Nitrogen and Phosphorus Loading from Drained Wetlands Adjacent to Upper Klamath and Agency Lakes, Oregon

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 97–4059

Prepared in cooperation with the
BUREAU OF RECLAMATION

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

Frontispiece. Upper Klamath National Wildlife Refuge at northern end of Upper Klamath Lake looking southeast. An example of an undrained wetland consisting of a reed-sedge plant community.

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Portland, Oregon
1997

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[In pocket]

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
micrometer (µm)	0.00003937	inch
centimeter (cm)	0.3937	inch
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Volume	
milliliter (mL)	0.06102	cubic inch
liter (L)	0.2642	gallon
cubic centimeter (cm^3)	0.06102	cubic inch
cubic foot (ft^3)	0.02832	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Mass	
milligram (mg)	0.00003527	ounce, avoirdupois
kilogram (kg)	2.205	pound avoirdupois
pound, avoirdupois (lb)	0.4536	kilogram
ton, short (2,000 lb)	0.9072	megagram (metric ton)
	Density	
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot
	Concentration, in water and soil	
milligrams per liter (mg/L)	1	parts per million (ppm)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
	Power	
horsepower	0.7457	kilowatt (kW)
kilowatt (kW)	1,000	joule per second
	Energy	
kilowatt-hour (kWh)	3,600,000	joule
	Application rate	
pounds per acre per year [(lb/acre)/yr]	1.121	kilograms per hectare per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F} = (1.8 \times {}^{\circ}\text{C}) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C} = ({}^{\circ}\text{F} - 32) / 1.8$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

DEFINITION OF TERMS

Aerobic. Pertaining to or caused by the presence of oxygen.

Algal bloom. The rapid proliferation of passively floating, simple plant life, such as blue-green algae, in and on a body of water.

Alluvial. Pertaining to recent clastic deposits resulting from sediment transported by rivers.

Anaerobic. Pertaining to or caused by the absence of oxygen.

Aquifer. A unit of rocks or unconsolidated earth materials with sufficient permeability to yield water in a usable quantity to a well or spring.

Artesian. Ground water under pressure in an aquifer confined by less permeable rocks. If the aquifer is tapped by a well, the ground water will rise above the top of the aquifer and, under sufficient pressure, may rise above the land surface, creating a flowing artesian well.

Bulk density. Dry-matter mass per unit volume of in-situ material.

Caldera. A volcanic depression or crater generally circular in form with a diameter many times that of the enclosed volcanic vents. Can be formed by collapse, explosion, or erosion.

Clastic. Consisting of fragments of rocks that have been individually moved from their places of origin.

Content. A concentration generally expressed as a proportion of mass or volume.

Diatomaceous earth. See Diatomite.

Diatomite. A friable, light-colored sediment or sedimentary rock of low density, consisting of nearly pure silica composed principally from diatoms. Dry diatomite is normally white. Other colors are due to included sediment or organic impurities.

Diatom. Microscopic single-celled plant growing in marine or fresh water. (Diatoms are present today in Upper Klamath Lake.) Diatoms are a type of alga that secretes siliceous shell-like frustules in a great variety of forms that can accumulate in sediments in enormous numbers.

Escarpment. A long cliff or steep slope separating two comparatively level or more gently sloping surfaces and resulting from erosion or faulting.

Eutrophic. Applied to a highly productive body of water rich in dissolved plant nutrients. The decay of the organic matter produced may lead to the depletion of oxygen.

Fluvial. Pertaining to, produced by, or formed in a river.

Graben. A depressed segment of the earth’s crust bounded on at least two sides by faults.

Hemic peat. See Peat, hemic.

Holocene. The period of time since the last ice age, about 10,000 years ago.

Inorganic. Containing no carbon; matter other than plant or animal.

Lacustrine. Pertaining to, produced by, or formed in a lake.

Muck. A soft, wet, organic-rich mud.

Nutrient. Any inorganic or organic compound needed to sustain plant or animal life.

Organic. Containing carbon, but possibly also containing other elements.

Peat. Partly decayed vegetable matter, inorganic minerals, and water in varying proportions (Cameron, 1973, p. 505).

Peat, hemic. The moderately decomposed peat. Generally reddish brown to medium brown but turns dark brown upon exposure to air. It consists predominantly of plant particles having diameters between about 0.01 and 0.1 inches; they are fragments of roots, stems, leaves, wood, bark, or seeds. Freshwater and saltwater marshes produce hemic peat from sedges, rushes, and grasses (Cameron and others, 1989, p. 110–111).

Peat, sapric. The most decomposed peat. Fine grained, generally dark brown to black, and, under compression, retains moisture and deforms as a paste. Although plant remains are basically unidentifiable in hand specimens, pollen and microscopic studies show that sapric peat is generally derived from small and easily decomposed algal and herbaceous aquatic plants of ponds and marshes (Cameron and others, 1989, p. 110).

Pleistocene. The period of time between the beginning of extensive glaciation about 1.6 millions years ago and the last ice age about 10,000 years ago.

Pluvial lake. A lake formed during a period of increased rainfall.

Quaternary. The period of time since the beginning of extensive glaciation about 1.6 millions years ago, and which can be further subdivided into the Pleistocene and the Holocene.

Riparian. Pertaining to the banks of a body of water.

Sapric peat. See Peat, sapric.

Subsidence. The gradual downward settling or sinking of the Earth’s surface with little or no horizontal motion.

Theissen polygon. A polygon resulting from a method of interpolating between specific points. Theissen polygons are constructed by connecting the perpendicular bisectors of the lines connecting adjacent data points. The entire Theissen polygon is assumed to be represented by the data point contained in the polygon.

Total nitrogen. The sum of ammonia plus organic nitrogen in unfiltered water or soil samples and nitrite-plus-nitrate nitrogen in filtered water or soil samples.

Total phosphorus. Phosphorus in unfiltered water or in soil samples following acid digestion.

Wetlands. In general terms, lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface (Cowardin and others, 1979, p. 3).

Yield. The mass of a constituent per area.

ACKNOWLEDGMENTS

The authors would like to thank Ron Cameron, a U.S. Geological Survey volunteer, for his expertise and tireless efforts during the collection of soil samples. We are grateful to the many property owners and their staffs; members of the Bureau of Reclamation, Bureau of Land Management, and the U.S. Fish and Wildlife Service; and the many citizens of Klamath County who cooperated and assisted in this investigation. Frank Packard (U.S. Geological Survey) provided guidance and encouragement throughout the study. Jon House, Charlie Collins, Jim Poole, and Don Anderson (U.S. Geological Survey) assisted in the collection of field data. Jacob Kann (the Klamath Tribes) contributed through his knowledge of the lake and the surrounding areas. Finally, the late Cornelia Cameron (U.S. Geological Survey) is gratefully acknowledged for her assistance in the development of the conceptualization and recognition of the significance of the decomposition of peat soils.

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ABSTRACT

Upper Klamath Lake and the connecting Agency Lake constitute a large, shallow lake in south-central Oregon that the historical record indicates has likely been eutrophic since its discovery by non-Native Americans. In recent decades, however, the lake has had annual occurrences of near-monoculture blooms of the blue-green alga *Aphanizomenon flos-aquae* that are thought to be a result of accelerated eutrophication. In 1988, two sucker species endemic to the lake, the Lost River sucker (*Deltistes luxatus*) and the shortnose sucker (*Chasmistes brevirostris*), were listed as endangered by the U.S. Fish and Wildlife Service, and it has been proposed that their decline is due to the poor water quality associated with extremely long and productive algal blooms. It has also been proposed that the effluent drained from wetlands has contributed to accelerated eutrophication (Bortleson and Fretwell, 1993).

Since the turn of century, most of the wetlands adjacent to Upper Klamath Lake have been drained for agriculture—cultivation of crops and grazing of cattle. Wetland areas were reclaimed from the lake by building dikes to isolate them from the lake, constructing a series of drainage ditches, and installing pumps to drain the water and maintain a lowered water table. A consequence of lowering the water table is the increased ability of air and oxygenated water to move through the subsurface and facilitate the rapid aerobic decomposition of the peat soils. Nutrients, nitrogen and phosphorus, are then liberated, leach into adjacent ditches, and are subsequently pumped to the lake or its tributaries. The rate of peat decomposition may be related to the time since drainage and the type of agricultural land use. On lands cultivated for crops, farming practices, such as disking and furrowing, could enhance the movement of air and oxygenated water, resulting in rapid rate of decomposition. In contrast, on grazed lands, the compaction of soils by cattle probably inhibits the movement of air and oxygenated water and results in a slower rate of decomposition relative to drained wetlands used for the cultivation of crops.

This report presents the results of a cooperative study between the U.S. Geological Survey and the Bureau of Reclamation whose overall objective was to determine the nutrient loading to Upper Klamath Lake from adjacent drained wetlands. Nutrient loading from drained wetlands was estimated using two independent techniques. The first method involved the measurement of the quantity and quality of water discharged by pumps draining the wetlands. The second method was used to estimate the initial (before drainage) and present-day nutrient mass of the organic soils within the drained wetlands and to calculate the change (or loss) in nutrient mass.

In an effort to estimate the nutrient contributions from the water pumped off selected drained wetlands adjacent to Upper Klamath Lake, annual loads and yields of total nitrogen and total phosphorus were estimated from concentration data and the volume of water pumped during the water year. In general, there was little variation among sites or among years in the annual total nitrogen (median load of about 18 tons per year and median yield of about 8 pounds per acre per year) or the annual total phosphorus (median load of about 3 tons per year and median yield of about 2 pounds per acre per year) contributions. The sum of the annual loads of nitrogen and phosphorus calculated for each of the pumping stations in 1995 was 80 tons per year and 15 tons per year, respectively.

In 1995, soil-coring activities were undertaken to ascertain the nature and extent of the organic soils in the drained and undrained wetlands. The present-day nutrient mass was calculated for each drained wetland using the nutrient content (concentration) and the present-day peat mass. The initial nutrient mass prior to drainage was estimated for each drained wetland by using the initial nutrient content (assumed to be equal to the nutrient content of the undrained wetlands) and the initial peat mass as determined using the amount of accumulated decomposition residue. The cumulative loss of nutrient mass since drainage was calculated as the change between initial and present-day nutrient mass for each drained area.

The cumulative yield of total nitrogen and total phosphorus loss from the organic soils of individual wetlands since drainage ranged from 3,000 to 70,000 pounds per acre and from 0 to 1,300 pounds per acre, respectively. For all the drained wetlands sampled, the cumulative nitrogen and phosphorus loss since drainage totaled 250,000 tons and 4,300 tons, respectively. This represents about 30 percent and 22 percent of the mass of nitrogen and phosphorus, respectively, that initially existed in the organic soils. The loss of nutrients from the drained wetlands is considered to be a maximum estimate of the possible contribution of nutrients to Upper Klamath Lake from the peat soils of the drained wetlands sampled. However, not all the nutrients released by the soils are discharged to the lake. Nutrients lost from the peat soils of the drained wetlands may have been taken up by crops and harvested or consumed by grazing cattle. In addition, nitrogen can be lost to the atmosphere by denitrification and the volatilization of ammonia; phosphorus may be bound to adjacent soil layers by adsorption.

The annual nutrient loss for the period 1994–95 was calculated using a first-order rate law to describe nutrient loss since drainage began. For individual drained wetlands, the yield of nitrogen and phosphorus lost from the organic soils for the period 1994–95 ranged from 27 to 540 pounds per acre per year and from 0 to 15 pounds per acre per year, respectively. The total mass of nitrogen and phosphorus loss during this period was 3,000 tons per year and 60 tons per year, respectively, for all drained wetlands that were sampled. The yield and mass of nutrient loss determined in this fashion reflect what might be expected on the basis of time-averaged or long-term contributions of nutrients to the lake and do not reflect the specific conditions existing during the period 1994–95.

The results of this study could be useful in helping to prioritize which drained wetlands may provide the greatest benefits with regard to reducing nutrient loads to the lake if restoration or land-use modifications are instituted. Recent acquisition and planned restoration of drained wetland areas at the Wood River and Williamson River North properties may produce significant reduction in the quantity of nutrients released by the decomposition of peat soils of these areas. If the water table rises to predrainage levels, the peats soils may become inundated most of the year, resulting in the continued long-term storage of nutrients within the peat soils by reducing aerobic decomposition. The maximum benefit, in terms of decreasing potential nutrient loss due to peat decomposition, could be the reduction of total nitrogen and total phosphorus loss to about one-half that of the 1994–95 annual loss estimated for all the drained wetlands sampled for this study.

