An Assessment of the Effects of Agriculture on Water Quality in the Tulelake Region of California

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AN ASSESSMENT OF THE EFFECTS OF AGRICULTURE ON WATER QUALITY IN THE TULELAKE REGION OF CALIFORNIA

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UNIVERSITY OF CALIFORNIA - U.S. DEPARTMENT OF AGRICULTURE - MODOC & SISKIYOU COUNTIES COOPERATING

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Preface

This assessment of agriculture's effects on water quality in the Tulelake Irrigation District was initiated at the request of members of the Tulelake Growers' Committee, a group of farmers operating in the district. It is part of a larger, innovative effort on the part of farmers there to develop a systems approach to the irrigation and water quality issues affecting their livelihoods and futures. Together with scientists from the University of California (UC), the Tulelake Growers requested and received funding from the W. K. Kellogg Foundation's Farming Systems Program to support these efforts. A number of activities were carried out based on funding from the Kellogg Foundation, including community-based projects in Tulelake; a graduate seminar on farming systems research and the environment, carried out at UC Davis, but focused on the issues affecting Tulelake; and an assessment of existing and original data analyzing water quantity and water quality issues in the region. Agriculture is assumed to be an important contributor to nonpoint source pollution. This assumption is especially important in the Tulelake region, where agriculture takes place next to and within an important national wildlife refuge. Knowing that results might create difficult challenges for farmers in the district, the growers' committee nevertheless wanted an assessment of the effects of agriculture on water quality, with the understanding that problems can only be usefully addressed after they have been clearly identified. Consequently, our intent in evaluating existing data was to search for water quality characteristics with a plausible link to the irrigated agriculture of the district. Not only were water quality data evaluated, but an attempt was also made to identify processes that might provide an explanation for patterns observed in the data. A link between observed effect and possible cause is essential to address water quality problems. Because some of these processes are complex, the data often inadequate, and the area involved large, the best that can be done is to propose informed hypotheses linking the patterns and processes observed. In many instances, the data do not allow greater certainty. This is not very satisfying for most scientists, and when there is little certainty, those who must make difficult regulatory decisions have a greater burden. Worse, however, is false certainty. Many would agree with the French writer Georges Bernanos who suggested that poorly stated problems are the worst, most corrupting lies. *This effort was attempted and is offered primarily as an exercise in problem definition—the first step in developing a research and demonstration program to address the most important water quality issues connected to agriculture in the Tulelake Irrigation District.*

Stephen R. Kaffka
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List of Miscellaneous Abbreviations

BOD	Biological oxygen demand
CIMIS	California Irrigation Management Information System
EC	Electrical conductivity
ET	Evapotranspiration
HPLC	high-pressure liquid chromatography
KID	Klamath Irrigation District
LKL	Lower Klamath Lake
LKLNWR	Lower Klamath Lake National Wildlife Refuge
No.	Number
SD	Standard deviation
TDS	total dissolved solids
TID	Tulelake Irrigation District
TLNWR	Tule Lake National Wildlife Refuge
UKL	Upper Klamath Lake
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

List of Units of Measure

acre-feet	acre-ft
centimeter	cm
cubic feet per second	cfs
feet	ft
gram	gram
hectare	ha
horsepower	hp

kilogram	kg
meter	m
microsiemens	µs
milliequivalent	meq
parts per million	ppm
year	yr

List of Abbreviations for Elements and Chemicals

ammonia	NH_3
ammonium	NH_4
bicarbonate	HCO_3
calcium	Ca
carbonate	CO_3
carbon dioxide	CO_2
chlorine	Cl
DDD	2, 2-bis (para-chloropheny 1) -1, 1-dichloroethane
DDE	dichloro diphenyl trichloroethylene
DDT	dichloro diphenyl trichloroethane
hydrogen	H
iron	Fe
magnesium	Mg
nitrate	NO_3
orthophosphate	PO_4^{3-}
oxygen	O
phosphate	PO_4
phosphorous	P
potassium	K
sodium	Na
sulfate	SO_4

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Overview

The Upper Klamath Basin is a high desert, mountain valley straddling the California-Oregon border east of the Cascade Range. Irrigated agriculture is vital to the economy of the small communities located there. The Basin is also the location of wildlife refuges that are critical for migrating waterfowl using the Pacific flyway and is the source of the headwaters for the Klamath River, important for its scenery, trout and anadromous salmon fisheries, and its water. A six-year drought and identification of two endangered fish species in Upper Klamath Lake have led to heightened focus on the relationship between agriculture and wildlife and fisheries in the Basin. Two regulatory issues threaten to harm the area's farming communities and further erode the economy of the region: (1) possible restrictions on agricultural water use, and (2) concerns that the quality of water flowing from farms into the area's refuges may impair in some way the refuges' wildlife habitat.

Previous studies have indicated that the important water quality issues in the Tulelake National Wildlife Refuge are (1) high pH (as high as pH 10.0 at times during summer and fall) associated with high concentrations of NH_3 (NH_3 reaches 0.2-1.3 ppm) and (2) low concentration of dissolved O, (DO can reach levels lower than 4 ppm during summer nights). These two phenomena are related to the activity of the algae which thrive in the naturally eutrophic waters of the basin's lakes, rivers, irrigation canals, and drainage ditches. Algae growth rates and biomass in summer can be quite high, influencing pH. The subsequent death and decomposition of algae liberates NH_3, which also affects the DO content and pH of lake water. One or more of these water quality characteristics may influence the survival of the sucker fish species considered to be endangered in the basin. All older reports on Upper Klamath Lake suggest that waters were highly eutrophic, but no sufficiently reliable data exist to determine whether algal growth is worsening, stable, or is decreasing.

More directly related to agriculture are suggestions that nutrients and pesticides used and then lost from farmers' fields in drainage water have impaired the function of the wildlife refuges as habitat for fish and bird species. Additionally, during the recent six-year drought, water supply was thought by some to be inadequate for both wildlife enhancement and agriculture.

To assess the effects of agriculture on water quantity and quality in the Tulelake area of California, a review of older and newly collected data was made. This review indicates that:

▶ Crops produced in the Tulelake Irrigation District (TID) transpire approximately 120,000 acre-feet of water a year. This amount is equivalent to 8% to 9% of the water carried by the Klamath River as it flows past Keno, Oregon, each year. However, some of the water used by farmers in the TID is derived directly from the Lost River, and some is drainage water from the Klamath Irrigation District, immediately north of the TID. The net reduction of flow in the Klamath River resulting from water use by farmers in the TID therefore represents just a small percentage of annual river flows and is less than the multiyear variation in flow.

▶ In general, water diverted for irrigation is used efficiently. About half the water entering the TID is used for crop evapotranspiration. Excess water in drainage systems fills the Tule Lake Sumps, benefiting wildlife. Depending on the crop, seasonal water use is less than or equal to the amount of water evaporated from an open lake surface. Because most crops in the Basin are short-season annuals, they will transpire less water than comparable areas of perennial aquatic vegetation and less than equivalent areas of open water in the same location. Tule Lake was a large open water surface before its size was reduced 80% to 90% by drainage, starting in 1905. The amount of water currently used by crops is estimated to be 50% to 60% less than evaporative losses from Tule Lake before 1905.

▶ Irrigation in general and the reuse of drainage water for further irrigation increase the amount of dissolved salts present in the waters returning to the Tule Lake Sumps compared to input water derived from Upper Klamath Lake via the Lost River.

▶ Salt concentrations measured in the Tule Lake Sumps appear to have declined over the last five decades, indicating that salinity management practices are effective. On average, salinity levels are low to moderate (500-600 µs/cm) at the point waters leave the Tule Lake Sumps.

▶ Available data indicate that P concentrations in the Tule Lake Sumps have remained stable over at least the last decade. They are weakly correlated with EC measurements, suggesting that processes other than simple leaching are controlling P concentrations. P was detected in the subsurface tile drain water samples collected for this study. Concentrations were approximately equal to or less than the range of values reported for the Tule Lake Sumps and within the range reported for agricultural soils in other northwestern locations.

▶Crop recovery of P is a quantitatively significant sink. More P is recovered by crops than is removed in drainage water via pump D from the Tule Lake Sumps. Pump D removes all of the flow leaving the Tule Lake Sumps.

▶ Because P concentrations in the Tule Lake Sumps appear to have remained stable over an extended period and for other reasons, it appears that current P losses from agriculture are not significant compared to the high amounts of P already present in surface waters in the region. However, the chemistry and behavior of P are complex, and there are numerous possible sources and sinks for P in the district. Further analysis is required.

▶ Only small amounts of N appear to be lost from agricultural fields in drainage water. Denitrification may be an important sink. Some N-fixing algae species are present in the surface waters of the Basin. Compared to the activity of N-fixing algae, losses of N from agriculture in the TID are unlikely to affect the total amount of N entering lakes and rivers in the region.

▶ Based on results from an intensive monitoring effort conducted cooperatively by the United States Fish and Wildlife Service (USFWS) and the United States Geological Survey (USGS) in 1991 and 1992, pesticides in current use have not been detected in amounts of toxicological significance in waters in the TID or Tule Lake.

▶ Bioassay tests were carried out with minnows, frogs, and ducklings, using surface water samples collected throughout the Basin. These tests identified pH, DO, and NH_3 levels as potentially harmful water quality characteristics, but found no harm to these species from pesticide residues.

I Introduction

The Klamath Basin is located in a high desert environment with an average precipitation of only 10 inches (25.4 cm). Average water use by an adequately supplied crop in this region ranges from less than 24 to approximately 36 inches (61 to 91 cm) a year, so little agricultural production would occur without the use of irrigation water. Irrigation was made possible by the extensive development of water storage and delivery systems by the U.S. Bureau of Reclamation (USBR), beginning in the early 1900s (Figure I-1). The principal source of water for the TID in the California portion of the Upper Klamath Basin watershed is seasonal snowmelt impounded in Upper Klamath Lake to regulate Klamath River flow rates and to supply upper Basin irrigators through the summer months (Appendix A).

The Tulelake region was one of the last areas homesteaded in the continental United States, with final allotments made only after the end of the Second World War. The soils of the region are reclaimed from the lake bed, are very fertile, and have excellent structure because they contain high amounts of organic matter and diatomaceous earth. Over time, reclamation activities and improvements in irrigation practices and drainage have made possible careful control of the region's shallow groundwater hydrology. Agriculture is moderately intensive. High light intensities and cool temperatures during the growing season have led to world-record crops of triticale and spring wheat and excellent yields of potatoes, sugarbeets, and barley. High-quality alfalfa and onions for dehydration also are grown.

The proximity of farming and wildlife is striking. Farm fields border on or are located within the Tule Lake National Wildlife Refuge (TLNWR) and Lower Klamath Lake National Wildlife Refuge (LKLNWR) and water flows directly into the refuges' marshes from irrigation drainage canals. These refuges support large populations of migratory and permanent waterfowl. Under contract with the USFWS, crops are grown within the refuges, to supply grain for the waterfowl. But the large bird populations also depend on growers' fields throughout the fall-spring period. The bald eagle, recently removed from the Federal Endangered Species List, is abundant in the winter, increasing in number and apparently flourishing in the Basin. Other species, however, may not be faring as well. In 1988, two mullet-type fish found in the area's lakes and rivers, the Lost River sucker and the shortnose sucker, were placed on the endangered species list by the USFWS. In early spring of 1992, after six years of drought had reduced water supplies in the Upper Klamath Basin to record low levels, the USFWS, based on its assessment of the needs of these two endangered fish species, declared that farmers would receive no irrigation water in 1992. On short notice, this decision would have eliminated irrigated agriculture on 200,000 acres of prime land and caused severe economic hardship to—and perhaps the collapse of—many area farm communities. Fortunately for these rural communities, new information permitted a reconsideration of the two species' water requirements and irrigation was allowed to proceed in 1992, but at reduced rates. High levels of precipitation in 1992-93 restored water levels in the basin to normal, abundant levels. However, concerns about the effect of agriculture on water quality remain (Sorenson and Schwarzbach, 1991), and demand exceeds developed water supplies in much of the western United States.

This report focuses primarily on the results of water quality and hydrologic analyses in the Tulelake region. It includes historical and current data collected and made available or published by the USBR, the USGS, the USFWS, and other groups, investigators and sources. Data collected by the authors during 1993 are also included in this report.

II Water Quantity

Water Balance and Use Efficiency in the Tulelake Area

Water enters the Tulelake area as (1) precipitation, (2) in the Lost River, (3) when diverted for irrigation by the TID in the J canal, (4) as drainage from the KID in drains emptying into the J canal and into the Lost River, and (5) at the end of the D canal (see Figures I-1 and II-1). In Table II-1, a water balance computed for the Tule Lake Sumps A and B is presented. There are eight pumping plants around the two sumps to move water from the drainage canals into the sumps, or back from the sumps to the canals. The total amount of water pumped into the sumps (see Column 1 of Table II-1) was calculated based on the monthly records of the TID. There are two California Irrigation Management Information System (CIMIS) weather stations in the Tulelake area. We derived data for precipitation for the last five years (1988 to 1992) from the CIMIS stations. The TID also provided us with a monthly record of water distributed from the Anderson-Rose Dam (at the head of the J canal) to the Lost River (Figure I-1), another source of water supply to the sumps. As one output, evaporation from a free water surface was calculated directly from CIMIS data for pan evaporation, using the average water surface area of the two sumps (13,000 acres), modified by a factor accounting for the difference between pan and large lake evaporation (Schwab et al., 1981). The amount of water pumped out of the sumps by pump D comes from TID monthly records. Because the average depth of the Tule Lake Sumps is only about 4 feet (102 m), their storage capacity is approximately 52,000 acre-feet. From Table II-1, it can be determined that, using D pump, the TID pumps almost twice the amount of water that can be stored in the sumps at any given time into Lower Klamath Lake during a normal year (90,000 to 100,000 acre ft per yr). In theory, the volume of water in the sumps is exchanged twice every year, though mixing and exchange are unlikely to occur uniformly throughout the sumps.

Farmers use water efficiently. Water entering the TID and not used for crop production ends up in the sumps, where it supports resident and migratory waterfowl populations and other aquatic species. The water balance for the district as a whole (Table II-2) is not precise because crop evapotranspiration (ET) is only an estimate and the amount of water entering the district as drainage from the KID, to the north, is poorly quantified. This amount derived from KID is estimated by District personnel as approximately 30,000 to 40,000 acre-feet in a normal year (Table II-1). Table II-3 contains several estimates of water-use efficiency in the TID. Water-use efficiency can be calculated in a number of different ways. Over the five-year period for which data are presented, approximately 70% of the water diverted specifically for irrigation was used by crops as ET on a district-wide basis (Table II-3, Col. A), although total crop water-use efficiency for the TID distribution and application systems was 54.9% (Table II-3, Col. C).

Agriculture influences water quality in the Tule Lake Sumps because a large portion of the water entering the sumps is agricultural drainage water. The higher the efficiency with which water is applied, the less drainage water produced (Wood and Orlob, 1963). The efficiency with which water is used in irrigation influences some of the characteristics of drainage water. Because no irrigation system, regardless of type, can apply water in equal amounts to every part of a field large enough for commercial farming, some additional irrigation is required to ensure that the driest part of a field is adequately watered. When a sprinkler irrigation system is used in a timely, careful manner, a minimum of 15% more water will be applied than is needed to replace crop ET. Under farm conditions, the amount required is actually higher.[1] The true efficiency of an irrigation system is difficult to measure. However, many studies have shown that an efficiency of 75% can be used to calculate gross irrigation requirements when irrigating with wheel-line or hand-move sprinkler systems, and 85% when irrigating with center-pivot systems. The irrigation efficiency of flood systems varies from 65% to 80% at best, depending on soil type, slope, border length, and other factors.

Excess water applied as irrigation or as precipitation leaches through soils and reappears in the district's drains. This water ends up in the Tule Lake Sumps. Irrigation efficiency might be improved marginally in the TID, but it is not clear what significant benefit might be gained.

On average, approximately 120,000 acre-feet of water are used to meet crop ET requirements in the TID. This water is derived primarily from Upper Klamath Lake but also in part from the Lost River and from drainage water from the KID, to the north and immediately upstream of the TID. This amount of water equals 9% to 10% of the water flowing in the Klamath River at Keno, Oregon, during an average year (1,205,000 acre- ft).[2] Since up to 25% of the water used in the TID for irrigation is derived from sources other than Upper Klamath Lake, the percentage reduction in Klamath River volume by crop transpiration in the TID is less than 9% to 10% of the river's annual flow at that point. The amount diverted is also less than the interannual variation in flow reported for the river. However, some water is diverted at periods of low flow in late summer. Irrigation of potatoes, onions, and alfalfa

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[1] Gross irrigation requirements are determined by dividing net crop water needs by the efficiency with which the system operates:

Gross requirement = Net Requirement / System Efficiency

For example, if alfalfa uses 4 inches of water (the net requirement is 4 inches) and the system efficiency is 80%, the application required to meet plant needs uniformly is 5 inches (4"/0.8).

[2] U.S. Army Corps of Engineers estimate (1963).

continues until the middle of September. Irrigation of other crops such as sugarbeets, barley, and wheat ceases in August. Diversions for irrigation are highest in spring when river flows are high and lowest at the end of the growing season (September), when supplies are low. Late-season diversions may influence aquatic life in the Klamath River more at those times. During periods of drought, however, irrigation in the TID may consume an amount equivalent to 10% to 15% of the river's flow at Keno.

For comparison, Tule Lake prior to 1905 had a surface area varying between 80,000 to 100,000 acres. Current evaporation rates from lakes in the region are approximately 3 acre-feet per acre per year. This rate of loss times the original surface area of the lake equals approximately 300,000 acre-feet per year lost to evaporation--more than twice the amount of water used by farmers for crop ET from the same area currently. By this reckoning, current consumptive water use in the area of the TID is approximately 60% lower than historical evaporative losses from Tule Lake prior to reclamation.

III Water Quality

Historical Data

USBR data. Surveys and analyses of water quality in the Upper Klamath Basin have been carried out by the Klamath Project Office of USBR, Klamath Falls, Oregon, since the early days of the reclamation project.[3] Methods, times of collection, and other factors relevant to the interpretation of the data itself vary. This makes the comparison of data collected at different times and for different purposes difficult because methods of sample collection and handling, methods of analysis, time of collection, units in which data are reported, and method of averaging or aggregation influence the values reported and their interpretation. All the historical data collected and reported have limitations of these kinds associated with their use. Nevertheless, the older data can help us develop better informed hypotheses about the behavior of the soil-water system in the TID. These hypotheses can lead to new ways to address water quality problems that might originate with agriculture or other sources in the Basin.

Figure I-1 is a map of the Klamath Project region. Most of the early water quality sampling sites were located at pumping plants. Unfortunately, many of the pumping plant locations have changed over time. Pump D, however, which is used to transfer water from the Tule Lake Sumps to Lower Klamath Lake, has been a consistent sampling location. There are many internal pathways for water in the TID, but all water leaving the district must pass through pump D. Due to its position in the system, it represents overall water quality in the sumps. The net effect of reclamation, agricultural activity, and wildlife use in the district as a whole are reflected by sample results from pump D. Water from the sumps, via pump D, is the principal source of water for Lower Klamath Lake. Figure III-1 shows EC values (measured as specific conductance) collected from the early 1940s until 1990, together with linear and third-order regression equations fitted to the data.[4] The data depict a downward trend for salinity during the period after 1965.

On first view, much of the data collected in the TID and TLNWR by the bureau do not appear to provide insight about important processes or patterns in the region. An example is provided in Figure III-2(A). Data collected at pumps 5, 6, D, and F for HCO_3 and EC are plotted together. When organized by location or seasonally, however, some patterns do emerge (Figure III-2(B)).

Regression analysis can be used to suggest further trends or recurring patterns. Figure III-2(C) depicts the same data plotted by time of year, after

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[3] All data are reported with the permission of the USBR.

[4] All data used for analysis and plotted in Figures III-1 through IV-2 are reproduced in Appendix C, in the corresponding tables.

creating a fitted surface for HCO_3, EC, and day-of-year data. Likewise, relationships with such factors as time of year vary with sample locations. In some locations patterns are clearer than in others (Figure III-3). The cause for such differences is not apparent.

Not all water quality characteristics behave similarly. When P data are plotted versus EC (Figure III-4), no correlation can be discerned, suggesting that the two water quality characteristics behave independently in the environment.

Figure III-5 depicts changes in NH_3-N, NO_3-N, and P concentrations, the N:P ratio, pH, and specific conductance for the 10-year period from 1980 to 1990 at pump D. Data reported for each year are the averages of varying numbers of samples.[5] Sampling times during the day and year varied during the period. These differences in collection procedure can influence some of the constituent measurements, particularly pH. Average P concentrations fluctuate from a mean of 0.2 through 0.4 ppm, though there are lower and higher yearly means. Overall, the P data imply an equilibrium condition. When quarterly averages are created for the entire decade, the patterns in Figure III-6 are suggested. Cubic regression equations are fitted to the data as well (Table III-2). These data suggest that pH increases during the growing season, when biological activity in the lakes and farming activities are greatest. EC is highest in May (day 130), when the irrigation diversions have become significant. Average P and N concentrations appear to decline during the late spring to fall period, when crop growth and nutrient recovery occur, and when algae populations are highest and other aquatic plant species are active. Of the factors analyzed, EC is best predicted by regression analysis (Table III-2). Other factors (NH_3-N, P) are less well predicted, suggesting that they do not behave in the same manner as the salts that account for most of EC. From 1980 to 1982 sampling by USBR was more intensive than during the other years of the decade. Monthly average values for NH_3-N, NO_3-N, and P can therefore be calculated and are compared to the seasonal (quarterly) averages depicted in Figure III-7. For the three-year period, concentrations of all three factors appear to rise in winter and early spring, and decline through summer and early fall. It appears that high winter concentrations of N are characteristic of the sumps. If they are, high values may reflect the presence and activity of large numbers of migratory waterfowl in the basin during those months, combined with a lower rate of discharge from the lake. Also, algal fixation and recovery of N and growth are reduced and no crop growth and uptake are occuring. Pump D is operated at lower rates during the winter months (Figure III-7(F)), and the addition of drainage water to the sumps from TID canals is greatly reduced (TID, 1988- 1992). P fluctuated less

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[5] Water samples collected from 1980 to 1984 were analyzed by the Oregon Institute of Technology, Klamath Falls, Oregon. Water samples collected from 1985 to 1991 were analyzed by the Klamath Consulting Service Inc., Klamath Falls, Oregon.

than the other water quality parameters, but it may also have been higher in winter and spring.

Figure III-8 shows daily pH changes in Upper Klamath Lake (UKL) nd in Tule Lake Sump A, based on samples colleted by the USBR on July 10, 1992, with hydraulic labs placed in both locations. The pH remained high and constant in Tule Lake but exhibited diurnal fluctuation in UKL. MacCoy (1994) reported daily pH fluctuations of approximately equal magnitude in samples collected in UKL in early July and August 1992 and in agricultural drains in the Tulelake area. This suggests that such changes are characteristic for those water bodies and that there are similar, biotic influences on pH in both UKL and the TID drains.

