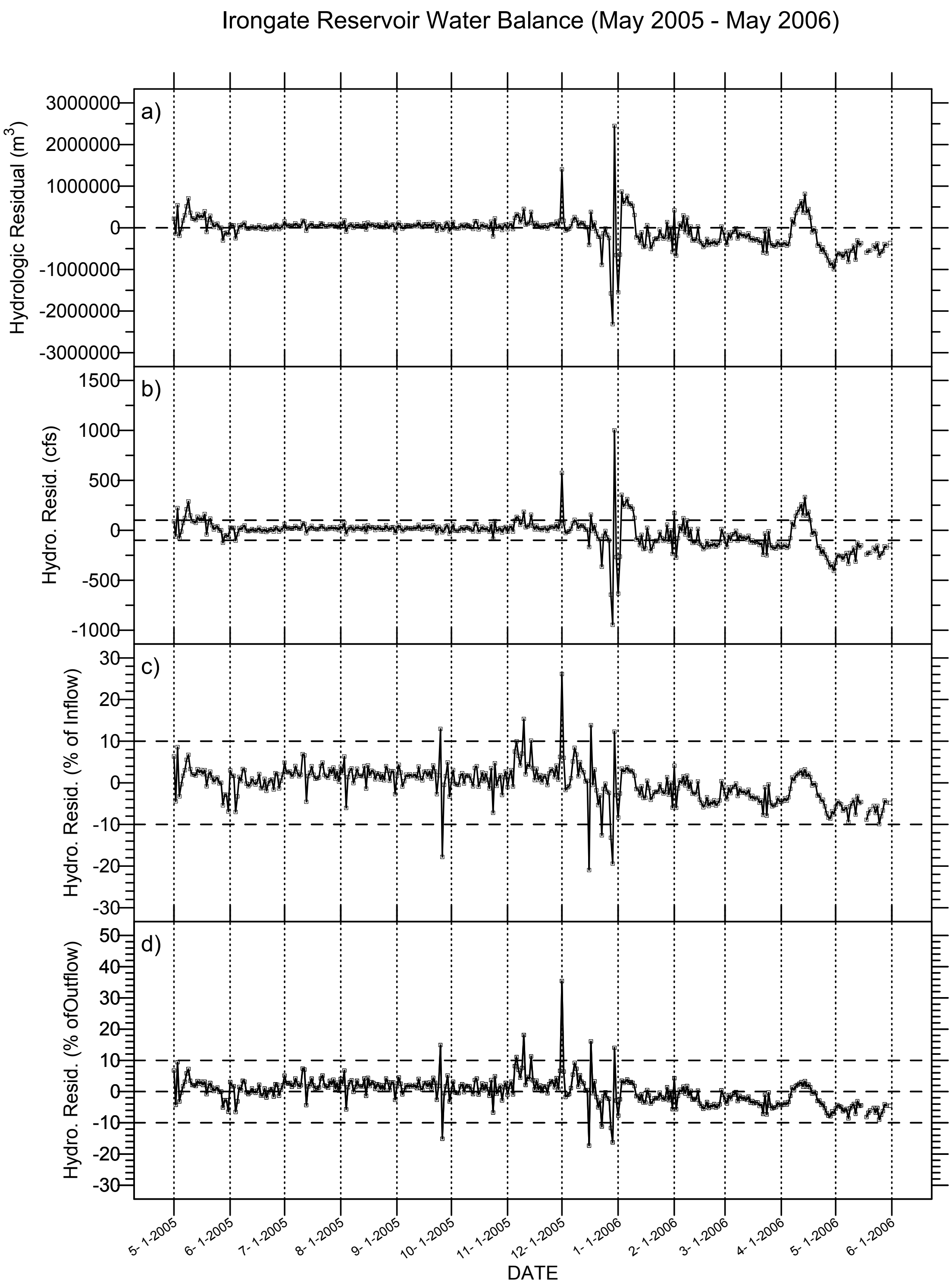


Fig. 29. Daily time series of Iron Gate Reservoir water balance; hydrologic residual, May 2005 - May 2006

3.4 NUTRIENT BUDGETS

As described in the methods, hydrologic budget terms were multiplied by nutrient concentration to obtain estimates of nutrient mass in kilograms. These terms, as well as the retention term, were computed for TP and TN. Negative retention values denote a source from within the system (e.g., from internal loading or nitrogen fixation), and positive values denote a sink.

As noted above, calculated daily loads are shown below to illustrate budget development; however, these daily values were summarized for biweekly sample periods, the river periphyton growing season (~July-September), reservoir growing season (end of May-September), study start through turnover (end of May-early December), and annually (May 2005-May 2006).

3.4.1 Copco Reservoir

3.4.1.1 Phosphorus

Daily time series for major nutrient mass-balance terms for Copco Reservoir are presented in Figs. 29-30 and Appendix E4. On a whole season basis the Klamath River above Shovel Creek contributed 98.5% of the TP load, with Shovel Creek contributing the remainder (Appendix A3). TP loading declined along with flow from the study's first sample in May through the end of June, 2005 (Fig. 30). Following a short period of increasing loading in the first half of July (driven by increasing concentration), loading then generally decreased along with concentration through mid-December. With the onset of higher flows in mid-December, TP loading increases sharply and follows roughly the same trajectory as flow through the end of the study period, showing several peaks corresponding with high-flow events. Atmospheric input was very low for all time periods, generally not exceeding 0.1% of total input load (Appendix A3).

In-reservoir TP storage climbed steadily to a peak in early August, then decreased consistently to a low in mid-December. In-reservoir TP then climbed again through early January before falling again until late January, where after a short rise it remained relatively constant through the end of the study in mid-May 2006.

TP retention varied over the study period in Copco Reservoir. From May through mid-December it alternates between negative and positive, with total retention over that period equivalent to 1.6% of total inflow load. Retention is then negative (which denotes a source from within the system) in late December 2005 through early January 2006, a period with a large hydrologic residual and thus substantial uncertainty regarding tributary flows. Retention is then consistently positive from mid-January 2006 through the end of the study period.

On a seasonal time scale, TP retention in Copco was generally low, ranging from +1.6% to +9.4% across the four summarized seasonal periods (see bottom of Table 5). Over the entire May 2005 to May 2006 study period, 29.3 metric tons (MT) (9.4%) of the total inflow load of 312.4 MT of TP was retained (Table 5). However, uncertainties regarding flows and concentrations during the extreme flow events in late December 2005 / early January 2006 reduced data accuracy during that period and hence any summaries that incorporate that period. Copco TP retention was +4.3% (1.5 of 38.1 MT) for the main river periphyton growing season period 6/29/2005-9/21/2005, +3.3 (2.2 of 65.5 MT) for the main reservoir phytoplankton growing season period 5/18/2005-10/5/2005, and +1.6% (1.4 of 85.4 MT) for the period 5/18/2005-12/14/2005 that spans from the study's beginning until the completion of turnover (Table 5).

3.4.2.2 Nitrogen

On a whole season basis KRAC contributed 99.4% of the TN load (Appendix A3). TN loading at KRAC followed a similar pattern to TP for the high-flow period, but a different pattern during the low-flow season. After dropping between mid-May and the end of June, TN loading then rose steadily to a peak in early October before dropping gently to a low in mid-December 2005, then rising sharply with the onset of higher flows (Fig. 31b). Shovel Creek contributed 0.4% of the load on a whole season basis, a maximum of 1.2% in any single sampling period, but was near zero for July-November (Appendix A3). Atmospheric input was very low for all time periods, generally not exceeding 0.5% of total input load.

In-reservoir TN showed minor fluctuations from mid-May through mid-June before increasing sharply through mid-August, where TN then alternated between increasing and decreasing but exhibited an overall modest upward trajectory. TN storage mass dropped in December, as the reservoir water surface elevation was lowered, even though concentration remained essentially unchanged. TN then rose sharply to a peak in early January as the reservoir refilled and KRAC inflow loaded increases with the onset of higher flows. TN storage mass then steadily declined through the end of the study period. From mid-May though October, although it fluctuated up and down, TN retention was mostly positive or near zero, with only one period of negative retention in later July. Retention was negative or near-zero in November and December, and then consistently positive from January through the end of the study in May.

On seasonal time scales, TN retention in Copco was higher than TP, ranging from +9.1% to +18.2% across four different summarized seasonal periods (Table 6). Over the entire study period, 305 MT (9.1%) of the total inflow load of 3352 MT of TP was retained (Table 6). Copco TN retention was +14.3% (50 of 348 MT) for the main river periphyton growing season period 6/29/2005-9/21/2005, +18.2% (115 of 629 MT) for the main reservoir phytoplankton growing season period 5/18/2005-10/5/2005, and +11.3% (109 of 962 MT) for the period 5/18/2005-12/14/2005 that spans from the study's beginning until the completion of turnover (Table 6).

3.4.2 Iron Gate Reservoir

3.4.2.1 Phosphorus

Daily time series for major nutrient mass-balance terms for Iron Gate Reservoir are presented in Figs. 32-33 and Appendix E4. On a whole-season basis the KRAI (Copco Outflow) contributed 97.2% of the TP load (Appendix A3). TP loading declined as flow dropped over the second half of May, which then remained steady or increased though September before declining though mid-December and then rising sharply with the arrival of higher flows (Fig. 32b). Small tributaries (Jenny, Fall, and Camp Creeks) represented a maximum of 6.1% of the total TP load in the late December/early January sampling period (Appendix A3). Atmospheric input was very low for all time periods, generally not exceeding 0.1% of total input load.

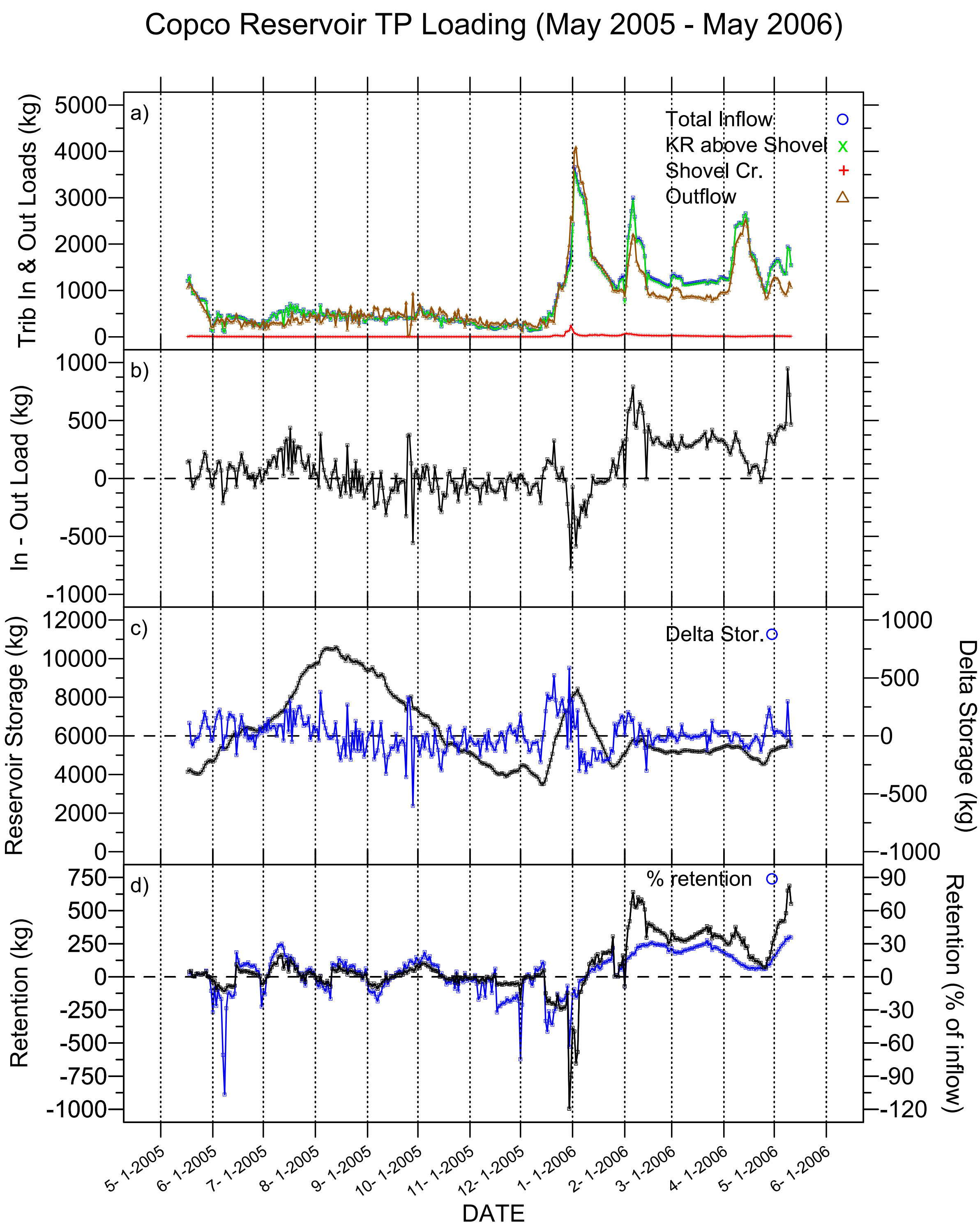


Fig. 30. Daily time series of Copco Reservoir total phosphorus loading (horizontal dashed line placed at zero for ΔStor and retention), May 2005 - May 2006.

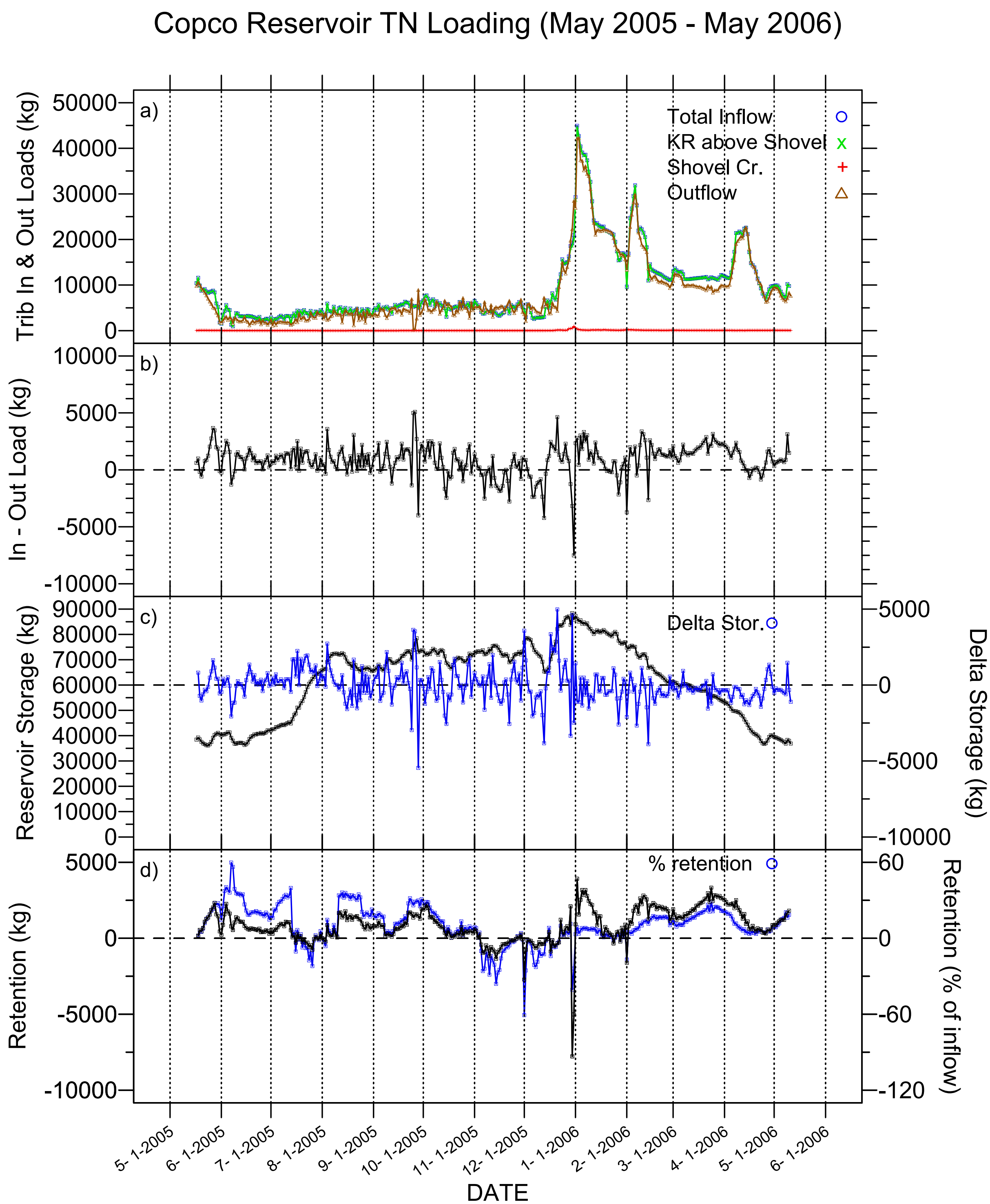


Fig. 31. Daily time series of Copco Reservoir total nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), May 2005 - May 2006.

Iron Gate Reservoir TP storage remains steady through mid June, climbs steadily to a peak in mid-September, then declines to a low in mid-December, spikes to another peak in early January, then drops back down and remains relatively steady through the end of the study (Fig. 32c). Similar to Copco TP, retention fluctuates between positive and negative through the end of October. Retention is negative in November and highly negative in December, indicating a possible TP source from reservoir turnover. TP retention then alternates between positive and near-zero through the end of the study period in May.

On seasonal time scales, TP retention in Iron Gate was low, ranging from -2.4% to 3.1 across four different summarized seasonal periods (Table 5). Over the entire study period, Iron Gate Reservoir retained 9.0 MT (3.1%) of the total 289.8 MT of TP inflow (Table 5). Iron Gate TP retention was -2.4% (-0.84 of 35.32 MT) for the main river periphyton growing season period 6/29/2005-9/21/2005 that is the typically the time of year with worst water quality in the river downstream of Iron Gate Dam, +0.5 % (0.3 of 61.2 MT) for the main reservoir phytoplankton growing season period 5/18/2005-10/5/2005, and 0.9% (0.74 of 85.8 MT) for the period 5/18/2005-12/14/2005 that spans from the study's beginning until the completion of turnover (Table 5).

3.4.2.2 Nitrogen

On a whole season basis KRAI (Copco Outflow) contributed 98.2% of the TN load (Appendix A3). Unlike TP load, there was not a pronounced late-winter/spring loading peak (Fig 33b). TN loading decreased sharply over the second half of May, declined very slightly through mid-July, then steadily increased through September and then remained steady through mid-December, when TN loading increased substantially with the onset of high flows.

Small tributaries (Jenny, Fall, and Camp Creeks) represented a maximum of 3.6% of the total TN load in the mid-December through early January sampling period (Appendix A3). Atmospheric input was very low for all time periods, generally not exceeding 0.5% of total input load. TN storage decreases slightly from mid-May to mid-July before increasing to a peak in late January and then decreasing until the study ended in May.

From mid-May through September, retention alternates between positive and negative, with the magnitude of the positive values generally being larger than the magnitude of the negative values. From October through mid-December, retention is generally negative with some positive values. Then from mid-December through May, retention is generally positive, but with some negative values.

On seasonal time scales, TN retention was higher than TP retention, and varied depending upon the time of year (Table 6). Over the entire study period, Iron Gate Reservoir retained 312 MT (+10.0%) of the total 3112 MT of TN inflow (Table 6). Iron Gate TN retention was +20.3% (55 of 287 MT) for the main river periphyton growing season period 6/29/2005-9/21/2005 that is the typically the time of year with worst water quality in the river downstream of Iron Gate Dam, +15.3 % (74 MT of 486 MT) for the main reservoir phytoplankton growing season period 5/18/2005-10/5/2005, and 6.5% (54 of 835 MT) for the period 5/18/2005-12/14/2005 that spans from the study's beginning until the completion of turnover (Table 6).

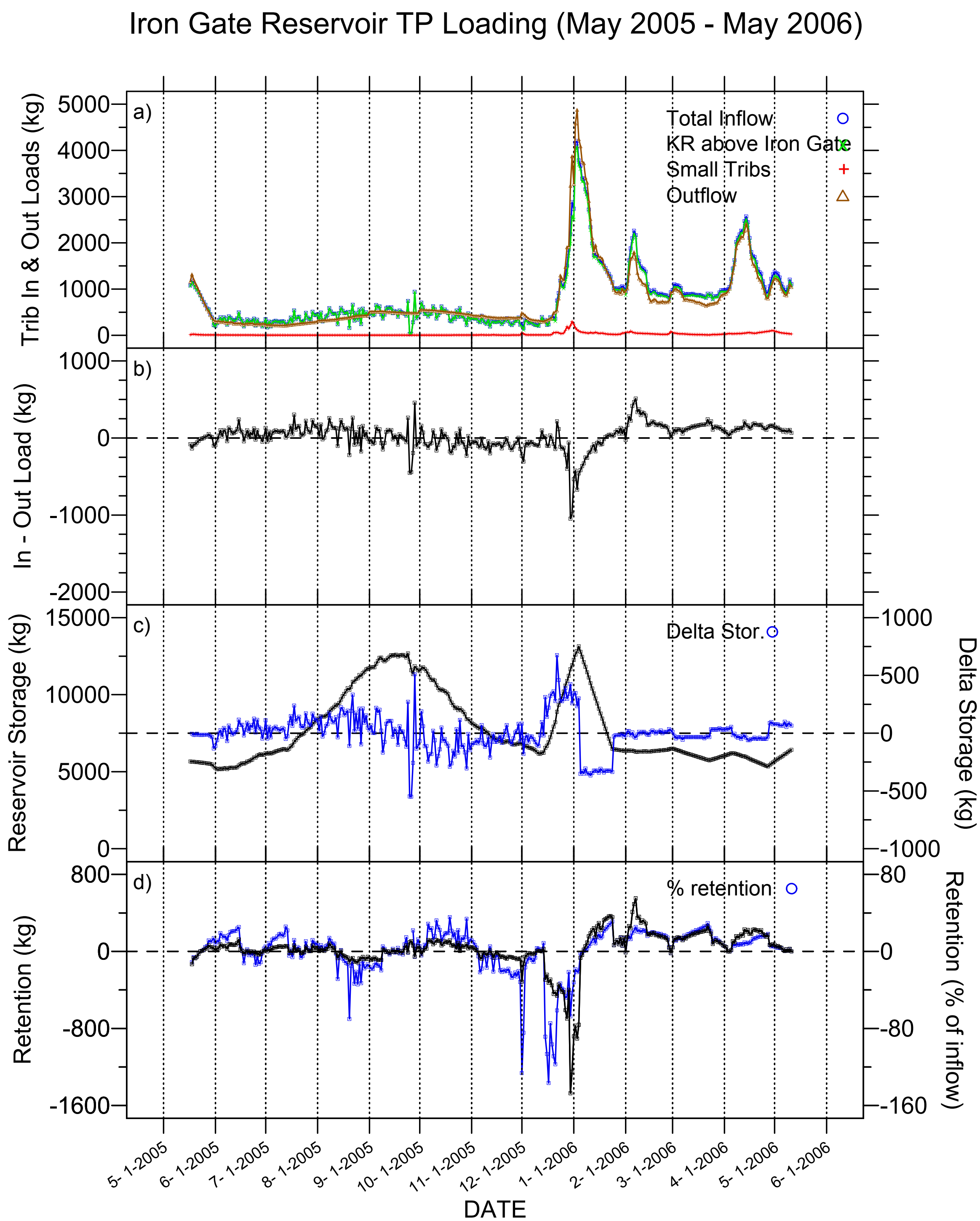


Fig. 32. Daily time series of Iron Gate Reservoir total phosphorus loading (horizontal dashed line placed at zero for ΔStor and retention), May 2005 - May 2006.

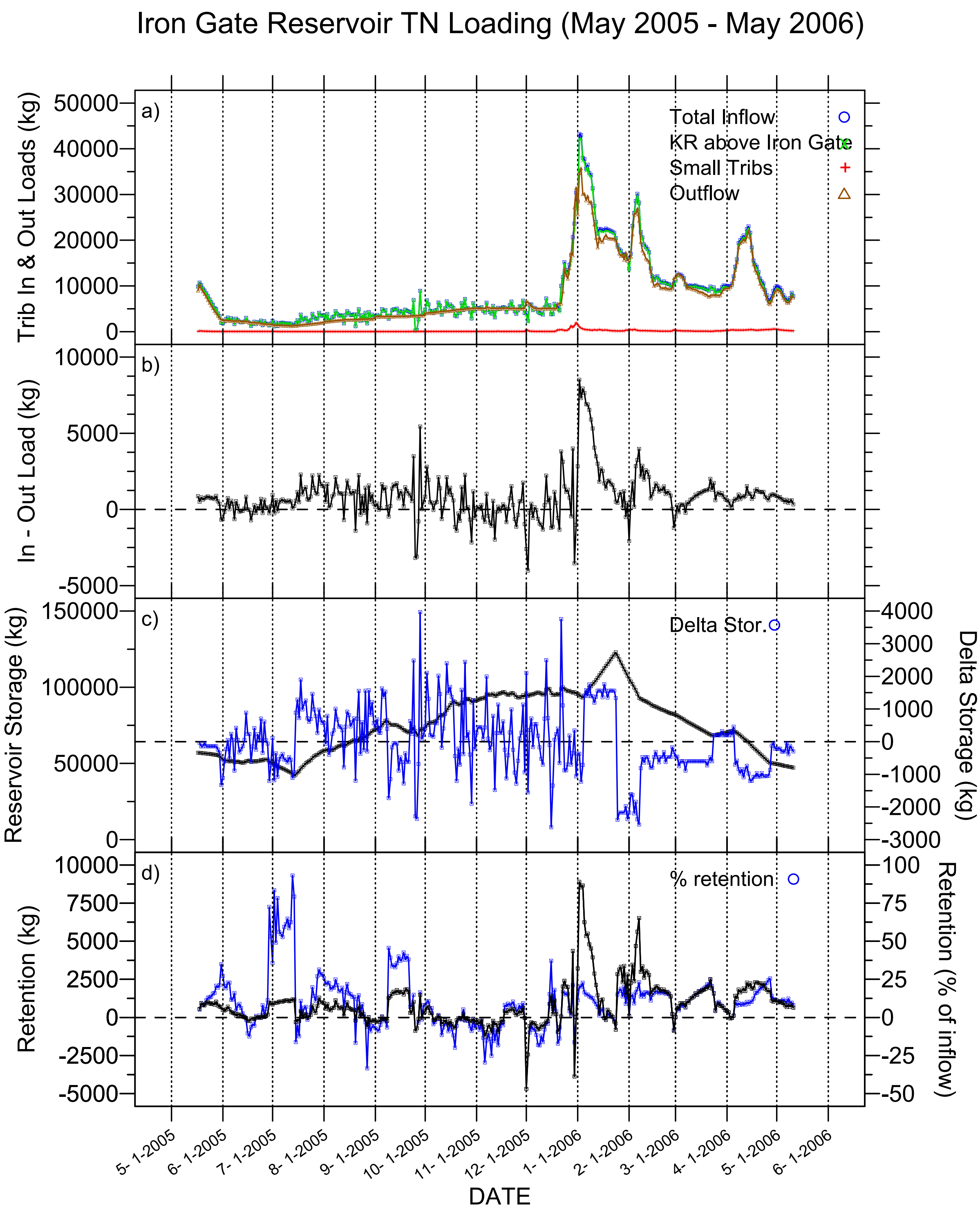


Fig. 33. Daily time series of Iron Gate Reservoir total nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), May 2005 - May 2006.

3.4.3 Combined Analysis of Iron Gate and Copco Reservoirs

The above analyses for Copco and Iron Gate Reservoirs separately are intended to allow for evaluation of management actions that may apply to the reservoirs individually. However, the combined effect of the reservoirs in tandem is useful given that the outflow from Copco is also the inflow to Iron Gate. To evaluate net retention of the entire reservoir system, combined retention was calculated by summing daily retention values for each reservoir. Combined retention as a percent of inflow was calculated as the combined retention divided by the sum of the external input loads (Klamath River above Copco + Shovel Creek + Copco atmospheric input + Jenny Creek + Fall Creek + Camp Creek + Iron Gate atmospheric input). Note that for the purposes of this combined analysis, KRAI was not included because it is a linkage between the two reservoirs and not an additional external input.

The results of the combined retention, as well the individual retentions are shown in Tables 5 and 6.

Temporal patterns in retention were generally similar in Iron Gate and Copco, thus the combined retention of two reservoirs is often, though not always, more extreme (more positive or more negative) than the separate retention of each reservoir. On a relative (as percent of inflow) basis at most seasonal time scales, TN retention was higher than relative TP retention, except for January through May 2006 when relative retention for TP and TN were similar and both were consistently positive.

Over the entire study period, Iron Gate and Copco Reservoirs retained 38.3 MT (11.1%) of the total 320.6 MT of TP inflow (Table 5), with the substantial majority of that retention occurring in the winter and spring of 2006. Combined TP retention was +1.8% (0.7 of 38.4 MT) for the main river periphyton growing season period 6/29/2005-9/21/2005, +3.7% (2.5 MT of 66.2 MT) for the main reservoir phytoplankton growing season period 5/18/2005-10/5/2005, and +2.4% (2.1 of 86.5 MT) for the period 5/18/2005-12/14/2005 that spans from the study's beginning until the completion of turnover (Table 5).

Over the entire study period, Iron Gate and Copco Reservoirs retained 618 MT (18.1%) of the total 3410 MT of TN inflow (Table 6). Combined TN retention was +29.8% (104 of 350 MT) for the main river periphyton growing season period 6/29/2005-9/21/2005, +29.8% (189 MT of 634 MT) for the main reservoir phytoplankton growing season period 5/18/2005-10/5/2005, and +16.8% (163 of 971 MT) for the period 5/18/2005-12/14/2005 that spans from the study's beginning until the completion of turnover (Table 6). Increased growing season retention may reflect increased residence time and settling of organic matter; however, residence time alone does not appear to fully explain the temporal dynamics of TN retention because residence time in Copco/Iron Gate Reservoirs in October/November was only slightly lower than in August/September, yet retention was low or negative in October/November while retention was much higher in August/September (Fig. 23, Fig. 27, Table 6). The current data do not allow the determination of the eventual fate of settled organic matter; it could remain permanently in the sediment or could undergo ammonification and re-enter the water column at a later time.

Table 5. Total phosphorus inflow and retention for Copco and Iron Gate Reservoirs, May 2005 - May 2006, summarized by sampling interval.