INTRODUCTION

Upper Klamath Lake and the connecting Agency Lake constitute a large, shallow lake in south-central Oregon (fig. 1). For purposes of subsequent discussion, the name “Upper Klamath Lake” will be understood to include Agency Lake. The historical record indicates that the lake has likely been eutrophic since its discovery by non-Native Americans (Bortleson and Fretwell, 1993). In recent decades, however, the lake has had annual occurrences of near-monocultural blooms of the blue-green alga *Aphanizomenon flos-aquae* that are thought to be a result of accelerated eutrophication. In 1988, two sucker species endemic to the lake, the Lost River sucker (*Deltistes luxatus*) and the shortnose sucker (*Chasmistes brevirostris*),

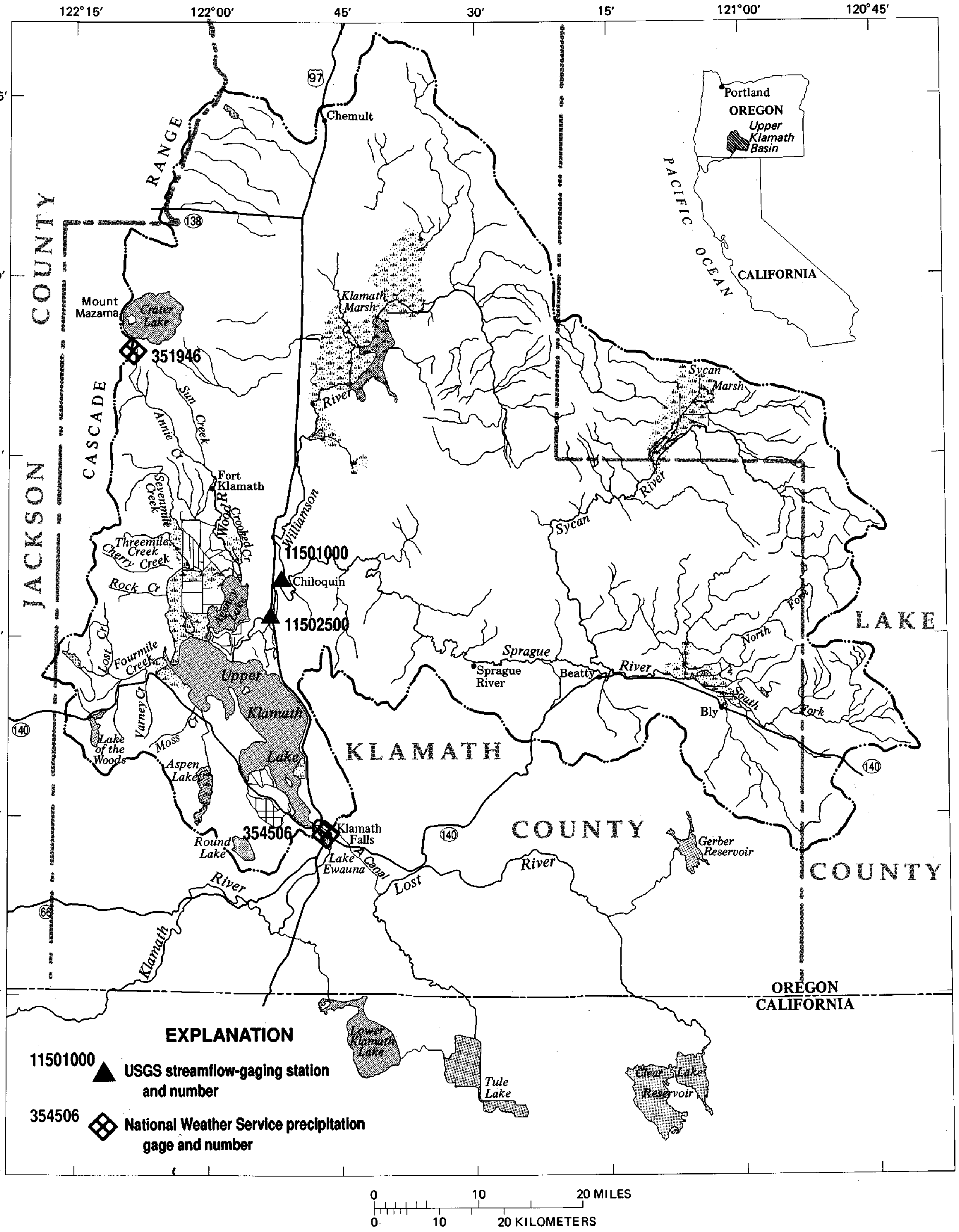

Figure 1. Upper Klamath Lake Basin and vicinity.

were listed as endangered by the U.S. Fish and Wildlife Service (Federal Register, 1988), and it has been proposed that their decline is due to the poor water quality associated with extremely long and productive algal blooms. It has also been proposed that the effluent from wetlands drained for agriculture has contributed to worsening water quality through an increase in nitrogen and phosphorus released by the accelerated decomposition of peat soils exposed to air or oxygenated water (Bortleson and Fretwell, 1993).

The U.S. Geological Survey (USGS), in cooperation with the Bureau of Reclamation, developed a study in 1991 to assess nutrient loading and water-quality characteristics of Upper Klamath Lake. Three reports have already been published as part of this study. Brownell and Rinallo (1995) prepared an extensive bibliography of water-related research in the Upper Klamath Basin. Laenen and LeTourneau (1996) estimated the wind-induced resuspension of bed sediment during periods of low lake elevation. Wood and others (1996) studied the relation between selected water-quality variables and lake level. The following is a report on nutrient loading from drained wetlands adjacent to Upper Klamath Lake.

Purpose

The purpose of this report is to describe the nitrogen and phosphorus loading to Upper Klamath Lake from adjacent drained wetlands. A brief description of the soils in the undrained and drained wetlands is included to provide a basis on which the estimates of nutrient loading were made. Implications of nutrient loading from regional ground-water discharge were considered, but estimates of this component of loading were not within the scope of the study. Results from this report will be of use to resource managers. Possible uses of the information are to:

- Quantify the contribution of nutrients from drained wetlands to Upper Klamath Lake relative to other sources of nutrients to the lake.
- Provide sufficient information to guide efforts to reduce nutrient loading to Upper Klamath Lake by indicating whether modifying present-day land-use practices or restoring the drained wetlands will provide benefits in terms of reducing nutrient loads to the lake.
- Identify which drained wetlands may provide the greatest benefits if restoration or land-use modifications are instituted.
- Provide baseline data on conditions within the drained wetlands for later comparisons to monitor the effectiveness of land-use modifications or restoration activities.
- Provide insight on the possible effects on water quality resulting from rotating between flooded wetlands and agricultural cropland as has been proposed for parts of the nearby Tule and Lower Klamath Lakes National Wildlife Refuges.

Approach

The study involved two phases of activity: (1) water samples and discharge measurements were collected to determine the concentration and quantity of discharge from pumps draining selected wetlands used for agriculture, and were subsequently used to calculate nutrient loads to Upper Klamath Lake; and (2) soil samples were collected from drained wetlands, analyzed, and compared with samples collected from undrained wetlands to estimate the loss of nutrients from the decomposition of organic soils due to the exposure to oxygen after drainage.

Previous Work

Several studies have focused on the eutrophication problems in Upper Klamath Lake. Phinney and Peek (1961) stated that the source of nutrient-rich water entering Upper Klamath Lake was a result of the natural drainage from undrained wetlands and the drainage water from wetlands drained for agriculture and was a consequence of leachate from the organic part of the wetland soils. However, they made no attempt to quantify the nutrient load or to describe the relative contributions of undrained versus drained wetlands to the nutrient load to the lake.

Miller and Tash (1967) constructed a preliminary nutrient budget for Upper Klamath Lake for the period of March 1965 through April 1966 and calculated the nutrient load from springs, streams, rivers, canals, and agricultural drainage. This represented a 14-month budget, which cannot easily be adjusted to an annual budget due to the lack of monthly data and to the uneven distribution of water volumes and nutrient concentrations over the course of a year. In their budget, agricultural drainage accounted for only 5 percent of the inflow of water but contributed 20 percent of the incoming nitrogen load and

26 percent of the incoming phosphorus load to the lake. Miller and Tash (1967) did not discuss the cause(s) of the high nutrient concentrations in agricultural drainage. Since 1966, the area of wetlands drained for agriculture adjacent to Upper Klamath Lake has increased by about 30 percent (7,200 acres).

The U.S. Army Corps of Engineers (1982) collected additional water-quality and discharge data to supplement the work of Miller and Tash (1967). However, no new data for agricultural drainage were collected and the major conclusions from Miller and Tash remained unchanged.

A later study of Upper Klamath Lake prepared by the Klamath Consulting Service (1983) discussed restoration alternatives designed to reduce the eutrophication-induced problems in the lake. They concluded that “human contribution to the problem is minimal” and that the eutrophication of Upper Klamath Lake was a result of “naturally occurring high nutrient load.” Water-quality data collected during this study did not include direct measurements of agricultural or wetland drainages.

Additional studies of the process and consequences of eutrophication of Upper Klamath Lake are presented in the Bureau of Reclamation’s 1991 and 1992 annual reports on environmental research in the Klamath Basin, Oregon, edited by Campbell (1993a, 1993b). These reports describe research and preliminary results from studies that are or were in progress and as yet contain little interpretation with regard to nutrient loading from drained or undrained wetlands. Included are progress reports of a study that is assessing the importance of drained and undrained wetlands on water quality of Upper Klamath Lake by evaluating the quality of water discharged from these areas (Sartoris and Sisneros, 1993; Sartoris and others, 1993). Also of interest in the 1991 annual report is the work by Carlson (1993) that documents the change in land use and area of wetlands from 1940 to 1989. Carlson estimated that about 73,000 acres of undrained wetlands existed adjacent to Upper Klamath Lake and in portions of the Wood River Valley in 1940. About 20,000 acres of the wetlands adjacent to the lake were subsequently drained for agriculture by 1989.

Gearheart and others (1995a; 1995b; 1995c) examined watershed strategies for improving the water quality of Upper Klamath Lake. Their approach included a review of written literature and an assessment of research currently in progress. A steady-state lake model was developed using previously available data to show the relationship between loading rates, settling rates, and annual average in-lake total phosphorus concentrations. The effects of several management practices identified for different land-use activities were evaluated with regard to total cost and time to reach various in-lake total phosphorus levels. The study concluded that the loss of wetlands in the Upper Klamath Lake watershed has significantly changed the hydrology, biochemistry, and related ecology of the area and that source reduction, through the use of best management practices, is the only economic and technically effective strategy for managing the lake for sensitive fish species (Gearheart and others, 1995b). However, although the importance of agricultural drainage and the decomposition of peat soils is mentioned, these factors were not quantified due to the lack of data.

Background and Description of the Study Area

Physiography and Hydrography

Upper Klamath Lake is in a large, flat valley adjacent to the eastern slopes of the Cascade Range in south-central Oregon (fig. 1). It is the largest lake (by area) wholly within Oregon, having a surface area of about 140 mi^2 (square miles) at maximum lake-surface elevation, a length of about 25 mi (miles), and a width ranging from 2.5 to 12.5 mi. (Representative physical characteristics of the lake are summarized in table 1.) Despite its large size, the lake is shallow and has a mean summer depth of about 8 ft (feet) and a maximum depth of about 58 ft (U.S. Army Corp of Engineers, 1979, 1982).

The drainage area for Upper Klamath Lake is about 3,800 mi^2. The principal tributaries to the lake are the Williamson and Wood Rivers (fig. 1). The Williamson River is the largest, with much of its flow derived from the Sprague River. In addition to streams, spring flow and ground-water seepage provide continuous inflow to the lake throughout the year (Illian, 1970). Upper Klamath Lake is drained at the southern end by the Link River, which flows through a short reach and enters Lake Ewauna at Klamath Falls. The headwaters of the Klamath River proper are about 1 mi south of Klamath Falls where Lake Ewauna flows into the Klamath River. Link River Dam on the Link River regulates the flow from Upper Klamath Lake. Since 1919, the operation of Link River Dam

Table 1. Physical characteristics of Upper Klamath and Agency Lakes, Oregon

[Source of data: U.S. Army Corp of Engineers (1979, p. 43); mi^2, square miles; ft, feet; acre-ft, acre-feet]

Drainage area	3,800 mi^2
Lake surface elevation	
*Minimum	4,137.0 ft
Mean summer	4,141.3 ft
Maximum	4,143.3 ft
Surface area	
At minimum lake surface elevation	60,000 acres
At mean summer lake surface elevation	77,500 acres
At maximum lake surface elevation	90,000 acres
Volume	
At minimum lake surface elevation	350,000 acre-ft
At mean summer lake surface elevation	620,000 acre-ft
At maximum lake surface elevation	875,000 acre-ft
Average depth	
At minimum lake surface elevation	5.8 ft
At mean summer lake surface elevation	8.0 ft
At maximum lake surface elevation	9.7 ft

* In 1994, the lake-surface elevation was 4,136.8 ft (Mark Buettner, Bureau of Reclamation, written commun., 1996).

has allowed seasonal lake-stage elevations to be maintained at levels either higher or lower than pre-dam levels. A rock sill was cut away to allow lake levels to be drawn about 3 ft lower than historical levels. Since the dam was built, the lake level normally has been maintained between 4,137 and 4,143 ft.

Climate

The semiarid climate in the Upper Klamath Basin is characterized by hot, dry summers and moderately wet winters with moderate to low temperatures. Precipitation is variable throughout the basin owing to the diverse topography of the area and a rain shadow created by the Cascade Range. From 1961 to 1990, mean annual precipitation at the Klamath Falls Airport was 13.5 inches (standard deviation is about 2.8 inches). During this study, precipitation at the Klamath Falls Airport in Klamath Falls was 15.8 inches, 9.8 inches, and 18.3 inches for 1993, 1994, and 1995, respectively. About 72 percent of the precipitation occurs in the 6-month period from October through March. Snowfall averages about 35 inches per year. The mean annual temperature at Klamath Falls Airport from 1961 to 1990 was 48°F (degrees Fahrenheit), the mean maximum temperature during July and August was 84°F, and the mean minimum temperature during December and January was 21°F (National Oceanic and Atmospheric Administration, 1994, 1995, 1996).

