

## NUTRIENT LOADING IN THE KLAMATH IRRIGATION PROJECT

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### **A**bstract

In response to the Federal Clean Water Act, the Oregon Department of Environmental Quality (DEQ) is in the process of establishing water quality management plans for bodies of water that are listed as water quality limited. Many water bodies in the Klamath Basin are included on the 303d list based on temperatures exceeding standards for cool-water fish species. The Klamath River above Keno, Oregon also is listed for chlorophyll-a and other parameters associated with the nutrient-rich condition of the highly eutrophic status of Klamath Lake and its discharge waters. The DEQ process ultimately will lead to establishment of Total Maximum Daily Loads (TMDLs) for Lost River, Klamath Straits Drain, and the Klamath River to achieve water quality standards applicable to the Klamath Basin, established by the DEQ. The discharge of drainage waters from the Klamath Irrigation Project and two wildlife refuges from the Straits Drain to Klamath River above Keno has been identified as a source of nutrient loading that will be assigned a TMDL. It is widely assumed that agricultural activities within the Klamath Irrigation Project are a significant source of nutrients discharged to Klamath River at the Straits Drain.

Klamath Lake and the Klamath River above Keno are the major sources of irrigation supply to the Klamath Project.

Diversions to the project include the A Canal, which diverts approximately 225,000 to 275,000 acre-feet (AF) directly out of Klamath Lake annually. Diversions out of Klamath River to the North and ADY Canals contribute about 100,000 AF to agricultural and wildlife refuge supplies annually. In 1999, Klamath Experiment Station staff monitored the nutrient concentration at these diversion points on approximately 2-week intervals to estimate total phosphorus (TP) and total nitrogen (TN) loading to the Klamath Project from these sources. Estimates based on these data and flow data provided by the Bureau of Reclamation (BOR) indicate 1999 loading of approximately 2.0 million lb TN and 170,000 lb TP. Estimates of nutrient loading at the A Canal diversion for 1991-98 also were calculated. These were based on flow data provided by BOR and nutrient concentrations monitored at the Fremont Bridge near the A Canal diversion in a study funded by the BOR. The BOR currently is monitoring loading contributions from the Lost River. University of California at Davis personnel are monitoring several locations on the California side of the Klamath Project and the discharge to Klamath River at the Straits Drain. A compilation of data from all studies, including the Lost River study, eventually will be needed to establish allocations for TMDLs at Straits Drain by DEQ.

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### Introduction

Poor water quality in Klamath (including Agency) Lake is associated with excessive algae production. High phosphorus content supports the blue-green algae, *Aphanizomenon flos-aquae*, which further degrades water quality by fixing atmospheric nitrogen in the biomass. At periods of high algae biomass, chlorophyll-a levels exceed water quality standards. As algae masses die and decay, elevated pH, dissolved oxygen depletion, and release of un-ionized ammonia produce conditions detrimental to fish species resident in the lake.

Extensive data has been collected in recent years to document the degree of water quality degradation in Klamath Lake. The lake and its discharge waters in the upper reaches of Klamath River are listed for impairments to temperature, chlorophyll-a, pH, and dissolved oxygen in Oregon's 303d list of water quality limited water bodies. The DEQ recently appointed a committee and attempted to assign TMDLs for the Klamath River. The process was put on hold pending the development of a TMDL plan for Klamath Lake and its tributaries. During the TMDL planning process for the Klamath River, discharge from the Klamath Irrigation Project at the Straits Drain was identified as a source of contaminants requiring assignment of TMDLs. Agricultural activities within the project are widely thought to be a major source of nutrient loading to discharge waters. However, multiple water sources and diversion pathways, the influence of wildlife refuges, and the relative contribution of natural and other inputs complicates assessment of this complex system.

The following text is taken directly from "A Citizens' Guide for Improving Water Quality in the Klamath River, Lake Ewauna, Lost River, and Tributary Streams to the Lost River." The Klamath TMDL Advisory Committee submitted this report.

