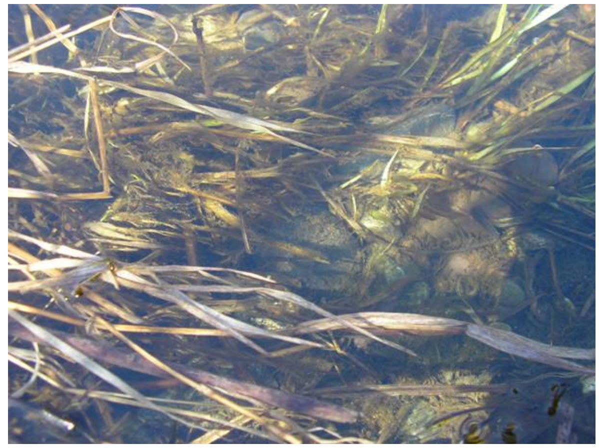
KLAMATH RIVER NITROGEN LOADING AND RETENTION DYNAMICS 1996-2004



PREPARED FOR THE

YUROK TRIBE ENVIRONMENTAL PROGRAM

BY

KIER ASSOCIATES, FISHERIES AND WATERSHED PROFESSIONALS
BLUE LAKE AND ARCATA, CALIFORNIA

AND

AQUATIC ECOSYSTEM SCIENCES LLC
ASHLAND, OREGON

JULY, 2006

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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. These upper tributaries drain into large, shallow Upper Klamath Lake, and, then, after a short reach known as the Link River, which flows into Lake Ewuana, the Klamath River proper begins. From this point the River continues through a series of federally-licensed hydroelectric project impoundments, including Keno, J.C. Boyle, Copco, and Iron Gate Reservoirs. After Iron Gate Dam, the river flows 190 miles to the Pacific Ocean. During this 190-mile trip, the river picks up many substantial tributaries including the Shasta River, Scott River, Salmon River, and Trinity River. With the exception of the Shasta, and, perhaps, the Scott, nearly all these tributaries are cleaner and cooler than the mainstem Klamath, improving mainstem water quality through dilution.

Study Goals

The overall goals of this study were to 1) compile existing nutrient and hydrologic data for the Klamath River and its tributaries from Link River to Klamath Glen, which is near the river's mouth, 2) calculate nitrogen loads to assess the downstream transport of nitrogen, 3) construct mass-balance nitrogen budgets for the river reaches below Iron Gate Dam in order to estimate the degree of nitrogen retention in the free-flowing reaches of the river, and 4) to compare nitrogen retention in free-flowing river reaches with retention in Iron Gate and Copco Reservoirs.

This study focuses solely on nitrogen because it is generally considered to be the nutrient which most often drives plant and algal growth in the Klamath River (PacifiCorp 2004, Kier Associates 2005). The methodology used here could also be applied to the assessment other nutrients, such as phosphorus, which at times may contribute to water quality issues in the river.

Fig. 1. Regional location of Klamath River Basin

Background Information on Nutrient Dynamics in Rivers

As outlined in Seitzinger et al (2002), processes such as denitrification, organic matter burial in sediments, sediment sorption, and plant and microbial uptake can remove nitrogen from river networks. These natural nutrient reduction processes have the potential to enhance water quality in free-flowing rivers, such as that which occurs below Iron Gate Dam on the Klamath River.

While these processes can substantially reduce nutrient concentrations, the rate at which this occurs varies based upon environmental conditions, and it has an upper limit. For example, both algal assimilation and denitrification processes are temperature-dependent processes (Sjodin 1997, Biggs 2000), and are most effective during the warm summer, particularly during July and August and the early autumn months.

Assimilative capacity of periphyton and macrophytes
Both periphytic (including attached algae and microorganisms) and macrophyte communities can sequester riverine nutrients and assimilate them into their cells as they grow. These organisms can also release nutrients when they die and decompose. The nutrient uptake and assimilation process can reduce nutrient concentration, while the decomposition/release process can increase nutrient concentration. The net effect on nutrient concentration is stream reach-specific.

This processing or "spiraling" of nutrients can present a mix of implications for downstream ecosystems. Nitrogen uptake may sequester nutrients for long periods resulting in seasonal alterations of downstream nutrient loads. Processing may also alter the partitioning of the nutrient forms (inorganic/organic, dissolved/particulate) with attendant implications for the availability of nutrients reaching downstream systems. In the case of nitrogen, significant in-stream removal can occur through denitrification (see below for details). For dissolved organic carbon (DOC), more intense utilization within the stream ecosystem can directly reduce downstream loading.

Biggs (2000) described the factors which govern periphyton biomass growth and decay, indicating that the most important among them are the amount of available nutrients, light, temperature, and the number of days since scouring flows (Biggs 2000). U.S. EPA (2000b), Watercourse Engineering (2003b) and Tetra Tech (2004b) also review these factors.

Kier Associates (2005) summarized the results of periphyton investigations on the Klamath River in 2004, including Eilers (2005), NCRWQCB et al. (2005), and U.S. EPA (2002), noting that the general pattern in 2004 was that biomass accrual began in July and continued until the first scouring flow. Tanner and Anderson (1996) similarly found that scour triggered periphyton sloughing and decay in Oregon's South Fork Umpqua River. These researchers also found that, similar to the "zone of recovery" phenomenon described by Biggs (2000), periphyton played a key role in nutrient dynamics and that downstream of major nutrient sources (in the Umpqua case, wastewater treatment plants) there was a five- to ten mile reach of large periphyton biomass and attendant reduction in nutrient concentration (Tanner and Anderson 1996).

Denitrification in the river's hyporheic zone
Denitrification is a process in which certain organisms can convert nitrate (NO_3) to atmospheric nitrogen (N_2). The result is often improved water quality due to reduced productivity, the result of converting a form of nitrogen that is readily available for plant uptake – nitrate – to a stable form of nitrogen that is essentially unusable by non-nitrogen fixing stream algae – atmospheric nitrogen. For denitrification to occur, adequate nitrate levels and low levels of dissolved oxygen must be present.

Denitrification is known to occur in the hyporheic zones of rivers and streams (Sjodin et al., 1997 and Holmes, 1996). The hyporheic zone is the area of water-saturated sediment beneath and beside streams where ground water and surface water mix (Edwards, 1998). Denitrification most often occurs in the presence of the following conditions: low hydraulic conductivity, long flow path, reduced oxygen supply, adequate nitrate supply, and adequate supply of labile organic carbon (Edwards, 1998).

The amount of nitrogen removed from some rivers by denitrification can be substantial, especially those with a high rate of interchange between surface water and alluvial gravels. In Colorado's South Platte River, for example, denitrification rates varied between 2- and 100 mg of nitrogen per square meter per hour. During mid-summer, a 90% reduction of nitrate was achieved in one 6 km long reach. On an annual basis, close to half the nitrate input to a 100-km reach was removed by denitrification (Sjodin et al., 1997).

Denitrification provides unique benefits to water quality. First, it permanently removes nitrogen from the river system. In contrast, nutrient assimilation by periphyton stores the nutrients in the cells of the algae, where it will eventually be released – though often such release does not occur until the fall when water temperatures have decreased and the nutrients have less adverse effect on water quality. Second, denitrification removes nitrogen without affecting dissolved oxygen and pH levels. By comparison, when periphyton are growing and assimilating nutrients, they contribute to severe diurnal fluctuations in dissolved oxygen and pH that can harm fish populations.

Finally, sedimentation of particulate N or adsorption of inorganic N to suspended solids and sediment can also contribute to nitrogen removal in rivers.

The mass-balance approach taken here to estimate nitrogen retention in river reaches does not distinguish among the processes described above, but rather provides the net removal (or in some cases, the release) due to some combination of these processes.

Inventory of Past and Current Klamath River Nutrient Studies

An initial step in using existing data for this analysis was a review of relevant past and current studies and the data generated. Agencies involved in data collection include PacifiCorp, U.S. Geologic Survey (USGS), U.S. Fish and Wildlife Service's (USFWS) Arcata Office, the U.S. Bureau of Reclamation (USBR), U.S. Bureau of Land Management (BLM), U.S. Environmental Protection Agency (EPA), U.S. Forest Service, the Karuk Tribe, Yurok Tribe, the North Coast Regional Water Quality Control Board (NCRWQCB), California Department of Water Resources, Oregon Department of Environmental Quality (ODEQ), the City of Klamath Falls, and several private concerns and contractors.

Much of the nutrient and automated probe water quality data collected in the Klamath River and its tributaries has been compiled into a single Microsoft Access database. The database was begun by PacifiCorp (2004) and added to through other studies, such as the development of Total Maximum Daily Load plans (Tetra Tech 2004a, St. John 2004) and nutrient budgets for Iron Gate and Copco Reservoirs (Kann and Asarian 2005). As part of the study described in this report, PacifiCorp's 2004 grab sample data were added to the database, and the complete database is included here as an electronic appendix.

Analytical Context and Definition of Important Terms

This study investigates the nitrogen dynamics of the Klamath River and pays particular attention to the quantification of the relative retention of the free-flowing river reaches between Iron Gate Dam and Klamath Glen, which is near the river's mouth. The calculation of retention requires the integration of the effects of both nutrient concentration and nutrient load. Load is mass per unit of time calculated by multiplying the nutrient concentration by the water flow rate. It is typically expressed in kilograms per day.

In the Klamath River basin nearly all of the tributaries below Keno contribute water with lower nutrient concentrations than that of the mainstem river. The river's nutrient concentrations typically decrease, therefore, as it flows downstream from Keno (Kier Associates, 2005).

While the addition of these low-nutrient inflows should consistently decrease mainstem nutrient concentrations, absent nutrient retention the total nutrient load would actually rise with each tributary input (i.e., although low, these tributary inputs nevertheless increase the total nutrient load). If, on the other hand, significant retention does occur, then the total nutrient load can decrease as the river flows downstream, despite additional tributary contributions.

Thus, in order to assess the location, magnitude, and seasonal timing of nitrogen sources and sinks in the Klamath River below Iron Gate Dam, we constructed mass-balance nitrogen budgets for the free-flowing river reaches. Such mass-balance calculations provide a basic approach for estimating N removal (Seitzinger et al. 2002) by allowing all inputs, including those of the tributaries, and outputs to each river reach to be compared, thereby yielding an assessment of the net changes that occur inside each reach

Once a budget has been constructed, nitrogen retention can be calculated as the difference between the mass of nitrogen in waters entering a river reach (including mainstem as well as tributary inputs) and the mass of nitrogen exiting the downstream end of a reach. Positive retention indicates nutrient storage (e.g., via algal or macrophyte uptake) or denitrification in a reach, while negative retention indicates nutrient release. Said another way, retention is the amount of nitrogen assimilated (positive retention) or released (negative retention) within a given reach.

In order to standardize among the reaches and years for reach length and incoming load, final retention results are expressed as percent retention per mile (%/mi).

METHODS

Development of Hydrologic and Nitrogen Loads and Mass-Balance Analysis for Nitrogen

Nutrient data sources

As described above, this analysis uses data assembled into the Klamath TMDL database from several sources including PacifiCorp, U.S. Geologic Survey (USGS), U.S. Fish and Wildlife Service (USFWS) Arcata Office, U.S. Bureau of Reclamation (USBR), Karuk Tribe, Yurok Tribe, North Coast Regional Water Quality Control Board (NCRWQCB, including its Surface Water Ambient Monitoring Program, SWAMP), California Department of Water Resources, the Oregon Department of Environmental Quality (ODEQ), and various private companies and contractors. There were varying degrees of coordination between these agencies in terms of sampling protocols; the dates and frequency of sample collection; the location of samples; and the laboratories used for analysis.

Figure 2 and Table 1 show the locations of mainstem and tributary sites that were commonly sampled and which were used in the analysis presented here.

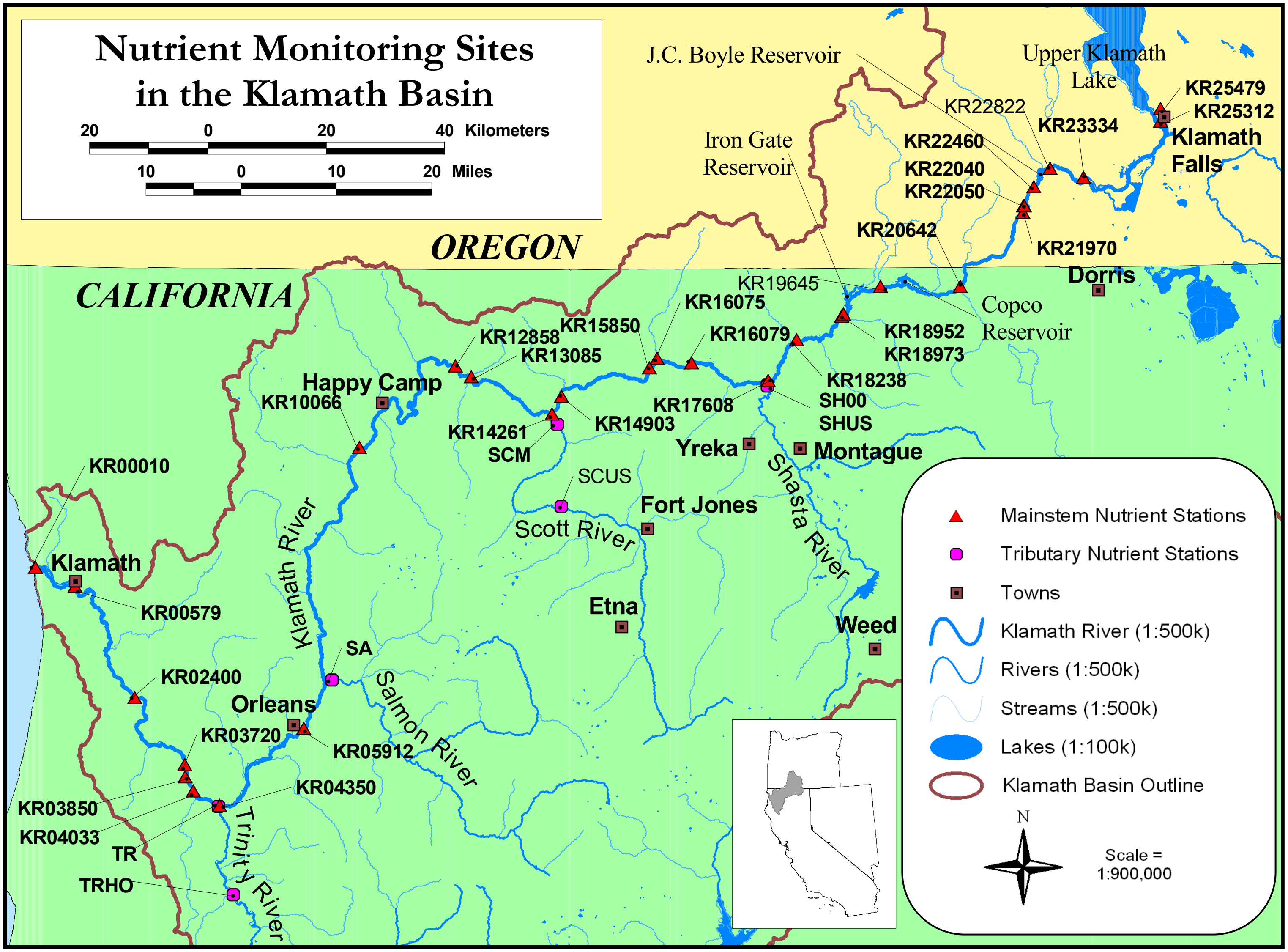

Figure 2. Location of nutrient sampling sites in the mainstem Klamath River and its tributaries. Note that the Site ID code for mainstem stations begins with "KR", followed by 5-digit river mile (i.e. KR18973 is river mile 189.73).

Table 1. Key and description for nutrient sampling locations shown in Fig. 2. Note that the Site ID code for mainstem stations begins with "KR", followed by 5-digit river mile (i.e. KR18973 is river mile 189.73).

Site ID	River Mile	Site Name	Latitude	Longitude
KR00010	0.10	Klamath River Estuary Mainstem	41.543610	-124.078890
KR00579	5.79	Klamath River at Klamath Glen	41.515280	-123.998890
KR02400	24.00	Klamath River at Johnson's Point	41.347630	-123.876000
KR03720	37.20	Klamath River at Young's Bar	41.246600	-123.773300
KR03850	38.50	Klamath River above Tully Creek	41.228060	-123.772220
KR04033	40.33	Klamath River at Martins Ferry	41.207220	-123.755280
KR04350	43.50	Klamath River at Weitchpec	41.185830	-123.703056
KR05912	59.12	Klamath River at Orleans	41.303330	-123.533330
KR10066	100.66	Klamath River below Happy Camp	41.729720	-123.424440
KR12858	128.58	Klamath River at Seiad Valley	41.854170	-123.230280
KR13085	130.85	Klamath River at Seiad Valley (2.25 mi above gage)	41.837333	-123.197500
KR14261	142.61	Klamath River above Scott River	41.781530	-123.033110
KR14903	149.03	Klamath River below Everill Creek	41.808133	-123.014067
KR15850	158.50	Klamath River at Round Bar Pool	41.851000	-122.835530
KR16075	160.75	Klamath River d/s Beaver Creek	41.865800	-122.819300
KR16079	160.79	Klamath River at Gottsville River Access	41.858450	-122.750220
KR17608	176.08	Klamath River above Shasta River	41.831280	-122.593467
KR18238	182.38	Klamath River u/s Cottonwood Creek	41.892730	-122.535400
KR18952	189.52	Klamath River below Iron Gate Dam (USGS Gage)	41.928056	-122.443056
KR18973	189.73	Klamath River below Iron Gate Dam (Hatchery Br.)	41.931600	-122.440000
KR19645	196.45	Copco Dam Outflow	41.973250	-122.363580
KR20642	206.42	Klamath River u/s Shovel Creek	41.972100	-122.201600
KR21970	219.70	Klamath River below Boyle powerhouse at USGS gage	42.083112	-122.071746
KR22040	220.40	Klamath River at J.C. Boyle Powerhouse	42.093060	-122.070830
KR22050	220.50	Klamath River above J.C. Boyle Powerhouse	42.093610	-122.069170
KR22460	224.60	Klamath River below J.C. Boyle Reservoir	42.121700	-122.049400
KR22822	228.22	Klamath River above J.C. Boyle Reservoir	42.149900	-122.015400
KR23334	233.34	Klamath River below Keno Dam	42.135300	-121.947220
KR25312	253.12	Link River at Mouth	42.218900	-121.788300
KR25479	254.79	Upper Klamath Lake at Fremont St Bridge	42.238300	-121.788060
SA	-	Salmon River at Somes Bar	41.376900	-123.477200
SCM	-	Scott River at Mouth	41.765830	-123.022800
SCUS	-	Scott River at USGS Gage	41.640500	-123.014500
SH00	-	Shasta River at Mouth	41.825000	-122.595100
SHUS	-	Shasta River at USGS Gage	41.823167	-122.595000
TR	-	Trinity River at Weitchpec	41.184330	-123.704167
TRHO	-	Trinity River at Hoopa	41.050400	-123.673300

Many of the samples in the database were collected at suboptimal sampling frequency, with samples typically collected at monthly or bimonthly intervals. The analysis provided here focuses primarily on the years 1998-2002 at sites with bi-weekly (samples taken at least once every two weeks) sampling frequency. Although these were the only years in which more than one site was sampled at bi-weekly intervals, we also used monthly data from 1996, 1997, 2003, and 2004 to calculate nitrogen loads. However, monthly data were not utilized for the development of reach-by-reach nitrogen budgets. Figures 3 through 5 summarize the sampling frequency for each sample site on the mainstem Klamath River. Because our analysis focuses on nitrogen loading at riverine locations, we did not utilize data collected in the reservoirs. Previous efforts summarizing 2002 reservoir loading are contained in Kann and Asarian (2005). Data sources utilized for each year are shown in Table 2.

Table 2. Data sources used in nutrient loading analysis and budgets.

Year	USFWS/ Yurok/Karuk	USBR	ODEQ	USGS	PacifiCorp	NCRWQCB/ SWAMP
1996			x	x		NCRWQCB
1997			x	x		NCRWQCB
1998		x	x	x		
1999		x	x	x		
2000		x	x	x	x	
2001	x	x	x		x	
2002	x		x	x	x	SWAMP
2003	x	x	x	x	x	SWAMP
2004	x		x		x	

Additional information on some of these datasets can be found in published reports, including USBR 2000 (Watercourse Engineering 2003a), PacifiCorp 2001-2004 (PacifiCorp 2004), USGS/USBR 1996-1998 (Campbell 1999, Campbell 2001), USGS 2002-2003 (Flint et al 2005), and USFWS/Yurok/Karuk 2001-2004 (ARFO 2005, Armstrong and Ward 2005, Turner 2005).

Nutrient data collected for stations in the J.C. Boyle Peaking Reach (KR22040, KR21970, KR20932, and KR20642) may be 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 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 (peaking reach). 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.

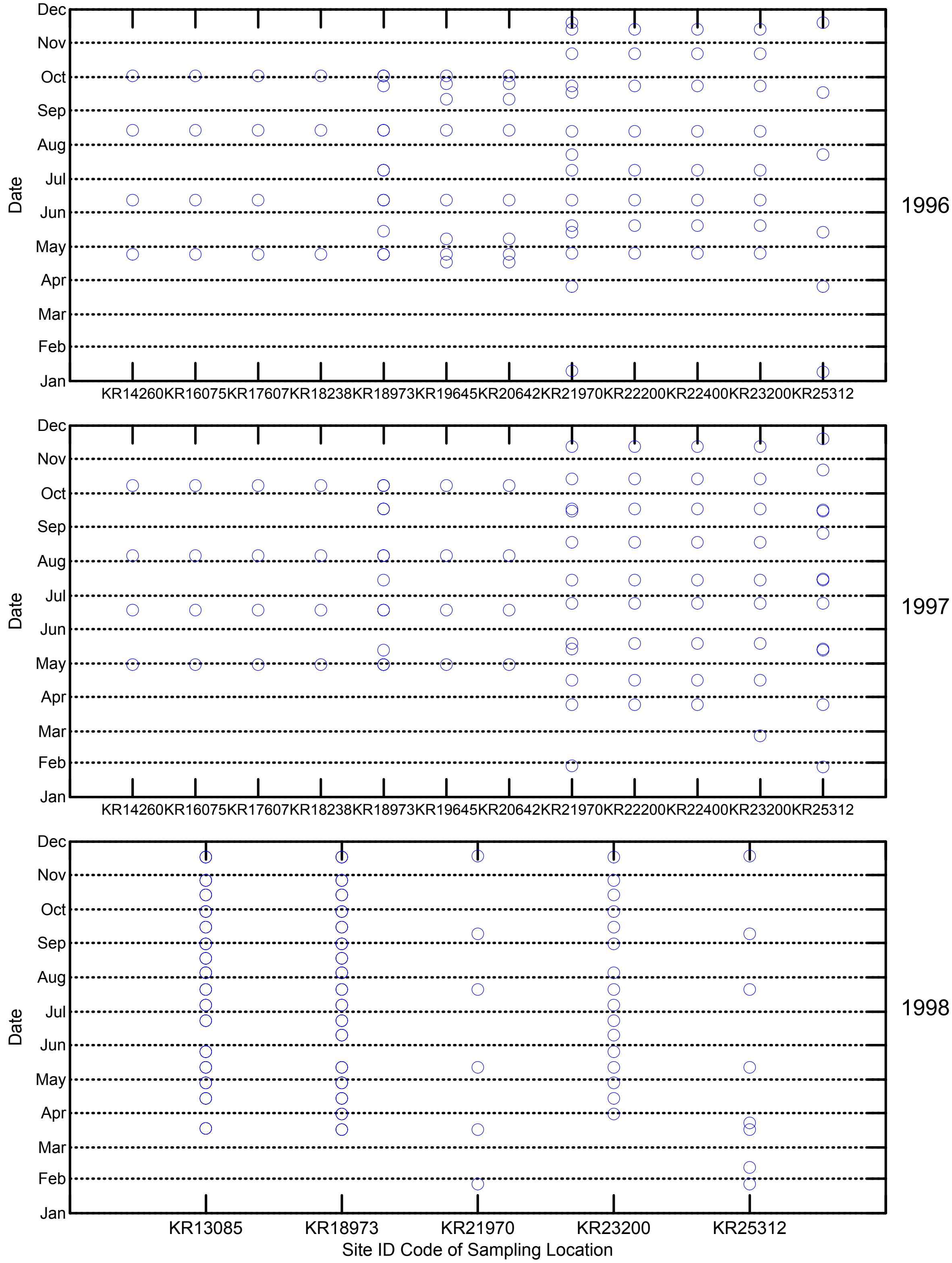

Figure 3. Dates and locations of data utilized in analysis for years 1996-1998. Only mainstem non-reservoir sites are shown. Site ID codes begin with "KR", the 5-digit river mile (i.e. KR21970 = river mile 219.70).

