2002 NUTRIENT AND HYDROLOGIC LOADING TO IRON GATE AND COPCO RESERVOIRS, CALIFORNIA

PREPARED FOR THE

KARUK TRIBE OF CALIFORNIA, DEPARTMENT OF NATURAL RESOURCES

BY

KIER ASSOCIATES, FISHERIES AND WATERSHED PROFESSIONALS
MILL VALLEY AND ARCATA, CALIFORNIA

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ASHLAND, OREGON

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Citation:
Kann, J., and E. Asarian. 2005. 2002 Nutrient and Hydrologic Loading to Iron Gate and Copco Reservoirs, California. Kier Associates Final Technical Report to the Karuk Tribe Department of Natural Resources, Orleans, California. 59pp + appendices.

INTRODUCTION

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 Ewuana, 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 (Figure 1), located near the town of Yreka in northern California's Siskiyou County. Copco Dam, completed in 1918, was the first major hydropower development on the mainstem Klamath River. Iron Gate Dam was subsequently constructed downstream of Copco Dam in 1966. PacifiCorp, owned by Scottish Power, operates these reservoirs as part of the Klamath Hydroelectric Project (KHP) to regulate flows and generate electricity.

Typically, such reservoirs have the potential to alter algal and nutrient dynamics, specifically with respect to the fate and transport of algae and nutrients in the riverine environment. Previous data and analysis (PacifiCorp 2004a, 2004b, 2005) show that the reaches of the Klamath River above the reservoirs are eutrophic (rich in both nitrogen and phosphorus), and that the reservoirs experience strong thermal stratification accompanied by extensive algae blooms and an anoxic hypolimnion. To date, there has not been a comprehensive analysis of existing nutrient data, specifically with respect to development of nutrient mass-balance time-series for both reservoirs. These analyses allow evaluation of such factors as: additional input of nitrogen to the river system via nitrogen fixation by algae, conversion of organic nutrient forms to inorganic forms and visa versa, and alteration of seasonal phosphorus and nitrogen dynamics. The intent of this study is to provide a preliminary exploration of these factors by constructing mass-balance nutrient budgets using existing flow and nutrient data.

Study goals

The overall goals of this study were to 1) compile existing 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) identify data gaps to help design future studies. PacifiCorp, the Bureau of Reclamation, USFWS, and other agencies have collected extensive nutrient data on the Klamath River; however, this data has not yet been fully analyzed with respect to specific reservoir effect on nutrients.

A crucial step in determining the effect of reservoirs on water quality is the development of hydrologic and nutrient budgets on a seasonal basis. Our analysis will focus on assembling existing hydrologic (riverine discharge and reservoir volume data) and nutrient (riverine and in-reservoir concentrations of nitrogen and phosphors in total and dissolved forms) data. These data will be assembled for inflow, outflow, and in-reservoir stations for both Copco and Iron Gate Reservoirs. The construction of a nutrient budget involves combining nutrient concentration data with the hydrologic data to compute nutrient mass. When computed for reservoir inflow, outflow, and in-reservoir change in mass on a minimum of a monthly basis, such data can be used to determine temporal nutrient dynamics and determination of the relative fate of nutrients in project reservoirs.

Due to limitations in the spatial and temporal resolution of the available data (described in other sections of this report), the conclusions of the study should be considered preliminary. Detailed data are currently being collected by the State Water Resources Control Board (SWRCB; 2005-2006), and the analysis of those data, should provide more reliable conclusions with regard to the nutrient dynamics of Iron Gate and Copco Reservoirs. Aside from the construction of the nutrient budgets, this study was also useful in that it assembled additional data into an ongoing centralized database that will have lasting value and can be used for a variety of analyses.

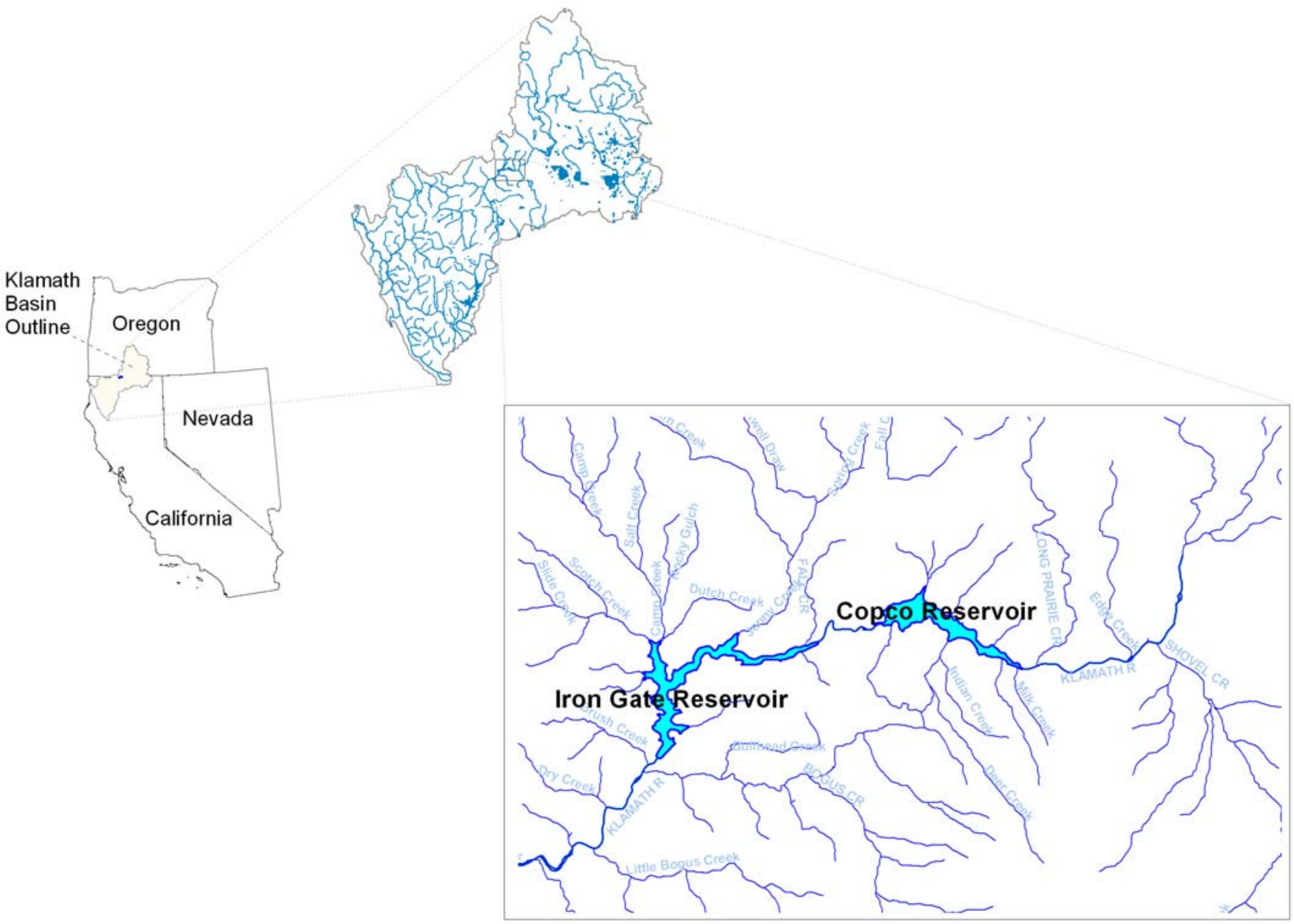


Fig. 1. Regional location of Iron Gate and Copco Reservoirs.

Review of Past and Current Nutrient Studies

An initial step in utilizing existing data to develop this preliminary analysis was a review of relevant past and current studies. Extensive amounts of water quality data have been collected in and around Iron Gate and Copco Reservoirs. Agencies involved in data collection include PacifiCorp, U.S. Geologic Survey (USGS), U.S. Fish and Wildlife Service (USFWS) Arcata Office, U.S. Bureau of Reclamation (USBR), U.S. Bureau of Land Management (BLM), U.S. Environmental Protection Agency (EPA), U.S. Forest Service, Karuk Tribe, North Coast Regional Water Quality Control Board (NCRWQCB), California Department of Water Resources and various private companies and contractors.

TMDL Study

The Oregon Department of Environmental Quality (DEQ) and California North Coast Regional Water Quality Control Board (NCRWQCB) are working cooperatively to develop Total Maximum Daily Loads (TMDLs) for the impaired waterbodies in the Klamath Basin, including the Lost River, Klamath Straits Drain and Klamath River from Link River to the Pacific Ocean (St. John, 2004). As part of this TMDL development effort, EPA/NCRWQCB contractors added to PacifiCorp's water quality database (Tetra Tech, 2004). As part of the study described in this report, significant additional Klamath basin water quality data were added to the existing database: California Department of Water Resources 2000-2004, PacifiCorp 2000-2003, U.S. Fish and Wildlife Service 2001-2004. The updated database is included as Appendix A and is being actively utilized by EPA/TetraTech/ NCRWQCB/Oregon Department of Environmental Quality in the development of the Mainstem Klamath TMDL.

EPA 1978 Iron Gate Eutrophication Study

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, but the reservoir itself was only sampled on three occasions. The analysis summed the incoming and outgoing loads for the year and concluded the annual mass of nitrogen outflow from Iron Gate Reservoir was 21% higher than inflow, and that annual outflow mass of phosphorus was 7% less than inflow. The study also found that the mainstem Klamath dominated the incoming loads, with less than 2% of the phosphorus load and 3% of the nitrogen load coming from tributaries. This study did not produce a true mass-based budget because in-reservoir mass was not included, and this study did not attempt to examine retention patterns as data were summed over the entire year.

PacifiCorp

PacifiCorp's (2004a) Final License Application presented limited water quality data; however, some important details were obscured by averaging data over broad spatial and temporal scales. In addition, they postulated that retention of organic matter and nutrients in the reservoirs results in a net decrease in organic matter and nutrients that would otherwise continue downstream (PacifiCorp 2004a). PacifiCorp contractor Watercourse Engineering (principal Mike Deas) is currently finishing up a water quality modeling effort for the Klamath River, utilizing a highly complex computer model to simulate water quality, including flow, temperature, dissolved oxygen, pH, nutrients and algae.

PacifiCorp's model has been adequately calibrated and verified for flow and temperature, and accuracy for these parameters has been shown to be good (for instance, to within approximately 1 degree Celsius for temperature). The model, however, has not been adequately calibrated or validated for more complex parameters such as dissolved oxygen, nutrients, and algae.

PacifiCorp released its first round of modeling in February 2004 (PacifiCorp, 2004a). After a review from Dr. Scott Wells of Oregon State University, PacifiCorp is revising and re-running all model scenarios. Modeling for the "existing condition" scenario was completed and released in April 2005 (PacifiCorp, 2005b), and additional scenarios are pending.

Sate Water Resources Control Board 2005-2006 Study

The SWRCB recently received a Clean Water Act Section 104(b) grant from the U.S. Environmental Protection Agency Region IX to conduct a nutrient cycling study on Iron Gate and Copco Reservoirs (Kanz, 2005).

Once collected, the data will be used to construct a detailed nutrient budget for each reservoir. Because nutrient data will be collected more frequently (every two weeks rather than monthly) and will encompass an entire year (rather than March to November), as well as include additional spatial coverage and algal sampling, the 2005 study is expected to be an improvement over the analysis of existing data described in this report. The study is expected to provide information on important reservoir processes that have not yet been evaluated, including seasonal patterns of nutrient flux and the potential for nitrogen fixation by blue-green algae.

Sampling began in May 2005 and will continue through May 2006, with final results available soon thereafter. Preliminary results may be released and incorporated into the Klamath TMDL in late 2005

DEVELOPMENT OF MASS-BALANCE ANALYSIS FOR WATER AND NUTRIENTS

Reservoir and inflow nutrient data

In-reservoir data

In preparation for its effort to relicense the Klamath Hydroelectric Project, PacifiCorp has collected a large amount of water quality data in the Klamath River Basin, including Iron Gate and Copco reservoirs. Sampling began in 2000 and is continuing through at least 2005. Nutrient data for 2000-2003 were released to the public (PacifiCorp, 2004b). In 2002, the year with the largest quantity of data collected, samples were taken approximately once monthly from March 27 to November 13. There was one site in each reservoir, located in the deepest section near the outlets of the reservoir

(Figure 2; Table 1). Given the increased consistency and frequency of data in 2002, this year was chosen as the test year for this mass-balance analysis.

Detailed information on standard operating procedures, analytical methods, and detection limits are contained in Water Resource Final Technical Report Appendix 3A of PacifiCorp's Final License Application (PacifiCorp, 2004a), and are briefly summarized here. Because the reservoirs thermally stratify, samples were taken at three depths intended to correspond with the epilimnetic (surface), metalimnetic (middle), and hypolimnetic (bottom) layers. Epilimnetic samples were always taken at a depth of one meter, but depths for metalimnetic and hypolimnetic samples varied. Parameters analyzed included biological oxygen demand (BOD), chlorophyll-a (CHLA), ammonia (NH3), nitrate-plus-nitrite (NO3), total Kjeldahl nitrogen (TKN), orthophosphate (PO4), and total phosphorus (TP). All sampling trips included at least one duplicate, a blank, and a sample spiked with a known concentration of the parameter to be analyzed.

Bathymetry information (underwater topography) was obtained from PacifiCorp as an ArcInfo Digital Elevation Model (DEM) grid (Scott, 2005), based on surveys by Eilers and Gubala (2003). We used the bathymetry grid to construct curves of the relationship between reservoir elevation (every 0.1 feet), volume, and surface area. The fact that bathymetric surveys were conducted on a day when the reservoirs were not completely full necessitated extrapolating to the outer edge of each reservoir. For Iron Gate, the extrapolation was conducted by assuming that the slope (5.6 feet measured vertically) of land above the surveyed water's edge had the same slope as the 5.6 feet extending below the water's edge. A similar extrapolation of 5.7 feet was conducted for Copco.

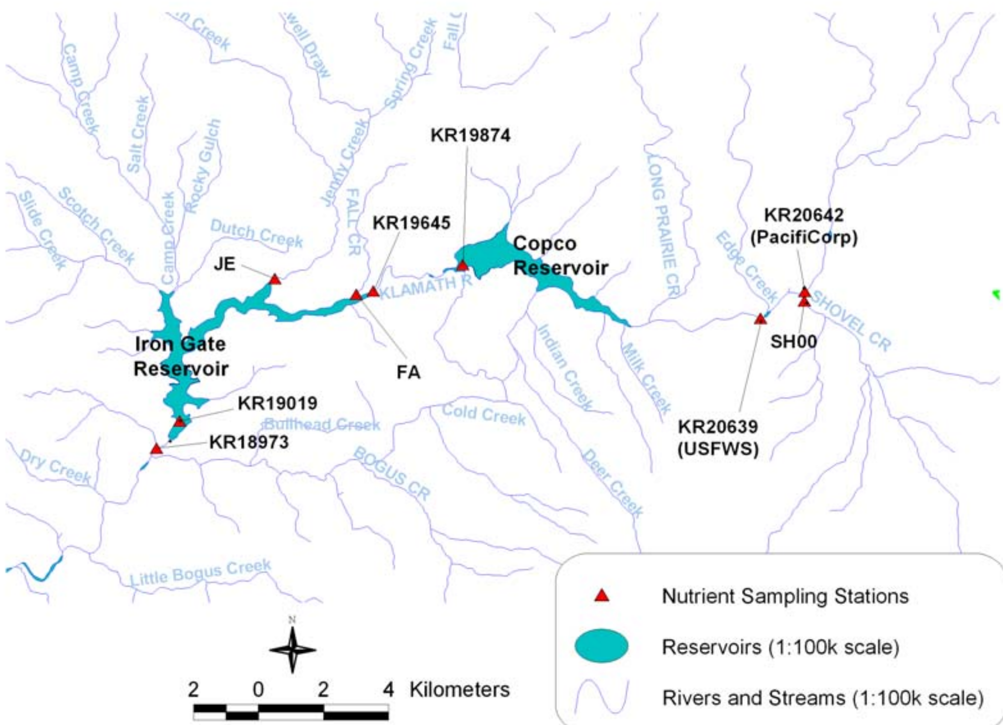


Fig. 2. Location of discharge measurements and nutrient sample sites for Copco and Iron Gate reservoir inflows and outflows.

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

Site ID	Description	Source
KR20642 / KR20639	Klamath River above Copco 1	PacifiCorp / USFWS
SR00	Shovel Creek	PacifiCorp
KR19874	Copco Lake near Copco	PacifiCorp
KR19645	Copco Dam Outflow (Iron Gate inflow)	PacifiCorp / USFWS
FA	Fall Creek	PacifiCorp
JE	Jenny Creek	PacifiCorp
KR19019	Iron Gate Reservoir	PacifiCorp
KR18973	Klamath River below Iron Gate Dam	PacifiCorp / USFWS

Table 2. Comparison of extrapolated and non-extrapolated elevation, surface area, and volume of Iron Gate and Copco Reservoirs, with comparison to numbers provided in the Final License Application (PacifiCorp, 2004a).

Reservoir	Parameter	Final License Application (normal full pool)	DEM (no extrapolation)	DEM (extrapolated to normal full pool)	DEM (extrapolated to max 1990-2004 stage height)
	Elevation (ft)	2607.5	2601.8	2607.5	2607.5
Copco	Surface Area (ft^2)	43560000	40416331	44043753	44043753
	Volume (ft^3)	2041526520	1467098063	1707951540	1707951540
	Elevation (ft)	2,328.0	2325.4	2,328.0	2330.9
Iron Gate	Surface Area (ft^2)	41120640	40597165	42325052	44300453
	Volume (ft^3)	2561066640	2215444780	2327452057	2453127929

The use of the measured nutrient data in mass-balance analyses required computing lake-wide mean nutrient concentration for each sample date. This was accomplished by 1) examining temperature and dissolved oxygen profiles to delineate reservoir layers represented by each sample, 2) utilizing the reservoir water surface elevation–volume curve to assign a volume to this layer, 3) multiplying layer volume by nutrient concentration to determine nutrient mass (kg) for each layer, and 4) summing the mass in each of the layers and dividing total mass by total reservoir volume. Reservoir-wide mean nutrient concentrations are contained in Appendix J.

Inflow data

In 2002, PacifiCorp collected nutrient samples on the Klamath River and tributaries to Iron Gate and Copco on the same days that it collected in-reservoir samples. Samples were collected once a month from March 27 to November 13. Sites included the Klamath River above Copco Reservoir, the outlet of Copco 2, the Klamath River below Iron Gate Dam, Fall Creek, Jenny Creek, and Shovel Creek (Fig. 2; Table 1, raw data contained in Appendix I). Because no samples were collected from Camp Creek, Camp Creek nutrient concentrations were estimated by assuming concentrations to be the same as Jenny Creek (its nearest neighbor for which there was data). The U.S. Fish and Wildlife Service also collected samples approximately bi-weekly from early June through mid-September in the Klamath River above Copco Reservoir, at the outlet of Copco 2, and in the Klamath River below Iron Gate Dam (Armstrong and Ward, 2005; ARFO, 2005; Turner, 2005). For dates when both USFWS and PacifiCorp data coincided (which occurred on two days in the Klamath River below Iron Gate Dam), an average value was used to characterize that date.

Both lake 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. Because no sample was collected for Shovel Creek on the first sampling date (March 27), the April 14 concentrations were substituted for the March 27 – April 13 period.

Nutrient parameters utilized in this study included: ammonia (NH_3-N), nitrate-plus-nitrite (NO_2+NO_3-N), total Kjeldahl nitrogen (TKN), orthophosphate (PO_4), and total phosphorus (TP). Total nitrogen was computed as TKN plus NO_2+NO_3-N, organic N as TKN minus NH_3-N, and total inorganic nitrogen (TIN) as NO_2+NO_3-N + NH_3-N. All sampling trips included at least one duplicate, blank, and a sample spiked with a known concentration of the parameter to be analyzed. Reporting limits were similar between the portions of the PacifiCorp and USFWS datasets that were used for the nutrient budgets (Tables 3 and 4). The original USFWS data set contained numerous samples with high reporting limits. However, these were excluded from data utilized in construction of the nutrient budgets; data excluded were non-detect samples for total Kjeldahl nitrogen with reporting limits of 0.5 or 1.0 mg/L, and non-detect ammonia samples with a reporting limit of 0.2 mg/L. These reporting limits are high relative to values expected for the system, such that setting the values for these non-detect samples at one half the reporting limit (as was done did for other non-detect samples in the dataset) introduces more error than simply excluding the data.

Table 3. Reporting limits for PacifiCorp 2002 nutrient samples, from PacifiCorp (2004a).

Parameter Code	Parameter	Reporting Limit (mg/L)
NH3	Ammonia	0.05
NO3	Nitrate + Nitrite as N	0.05
TKN	Total Kjeldahl Nitrogen	0.1
PO4	Orthophosphate	0.05
TP	Total Phosphorus	0.02

Table 4. Reporting limits for USFWS 2002 nutrient samples used in the nutrient budget.

Parameter Code	Parameter	Reporting Limit (mg/L)	Number of samples
NH3_Total	Ammonia Nitrogen	0.1	31
NO2_Total	Nitrite (as Nitrogen)	0.05	30
NO3_Total	Nitrate (as Nitrogen)	0.05	30
PO4_Total	Orthophosphate Phosphorus	0.01	30
TKN	Nitrogen- Total Kjeldahl	0.1	29
TP	Total Phosphate Phosphorus	0.02	30

Reservoir and inflow hydrologic data

Reservoir data

Daily reservoir elevation data for the years 1990-2004 were obtained from PacifiCorp, who submitted the data to FERC. PacifiCorp records elevations at Iron Gate and Copco Reservoirs hourly with an automated gage, but we were only able to obtain the 8 a.m. reading. 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 from a rain gage operated in Montague by the Siskiyou County Air Pollution Control District (NADP/NTN Monitoring Location CA76: sponsored by the USGS and published on the National Atmospheric Deposition Program (2005) website: www.nadp.sws.uiuc.edu/sites/siteinfo.asp?id=CA76&net=NTN). Precipitation volume entering the lake was then computed for each day by multiplying precipitation by lake surface area. Lake surface area was computed from elevation–surface area curves derived from bathymetric surveys by Eilers and Gubala (2003).