*"The quality of water from the Upper Klamath Lake generally controls the applicable numeric criteria for the Klamath River and at times the Lost River, particularly for critical parameters like ammonia. In essence, the lake quality becomes the 'yardstick' to measure the success of management strategies because the goal is for humans to not make conditions worse. That is not to imply that the over-abundant algae production in the lake is derived only from 'natural' sources of nutrients. On the contrary, human activities have in all likelihood accelerated the rate of eutrophication by contributing nutrients from various pathways such as point source discharges and management of the land over the past century.*

*"This process has not attempted to differentiate between the natural versus human-related causes for the poor lake quality because much of the enormous quantity of surplus nutrients stored and cycled in the lake today is likely from past activities – from both natural sources and anthropogenic activities. This plan takes a more practical approach by defining the natural background quality from Upper Klamath Lake as the reference condition to establish management objectives and TMDLs."*

This study was initiated to estimate total nutrient loading to the Klamath Irrigation Project from water diverted to

agricultural lands from Klamath Lake and Klamath River. A BOR study is underway to monitor multiple sites along the Lost River, which contributes flows from Gerber and Clear Lake reservoirs to project supplies. Personnel from the University of California at Davis are monitoring numerous sites in the California portion of the project, including sites above, between, and below Tulelake and Lower Klamath Wildlife Refuges. They are also monitoring discharge to Klamath River at the Straits Drain. This report presents an analysis of nutrient inputs to the Klamath Irrigation Project from Klamath Lake and Klamath River.

### Procedures

Water samples were collected as grab samples, except in the case of three 24-sample sets collected with an ISCO automatic sampler at A Canal headworks. Samples of approximately 125 ml were refrigerated during the collection trips and frozen as soon as possible after collection. Duplicate samples were collected on 9 of 13 sample dates from the North and ADY Canals, and 8 of 13 sample dates for grab samples from the A Canal. Samples remained frozen until analyses were performed at the Oregon State University (OSU) Soils Laboratory. All samples were analyzed for unfiltered TP and TN using Kjeldahl digestion procedures. While it is recognized that specific components of nutrients are important, transformations occur within the project. Total N and total P loading provide a useful indication of the overall nutrient balance in the system. TMDL assignment will be based on a more detailed analysis of nutrient components.

Samples from the A Canal were collected from the metal walkway about 100 feet downstream from the intake headworks. The flow at this point is highly turbulent with little possibility for stratification in the water column. Samples for the North Canal were collected west of Highway 97, east of the railroad tracks. The ADY canal samples were collected east of Highway 97 at the discharge point near F and FF pumps.

An automated ISCO sampler was used to collect 24 samples at 2-hour intervals on July 9-11, July 27-29, and August 31-September 2 at A Canal headworks. Samples were collected in an ice-water chamber, but the ice melted before the 48-hour period ended. Samples were frozen soon after the last sample was collected.

Daily flow data were provided by the BOR for each site. Flow volumes for the A Canal are considered accurate estimates. Less accuracy is asserted for the lower flows at the North and ADY Canals. Calculations of nutrient loading were based on flows for days mid-way between sample dates. For example, samples were collected on June 21, July 1, and July 9, and nutrient loading for the July 1 sample date was calculated based on flows for June 27 through July 5. The 1999 data represents the total diversion for the A Canal during the irrigation season. Diversions at the North and ADY Canals occur at later times to winter-flood areas in Lower Klamath Lake agricultural fields and the Lower Klamath Wildlife Refuge. Sampling of the ADY and North Canals after October 1999 is not included in this report.

Dr. Jacob Kann has collected Klamath Lake nutrient concentration data at

the Fremont Bridge since 1991. This site at the southern end of the lake is approximately 1500 feet from the intake to A Canal. The data were developed on a contract with the BOR and are available to the public, but they have not been published to date. During the irrigation season, samples were collected on an approximate 2-week schedule. TP and TN data from this study were combined with BOR A Canal flow data to estimate nutrient loading to the A Canal for the years 1991-98.