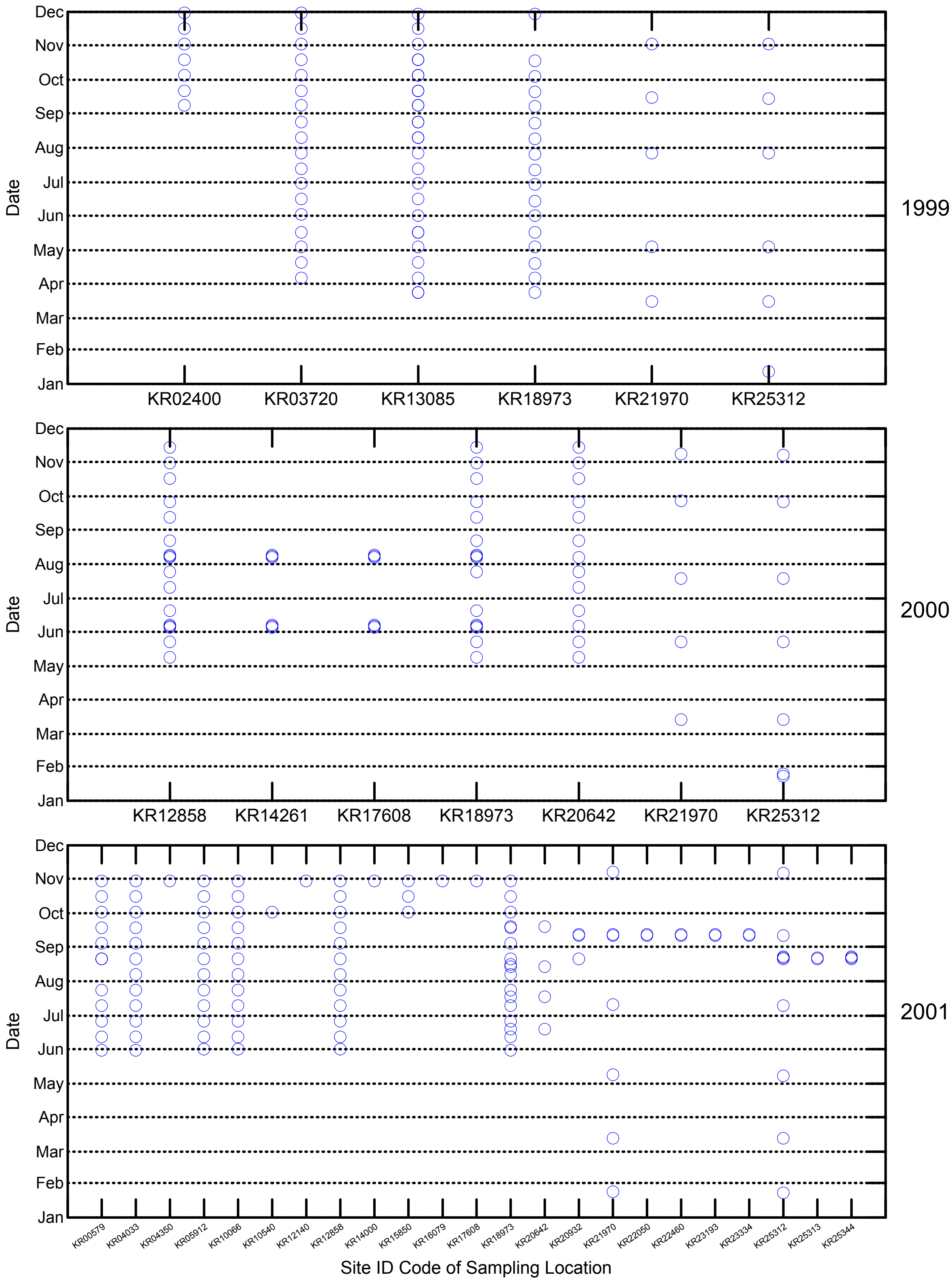

Figure 4. Dates and locations of data utilized in analysis for years 1999-2001. Only mainstem non-reservoir sites are shown. Site ID codes begin with "KR", the 5-digit river mile (i.e. KR21970 = river mile 219.70).

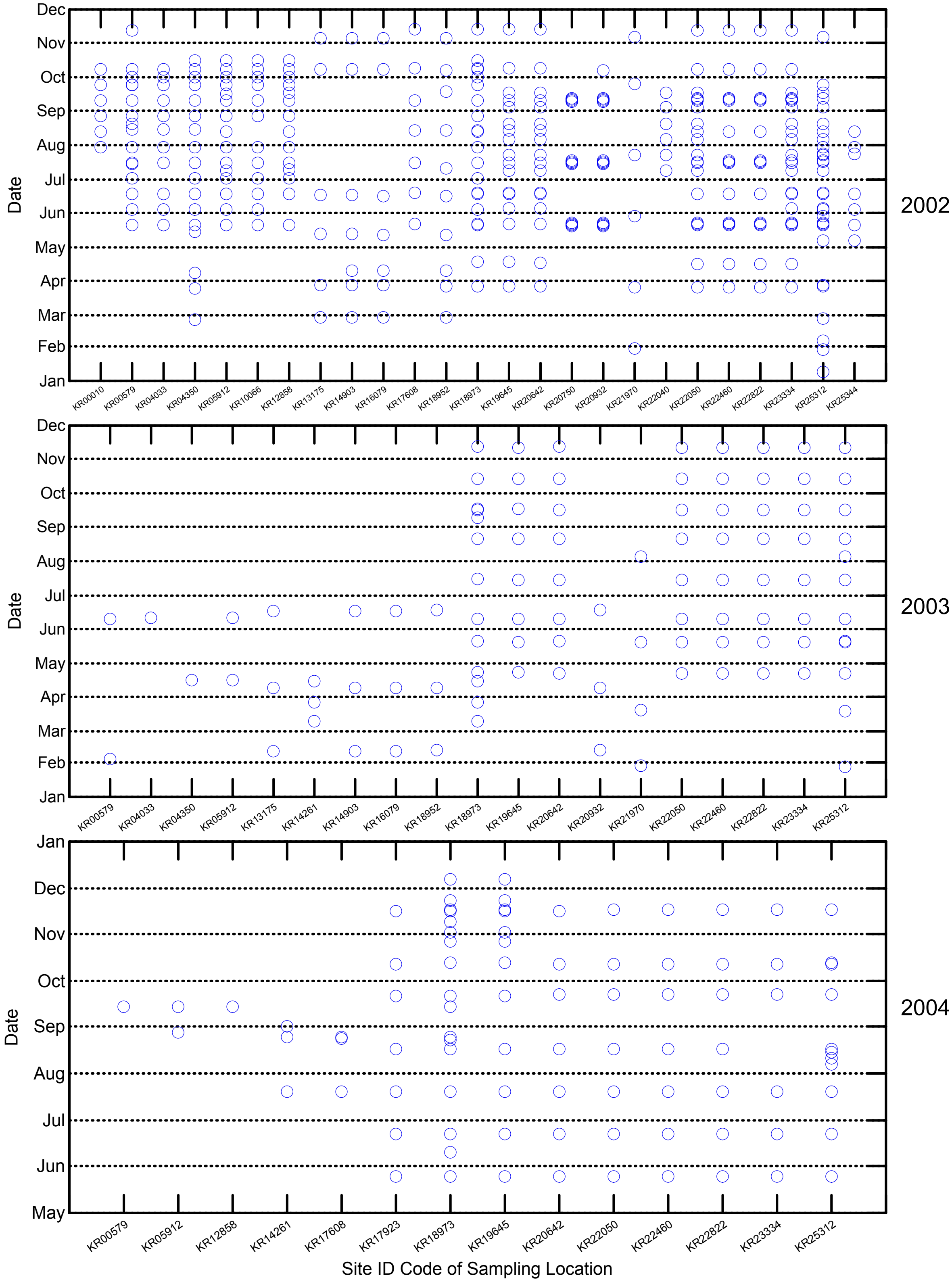

Figure 5. Dates and locations of data utilized in analysis for years 2001-2004. Only mainstem non-reservoir sites are shown. Site ID codes begin with "KR", the 5-digit river mile (i.e. KR21970 = river mile 219.70).

Due to the use of different laboratories, reporting limits vary between datasets and even within datasets. Table 3 shows the reporting limits for nitrogen parameters in the datasets most heavily used in this analysis.

Table 3. Reporting limits for nitrogen parameters in the USFWS/Yurok/Karuk 2001-2004 dataset (AFWO 2005, Armstrong and Ward 2005, Turner 2005), PacifiCorp 2001-2004 and USBR 2001 dataset (PacifiCorp 2004), USBR 2000 dataset (Watercourse Engineering 2003a), USGS 2002 dataset (Flint et al. 2005).

Agency/Tribe	Parameter Code	Parameter Name	Year	Reporting Limit	Number of Samples
USFWS/Yurok/Karuk	NH3	Ammonia	2001	0.05	26
USFWS/Yurok/Karuk	NH3	Ammonia	2001	0.1	130
USFWS/Yurok/Karuk	NH3	Ammonia	2002	0.1	230
USFWS/Yurok/Karuk	NH3	Ammonia	2003	0.1	25
USFWS/Yurok/Karuk	NH3	Ammonia	2003	0.2	3
USFWS/Yurok/Karuk	NH3	Ammonia	2004	0.05	13
USFWS/Yurok/Karuk	NH3	Ammonia	2004	0.1	80
USFWS/Yurok/Karuk	NO3	Nitrate	2001	0.05	51
USFWS/Yurok/Karuk	NO3	Nitrate	2001	0.1	105
USFWS/Yurok/Karuk	NO3	Nitrate	2001	0.2	1
USFWS/Yurok/Karuk	NO3	Nitrate	2002	0.05	234
USFWS/Yurok/Karuk	NO3	Nitrate	2002	0.1	4
USFWS/Yurok/Karuk	NO3	Nitrate	2003	0.05	57
USFWS/Yurok/Karuk	NO3	Nitrate	2003	0.1	9
USFWS/Yurok/Karuk	NO3	Nitrate	2004	0.05	88
USFWS/Yurok/Karuk	NO3	Nitrate	2004	0.1	5
USFWS/Yurok/Karuk	TKN	Total Kjeldahl Nitrogen	2001	0.1	156
USFWS/Yurok/Karuk	TKN	Total Kjeldahl Nitrogen	2002	0.1	229
USFWS/Yurok/Karuk	TKN	Total Kjeldahl Nitrogen	2003	0.1	12
USFWS/Yurok/Karuk	TKN	Total Kjeldahl Nitrogen	2003	1	3
USFWS/Yurok/Karuk	TKN	Total Kjeldahl Nitrogen	2004	0.5	33
PacifiCorp/USBR	NH3	Ammonia	2001- 2004	0.05	
PacifiCorp/USBR	NO3/NO2	Nitrate + Nitrite	2001- 2004	0.05	
PacifiCorp/USBR	TKN	Total Kjeldahl Nitrogen	2001- 2004	0.1	
USBR	NH3	Ammonia	2000	0.05	
USBR	NO3/NO2	Nitrate + Nitrite	2000	0.05	
USBR	TKN	Total Kjeldahl Nitrogen	2000	0.2	
USGS	NH3	Ammonia	2002	0.013	
USGS	NO3/NO2	Nitrate + Nitrite	2002	0.015	
USGS	TKN	Total Kjeldahl Nitrogen	2002	0.1	

As shown here, reporting limits differed among laboratories, and the original USFWS data set contained numerous samples with high reporting limits for total Kjeldahl nitrogen (TKN) and ammonia. For example, reporting limits were sometimes 0.5 or 1.0 mg/L for TKN, and 0.2 mg/L for ammonia. These reporting limits are high relative to the values expected for the system, such that setting the values for non-detect samples at one half the reporting limit introduces more error than simply excluding the data. Thus, many of the samples were excluded in the years 2003-2004 because of the high frequency of non-detect samples with high reporting limits.

Moreover, the numeric value assigned to non-detect samples in the database varies by agency. In the USFWS/Yurok/Karuk dataset, non-detects are set at half the reporting limit, as are some of PacifiCorp's non-detect samples, though others were estimated using frequency distributions. Numeric values for USBR's non-detect samples were estimated using frequency distributions.

Hydrologic data

Streamflow data for the Klamath River gages listed in Table 4 were obtained from USGS (website: http://waterdata.usgs.gov/usa/nwis).

Table 4. USGS flow gages utilized in analysis

Site Number	Station Name
11507500	LINK RIVER AT KLAMATH FALLS, OR
11509500	KLAMATH RIVER AT KENO, OR
11510700	KLAMATH RIVER BLW JOHN C.BOYLE PWRPLNT, NR KENO,OR
11516530	KLAMATH R BL IRON GATE DAM CA
11517500	SHASTA R NR YREKA CA
11519500	SCOTT R NR FORT JONES CA
11520500	KLAMATH R NR SEIAD VALLEY CA
11521500	INDIAN C NR HAPPY CAMP CA
11522500	SALMON R A SOMES BAR CA
11523000	KLAMATH R A ORLEANS
11530000	TRINITY R A HOOPA CA
11530500	KLAMATH R NR KLAMATH CA

Because not all nutrient samples were taken at USGS stream gages, discharge was estimated at some locations in order to calculate nutrient loads. Following a method similar to that described in PacifiCorp (2005d), we developed a daily flow record for hydrologic years 1962-2004. The river was divided into three reaches: Iron Gate to Seiad, Seiad to Orleans, and Orleans to Klamath Glen.

Five-day moving averages of all gages were calculated and accretions for the three reaches between the mainstem gages were developed by calculating the difference between the five-day moving averages of the upstream gage, downstream gage, and any gaged tributaries in the reach.

The accretion was then distributed to tributaries along the reach in proportion to their watershed area. Twenty-nine ungaged tributaries from Iron Gate to the Klamath Glen were used in the calculations (Table 5). Mainstem flows were then calculated for the mainstem location just downstream of each of the 29 ungaged tributaries and the five gaged tributaries by combining the flow at the reach's upstream gage with the appropriate gaged and ungaged tributaries. (The resulting flow record is included as an electronic appendix to this report.) Discharge estimates could then be applied to each nutrient concentration value in order to generate site-specific loads.

Table 5. Details regarding method for developing discharge estimates for ungaged tributaries. Although gaged tributaries are included in the table, they were not part of the accretion calculation; they are included to provide information such as watershed area, location, and ID discharge code (these codes would be necessary to use Appendix C),

				(km^2)	(km^2)	
Creek Name	River Mile	ID_Discharge	Reach	Watershed Area	Total Area of Accretion	Watershed Area as Fraction of Total
Little Bogus	187.00	T_18700	Iron Gate to Seiad	38.4	1606.2	0.024
Willow Cr	185.00	T_18500	Iron Gate to Seiad	151.1	1606.2	0.094
Cottonwood C	182.00	T_18200	Iron Gate to Seiad	257.0	1606.2	0.160
Shasta R	176.68	SH00	Iron Gate to Seiad	2032.0		
Humbug Cr	171.48	T_17148	Iron Gate to Seiad	95.5	1606.2	0.059
Beaver Cr	161.00	T_16100	Iron Gate to Seiad	279.8	1606.2	0.174
Barkhouse Cr	157.31	T_15731	Iron Gate to Seiad	41.5	1606.2	0.026
Horse Cr	147.40	T_14740	Iron Gate to Seiad	157.7	1606.2	0.098
Scott R	143.00	SCUS	Iron Gate to Seiad	2107.0		
Scott Tribs	143.00	SCUS_ds	Iron Gate to Seiad	395.5	1606.2	0.246
Grider Cr	130.29	T_13029	Iron Gate to Seiad	119.4	1606.2	0.074
Seiad Cr	130.06	T_13006	Iron Gate to Seiad	70.4	1606.2	0.044
Thompson Cr	123.00	T_12300	Seiad to Oreans	94.1	1030.0	0.091
Indian Cr	106.73	IC	Seiad to Oreans	307.0		
Elk Cr	105.46	T_10546	Seiad to Oreans	245.7	1030.0	0.239
Clear Cr	98.57	T_09857	Seiad to Oreans	285.4	1030.0	0.277
Independence	94.00	T_09400	Seiad to Oreans	46.7	1030.0	0.045
Ukonom Cr	89.88	T_08988	Seiad to Oreans	84.6	1030.0	0.082
Dillon Cr	84.00	T_08400	Seiad to Oreans	187.3	1030.0	0.182
Rock Cr	79.04	T_07904	Seiad to Oreans	86.1	1030.0	0.084
Salmon R	66.00	SA	Seiad to Oreans	1943.0		
Camp Cr	56.94	T_05694	Orleans to Klamath Glen	108.9	1522.3	0.072
Boise Cr	55.53	T_05553	Orleans to Klamath Glen	40.2	1522.3	0.026
Red Cap Cr	52.71	T_05271	Orleans to Klamath Glen	158.0	1522.3	0.104
Bluff Cr	49.54	T_04954	Orleans to Klamath Glen	192.2	1522.3	0.126
Trinity R	43.42	TRHO	Orleans to Klamath Glen	5536.8		
Trinity Trib	43.42	TRHO_ds	Orleans to Klamath Glen	300.3	1522.3	0.197
Little Pine	40.75	T_04075	Orleans to Klamath Glen	119.7	1522.3	0.079
Tully Cr	38.54	T_03854	Orleans to Klamath Glen	44.3	1522.3	0.029
Roach Cr	31.49	T_03149	Orleans to Klamath Glen	74.7	1522.3	0.049
Pecwan Cr	25.37	T_02537	Orleans to Klamath Glen	71.6	1522.3	0.047
Tectah Cr	22.00	T_02200	Orleans to Klamath Glen	49.6	1522.3	0.033
Ah Pah Cr	17.17	T_01717	Orleans to Klamath Glen	39.7	1522.3	0.026
Blue Cr	16.28	T_01628	Orleans to Klamath Glen	323.2	1522.3	0.212

Calculation of total nitrogen concentrations and temporal interpolation

TKN and NO_3/NO_2 were summed in order to calculate total nitrogen (TN) concentrations. If multiple samples were taken per day at a site, TN values were averaged to obtain a single value per day. Intervals between nutrient samples were linearly interpolated to create a daily record of concentration that could be combined with daily flow records described above.

For the years 1998-2002, interpolations were performed only for sites and years with data of approximately bi-weekly or better temporal resolution. An examination of sampling frequency of available data shows that samples were missing occasionally, or that intervals between samples varied (Figs. 3-5). For example, even though there are bi-weekly data for most of the year at site KR18973 (Klamath River below Iron Gate Dam) in 1998, there is a month-long gap from May 12 to June 10. For purposes of this study we interpolated across such gaps when they were less than 30 days and where there were minimal gaps at a site in a given season. The 1998-2002 biweekly data were used in the calculation of nitrogen loads as well as in the construction of reach-specific nutrient budgets.

There were very few sites with bi-weekly data for the years 1996-1997 and 2003-2004. For those years we interpolated sites and years with data of approximately monthly or better temporal resolution. Gaps of up to 45 days were interpolated as long as there were not more than a few gaps longer than 30 days in a season. Nitrogen loads were calculated from these data and are included in the figures and tables of the Nitrogen Loads portion of the results/discussion section below; however, these had insufficient sampling intervals (monthly) to be utilized in the construction of the reach-specific nitrogen budgets.

Nitrogen load calculations

Using daily discharge and nutrient concentration records described above for each site and day, TN concentration (in mg/L) was multiplied by discharge (in cubic feet per second) and a unit conversion factor of 2.4469 was applied in order to obtain TN load in kilograms-per-day.

Daily average discharge and flow-weighted mean nutrient concentration were then computed for the June-October period of most frequent data collection. Flow-weighted mean concentration was computed as the total June-October daily load divided by the total discharge for the same period. In the years 1996 and 2004 there were no October data at most sites so summaries were only computed for the June-September period.

Nitrogen budget construction for river reaches

To estimate relative nitrogen assimilation or release of the free-flowing reaches of the Klamath River we conducted detailed analysis of river reaches from Iron Gate to Klamath Glen. The borders between the reaches were the bi-weekly sampling stations (see results section below for a list of years and reaches). Where data availability permitted, a record of discharge, TN concentration, and load were assembled for the upstream end of the reach, the downstream end of the reach, as well as the measured tributaries and estimated accretions.

Reach-specific unmeasured accretions (as described above) were assigned a constant TN concentration of 0.11 mg/L. This is the equivalent value used by PacifiCorp (2005d, 2006) in its water quality modeling, representing the sum of 0.05 mg/L ammonia, 0.05 mg/L nitrate/nitrite, and 0.01 mg/L organic matter. We reviewed the limited available data on these small tributaries.

The average TN value calculated from USFWS sampling during the late season low-flow period in six streams on October 30, 2001 was 0.36 mg/L, while TN was not detected with a 0.1 mg/L reporting limit in the NCRWQCB's sampling of six streams on June 29, 2005 during early summer snowmelt. Given the available data, PacifiCorp's TN value of 0.11 mg/L provides a reasonable approximation and there is no sufficient basis to justify seasonally varying the value for these analyses. This value is nearly identical to the U.S. EPA (2000a) frequency-based determination of 0.12 mg/L average TN concentration for reference streams in forested mountains of the western United States (the zone classified as Aggregated Ecoregion 2, in which the Klamath River is located). As discussed in more detail in the results/discussion section below, because unmeasured accretion typically represents only a small portion of the total hydrologic load, the nitrogen budget is relatively insensitive to varying accretion concentration.

Expected load, defined as the sum of the upstream mainstem load, the measured tributary load, and the unmeasured tributary accretion load (calculated using assumed concentration described above) was calculated for each day. Observed load, defined as the measured load at the downstream edge of the reach was also calculated for each day. Retention was then calculated as the expected load minus the observed load. Positive retention indicates nutrient storage (e.g., via algal or macrophyte uptake) or denitrification in a reach, while negative retention indicates nutrient release.

In order to standardize among the reaches and years for reach length and incoming load, final retention results are expressed as percent retention per mile (%/mi). This allows for all reaches and years to be compared on an equal basis. Percent retention was calculated as retention divided by incoming load. Percent retention per mile was calculated as percent retention divided by reach length.

The daily discharge, loads, and retention were then summed for monthly intervals, and for the June-October and July-September periods. The purpose of summing over these periods was to facilitate comparisons among both reaches and years, and to allow for the computation of flow (volume)-weighted mean concentrations (total load divided by total discharge) for the summarized periods. Flow-weighted mean concentration allows concentration to be compared among reaches and time periods by giving appropriate weight to high and low flow periods.

RESULTS AND DISCUSSION

FLOW DATA

Monthly average discharge data at six USGS flow gages on the mainstem Klamath River for hydrologic years 1996-2004 shows substantial variation between gages, seasons, and years (Figure 6). As expected, based on accretion from springs and tributaries, discharge increases as the river flows downstream. For example, the Scott River, Shasta River, and other smaller tributaries that enter between Iron Gate and Seiad Valley lead to substantially higher winter and springtime flows at Seiad Valley than occur at Iron Gate. Summer flows are only slightly higher, however, at Seiad Valley.

The trend in inter-annual variability is relatively similar at the Keno, J.C. Boyle, and Iron Gate stations. At those sites, the lowest winter flows occurred in 2001-2004 and the lowest summer flows occurred in 1997, 2002, and 2004.

From Seiad to Klamath Glen average monthly winter and early spring flows were far lower in 2001 than in any other year. The lowest late summer discharge occurred in 2002, however. The years 2001, 2002, and 2004 had low winter-, spring- and summer flows from Seiad to Klamath Glen. The years 1998 and 1999 had substantially higher spring and summer flows at Seiad Valley, Orleans, and Klamath Glen. Spring and summer flows for those years were also high at the gages further upstream, but the differences were not as dramatic.

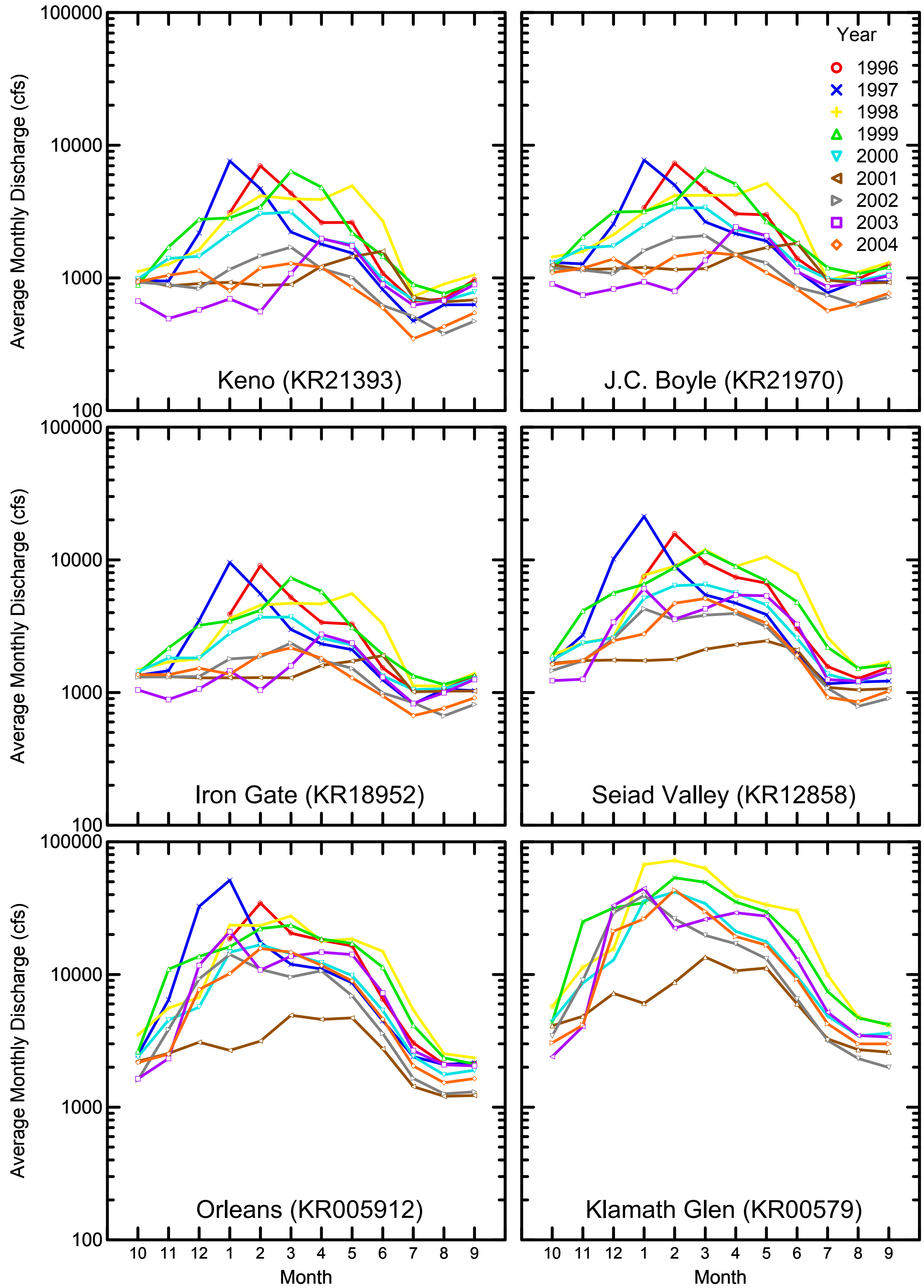

Figure 6. Monthly summaries of Klamath River discharge data for hydrologic years 1996-2004 at USGS flow gages. Note that there are no Klamath Glen data for the hydrologic years 1996-1997.

NITROGEN LOADS

June-October Means

Seasonal and monthly summaries of the nutrient loading analysis are presented in Table 6 and Figure 7. Data from most years was summarized over the June-October period, but the lack of data in October 1996 and 2002 required that those years be summarized over the June-September period. Data from 1998-2002 are based on bi-weekly samples, while those for 1996-1997 and 2003-2004 are based on monthly samples. Due to the differences in sampling frequency, the 1998-2002 data should be considered more reliable.

While we present and discuss the summaries to provide an understanding of the major differences between sites and years, it is important to note that examining summaries over a four- to five month period masks shorter-term variations which could have as much, if not more, ecological significance than the net average for the longer period. For that reason, we have provided the daily details in Appendix A as Figures A1-A7.