Other water quality studies. Salinity was recognized as a problem in the Upper Klamath Basin from the time when agriculture was first attempted. Not only were there alkali deposits and saline ponds in lower landscape positions, but the first attempts at drainage and irrigation resulted in salinization (USBR, 1912). In 1961, Wilson et al. published the results of a four-year study of drainage and salinity in the TID, focusing on the Tulelake lease lands.[6] The researchers determined water table levels and analyzed soil and water samples to characterize the nature and levels of salinity. Pockets of high salinity were found within the lease lands. The water used to irrigate the lease lands area, then as now, was composed primarily of drainage water from the northeastern portions of the TID or was pumped directly out of the Tule Lake Sumps. This recycled water has a higher EC than does water entering the northeastern areas of the TID in the J canal. At the time of the study, irrigation water in the lease lands was surface-applied and drainage return flows were carried in surface ditches to a collection point and then discharged into the sumps. These irrigation and drainage practices were not able to remove sufficient amounts of the soluble salts already present in the lease land soils (deposited over geologic time in the original Tule Lake bed) together with salts being introduced with the irrigation water. Consequently, salinization problems developed. Some of Wilson et al.'s data regarding concentrations of specific cations and anions in newly installed tile lines are reported in Table III-3 along with older and more recent estimates from other locations in the area (Table III-4). More of their results are reproduced in Appendix B, Table B1. Based on Wilson et al.'s recommendations, drain tiles were installed throughout the area. The USBR improved the overall drainage system and subsequently, evaluated the consequences of these changes for portions of the lease lands. Results of their analyses were published in project histories for the years 1963 to 1973. Mass balances for salinity for Sump 2, a location with some of the highest previous salinity levels, were calculated based on water quality

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[6] The Tulelake lease lands are a part of the Tule Lake National Wildlife Refuge. They are available for farming on a year-to-year basis, under leases won by competitive bidding.

samples and quantification of water- soluble inputs and outputs. Results are summarized in Table III-5. More salts were exported than imported, and the quantities of salt involved gradually declined until the ratio of exported salts to imported salts approached equilibrium.

In 1991, Sorenson and Schwarzbach reported the results of a two-year water and environmental quality investigation. They collected water samples, bottom sediment, and various biological tissues from the river, canals, and lakes. The samples were then analyzed for major chemical constituents and trace elements. They found that water was progressively enriched with salts as it passed through the TID to the sumps. Figure III-9 depicts the sampling locations and relative EC concentrations they reported. Appendix Table B-2 contains results from their water quality analyses at six locations in the Tulelake area. They were unable to detect residues of currently used pesticides in water samples or in the gastrointestinal tracts of the waterfowl they examined.

In 1994, MacCoy reported the results of an extensive three-year (1990 through 1992) survey of physical, chemical, and biological phenomena associated with irrigation drainage waters in the Upper Klamath Basin. The survey, carried out by the USFWS and USGS, involved collecting water samples and tissue samples from various wildlife species. These samples were analyzed to determine their pH, concentrations of pH, major cations and anions, and level of pesticide residues. Samples were collected in the TLNWR and LKLNWR, including portions leased to farmers. Weekly samples were collected during June, July, and August in 1991 and 1992. A simplified map indicating MacCoy's sampling locations is presented in Figure III-10.

Specific conductivity (EC) varied substantially among sites, times within years, and years. The majority of values reported are less than the US EPA's drinking water standard (700 µs/cm). However, specific locations within the refuge were associated with higher levels, particularly those locations immediately south and east of Sump A. (Figure III-11A). These areas were also found to have higher salt concentrations in our analysis in 1993 (see the section called "1993 Data" later in this chapter) and correspond to the locations studied by Wilson et al. (1961). Wilson's group studied these areas because of salt management problems in the 1950s.

The 1993 analysis determined inorganic N and P concentrations. NO_3-N was either not detected or reported only in concentrations well below drinking water standards (10 ppm) throughout the area. NH_3-N, however, was reported on occasion and at a number of sites at levels above those thought toxic to some forms of aquatic life (>0.2 ppm). P is present in the soils and waters of the Upper Klamath Basin generally at levels sufficient to create eutrophic conditions (0.1 ppm; Wetzel, 1976), and it is the major reason why the lakes and other slow-moving surface waters support abundant populations of algae. Miller and Tash (1967) estimated that the top inch of sediment in UKL contained 32,000 tons of P. Even more is present if deeper sediment levels are included. This sediment is constantly resuspended because of the lake's shallowness and wave action due to high average wind speeds. Also, the N:P ratio is very low (approximately 2.5:1). Sedimentary P and the N:P ratio provide the conditions required for the massive algal blooms common to UKL (Bond et al., 1968).

To evaluate changes in P concentrations with location, the USFWS-USGS group analyzed water collected in 1992 at several sites and dates during the growing season. The water was moving from UKL to the TLNWR (MacCoy, 1994). Relative concentrations are depicted in Figure III-11(B), and average concentrations by location are in Figure III-12. Average P concentrations increased as water moved from UKL to Anderson-Rose Dam, and then declined as it passed through the TID drains and into the sumps, until P levels returned to levels similar to those found in UKL at the pump D sampling point. There was a great deal of variance in the values reported. However, such variance seems to be a characteristic of all the P data available for the region, making it difficult to identify P sources and sinks unambiguously.

Despite an intensive effort, most pesticides for which chemical analyses were carried out were either not detected or were detected rarely and only at extremely low concentrations (parts per 10 billion to parts per 100 billion) with no toxicological significance. Bioassay results are discussed later, in Chapter IV.

1993 Data

To date, no water quality data has been reported for privately farmed lands in the TID, and no data useful for evaluating water quality patterns were available prior to MacCoy (1994). The use of water for irrigation in the western United States often results in the concentration of salts in drainage water and may result in enrichment of N and other constituents. To determine whether water quality characteristics were distributed in the TID in a recognizable pattern and to compare more recent values with reported data, we collected samples throughout the TID and elsewhere in the Basin in July and August of 1993, including from agricultural tile drains. Additionally, samples were collected to monitor any changes in water quality as it passed through the reclamation project's and irrigation district's water diversions on its way toward the Tule Lake Sumps, and in the sumps themselves.

Methods of collection and analysis. All of the water samples were collected in previously cleaned, 50-ml plastic bottles; stored immediately on ice; and transported to Davis, California, where they were then analyzed. The EC and the pH of all water samples were measured at 20°C with a 5800-05 Solution Analyzer manufactured by the Cole Parmer Instrument Co., calibrated with pH 7.0 and 10 standard solutions, and with a 1400 µS/cm standard solution for EC measurements. The concentrations of NH_4 and NH_3 in water samples were measured by an NH_4 analyzer based on the technology developed by Carlson (1978). The concentrations of Na, K, Mg, and Ca in water samples were analyzed using a high pressure liquid chromatography (HPLC) method developed by Goyal et al. (1993). All water samples were filtered and diluted by a factor of 20 for the HPLC method. Chloride and SO_4 were analyzed by a standard HPLC method, using a Welson Ion Analyzer. Following digestion, the concentration of P in water samples was analyzed by a colorimetric method using a UV160V UV Visible Recording Spectrophotometer manufactured by Shimadzu, Inc. (Harwood et al., 1969). The concentrations of CO_3 and HCO_3 were analyzed using a titration method (Page et al., 1982).

The locations where samples were collected are depicted in Figure III-13. Samples were first collected along a transect from UKL to Tule Lake, to track changes as water flowed from the source to the endpoint. As Figure III-13(A) shows, K1 was collected in UKL at the North Link River Dam; K2 in the Link River at the South Link River Dam; K3, K4, and K5 in the Lost River north of the Anderson-Rose Dam; and K6 to K10 in the J Canal, from north to south. Within the TID, samples were collected along north-to-south and west-to-east directions in the irrigation and drainage canals. This was done to determine if water quality parameters were uniform or followed some pattern. Fourteen samples were collected in the drainage channels along a vertical (north-to-south) direction marked as V1 to V14, and 19 samples in a horizontal (west-to-east) direction marked as H1 to H19 in Figure III-13(B). Ten water samples were collected in Tulelake Sump A, and eight samples in Sump B (with the help of USBR). This was done to characterize the variability of pH, NH_3, and PO_4 in the Tule Lake Sumps. All of the samples were collected 1 foot (25 cm) below the water surface. Eight tile lines installed in agricultural fields on both private and lease lands were also sampled. These sample sites were located in fields with various crops. The specific locations of these tile lines are not shown.

Results. The results of analyses of water samples collected from tile lines draining farm fields are reported in Table III-6. There were eight water samples collected from different crop fields. Figure III-14 is the plot of values for NH_3-N, NO_3-N, P, pH, EC, Cl, and SO_4 detected in samples by location as water moved into and through the TID in agricultural drains and canals.[7] Figure III-15 is the

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[7] Appendix B, Tables B-4 and B-5 report the results of analyses of water samples collected from drainage channels listed as H2-H19 and V1-V14. Sample H1 was lost. Appendix B, Tables B-6 and B-7 contain the results of analyses of water samples collected from Tule Lake Sumps 1A and 1B, listed as TA01-TA10 and TB01-TB08, respectively. USBR personnel aided in the collection of these samples. Values plotted as T (tile drains) are the average of all the locations indicated in Table III-7. Values plotted as D (field drains) are the average of all samples collected in drainage channels (Appendix B, Tables B-5 and B-6). L (Tule Lake) is the average of the samples collected in sumps A and B.

plot of NH_3-N, P, and pH by location within the district's drainage channels.[8] Analysis for NO_3-N was performed but none was detected. Figure III-16 depicts the distribution of NH_3, P, and pH values in Tule Lake Sumps A and B.

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[8] These locations correspond to those shown in Figure III-13(B).

IV Discussion of Water Quality Issues

Analyses of Water Samples in the TID

Major dissolved constituents in tile lines. When land in the Tulelake area was first used for farming, salinization was a significant problem. Wilson et al. (1961) documented the existence of a shallow, unconfined aquifer 2 to 4 feet (0.6 to 1.2 m) beneath the soil surface and analyzed the nature and extent of salinity problems on newly reclaimed lands. They recommended using tile drains instead of surface drains for fields. Based on their recommendations, the water table has been better controlled through the use of tile lines, pumps, and sprinkler irrigation. Salinity problems that restrict crop growth in that part of the Tulelake area have been reduced. EC levels in the southwest portion of the district, however, remain higher than those in the northeastern part, by and large (MacCoy, 1994). The reuse of drainage water for irrigation leads to these higher salinity levels. The soils in that location may also be higher in salinity than elswhere in the district.

Major dissolved constituents in irrigation drainage channels. Water samples H15-H19 and V12-V14 had much higher dissolved salts, particularly SO_4, than samples from other locations (Appendix B, Tables B-4 and B-5). Both sets of samples derive from the same approximate location, near the southwest corner of the wildlife refuge, also corresponding to the approximate location of drain tile sample 5 (Table III-7). To help discern spatial patterns, relative salinity and P concentrations detected in input waters and irrigation and drainage canals were plotted by location in Figures IV-1 and IV-2. The data for EC and P in Figure IV-1 were aggregated to simplify presentation. EC values follow the repeatedly observed and reported pattern of increasing concentration in a roughly northeast-to-southwest direction. This pattern is characteristic and has a simple physical explanation consistent with the reuse of drainage water and the behavior of simple salts in solution. With each reuse, the drainage water picks up more soluble material.

P concentration values are less easy to interpret, and the data available are more limited. Many of the higher concentrations observed occur in the southwest portion of the district, but not all (Figure IV-2(B)). This once again suggests that P and salinity levels are not correlated. Where some higher concentrations were detected in canals draining privately owned land elsewhere in the TID, results might be related to agricultural practice, perhaps overfertilization or the presence of a specific crop nearby. The P concentrations reported from individual drain tiles varied from 0.01 to 0.46 ppm (Table III-6). Because sampling was limited, it is not possible to determine whether observations are characteristic. Another difficulty results from the fact that the same canal can act as a drain and a water source at the same time. Further systematic sampling is required to determine whether concentrations observed are characteristic of specific locations and if there are areas within the TID region contributing a disproportionate amount of nutrients to the drains and sumps. More likely, however, these data may reflect the variability to be found in P concentrations in samples collected from drainage ditches rather than long-term, geographical patterns of enrichment or deposition. Similarly, the background rate of P loss from soils and effects of specific agricultural practices or crops on losses of P from soils need to be defined by further research. Such research would help focus environmental policy and management on areas or practices having the most impact.

Major dissolved constituents in the Tule Lake Sumps. Average EC values in tile lines, surface drains, and Tule Lake itself are approximately equal if one high value is excluded from Table III-7. The values reported are also similar to those from samples collected in Tule Lake in 1988 and 1989 and published by Sorenson and Schwarzbach (1991). This similarity indicates little change over the last five years. Longer-term data from 1945 to 1990 indicate decreasing EC values at pump D over that extended period (Figure III-1). The similarity of EC values for subsurface tiles, drains, and the lake suggest that average soil EC contents in the TID influences lake water quality and that the fields and sumps may currently be at equilibrium. It is important to keep in mind that approximately 25% of the water entering the TID for irrigation purposes (approximately 40,000 acre-ft) is itself drainage water from the KID, which carries salts leached from soils in that district.

The TID is part of the larger Upper Klamath Basin Reclamation Project. One of the most important purposes of reclamation was to improve the land for agriculture. This objective required that naturally occurring salts be removed from the land and this has been achieved. Because there was no outlet to the sea prior to initiation of the project, over geologic time salts accumulated in the water and sediments beneath Tule Lake.[9] When the soils of the old lake bed were first farmed, salinity quickly became a problem. Early reports discuss the development of white and black alkali conditions.[10] Natural salinization processes were interrupted and reversed when an outlet was created to Lower Klamath Lake and then to the Klamath

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[9] The oldest water quality analysis for Tule Lake dates from 1902 and is reported by Helleman in the Project History for 1905-1912 (USBR, 1912). Twenty water samples were collected on a transect across old Tule Lake. These samples were analyzed for total dissolved solids (TDS). Expressed in conductivity terms, the average value was equal to 420 µs/cm. Old Tule Lake was the low point in the basin's landscape and had no natural outlet to the sea. This resulted in the millennia-long accumulation of salts in the lake bottom. Values from Lower Klamath Lake from approximately the same time, but before water was diverted to it from the Lost River drainage and Tule Lake, were similar (480 µS/cm); samples from UKL averaged 200 µS/cm, similar to current analyses.

[10] Vorhees (USBR, 1912) reported that, following an initial attempt to farm land drained from Lower Klamath Lake, "...chemical analyses show the presence in soil and water of large quantities of soluble salts, chiefly carbonates of sodium, calcium and magnesium, in other words, lime and black alkali."

River. Irrigation and drainage over the last 50 years have flushed accumulated salts out of the Upper Klamath Basin and into the Pacific Ocean, via the Klamath River. Soils and surface waters in the region are now less salty than before.

Phosphorus data. Figure III-5(A) depicts the concentration of P in the Tule Lake Sumps during the 10-year period from 1980 to 1990; Figure III-6 reports more frequent measurements taken during a subset of those years, and Figure III-7 presents the apparent annual cycle of several water quality parameters. The figures reveal that the concentration of phosphorus varied, tending to rise modestly during the winter months. These apparent changes in P concentration are suggestive, but the data available are not sufficient to support firm conclusions about the processes controlling P in the Tulelake region.

It is difficult to determine consistent average values for P concentrations in the waters of the region.[11] Depending on how data are aggregated, different average values can be reported. Many values published over the last four decades for UKL and the Klamath River fall in the range 0.2 to 0.3 ppm total P, though higher and lower values also were reported frequently (MacCoy, 1994; Ehinger, 1992; Klamath Consulting Service, 1983; State of Oregon Department of Environmental Quality, 1976; Federal Water Pollution Control Authority, 1969; Oregon State Sanitary Authority, 1964). Similarly, values derived from samples taken in the canal near the pump D vary from 0.1 to 0.6 ppm. Over the 10-year period from 1980 to 1990, they averaged approximately 0.4 ppm.[12] But data collected in the summer of 1992 by the USFWS and USGS averaged 0.25 ppm (MacCoy, 1994), approximately equal to the value for the same period reported for UKL. Our analyses of water samples collected in the sumps in August 1993 (Table III-7) averaged 0.1 ppm total P (range: 0.01 to 0.29 ppm); while the average for tile lines draining farm lands was 0.3 ppm. To improve understanding of the factors controlling P in the Upper Klamath Basin, further systematic analysis is needed to define more accurately the origin and behavior of P. On the whole, however, the concentration of P in the Tule Lake Sumps appears to be higher than in UKL.

Nevertheless, there are some reasons to hypothesize that irrigated agriculture currently does not contribute to P loads in the Basin in amounts that enhance eutrophication. The first is the fact that waters entering the Tulelake area are already rich in P. The P concentrations reported in all available

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[11] If sediments in the TID are assumed to contain P in amounts equivalent to those in UKL and we assume that the bulk density of those sediments is 1 g cm, then only 0.07 g of sediment in suspension is needed to raise total P concentrations in surface waters by 0.1 ppm. P concentrations in water samples would then have a tendency to vary significantly as a function of chance or deliberate disturbance of sediments at the place and time of sample collection.

[12] The oldest P concentration values we have found date from 1945 to 1947. The average of six samples collected at pump D over the three years was 0.58 ppm P. The values are converted from PO_4 equivalents. (USBR, 1945-1947).

studies are well above levels many limnologists think are limiting to algae growth (>0.1 ppm total P) (Ryding and Rast, 1989; Wetzel, 1975). Because this basin is located in a region with high background concentrations of P in water and soil (Stevenson, 1986),[13] enrichment occurs naturally as water moves downstream from UKL and Clear Lake through the watershed to the Tule Lake Sumps (Figure I-1). For example, values of P and other elements in the waters of the Upper Klamath Basin were measured over the period 1959 to 1963 by the Oregon State Sanitary Authority (1964). The values the authority reported for P, NH_3-N, and EC are summarized in Table III-7. For orthophosphate (a smaller water- soluble fraction contained within the total P fraction), concentrations increased from the headwaters of Upper Klamath Lake, in the Sprague and Williamson Rivers, to the Klamath River just below Klamath Falls. At this point on the river, no agricultural drainage water from the KID or TID has been returned. Between these two points, P concentrations increased from 20% to 70%, depending on which river is used as a comparison. Further downriver, at Keno, the Klamath Straits Drain has returned agricultural drainage water to the river from the KID and TID, this water first having passed through Lower Klamath Lake. In contrast to the effect of UKL, orthophosphate concentrations increased by 0.06 ppm, an amount equivalent to 20% of the orthophosphate in the river at Keno, compared to approximately 50% contributed from UKL. This smaller increase derives collectively from a large area: the Lost River drainage as a whole, the KID and TID, and Lower Klamath Lake and adjacent natural and managed areas. The most significant effect of the lower drainage region was on salinity. NH_3-N was unaffected while P increased less than salinity, suggesting that the two phenomena were not strongly linked. In general, the authors concluded that anthropogenic influences on water quality in the Basin were of little consequence compared to natural enrichment processes[14].

The second reason to hypothesize that

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[13] Stevenson reports P contents of soils in the Pacific Northwest ranging from 0.04% to 0.13 %. These values are higher than for any other region of the country.

[14] "Upper Klamath Lake is one of the eutrophic lakes..studied by the Federal Water Pollution Control Administration to determine the significance of its watershed as a source of algal nutrients. It was reported (1967) that the principal nutrients, P, N and Fe..are supplied through natural geological environments in quantities fully sufficient to maintain algal blooms. Man's contaminating contributions, although accelerating the eutrophication process, are minor in comparison" (page 62). The State of Oregon's Department of Environmental Protection (1976) also concurred with this view: "Substantial water quality data from Klamath River monitoring stations, coupled with studies of limnological factors, indicate that the localized Dissolved Oxygen (DO) deficiencies are caused primarily by respiration of massive algal blooms and by water quantity manipulations. Natural Biological Oxygen Demand (BOD) loadings (algal) entering the river from Upper Klamath Lake are many times greater than those added by man's activities" (page 15). And: "The major water quality problem in Link River, Lake Ewauna and the Klamath River is a severe DO deficiency caused by large algae populations passing from Upper Klamath Lake" (page 62).

irrigated agriculture does not contribute significantly to P enrichment in the region is that P concentrations do not appear to have increased recently. Some P was detected in samples collected from tile lines in the TID (0.3 ppm average; range, as specified in Table III-6: 0.09 to 0.46 ppm). These data suggest that some transfer of P from topsoil to the sumps might take place. If enrichment were occurring, however, an increase in P concentrations over time should have been detectable. Alternatively, P deposition as sediment in the Tule Lake Sumps might obscure P losses from farmland. Sediment has accumulated in the sumps, but the rate of sediment deposition and its influence on nutrient cycles is unknown. Measurements of P concentration in water samples do not allow any direct inference about the effects of deposition.

P deposition in anaerobic sediments may not be sufficient to mask high losses of P from farmlands if losses were occurring. Mitsch and Gosselin (1993) report that P is more soluble under anaerobic than aerobic conditions. They noted also that several studies have documented higher concentrations of soluble P in poorly drained than in oxidized soils. In a recent study, Moore and Reddy (1994) reported that P solubility and rates of flux were orders of magnitude higher under anaerobic than aerobic conditions in soils found in and around Lake Okeechobee, Florida. For several California soils used for rice production, Sah and Mikkelsen (1989) reported that soils with high levels of organic matter, when flooded and then drained, had lower rates of P availability to crops than under flooded conditions. Richardson (1985) reported that aerobic mineral soils were capable of retaining more P against leaching loss than comparable anaerobic soils in northern temperate wetlands.[15] If similar phenomena apply in the soils of the TID, the conversion of flooded soils to a drained condition may have served to increase P retention in farmland and reduced rates of flux on average, especially given the high rates of sediment disturbance common to the shallow lakes in the region (Bond et al., 1968). The chemistry of P, however, is very complex and the depth of soil affected by drainage and tillage is large. Little research has focused on soils with relatively high pH and organic matter, such as those found in the TID.

Third, P does not leach readily from aerobic soils, even when soluble P fertilizer is applied. Russell (1973) reports P export in water from aerobic mineral soils occurring typically in the range 0.1 to 1.2 kg ha^{-1} yr^{-1} and does not regard fertilizer P applied at agronomic levels as a source of P that can be leached to groundwater. The more typical pathway for movement of P is via surface runoff and soil erosion, toward streams and rivers. Because fields are flat in the TID and bordered by berms, soil erosion by water is rare.[16] Stevenson (1986)

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[15] Similar processes seem to govern N availability as well (Patrick and Mahapatra, 1968).

[16] Gusty winds and vehicles traveling on unpaved roads produce an unknown amount of dust, however, some of which settles in waterways.

reported that P concentrations in subsurface drain water from the various sites in the western United States varied from 0.01 to 0.43 ppm. This range is similar to that found in tile drains in the TID.

In the delta region formed by California's San Joaquin and Sacramento Rivers (the Delta), organic soils have been used for agriculture for most of the century. When drained and tilled, abundant organic matter in these soils begins to break down (oxidize), releasing the nutrients contained. Sufficient nutrients are released by this process each year, so little N or P fertilizer needs to be applied to grain crops. Extensive sampling of these soils was conducted in the 1970s. These studies focused primarily on salinity and NO_3-N, but some additional analyses for other solutes, including PO_4-P, were reported (Meyer, 1975; Meyer et al., 1974). Salinity varied without apparent pattern. NO_3-N was often found in high concentration in the top 12 to 18 inches (30 to 46 cm), but declined with depth and increasing soil moisture. Crop recovery and denitrification were suspected as the pathways for loss of NO_3-N. More importantly in the present context, extractable PO_4-P occurred at concentrations lower than 0.1 ppm in all the samples analyzed, suggesting leaching of large amounts of PO_4-P was unlikely. The organic soils of the Delta and those of the TID have some important differences that may result in different behavior on the part of P. Nevertheless, experience in the Delta suggests that farming organic soils does not necessarily result in significant P loss in drainage waters.

