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# Nutrient Loading of Surface Waters in the Upper Klamath Basin: Agricultural and Natural Sources



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# Nutrient Loading of Surface Waters in the Upper Klamath Basin: Agricultural and Natural Sources

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NUTRIENT LOADING OF SURFACE WATERS  
IN THE UPPER KLAMATH BASIN:  
AGRICULTURAL AND NATURAL SOURCES

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K.A. Rykbost and B.A. Charlton<sup>1</sup>

**A**bstract

Implementation of the Federal Clean Water Act and Oregon Senate Bill 1010 is proceeding under two simultaneous processes in Oregon. The Oregon Department of Environmental Quality is responsible for developing Total Maximum Daily Load (TMDL) allocations for water-quality limited water bodies. The Oregon Department of Agriculture is striving to develop Management Area Plans to provide guidance for management of private agricultural lands to meet Clean Water Act objectives. Both processes seek input from local advisory committees comprised of landowners and other stakeholders, and technical review committees.

Klamath Lake and Klamath River have been designated water quality impaired for several parameters including nutrients. Researchers have attempted to determine the extent of agriculture's contributions to nutrient enrichment of surface waters in the Upper Klamath Basin. Two United States Geological Survey (USGS) studies focused attention on drainage of agricultural lands adjacent to Klamath Lake as a significant source of nutrient loading in the lake.

A preliminary draft report by the Klamath River TMDL committee identified the outlet for drainage waters from the Klamath Irrigation Project to the Klamath River at the Straits Drain as a point source for nutrient loading. Preparation of a final TMDL for this sub-watershed was tabled pending

development of a TMDL for Klamath Lake and its tributaries. Insufficient data are available to determine the relative contributions of agricultural activities, natural background sources, and other potential sources of nutrient enrichment to establish numerical limits for nutrient loading from agricultural lands.

From 1998 through 2000, the Klamath Experiment Station has investigated nutrient loading from drainage of agricultural lands adjacent to Klamath Lake, natural background sources including major springs and several artesian wells, and loading to the Klamath Irrigation Project from diversions out of Klamath Lake and Klamath River. Findings indicate contributions from agricultural lands adjacent to Klamath Lake have been overestimated, and the Klamath Irrigation Project is probably a net sink for nutrients diverted out of Klamath Lake and Klamath River. Data to support these assertions are presented.

### Introduction

Most of the surface waters in the Klamath Basin are included in the Oregon Department of Environmental Quality (DEQ) 303D list as water-quality limited. While the only criterion for listing of many streams is temperature, based on a preliminary standard of 64<sup>0</sup>F, Klamath Lake and Klamath River are listed for chlorophyll a, dissolved oxygen, un-ionized ammonia, and pH. The DEQ is working toward development of TMDL allocations for Klamath River and

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Klamath Headwater regions. During the Klamath River TMDL planning process, discharge from the Klamath Irrigation Project (KIP) at the Straits Drain was identified as a source of contaminants requiring assignment of TMDLs. Agricultural activities within KIP are widely thought to be a major source of nutrient loading to discharge waters. However, multiple water sources and diversion pathways, the influence of two wildlife refuges within KIP, and other inputs complicate assessment of this complex system.

Klamath and Agency lakes (referred to as Klamath Lake), the main source of water supply for KIP, is in advanced stages of eutrophication. The 80,000-acre lake has an average depth of only 8 feet. High phosphorus (P) content in the lake supports massive blue-green algae (*Aphanizomenon flos-aquae*) blooms in summer months. The die-off of algae blooms creates conditions toxic to resident fish, including pH near 10.0, dissolved oxygen levels less than 2.0 mg/l, and un-ionized ammonia concentrations near 1.0 ppm. Fish kills associated with poor water quality in 1995, 1996, and 1997 depleted stocks of shortnose suckers (*Chasmistes brevirostris*) and Lost River suckers (*Deltistes luxatus*), listed as endangered under the Endangered Species Act. Conditions favorable for algae blooms existed before the region was settled; early explorers documented foul water conditions in Klamath Lake in the 1840s.