As we noted in the discharge discussions above, average daily discharge for the period May-October was highest in 1998, followed by 1999 (Fig. 7, Table 6). The year 2000 was a moderate flow year, and 2001, 2002, and 2004 were droughts. Although discharges in the lower reaches of the river were similar for 2001 and 2002, flows at Iron Gate Dam were several hundred cfs higher in 2001 than 2002. Consequently, Iron Gate releases represented a higher percentage of flow in 2001 than 2002. Because Iron Gate water has much higher nutrient concentrations than downstream accretions, this may account for the fact that nutrient concentrations in the lower river reaches were higher in 2001 than in any other year during the 1996-2004 period.

Flow-weighted June-October mean total nitrogen (TN) concentrations appear to cluster into two groups, higher in 2000 and 2001, and lower in 1998, 1999, and 2002 (Fig. 7, Table 6). The overall trend in TN concentration from the Link River (KR25312) to Klamath Glen (KR00579) shows a decrease as the water flows downstream; however there are some exceptions to that trend.

First, the longitudinal profile of TN concentration begins to flatten out around Orleans (KR05912) or Weitchpec (KR04350), sometimes showing a slight increase from there down to Klamath Glen (KR00579). Second, in 2000 and 2002 (the only years for which there are biweekly data for KR20642 above Copco), there are increases in concentration around Iron Gate and Copco Reservoirs. In 2000, there is an increase in TN concentration from 1.3 mg/L above Copco Reservoir to 1.7 mg/L below Iron Gate Reservoir. In 2002, concentration increases slightly from above Copco to below Copco, then decreases to below Iron Gate.

Nitrogen loads show a more complex pattern than discharge or TN concentration (Fig. 7, Table 6), but some patterns are evident. First, nitrogen load was substantially lower in 2002 and 2004 than the other years analyzed. Discharges were lower in those years than other years, as were concentrations, but to a lesser extent. Second, Link River (KR25312) typically has the highest nitrogen loads (and concentrations). Third, after decreasing in the middle portion of the river, nitrogen loads rise below Orleans (KR05912), likely due in large part to inputs of high-volume water from the Trinity River.

Finally, the patterns between Keno Dam (KR23334/KR23200) and Iron Gate Dam (KR18973) vary among years. Of the fours years for which there are data for above Copco Reservoir (KR20642) and below Iron Gate Dam (KR18973), the loads below Iron Gate were higher than above Copco in 2000 and 2004, and lower than above Copco in 2002 and 2003. It should also be noted, however, that simply comparing loads upstream and downstream of a reservoir does not allow quantification of in-reservoir mass and internal load. In order to determine nutrient dynamics in reservoirs, construction of a reservoir-specific nutrient budget, such as that constructed for the year 2002 for Iron Gate and Copco Reservoirs (Kann and Asarian 2005), is required.

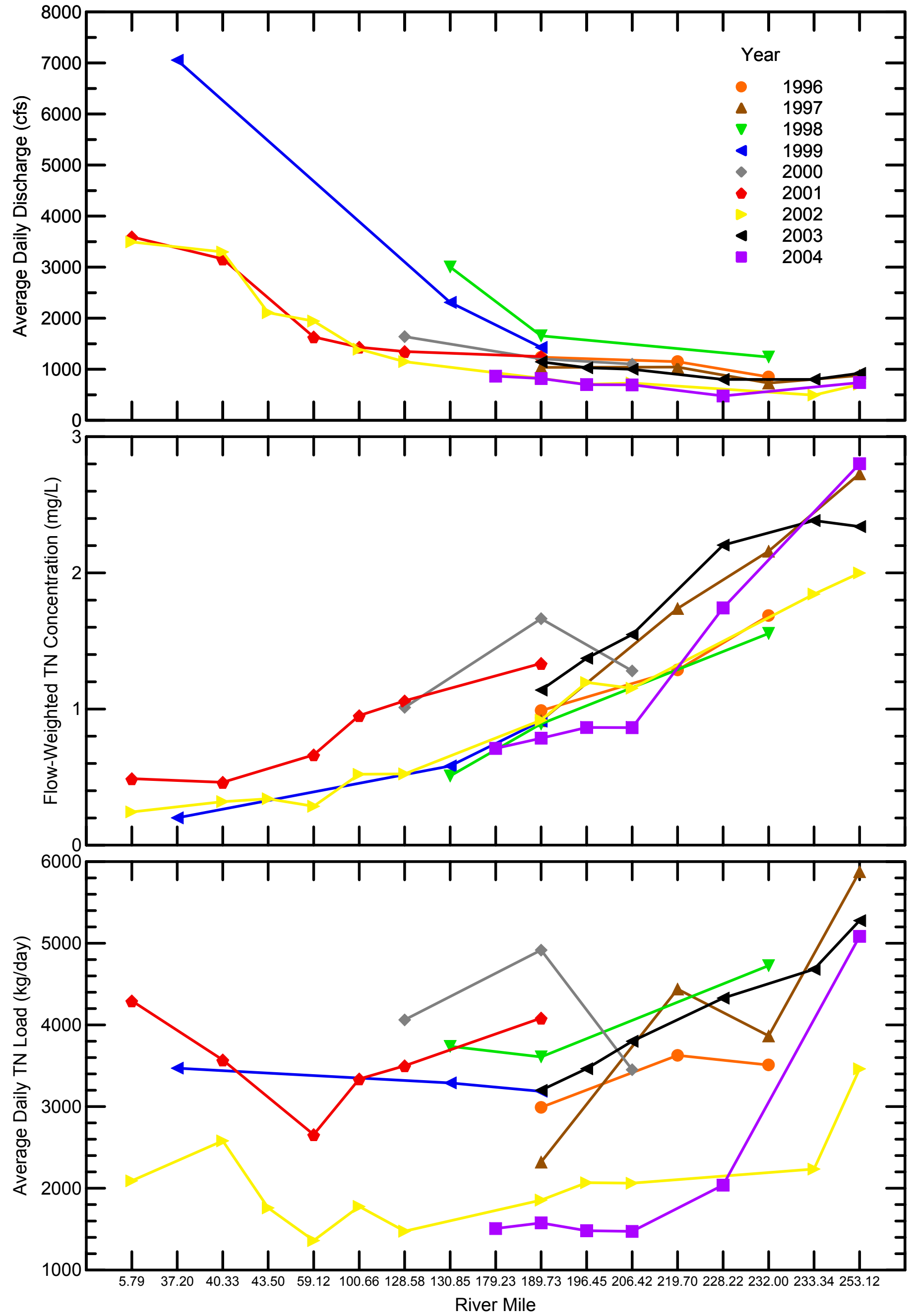

Figure 7. Summary of daily average discharge, flow-weighted mean concentration, and average daily total nitrogen loads for mainstem Klamath River sites from Link River (river mile 253.12) to Klamath Glen (RM 5.79) for months June-October, years 1996-2004. Data from 1998-2002 are based on bi-weekly samples, while 1996-1997 and 2003-2004 are based on monthly samples. Note that due to lack of October data in 1996 and 2002, those years are summarized over the June-September period instead.

Table 6. Summary of daily average discharge, flow-weighted mean concentration, and average daily total nitrogen loads for mainstem Klamath River sites from Link River (river mile 253.12) to Klamath Glen (RM 5.79) for months June-October in the years 1996-2004. Data from 1998-2002 are based on bi-weekly samples, while 1996-1997 and 2003-2004 are based on monthly samples. Due to lack of data in October 1996 and 2002, those years are summarized over the June-September period instead.

Year	Site ID	River Mile	Site Name	Sampling Interval	Days	Discharge Total ($Hm^3 = m^3x10^6$)	Discharge Daily Average (kg/day)	Conc. Flow-weighted (mg/L)	Load Total (kg)	Load Total (metric tons)	Load Daily Average (kg/day)
1996	KR23200	232.00	d/s Keno	Monthly	122	253973539	851	1.69	428089	428	3509
1996	KR21970	219.70	d/s Boyle PH	Monthly	122	343818813	1152	1.29	442359	442	3626
1996	KR18973	189.73	d/s Iron Gate	Monthly	122	369041458	1236	0.99	364801	365	2990
1997	KR25312	253.12	Link River	Monthly	153	329643921	881	2.73	899039	899	5876
1997	KR23200	232.00	d/s Keno	Monthly	153	273849707	731	2.16	591388	591	3865
1997	KR21970	219.70	d/s Boyle PH	Monthly	153	390728333	1044	1.74	679111	679	4439
1997	KR18973	189.73	d/s Iron Gate	Monthly	122	309669876	1037	0.91	283121	283	2321
1998	KR23200	232.00	d/s Keno	Bi-weekly	153	464786208	1241	1.56	722911	723	4725
1998	KR18973	189.73	d/s Iron Gate	Bi-weekly	153	620044460	1656	0.89	552097	552	3608
1998	KR13085	130.85	Seiad Valley	Bi-weekly	153	1125196200	3006	0.51	571773	572	3737
1999	KR18973	189.73	d/s Keno	Bi-weekly	140	489918318	1430	0.91	446134	446	3187
1999	KR13085	130.85	d/s Iron Gate	Bi-weekly	153	865342113	2311	0.58	503336	503	3290
1999	KR03720	37.20	Seiad Valley	Bi-weekly	153	2642085753	7057	0.20	531085	531	3471
2000	KR20642	206.42	u/s Copco	Bi-weekly	153	412415207	1102	1.28	527991	528	3451
2000	KR18973	189.73	d/s Iron Gate	Bi-weekly	153	452187120	1208	1.66	752088	752	4916
2000	KR12858	128.58	Seiad Valley	Bi-weekly	153	614147431	1640	1.01	621291	621	4061
2001	KR18973	189.73	d/s Iron Gate	Bi-weekly	152	464977066	1250	1.33	620726	621	4084
2001	KR12858	128.58	Seiad Valley	Bi-weekly	152	501761314	1349	1.06	531982	532	3500
2001	KR10066	100.66	Happy Camp	Bi-weekly	152	533292730	1434	0.95	507496	507	3339
2001	KR05912	59.12	Orleans	Bi-weekly	152	608372747	1636	0.66	403743	404	2656
2001	KR04033	40.33	Martins Ferry	Bi-weekly	152	1176530429	3163	0.46	542728	543	3571
2001	KR00579	5.79	Klamath Glen	Bi-weekly	152	1336570187	3594	0.49	652757	653	4294
2002	KR25312	253.12	Link River	Bi-weekly	116	200939428	708	2.00	401659	402	3463
2002	KR23334	233.34	d/s Keno	Bi-weekly	122	147839251	495	1.84	272653	273	2235
2002	KR20642	206.42	u/s Copco	Bi-weekly	122	218410294	732	1.15	251640	252	2063
2002	KR19645	196.45	d/s Copco	Bi-weekly	122	211165023	707	1.19	252288	252	2068
2002	KR18973	189.73	d/s Iron Gate	Bi-weekly	122	246542303	826	0.92	226326	226	1855
2002	KR12858	128.58	Seiad Valley	Bi-weekly	122	343877538	1152	0.52	179942	180	1475
2002	KR10066	100.66	Happy Camp	Bi-weekly	122	416406182	1395	0.52	216914	217	1778
2002	KR05912	59.12	Orleans	Bi-weekly	122	580233397	1944	0.29	165788	166	1359
2002	KR04350	43.50	Weitchpec	Bi-weekly	122	629507077	2109	0.34	214685	215	1760
2002	KR04033	40.33	Martins Ferry	Bi-weekly	122	984927622	3299	0.32	314847	315	2581
2002	KR00579	5.79	Klamath Glen	Bi-weekly	122	1043847540	3497	0.24	255089	255	2091
2003	KR25312	253.12	Link River	Monthly	153	345054497	922	2.34	807342	807	5277
2003	KR23334	233.34	d/s Keno	Monthly	153	300354528	802	2.38	716079	716	4680
2003	KR22822	228.22	u/s Boyle Res.	Monthly	153	300354528	802	2.20	662025	662	4327
2003	KR20642	206.42	u/s Copco	Monthly	153	375736176	1004	1.55	581403	581	3800
2003	KR19645	196.45	d/s Copco	Monthly	153	386035179	1031	1.37	529916	530	3464
2003	KR18973	189.73	d/s Iron Gate	Monthly	153	429719684	1148	1.14	489540	490	3200
2004	KR25312	253.12	Link River	Monthly	122	221341680	741	2.80	620105	620	5083
2004	KR22822	228.22	u/s Boyle Res.	Monthly	122	142668951	478	1.74	248653	249	2038
2004	KR20642	206.42	u/s Copco	Monthly	122	208050119	697	0.86	179575	180	1472
2004	KR19645	196.45	d/s Copco	Monthly	122	208904088	700	0.86	180533	181	1480
2004	KR18973	189.73	d/s Iron Gate	Monthly	122	244626381	819	0.79	192274	192	1576
2004	KR17923	179.23	I-5 Rest Stop	Monthly	120	254345001	866	0.71	180796	181	1507

NITROGEN BUDGETS FOR RIVER REACHES

As noted above, to standardize among the reaches and years for reach length and incoming load, final retention results are expressed as percent retention per mile (%/mi).

The results of reach-by-reach mass-balance total nitrogen budgets for river reaches from Iron Gate Dam to Klamath Glen show that substantial retention occurs in much of this portion of the river (Table 7).

Table 7. Summary of total nitrogen retention (expressed as % retention per mile) for Klamath River reaches from Iron Gate Dam to Klamath Glen for the June-October period, 1998-2002. Positive retention indicates nitrogen storage (or denitrification) and negative retention indicates nitrogen release.

			TN Retention (% of incoming per mile)								
Reach Name	Length (miles)	Year	May	Jun	Jul	Aug	Sep	Oct	Nov	Jul to Sep	Jun to Oct
Iron Gate to Seiad Valley	58.88	1998	0.18	0.05	0.29	0.51	0.36	0.24	0.06	0.39	0.24
Iron Gate to Seiad Valley	58.88	1999	0.04	0.07	0.33	0.25	0.27	0.10	0.13	0.29	0.21
Iron Gate to Seiad Valley	61.15	2000	0.09	0.31	1.07	0.02	0.06	0.02	0.26	0.55	0.41
Iron Gate to Seiad Valley	61.15	2001		0.48	0.44	0.30	-0.09	0.23		0.20	0.27
Iron Gate to Seiad Valley	61.15	2002	-0.32	0.18	0.63	0.68	0.51	0.13		0.61	0.44
Seiad Valley to Youngs Bar	93.65	1999	0.11	0.25	0.38	0.23	0.23	0.11	-0.24	0.28	0.24
Seiad Valley to Happy Camp	27.92	2001		-0.28	0.05	-0.15	0.84	0.23		0.32	0.19
Seiad Valley to Happy Camp	27.92	2002	-0.05	-0.55	-1.21	-0.70	0.23	-0.69		-0.55	-0.58
Happy Camp to Orleans	41.54	2001		0.42	0.77	0.90	0.42	0.32		0.70	0.53
Happy Camp to Orleans	41.54	2002	0.46	0.79	0.91	0.60	0.55	0.65		0.72	0.73
Mean for reaches starting above Orleans			0.07	0.17	0.37	0.27	0.34	0.13	0.05	**0.35**	**0.27**
Orleans to Martins Ferry	18.79	2001		0.57	-1.71	-0.51	0.56	-0.95		-0.44	-0.40
Orleans to Martins Ferry	18.79	2002	-2.20	-3.63	-3.46	0.86	0.72	2.60		-0.93	-1.63
Martins Ferry to Klamath Glen	34.54	2001	-0.30	0.81	0.15	-4.62	-0.38	0.47		-1.60	-0.48
Martins Ferry to Klamath Glen	34.54	2002	0.06	1.08	1.31	-2.07	-0.60	-1.18		0.15	0.54
Youngs Bar to Johnson's Point	13.2	1999					0.35	-0.55	0.03		
Mean for reaches starting below Orleans			-0.81	-0.29	-0.93	-1.58	0.13	0.08	0.03	**-0.70**	**-0.49**

Spatial patterns in retention are evident. In general reaches above Orleans (river mile 59.12) exhibited positive retention (assimilation or denitrification) while reaches from Orleans down to Klamath Glen showed negative retention (release).

Nine of ten reach-season means upstream of Orleans had positive net retention for the period June-October, ranging from -0.58 %/mi to +0.73 %/mi, with a mean of +0.27 (Table 7, Fig.8). For the shorter July through September period, mean retention was higher, averaging 0.35%/mi.
As points of reference, extrapolating these averages out across the 130 miles from Iron Gate to Orleans yields a 35% load reduction for the 0.27%/mi rate and 46% load reduction for the 0.35%/mi rate.

Three of four reach-season means downstream of Orleans had negative net retention for the period June-October, ranging from -1.63 %/mi to +0.54 %/mi, with a mean of -0.49 (Table 7, Fig.8).

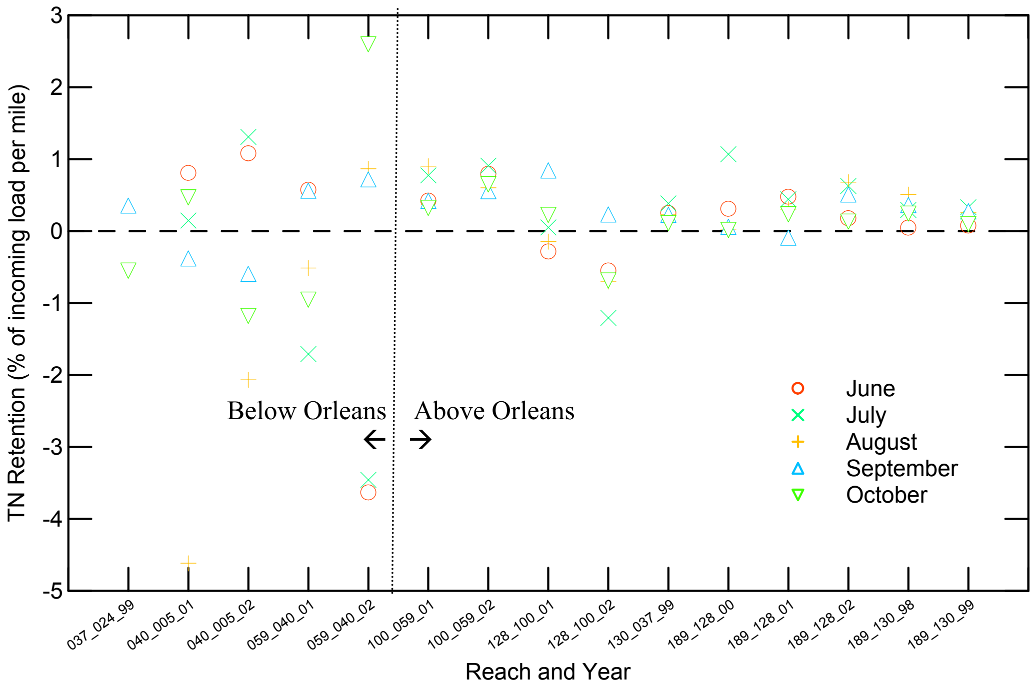

Figure 8. Spatial and temporal summary of total nitrogen retention on a monthly basis for mainstem Klamath River reaches from Iron Gate to Klamath Glen. Labels on x-axis begin with upstream river mile, then downstream river mile, then year (i.e. 189_130_99 is Iron Gate to Seiad 1999).

Above Orleans, the median monthly retention was positive for all months in the June-October analysis window (and the inter-quartile range was positive in four of five months) but was usually highest in July and lowest in June and October (Fig. 9). Below Orleans, median retention was positive in June, negative in July and August, neutral in September, and slightly negative in October (Fig. 9).

Figure 10 shows daily retention for river reaches beginning upstream of Orleans for the years 1998-2002, providing additional temporal resolution to illustrate the summaries provided above. Figure 11 is similar, except for the reaches beginning downstream of Orleans.

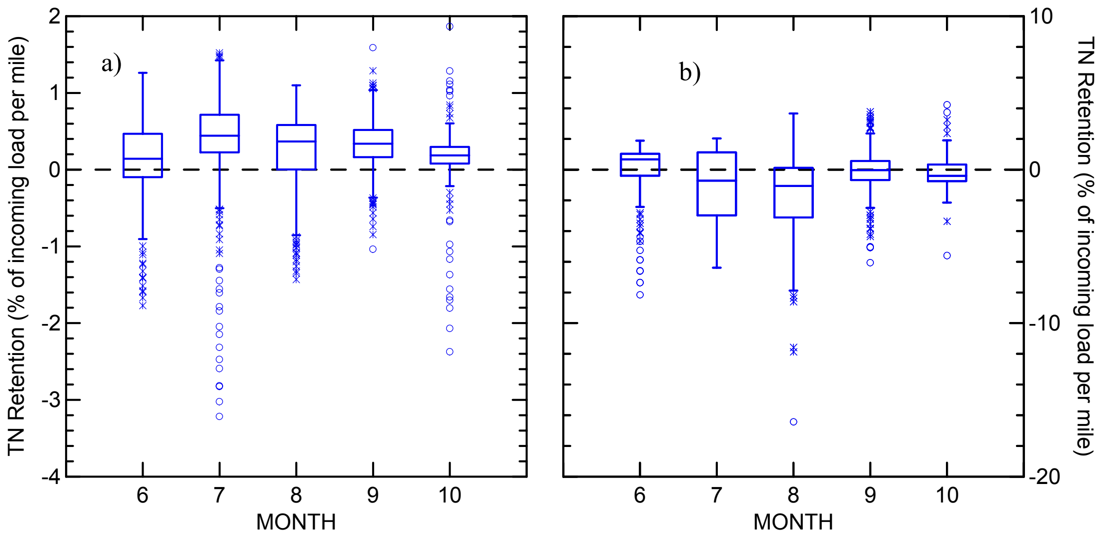

Figure 9. Box plot of total nitrogen retention for river reaches beginning upstream of Orleans (a) and downstream of Orleans (b). Each box summarizes/combines daily data from multiple reach-years to show overall monthly patterns. Note that the scale of the Y-axis is 5 times smaller in a) than b).

Figures 12 through 25 show the daily total nitrogen budgets for individual river reaches for the months June-October. There is one page of graphs for each reach and year with available data. The top three cells in each figure show daily discharge, interpolated TN concentration, and calculated TN load for the top of the reach, the bottom of the reach, each measured tributary, and ungaged/ unmeasured accretion. Also shown on the discharge and load graphs are total inflow (sum of mainstem, measured tributaries and unmeasured tributary accretions) and the hydrologic residual; defined as total inflow minus total outflow. Because accretion was calculated as the difference between gages, the hydrologic residual serves as a computation check and should be close to zero. The bottom cell in each figure shows TN retention expressed as a percent of incoming load (sum of mainstem, measured tributaries and unmeasured tributary accretion load). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load. The combined results for the entire June-October period are summarized in Table 8.

Table 8. Summary of total nitrogen retention for Klamath River reaches from Iron Gate Dam to Klamath Glen for months June-October 1998-2002. Positive retention indicates nitrogen storage (or denitrification) and negative retention indicates nitrogen release. In total nitrogen retention columns: positive = sum for days with positive retention, negative = sum for days with negative retention, and net = sum for all days (same as positive plus negative).