Other precipitation data considered but not used were the California Department of Forestry's Brazie Ranch station (station ID "BRZ"), available in real-time on the CDEC website. However, these data were not QAQC'd and appeared to have reliability issues. The U.S. Bureau of Land Management (2005) operates a rain gage at Jenny Creek several miles upstream from Iron Gate reservoir, but this station is located at approximately 3000 feet elevation, significantly higher than Iron Gate and Copco reservoirs. The U.S. Forest Service (2005) rain gage at Yreka (station ID "YRK") publishes monthly data available for downloaded from the California Data Exchange Center (CDEC) website.

Daily class A pan evaporation data obtained from the Oregon State University (OSU, 2005) Klamath Experiment Station located in Klamath Falls were corrected to approximate open-water evaporation by multiplying by 0.7 (Farnsworth et al. 1982). These data were only available for May-September, so long-term mean monthly evaporation values for the same station (WRCC, 2005) were used to fill in missing observations during the months of January, February, March, April, October, and December. Where monthly data were used, data were divided by the number of days in each month. No data were available for November, so evaporation was assumed to be zero for all days in that month. Evaporative loss from the lake surface was computed by multiplying daily open-water evaporation estimates by lake surface area to obtain total daily volume lost.

Inflow data

Streamflow data for the Klamath River below J.C. Boyle Powerhouse (USGS gage 11510700) were obtained from USGS (website: http://waterdata.usgs.gov/usa/nwis/uv?site_no=11510700), and data from this site were used as the hydrologic inflow to Copco Reservoir. The gage is located 16 miles upstream from Copco Reservoir, and although travel time from the gage to Copco Reservoir is unknown, based on PacifiCorp (2004a) modeling results the travel time is estimated to be approximately 1/2 day. Travel time likely introduced some errors at a daily time scale, but the daily errors should cancel each other out across longer time scales. Had more detailed information on travel times at various flows been available, hourly hydrologic data could have been adjusted to account for travel time thus improving data accuracy.

Discharge data were not available for Shovel Creek, the only significant tributary flowing into the Klamath River between Copco Reservoir and USGS site 11510700. A monthly hydrograph was synthesized for this station by assuming a summer base flow of 5 cfs (based on Karuk Tribe measured flow in Shovel Creek at 5 cfs in early July 2005), and that the hydrograph peaks with snowmelt in April at 50 cfs (rough estimate based on watershed size and stream characteristics).

Daily lake outflow volume for Copco Reservoir (station KR19645 Table 1; also the inflow to Iron Gate) was obtained from PacifiCorp (2005a). Daily outflow from Iron Gate reservoir was computed by adding together spillway and turbine flows releases, obtained from PacifiCorp (2005a), with releases to the Iron Gate Hatchery, obtained from the Department of Fish and Game (Rushton pers. comm.). Data were also obtained for the Klamath River below Iron Gate Dam (USGS gage number 11516530), but these data were not used because they also contain flows from Bogus Creek, which is not an outlet from Iron Gate, and there are no reliable flow records for Bogus Creek.

Flow data for Jenny Creek were obtained from the BLM (2005) station located approximately 1 mile below the confluence of Spring Creek and Jenny Creek. It is unknown if there are any significant water diversions in the approximately 4 miles of Jenny Creek between the gage and Iron Gate reservoir. Flows over ~ 80 cfs are extrapolated because no measurements were taken during high flow events that prevent wading. Such flows did occur often from early January through early May.

Monthly average Fall Creek flow values were calculated from a flow gage operated by USGS from 1933 to 1959. These values were then adjusted downward to incorporate the City of Yreka's municipal diversion municipal use. Monthly total diversion records from 2002 were obtained from the City of Yreka (Taylor, pers. comm.) and these were subtracted from average 1933-1959 monthly flows. 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 no flow measurements were taken in Camp Creek for the year 2002, measurements taken once per month in 1975 (EPA 1978) were used to estimate flows for input to the hydrologic budget.

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:

$$\text{Hydrologic Residual} = \text{outflow} + \text{evaporation} + \Delta\ \text{lake storage} - \text{tributary inflow} - \text{precipitation}$$

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

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 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 inputs (the sum of wetfall and dryfall) 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).

Nutrient retention

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

$$\text{Net Retention} = \text{tributary inputs} + \text{atmospheric inputs} - \text{outputs} - \Delta\ \text{reservoir storage}$$

Net retention reflects 1) net losses from the water column resulting from sedimentation, 2) atmospheric fixation (nitrogen), 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.

Caveats (discussion of data limitations)

While this study can provide a good preliminary analysis yielding valuable insight into nutrient dynamics of the reservoirs, compilation and analysis of the available data described above indicated several limitations in the data that should be discussed at the outset. The limitations outlined below are being addressed in the current SWQCB nutrient study being performed on the reservoirs.

<u>Temporal resolution</u>

Partial year of data not including full turnover

The available data utilized for this analysis covers only part of the year 2002 (March 27 to November 13). Although this interval does span the summer algal growing season, it did not incorporate complete turnover in Iron Gate reservoir (see Appendix I for data). The temperature and dissolved oxygen profiles from the last sampling date, November 13, indicate that while stratification had become much less pronounced, anoxic conditions were still present in the deepest parts of the reservoir (top to bottom temperature difference was ~4°C). Temperature and dissolved oxygen profiles from same date in Copco Reservoir indicate that stratification was less pronounced than Iron Gate; however, low dissolved oxygen was still evident at the deepest sample in the reservoir.

Sampling frequency

Nutrient samples were collected approximately once per month at the in-reservoir sampling sites in Iron Gate and Copco Reservoirs. An examination of volume-weighted nutrient concentrations in the reservoirs shows substantial differences between sampling dates, with concentrations changing by up to a factor of three between samples. Based on these differences and data from other productive reservoir systems, it is highly likely that changes in algae and nutrients occur at a shorter timescale than monthly. Thus, in general a minimum of biweekly sampling is recommended to determine both among and within seasonal variation in nutrient sources and sinks.

PacifiCorp's monthly sampling frequency for samples collected at small tributaries such as Fall, Jenny, and Shovel Creeks is likely to be adequate because flow and nutrients concentrations of these tributaries are small relative to the mainstem Klamath River. A possible exception to this is Jenny Creek which has the potential to contribute higher loading during the late March through early May period of high-flow. Future studies should pay special attention to Jenny Creek during the high-flow months in winter and spring.

The temporal resolution of sampling at the river inflows and outflows from Iron Gate and Copco reservoirs was greater than at in-reservoir sites, with samples taken approximately once every two weeks during the USFWS sampling season from June 4 through September 17 (plus a May 21 sample in the Klamath River below Iron Gate). USFWS and PacifiCorp did not coordinate the timing of their sampling events, so there are major variations in the intervals between sampling events, ranging between 1 and 20 days, with a mean of 10 days. Outside of the USFWS sampling season, samples were collected once per month which is likely to be suboptimal for capturing fall turnover dynamics. Summaries of the timing of sample collection are contained in appendices F and G.

Spatial/Vertical resolution

Vertical resolution

In 2002 PacifiCorp sampled at one station in each reservoir, with additional samples collected at three depths to represent the epilimnion, metalimnion, and hypolimnion. PacifiCorp recognized that 3 samples may not adequately characterize vertical variability (pers. comm. Mike Deas-Watercourse Engineering), and in sampling conducted subsequent to 2002, samples have been collected at 5 depths in Copco and 6 depths in Iron Gate. Such increased resolution is necessary to encompass nutrient variability that occurs within a designated stratified layer.

Possibly due to sampling gear limitation, the deepest 2002 PacifiCorp samples were taken at 25 m and 30 m in Copco and Iron Gate, respectively. These depths do not encompass the deepest layers of the hypolimnion, with the average distance between the hypolimnion sample depth and the reservoir bottom depth at 7.09 m (23 ft) in Copco and 16.02 (53 ft) meters in Iron Gate. Although the lower 7.09 meters of Copco Reservoir represent only 0.3% of its total volume, the lower 16.02 meters in Iron Gate Reservoir represent 6.5% of its total volume (see Appendix H for details). Thus, given high nutrient concentrations expected for the lowermost layer of the hypolimnion, it is likely for Iron Gate that absence of data for the lower 16 m has the potential to skew mass calculations.

Spatial resolution
There is also evidence to indicate that nutrient concentrations in the reservoirs vary spatially as well as vertically. For example, the EPA (1978) collected data in Iron Gate reservoir in 1975 at four to six depths at two sites on three sampling dates. These data indicate variation in nutrient concentrations between the sites on all three sampling dates, sometimes even exceeding the variation between surface and bottom.

Because change in reservoir nutrient mass is a critical component of the mass-balance approach used to determine nutrient retention, an accurate characterization of spatial and vertical variability is essential.

<u>Reservoir elevation data</u>

As noted above, although hourly lake elevation data for the years 1990-2004 were collected by PacifiCorp, we were only able to obtain the 8 a.m. reading. Utilizing only 8 a.m. stage has the potential to introduce error to the hydrologic and nutrient budgets through calculation of budget terms that rely on changes in reservoir volume (e.g., Δ reservoir storage). Although some of these errors are likely to be small because errors from adjacent days tend to cancel each other out (stage measurement was taken at exactly the same time each day), access to hourly elevation would increase the accuracy of budget calculations.

WATER AND NUTRIENT BUDGETS

Hydrologic Budget

Although nutrient data were only available from March 27^{th} to November 6^{th}, hydrologic data were available for the entire 2002 calendar year. Only the portion coinciding with the Mar-Nov period was used to construct the nutrient budgets; however, graphical representations for hydrology are shown for the entire calendar year. 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.

<u>Copco Reservoir</u>
Daily time series for major water balance terms for Copco Reservoir are presented in Figs. 3-6 and Appendix E. As expected for a mainstem reservoir, inflow to Copco was dominated by the Klamath River, which showed a pronounced late-winter/spring runoff peak, and then declined to summer minimum flows that are influenced by upstream irrigation withdrawal (Fig. 3c). Shovel Creek represented only a small portion of the total inflow, ranging between <1 to 3.2% of the total inflow for the Apr-Nov period (Table 5).

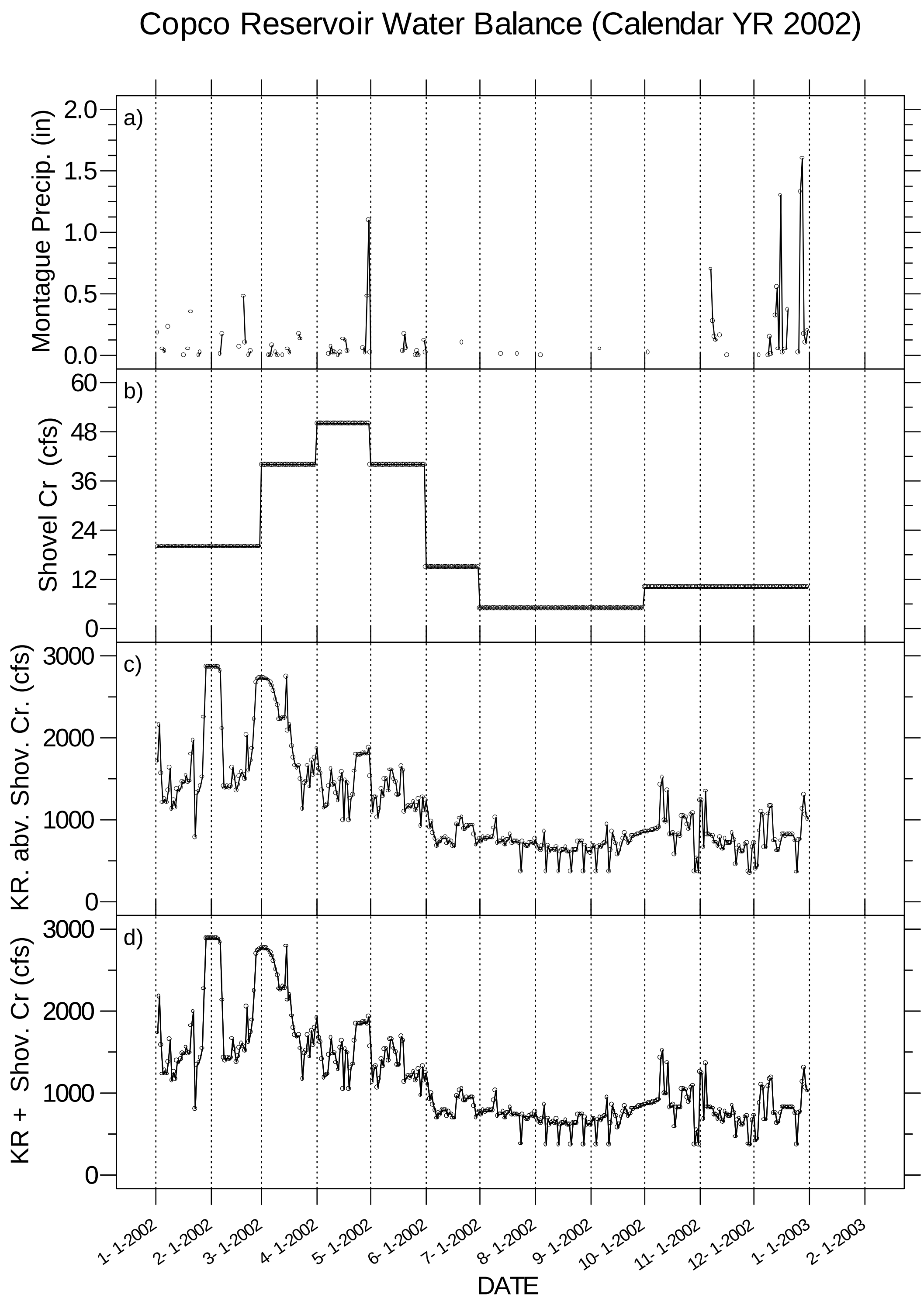


Fig. 3. Daily time series of Copco Reservoir water balance input terms, 2002.

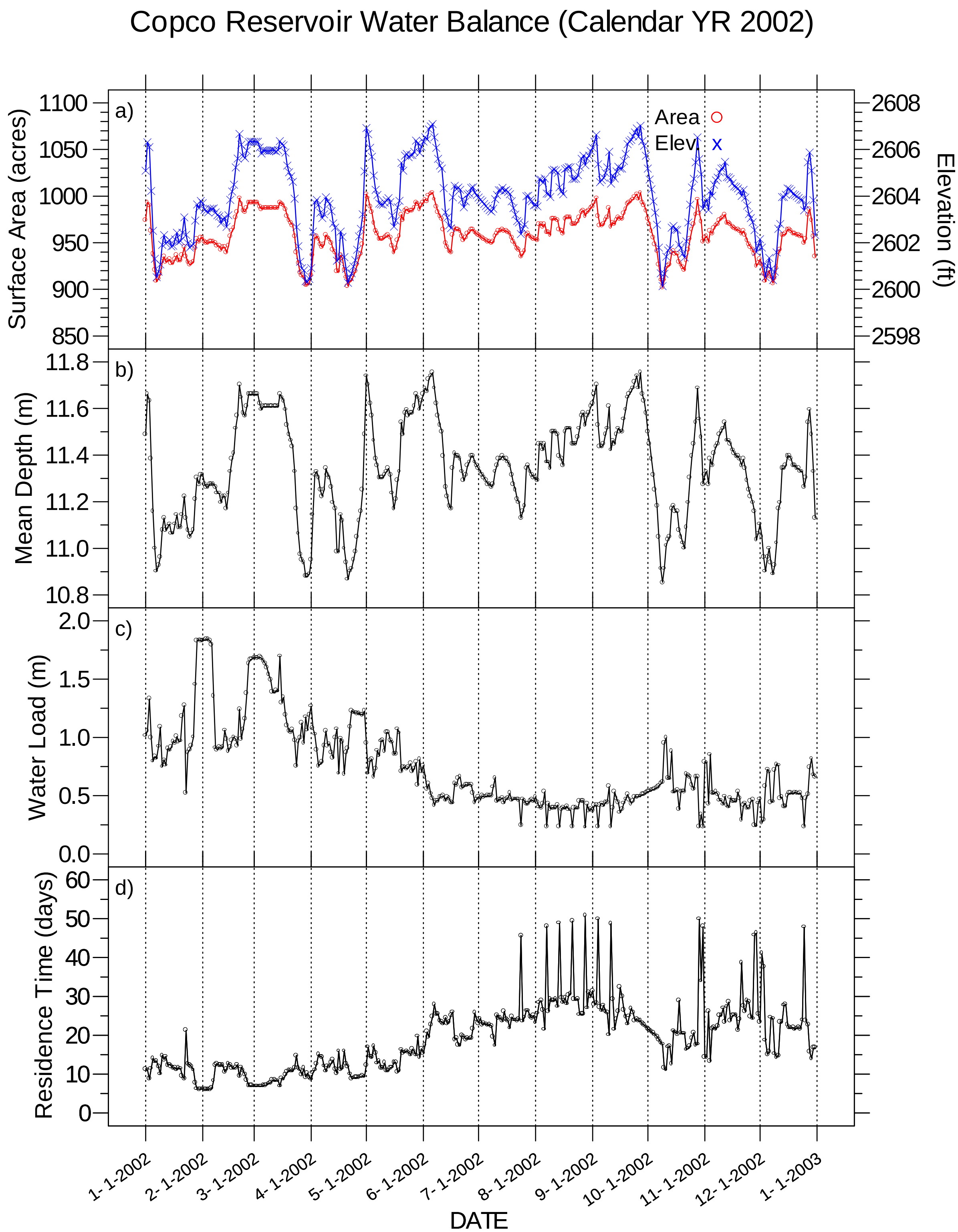


Fig. 4. Daily time series of Copco Reservoir water balance reservoir terms, 2002.

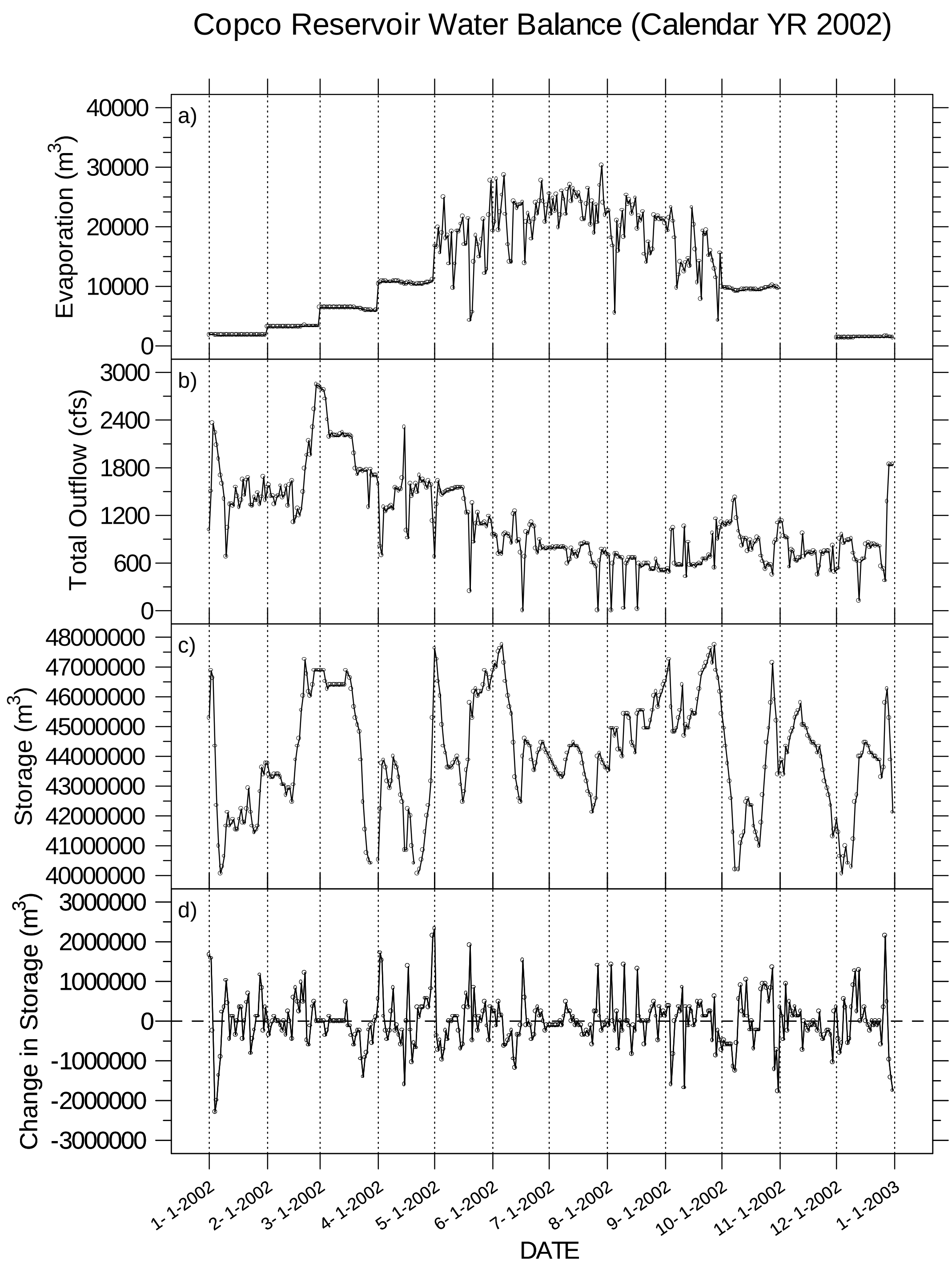


Fig. 5. Daily time series of Copco Reservoir water balance reservoir terms and outflow, 2002.