Nutrient loads in Klamath Lake and its tributaries have been monitored and documented (Campbell and Ehinger, 1993, Campbell et al, 1993, Kann and Walker, 1999, Miller and Tash, 1967, Sartoris and Sisneros, 1993, and Snyder and Morace, 1997). USGS studies of

drainage from agricultural lands adjacent to Klamath Lake implicated these lands as major sources of P loading (Miller and Tash, 1967 and Snyder and Morace, 1997). Findings from these and other studies have been used to support acquisition of private lands adjacent to the lake and conversion to wetlands. Three major parcels totaling over 15,000 acres have been purchased to date with public funds. About one-half of the property is intended for additional water storage and the remainder for conversion to wetlands, which are projected to serve as filters to remove nutrients in drainage waters from upland agricultural lands and provide refugial habitat for juvenile suckers.

Studies by the USGS of drainage waters from agricultural lands failed to consider nutrient loading in water diverted onto these properties. Over 7,000 acres adjacent to southern portions of Klamath Lake are irrigated with water diverted from Klamath Lake in late fall and early winter. A long-term study of water quality in Klamath Lake identified high nutrient content in Howard Bay, the source of irrigation water for over 6,000 acres of these agricultural lands (Kann and Walker, 1999). Nutrient loading to KIP from the major diversions out of Klamath Lake and Klamath River was not documented prior to 1999. The Klamath Experiment Station (KES) initiated a water-quality monitoring study in 1998 to further define nutrient loading from natural and agricultural sources.

### **Objectives**

1. Determine total phosphorus (TP) and total Kjeldahl nitrogen (TKN) concentration in natural background sources including major springs and artesian wells;

2. Determine nutrient content of irrigation water applied to and drainage water from agricultural properties adjacent to Klamath Lake;
3. Determine nutrient loading to the Klamath Irrigation Project at A Canal, North Canal, and ADY Canal diversions.

**Methods**

Most water samples were collected as grab samples, refrigerated immediately, and delivered to the Oregon State University Department of Crop and Soil Science Central Analytical Laboratory within 24 hours, or frozen for batch delivery at a later date. Duplicate samples were frequently taken for quality control purposes. On three occasions in 1999, 24-sample sets were collected with an ISCO automatic sampler at the A Canal headworks over 48-hour periods. Frozen samples were kept frozen until analyzed. All samples were analyzed for unfiltered TP and TKN using Kjeldahl digestion procedures and appropriate control samples.

Sampling sites included several springs that are the source of tributaries to Klamath Lake. These include the headwaters of Spring Creek, Wood River, Crystal Creek, and Fort Creek. Artesian wells sampled are reported to represent at least three different aquifers in the Fort Klamath Valley. Diked and drained agricultural land adjacent to Klamath Lake was monitored over 2

years to determine nutrient concentrations in water applied onto these properties and drainage from them into Klamath Lake. During 1999 and 2000, the diversions from Klamath Lake and Klamath River at headworks for the A, North, and ADY canals were sampled on an approximate 10- to 14-day schedule from May through October. Nutrient loading to KIP was calculated using flow data at the diversions reported by the Bureau of Reclamation's (BOR) Klamath Project Office.

**Results**

Most of the samples collected were analyzed for TP and TKN. However, P is the limiting nutrient for blue-green algae and phosphorus drives the algae bloom cycle. Subsequent die-off of algae blooms contributes to water quality problems related to pH, dissolved oxygen, and un-ionized ammonia. Blue-green algae fix nitrogen; during summer months, Klamath Lake is a nitrogen factory with algae driving the process. Phosphorus concentrations of 0.02 to 0.09 ppm are considered adequate to support blue-green algae present in the lake (Chu, 1943).

Springs are the source for several tributaries feeding Klamath Lake. Spring Creek contributes much of the flow in the Williamson River in late summer. Wood River, and Fort Creek are important sources of inflow. Each of the springs feeding these streams was found to have TP concentrations at levels not limiting to blue-green algae (Table 1).

**KLAMATH BASIN NUTRIENT LOADING**

Table 1. Nutrient concentrations in artesian wells and springs in the Upper Klamath Basin, OR.