				Total Phosphorus Inputs (total metric tons)			**Total Phosphorus Retention (total metric tons)**			**Total Phosphorus Retention (metric tons per day)**			**Total Phosphorus Retention (percent of inflow)**		
Sample Interval	**Interval Start**	**Interval End**	**Days in Interval**	**Copco**	**Iron Gate**	**IG & Copco**	**Copco**	**Iron Gate**	**IG & Copco**	**Copco**	**Iron Gate**	**IG & Copco**	**Copco**	**Iron Gate**	**IG & Copco**
1	5/18/05	6/2/05	16	11.58	11.00	11.77	0.17	-0.04	0.14	0.011	-0.002	0.009	1.5	-0.3	1.2
2	6/3/05	6/15/05	13	4.96	4.64	5.03	-0.88	0.86	-0.02	-0.068	0.066	-0.001	-17.7	18.6	-0.4
3	6/16/05	6/28/05	13	4.42	3.75	4.48	0.46	-0.12	0.34	0.035	-0.010	0.026	10.4	-3.3	7.5
4	6/29/05	7/14/05	16	6.35	4.30	6.41	0.91	0.53	1.45	0.057	0.033	0.090	14.4	12.4	22.6
5	7/15/05	7/27/05	13	7.34	4.75	7.38	0.65	0.11	0.76	0.050	0.008	0.059	8.9	2.3	10.3
6	7/28/05	8/11/05	15	7.32	6.52	7.36	-0.18	0.48	0.29	-0.012	0.032	0.020	-2.5	7.3	4.0
7	8/12/05	8/25/05	14	6.29	6.25	6.33	0.64	-0.89	-0.25	0.046	-0.064	-0.018	10.2	-14.2	-3.9
8	8/26/05	9/8/05	14	5.60	6.89	5.65	-0.41	-1.07	-1.48	-0.029	-0.076	-0.106	-7.3	-15.5	-26.2
9	9/9/05	9/21/05	13	5.20	6.61	5.24	-0.07	0.00	-0.07	-0.005	0.000	-0.005	-1.3	0.0	-1.3
10	9/22/05	10/5/05	14	6.49	6.45	6.54	0.87	0.44	1.31	0.062	0.032	0.094	13.4	6.9	20.1
11	10/6/05	10/19/05	14	5.77	6.83	5.83	0.45	1.38	1.83	0.032	0.099	0.131	7.8	20.2	31.5
12	10/20/05	11/3/05	15	5.09	5.86	5.16	-0.18	0.72	0.54	-0.012	0.048	0.036	-3.6	12.3	10.4
13	11/4/05	11/17/05	14	2.98	4.27	3.07	-0.24	-0.32	-0.55	-0.017	-0.023	-0.039	-7.9	-7.4	-18.0
14	11/18/05	11/30/05	13	3.22	3.80	3.28	-0.69	-0.83	-1.52	-0.053	-0.064	-0.117	-21.5	-21.9	-46.4
15	12/1/05	12/14/05	14	2.79	3.85	2.97	-0.14	-0.52	-0.66	-0.010	-0.037	-0.047	-5.0	-13.5	-22.2
16*	12/15/05	1/4/06	21	28.44	31.88	30.39	-6.44	-12.15	-18.58	-0.307	-0.578	-0.885	-22.6	-38.1	-61.2
17*	1/5/06	1/24/06	20	38.76	41.83	39.68	1.78	4.14	5.92	0.089	0.207	0.296	4.6	9.9	14.9
18	1/25/06	2/7/06	14	23.26	19.31	23.90	3.33	2.80	6.13	0.238	0.200	0.438	14.3	14.5	25.7
19	2/8/06	3/1/06	22	31.17	23.74	31.92	8.74	4.12	12.86	0.397	0.187	0.585	28.1	17.4	40.3
20	3/2/06	3/23/06	22	26.42	20.18	26.91	6.80	3.83	10.63	0.309	0.174	0.483	25.7	19.0	39.5
21	3/24/06	4/5/06	13	16.12	12.31	16.42	3.80	0.95	4.75	0.293	0.073	0.365	23.6	7.7	28.9
22	4/6/06	4/27/06	22	40.93	38.46	42.07	4.27	4.01	8.28	0.194	0.182	0.377	10.4	10.4	19.7
23	4/28/06	5/11/06	14	21.95	16.31	22.82	5.62	0.55	6.17	0.402	0.039	0.441	25.6	3.4	27.0
Core Growing season	6/29/05	9/21/05	85	38.09	35.32	38.37	1.55	-0.84	0.71	0.018	-0.010	0.008	4.1	-2.4	1.8
Growing season	5/18/05	10/5/05	141	65.55	61.17	66.19	2.17	0.30	2.48	0.015	0.002	0.018	3.3	0.5	3.7
Start until Turnover	5/18/05	12/14/05	211	85.40	85.78	86.51	1.37	0.74	2.11	0.007	0.004	0.010	1.6	0.9	2.4
All dates*	5/18/05	5/11/06	359	312.45	289.80	320.63	29.29	9.00	38.28	0.082	0.025	0.107	9.4	3.1	11.9

*Note: Quality of results for periods 16 and 17 are compromised due to large uncertainties in flows during extremely high flow events.

Table 6. Total nitrogen inflow and retention for Copco and Iron Gate Reservoirs, May 2005 - May 2006, summarized by sampling interval.

				Total Nitrogen Inputs (total metric tons)			**Total Nitrogen Retention (total metric tons)**			**Total Nitrogen Retention (metric tons per day)**			**Total Nitrogen Retention (percent of inflow)**		
Sample Interval	**Interval Start**	**Interval End**	**Days in Interval**	**Copco**	**Iron Gate**	**IG & Copco**	**Copco**	**Iron Gate**	**IG & Copco**	**Copco**	**Iron Gate**	**IG & Copco**	**Copco**	**Iron Gate**	**IG & Copco**
1	5/18/05	6/2/05	16	117.35	98.61	118.65	17.96	12.75	30.70	1.12	0.80	1.92	15.3	12.9	25.9
2	6/3/05	6/15/05	13	44.0	32.4	44.5	16.4	3.4	19.7	1.26	0.26	1.52	37.2	10.3	44.3
3	6/16/05	6/28/05	13	36.3	24.6	36.8	7.2	-0.3	6.9	0.56	-0.02	0.53	19.9	-1.2	18.9
4	6/29/05	7/14/05	16	42.9	27.4	43.4	10.8	16.6	27.4	0.67	1.04	1.71	25.1	60.5	63.1
5	7/15/05	7/27/05	13	49.1	35.2	49.4	-2.4	1.8	-0.6	-0.19	0.14	-0.05	-5.0	5.2	-1.2
6	7/28/05	8/11/05	15	63.5	51.1	64.0	3.9	11.9	15.8	0.26	0.79	1.05	6.2	23.2	24.7
7	8/12/05	8/25/05	14	60.4	46.9	60.8	19.4	5.9	25.4	1.39	0.42	1.81	32.2	12.7	41.7
8	8/26/05	9/8/05	14	62.4	51.8	62.9	10.7	-2.8	7.9	0.76	-0.20	0.56	17.1	-5.4	12.6
9	9/9/05	9/21/05	13	69.2	56.2	69.6	7.3	21.1	28.3	0.56	1.62	2.18	10.5	37.5	40.7
10	9/22/05	10/5/05	14	83.9	61.7	84.4	23.6	4.0	27.6	1.68	0.29	1.97	28.1	6.5	32.7
11	10/6/05	10/19/05	14	76.0	71.3	76.5	9.6	-4.0	5.6	0.68	-0.29	0.40	12.6	-5.6	7.3
12	10/20/05	11/3/05	15	83.9	73.7	84.4	5.4	-2.2	3.2	0.36	-0.15	0.22	6.4	-3.0	3.8
13	11/4/05	11/17/05	14	56.4	68.3	57.2	-10.4	-7.5	-18.0	-0.75	-0.54	-1.29	-18.5	-11.0	-31.5
14	11/18/05	11/30/05	13	65.7	67.7	66.3	-2.0	5.1	3.0	-0.15	0.39	0.23	-3.1	7.5	4.6
15	12/1/05	12/14/05	14	50.7	68.6	52.2	-8.4	-11.6	-20.0	-0.60	-0.83	-1.43	-16.5	-17.0	-38.4
16*	12/15/05	1/4/06	21	364.8	357.8	378.0	-0.2	41.5	41.3	-0.01	1.97	1.97	-0.1	11.6	10.9
17*	1/5/06	1/24/06	20	542.0	525.8	548.8	28.2	39.1	67.4	1.41	1.96	3.37	5.2	7.4	12.3
18	1/25/06	2/7/06	14	285.6	288.0	289.8	9.8	44.4	54.1	0.70	3.17	3.87	3.4	15.4	18.7
19	2/8/06	3/1/06	22	323.8	294.0	327.7	44.8	39.8	84.6	2.04	1.81	3.84	13.8	13.5	25.8
20	3/2/06	3/23/06	22	261.5	227.5	264.6	42.1	30.9	73.1	1.92	1.41	3.32	16.1	13.6	27.6
21	3/24/06	4/5/06	13	152.6	127.6	155.8	33.8	7.1	40.9	2.60	0.55	3.15	22.1	5.6	26.3
22	4/6/06	4/27/06	22	341.0	338.5	349.6	23.6	42.4	66.1	1.07	1.93	3.00	6.9	12.5	18.9
23	4/28/06	5/11/06	14	118.9	117.4	124.2	14.4	12.8	27.2	1.03	0.91	1.94	12.1	10.9	21.9
Core Growing season	6/29/05	9/21/05	85	347.5	268.6	350.1	49.6	54.6	104.2	0.584	0.642	1.226	14.3	20.3	29.8
Growing season	5/18/05	10/5/05	141	629.0	485.9	634.4	114.7	74.4	189.1	0.814	0.528	1.341	18.2	15.3	29.8
Start until Turnover	5/18/05	12/14/05	211	961.7	835.5	971.1	108.9	54.1	162.9	0.516	0.256	0.772	11.3	6.5	16.8
All dates*	5/18/05	5/11/06	359	3352.0	3112.1	3409.5	305.4	312.1	617.6	0.851	0.869	1.720	9.1	10.0	18.1

*Note: Quality of results for periods 16 and 17 are compromised due to large uncertainties in flows during extremely high flow events.

3.4.4 Sensitivity of retention to hydropower peaking effects on KRAC

As noted above in the Method section, nutrient samples collected at KRAC (Copco inflow) in the J.C. Boyle Peaking Reach are impacted by hydropower peaking operations. An examination of the timing of sample collection at KRAC (Appendix A2) indicates that with the exception of the June 1, 2005 sample (which was adjusted to represent the daily mean), all KRAC samples were collected at times which should approximate the daily flow-weighted average concentration. However, due to a limited amount of data, there is some uncertainty regarding that conclusion. To assess the potential effect of this uncertainty on the results of this study, we conducted a sensitivity analysis in which we compared retention calculated using KRAC concentrations equal to 90% (-10%), 100% (no adjustment) and 110% (+10%) of measured KRAC concentrations (Tables 7 and 8). The ±10% adjustment range is based on observed variability in concentration during diel studies carried out in 2006 (Note: this is not the daily range, but the range observed only during the times our samples were collected; See appendix A2). These adjustments were made only for the period in which hydropower peaking occurred (6/14/2005 through 12/14/2006, inclusive). The KRAC sample timing issue only affects retention in Copco Reservoir, not in Iron Gate Reservoir, as KRAC load is not a term in the Iron Gate nutrient budget.

The results of the sensitivity analysis show that the retention results are sensitive to changes in KRAC concentration (Tables 7 and 8). For example, the range in total TP retention in Copco Reservoir as a percent of inflow from the beginning of the study through the completion of turnover (May 18 – December 14) was 18.2% (from -8.3% to 9.9%; Table 7). For the same period (May 18 – December 14), the combined TP retention range of Iron Gate and Copco Reservoirs was 17.8% (from -7.3% to 10.5%) For TN during the May 18 – December 14 sample period the Copco-only range was 16.8% (from 2.1% to18.9%; Table 8), and the combined Copco-Iron Gate range was 15.5% (from 8.3% to 23.8%).

This sensitivity analysis confirms the importance of correctly representing KRAC concentrations in the nutrient budgets for Copco Reservoir, and for combined analyses of Copco and Iron Gate Reservoirs. While we have reasonable confidence that our KRAC samples represent the daily flow-weighted averages (Appendix A2), an error of 10% can affect net retention results. Thus, further data collection and analysis to better understand sub-daily changes in KRAC concentrations is warranted, and would improve confidence in the accuracy of the retention results reported here. Nonetheless, as shown in Tables 7 and 8, combined Copco-Iron Gate retention for TP (start to turnover) was relatively low (ranging between slightly negative and slightly positive). For TN the range was always positive; however, the maximum percent retained (23.8%: for the start to turnover period) was still only 7% higher than the uncorrected values shown above.

Table 7. Sensitivity of total phosphorus (TP) retention to changes in TP concentration at Klamath River above Copco (KRAC) station. Retention is compared using 3 levels of KRAC TP concentration: 90% (-10%), 100% (no adjustment), and 110% (+10%). Data are summarized by sampling interval, as well as several seasonal time scales.

				Total Phosphorus Retention (metric tons)						Total Phosphorus Retention (% of inflow)					
				Copco			Iron Gate + Copco			Copco			Iron Gate + Copco		
Sample Interval	**Interval Start**	**Interval End**	**Days in Interval**	**90%**	**100%**	**110%**	**90%**	**100%**	**110%**	**90%**	**100%**	**110%**	**90%**	**100%**	**110%**
1	5/18/05	6/2/05	16	-0.32	0.17	0.67	-0.36	0.14	0.63	-2.9	1.5	5.5	-3.2	1.2	5.2
2	6/3/05	6/15/05	13	-1.37	-0.88	-0.39	-0.51	-0.02	0.47	-30.7	-17.7	-7.1	-11.2	-0.4	8.6
3	6/16/05	6/28/05	13	0.02	0.46	0.90	-0.10	0.34	0.77	0.5	10.4	18.5	-2.5	7.5	15.7
4	6/29/05	7/14/05	16	0.28	0.91	1.55	0.81	1.45	2.08	4.9	14.4	22.2	14.1	22.6	29.6
5	7/15/05	7/27/05	13	-0.08	0.65	1.39	0.03	0.76	1.49	-1.2	8.9	17.2	0.4	10.3	18.4
6	7/28/05	8/11/05	15	-0.91	-0.18	0.55	-0.44	0.29	1.03	-13.9	-2.5	6.8	-6.6	4.0	12.7
7	8/12/05	8/25/05	14	0.02	0.64	1.27	-0.87	-0.25	0.38	0.3	10.2	18.4	-15.3	-3.9	5.5
8	8/26/05	9/8/05	14	-0.97	-0.41	0.15	-2.04	-1.48	-0.92	-19.2	-7.3	2.4	-40.1	-26.2	-14.9
9	9/9/05	9/21/05	13	-0.59	-0.07	0.45	-0.59	-0.07	0.45	-12.6	-1.3	7.9	-12.4	-1.3	7.8
10	9/22/05	10/5/05	14	0.22	0.87	1.52	0.67	1.31	1.96	3.8	13.4	21.3	11.3	20.1	27.3
11	10/6/05	10/19/05	14	-0.12	0.45	1.03	1.26	1.83	2.41	-2.4	7.8	16.2	24.0	31.5	37.6
12	10/20/05	11/3/05	15	-0.69	-0.18	0.32	0.03	0.54	1.04	-15.1	-3.6	5.7	0.6	10.4	18.4
13	11/4/05	11/17/05	14	-0.53	-0.24	0.06	-0.85	-0.55	-0.26	-19.7	-7.9	1.7	-30.4	-18.0	-7.7
14	11/18/05	11/30/05	13	-1.01	-0.69	-0.37	-1.84	-1.52	-1.20	-34.8	-21.5	-10.5	-62.1	-46.4	-33.4
15	12/1/05	12/14/05	14	-0.41	-0.14	0.13	-0.93	-0.66	-0.39	-16.3	-5.0	4.2	-34.4	-22.2	-12.0
16	12/15/05	1/4/06	21	-7.01	-6.44	-5.87	-19.15	-18.58	-18.02	-25.1	-22.6	-20.2	-64.2	-61.2	-58.2
17	1/5/06	1/24/06	20	1.78	1.78	1.78	5.92	5.92	5.92	4.6	4.6	4.6	14.9	14.9	14.9
18	1/25/06	2/7/06	14	3.33	3.33	3.33	6.13	6.13	6.13	14.3	14.3	14.3	25.7	25.7	25.7
19	2/8/06	3/1/06	22	8.74	8.74	8.74	12.86	12.86	12.86	28.1	28.1	28.1	40.3	40.3	40.3
20	3/2/06	3/23/06	22	6.80	6.80	6.80	10.63	10.63	10.63	25.7	25.7	25.7	39.5	39.5	39.5
21	3/24/06	4/5/06	13	3.80	3.80	3.80	4.75	4.75	4.75	23.6	23.6	23.6	28.9	28.9	28.9
22	4/6/06	4/27/06	22	4.27	4.27	4.27	8.28	8.28	8.28	10.4	10.4	10.4	19.7	19.7	19.7
23	4/28/06	5/11/06	14	5.62	5.62	5.62	6.17	6.17	6.17	25.6	25.6	25.6	27.0	27.0	27.0
Core growing season	6/29/05	9/21/05	85	-2.25	1.55	5.35	-3.09	0.71	4.51	-6.6	4.1	12.8	-8.9	1.8	10.7
Growing season	5/18/05	10/5/05	141	-3.70	2.17	8.04	-3.39	2.48	8.35	-6.2	3.3	11.3	-5.6	3.7	11.6
Start until turnover	5/18/05	12/14/05	211	-6.46	1.37	9.21	-5.72	2.11	9.95	-8.3	1.6	9.9	-7.3	2.4	10.5
All dates*	5/18/05	5/11/06	359	20.88	29.29	37.69	29.88	38.28	46.69	6.9	9.4	11.7	9.6	11.9	14.2

*Note: Quality of results for periods 16 and 17 are compromised due to large uncertainties in flows during extremely high flow events.

Table 8. Sensitivity of total nitrogen (TN) retention to changes in TN concentration at Klamath River above Copco (KRAC) station. Retention is compared using 3 levels of KRAC TN concentration: 90% (-10%), 100% (no adjustment), and 110%(+10%). Data are summarized by sampling period, as well as several seasonal time scales.

				Total Nitrogen Retention (metric tons)						Total Nitrogen Retention (% of inflow)					
				Copco			Iron Gate + Copco			Copco			Iron Gate + Copco		
Sample Interval	Interval Start	Interval End	Days in Interval	90%	100%	110%	90%	100%	110%	90%	100%	110%	90%	100%	110%
1	5/18/05	6/2/05	16	11.90	17.96	24.02	24.64	30.70	36.76	10.7	15.3	19.5	21.9	25.9	29.5
2	6/3/05	6/15/05	13	11.99	16.35	20.72	15.34	19.71	24.07	30.3	37.2	42.9	38.2	44.3	49.2
3	6/16/05	6/28/05	13	3.63	7.23	10.84	3.35	6.95	10.55	11.1	19.9	27.1	10.1	18.9	26.1
4	6/29/05	7/14/05	16	6.50	10.77	15.03	23.11	27.38	31.64	16.8	25.1	31.9	59.0	63.1	66.4
5	7/15/05	7/27/05	13	-7.32	-2.43	2.46	-5.48	-0.59	4.29	-16.6	-5.0	4.6	-12.3	-1.2	7.9
6	7/28/05	8/11/05	15	-2.42	3.91	10.25	9.46	15.79	22.12	-4.2	6.2	14.7	16.4	24.7	31.5
7	8/12/05	8/25/05	14	13.40	19.42	25.44	19.34	25.36	31.38	24.6	32.2	38.3	35.3	41.7	47.0
8	8/26/05	9/8/05	14	4.46	10.68	16.91	1.67	7.90	14.12	7.9	17.1	24.6	3.0	12.6	20.4
9	9/9/05	9/21/05	13	0.35	7.25	14.15	21.45	28.35	35.25	0.6	10.5	18.6	34.2	40.7	46.1
10	9/22/05	10/5/05	14	15.20	23.57	31.93	19.20	27.56	35.93	20.1	28.1	34.6	25.3	32.7	38.8
11	10/6/05	10/19/05	14	1.99	9.57	17.15	-2.01	5.57	13.15	2.9	12.6	20.5	-2.9	7.3	15.6
12	10/20/05	11/3/05	15	-2.96	5.41	13.77	-5.13	3.23	11.60	-3.9	6.4	14.9	-6.7	3.8	12.5
13	11/4/05	11/17/05	14	-16.06	-10.45	-4.84	-23.60	-17.99	-12.38	-31.6	-18.5	-7.8	-45.7	-31.5	-19.7
14	11/18/05	11/30/05	13	-8.55	-2.01	4.53	-3.50	3.04	9.58	-14.5	-3.1	6.3	-5.9	4.6	13.2
15	12/1/05	12/14/05	14	-13.40	-8.39	-3.37	-25.05	-20.03	-15.02	-29.3	-16.5	-6.0	-53.1	-38.4	-26.2
16	12/15/05	1/4/06	21	-9.83	-0.19	9.46	31.63	41.27	50.92	-2.8	-0.1	2.5	8.6	10.9	13.1
17	1/5/06	1/24/06	20	28.25	28.25	28.25	67.38	67.38	67.38	5.2	5.2	5.2	12.3	12.3	12.3
18	1/25/06	2/7/06	14	9.76	9.76	9.76	54.13	54.13	54.13	3.4	3.4	3.4	18.7	18.7	18.7
19	2/8/06	3/1/06	22	44.79	44.79	44.79	84.59	84.59	84.59	13.8	13.8	13.8	25.8	25.8	25.8
20	3/2/06	3/23/06	22	42.13	42.13	42.13	73.07	73.07	73.07	16.1	16.1	16.1	27.6	27.6	27.6
21	3/24/06	4/5/06	13	33.78	33.78	33.78	40.92	40.92	40.92	22.1	22.1	22.1	26.3	26.3	26.3
22	4/6/06	4/27/06	22	23.64	23.64	23.64	66.06	66.06	66.06	6.9	6.9	6.9	18.9	18.9	18.9
23	4/28/06	5/11/06	14	14.41	14.41	14.41	27.21	27.21	27.21	12.1	12.1	12.1	21.9	21.9	21.9
Core growing season	6/29/05	9/21/05	85	14.97	49.60	84.23	69.55	104.18	138.81	4.8	14.3	22.0	22.0	29.8	36.1
Growing season	5/18/05	10/5/05	141	57.70	114.72	171.74	132.08	189.10	246.13	10.1	18.2	25.0	22.9	29.8	35.6
Start until turnover	5/18/05	12/14/05	211	18.72	108.86	198.99	72.79	162.92	253.06	2.1	11.3	18.9	8.3	16.8	23.8
All dates*	5/18/05	5/11/06	359	205.65	305.43	405.22	517.77	617.55	717.33	6.3	9.1	11.7	15.6	18.1	20.4

*Note: Quality of results for periods 16 and 17 are compromised due to large uncertainties in flows during extremely high flow events.

3.4.5 Comparison with previous Klamath Reservoir and other literature studies

3.4.5.1 Previous Klamath Reservoir Studies

In cooperation with the SWRCB and the California National Guard, the U.S. EPA (1978) conducted nutrient sampling in Iron Gate Reservoir in 1975 as part of its National Eutrophication Study (U.S. EPA, 1975). Samples at tributaries and the Klamath River inlet and outlet were taken once per month for 12 months; however, in-reservoir mass was not calculated so the study did not include true mass-based nutrient budgets. The U.S. EPA analysis summed the incoming and outgoing loads for the year and concluded the annual outflow mass of phosphorus was 7% less than inflow (373 metric tons and 345 MT, respectively). This is similar, though somewhat higher, than the +3.1% TP retention for May 2005 – May 2006 presented above. U.S. EPA reported that annual mass of nitrogen outflow from Iron Gate Reservoir was 21% higher than inflow (4944 MT and 4085 MT, respectively). In contrast, the current study found that TN retention for the May 2005 – May 2006 period was +10.0%. Although not evaluated here, the observed differences in this study and the EPA study are possibly due to study methodology and/or hydrologic differences between the years. The U.S. EPA study also found that the mainstem Klamath dominated the incoming loads to Iron Gate, with less than 2% of the phosphorus load and 3% of the nitrogen load coming from tributaries, very similar to the May 2005 – May 2006 tributary load contributions of 2.9% and 1.7% for phosphorus and nitrogen, respectively.

The 2002 nutrient budgets for Iron Gate and Copco Reservoirs (Kann and Asarian 2005) spanned April 1 – Nov 13. Because sampling for this study did not start until May of 2005, comparisons for the whole April – November 2002 period were made by combining the periods 5/18/2005 – 11/17/2005 and 4/5/2006 – 5/11/2006. Inflow TN and TP loads as well as discharge were substantially higher in 2005-2006 than in 2002. For the comparable periods, TP retention was lower in 2005-2006 than 2002 on both a relative (% of inflow) and absolute mass basis; TP retention at Copco and Iron Gate was 10% (15.9 MT) and 5.2% (7.6 MT) of inflow in 2005-2006, compared to 26% (36.3 MT) and 25.5% (32.3 MT) for 2002. Although TN retention was substantially higher on an absolute basis in 2005-2006 than 2002, it was similar on a relative (% of inflow) basis; TN retention at Copco and Iron Gate was 13.1% (305.4 MT) and 9.6% (312.1 MT) of inflow in 2005-2006, compared to 8% (48.2 MT) and 12.1% (65.8 MT), respectively, for 2002.

Differences at shorter temporal scales are also apparent between the 2002 and 2005-2006 data. For instance, TN and TP retention in Copco and Iron Gate Reservoirs oscillated between negative and positive from June through November 2002, with some substantial negative retention (nutrient release) of both TP and TN. In contrast, although they did occur, periods of negative TN retention at Iron Gate and Copco Reservoirs in 2005 were less common and of smaller magnitude than 2002. Retention patterns for 2005-2006 and 2002 were more similar for TP than for TN, with periods of negative retention occurring regularly at both Iron Gate and Copco Reservoirs from June through September in 2005 (Table 5).

Evaluation of additional years of data is necessary to further understand the differences in retention patterns between the 2002 Kann and Asarian study and the 2005-2006 study. In this fashion, inter-annual differences in hydrology and loading, as well as differences in sampling methodology (e.g. better temporal and spatial resolution in the 2005-2006 data) can be evaluated.

3.4.5.2 Other Literature Studies

Observed retention in this study was compared to estimated retention from a variety of cross-sectional lake and reservoir studies (e.g., Walker 1985; Kronvang 2004). These studies developed empirical models to predict nutrient retention from a combination of parameters including annual hydraulic residence time (HRT), inflow nutrient load, volume-weighted mean inflow, and volume-weighted reservoir concentration. Models varied as to which combination of parameters were included. In some cases residence time alone accounted for a large proportion of variability in retention among lakes and reservoirs (Walker 1985).

Predicted TP retention for Copco and Iron Gate using the Kronvang et al. (2004) Tier 4 P retention model (equation 10, p. 40); was 1.4% and -1.9% of inflow TP load. These predicted values are comparable but slightly lower (8% and 5% lower, respectively) to the observed TP retention percentages of 9.4% and 3.1% for Copco and Iron Gate (all dates; Table 5). Using several equations shown in Walker (1985), predicted TP retention as a percent of inflow for Copco and Iron Gate was:

Model (from Walker 1985)	Copco	Iron Gate
BATHTUB - Reservoirs	26%	27%
Vollenweider - Northern Natural Lakes	12%	14%
Canfield/Bachman – Reservoirs	29%	29%
Canfield/Bachman - Natural Lakes	11%	12%

Interestingly, the predictions using reservoir equations are higher than the observed values for Copco and Iron Gate, while predictions using equations from natural lakes are closer to the range observed here, especially for Copco (9%). Possibilities to account for the lower values observed in this study include 1) P release from bottom sediments (a phenomenon known to occur in the type of prolonged anaerobic conditions observed in 2005; Fig. 9 above), and 2) the percent of incoming TP load comprised of dissolved SRP is generally >70% (Fig. 17, above) for much of the May-November period when retention was generally low and periodically negative. Note that TP retention is higher in winter/early spring when the percent of TP comprised of particulate P increases (SRP decreases; Fig. 17). Evidence pointing to offsetting of predicted reservoir retention by internal P loading includes the negative net retention that occurred in August through mid-September (for both reservoirs; Table 5), coinciding with maximum anaerobic conditions in the water column (Fig. 9).

Predicted TN retention for Copco and Iron Gate using the Kronvang et al. (2004) Tier 3 N retention model (equation 3, p. 25); was 8.7% and 9.5% of inflow TN load. These predicted values are very comparable to the observed TN retention percentages of 9.1% and 10% for Copco and Iron Gate (all dates; Table 6). Using Walker's (1985) "Model 05" (p. 72) based on data from 53 Army Corp of Engineers Reservoirs, predicted TN retention as a percent of inflow for Copco and Iron Gate was 10.3% and 9.4%. These predicted values are also close to the observed values of 9.1% (Copco) and 10% (Iron Gate). Agreement between expected retention relationships developed for other reservoirs (Walker 1985; Kronvang et al. 2004) and the observed TN retention for our system indicates that for 2005, the observed retention values of ~10% of inflow are in the rage expected based on observed inflow load and HRT. These retention values reflect the net effect of nutrient gains (e.g., fixation of atmospheric nitrogen by blue-green algae or possible ammonification of organic sediment material) and losses (e.g., settling of organic matter or denitrification).

Further comparison of Copco and Iron Gate retention values with a study of 23 lakes and reservoirs (Seitzinger et al. 2002) indicates that the observed retention values were similar to the 15% expected based on the relationship of the mean depth to time of travel ratio and % N removed (see Asarian and Kann 2006a for more detailed description of Seitzinger) . Thus, comparison with a broad range of lakes and reservoirs indicates that the observed retention values for 2005-2006 fell within the range expected based upon systems with similar morphometric and hydraulic characteristics.

3.5 PHYTOPLANKTON

Phytoplankton dynamics are an important aspect of understanding reservoir nutrient dynamics as well as overall water quality patterns, particularly in such systems as Copco and Iron Gate that have extensive blooms of both toxic and non-toxic cyanobacteria (Kann 2006, Kann and Corum 2006).

3.5.1 Longitudinal Analysis

3.5.1.1 Total Biovolume and Chlorophyll a

Box plots of total phytoplankton biovolume for all sample dates and Jun-Sep 2005 dates showed an increasing trend in biovolume from KRAC to Copco and Iron Gate Reservoir stations (top panel; Figs. 34 and 35). Due to water withdrawal depths (7 to 9.8 m in Copco and 4 – 6.4 m in Iron Gate[9]) generally low in the photic zone, total biovolume below the reservoirs (KRAI and KRBI) tended to be lower than KRAC when the entire sampling season was evaluated (Fig. 34). However, for the Jun-Sep period, the KRAI station directly below Copco had higher median (3x higher) and upper quartile (1.5x higher) values than did KRAC (Fig. 35; Table 9). While values of the distribution of total biovolume at KRBI were also slightly elevated (1.5x higher) compared to those above Copco, upper quartile values were slightly lower for the Jun-Sep period (Fig. 35; Table 9). However, for Chlorophyll *a,* which also indicates algal biomass, median and upper quartile values below Iron Gate were substantially elevated (3-4x) compared to that above Copco for this same period (Fig. 36). This trend of elevated chlorophyll through the reservoir complex and below was evident for all evaluated reservoir depths, and not only for the surface to 1 m layer (Fig. 36). A possible explanation for the higher below reservoir chlorophyll values at KRAI and KRBI compared to those for algal biovolume is that measures of chlorophyll provide a better estimation of actively growing phytoplankton than do estimates of algal biovolume. For example, much of the above Copco measured biovolume may represent algal remains being washed into the system from Upper Klamath Lake or from upstream scoured attached algae.

[9] According to PacifiCorp (2005b), the elevation of penstock intakes is 2575 ft in Copco and 2309 ft in Iron Gate. During the May 2005 – May 2006 study period, water surface elevations in Copco ranged from 2598 to 2607 ft, thus release depths were 23 to 32 ft (7 to 9.8 m) below the water surface. In the same period, water surface elevations in Iron Gate ranged from 2322 to 2330 ft, thus release depths were 13 to 21 ft (4.0 to 6.4 m)

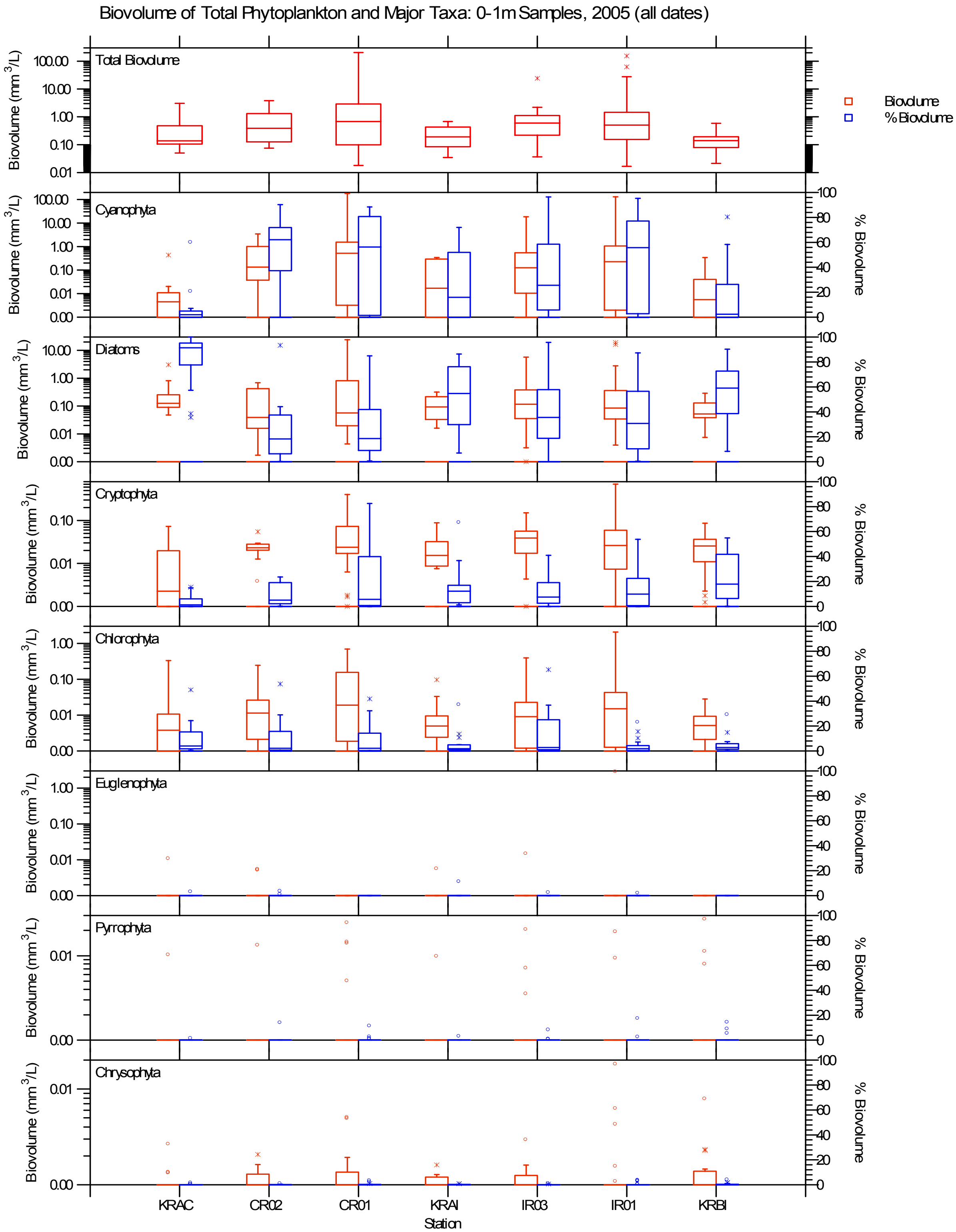


Fig. 34. Total phytoplankton biovolume, and total and percent biovolume of the Cyanophyta, Diatoms, Cryptophyta, Chlorophyta, Euglenophyta, Pyrrophyta, and Chrysophyta for surface to 1 m samples for all 2005 sample dates. The line inside each box is the median and the edges of each box are the 25th and 75th percentiles. The whiskers represent data points beyond 1.5 times the interquartile (75th-25th) range.