					Total Nitrogen Load						Discharge						Flow Weighted TN Concentration						Total Nitrogen Retention						
					(Metric Tons)						(Hm3 = m3 x 106)						(mg/L)						(Metric Tons)			(as % of inflow)			(% per mile)
Upstream Site ID	Downstr. Site ID	Reach Name	Year	Days	KR In	KR Out	Trib 1	Trib 2	Accretion	Total In	KR In	KR Out	Trib 1	Trib 2	Accretion	Total In	KR In	KR Out	Trib 1	Trib 2	Accretion	Total In	Net	Positive	Negative	Net	Positive	Negative	Net
KR 18973	KR 13085	Iron Gate to Seiad Valley	1998	153	552	572	36	55	24	667	620	1125	79	204	222	1125	0.89	0.51	0.45	0.27	0.11	0.59	95	102	-7	**14.3**	15.3	-1.0	**0.24**
KR 18973	KR 13085	Iron Gate to Seiad Valley	1999	140	446	456	15	39	18	519	490	807	31	122	164	807	0.91	0.56	0.48	0.32	0.11	0.64	63	69	-6	**12.1**	13.3	-1.1	**0.21**
KR 18973	KR 12858	Iron Gate to Seiad Valley	2000	153	752	621	23	45	8	827	452	614	30	63	68	614	1.66	1.01	0.74	0.72	0.11	1.35	206	227	-20	**24.9**	27.4	-2.5	**0.41**
KR 18973	KR 12858	Iron Gate to Seiad Valley	2001	152	621	532	12	1	1	636	465	502	18	9	10	502	1.33	1.06	0.69	0.15	0.11	1.27	104	115	-11	**16.3**	18.0	-1.7	**0.27**
KR 18973	KR 12858	Iron Gate to Seiad Valley	2002	138	265	218	9	20	4	299	294	399	14	50	41	399	0.90	0.55	0.60	0.41	0.11	0.75	80	87	-7	**26.9**	29.1	-2.2	**0.44**
KR 13085	KR 03720	Seiad Valley to Youngs Bar	1999	153	503	531	29	59	92	683	865	2642	349	592	836	2642	0.58	0.20	0.08	0.10	0.11	0.26	152	170	-19	**22.2**	25.0	-2.7	**0.24**
KR 12858	KR 10066	Seiad Valley to Happy Camp	2001	152	532	507			3	535	502	533			32	533	1.06	0.95			0.11	1.00	28	46	-18	**5.2**	8.6	-3.4	**0.19**
KR 12858	KR 10066	Seiad Valley to Happy Camp	2002	138	218	264			9	227	399	478			79	478	0.55	0.55			0.11	0.48	-37	10	-46	**-16.1**	4.4	-20.4	**-0.58**
KR 10066	KR 05912	Happy Camp to Orleans	2001	152	507	404	10		1	518	533	608	64		11	608	0.95	0.66	0.15		0.11	0.85	115	115	0	**22.1**	22.1	0.0	**0.53**
KR 10066	KR 05912	Happy Camp to Orleans	2002	138	264	201	20		4	288	478	650	137		35	650	0.55	0.31	0.15		0.11	0.44	87	90	-2	**30.3**	31.1	-0.8	**0.73**
KR 05912	KR 04033	Orleans to Martins Ferry	2001	152	404	543	83		18	505	608	1177	403		165	1177	0.66	0.46	0.21		0.11	0.43	-38	31	-69	**-7.5**	6.1	-13.6	**-0.40**
KR 05912	KR 04033	Orleans to Martins Ferry	2002	130	184	325	58		7	249	616	1035	357		62	1035	0.30	0.31	0.16		0.11	0.24	-76	32	-108	**-30.6**	12.8	-43.4	**-1.63**
KR 04033	KR 00579	Martins Ferry to Klamath Glen	2001	152	543	653			18	560	1177	1337			160	1337	0.46	0.49			0.11	0.42	-92	93	-186	**-16.5**	16.7	-33.2	**-0.48**
KR 04033	KR 00579	Martins Ferry to Klamath Glen	2002	130	325	269			7	331	1035	1096			61	1096	0.31	0.25			0.11	0.30	62	101	-39	**18.7**	30.4	-11.7	**0.54**
KR 03720	KR 02400	Youngs Bar to Johnson's Point	1999	54	193	200			2	194	512	528			16	528	0.38	0.38			0.11	0.37	-6	4	-10	**-3.0**	2.0	-5.0	**-0.23**

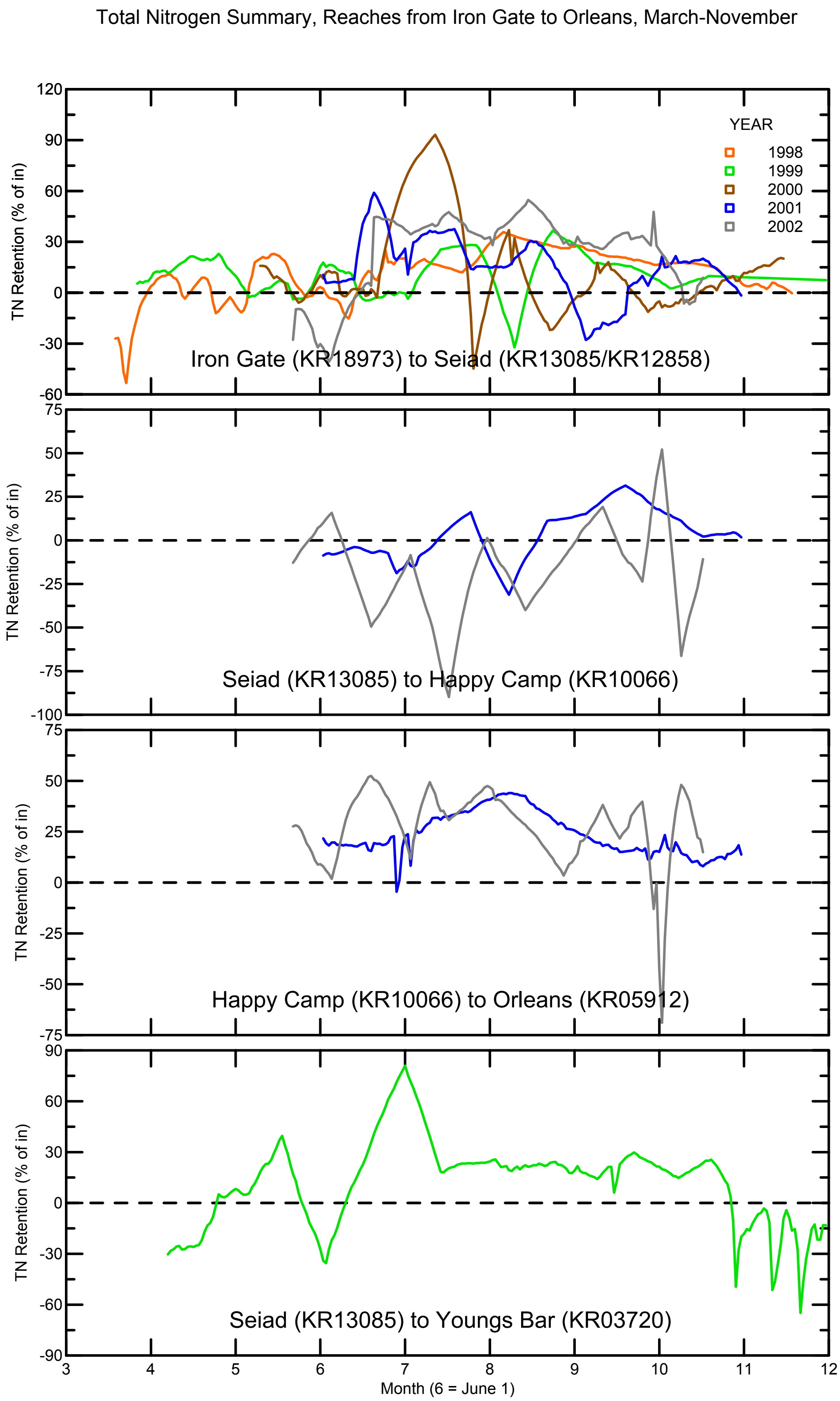

Figure 10. Daily total nitrogen retention, expressed as the percent of incoming load for each reach on the Klamath River above Orleans for the years 1998-2002.

Total Nitrogen Summary, Reaches from Orleans to Klamath Glen, March-November

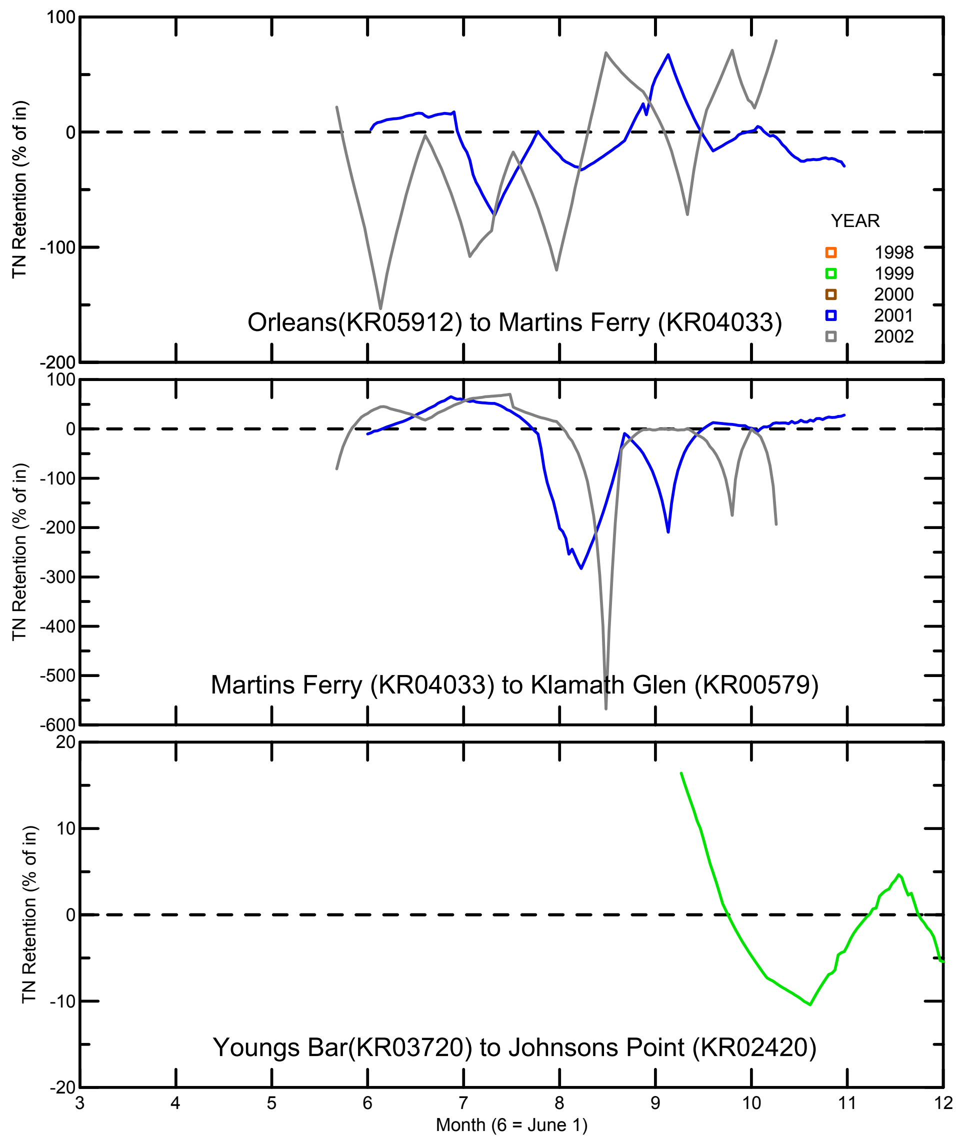

Figure 11. Daily total nitrogen retention, expressed as the percent of incoming load for each reach on the Klamath River below Orleans for the years 1998-2002.

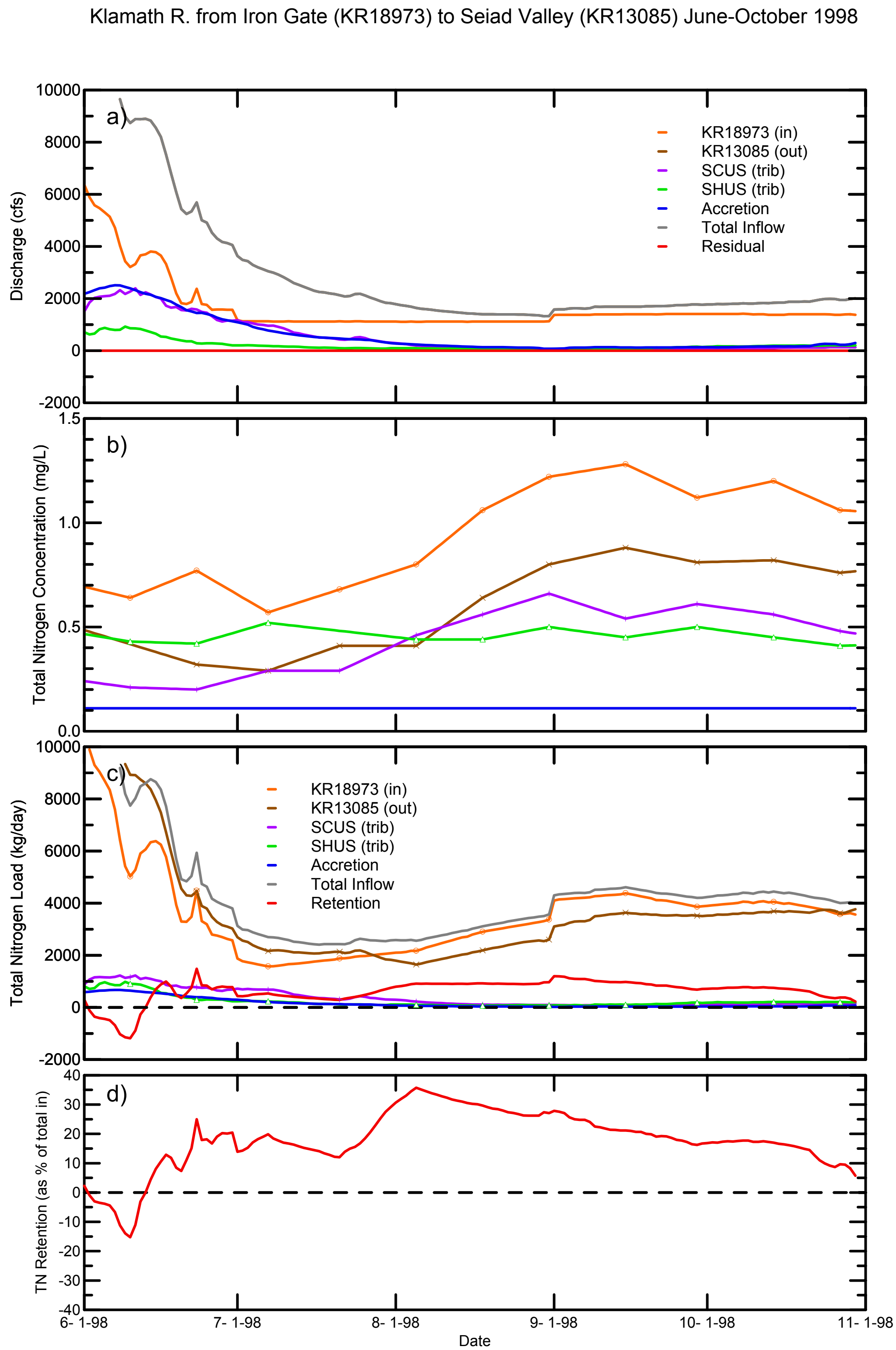

Figure 12. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 1998 in the Klamath River reach from Iron Gate (site KR18973) to Seiad Valley (site KR13085). Measured tributaries are Scott (SCUS) and Shasta (SHUS) Rivers. Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

Klamath R. from Iron Gate (KR18973) to Seiad Valley (KR13085) June-October 1999

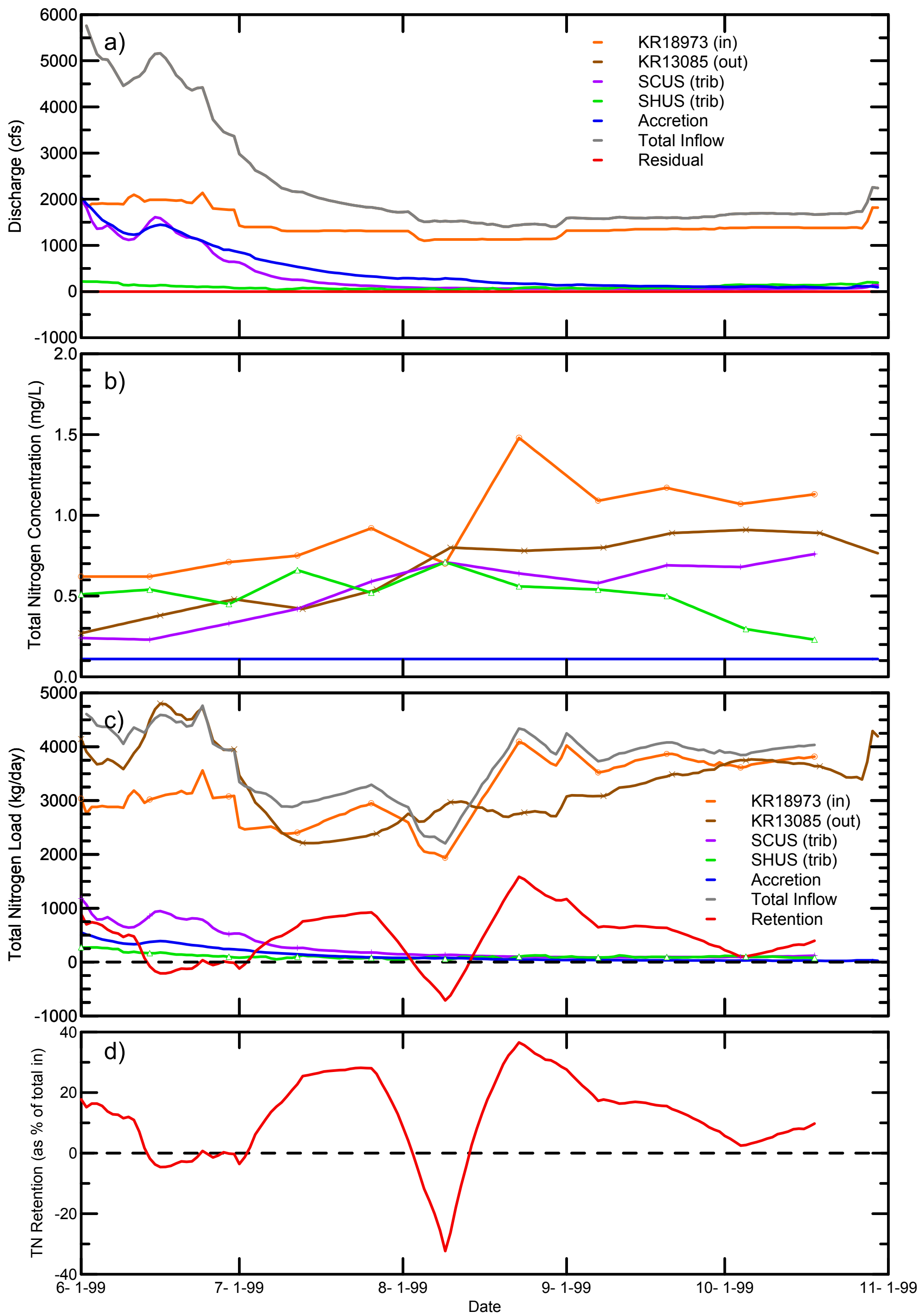

Figure 13. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 1999 in the Klamath River reach from Iron Gate (site KR18973) to Seiad Valley (site KR13085). Measured tributaries are Scott (SCUS) and Shasta (SHUS) Rivers. Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

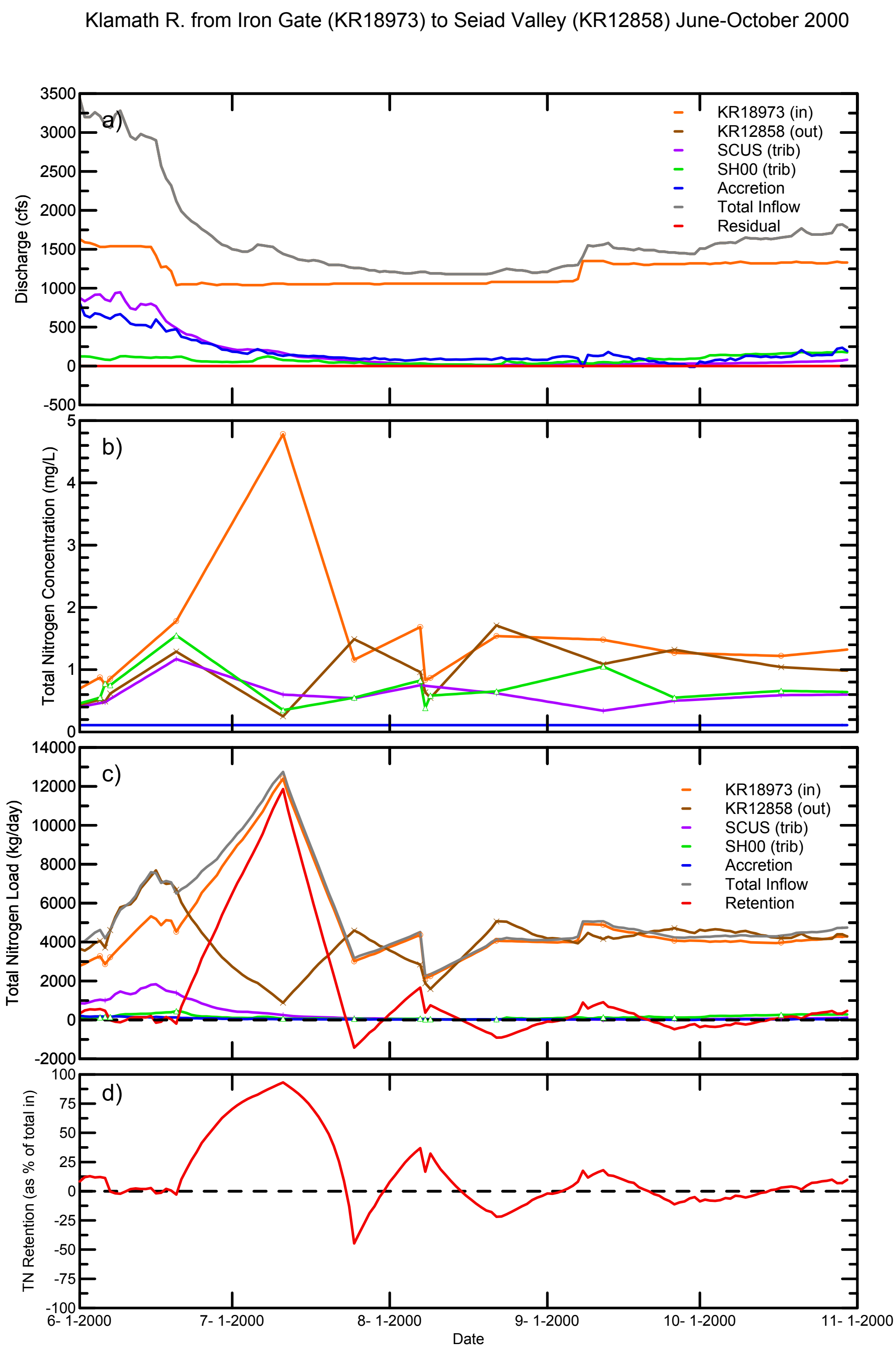

Figure 14. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2000 in the Klamath River reach from Iron Gate (site KR18973) to Seiad Valley (site KR12858). Measured tributaries are Scott (SCUS) and Shasta (SH00) Rivers. Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

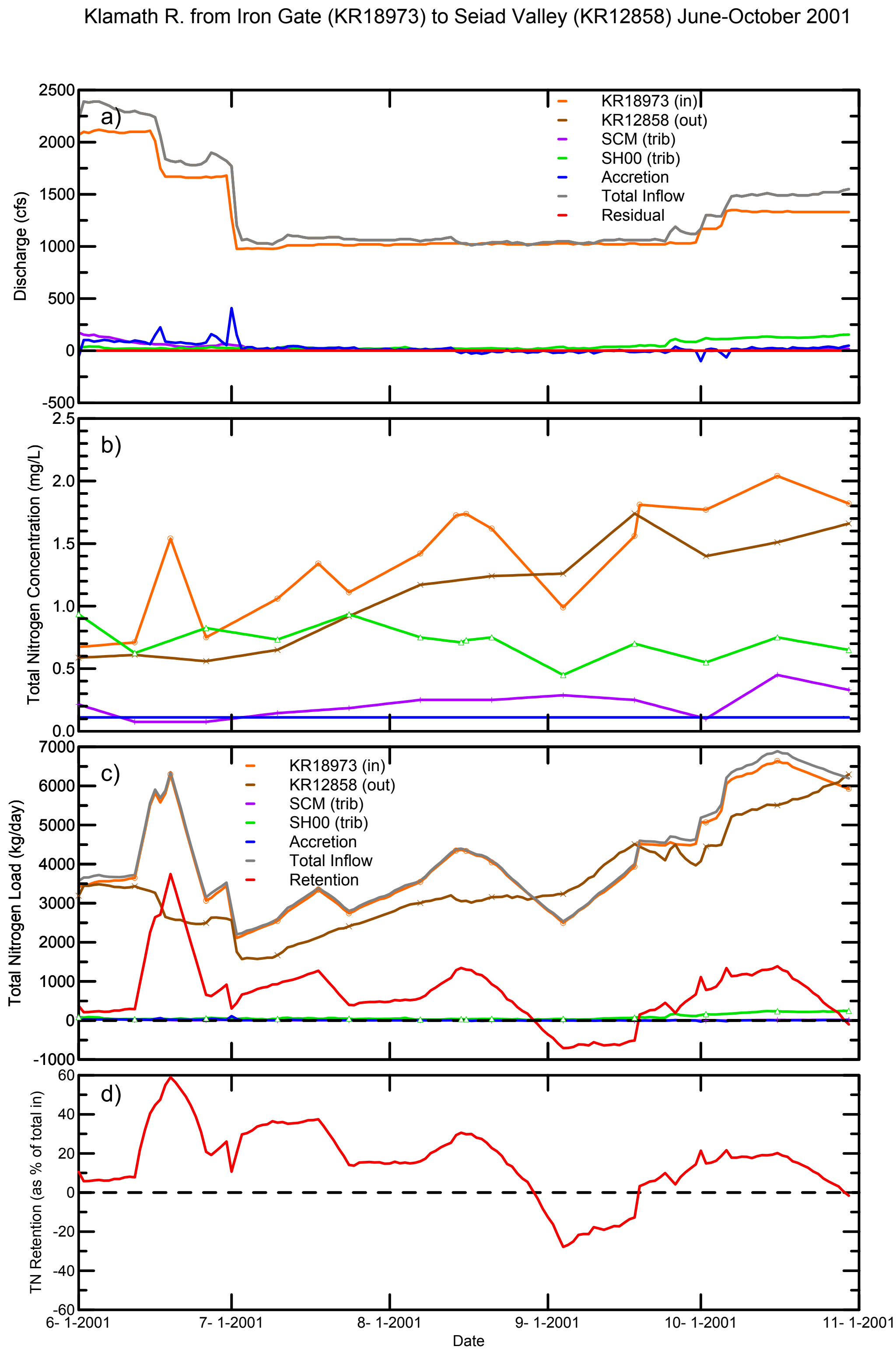

Figure 15. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2001 in the Klamath River reach from Iron Gate (site KR18973) to Seiad Valley (site KR12858). Measured tributaries are Scott (SCM) and Shasta (SH00) Rivers. Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

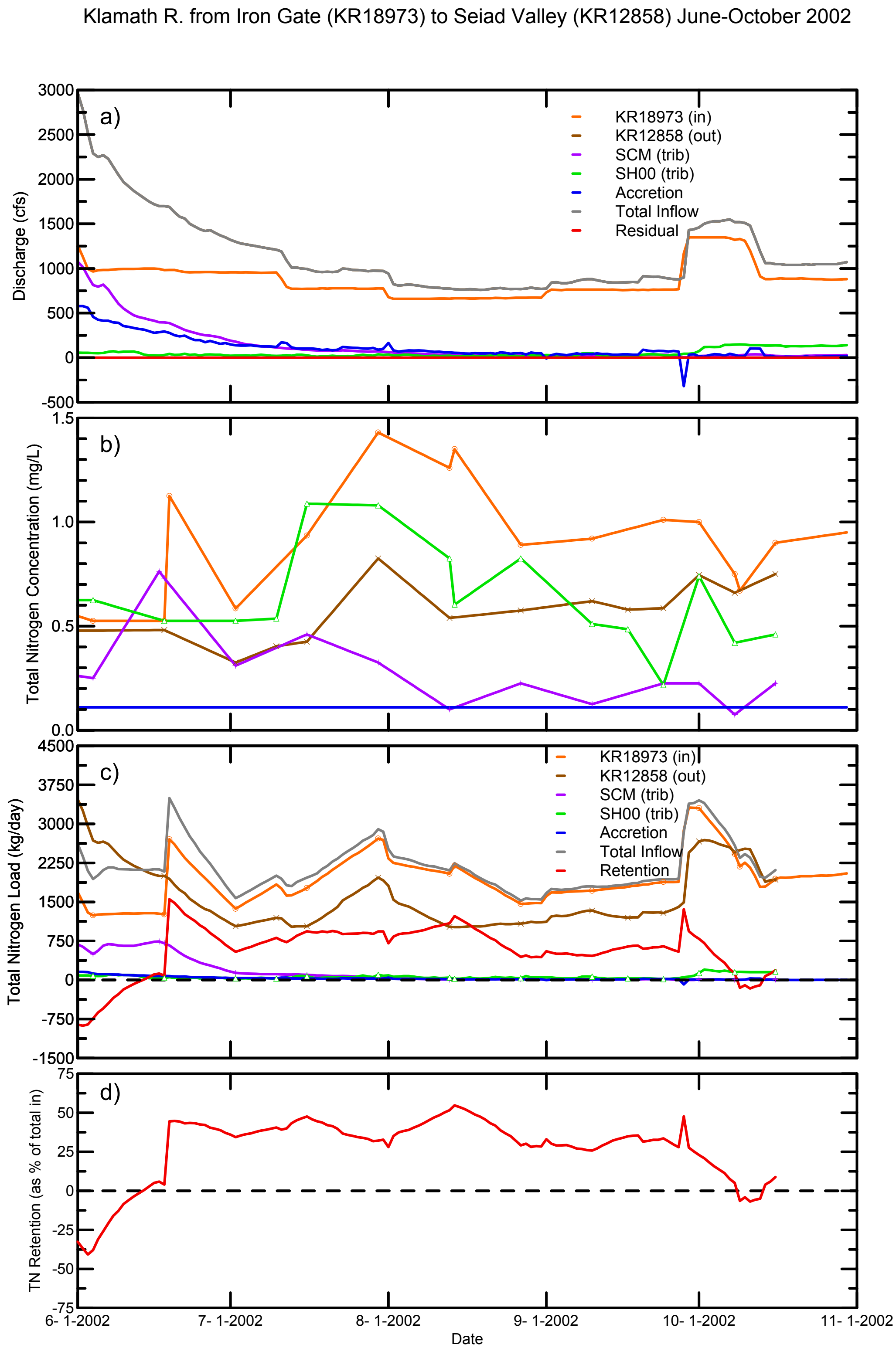

Figure 16. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2002 in the Klamath River reach from Iron Gate (site KR18973) to Seiad Valley (site KR12858). Measured tributaries are Scott (SCM) and Shasta (SH00) Rivers. Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