Springs	Sample date	Total phosphorus	Total Kjeldahl nitrogen	Wells	Sample date	Total phosphorus	Total Kjeldahl nitrogen
		--- ppm ---				--- ppm ---	
Annie Creek Spring	09/03/99	0.03	< 0.2	Sevenmile	08/18/98	0.09	--
	09/03/99	0.04	< 0.2		09/30/98	0.10	0.2
Crystal Creek Spring	08/11/98	0.11	--	A. McAuliffe Ranch	08/18/98	0.09	--
	07/28/99	0.07	< 0.2		09/30/98	0.11	0.1
Mares Egg Spring	09/30/98	0.07	0.2	Fort Klamath Telephone Company	09/30/98	0.31	0.3
					09/03/99	0.31	< 0.2
Blue Spring	09/30/98	0.06	0.1	Horseshoe Resort	09/30/98	0.69	0.5
					09/03/99	0.71	0.5
Kimball Park Spring (Wood River Source)	09/30/98	0.07	0.1	Church House	09/30/98	0.75	0.5
	09/03/99	0.06	< 0.2		09/03/99	0.73	0.6
Fort Creek Spring	09/30/99	0.09	0.1	Porter Residence	08/18/98	0.79	--
	09/03/99	0.06	< 0.2		09/30/98	0.75	0.5
					09/03/99	0.76	0.5
Spring Creek Spring	09/30/98	0.08	0.1	W. McAuliffe Residence	08/18/98	1.20	--
	09/03/99	0.09	< 0.2		09/30/98	1.13	1.3
	09/03/99	0.09	< 0.2				
Barkley Spring	11/04/98	0.08	< 0.2	McNeary Residence	09/30/98	1.56	1.9
Malone Spring	07/28/99	0.06	0.4	Wood River Ranch Northwest	11/04/98	2.58	9.1
					12/30/98	1.86	8.7
Odessa Spring	09/30/98	0.04	0.19		04/06/99	2.77	6.0
					03/15/00	2.28	8.5
Harriman Spring	09/30/98	0.04	0.20	Wood River Ranch Corral	11/04/98	5.87	5.8
Threemile Creek Spring	09/30/98	0.02	0.19		12/30/98	6.10	5.8
					04/06/99	5.90	7.3
					03/15/00	3.23	5.7

Over 1,500 artesian wells reportedly have been developed in the Fort Klamath Valley. Over 800 of these are still in use or are not capped (L. Porter, personal communication). Local residents suggested that at least three aquifers are represented by the wells sampled in this study. The Sevenmile and A. McAuliffe wells are reportedly from a 460-foot deep aquifer located in the western side of the valley (Table 1). Six wells sampled were located within 5 miles of Fort Klamath in the center of the valley. Well drilling data indicates these are all from a 230-foot deep aquifer. Two wells on the Wood River Ranch property are of unknown depth. The very high nutrient contents in these and a third well on the property sampled in a previous study (Snyder and Morace, 1997) suggest a different aquifer may be involved. The water volume discharged by artesian wells is minimal and nutrient loading from this source is probably not significant in the overall picture. However, springs adjacent to and within the lake are estimated to be the source of about 17 percent of the inflow to Klamath Lake and 25 percent of P loading (Miller and Tash, 1967).

Snyder and Morace (1997) monitored drainage discharge from several properties in 1993-95, including Running Y Ranch properties (Wocus Marsh and East Caledonia Marsh) near Howard Bay and the Wood River Ranch property at the north end of Agency Lake. The KES study sampled Running

Y Ranch drains as well as the inflow to the properties during 1998 through 2000. The West Caledonia Marsh property was also sampled by KES in 1999 and 2000. Wood River Ranch drains and inlets were sampled by KES in 1999 and 2000. Nutrient concentration data from these studies are presented in Table 2.

The KIP provides water to about 220,000 acres, including Tulelake and Lower Klamath national wildlife refuges. Major points of diversion to the project include the A Canal at the south end of Klamath Lake and the North and ADY canals that divert water out of the Klamath River about 8 and 10 miles downstream from Klamath Lake, respectively. During 1999 and 2000, the KES study monitored these diversions on about 2-week intervals from May through October. Mean TP and TKN values for each sample date are shown in Table 3. On most dates, means are for duplicate samples. Means for July 9, July 27, and August 31, 1999 include 24 samples from an ISCO automated sampler and grab samples taken at the beginning of the sampling period. Using flow volumes provided by the BOR, nutrient loading was calculated for each diversion for time-periods midway between sampling dates. Total nutrient loading to the KIP from Klamath Lake and Klamath River diversions is estimated at approximately 170,000 lb P and 2 million lb N in 1999 and 180,000 lb P and 2 million lb N in 2000 (Figures 1-4).



**KLAMATH BASIN NUTRIENT LOADING**

Table 2. Concentration of total phosphorus (TP) and total Kjeldahl nitrogen (TKN) in inflow and drainage water of Wocus Marsh, East Caledonia Marsh, West Caledonia Marsh, and Wood River Ranch in the Klamath Basin as measured by Snyder and Morace (1993-1995) and Klamath Experiment Station (1998-2000).