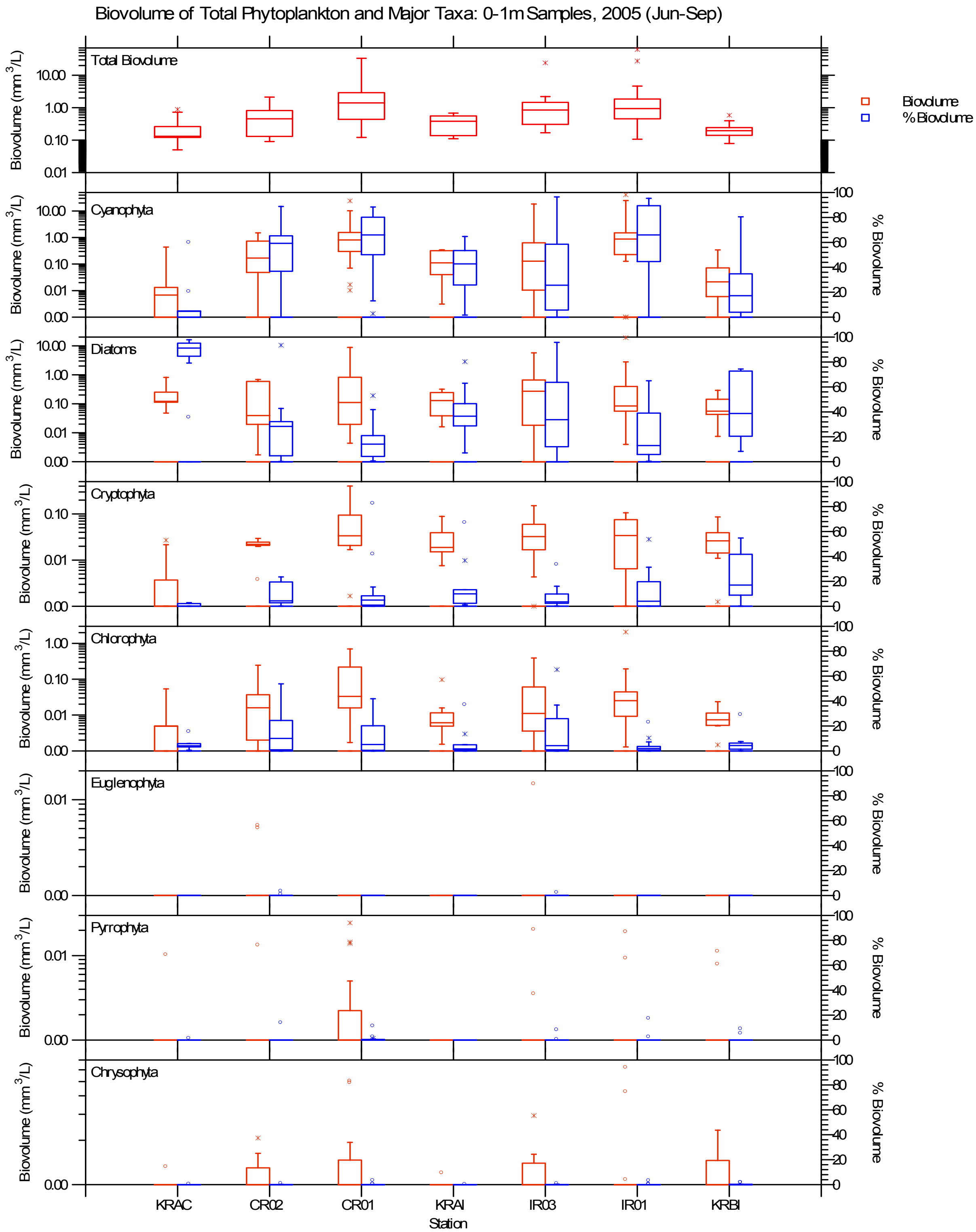


Fig. 35. Total phytoplankton biovolume, and total and percent biovolume of the Cyanophyta, Diatoms, Cryptophyta, Chlorophyta, Euglenophyta, Pyrrophyta, and Chrysophyta for surface to 1 m samples for all 2005 sample dates. The line inside each box is the median and the edges of each box are the 25th and 75th percentiles. The whiskers represent data points beyond 1.5 times the interquartile (75th-25th) range

Table 9. Summary of biovolume data by station for surface to 1m samples during the period June- September, 2005. For each site, statistics include the number of samples (N) and the lower quartile, median, and upper quartile biovolume for major taxonomic groups.

			Biovolume (mm^3/L)							
Station	Description	Parameter	Total	Cyanophyta	Chlorophyta	Diatoms	Cryptophyta	Chrysophyta	Euglenophyta	Pyrrophyta
KRAC	KR abv Copco	N of cases	9	9	9	9	9	9	9	9
KRAC	KR abv Copco	Lower Quartile	0.114	0.00	0.00	0.103	0.00	0.00	0.00	0.00
KRAC	KR abv Copco	Median	0.131	0.007	0.005	0.121	0.00	0.00	0.00	0.00
KRAC	KR abv Copco	Upper Quartile	0.378	0.015	0.009	0.253	0.008	0.00	0.00	0.00
CR02	Copco upper	N of cases	9	9	9	9	9	9	9	9
CR02	Copco upper	Lower Quartile	0.127	0.040	0.002	0.016	0.021	0.00	0.00	0.00
CR02	Copco upper	Median	0.452	0.168	0.016	0.039	0.022	0.00	0.00	0.00
CR02	Copco upper	Upper Quartile	1.142	0.897	0.052	0.597	0.025	0.001	0.00	0.00
CR01	Copco nr dam	N of cases	15	15	15	15	15	15	15	15
CR01	Copco nr dam	Lower Quartile	0.427	0.285	0.015	0.019	0.021	0.00	0.00	0.00
CR01	Copco nr dam	Median	1.405	0.811	0.033	0.111	0.034	0.00	0.00	0.00
CR01	Copco nr dam	Upper Quartile	2.926	1.557	0.261	1.030	0.096	0.002	0.00	0.004
KRAI	KR abv IG	N of cases	9	9	9	9	9	9	9	9
KRAI	KR abv IG	Lower Quartile	0.135	0.031	0.005	0.034	0.014	0.00	0.00	0.00
KRAI	KR abv IG	Median	0.383	0.112	0.006	0.130	0.019	0.00	0.00	0.00
KRAI	KR abv IG	Upper Quartile	0.567	0.326	0.013	0.247	0.040	0.001	0.00	0.00
IR03	IGR upr half	N of cases	11	11	11	11	11	11	11	11
IR03	IGR upr half	Lower Quartile	0.276	0.009	0.003	0.019	0.016	0.00	0.00	0.00
IR03	IGR upr half	Median	0.843	0.130	0.011	0.271	0.032	0.00	0.00	0.00
IR03	IGR upr half	Upper Quartile	1.531	0.695	0.077	0.746	0.061	0.001	0.00	0.00
IR01	IGR nr dam	N of cases	13	13	13	13	13	13	13	13
IR01	IGR nr dam	Lower Quartile	0.426	0.203	0.009	0.049	0.006	0.00	0.00	0.00
IR01	IGR nr dam	Median	0.938	0.878	0.025	0.083	0.034	0.00	0.00	0.00
IR01	IGR nr dam	Upper Quartile	2.561	2.191	0.063	0.478	0.076	0.001	0.00	0.00
KRBI	KR bel IGD	N of cases	9	9	9	9	9	9	9	9
KRBI	KR bel IGD	Lower Quartile	0.123	0.006	0.005	0.041	0.013	0.00	0.00	0.00
KRBI	KR bel IGD	Median	0.193	0.021	0.007	0.056	0.026	0.00	0.00	0.00
KRBI	KR bel IGD	Upper Quartile	0.281	0.103	0.012	0.164	0.050	0.002	0.00	0.003

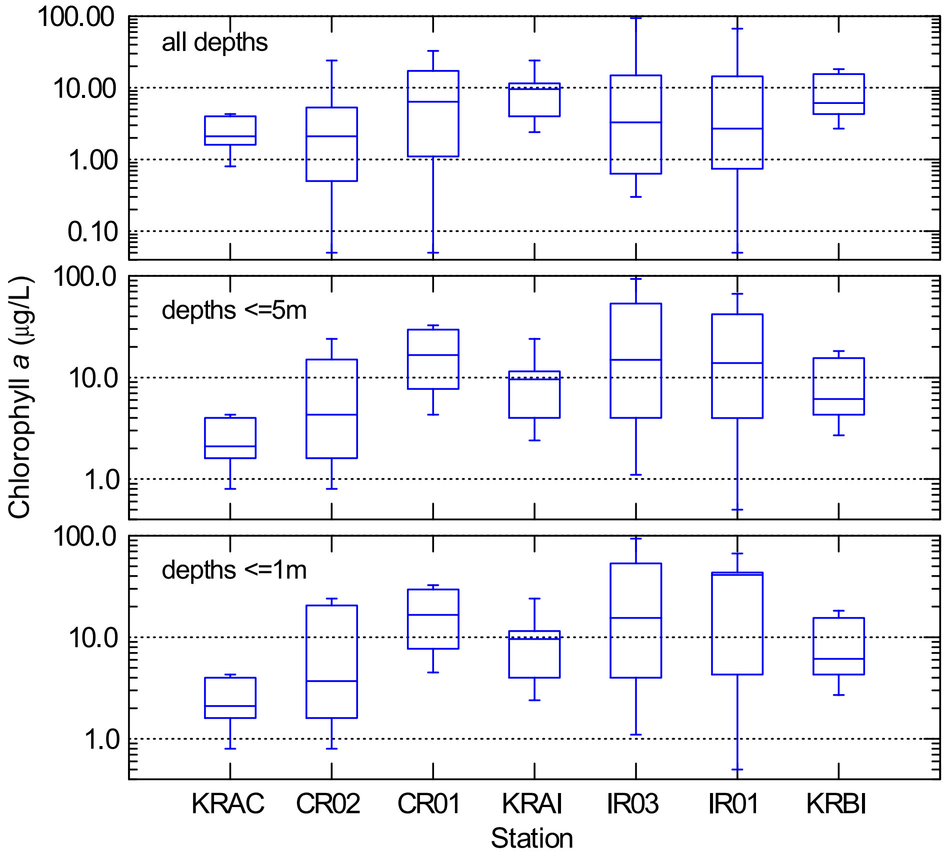


Fig. 36. Longitudinal Chlorophyll *a* concentrations for all measured reservoir depths (top panel), depths ≤ 5m (middle panel), and depths ≤ 1m (bottom panel), June-September, 2005. Note that values for river stations KRAC, KRAI, and KRBI are only for the surface to 1 m layer which represents the entire mixed water column.

3.5.1.2 Major Taxonomic Groups

Cyanophyta

As expected based upon previous observations of large blue-green algal blooms in the reservoirs, the longitudinal trend in both total biovolume and percent biovolume of the Cyanophyta increased substantially through the reservoirs and below at KRBI (Figs. 34 and 35). For the June-September period median and upper quartile biovolume values were 20x to >100x higher in Copco and Iron Gate Reservoirs than they were above Copco, and were 3-7 times higher at KRBI, below Iron Gate (Table 9). The trend in Cyanophyta percent composition was more pronounced through the reservoir complex than absolute biomass, with upper quartile levels in Copco and Iron Gate increasing from <5% above Copco to >80% in Copco and Iron Gate Reservoirs, and >30% at KRBI (Fig. 35). Similar to Kann and Asarian (2006), these trends in the upper distribution indicate that periodic high values of both biovolume and percent biovolume of Cyanophyta occurred in the reservoir complex and below relative to stations directly upstream.

Other dominant groups
As expected as the system changed from the riverine environment of the Klamath River to the lacustrine environment of the reservoirs, a reverse trend to that noted for the Cyanophytes occurred for the Diatoms. Diatoms decreased in prevalence from KRAC to the in-reservoir stations and at KRBI (Fig. 35 and Table 9). Diatoms comprised >90% of the composition at KRAC, with median values decreasing substantially to ~40% at KRBI. Other major taxonomic groups that increased in prevalence in the reservoirs were the Cryptophyta (cryptophytes) and Chlorophyta (green algae). As with the Cyanophyta, the species in these groups (e.g., *Cryptomonas erosa* and *Actinastrum hantzschii*) tend to be more lacustrine. Relative to diatoms and the Cyanophyta, the Euglenophyta (euglena), Pyrrophyta (dinoflagellates), and Chrysophyta (golden algae) comprised a very minor portion of the overall biovolume at all stations.

3.5.2 Seasonal Trends

3.5.2.1 Major Taxonomic Groups- Reservoir Stations

Seasonal trends for major taxonomic groups are shown for reservoir stations at each measured depth (Figs. 37-40). As expected based on the above June-Sep analyses, Cyanophyta biomass and composition increased beginning in June and continued into October in both reservoirs. Peak cyanophyte biovolume and percent composition tended to occur between July and September, with early (May-June) and later season (October-December) phytoplankton dominated by Diatoms and cryptophytes, and to a lesser extent chlorophytes.

As expected based on expected water column light attenuation, overall biovolume decreased with increasing depth. The biomass and percent composition of the cyanophytes was highest at surface samples, remained relatively high at 1m, and although the peak was more contracted there was continued prevalence even at depths of 5m and ≥10m. In general, diatoms and cryptophytes, and occasionally chlorophytes, showed increased dominance at depths of 5m or greater, but there were significant periods during the season at CR01 and IR01 when cyanophyte dominance was >50% of the total biovolume those depths (Figs. 37 and 39).

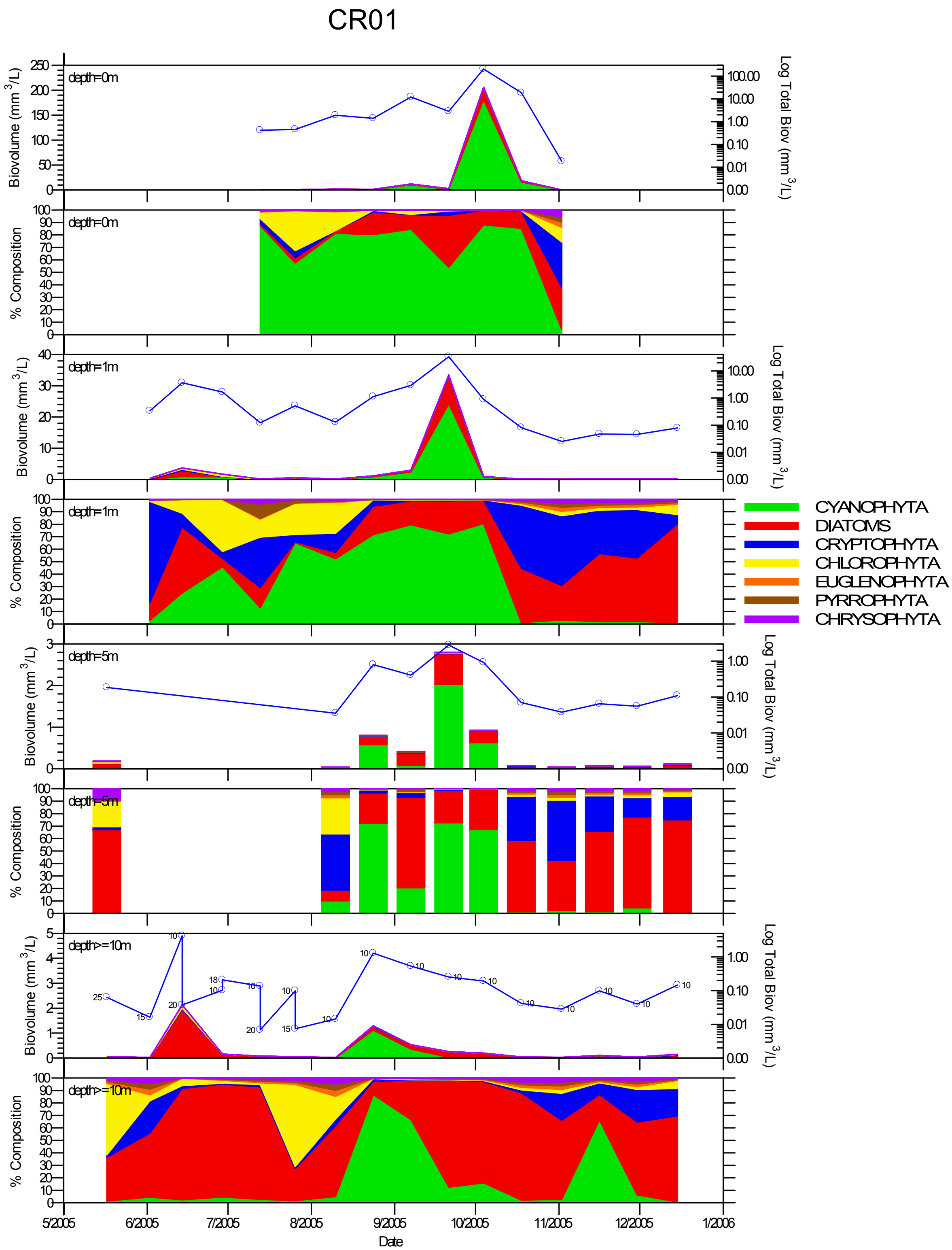


Fig. 37. Biovolume and percent biovolume of major phytoplankton taxonomic groups at measured depths for reservoir station CR01, 2005. Notes: 1) surface samples were collected mid July-early November, 2) the total biovolume (blue line) is shown with a log scale on the right axis, and 3) labels for depth ≥10m panel denote the depth sample was collected.

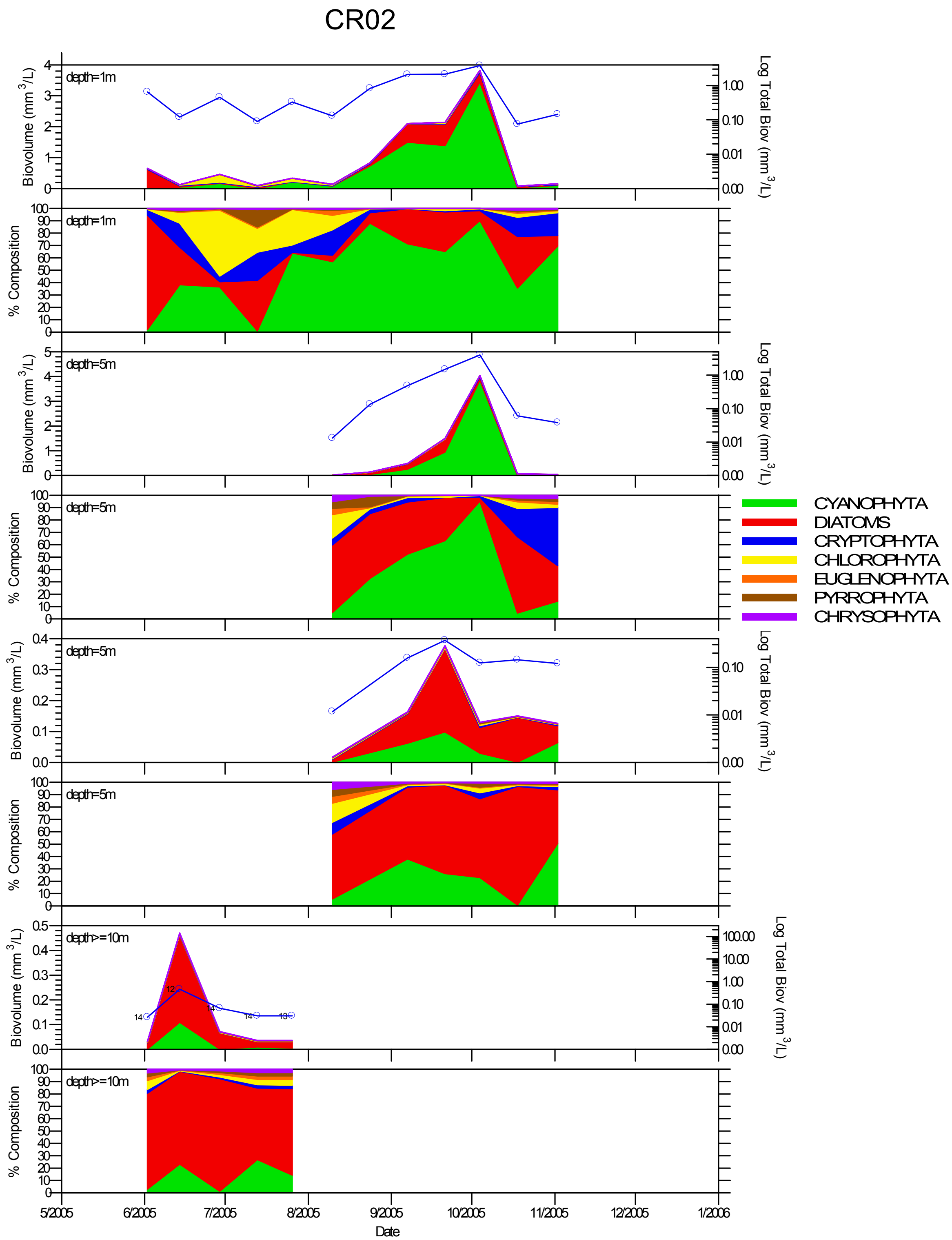


Fig. 38. Biovolume and percent biovolume of major phytoplankton taxonomic groups at measured depths for reservoir station CR02, 2005. Notes: 1) surface samples were not collected at this station, 2) the total biovolume (blue line) is shown with a log scale on the right axis, and 3) labels for depth ≥10m panel denote the depth sample was collected.

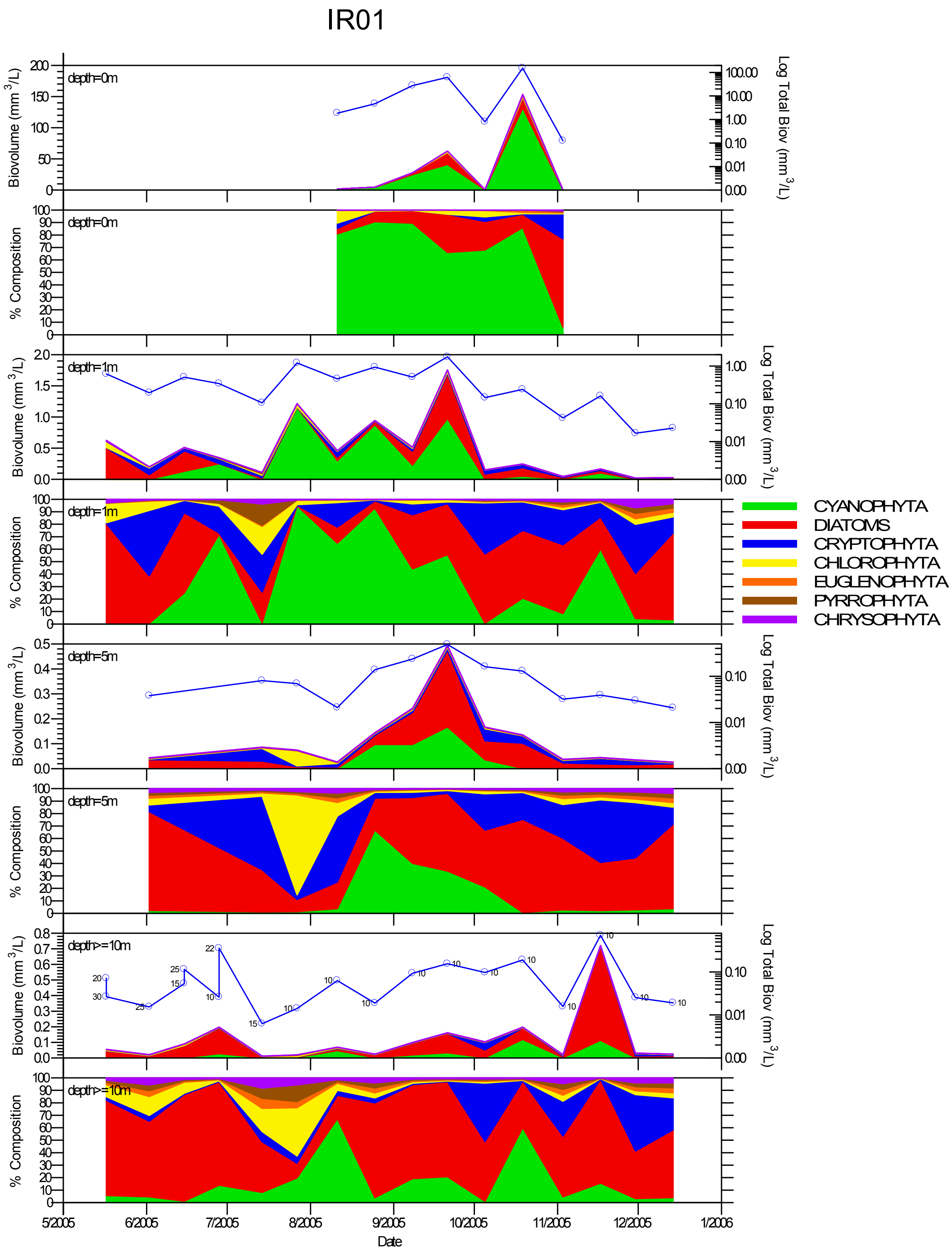


Fig. 39. Biovolume and percent biovolume of major phytoplankton taxonomic groups at measured depths for reservoir station IR01, 2005. Notes: 1) surface samples were collected mid July-early November, 2) the total biovolume (blue line) is shown with a log scale on the right axis, and 3) labels for depth ≥10m panel denote the depth sample was collected.

IR03

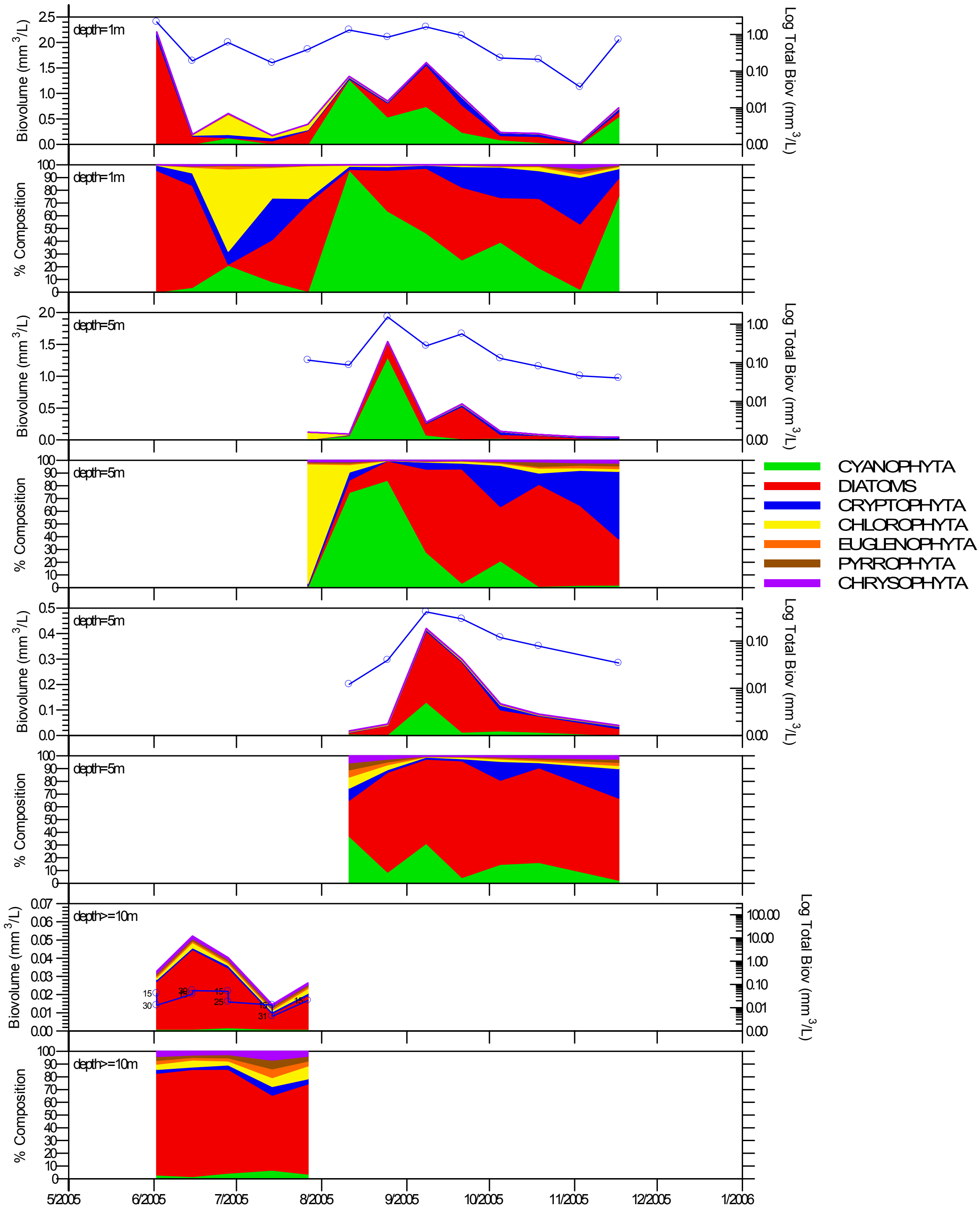


Fig. 40. Biovolume and percent biovolume of major phytoplankton taxonomic groups at measured depths for reservoir station IR03, 2005. Notes: 1) surface samples were not collected at this station, 2) the total biovolume (blue line) is shown with a log scale on the right axis, and 3) labels for depth ≥10m panel denote the depth sample was collected.

These data clearly show that overall biovolume as well as biovolume and percent composition of cyanophyte species can remain high (relative to inflow quantities) even at reservoir depths significantly below the surface. This trend is confirmed by chlorophyll data which also showed elevated values at depths ≥5m (Fig. 41). Peak values at 5 m during the July-September period were greater than 5x higher than inflow values at KRAC (see Fig. 36 above). For CR01, values exceeded 10 μg/L during two peaks in July and August. Depths ≥10 m showed very low chlorophyll throughout the season.