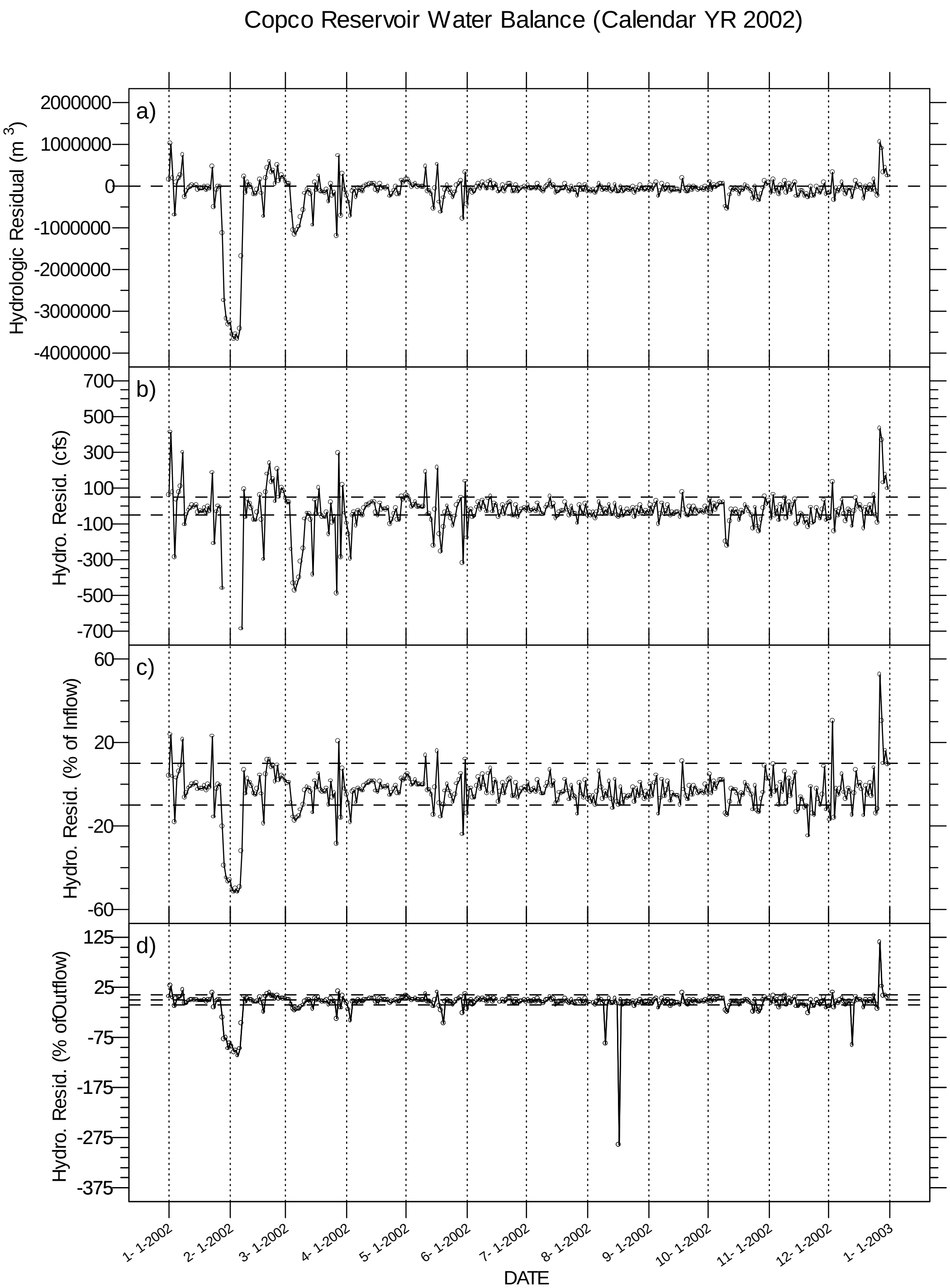


Fig. 6. Daily time series of Copco Reservoir water balance; hydrologic residual, 2002.

Table 5. Partial year (Apr-Nov) and monthly flow and nutrient mass-balance for Copco Reservoir, 2002.

						LOADS						LOADS						Flow-weighted mean concentration					
Month	Term	hm3	acre-feet	mean cfs	% total	metric tons						%						ppb					
						TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN
Totals *	Klamath above Copco	523	423891	941	98%	134.68	80.54	54.14	596.77	226.81	369.96	98%	98%	98%	99%	100%	100%						
April 1 -	Shovel Creek	10	8116	18	1.9%	2.93	1.89	1.04	1.51	0.73	0.78	2%	2%	2%	0%	0%	0%						
Nov 13.	Tributary inflow	533	432006	959	100%	137.61	82.43	55.18	598.28	227.54	370.74	100%	100%	100%	100%	100%	100%	258	155	104	1123	427	696
	Precip.	0	333	1	0.08 %	0.04	0.00	0.00	2.61	0.00	0.00	0%	0%	0%	0%	0%	0%						
	Total inflow	533	432339	960	100%	137.65	82.43	55.18	600.89	227.54	370.74	100%	100%	100%	100%	100%	100%	258	155	104	1127	427	695
	Evaporation	3.63	2864	47.2																			
	Net inflow	532	432289	910		137.65	82.43	55.18	600.89	227.54	370.74												
	Klamath below Copco	508	412120	915		118.22	78.07	40.15	531.47	134.33	397.14							233	154	79	1046	264	782
	Storage increase	24	20169	-5		-16.86	-2.61		21.22	16.97	4.25												
	Retent.					36.29	6.97		48.20	76.23	-30.65	26%	8%		8%	34%	-8%						
Apr	Klamath River above Copco 1	110	89218	1499	97%	48.51	20.65	27.86	114.45	33.58	80.88	97%	96%	98%	99%	99%	100%	441	188	253	1040	305	735
	Shovel Creek	4	2976	50	3.2%	1.61	0.95	0.66	0.33	0.20	0.13	3%	4%	2%	0%	1%	0%	439	260	179	90	54	37
	Tributary inflow	114	92194	1549	100%	50.12	21.60	28.52	114.78	33.77	81.01	100%	100%	100%	100%	100%	100%	441	190	251	1010	297	713
	Precip.	0	166	3	0.18 %	0.01	0.00	0.00	0.34	0.00	0.00	0%	0%	0%	0%	0%	0%						
	Total inflow	114	92360	1552	100%	50.13	21.60	28.52	115.12	33.77	81.01	100%	100%	100%	100%	100%	100%	440	190	250	1011	297	711
	Evaporation	.318	258	4.3																			
	Net inflow	113	92310	1502		50.13	21.60	28.52	115.12	33.77	81.01												
	Klamath below Copco	105	85279	1433		30.24	20.22	10.02	99.64	25.45	74.19							288	192	95	948	242	706
	Storage increase	8	7032	69		-11.84	-1.53		-0.27	-1.00	0.74												
	Retent.					31.73	2.92		15.75	9.33	6.09	63%	14%		14%	28%	8%						
May	Klamath above Copco	98	79703	1296	97%	23.48	14.97	8.51	85.25	21.45	63.80	96%	97%	96%	99%	99%	99%	239	152	87	867	218	649
	Shovel	3	2460	40	3.0%	0.87	0.51	0.37	0.59	0.23	0.36	4%	3%	4%	1%	1%	1%	288	168	120	196	77	119

						LOADS						LOADS						Flow-weighted mean concentration					
Month	Term	hm3	acre-feet	mean cfs	% total	metric tons						%						ppb					
						TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN
	Creek																						
	Tributary inflow	101	82164	1336	100%	24.35	15.48	8.88	85.84	21.68	64.16	100%	100%	100%	100%	100%	100%	240	153	88	847	214	633
	Precip.	0	35	1	0.04 %	0.01	0.00	0.00	0.36	0.00	0.00	0%	0%	0%	0%	0%	0%						
	Total inflow	101	82199	1336	100%	24.36	15.48	8.88	86.20	21.68	64.16	100%	100%	100%	100%	100%	100%	240	153	88	851	214	633
	Evaporation	.53	430	6.9																			
	Net inflow	100	82149	1286		24.36	15.48	8.88	86.20	21.68	64.16												
	Klamath below Copco	97	79046	1285		16.13	11.32	4.80	71.25	13.45	57.80							165	116	49	731	138	593
	Storage increase	3	3103	1		-1.37	-0.89		-0.64	-4.24	3.59												
	Retent.					9.60	5.04		15.59	12.47	2.76	39%	33%		18%	58%	4%						
Jun	Klamath above Copco	62	50533	849	98%	17.29	10.40	6.90	70.90	19.26	51.63	99%	99%	98%	99%	100%	100%	278	167	111	1138	309	829
	Shovel Creek	1	893	15	1.7%	0.25	0.10	0.14	0.33	0.07	0.26	1%	1%	2%	0%	0%	0%	223	93	130	296	62	234
	Tributary inflow	63	51426	864	100%	17.54	10.50	7.04	71.22	19.33	51.89	100%	100%	100%	100%	100%	100%	277	166	111	1123	305	818
	Precip.	0	10	0	0.02 %	0.01	0.00	0.00	0.35	0.00	0.00	0%	0%	0%	0%	0%	0%						
	Total inflow	63	51435	864	100%	17.55	10.50	7.04	71.57	19.33	51.89	100%	100%	100%	100%	100%	100%	277	166	111	1129	305	818
	Evaporation	.66	533	9																			
	Net inflow	62	51385	814		17.55	10.50	7.04	71.57	19.33	51.89												
	Klamath below Copco	64	51737	869		15.06	7.73	7.33	68.85	9.49	59.36							236	121	115	1079	149	931
	Storage increase	-1	-352	-55		5.08	3.42		8.30	4.68	3.62												
	Retent.					-2.60	-0.66		-5.59	5.15	-11.09	-15%	-6%		-8%	27%	-21%						
Jul	Klamath above Copco	56	45648	742	99%	14.12	10.15	3.97	75.14	30.90	44.24	100%	100%	99%	99%	100%	100%	251	180	71	1335	549	786
	Shovel Creek	0	308	5	0.7%	0.06	0.04	0.02	0.09	0.04	0.05	0%	0%	1%	0%	0%	0%	166	105	62	229	109	120
	Tributary inflow	57	45955	747	100%	14.18	10.19	3.99	75.23	30.94	44.29	100%	100%	100%	100%	100%	100%	250	180	70	1328	546	782
	Precip.	0	2	0	0.00 %	0.01	0.00	0.00	0.35	0.00	0.00	0%	0%	0%	0%	0%	0%						
	Total inflow	57	45957	747	100%	14.19	10.19	3.99	75.58	30.94	44.29	100%	100%	100%	100%	100%	100%	250	180	70	1334	546	782

						LOADS						LOADS						Flow-weighted mean concentration					
Month	Term	hm3	acre-feet	mean cfs	% total	metric tons						%						ppb					
						TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN
	Evaporation	.74	602	9.8																			
	Net inflow	56	45907	697		14.19	10.19	3.99	75.58	30.94	44.29												
	Klamath below Copco	55	44352	721		12.68	9.05	3.62	66.73	13.25	53.48							232	166	66	1220	242	978
	Storage increase	1	1555	-24		-2.71	3.38		-5.79	5.01	-10.80												
	Retent.					4.21	-2.25		14.65	12.69	1.61	30%	-22%		19%	41%	4%						
Aug	Klamath above Copco	47	38344	623	99%	9.81	7.43	2.38	47.67	22.29	25.38	100%	99%	100%	99%	100%	100%	207	157	50	1008	472	537
	Shovel Creek	0	308	5	0.8%	0.03	0.04	-0.01	0.05	0.06	-0.01	0%	1%	0%	0%	0%	0%	92	118	-26	130	150	-20
	Tributary inflow	48	38651	628	100%	9.84	7.48	2.37	47.72	22.35	25.37	100%	100%	100%	99%	100%	100%	207	157	50	1001	469	532
	Precip.	0	0	0	0.00 %	0.01	0.00	0.00	0.36	0.00	0.00	0%	0%	0%	1%	0%	0%						
	Total inflow	48	38651	628	100%	9.85	7.48	2.37	48.08	22.35	25.37	100%	100%	100%	100%	100%	100%	207	157	50	1009	469	532
	Evaporation	.62	503	8.2																			
	Net inflow	47	38601	578		9.85	7.48	2.37	48.08	22.35	25.37												
	Klamath below Copco	42	33941	552		9.83	6.42	3.41	39.53	14.94	24.59							235	153	81	945	357	588
	Storage increase	5	4661	27		-2.35	-0.21		5.02	5.08	-0.06												
	Retent.					2.37	1.27		3.53	2.33	0.83	24%	17%		7%	10%	3%						
Sep	Klamath above Copco	53	42590	715	99%	10.54	6.88	3.66	57.90	20.30	37.60	100%	99%	101%	99%	100%	100%	201	131	70	1103	387	716
	Shovel Creek	0	298	5	0.7%	0.02	0.06	-0.03	0.03	0.04	-0.01	0%	1%	-1%	0%	0%	0%	64	154	-90	78	99	-21
	Tributary inflow	53	42887	720	100%	10.56	6.93	3.63	57.93	20.34	37.59	100%	100%	100%	99%	100%	100%	200	131	69	1095	385	711
	Precip.	0	4	0	0.01 %	0.01	0.00	0.00	0.35	0.00	0.00	0%	0%	0%	1%	0%	0%						
	Total inflow	53	42892	721	100%	10.57	6.93	3.63	58.28	20.34	37.59	100%	100%	100%	100%	100%	100%	200	131	69	1102	385	711
	Evaporation	.47	379	6.4																			
	Net inflow	52	42842	671		10.57	6.93	3.63	58.28	20.34	37.59												
	Klamath below Copco	51	41209	692		15.02	6.61	8.41	77.14	11.12	66.02							296	130	165	1518	219	1299
	Storage increase	1	1633	-22		-2.25	-3.69		1.33	-2.81	4.14												

						LOADS						LOADS						Flow-weighted mean concentration					
Month	Term	hm3	acre-feet	mean cfs	% total	metric tons						%						ppb					
						TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN
	Retent.					-2.20	4.01		-20.19	12.03	-32.57	-21%	58%		-35%	59%	-87%						
Oct	Klamath above Copco	68	55404	901	99%	7.89	7.08	0.81	104.07	55.38	48.69	99%	98%	114%	100%	100%	100%	116	104	12	1523	811	713
	Shovel Creek	1	615	10	1.1%	0.05	0.15	-0.10	0.06	0.07	-0.01	1%	2%	-14%	0%	0%	0%	68	204	##	81	93	-12
	Tributary inflow	69	56019	911	100%	7.95	7.23	0.71	104.13	55.45	48.68	100%	100%	100%	100%	100%	100%	115	105	10	1508	803	705
	Precip.	0	2	0	0.00 %	0.01	0.00	0.00	0.35	0.00	0.00	0%	0%	0%	0%	0%	0%						
	Total inflow	69	56021	911	100%	7.95	7.23	0.71	104.48	55.45	48.68	100%	100%	100%	100%	100%	100%	115	105	10	1513	803	705
	Evaporation	.3	241	3.9																			
	Net inflow	68	55971	861		7.95	7.23	0.71	104.48	55.45	48.68												
	Klamath below Copco	68	55466	902		14.98	12.56	2.42	77.65	29.73	47.91							219	184	35	1135	435	701
	Storage increase	0	505	-41		-1.86	-2.65		5.85	4.98	0.87												
	Retent.					-5.17	-2.68		20.98	20.73	-0.10	-65%	-37%		20%	37%	0%						
Nov*	Klamath above Copco	28	22452	870	98%	3.05	2.99	0.05	41.39	23.65	17.74	99%	99%	109%	100%	100%	100%	110	108	2	1495	854	641
Nov 1 -	Shovel Creek	0	258	10	1.1%	0.02	0.03	0.00	0.03	0.03	0.00	1%	1%	-9%	0%	0%	0%	66	80	-14	98	89	9
Nov 13.	Tributary inflow	28	22710	880	99%	3.07	3.02	0.05	41.42	23.68	17.75	100%	100%	100%	100%	100%	100%	109	108	2	1479	846	634
	Precip.	0	114	4	0.50 %	0.00	0.00	0.00	0.15	0.00	0.00	0%	0%	0%	0%	0%	0%						
	Total inflow	28	22824	885	100%	3.07	3.02	0.05	41.58	23.68	17.75	100%	100%	100%	100%	100%	100%	109	107	2	1477	841	631
	Evaporation	0	0	0																			
	Net inflow	27	22774	835		3.07	3.02	0.05	41.58	23.68	17.75												
	Klamath below Copco	26	21091	818		4.29	4.14	0.15	30.69	16.91	13.78							165	159	6	1180	650	530
	Storage increase	1	1683	17		0.44	-0.44		7.42	5.28	2.14												
	Retent.					-1.66	-0.69		3.47	1.49	1.83	-54%	-23%		8%	6%	10%						

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. 4). These computations show mean depth to fluctuate a maximum of 0.9 m, with less variation occurring during the Jul-Sep period (Fig. 4b). Water load and residence time are inversely proportional and residence time is on the order of ~10 days during the winter and spring, increasing to 25-30 days during the summer (Fig. 4d).

Given small surface area relative to total reservoir volume, evaporation represented 0.7% of the outflow volume over the season, peaking in July at a cfs equivalent of 9.8 (Fig. 5a; Table 5). The general trend of total outflow mirrors that of total inflow during the Apr-Nov period, and reservoir storage and change in storage fluctuate on a seasonal and daily basis to meet PacifiCorp hydropower needs and minimum in-stream flows for fish (Figs. 5b,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. Aside from large residuals occurring in February and early March (Fig. 6a; outside the Apr-Nov period of this study), the residual term was generally within ±50 cfs for the period encompassing this analysis (Fig. 6b). This translates to values that tended to be ±10 % of either inflow and outflow volumes (Figs. 6c,d). Various spikes exceeding the ±10 % 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.

<u>Iron Gate Reservoir</u>
Daily time series for major water balance terms for Iron Gate Reservoir are presented in Figs. 7-10 and Appendix E. 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 late-winter/spring runoff peak, and then declined to summer low flows (Fig. 7c). Tributaries were more important than they were for Copco Reservoir, contributing ~9% for the Apr-Nov period, and as much as 15% during the April snowmelt period (Table 6). However, see caveats above regarding Jenny Creek high flow estimates. Copco outflow contributed 92-95% 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. 8). These computations show mean depth to fluctuate a maximum of 0.3 m, with less variation occurring during the Jul-Sep period (Fig. 8b). Daily spikes >300 days in residence time appear to be driven by sharply reduced water load as regulated by Copco outflow (Fig. 8c,d). However, aside from these spikes, residence time is on the order of ~10-20 days during the winter and spring, increasing to 30-40 days during the summer (Fig. 8d).

As with Copco, evaporation represented only a small portion of the total outflow volume (0.6% over the season), peaking in July at a cfs equivalent of 9.6 (Fig. 9a; Table 6). However, unlike Copco Reservoir, Iron Gate outflow fluctuation is muted relative to inflow (Fig. 9b). Reservoir storage and change in storage fluctuates on a seasonal and daily basis to meet PacifiCorp hydropower needs and minimum in-stream flows for fish (Figs. 9b,c,d).

Irongate Reservoir Water Balance (Calendar YR 2002)

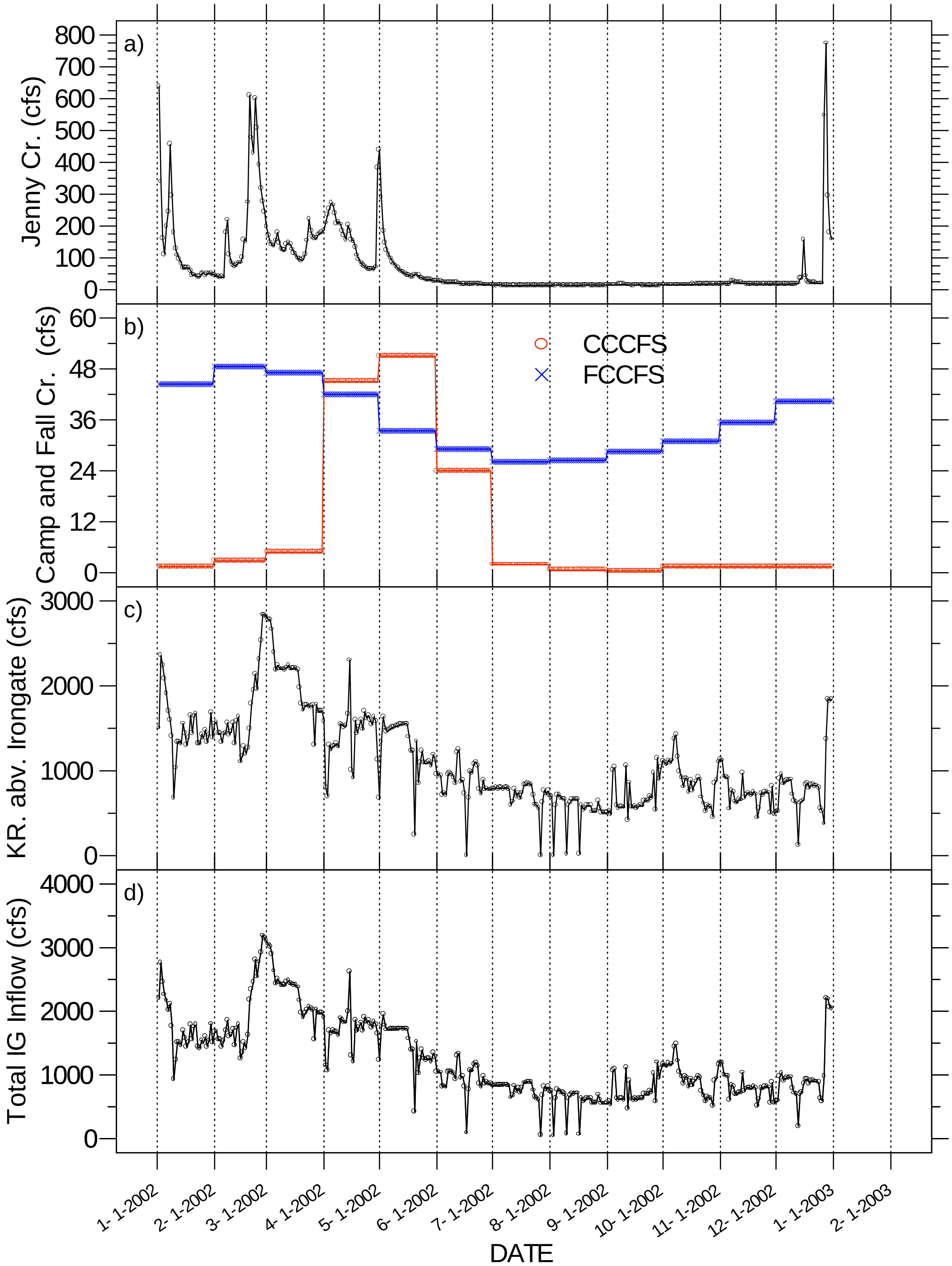


Fig. 7. Daily time series of Iron Gate Reservoir water balance input terms, 2002.