### **Results and Discussion**

Standard analytical procedures followed in the OSU Soils Laboratory included the use of blank and known spiked samples. For brevity, only the data from actual samples is presented in this report. TP data are reported to a precision of 0.01 ppm and TN to 0.1 ppm. Where duplicate samples were collected, calculations are based on the mean of the samples. Data for all grab samples from the three diversion points are presented in Table 1. In most cases, good agreement was observed between duplicate samples. Notable exceptions were ADY Canal samples on September 13 and A Canal samples on October 4. Seasonal trends in nutrient concentrations were evident. TP and TN were low through early June, peaked in early July, and remained relatively high through September. These data are consistent with nutrient levels observed in several locations in Klamath Lake from 1991 through 1998. The high concentrations are indicative of blue-green algae content.

The diversions from Klamath River are located approximately 10 miles (North

Canal) and 15 miles (ADY Canal) downstream from Klamath Lake. Several point source discharges between Klamath Lake and these diversions influence water quality. Important discharges include the Lost River Diversion Channel and the water treatment facilities for the Klamath Falls metropolitan area. Flow velocities through the reach from Lake Ewauna to Keno are low. Although nutrient contents vary between diversion points on some sample dates, the trends are very similar.

The 1999 flow data for each diversion are summarized in Table 2. Nutrient loading was calculated for each period as the product of volume and nutrient concentration. The cumulative TP and TN loading for 1999 are shown in Figures 1 and 2. Using total flow volumes and total nutrient loads, the mean nutrient concentration for each diversion can be calculated. On this basis, TP averaged 0.165, 0.175, and 0.195 ppm for A, North, and ADY diversions, respectively. TN averaged 2.11, 1.72, and 1.95 ppm, respectively. The trend for increasing phosphorus content in downstream diversions may indicate a contribution from point sources below Klamath Lake. These could include discharges from the Klamath Falls municipal waste treatment facilities, storm water drainage from Klamath Falls, and the Lost River Diversion Channel.

Total nutrient loading to the Klamath Irrigation Project from these three diversions in 1999 is estimated at about 2.0 million lb N and 170,000 lb P. Although these quantities seem very high, they represent less than 10 lb/acre N and less than 1 lb/acre P for the total land area within the irrigation project.

Although the three diversions

monitored account for the majority of water supply for the project, there are other sources. The Lost River Diversion Channel allows transfer of water between Lost River and Klamath River. In years when Clear Lake and Gerber Reservoir storage is limited, additional diversion out of Klamath River can be used to augment A Canal supplies. This was not required in 1999. The relative volume of Lost River contributions to Klamath Project supply varies from year to year and is very difficult to quantify because of blending with return flows and Klamath River flows. Minimum Lost River flows enter southern portions of the Klamath Project during the summer irrigation season. In the current period of above normal water supply throughout the watershed, high volumes of Lost River flows were diverted to Klamath River in 1999.

Nutrient content observations at the Fremont Bridge from 1991 to 1998 were used to estimate nutrient loading to the A canal during these years (unpublished data from Dr. Jacob Kann, contract with BOR). Sampling frequency during the April to October diversion period was 12, 19, 18, 18, 11, 14, 12, and 14 samples in 1991-98, respectively. A Canal flow data from the BOR were apportioned to correspond to sampling intervals as described for the 1999 study. Total flow volume and TP and TN loading estimates for the A Canal are shown in Figure 3. A Canal diversions ranged from approximately 220,000 AF in 1993 to a high of 277,000 AF in 1999. TP loading estimates ranged from a low of about 65,000 lb in 1993 and 1994 to a high of approximately 140,000 lb in 1997. TN loading estimates ranged from

approximately 800,000 lb in 1994 to about 1,580,000 lb in 1999. Mean TP content ranged from 0.102 ppm in 1993 to 0.203 ppm in 1997 with a 9-year average of 0.145 ppm. Mean TN content ranged from 1.30 ppm in 1994 to 2.29 ppm in 1995, and averaged 1.92 ppm over 9 years.