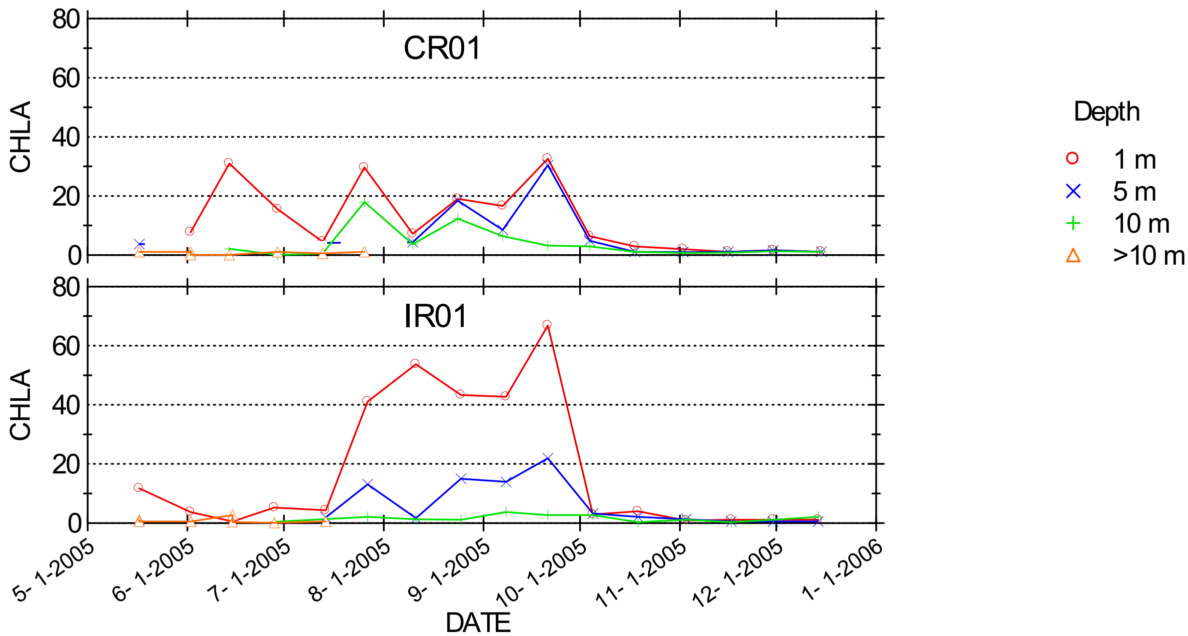


Fig. 41. Chlorophyll a (CHLA: μg/L) at measured depths for reservoir stations CR01 and IR01, 2005.

3.5.2.2 Major Taxonomic Groups - River Stations

Seasonal trends of major taxonomic groups for the three river stations (KRAC, KRAI, and KRBI) are shown in Figure 42. In contrast to the reservoirs, aside from a cyanophyte peak occurring in late June, at KRAC was dominated by diatoms for the majority of the season (Fig. 42; top panel). Downstream at KRAI and at KRBI the Cyanophyta increased in importance on a seasonal basis, at times accounting for >50% of the composition. As mentioned above, these values were lower than the in-reservoir upper water column values because water released from the reservoirs is drawn from lower in the water column; as noted previously, release depths are 7 to 9.8 m below the surface in Copco and 4 – 6.4 m in Iron Gate. Seasonal composition trends at these below reservoir stations tended to follow those of reservoir stations directly upstream.

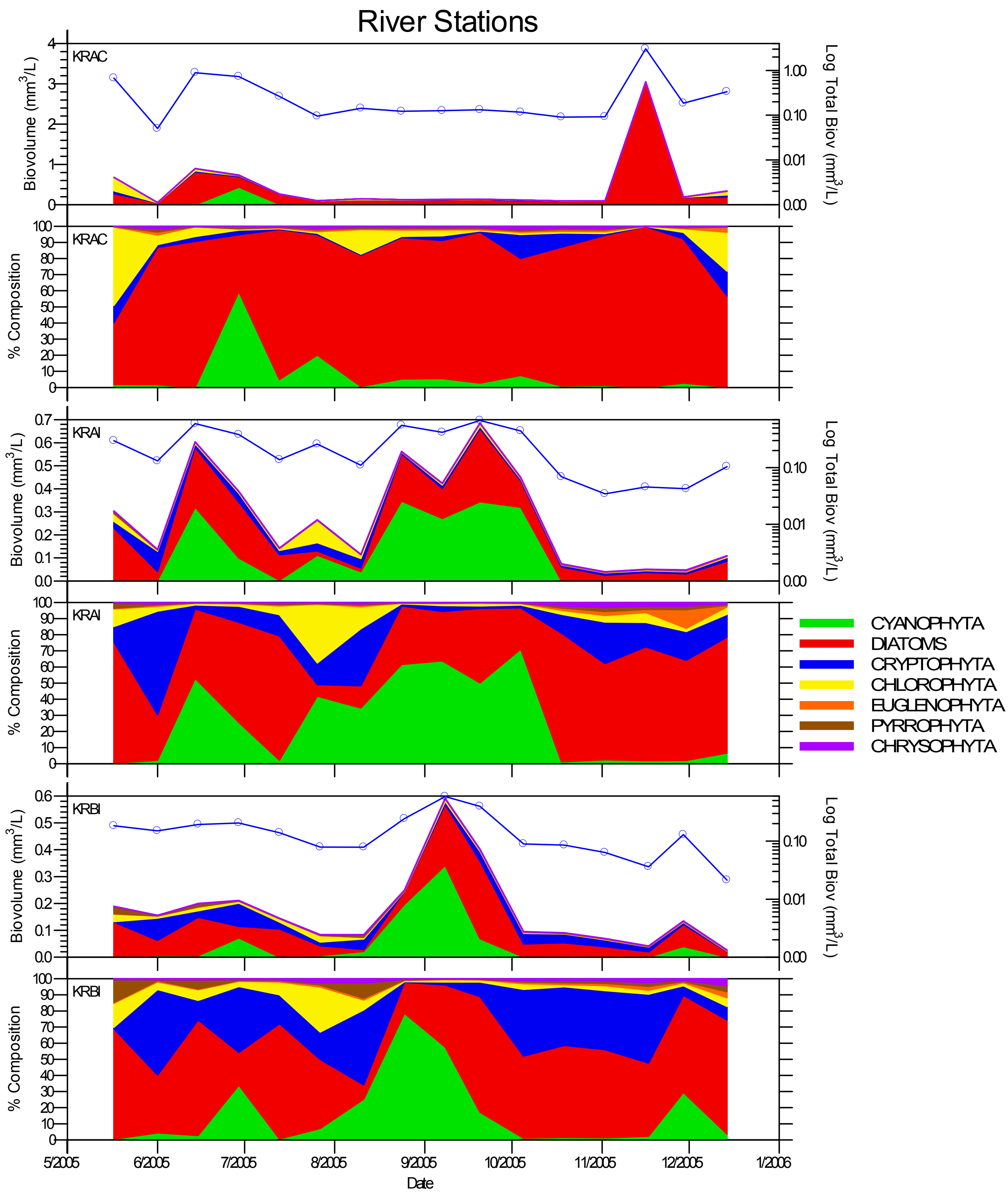


Fig. 42. Biovolume and percent biovolume of major phytoplankton taxonomic groups at Klamath River stations KRAC, KRAI, and KRBI, 2005. Note: the total biovolume (blue line) is shown with a log scale on the right axis.

3.5.2.3 Species/Generic Composition- Reservoirs Stations

Seasonal trends for dominant species/genera are shown for the main reservoir stations CR01 and IR01 (Figs. 43-44). The intent of this section is not to provide detailed information on individual species, but rather to determine those species that comprise the major taxonomic groups described in the above figures.

The dominant June-September surface and 1 m species in Copco Reservoir were *Aphanizomenon flos-aquae* (APFA) and *Microcystis aeruginosa* (MSAE), although MSAE showed both greater biomass and composition at the surface depth (Fig. 43). Prior to the period of major cyanophyte dominance in July, early season composition was dominated by *Cryptomonas* (Cryptophyta) and S*tephanodiscus* (Diatom) at the 1 m depth. *Cryptomonas,* along with the diatom *Nitzschia,* increased in importance during the fall months. Although relative biovolume was much lower, APFA and MSAE were still present and occasionally constituted relatively high percentages of the composition at the 5 and 10 m depths. The diatom *Nitzschia* and the chlorophyte *Schroderia* increased in composition at the 10 m depth.

In Iron Gate Reservoir, APFA was less prevalent, and MSAE more prevalent relative to Copco Reservoir at all depths (Fig. 44). Moreover, MSAE still constituted up to ~60% of the composition at 5 m. Other differences include the presence of the cyanophyte *Gloeotrichia echinulata* (GTEC) during mid-July to early September, chiefly at the 1 m depth. Also of occasional importance were the cyanophyte *Anabaena*, the diatom *Melosira*, and the chlorophyte *Schroderia.* Seasonal pattern in Iron Gate included spring-early summer dominance by diatoms (e.g., *Stephanodiscus, Melosira* and *Fragilaria*) and *Cryptomonas*, summer dominance by the Cyanophyta (e.g., *Aphanizomenon*, *Microcystis,* and *Gloeotrichia*) and *Nitzschia* at deeper depths, and fall dominance by *Cryptomonas* and the diatoms *Melosira* and *Fragilaria* (Fig. 44). These figures also confirm that relevant (i.e., with respect to toxic and eutrophic species) blue-green algal species are not only relegated to surface depths.

3.5.2.4 Species/Generic Composition- River Stations

In contrast to the reservoirs, aside from a cyanophyte peak consisting of APFA occurring in late June, at KRAC was dominated by a variety of periphytic or attached diatom genera typical of riverine systems (e.g., *Cocconeis*, *Gomphonema*, and *Navicula)* and other more planktonic diatoms (e.g., *Stephanodiscus* and *Fragilaria*) for the majority of the season (Fig. 45; top panel). The seasonal pattern showed *Stephanodiscus* to be more prevalent in the spring and fall, while *Nitzschia*, *Navicula*, and *Cocconeis* were more prevalent during the summer. Downstream to KRAI and at KRBI, APFA and MSAE increased in importance on a seasonal basis, at times accounting for >50% (for APFA at KRAI) and >70% (for MSAE at KRBI) of the composition.

As expected based on trends shown above, seasonal composition at these below reservoir stations tended to follow those of reservoir stations directly upstream. Similar to the reservoirs which showed MSAE to be more prevalent at various depths than Copco, these results also show the same trend of increased MSAE below Iron Gate relative to below Copco.

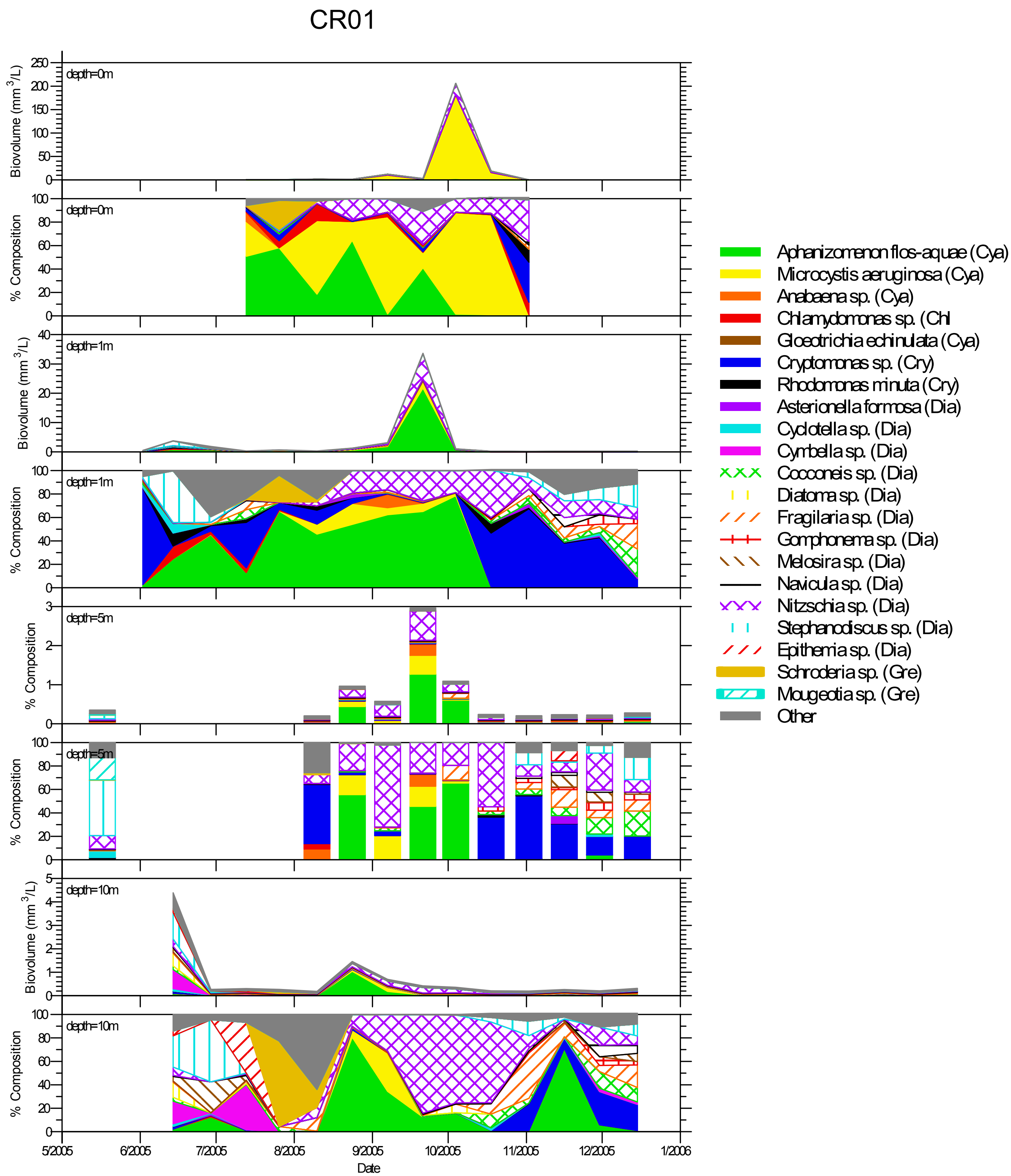


Fig. 43. Biovolume and percent biovolume of dominant species of phytoplankton at measured depths for reservoir station CR01, 2005.

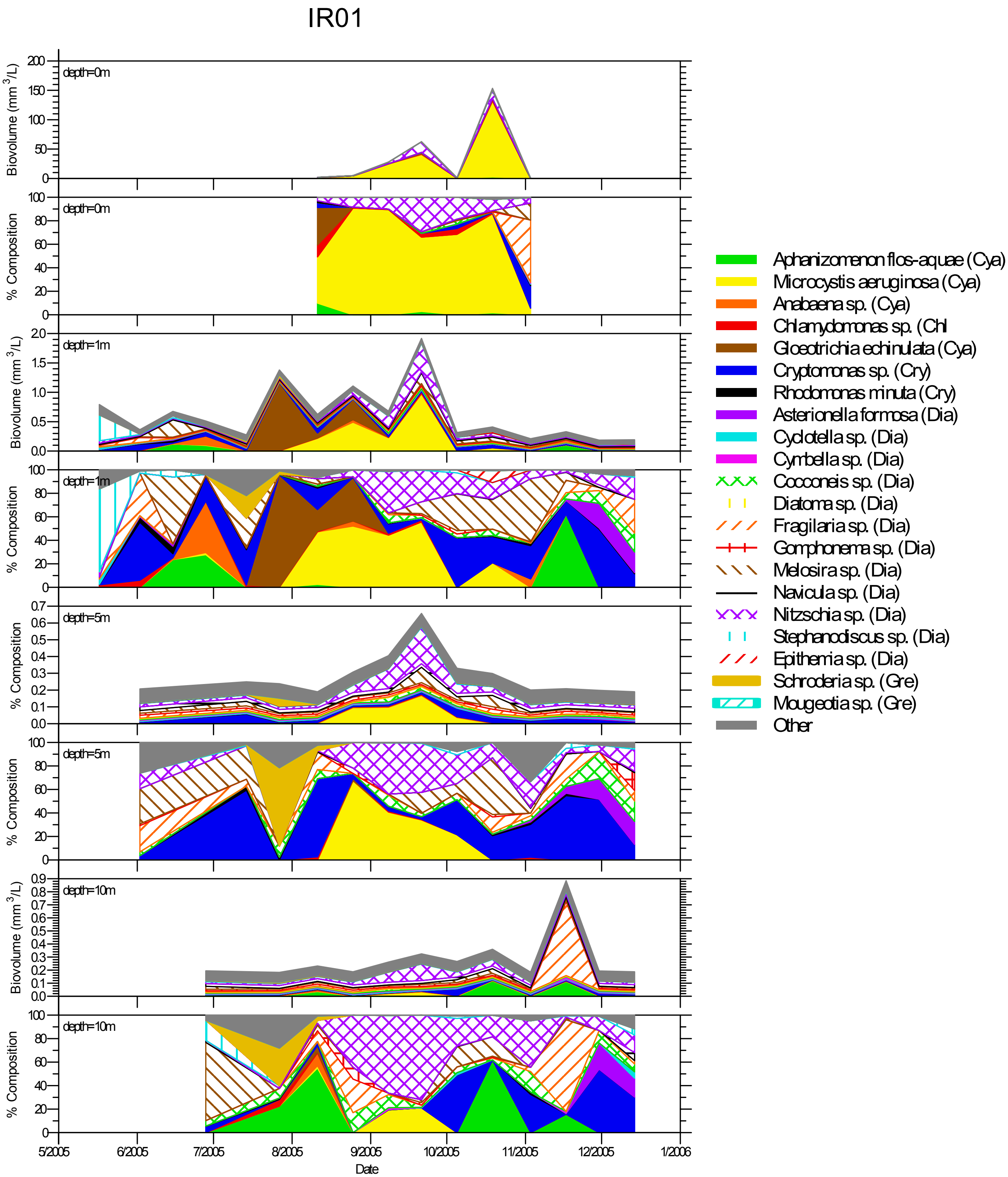


Fig. 44. Biovolume and percent biovolume of dominant species of phytoplankton at measured depths for reservoir station IR01, 2005.

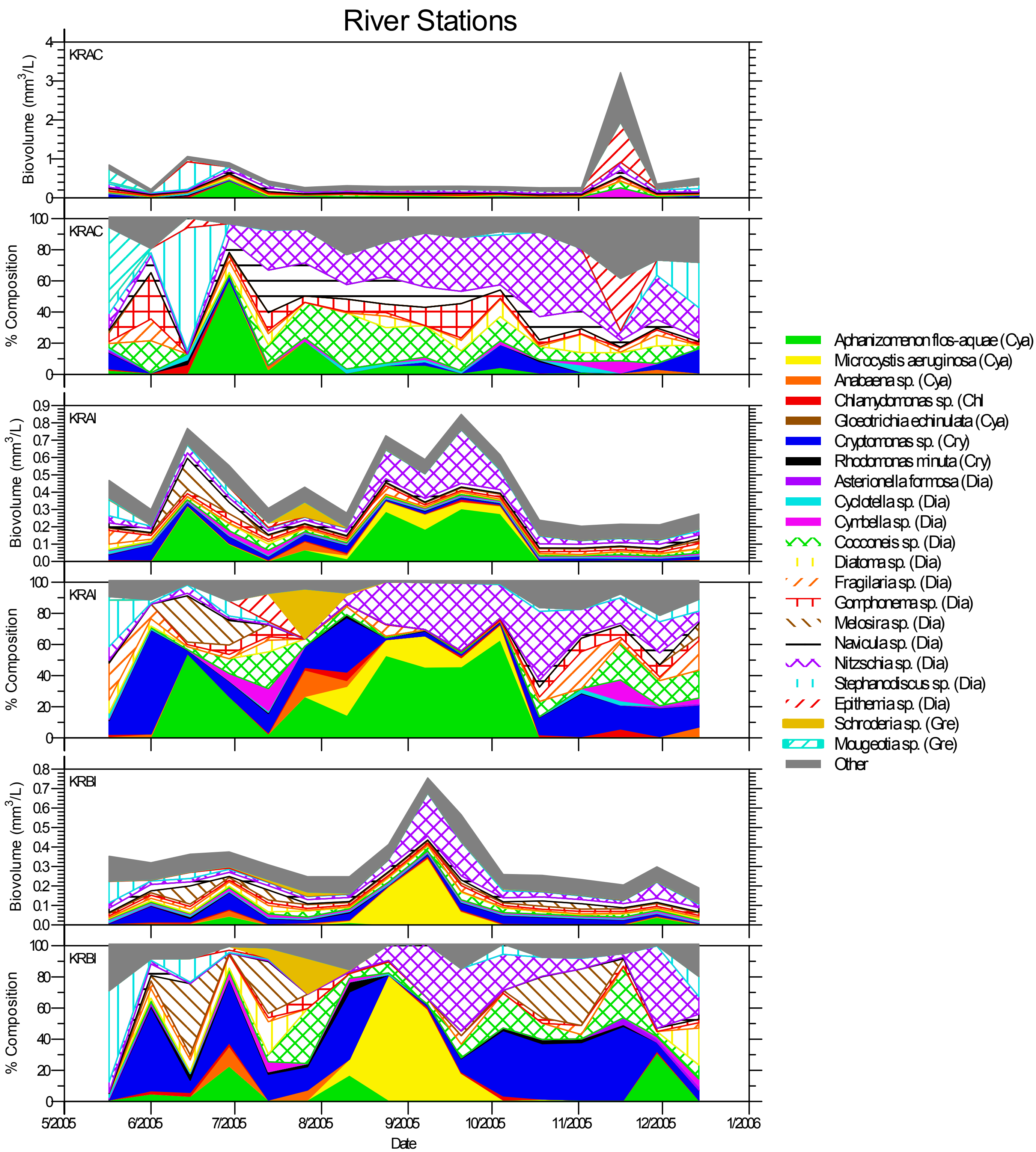


Fig. 45. Biovolume and percent biovolume of dominant species of phytoplankton at Klamath River stations KRAC, KRAI, and KRBI, 2005.

3.5.2.5 Nitrogen Fixing Species

As noted above, several nitrogen fixing blue-green algal species are present in the Klamath River reservoir system. These species include *Aphanizomenon flos-aquae*, *Anabaena sp.,* and *Gloeotrichia echinulata* and can play an important role in introducing nitrogen into aquatic systems. Because heterocysts (specialized cyanobacterial cells that function as the site of nitrogen fixation), can indicate active fixation their relative abundance has been used to evaluate potential fixation trends.

Time-series of the ratio of number of heterocysts to number of vegetative cells shows that no heterocysts were detected at KRAC. (Fig. 46; top panel). In contrast, the heterocyst ratio increased towards the end of June, peaked in July and early August, and then declined during the end of September in Copco Reservoir (Fig. 46; 2nd panel). There were several instances of elevated heterocyst ratio at KRAI (Fig. 46; 3rd panel), and for Iron Gate, all three species showed instances when the ratio was elevated (Fig. 46, 4th panel). Elevated ratios were observed on only one date (late June) at KRBI (Fig. 46; bottom panel). As shown above, the biovolume of these species was low at depths where water is withdrawn from Iron Gate. Peak heterocyst ratios at IR01 and CR01 were similar to those previously observed in Upper Klamath Lake (Kann 1998).

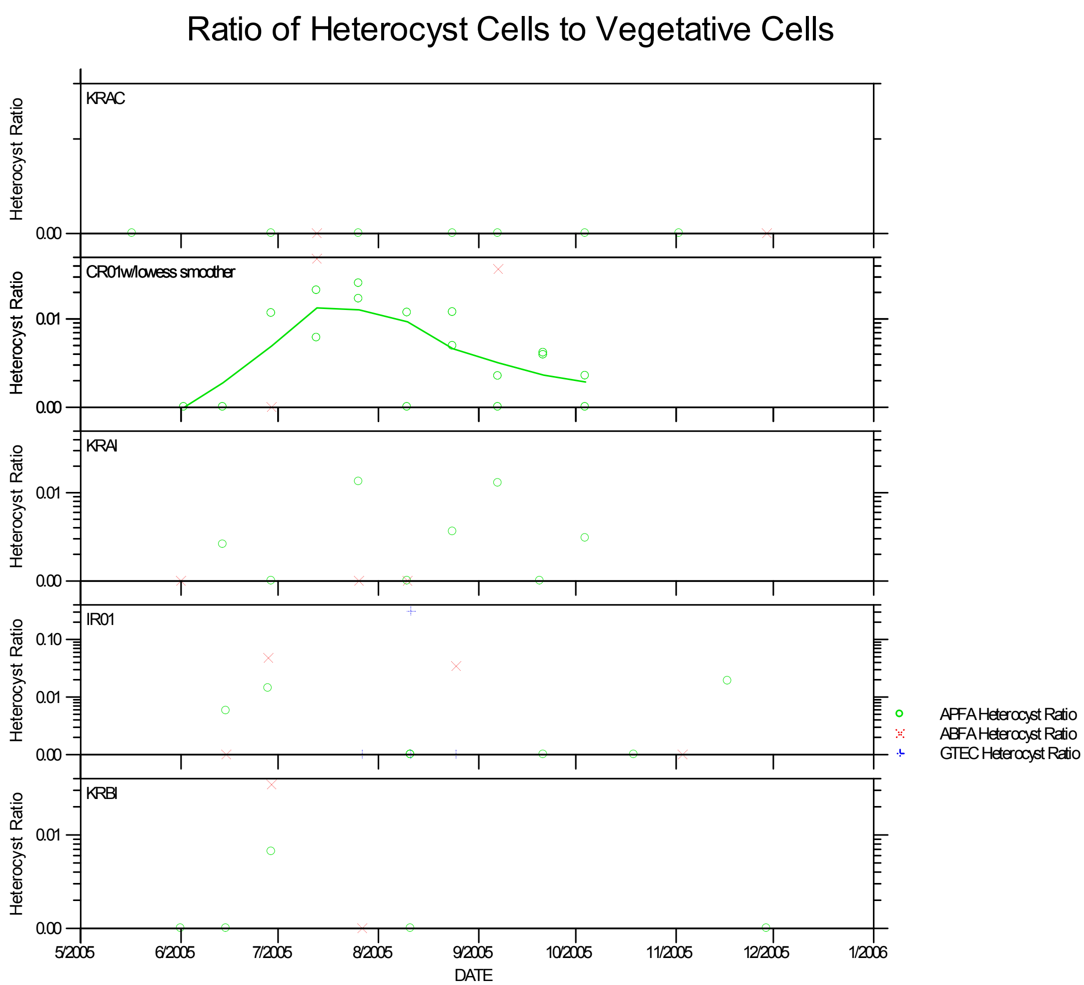


Fig. 46. Ratio of number of heterocysts to vegetative cells for *Aphanizomenon* (APFA), *Anabaena* (ABFA), and *Gloeotrichia* (GTEC) at Klamath River and reservoir stations KRAC, CR01, KRAI, IR01, and KRBI, 2005.

Further longitudinal examination of trends in cyanobacteria and nitrogen fixing species shows that for 2005, biovolume and percent composition of N-fixing species increased in Copco stations and at KRAI (relative to KRAC), increased again in Iron Gate (although not as much as in Copco), and then were similar to KRAC at KRBI below Iron Gate (Fig. 47). However, during this same period, MSAE (which is not an N-fixing species) tended to be higher in Iron Gate than at upstream stations (it was not detected at all at KRAC), and accounted for much of the Cyanophyta increase observed at KRBI below Iron Gate.

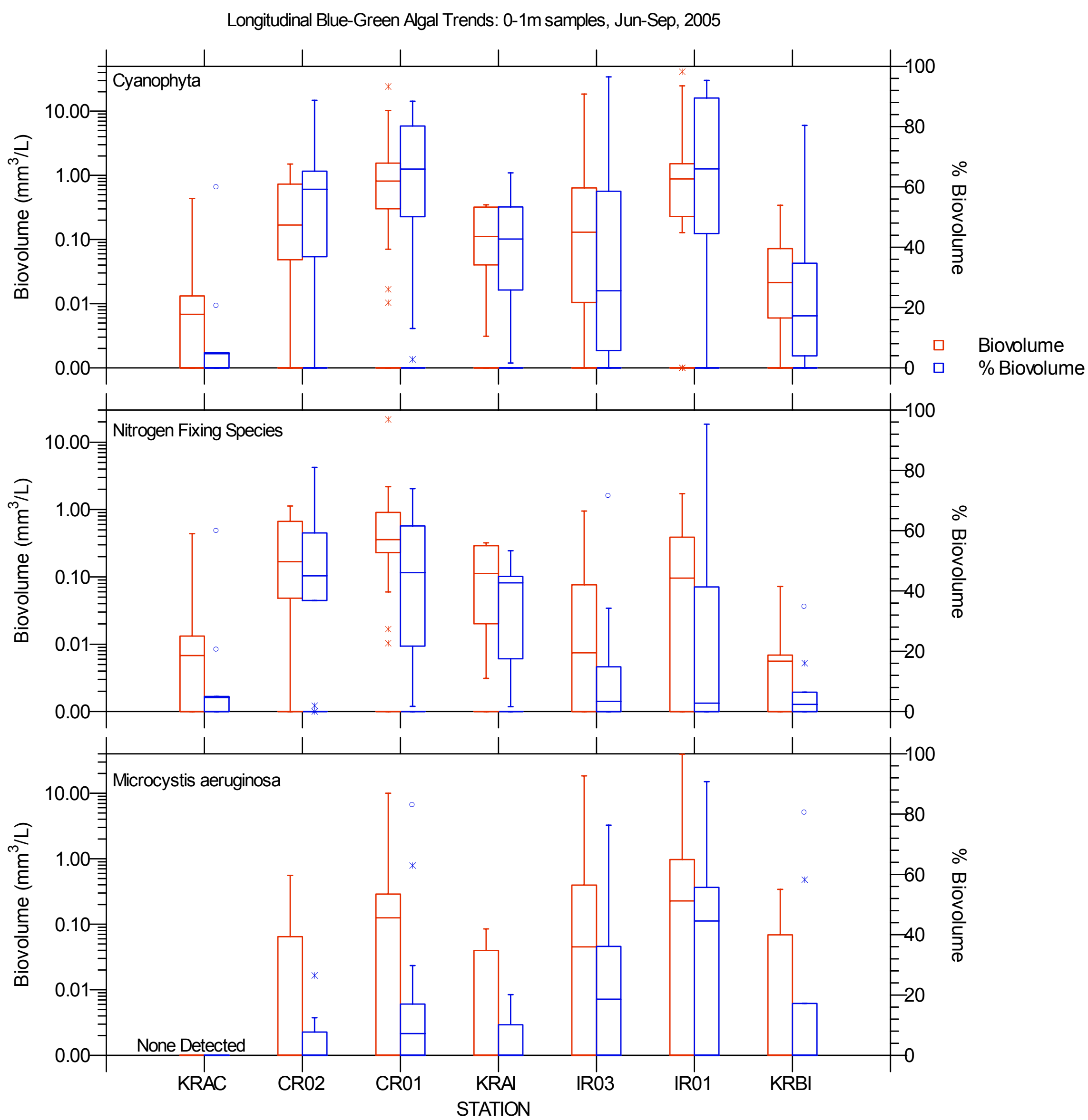


Fig. 47. Biovolume and percent composition of the Cyanophyta (top panel), nitrogen-fixing species (middle panel), and *Microcystis aeruginosa* (bottom panel), 2005.

4. CONCLUSIONS

The study described herein examined longitudinal, temporal, and depth trends in physical and chemical water quality in Copco and Iron Gate Reservoirs from May 2005 to May 2006, and phytoplankton from May 2005 to December 2005. The study incorporated increased spatial (additional sites and depths) and temporal (biweekly) resolution compared to previous reservoir studies.

Both reservoirs thermally stratified during the warm summer months, with the deeper waters (hypolimnion) in both reservoirs exhibiting low levels of dissolved oxygen as well as high concentrations of NH3 and SRP. The upper water column layers (epilimnion) in both reservoirs hosted large blooms of phytoplankton and had elevated pH. Concentrations of TN were consistently lower at KRBI than KRAC for the mid-July through September period, while TP concentration was lower at KRBI for the Mid-July through August period. This is likely due to 1) nutrient storage in the water column (Figs. 30-33) and sediments of the reservoirs, 2) penstock intakes that draw water from intermediate depths where concentrations are lower, and 3) possible atmospheric losses through denitrification (for nitrogen only).

Over the entire study period, Iron Gate and Copco Reservoirs combined retained 11.9% of TP inflow. A majority of that retention occurred in the winter and spring period of high flow when the percent of TP comprised of particulate P was high. During the main reservoir phytoplankton growing season (5/18/2005-10/5/2005) combined TP retention was 3.7%, while for the period encompassing turnover (5/18/2005-12/14/2005) it was 2.4%. This relatively low retention during the growing season period is likely due to a combination of two factors: 1) A high percentage of the incoming phosphorus load was in dissolved form, which is less likely to settle than particulate phosphorus, and 2) in many reservoirs, internal phosphorus loading commonly occurs during the type of low and prolonged dissolved oxygen conditions observed in this study.