Geology

The north-northwest trending Klamath Basin corresponds, in part, to a down-faulted crustal block, which is 6–9 mi wide (Sherrod, 1993). It is known as the Klamath graben and extends north toward Crater Lake in the Cascade Range and is bounded by high, steep escarpments, especially along the eastern rim. As much as 6,600 ft of unconsolidated sediment fills the graben. Rocks in the area are predominantly of volcanic origin, consisting of unconsolidated or consolidated volcanic materials or unconsolidated sediments largely derived from volcanic rocks (Leonard and Harris, 1974).

Parts of the Upper Klamath Lake drainage were heavily glaciated during the Pleistocene. None of these glaciers reached as far as Upper Klamath Lake, but glacial runoff flowed into the basin (Adam and others, 1994). During this time, a large pluvial lake (Lake Modoc) covered much of the basin floor. Lake Modoc consisted of several connected arms having an overall length of about 75 mi that extended from Fort Klamath in the north to south of Tule Lake in California (Dicken, 1980). At maximum extent, the lake covered an area of about 1,100 mi^2 and had an elevation of about 4,240 ft, equivalent to about 100 ft above the present-day Upper Klamath Lake. Large quantities of ash and pumice as well as accumulations of diatoms and peat were deposited in the basin. The thickness of these sediments reaches hundreds of feet in some areas (Dicken and Dicken, 1985). At the end of the Pleistocene, perhaps 10,000 years ago, Lake Modoc began to shrink, forming several smaller lakes—Upper Klamath Lake in Oregon and Lower Klamath and Tule Lakes in California (Dicken, 1980).

After the lowering of Lake Modoc, wetlands became established in many areas of the lake. Lake sediments consist of Quaternary-age deposits of lacustrine diatomaceous clays and silts; alluvial floodplain deposits of volcanic ash-rich clays, silts, and sands; and deposits of peat and other organic materials (Cahoon, 1985; Bureau of Land Management, 1995).

About 6,900 years ago, a massive eruption occurred from what is now referred to as Mount Mazama at the northern end of the Upper Klamath Lake drainage (Bacon and Lanphere, 1990). Mount Mazama collapsed during this climactic eruption, forming the caldera now occupied in part by Crater Lake and generating a pumice and ash deposit over an enormous area of western North America (Geitgey, 1992). Owing to prevailing winds, most of the pumice and ash was deposited to the northwest of Mount Mazama. The thickness of air-fall pumice is presently about 6 inches on the upland areas immediately north of Agency Lake and decreases rapidly southward (Walker, 1951; Williams, 1965). The area of the Wood River Valley extending southward into Upper Klamath Lake contains washed pumice and ash resulting from the deposition and movement of volcanic materials moved down from Mount Mazama along its southwestern drainages (Williams, 1965). Pumice and ash ejected from Mount Mazama during the climactic eruption and possibly during earlier Holocene eruptions underlie the present-day wetlands in many areas (Smith, 1988). These deposits may represent air-fall and flow pumice, or may, in part, have been reworked and transported by water.

Cores drilled in the wetlands near the southwestern part of Upper Klamath Lake reflect the long-term and recent history of Upper Klamath Lake. A 166-foot core obtained by Adam and others (1994) from Wocus Marsh has alternating intervals of highly organic and inorganic sediments that were deposited over a period of perhaps the last 1 million years. Peat deposits are present to a depth of about 85 ft and may be nearly 400,000 years old. In a core from Caledonia Marsh, lacustrine clays, which are present in the section below about 17 ft, are in sharp contact with overlying organic-rich clay deposited in the marsh. On the basis of estimated sedimentation rates, the change happened about 11,000 years ago near the end of colder climatic conditions at the end of the Wisconsin Glaciation (or most recent glaciation) and subsequent lowering of Lake Modoc (Rosenbaum and others, 1995). The lacustrine clays resulted from the past deep-water environment of Lake Modoc and the organic-rich clays represent the more recent shallower environments of Upper Klamath Lake. Volcanic materials resulting from the deposition of ash from Mount Mazama were observed at about 10.5 ft in the Caledonia Marsh core.

Regional Ground-Water Flow

The surrounding mountains are recharge areas for the regional ground-water flow system from which ground water moves toward the lowlands. Ground water is discharged by upward seepage in all the lowland areas, by the many springs that contribute to streamflow, by evapotranspiration in the prominent wetlands around Upper Klamath Lake, and by seepage to Upper Klamath Lake (Illian, 1970; Leonard and Harris, 1974). Strong upward flow gradients are evident from the many flowing artesian wells adjacent to the lake, especially in the lower Wood River Valley.

Soils and Vegetation

The soils of the wetlands adjacent to Upper Klamath Lake formed from the alluvial, lacustrine, and organic materials that were deposited in Upper Klamath Lake. The alluvial sediments consist of clays, silts, and sands derived from the volcanic rocks that dominate the area and have been eroded and transported by tributaries to the lake. The most abundant lacustrine sediments now accumulating in Upper Klamath Lake are diatomaceous and organic materials. Diatoms are growing today in Upper Klamath Lake, resulting in the deposition of diatomaceous clays and silts throughout the lake (Peterson and McIntyre, 1970; Bureau of Land Management, 1995). The organic material, in the form of peat, developed over thousands of years from the annual growth, death, and decomposition of wetland vegetation. Volcanic ash, sedimentary materials, and diatomaceous material are layered within the peat (Sorenson and Schwarzbach, 1991).

Vegetation associated with the wetland areas is a typical sedge-reed community, including bulrush, cattails, and wocus lily (Cahoon, 1985; Johnson and others, 1985).

Peat Formation and Decomposition

The peat material underlying the drained and undrained wetlands adjacent to Upper Klamath Lake appear to be of the reed-sedge type (Peterson and McIntyre, 1970). The following discussion of the cycle of peat development for a reed-sedge type of vegetation is adapted from descriptions by Cameron (1970, 1973, 1975). The normal sequence in these deposits of the filled-basin type consists of a basal inorganic clay grading upward to organic clay containing diatoms and algal debris overlain by peaty clay, clayey peat, and finally reed-sedge peat. This stratigraphy records a history of changing environments during which the pond, receiving only inorganic clay at first, continues to fill with clay and floating plants, such as algae and pond weeds, until the water becomes shallow enough to support growth of rooted plants such as pond lilies and bulrushes. As vegetative remains accumulate, water of the vestigial pond is eventually replaced by marsh grass, reeds, and sedges.

Boundaries are gradational between stratigraphic units belonging to the same cycle. Discontinuities mark the interruption of one cycle and the beginning of another. The discontinuities can also consist of deposits of clastic debris and beds of peat with clay, sand, or silt between the beds of peat. The clastic debris represent episodes of ponding or flooding.

Peat forms when the rate of accumulation of plant material exceeds the rate of decay by bacterial and chemical action. Plant material is added primarily at the surface, where it may fall into water or upon water-saturated soil and become buried. Decay, on the other hand, can take place not only at the surface, but throughout the peat thickness. However, the rate of decay generally is highest in the unsaturated surface layers and lowest in the saturated zones of peat (Cameron, 1989). Compared to unsaturated organic deposits, a deposit saturated with water is relatively free from dissolved oxygen. Aerobic microbial communities decay vegetable matter more rapidly and completely than anaerobic microbial communities which cannot degrade many organic constituents (Broadbent, 1960). Peat may continue to exist indefinitely unless the land is drained and decomposition begins (Cameron, 1973).

Peat starts to form as soon as plants die and a series of changes begin that are generally faster at first, becoming slower as time goes on. These changes are called decay, decomposition, breakdown, or humification. The processes encompassed by them are (1) loss of organic matter, as a gas or as soluble breakdown products, as a result of leaching and attack by microorganisms; (2) loss of physical structure; and (3) change of chemical state, that is, the production of new types of molecules by microorganisms (Cameron, 1989). For the purposes of this report, the term “decomposition” will be used to describe all of these processes. Peat decomposition is accompanied by loss of water, carbon dioxide, and other volatile products, and results in concentrating the inorganic fraction (Brown and Farnham, 1976). In soils having a high content of organic materials, especially acid peat soils (low pH), the essential nutrients (calcium, potassium, nitrogen, and phosphorus) are mobile and easy to leach out because at lower pH such soils have a lower cation exchange capacity (Goode and others, 1977).

Climate, topography, and changes in water table depth are the chief factors governing the formation and preservation of peat deposits (Cameron, 1989). Microbial activity increases with increasing temperature, thus inducing greater rates of decomposition. The topography governs the type of incoming waters which provide nutrients for the formation of the peat deposit and may influence the position of the water table. Fluctuating water tables within the deposit can permit oxygenation of the organic material, thereby allowing aerobic microbes to decompose the plant fibers. Fluctuation of oxygenated water is generally greatest near the surface and near water bodies where the water table seasonally rises and falls. Where water tables remain high, peat accumulates faster than it decays (Cameron and others, 1989). Other factors that can influence the preservation of peat are land use, plant cover, and pH, high values of which can promote microbial activity (Eggelsmann, 1976; Cameron, 1989).

Peat Properties

An estimate of the degree of decomposition is one of the most useful qualitative properties for the description and categorization of peat. Three major categories were used to describe the peat within the soils around Upper Klamath Lake: hemic peat, hemic/sapric peat, and sapric peat. Hemic peat is undecomposed to moderately decomposed peat, sapric peat is the most decomposed peat, and hemic/sapric peat is intermediate to hemic and sapric peat.

The color of peat material is representative of the degree of decomposition of the peat (Cameron, 1973, 1975). Hemic peat that is newly exposed or has been well protected from the air is generally light yellow or brown. Partially decomposed hemic or hemic/sapric peat is brown to dark brown. Well-decomposed sapric peat is black. The appearance of alternating colored narrow bands of dark decomposed and light undecomposed soil materials may be due to microbiological differences which are, in turn, probably connected with the position and fluctuation of the water table (Cameron, 1970, 1989).

Fiber content refers to the proportion of stem, leaf, or other plant fragments that make up peat. The proportion of fiber is generally closely linked to the extent of decomposition (Cameron, 1975, 1989). As decomposition proceeds, the size of organic particles or fibers decreases (Boelter, 1969).

Ash consists of the inorganic solids remaining after a test portion of dry peat has been heated to a temperature of generally 450°–550°C (degrees Celsius) to remove the organic matter (Cameron, 1973).

Ash content is a concentration and is generally expressed in weight percent on the dry basis. The inorganic components of peat include minerals from the substrate and elements absorbed by plants from ground water or surface water, including incoming floodwaters and runoff from surrounding uplands or the drainage basin. Also, minerals are introduced as suspended detritus, precipitated from solutions, or deposited by wind, such as dust or volcanic ash (Brown and Farnham, 1976; Cameron and others, 1989).

Bulk density (dry-matter mass per unit volume of in-situ peat) is commonly used as an indicator of the degree of decomposition (Brown and others, 1984; McDonnell and Farrell, 1984; Mulqueen, 1986). As decomposition proceeds, the size of organic particles or fibers decrease, allowing for greater compaction and higher bulk density (Boelter, 1969).

The pH of the peat materials influences microbial activity, decomposition, and the leaching of nutrients from the organic material. Strongly acid soils support a limited variety of microbes. In-situ pH of natural peat is normally acidic, although it ranges from 3.2 to 7.5 (Cameron, 1975).

Drainage of Wetlands and Effects of Land Use

Drainage of wetlands results in a lowering of the water table, which improves aeration of peat soils and enhances soil microbial activity, thereby accelerating the decomposition of organic matter (Maciak, 1972; Lee and Manoch, 1974; Lévesque and Mathur, 1979; Mathur and Farnham, 1985; Efimov and Lunina, 1988; Petukhova, 1988; Laine and others, 1992). The rate is dependent on climate, land use, and ground-water level (Efimov and Lunina, 1988; Petukhova, 1988).

Where the land use is agriculture, the type of agriculture is also an important factor with regard to the rate and extent of decomposition of organic soils. Decomposition is generally greater for tilled areas than for non-tilled areas such as grasslands or pasture (Eggelsmann, 1976; Lévesque and Mathur, 1979; Mathur and Farnham, 1985; Levanon and others, 1987; Petukhova, 1988; Voznjuk and others, 1988; Berglund, 1992; Bartels and Scheffer, 1996). Tillage breaks up the soil surface and enhances the movement of air and oxygenated water in the soil. Areas used for grazing are trampled by cattle, resulting in compaction of the surface soils, which inhibits the movement of air and oxygenated water into the subsurface and may slow the rate of decomposition of the organic materials (Schalitz and others, 1996). Adding soil amendments such as lime [CaO or $Ca(OH)_2$], to raise soil pH, or nitrogen fertilizer can further accelerate the decomposition of organic soils (Kaunisto, 1976; Kuntze, 1984, 1992; Mathur and Farnham, 1985; Efimov and Lunina, 1988).

After drainage, the rate of decomposition of organic matter is high initially and declines exponentially with time. This has been observed in laboratory studies as well as in the field, where it also may be manifested by subsidence (Broadbent, 1960; Gallagher, 1978; Mathur and Farnham, 1985; Petukhova, 1988).

Organic materials undergo subsidence soon after drainage, primarily as the result of decomposition. Initially, subsidence occurs because of the lowered water table and subsequent loss of buoyancy as the underlying layers become compacted by the extra weight (Mulqueen, 1986). This is followed by continued subsidence from the decomposition of the organic materials (Stephens, 1956; Lynn and others, 1974). The maximum rate of subsidence occurs initially and decreases exponentially with time, as it is closely related to the rate of decomposition (Eggelsmann, 1976; Nesterenko, 1976). Factors affecting subsidence include depth of drainage, land use, wind erosion, loss by fire, mineralization, initial peat thickness, peat density, climatic conditions, and the amount of time since drainage began (Nesterenko, 1976; Berglund, 1992).