Site	Study	No. sample dates	No. samples	Inflow		Drainage	
				TP	TKN	TP	TKN
----- ppm -----							
Wocus Marsh							
	1993-1995	9	9	--	--	0.21	4.2
	1998-2000	19	29	0.13	2.8	--	--
	1998-2000	24	41	--	--	0.18	3.8
East Caledonia Marsh							
	1993-1995	3	3	--	--	0.24	4.2
	1998-2000	10	16	0.06	1.1	--	--
	1998-2000	16	27	--	--	0.24	3.7
West Caledonia Marsh							
	1998-2000	5	9	0.06	1.3	--	--
	1998-2000	9	18	--	--	0.17	2.6
Wood River Ranch – Sevenmile Canal							
	1993-1995	6	6	--	--	0.93	3.3
	1999-2000	11	22	--	--	0.49	3.0
Wood River Ranch – Wood River							
	1993-1995	6	6	--	--	0.98	2.7
	1999-2000	5	10	--	--	0.86	3.5
Wood River Ranch – Inflow 1999-2000							
	Fall	11	22	0.12	0.7	--	--
	Spring	15	30	0.21	1.8	--	--

Table 3. Nutrient concentrations of unfiltered samples collected at A, North, and ADY diversion canals during 1999 and 2000 and analyzed for total phosphorus (TP) and total Kjeldahl nitrogen (TKN), Klamath Falls, OR.

Sample date	A Canal		North Canal		ADY Canal	
	TP	TKN	TP	TKN	TP	TKN
-----ppm-----						
<u>1999</u>						
05/13	0.050	0.55	0.100	0.65	0.145	0.90
05/25	0.065	0.55	0.125	0.70	0.110	0.70
06/09	0.070	0.60	0.150	0.90	0.100	0.60
06/21	0.100	1.25	0.105	1.05	0.145	1.55
07/01	0.140	2.30	0.160	2.60	0.180	2.40
07/09	0.270	4.60	0.180	2.30	0.300	4.20
07/27	0.340	3.20	0.150	1.70	0.140	1.90
08/06	0.210	2.00	0.185	1.95	0.195	1.55
08/19	0.305	3.75	0.290	1.80	0.150	1.15
08/31	0.210	1.90	0.310	3.30	0.275	2.85
09/13	0.230	2.60	0.235	2.85	0.565	6.30
09/23	0.245	3.00	0.260	2.05	0.225	2.10
10/04	0.150	2.80	0.140	1.65	0.155	1.95
Mean	0.183	2.24	0.184	1.81	0.207	2.17
<u>2000</u>						
05/01	0.050	0.50	0.100	0.65	0.100	0.70
05/16	0.070	0.65	0.165	0.85	0.095	0.65
06/02	0.105	1.30	0.150	1.20	0.135	1.05
06/21	0.175	2.90	0.210	1.55	0.255	3.05
06/28	0.180	2.75	0.225	1.85	0.260	2.25
07/07	0.335	4.00	0.265	2.30	0.340	2.05
07/19	0.225	2.70	0.275	2.45	0.250	2.25
07/27	0.270	2.75	0.325	3.05	0.345	2.70
08/07	0.250	2.90	0.345	3.60	0.325	3.55
08/17	0.185	2.00	0.210	2.70	0.245	2.90
09/03	0.195	2.35	0.225	2.05	0.225	2.65
09/08	0.250	2.85	0.240	1.50	0.285	1.80
09/15	0.370	3.80	0.330	1.90	0.350	2.15
09/26	0.225	2.60	0.275	1.35	0.295	1.55
10/12	0.190	2.25	0.190	2.10	0.165	1.80
Mean	0.205	2.42	0.235	1.94	0.245	2.07