Over the entire study period, Iron Gate and Copco Reservoirs combined retained 18.1% of TN inflow. For the main reservoir phytoplankton growing season (5/18/2005-10/5/2005) combined TN retention was 29.8%, while for the period encompassing turnover (5/18/2005-12/14/2005) it was 16.8%. Higher percent retention during summer months may reflect settling of organic matter and algal material, and/or denitrification.

When evaluated over shorter temporal scales (e.g. 14-day sampling periods to several months) the nutrient budgets showed that reservoirs acted as both sources and sinks for nitrogen and phosphorus, but that when compared to a similar analysis using 2002 data (Kann and Asarian 2005) alternating source/sink periods were not as apparent in 2005-2006. Substantial variability in retention occurred within and between seasons. During the algal growing season, TN retention was higher overall than TP retention, and showed more consistently positive retention, while TP oscillated between negative and positive retention. Negative retention values can denote a source from within a reservoir (nitrogen fixation or nutrient release from sediments), while positive retention reflects net losses from the water column resulting from sedimentation or denitrification.

Although periods of net negative retention were not as extreme in the 2005-2006 study compared to

2002, overall net retention accounted for a relatively low (<20%) percentage of inflow on an annual basis (11.9% for TP, and 18.1% for TN). These observed values were generally within the range predicted using models developed from a broad range of lakes and reservoirs that incorporate inflow loading and other hydraulic characteristics.

Phytoplankton showed patterns that varied by site and sampling depth. Iron Gate and Copco Reservoirs hosted large blooms of blue-green algae, including toxigenic (*Microcystis aeruginosa*) and nitrogen-fixing (*Aphanizomenon flos-aquae*, *Anabaena sp.,* and *Gloeotrichia echinulata*) species. These blue-green algae were most concentrated in reservoir sites at upper water column depths, and though concentrations generally declined with increasing depth, they were present throughout the water column and were at times the most abundant taxonomic group even at depths of up to 10m. Similar to previous studies, longitudinal trends show the importance of the reservoirs for providing habitat conducive for growth of blue-green algae (relative to the upstream river, data showed increased blue green algae at surface and intermediate reservoir depths and in the river downstream). Increases in heterocyst abundance and the ratio of heterocysts to vegetative cells in the reservoirs indicate the potential for nitrogen fixation in the reservoirs.

In summary, these results provide an initial assessment of the complex set of interactions between hydrology, loading, and algal dynamics that drive water quality in the Klamath River system.

Recommendations for further study

The sampling program used for this study will continue through fall 2007, and these additional data will provide opportunities for evaluation of inter-annual variability and further insights into the reservoirs' internal dynamics. Recommendations for further study and analysis include:

- Evaluation of retention for the current with-dam condition compared to a potential without-project condition (i.e., retention that would occur in a restored free-flowing river). For example, Asarian and Kann (2006) constructed preliminary mass-balance nutrient budgets for free-flowing river reaches directly downstream of Iron Gate Dam, and found consistent moderate levels of nitrogen retention in the reach immediately downstream of Iron Gate Dam.

- Evaluation of inter-annual differences in hydrology and loading among the various study years, including 2006 and 2007 results, to further understand the differences in retention patterns between the 2002 Kann and Asarian study and the current 2005-2006 study.

- Evaluation of the predicted effect of the observed retention dynamics on downstream water quality. For example, the current study provides information on the percentage of inflow nutrient loads that are retained in the reservoirs, but the effects of this level of retention on downstream nutrient concentrations, biological oxygen demand, nutrient spiraling, periphyton/macrophyte growth, and resulting dissolved oxygen/pH concentrations are largely unknown and merit further study.

- Modeling to predict downstream and in-reservoir concentrations and load under varying residence times and/or inflow loading.

- Increased sampling resolution to decrease uncertainty associated with peaking effects on measured concentration at the Klamath River above Copco sampling station.

- Further studies to understand internal loading, nitrogen fixation and denitrification within the reservoirs. The current study provides information on the combined net effect of these processes, but not on the relative contribution of each. This information would be useful in assessing the likely effectiveness of various proposed management/mitigation actions.

- Collection and analysis of paleolimnological sediment cores (e.g. radioisotope dating) to determine sedimentation rates and nutrient composition of sediments.

5. LITERATURE CITED

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APPENDICES

A1. Temperature, dissolved oxygen, nutrient depth profiles for all sites in Iron Gate and Copco Reservoirs

A2. Assessing and correcting for diel variations in nutrient concentrations in the Klamath River above Copco Reservoir

A3. Table of detailed results of hydrologic and nutrient budgets, summarized by sampling period

APPENDIX A1

Temperature, dissolved oxygen, nutrient depth profiles for all sites in Iron Gate and Copco Reservoirs

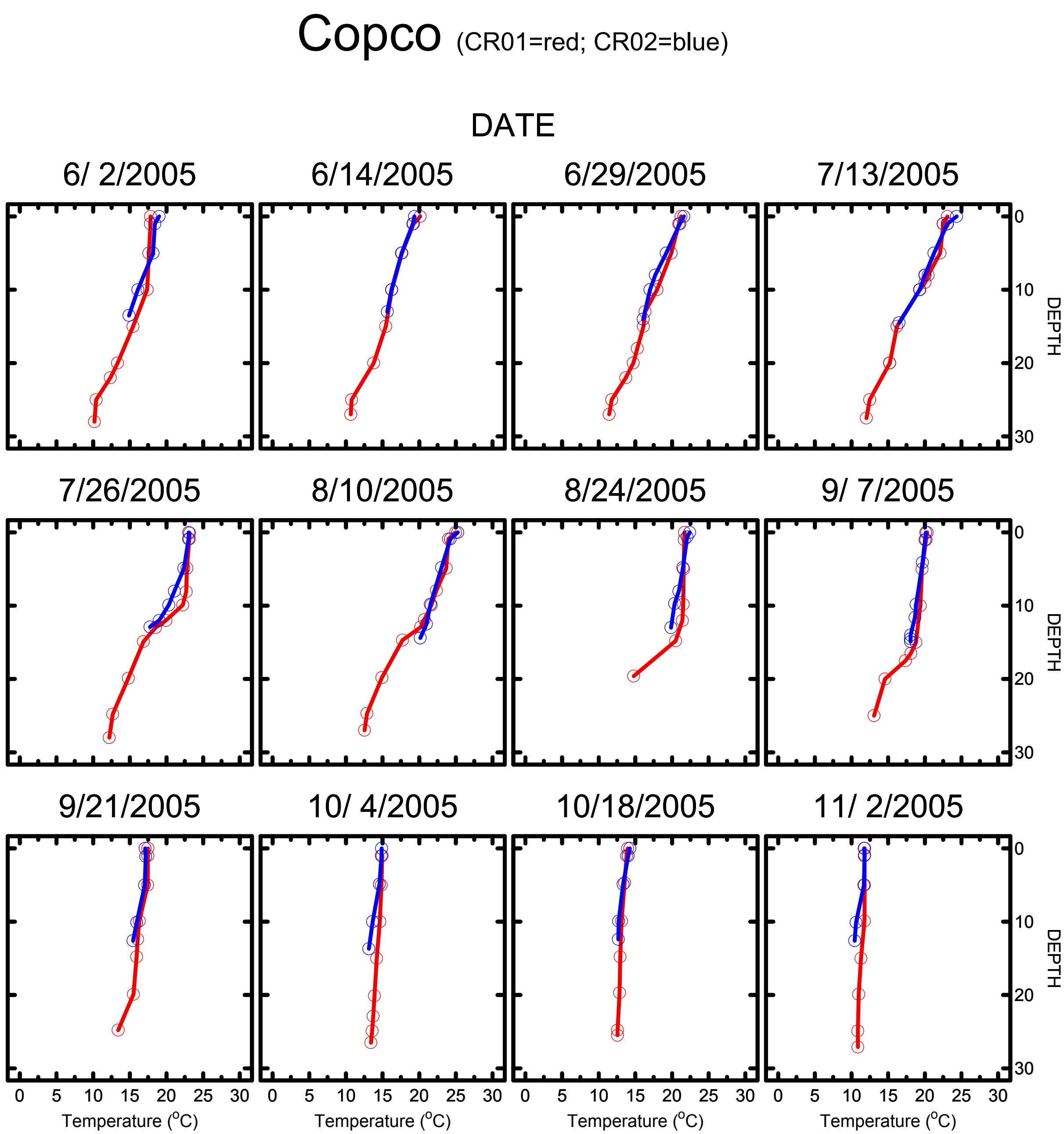

Fig. A1-1. Depth profiles of temperature at Copco Reservoir sites CR01 and CR02, for dates when both sites were sampled.

Copco (CR01=red; CR02=blue)

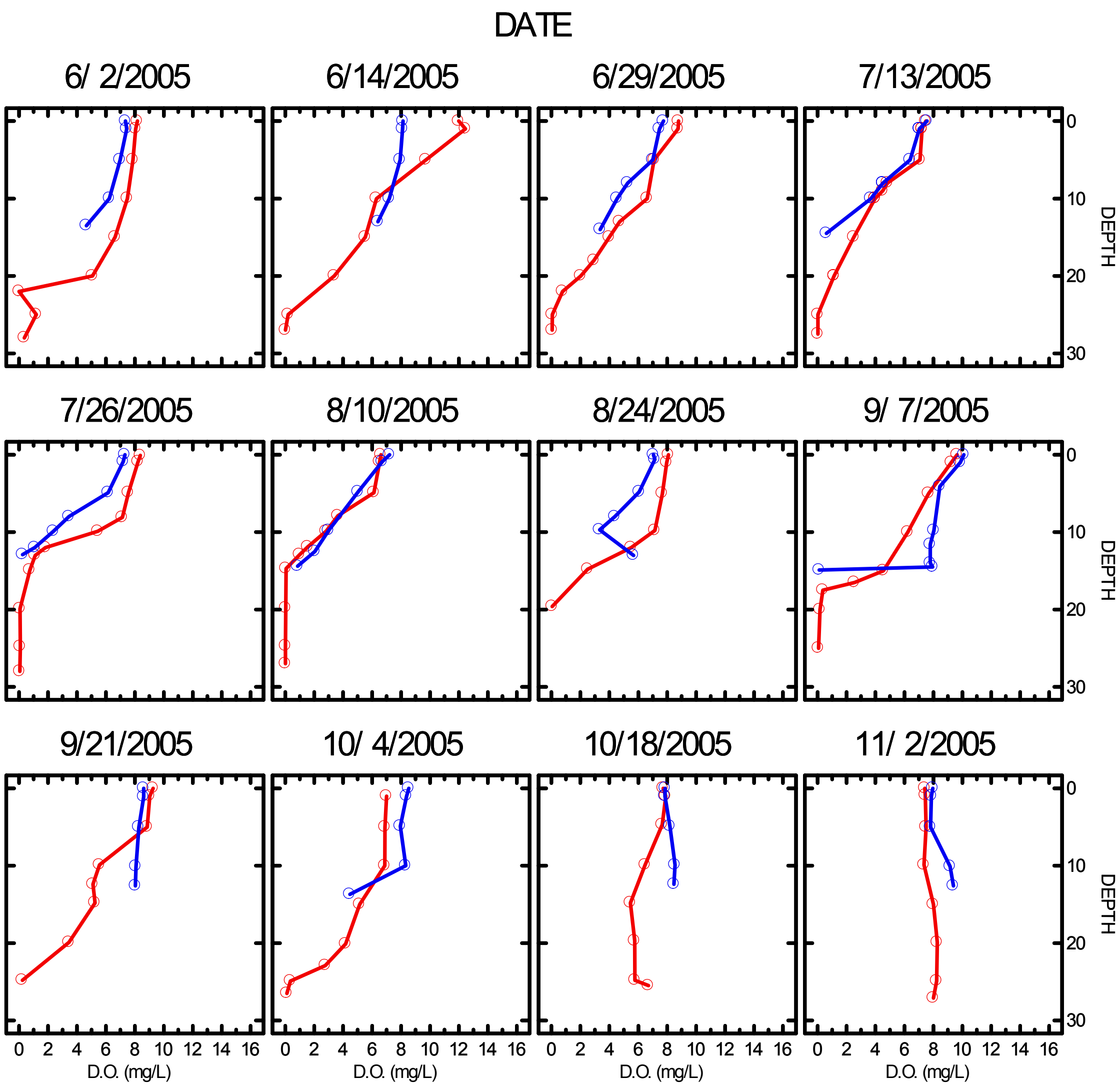

Fig. A1-2. Depth profiles of dissolved oxygen (D.O.) at Copco Reservoir sites CR01 and CR02, for dates when both sites were sampled.

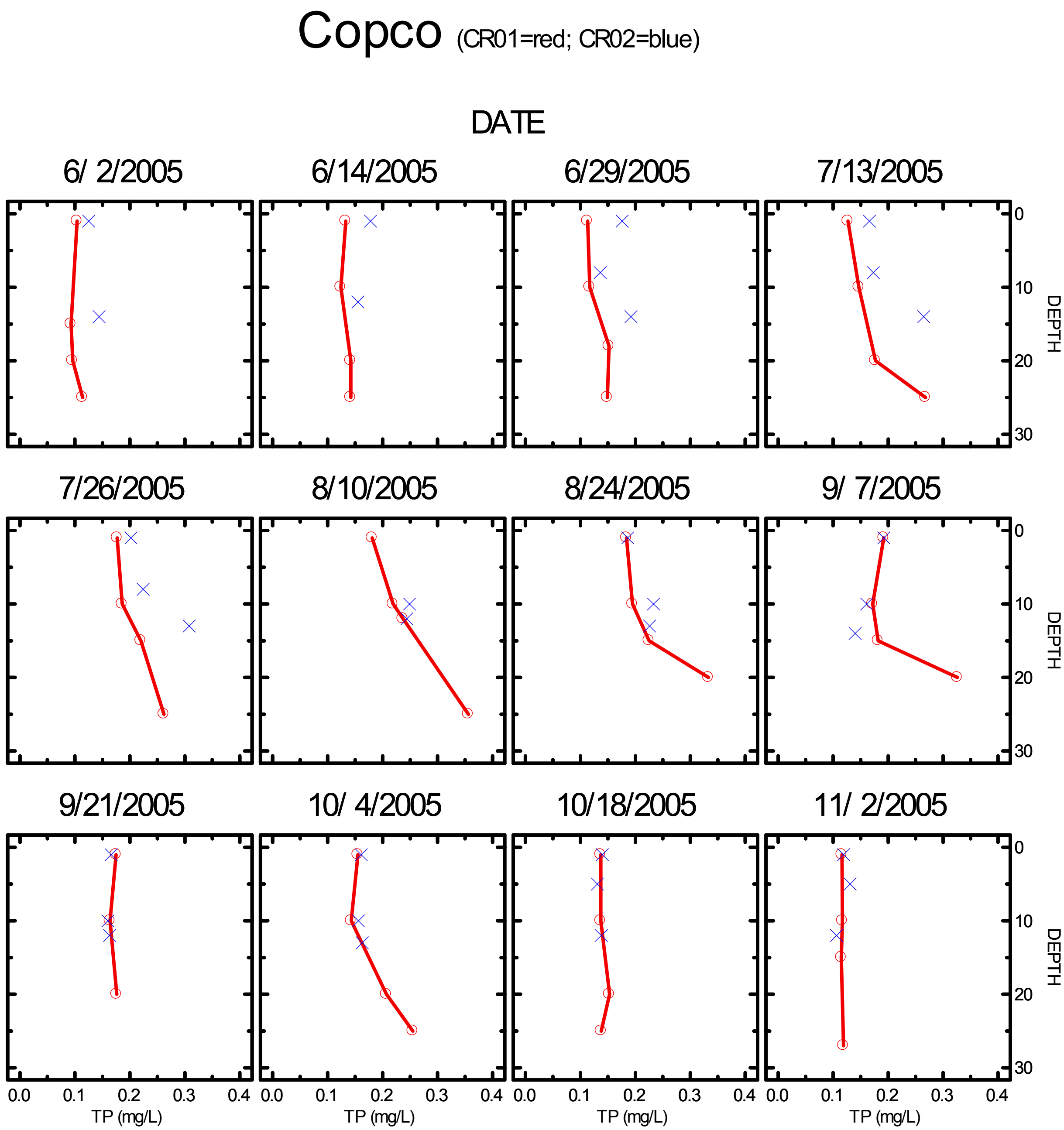

Fig. A1-3. Depth profiles of total phosphorus (TP) at Copco Reservoir sites CR01 and CR02, for dates when both sites were sampled.

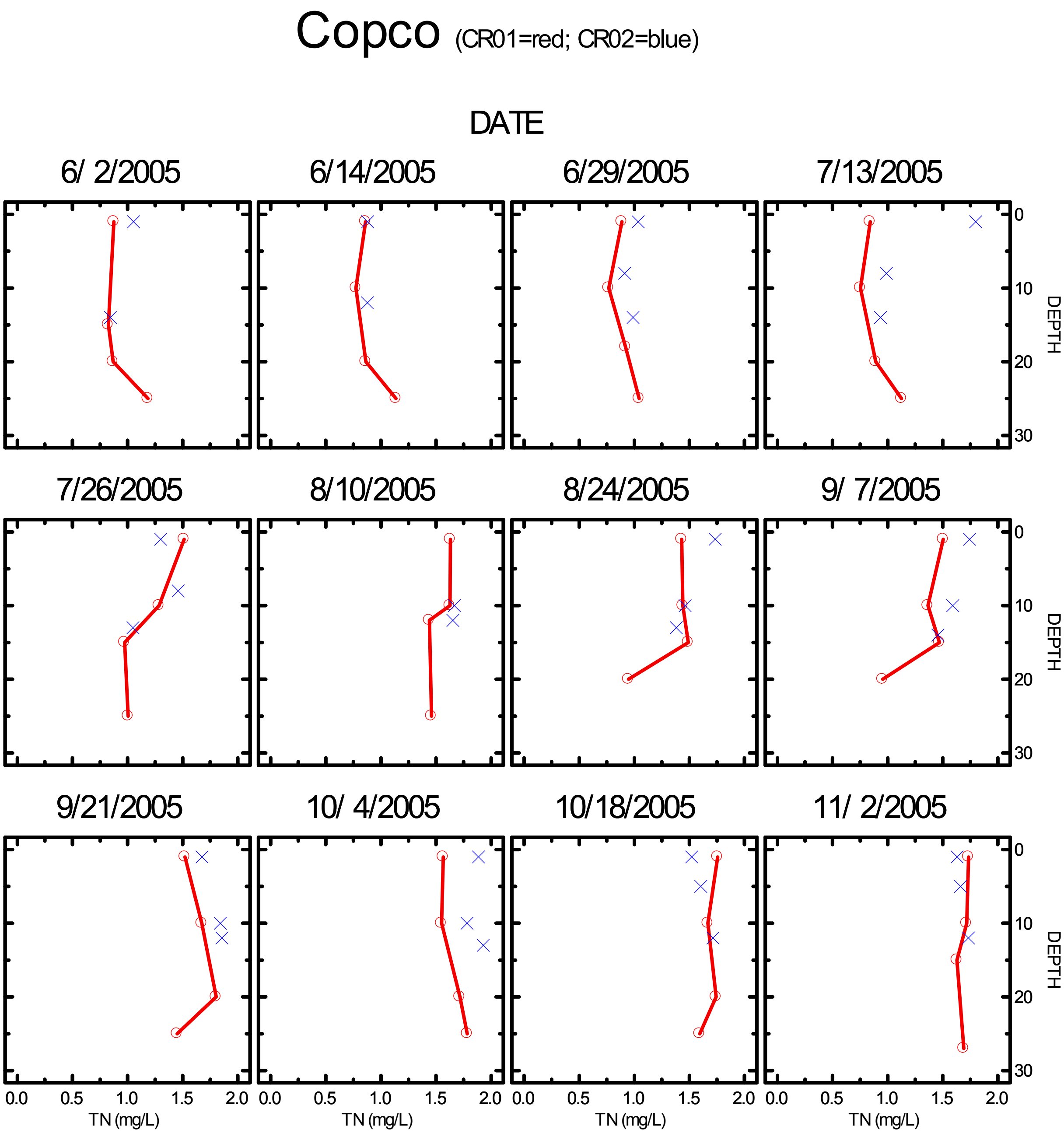

Fig. A1-4. Depth profiles of total nitrogen (TN) at Copco Reservoir sites CR01 and CR02, for dates when both sites were sampled.

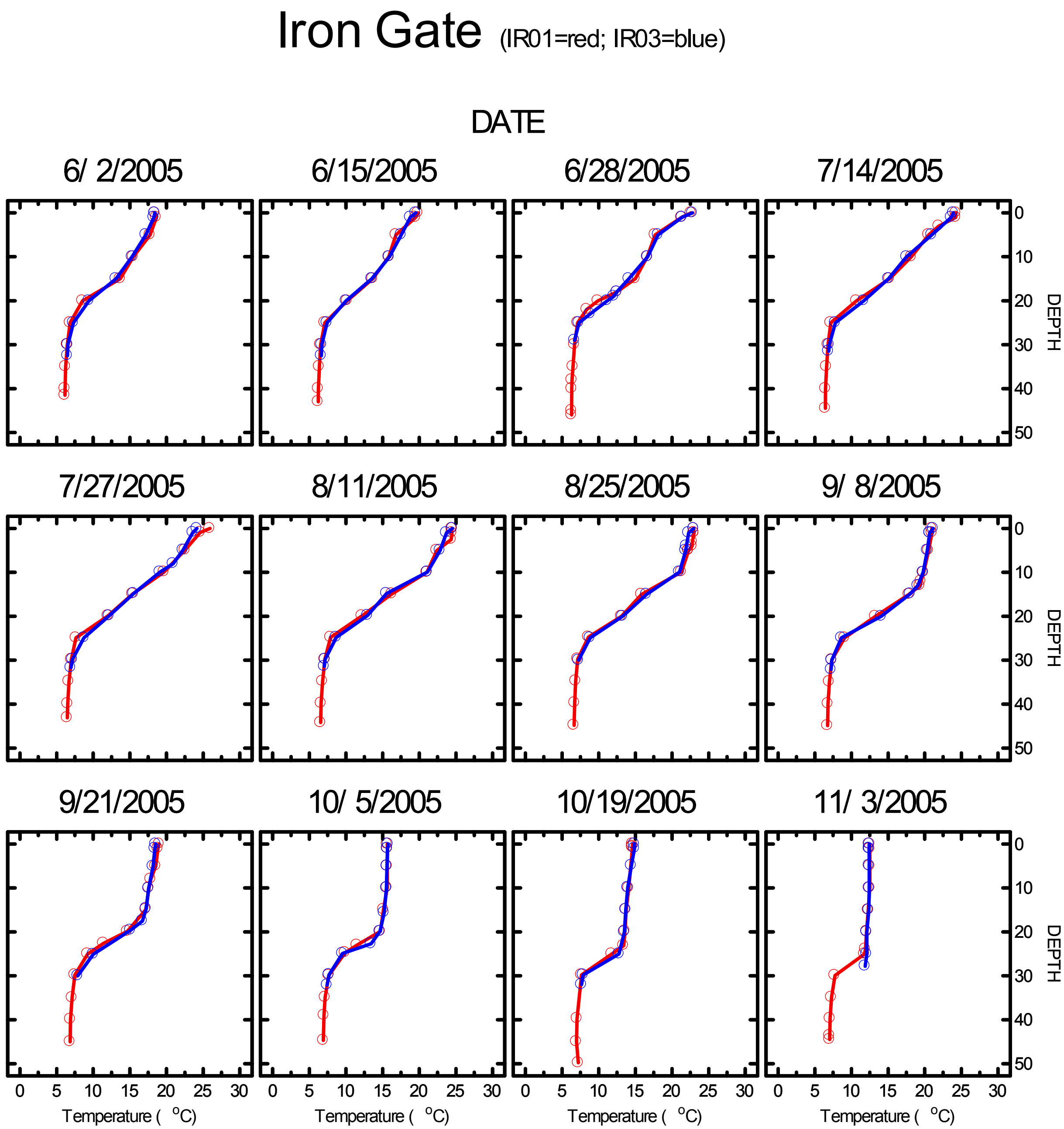

Fig. A1-5. Depth profiles of temperature at Iron Gate Reservoir sites IR01 and IR03, for dates when both sites were sampled.

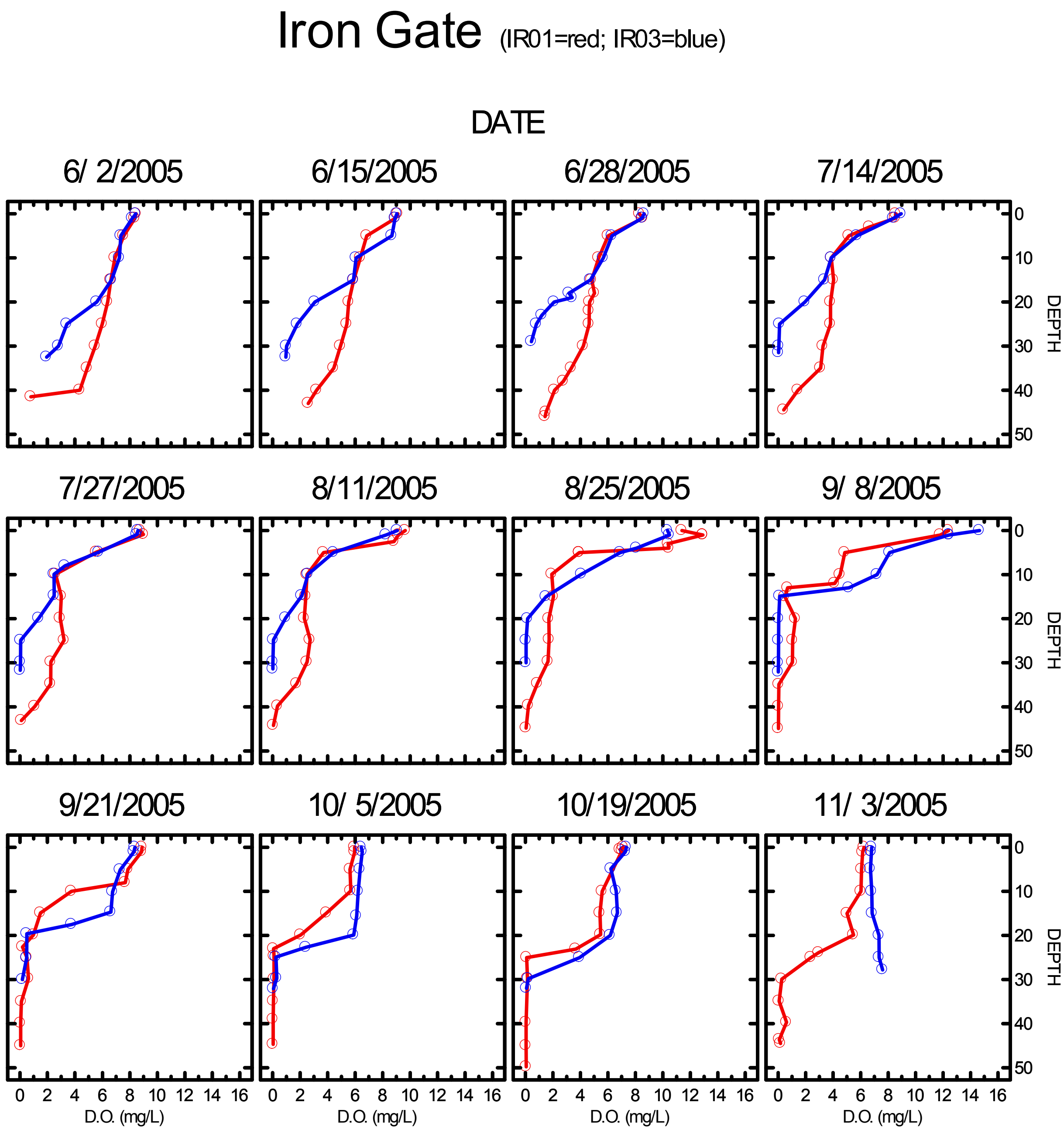

Fig. A1-6. Depth profiles of dissolved oxygen (D.O.) at Iron Gate Reservoir sites IR01 and IR03, for dates when both sites were sampled.

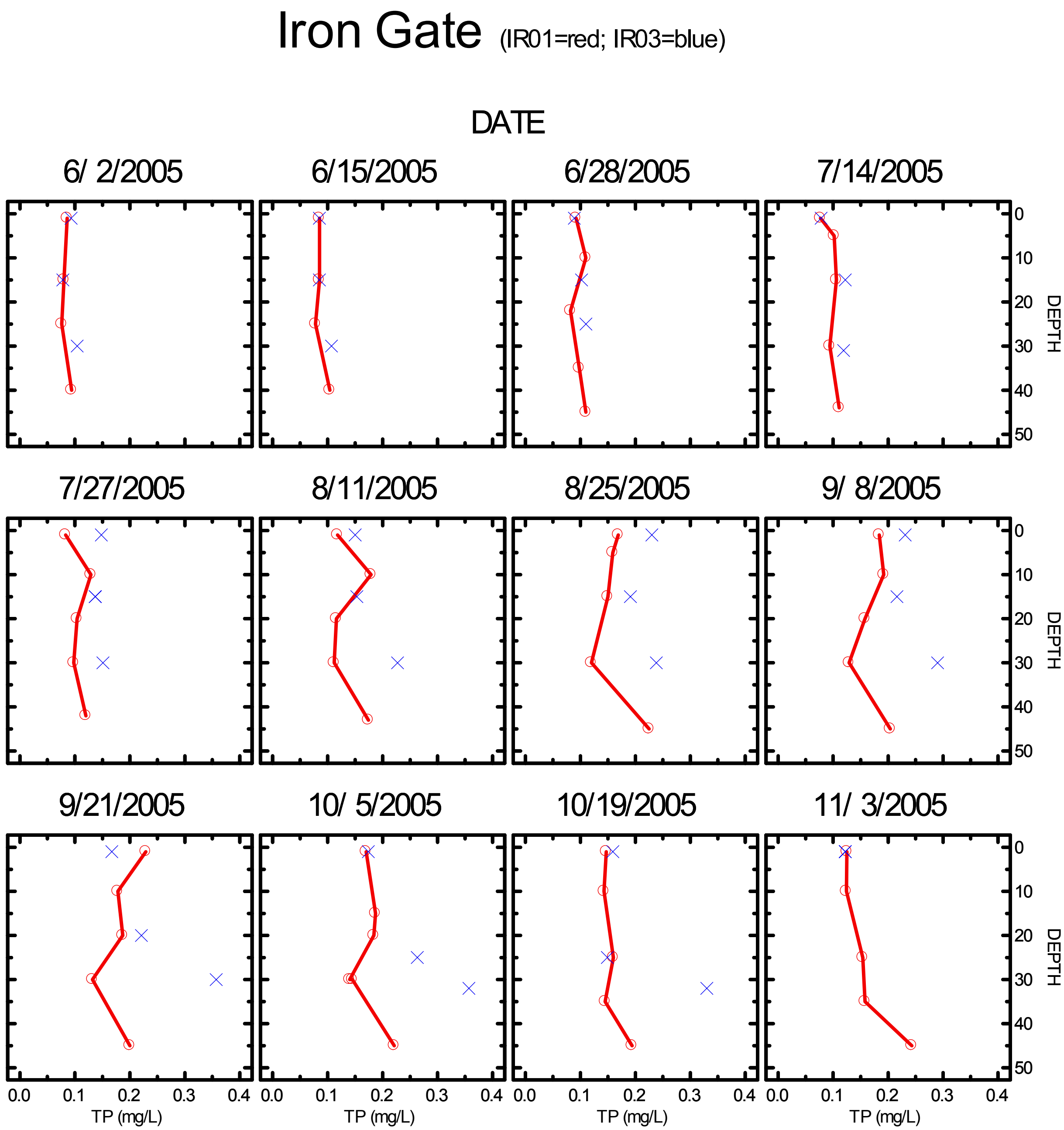

Fig. A1-7. Depth profiles of total phosphorus (TP) at Iron Gate Reservoir sites IR01 and IR03, for dates when both sites were sampled.