Land and Water Use

Historical

Land has been used for agriculture for more than 100 years in the region, possibly dating back to 1860. The wetlands provided wild hay harvested for cattle, and the preferred location for cattle grazing was in and near the wetlands on the margins of the lakes (Akins, 1970). Beginning before 1900, dikes were built in the low-lying marshy areas to prevent flooding of the wetlands where farmers cut wild hay (Dicken and Dicken, 1985). Since then, large areas of the wetlands that surround Upper Klamath Lake have been diked, ditched, and drained for agricultural use. Much of the wetlands were converted to pasture for grazing of cattle, particularly at the northern end of the lake, where temperatures are cooler and less suitable for cultivated crops. Areas of higher ground on the central and southern shores of Upper Klamath Lake were commonly cultivated for crops such as cereal hay and potatoes.

The drained wetlands have been incised by a series of deep interconnecting ditches and canals. To facilitate surface drying and agricultural usage, water that has accumulated from precipitation and surface runoff from adjacent slopes (especially during October through March), as well as irrigation and seepage of ground water, is seasonally or continually pumped from the canals and ditches to Upper Klamath Lake or its tributaries. At least 15 pumping stations situated around the lake drain the wetlands used for agriculture. Many of the drained wetlands were initially tilled to remove native vegetation and some of the drained wetlands were levelled to assist tillage.

Present Day

Presently, Upper Klamath Lake serves as a reservoir to provide water for agricultural use, electrical-power generation, recreational use, and extensive wildlife use. The area around the lake is an important agricultural area for crops and livestock. Farming in the area consists of row and field crops, including hay, barley, wheat, and potatoes. Pasture is used for grazing of livestock such as beef cattle, dairy cows, and sheep. Some of the drained wetland areas are used as pastures only during the spring and summer. Algae is harvested from the lake and at its outlet near the Link River and processed for sale as a health food product.

The Klamath Basin is a key area on the Pacific Flyway and a major resting place for migratory waterfowl, as well as a residence for a large variety of wildlife. Around Upper Klamath Lake are several areas where wetlands and parts of the lake have been set aside for wildlife. The Upper Klamath National Wildlife Refuge consists of two areas. A 13,800-acre area adjacent to the northwestern edge of Upper Klamath Lake and a 1,200-acre unit at Hanks Marsh on the eastern side of the lake. The State of Oregon has two wildlife refuges along Upper Klamath Lake—1,300 acres at the Shoalwater Bay Wildlife Area at the southern end of Shoalwater Bay and 370 acres at the Squaw Point Wildlife Area along the northern shore of Howard Bay. During fall and spring, nearly 1 million ducks, geese, swans and other birds migrating the Pacific Flyway flock to the wetland areas in and around the wildlife refuges in the Klamath Basin to rest and feed before continuing their journey. The area around Upper Klamath Lake also supports large concentrations of wetland birds such as pelicans, grebes, cormorants, egrets, and herons and provides important habitat for a number of introduced and native fish species, including the endangered shortnose and Lost River suckers.

The drained wetlands adjacent to Upper Klamath Lake have recently been the focus of efforts to improve water quality and fish habitat in Upper Klamath Lake. Between 1993 and 1996, about 8,000 acres, consisting predominantly of drained wetlands adjacent to Upper Klamath Lake, were acquired in separate acquisitions by the Bureau of Land Management (BLM) and the Nature Conservancy. The Wood River Property, consisting of about 3,200 acres, was purchased by the BLM with the intent of wetland restoration (Bureau of Land Management, 1995).

The Nature Conservancy purchased nearly 4,800 acres of the Williamson River North property, which will be managed in partnership with the Natural Resources Conservation Service for the purpose of wetland/riparian restoration directed to benefit the endangered Lost River and shortnose suckers (CH2M Hill, 1996). The Bureau of Land Management (1995) has stated that it is possible that additional lands could be acquired in the same general area for the purpose of wetland restoration.

METHODS

Nutrient loads from the drained wetlands were estimated using two methods. The first method involved the collection of samples for the determination of water quality and estimation of the quantity of water pumped from the drained wetlands. The second method involved the description of soil cores and the collection and analysis of soil samples from the drained and undrained wetlands.

Data Collection

Water Samples

Sampling

Six pumping stations used to remove water from five drained wetland areas were sampled intermittently by the USGS from 1993 through 1995 (fig. 2). The sampling schedule was designed for samples to be collected approximately every 3 weeks; however, the pumps were not always operating when sampling was scheduled. Samples were collected in a 3-liter polyethylene bottle attached to a long handle (to facilitate collection). At four of the six pumping stations, the samples were collected from the discharge pipes.

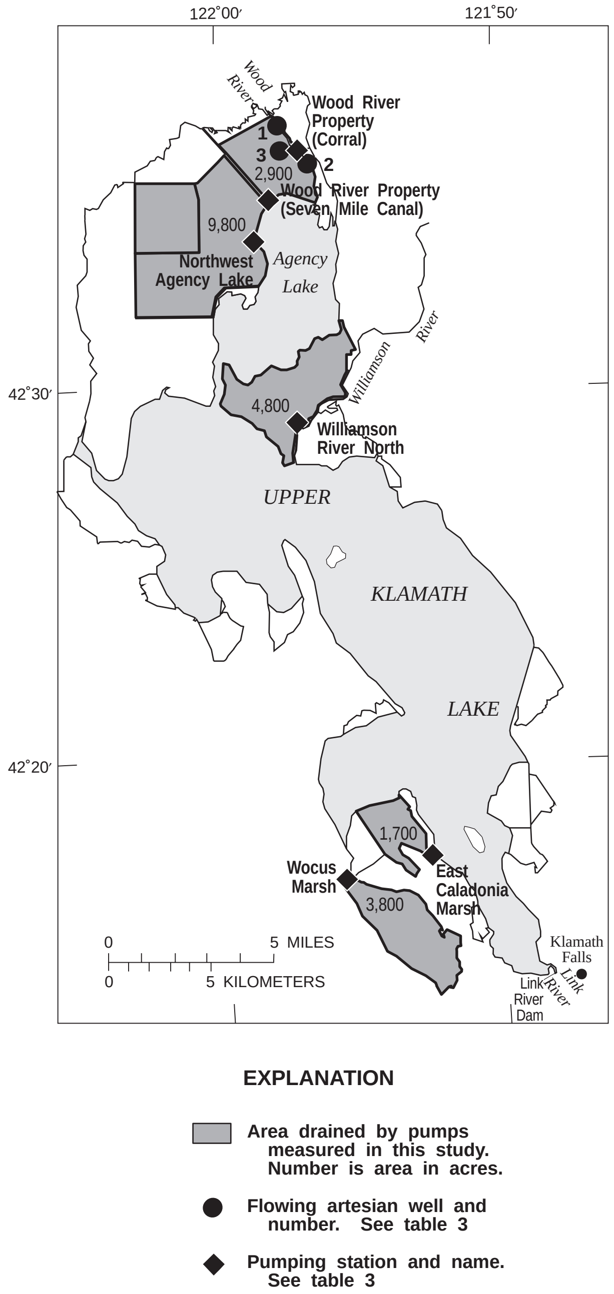

Figure 2. Location of selected drained wetlands, pumping stations, and flowing artesian wells adjacent to Upper Klamath Lake, Oregon.

At the Northwest Agency Lake and Williamson River North pumping stations, however, the discharge pipes are submerged. As a result, the samples were collected from the mouth of the intake pipe at the Northwest Agency Lake station and from an intermediate-discharge access pipe at the Williamson River North station.

Approximately three bottle volumes were collected at each pumping station and then combined into a churn splitter. The churn splitter was used in the field to resuspend the water-sediment mixture prior to subsampling for unfiltered-water analyses. The water remaining in the churn splitter was filtered through a 0.45-micrometer (µm) filter.

Nutrient samples in 1993 and 1994 were preserved with mercuric chloride and chilled to 4°C. Samples in 1995 were chilled but had no preservative added. Extensive study has demonstrated that both methods of preservation are equivalent (Bartholomay and Williams, 1996). All water-quality samples were immediately stored on ice and shipped to the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, for analysis.

In addition to the pumping stations, three flowing artesian wells on the Wood River Property (fig. 2) were sampled for nutrients in an attempt to estimate possible ground-water inputs to the property. Well 1 was sampled once each year, whereas wells 2 and 3 were sampled only once each in 1995. Because the wells were freely flowing, the sample water was collected directly into the churn splitter and then processed as for water-quality samples from the pumping stations.

Quality-assurance samples consisting of replicate splits were collected at four of the six pumping stations and one of the three flowing artesian wells and were included with routine water-quality samples to quantify the precision involved in the process. The replicate split samples were collected by extracting a second sample from the churn splitter during processing. Results of the quality-assurance analyses are in Appendix I.

Analytical Methods

Water-quality samples were analyzed at the NWQL for ammonia, ammonia plus organic nitrogen, nitrite, nitrite plus nitrate, phosphorus, and orthophosphate in filtered water[1] and ammonia plus organic nitrogen and phosphorus in unfiltered water[2]. The analytical methods used and their corresponding minimum reporting levels are shown in table 2.

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[1] The term "filtered water" is an operational definition referring to the chemical analysis of that part of a water-suspended sediment sample that passes through a nominal 0.45-µm filter.

[2] Conversely, the term "unfiltered water" refers to the chemical analysis of a water sample that has not been filtered or centrifuged, nor in any way altered from the original matrix.

Table 2. Methods and minimum reporting levels for nutrients in water sampled adjacent to Upper Klamath Lake, Oregon, 1993–95

[STORET, U.S. Environmental Protection Agency’s STOrage and RETrieval system. Method reference number corresponds to: (a) Fishman, 1993; (b) Charles J. Patton, U.S. Geological Survey National Water Quality Laboratory, written commun., 1996; or (c) Patton and Truitt, 1992. N, nitrogen; P, phosphorus]

STORET code	Constituent name	Method reference number	Minimum reporting level (milligrams per liter)
00608	Ammonia as N, filtered and undigested	(a) I–2522–90	0.01
00623	Ammonia plus organic nitrogen as N, filtered and digested	(b) I–2515–91	.2
00625	Ammonia plus organic nitrogen as N, unfiltered and digested	(b) I–4515–91	.2
00613	Nitrite as N, filtered and undigested	(a) I–2540–90	.01
00631	Nitrite plus nitrate as N, filtered and undigested	(a) I–2546–91	.005
00665	Phosphorus as P, unfiltered and digested	(c) I–4610–91	.01
00666	Phosphorus as P, filtered and digested	(c) I–2610–91	.01
00671	Orthophosphate as P, filtered and undigested	(a) I–2601–90	.01

Discharge Determinations

Discharge was determined once at each pumping station on May 5–6, 1994 (table 3). Each pumping station consisted of one to four individual pumps, each having its own discharge pipe. An electromagnetic velocity meter (model PVM-2A, Montedoro-Whitney Corporation, San Luis Obispo, California) was used to measure the velocity three to four times at each operating pump. The velocity was measured using the “time-averaged” method (Montedoro-Whitney Corporation, 1984, section II) at five of the six stations. This method involves moving the probe continuously over a 40-second time period in a pattern designed to cover the entire wetted cross-sectional area of the discharge pipe. At the sixth station (Northwest Agency Lake), the meter was used in the “instantaneous” mode to measure velocity in the star pattern (top, bottom, left, right). This method was used because the large velocities and volumes of water at this station made the continuous movement involved in the “time-averaged” method difficult. The diameter of the discharge pipe and wetted height were measured and used to determine the cross-sectional area of water flow. The discharge for each pump was calculated as the product of the wetted cross-sectional area and the mean of the velocity measurements. These discharge values for each pump were summed to calculate a total discharge for each pumping station.

Discharge was measured using a volume method (a certain volume was collected in a given time period) at flowing artesian well 1 in 1994 and at flowing artesian wells 2 and 3 in 1995.

Table 3. Discharge of selected pumping stations and flowing artesian wells adjacent to Upper Klamath Lake, Oregon, 1994–95

[Discharge values for pumping stations were based on the sum of the average (n = 3–4) discharge values calculated for each operating pump at a pumping station. Estimated discharge with all pumps operating was based on a ratio of the horsepower of the pumps composing the pumping station. ft^3/s, cubic feet per second; --, not applicable]

Station name	Date	Number of operating pumps	Discharge (ft^3/s)	Total horsepower of pumping station	Estimated discharge with all pumps operating (ft^3/s)
Pumping stations					
Wocus Marsh	05–05–94	3 of 4	15.6	130	22.5
East Caledonia Marsh	05–05–94	1 of 1	.85	50	.85
Williamson River North	05–06–94	2 of 2	26.0	200	26.0
Northwest Agency Lake	05–06–94	2 of 4	100	600	200
Wood River Property (Seven Mile Canal)	05–06–94	1 of 1	4.30	50	4.30
Wood River Property (Corral)	05–06–94	1 of 2	14.4	100	28.8
Flowing artesian wells					
Flowing artesian well #1	05–05–94	--	6.3×10^{-3}	--	--
Flowing artesian well #2	05–24–95	--	5.8×10^{-3}	--	--
Flowing artesian well #3	07–18–95	--	1.3×10^{-2}	--	--

Soil Samples

Soil cores were obtained to evaluate the extent and state of decomposition of the organic soils in the drained and undrained wetlands. This was done by describing the soil stratigraphy and collecting samples of material for physical and chemical analysis.