Klamath R. from Seiad Valley (KR12858) to Happy Camp (KR10066) to June-October 2001

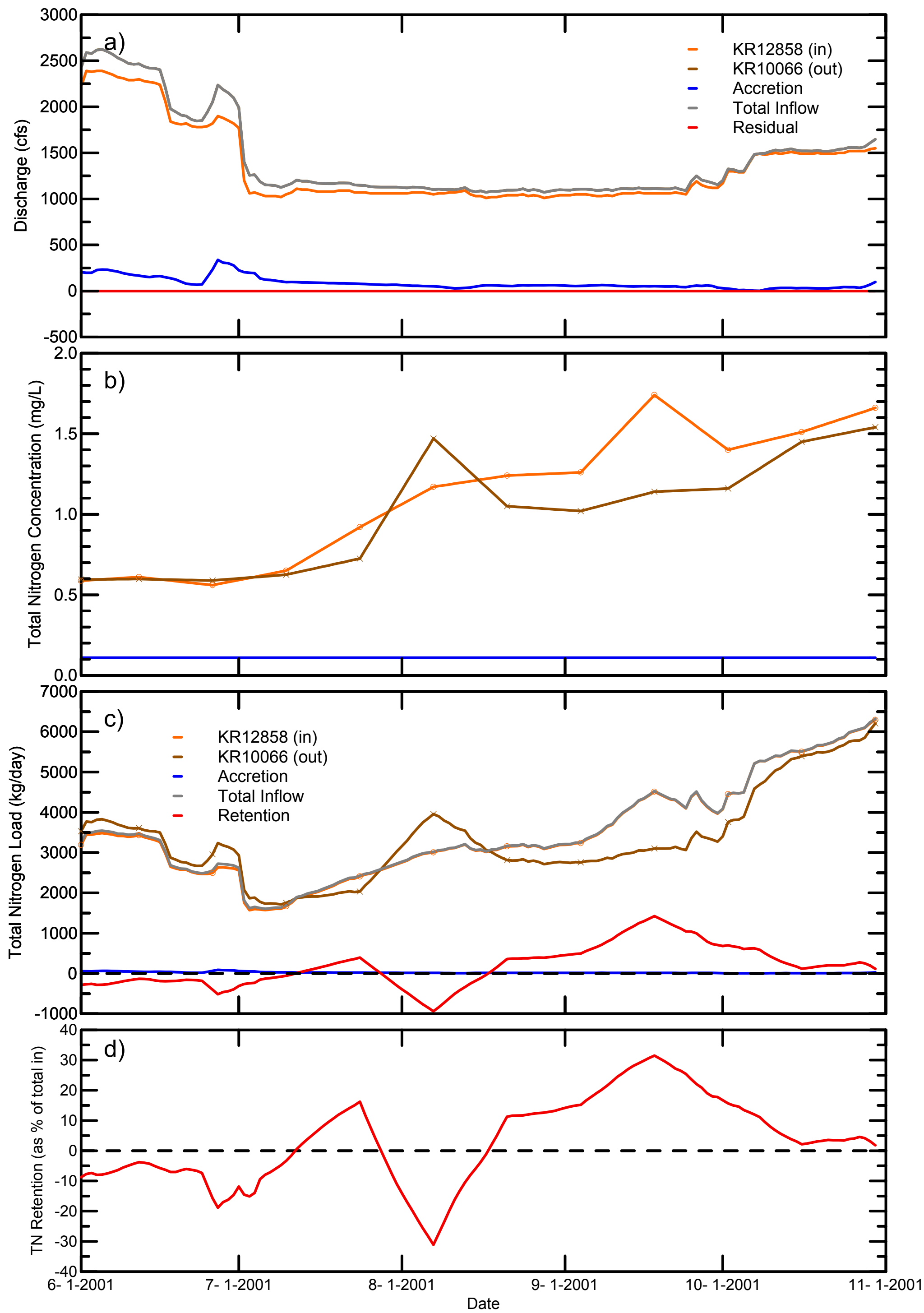

Figure 17. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2001 in the Klamath River reach from Seiad Valley (site KR12858) to Happy Camp (KR10066). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

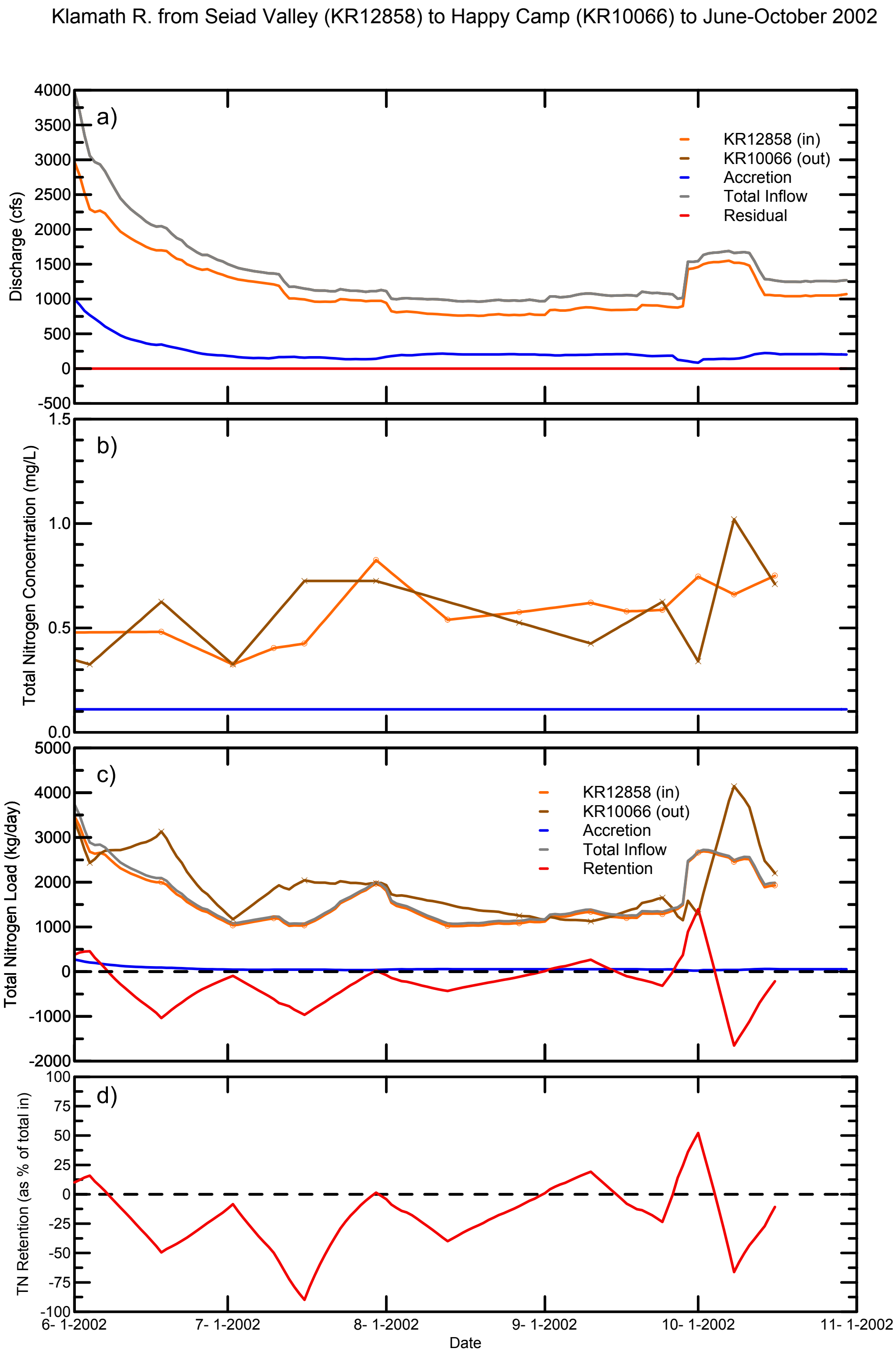

Figure 18. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2002 in the Klamath River reach from Seiad Valley (site KR12858) to Happy Camp (KR10066). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

Klamath R. from Seiad Valley (KR13085) to Young's Bar (KR03720) June-October 1999

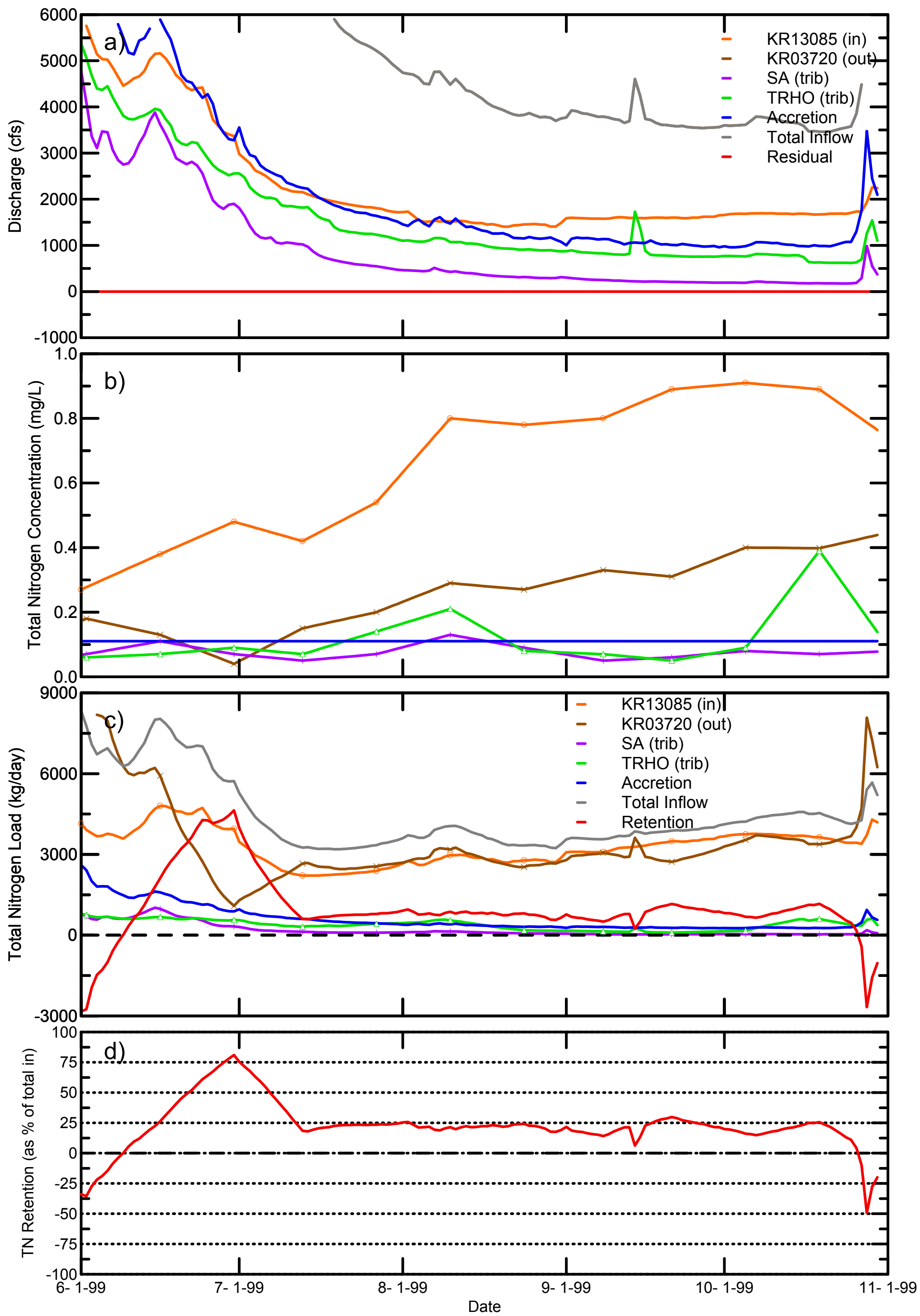

Figure 19. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 1999 in the Klamath River reach from Seiad Valley (site KR13085) to Young's Bar (KR03720). Measured tributaries are Salmon (SA) and Trinity (TRHO) Rivers. Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

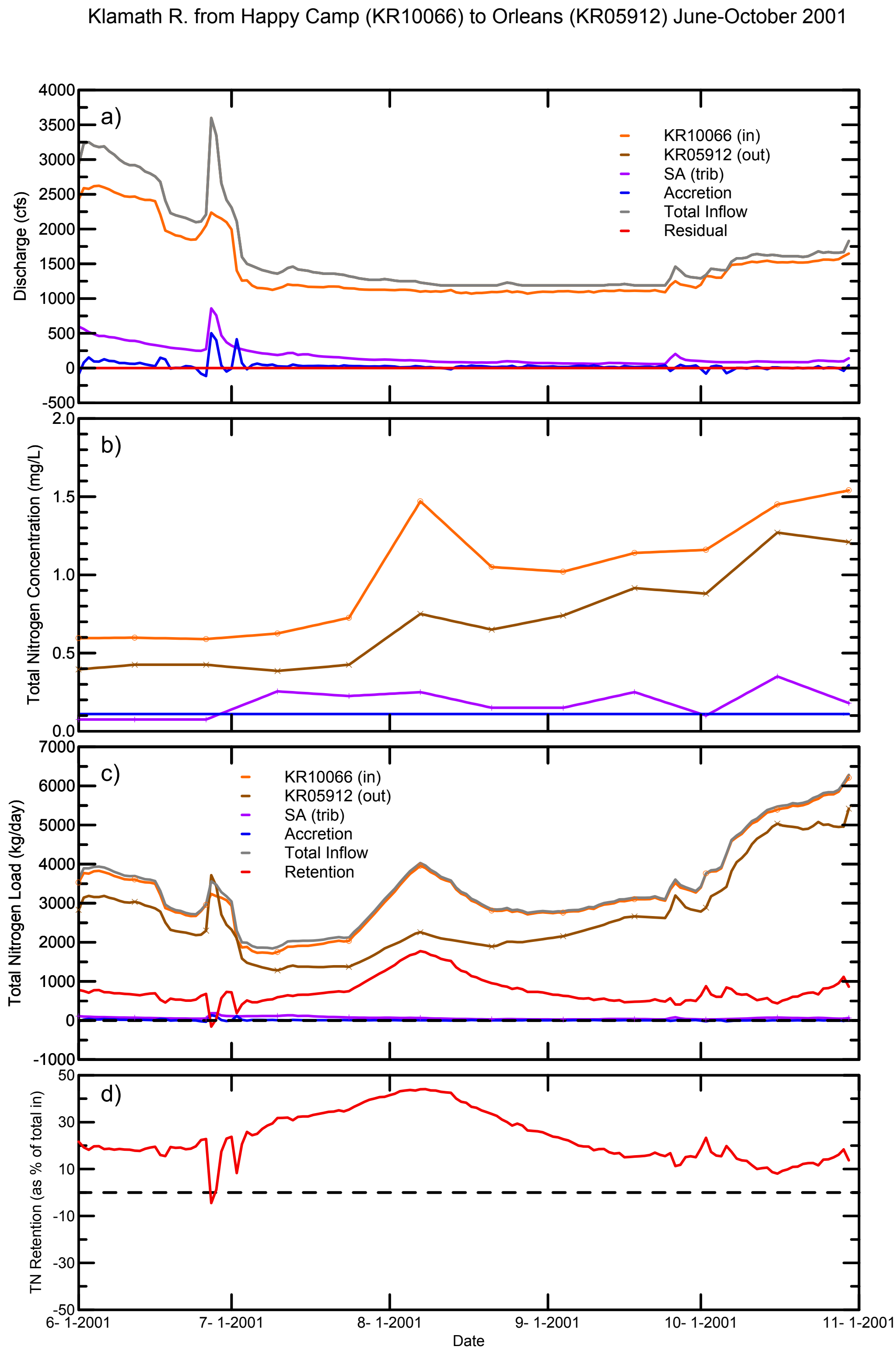

Figure 20. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2001 in the Klamath River reach from Happy Camp (site KR10066) to Orleans (KR05912). Measured tributary is the Salmon River (SA). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

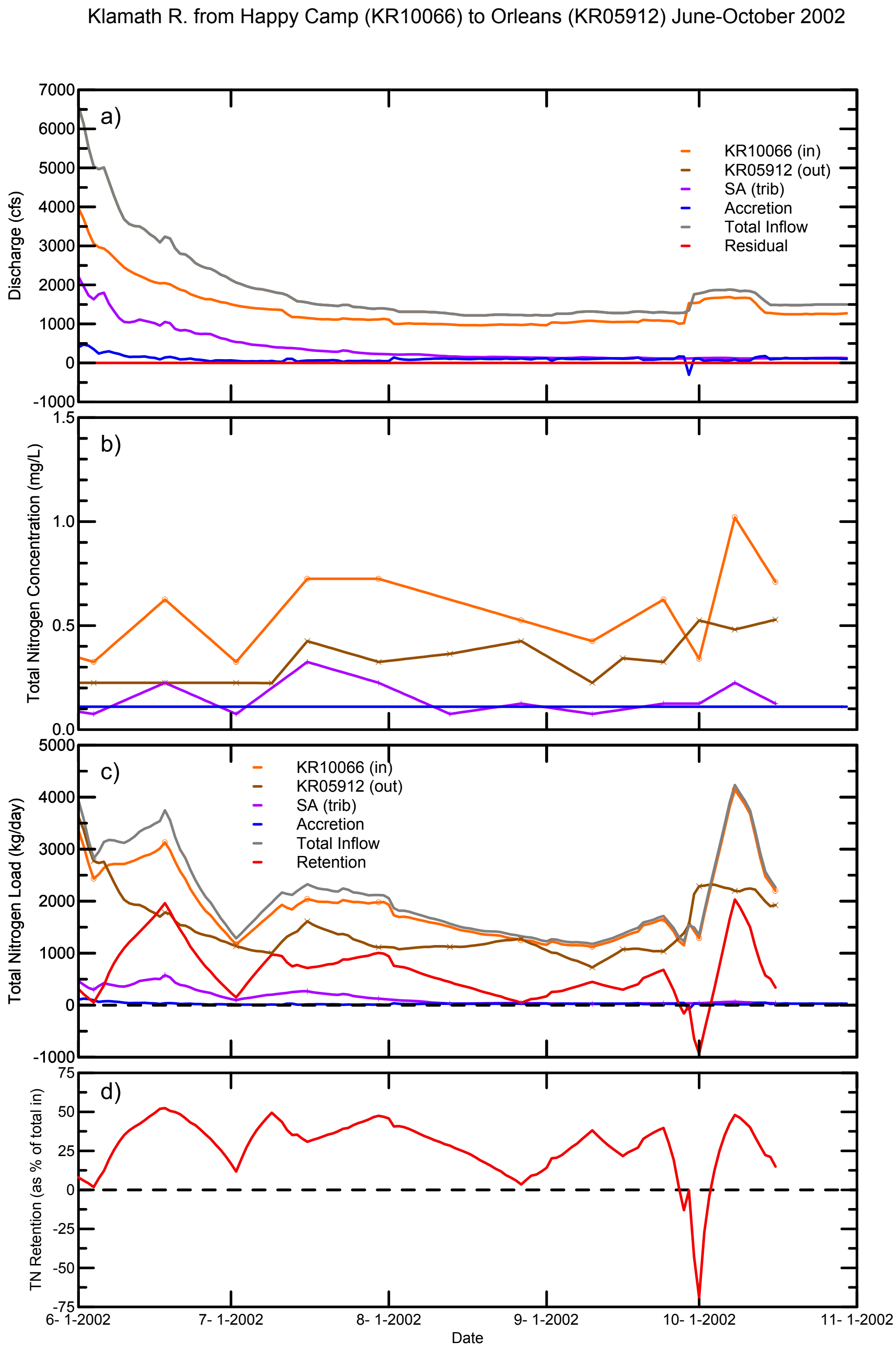

Figure 21. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2002 in the Klamath River reach from Happy Camp (site KR10066) to Orleans (KR05912). Measured tributary is the Salmon River (SA). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

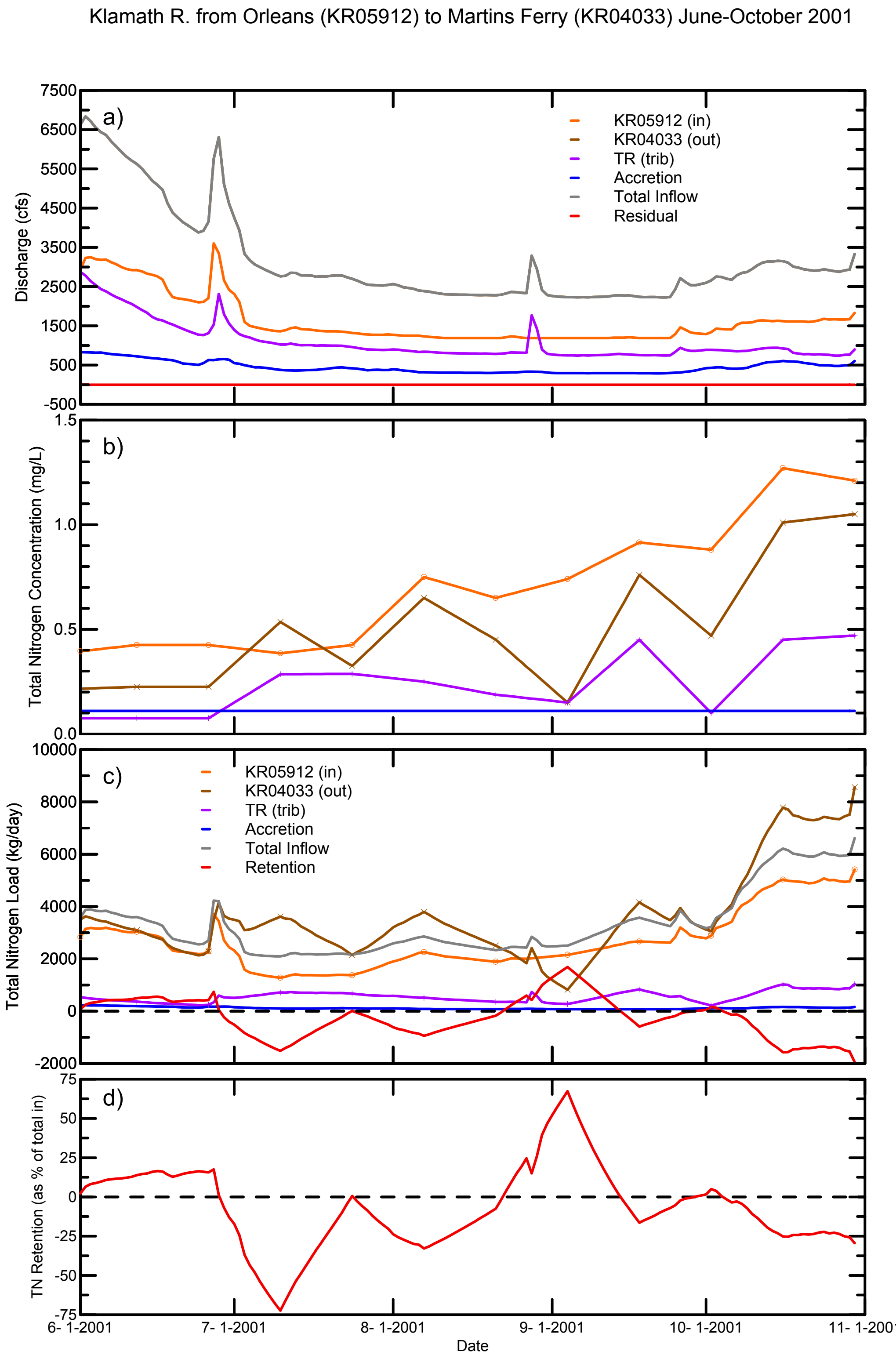

Figure 22. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2001 in the Klamath River reach from Orleans (site KR05912) to Martins Ferry (site KR03720). Measured tributary is the Trinity River (TR). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