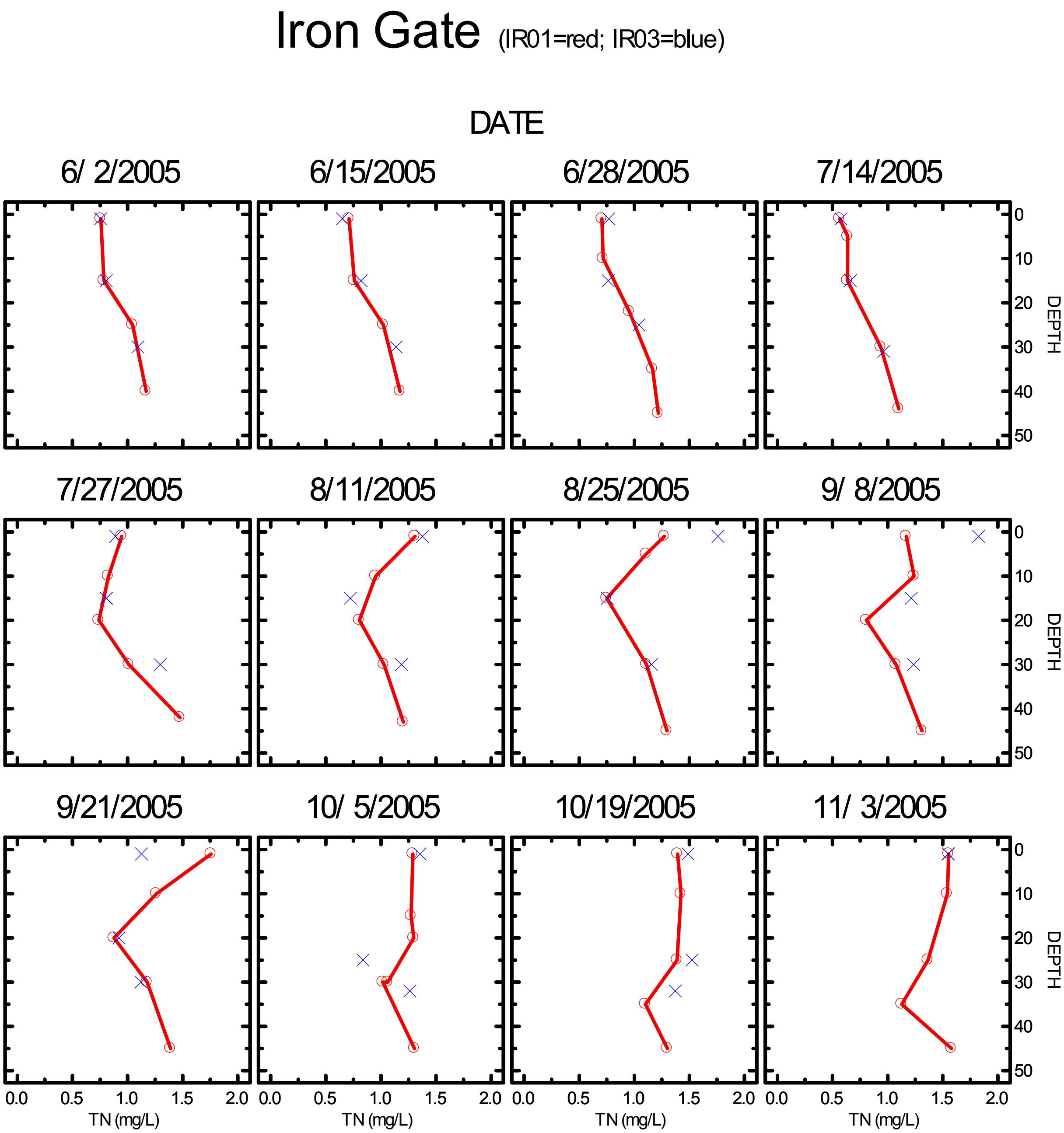

Fig. A1-8. Depth profiles of total nitrogen (TN) at Iron Gate Reservoir sites IR01 and IR03, for dates when both sites were sampled.

APPENDIX A2

Assessing and correcting for diel variations in nutrient concentrations in the Klamath River above Copco Reservoir

Nutrient data collected for stations in the J.C. Boyle Peaking Reach, including the Klamath River above Copco (KRAC) station utilized in this study, are impacted by hydropower peaking operations. For example, during hydropower peaking operations, which typically occur in mid-afternoon, 1500-3000 cubic feet per second (cfs) of water is diverted from J.C. Boyle Dam to a powerhouse 8 miles downstream from the dam (PacifiCorp 2004). Typical releases from J.C. Boyle Dam are approximately 100 cfs, with approximately 225 cfs of spring water entering the river between the dam and the downstream powerhouse where the peaking reach begins. During non-peaking periods, no water is released from the powerhouse, resulting in approximately 325 cfs of water through the peaking reach and below. Therefore, depending on what time of day the samples are taken, the extent of dilution of nutrients by the inflow of spring water into the dewatered river could be greater than that of samples taken when the river is flowing fully. This is a potential source of error in studying the nutrient dynamics of Copco Reservoir because the peaking reach is the input to the reservoir.

Using biweekly nutrient data and daily hydrologic data, this study constructs daily budgets for nitrogen and phosphorus, including the calculation of retention. Ideally for this purpose, the samples collected at KRAC would accurately represent the flow-weighted daily average concentration; however, due to reasons described above, we cannot assume that this is true without first investigating that assumption.

To assess how this hydropower peaking issue could potentially impact the results of this study, we utilized several datasets and approaches, each described in more detail below:

1. Hourly PacifiCorp water quality model outputs between J.C. Boyle Dam and Copco Reservoir for the years 2000-2004.

2. Multiple nutrient samples per day at KRAC during six different days from mid-June though early November 2006 by the Karuk Tribe DNR. [Also PacifiCorp's multiple times per day sampling in 2002].

3. Conductivity data collected with automated probe by the U.S. Fish and Wildlife Service in summer 2002 at several locations between J.C. Boyle Dam and Copco Reservoir.

Before examining those datasets in detail below, we first provide some background information.

First, it should be noted that peaking does not occur on all days. During the study period, peaking occurred nearly every day in May-November 2005, many days in December 2005, and sporadically during other times of year (Fig. A2-1).

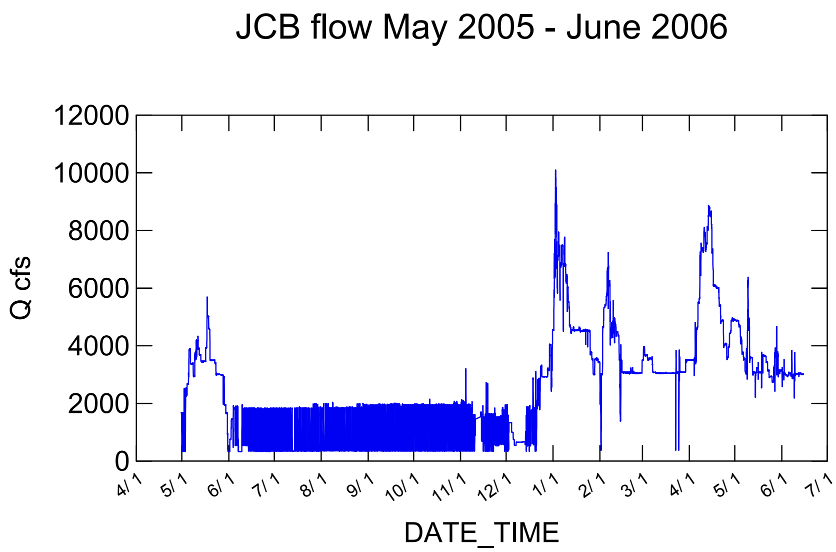

Fig. A2-1. Discharge in the Klamath River at the USGS gage below J.C. Boyle Powerhouse, in cubic feet per second (cfs) for May 2005 – June 2006.

Water from the powerhouse must travel approximately 16 miles downstream to Copco Reservoir, with the travel time varying depending upon the flow magnitude but is approximately 8-12 hours.

To confound this uncertainty regarding travel time, there also may be a lag in nutrient concentrations. That is, because rivers do not behave as perfect plug flow systems, on the descending limb of the hydrograph, nutrient concentrations may fall more slowly than would be expected based on flow alone. Reasons could be that nutrients could become temporarily trapped in eddies and slow waters at channel margins during high flows, then as flow drops, those nutrients could slowly (on the order of hours) spiral downstream.

Concentration should decrease at a slower rate relative to flow on the descending limb of the hydrograph due to effects form the ratio of spring water to powerhouse/dam water. For example, t at high flow (e.g. 1575 cfs), the water at KRAC would be approximately 1350 cfs powerhouse/dam water and only 225 cfs spring water, a 7:1 ratio. At the middle of the descending limb, at 788 cfs, total flow has dropped in half from the peak, with 563 cfs powerhouse/dam water and 225 cfs spring water, a ratio of 2.5:1, but because TN concentrations in the powerhouse/dam water at typically at least 10 times higher than the spring water, there would be very little change in TN concentration. However, as flow gets closer to baseline, concentration should begin to change more rapidly. Also, because TN:TP ratios are much lower (that is, there is relatively more TP) in the spring water than in powerhouse/dam water, daily peaking-caused fluctuation in concentrations should be less for TP than for TN.

A useful metric, referred to often below, for assessing sample timing is the number of hours since flow at the powerhouse returned to baseline (non-peaking). During days affecting by hydropower peaking, most 2005 nutrient samples were collected between 7 and 11 hours after flow returned to baseline at J.C. Boyle (Fig. A2-2), which is in the middle of the descending limb.

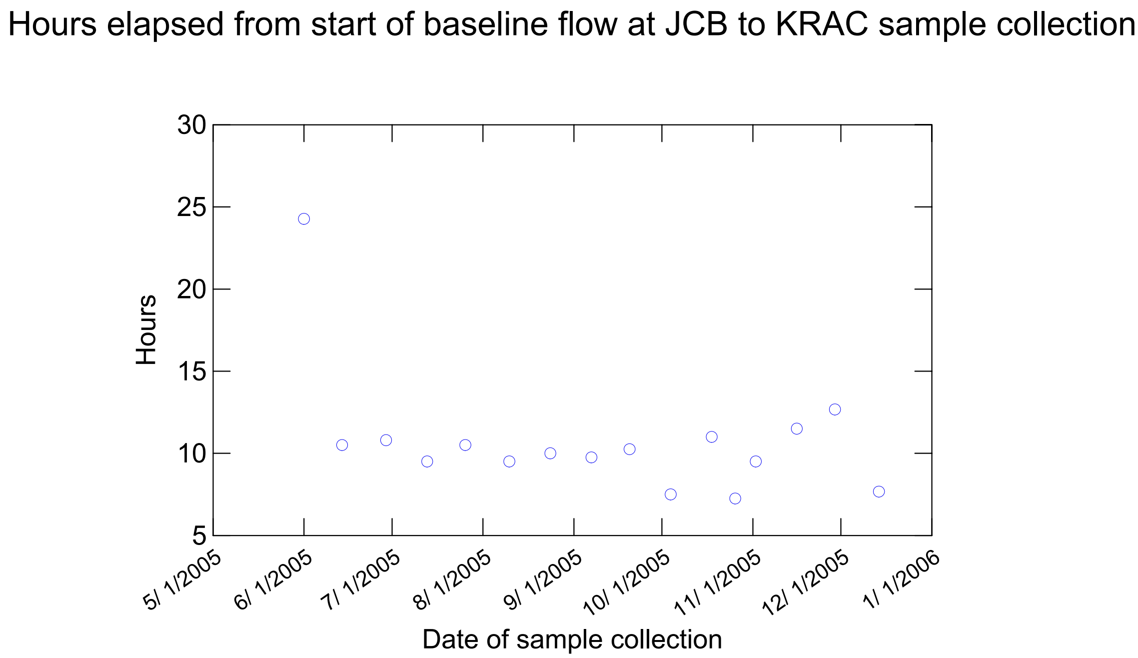

Fig. A2-2. Timing of nutrient sample collection during the 2005 peaking season.

Hourly PacifiCorp water quality model outputs between J.C. Boyle Dam and Copco Reservoir for the years 2000-2004.

Examining outputs from PacifiCorp's water quality model provides a good overview of how peaking flows move through the J.C. Boyle Bypass Reach (Fig. A2-3). As the flood wave moves from the J.C. Boyle Powerhouse, it widens and attenuates. PacifiCorp's water quality model generally predicts flow more accurately than it does for other parameters such as nutrients and algae (Wells et al. 2004), due to the lack of a flow gage above Copco Reservoir for calibration and discrepancies between the USGS gage and the outputs (as described below), it is unknown whether the model predicts the timing and magnitude of flow accurately enough to be relied upon for determining the precise part of the hydrograph in which the 2005-2006 nutrient samples were collected.

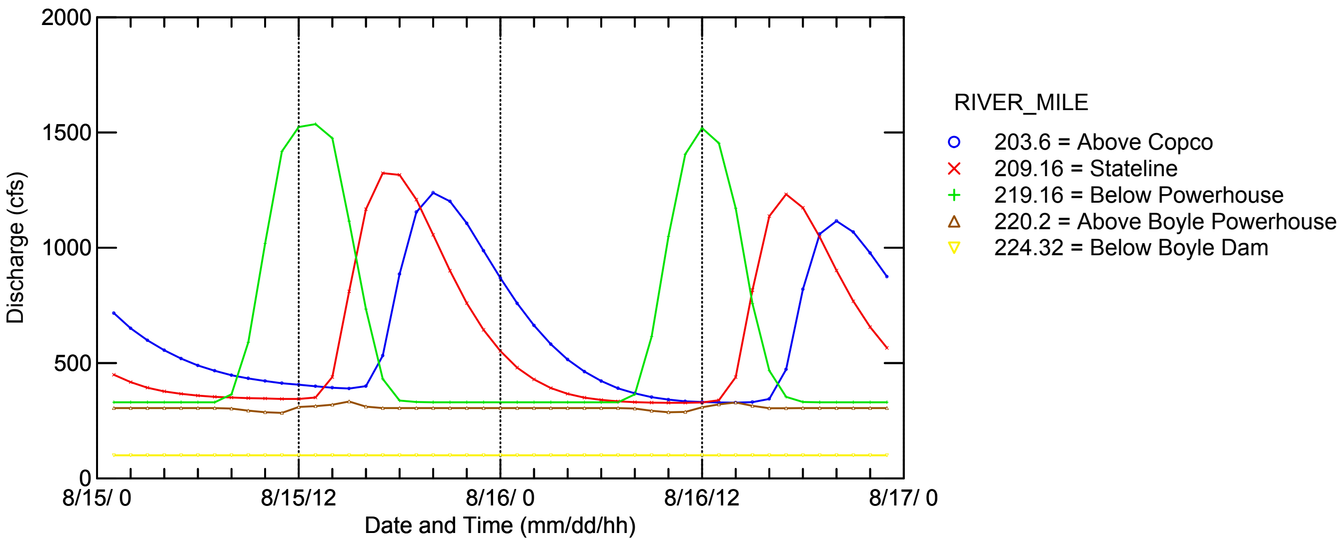

Fig. A2-3. Hourly discharge during one-turbine (1500 cfs) peaking in the Klamath River between J.C. Boyle Dam and Copco Reservoir in mid-August 2004. Data are outputs from PacifiCorp water quality model. Below the powerhouse, the ramping up begins around 0800 hours, peaks at 1200-1300, ramped down by 1800. At the stations downstream, the peak is reduced and the hydrograph widens. It takes approximately 8 hours for the peak to reach Copco Reservoir downstream. The first signs of ramping up appear at Copco about 8 hours after ramping begins at the powerhouse. Flow returns to baseline 12-14 hours later at Copco than at Boyle. The baseline flow period at Copco runs about 6 hours from 1000-1600.

Comparison of the predicted versus observed flow at the J.C. Boyle Powerhouse (Figs. A2-4 and A2-5) indicates some substantial differences in both timing and magnitude that call into question how accurately the model estimate hourly flows above Copco Reservoir. The model outputs matched the magnitude and timing of the USGS gage on some days (Fig. A2-4), but on other days timing was offset by as much as 4 hours and magnitudes differed by up to 100 cfs (Fig. A2-5). If flow predictions are off at J.C. Boyle USGS flow gage, it seems likely that they would also be off downstream.

The primary technique used by PacifiCorp to calibrate flow in its water quality model for reaches below dams was an iterative process in which predicted and observed diurnal patterns in water temperature were compared, and then bed roughness and slope coefficients were adjusted so that predicted and observed diurnal phase of temperature fluctuations matched (see Appendix G in PaciCorp 2005b for details). If the timing of flows was off at the J.C. Boyle gage (see discussions above) during model calibration days (this is unknown), it is seems unlikely that the model could be adequately calibrated using downstream temperature data. In addition, daily peaking cycles could make this calibration technique more difficult to apply in the Peaking Reach than a reach with static dam releases such as Iron Gate.

A small part of the difference in timing could be explained by the slight difference in the locations of the USGS gage and the model output location. The J.C. Boyle powerhouse return is located at node 97 of the Fullflow Reach (PacifiCorp 2005b), and the first reporting station below the powerhouse is node 103. Node spacing is 75 meters (PacifiCorp 2005b), so node 103 is approximately 0.28 miles (6 nodes*75m=450m=0.28mi) below the J.C. Boyle Powerhouse. The USGS gage is located approximately 0.7 miles below the Powerhouse, approximately 0.4 miles below node 103. With travel times of 8-16 hours for the 16 mile reach, these 0.4 miles should have a travel time of approximately 0.4 to 0.2 hours. Additionally, the PacifiCorp model runs at an hourly timestep, whereas the USGS gage reports data every 30 minutes. The hourly timestep appears to result in hydrographs at the J.C. Boyle gage that are more rounded (smoother transitions) than the observed in the half-hour USGS data (Figs. A2-4 and A2-5).

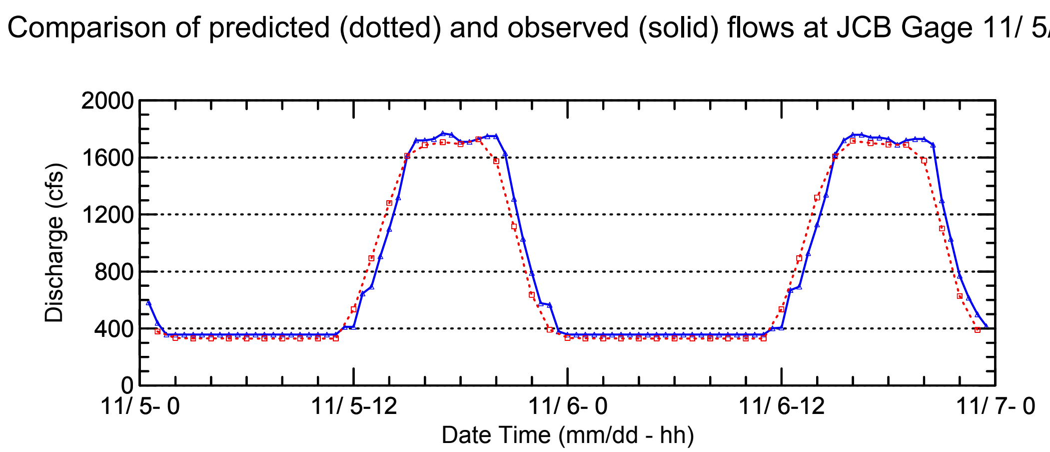

Fig. A2-4. Comparison of predicted (PacifiCorp model) and observed (USGS data) discharge in the Klamath River below J.C. Boyle Powerhouse for a two-day period in early November 2002. Note: the USGS gage is located approximately 0.4 miles below node 103, the closest model reporting station. This time period illustrates a good case for the match.

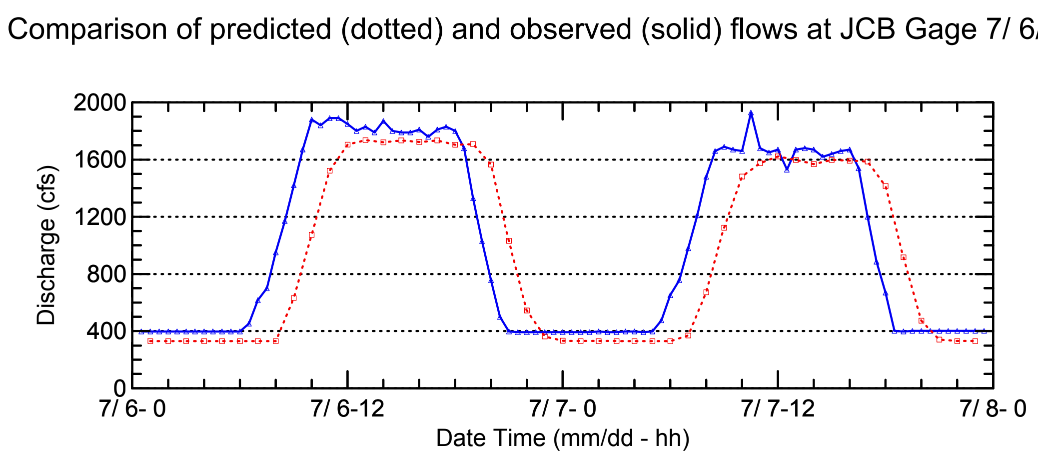

Fig. A2-5. Comparison of predicted (PacifiCorp model) and observed (USGS data) discharge in the Klamath River below J.C. Boyle Powerhouse for a two-day period in early July 2002. Note: the USGS gage is located approximately 0.4 miles below node 103, the closest model reporting station. This time period illustrates a bad (though not worse) case scenario for the match.

Despite apparent differences between the model outputs and the USGS gage, it is the only currently available estimate of discharge near the Klamath River above Copco sampling station utilized in this study, and thus provides potentially useful information regarding the how the timing of sample collected could affect the results of the study.

A comparison of the model's predictions for flow, TN, and TP (Fig. A2-6) shows that the model predicts that concentrations remain high for many hours into the descending limb of the hydrograph, not reaching their minimum for hours after the flow has returned to baseline. However, given that the model also shows some counter-intuitive patterns (that appear to be incorrect), such as that TN and TP concentrations do not rise (or rise slowly) with arrival of the start of the peaking hydrograph, it is unknown how accurate the model's prediction of the decrease in concentration at the end of the hydrograph is. Measured data show that specific conductance immediately spikes to a peak with the arrival of the first signs of peaking (beginning of ascending limb), remains high into well into the descending limb, and then tapers off relatively quickly over a period of about 4 hours. The conductance data are discussed in more detail below.

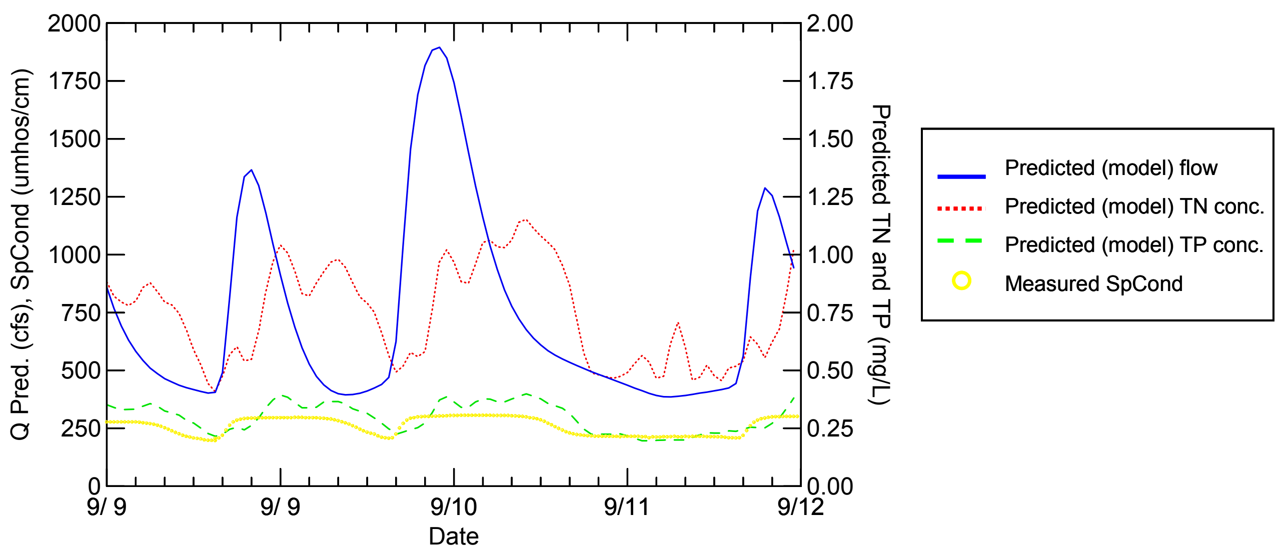

Fig. A2-6. Predicted flow, TN, TP from the PacifiCorp model, and specific conductance measured by the USFWS, in the Klamath River above Copco Reservoir September, 2002.

Multiple nutrient samples per day at KRAC during six different days from mid-June though early November 2006 by the Karuk Tribe DNR

The Karuk Tribe continued to collect data at the same locations until November 2006. On six occasions from June until early November, three or more samples were collected per day at KRAC (Figs. A2-7 through A2-12).

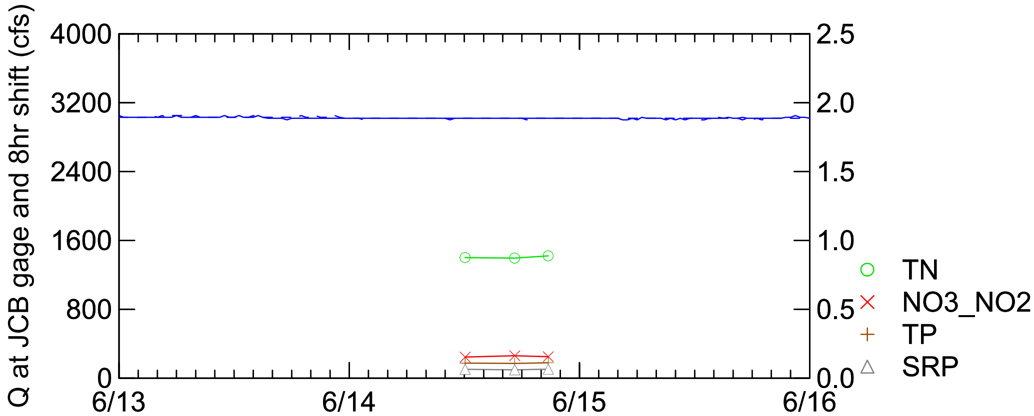

Fig. A2-7. Results of multiple nutrient samples per day at KRAC, June 14 2006. Solid blue line is discharge in cfs at USGS gage below J.C. Boyle Powerhouse. Dotted blue line is that discharge lagged 8 hours, the approximate amount of time it takes for the first signs of peaking to arrive at KRAC. Note that transit time is slower at lower flows, so this dotted line is only useful for knowing the flow at KRAC relative to start of the ascending limb, it does not provide information about the descending limb of the hydrograph.

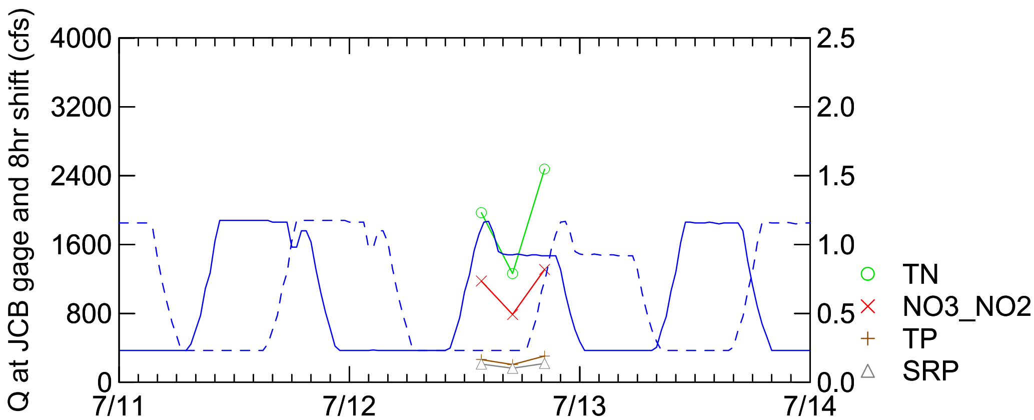

Fig. A2-8. Results of multiple nutrient samples per day at KRAC, July 12, 2006. See other captions for details.

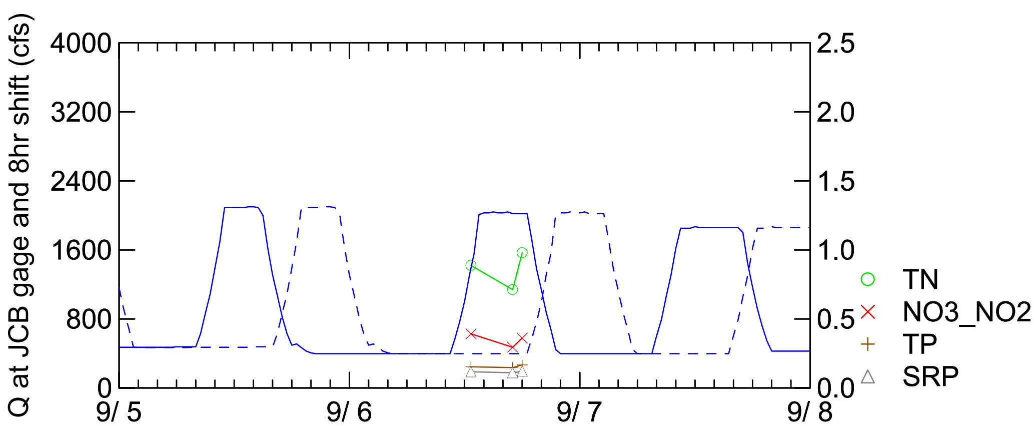

Fig. A2-9. Results of multiple nutrient samples per day at KRAC, September 6, 2006. See other captions for details.

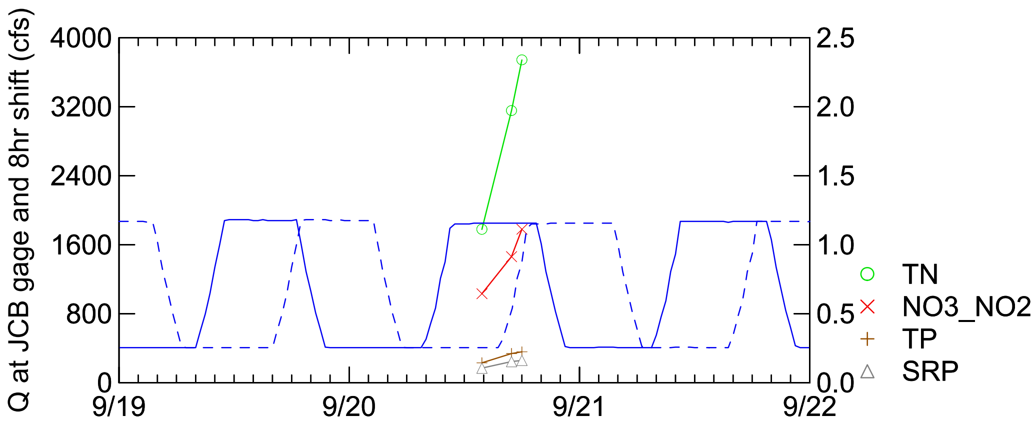

Fig. A2-10. Results of multiple nutrient samples per day at KRAC, September 22, 2006. See other captions for details.

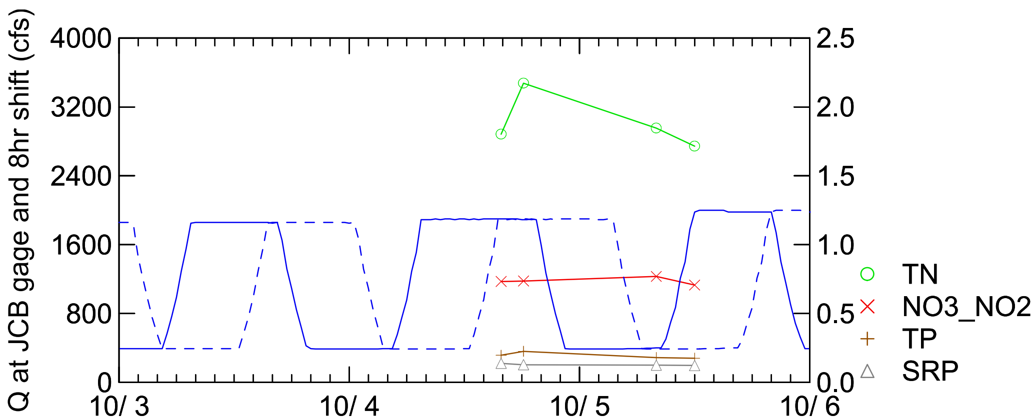

Fig. A2-11. Results of multiple nutrient samples per day at KRAC, October 4-5, 2006. See other captions for details.