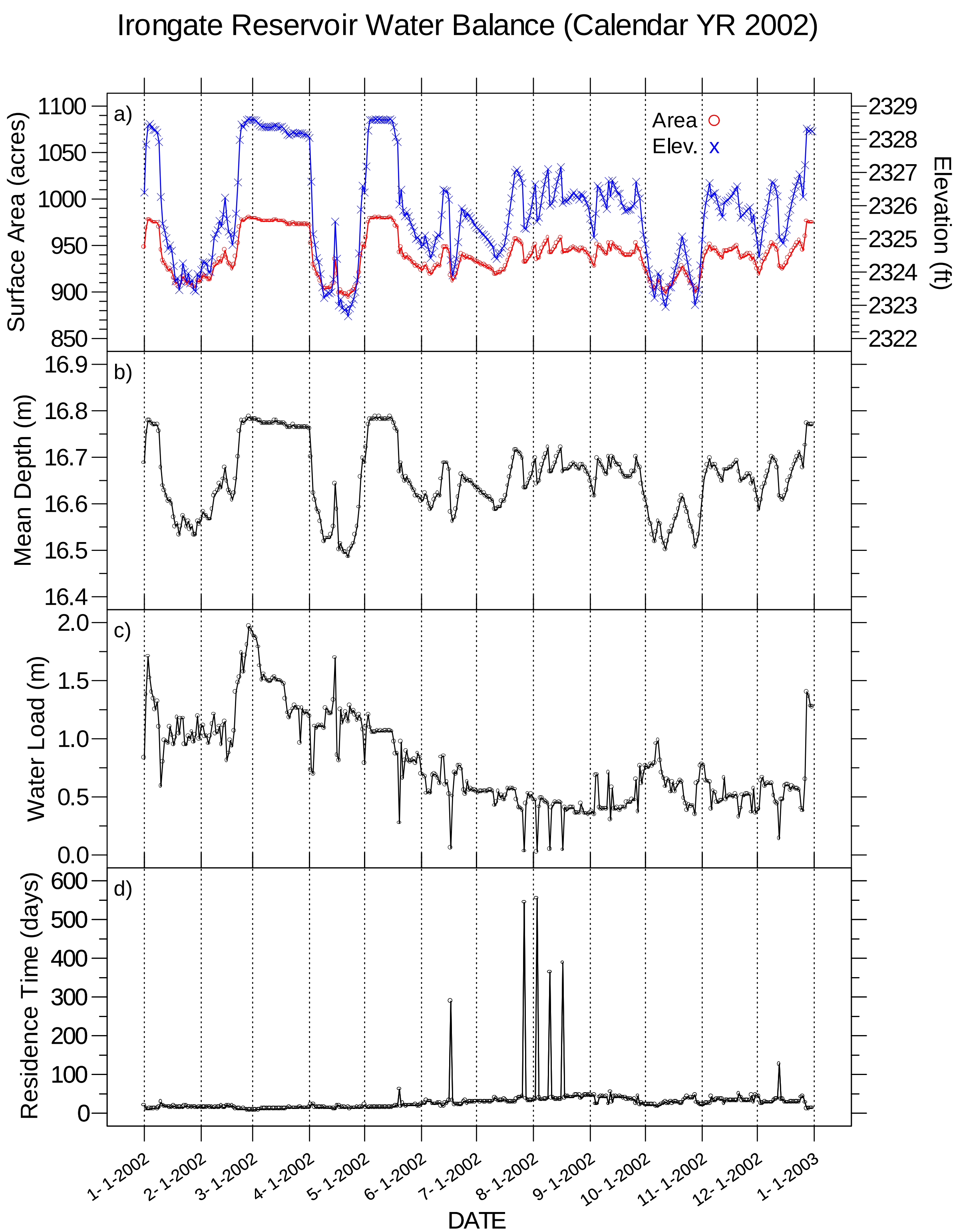


Fig. 8. Daily time series of Iron Gate Reservoir water balance reservoir terms, 2002.

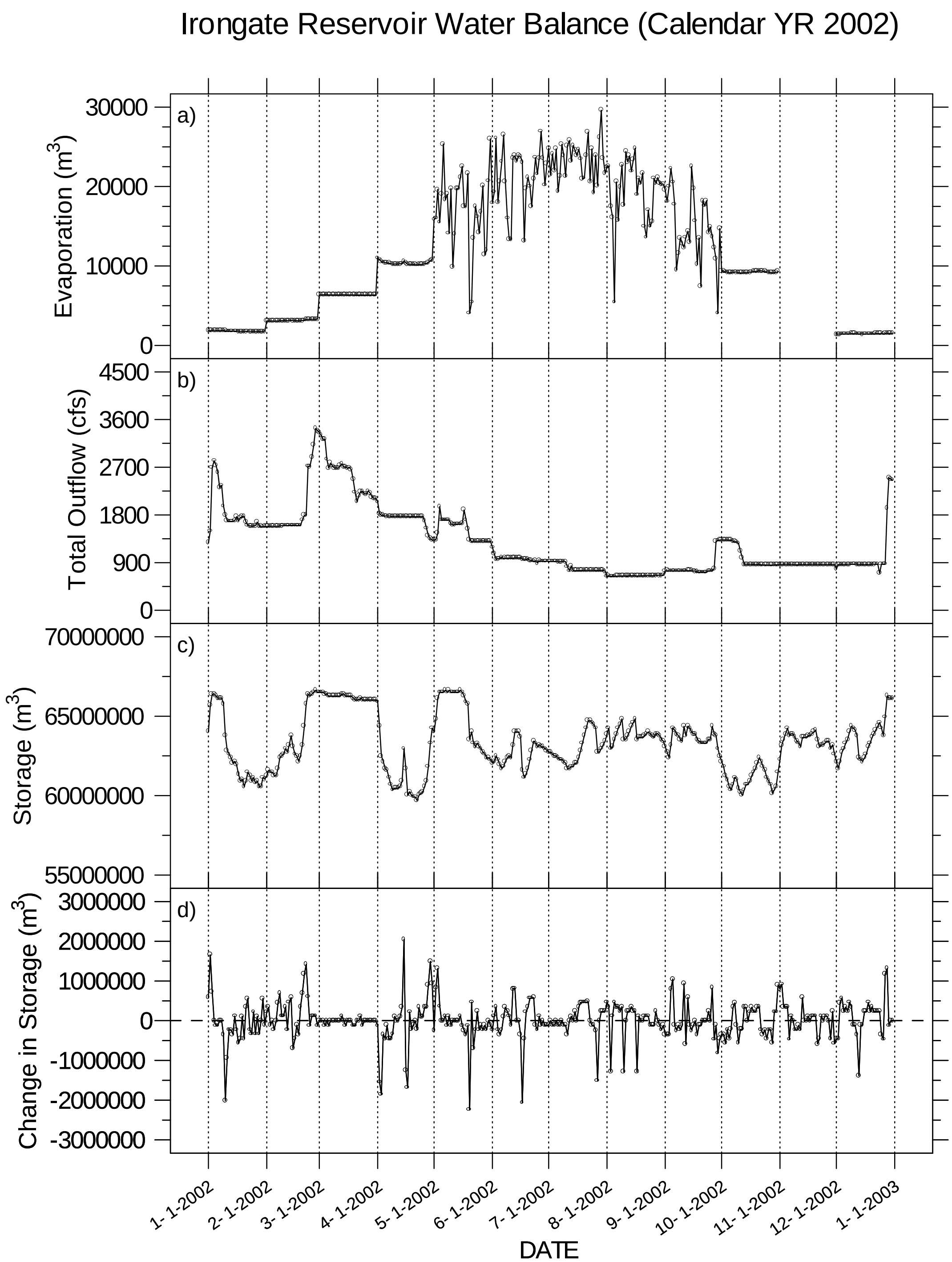


Fig. 9. Daily time series of Iron Gate Reservoir water balance reservoir terms and outflow, 2002.

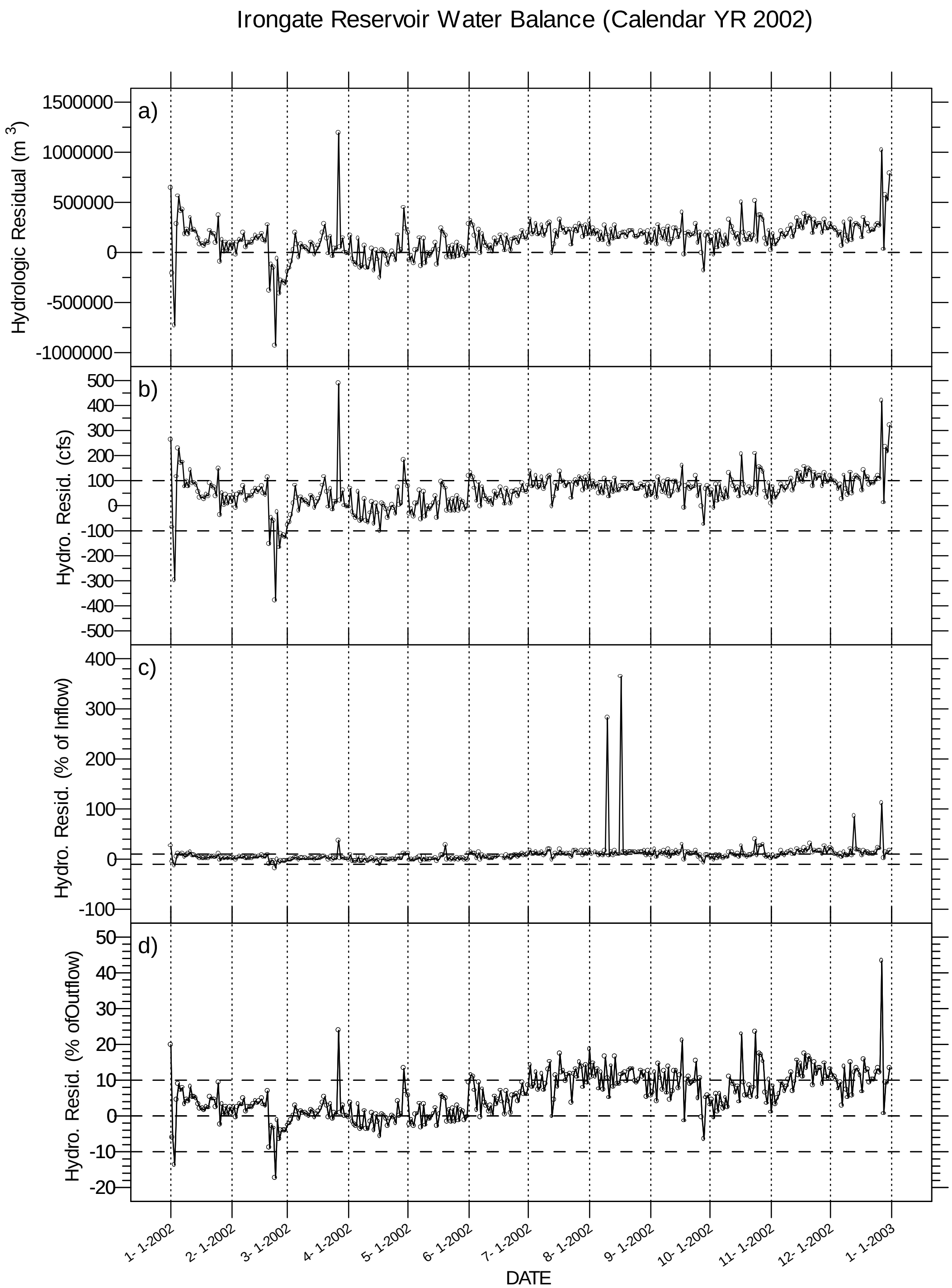


Fig. 10. Daily time series of Iron Gate Reservoir water balance; hydrologic residual, 2002.

Table 6. Partial year (Apr-Nov) and monthly flow and nutrient mass-balance for Iron Gate Reservoir, 2002.

						LOADS						LOADS						Flow-weighted mean concentration					
Month	Term	hm3	acre-feet	mean cfs	% total	metric tons						%						ppb					
						TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN
Totals *	Copco Outflow	508	412120	915	91%	118.2	78.1	40.2	531.5	134.3	397.1	93.3%	94.3%	91.5%	98.0%	97.0%	98.9%						
April 1 -	Fall Creek	17	14041	31	3%	2.8	1.4	1.4	3.7	2.1	1.7	2.2%	1.7%	3.3%	0.7%	1.5%	0.4%						
Nov 13.	Jenny Creek	25	20097	45	4%	4.1	2.5	1.6	3.4	1.5	1.9	3.3%	3.0%	3.8%	0.6%	1.1%	0.5%						
	Camp Creek	9	7545	17	2%	1.5	0.9	0.6	1.3	0.6	0.8	1.2%	1.0%	1.4%	0.2%	0.4%	0.2%						
	Tributary inflow	560	453804	1008	100%	126.6	82.8	43.9	539.9	138.5	401.4	100.0 %	100.0 %	100.0 %	99.5%	100.0 %	100.0 %	226	148	78	965	247	717
	Precip.	0	324	0.7	0.1%	0.0	0.0	0.0	2.6	0.0	0.0	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%						
	Total inflow	560	454128	1008	100%	126.7	82.8	43.9	542.5	138.5	401.4	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	226	148	78	969	247	717
	Evap	3.5	2864	47.2																			
	Net inflow	559	454078	958		126.7	82.8	43.9	542.5	138.5	401.4												
	Iron Gate outflow	588	476598	1058		111.7	66.9	44.8	469.9	131.5	335.8							190	114	76	800	224	571
	Storage increase	-29	-22520	-100		-17.3	-9.9		6.7	9.8	-3.1												
	Retent.					32.3	25.8		65.8	-2.9	68.7	25.5%	31.1%		12.1%	-2.1%	17.1%						
Apr	Copco Outflow	105	85279	1433	85%	30.2	20.2	10.0	99.6	25.4	74.2	87.5%	89.1%	84.4%	97.5%	96.4%	98.3%	288	192	95	948	242	706
	Fall Creek	3	2500	42	2%	0.7	0.4	0.3	0.3	0.2	0.1	2.1%	1.9%	2.6%	0.3%	0.7%	0.1%	239	140	98	88	63	25
	Jenny Creek	12	9637	162	10%	2.8	1.6	1.2	1.6	0.6	1.0	8.2%	7.2%	10.1%	1.5%	2.3%	1.3%	238	137	101	131	50	81
	Camp Creek	3	2678	45	3%	0.8	0.4	0.3	0.4	0.2	0.2	2.2%	1.8%	2.9%	0.4%	0.6%	0.3%	229	125	105	121	50	71
	Tributary inflow	123	100094	1681	100%	34.6	22.7	11.9	101.9	26.4	75.5	100.0 %	100.0 %	100.0 %	99.7%	100.0 %	100.0 %	280	184	96	825	214	611
	Precip.	0.2	162.77	2.7	0.2%	0.0	0.0	0.0	0.3	0.0	0.0	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%						
	Total inflow	124	100257	1684	100%	34.6	22.7	11.9	102.2	26.4	75.5	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	280	184	96	827	214	610
	Evap	.31	252	4.2																			
	Net inflow	123	100207	1634		34.6	22.7	11.9	102.2	26.4	75.5												
	Iron Gate outflow	127	103234	1734		21.6	13.3	8.3	89.4	24.1	62.8							170	105	65	702	189	493

Month	Term	hm3	acre-feet	mean cfs	% total	LOADS metric tons TP	PO4	PP	TOTN	TIN	ORGN	LOADS % TP	PO4	PP	TOTN	TIN	ORGN	Flow-weighted mean concentration ppb TP	PO4	PP	TOTN	TIN	ORGN
	Storage increase	-5	-3027	-100		-7.7	-12.8		-18.0	-9.4	-8.6												
	Retent.					20.7	22.1		30.8	11.8	21.3	59.8%	97.5%		30.2%	44.6%	28.2%						
May	Copco Outflow	97	79046	1285	89%	16.1	11.3	4.8	71.2	13.4	57.8	87.2%	90.7%	79.9%	96.7%	94.8%	97.8%	165	116	49	731	138	593
	Fall Creek	3	2055	33	2%	1.0	0.3	0.7	0.3	0.2	0.1	5.2%	2.2%	11.4%	0.4%	1.5%	0.2%	379	108	271	127	83	44
	Jenny Creek	6	5032	82	6%	0.9	0.6	0.4	1.0	0.3	0.7	4.9%	4.4%	6.0%	1.4%	2.3%	1.2%	147	89	58	164	51	113
	Camp Creek	4	3137	51	4%	0.5	0.3	0.2	0.7	0.2	0.5	2.7%	2.7%	2.7%	1.0%	1.5%	0.9%	128	87	41	184	54	130
	Tributary inflow	110	89270	1451	100%	18.5	12.5	6.0	73.3	14.2	59.1	100.0 %	100.0 %	100.0 %	99.5%	100.0 %	100.0 %	168	113	55	666	129	537
	Precip.	0.04	33.851	0.55	0%	0.0	0.0	0.0	0.4	0.0	0.0	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%						
	Total inflow	110	89304	1452	100%	18.5	12.5	6.0	73.7	14.2	59.1	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	168	113	55	669	129	537
	Evap	.52	425	6.9																			
	Net inflow	109	89254	1402		18.5	12.5	6.0	73.7	14.2	59.1												
	Iron Gate outflow	115	92892	1510		15.6	7.7	7.9	65.1	25.4	39.7							136	67	69	568	222	346
	Storage increase	-5	-3639	-108		-0.8	0.4		-2.5	-5.6	3.0												
	Retent.					3.7	4.4		11.1	-5.7	16.4	20.0%	35.2%		15.1%	-40.1%	27.8%						
Jun	Copco Outflow	64	51737	869	92%	15.1	7.7	7.3	68.9	9.5	59.4	94.1%	95.9%	92.4%	97.6%	93.3%	98.9%	236	121	115	1079	149	931
	Fall Creek	2	1733	29	3%	0.5	0.2	0.4	1.0	0.3	0.7	3.3%	2.1%	4.5%	1.4%	3.4%	1.1%	249	81	168	465	160	305
	Jenny Creek	1	1211	20	2%	0.2	0.1	0.1	0.2	0.2	0.0	1.1%	0.9%	1.4%	0.2%	1.5%	0.0%	123	48	75	111	102	9
	Camp Creek	2	1429	24	3%	0.2	0.1	0.1	0.2	0.2	0.0	1.3%	1.0%	1.7%	0.3%	1.8%	0.0%	122	47	75	106	104	2
	Tributary inflow	69	56111	943	100%	16.0	8.1	7.9	70.2	10.2	60.0	100.0 %	100.0 %	100.0 %	99.5%	100.0 %	100.0 %	231	117	115	1015	147	868
	Precip.	0.01	9.2611	0.156	0%	0.0	0.0	0.0	0.3	0.0	0.0	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%						
	Total inflow	69	56120	943	100%	16.0	8.1	7.9	70.5	10.2	60.0	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	231	116	115	1019	147	868
	Evap	.63	512	8.6																			
	Net inflow	68	56070	893		16.0	8.1	7.9	70.5	10.2	60.0												

						LOADS						LOADS						Flow-weighted mean concentration					
Month	Term	hm3	acre-feet	mean cfs	% total	metric tons						%						ppb					
						TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN
	Iron Gate outflow	71	57853	972		11.1	6.1	5.0	47.8	6.8	41.0							155	85	70	670	96	574
	Storage increase	-3	-1782	-79		-7.8	1.3		7.7	4.2	3.5												
	Retent.					12.7	0.7		15.0	-0.9	15.6	79.3%	8.5%		21.3%	-8.8%	26.0%						
Jul	Copco Outflow	55	44352	721	94%	12.7	9.1	3.6	66.7	13.2	53.5	97.8%	97.0%	100.1 %	98.4%	97.8%	99.2%	232	166	66	1220	242	978
	Fall Creek	2	1608	26	3%	0.2	0.2	0.0	0.6	0.2	0.4	1.7%	2.0%	1.1%	0.9%	1.6%	0.7%	114	93	21	309	109	200
	Jenny Creek	1	861	14	2%	0.0	0.1	0.0	0.1	0.1	0.0	0.3%	0.9%	-1.1%	0.2%	0.5%	0.1%	42	78	-36	109	68	40
	Camp Creek	0	117	2	0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.1%	-0.1%	0.0%	0.1%	0.0%	41	79	-37	108	68	40
	Tributary inflow	58	46938	763	100%	13.0	9.3	3.6	67.5	13.5	53.9	100.0 %	100.0 %	100.0 %	99.5%	100.0 %	100.0 %	224	161	63	1166	234	932
	Precip.	0	1.565	0.025	0%	0.0	0.0	0.0	0.3	0.0	0.0	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%						
	Total inflow	58	46940	763	100%	13.0	9.3	3.6	67.8	13.5	53.9	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	224	161	63	1172	234	932
	Evap	.73	590	9.6																			
	Net inflow	57	46890	713		13.0	9.3	3.6	67.8	13.5	53.9												
	Iron Gate outflow	62	49955	812		11.7	8.5	3.2	58.8	12.4	46.4							190	137	52	955	201	754
	Storage increase	-5	-3066	-99		-2.3	1.0		13.3	4.4	8.9												
	Retent.					3.6	-0.1		-4.3	-3.2	-1.4	28.0%	-1.2%		-6.3%	-23.9%	-2.6%						
Aug	Copco Outflow	42	33941	552	93%	9.8	6.4	3.4	39.5	14.9	24.6	98.8%	96.8%	102.9 %	97.2%	97.4%	98.5%	235	153	81	945	357	588
	Fall Creek	2	1628	26	4%	0.1	0.1	-0.1	0.5	0.3	0.2	0.8%	2.1%	-1.9%	1.2%	1.9%	0.8%	38	70	-32	242	145	96
	Jenny Creek	1	891	14	2%	0.0	0.1	0.0	0.3	0.1	0.2	0.4%	1.0%	-0.9%	0.7%	0.7%	0.7%	35	62	-27	253	99	154
	Camp Creek	0	37	1	0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	35	62	-27	254	99	155
	Tributary inflow	45	36496	593	100%	9.9	6.6	3.3	40.3	15.3	25.0	99.9%	100.0 %	100.0 %	99.1%	100.0 %	100.0 %	221	147	74	896	341	555
	Precip.	0	0.0781	0.001	0%	0.0	0.0	0.0	0.4	0.0	0.0	0.1%	0.0%	0.0%	0.9%	0.0%	0.0%						
	Total inflow	45	36496	593	100%	10.0	6.6	3.3	40.7	15.3	25.0	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	221	147	74	903	341	555
	Evap	.60	490	8.0																			