Fourth, crop recovery of P is a pathway for its removal from the Basin. Table IV-1 depicts average fertilizer recommendations and amounts of nutrients removed by an average crop. Most of the crops grown recover more P than is applied as fertilizer. An estimate of the amounts of N and P applied and recovered from the Tulelake lease lands area is presented in Table IV-2. Extrapolating cropping patterns on the lease lands to other locations in the TID allows for an estimate of crop recovery for the district as a whole. Compared to the amount of P removed from the TID when water is pumped into Lower Klamath Lake (LKL), the amount recovered in crops in the TID as a whole is two or more times larger.[17] Crop removal, therefore, is a relatively important P sink.

Figures III-6 and III-7 indicate that P concentrations in water may decline moderately

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[17] Because estimates of P concentration and crop nutrient composition are approximate at best, it is possible to use round figures for estimating relative P fluxes. If 0.4 ppm is used as an average P concentration for water passing through pump D and 100,000 acre-feet per year are pumped, then approximately 100,000 pounds of P are removed from the TID and TLNWR each year through this means. Crop recovery in the lease lands area accounts for 180,000 to 200,000 pounds a year. The lease lands are approximately 30% of the land area used for farming in the TID. Assuming a similar mixture of crops is grown district-wide, approximately 600,000 pounds of P are recovered by crops each year. Some of the P recovered is derived from fertilizer, but much comes from soils or irrigation water (Table IV-2). Not all P recovered by crops is removed in agricultural products, so the ratio of P removed by crops to P removed with drainage water is reduced by the amount remaining as crop residue.

during the warm months of the growing season. In addition to increased algal growth in summer, crop recovery and removal may contribute to that decline. However, pump D also moves a larger water volume during summer and fall than during winter. When water is pumped from Tule Lake to LKL, from LKL to the Klamath River, and ultimately to the ocean, the nutrients and salts dissolved in that water (including P) are removed from the Basin. Agriculture and the operation of the reclamation project together reduce the amount of P present in the ecosystems. If the removal of P is salutary for water quality in the Basin, then agriculture may help improve water quality.

Lastly, simple mass balance calculations suggest that agriculture may not be a net source of P. Approximately half the water entering the TID is lost through crop transpiration and evaporation from the surface of the sumps (Table II-3). If input concentrations of P are assumed to be approximately equal to 0.2 ppm (MacCoy, 1994) and output concentrations are assumed to be equal to approximately 0.4 ppm (Figures III-5 through III-7), then the doubling of average P concentrations observed would be consistent with the simple loss of half the water entering the system. Neither net additions nor removals due to farming need be hypothesized. On the other hand, if the average P concentration at pump D is closer to 0.25 ppm, the amount reported by MacCoy (1994), then input and output concentrations are approximately equal. Since less water is removed from the TID than enters it, agricultural crops and farmlands under these circumstances may store and also act as a sink for up to half the P entering the district. These two hypotheses about the behavior of P suggest mechanisms accounting for the upper and lower range in P concentration values reported for pump D samples. Both hypotheses suggest that farming currently does not result in significant loading of surface waters in the TID with P. Processes affecting P movement in the system are complex, however, and a better determination of patterns and processes awaits a more comprehensive analysis.

Nitrate. From Figure III-5(A), it can be determined that the NO_3-N concentration in Sump A was low during the 10-year period depicted. In 1986 the US Environmental Protection Agency (USEPA) established the standard for N as NO_3 in drinking water. The permissible level is 10 ppm. Standard methods cannot accurately measure levels below 0.3 ppm. The 10-year average in Tule Lake Sump A derived from these data is 0.35 ppm, nearly 30 times lower than the EPA standard. In Figures III-6 and III-7, both the N and NH_3-N concentrations reported were higher during the early months of each year. Because most agricultural activities start no earlier than the middle of March or early April, higher concentrations in the winter months may reflect the activities of large overwintering populations of migratory waterfowl in the refuge, combined with lower levels of discharge from Tule Lake. Subsurface drainage of farm fields is substantially reduced during winter, making increased loss from soils at this time unlikely.

NO_3-N does not seem to be present in the waters of the basin to any significant degree. An intensive sampling protocol reported by MacCoy (1994) supports the observation that NO_3 is not a water quality problem in the region. Nitrate has not been detected in large amounts historically in the region and N levels in Tule Lake and other surface waters in general are low relative to P. The highest levels detected in our survey were found in the subsurface tile drains (Figure III-14). Sampling in 1993 indicated some leaching of NO_3 to drainage tiles during August. Samples averaged 1.2 ppm NO_3-N. These levels are very low for agricultural systems in general. If values detected in August 1993 are representative of the entire season, then the loss of N from farm fields does not appear to be large enough to influence the Tule Lake ecosystem significantly.

Denitrification, the conversion of NO_3 to gaseous forms, may be an important process in the Tulelake region, as it appears to be in the San Joaquin-Sacramento Delta region. For denitrification to occur, NO_3-N, saturated soil conditions, a carbon source, and microbial activity are needed. In the highly organic soils of the Tulelake area, these conditions are well provided. Denitrification may serve to reduce potentially higher leaching losses. Additionally, just as with P, more N is removed by crops than is added as fertilizer (Tables IV-1 and IV-2).

EC, NH_3, and pH. All the data reported show that EC levels in the tile lines, the drainage channels, and sumps A and B are two to three times higher than EC levels in the irrigation water that comes from UKL. However, even these levels are relatively low. The EC of agricultural drainage water is lower than the EC specified by USEPA's drinking water standard. The USEPA standard (1986) for the EC of drinking water is 700 µs/cm. The recent average value of EC in the sumps was 550 µs/cm. The data in Figure III-14(B) also suggest a relationship between EC and the concentration of SO_4. SO_4 is the most abundant anionic constituent in waters of the region.

The Tulelake area is a topographic low point in the Upper Klamath Basin. Historically, water and salt flowing into the area accumulated because there was no outlet. The water balance presented in Table II-1 indicates that a quantity of water equal to approximately twice the volume of the Tule Lake Sumps is replaced each year by pumping water out of the lake and bringing in fresh water from the Lost River and UKL. Because of this exchange, during the 47 years represented by the data in Figure III-1, the salt concentration in the waters of the sumps has been exchanged approximately twice each year with river and irrigation drainage water. Relative to historic levels, current rates of enrichment from these water sources are very low and did not lead to increases in EC, even after six years of drought.

Relative to other freshwater systems, NH_3 is present in the Upper Klamath Basin in significant amounts. Figure III-5 indicates that during the 10-year period from 1980 to 1990, the average concentration of NH_3 exceeded 0.2 ppm. In 1985, the average level of NH_3 detected in samples was 1.3 ppm. According to USEPA (1986), NH_3 concentrations greater than 0.2 ppm could harm some species of fish. Whether or not fish in the Upper Klamath Basin are harmed by existing levels is unknown.

Figures III-6 and III-7 indicate higher values of NH3 in the early months of each year. There is little agricultural activity during this period and topsoil often is frozen. NH_3 accumulation occurs naturally because of the death and decomposition of algae and because nitrification is inhibited under anaerobic conditions (Patrick and Mahapatra, 1968). High concentrations of NH_3 may be enhanced by the accumulation of waterfowl wastes. Perhaps most importantly, less water is pumped out of Tule Lake at that time (Figure III-7(F)). In Figures III-6 and III-7, a clear decrease in the concentration of NH_3 can be discerned when irrigation water from UKL is diverted to the agricultural fields of the TID in spring. Pumping of water from the sumps to LKL increases in late March, when the irrigation system begins operating for the year. The system replaces stored water with freshly imported water, apparently reducing NH_3 concentrations. Large numbers of waterfowl also depart the refuge in spring. The springtime decrease in NH_3-N concentration may be enhanced by volatilization of NH_3 from water coming into the system flow that has been aerated by flow through the river and irrigation canals, after agitation by pumps, and movement through sprinkler irrigation systems.

In our survey, the average concentration of NH_3 in tile drains was lower than values for any other samples collected (Figure III-14). The concentrations of NH_3 measured in the irrigation canals, drainage channels, and in the sumps were higher than those in the tile lines draining farm fields. If samples collected in August are characteristic, then there is little or no net loss of NH_3 from farm fields. NH_3 in waters in the TID and TLNWR does not result from agricultural practices. Higher levels of NH_3 in drainage channels and the sumps relative to the tile drains is most likely due to decomposition of algae and possibly also to activities of waterfowl.

Data from all sources confirm that the pH of this water system is high, especially during the summer. Our observations (Figure III-16) indicated that values for pH in the two Tule Lake Sumps were in the range of 9.5 to 10.0 in the summer of 1993. There is no EPA standard for pH in fresh water or drinking water. However, a high pH appears to be strongly correlated with a high concentration of NH_3 in the waters of the Upper Klamath Basin.

N:P ratios. Both the absolute and relative quantities of essential nutrients in a lake are primary factors regulating algal biomass (Ryding and Rast, 1989). Algal populations in general contain approximately 7 to 8 parts N to 1 part P on a mass basis. If the N:P ratio is higher than this, P may limit algal growth, whereas a lower value indicates that N is limiting and P is abundant. For the Tule Lake Sumps and other surface waters of the Upper Klamath Basin, N appears to be limiting. Figure III-5(B) shows that the N:P ratio was 3:1 or less during the 10-year period reported for the Tule Lake Sumps. Ehinger (1992) indicated that N:P ratios similar to those reported in waters in the Basin may cause the monospecific blue-green algae blooms characteristic of UKL. Blue-green algae respond to high concentrations of P. Some species are capable of fixing atmospheric N. When N supplies are low relative to P, N-fixing species of algae can be favored. Therefore, when P is abundant, the loss of modest quantities of N from neighboring terrestrial environments is not likely to affect ecological processes significantly.

Algae and Water Quality

Despite low N:P ratios, the Tule Lake Sumps have a more diverse phytoplankton population than does UKL. Although blue-green algae are present, they do not dominate the phytoplankton community in the sumps. In UKL one blue-green alga, *Aphanizomenon flos-aquae*, dominates in the summer (Ehinger, 1992). In the Tule Lake Sumps, seasonal changes of the algae species are very clear. In the winter and early spring, the color of the lake is brown; diatoms dominate in the water. Blue-green algae dominate in the later spring, green algae in the summer cause the color of the water to change from brown to green. Diatoms in the fall season cause the color to change back to brown.

Algal activity in the lakes, canals, and drainage ditches could cause or contribute significantly to most of the obvious or potentially harmful water quality problems in the Tule Lake Sumps. These problems include high pH, high concentrations of NH_3, and low levels of DO. When algae produce significant amounts of biomass in the lake, large amounts of ammonium (NH_4^+) will be released when the algae die and decompose. At high pH, more NH_4 will transform to NH_3, (Thurston et al., 1979; Appendix B, Table B-8), resulting in potentially toxic concentrations. Higher average values for pH appear to be characteristic of the warm months and peak at the end of the summer. The seasonal pH changes are consistent with the development of algae populations (Figure III-7).

There are large pH differences between values in tile drains and those in drainage canals and in the Tule Lake Sumps (Figure III-12). MacCoy (1994) reported analogous daily pH changes in UKL and the drainage canals in the TID. This suggests that biological processes in the drainage ditches and sumps are similar and influence pH. Large algae blooms in the summer will cause low DO during the night. This is due to algal respiration, which consumes O_2 and releases CO_2. Similar effects have been observed in lowland rice production systems elsewhere (Mikkelsen and DeDatta, 1979). Photosynthesis and respiration by algae and other aquatic vegetation seem to have a strong effect on pH values in UKL and surface drains in the TID, but they may have less effect in the Tule Lake Sumps (Figure III-8). SO_4 is the most common anion in the Tule Lake Sumps. It is possible that SO_4 reduction and other reactions related to the higher levels of dissolved salts may help maintain pH at levels in the sumps that, compared to levels in UKL, seem steady. If so, NH_3 concentrations may be increased somewhat because of this phenomenon.

There does not seem to be a direct connection between current farming practices and algae growth. Algae do develop, however, in agricultural drains in the TID and must be managed to maintain drain functions. Not much is known about this phenomena nor about its relative contribution to overall water quality in the Tule Lake Sumps. A high-rate algae production and harvest system might be useful in further reducing the P content of water in the lake, should reduction be thought desirable.

Pesticide Residues and Bioassays

MacCoy (1994) reported the results of numerous bioassays and analyses for pesticide residues (particularly insecticides and fungicides) in the waters of Upper Klamath Basin, especially in the national wildlife refuges. The only pesticides or pesticide residues detected to any extent were organochlorine insecticides (DDT and related compounds) banned many years ago for their persistence. Pesticides in current use were not detected or else were found to occur at levels near the resolution limits of the methods used (1 part per 10 billion to one or more parts per 100 billion). These infinitesimal amounts are not considered harmful. In a previous, more limited effort, Sorenson and Schwarzbach (1991) reported on a survey of pesticide residues. They, too, were able to detect only DDT, DDE, DDD, or chlordane at the part-per-billion level in water and biological samples. Currently used materials were not detected in water samples nor in the gastrointestinal tracts of mallards, western grebes, or coots. In a similar, recent effort elsewhere in the Pacific Northwest, Wan et al. (1994) evaluated the occurrence of six commonly used organophosphate pesticide residues in drainage ditches in the Fraser River Valley of British Columbia. Of the five pesticides, two (diazinon and dimethoate) were detected consistently. Two others (malathion and azinophos-methyl) were never detected, and two (fenusulphoton and parathion) were sporadically identified. When detected, the pesticides were measured at 0.1 to 0.01 ppb, an amount Wan et al. regarded as of no toxicological significance.

One reason residues are not detected is that newer pesticides are used at lower rates and farmers are better at handling and applying them. Another reason is that some of the most common types of pesticides (carbamate and organophosphate pesticides) tend to be unstable at pH levels greater than 8.0 (Eto, 1974; Kuhr and Dorough, 1979). For the organophosphate compounds, hydrolysis rates increase tenfold between pH 6.0 and 7.0, and another tenfold between pH 7.0 and 8.0 (Eto, 1974). Carbamate pesticides are esters and are prone to hydrolysis and to biologically mediated cleavage by esterase enzymes; short-lived compounds result (Kuhr and Dorough, 1976; Norris et al., 1991). High pH levels (8.0 to 10.0) were reported by MacCoy in 1994 and are similar to those reported historically and in all current analyses. Aldicarb, a carbamate pesticide used on potatoes and occasionally on sugarbeets, has been studied extensively. When it degrades, it can form either toxic (pesticidal) compounds (sulfoxides and sulfones) or nontoxic oximes. At the pH levels found in the drainage canals and surface waters of the Upper Klamath Basin, oxime formation should dominate (Lemley et al., 1988). Not all the pesticides sampled belong to these two groups, however, yet few were detected. Other types of pesticides may also undergo rapid degradation in the surface waters of the region, or they may adhere strongly to the highly organic soils found there.

Various wildlife surveys and bioassays were carried out to assess the condition of wildlife in the national wildlife refuges. The data are reported by MacCoy (1994) and by Boyer (1993), Littleton (1993), and Moore (1993). Boyer (1993) reported frog-call survey data and data on the effects of laboratory tests of water collected from various points in the TLNWR and LKLNWR, as well as from the Lost River and UKL. Boyer believed frog-call survey results suggested low numbers of reproductive frogs. But, because there were no previous data, no comparison could be made and no hypothesis formed about frog populations. Of the frogs detected, a larger number was reported in the TLNWR than in the LKLNWR, where far less agriculture occurs.

In addition, Boyer tested larval frog mortality and developmental malformation under laboratory conditions. The African clawed frog (a non-native species) was exposed to water collected from different locations in the Upper Klamath Basin — particularly from TLNWR and LKLNWR. Both mortality and malformation occurred in 1991 and 1992. However, results from both 1991 and 1992 were highly variable and inconsistent, with mortality at times being highest in water collected from UKL. There was no consistent correlation of mortality with location and no significant differences were observed. Tadpole mortality was also evaluated but none was observed. Of the water quality factors analyzed, NH_3-N and high pH were the factors Boyer identified at levels that might have harmed the non-adapted frog larvae under test conditions.

Data on the effects of regional water quality on fathead minnows were reported by Littleton (1993). Littleton also carried out fish health surveys using fish captured in the waters of the region. For the water quality experiments, fathead minnows were imported from a biological supply firm in New Hampshire and exposed to water collected from various points in the area or were exposed in situ using exclosures. Variable and inconclusive effects on mortality and malformation were reported. DO and pH were considered to be the factors most responsible for harmful effects on the test minnows. No pesticide effects were detected and were ruled out as unlikely based on the extremely low residue levels present. Littleton reported that resident, naturalized fathead minnows were abundant. The author also suggested that tests using non-adapted populations may not reflect the behavior of adapted populations. This is especially true, she noted, when exclosures, which limit the avoidance behavior of the fish are used.

Moore (1993) attempted to evaluate the effects of agricultural drain water on mallard ducklings. She reported no toxic or sub-toxic effects of any kind from pesticides. Rather, she suggested that the physical structure of irrigation and drainage canals and low invertebrate population numbers in the canals and ditches might influence survivorship more. However, no data were offered to support this speculation.

When aquatic organisms and waterfowl are exposed to pesticides or other stressful environmental hazards under laboratory conditions, harm frequently occurs (Kendall and Lacher, 1993). Grue (1993a), however, noted that despite such results relatively few cases of either chronic or acute adverse effects on wildlife populations from pesticides have been reported. Hill (1993) stated that direct extrapolation of acute or subacute exposures from laboratory tests to the field is not possible. Grue (1993b) referred to the extrapolation of laboratory results to conditions in the field as "leaps of faith."

V Conclusions

1. Water is used with reasonable efficiency by farmers in the Tulelake region, given the limitations of irrigation efficiency associated with all systems. Less water is used to produce crops than would evaporate from an equivalent area of lake surface.

2. Historically, salts accumulated in the water and sediments of Tule Lake. From an agricultural perspective, salinity is currently well managed by removal of soluble salts from the soils of the region by drainage. Reclamation of this area has removed large quantities of salts from the lake and the region's soils.

3. EC levels in the Tule Lake Sumps have declined from 1945 to 1990 and appear to be in rough equilibrium with the average water quality of drainage water from farmland. Compared to other fields in the region, some areas within the lease lands appear to contribute higher amounts of sulfates, Ca, and Mg to the sumps. This phenomenon requires further investigation.

4. NO_3-N losses from farmland appear to have little significance in the region.

5. Background P levels in the Upper Klamath Basin are high.

6. Naturally high P levels sustain high levels of algae growth in UKL and probably in irrigation and drainage canals in the Tulelake region as well. These algae flourish at low N levels, and some species are capable of fixing atmospheric N. The death and decomposition of these algae contribute significant amounts of NH_3 to the Basin's surface waters and strongly influence pH and DO.

7. P concentrations appear to be higher in Tule Lake than in UKL, the source of most irrigation water for the TID. P concentrations are not correlated with EC.

8. P recovery by crops is a quantitatively important pathway for P removal from soils and surface waters in the TID. Compared to P concentrations in UKL, P concentrations in the Tule Lake Sumps are high. The cause of the high levels may be crop transpiration and evaporation from the surface of the sumps. These processes may concentrate existing P in half the water volume. In this case, agriculture would have little net effect on P loading in the sumps. Alternatively, if (as some recent data suggest) P concentrations in the sumps are not much greater than those observed in UKL, then significant P storage and removal occurs in soils, sediments, and crops in the TID. If this second circumstance is the case, agriculture should reduce P loading in the Tule Lake Sumps.

9. Few detectable residues of currently approved pesticides used in the TID have been found in water or biological tissues. Those detected have been measured at levels considerably below the lowest levels found to harm wildlife in laboratory studies. No causal link between pesticide use in the TID and frog, minnow, or duckling reproduction or survival was demonstrated in studies attempting to identify

such a relationship. All available evidence suggests that current pesticide use does not affect wildlife in the region.

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Figures, Tables and Appendices

Figures

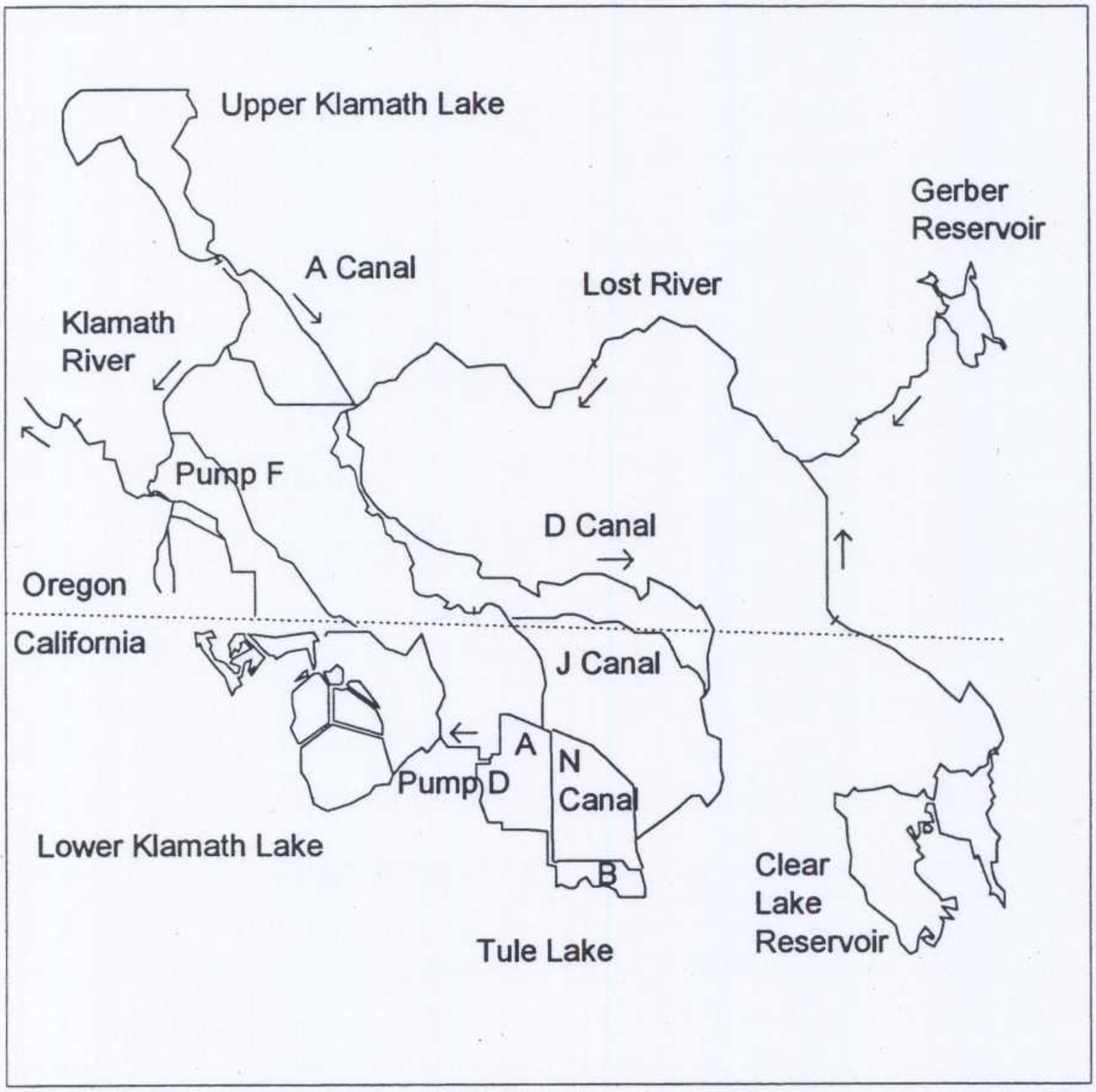

Figure I-1. The Upper Klamath Basin, including the Tulelake Region.