# KLAMATH BASIN NUTRIENT LOADING

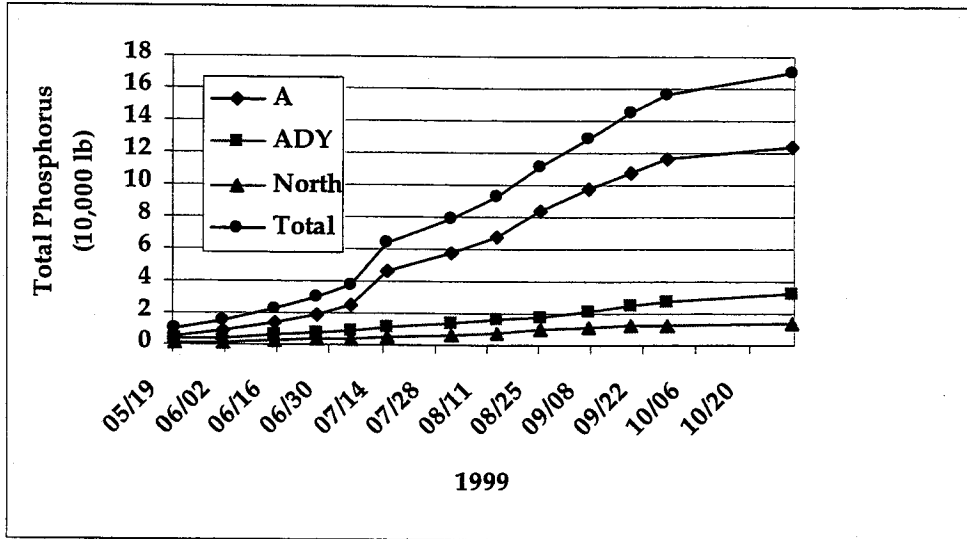


Figure 1. Total phosphorus loading in the Klamath Irrigation Project from the A, North, and ADY canals in 1999.

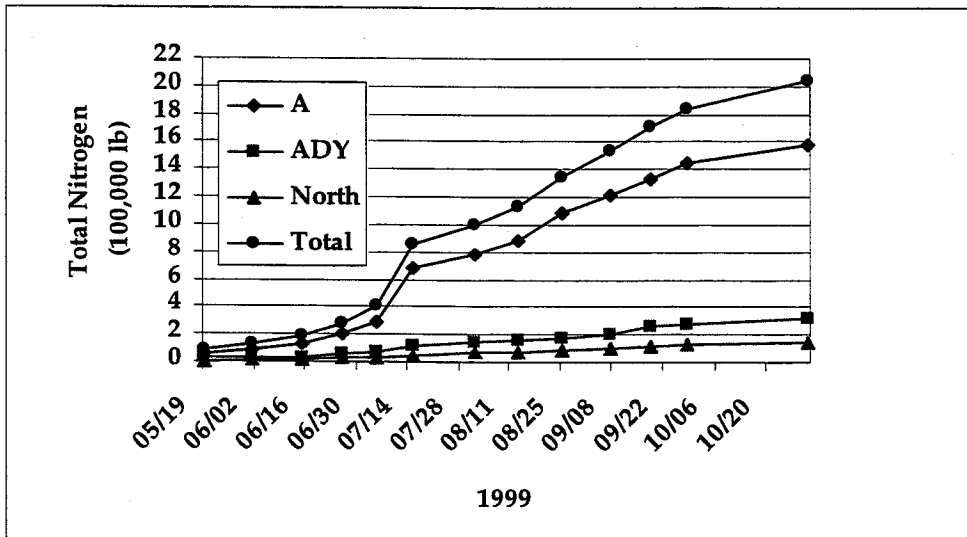


Figure 2. Total Kjeldahl nitrogen loading in the Klamath Irrigation Project from the A, North, and ADY canals in 1999.