						LOADS						LOADS						Flow-weighted mean concentration					
Month	Term	hm3	acre-feet	mean cfs	% total	metric tons						%						ppb					
						TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN
	Net inflow	44	36446	543		10.0	6.6	3.3	40.7	15.3	25.0												
	Iron Gate outflow	49	40106	652		9.4	6.6	2.8	58.3	13.3	45.0							190	134	56	1179	270	909
	Storage increase	-5	-3659	-109		1.8	-0.4		5.0	0.8	4.1												
	Retent.					-1.2	0.4		-22.6	1.2	-24.1	-12.4%	5.7%		-55.6%	7.7%	-96.7%						
Sep	Copco Outflow	51	41209	692	94%	15.0	6.6	8.4	77.1	11.1	66.0	99.0%	98.8%	99.2%	99.0%	96.0%	100.0 %	296	130	165	1518	219	1299
	Fall Creek	2	1699	29	4%	0.1	0.1	0.0	0.4	0.3	0.0	0.5%	0.8%	0.3%	0.5%	3.0%	0.0%	37	25	13	169	167	3
	Jenny Creek	1	896	15	2%	0.1	0.0	0.0	0.1	0.1	0.0	0.5%	0.4%	0.5%	0.1%	1.0%	0.0%	64	24	40	89	100	-11
	Camp Creek	0	23	0	0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	64	24	40	89	100	-11
	Tributary inflow	54	43827	736	100%	15.2	6.7	8.5	77.6	11.6	66.0	100.0 %	100.0 %	100.0 %	99.6%	100.0 %	100.0 %	281	124	157	1436	214	1222
	Precip.	0	3.957	0.066	0%	0.0	0.0	0.0	0.3	0.0	0.0	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	1157					
	Total inflow	54	43831	736	100%	15.2	6.7	8.5	77.9	11.6	66.0	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	281	124	157	1442	214	1222
	Evap	.45	362	6.1																			
	Net inflow	53	43781	686		15.2	6.7	8.5	77.9	11.6	66.0												
	Iron Gate outflow	59	47543	799		14.2	8.2	6.0	56.2	16.5	39.7							242	140	102	960	282	677
	Storage increase	-6	-3762	-112		0.5	-0.1		-19.6	1.4	-21.1												
	Retent.					0.6	-1.4		41.3	-6.4	47.4	3.7%	-21.3%		53.0%	-55.0%	71.8%						
Oct	Copco Outflow	68	55466	902	95%	15.0	12.6	2.4	77.6	29.7	47.9	98.8%	99.0%	98.3%	98.7%	98.4%	99.6%	219	184	35	1135	435	701
	Fall Creek	2	1906	31	3%	0.1	0.1	0.0	0.5	0.4	0.2	0.9%	0.7%	2.0%	0.7%	1.2%	0.4%	56	36	21	233	157	76
	Jenny Creek	1	1017	17	2%	0.0	0.0	0.0	0.1	0.1	0.0	0.2%	0.3%	-0.3%	0.1%	0.3%	0.0%	28	34	-6	75	77	-2
	Camp Creek	0	87	1	0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	28	34	-6	75	78	-3
	Tributary inflow	72	58475	951	100%	15.1	12.7	2.5	78.3	30.2	48.1	100.0 %	100.0 %	100.0 %	99.6%	100.0 %	100.0 %	210	176	34	1086	419	667
	Precip.	0	1.5234	0.025	0%	0.0	0.0	0.0	0.3	0.0	0.0	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%						
	Total inflow	72	58477	951	100%	15.2	12.7	2.5	78.6	30.2	48.1	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	210	176	34	1091	419	667

						LOADS						LOADS						Flow-weighted mean concentration					
Month	Term	hm3	acre-feet	mean cfs	% total	metric tons						%						ppb					
						TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN	TP	PO4	PP	TOTN	TIN	ORGN
	Evap	.29	232	3.8																			
	Net inflow	71	58427	901		15.2	12.7	2.5	78.6	30.2	48.1												
	Iron Gate outflow	77	62692	1019		22.0	12.1	9.9	67.3	21.4	46.0							285	157	128	871	276	595
	Storage increase	-6	-4265	-119		-0.9	0.3		10.8	8.6	2.2												
	Retent.					-6.0	0.3		0.6	0.3	-0.1	-39.7%	2.5%		0.7%	0.9%	-0.1%						
Nov*	Copco Outflow	26	21091	818	93%	4.3	4.1	0.1	30.7	16.9	13.8	98.1%	98.9%	82.3%	98.9%	99.2%	99.6%	165	159	6	1180	650	530
Nov 1 -	Fall Creek	1	913	35	4%	0.1	0.0	0.0	0.1	0.1	0.0	1.3%	0.7%	15.3%	0.4%	0.5%	0.3%	52	28	24	112	78	34
Nov 13.	Jenny Creek	1	552	21	2%	0.0	0.0	0.0	0.1	0.0	0.0	0.5%	0.4%	2.3%	0.2%	0.2%	0.1%	29	23	6	75	56	19
	Camp Creek	0	36	1	0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	29	23	6	75	56	19
	Tributary inflow	28	22592	876	100%	4.4	4.2	0.2	30.9	17.0	13.8	99.9%	100.0 %	100.0 %	99.5%	100.0 %	100.0 %	157	150	6	1108	612	497
	Precip.	0	111	4	0%	0.0	0.0	0.0	0.1	0.0	0.0	0.1%	0.0%	0.0%	0.5%	0.0%	0.0%						
	Total inflow	28	22703	880	100%	4.4	4.2	0.2	31.0	17.0	13.8	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	156	150	6	1108	609	494
	Evap	1	50	50																			
	Net inflow	27	22653	830		4.4	4.2	0.2	31.0	17.0	13.8												
	Iron Gate outflow	28	22323	865		6.1	4.4	1.7	26.9	11.6	15.4							223	160	63	979	420	558
	Storage increase	-1	330	-35		-0.1	0.4		10.2	5.4	4.9												
	Retent.					-1.7	-0.6		-6.1	0.1	-6.4	-38.3%	-14.0%		-19.7%	0.7%	-46.2%						

Iron Gate had several spikes in the hydrologic residual in the period prior to April (Fig. 10a), and although the residual term was less extreme during the Apr-Nov period it tended to be skewed above zero, indicating a consistent bias in one or more of the budget terms. For example, such a skew could occur if inflow or daily volume change was underestimated, or if outflow was overestimated. However, despite this skew, overall quantity of the residual was low relative to total inflow or outflow, and was generally within ±100 cfs for the period encompassing this analysis (Fig. 10b). This translates to values that, with the exception of two spikes in August, tended to be ±15 % of either inflow and outflow volumes (Figs. 10c,d).

Nutrient Concentration

Copco Reservoir

Time series of all nutrient parameters for inflow, in-reservoir and outflow terms are shown in figures 11 and 12. Volume weighted mean-monthly values are shown in Table 5. Reservoir values for ammonia (NH_4-N) tended to be higher than inflow and outflow values beginning in June, and with the exception of September, inflow NO_2+NO_3-N concentration tended to be higher than in-reservoir and outflow (Fig. 11). Total N and organic N diverge in June among the three terms, with the concentration of both increasing in the outflow for several periods during June-September (Fig. 11). Total phosphorus concentration tended to be highest during spring runoff, declined prior to June, and increased again during the summer growing season (Fig. 12). Outflow concentration for both TP and SRP occasionally exceeded inflow concentration later in the season, and SRP in-reservoir increased ~3x during Jul-Sep (Fig. 12).

Iron Gate Reservoir

Time series of all nutrient parameters for inflow, in-reservoir and outflow terms are shown in figures 13 and 14. Volume weighted mean-monthly values are shown in Table 6. Inflow dynamics are driven by the Copco outflow, yet on several occasions nitrogen concentration increased both in-reservoir and in the Iron Gate outflow (Fig. 13). Specifically, organic and TN exceed inflow during Aug-Sep (Fig. 13). As with Copco, total phosphorus concentration tended to be highest during spring runoff; however, several large spikes in inflow concentration occurred in July and September (Fig. 14). Outflow concentration for TP exceeded inflow concentration later September and October (Fig. 14).

The nutrient graphs for Copco and Iron Gate, particularly those for in-reservoir trends, reveals the limitation of the monthly sample collection interval, with large increases or decreases in concentration occurring over the monthly period (Figs. 11-14).

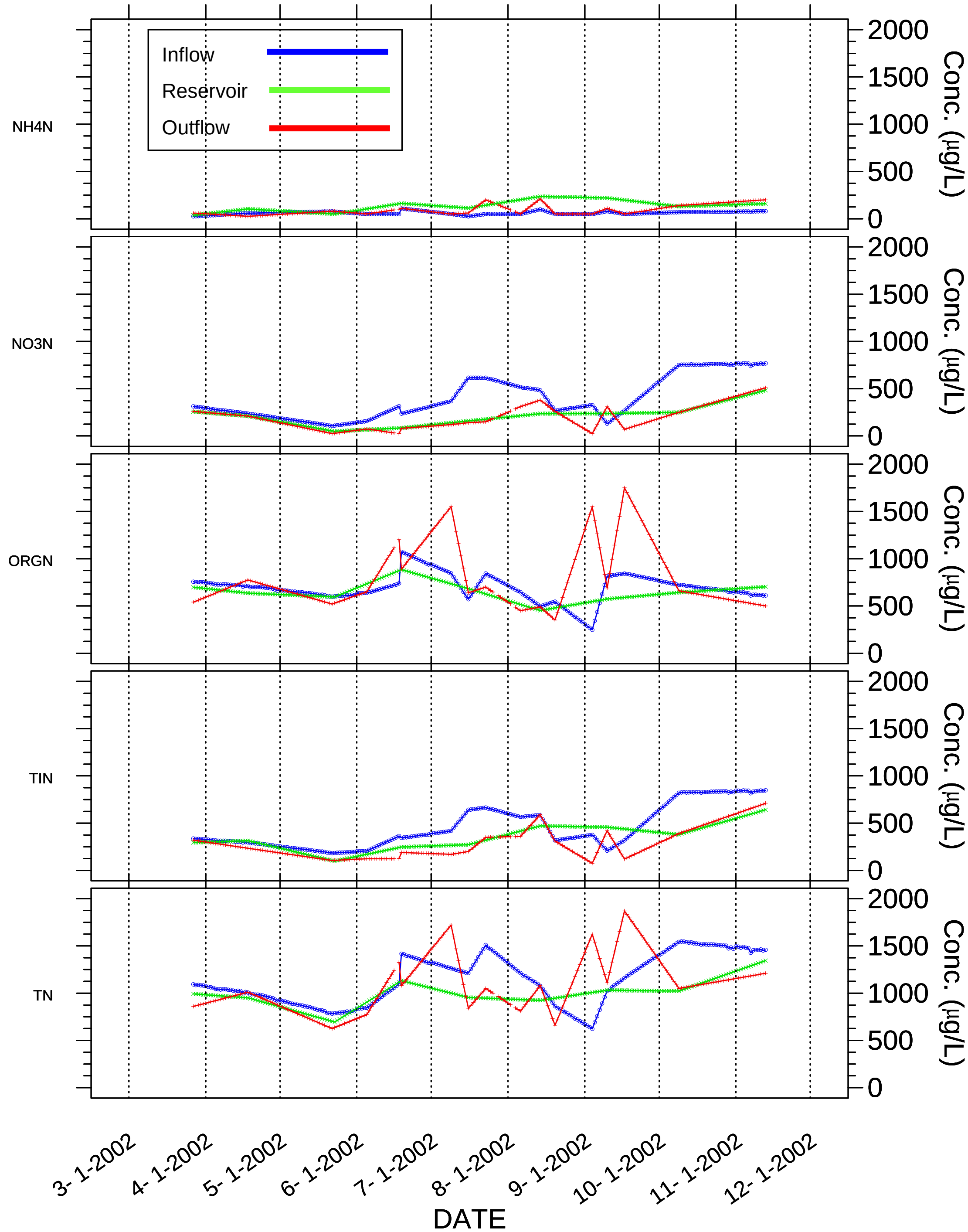


Fig. 11. Daily time series of Copco Reservoir nitrogen concentrations, Apr-Nov 2002.

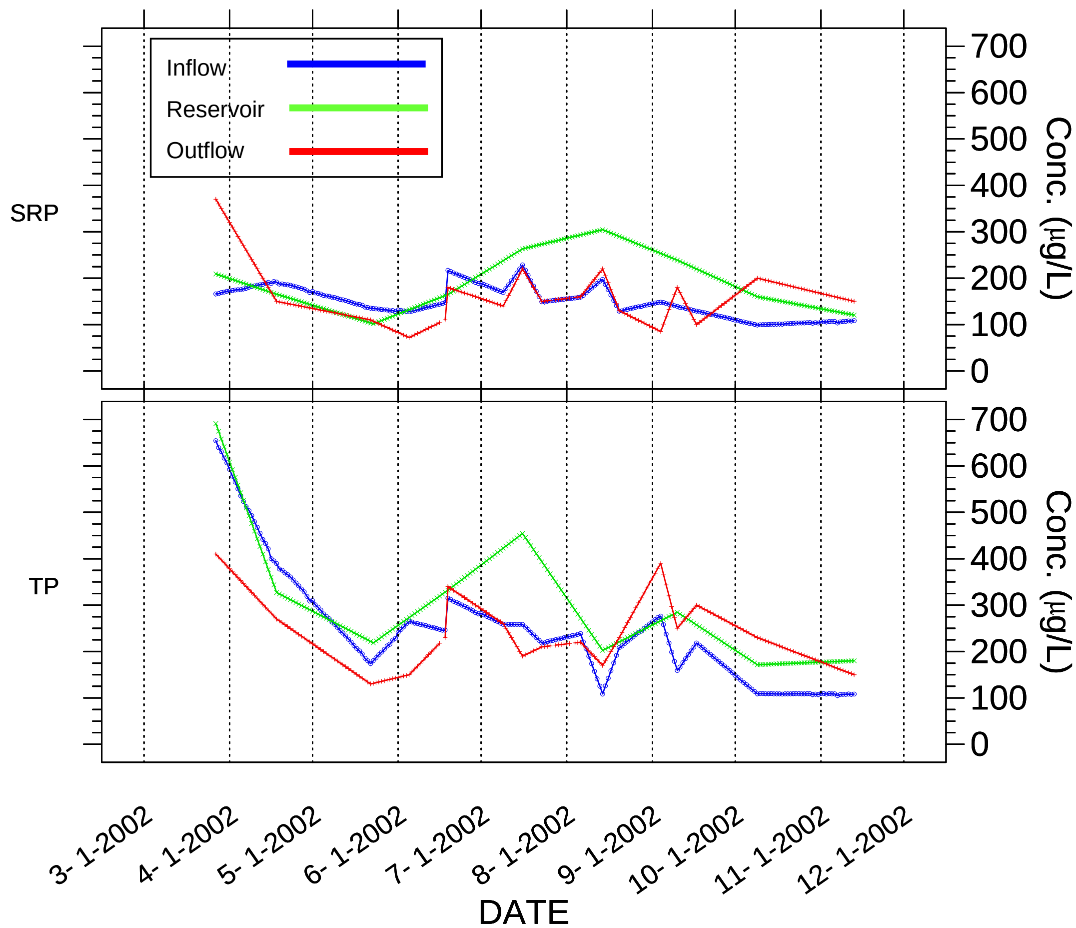


Fig. 12. Daily time series of Copco Reservoir phosphorus concentrations, Apr-Nov 2002.

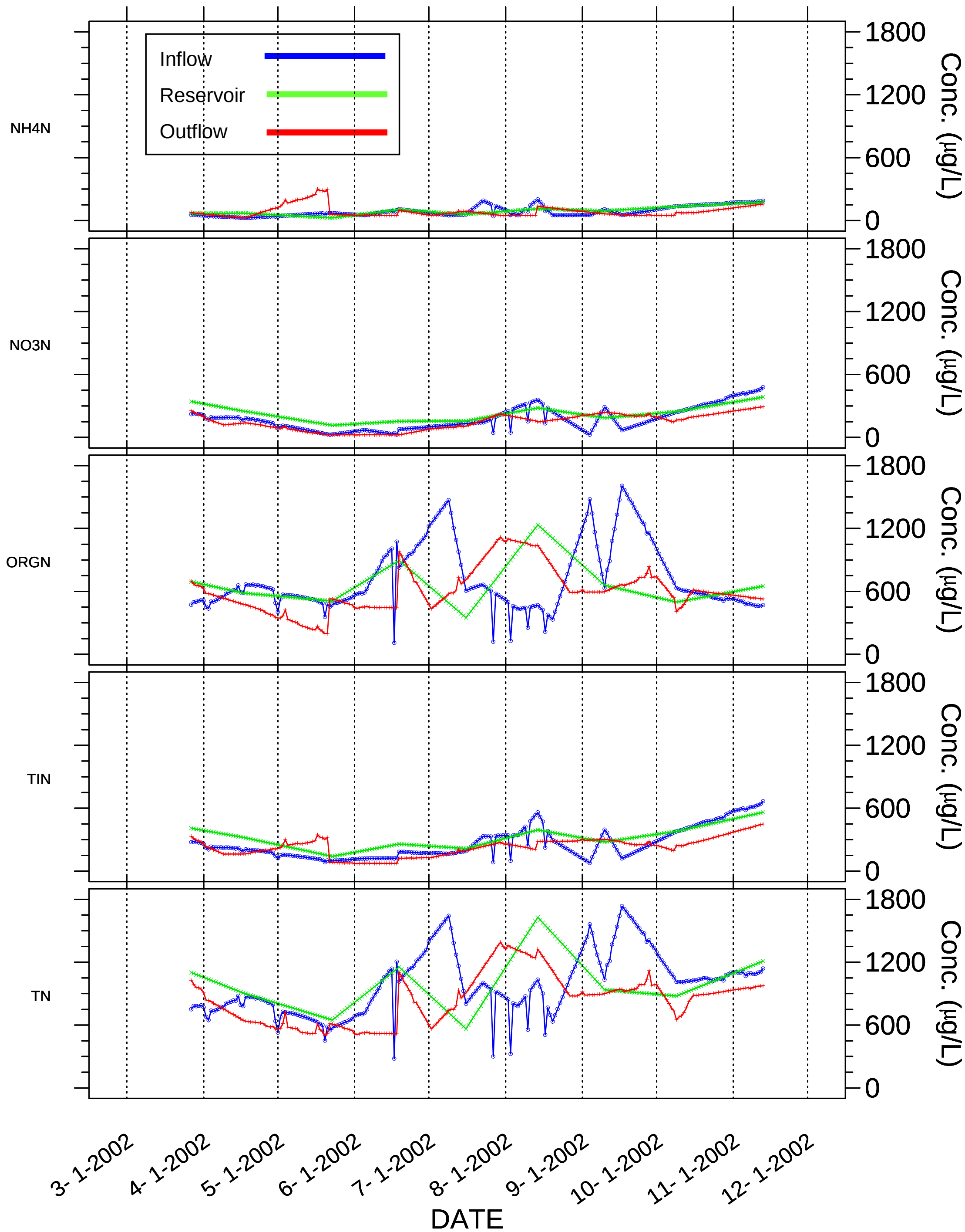


Fig. 13. Daily time series of Iron Gate Reservoir nitrogen concentrations, Apr-Nov 2002.

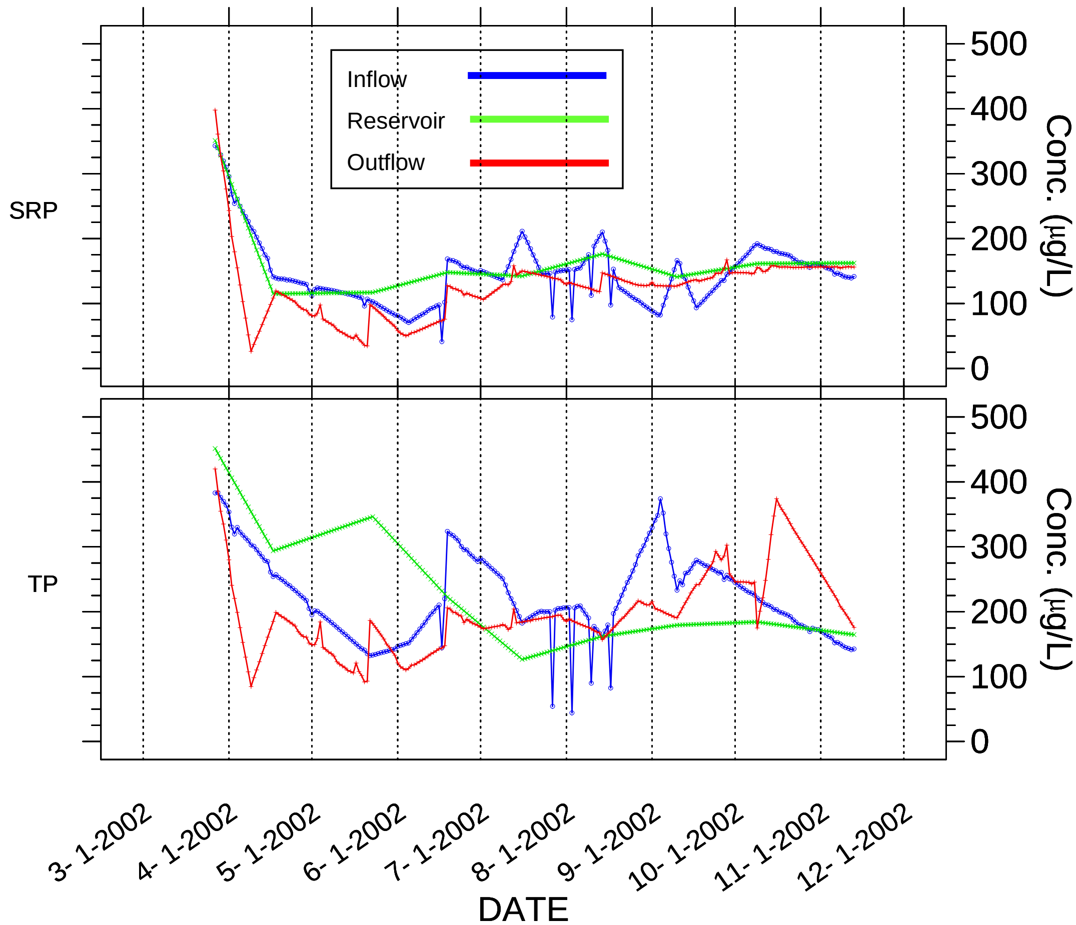


Fig. 14. Daily time series of Iron Gate Reservoir phosphorus concentrations, Apr-Nov 2002.