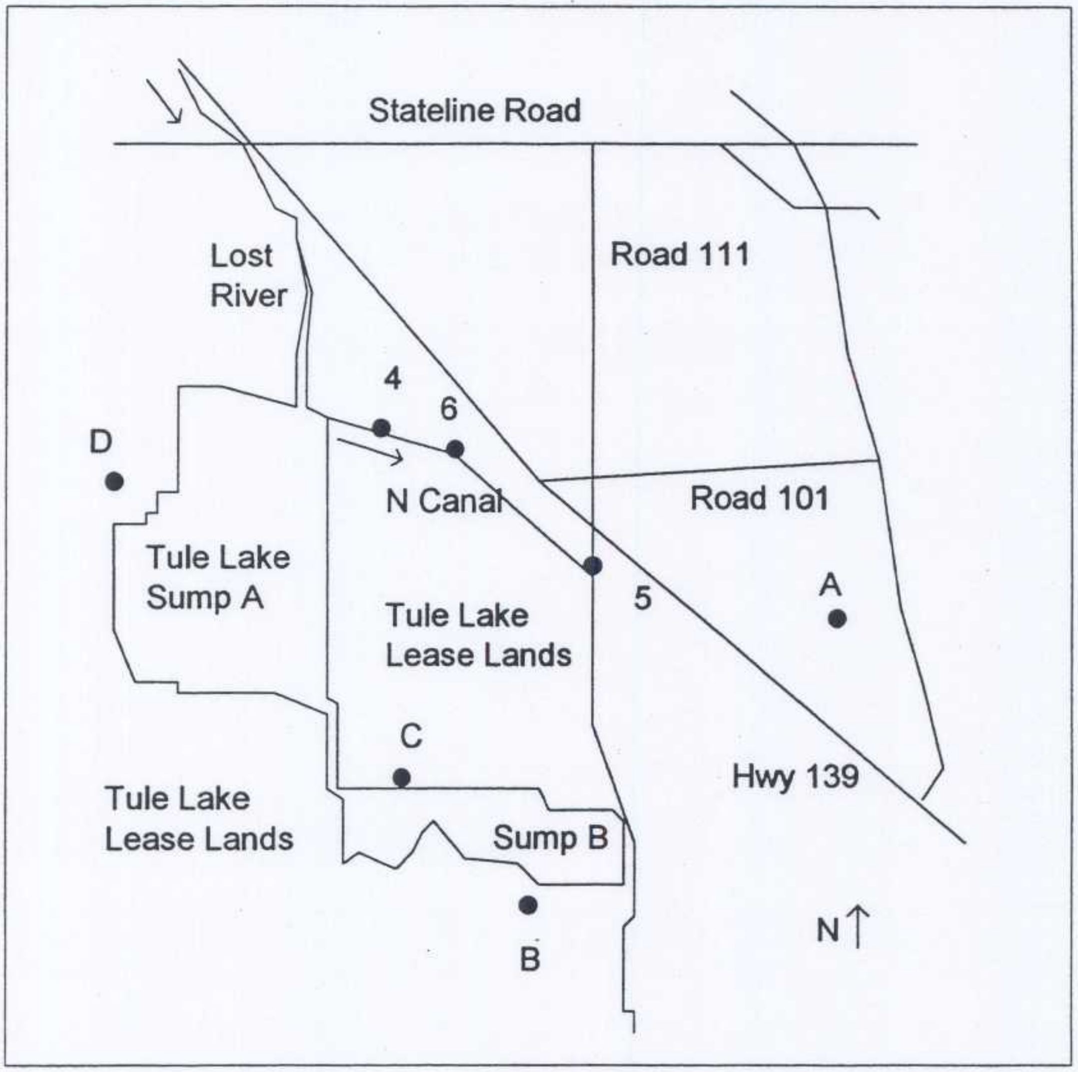

Figure II-1. Detail of the Tulelake Irrigation District (TID).

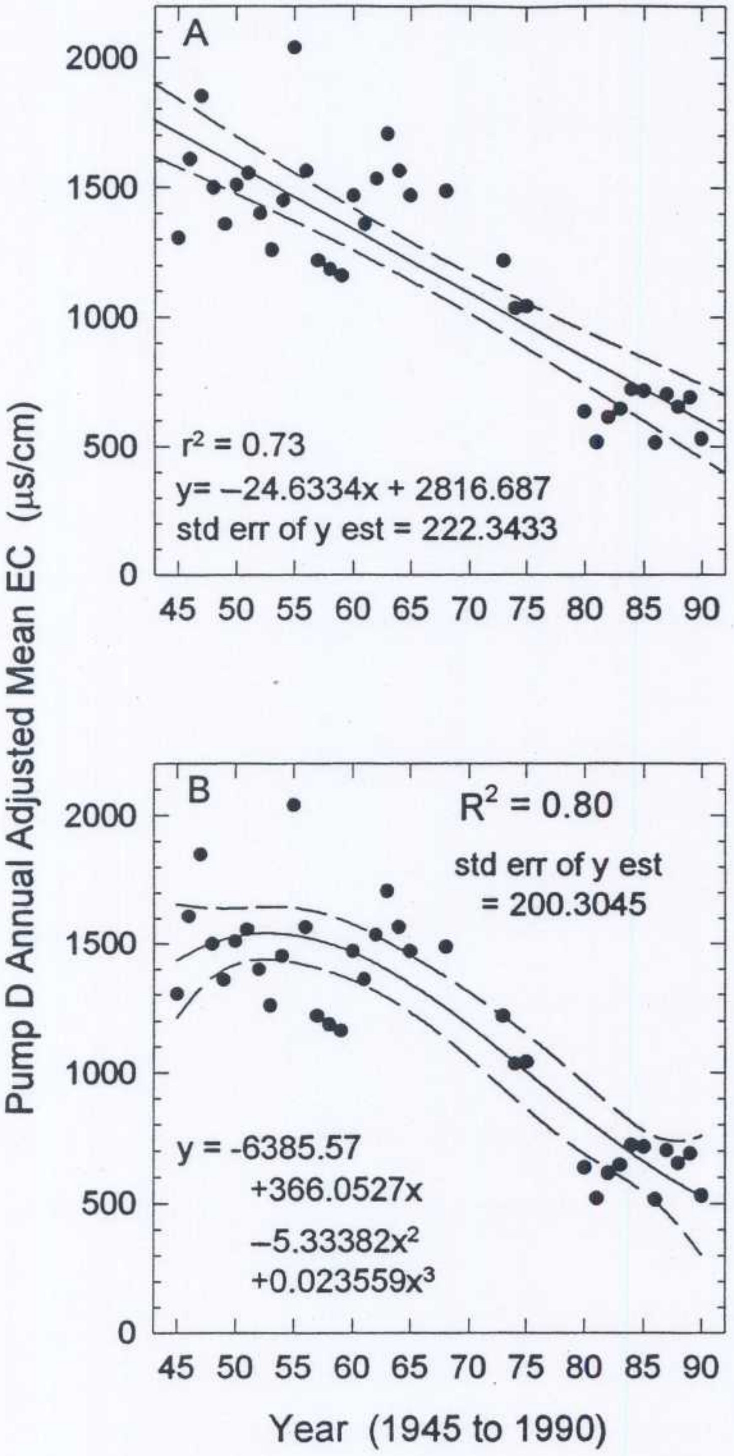

Figure III-1. Long-term trends, 1945 to 1990, in specific conductance, (EC), measured at pump D in the TLNWR. (A) Best-fit straight line. (B) Best-fit cubic line. Data for this figure are listed in Table C-1.

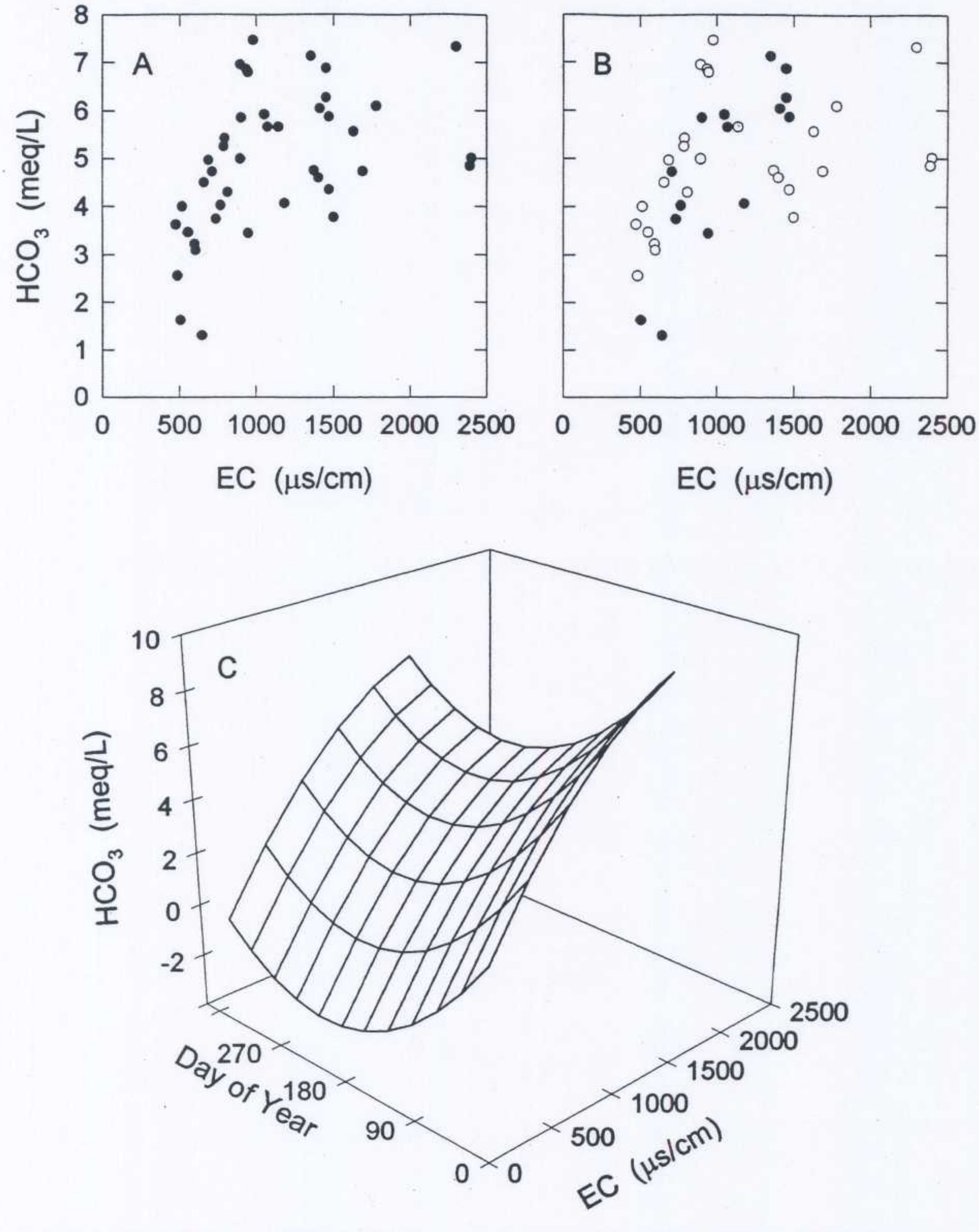

Figure III-2. (A) HCO_3 and EC data for diverst locations in the TID, not sorted for location or time of year. (B) the same data, with pump D data highlighted (*). (C) A fitted surface for HCO_3, EC, and day-of-year data, using quadratic regression models for pump D data. Data for this figure are listed in Tables C-3, C-4, C-5, and C-6.

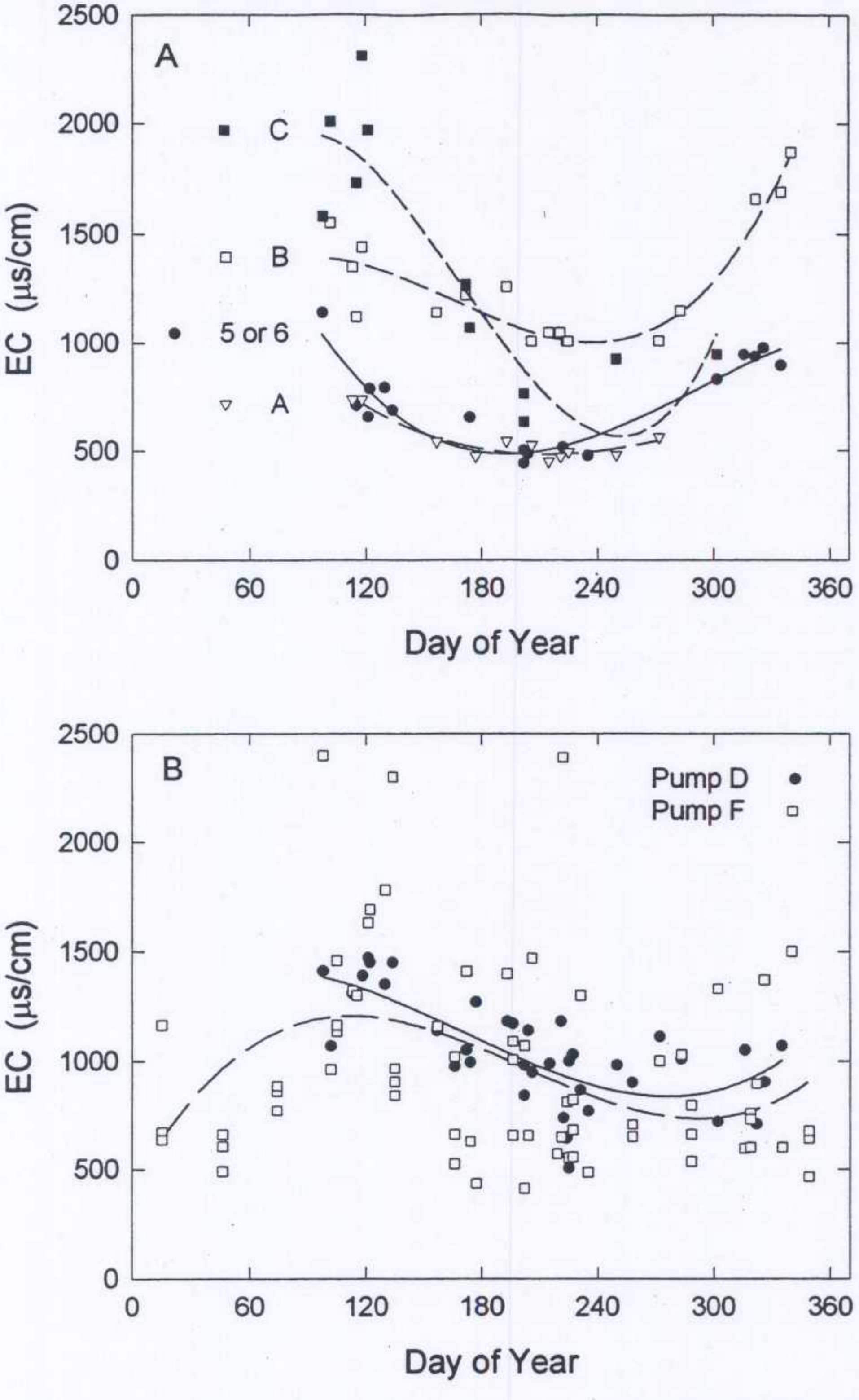

Figure III-3. EC data, by location and time of year, for six locations within the TID. (A) Data for pumps 5 or 6, A, B, and C, with best-fit cubic lines. Pumps 5 and 6 were considered as one unit. (B) Data for pumps D and F, with best-fit cubic lines. Regression equations are found in Table III-10. Data for this figure are listed in Tables C-3, C-4, C-5, and C-6.

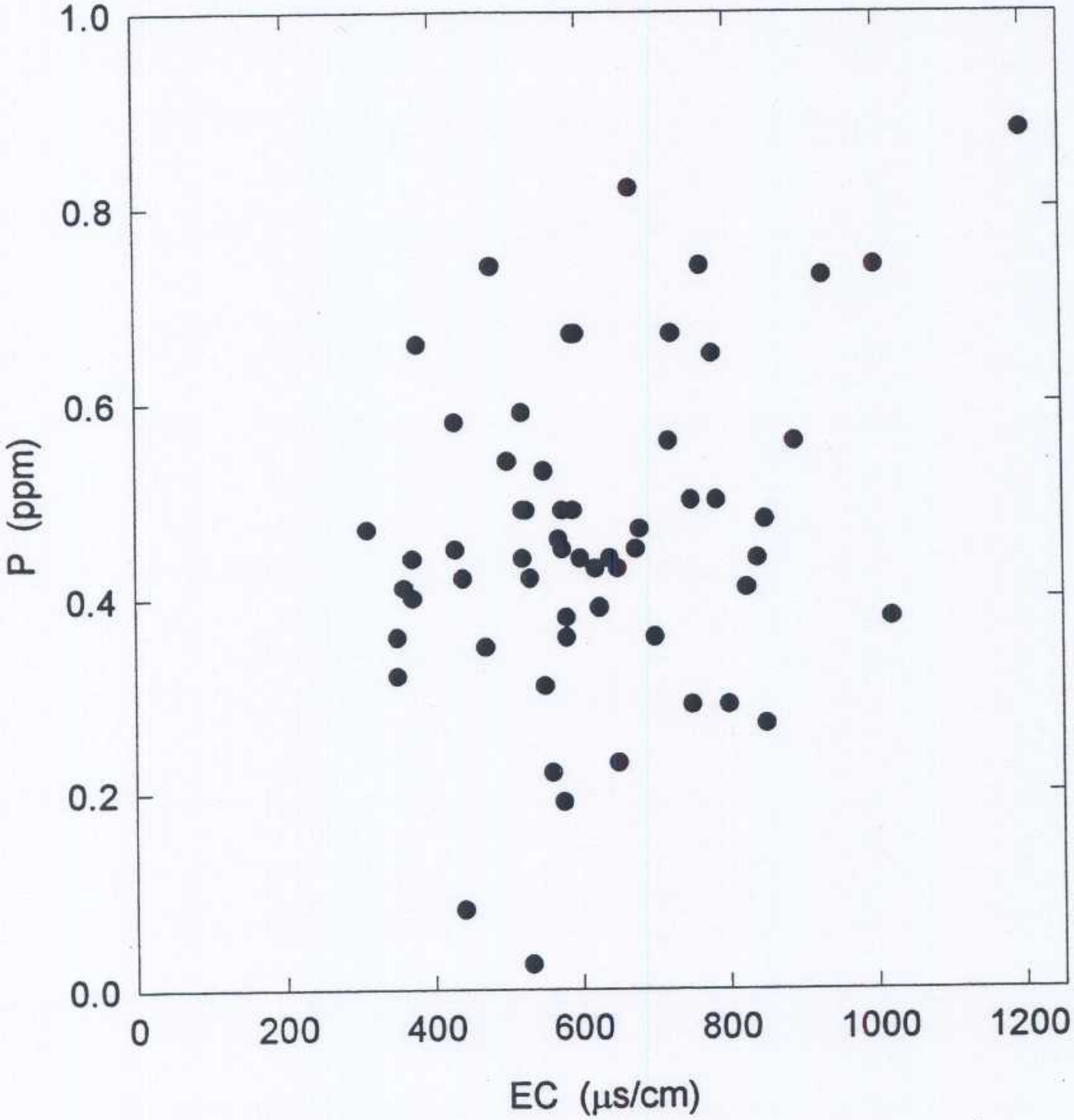

Figure III-4. P:EC data from samples collected at pump D from 1980 to 1990. Data for this figure are listed in Table C-5.

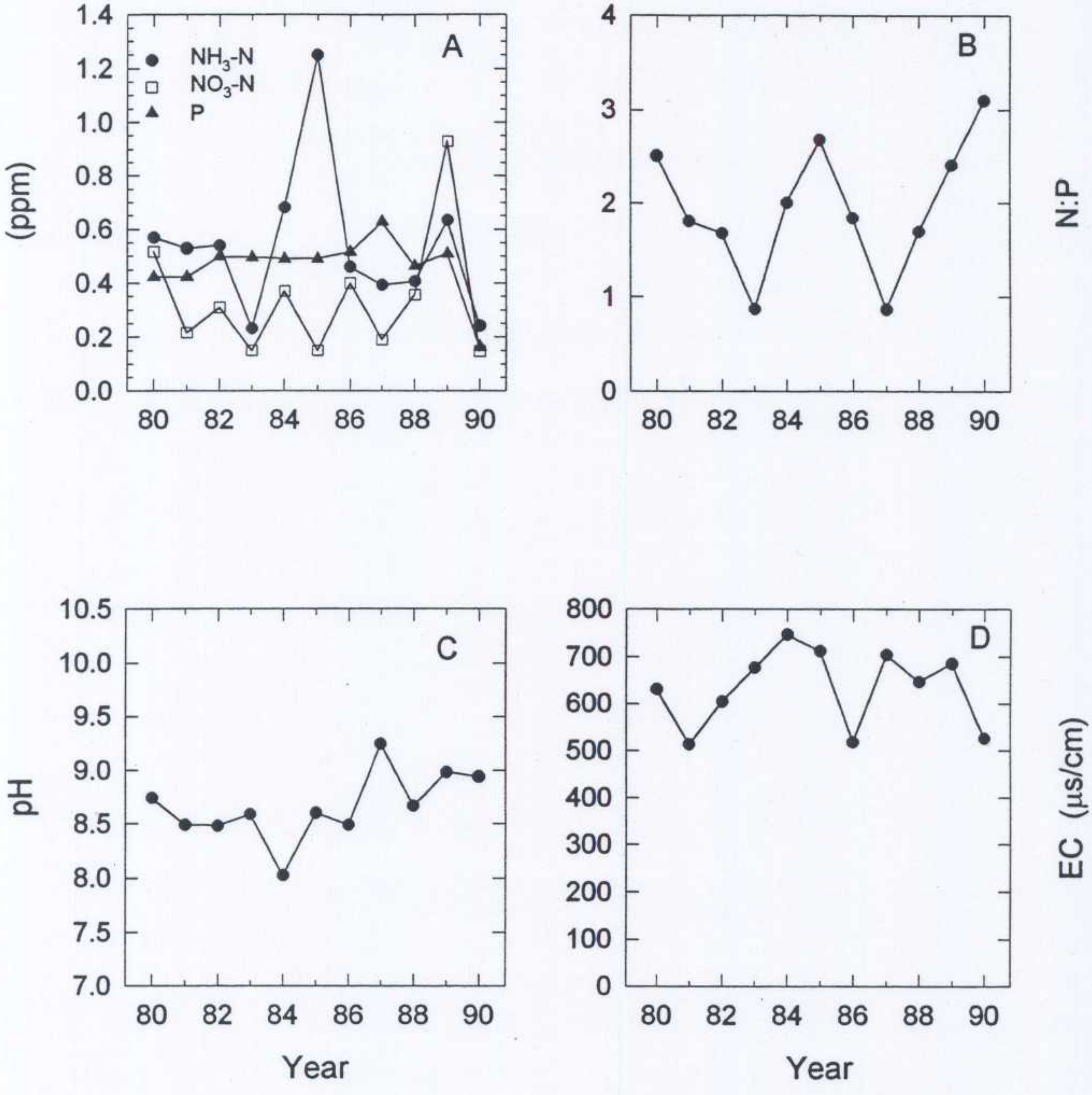

Figure III-5. Yearly averages for selected water quality parameters at pump D in the TLNWR (USBR data). Data for this figure are listed in Table C-7.