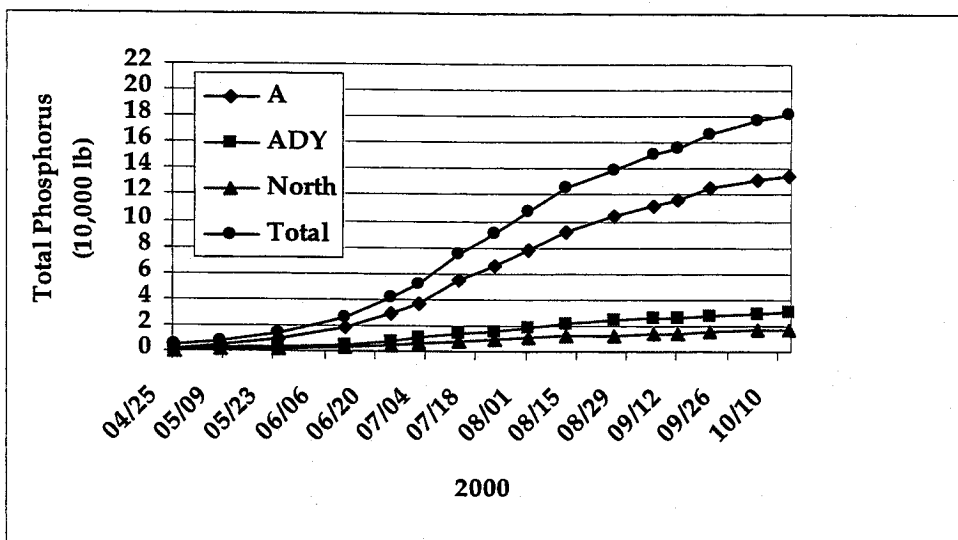


Figure 3. Total phosphorus loading in the Klamath Irrigation Project from the A, North, and ADY canals in 2000.

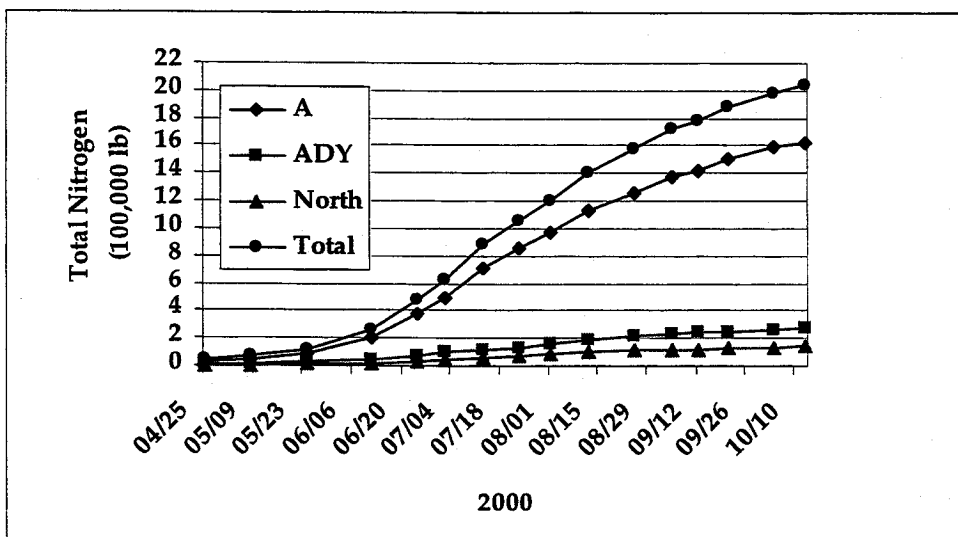


Figure 4. Total Kjeldahl nitrogen loading in the Klamath Irrigation Project from the A, North, and ADY canals in 2000.

## **Discussion**

Natural sources of P in springs feeding tributaries and in artesian wells are sufficient to support blue-green algae blooms. Miller and Tash (1967) suggested nutrients contained in the top inch of lake sediments would sustain algae production if all external loading were eliminated for decades. Kann and Walker (1999) estimated internal loading from lake sediments account for 61 percent of P loading. The eutrophic condition of Klamath Lake prior to the arrival of settlers attests to the effects of natural nutrient sources, absent anthropogenic contributions.

Nutrient loading in Klamath Lake is unquestionably enhanced by the drainage of irrigation water from agricultural properties adjacent to the lake. Prior to reclamation, all of these properties were either permanent or seasonal wetlands. Following construction of dikes and drainage systems, the properties were managed for pastures and/or crop production. Soils are high in organic matter content and native fertility; therefore pastures and hay crops on these lands are generally not fertilized. Natural processes associated with mineralization of these soils release nutrients subject to transport in drainage water.

Drainage water from agricultural land adjacent to Klamath Lake was estimated to account for 26.5 percent of external P loading and 20 percent of N loading by Miller and Tash (1967). Estimates did not account for nutrient loading to these properties from water applied to the properties. Several properties at the southern end of Klamath Lake are irrigated with water diverted from Klamath Lake in late fall and early winter. After allowing for

infiltration and recharging of the soil profile, water is pumped off in the spring to prepare fields for planting. KES data indicate water diverted onto Wocus Marsh in 1998 and 1999 had TP and TKN concentrations 72 and 74 percent as high as concentrations in drainage water, respectively. The intake and discharge points for this property are about 500 feet apart, resulting in recirculation of much of the water diverted onto the property. Nutrient concentrations in discharge water were similar in KES and USGS studies (Table 2). Mass loading cannot be calculated, as there is no means to measure the inflow volume of irrigation water diverted from Klamath Lake. However, the purpose for irrigating is to recharge the soil profile, and inflow volume undoubtedly exceeds drainage discharge.