Nutrient Budget

As described in the methods, hydrologic budget terms were multiplied by nutrient concentration to obtain estimates of nutrient mass in kg. These terms, as well as the retention term were computed for total phosphorus, total nitrogen, the inorganic P and N forms (SRP, NH_4-N, NO_2+NO_3-N, and the estimated organic N component. While it is instructive to evaluate the loading and retention dynamics of the inorganic and organic forms, these forms are subject to transformation to another compound by reaction. For example, inorganic forms can be taken up by algae and incorporated into organic forms, and organic forms can be bacterially decomposed back to inorganic forms (e.g., ammonification). Unless the reaction equations for these transformations are included in the model, these parameters do not adhere to the requirement of mass-balance mechanistic models that are based on conservation of mass principles. In other words, the assumption that negative retention values denote a source from within the system (e.g., from internal loading or nitrogen fixation), and that positive values denote a sink, requires that all transfers of matter across a system's boundaries and all transformations are expressed in the mass-balance equation (Chapra 1997). In the development of simple mass-balance equations for this exercise, the only parameters that meet this requirement with current data are the total forms of N and P. Thus, TP and TN are the focus of this analysis.

Copco Reservoir

Phosphorus

Daily time series for major nutrient mass-balance terms for Copco Reservoir are presented in Figs. 15-21 and Appendices M, N, O, P, Q, R, and S. On a whole season basis the Klamath River above Shovel Creek contributed 98% of the TP load (Table 5). As with flow, there was a pronounced late-winter/spring TP loading peak, which then declined through August to minimum loadings persisting through November (Fig. 15b). Shovel Creek represented a maximum of 4% of the total TP load in May (Table 5). Although reservoir TP storage declines with inflow loading through May, TP storage then increases through mid-July even while inflow load continues to decrease (Fig. 15c). Reservoir TP storage then decreases through mid August (although as noted above, sharp linear changes are driven by monthly samples), with another increase and decrease occurring in September and October (Fig. 15c). These periods of increase are associated with negative net retention values in June-July, August-September, and October (Fig. 15d). For TP; negative net retention values denote a source such as internal loading from within the reservoir. Thus, while these data indicate that over the Apr-Nov period Copco Reservoir acts as a net sink for TP (26% retention; Table 5), these analyses provide evidence that Copco Reservoir also periodically acts as a source; especially during critical times when nutrients would be available for downstream growth of algae and macrophytes.

Nitrogen

On a whole season basis the Klamath River above Shovel Creek contributed 99% of the TN load (Table 5). Unlike TP, however, there was not as pronounced a late-winter/spring loading peak, and TN loading then increased again in September (Fig. 17b) Shovel Creek represented a maximum of <1% of the total TN load in May (Table 5). Reservoir TN storage declines with inflow loading through mid-May, and then increases or remains steady through November (Fig. 17c). The retention pattern is one of positive retention between April and late May, and then alternating periods of negative and positive retention through November (Fig 17d).

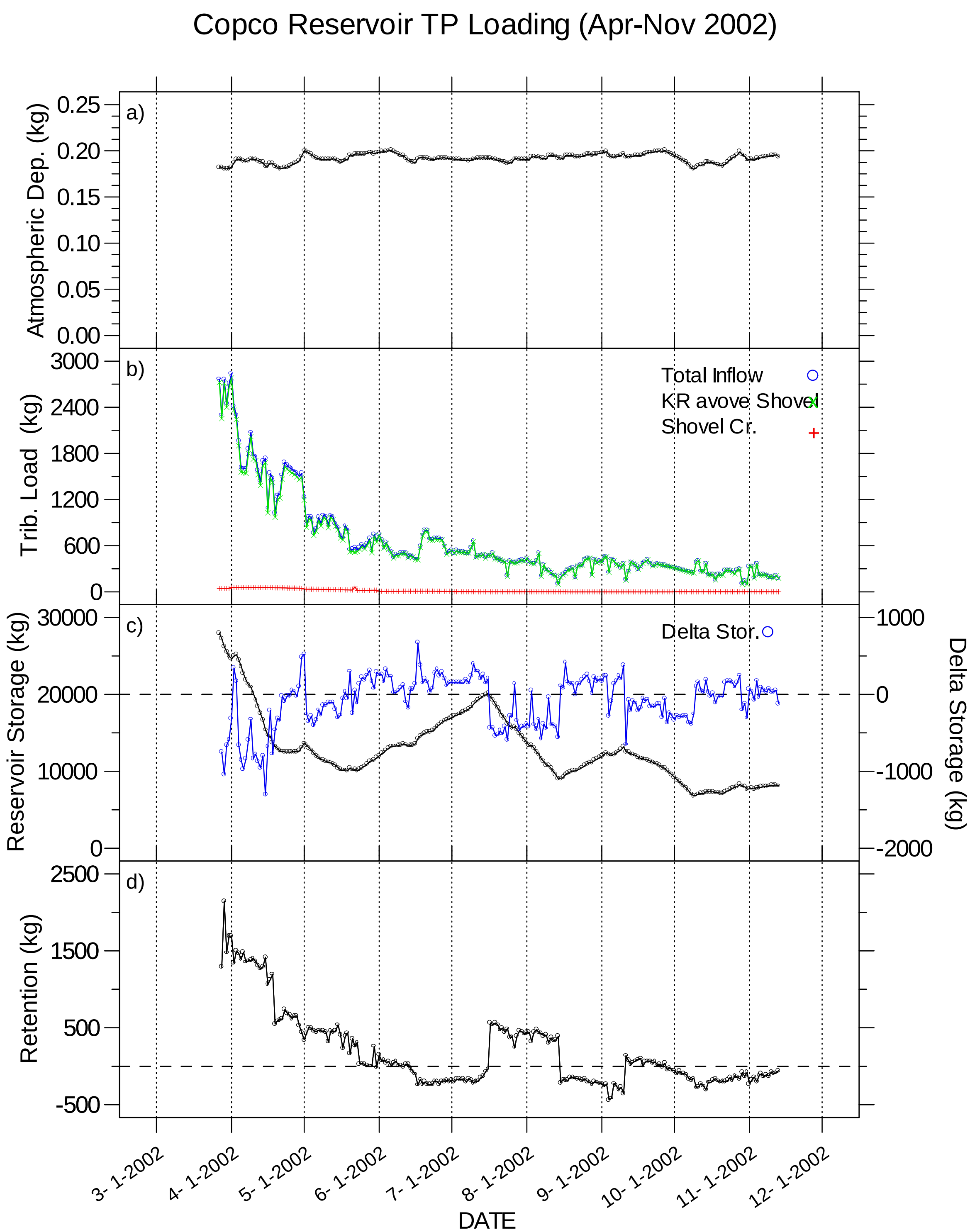


Fig. 15. Daily time series of Copco Reservoir total phosphorus loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

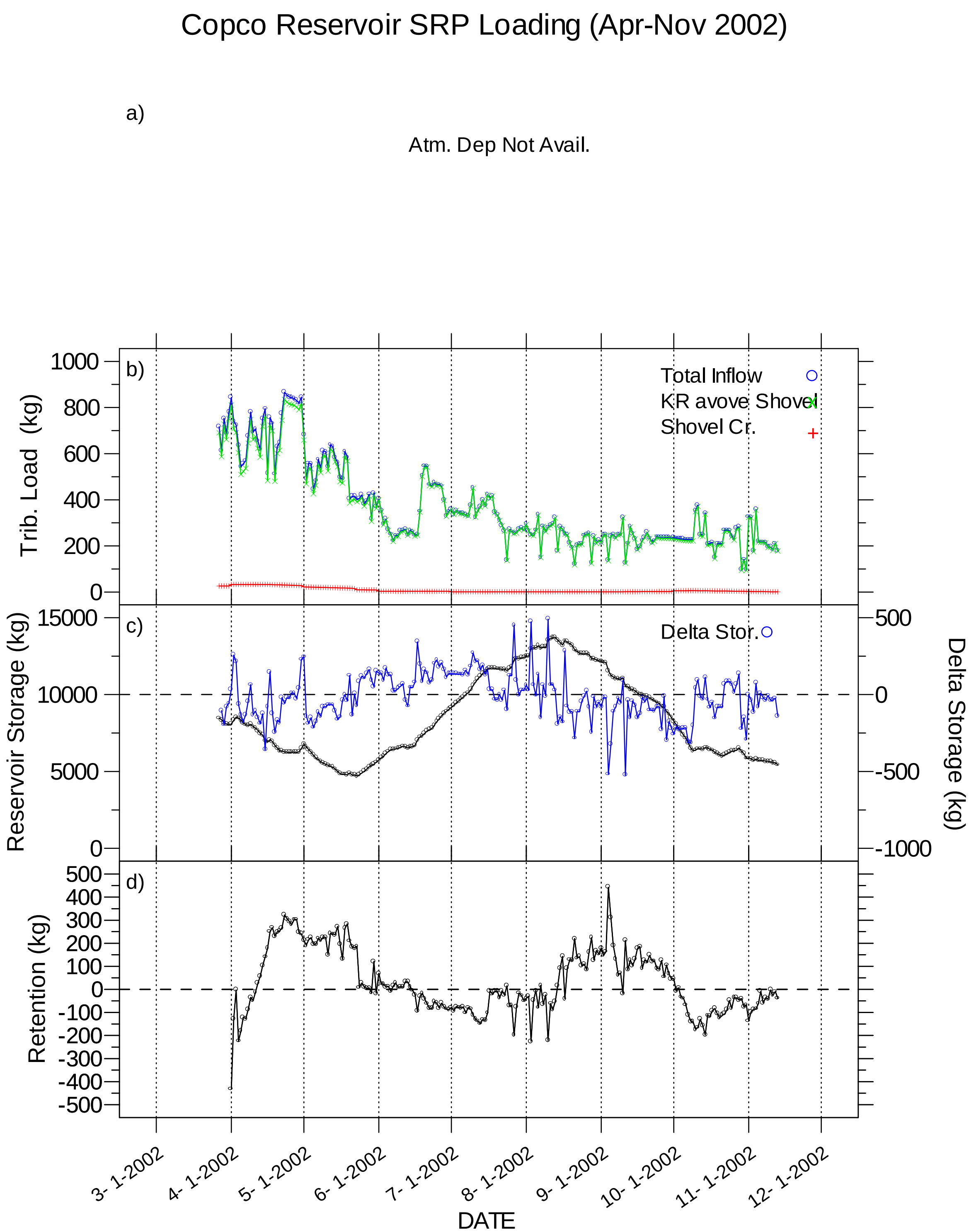


Fig. 16. Daily time series of Copco Reservoir SRP loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

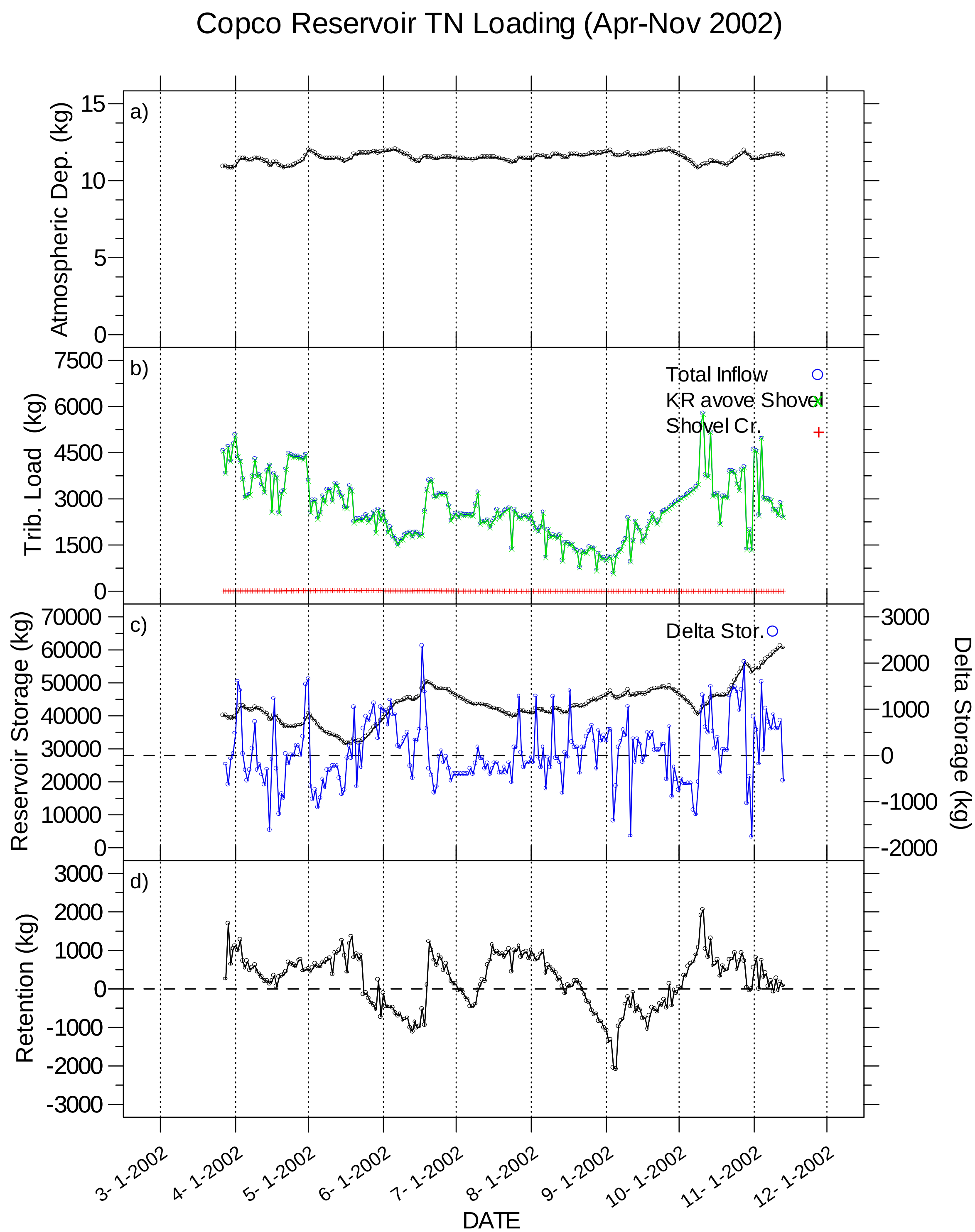


Fig. 17. Daily time series of Copco Reservoir total nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

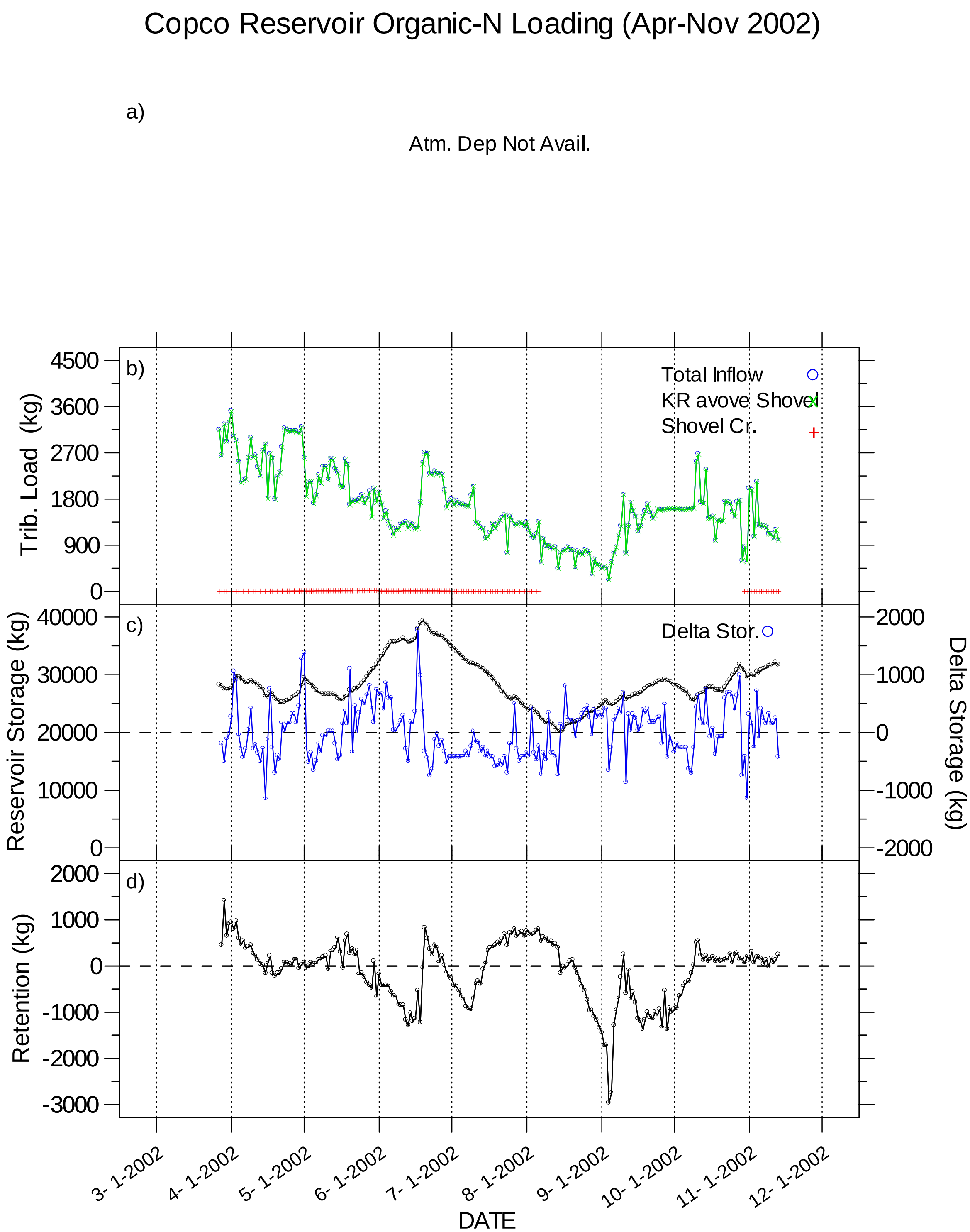


Fig. 18. Daily time series of Copco Reservoir organic nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

Copco Reservoir TIN Loading (Apr-Nov 2002)

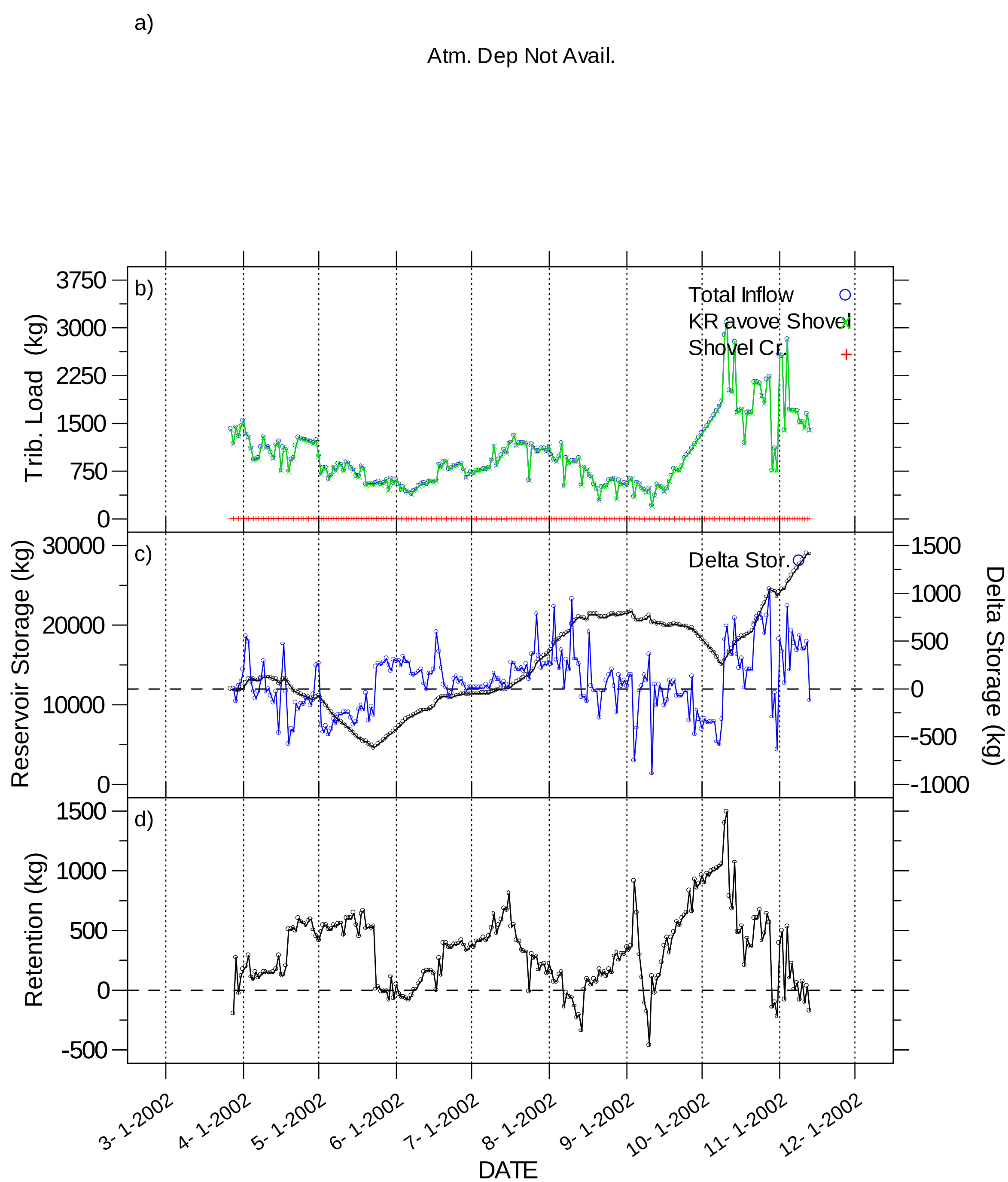


Fig. 19. Daily time series of Copco Reservoir total inorganic nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

Copco Reservoir NO_3-N Loading (Apr-Nov 2002)