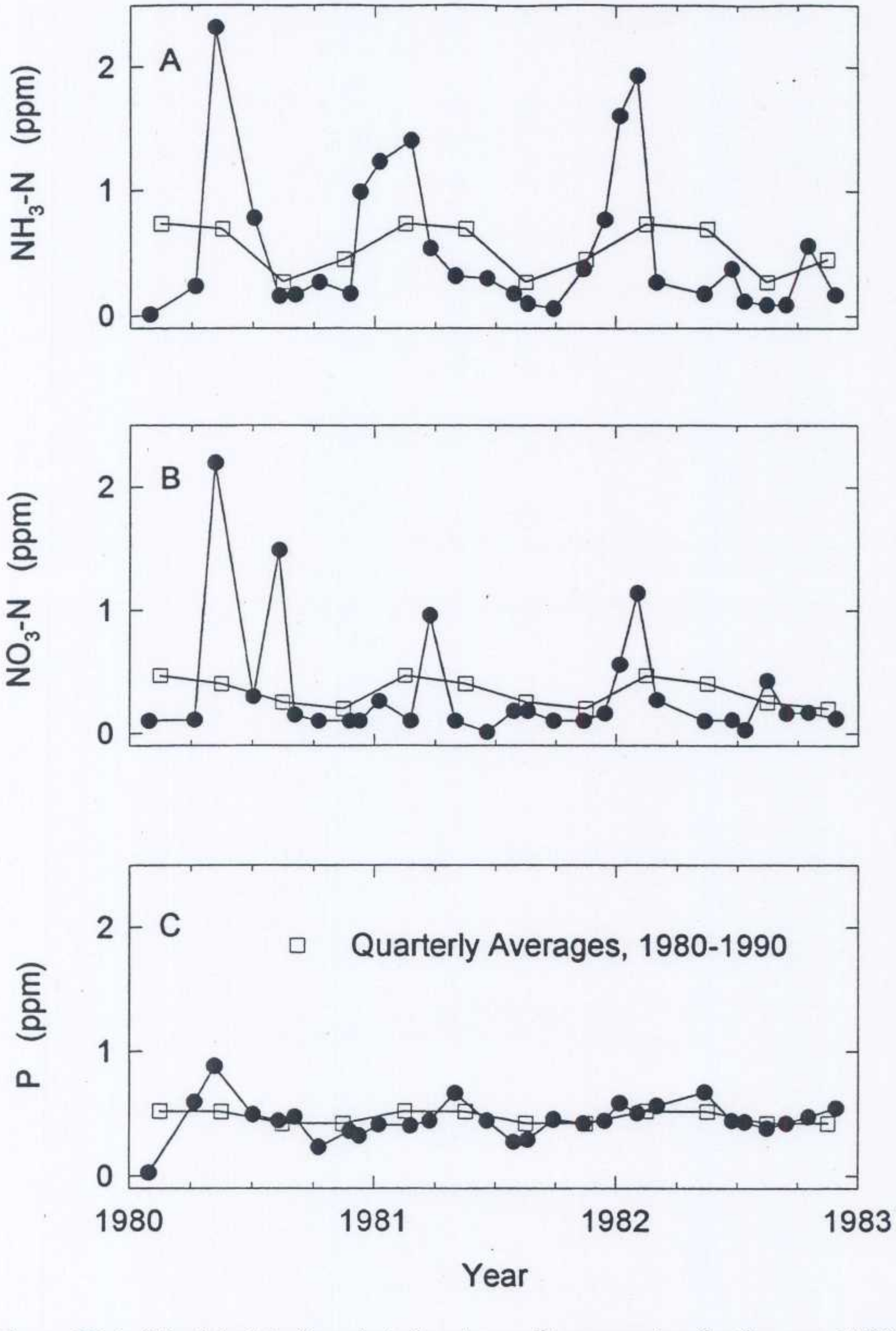

Figure III-6. Monthly data for selected water quality parameters for the years 1980 through 1982, and the corresponding quarterly averages (open symbols). Data for this figure are listed in Table C-7.

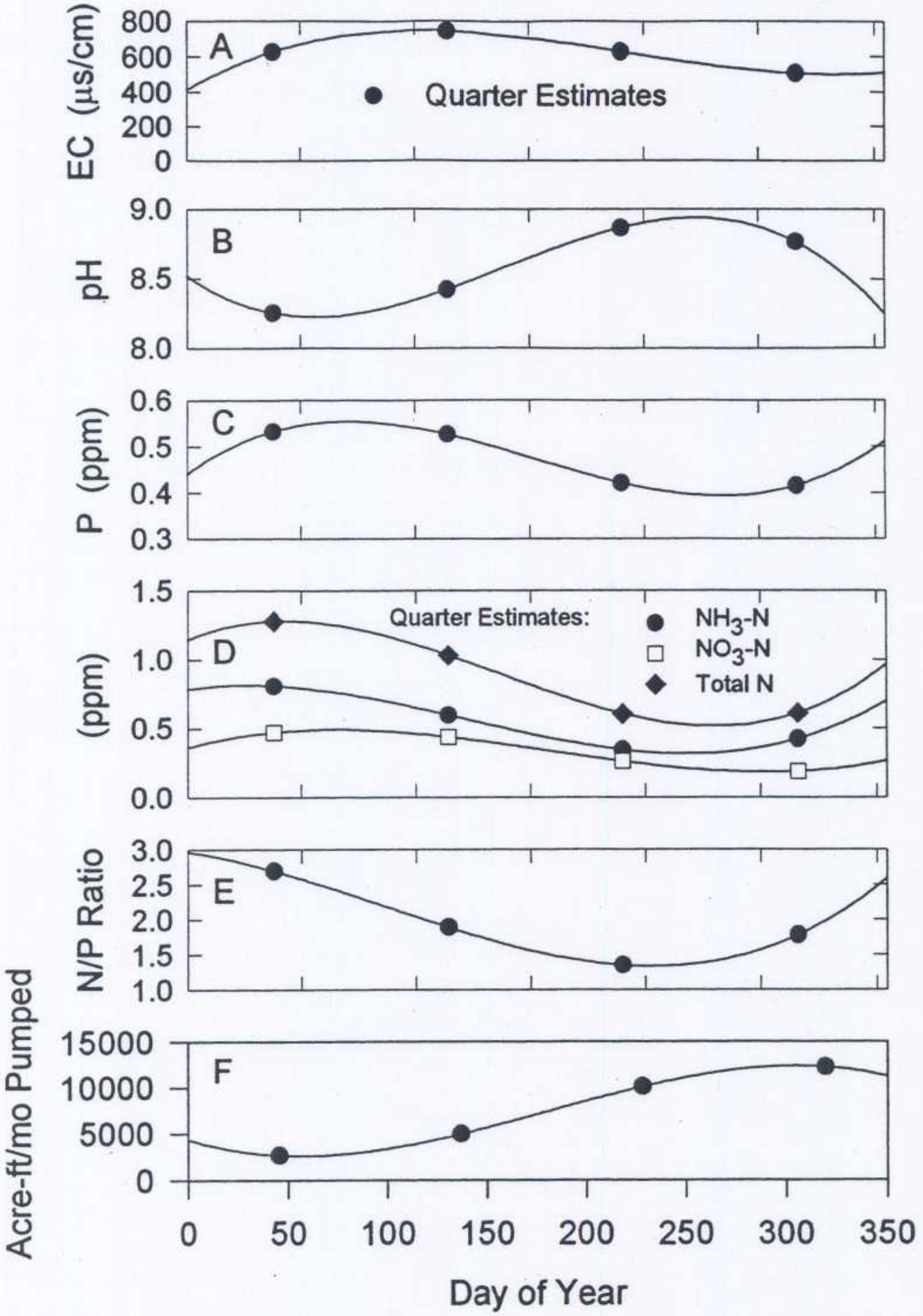

Figure III-7. (A-E) Seasonal changes in selected water quality parameters for the years 1980 through 1990 and regression relationships derived from the data. Points are averages of 40 or more values, grouped quarterly. (F) A fitted curve for pump D rates during the same period. Coefficients for the regression lines are in Table III-1 and III-2. (USBR and TID data). Data for Figure III-7 are listed in Table C-2.

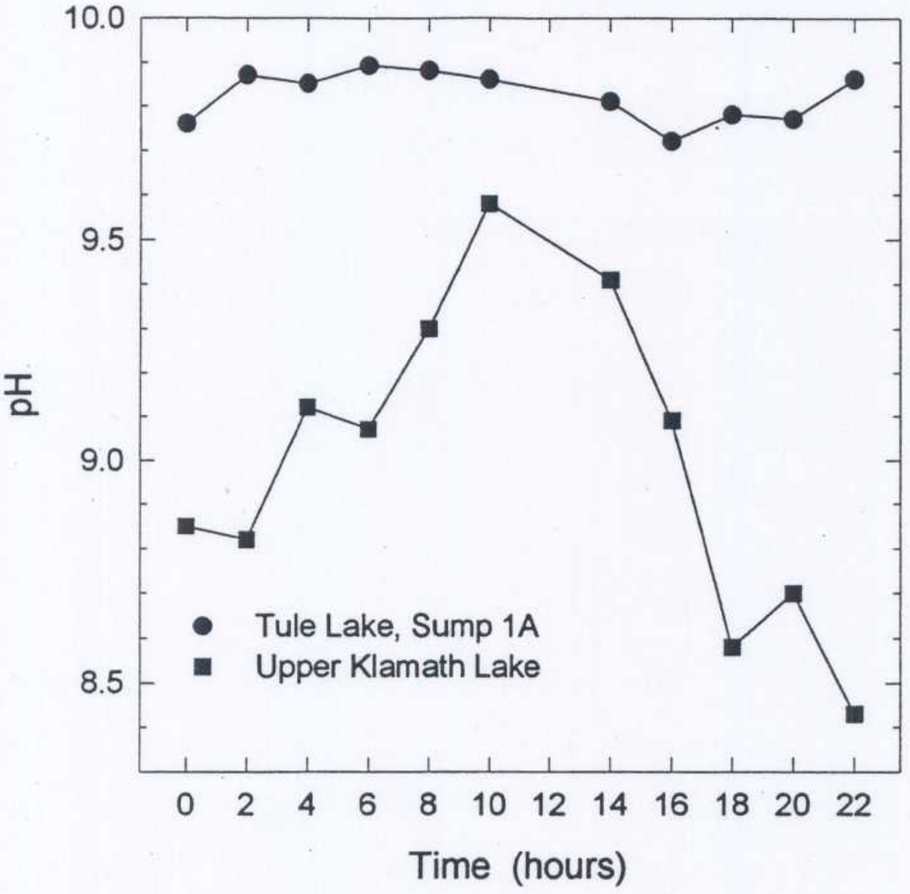

Figure III-8. Day-long measurements of pH made on July 14, 1992, in Upper Klamath Lake and Tule Lake sump 1A (USBR data). Data for this figure are listed in Table C-8.

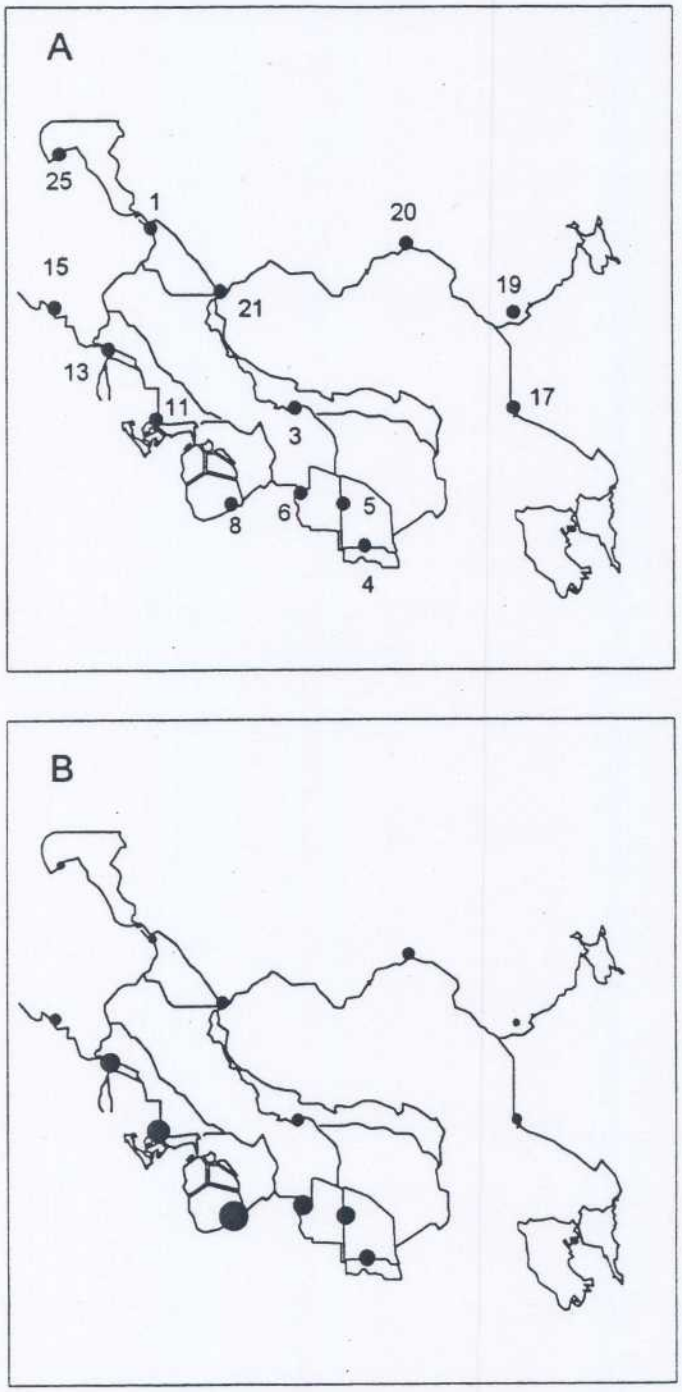

Figure III-9. (A) Sampling locations for the data of Sorenson and Schwarzbach (1991). (B) EC data from Sorenson and Schwarzbach. Diameter of dark circles is proportional to EC (µs/cm).

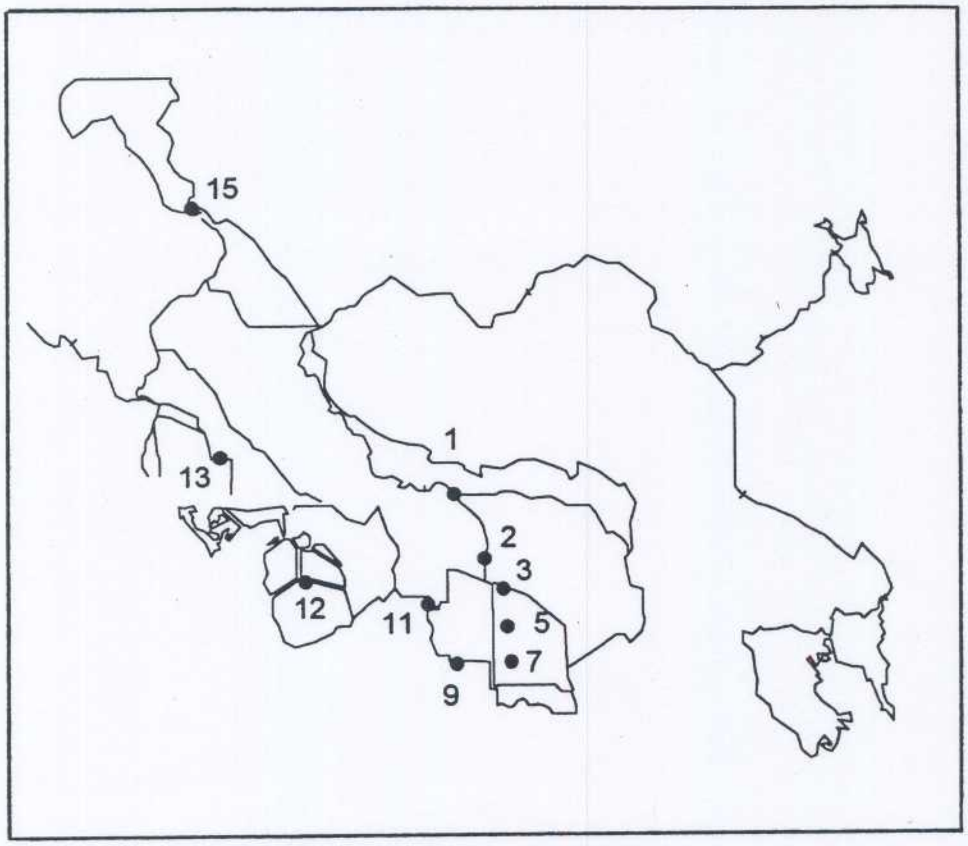

Figure III-10. Sampling locations from MacCoy (1994).

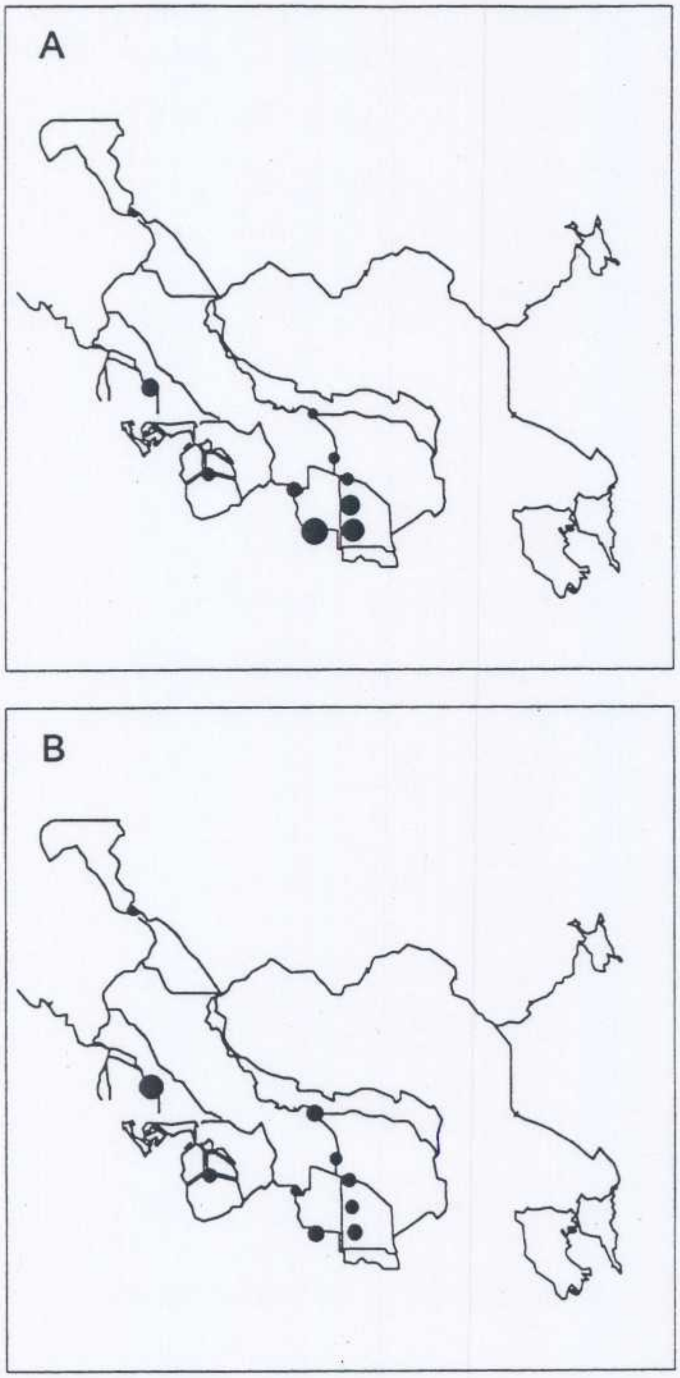

Figure III-11. Relative concentrations of water samples, ploted by location. Diameters of dark circles are proportional to concentration. (A) EC. (B) Concentrations of P. Data for both graphics is from MacCoy (1994).

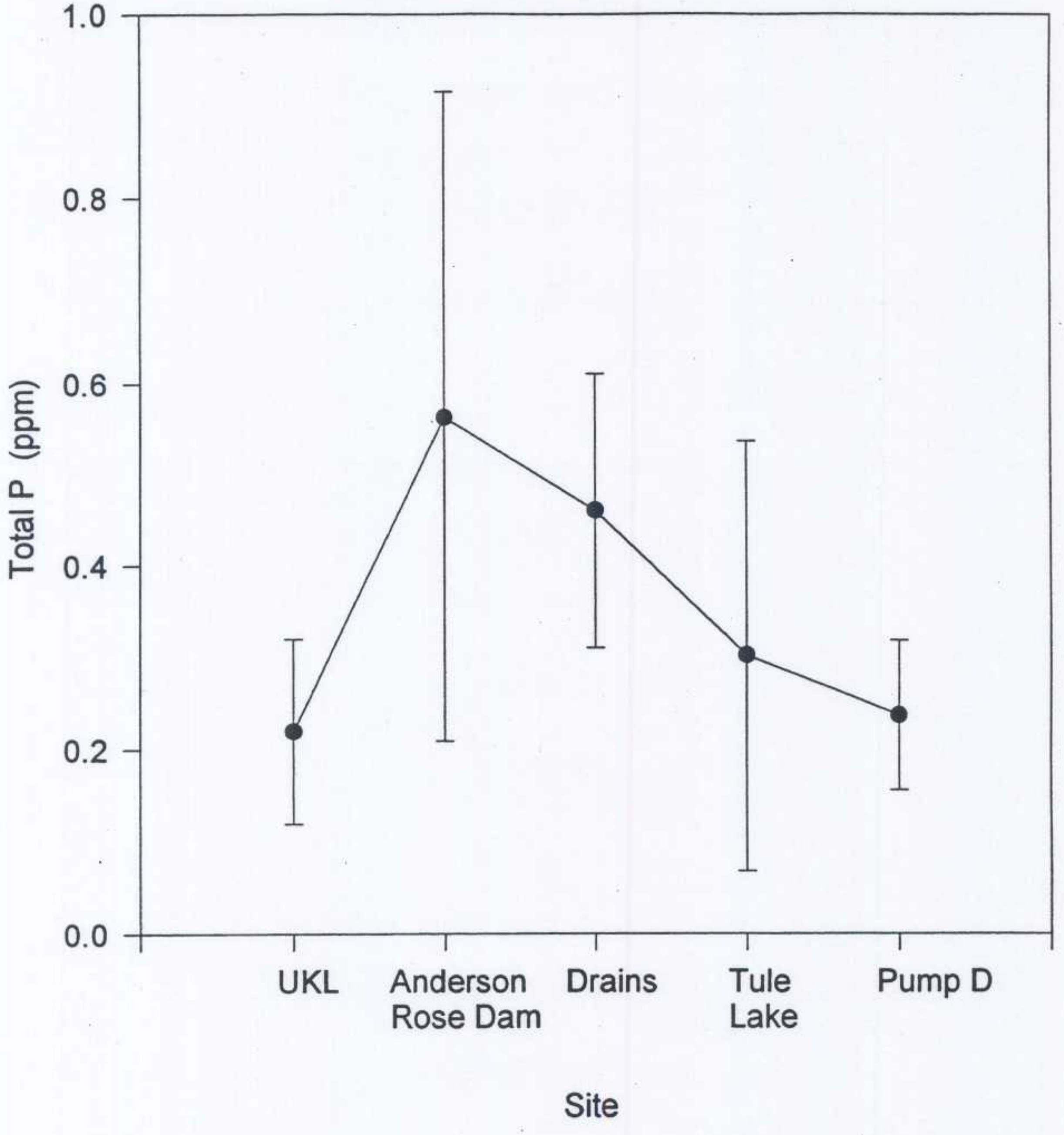

Figure III-12. Changes in P concentration, with location, in the summer of 1992 (MacCoy, 1994).