The Fremont Bridge nutrient data set provides an opportunity to determine mean seasonal nutrient content over 8 years and to compare this with A Canal data obtained in 1999 (Table 3). The 1999 data agrees well with the 1991-98 data for May, June, and October. Nutrient content for July through September was higher in 1999, but was very similar to data from 1997.

An automated ISCO sampler was installed at A Canal headworks to collect time-series samples on three occasions. The first set of samples was obtained in early July. The initial installation on July 7 ended in a power supply failure after seven samples were collected (Table 4). A complete set of 24 samples at 2-hour intervals was obtained from July 9-11. This period corresponded with a very high algae biomass and high TP and TN content entering the Canal. A distinct diurnal nutrient content pattern was observed. Peak loading occurred at the first sample after sunset on both days. Lowest nutrient levels were observed from mid-morning to early afternoon. It has been suggested that this may be related to a shift in algae position in the water column when photosynthesis ceases after sunset. Highly turbulent flow at the canal-sampling site would thoroughly homogenize any stratified algae column at the lakeside intake.

Time-series samples also were

obtained on July 27-29 and August 31-September 2 (Table 4). Algae content was much less than during early July. TP and TN content did not follow the diurnal pattern observed in early July. The first sample on July 27 and the 2:30 sample on September 1 appear to be aberrant. All other samples in both time-series were similar in nutrient levels.

### **Summary**

The Klamath Irrigation Project is receiving high loading of phosphorus and nitrogen at the major diversion points from Klamath Lake and Klamath River. Data obtained in this study are consistent with data from studies of Klamath Lake water quality, including a major effort conducted over several years by the Klamath Tribe under a contract with the BOR. In the relatively dry summer of 1999, total diversions for A, North, and ADY canals were nearly 370,000 AF and contained an estimated 170,000 lb total phosphorus and 2.0 million lb total nitrogen. No effort was made to differentiate between forms of P and N. The major component is algae biomass. Maximum loading occurred in early July when nutrient contents peaked at about 0.3 ppm TP and 5.0 ppm TN at the A Canal diversion. This is also a period of maximum water diversion for irrigation.

Time-series sampling at A Canal headworks was conducted to determine if time of sampling would influence results. At the early July sampling period, a large diurnal pattern was found, with high nutrient content occurring in the first sample after sunset and low content during late morning and early afternoon. Nutrient contents doubled from low to

high levels both days. Late July and early September samples did not demonstrate diurnal patterns. This indicates that at peak algae blooms, sample time may be important for the A Canal; but, in general, time of sampling probably is not critical.

Data obtained from 1991-98 by Dr. Jacob Kann under a BOR contract was used to estimate A Canal nutrient loading and to compare with 1999 estimates. Maximum TP loading was estimated for 1997 and maximum TN loading for 1999. Minimum loading occurred in the drought year of 1994. Diversion volume was only slightly lower in 1994 than in other years, but nutrient content measured at nine sites in Klamath/Agency Lake was low compared with other years.

To put nutrient loading to the Klamath Irrigation Project in perspective, the nutrient load discharged from the project to the Klamath River at Straits Drain must be known. Total discharge volume at Straits Drain averages about 110,000 AF annually, or about 30 to 40 percent of diversion to the project. Very preliminary estimates from BOR sampling indicate nutrient loading in the Klamath River from project drainage, including drainage from two wildlife refuges, is substantially below the project loading estimates outlined in this report.

Monitoring of nutrient loading at the three diversions will resume in 2000. All data will be provided for consideration by the DEQ in establishment of TMDL allocations for Lost River and the Straits Drain.

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**Table 1.** Nutrient concentration of unfiltered samples collected at A, North, and ADY diversion canals during 1999 and analyzed for total phosphorus (TP) and total nitrogen (TN) to determine nutrient loading in the Klamath Irrigation Project, Klamath Falls, OR.