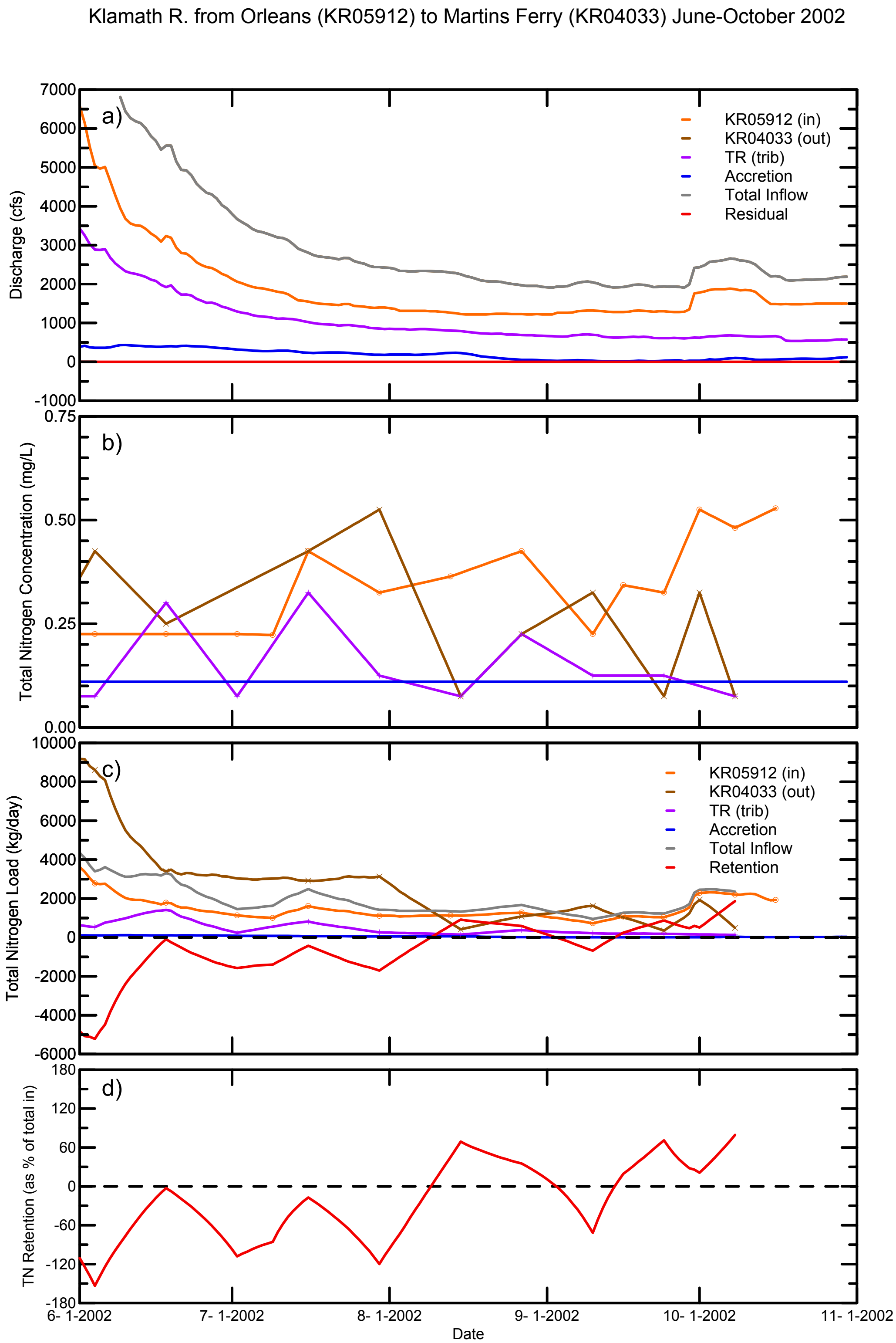

Figure 23. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2002 in the Klamath River reach from Orleans (site KR05912) to Martins Ferry (site KR03720). Measured tributary is the Trinity River (TR). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

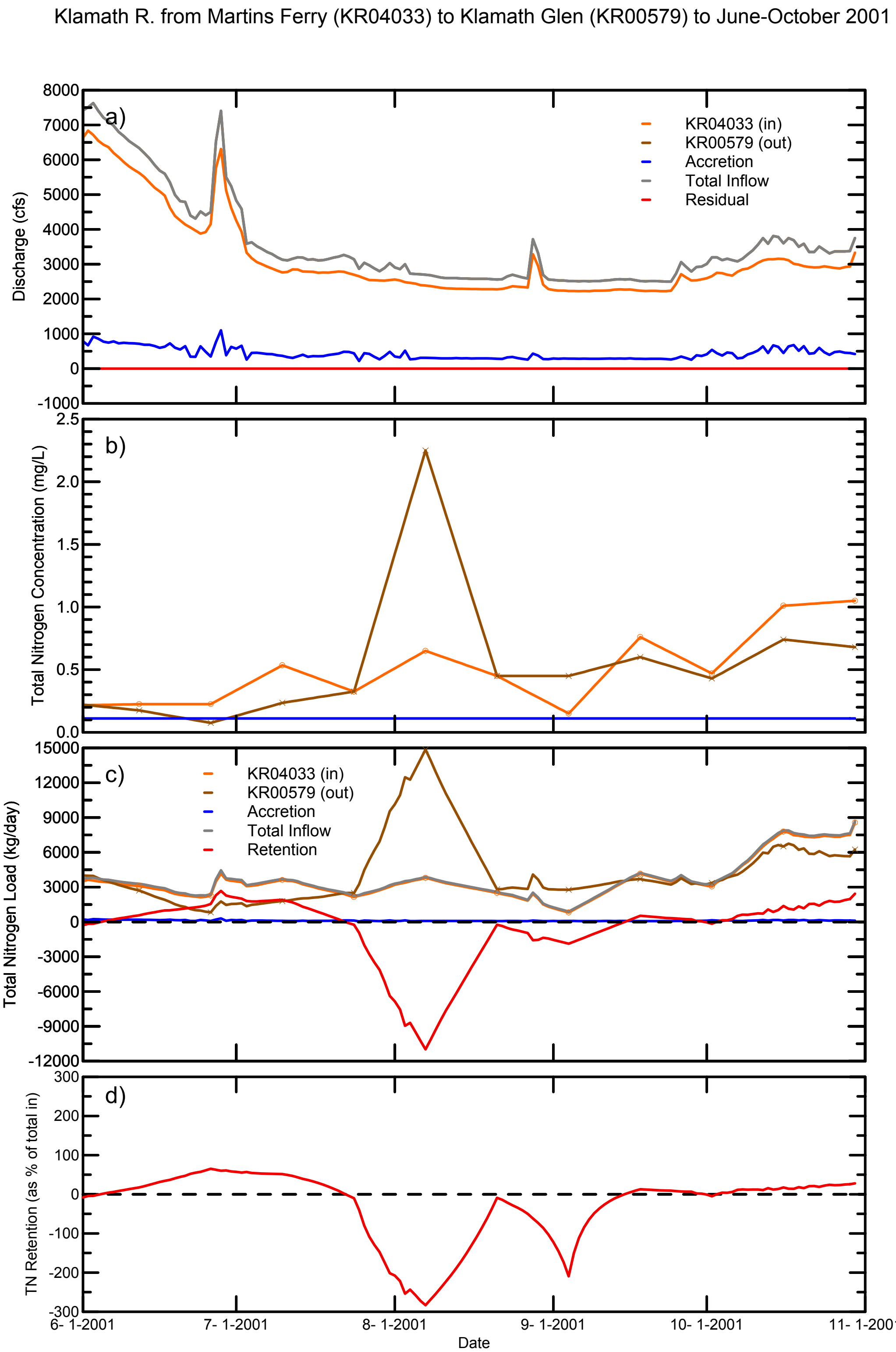

Figure 24. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2001 in the Klamath River reach from Martins Ferry (site KR03720) to Klamath Glen (KR00579). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

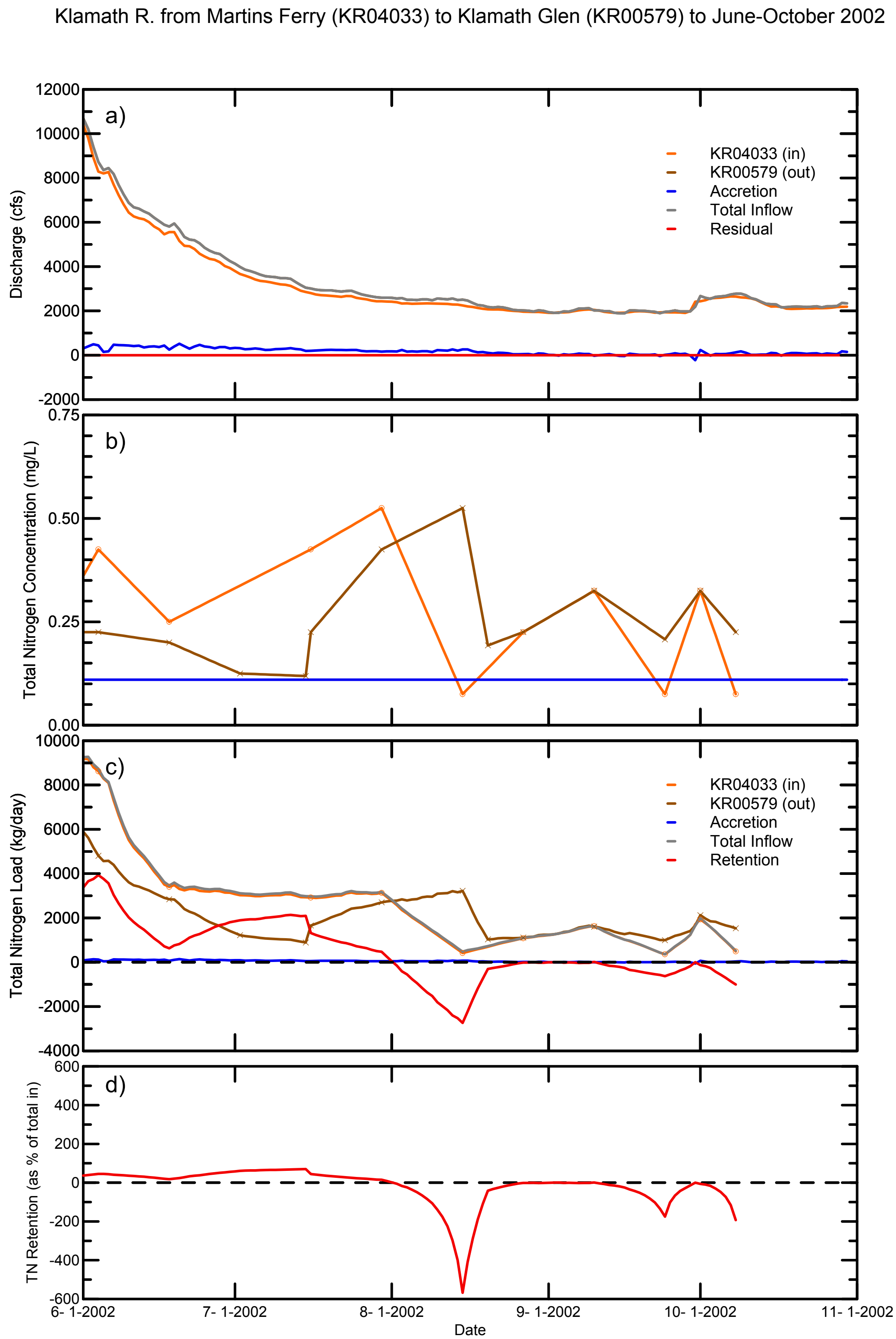

Figure 25. Daily total nitrogen (TN) budget (discharge, TN concentration, TN load, and TN percent retention), for the months June-October 2002 in the Klamath River reach from Martins Ferry (site KR03720) to Klamath Glen (KR00579). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

It should be noted that one reach-season, Martins Ferry (KR04033) to Klamath Glen (KR00579) in 2001, showed negative retention four times greater than the other reaches below Orleans. This result ed primarily from a seemingly anomalous data point, where the July-September -1.63 %/mi retention (Table 7) value for this reach was due to a single TKN measurement on 8/7/2001 at Klamath Glen of 2.2 mg/L (Fig. 24). Of 166 TKN samples in the database collected from 1974 to 2004, this was the highest measurement, with no other samples over 2.0 mg/L and only eight others over one mg/L (Appendix B). The next highest TKN sample from 1993-2004 was 0.59 mg/L in 2004. This indicates that that the 8/7/2001 sample was likely anomalous and may not have been representative of conditions at the site; however, most of the samples taken on that day were somewhat higher than previous and subsequent samples. The sample was only several times (rather than an order of magnitude) larger than a typical sample, so this data point was included in the analysis with the caveat that its impact is noted when interpreting the results. Field notes written at the time of the sample collection stated that the water was "low, relatively clear" providing additional evidence that this was not a representative sample (Turner, pers. comm.)

Similarly, most of the positive retention in the Iron Gate (KR18973) to Seiad Valley (KR12858) reach for the 2000 season was due to a single high sample on 7/11/2000 at Iron Gate, when TKN was 4.5 mg/L (Fig. 14). There are 313 TKN samples in the database below Iron Gate taken from 1971 to 2004 and this was the highest measurement, with no other samples over 2.0 mg/L, but approximately 25% of the samples are over 1 mg/L (Appendix B). As above, while this sample does seem somewhat anomalous, it is several times (rather than an order of magnitude) larger than a typical sample, so this data point was not excluded from the analysis. Average seasonal retention in this reach-season was only the fourth highest calculated for reaches from Iron Gate to Orleans, indicating that inclusion of this data point does not obviate the consistently observed pattern of positive retention between Iron Gate and Orleans.

Detailed examination of the inter-annual variability in retention is beyond the scope of this paper; however, a comparison of discharge, load, and retention in the Iron Gate to Seiad Valley reach for the years 1998-2002 (Fig. 26) shows that flows were lowest in 2002, the same year with the lowest nitrogen loads and highest overall percent nitrogen retention (although nitrogen retention in kg/day was only intermediate). Nitrogen concentrations at Iron Gate in 2002 were intermediate from June through mid-August, and then were lower than those of later years (Figure 26). However, lower flow did not result in higher retention in other years. For instance, 2001 had the second-lowest (after 2002) July-September flow, but percent retention in those months was the lowest of any year.

Nitrogen concentrations were higher at Iron Gate on most days in 2001 than in other years (Figure 26).

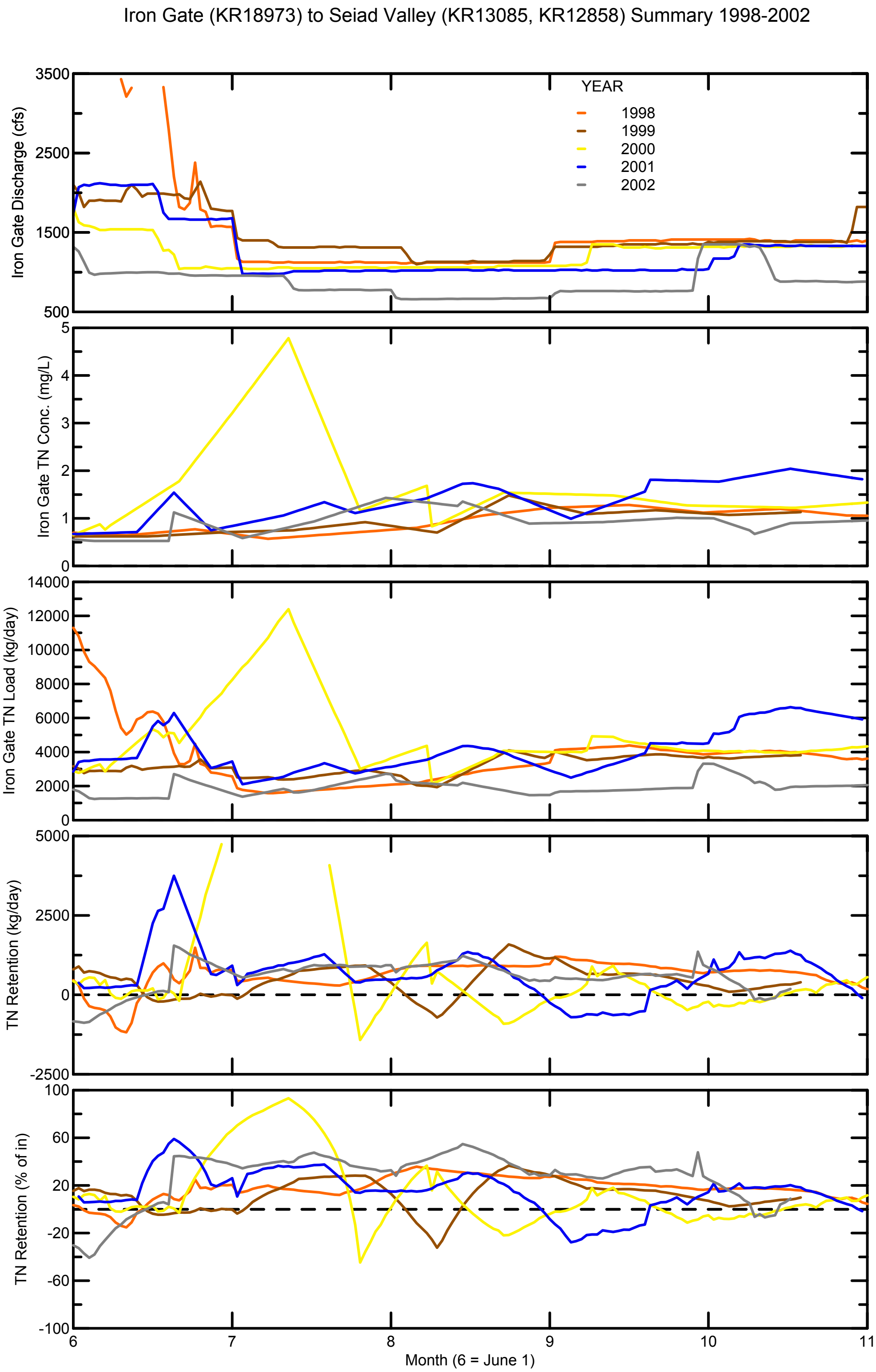

Figure 26. Daily discharge, TN concentration, TN load, and TN retention (expressed both as mass and as percent of inflow load), for the months June-October 2002 in the Klamath River reach from Iron Gate Dam (site KR18973) to Seiad Valley (KR12858/KR13085). Retention is the difference between the observed outflow load and expected (sum of all inputs) outflow load.

SENSITIVITY OF RETENTION TO CONSTANT UNMEASURED ACCRETION CONCENTRATION VALUE OF 0.11 MG/L

As described in the methods section above, the TN concentration for the unmeasured accretions was set to a constant 0.11 mg/L. To evaluate the potential effects on the results of this assumption, we calculated accretion load as a percent of total daily load for each reach (Fig. 27).

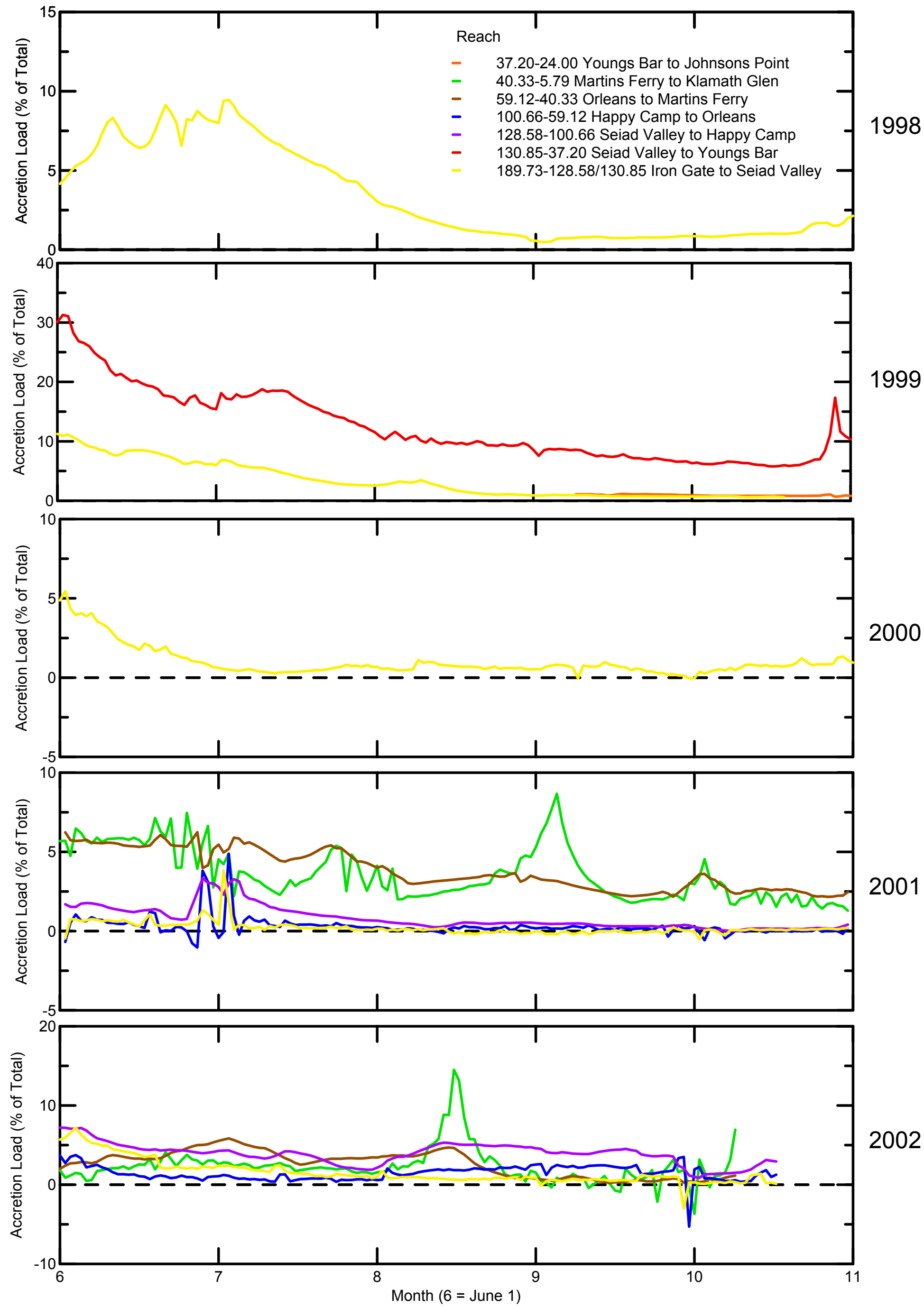

Figure 27. Accretion load expressed as the percent of total daily inflow load for analyzed Klamath River reaches, 1998-2002. Note that the scale of y-axes varies between years.

Several patterns are evident. First, the percentage of accretion load was higher in earlier months of the year and less in the later months. By far the highest percentage of accretion load was in the Seiad to Young's Bar reach in 1999, beginning at 31% in early June and then dropping to 6% in October. This is not surprising given that at 94 miles it was longest reach that we analyzed.

Aside from that reach, the percentage accretion load was generally 5% or lower, except during late spring/early summer runoff in some reaches, and two spikes from Martins Ferry to Klamath Glen (one in September 2001 and one in August 2002). Accretion percentage was typically less than 2% in August and September in the Iron Gate to Seiad Valley reach. The sensitivity of computed TN retention to the assumption of using 0.11 mg/L TN was further evaluated by assigning 0.055 mg/L (½ of 0.11) and 0.25 mg/L (~2.3x) to the accretion TN value and re-computing retention (Tables 9 and 10). The mean TN retention range above Orleans was 0.03% for Jul-Sep and 0.08% for Jun-Oct (Table 9). The range in TN retention rates below Orleans was slightly more variable with a maximum difference of 0.24% (Table 9). The Iron Gate to Seiad reach was the least sensitive to varying TN concentration (Table 9). Monthly comparisons show greater sensitivity in the early months (May and June), and little sensitivity during Jul-Oct (Table 10). Based on these analyses we conclude that the TN retention rates discussed below are relatively insensitive to the assumption of using 0.11 mg/L for accretion TN concentration.

Table 9. Sensitivity of total nitrogen retention rate to varying accretion total nitrogen concentration: sites and years shown separately. The total nitrogen concentration value used in the final reported results was 0.11 mg/L.

		Retention (% per mile)					
		July to September Period			June to October Period		
Reach Name	Year	0.055 mg/L accretion	0.11 mg/L accretion	0.25 mg/L accretion	0.055 mg/L accretion	0.11 mg/L accretion	0.25 mg/L accretion
Iron Gate to Seiad Valley	1998	0.37	0.39	0.43	0.22	0.24	0.31
Iron Gate to Seiad Valley	1999	0.27	0.29	0.32	0.18	0.21	0.27
Iron Gate to Seiad Valley	2000	0.55	0.55	0.56	0.40	0.41	0.42
Iron Gate to Seiad Valley	2001	0.20	0.20	0.20	0.27	0.27	0.27
Iron Gate to Seiad Valley	2002	0.60	0.61	0.62	0.43	0.44	0.46
Seiad Valley to Youngs Bar	1999	0.23	0.28	0.38	0.18	0.24	0.36
Seiad Valley to Happy Camp	2001	0.31	0.32	0.35	0.18	0.19	0.21
Seiad Valley to Happy Camp	2002	-0.63	-0.55	-0.37	-0.66	-0.58	-0.38
Happy Camp to Orleans	2001	0.70	0.70	0.70	0.53	0.53	0.54
Happy Camp to Orleans	2002	0.70	0.72	0.74	0.72	0.73	0.76
Mean for reaches starting above Orleans		**0.33**	**0.35**	**0.39**	**0.24**	**0.27**	**0.32**
Orleans to Martins Ferry	2001	-0.54	-0.44	-0.19	-0.50	-0.40	-0.15
Orleans to Martins Ferry	2002	-1.01	-0.93	-0.74	-1.73	-1.63	-1.39
Martins Ferry to Klamath Glen	2001	-1.67	-1.60	-1.43	-0.53	-0.48	-0.35
Martins Ferry to Klamath Glen	2002	0.13	0.15	0.22	0.52	0.54	0.60
Youngs Bar to Johnson's Point	1999	na	na	na	na	na	na
Mean for reaches starting below Orleans		**-0.77**	**-0.70**	**-0.53**	**-0.56**	**-0.49**	**-0.32**

Table 10. Sensitivity of total nitrogen retention rate to varying accretion total nitrogen concentration: sites and years averaged together and months shown separately. The total nitrogen concentration value used in the final reported results was 0.11 mg/L.

	Retention (% per mile)					
	Above Orleans			Below Orleans		
Month	0.055 mg/L accretion	0.11 mg/L accretion	0.25 mg/L accretion	0.055 mg/L accretion	0.11 mg/L accretion	0.25 mg/L accretion
May	0.00	0.07	0.23	-0.88	-0.81	-0.65
June	0.13	0.17	0.27	-0.39	-0.29	-0.07
July	0.34	0.37	0.43	-1.03	-0.93	-0.69
August	0.25	0.27	0.31	-1.67	-1.58	-1.37
September	0.32	0.34	0.37	0.10	0.13	0.21
October	0.12	0.12	0.16	0.04	0.08	0.17
November	0.02	0.05	0.12	0.00	0.03	0.11
July to Sept	**0.33**	**0.35**	**0.39**	**-0.77**	**-0.70**	**-0.53**
June to Oct	**0.24**	**0.27**	**0.32**	**-0.56**	**-0.49**	**-0.32**

COMPARISON OF RIVER AND RESERVOIR RETENTION IN 2002

An important issue concerning the effect of Copco and Iron Gate Reservoirs on water quality in the Klamath River system is the relative benefit/detriment of these reservoirs to downstream water quality. Previous reviews postulated that the reservoirs act to improve water quality by acting as nutrient sinks (PacifiCorp 2004, 2005c, 2006). Kann and Asarian (2005) showed, however, that while net retention was positive for the reservoirs over the entire April to November season (including spring runoff) in 2002, significant periods of nutrient release also occurred during critical summer periods when nutrients would be available for the downstream growth of periphyton and macrophytes.