Nutrient concentrations in inflowing Caledonia Marsh irrigation water were less than in Wocus Marsh (Table 2). Inflowing TP concentrations were 25 and 35 percent of concentrations in drainage from east and west sections, respectively, while TKN concentrations were 30 and 50 percent, respectively. Intake and discharge points are far apart for both sections with virtually no opportunity for recirculation of drainage water.

The Wocus and Caledonia Marsh properties are actively used for agriculture. Wocus Marsh is predominantly pasture with less than 25 percent used for grain and row crop production. Caledonia Marsh is primarily used for spring grain production, with less than 20 percent used for row crops, including onions and potatoes. These properties were drained and developed for agricultural production in the 1890s (Wocus) and

1910s (Caledonia) (Snyder and Morace, 1997). The situation at the Wood River Ranch is quite different. This property was drained and developed between 1940 and 1957, was used exclusively as pasture for cattle production until 1995, and since 1996 is undergoing restoration to seasonal wetlands.

The Wood River Ranch property receives diversion water from the Sevenmile Canal and tail water from irrigated upstream properties at the north boundary, and discharges drainage at the mouths of the Wood River and Sevenmile Canal. Snyder and Morace (1997) determined high P content in drainage water from both discharge points on this property (Table 2). Cattle were removed from the property following transfer of ownership to Federal agencies in 1995. KES data from discharge sampling 4 and 5 years later indicate high P loading continued after cattle were removed from the property. TP concentrations in drainage water were 53 and 88 percent of values observed by Snyder and Morace (1997) for Sevenmile and Wood River pumping station, respectively (Table 2). TP concentrations in water diverted onto this property for wetlands varied depending on the time of diversion. Water diverted in April and May in 1999 and 2000 averaged 0.21 ppm TP, while water diverted in September and October averaged 0.12 ppm TP (Table 2). All drainage samples were obtained in March and April. Interestingly, water diverted onto the Wood River Ranch is at least partially drainage water from pastures upstream from this property. While the long-term objective of converting the Wood River Ranch to wetlands is to provide scrubbing or filtering of nutrients, evidence to date indicates significant enhancement of

nutrient content in water passing through this property.

An extensive data set developed from 1991 to 1998 by Kann and Walker (1999) documents lake-wide mean nutrient concentrations in Klamath Lake at up to nine continuously monitored sites on approximately 2-week intervals through spring, summer, and fall months (Table 4). Less frequent monitoring was conducted through the winter. TP concentrations cited vary from lows of 0.04 or 0.05 ppm in winter months to 0.30 ppm or more in the summer. Kann and Walker (1999) are also presented data for the Fremont Bridge site (not shown here), which is within 1,000 feet of the intake for the A Canal diversion at the south end of Klamath Lake. Concentrations at this site ranged from 0.03 to 0.49 ppm TP and from 0.17 to 5.87 ppm total nitrogen (TN). The nutrient concentration in A Canal diversions out of Klamath Lake can be expected to be about the same as values observed at Fremont Bridge for May through October.

In 1999, A Canal samples ranged from 0.05 ppm TP in May to 0.34 ppm TP in late July. TKN concentrations ranged from 0.5 ppm in May to a high of 4.6 ppm in early July. In 2000, ranges were from 0.04 to 0.38 ppm TP and 0.5 to 4.3 ppm TKN. Using flow data from the BOR, total nutrient loading to the A Canal in 1999 was estimated at about 124,000 lb P and 1,578,000 lb N in the total water diversion for the season of 277,000 acre-feet (Figures 1 and 2). This represents a season-long mean concentration of 0.166 ppm TP and 2.11 ppm TKN. Slightly higher loading was estimated for 2000 (Figures 3 and 4), with mean nutrient concentrations of 0.184 ppm TP and 2.23 ppm TKN. Total 2000 loading was 134,700 lb P and

## KLAMATH BASIN NUTRIENT LOADING

Table 4. Lake-wide mean concentrations of total phosphorus (TP), total nitrogen (TN), and ammonia nitrogen, (NH<sub>4</sub>-N) by month for Upper Klamath/Agency Lake, 1991-1998.<sup>1</sup>

Month	No. samples	Total phosphorus (TP)	Total nitrogen (TN)	Ammonia nitrogen (NH <sub>4</sub> -N)
		----- ppm -----		
January	6	0.09	1.42	0.48
February	22	0.07	0.95	0.08
March	40	0.05	0.60	0.08
April	84	0.06	0.72	0.04
May	105	0.06	0.67	0.05
June	142	0.12	1.67	0.14
July	149	0.22	2.25	0.35
August	146	0.19	2.03	0.21
September	127	0.19	1.88	0.27
October	118	0.14	1.73	0.23
November	34	0.09	1.21	0.26
December	1	0.09	2.42	0.84

<sup>1</sup>Data from Appendix I, Kann and Walker, 1999.