Sampling

During August 1993, a reconnaissance was made of the soils in the drained and undrained wetlands. Fifteen sites were selected for coring and description. Occasional grab samples were collected, but none were submitted for laboratory analysis. The locations of the cores and summaries of the soil materials are presented in plates 1 and 2, figure 3, and Appendix II. Although these cores provide additional information with regard to the extent and thickness of the organic soils, they were not used in the present analysis because of the lack of complete descriptions.

For the present analysis, coring and sampling took place during the first 3 weeks of August 1995. Eleven drained wetland areas were selected for coring and sampling, representing about 74 percent of the approximately 31,000 acres of drained wetlands adjacent to Upper Klamath Lake (fig. 3, table 4). These areas were selected because they were thought to be representative of the variety of drained wetlands adjacent to the lake with regard to age (time since drainage began) and type of agricultural use.

Five undrained wetland areas were also selected for coring and sampling (fig. 3, table 4) to characterize the physical and chemical properties of the organic materials for undrained wetland areas. The five undrained wetlands constitute nearly all of the 17,400 acres of undrained wetlands around the Upper Klamath Lake. These areas consist of parts of the National and State Wildlife Refuges and the Wood River Marsh, part of which is managed by the Bureau of Land Management and the rest privately held.

Drained and undrained wetland areas were delineated using information from State land-use maps, Natural Resources Conservation Service county soils maps, and USGS 1:24,000-scale topographic maps and orthophotos. These areas are generally designated as peat, muck, or silt loam on county soil maps (Cahoon, 1985) and are within dikes or levees, as shown on USGS topographic maps. The Oregon Water Resources Department land-use map for the Klamath Drainage Basin (Oregon Water Resources Department, 1978) classifies the drained wetlands as "irrigated agriculture" and classifies the undrained wetlands as "other." On some drained wetlands, the shoreward extent of the preexisting undrained wetlands was difficult to discern. In these instances, the 4,140-foot contour on USGS topographic maps was taken to represent the shoreline prior to drainage.

Core sites were selected to provide a good spatial representation of each drained area (fig. 3). During 1995, a total of 61 core sites were selected—51 on drained wetland areas and 10 on undrained wetland areas. The locations of all core sites are shown in plates 1 and 2. The location of each core site was established by use of a global positioning system (GPS) receiver and compared with locations as estimated using a 1:24,000-scale USGS topographic map. The GPS receiver used was a version provided by permission of the U.S. Department of Defense that has a horizontal accuracy of about 50 ft as configured for use during this study. Further details of site location and depth for each core are presented in Appendix II.

Core samples for stratigraphy were obtained using either a Macaulay peat sampler or a Davis soil auger. Most samples were taken using the Macaulay peat sampler, a hand-driven single-person auger that was designed specifically for the retrieval of undisturbed samples of peat suitable for peat stratigraphy investigations (fig. 4). It has attained widespread acceptance in peat investigations (Finney and others 1974; Brown and others, 1984). Through the use of extension rods, it is possible to obtain samples at depths of greater than 25 ft without compacting or distorting the soil material. A large diameter Macaulay sampler was used primarily; however, on a few occasions a small diameter Macaulay sampler was used, particularly for soils having a large content of clay, sand, or gravel. The internal dimensions of the sample chamber (barrel) for the large diameter Macaulay sampler are a length of 20.2 inches and a diameter of 1.4 inches. The sample chamber of the small Macaulay sampler has a barrel 12.1 inches in length and 0.94 inches in diameter. The cores retrieved by the Macaulay samplers are equal in length and diameter to the barrel and are semicircular in section. The sampler cuts the core from the side of the hole after the sampler is inserted into the soil. This helps to retain the original dimensions of the soil material and reduces the amount of disturbance to the sample from the current and previous insertions. The Macaulay peat sampler permits the collection of volumetrically intact samples for use in determining soil bulk density.

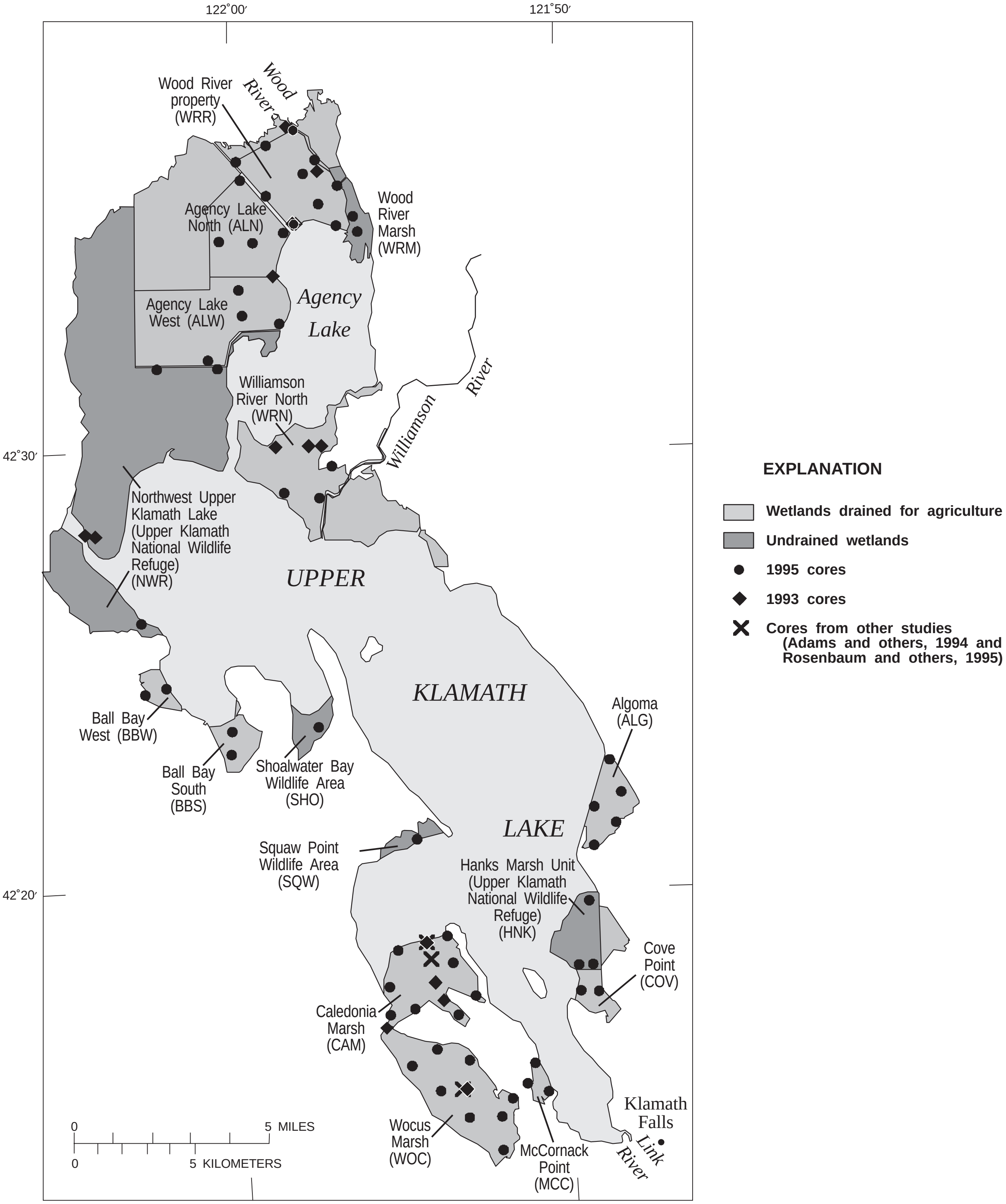

Figure 3. Location of core sites in the drained and undrained wetlands.

Table 4. Descriptions of drained and undrained wetlands adjacent to Upper Klamath Lake, Oregon, sampled during 1993 and 1995
[BLM, Bureau of Land Management; --, not applicable; USFWS, U.S. Fish and Wildlife Service; ODFW, Oregon Department of Fish and Wildlife]

Name	Abbreviation	Area (acres)	Year drained	Land use	Land ownership
Drained wetlands sampled					
McCornack Point	MCC	260	1889	Crop cultivation	Private
Wocus Marsh	WOC	3,800	1896	Mixed agriculture[1]	Private
Algoma	ALG	1,200	1914	Crop cultivation	Private
Caledonia Marsh	CAM	2,500	1916	Crop cultivation	Private
Ball Bay South	BBS	800	1919	Cattle grazing	Private
Williamson River North	WRN	3,200	1920	Crop cultivation	Private
Cove Point	COV	550	1919–40	Crop cultivation	Private
Ball Bay West	BBW	410	1946–47	Cattle grazing	Private
Wood River Property	WRR	2,900	1940–57	Cattle grazing[2]	BLM
Agency Lake North	ALN	2,600	1962	Cattle grazing	Private
Agency Lake West	ALW	4,600	1968–71	Cattle grazing	Private
Total		22,820			
Undrained wetlands sampled					
Upper Klamath National Wildlife Refuge					
Northwest Upper Klamath Lake	NWR	13,800	--	Wildlife Refuge	USFWS
Hanks Marsh Unit	HNK	1,200	--	Wildlife Refuge	USFWS
Shoalwater Bay Wildlife Area	SHO	1,300	--	Wildlife Refuge	ODFW
Wood River Marsh	WRM	700	--	Undefined	Private and BLM[3]
Squaw Point Wildlife Area	SQW	370	--	Wildlife Refuge	ODFW
Total		17,370			

[1] Crop cultivation and cattle grazing within the same drained area.
[2] Area was predominantly used for grazing until 1995 and is presently (1996) undergoing restoration to predrainage conditions.
[3] Sampling only performed on BLM portion of Wood River Marsh.

A Davis soil auger was used when unconsolidated soil materials or hardened soils were encountered. This generally occurred in the upper 1 or 2 ft of the surface soils or when compacted clays, sands, or gravels were encountered. The Davis auger is a hand-driven single-person device with a barrel 8 inches in length and 4 inches in diameter. The Davis auger cuts material using two circular prongs with the debris accumulating in the central barrel. Samples obtained from the Davis auger can only be approximately located as being between the current hole depth and the depth of the previous soil material collected, thereby diminishing the precision of stratigraphy possible. The Davis auger does not permit the collection of volumetrically intact samples for use in determining soil bulk density.

At each core site, the freshly exposed core or soil material was carefully examined and described in the field with regard to depth and thickness of layers, color, and lithology (content and nature of plant detritus and mineral material), consistency, and sedimentary structures. Each barrel length section of core from the Macaulay peat samplers or soil material from the Davis auger was photographed prior to subsample collection to show the planned location of samples to be collected.

The peat soils were categorized in the field on the basis of fiber content, color, texture, and the degree of decomposition. Preliminary determination of the degree of decomposition was accomplished using the field assessment method devised by Von Post and Granlund and described by Lucas (1982) and Cameron (1989). The determination is based on factors that include the color of the water expelled when peat is squeezed in the hand and the proportion and character of the material which remains in the hand after squeezing. To make a rating, a small quantity of fresh wet peat is squeezed in the palm of the hand. Observations are made as to the nature of squeezed water—clear, turbid, muddy, none; the amount of peat squeezed through fingers—none, little, one-third, two-thirds, all; and the nature of the residue—unaltered fibrous, most remains identifiable, some remains identifiable, few identifiable, none identifiable.

Insertion of Macaulay peat sampler

Withdrawal of Macaulay peat sampler

Macaulay peat sampler opened to expose soil sample

Figure 4. Method of soil-core collection from drained and undrained wetlands.

Although widely used, the method is subject to the bias and experience of the observer and therefore gives only qualitative results and relative comparisons (Chason and Siegel, 1986). For this reason, peat materials were characterized in the field into one of only three groups: hemic peat, hemic/sapric peat, or sapric peat.

Soil coring was stopped when either the soil samplers were unable to penetrate the soil further or a reasonable certainty had been obtained that any organic materials possibly remaining at greater depths were hydraulically isolated. The estimation of hydraulic isolation was based on a judgement that a sufficient depth had been obtained or that sufficient thickness of clay or other inorganic materials having low permeability (the ability to transmit water) had been encountered, or both, such that any organic materials that might be found at greater depths are probably unaffected by land-use activities at the surface. The total depths of the soil cores examined ranged from 2.0 to 18.8 ft and had a mean of 8.8 ft and a median of 9.4 ft.

A total of 229 samples of soil materials were collected for possible laboratory analysis of total mass, dry mass, moisture content, ash content, total carbon content, total nitrogen content, nitrite plus nitrate as nitrogen content, and total phosphorus content. In addition, some of the samples were also submitted for determining soil pH, inorganic carbon content, and total inorganic phosphorus content. Samples were selected to represent the prevailing soil types present within the core with emphasis on organic soil materials. Samples also included inorganic soil materials such as clays, sands, pumice, and volcanic ash to help characterize the properties of these materials.

The large Macaulay sampler was used to collect 165 samples, and 10 samples were collected using the small Macaulay sampler. Soil samples were collected from the Macaulay samplers by cutting off a 0.2 to 0.6 ft length of soil material using a stainless steel knife. The Davis auger was used to collect 54 samples. Most of these samples were collected from the near surface. Sample intervals for the Davis auger ranged from 0.1 to 1.0 ft. Soil material to be sampled was removed from the barrel of the Davis auger using a stainless steel knife and placed on a clean plastic placard used for description, photo documentation, and sample collection.