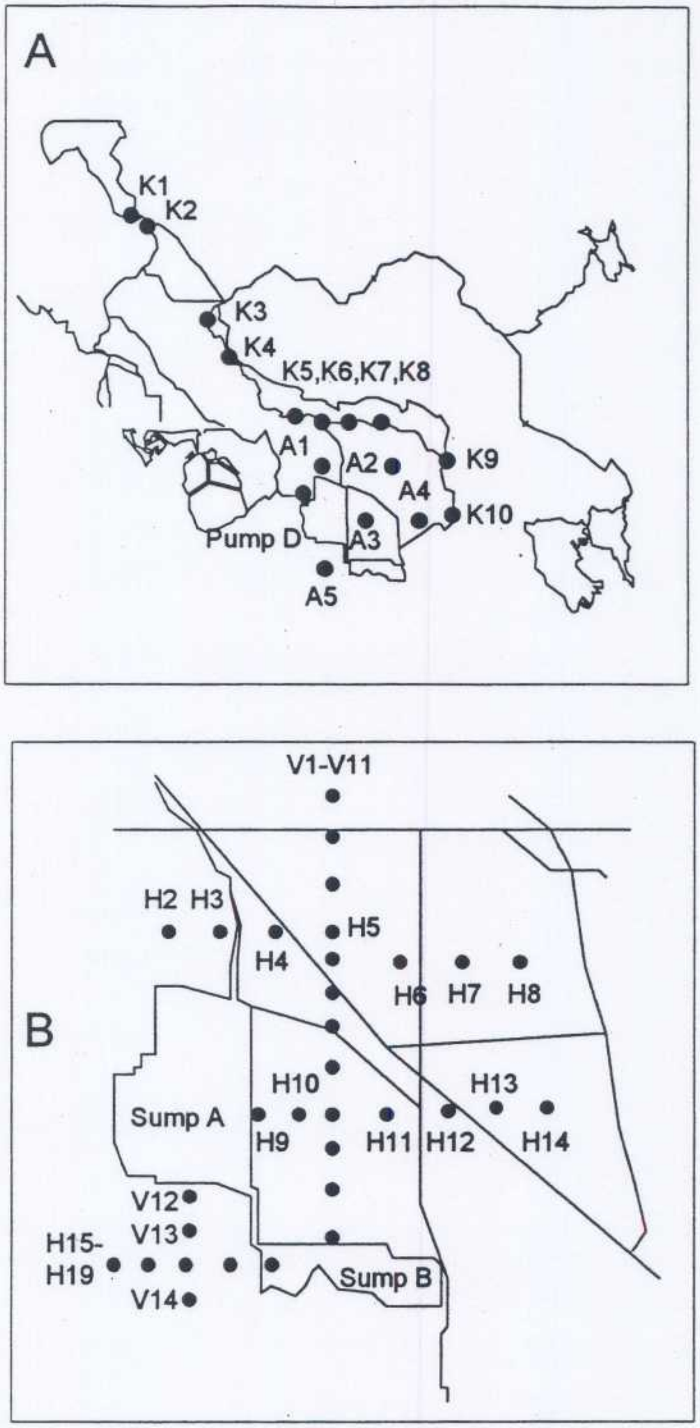

Figure III-13. Sampling locations for data collected by the authors in the TID and elsewhere in the Upper Klamath Basin in 1993.

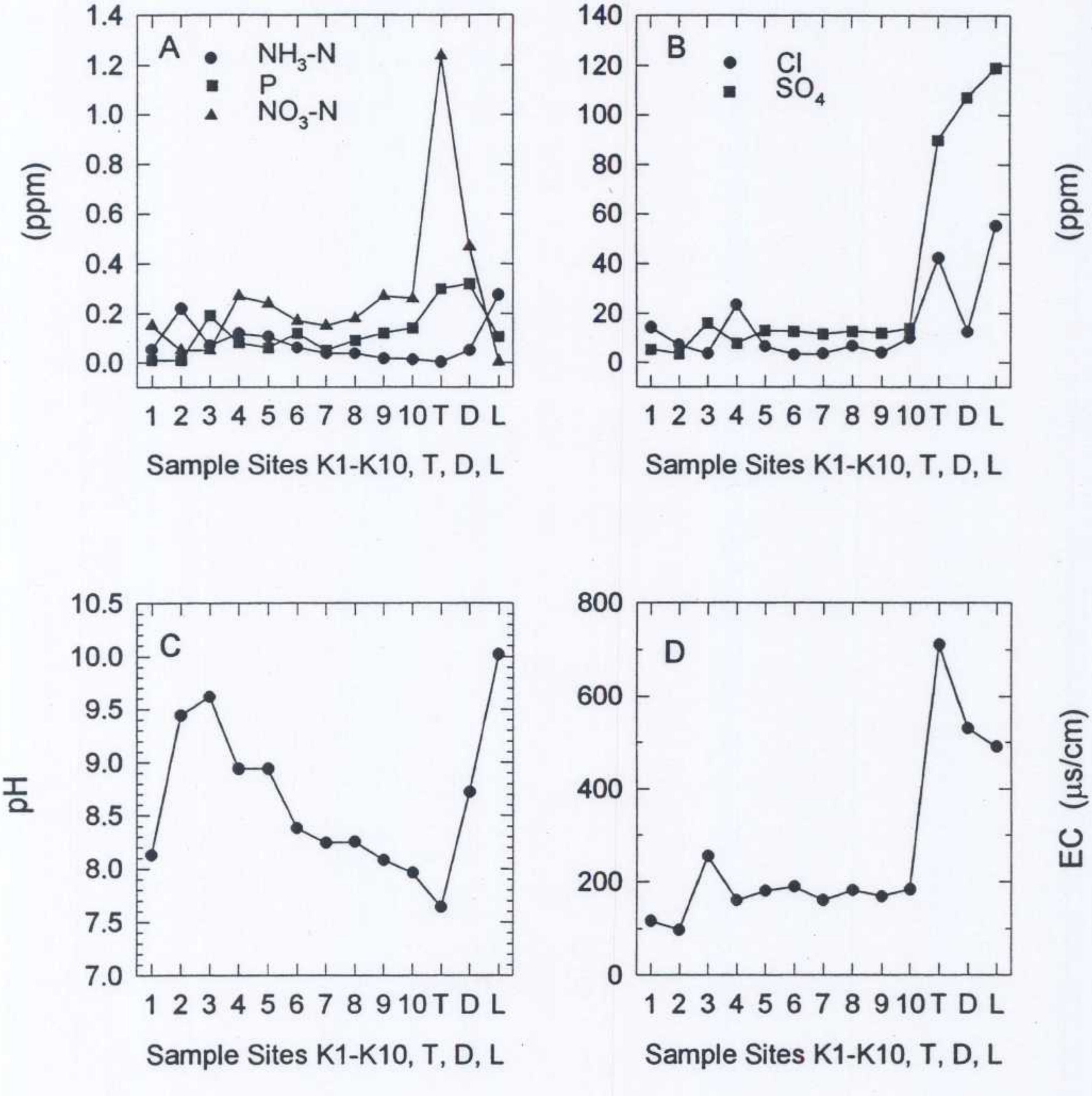

Figure III-14. Water quality data from sample locations indicated in Figure III-13. (A) NH$_3$-N, P, and NO$_3$-N. (B) Cl and SO$_4$. (C) pH. (D) T=tile lines, D=drainage canals, L=the Tule Lake Sumps. Data for Figure III-14 are listed in Table C-9.

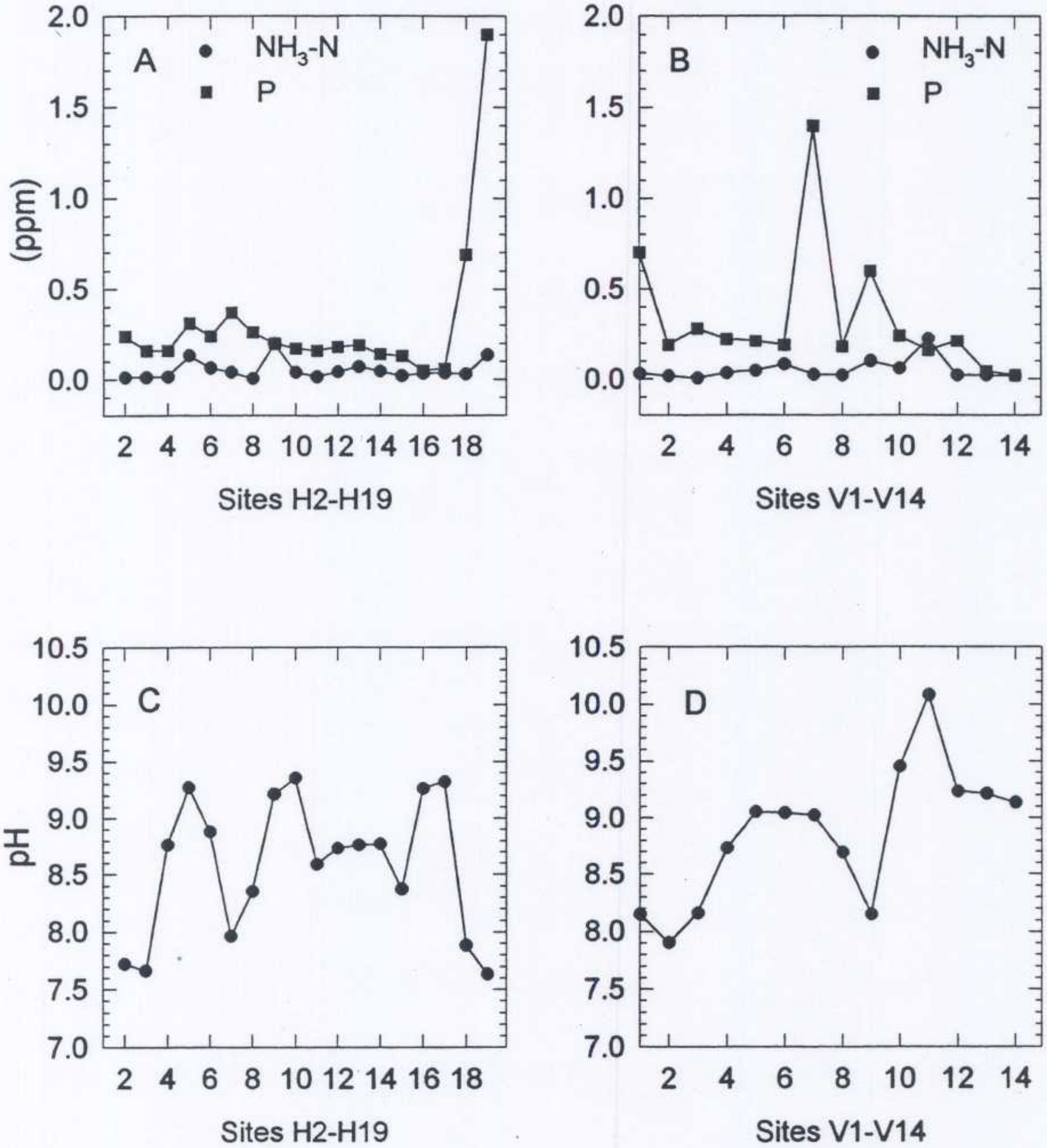

Figure III-15. Water quality data associated with locations indicated in Figure III-13 (B) (1993). Data for Figure III-15 are listed in Table C-12.

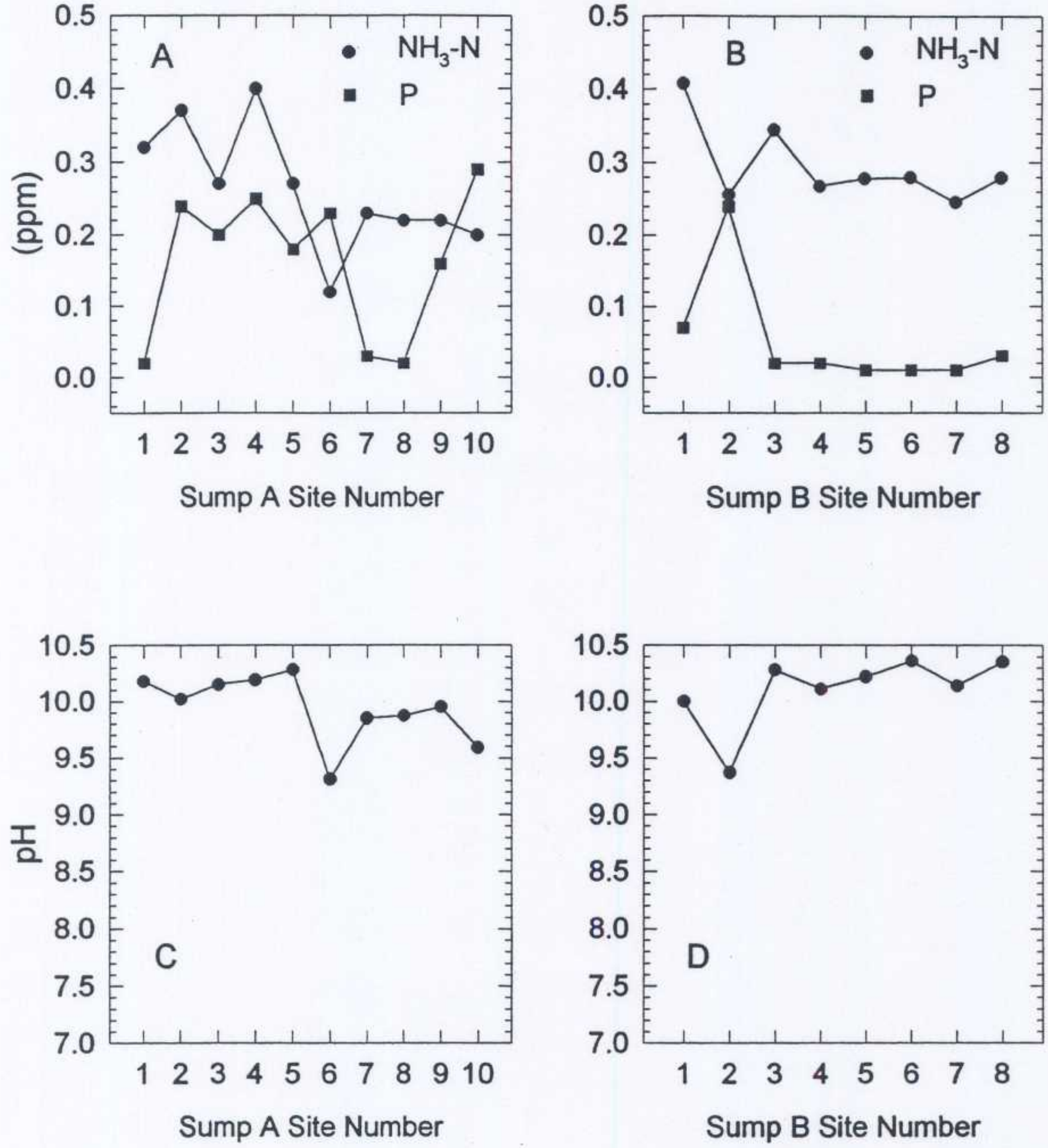

Figure III-16. Water quality data from samples collected in Tule Lake Sumps A and B. Data for this figure are listed in Table C-12.

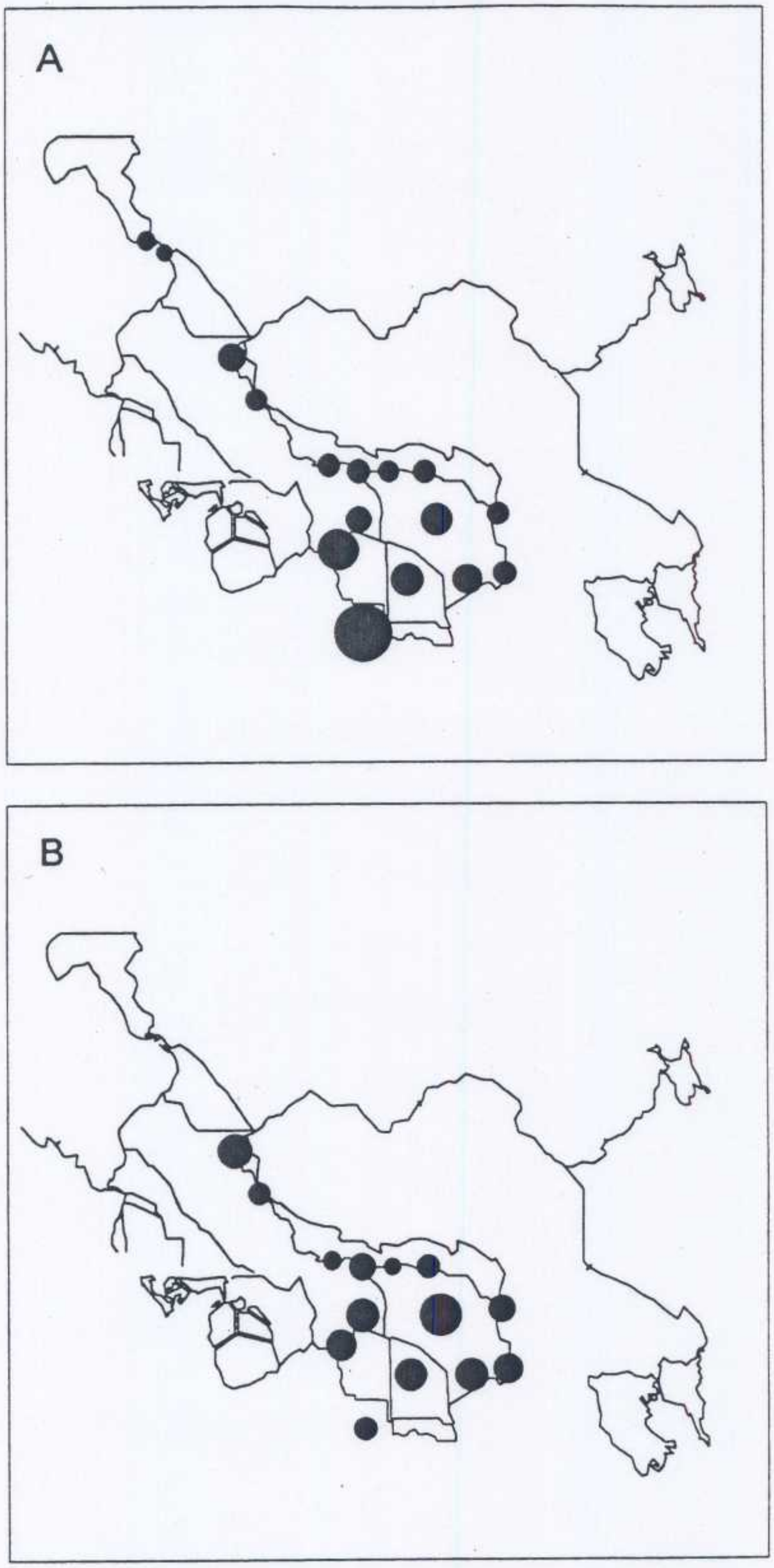

Figure IV-1. Relative concentrations of (A) EC and (B) P, for samples collected at sites identified in Figure III-13 (A). Diameters of the dark circles are proportional to concentration. Data for this figure are listed in Table C-10.

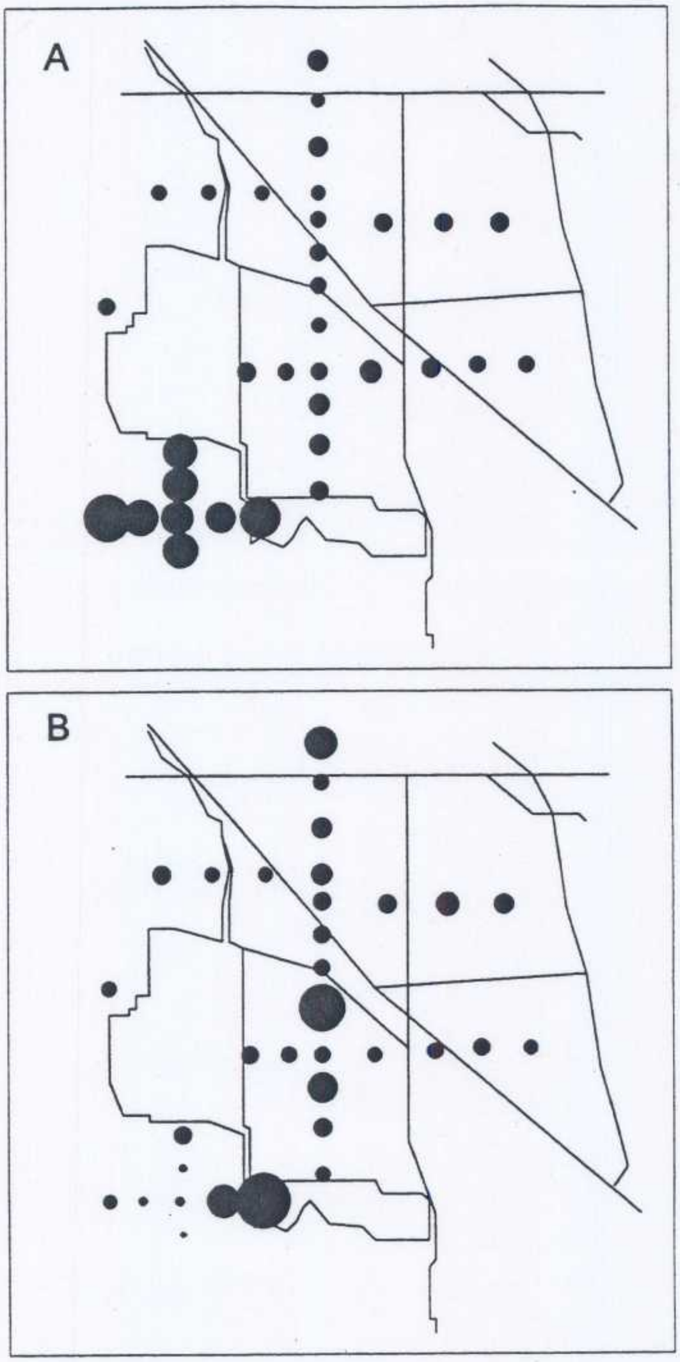

Figure IV-2. Relative concentrations of (A) EC and (B) P, for samples collected at sites identified in Figure III-13 (B). Diameters of dark circles are proportional to concentration. Data for this figure are listed in Table C-11.