1,626,000 lb TKN in a total water diversion of 271,000 acre-feet.

Several opportunities for changes in nutrient status occur between the outlet from Klamath Lake and Klamath River diversions to North and ADY canals. These include storm drain discharges, discharge from a water treatment plant, influence of a lumber mill with log decks in the river, decomposition of submerged wood debris, and effects from marshes and waterfowl habitat along the river. The 1999 diversion into the North Canal totaled about 30,000 acre-feet with nutrient loading estimated at 14,000 lb TP and 140,000 lb TKN. Mean nutrient concentrations were 0.175 ppm TP and 1.72 ppm TKN.

The ADY Canal diversion totaled about 61,000 acre-feet. Nutrient loading was estimated at 32,000 lb TP and 322,000 lb TKN, with mean concentrations of 0.195 ppm TP and 1.95 ppm TKN. There appeared to be a slight increase in P content below the outlet to Klamath Lake while N concentration was higher in the A Canal than in either diversion from Klamath River.

Results of the 2000 monitoring for KIP diversions were similar to 1999 findings (Figures 3 and 4). Mean nutrient concentrations were 0.222 ppm TP and 1.82 ppm TKN for the North Canal and 0.220 ppm TP and 1.93 ppm TKN for the ADY Canal. High nutrient peaks occurred in early July in both years.

Personnel from the University of California, Davis have monitored numerous sites in the California portion of the KIP, as well as the discharge to the Klamath River at the Straits Drain. Estimates from this study indicate an annual P discharge at the Straits Drain of approximately 100,000 lb P (S. Kaffka,

personal communication). With no consideration for loading from the Lost River, municipal sources, or two National Wildlife Refuges within the KIP, the P discharge appears to represent approximately 60 percent of P diverted to the KIP from Klamath Lake and Klamath River.

### **Conclusions**

In all cases where comparisons were possible, nutrient concentrations observed in water samples collected during the KES study are in general agreement with data reported in previous studies. This is true for samples from springs with relatively low nutrient concentrations, and for artesian wells that had high P concentrations. No evidence suggests errors in sample analyses or indicates major changes in nutrient status of water sources over the years covered by various studies.

Natural background sources feeding tributaries to Klamath Lake are enriched with P at their source. While drainage water from agricultural properties adjacent to Klamath Lake do contribute nutrients to the lake, some of these properties are irrigated with Klamath Lake water that is high in nutrients at the point of diversion. Previous studies that have not accounted for this have overestimated contributions from drainage of agricultural lands to nutrient loading of the lake.

Approximately 75 percent of water supplied to the KIP is diverted from Klamath Lake or Klamath River via the A Canal, North Canal, or ADY Canal. Estimates from sampling of these diversions in 1999 and 2000 indicate nutrient loading to KIP of approximately 180,000 lb P and 2 million lb N annually. Preliminary data from a University of California, Davis study



estimates nutrient loading to the Klamath River from the outlet for the KIP at the Straits Drain of approximately 100,000 lb P. With no consideration for loading from other sources, the KIP appears to provide a net sink for nutrients diverted out of Klamath Lake. The nutrient contributions from two national wildlife refuges and two municipalities located within KIP are not well documented. However, drainage water from the majority of agricultural lands within KIP passes through and is retained in the refuges for extended periods during summer months. Some enrichment from natural processes and resident waterfowl in the refuges is likely.

Comparing P concentrations between the A Canal and diversions out of the Klamath River at North and ADY canals indicates some P enrichment occurs within the Klamath River above the Straits Drain. No attempt has been made in this study to determine the source of this loading.

In assigning TMDL allocations for the Straits Drain, it is imperative that nutrients discharged to the Klamath River at this point are not considered wholly or in large part an agricultural contribution. High nutrient inputs to the KIP from Klamath Lake and Klamath River must be recognized as background sources beyond the control of agricultural interests.

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