Samples were placed in labeled plastic bags that were immediately sealed and stored on ice. The sample location and length were recorded and the unused part of the soil core material was discarded prior to the retrieval of the next length of core or soil material. The samples were later stored in a refrigerator until analyzed to retard biochemical activity. Of the 229 samples collected, 181 were submitted for laboratory analysis. Of these, 136 were from drained areas and 45 from undrained areas. All samples consisting primarily of organic materials (on the basis of observation) were submitted for laboratory analysis. Of the remaining samples, several samples characteristic of soil end-members such as clay, sand, pumice, and volcanic ash were selected for analysis to determine the physical and chemical characteristics of these inorganic soil materials.

Analytical Methods

Soil samples were analyzed by the Soil, Water, and Plant Testing Laboratory at Colorado State University in Fort Collins, Colorado, using methods published in the Annual Book of ASTM (American Society for Testing and Materials) Standards (Canning and others, 1991); Methods of Soil Analysis American Society of Agronomy, and Soil Science Society of America (Page and others, 1982); and Soil Survey Laboratory Methods Manual (U.S. Department of Agriculture, 1991) (table 5).

Twenty-two replicate-split samples were submitted for analysis in addition to the 181 original samples. Results of the quality-assurance analysis are presented in Appendix I. Replicate-split samples for quality assurance and quality control were collected by dividing a sample in half and labeling with a separate code so that the sample would be unidentifiable as a replicate by the laboratory.

Soil samples were weighed to determine a total mass and milled prior to analysis, and subsamples were taken for the following determinations: Dry mass was determined by drying at 105°C and is expressed as the percentage of the total mass, with the remainder equal to the percent moisture content. Percent ash content was determined by igniting the oven-dried sample in a muffle furnace at 750°C. The substance remaining after ignition is the ash. Ash content is expressed as the percentage of the initial dry mass. Soil pH was measured using a pH electrode in a saturated paste of deionized water and soil and is reported in standard pH units. Total carbon was

Table 5. Methods and detection limits for analyses of soils sampled adjacent to Upper Klamath Lake, Oregon, 1995

[C, carbon; N, nitrogen; P, phosphorus; mg, milligram; kg, kilogram. Method reference number corresponds to (a) ASTM (American Society for Testing and Materials) (Canning and others, 1991); (b) Soil Survey Laboratory Methods Manual (U.S. Department of Agriculture, 1991); or (c) Methods of Soil Analysis (Page and others, 1982)]

Constituent name and units	Method reference number	Detection limit
Dry mass, as percentage of total mass	(a) 2974–87	0.1 percent
Percent moisture, as percentage of total mass	(a) 2974–87	.1 percent
Percent ash content, as percentage of oven-dried mass	(a) 2974–87	.1 percent
Soil pH, in standard pH units	(b) 8C1b	.1 standard pH units
Total carbon, as percentage of oven-dried mass as C	(b) 6A2d	.1 percent
Inorganic carbon, as percentage of oven-dried mass as C	(b) 6E1c	.01 percent
Total nitrogen, as percentage of oven-dried mass, as N	(c) 31–1	.01 percent
Nitrite plus nitrate, as mg of N per kg of oven-dried mass	(c) 33–2	1 mg/kg
Total inorganic phosphorus, as mg of P per kg of oven-dried mass	(c) 24–4.2	1 mg/kg
Total phosphorus, as mg of P per kg of oven-dried mass	(c) 24–2.3	10 mg/kg

determined by dry combustion using a Leco CHN (carbon-hydrogen-nitrogen) furnace and is reported as the percentage of the oven-dried mass, as carbon. Inorganic carbon (carbonate carbon) was determined by weight loss with the addition of hydrochloric acid and is reported as the percentage of the oven-dried mass, as carbon. Total nitrogen was determined using a Leco CHN furnace and is reported as the percentage of the oven-dried mass, as nitrogen. Nitrite plus nitrate was determined using a 2 molar potassium chloride extract and analysis by flow injection using zinc reduction and is reported as the milligrams of nitrogen per kilogram of the oven-dried mass. Total inorganic phosphorus was determined using a sequential extraction and is reported as the milligrams of phosphorus per kilogram of the oven-dried mass. Analysis of total phosphorus (TP) was performed using a perchloric acid digestion and is reported as the milligrams of phosphorus per kilogram of the oven-dried mass.

Total carbon in soils is the sum of organic and inorganic carbon. Most of the organic carbon is associated with the organic matter fraction, and the inorganic carbon is generally found with carbonate minerals (U.S. Department of Agriculture, 1996). The difference between total and inorganic carbon is an estimate of the organic carbon. Of 46 samples analyzed for inorganic carbon, 42 samples (91 percent) had values below the detection limit. Of the remaining four samples, two were either sand or clay. The remaining two samples were of sapric peats taken from cores near the mouths of small drainages at the southern end of Caledonia Marsh. Inorganic carbon accounted for less than 0.2 percent of the total carbon. On the basis of these results, total carbon was used as an estimate of the total organic carbon.

Total nitrogen (TN) in the soils, as used in this report, is the sum of organic and inorganic nitrogen. The inorganic nitrogen generally occurs as nitrate or nitrite. Inorganic nitrogen accounted for less than 3 percent of the total nitrogen for any of the samples analyzed.

Bulk density was calculated as the dry mass at 105°C, determined by laboratory analyses, divided by the volume of the sample collected. The volumes of the sampling chambers of the large and small Macaulay samplers were determined by displacement of water. The large sampler had a volume of 268 cm^3 (cubic centimeter) and the small sampler had a volume of 69 cm^3. Because the samples consisted of a partial length of the core sample obtained using the Macaulay samplers, the sample volume was calculated as the sample length divided by the length of the Macaulay sample chamber, multiplied by the measured volume of the entire sample chamber. As previously discussed, it was not possible to calculate the bulk density of samples collected using the Davis auger. Therefore, the 29 samples of sapric peat collected from the drained wetlands using the Davis auger were assigned a bulk density of 0.2448 g/cm^3 (grams per cubic centimeter), the median value for drained sapric peats collected using the Macaulay samplers.

Data Analysis

Estimation of Nutrient Loads Using Sampling and Measurement of Pump Discharge

Nutrient concentrations were measured during 1993–95 and the electrical meters associated with the pumping stations were monitored to determine the annual volume of water pumped based on the power consumption in May 1994. Given the concentration and volume of water pumped during the water year[3], an annual load can be calculated. It is important to note that this method gives a crude estimate and has many assumptions and inherent errors associated with it (these assumptions are listed in the “Limitations and Concerns Involved in Calculations of Nutrient Loads and Yields” section under this heading). For these reasons, these loading estimates should be used only as an indication of the order of magnitude of nutrient contributions from these areas.

Calculation of Volume of Water Pumped

The volume of water pumped from the drained wetlands was estimated from power-consumption data using an adaptation of the method detailed by Hurr and Litke (1989). To determine this volume, a relation was established between the volume of water pumped and the energy consumed. This relation is represented by the power-consumption coefficient (PCC), which is the ratio of the instantaneous power demand to the simultaneously measured discharge.

The power demand is calculated by:

$$P = rate \times Kh\ factor \times M \times 3.6, \qquad (1)$$

where:

P = instantaneous power demand, in kilowatts (kW);
rate = the average rate of disk revolution, in revolutions per second;
Kh factor = the disk constant, in watt-hours per revolution;
M = the meter multiplier, unitless; and
3.6 = a conversion factor for watts to kilowatts and seconds to hours.

The *Kh factor* and meter multiplier are printed on the meter.

The power demand is then divided by the corresponding discharge for the pumping station to yield the PCC. The PCC values calculated for these pumping stations are given in table 6. According to Hurr and Litke (1989), for open-discharge irrigation wells powered by electricity and pumping ground water from a depth of less than 50 ft, typical values of PCC range from 75 to 150 kWhr/acre-ft (kilowatt-hours per acre-foot) of water. The values for the Northwest Agency Lake pumping station and Wood River Property (Corral) pumping station are low when compared to this range, but they had respective lifts of only 2.0 ft and 7.8 ft when measured. For any of the pumping stations, the maximum lift is about 20 ft, but typically less than that, and the maximum head change is only about 5 ft during the water year.

Because the discharge at each pumping station was measured only once (in May 1994) during the study period (1993–95), the PCC established for May 1994 was used to calculate volumes throughout the study period. This practice was based on the assumption that the relation between pumping rate and power demand is constant. This relation is not always constant, however, as described by Hurr and Litke—(1989, p. 24).

> For example, pumping head may increase due to drawdown from extensive pumpage, pump efficiency may decrease as the pump ages, and changes in the irrigation-water distribution system may alter the load against which the pump must work.

In this study, however, pumping head changed by only about 5 ft over the year, and pump efficiency is not expected to greatly change over a 3-year period.

Once the PCC has been established for the pumping station, the volume of water pumped during a given time frame can be calculated based on the electrical meter readings at the bounds of the time frame. For this report, an estimate of the annual load was desired, so the volume of water pumped was determined for the water year. By using the monthly meter readings, the volumes pumped during these time periods can be summed to determine an annual volume of water pumped.

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[3] A water year is the 12-month period beginning October 1 and ending September 30 in the following year. The water year is designated by the calendar year in which it ends. The pumping season is generally from March to September with little pumping outside this time period.

Table 6. Power-meter information, power demand, discharge, power-consumption coefficient, and lift for selected pumping stations adjacent to Upper Klamath Lake, Oregon, May 5–6, 1994

[East Caledonia Marsh pumping station was excluded because there were too few data to calculate loads. Whr/rev, watt-hours per revolution; kW, kilowatts; ft^3/s, cubic feet per second; PCC, power-consumption coefficient; kWhr/acre-ft, kilowatt-hours per acre-foot of water]

Pumping station	Kh factor (Whr/rev)	Meter multiplier (unitless)	Power demand (kW)	Discharge (ft^3/s)	PCC (kWhr/acre-ft)	Average lift (feet)
Wocus Marsh	4.8	80	88.7	15.6	68.9	5.6
Williamson River North	3.6	40	180.5	26.0	84.1	10.1
Northwest Agency Lake	3.6	120	180.6	100	21.8	2.0
Wood River Property (Seven Mile Canal)	43.2	1	42.0	4.30	118	16.7
Wood River Property (Corral)	1.2	160	44.1	14.4	36.9	7.8

Calculation of Nutrient Loads and Yields

The annual nutrient loads were calculated as the product of the annual volume of water pumped and the annual median concentrations. In this study, loads were determined for total nitrogen and total phosphorus. Total phosphorus concentrations are equal to the measured values from the analysis of phosphorus in unfiltered water. Total nitrogen concentrations are calculated by adding the results of the analyses for ammonia plus organic nitrogen in unfiltered water and nitrite plus nitrate nitrogen in filtered water.

Although all six pumping stations were monitored from 1993 through 1995, loads were only calculated for stations and years having three or more nutrient determinations (note that the maximum number of samples for any station and year was five). This limitation excludes the East Caledonia Marsh pumping station from the annual load calculations. Also, the two pumping stations at Wood River Property drain the same area; therefore, the volumes of water pumped were calculated for each pumping station and then added to yield one volume to be used in calculating the annual load for the area. Because of these limitations on the analysis, loads were calculated for only 8 of the possible 18 year-station combinations.

By dividing the annual nutrient load by the drained area that it represents (fig. 2), an annual nutrient yield is obtained. The yield is an area-normalized value that makes inter-area comparisons possible. The load value is related to the size of the drained area, whereas the yield value is based on a common unit of area and is not affected by the size of the drained land area.

Limitations and Concerns Involved in Calculations of Nutrient Loads and Yields

Many assumptions and inherent errors are associated with the calculations of nutrient loads and yields. An estimate of error is not provided with the calculated loads and yields because it is not possible to quantify the error associated with each of the assumptions. For these reasons, the calculated nutrient loads and yields should be used only as an order-of-magnitude estimation with consideration of the limitations and concerns listed below.

- The relation between pumping rate and power demand is assumed to be constant over the study period (1993–95).

  This assumption, that the pumping head and pump efficiency remained constant, is not true. Pumping head only changed, however, by about 5 ft over the year, and the pump efficiency is not expected to greatly change over a 3-year period.

- The annual nutrient concentration is assumed to be represented sufficiently by the median concentration from at least three samples collected during the year.

  The ability of the median to adequately represent the annual nutrient concentration depends on the number of data points and their distribution. For these data the range/median ratio varied from 7 to 250 percent. Conceptually, the nutrient concentrations are expected to increase as the pumping season progresses—as the low-concentration standing water is removed and subsequent drainage of the high-concentration pore waters occurs. This trend, however, was not always apparent in the data.

- The loads calculated are an integration of all possible inputs/outputs and not a treatment of each source individually.

  Possible inputs of nutrients include:

  decomposition of the peats;
  fertilizer applications;
  cattle waste deposition;
  waterfowl waste deposition;
  precipitation;
  atmospheric deposition;
  fixation of atmospheric nitrogen by
  microorganisms associated with plants;
  seepage through the dikes from the lake,
  adjacent river, or canal;
  flood irrigation from the lake, adjacent river,
  or canal;
  sprinkler irrigation from the adjacent river
  or canal; and
  runoff from adjacent land
  (particularly at the Wocus Marsh and
  East Caledonia Marsh pumping stations).

  Possible outputs include:

  agricultural products;
  cattle uptake;
  waterfowl uptake;
  erosion by wind and water;
  denitrification; and
  ammonia volatilization.