Sample date	A Canal		North Canal		ADY Canal	
	TP	TN	TP	TN	TP	TN
	ppm					
5/13	0.05	0.50	0.10	0.70	0.11	0.70
	0.05	0.60	0.10	0.60	0.18	1.10
5/25	0.07	0.50	0.13	0.70	0.11	0.70
	0.06	0.60	0.12	0.70	0.11	0.70
6/9	0.07	0.60	0.15	0.90	0.10	0.60
6/21	0.11	1.30	0.11	1.20	0.15	1.60
	0.09	1.20	0.10	0.90	0.14	1.50
7/1	0.14	2.30	0.16	2.60	0.18	2.40
7/9	0.27	4.60	0.18	2.30	0.30	4.20
7/27	0.34	3.20	0.15	1.70	0.14	1.90
8/6	0.21	2.00	0.19	1.90	0.20	1.70
			0.18	2.00	0.19	1.40
8/19	0.34	3.80	0.29	1.80	0.15	1.20
	0.27	3.70	0.29	1.80	0.15	1.10
8/31	0.20	1.90	0.32	3.30	0.29	2.80
	0.22	1.90	0.30	3.30	0.26	2.90
9/13	0.21	2.40	0.26	2.90	0.66	7.70
	0.25	2.80	0.21	2.80	0.47	4.90
9/23	0.24	3.00	0.26	2.10	0.22	2.00
	0.25	3.00	0.26	2.00	0.23	2.20
10/4	0.17	1.80	0.15	1.70	0.15	1.90
	0.13	3.80	0.13	1.60	0.16	2.00

## *Research in the Klamath Basin*

**Table 2.** Volume of diversion to the Klamath Irrigation Project at A Canal, North Canal, and ADY Canal corresponding to nutrient sampling dates in 1999.

Period	Diversion volume <sup>1</sup>		
	A Canal	North Canal	ADY Canal
————— 1,000 AF —————			
4/1 - 5/19	38.7	2.9	9.1
5/20 - 6/1	23.2	2.0	2.6
6/2 - 6/15	24.0	2.8	4.9
6/16 - 6/26	20.0	2.4	4.2
6/27 - 7/5	15.2	1.9	3.6
7/6 - 7/15	27.8	2.3	3.5
7/16 - 8/1	22.4	3.6	5.8
8/2 - 8/13	18.4	1.9	4.3
8/14 - 8/25	19.1	2.3	3.7
8/26 - 9/7	20.1	2.1	4.2
9/8 - 9/18	16.5	1.6	2.8
9/19 - 9/28	14.1	1.2	2.7
9/29 - 10/31	17.5	3.3	10.0
<b>Total</b>	<b>277.0</b>	<b>30.3</b>	<b>61.4</b>

<sup>1</sup>Data from Bureau of Reclamation, Klamath Project.

**Table 3.** Mean monthly concentration of total phosphorus (TP) and total nitrogen (TN) in Klamath Lake at Fremont Bridge for 1991-98 and in A Canal in 1999.

Month	Fremont Bridge <sup>1</sup>		A Canal <sup>2</sup>			
	Number of samples	Concentration		Number of samples <sup>3</sup>	Concentration	
		TP	TN		TP	TN
		—— ppm ——			—— ppm ——	
January	13	0.08	1.50			
February	16	0.07	1.25			
March	19	0.06	0.84			
April	21	0.06	0.81			
May	16	0.06	0.66	4	0.06	0.55
June	16	0.11	1.57	3	0.09	1.03
July	17	0.20	2.79	58	0.24	3.60
August	19	0.18	2.22	5	0.25	2.66
September	16	0.18	2.05	28	0.24	2.56
October	21	0.16	2.14	2	0.15	2.80
November	13	0.10	1.78			
December	6	0.07	1.75			

<sup>1</sup> Unpublished data from Dr. Jacob Kann, BOR contract.

<sup>2</sup> KES data from A Canal headworks.

<sup>3</sup> All samples from ISCO samples are included in July and September means.

**Table 4.** Content of total phosphorus (TP) and total nitrogen (TN) in time-series samples obtained at A Canal headworks in 1999.