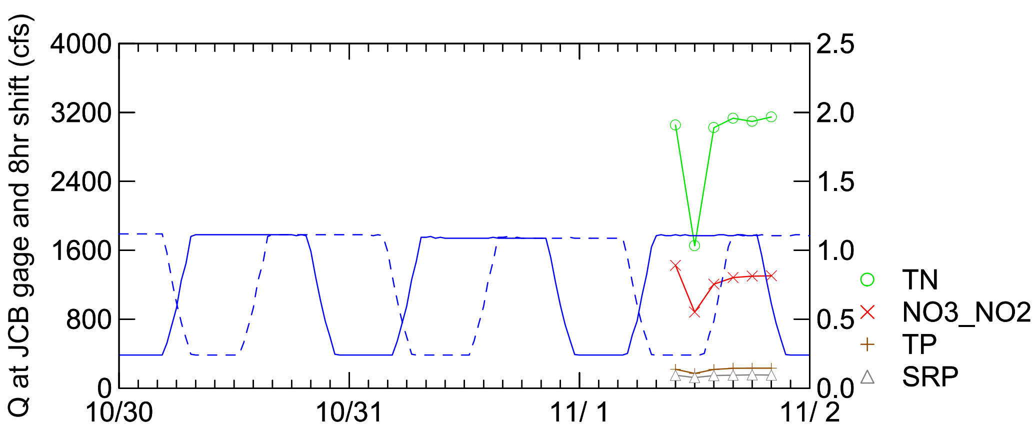

Fig. A2-12. Results of multiple nutrient samples per day at KRAC, November 1, 2006. See other captions for details.

The June 14 samples were collected prior to the start of peaking season (Fig. A2-7), leaving five sets of samples with which to analyze the effects of peaking. The samples were collected at various points of the daily hydrograph. Samples on July 12, September 22, and November 1 appear to capture both the highest and lowest concentrations of the day (Figs. A2-8,A2-10,A2-12). On September 6, all three samples were clustered around the trough of the hydrograph (just before, at, and just after), resulting in only low and moderate concentrations being sampled, but not high concentrations (Fig. A2-9). On October 4 and 5, only moderate and high concentrations were sampled (Fig. A2-11).

Water arriving at KRAC is composed of water released from J.C. Boyle Dam, water from the J.C. Boyle Powerhouse, and water from the springs in the J.C. Boyle Bypass Reach. Using a combination of measured concentrations at KRAC, assumed concentrations at the springs, assumed discharge for the springs, and measured discharge at the JCB gage, we utilized the solution mixing formula:

$$C_1Q_1 + Q_2V_2 = C_3Q_3$$

Where: C_1 = concentration of springs, C_2 =concentration of JC Boyle Dam release water (dam spillway and powerhouse assumed equivalent), and C_3 is concentration at KRAC. Similarly, Q_1 = discharge of springs, Q_2 = discharge of JC Boyle Dam release water (dam releases and powerhouse combined), and Q_3 is discharge at KRAC.

For the purposes of these calculations, the TN concentrations of the springs in the J.C. Boyle Bypass reach were assumed to be 0.15 mg/L, the same concentration used by PacifiCorp (2005b) in its water quality model. The TP concentration of those springs was assumed to be 0.08 mg/L, the value being used in the Mainstem Klamath River TMDL water quality model (the 0.15 mg/L value used by PacifiCorp sometimes resulted in negative values for river concentrations). The discharge from the springs was assumed to be a constant 225 cfs.

For July 12, September 20, and November 1, 2006, the days for maximum KRAC concentration was known, the mixing equation was applied for two situations: daily maximum flow and concentration (solving for JCB powerhouse/dam concentration), and daily average flow and concentration (solving for KRAC daily average concentration). For details, see footnote[10].

We then divided the observed concentrations for each sample by the calculated daily flow-weighted averages. That percent was then plotted against the number of hours that had elapsed since flow returned to baseline at JC Boyle, a measure of a sample's position along the descending limb of the hydrograph (Figs. A2-13 and A2-14). While there are only nine data points and substantial scatter,

[10] For each day in which maximum KRAC concentration was known (from the samples described above), we used the daily maximum discharge observed at J.C. Boyle gage, and re-arranged the mixing formula to solve for the J.C. Boyle powerhouse/dam concentration. The shape of the hydrograph certainly changes shape as the water flows downstream from the JCB gage to KRAC, but the daily average flow and daily average flow-weighted concentration can reasonably be assumed to be identical, because it is the same water. Thus, the JCB powerhouse/dam concentration was then used in conjunction with the daily average JCB gage flow to derive a daily flow-weighted average concentration for KRAC using the mixing equation (same as JCB gage).

the results do provide an indication that most 2005 samples were collected at times (less than 12 hours since flows returned to baseline at JCB gage, see Fig. A2-2.) that represent the approximate daily flow flow-weighted average (sample TN = ~100% of daily flow-weighted mean in Fig. A2-13 and TP=~100% in Fig. A2-14).

The two descending limb samples from September 4 were also added to Figs. A2-13 and A2-14 using a slightly different method, because the maximum KRAC concentration on that day was not measured. The minimum KRAC concentration was used to calculate the JCB powerhouse/dam concentration, then that was used to calculate the flow-weighted average for KRAC. Then the two descending limb samples from that day were then expressed as a percent of the daily flow-weighted average and added to the graph.

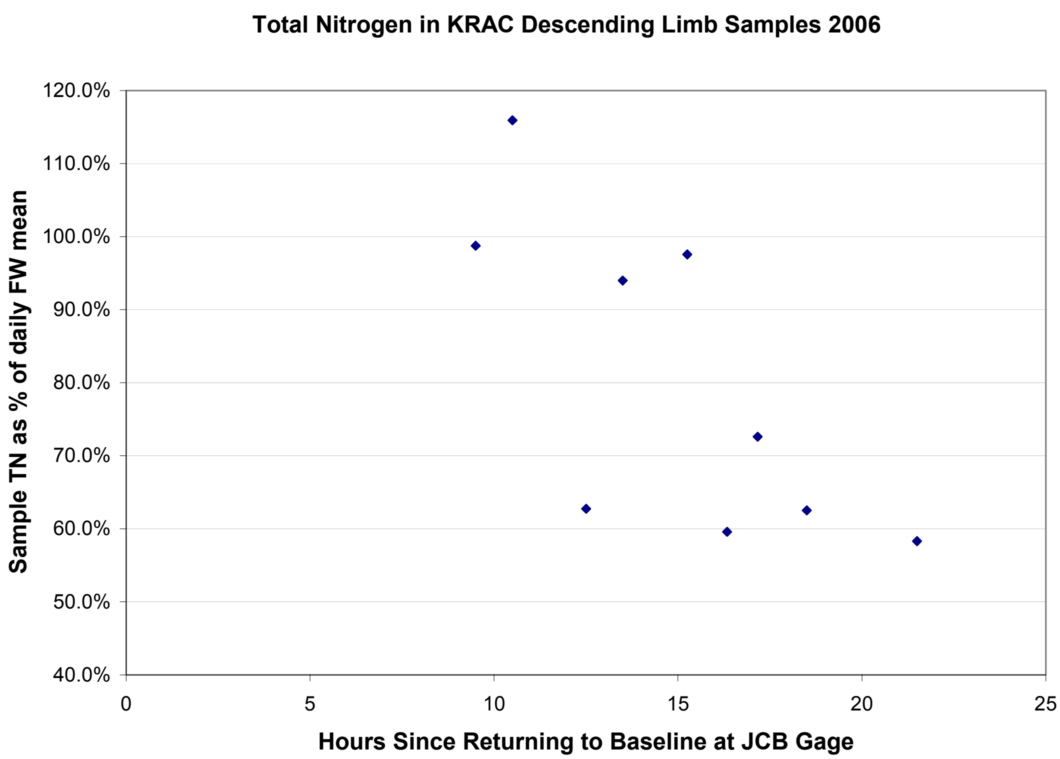

Fig. A2-13. Total nitrogen as a percent of estimated daily flow-weighted average, for samples collected on the descending limb of the peaking hydrograph in the Klamath River above Copco Reservoir (KRAC).

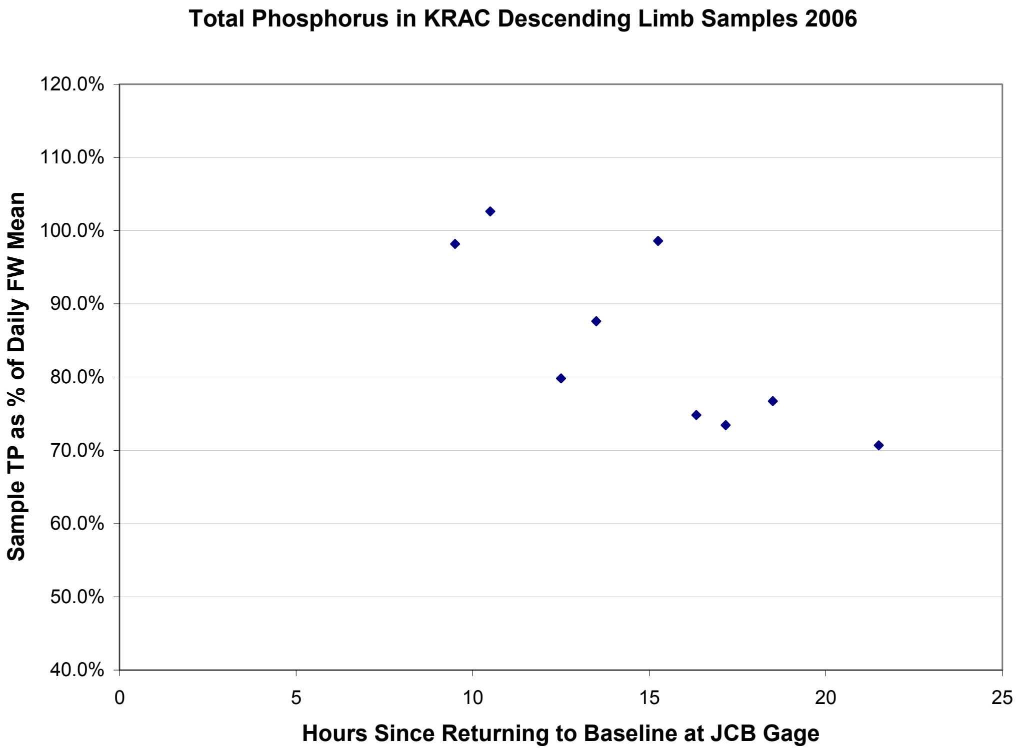

Fig. A12-14. Total phosphorus as a percent of estimated daily flow-weighted average, for samples collected on the descending limb of the peaking hydrograph in the Klamath River above Copco Reservoir (KRAC).

Conductivity data collected by the U.S. Fish and Wildlife Service in summer 2002

The U.S. Fish and Wildlife Service (USFWS) deployed automated multi-parameter water quality probes at several locations between J.C. Boyle Dam and Copco Reservoir in summer 2002. The USFWS dataset shows substantially differences in specific conductivity between water at the bottom of the JCB Bypass Reach and the water coming from the JCB Powerhouse. Specific conductance is a useful tool for gaging the concentration of total dissolved solids (Droste et al. 1997). Although nitrogen and phosphorus account for only a small amount of the total dissolved solids in Klamath River water, specific conductivity is a useful tool for determining the sources of water observed in the JCB Peaking reach at any given point in time.

Specific conductance data for the Klamath River below Shovel Creek in summer 2002 show that conductance remains at daily maximum levels through 10 hours (since return to baseline at JCB gage), and remained near maximum through 13 hours in September samples and 15 hours in August samples (A2-15).

It should be noted that the daily fluctuations in specific conductance are less than the daily fluctuations in TN and TP. Thus, the steepness of the decreasing specific conductance is not directly applicable to TN and TP; however it does provide evidence with a higher spatial resolution to support the trends described above regarding how TN and TP concentrations are affected by peaking.

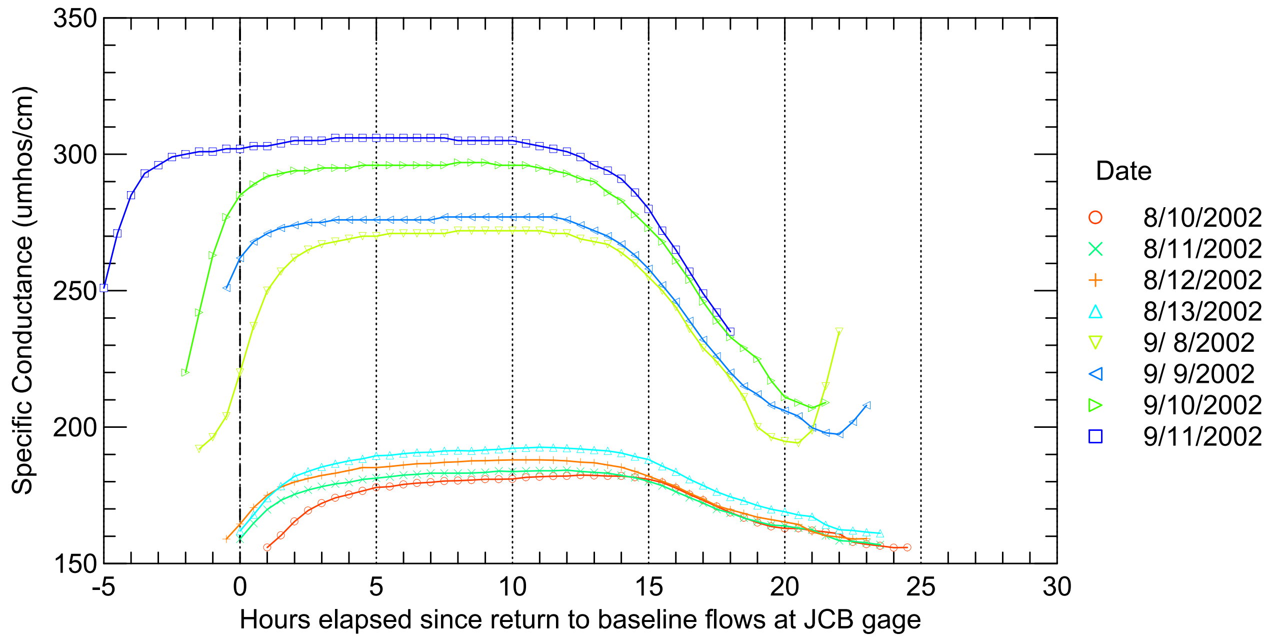

Fig. A2-15. Specific conductance (in units of µmho/cm) of water in the Klamath River below Shovel Creek, a short distance downstream from the KRAC sampling station, for a selection of days in summer 2002. Data were collected by the USFWS using an automated multiparameter water quality probe.

Conclusions and actions

Based on the information presented above, we conclude that all 2005 samples collected at KRAC during days affected by hydropower peaking, with the exception of the June 1 sample describe below, represent a concentration similar enough to the flow-weighted that no correction is necessary.

To gage the potential effect of how diel variation in KRAC concentration could affect final nutrient budget results, we conducted a sensitivity analysis in which we compared retention calculated using KRAC concentrations equal to 90% and 110% of measured KRAC concentrations (see section 3.4.4 for details).

Another issue that needed to be addressed was that flows preceding the June 1, 2005 sample were abnormal. Peaking had not occurred in many months, but began soon after. Prior to the sample, the river being held at low-flow (no releases from the JCB powerhouse) for over 24 hours (Fig. A2-16). This should have allowed ample time for all powerhouse water to move through the system past KRAC. Thus, while that sample accurately represented conditions on that day (bypass flow), it did not represent conditions on the surrounding days, which were transitioning from constant high flows to peaking flows. Thus TN and TP samples were corrected by applying the mixing equation describe above. First, the mixing equation was applied using June 1 daily average flow and the measured concentration to derive the JCB powerhouse/dam TN and TP concentrations. Those concentrations were then applied to the mixing equation using a 14-day average of flow (the length of the sampling interval) to derived a new TN and TP concentration for KRAC. In this fashion, TP concentration was increased from 0.09 to 0.107 mg/L and TN was increased from 0.582 to 1.314 mg/L.

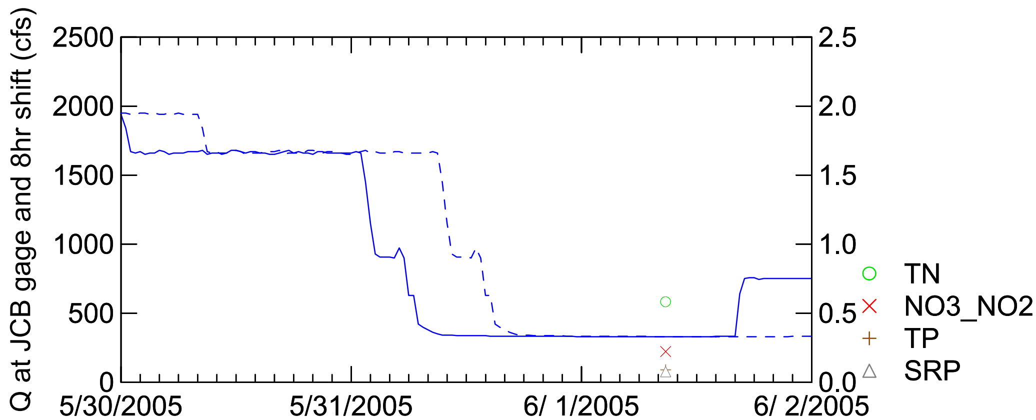

Fig. A2-16. Timing of sample collection for June 1, 2005 sample at KRAC. Solid blue line is discharge in cfs at USGS gage below J.C. Boyle Powerhouse. Dotted blue line is that discharge lagged 8 hours, the approximate amount of time it takes for the first signs of peaking to arrive at KRAC.

APPENDIX A3

Table A3-1. Flow and nutrient mass-balance for Copco Reservoir, May 2005 - May 2006, summarized by sampling interval.

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	Metric Tons TN	% TP	% TN	CONC. mg/L TP	mg/L TN
Entire Study 5/18/2005 - 5/11/2006	359	Klamath abv. Copco	2110	2603033	2403	96.1	307.8	3332.8	98.5	99.4	0.146	1.579
		Shovel Creek	83	102633	95	3.8	4.6	15.0	1.5	0.4	0.055	0.181
		Trib. inflow	2194	2705666	2497	99.9	312.4	3347.9	100.0	99.9	0.142	1.526
		Precipitation	2	2446	2	0.1	0.1	4.1	0.0	0.1		
		Total inflow	2196	2708112	2500	100.0	312.4	3352.0	100.0	100.0	0.142	1.527
		Evaporation	4	4798	4							
		Net inflow	2199	2712909	2504		312.4	3352.0				
		Copco outflow	2173	2679840	2474		281.6	3054.6			0.130	1.406
		Change storage	0	-150	0		1.5	-1.6				
		Retention					29.3	305.4	9.4	9.1		
Interval 1 5/18/2005 - 6/ 2/2005	16	Klamath abv. Copco	106	130188	2696	96.6	11.4	116.7	98.6	99.4	0.108	1.105
		Shovel Creek	4	4434	92	3.3	0.2	0.5	1.4	0.4	0.044	0.140
		Trib. inflow	109	134622	2788	99.9	11.6	117.2	100.0	99.8	0.106	1.074
		Precipitation	0	93	2	0.1	0.0	0.2	0.0	0.2		
		Total inflow	109	134715	2790	100.0	11.6	117.3	100.0	100.0	0.106	1.074
		Evaporation	0	329	7							
		Net inflow	109	135043	2797		11.6	117.3				
		Copco outflow	111	136630	2830		10.8	97.3			0.098	0.878
		Change storage	-1	-1638	-34		0.6	2.1				
		Retention					0.2	18.0	1.5	15.3		
Interval 2: 6/ 3/2005 - 6/15/2005	13	Klamath abv. Copco	38	47183	1203	97.0	4.9	43.6	98.9	99.3	0.128	1.141
		Shovel Creek	1	1459	37	3.0	0.1	0.2	1.0	0.4	0.044	0.140
		Trib. inflow	39	48642	1240	100.0	5.0	43.8	99.9	99.7	0.126	1.111
		Precipitation	0	3	0	0.0	0.0	0.2	0.1	0.3		
		Total inflow	39	48645	1240	100.0	5.0	44.0	100.0	100.0	0.126	1.115
		Evaporation	0	327	8							
		Net inflow	40	48973	1248		5.0	44.0				
		Copco outflow	41	50300	1282		4.6	31.9			0.112	0.781
		Change storage	-2	-2046	-52		1.3	-4.2				
		Retention					-0.9	16.4	-17.7	37.2		
Interval 3: 6/16/2005 - 6/28/2005	13	Klamath abv. Copco	34	42047	1072	97.2	4.4	36.0	99.0	99.2	0.128	1.057
		Shovel Creek	1	1201	31	2.8	0.0	0.1	1.0	0.4	0.044	0.140
		Trib. inflow	35	43248	1102	99.9	4.4	36.2	99.9	99.6	0.126	1.031
		Precipitation	0	25	1	0.1	0.0	0.2	0.1	0.4		
		Total inflow	35	43273	1103	100.0	4.4	36.3	100.0	100.0	0.126	1.035

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	TN	% TP	TN	CONC. mg/L TP	TN
		Evaporation	0	335	9							
		Net inflow	35	43608	1112		4.4	36.3				
		Copco outflow	31	38322	977		3.7	24.1			0.119	0.774
		Change storage	4	4740	121		0.3	5.0				
		Retention					0.5	7.2	10.4	19.9		
Interval 4: 6/29/2005 - 7/14/2005	16	Klamath abv. Copco	32	39355	815	99.1	6.3	42.7	99.7	99.5	0.198	1.337
		Shovel Creek	0	343	7	0.9	0.0	0.0	0.2	0.1	0.046	0.152
		Trib. inflow	32	39698	822	100.0	6.3	42.7	99.9	99.6	0.197	1.327
		Precipitation	0	0	0	0.0	0.0	0.2	0.1	0.4		
		Total inflow	32	39699	822	100.0	6.3	42.9	100.0	100.0	0.197	1.333
		Evaporation	0	465	10							
		Net inflow	33	40163	832		6.3	42.9				
		Copco outflow	33	40290	834		4.2	26.9			0.130	0.824
		Change storage	0	152	3		1.2	5.2				
		Retention					0.9	10.8	14.4	25.1		
Interval 5: 7/15/2005 - 7/27/2005	13	Klamath abv. Copco	28	34168	871	99.3	7.3	48.9	99.8	99.6	0.265	1.764
		Shovel Creek	0	232	6	0.7	0.0	0.0	0.1	0.1	0.050	0.176
		Trib. inflow	28	34400	877	100.0	7.3	48.9	100.0	99.7	0.263	1.753
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.3		
		Total inflow	28	34400	877	100.0	7.3	49.1	100.0	100.0	0.263	1.759
		Evaporation	0	381	10							
		Net inflow	28	34781	887		7.3	49.1				
		Copco outflow	28	35041	893		4.7	34.9			0.166	1.227
		Change storage	0	-152	-4		2.0	16.6				
		Retention					0.7	-2.4	8.9	-5.0		
Interval 6: 7/28/2005 - 8/11/2005	15	Klamath abv. Copco	32	39437	871	99.3	7.3	63.3	99.8	99.7	0.228	1.981
		Shovel Creek	0	257	6	0.6	0.0	0.0	0.1	0.1	0.051	0.157
		Trib. inflow	32	39693	877	100.0	7.3	63.4	100.0	99.7	0.227	1.969
		Precipitation	0	8	0	0.0	0.0	0.2	0.0	0.3		
		Total inflow	32	39701	877	100.0	7.3	63.5	100.0	100.0	0.227	1.974
		Evaporation	0	409	9							
		Net inflow	33	40110	886		7.3	63.5				
		Copco outflow	34	41414	915		6.5	50.7			0.193	1.510
		Change storage	-1	-1206	-27		1.0	8.9				
		Retention					-0.2	3.9	-2.5	6.2		
Interval 7: 8/12/2005 - 8/25/2005	14	Klamath abv. Copco	32	38969	922	99.2	6.3	60.2	99.8	99.7	0.199	1.905
		Shovel Creek	0	309	7	0.8	0.0	0.0	0.2	0.1	0.051	0.139
		Trib. inflow	32	39278	930	100.0	6.3	60.2	100.0	99.7	0.197	1.891
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.3		
		Total inflow	32	39278	930	100.0	6.3	60.4	100.0	100.0	0.198	1.897

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	TN	% TP	TN	CONC. mg/L TP	TN
		Evaporation	0	370	9							
		Net inflow	32	39648	938		6.3	60.4				
		Copco outflow	32	39127	926		6.2	46.4			0.196	1.464
		Change storage	0	601	14		-0.6	-5.5				
		Retention					0.6	19.4	10.2	32.2		
Interval 8: 8/26/2005 - 9/ 8/2005	14	Klamath abv. Copco	35	43176	1022	99.5	5.6	62.2	99.8	99.7	0.160	1.778
		Shovel Creek	0	235	6	0.5	0.0	0.0	0.2	0.0	0.050	0.140
		Trib. inflow	35	43411	1027	100.0	5.6	62.3	100.0	99.7	0.159	1.769
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.3		
		Total inflow	35	43411	1027	100.0	5.6	62.4	100.0	100.0	0.159	1.774
		Evaporation	0	307	7							
		Net inflow	35	43717	1035		5.6	62.4				
		Copco outflow	36	44352	1050		6.8	51.3			0.190	1.428
		Change storage	0	-451	-11		-0.8	0.4				
		Retention					-0.4	10.7	-7.3	17.1		
Interval 9: 9/ 9/2005 - 9/21/2005	13	Klamath abv. Copco	34	41365	1054	99.4	5.2	69.0	99.8	99.7	0.155	2.058
		Shovel Creek	0	252	6	0.6	0.0	0.0	0.2	0.0	0.049	0.141
		Trib. inflow	34	41617	1061	100.0	5.2	69.0	100.0	99.8	0.154	2.046
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.2		
		Total inflow	34	41617	1061	100.0	5.2	69.2	100.0	100.0	0.154	2.051
		Evaporation	0	236	6							
		Net inflow	34	41854	1067		5.2	69.2				
		Copco outflow	36	44909	1145		6.6	55.8			0.180	1.532
		Change storage	-2	-2520	-64		-1.3	6.2				
		Retention					-0.1	7.3	-1.3	10.5		
Interval 10: 9/22/2005 - 10/ 5/2005	14	Klamath abv. Copco	38	46529	1101	99.2	6.5	83.7	99.7	99.8	0.172	2.218
		Shovel Creek	0	361	9	0.8	0.0	0.0	0.2	0.0	0.049	0.141
		Trib. inflow	38	46890	1110	100.0	6.5	83.7	100.0	99.8	0.171	2.202
		Precipitation	0	16	0	0.0	0.0	0.2	0.0	0.2		
		Total inflow	38	46906	1110	100.0	6.5	83.9	100.0	100.0	0.171	2.205
		Evaporation	0	223	5							
		Net inflow	38	47129	1115		6.5	83.9				
		Copco outflow	38	47374	1121		6.4	61.3			0.167	1.595
		Change storage	0	-292	-7		-0.8	-1.0				
		Retention					0.9	23.6	13.4	28.1		
Interval 11: 10/ 6/2005 - 10/19/2005	14	Klamath abv. Copco	40	49540	1173	99.2	5.8	75.8	99.7	99.7	0.143	1.888
		Shovel Creek	0	394	9	0.8	0.0	0.0	0.3	0.1	0.048	0.142
		Trib. inflow	40	49934	1182	100.0	5.8	75.9	100.0	99.8	0.142	1.874
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.2		
		Total inflow	40	49935	1182	100.0	5.8	76.0	100.0	100.0	0.143	1.878

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	TN	% TP	TN	CONC. mg/L TP	TN
		Evaporation	0	165	4							
		Net inflow	41	50100	1186		5.8	76.0				
		Copco outflow	45	55151	1305		6.8	70.8			0.152	1.584
		Change storage	-4	-4556	-108		-1.5	-4.4				
		Retention					0.5	9.6	7.8	12.6		
Interval 12: 10/20/2005	15	Klamath abv. Copco	47	58183	1285	99.0	5.1	83.6	99.6	99.7	0.107	1.773
-		Shovel Creek	0	467	10	0.8	0.0	0.1	0.4	0.1	0.053	0.149
11/ 3/2005		Trib. inflow	48	58650	1296	99.8	5.1	83.7	99.9	99.8	0.107	1.760
		Precipitation	0	116	3	0.2	0.0	0.2	0.1	0.2		
		Total inflow	48	58766	1298	100.0	5.1	83.9	100.0	100.0	0.107	1.760
		Evaporation	0	140	3							
		Net inflow	48	58905	1301		5.1	83.9				
		Copco outflow	45	55518	1226		5.8	73.1			0.129	1.624
		Change storage	3	3684	81		-0.5	5.4				
		Retention					-0.2	5.4	-3.6	6.4		
Interval 13:	14	Klamath abv. Copco	35	42605	1008	96.5	2.9	56.1	98.3	99.4	0.085	1.624
11/ 4/2005 -		Shovel Creek	1	1163	28	2.6	0.0	0.2	1.6	0.3	0.052	0.204
11/17/2005		Trib. inflow	35	43768	1036	99.1	3.0	56.3	99.9	99.7	0.084	1.586
		Precipitation	0	397	9	0.9	0.0	0.2	0.1	0.3		
		Total inflow	36	44165	1045	100.0	3.0	56.4	100.0	100.0	0.083	1.576
		Evaporation	0	0	0							
		Net inflow	36	44165	1045		3.0	56.4				
		Copco outflow	40	49165	1164		4.2	67.5			0.105	1.694
		Change storage	-2	-1861	-44		-1.0	-0.6				
		Retention					-0.2	-10.4	-7.9	-18.5		
Interval 14: 11/18/2005	13	Klamath abv. Copco	39	48635	1240	98.0	3.2	65.4	98.9	99.5	0.081	1.659
-		Shovel Creek	1	861	22	1.7	0.0	0.2	1.1	0.2	0.049	0.228
11/30/2005		Trib. inflow	40	49496	1262	99.7	3.2	65.6	99.9	99.8	0.080	1.634
		Precipitation	0	127	3	0.3	0.0	0.1	0.1	0.2		
		Total inflow	40	49623	1265	100.0	3.2	65.7	100.0	100.0	0.080	1.633
		Evaporation	0	0	0							
		Net inflow	40	49623	1265		3.2	65.7				
		Copco outflow	39	48032	1224		3.7	67.1			0.096	1.723
		Change storage	2	2587	66		0.2	0.6				
		Retention					-0.7	-2.0	-21.5	-3.1		
Interval 15:	14	Klamath abv. Copco	28	34868	825	93.4	2.7	50.2	96.6	98.9	0.095	1.775
12/ 1/2005 -		Shovel Creek	2	2325	55	6.2	0.1	0.4	3.3	0.8	0.049	0.211
12/14/2005		Trib. inflow	30	37193	880	99.6	2.8	50.6	99.9	99.7	0.092	1.677
		Precipitation	0	139	3	0.4	0.0	0.2	0.1	0.3		

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	TN	% TP	TN	CONC. mg/L TP	TN
		Total inflow	30	37332	884	100.0	2.8	50.7	100.0	100.0	0.092	1.676
		Evaporation	0	25	1							
		Net inflow	30	37358	884		2.8	50.7				
		Copco outflow	39	47922	1134		3.7	67.1			0.094	1.728
		Change storage	-6	-7540	-178		-0.7	-8.0				
		Retention					-0.1	-8.4	-5.0	-16.5		
Interval 16: 12/15/2005 - 1/ 4/2006	21	Klamath abv. Copco	170	209315	3303	87.9	27.3	360.1	95.9	98.7	0.161	2.122
		Shovel Creek	23	28018	442	11.8	1.2	4.4	4.1	1.2	0.051	0.195
		Trib. inflow	192	237333	3745	99.7	28.4	364.6	100.0	99.9	0.148	1.895
		Precipitation	1	706	11	0.3	0.0	0.2	0.0	0.1		
		Total inflow	193	238039	3756	100.0	28.4	364.8	100.0	100.0	0.147	1.890
		Evaporation	0	40	1							
		Net inflow	193	238080	3757		28.4	364.8				
		Copco outflow	182	224777	3547		29.9	344.6			0.164	1.891
		Change storage	6	7395	117		4.9	20.4				
		Retention					-6.4	-0.2	-22.6	-0.1		
Interval 17: 1/ 5/2006 - 1/24/2006	20	Klamath abv. Copco	257	316930	5251	95.4	38.1	539.4	98.4	99.5	0.148	2.099
		Shovel Creek	12	14823	246	4.5	0.6	2.3	1.6	0.4	0.053	0.193
		Trib. inflow	269	331753	5497	99.9	38.8	541.7	100.0	100.0	0.144	2.014
		Precipitation	0	300	5	0.1	0.0	0.2	0.0	0.0		
		Total inflow	269	332053	5502	100.0	38.8	542.0	100.0	100.0	0.144	2.013
		Evaporation	0	45	1							
		Net inflow	269	332098	5502		38.8	542.0				
		Copco outflow	270	332589	5510		40.9	518.9			0.152	1.925
		Change storage	-1	-869	-14		-3.9	-5.2				
		Retention					1.8	28.2	4.6	5.2		
Interval 18: 1/25/2006 - 2/ 7/2006	14	Klamath abv. Copco	143	176572	4179	93.2	22.6	283.7	97.3	99.3	0.158	1.982
		Shovel Creek	10	12616	299	6.7	0.6	1.7	2.7	0.6	0.061	0.168
		Trib. inflow	153	189188	4478	99.9	23.3	285.5	100.0	99.9	0.152	1.861
		Precipitation	0	231	5	0.1	0.0	0.2	0.0	0.1		
		Total inflow	154	189419	4483	100.0	23.3	285.6	100.0	100.0	0.151	1.860
		Evaporation	0	43	1							
		Net inflow	154	189461	4484		23.3	285.6				
		Copco outflow	155	190714	4514		18.7	283.8			0.121	1.835
		Change storage	-3	-3257	-77		1.3	-7.9				
		Retention					3.3	9.8	14.3	3.4		
Interval 19: 2/ 8/2006 - 3/ 1/2006	22	Klamath abv. Copco	187	230259	3468	95.8	30.5	322.0	98.0	99.5	0.164	1.725
		Shovel Creek	8	10002	151	4.2	0.6	1.5	2.0	0.5	0.076	0.188
		Trib. inflow	195	240261	3619	99.9	31.2	323.6	100.0	99.9	0.160	1.661