- Loads calculated for all pumping stations, except Wocus Marsh, are primarily delivered to the lake or its tributaries.

  The load calculated for the Wocus Marsh pumping station, however, is not always directed to the lake. During some times of the year, the pumped water is diverted from entering the lake and is recirculated for irrigation within the Wocus Marsh.

- The primary area drained by the pumping station at Northwest Agency Lake is about 7,200 acres; however, this pumping station is sometimes used to drain an additional 2,600 acre area. Although there is a 30-horsepower pump in the additional area, the pumps in the Northwest Agency Lake pumping station total 600 horsepower and, therefore, are considered the primary pumping device.

  The total area of 9,800 acres was used for the drained area in the yield calculations for the Northwest Agency Lake area.

Estimation of Nutrient Loss Using Change in Nutrient Mass of Drained Wetland Soils

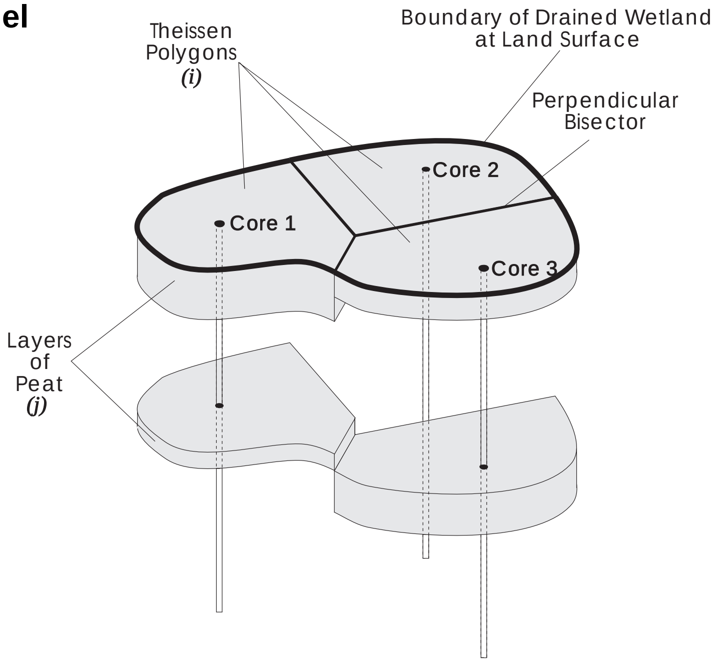
The cumulative loss of nutrients from soils of the drained wetlands was determined by estimating the present-day nutrient mass and subtracting this from an estimate of the initial nutrient mass prior to drainage. The change in nutrient mass is an estimate of the maximum amount of nutrients from the drained wetland soils that could have been pumped into Upper Klamath Lake. Estimates of annual nutrient loss were determined by calculation of decay rates for the period from when drainage began to the present.

Calculation of Present-Day Peat and Nutrient Masses

The present-day nutrient mass of the peat materials within each drained wetland was determined from the volume, bulk density, and nutrient concentrations of peat layers obtained from the analysis of soil cores. This method was used by Laine and others (1992) to estimate the stores of carbon in peat layers of drained wetlands. Layers of peat material are not necessarily continuous over the entire drained area. Therefore, each area was subdivided by using Theissen polygons. The method of Theissen polygons assumes that the influence of any core site can be applied halfway to the next core site in any direction (Chow, 1964). The polygons are constructed by plotting the locations of all the core sites within a drained area and drawing connecting lines between the sites. The perpendicular bisectors for each connecting line are then found and joined to form a polygon around each core site (fig. 5). Data from the core site in the polygon is used to represent the entire polygonal area. This method is generally more accurate than simple arithmetical averaging (Linsley and others, 1982).

The dry mass of peat in each layer is the product of the layer volume and its bulk density. Similarly, the mass of nutrient in each layer is the product of the layer volume, bulk density, and it nutrient concentration. Summing the masses for all the layers of all the Theissen polygons in a wetland area produces the present-day mass for the area. This calculation is detailed in figure 5 and a sample calculation is presented in table 7.

Conceptual Model



Equations

Present-day peat mass:

$$M = \sum_{i=1}^{n} \sum_{j=1}^{l_i} (A_i h_{i,j} \rho_{i,j})$$

Initial peat mass (prior to drainage):

$$M^{o} = \sum_{i=1}^{n} \sum_{j=1}^{l_i} (A_i h_{i,j} \rho_{i,j}) \left(\frac{R_{i,j}}{R^{o}} \right)$$

Present-day nutrient mass:

$$N = \sum_{i=1}^{n} \sum_{i=1}^{l_i} (A_i h_{i,j} \rho_{i,j}) C_{i,j}$$

Initial nutrient mass (prior to drainage):

$$N^{o} = \sum_{i=1}^{n} \sum_{i=1}^{l_i} (A_i h_{i,j} \rho_{i,j}) \left(\frac{R_{i,j}}{R^{o}} \right) C^{o}$$

where:

i = polygon index (i=1 to n)
n = number of Theissen polygons
j = layer index (j=1 to l_i)
l_i = number of layers for polygon i
A_i = area of polygon i (note: all layers are of equal area for each polygon i)
$h_{i,j}$ = thickness of layer j for polygon i
$\rho_{i,j}$ = bulk density of layer j for polygon i
$R_{i,j}$ = ash content in layer j for polygon i
R^{o} = ash content prior to drainage
$C_{i,j}$ = nutrient concentration (either N [nitrogen] or P [phosphorus]) in layer j for polygon i
C^{o} = nutrient concentration (either N or P) prior to drainage

Figure 5. Calculation of peat and nutrients of a drained wetland area. (The conceptual model and equations pertain to a hypothetical drained wetland area containing three core sites. Cores 1 and 3 each intersect two peat layers that are separated by clay or other mineral soil; core 2 intersects only one peat layer.)

Table 7. Sample calculation of peat and nutrients of a drained wetland area

[See figure 5 for conceptual model and equations used in the sample calculation. Data for the sample calculation are not from an actual site. Values of initial ash content (R^o) and initial total nitrogen concentration (C^o) used in calculations are 52 and 2.4 percent dry mass, respectively. Initial is prior to the beginning of drainage of a wetland for agricultural use. Present day is 1995. Cumulative loss is the difference between initial and present day. Values calculated for individual layers are presented using two significant figures. Sums were calculated using masses for individual layers and are rounded to the nearest 10,000 and 100 tons for peat and total nitrogen, respectively.]

	Core 1		Core 2	Core 3		Total
			Input values			
Area (acres)	$A_1 = 800$		$A_2 = 1{,}000$	$A_3 = 900$		2,700
Number of layers	$l_1 = 2$		$l_2 = 1$	$l_3 = 2$		--
Layer thickness (feet)	$h_{1,1} = 2.4$	$h_{1,2} = 0.9$	$h_{2,1} = 1.8$	$h_{3,1} = 1.2$	$h_{3,2} = 2.0$	--
Bulk density of layer (grams per cubic centimeter)	$\rho_{1,1} = 0.24$	$\rho_{1,2} = 0.16$	$\rho_{2,1} = 0.25$	$\rho_{3,1} = 0.23$	$\rho_{3,2} = 0.13$	--
Total nitrogen concentration (percent dry mass)	$C_{1,1} = 1.4$	$C_{1,2} = 1.8$	$C_{2,1} = 0.8$	$C_{3,1} = 1.2$	$C_{3,2} = 2.0$	--
Ash content (percent dry mass)	$R_{1,1} = 58$	$R_{1,2} = 53$	$R_{2,1} = 62$	$R_{3,1} = 60$	$R_{3,2} = 54$	--
			Calculated peat mass			
Present day (tons)	630,000	160,000	610,000	340,000	320,000	2,060,000
Initial (tons)	700,000	160,000	730,000	390,000	330,000	2,310,000
Cumulative loss (tons)	70,000	0	120,000	50,000	10,000	250,000
			Calculated total nitrogen mass and yield			
Present day (tons)	8,800	2,800	4,900	4,100	6,400	27,000
Initial total (tons)	17,000	3,800	18,000	9,400	7,900	56,100
Cumulative loss (tons)	8,200	1,000	13,100	5,300	1,500	29,100
Cumulative loss (pounds per acre)	--	--	--	--	--	22,000

Calculation of Initial Peat and Nutrient Masses Prior to Drainage

When a peat soil is drained and exposed to oxygen, the organic portion undergoes aerobic decomposition but the inorganic (mineral) component does not. Over time, the organic content decreases and the inorganic residue, or ash, becomes proportionally more concentrated. This proportional increase in the ash content can be used to estimate the mass of peat before drainage and subsequent decomposition (fig. 5, table 7). The calculation hinges on the following assumptions:

1. Ash is conservative—that is, ash is not lost during or after decomposition.
2. All peat soils in the wetlands adjacent to Upper Klamath Lake had the same initial ash content before decomposition.
3. Present-day undrained wetlands are representative of the drained wetlands prior to drainage.

This method is similar to that of Broadbent (1960), Segeberg (1962, as cited in Eggelsmann, 1976), and Laine and others (1992). Similarly, the initial nutrient mass can be estimated if it is also assumed that all the peat soils in the wetlands had the same initial nutrient concentration before decomposition (fig. 5, table 7). Initial masses will be underestimated if ash or nutrients are lost by wind or water erosion, uptake by crop or forage, or leaching by water.

The reference values of initial ash content (R^o) and initial nutrient content (C^o) were estimated from data from present-day undrained wetlands adjacent to Upper Klamath Lake. Initial values were determined by minimizing the differences between the calculated and observed present-day ash or nutrient mass per area summed over all peat layers encountered by the soil cores from the undrained wetlands (table 8). The mass per area was used because it incorporates a weighting by layer thickness and bulk density.

If the estimate of initial mass of peat was less than the present-day mass, it indicates that the initial ash content was over estimated or that the present-day ash content was underestimated, perhaps as a result of erosional losses. This situation occurred for 54 percent of the layers. In these instances, it was assumed that no decomposition took place and the initial peat mass was set equal to the present-day mass in the layer.

If the estimate of initial masses of nitrogen or phosphorus were less than the present day masses, either the initial peat mass or nutrient content was underestimated or the present-day masses received additional inputs of nutrients, perhaps as a result of fertilizer or animal waste. This situation occurred for 0 and 14 percent of the layers for nitrogen and phosphorus, respectively. In these instances, the initial phosphorus mass was set equal to the present-day mass in the layer.

Calculation of Peat and Nutrient Loss Since Drainage

The cumulative loss of peat and nutrient mass from the drained wetland soils since drainage was calculated as the initial mass minus the present-day mass. This calculation was performed on individual peat layers within each Theissen polygon and the results were summed to determine the loss in mass of peat, TN, and TP for each drained wetland.

Calculation of Decay Rates and Annual Estimates of Peat and Nutrient Loss

Estimates of annual losses of nutrients from the peat soils of the drained wetlands are needed to facilitate comparisons with estimates of annual nutrient loading to Upper Klamath Lake. Initial and present-day masses and length of time since drainage began were used to calculate rate constants *(k)* according to the first-order rate law:

$$A_t = Ae^{-kt} \qquad (2)$$

where:

A_t = nutrient mass of drained wetland at time t, in tons;

A = initial nutrient mass of drained wetland at start of drainage, in tons;

Table 8. Calculation of initial ash and nutrient content

[S, sum of residual differences; c, core index (c = 1 to n); n, number of cores in all undrained wetlands; j, layer index (j = 1 to l_c); l_c, number of layers for core c; $h_{c,j}$, thickness of layer j for core c; $\rho_{c,j}$, bulk density of layer j for core c; $R_{c,j}$, ash content in layer j for core c; R^o, initial ash content; $C_{Nc,j}$, nitrogen content in layer j for core c; C_N^o, initial nitrogen content; $C_{Pc,j}$, phosphorus content in layer j for core c; C_P^o, initial phosphorus content; mg, milligrams; kg, kilograms]

Component	Minimized function	Range of present-day values from soil samples	Calculated initial content
Ash	$S = \sum_{c=1}^{n}\sum_{j=1}^{l_c}\left\lvert h_{c,j}\rho_{c,j}\left(\frac{R_{c,j}}{R^o} - 1\right)\right\rvert$	$R_{c,j}$ = 10–74 percent	R^o = 52 percent
Nitrogen	$S = \sum_{c=1}^{n}\sum_{j=1}^{l_c}\left\lvert h_{c,j}\rho_{c,j}\left(\frac{C_{Nc,j}}{C_N^o} - 1\right)\right\rvert$	$C_{Nc,j}$ = 1.3–3.8 percent	C_N^o = 2.4 percent
Phosphorus	$S = \sum_{c=1}^{n}\sum_{j=1}^{l_c}\left\lvert h_{c,j}\rho_{c,j}\left(\frac{C_{Pc,j}}{C_P^o} - 1\right)\right\rvert$	$C_{Pc,j}$ = 190–970 mg/kg	C_P^o = 620 mg/kg

e = base of Napierian logarithms, 2.71828, dimensionless;
k = rate constant, in 1/years; and
t = time since drainage of wetland began, in years.

Equation 2 gives the nutrient mass A_t that remains at any time t of the initial nutrient mass (A) that was present prior to drainage of the wetland ($t = 0$). The rate constant (k) is the fraction of the nutrient mass that is lost on an annual basis and, when multiplied by 100, can be expressed as a percentage using units of percent per year. Rate constants were individually determined for TN and TP for each drained wetland area. The rate constants were used to calculate the nutrient mass existing at each drained wetland for the following pairs of consecutive years: 1965 and 1966, 1992 and 1993, 1993 and 1994, and 1994 and 1995. The difference between the nutrient masses calculated for any 2 consecutive years is the annual nutrient loss for that time period.