Date	Time	Content		Date	Time	Content		Date	Time	Content		
		TP	TN			TP	TN			TP	TN	
		ppm				ppm				ppm		
7/7	10:30	0.27	4.90									
	12:30	0.23	4.40									
	14:30	0.26	4.80									
	16:30	0.24	4.70									
	18:30	0.23	4.30									
	20:30	0.27	4.80									
	22:30	0.32	5.60									
7/9	14:30	0.20	3.40									
	16:30	0.27	4.60	7/27	16:30	0.34	3.20	8/31	16:30	0.22	2.30	
	18:30	0.27	4.70		18:30	0.18	1.60		18:30	0.24	2.30	
	20:30	0.24	4.60		20:30	0.19	1.80		20:30	0.25	2.60	
	22:30	0.48	9.20		22:30	0.16	1.60		22:30	0.23	2.40	
7/10	0:30	0.42	7.70	7/28	0:30	0.17	1.40	9/1	0:30	0.23	2.30	
	2:30	0.36	6.40		2:30	0.20	1.60		2:30	0.36	4.70	
	4:30	0.33	5.70		4:30	0.16	1.40		4:30	0.24	2.40	
	6:30	0.25	4.30		6:30	0.15	1.50		6:30	0.27	2.80	
	8:30	0.21	3.60		8:30	0.18	1.60		8:30	0.26	2.80	
	10:30	0.23	3.80		10:30	0.17	1.50		10:30	0.26	2.20	
	12:30	0.22	3.70		12:30	0.18	1.70		12:30	0.23	2.50	
	14:30	0.23	4.30		14:30	0.14	1.60		14:30	0.26	2.70	
	16:30	0.26	4.80		16:30	0.19	2.00		16:30	0.24	2.50	
	18:30	0.30	5.30		18:30	0.22	2.10		18:30	0.22	2.60	
	20:30	0.37	6.60		20:30	0.20	1.80		20:30	0.24	2.30	
	22:30	0.44	7.80		22:30	0.18	1.70		22:30	0.20	2.20	
	7/11	0:30	0.38	6.40	7/29	0:30	0.17	1.60	9/2	0:30	0.28	2.50
		2:30	0.33	5.80		2:30	0.16	1.40		2:30	0.23	2.30
4:30		0.25	4.50		4:30	0.19	1.40		4:30	0.23	2.50	
6:30		0.28	4.80		6:30	0.16	1.30		6:30	0.20	2.40	
8:30		0.25	4.30		8:30	0.17	1.40		8:30	0.28	2.50	
10:30		0.26	4.50		10:30	0.18	1.60		10:30	0.20	2.10	
12:30		0.23	3.90		12:30	0.16	1.60		12:30	0.20	2.20	
					14:30	0.19	1.90		14:30	0.21	2.40	
Mean		0.29	5.10			0.18	1.68			0.24	2.50	

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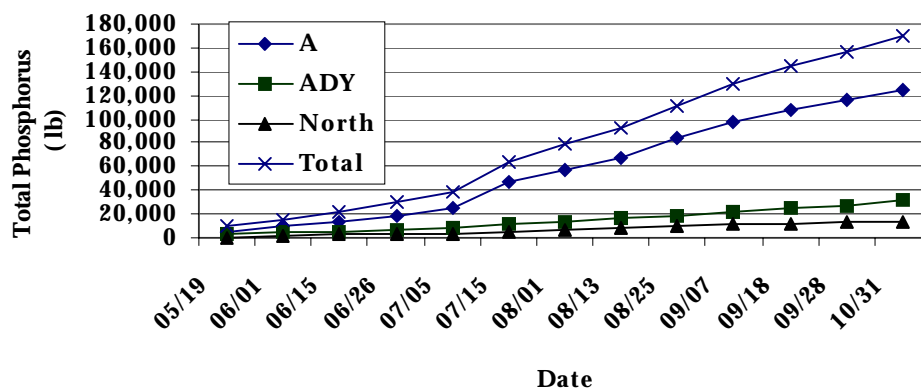


Figure 1. Total phosphorus loading in the Klamath Irrigation Project from the A, North, and ADY Canals in 1999.