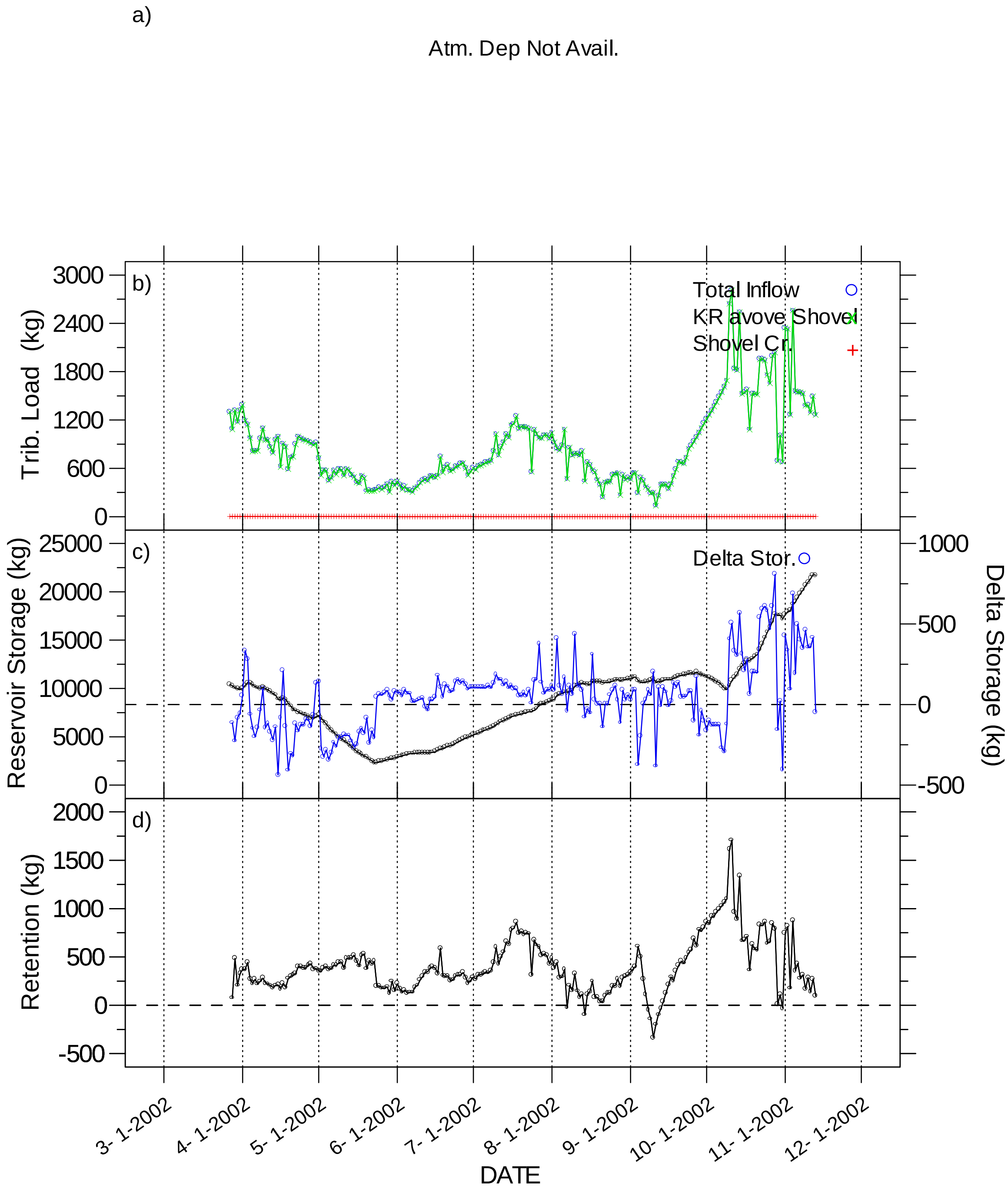


Fig. 20. Daily time series of Copco Reservoir nitrate-nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

Copco Reservoir NH_4-N Loading (Apr-Nov 2002)

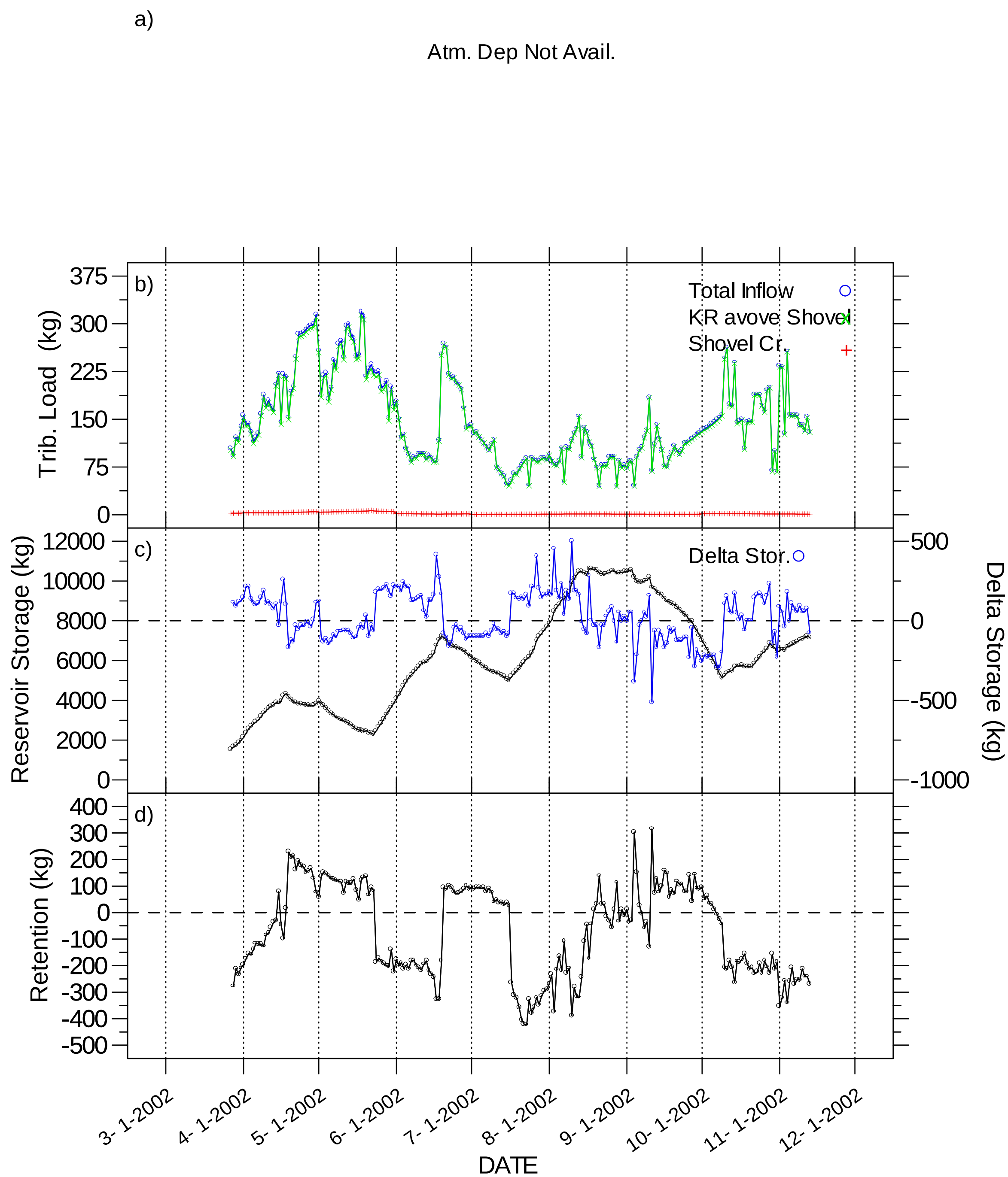


Fig. 21. Daily time series of Copco Reservoir ammonia-nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

As for TP, negative net retention values denote a source from within the reservoir system. In addition, for TN, these net negative retention trends may reflect input of nitrogen to the system by nitrogen fixing cyanobacteria. Genera capable of fixing atmospheric nitrogen that are known to bloom in both reservoirs include *Aphanizomenon*, *Anabaena* and *Gloeotrichia*. Again, while these data indicate that over the Apr-Nov period Copco Reservoir acted as a net sink for TN (8% retention; Table 5), Copco Reservoir also periodically acted as a source; especially during critical times (e.g., June and August) when nutrients would be available for downstream growth of algae and macrophytes. Organic-N retention patterns (Fig. 18d) follow closely those of TN, indicating that a large portion of the TN is in an organic form (possibly in the form of algal biomass).

Iron Gate Reservoir

Phosphorus

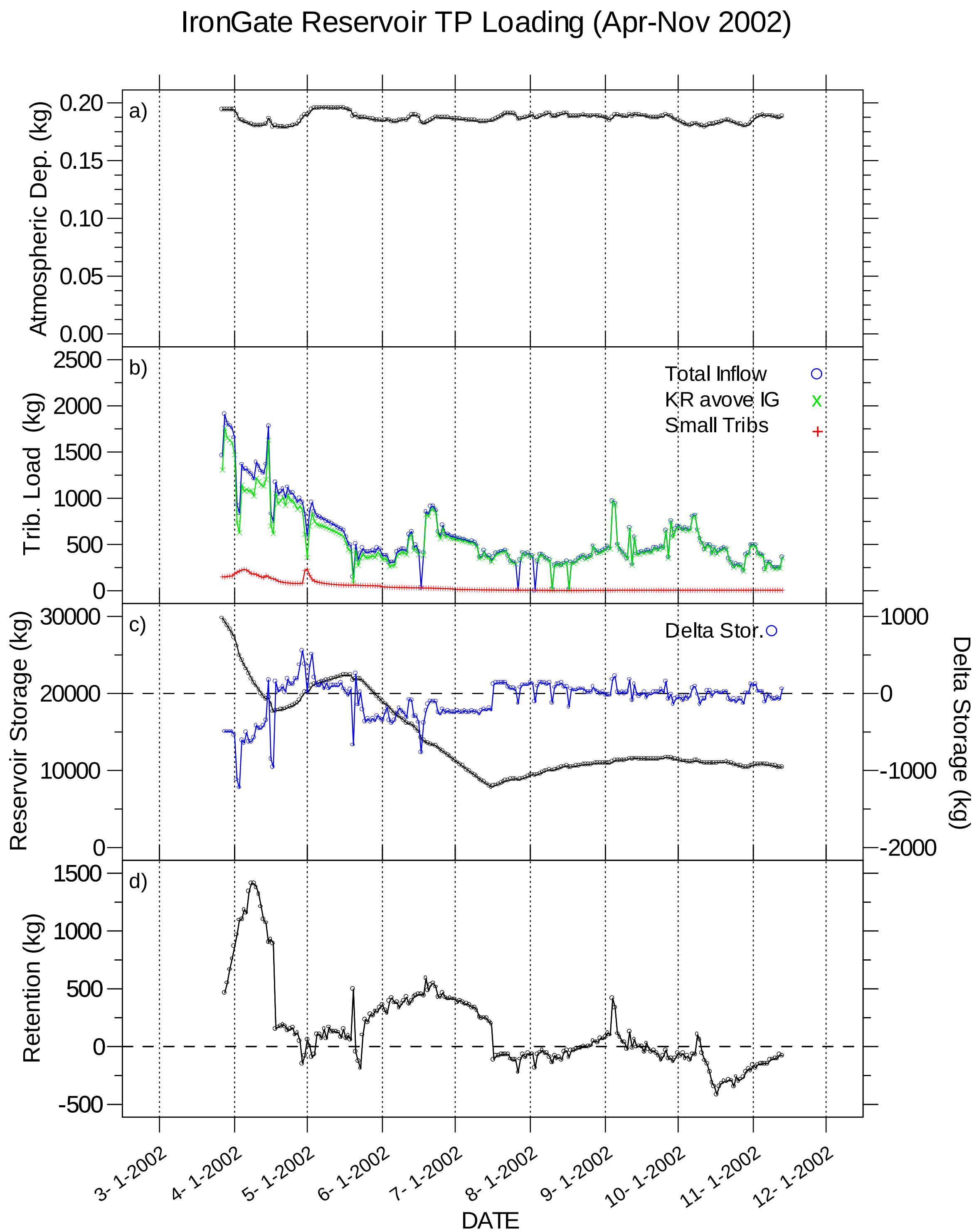
Daily time series for major nutrient mass-balance terms for Iron Gate Reservoir are presented in Figs. 22-28 and Appendices T, U, V, W, X, Y, and Z. On a whole-season basis the Klamath River above Iron Gate (Copco Outflow) contributed 93% of the TP load (Table 6). As with flow, there was a pronounced late-winter/spring TP loading peak, which then declined through July with a smaller increase through November (Fig. 22b). Small tributaries (Jenny, Fall, and Camp Creeks) represented a maximum of 15% of the total TP load in Apr (Table 6).

Reservoir TP storage shows an overall decline through mid July, and then remains steady through November (Fig. 22c). The early season inflow peak is associated with a sharp increase in retention (Fig. 22d). To the extent that Jenny Creek flows are overestimated (see above caveat discussion), the early season retention increase may also be overestimated. For example, the nutrient budget indicates that Jenny Creek contributed 8% of the total incoming phosphorus load to Iron Gate reservoir in April and 5% in May (Table 6), and these loads equate to 14% of the April retention and 25% of the May retention. The initial retention peak is followed by periods of neutral retention, positive retention (mid-June to mid-July), and negative retention (mid-July to mid-Aug).

Beginning in September, retention values are again negative indicating a possible TP source from reservoir turnover; although as with Copco, the critical period of reservoir turnover was not encompassed by the available data. While these data indicate that over the Apr-Nov period Iron Gate Reservoir acts as a net sink for TP (26% retention; Table 6), these analyses also provide evidence that there are critical periods when the reservoir acts as a source.

Nitrogen

On a whole season basis the Klamath River above Iron Gate (Copco Outflow) contributed 98% of the TN load (Table 6). Unlike TP load, there was not a pronounced late-winter/spring loading peak (Fig 24b). TN loading was lowest in July and August, and then increased again in September to values similar to those in April (Fig. 24b). Small tributaries (Jenny, Fall, and Camp Creeks) represented a maximum of 2% of the total TN load in Apr (Table 6). The retention pattern shows two peaks of increasing TN storage, one in June and the other in August (Fig. 24c). Both periods of storage increase are associated with net negative retention, with the July-Aug span showing substantial net release of TN from the reservoir (Fig. 24d). Moreover, as noted above, the critical period of reservoir turnover was not encompassed by the available data set. During reservoir turnover phosphorus and nitrogen in bottom layers can be mixed into the water column and potentially released downstream. To the extent this is occurring, inclusion of the turnover period would lead to increased negative retention values.



IronGate Reservoir TP Loading (Apr-Nov 2002)
a)
Atmospheric Dep. (kg)
0.20
0.15
0.10
0.05
0.00
b)
Trib. Load (kg)
2500
2000
1500
1000
500
0
Total Inflow
KR avove IG
Small Tribs
c)
Reservoir Storage (kg)
30000
20000
10000
0
Delta Stor.
Delta Storage (kg)
1000
0
-1000
-2000
d)
Retention (kg)
1500
1000
500
0
-500
3- 1-2002
4- 1-2002
5- 1-2002
6- 1-2002
7- 1-2002
8- 1-2002
9- 1-2002
10- 1-2002
11- 1-2002
12- 1-2002
DATE

Fig. 22. Daily time series of Iron Gate Reservoir total phosphorus loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

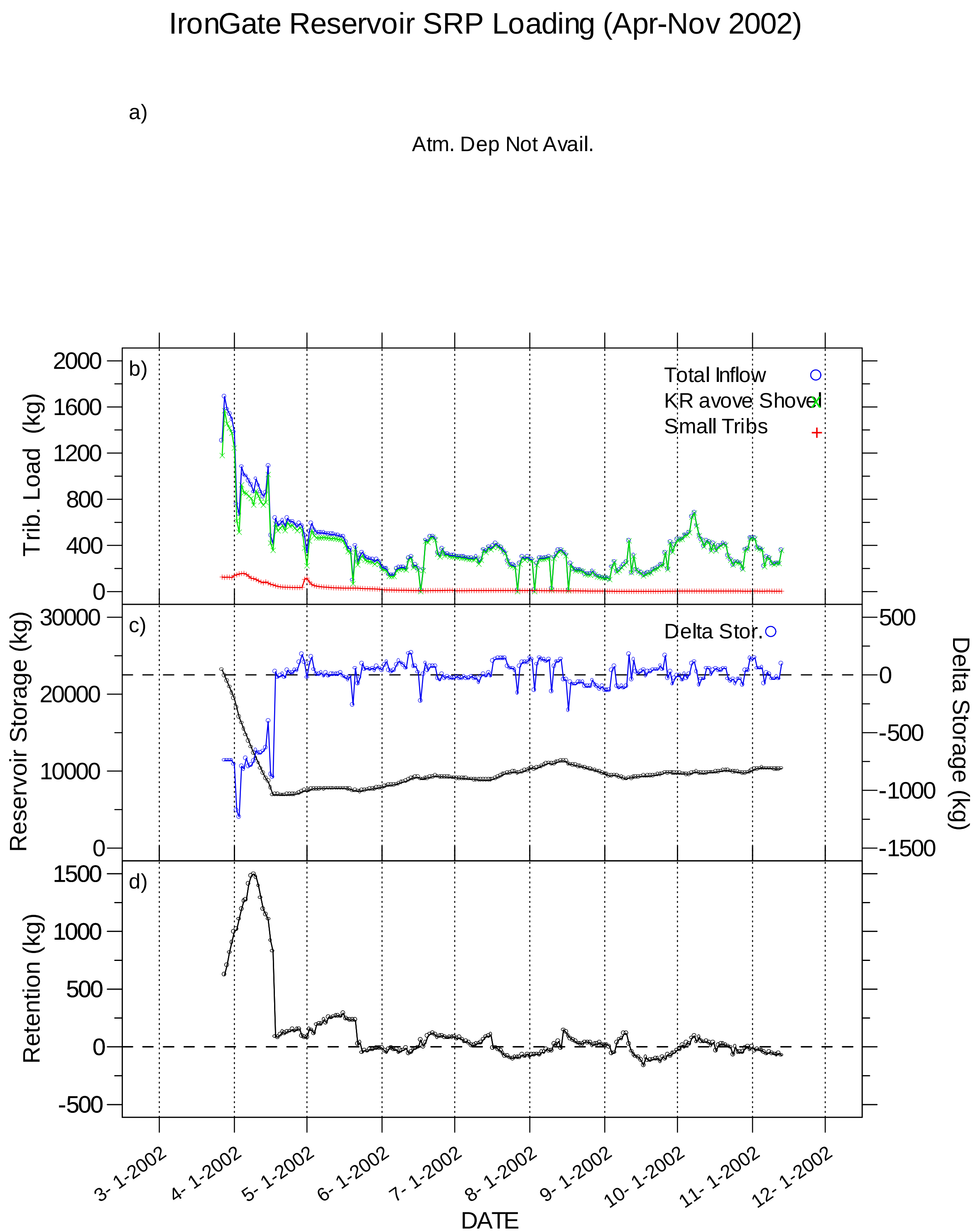


Fig. 23. Daily time series of Iron Gate Reservoir SRP loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

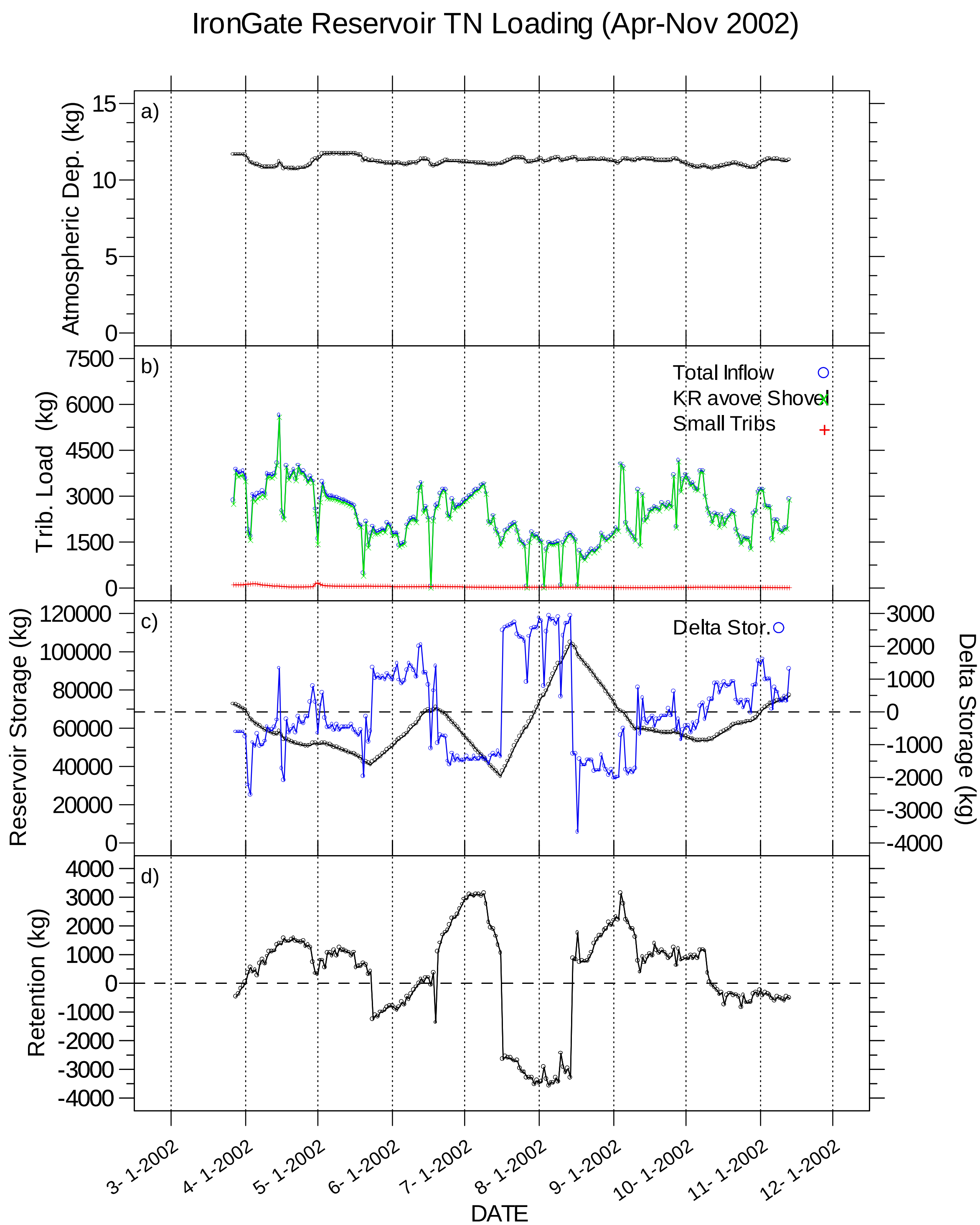


Fig. 24. Daily time series of Iron Gate Reservoir total nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