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	DISCHARGE acre-feet x 10⁶	DISCHARGE mean cfs	DISCHARGE % Total	LOADS Metric Tons TP	LOADS Metric Tons TN	LOADS % TP	LOADS % TN	CONC. mg/L TP	CONC. mg/L TN
		Precipitation	0	130	2	0.1	0.0	0.2	0.0	0.1		
		Total inflow	195	240391	3621	100.0	31.2	323.8	100.0	100.0	0.160	1.662
		Evaporation	0	90	1							
		Net inflow	195	240480	3622		31.2	323.8				
		Copco outflow	184	226764	3416		23.0	290.2			0.125	1.578
		Change storage	5	6780	102		-0.6	-11.1				
		Retention					8.7	44.8	28.1	13.8		
Interval 20: 3/ 2/2006 - 3/23/2006	22	Klamath abv. Copco	172	211729	3189	96.5	26.0	260.2	98.4	99.5	0.152	1.516
		Shovel Creek	6	7555	114	3.4	0.4	1.1	1.6	0.4	0.068	0.178
		Trib. inflow	178	219285	3303	100.0	26.4	261.3	100.0	99.9	0.149	1.470
		Precipitation	0	28	0	0.0	0.0	0.3	0.0	0.1		
		Total inflow	178	219313	3303	100.0	26.4	261.5	100.0	100.0	0.149	1.471
		Evaporation	0	173	3							
		Net inflow	178	219486	3306		26.4	261.5				
		Copco outflow	173	213968	3223		19.7	224.4			0.114	1.294
		Change storage	-1	-1041	-16		-0.1	-5.0				
		Retention					6.8	42.1	25.7	16.1		
Interval 21: 3/24/2006 - 4/ 5/2006	13	Klamath abv. Copco	107	132210	3370	97.1	16.0	152.0	99.0	99.6	0.149	1.418
		Shovel Creek	3	3910	100	2.9	0.2	0.5	1.0	0.3	0.050	0.166
		Trib. inflow	110	136120	3470	100.0	16.1	152.5	100.0	99.9	0.146	1.382
		Precipitation	0	60	2	0.0	0.0	0.2	0.0	0.1		
		Total inflow	110	136180	3471	100.0	16.1	152.6	100.0	100.0	0.146	1.383
		Evaporation	0	132	3							
		Net inflow	111	136312	3475		16.1	152.6				
		Copco outflow	105	129246	3294		12.0	124.5			0.115	1.188
		Change storage	0	593	15		0.3	-5.6				
		Retention					3.8	33.8	23.6	22.1		
Interval 22: 4/ 6/2006 - 4/27/2006	22	Klamath abv. Copco	329	406317	6120	98.6	40.7	339.9	99.4	99.7	0.124	1.032
		Shovel Creek	5	5569	84	1.4	0.2	0.8	0.5	0.2	0.049	0.188
		Trib. inflow	334	411887	6204	100.0	40.9	340.7	100.0	99.9	0.123	1.020
		Precipitation	0	67	1	0.0	0.0	0.3	0.0	0.1		
		Total inflow	334	411953	6205	100.0	40.9	341.0	100.0	100.0	0.123	1.021
		Evaporation	0	295	4							
		Net inflow	334	412248	6209		40.9	341.0				
		Copco outflow	335	413631	6230		37.3	329.9			0.111	0.984
		Change storage	-1	-1770	-27		-0.7	-12.5				
		Retention					4.3	23.6	10.4	6.9		
Interval 23: 4/28/2006 - 5/11/2006	14	Klamath abv. Copco	149	183452	4342	96.9	21.8	118.1	99.1	99.3	0.146	0.794
		Shovel Creek	5	5848	138	3.1	0.2	0.7	0.9	0.6	0.042	0.141
		Trib. inflow	153	189300	4481	100.0	22.0	118.7	100.0	99.9	0.143	0.774

Sample Interval	Days	Term	DISCHARGE				LOADS				CONC.	
							Metric Tons		%		mg/L	
			m^3 x 10^6	acre-feet x 10^6	mean cfs	% Total	TP	TN	TP	TN	TP	TN
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.1		
		Total inflow	153	189300	4481	100.0	22.0	118.9	100.0	100.0	0.143	0.775
		Evaporation	0	266	6							
		Net inflow	154	189566	4487		22.0	118.9				
		Copco outflow	142	174603	4133		15.4	112.2			0.109	0.793
		Change storage	2	2516	60		0.9	-1.2				
		Retention					5.6	14.4	25.6	12.1		

Table A3-2. Flow and nutrient mass-balance for Iron Gate Reservoir, May 2005 - May 2006, summarized by sampling interval.

			DISCHARGE				LOADS				CONC.	
							Metric Tons		%		mg/L	
Sample Interval	Days	Term	$m^3 \times 10^6$	acre-feet x 10^6	mean cfs	% Total	TP	TN	TP	TN	TP	TN
Entire Period 5/18/2005 - 5/11/2006	359	Copco outflow	2173	2679840	2474	89.1	281.6	3054.6	97.2	98.2	0.130	1.406
		Fall Creek	33	40767	38	1.4	1.0	6.4	0.4	0.2	0.031	0.194
		Jenny Creek	196	241841	223	8.0	6.0	40.1	2.1	1.3	0.031	0.204
		Camp Creek	34	42118	39	1.4	1.0	6.9	0.4	0.2	0.031	0.202
		Trib. inflow	2436	3004566	2773	99.9	289.7	3108.0	100.0	99.9	0.119	1.276
		Precipitation	2	2461	2	0.1	0.1	4.1	0.0	0.1		
		Total inflow	2438	3007027	2776	100.0	289.8	3112.1	100.0	100.0	0.119	1.277
		Evaporation	4	4646	4							
		Net inflow	2442	3011673	2780		289.8	3112.1				
		Klam. bel. IG Dam	2415	2979057	2750		280.0	2809.8			0.116	1.163
		Change in storage	0	-301	0		0.8	-9.8				
		Retention					9.0	312.1	3.1	10.0		
Interval 1: 5/18/2005 - 6/ 2/2005	16	Copco outflow	111	136630	2830	94.7	10.8	97.3	98.3	98.7	0.098	0.878
		Fall Creek	1	1648	34	1.1	0.0	0.2	0.4	0.2	0.029	0.170
		Jenny Creek	3	4097	85	2.8	0.1	0.6	0.9	0.6	0.030	0.185
		Camp Creek	1	1831	38	1.3	0.0	0.3	0.4	0.3	0.030	0.185
		Trib. inflow	117	144206	2987	99.9	11.0	98.4	100.0	99.8	0.094	0.842
		Precipitation	0	92	2	0.1	0.0	0.2	0.0	0.2		
		Total inflow	117	144299	2988	100.0	11.0	98.6	100.0	100.0	0.094	0.843
		Evaporation	0	331	7							
		Net inflow	117	144630	2995		11.0	98.6				
		Klam. bel. IG Dam	122	150976	3127		11.5	90.8			0.094	0.742
		Change in storage	-5	-6401	-133		-0.5	-5.0				
		Retention					0.0	12.7	-0.3	12.9		
Interval 2: 6/ 3/2005 - 6/15/2005	13	Copco outflow	41	50300	1282	94.5	4.6	31.9	98.4	98.3	0.112	0.781
		Fall Creek	1	1181	30	2.2	0.0	0.2	0.6	0.5	0.029	0.170
		Jenny Creek	1	1126	29	2.1	0.0	0.2	0.6	0.5	0.030	0.185
		Camp Creek	0	603	15	1.1	0.0	0.1	0.3	0.3	0.030	0.185
		Trib. inflow	43	53210	1356	100.0	4.6	32.3	99.9	99.6	0.108	0.748
		Precipitation	0	3	0	0.0	0.0	0.1	0.1	0.4		
		Total inflow	43	53212	1356	100.0	4.6	32.4	100.0	100.0	0.108	0.751
		Evaporation	0	314	8							
		Net inflow	43	53527	1364		4.6	32.4				
		Klam. bel. IG Dam	41	50988	1300		3.5	29.6			0.086	0.717
		Change in storage	1	1846	47		0.2	-0.6				
		Retention					0.9	3.4	18.6	10.3		
Interval 3: 6/16/2005 - 6/28/2005	13	Copco outflow	31	38322	977	93.9	3.7	24.1	98.4	98.0	0.119	0.774
		Fall Creek	1	1181	30	2.9	0.0	0.2	0.7	0.7	0.029	0.170
		Jenny Creek	1	796	20	2.0	0.0	0.1	0.5	0.5	0.030	0.185

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	Metric Tons TN	% TP	% TN	CONC. mg/L TP	mg/L TN
		Camp Creek	0	496	13	1.2	0.0	0.1	0.3	0.3	0.030	0.185
		Trib. inflow	33	40795	1040	99.9	3.8	24.4	99.9	99.4	0.113	0.738
		Precipitation	0	24	1	0.1	0.0	0.1	0.1	0.6		
		Total inflow	33	40819	1040	100.0	3.8	24.6	100.0	100.0	0.113	0.742
		Evaporation	0	317	8							
		Net inflow	33	41136	1049		3.8	24.6				
		Klam. bel. IG Dam	34	41625	1061		3.2	23.7			0.093	0.703
		Change in storage	-1	-999	-25		0.7	1.1				
		Retention					-0.1	-0.3	-3.3	-1.2		
Interval 4: 6/29/2005 - 7/14/2005	16	Copco outflow	33	40290	834	94.3	4.2	26.9	98.6	98.1	0.130	0.824
		Fall Creek	1	1430	30	3.3	0.0	0.2	0.8	0.7	0.029	0.170
		Jenny Creek	1	668	14	1.6	0.0	0.1	0.4	0.4	0.030	0.185
		Camp Creek	0	337	7	0.8	0.0	0.1	0.2	0.2	0.030	0.185
		Trib. inflow	35	42725	885	100.0	4.3	27.3	99.9	99.4	0.124	0.787
		Precipitation	0	0	0	0.0	0.0	0.2	0.1	0.6		
		Total inflow	35	42725	885	100.0	4.3	27.4	100.0	100.0	0.124	0.792
		Evaporation	0	431	9							
		Net inflow	35	43156	894		4.3	27.4				
		Klam. bel. IG Dam	36	44349	918		3.5	21.4			0.097	0.597
		Change in storage	-1	-848	-18		0.3	-10.6				
		Retention					0.5	16.6	12.4	60.5		
Interval 5: 7/15/2005 - 7/27/2005	13	Copco outflow	28	35041	893	95.7	4.7	34.9	99.2	99.0	0.166	1.227
		Fall Creek	1	966	25	2.6	0.0	0.1	0.5	0.4	0.029	0.170
		Jenny Creek	0	454	12	1.2	0.0	0.1	0.2	0.2	0.030	0.185
		Camp Creek	0	139	4	0.4	0.0	0.0	0.1	0.1	0.030	0.185
		Trib. inflow	30	36600	933	100.0	4.7	35.1	99.9	99.6	0.160	1.182
		Precipitation	0	0	0	0.0	0.0	0.1	0.1	0.4		
		Total inflow	30	36600	933	100.0	4.8	35.2	100.0	100.0	0.160	1.187
		Evaporation	0	358	9							
		Net inflow	30	36958	942		4.8	35.2				
		Klam. bel. IG Dam	29	35839	914		3.2	19.9			0.110	0.686
		Change in storage	1	1274	32		1.4	13.5				
		Retention					0.1	1.8	2.3	5.2		
Interval 6: 7/28/2005 - 8/11/2005	15	Copco outflow	34	41414	915	96.2	6.5	50.7	99.4	99.2	0.193	1.510
		Fall Creek	1	1032	23	2.4	0.0	0.2	0.4	0.3	0.030	0.196
		Jenny Creek	0	499	11	1.2	0.0	0.1	0.2	0.1	0.030	0.185
		Camp Creek	0	84	2	0.2	0.0	0.0	0.0	0.0	0.030	0.185
		Trib. inflow	35	43029	951	100.0	6.5	50.9	100.0	99.7	0.187	1.460
		Precipitation	0	7	0	0.0	0.0	0.2	0.0	0.3		
		Total inflow	35	43037	951	100.0	6.5	51.1	100.0	100.0	0.187	1.465

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	TN	% TP	TN	CONC. mg/L TP	TN
		Evaporation	0	385	9							
		Net inflow	35	43422	959		6.5	51.1				
		Klam. bel. IG Dam	36	44277	978		4.7	32.8			0.130	0.914
		Change in storage	-1	-710	-16		1.4	6.4				
		Retention					0.5	11.9	7.3	23.2		
Interval 7: 8/12/2005 - 8/25/2005	14	Copco outflow	32	39127	926	96.1	6.2	46.4	99.3	99.1	0.196	1.464
		Fall Creek	1	1065	25	2.6	0.0	0.2	0.4	0.4	0.030	0.212
		Jenny Creek	0	470	11	1.2	0.0	0.1	0.2	0.1	0.029	0.183
		Camp Creek	0	34	1	0.1	0.0	0.0	0.0	0.0	0.029	0.183
		Trib. inflow	33	40695	963	100.0	6.2	46.7	100.0	99.7	0.189	1.416
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.3		
		Total inflow	33	40695	963	100.0	6.3	46.9	100.0	100.0	0.189	1.420
		Evaporation	0	348	8							
		Net inflow	33	41043	971		6.3	46.9				
		Klam. bel. IG Dam	34	41591	984		5.3	36.4			0.157	1.079
		Change in storage	0	-423	-10		1.9	4.5				
		Retention					-0.9	5.9	-14.2	12.7		
Interval 8: 8/26/2005 - 9/ 8/2005	14	Copco outflow	36	44352	1050	96.3	6.8	51.3	99.4	99.2	0.190	1.428
		Fall Creek	1	1220	29	2.6	0.0	0.2	0.4	0.4	0.031	0.207
		Jenny Creek	0	485	11	1.1	0.0	0.1	0.2	0.1	0.028	0.179
		Camp Creek	0	21	0	0.0	0.0	0.0	0.0	0.0	0.028	0.178
		Trib. inflow	37	46078	1091	100.0	6.9	51.6	100.0	99.7	0.184	1.382
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.3		
		Total inflow	37	46078	1091	100.0	6.9	51.8	100.0	100.0	0.184	1.386
		Evaporation	0	288	7							
		Net inflow	38	46366	1097		6.9	51.8				
		Klam. bel. IG Dam	37	46022	1089		6.6	42.5			0.177	1.140
		Change in storage	0	565	13		1.3	12.0				
		Retention					-1.1	-2.8	-15.5	-5.4		
Interval 9: 9/ 9/2005 - 9/21/2005	13	Copco outflow	36	44909	1145	96.1	6.6	55.8	99.3	99.2	0.180	1.532
		Fall Creek	1	1272	32	2.7	0.0	0.2	0.5	0.4	0.031	0.202
		Jenny Creek	0	499	13	1.1	0.0	0.1	0.2	0.1	0.026	0.175
		Camp Creek	0	36	1	0.1	0.0	0.0	0.0	0.0	0.026	0.175
		Trib. inflow	38	46716	1191	100.0	6.6	56.0	100.0	99.7	0.174	1.480
		Precipitation	0	0	0	0.0	0.0	0.1	0.0	0.3		
		Total inflow	38	46716	1191	100.0	6.6	56.2	100.0	100.0	0.175	1.484
		Evaporation	0	228	6							
		Net inflow	38	46944	1197		6.6	56.2				
		Klam. bel. IG Dam	37	45780	1167		6.4	43.2			0.174	1.163
		Change in storage	1	1716	44		0.2	-8.1				
		Retention					0.0	21.1	0.0	37.5		

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	TN	% TP	TN	CONC. mg/L TP	TN
Interval 10: 9/22/2005 - 10/ 5/2005	14	Copco outflow	38	47374	1121	95.6	6.4	61.3	99.2	99.2	0.167	1.595
		Fall Creek	1	1520	36	3.1	0.0	0.2	0.6	0.4	0.031	0.197
		Jenny Creek	0	603	14	1.2	0.0	0.1	0.2	0.1	0.025	0.171
		Camp Creek	0	48	1	0.1	0.0	0.0	0.0	0.0	0.025	0.170
		Trib. inflow	40	49545	1173	100.0	6.4	61.6	100.0	99.7	0.161	1.533
		Precipitation	0	16	0	0.0	0.0	0.2	0.0	0.3		
		Total inflow	40	49561	1173	100.0	6.5	61.7	100.0	100.0	0.161	1.537
		Evaporation	0	214	5							
		Net inflow	40	49774	1178		6.5	61.7				
		Klam. bel. IG Dam	42	52027	1231		7.0	51.2			0.167	1.214
		Change in storage	-2	-2281	-54		-1.0	6.5				
		Retention					0.4	4.0	6.9	6.5		
Interval 11: 10/ 6/2005 - 10/19/2005	14	Copco outflow	45	55151	1305	95.9	6.8	70.8	99.1	99.3	0.152	1.584
		Fall Creek	1	1676	40	2.9	0.0	0.3	0.6	0.4	0.032	0.192
		Jenny Creek	0	615	15	1.1	0.0	0.1	0.2	0.1	0.024	0.166
		Camp Creek	0	87	2	0.2	0.0	0.0	0.0	0.0	0.024	0.166
		Trib. inflow	47	57529	1362	100.0	6.8	71.2	100.0	99.8	0.146	1.526
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.2		
		Total inflow	47	57529	1362	100.0	6.8	71.3	100.0	100.0	0.147	1.529
		Evaporation	0	162	4							
		Net inflow	47	57692	1366		6.8	71.3				
		Klam. bel. IG Dam	46	56916	1347		7.3	61.8			0.158	1.339
		Change in storage	1	1276	30		-1.8	13.6				
		Retention					1.4	-4.0	20.2	-5.6		
Interval 12: 10/20/2005 - 11/ 3/2005	15	Copco outflow	45	55518	1226	95.0	5.8	73.1	98.8	99.2	0.129	1.624
		Fall Creek	2	1968	43	3.4	0.1	0.3	0.9	0.4	0.033	0.198
		Jenny Creek	1	703	16	1.2	0.0	0.1	0.2	0.1	0.025	0.143
		Camp Creek	0	119	3	0.2	0.0	0.0	0.0	0.0	0.025	0.141
		Trib. inflow	47	58307	1288	99.8	5.9	73.5	100.0	99.8	0.124	1.555
		Precipitation	0	112	2	0.2	0.0	0.2	0.0	0.2		
		Total inflow	47	58419	1291	100.0	5.9	73.7	100.0	100.0	0.124	1.556
		Evaporation	0	139	3							
		Net inflow	47	58558	1294		5.9	73.7				
		Klam. bel. IG Dam	49	60835	1344		6.9	74.0			0.140	1.501
		Change in storage	-2	-1978	-44		-1.7	1.8				
		Retention					0.7	-2.2	12.3	-3.0		
Interval 13: 11/ 4/2005 - 11/17/2005	14	Copco outflow	40	49165	1164	92.0	4.2	67.5	97.8	98.9	0.105	1.694
		Fall Creek	2	1998	47	3.7	0.0	0.3	1.1	0.4	0.030	0.176
		Jenny Creek	1	1384	33	2.6	0.0	0.2	0.8	0.4	0.029	0.213
		Camp Creek	0	487	12	0.9	0.0	0.1	0.3	0.1	0.029	0.206

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	Metric Tons TN	% TP	% TN	CONC. mg/L TP	mg/L TN
		Trib. inflow	43	53034	1255	99.3	4.3	68.1	99.9	99.8	0.099	1.585
		Precipitation	0	389	9	0.7	0.0	0.2	0.1	0.2		
		Total inflow	43	53423	1264	100.0	4.3	68.3	100.0	100.0	0.099	1.577
		Evaporation	0	0	0							
		Net inflow	43	53423	1264		4.3	68.3				
		Klam. bel. IG Dam	45	55862	1322		5.5	71.3			0.123	1.573
		Change in storage	1	701	17		-1.0	4.6				
		Retention					-0.3	-7.5	-7.4	-11.0		
Interval 14: 11/18/2005 - 11/30/2005	13	Copco outflow	39	48032	1224	94.7	3.7	67.1	98.4	99.2	0.096	1.723
		Fall Creek	1	1375	35	2.7	0.0	0.2	0.8	0.3	0.028	0.159
		Jenny Creek	1	828	21	1.6	0.0	0.2	0.5	0.2	0.029	0.243
		Camp Creek	0	356	9	0.7	0.0	0.1	0.2	0.1	0.029	0.244
		Trib. inflow	41	50591	1290	99.8	3.8	67.5	99.9	99.8	0.093	1.646
		Precipitation	0	123	3	0.2	0.0	0.1	0.1	0.2		
		Total inflow	41	50714	1293	100.0	3.8	67.7	100.0	100.0	0.092	1.646
		Evaporation	0	0	0							
		Net inflow	41	50714	1293		3.8	67.7				
		Klam. bel. IG Dam	42	51570	1314		4.9	65.6			0.116	1.570
		Change in storage	0	141	4		-0.2	-3.0				
		Retention					-0.8	5.1	-21.9	7.5		
Interval 15: 12/ 1/2005 - 12/14/2005	14	Copco outflow	39	47922	1134	85.7	3.7	67.1	95.3	97.9	0.094	1.728
		Fall Creek	1	1692	40	3.0	0.0	0.2	1.0	0.3	0.029	0.165
		Jenny Creek	4	5238	124	9.4	0.1	0.9	3.1	1.3	0.028	0.218
		Camp Creek	1	960	23	1.7	0.0	0.2	0.6	0.2	0.028	0.214
		Trib. inflow	45	55812	1321	99.8	3.8	68.5	99.9	99.8	0.085	1.513
		Precipitation	0	133	3	0.2	0.0	0.2	0.1	0.2		
		Total inflow	45	55946	1324	100.0	3.8	68.6	100.0	100.0	0.085	1.513
		Evaporation	0	25	1							
		Net inflow	45	55970	1325		3.8	68.6				
		Klam. bel. IG Dam	48	58854	1393		4.9	75.0			0.103	1.573
		Change in storage	0	141	3		-0.6	5.2				
		Retention					-0.5	-11.6	-13.5	-17.0		
Interval 16: 12/15/2005 - 1/ 4/2006	21	Copco outflow	182	224777	3547	77.2	29.9	344.6	93.9	96.3	0.164	1.891
		Fall Creek	2	2587	41	0.9	0.1	0.6	0.2	0.2	0.034	0.272
		Jenny Creek	42	51471	812	17.7	1.5	10.1	4.8	2.8	0.037	0.241
		Camp Creek	9	11571	183	4.0	0.3	2.3	1.1	0.6	0.037	0.244
		Trib. inflow	235	290406	4582	99.8	31.9	357.5	100.0	99.9	0.135	1.519
		Precipitation	1	711	11	0.2	0.0	0.2	0.0	0.1		
		Total inflow	236	291117	4594	100.0	31.9	357.8	100.0	100.0	0.135	1.516

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	Metric Tons TN	% TP	% TN	CONC. mg/L TP	mg/L TN
		Evaporation	0	41	1							
		Net inflow	236	291158	4594		31.9	357.8				
		Klam. bel. IG Dam	226	278211	4390		37.1	322.2			0.165	1.429
		Change in storage	6	7038	111		6.9	-5.9				
		Retention					-12.1	41.5	-38.1	11.6		
Interval 17: 1/ 5/2006 - 1/24/2006	20	Copco outflow	270	332589	5510	90.3	40.9	518.9	97.8	98.7	0.152	1.925
		Fall Creek	2	2660	44	0.7	0.1	0.6	0.2	0.1	0.031	0.270
		Jenny Creek	22	26575	440	7.2	0.7	4.9	1.7	0.9	0.032	0.229
		Camp Creek	5	6121	101	1.7	0.2	1.1	0.4	0.2	0.031	0.224
		Trib. inflow	298	367946	6096	99.9	41.8	525.6	100.0	100.0	0.140	1.762
		Precipitation	0	315	5	0.1	0.0	0.2	0.0	0.0		
		Total inflow	299	368261	6101	100.0	41.8	525.8	100.0	100.0	0.140	1.761
		Evaporation	0	48	1							
		Net inflow	299	368308	6102		41.8	525.8				
		Klam. bel. IG Dam	299	369136	6116		44.3	456.9			0.148	1.527
		Change in storage	-1	-1210	-20		-6.7	29.8				
		Retention					4.1	39.1	9.9	7.4		
Interval 18: 1/25/2006 - 2/ 7/2006	14	Copco outflow	155	190714	4514	85.8	18.7	283.8	96.7	98.5	0.121	1.835
		Fall Creek	2	1947	46	0.9	0.1	0.3	0.3	0.1	0.042	0.186
		Jenny Creek	20	24137	571	10.9	0.5	3.1	2.4	1.1	0.024	0.158
		Camp Creek	4	5210	123	2.3	0.1	0.7	0.5	0.2	0.024	0.160
		Trib. inflow	180	222008	5255	99.9	19.3	287.8	100.0	99.9	0.107	1.599
		Precipitation	0	246	6	0.1	0.0	0.2	0.0	0.1		
		Total inflow	180	222254	5261	100.0	19.3	288.0	100.0	100.0	0.107	1.598
		Evaporation	0	45	1							
		Net inflow	180	222299	5262		19.3	288.0				
		Klam. bel. IG Dam	178	219686	5200		16.7	273.4			0.094	1.535
		Change in storage	0	603	14		-0.2	-29.8				
		Retention					2.8	44.4	14.5	15.4		
Interval 19: 2/ 8/2006 - 3/ 1/2006	22	Copco outflow	184	226764	3416	88.6	23.0	290.2	96.8	98.7	0.125	1.578
		Fall Creek	3	3188	48	1.2	0.1	0.5	0.5	0.2	0.044	0.189
		Jenny Creek	18	21612	326	8.4	0.5	2.6	2.2	0.9	0.030	0.151
		Camp Creek	3	4131	62	1.6	0.1	0.5	0.4	0.2	0.030	0.150
		Trib. inflow	207	255695	3851	99.9	23.7	293.8	100.0	99.9	0.115	1.417
		Precipitation	0	133	2	0.1	0.0	0.3	0.0	0.1		
		Total inflow	207	255827	3853	100.0	23.7	294.0	100.0	100.0	0.114	1.418
		Evaporation	0	94	1							
		Net inflow	207	255921	3855		23.7	294.0				
		Klam. bel. IG Dam	202	249730	3761		19.4	265.5			0.096	1.311

Sample Interval	Days	Term	DISCHARGE m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	LOADS Metric Tons TP	Metric Tons TN	% TP	% TN	CONC. mg/L TP	mg/L TN
		Change in storage	-1	-753	-11		0.2	-11.3				
		Retention					4.1	39.8	17.4	13.5		
Interval 20: 3/ 2/2006 - 3/23/2006	22	Copco outflow	173	213968	3223	90.5	19.7	224.4	97.6	98.7	0.114	1.294
		Fall Creek	3	3092	47	1.3	0.1	0.5	0.3	0.2	0.027	0.180
		Jenny Creek	13	16320	246	6.9	0.4	2.0	1.8	0.9	0.027	0.148
		Camp Creek	3	3120	47	1.3	0.1	0.4	0.3	0.2	0.025	0.145
		Trib. inflow	192	236500	3562	100.0	20.2	227.2	100.0	99.9	0.105	1.185
		Precipitation	0	28	0	0.0	0.0	0.3	0.0	0.1		
		Total inflow	192	236529	3563	100.0	20.2	227.5	100.0	100.0	0.105	1.186
		Evaporation	0	174	3							
		Net inflow	192	236703	3565		20.2	227.5				
		Klam. bel. IG Dam	187	230442	3471		17.1	210.0			0.092	1.124
		Change in storage	0	-300	-5		-0.8	-13.5				
		Retention					3.8	30.9	19.0	13.6		
Interval 21: 3/24/2006 - 4/ 5/2006	13	Copco outflow	105	129246	3294	87.7	12.0	124.5	97.6	97.6	0.115	1.188
		Fall Creek	1	1765	45	1.2	0.0	0.3	0.3	0.2	0.025	0.191
		Jenny Creek	12	14691	374	10.0	0.2	2.4	1.9	1.9	0.020	0.205
		Camp Creek	1	1615	41	1.1	0.0	0.3	0.2	0.2	0.019	0.191
		Trib. inflow	119	147317	3755	100.0	12.3	127.4	100.0	99.9	0.103	1.067
		Precipitation	0	60	2	0.0	0.0	0.2	0.0	0.1		
		Total inflow	119	147377	3757	100.0	12.3	127.6	100.0	100.0	0.103	1.068
		Evaporation	0	132	3							
		Net inflow	120	147509	3760		12.3	127.6				
		Klam. bel. IG Dam	114	140435	3580		10.9	117.4			0.096	1.031
		Change in storage	0	600	15		0.5	3.1				
		Retention					0.9	7.1	7.7	5.6		
Interval 22: 4/ 6/2006 - 4/27/2006	22	Copco outflow	335	413631	6230	90.3	37.3	329.9	97.0	97.5	0.111	0.984
		Fall Creek	2	2819	42	0.6	0.1	0.4	0.2	0.1	0.026	0.177
		Jenny Creek	32	39460	594	8.6	1.0	7.5	2.7	2.2	0.032	0.234
		Camp Creek	2	2300	35	0.5	0.1	0.4	0.2	0.1	0.033	0.232
		Trib. inflow	371	458211	6902	100.0	38.5	338.2	100.0	99.9	0.104	0.910
		Precipitation	0	68	1	0.0	0.0	0.3	0.0	0.1		
		Total inflow	372	458278	6903	100.0	38.5	338.5	100.0	100.0	0.104	0.911
		Evaporation	0	306	5							
		Net inflow	372	458584	6907		38.5	338.5				
		Klam. bel. IG Dam	372	458476	6906		35.3	317.3			0.095	0.854
		Change in storage	0	-301	-5		-0.9	-21.3				
		Retention					4.0	42.4	10.4	12.5		
Interval 23: 4/28/2006 - 5/11/2006	14	Copco outflow	142	174603	4133	84.1	15.4	112.2	94.7	95.5	0.109	0.793
		Fall Creek	1	1483	35	0.7	0.0	0.2	0.3	0.2	0.034	0.162
		Jenny Creek	24	29109	689	14.0	0.8	4.5	4.7	3.9	0.032	0.192

Sample Interval	Days	Term	DISCHARGE				LOADS				CONC.	
							Metric Tons		%		mg/L	
			m³ x 10⁶	acre-feet x 10⁶	mean cfs	% Total	TP	TN	TP	TN	TP	TN
		Camp Creek	2	2415	57	1.2	0.1	0.4	0.4	0.3	0.031	0.187
		Trib. inflow	168	207611	4914	100.0	16.3	117.3	100.0	99.9	0.097	0.697
		Precipitation	0	0	0	0.0	0.0	0.2	0.0	0.1		
		Total inflow	168	207611	4914	100.0	16.3	117.4	100.0	100.0	0.097	0.698
		Evaporation	0	266	6							
		Net inflow	169	207877	4920		16.3	117.4				
		Klam. bel. IG Dam	158	195431	4626		14.7	107.6			0.093	0.679
		Change in storage	0	0	0		1.1	-3.0				
		Retention					0.5	12.8	3.4	10.9		