PacifiCorp (2005a) further noted that the retention effect of the reservoirs in tandem is important for evaluating the net downstream effect. We agree, although the reason for keeping the systems separate in Kann and Asarian (2005) was to allow for the evaluation of management actions that could involve either of the reservoirs separately.

Nonetheless, when evaluated for the combined retention effect there were still two significant periods when net negative retention (release) occurred for both TP and TN (Kann 2006). Reproduced here, for TN in 2002, the two periods of net nitrogen release from the reservoirs were 5/24 to 6/19 (30 metric tons) and 7/17 to 8/14 (68 metric tons) (Figure 28).

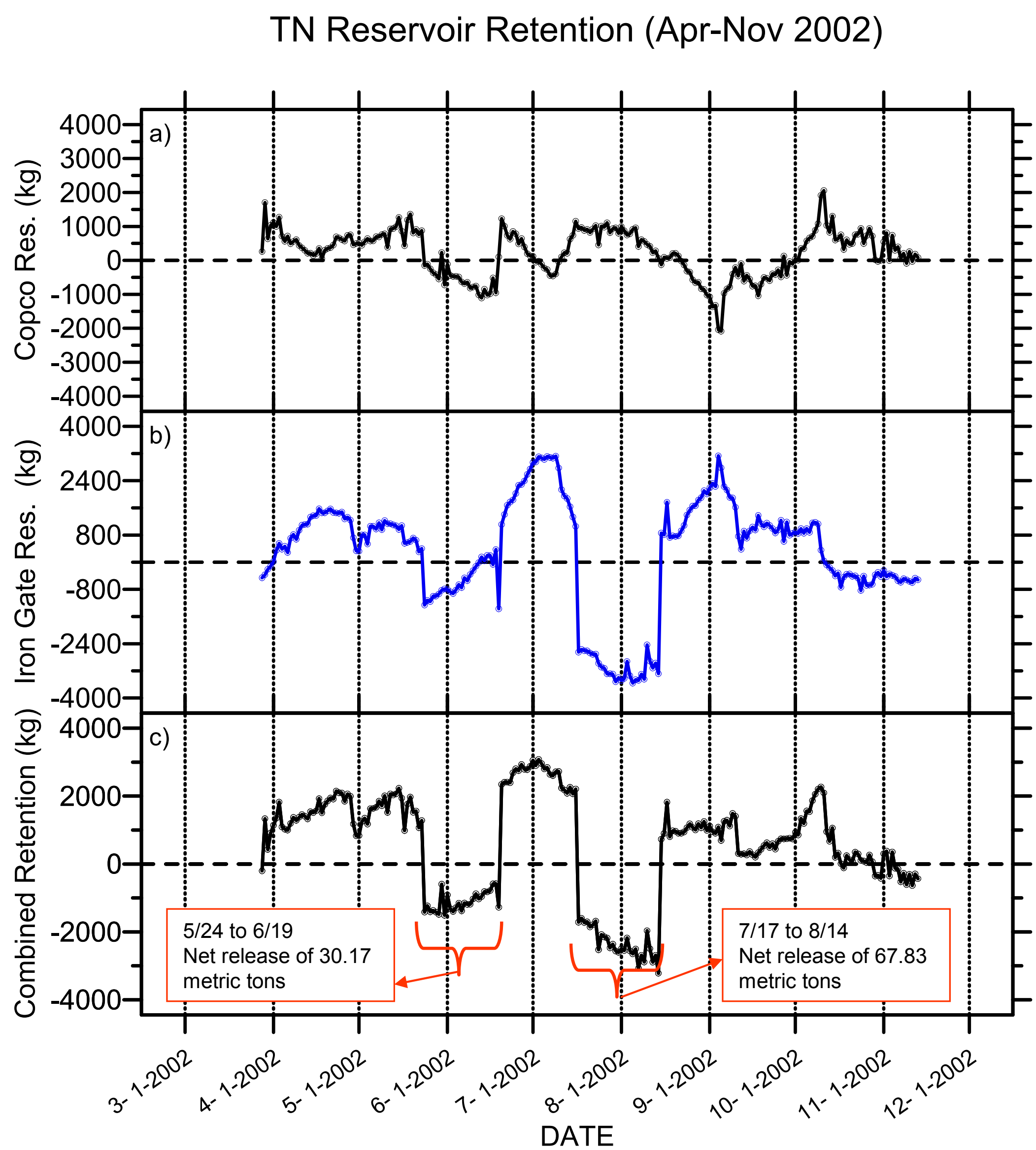

Figure 28. 2002 Combined TN retention in Iron Gate and Copco Reservoirs (from Kann 2006).

Even with the indication that there are significant periods when the reservoirs do not act as nutrient sinks, evaluation of the true reservoir effect on nutrient retention requires a further comparison of the combined retention of Iron Gate and Copco reservoirs with the retention that would occur absent these reservoirs, i.e., through the processes of plant uptake and denitrification that we discussed earlier.

To estimate potential retention in the pre-reservoir historic river channel that is currently inundated by Copco and Iron Gate Reservoirs, we applied retention rates calculated for the Klamath River reach from Iron Gate to Seiad Valley (Fig. 16). Retention rates for this particular reach were chosen because it is the reach directly below the reservoirs, is of similar gradient, and historic photos of the inundated area (Fig. 29) indicate that plant uptake and denitrification processes would likely have occurred here in the pre-dam era. Historical topographic maps included in the bathymetric survey report (Eilers 2003) and in December 16, 2005 submissions to the Federal Energy Regulatory Commission (FERC) by PacifiCorp show that large areas of river valley now submerged under Iron Gate and Copco reservoirs is low-gradient.

Copco Reservoir Site looking NW from Lennox Ranch, June 1910. (George Crowe photos)

Figure 29. Historic photo of an area now inundated by Copco Reservoir. The Lennox Ranch referred to in the photo caption was approximately halfway between the present-day upstream- and downstream ends of Copco Reservoir. Photo from Boyle (1976).

Given these assumptions, the following provides an initial comparison of the historic streambed -- now inundated -- with current reservoir retention. Overlapping data were available for both the river (Iron Gate to Seiad reach) and reservoirs from May 21 – October 16, 2002. Reservoir retention data were standardized to percent of incoming load per mile so that direct comparisons could be made.

As expected from the results of earlier analyses, the river consistently provided moderate positive retention (assimilation or denitrification), while the reservoirs alternate between highly positive and highly negative retention (Table 14; Figure 30).

Across the entire May 21 – October 16 period, the combined retention for the reservoirs was 10.8%, or 0.65%/mi (Table 11). River retention between Iron Gate and Seiad for the same period was 0.37%/mi (Table 11). To estimate the effect of the reservoir over and above that which would have occurred under historic non-inundated conditions, the river retention rate (0.37%/mi) was subtracted from the calculated reservoir retention rate (0.65%/mi) to yield an estimated retention rate of 0.27%/mi for the reservoirs only (Table 11). Applying the 0.27%/mi retention rate by 16.61 miles (the number of river miles inundated by the reservoirs) yields an overall retention of the incoming TN load of 4.6%. For the shorter July 1 – September 30 period when flows are the lowest, river retention (as %/mi) was higher than reservoir retention (0.61 %/mi versus 0.41 %/mi, respectively) with the estimated reservoir-only (reservoir minus estimated historic retention) effect being -3.3%.

The negative retention for the reservoir-only effect during this period indicates that when river retention is accounted for, the reservoirs may actually cause a net release of nutrients. This suggests that when retention due to natural river processes is factored into the reservoir retention estimated in Kann and Asarian (2005), the reservoir retention is minimal (4.6% of incoming load) or even negative (-3.3% of incoming load) during the periods evaluated (May 21 – October 16 and July 1 – September 30, respectively).

Table 11. Comparison of retention in the river reach from Iron Gate to Seiad Valley with the combined retention in Iron Gate and Copco Reservoirs. Estimated reservoir-only effect was calculated by subtracting the %/mi retention of the Iron Gate-Seiad reach from the %/mi retention of the reservoir reach (see retention as percent of inflow portion of the table). Estimated reservoir-only effect was calculated by multiplying the %/mile retention by the number of miles in the reservoirs (16.61). No river data were available before May 21 or after October 16, so those time periods were not be included in this table.

	River: Iron Gate to Seiad 61.15 miles			Reservoirs: Combined Iron Gate / Copco 16.69 miles			Retention as % of inflow				Retention as % of inflow per mile		
Time Period	Total Inflow	Retention	Retention	Total Inflow	Retention	Retention	River 61.15 miles	River 16.69 miles	Reservoir. 16.69 mi.	Estimated Reservoir Effect	Reservoir	River	Estimated Reservoir Effect
	Kg	Kg	Kg/mi	Kg	Kg	Kg/mi	%	%	%	%	% / mile	% / mile	% / mile
5/21 - 5/31	30257	-5861	-96	26005	-6529	-391	-19.4	-5.3	-25.1	**-19.8**	-1.50	-0.32	**-1.19**
6/1 - 6/30	69846	7622	125	71572	9438	565	10.9	3.0	13.2	**10.2**	0.79	0.18	**0.61**
7/1 - 7/31	66068	25301	414	75585	10359	621	38.3	10.5	13.7	**3.3**	0.82	0.63	**0.19**
8/1 - 8/31	62071	25808	422	48078	-19072	-1143	41.6	11.3	-39.7	**-51.0**	-2.38	0.68	**-3.06**
9/1 - 9/30	58972	18283	299	58281	21150	1267	31.0	8.5	36.3	**27.8**	2.17	0.51	**1.67**
10/1 - 10/16	41930	3398	56	58794	21095	1264	8.1	2.2	35.9	**33.7**	2.15	0.13	**2.02**
5/21 - 10/16	329143	74551	1219	338314	36441	2183	22.6	6.2	10.8	**4.6**	0.65	0.37	**0.27**
6/1 - 10/16	298886	80412	1315	312309	42970	2575	26.9	7.3	13.8	**6.4**	0.82	0.44	**0.38**
7/1 - 9/30	187111	69393	1135	181943	12436	745	37.1	10.1	6.8	**-3.3**	0.41	0.61	**-0.20**

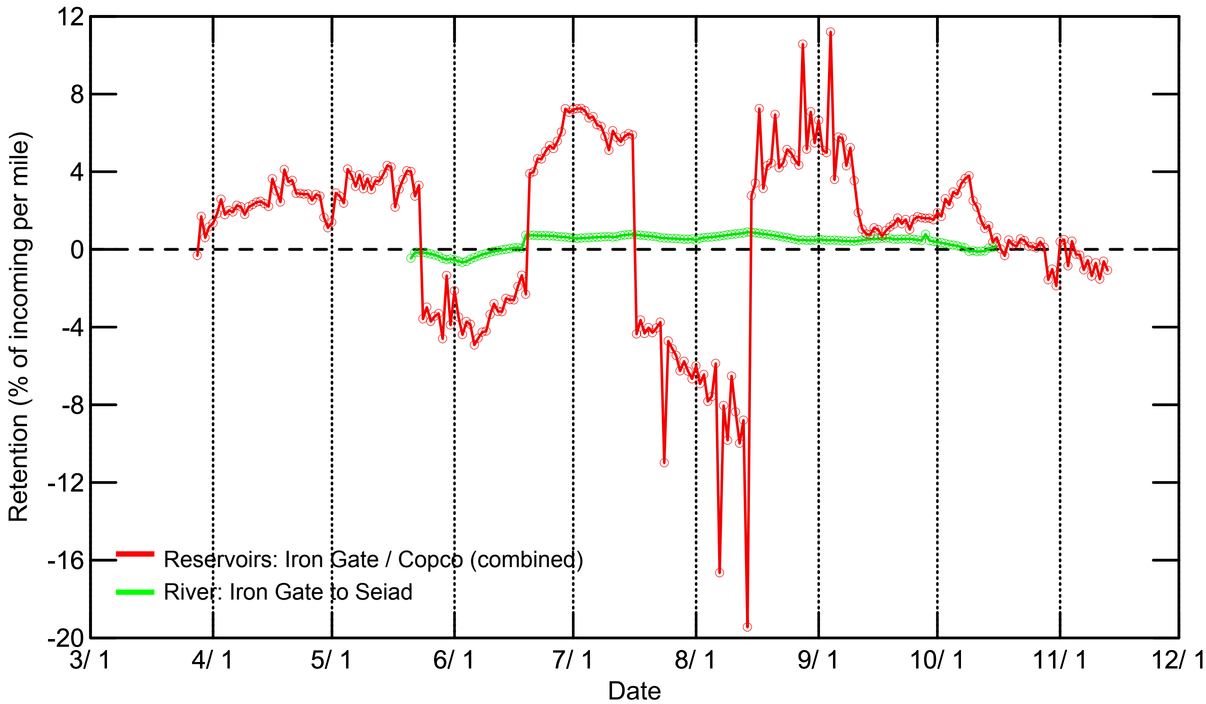

Figure 30. Comparison of combined retention in Iron Gate and Copco Reservoirs (from Kann and Asarian 2005) with retention in the river reach from Iron Gate to Seiad Valley, for the year 2002.

Although results for reservoir retention over the entire period evaluated were only slightly higher than that estimated for the historic pre-reservoir river channel (+4.6%), and lower (-3.3%) during the July-September period, these results are comparable to a large-scale nitrogen retention study that evaluated retention both within river networks and across multiple watersheds (Seitzinger et al. 2002). These authors concluded that although reservoirs increase both depth and water residence time, it is the ratio of these two characteristics that determines the proportion of N removed; thus the proportion of N input to a reservoir that is removed can be greater, less than, or similar to the proportion of N removed in that river section under pre-reservoir depth and water residence time (Seitzinger et al. 2002).

To further determine the comparability of our results to the empirical relationship developed by Seitzinger et al. (2002) we computed the ratio of depth to water residence time (defined as depth D:TOT where D is mean depth in meters and TOT is time of travel in years) for the reservoirs, the historic pre-reservoir channel, and the reach from Iron Gate to Seiad, and plotted this ratio and our measured or estimated retention on the empirical plot developed by Seitzinger et al. (2002). This plot (Figure 31) shows that our computed, and in the case of pre-reservoir river channel, estimated, retention values are similar to that expect based the D:TOT ratio for the respective reaches. It also indicates that efficiency of N removal varies significantly among reservoirs, and that the morphometric and hydraulic characteristics of Copco and Iron Gate Reservoirs place them at the lower end of the removal efficiency scale making them more similar to that expected from natural river reaches.

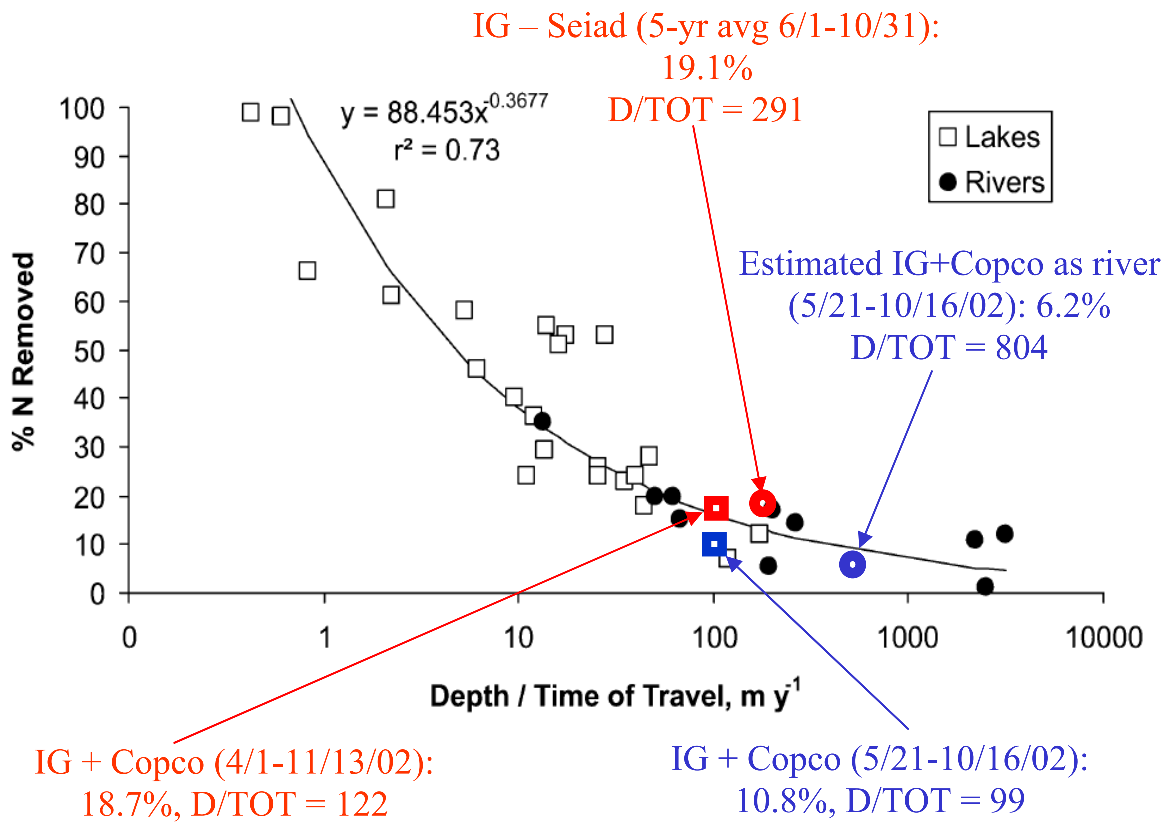

Figure 31. Comparison of Klamath River retention values with the expected relationship between mean depth to time of travel ratio (D:TOT) and % N removed (Seitzinger et al. 2002). Figure adapted from Seitzinger et al (2002). For details on calculation see Appendix B.

SUMMARY AND CONCLUSIONS

The analyses presented here investigated the nitrogen dynamics of the Klamath River with particular regard to quantifying the relative retention of the free-flowing river reaches between Iron Gate Dam, 190 miles upstream from the ocean, and Klamath Glen, which is near the river's mouth. Although analyses of all reaches provided useful information, we are most confident in the results from the Iron Gate-to-Seiad reach because it had the largest amount of data (five years of bi-weekly data), ungaged accretions represent only a tiny fraction of total TN load, and TN concentrations were high enough that detection limits were adequate.

An analysis of data from the June-October periods from 1998-2002 showed that the river reaches between Iron Gate Dam and Orleans typically showed positive nitrogen retention (assimilation/ denitrification) and that the river reaches below Orleans were more variable, having both periods of positive and negative retention (release) of nitrogen (Figure 17).

For the reaches above Orleans, the net June-October retention averaged +0.27% per mile, while retention in the July-September period was even higher at 0.35% per mile. As points of reference, extrapolating these averages out across the 130 miles from Iron Gate to Orleans yields a 35% load reduction for the 0.27%/mi rate and a 46% load reduction for the 0.35%/mi rate. These results are consistent with nitrogen reduction that would occur from the assimilative processes and/or denitrification described in the introduction.

To estimate potential retention in the pre-reservoir historic river channel that is currently inundated by Copco and Iron Gate Reservoirs, we applied retention rates calculated for the Klamath River reach from Iron Gate to Seiad Valley in 2002 (Fig. 16). Given the proximity and gradient similarity of the river reaches, including their appearance in pre-KHP historic photos, the retention rates calculated for the Iron Gate-to-Seiad Valley portion of the river provide a reasonable estimation of retention rates for the historic pre-reservoir river channel.

A comparison of temporal variability of river retention to reservoir retention showed that the river consistently provides moderate positive retention, while the combined retention of Iron Gate and Copco reservoirs alternates between positive and negative values (Figure 30). Thus, although overall reservoir nitrogen retention was positive for the entire evaluated period there were two significant periods in 2002 when the reservoirs were releasing nitrogen (i.e., retention was negative).

For the period May 21 to October 16, 2002 (the period of overlapping data for both the Iron Gate to Seiad reach and for the reservoirs) net retention in the reservoirs was 10.8%, while the estimated retention that would have occurred in a river of similar length was calculated to be 6.2%. The retention effect of the reservoir alone, then, was 4.6%.

Corresponding with the negative retention pulses in Figure 30, for the July 1 to September 30 period, we estimated that while net retention in the reservoirs was 6.8%, a much greater retention, 10.1%, would have occurred with a river of similar length in lieu of the reservoirs (Table 11). Thus, when retention that would have occurred under pre-reservoir river conditions is accounted for during this period, the reservoir-only net retention effect was -3.3%, indicating nitrogen release rather than retention.

Thus, this exercise indicates that when retention due to pre-reservoir natural river processes is factored into the reservoir retention estimated in Kann and Asarian (2005), the reservoir effect on retention was minimal (4.6% of incoming load) or even negative (-3.3% of incoming load) for the periods evaluated.

Overall these analyses confirm the importance of natural riverine nitrogen retention processes in the Klamath River system, and they underscore the need to factor these processes into evaluation of the hydrologic alterations attributable to the Klamath Hydroelectric Project.

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APPENDICES AT END OF DOCUMENT

A. Figures A1-A7, showing daily discharge, total nitrogen concentration, total nitrogen load for mainstem Klamath River sites with available data in the year 1998-2002

B. Calculations of depth and travel time used to compare data for Klamath River reaches with the chart from Seitzinger et al. (2002) shown in Figure 31.

ELECTRONIC APPENDICES ON CD

This report and all electronic appendices are available online at:
http://www.yuroktribe.org/departments/ytep/ytep.htm

C. Updated version of Klamath TMDL water quality database
C_KR_TMDL_database_with_PCorp_USFWS_CDWR_data.zip
[Also available online at:
http://www.krisweb.com/ftp/KlamWQdatabase/KR_TMDL_database_with_PCorp_USFWS_CDWR_data.zip]

D. Spatially interpolated flow record for mainstem Klamath River and tributaries 1962-2004
D_klamflow_1962_2004.dbf

E. Grab sample data table for Klamath River and tributaries.
Contains all measured parameters, including nutrient concentrations. Also includes discharge (as column DISCHARGE_CF, in cubic feet per second), and calculated total nitrogen load (as column L_TN_CALCT, in kilograms per day).
E_klamnutrientdischarge.xls

F. Daily reach-specific nutrient budgets 1998-2002
F_klamath_daily_nutrient_budgets_1998_2002.xls

G. Monthly nutrient budget by reach data
G_klamath_monthly_nutrient_budgets_1998_2002.xls

APPENDIX A: FIGURES A1-A7

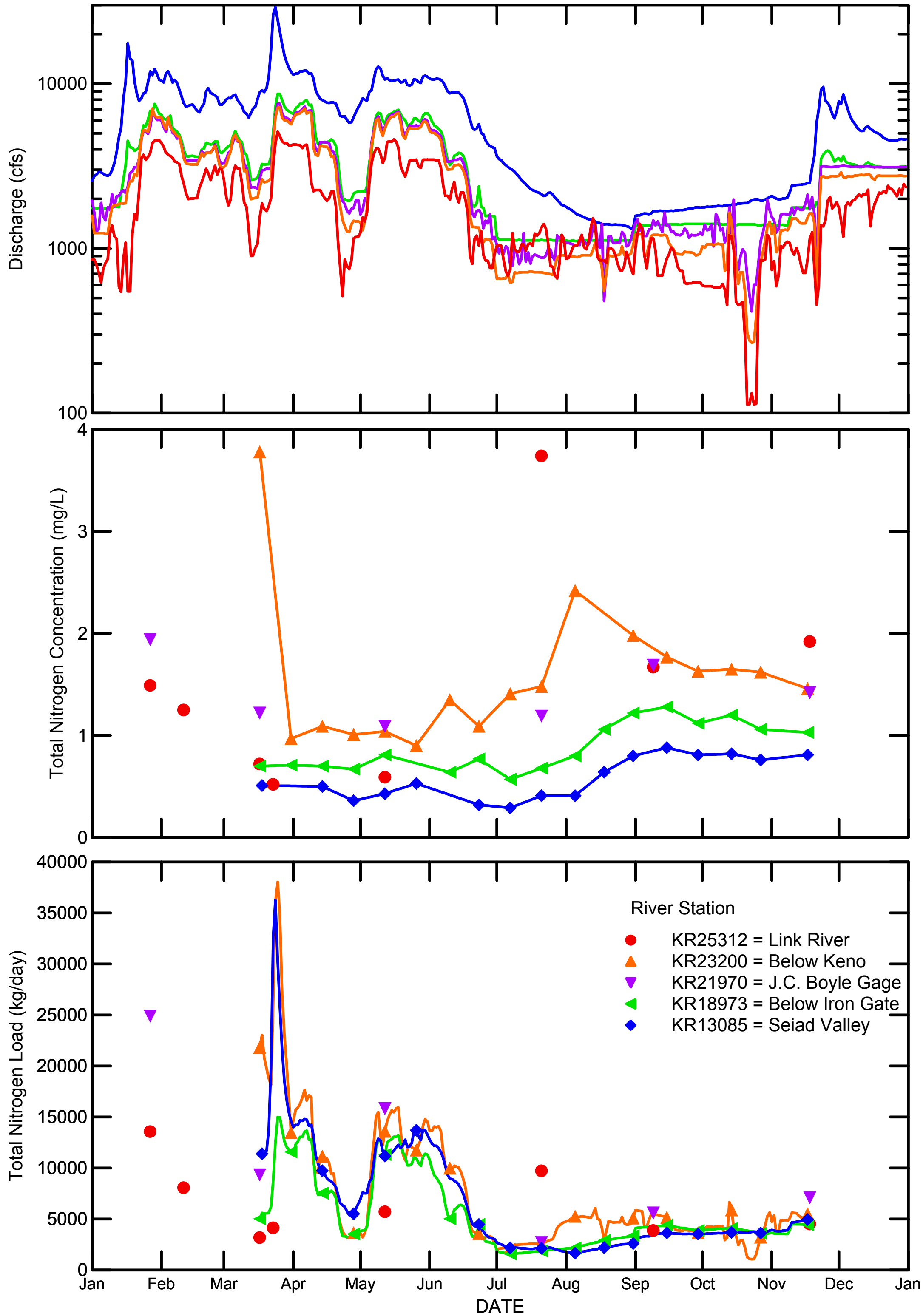

Figure A1. Daily discharge, total nitrogen concentration, total nitrogen load for all mainstem Klamath River sites with available data in the year 1998. The entire calendar year is shown here.