Tables

Table II-1. Water Balance for the Tule Lake Sumps 1A and 1B (*acre-ft*).*

Year	Inputs				Outputs			
	1	2	3	4	5	6	7	8
	TID Pumps	**Precipi-tation**	**Lost River**	**Sum of Inputs**	**ET$_0$**	**Pump D**	**Sum of Outputs**	**Balance (7−4)**
1988	68,776	8,743	16,173	93,692	33,193	93,796	126,989	33,297
1989	66,886	12,448	22,404	101,738	31,532	99,145	130,677	28,939
1990	66,515	9,501	21,723	97,739	34,831	95,344	130,175	32,436
1991	62,166	8,158	11,819	82,143	33,723	74,011	107,734	25,591
1992	43,629	7,648	14,654	65,931	32,685	28,361	61,046	−4,885

Notes

Column 1:	Based on TID records (12 months).
Column 3:	Based on TID records. Spill at Anderson-Rose Dam (12 months). Any additional amount of water draining into the river from the Klamath Irrigation District (KID) is not counted.
Column 5:	Calculated based on pan evaporation data and the surface area of the sumps. No additional amount is included for vegetation (cattails and tules).
Column 6:	Based on TID records (12 months).
Column 8:	Drainage from the KID into the TID via both the canals (J and O) and the river estimated at 40,000 acre-ft/yr by Earl Danosky (TID Manager). If included, then inputs to the sumps approximately balance the damage. Unaccounted water draining into the Lost River runs into the sumps directly. It is unclear how unaccounted water entering the canals reaches the sumps.

*Numbers in parentheses indicate which columns are used in calculations.

Table II-2. Water Balance for the TID (*acre-ft*).*

	Inputs						
Column Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Year	**J Canal**	**From Sumps**	**Precipi-tation**	**Other**	**Sum of (1+2)**	**Sum of (1+2+3)**	**Sum of (1 through 4)**
1988	158,057	37,236	16,131	33,297	195,293	211,424	244,721
1989	128,532	31,843	31,389	28,939	160,375	191,764	220,703
1990	141,269	36,652	26,321	32,436	177,921	204,242	236,678
1991	145,310	35,035	15,686	25,591	180,345	196,031	221,622
1992	135,893	29,748	11,129	−4,885	165,641	176,770	171,885

	Outputs			Balances	
Column Number	**8**	**9**	**10**	**11**	**12**
Year	**TID Pumps**	**Crop ET**	**Sum of (8+9)**	**Difference (7−10)**	**Difference (6−10)**
1988	106,012	106,204	212,216	32,505	−792
1989	98,726	121,530	220,256	447	−28,492
1990	103,167	121,751	224,918	11,760	−20,676
1991	97,201	123,411	220,612	1,010	−24,581
1992	73,347	118,418	191,765	−19,880	−14,995

Notes

Column 1:	From TID records.
Column 2:	See all notes Table II-1.
Column 3:	From weather records (average precipitation sump surface area).
Column 4:	See Table II-1, Column 8.
Column 8:	From TID records (12 months).
Column 9:	Crop acres * ET coefficient * ET_0.

*Numbers in parentheses indicate which columns are used in the calculations.

Table II-3. Water-Use Efficiency (WUE) Calculations (%).*

	Irrigation Diversions	Irrigation Diversions	Irrigation Diversions + Precipitation	All Water Inputs		
Column Letter	**A**	**B**	**C**	**D**	**E**	**F**
WUE based on	**Diversions**	**Diversions**	**Diversions + Precipitation**	**All Inputs**	**Negative Balance**	**Best Estimate**
Equation	**9/(1+2)**	**9/(1+2+4)**	**9/(1+2+3)**	**9/7**	**10/7**	**10/6**
Year						
1988	54	47.8	50	43.4	82	100
1989	76	64.2	64	55.1	94	115
1990	68	57.9	60	51.4	89	110
1991	68	59.9	63	68.9	94	113
1992	72	73.7	67	68.9	103	108
Mean (Standard Deviation)	67.6 (8.3)	60.7 (9.4)	60.8 (6.5)	54.9 (9.2)	92.4 (7.7)	109.2 (5.8)

Notes

Column A: WUE=crop use/irrigation diversions
Column B: WUE=crop use/(irrigation diversions +precipitation)
Column C: WUE=crop use/(all inputs)
Column D: Assumes negative balance from Table II-1 is a true input to the district
Column E: WUE=for well-accounted inputs and outputs

*Numbers in equations refer to column numbers from Table II-3.

Table III-1. Regression Parameters for Lines Plotted in Figure III-3.

Pump	Constant	Coefficient for X	Coefficient for X^2	Coefficient for X^3	R^2	Years
5 or 6	3328.9	−35.23	0.136	−0.0016	0.86	1945-62
B	694.0	17.21	−0.1283	0.00026	0.88	1948-63
A	1927.8	−15.77	0.0524	$-4.8*10^{-5}$	0.91	1948-63
C	233.1	43.67	−0.3311	0.00065	0.80	1951-61
D	1183.9	7.36	−0.0670	0.00013	0.53	1945-68
F	456.9	14.51	−0.0586	0.00014	0.12	1946-70

Table III-2. Regression Parameters for Lines Plotted in Figure III-7.*

Parameter	Coefficients			Constant	R^2	Significance Level
	x	x^2	x^3			
EC	6.2370	−0.03440	4.95×10^{-5}	407.500	0.25	.01
pH	−0.0098	9.1×10^{-5}	-1.80×10^{-8}	8.529	0.14	.01
P	0.0030	-2.4×10^{-5}	4.30×10^{-8}	0.437	0.12	.01
NH_3	0.0020	-3.6×10^{-5}	8.11×10^{-8}	0.784	0.09	.05
NO_3	0.0038	-3.0×10^{-5}	5.35×10^{-8}	0.358	0.07	.05
Total N	0.0057	-6.6×10^{-5}	1.35×10^{-7}	1.142	0.11	.05
N:P	−0.0042	-4.8×10^{-5}	1.56×10^{-7}	2.970	0.11	.05
Acre-ft/mo pumped	−66.5886	0.692755	−1.275507	4377.438	0.77	.01

*Regression Parameters are N=60, df=56

Table III-4. Comparison of Analyses of Water Samples from Tule Lake Sump 1A, Collected on Different Dates.

Sampling Year and Months	Milliequivalents per liter (*meq/L*)									
	Cl	SO_4	CO_3	HCO_3	Anions	Na	K	Mg	Ca	Cations
1946* April-May	1.50	8.26	0.10	6.87	16.73	7.98	0.36	4.65	3.70	16.69
1951* Nov.-Dec.	0.90	5.19	0.30	5.65	12.04	6.29	0.60	3.36	1.89	12.14
1988 Aug.**	0.37	3.33	1.73	1.13	6.56	3.83	0.24	1.81	1.25	7.13
1993† Aug.	1.46	2.48	1.25	1.73	6.91	3.05	0.18	1.68	1.48	6.39

*Data from USBR (1942-1974).
**Data from Table B-2, site no. 6 data collected at Tulelake sump 1A, pumping plant D.
†Average values of TA01-TA10 from Table B-6.

Table III-3. Comparison of Analysis of Water Samples, from Tile Lines, Collected in 1958 and 1993.

Sampling Date	Milliequivalent per liter (*meq/L*)									
	Cl	SO_4	CO_3	HCO_3	Anions	Na	K	Mg	Ca	Cations
June 1958*	5.86	55.94	N/A	6.55	68.35	27.37	0.68	18.19	23.51	69.75
Sept. 1958**	2.72	41.30	N/A	7.31	51.44	20.86	0.82	11.51	18.82	52.01
Aug. 1993†	1.19	1.87	1.10	3.05	7.21	2.56	0.18	1.82	2.28	6.84

*Average values of A1-A6 from Table B-3.
**Average value of B1-B6 from Table B-3.
†Average value of TL01-TL07 from Table III-7.

Table III-5. Salt-Balance Study of Sump 2 (TLNWR).

Year	**TDS Imports (I)** (*tons*)	**TDS Exports (E)** (*tons*)	**Exports Minus Imports**	**Ratio[*] E/I**
1963	19,920	27,890	7,970	1.4
1964	13,203	17,181	3,978	1.3
1965	17,919	30,186	12,267	1.7
1967	12,016	16,305	4,289	1.4
1968[†]	1,623	1,016	−582	0.6
1969	1,442	3,140	1,698	2.2
1970	1,516	1,938	416	1.3
1973	1,875	1,745	−129	0.9
Average of 1968 to 1973	1,614	1,960	351	1.25

[*] A ratio >1 indicates that more salt was exported than imported; <1 the reverse.

[†] From 1968 onward, results were expressed as a monthly average.

Source: USBR (1942-1974).

Table III-6. Water Quality Analyses regarding Tile Lines in the TID (August 1993).

Sample	**pH**	**EC** (*µs/cm*)	**NH_3-N** (*ppm*)	**NH_4-N** (*ppm*)	**NO_3-N** (*ppm*)	**P** (*ppm*)
1	8.10	510	0.01	0.18	0.09	0.31
2	7.90	318	0.00	0.05	0.89	0.09
3	7.86	357	0.00	0.15	2.19	0.40
4	7.70	372	0.01	0.30	4.77	0.46
5	7.05	2780 *	0.00	0.10	0.75	0.10
6	7.46	406	0.00	0.25	0.23	0.30
7	7.24	997	0.00	0.26	0.42	0.26
8	7.82	416	0.00	0.12	0.60	0.46
Mean	7.64	710** (483)	0.0025	0.18	1.24	0.298
TL Sump A (Mean of 10)	9.94	500	0.26	0.34	0.01	0.16
TL Sump B (Mean of 8)	10.10	480	0.29	0.37	0.00	0.05

* Primarily SO_4. One sample was extraordinarily high.

** Value in parentheses is average without sample 5.

Table III-7. Average PO_4, NH_3-N, and Specific Conductance of Waters in the Upper Klamath Basin (1959-1963).*

Location	**PO_4 (*ppm*)**	**% Change**	**NH_3-N (*ppm*)**	**% Change**	**EC (*µs/cm*)**	**% Change**
1. Sprague River near Chiloquin	0.131 (13.4,ND)	70**	0.51 (2.81,ND)	196**	189 (294,133)	
2. Williamson River near Chiloquin	0.183 (0.324,ND)	22**	0.33 (0.85,ND)	300**	167 (245,73)	52**
3. Klamath River at HWY 97	0.223 (0.553,ND)		1.00 (3.4,ND)		253 (345,172)	
4. Keno	0.288 (0.672,ND)	29	0.97 (3.75,ND)	(-3)	345 (669,189)	36

* Numerals in parentheses are the mean and range. The abbreviation ND means not detected.

** Calculated with reference to site 3.

Source: Oregon State Sanitary Authority (1964).

Table IV-1. Typical Recommended N and P Fertilizer Rates and Nutrient Removals for Major Crops Grown on the Tulelake Lease Lands.

	Average Fertilizer Rate *			**Removed by the Crop as Yield**	
Crop	**Yield** (*ton/acre*)**	**N** (*lb/acre*)†	**P** (*lb/acre*)	**N** (*lb/acre*)	**P** (*lb/acre*)
Potatoes	21.00	180	26	227	40
Barley	2.75	70	18	176	29
Wheat	3.25	120	18	189	33
Oats	2.50	60	18	179	31
Sugarbeets	21.00	80		179	19
Alfalfa	6.00		18	360	31
Onions	20.00	240	26	150	24

* Typical fertilizer recommendations based on U.C. and Oregon State University recommendations for the crops and the area. Figures represent average or typical recommendations only. Specific recommendations will vary from field to field, depending on the specific yield goals, crop variety, crop rotation, soil type, and residual soil fertility.

** Average yields of crops grown in the Tulelake lease lands. Data composited from reports of Siskiyou Agricultural Commissioner, TID, and U.C. Tulelake Farm Advisor. Yields will vary from field to field and from year to year.

† The pounds of N removed from the field with the harvest of crop. Calculated by multiplying the average yield by the percentage of the nutrient typically found in the yield portion of the crop. Alfalfa recovers available soil N and fixes atmospheric N to meet its needs if soil N is insufficient. It is not possible to distinguish between the two sources without careful analysis. These analyses have not been done at Tulelake to date, so we have not partitioned alfalfa N, atmospheric, and soil sources.

Table IV-2. Expected Fertilizer Input and Crop Nutrient Removal from the Tulelake Lease Lands.

Crop	Acreage*	Nitrogen (*lb×1,000*)			Phosphorus (*lb ×1,000*)		
		Expected Fertilizer Inputs**	Expected Nutrient Removal†	Balance (Input–Removal)‡	Expected Fertilizer Inputs**	Expected Nutrient Removal†	Balance (Input–Removal)‡
Potatoes	2,456	442	558	–115	65	91	–26
Barley	7,913	554	1,393	–839	139	230	–91
Wheat	1,776	213	336	–123	31	59	–28
Oats	2,326	140	416	–277	41	72	–31
Sugarbeets	443	35	79	–44		8	–8
Alfalfa[2]	428		154	–154	8	13	–6
Onions	475	114	71	43	13	11	1
Totals	15,817	1,498	3,007	–1,509	297	532	–191

* Average acreage of crops grown in the lease lands, 1991-1993.

** Total application of fertilizer N and P on the Tulelake lease lands, by crop, if typical fertilizer rate recommendations are followed.

† Expected nutrient removal from the lease lands, by crop, if average yields are attained. See Table II-1.

‡ Nutrients added as fertilizer minus nutrients removed by the harvest of the crop.

Appendix A: Water Supplies in the Klamath Project[18]

The Tulelake Basin has no natural outlet to the sea. Before it was reclaimed for agriculture and urban settlement, approximately 96,000 acres were seasonally submerged. Because of its agricultural potential, in 1905 the USBR began constructing irrigation and drainage structures to divert water from the basin and permit agriculture. The Tulelake Basin, together with Oregon land affected by flooding of the Klamath River, were organized into the Klamath Federal Reclamation Project. In 1906 a homestead program was started, and the first water delivered to homesteaded lands in 1909. Upon drainage and reclamation of the Tulelake area, additional homestead openings were allocated there, the last just after the Second World War. Altogether, irrigation service is provided to about 200,000 acres of private and public land in the Klamath Project.

The watershed area included in the Klamath Project contains approximately 9,500 square miles, the majority of which lies within Modoc and Siskiyou Counties in California, and Klamath County, Oregon. The two major water sources for the project are Upper Klamath Lake and Clear Lake. Clear Lake is connected to Tule Lake by the Lost River, and forms a closed basin. The largest of these sources is UKL, which forms a reservoir behind the Link River Dam. The reservoir has a capacity of 766,000 acre-feet. The Klamath River is fed by this lake and by diversions from the Lost River. Lost River, in turn, is supplied primarily by Clear Lake Reservoir and Gerber Reservoir. Except for flood events, there is no direct connection between the Lost River and Klamath River drainage systems.

The water control structures of the project include three dams. The Link River Dam is located on the Link River, at the head of the Klamath River, and it regulates the flow from Upper Klamath Lake Reservoir. Gerber Dam is located on Miller Creek, a tributary of the Lost River. The reservoir holds 94,300 acre-feet. The flow into Tule Lake is reduced by this structure. Clear Lake Dam and Reservoir, located at the primary source of the Lost River (in California), provides storage for irrigation and also reduces flow into Tule Lake.

Four diversion dams are included in the project: Malone Diversion Dam, Miller Creek Diversion Dam, Lost River Diversion Dam, and Lower Lost River Diversion Dam. Malone Diversion Dam, on Lost River, and Miller Creek Diversion Dam, on Miller Creek, divert water to serve land in Langell Valley. Lost River Diversion Dam controls downstream flow on the Lost River and consequently prevents expansion of Tulelake by diverting excess water to the Klamath River through the Lost River Diversion Channel. This channel serves to convey excess water during peak flows from the Lost River

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[18] Adapted with permission from Wilson et al., 1961.

to the Klamath River. Flow can also be reversed during periods of insufficient flow in the Lost River, with Klamath River water compensating for irrigation diversions from the Lost River, upstream in Oregon. During the irrigation season water is frequently diverted to the Lost River for use in the Tulelake area. Lost River water is used primarily in the Langell Valley and within the KID. The Lower Lost River Diversion Dam diverts water from Lost River to provide an irrigation supply for the land reclaimed from the Tule Lake bed, including the Tulelake lease lands.

Twenty-eight pumping plants are included in the project. Their power ranges from 15 to 3,650 hp, their lifts range from 4 to 67 feet, (1.2 to 20.4 m), and their capacities are from 3 to 300 cfs. There are 13 canals totaling 120 miles in length, with diversion capacities from 100 to 300 cfs. Laterals total 463 miles and drains, 340 miles.

The major portion of the Tulelake Division of the Klamath Project consists of three parts containing a total of 62,280 irrigable acres. Parts 1 and 2 contain 44,081 irrigable acres; Part 3, consisting of the Tulelake Lease Lands and Southwest Sump, contain 18,199 irrigable acres. The bulk of the water is obtained from UKL and a lesser amount from the Lost River at the Lost River Diversion Dam. Most of this water is delivered through the J Canal, but some Tulelake farmers use water directly from the Lost River and Tule Lake sumps. Additionally, some water enters the TID from surface drains in the KID and in the D Canal. (Water in D Canal is also derived from drainage water from the KID.) Pumping plants 1 through 6 are drainage pumps which deliver return flow from land in Tulelake Division Part 1 into the restricted sumps or into the N Canal. Water in the N Canal is for use on the lease lands. The drainage water pumped into the N Canal is diluted with water from the restricted sump. Pumping plants S and C pump drainage water from the Tulelake lease lands into the interconnected restricted sumps. Pumping plant D, in turn, delivers water from the restricted sump through a 6,600 foot concrete-lined tunnel (250 cfs capacity) to LKL. Additional pumps lift the water from LKL back into the Klamath River, completing the circuit.

Prior to 1957 the operation and maintenance of irrigation and drainage works of the Tulelake Division were under the jurisdiction of the USBR. In January 1957 the dikes, distribution, and drainage systems of this division were transferred to the newly formed TID.

Appendix B: 1993 Data Collected by the Authors

Table B-1. 1958 Water Quality Data regarding Tile Lines in the Irrigated Lease Lands (*meq/L*).

Location*	Cl	SO_4	HCO_3	Anions	Na	K	Mg	Ca	Cations
A1	9.30	68.68	7.08	85.06	36.18	0.67	21.66	28.00	86.51
A2	6.48	57.18	7.00	70.66	30.78	0.67	18.66	23.20	73.31
A3	8.79	70.00	8.45	87.24	36.18	1.02	22.66	28.00	87.86
A4	3.10	49.62	4.91	57.63	22.17	0.51	16.17	20.60	59.45
A5	3.27	48.76	5.94	57.97	21.74	0.67	16.17	21.10	59.68
A6	4.20	41.38	5.94	51.52	17.17	0.51	13.83	20.15	51.66
Average	5.86	55.94	6.55	68.35	27.37	0.68	51.66	23.51	69.75
SD	2.51	10.53	1.12	13.83	7.41	0.17	3.15	3.32	13.88
B1	3.66	40.64	6.62	50.94	21.65	0.82	10.58	18.70	51.75
B2	3.29	49.55	7.19	60.11	24.61	1.02	13.58	21.60	60.81
B3	3.04	46.33	7.65	57.12	23.91	0.82	14.58	18.37	57.68
B4	2.31	40.75	6.51	49.71	19.35	0.82	11.00	19.20	50.37
B5	2.03	37.63	7.54	47.44	18.78	0.82	9.67	18.70	47.97
B6	1.97	32.91	8.34	43.34	16.87	0.61	9.67	16.35	43.50
Average	2.72	41.30	7.31	51.44	20.86	0.82	11.51	18.82	52.01
SD	2.56	41.41	7.42	51.43	20.73	0.82	11.67	18.84	52.06

* Samples A1-A6 were collected on June 10, 1958. Samples B1-B6, respectively, were collected on September 16, 1958, at the same locations as were samples A1-A6.
Source: Adapted from Wilson et al. (1961).

Table B-2. Major Dissolved Constituents in Klamath Basin Waters, August 1988 (*meq/L*).*

Site No.**	**Cl**	**SO_4**	**CO_3**	**HCO_3**	**Anions**	**Na**	**K**	**Mg**	**Ca**	**Cations**
1	0.08	0.13	0.47	0.54	1.22	0.48	0.05	0.33	0.36	1.22
3	0.14	0.38	0.00	2.34	2.86	1.07	0.10	0.91	0.90	2.98
4	0.21	1.40	0.17	3.11	4.89	2.13	0.13	1.32	1.45	5.03
5	0.21	2.50	0.00	3.69	6.40	2.22	0.13	1.89	2.54	6.78
6	0.37	3.33	1.73	1.13	6.56	3.83	0.24	1.81	1.25	7.13
6s	0.37	3.54	N/A	N/A	3.82	3.83	0.25	1.81	1.25	7.14

* Water samples were collected from August 17 to August 23, 1988.
** Location of sampling sites
1: Link River below Link River Dam 5: Tule Lake sump 1A at pump 11
3: J Canal below Anderson-Rose Dam 6: Tule Lake sump 1A at pump D
4: Tule Lake sump 1B at pump C 6s: Tule Lake sump 1A at pump D
Source: Sorenson and Schwarzbach, (1991).

Table B-3. 1993 Analyses of Water Samples from Tile Lines (*meq/L*).*

Location	Cl	SO_4	CO_3	HCO_3	Anions	Na	K	Mg	Ca	Cations
TL01	0.37	0.64	0.96	2.56	4.53	2.37	0.27	2.14	1.65	6.43
TL02	1.34	0.50	1.12	2.18	5.14	2.21	0.14	1.37	1.32	5.04
TL03	1.94	0.58	0.64	2.88	6.04	1.77	0.19	1.35	1.49	4.80
TL04	1.19	0.64	2.88	3.68	8.39	4.37	0.11	1.33	2.34	8.16
TL05	1.88	1.36	0.32	3.04	6.60	1.64	0.13	1.38	2.26	5.42
TL06	0.39	8.48	0.80	3.52	13.19	4.21	0.21	3.33	4.68	12.42
TL07	1.25	0.87	0.96	3.52	6.60	1.37	0.17	1.86	2.21	5.61
Average	1.19	1.87	1.10	3.05	7.21	2.56	0.18	1.82	2.28	6.84
SD	0.58	2.71	0.77	0.52	2.69	1.14	0.05	0.68	1.05	2.51

* Water samples were collected on August 18, 1993, in the TID.

Table B-4. 1993 Analyses of Water Samples from Drainage Channels (*meq/L*).*

Location	Cl	SO_4	CO_3	HCO_3	Anions	K	Na	Mg	Ca	Cations
H2	0.11	0.36	0.48	1.30	2.25	1.00	0.12	0.86	0.91	2.89
H3	0.13	0.47	0.00	1.92	2.52	1.00	0.13	0.87	0.97	2.97
H4	0.09	0.35	0.48	1.52	2.44	0.98	0.11	0.86	0.95	2.90
H5	0.16	0.26	0.32	1.60	2.34	1.06	0.16	0.74	0.80	2.76
H6	0.15	0.70	0.64	2.32	3.81	1.49	0.26	1.14	1.20	4.07
H7	0.11	0.45	0.00	3.20	3.76	1.22	0.16	1.30	1.27	3.95
H8	0.08	0.49	0.00	3.44	4.01	1.85	0.26	1.55	1.32	4.97
H9	0.24	1.21	0.32	2.24	4.01	1.60	0.20	1.47	1.46	4.72
H10	0.09	0.65	0.64	1.60	2.98	1.23	0.22	0.97	1.13	3.54
H11	0.06	1.47	0.32	3.36	5.21	1.66	0.15	1.58	1.82	5.21
H12	0.28	0.61	0.32	2.72	3.93	1.62	0.28	1.28	1.40	4.58
H13	0.23	0.37	0.00	2.24	2.84	1.06	0.18	1.02	1.09	3.35
H14	0.24	0.34	0.32	2.40	3.30	0.98	0.14	1.20	1.12	3.44
H15	0.92	12.66	0.32	7.20	21.10	9.44	0.39	6.21	3.91	19.96
H16	0.53	6.84	1.92	2.24	11.53	5.68	0.35	4.03	1.45	11.51
H17	0.49	5.63	1.60	3.28	11.00	5.02	0.28	3.75	1.65	10.70
H18	0.42	3.19	0.00	6.08	9.69	4.73	0.37	2.83	1.69	9.62
H19	1.71	7.26	1.28	6.96	17.21	8.00	1.00	4.53	3.82	17.35
Average	0.34	2.41	0.50	3.09	6.33	2.76	0.27	2.01	1.55	6.58
SD	0.39	3.36	0.54	1.76	5.39	2.57	0.20	1.54	0.86	5.03

* Samples collected on July 14, 1993 (see Figure III-11 for sample locations).