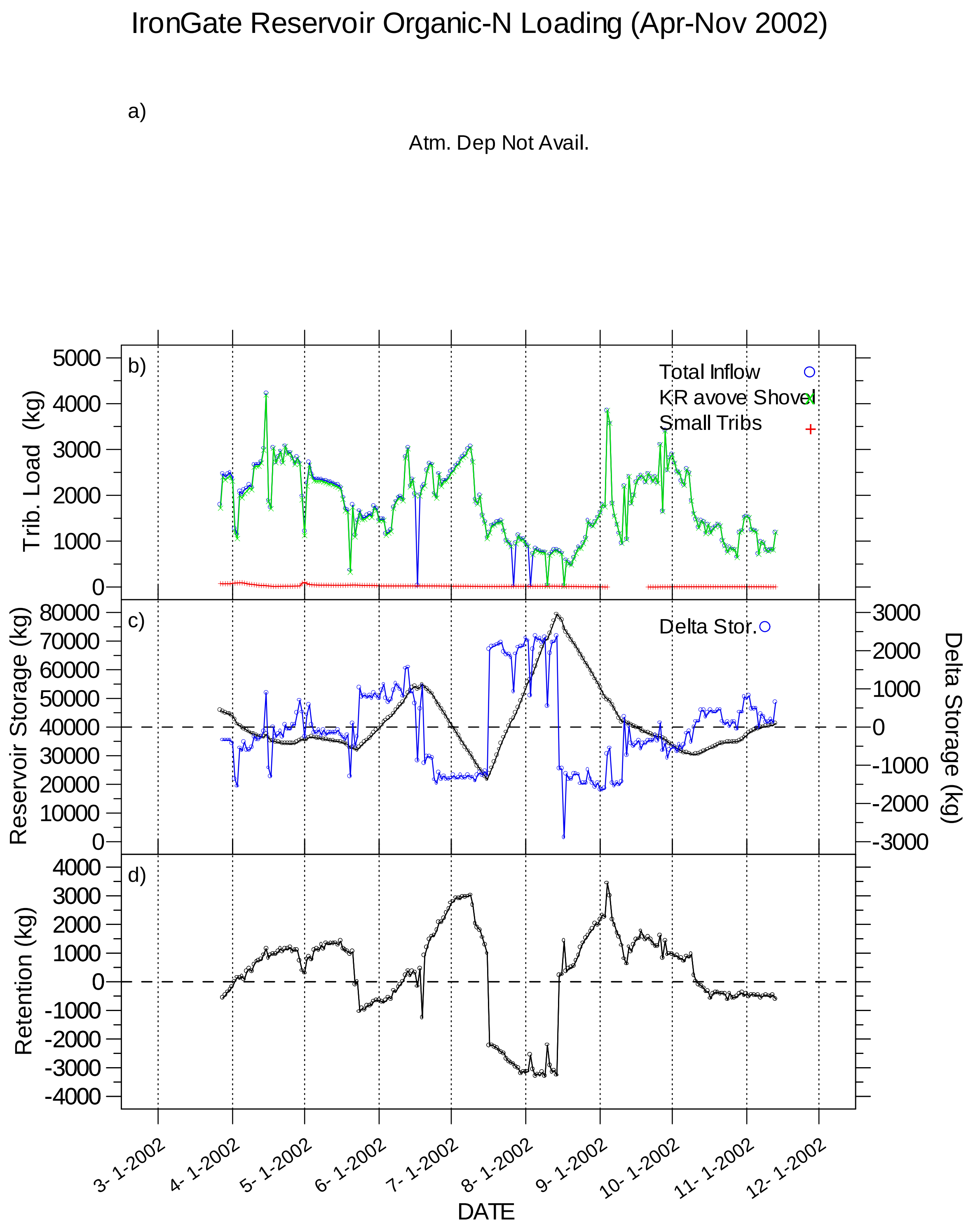


Fig. 25. Daily time series of Iron Gate Reservoir organic nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

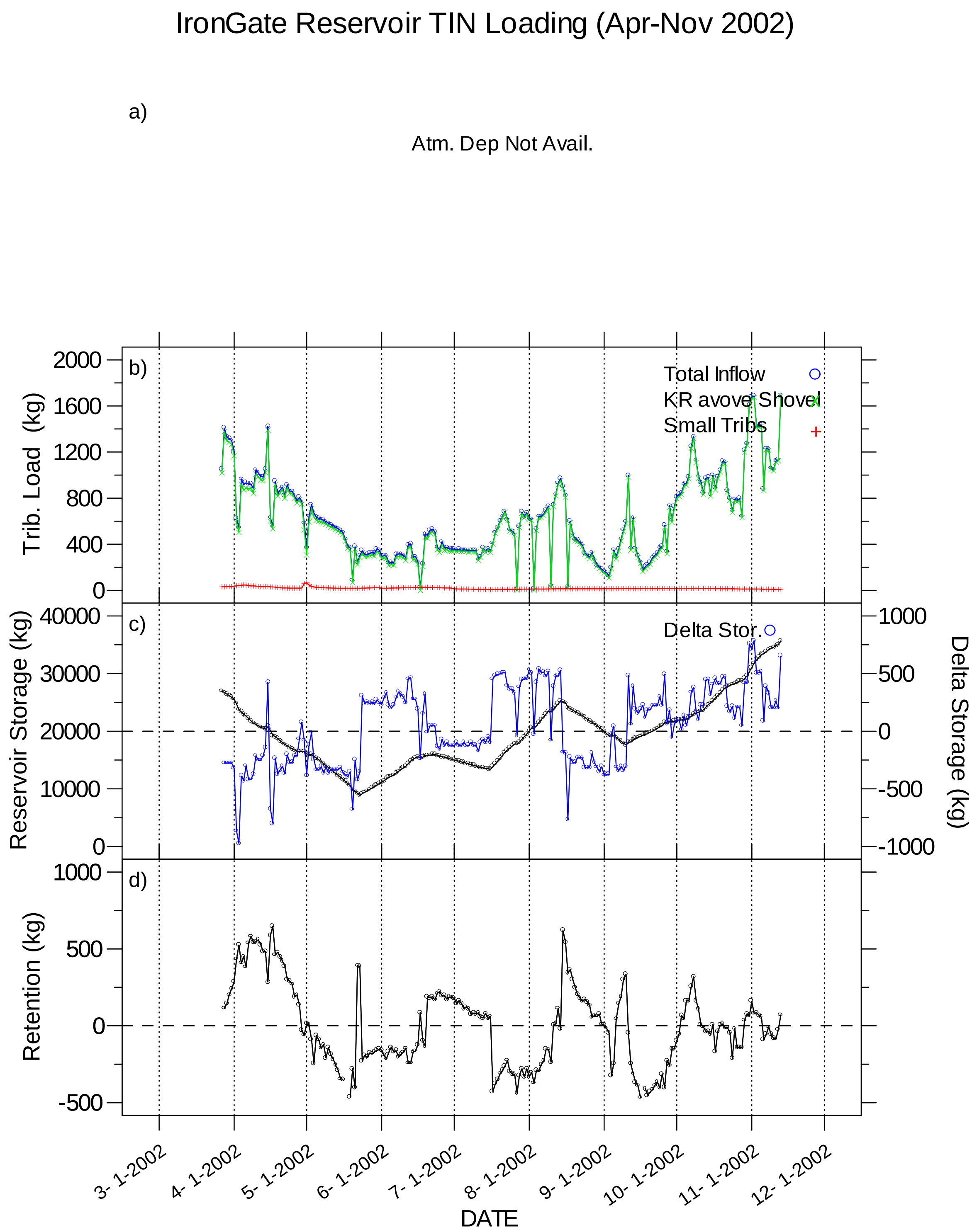


Fig. 26. Daily time series of Iron Gate Reservoir total inorganic nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

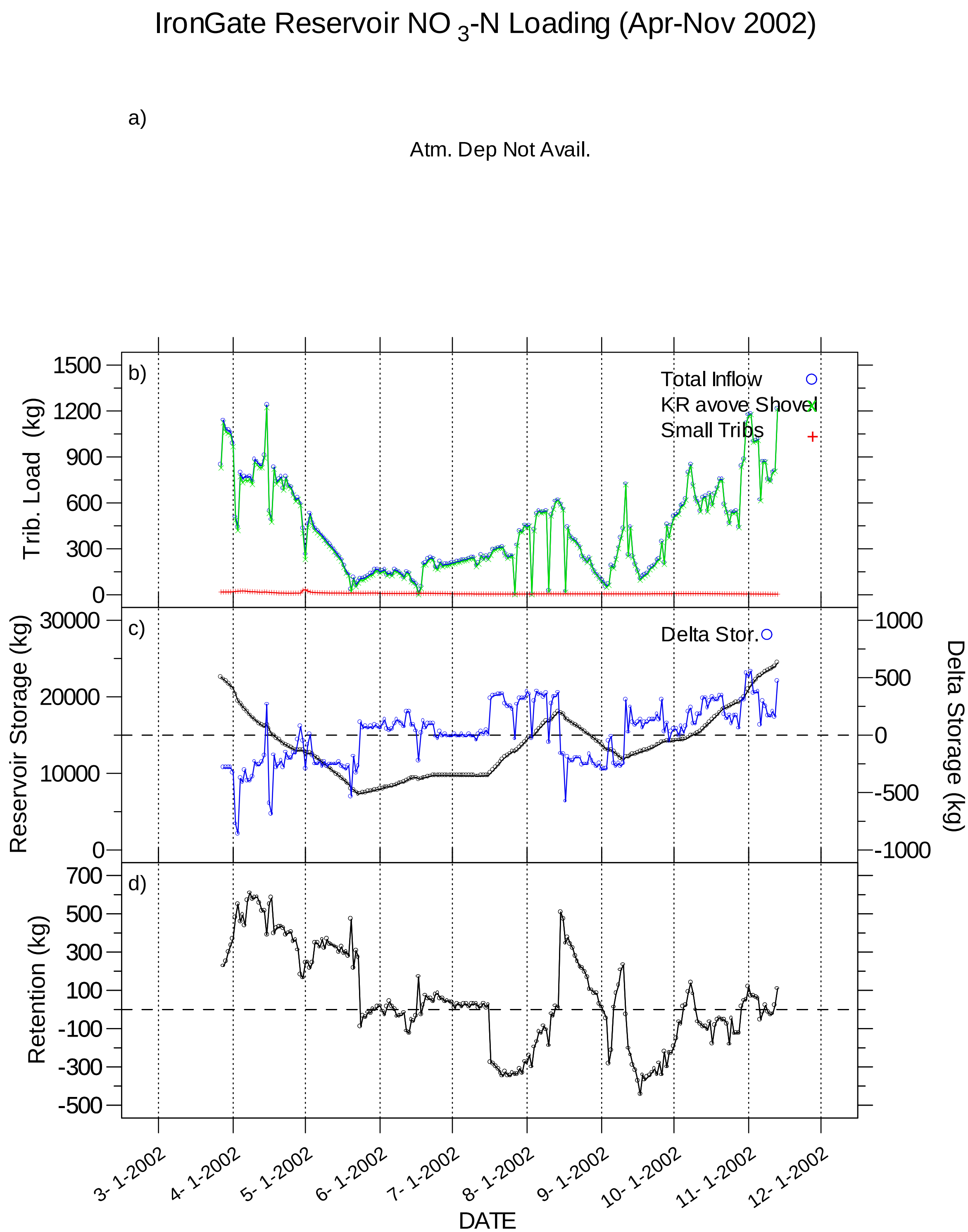


Fig. 27. Daily time series of Iron Gate Reservoir nitrate-nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

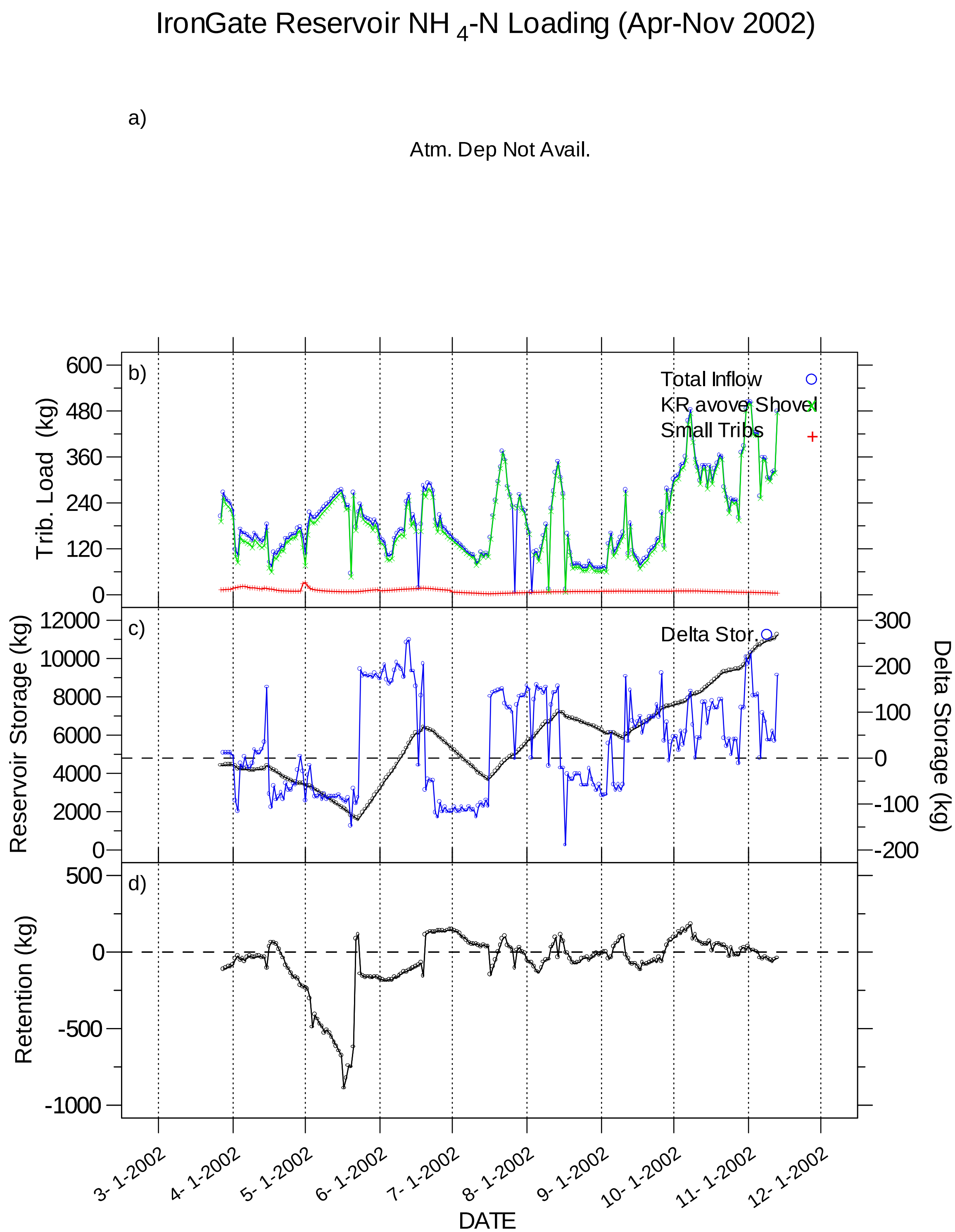


Fig. 28. Daily time series of Iron Gate Reservoir ammonia-nitrogen loading (horizontal dashed line placed at zero for ΔStor and retention), Apr-Nov 2002.

Again, for TN, these net negative retention trends may reflect input of nitrogen to the system by nitrogen fixing cyanobacteria. Large blooms of nitrogen-fixing *Aphanizomenon flos-aquae* and *Gloeotrichia echinulata* were noted in biweekly sampling occurring in July and August of 2005 (Kann 2005). While these data indicate that over the Apr-Nov period Iron Gate Reservoir acts as a net sink for TN (12% retention; Table 6), Iron Gate Reservoir also periodically acts as a substantial source; especially during critical times (e.g., June through August) when nutrients would be available for downstream growth of algae and macrophytes.

Organic-N retention patterns (Fig. 25d) follow closely that of TN, indicating that a large portion of the TN is in an organic form (possibly in the form of algal biomass). Atmospherically fixed nitrogen would be rapidly incorporated into the organic algal component. Retention patterns for TIN (in this case mostly comprised of NO_3/NO_2; Fig. 27d) also indicate that a portion of the nitrogen from the Iron Gate source is in a form readily available for downstream algal and macrophyte growth (Fig. 26d).

SUMMARY

Additional research being performed in 2005 will enhance the ability to understand nutrient dynamics in the Copco/Iron Gate Reservoir system. The analyses presented here will, however, provide a preliminary formulation of mass-balance budgets for hydrology, phosphorus, and nitrogen.

These preliminary analyses indicate that for the Copco/Iron Gate Reservoir system, the April-November period is characterized by periods of positive and negative retention for both phosphorus and nitrogen (net positive values denote a sink and net negative values denote a source). Despite acting as net sinks for P and N over the entire Apr-Nov period, both Copco and Iron Gate Reservoirs can act as a nutrient source during critical periods (e.g., June through September), making nutrients available at such periods for downstream growth of algae and macrophytes.

The more robust seasonal analysis presented here does not support an earlier PacifiCorp (2004a; 2005b) broad postulation that the reservoirs benefit water quality by processing organic matter and nutrients from upstream sources. With the given data set, there is a clear indication that the reservoirs periodically increase nutrient loading downstream. Likely pathways for this increased load include internal sediment loading and nitrogen fixation by cyanobacteria.

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ELECTRONIC APPENDICES

Files submitted on CD-ROM accompanying this report. Electronic appendices and this report are also available online at:
http://www.krisweb.com/ftp/KlamWQdatabase/Copco_IG_Budgets.zip

A. Master Klamath TMDL water quality database in Microsoft Access format. Includes all data in Appendices B, C, and D).
A_KR_TMDL_database_with_PCorp_USFWS_CDWR_data.zip
Available online at:
http://www.krisweb.com/ftp/KlamWQdatabase/KR_TMDL_database_with_PCorp_USFWS_CDWR_data.zip

B. Klamath nutrient data from U.S. Fish and Wildlife Service (Arcata office) 2001-2004. Database includes data in original format, as well as queries translating it into the format of master TMDL database.
B_wq_klamath_usfws_2001_2004.zip
Available online at:
http://www.krisweb.com/ftp/KlamWQdatabase/wq_klamath_usfws_2001_2004.zip

C. Klamath nutrient data from PacifiCorp 2000-2003. Database includes data in original format, as well as queries translating it into the format of master TMDL database.
C_wq_klamath_pcorp_2000_2003.zip
Available online at:
http://www.krisweb.com/ftp/KlamWQdatabase/wq_klamath_pcorp_2000_2003.zip

D. Klamath nutrient data from California Department of Water Resources 1999-2004. Database includes data in original format, as well as queries translating it into the format of master TMDL database.
D_wq_klamath_cwdr_1999_2004.zip
Available online at:
http://www.krisweb.com/ftp/KlamWQdatabase/wq_klamath_cwdr_1999_2004.zip

E. Hydrologic budgets for Iron Gate and Copco Reservoirs. Hydrologic budgets were constructed for calendar year 2002, but data from all available time periods are also included in the spreadsheet. Data include: precipitation, evaporation, tributary flows, reservoir bathymetry, reservoir inflow/outflows, reservoir elevation, and reservoir surface area.
E_IG_Copco_hydro_data_7_28_2005.xls

F. Summary table showing the dates on which nutrient samples were collected at each site and which agency collected the sample.
F_summary_of_sites_dates_2002_days_by_source.xls

G. Summary table showing the dates on which nutrient samples were collected at each site and the length of times between samples.
G_summary_of_sites_dates_2002_sampling_gaps.xls

H. Comparison of sampling depth versus total depth for each reservoir sample.
H_KlamathReservoirs_2002_WQ_sampling_depths.xls

I. Data from individual nutrient samples, before volume-weighting and interpolation
I_KlamathReservoirs_2002_WQ_all_parameters_2002_before_interpolation (not vol weighted).xls

J. Calculated volume-weighted nutrient concentrations. Data are for each sampling day and are not interpolated between days.
J_KlamathReservoirs_2002_WQ_all_parameters_2002_before_interpolation (vol_weighted).xls

K. Daily calculated volume-weighted and interpolated nutrient concentrations.
K_KlamathReservoirs_2002_WQ_interpolated_v2d_interpolated (vol_weighted).xls

L. Daily calculated volume-weighted and interpolated nutrient loads.
L_KlamathReservoirs_2002_WQ_loads.xls

M. Daily ammonia (NH3) budget for Copco Reservoir
M_Budget_Copco_NH3.xls

N. Daily nitrate (N03) budget for Copco Reservoir
N_Budget_Copco_NO3.xls

O. Daily organic nitrogen (ORGN) budget for Copco Reservoir
O_Budget_Copco_ORGN.xls

P. Daily ortho-phosphorus (PO4) budget for Copco Reservoir
P_Budget_Copco_PO4.xls

Q. Daily total inorganic nitrogen (TIN) budget for Copco Reservoir
Q_Budget_Copco_TIN.xls

R. Daily total nitrogen (TN) budget for Copco Reservoir
R_Budget_Copco_TOTN.xls

S. Daily total phosphorus (TP) budget for Copco Reservoir
S_Budget_Copco_TP.xls

T. Daily ammonia (NH3) budget for Iron Gate Reservoir
T_Budget_IronGate_NH3.xls

U. Daily nitrate (N03) budget for Iron Gate Reservoir
U_Budget_IronGate_NO3.xls

V. Daily organic nitrogen (ORGN) budget for Iron Gate Reservoir
V_Budget_IronGate_ORGN.xls

W. Daily ortho-phosphorus (PO4) budget for Iron Gate Reservoir
W_Budget_IronGate_PO4.xls

X. Daily total inorganic nitrogen (TIN) budget for Iron Gate Reservoir
X_Budget_IronGate_TIN.xls

Y. Daily total nitrogen (TN) budget for Iron Gate Reservoir
Y_Budget_IronGate_TOTN.xls

Z. Daily total phosphorus (TP) budget for Iron Gate Reservoir
Z_Budget_IronGate_TP.xls

AA. Bathymetry Grids for Copco and Iron Gate Reservoirs
AA_Bathymetry_grids_Copco_Iron_Gate.zip