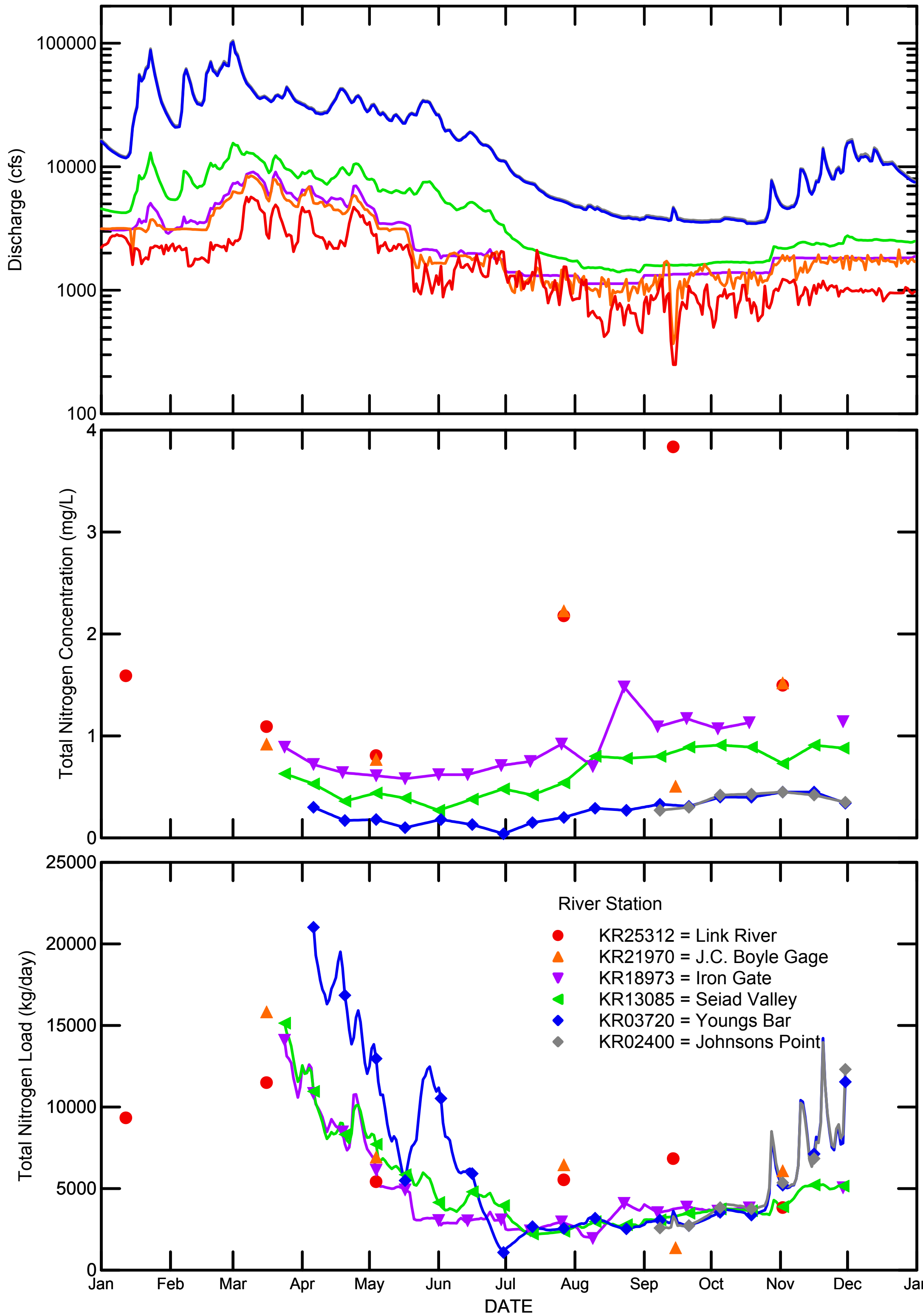

Figure A2. Daily discharge, total nitrogen concentration, total nitrogen load for all mainstem Klamath River sites with available data in the year 1999. The entire calendar year is shown here.

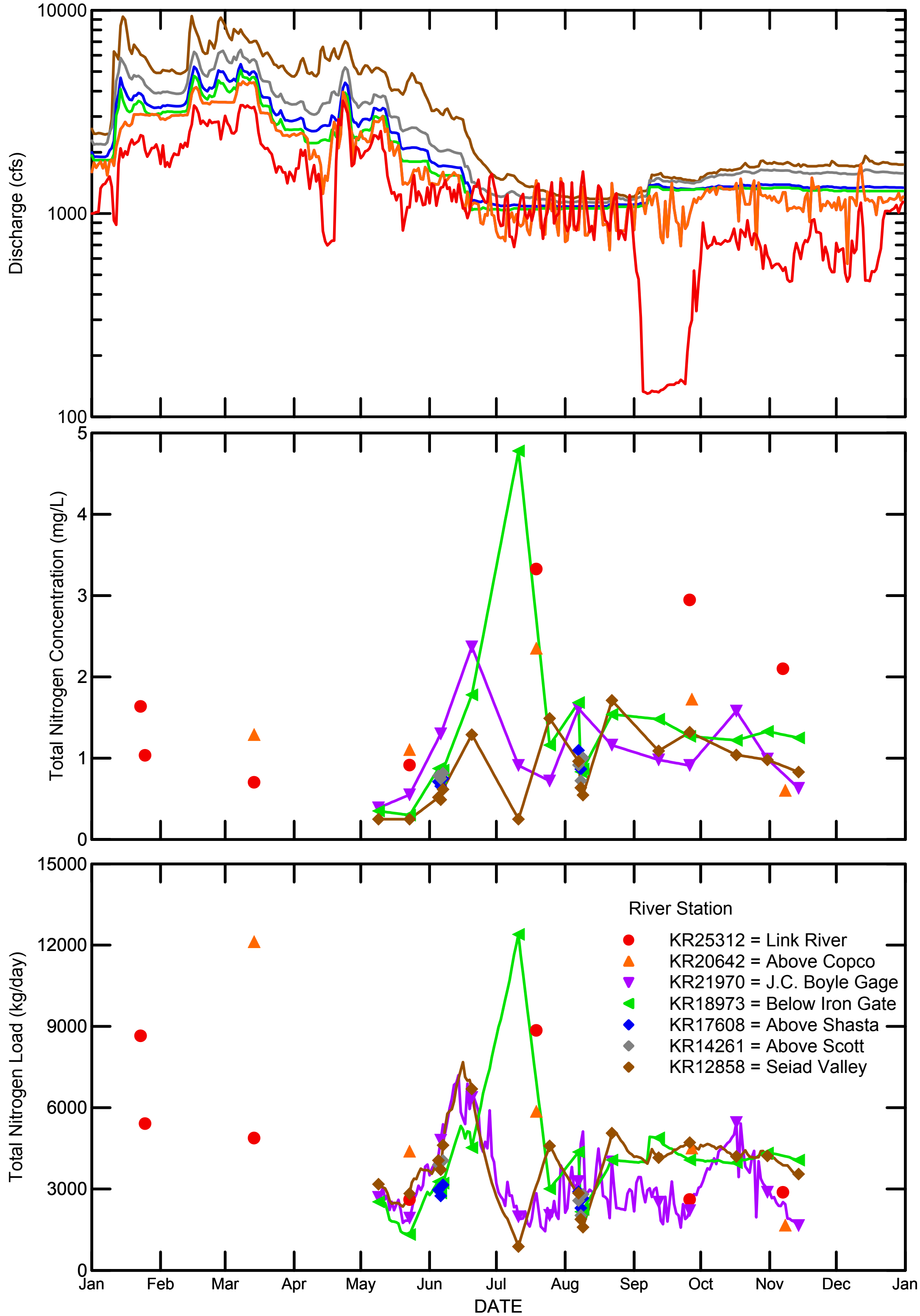

Figure A3. Daily discharge, total nitrogen concentration, total nitrogen load for all mainstem Klamath River sites with available data in the year 2000. The entire calendar year is shown here.

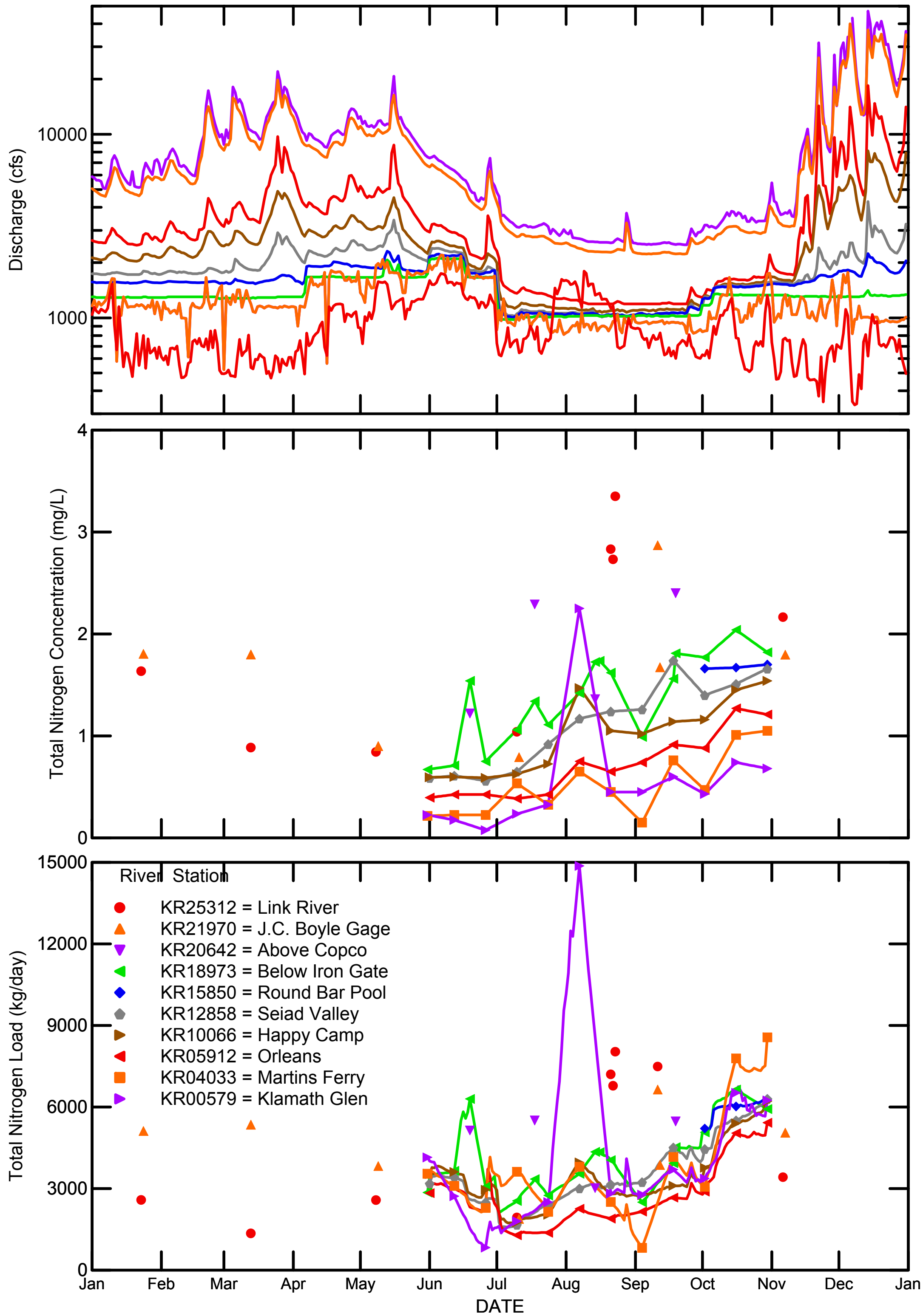

Figure A4. Daily discharge, total nitrogen concentration, total nitrogen load for all mainstem Klamath River sites with available data in the year 2001. The entire calendar year is shown here.

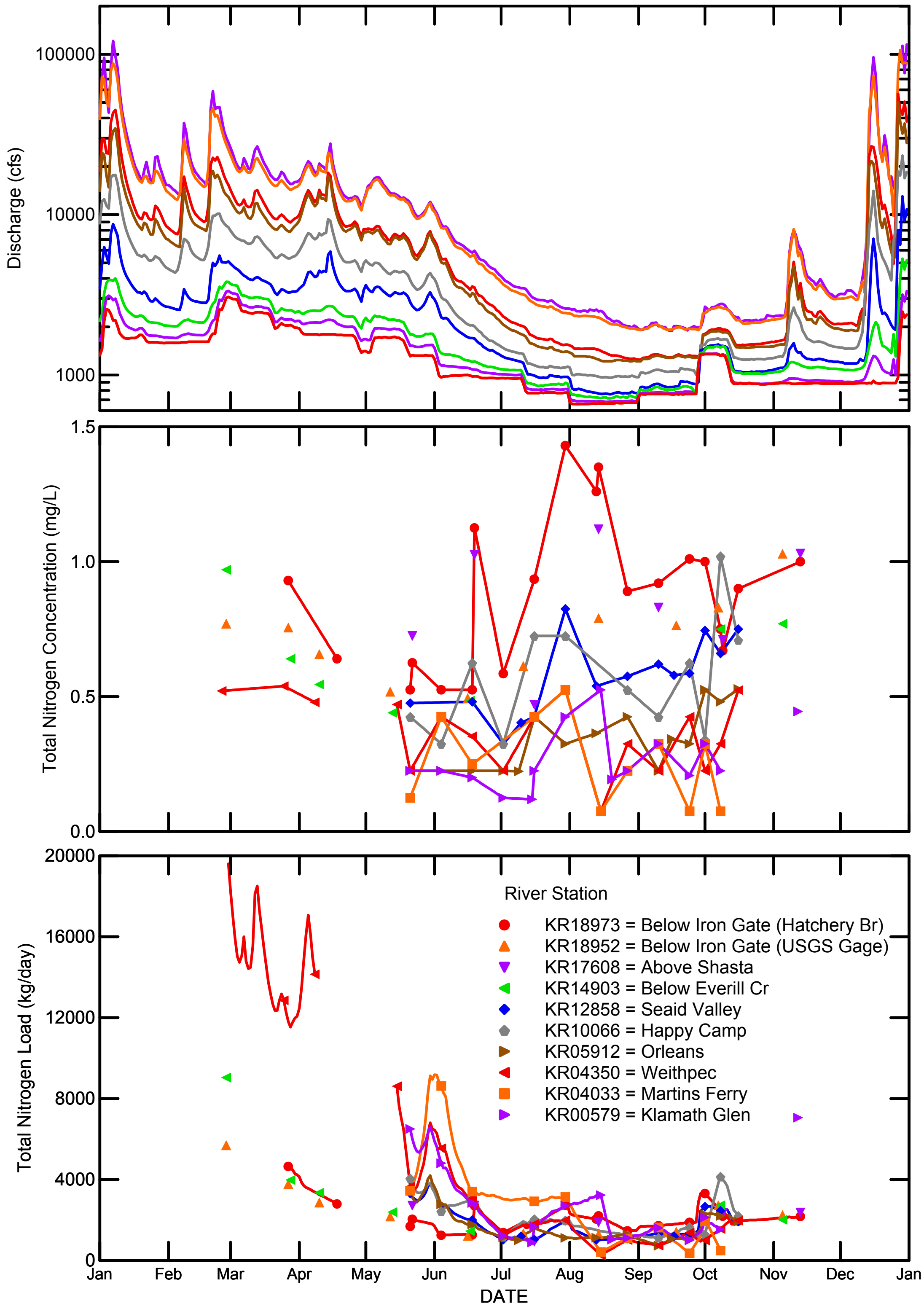

Figure A5. Daily discharge, total nitrogen concentration, total nitrogen load for all mainstem Klamath River sites with available data in the year 2002. The entire calendar year and only sites between Iron Gate Dam and Klamath Glen are shown here (there were too many sites too display all 2002 data on one graph).

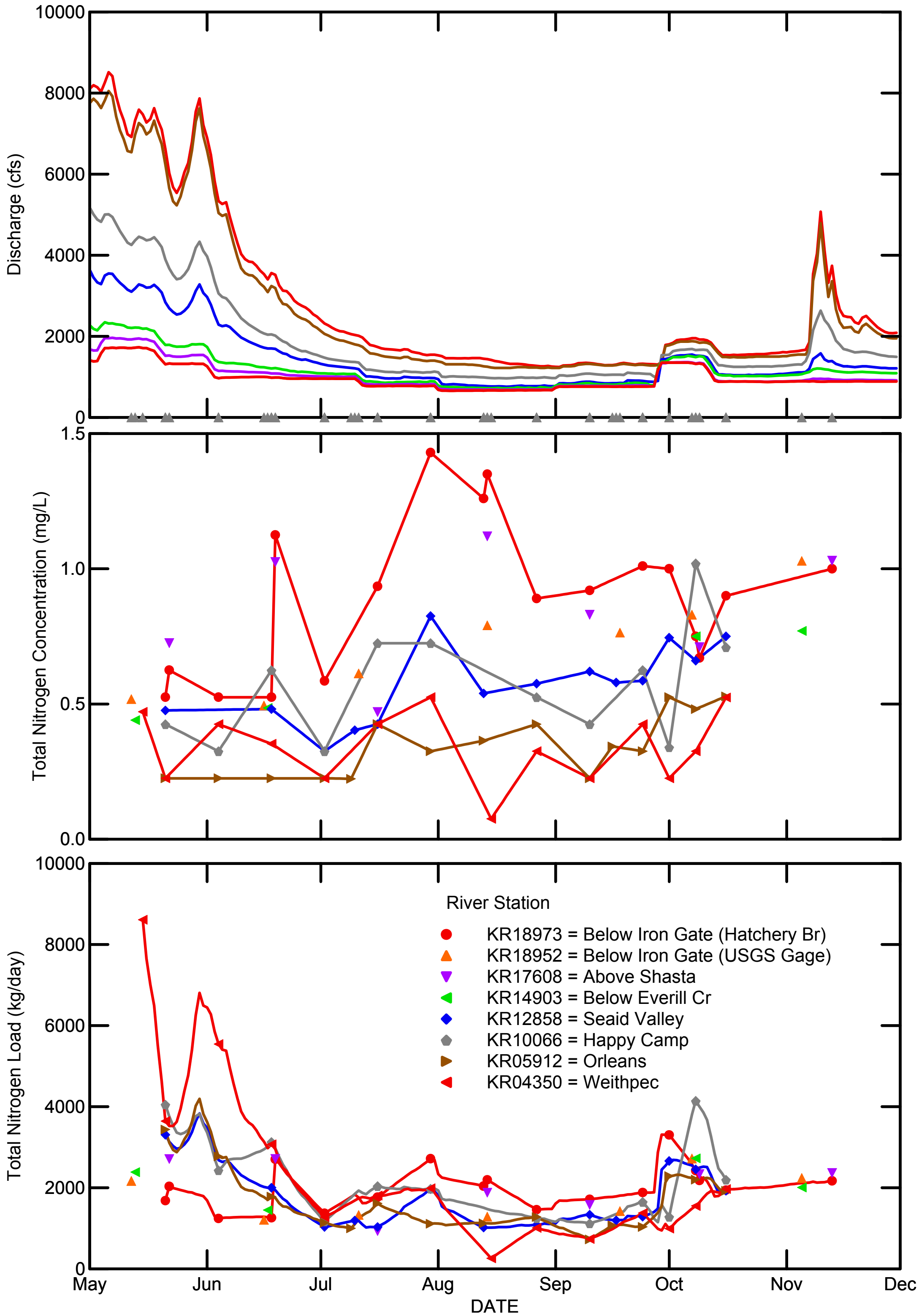

Figure A6. Daily discharge, total nitrogen concentration, total nitrogen load for all mainstem Klamath River sites with available data in the year 2002. The months May-November and only sites between Iron Gate Dam and Klamath Glen are shown here (there were too many sites too display all 2002 data on one graph).

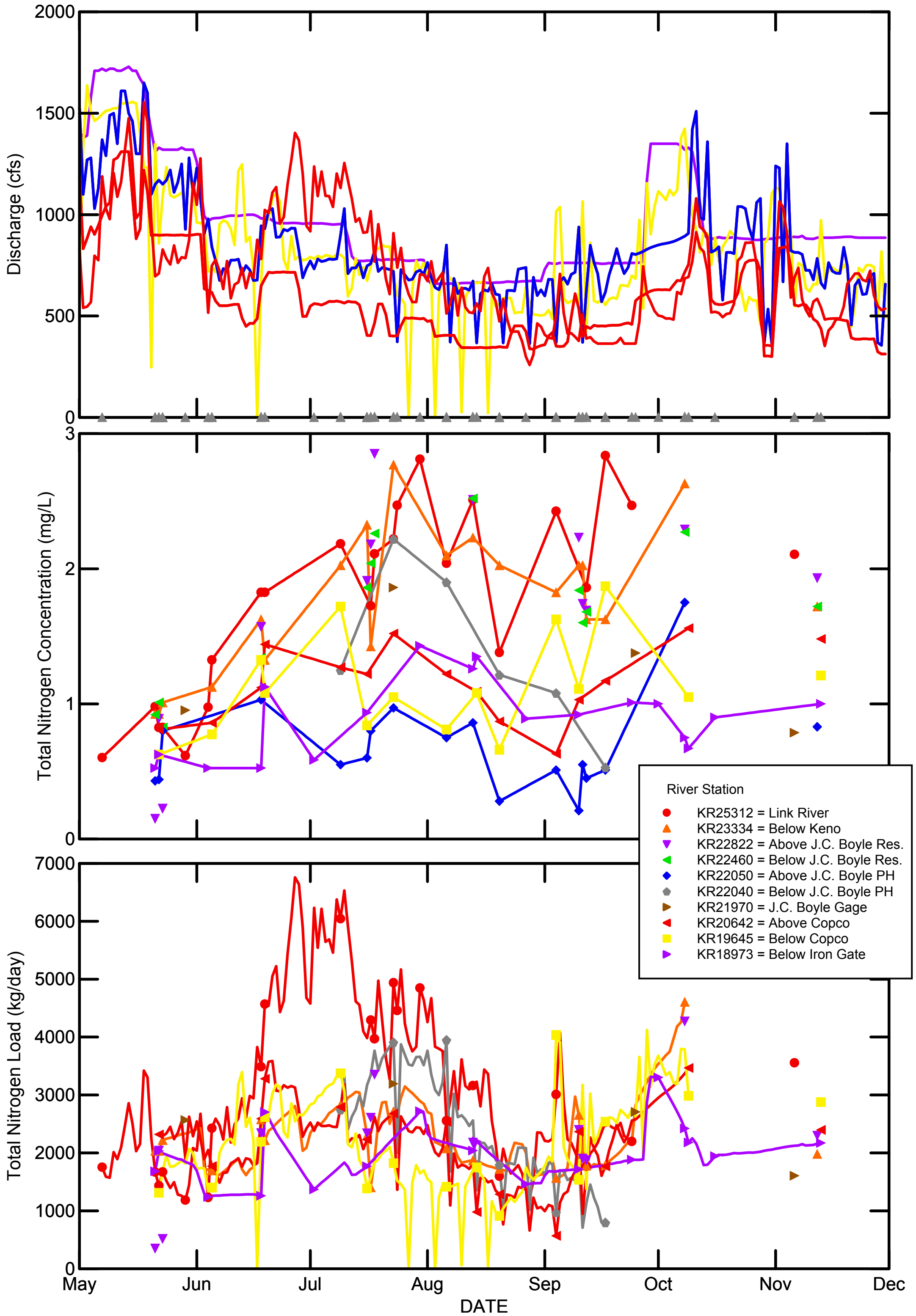

Figure A7. Daily discharge, total nitrogen concentration, total nitrogen load for all mainstem Klamath River sites with available data in the year 2002. The months May-November and only sites from Link River to Iron Gate Dam are shown here (there were too many sites too display all 2002 data on one graph).

APPENDIX B:

CALCULATIONS OF DEPTH AND TRAVEL TIME FOR FIGURE 31

Reach	Time Period	Percent N Retention[1]	(m³/day) Average Inflow[1]	(m³) Average Volume[1]	(days) Time of Travel[2]	(years) Time of Travel	(m²) Average Surface Area[3]	(m) Average Depth[4]	Depth (D) to Time of Travel (TOT) Ratio
Iron Gate and Copco Reservoirs combined	4/1/2002 - 11/13/2002	**18.7**	2572950	107246442	41.7	0.114	7675294	13.97	**122**
Iron Gate and Copco Reservoirs combined	5/21/2002-10/16/2002	**10.8**	2092047	107722462	51.5	0.141	7698874	13.99	**99**

1. From Kann and Asarian (2005)
2. Calculated as: average inflow / average volume
3. Calculated as: (average of daily Iron Gate surface area for period) + (average of daily Copco surface area for period)
4. Calculated as: average volume / average surface area

Reach	Time Period	Percent N Retention	(ft³/sec) Average Flow	(miles) Reach Length	(miles/hr) Velocity	(hours) Time of Travel	(years) Time of Travel	(ft/sec) Velocity[7]	(ft) Average Width[8]	(ft) Depth[9]	(m) Depth	Depth (D) to Time of Travel (TOT) Ratio
Estimated Iron Gate and Copco Reservoirs as river (based in per mile rates for Iron Gate to Seiad)	5/21/2002-10/16/2002	**6.2**	826	16.61	1.13[5]	14.7[5]	0.00167	1.66	112.7	4.40	1.34	**804**
Iron Gate to Seiad Valley	6/1-10/31 1998-2002	**19.1**	1284	60.5	1.33[6]	45.5[6]	0.00610	1.96	112.7	5.81	1.77	**291**

5. Based on travel time of 53.5 hours for the 60.5 miles from Iron Gate to Seiad at 800 cfs flow (Deas et al. 1999)
6. Based on travel time of 45.5 hours for the 60.5 miles from Iron Gate to Seiad at 1200 cfs flow (Deas et al. 1999)
7. Unit conversion from velocity miles/hr
8. Average width is from USFWS habitat typing surveys July 1997. Average daily flow Iron Gate flow for July 1997 was 820 cfs. Width of 112.7 feet was used for both rows in the table, as although average width was likely to be slightly higher at 1200cfs than 800cfs, there were no data to predict average channel width at 1200cfs. The final D/TOT ratio is relatively insensitive to minor changes in width (e.g. increasing width to 130 feet decreases D/TOT from 291 to 250).
9. Calculated as: Depth = Flow / (Width * Velocity)