Table B-5. 1993 Analyses of Water Samples from Drainage Channels(*meq/L*).*

Location	**Cl**	**SO_4**	**CO_3**	**HCO_3**	**Anions**	**K**	**Na**	**Mg**	**Ca**	**Cations**
V1	0.22	0.44	0.48	3.36	4.50	1.14	0.21	1.86	1.69	4.90
V2	0.06	0.32	0.64	1.44	2.46	0.75	0.12	0.81	0.92	2.60
V3	0.12	0.60	0.64	2.72	4.08	1.21	0.16	1.47	1.74	4.57
V4	0.13	0.42	0.64	1.84	3.03	1.41	0.31	1.05	1.13	3.90
V5	0.13	0.52	0.16	3.04	3.85	1.19	0.13	1.05	1.11	3.49
V6	0.10	0.69	0.16	1.84	2.79	0.94	0.10	0.94	1.13	3.10
V7	0.10	0.65	0.80	5.60	7.15	2.93	0.17	2.47	2.29	7.86
V8	0.10	0.61	0.16	2.16	3.03	1.13	0.11	1.22	1.39	3.84
V9	0.18	1.34	0.96	2.16	4.64	1.64	0.18	1.53	1.89	5.24
V10	0.13	1.38	1.12	1.52	4.15	1.56	0.15	1.48	1.79	4.98
V11	0.13	1.15	0.64	1.36	3.28	1.14	0.11	0.90	1.61	4.03
V12	0.60	6.34	0.64	4.16	11.74	5.25	0.32	4.04	2.62	12.22
V13	0.57	6.47	1.76	3.04	11.84	5.55	0.33	4.20	2.33	12.43
V14	0.68	6.67	0.64	4.32	12.31	5.58	0.32	4.03	2.21	12.14
Average	0.23	1.97	0.67	2.75	5.63	2.24	0.19	1.93	1.70	6.09
SD	0.21	2.38	0.41	1.21	3.48	1.75	0.08	1.20	0.51	3.44

* Samples collected on July 14, 1993 (see Figure III-11 for sample locations).

Table B-6. 1993 Analyses of Water Samples from Tule Lake Sump 1A (*meq/L*).*

Location	Cl	SO_4	CO_3	HCO_3	Anions	Na	K	Mg	Ca	Cations
TA01	0.46	5.52	1.28	1.12	8.38	5.25	0.34	2.07	1.23	8.89
TA02	1.20	1.35	1.60	0.80	4.95	2.03	0.13	0.95	1.18	4.29
TA03	1.48	0.96	0.96	1.76	5.16	2.77	0.14	0.67	1.21	4.79
TA04	1.35	0.87	1.60	1.28	5.10	1.90	0.17	1.14	1.38	4.58
TA05	2.06	0.60	1.28	1.28	5.22	2.35	0.10	0.89	1.26	4.59
TA06	1.78	0.55	0.32	2.24	4.89	2.10	0.11	1.10	1.38	4.70
TA07	1.35	5.13	1.28	2.88	10.64	4.76	0.23	3.29	1.61	9.89
TA08	1.83	4.61	1.28	2.24	9.96	4.37	0.24	2.85	1.45	8.91
TA09	1.39	2.63	1.60	0.96	6.58	2.39	0.15	1.73	1.71	5.98
TA10	1.66	2.55	1.28	2.72	8.21	2.57	0.19	2.14	2.38	7.27
Average	1.46	2.48	1.25	1.73	6.91	3.05	0.18	1.68	1.48	6.39
SD	0.42	1.85	0.36	0.71	2.10	1.18	0.07	0.84	0.34	2.05

* Samples collected on August 10, 1993 (see Figure III-11 for sample locations).

Table B-7. 1993 Analyses of Water Samples from Tule Lake Sump 1B (*meq/L*).*

Location	Cl	SO_4	CO_3	HCO_3	Anions	Na	K	Mg	Ca	Cations
TB01	0.14	1.97	0.96	2.40	5.47	2.80	0.27	2.14	1.65	6.86
TB02	1.71	1.59	0.96	2.56	6.82	2.21	0.18	1.79	1.90	6.08
TB03	1.90	3.08	1.28	1.60	7.86	4.41	0.18	1.27	0.95	6.80
TB04	1.80	2.37	0.96	1.12	6.25	3.81	0.24	0.56	0.76	5.37
TB05	1.60	1.50	1.28	0.64	5.02	2.66	0.22	0.53	1.42	4.83
TB06	1.39	0.64	1.28	0.96	4.27	1.94	0.41	0.89	1.05	4.29
TB07	1.44	2.30	1.28	1.60	6.62	3.67	0.35	1.40	1.17	6.59
TB08	1.42	2.39	1.60	1.76	7.17	3.44	0.16	1.66	1.40	6.67
Average	1.43	1.98	1.20	1.58	6.19	3.12	0.25	1.28	1.29	5.94
SD	0.52	0.69	0.21	0.63	1.11	0.80	0.08	0.55	0.35	0.93

* Samples collected on August 10, 1993 (see Figure III-11 for sample locations).

Table B-8. Percentage of Un-ionized NH_3 at Different Temperatures and H Ion Concentrations.

Temperature (°C)	pH						
	7.0	**7.5**	**8.0**	**8.5**	**9.0**	**9.5**	**10.0**
10	0.19	0.59	1.83	5.56	15.70	37.10	65.10
20	0.40	1.24	3.82	11.20	28.40	55.70	79.90
30	0.80	2.48	7.45	20.30	44.60	71.80	89.10

Source: Thurston et al. (1979).

Appendix C: Data for Figures

Table C-1. Data for Figure III-1.*

Year	EC (*µs/cm*)	Year	EC (*µs/cm*)
1945	1303	**1963**	1705
1946	1607	**1964**	1564
1947	1848	**1965**	1468
1948	1497	**1968**	1485
1949	1357	**1973**	1218
1950	1509	**1974**	1034
1951	1554	**1975**	1042
1952	1399	**1980**	636
1953	1258	**1981**	519
1954	1449	**1982**	615
1955	2039	**1983**	646
1956	1564	**1984**	722
1957	1218	**1985**	716
1958	1185	**1986**	516
1959	1162	**1987**	703
1960	1468	**1988**	653
1961	1358	**1989**	691
1962	1533	**1990**	531

* Adjusted mean electroconductivities for water at pump D

Table C-2. Data for Figure III-7.*

Quarter	EC (*µs/cm*)	pH	P (*ppm*)	NH_3-N (*ppm*)	NO_3-N (*ppm*)	Total N (*ppm*)	N:P Ratio
1	625	8.25	0.53	0.81	0.47	1.28	2.69
2	744	8.42	0.53	0.60	0.44	1.03	1.89
3	628	8.87	0.42	0.34	0.26	0.60	1.34
4	505	8.77	0.42	0.42	0.19	0.61	1.78

* Quarterly estimates of water-quality parameters, based on cubic regression model

Table C-3. Data for Figures III-2 and III-3.

Sample Site	Date	Day of Year	EC (μs/cm)	HCO_3 (*meq/L*)	PO_4 (*meq/L*)
Pump 5 or 6	05/10/45	130	790	5.42	0.05
	08/23/45	235	475	3.63	0.04
	05/02/46	122	786	5.25	0.04
	08/10/46	222	515	4.00	0.04
	11/22/46	326	977	7.46	0.09
	05/14/47	134	686	4.96	0.06
	11/12/47	316	946	6.79	
	05/01/50	121	656	4.50	
	11/18/50	322	936	6.85	
	04/08/51	98	1140	5.65	
	12/01/51	335	894	6.95	
	04/25/55	115	709		
	10/29/56	302	830		
	07/21/57	202	442		
	06/23/59	174	653		
	07/21/61	202	501		
	07/23/62	204	483		
Pump A	07/12/48	193	544	3.85	
	07/25/49	206	526	3.95	
	08/13/51	225	493	3.95	
	09/29/52	272	562		
	04/23/53	113	737		
	08/03/53	215	450		
	04/28/54	118	736		
	09/07/54	250	481		
	06/06/58	157	541		
	06/26/60	177	474		

Table C-4. Data for Figures III-2 and III-3.

Sample Site	Date	Day of Year	EC (μs/*cm*)	HCO_3 (*meq/L*)	PO_4 (*meq/L*)
Pump B	07/12/48	193	1260	6.81	
	12/06/49	340	1870	10.45	
	07/25/49	206	1010	5.72	
	11/18/50	322	1660	8.99	
	08/12/50	224	1010	6.24	
	08/13/51	225	1010	6.30	
	12/01/51	335	1690	9.75	
	09/29/52	272	1010		
	04/12/52	102	1550		
	08/03/53	215	1050		
	04/23/53	113	1350		
	04/28/54	118	1440		
	09/07/54	250	926		
	10/10/55	283	1150		
	04/25/55	115	1120		
	06/21/56	172	1220		
	06/06/58	157	1140		
Pump C	05/01/50	121	1970	6.00	
	04/08/51	98	1580	6.27	
	04/12/52	102	2010		
	04/28/54	118	2310		
	09/07/54	250	923		
	04/25/55	115	1730		
	06/21/56	172	1270		
	10/29/56	302	946		
	07/21/57	202	765		
	06/23/59	174	1070		
	07/21/61	202	634		

Table C-5. Pump D Data for Figures III-2, III-3, and III-4.

Date	Day of Year	EC (µs/cm)	HCO_3 (*meq/L*)	PO_4 (*meq/L*)
05/10/45	130	1350	7.13	0.05
08/23/45	235	766	4.03	0.07
05/02/46	122	1450	6.87	0.03
08/10/46	222	735	3.75	0.09
11/22/46	326	902	5.85	0.02
05/14/47	134	1450	6.26	0.05
11/12/47	316	1050	5.91	
07/12/48	193	1180	4.07	
07/25/49	206	948	3.45	
05/01/50	121	1470	5.87	
08/12/50	224	643	1.31	
11/18/50	322	707	4.73	
04/08/51	98	1410	6.04	
08/13/51	225	505	1.63	
12/01/51	335	1070	5.65	
04/12/52	102	1070		
09/29/52	272	1110		
04/23/53	113	1310		
08/03/53	215	989		
04/28/54	118	1390		
09/07/54	250	980		
10/10/55	283	1010		
06/21/56	172	1050		
10/29/56	302	717		
07/21/57	202	840		
06/06/58	157	1140		
06/23/59	174	993		
06/26/60	177	1270		
07/21/61	202	980		
07/23/62	204	1140		
08/09/63	221	1180		
08/13/64	225	1000		
08/19/65	231	865		
06/15/68	166	975		
07/15/68	196	1170		
08/15/68	227	1030		
09/15/68	258	900		

Table C-6. Pump F Data for Figures III-2 and III-3.

Date	Day of Year	EC (µs/*cm*)	HCO_3 (*meq/L*)	PO_4 (*meq/L*)
05/10/45	130	1780	6.08	0.04
08/23/45	235	485	2.56	0.02
05/02/46	122	1690	4.73	0.00
08/10/46	222	2390	4.85	0.04
11/22/46	326	1370	4.75	0.00
05/14/47	134	2300	7.32	0.06
11/12/47	316	595	3.22	
07/12/48	193	1400	4.60	
07/25/49	206	1470	4.36	
12/06/49	340	1500	3.78	
05/01/50	121	1630	5.56	
08/12/50	224	811	4.30	
11/18/50	322	895	4.99	
04/08/51	98	2400	5.01	
08/13/51	225	553	3.47	
12/01/51	335	600	3.10	
04/12/52	102	962		
09/29/52	272	1000		
04/23/53	113	1320		
08/07/53	219	570		
04/25/55	115	1300		
10/10/55	283	1030		
06/21/56	172	1410		
10/29/56	302	1330		
07/21/57	202	1070		
06/06/58	157	1160		
06/23/59	174	627		
06/26/60	177	434		
07/21/61	202	413		
07/23/62	204	654		
08/09/63	221	646		
08/13/64	225	550		
08/19/65	231	1300		
10/15/67	288	795		
11/15/67	319	730		
12/15/67	349	675		
01/15/68	15	1165		
02/15/68	46	490		
03/15/68	74	885		
04/15/68	105	1165		
05/15/68	135	840		
06/15/68	166	660		
07/15/68	196	655		
08/15/68	227	555		
09/15/68	258	705		
10/15/68	288	535		
11/15/68	319	755		
12/15/68	349	640		
01/15/69	15	670		
02/15/69	46	660		
03/15/69	74	770		
04/15/69	105	1135		
05/15/69	135	905		
06/15/69	166	525		
07/15/69	196	1005		
08/15/69	227	820		
09/15/69	258	650		
10/15/69	288	660		
11/15/69	319	600		
12/15/69	349	465		
01/15/70	15	635		
02/15/70	46	605		
03/15/70	74	860		
04/15/70	105	1460		
05/15/70	135	965		
06/15/70	166	1020		
07/15/70	196	1090		
08/15/70	227	680		

Table C-7. Data for Figures III-5 and III-6.

Year	Day of Year	EC (µs/*cm*)	pH	Total P (*ppm*)	NH_3-N (*ppm*)	NO_3-N (*ppm*)	Total N (*ppm*)	N:P Ratio
1980	29	530	8.8	0.03	0.01	0.10	0.11	4.40
	97	520	8.5	0.59	0.24	0.11	0.35	0.59
	127	1200	8.4	0.88	2.32	2.20	4.52	5.14
	184	520	8.5	0.49	0.78	0.30	1.08	2.20
	223	640	8.2	0.44	0.16	1.49	1.65	3.75
	247	680	7.8	0.47	0.17	0.15	0.32	0.68
	283	650	9.7	0.23	0.27	0.10	0.37	1.61
	329	580	9.5	0.36	0.18	0.10	0.28	0.78
	344	350	9.3	0.32	0.99	0.10	1.09	3.41
	Mean	630	8.7	0.42	0.57	0.52	1.09	2.51
1981	7	360	8.7	0.41	1.23	0.26	1.49	3.63
	54	372	8.2	0.40	1.40	0.10	1.50	3.75
	83	372	7.5	0.44	0.54	0.96	1.50	3.41
	121	380	8.3	0.66	0.32	0.10	0.42	0.64
	169	600	9.1	0.44	0.30	0.01	0.31	0.70
	210	850	9.6	0.27	0.18	0.18	0.36	1.33
	232	800	9.3	0.29	0.10	0.18	0.28	0.97
	271	430	8.3	0.45	0.06	0.10	0.16	0.36
	316	440	8.4	0.42	0.38	0.10	0.48	1.14
	348	520	7.5	0.44	0.77	0.16	0.93	2.11
	Mean	512	8.5	0.42	0.53	0.22	0.74	1.80
1982	6	430	7.7	0.58	1.60	0.56	2.16	3.72
	32	750	8.2	0.50	1.93	1.14	3.07	6.14
	61	720	8.2	0.56	0.27	0.27	0.54	0.96
	133	725	8.4	0.67	0.18	0.10	0.28	0.42
	174	840	8.7	0.44	0.38	0.11	0.49	1.11
	194	650	9.1	0.43	0.12	0.03	0.15	0.35
	228	580	8.6	0.38	0.09	0.43	0.52	1.37
	257	530	9.2	0.42	0.09	0.16	0.25	0.60
	290	310	8.1	0.47	0.56	0.17	0.73	1.55
	332	500	8.6	0.54	0.17	0.12	0.29	0.54
	Mean	604	8.5	0.50	0.54	0.31	0.85	1.68
1983	19	470	8.8	0.35	0.14	0.19	0.33	0.94
	46	590	8.8	0.67	0.06	0.10	0.16	0.24
	117	780	8.8	0.65	0.12	0.20	0.32	0.49
	144	750	6.7	0.29	0.56	0.10	0.66	2.28
	163	850	9.1	0.48	0.09	0.10	0.19	0.40
	230	595	8.9	0.67	0.53	0.26	0.79	1.18
	263	700	9.0	0.36	0.10	0.10	0.20	0.56
	Mean	676	8.6	0.50	0.23	0.15	0.38	0.87

Year	Day of Year	EC (*µs/cm*)	pH	Total P (*ppm*)	NH_3-N (*ppm*)	NO_3-N (*ppm*)	Total N (*ppm*)	N:P Ratio
1984	50	765	7.2	0.74	0.98	0.75	1.73	2.34
	126	1020	8.7	0.38	0.04	0.30	0.34	0.89
	246	625	8.8	0.39	0.05	0.10	0.15	0.38
	261	575	7.4	0.45	1.65	0.33	1.98	4.40
	Mean	746	8.0	0.49	0.68	0.37	1.05	2.00
1985	146	890	7.5	0.56	2.63	0.13	2.76	4.93
	245	570	9.4	0.46	0.72	0.10	0.82	1.78
	320	675	8.9	0.45	0.39	0.21	0.60	1.33
	Mean	712	8.6	0.49	1.25	0.15	1.39	2.68
1986	47	670	8.0	0.82	0.16	0.95	1.11	1.35
	138	350	7.6	0.36	1.10	0.37	1.47	4.08
	244	430	9.5	0.45	0.06	0.10	0.16	0.36
	315	620	8.9	0.43	0.50	0.17	0.67	1.56
	Mean	518	8.5	0.52	0.46	0.40	0.85	1.84
1987	47	1000	9.0	0.74	0.52	0.27	0.79	1.07
	118	785	9.7	0.50	0.05	0.16	0.21	0.42
	251	550	9.2	0.53	0.12	0.21	0.33	0.62
	305	480	9.1	0.74	0.88	0.12	1.00	1.35
	Mean	704	9.2	0.63	0.39	0.19	0.58	0.87
1988	142	825	8.5	0.41	0.76	0.23	0.99	2.41
	254	590	8.5	0.49	0.06	0.35	0.41	0.84
	310	525	9.1	0.49	0.40	0.49	0.89	1.82
	Mean	647	8.7	0.46	0.41	0.36	0.76	1.69
1989	142	930	8.4	0.73	1.78	2.00	3.78	5.18
	247	550	9.8	0.31	0.06	0.10	0.16	0.52
	323	575	8.8	0.49	0.06	0.69	0.75	1.53
	Mean	685	9.0	0.51	0.63	0.93	1.56	2.41
1990	149	575	8.8	0.19	0.26	0.23	0.49	2.58
	246	560	9.6	0.22	0.10	0.11	0.21	0.95
	318	440	8.5	0.08	0.36	0.10	0.46	5.75
	Mean	525	8.9	0.16	0.24	0.15	0.39	3.09

Table C-8. Data for Figure III-8.

Hour	Tule Lake pH	Upper Klamath Lake pH
0	9.76	8.85
2	9.87	8.82
4	9.85	9.12
6	9.89	9.07
8	9.88	9.30
10	9.86	9.58
14	9.81	9.41
16	9.72	9.09
18	9.78	8.58
20	9.77	8.70
22	9.86	8.43

Table C-9. Data for Figure III-14.

Site Name	NH_3-N *(ppm)*	NO_3-N *(ppm)*	P *(ppm)*	Cl *(ppm)*	SO_4 *(ppm)*	pH	EC *(µs/cm)*
KL01	0.05	0.15	0.01	14.18	5.28	8.13	116
KL02	0.22	0.05	0.01	7.09	3.36	9.44	97
KL03	0.07	0.05	0.19	3.55	15.84	9.62	255
KL04	0.12	0.27	0.08	23.40	7.68	8.94	160
KL05	0.11	0.24	0.06	6.38	12.96	8.94	180
KL06	0.06	0.17	0.12	3.19	12.48	8.38	189
KL07	0.04	0.15	0.05	3.55	11.52	8.24	160
KL08	0.04	0.18	0.09	6.74	12.48	8.25	181
KL09	0.02	0.27	0.12	3.90	12.00	8.08	168
KL10	0.01	0.26	0.14	9.93	13.92	7.96	183
T	0.00	0.56	0.33	42.34	89.62	8.65	450
D	0.06	0.08	0.32	12.35	107.0	8.69	307
L	0.19	0.08	0.16	55.17	4	9.79	563
					118.9		

Table C-10. Data for Figure IV-1.

Site Name	EC (µs/cm)	P *(ppm)*
KL01	116	0.01
KL02	97	0.01
KL03	255	0.19
KL04	160	0.08
KL04	180	0.06
KL06	189	0.12
KL06	160	0.05
KL08	181	0.09
KL09	168	0.12
KL10	183	0.14
Area 1	230	0.19
Area 2	339	0.29
Area 3	371	0.18
Area 4	293	0.17
Area 5	1103	0.09
Pump D	563	0.16

Table C-11. Data for Figures III-15 and IV-2.

Site Number	East-West Transect			North-South Transect		
	NH_3-N (*ppm*)	P (*ppm*)	pH	NH_3-N (*ppm*)	P (*ppm*)	pH
1	—	—	—	0.03	0.70	8.15
2	0.01	0.24	7.72	0.02	0.19	7.90
3	0.01	0.16	7.66	0.00	0.28	8.16
4	0.01	0.16	8.76	0.03	0.22	8.73
5	0.13	0.31	9.27	0.05	0.21	9.05
6	0.06	0.24	8.88	0.08	0.19	9.04
7	0.04	0.37	7.96	0.02	1.40	9.02
8	0.00	0.26	8.35	0.02	0.18	8.69
9	0.20	0.20	9.21	0.10	0.60	8.15
10	0.04	0.17	9.35	0.06	0.24	9.45
11	0.01	0.16	8.59	0.22	0.16	10.08
12	0.04	0.18	8.73	0.02	0.21	9.23
13	0.07	0.19	8,76	0.02	0.04	9.21
14	0.05	0.14	8.77	0.02	0.02	9.13
15	0.02	0.13	8.37			
16	0.03	0.05	9.26			
17	0.04	0.06	9.32			
18	0.03	0.69	7.88			
19	0.14	1.90	7.63			

Table C-12. Data for Figure III-16.

Sump A Transect Site	NH_3-N (*ppm*)	P (*ppm*)	pH	Sump B Transect Site	NH_3-N (*ppm*)	P (*ppm*)	pH
1	0.32	0.02	10.18	**1**	0.41	0.07	10.00
2	0.37	0.24	10.02	**2**	0.26	0.24	9.37
3	0.27	0.20	10.15	**3**	0.34	0.02	10.28
4	0.40	0.25	10.19	**4**	0.27	0.02	10.11
5	0.27	0.18	10.28	**5**	0.28	0.01	10.22
6	0.12	0.23	9.31	**6**	0.28	0.01	10.36
7	0.23	0.03	9.85	**7**	0.25	0.01	10.14
8	0.22	0.02	9.87	**8**	0.28	0.03	10.35
9	0.22	0.16	9.95				
10	0.20	0.29	9.59				