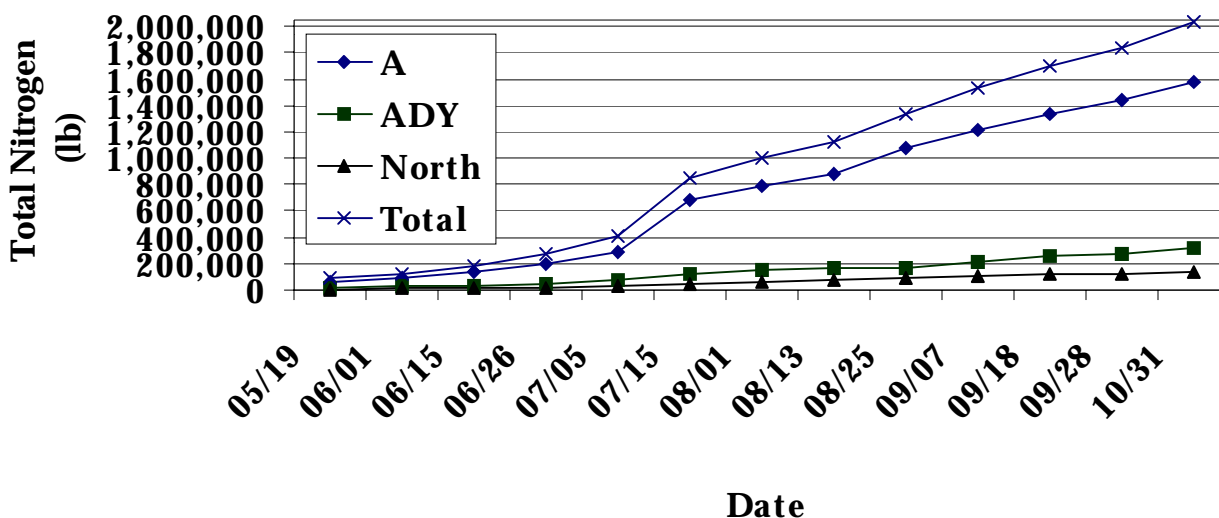
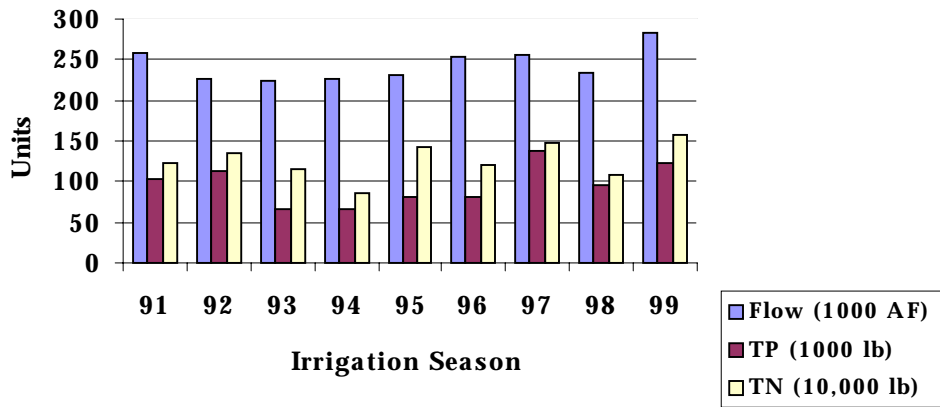


Figure 2. Total nitrogen loading in the Klamath Irrigation Project from the A, North, and ADY Canals in 1999.



**Figure 3.** Diversion volume and total phosphorus (TP) and total nitrogen (TN) loading to the Klamath Irrigation Project from the A Canal for 1991-1999. Nutrient content for 1991-1998 based on unpublished data from Dr. Jacob Kahn and BOR.