A first-order rate law is one of several possible models that might describe the decomposition of peat soils from the drained wetlands. Many factors influence the rate of decomposition. Rates may vary spatially within individual drained areas or temporally due to weather or changes in land-use management. These factors have not been incorporated in the present model. Therefore, annual nutrient losses calculated from the model should not be expected to accurately represent losses for a particular year which result from specific conditions.

DESCRIPTION OF SOILS ON UNDRAINED AND DRAINED WETLANDS

A comparison of the character and composition of the undrained and drained wetland soils provides insight into the effects of decomposition of the organic materials. The observation of these differences formed the basis for the analysis of nutrient loss from the drained wetlands soils and the possible significance of land use.

Initial Soil Properties of Undrained Wetlands

Soil cores from the peat materials in the undrained wetlands show the following sequence of beds from the bottom upward: clay, clay with hemic peat, hemic peat with clay, hemic peat (plates 1 and 2). This sequence or cycle is sometimes repeated, as in both cores from the Wood River Marsh and one core from the Upper Klamath National Wildlife Refuge at the northwest part of Upper Klamath Lake, and may be interrupted by layers of volcanic ash or pumice. The interfaces between varying lithologies are generally gradational but can be sharp. The maximum thickness observed of the basal pond clay is greater than 12 ft and varies from tan to light green with shades of gray found at greater depths. The combined thickness of the overlying clay with peat and peat with clay can range in thickness from 0 to 4 ft and the color of this material is generally tan to light green. This material is overlain by medium to dark brown reed-sedge hemic peat having a thickness ranging from 2 to 14 ft. On the surface, a dark brown muck may be found consisting of saturated decomposed organic material that can range in thickness from 0 to 1.5 ft. Although the same sequence of materials is generally observed in nearby cores, the lateral continuity of the lithologic layers could not be ascertained owing to the small number of cores collected in each of the undrained wetlands.

No sapric peat was observed in the five cores from the Upper Klamath National Wildlife Refuge at the northwest part of Upper Klamath Lake. As much as 6 ft of dark brown to black sapric peat was found in cores from Shoalwater Bay, Squaw Point, Hanks Marsh, and Wood River Marsh.

Thin clay layers of probable volcanic origin (hereafter referred to as volcanic ash) and pumice sand were observed in cores from the Wood River Marsh, Shoalwater Bay, and Hanks Marsh. The volcanic ash or pumice layers are white to light gray and range in thickness from 0.05 to 0.4 ft. Many of the peat materials directly above or below these layers show greater decomposition as indicated by the appearance of dark brown or black hemic peat or the presence of sapric peat. The deposition of volcanic ash may have increased the pH of the water in the wetlands, creating an environment favorable to microbial activity and resulting in an increased rate of decomposition. Alternatively, the volcanic deposits may have initiated a temporary alteration of the peat-forming vegetation in the wetlands by smothering, mechanical overloading, or chemical attack (Crowley and others, 1994), subsequently reducing the accumulation rate of plant material. These layers of volcanic ash, and pumice sand and gravel might also influence the movement of air and oxygenated water in the subsurface, which could affect decomposition rates.

Some of the deepest soil cores examined in the undrained wetlands (HNK-01, NWR-A2) contained a smooth gray clay at depths of between about 17 and 22 ft that may be representative of lacustrine deposits during the Pleistocene, when the lake surface of ancient Lake Modoc was about 100 ft higher than present day (see figure 6E for photograph of similar material in core CAM-08 from a drained wetland). This evidence could place the maximum age of the overlying peat deposits at about 10,000 years, the time when ancient Lake Modoc began to shrink.

Some of the physical and chemical properties of the peat soils of the undrained wetlands relative to the drained wetlands are summarized in figure 7. The peat soils have a low ash content (median of about 33 percent) and a low bulk density (median of about 0.12 g/cm^3) due to the high proportion of organic to inorganic material. The total nitrogen content is high (median of about 2.5 percent). The total phosphorus content (median of about 400 milligrams per kilogram (mg/kg) is similar to the drained wetlands.

Present-Day Soil Properties of Drained Wetlands

The occurrence of peat materials in the drained wetlands is similar to that of the undrained wetlands; however, many areas show a greater abundance of decomposed materials, such as sapric or hemic/sapric peat, particularly at or near the surface (fig. 6A–E). Hemic peat ranged in thickness from 0 to 12 ft, whereas sapric or hemic/sapric peat materials ranged from 0 to 8 ft. A greater abundance and frequency of volcanic ash and pumice was observed in the cores from the Wood River Property. The greater abundance may be due to the wetland’s location at the extreme northern end of Upper Klamath Lake and its proximity to the Wood River and other streams that drain the Wood River Valley (which extends northward toward Crater Lake). Volcanic ash or pumice is found in layers from 0.01 to 1.3 ft in thickness. Some areas, such as Algoma and Williamson River North, had considerably more clastic material, such as sand, which may be due to the areas’ proximity to the mouths of rivers or small drainage basins, where alluvial deposition can occur.

Correlating specific layers or horizons throughout a drained area can be difficult. Thickness can change over short distances, and horizons (or layers), such as those marked by volcanic ash or pumice, may be absent. This heterogeneity becomes more evident in areas having a greater density of core sites, such as the Wood River Property.

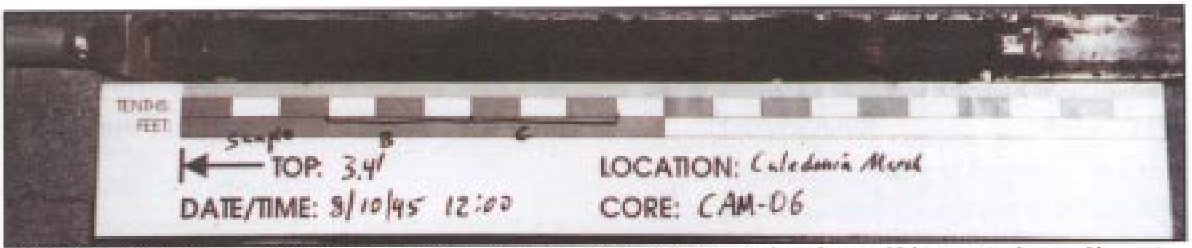
The Ball Bay South drained wetland had about 1.7 ft of organic material mixed with varying quantities of mineral soil and clay at the surface. No soil layers consisting exclusively of peat material were found up to a depth of 4.8 ft. It may be that little peat was formed at this location or that the peat which existed has nearly completely decomposed. Due to the lack of data, the Ball Bay South drained wetland was excluded from calculations of present-day or initial nutrient mass or loss.

The effects of decomposition of the peat soils in the drained wetlands are evident in their physical and chemical properties relative to the peat soils of the undrained wetlands (fig. 7). The peat soils of the drained wetlands have a higher ash content (median of about 50 percent) and a higher bulk density (median of about 0.18 g/cm^3). Total nitrogen content is lower (median of about 1.7 percent), indicating that some of the nitrogen has been lost from the peat soils. Total phosphorus content (median of about 440 mg/kg) is similar to that of the undrained wetlands but has a large range (90 to 1,500 mg/kg). The large range may be indicative of the occurrence of both phosphorus loss due to drainage and phosphorus accumulation due to adsorption or exchange with adjacent soil layers or ground water, or from agricultural sources such as cattle urine and feces or fertilizer for crops.

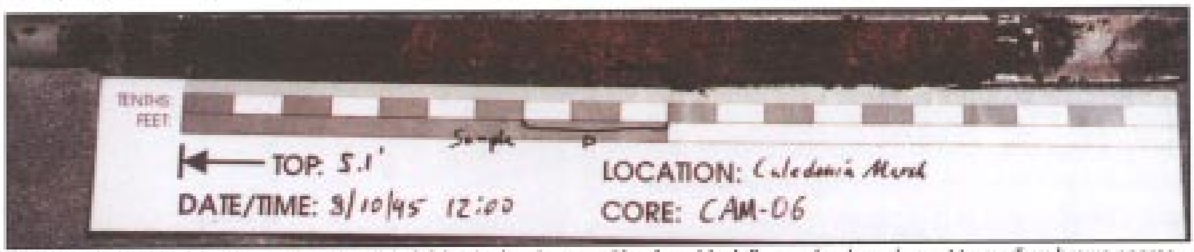
Subsidence is a further consequence of the drainage of wetlands. For the Lather muck soil type present in most of the drained wetlands, Cahoon (1985) reports that in the first few years after drainage subsidence can be as much as 10–20 inches and as much as 1 inch per year thereafter. Subsidence reported by land owners ranged from 1 ft to more than 13 ft at the Williamson River North property.

Age of Drained Wetlands

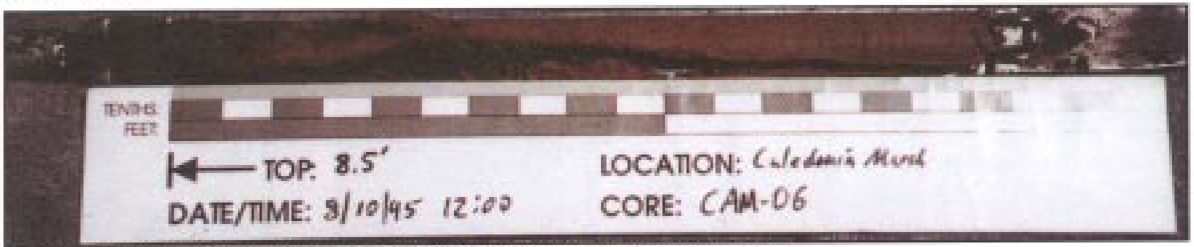
A chronology of the conversion of wetlands to agricultural use around Upper Klamath Lake was constructed. Present-day and past land owners were interviewed when possible and were the primary source of information. In addition, data from studies by Akins (1970) and Carlson (1993) discuss or identify changes in land use of the wetlands. These sources were supplemented by evaluating the changes in land use as indicated by the addition of dikes and canals or by the land use shown on various maps (Oregon Water Resources Department, 1978; USGS topographic maps and orthophotos at scales of 1:250,000, 1:100,000, 1:62,500, and 1:24,000).



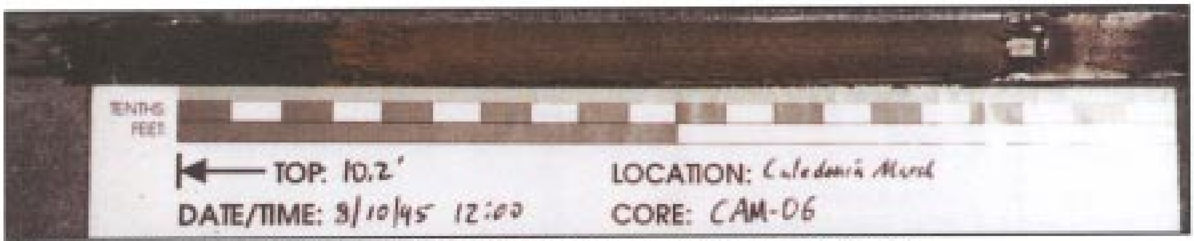
A. Shallow soil layers (depth = 3.4–5.1 feet), consisting of black fine-grained decomposed sapric peat. Light gray pumice sand layer at 4.8 feet may represent deposits from the climactic eruption of Mount Mazama about 6,900 years ago or reworked deposits that have subsequently been transported by water.



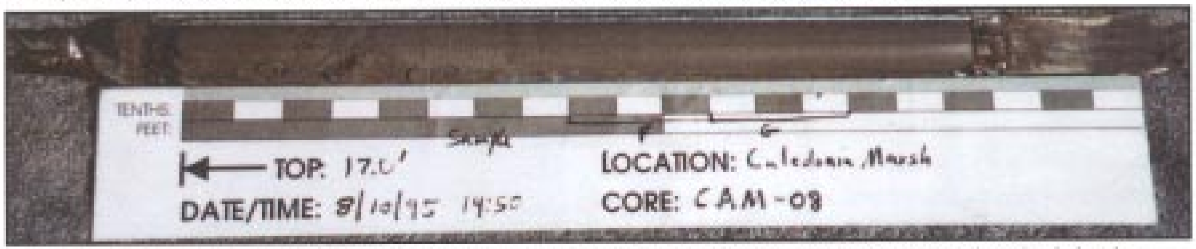
B. Moderately shallow soil layers (depth = 5.1–6.8 feet), showing transition from black fine-grained sapric peat to medium brown coarse-grained hemic peat.



C. Moderately deep soil layers (depth = 8.5–10.2 feet), showing olive clay with hemic peat.



D. Deep soil layers (depth = 10.2–11.9 feet), showing transition from olive clay with hemic peat to gray clay.



E. Very deep soil layers (depth = 17.0–18.7 feet), showing smooth gray clay that may be the result of lacustrine deposits during the Pleistocene, when lake level may have been 100 feet higher than the present day.

Figure 6. Examples of soils cores retrieved using Macaulay peat sampler from drained wetland used for cultivation. (Soil depths increase from left to right with depth of top of soil core indicated on placard. Placard is marked in increments of feet and tenths of feet. Core name and sample are indicated on placard. The locations of the cores, summaries of the soil materials, and descriptions of soil samples are presented in Appendixes II and III, and plates 1 and 2.)

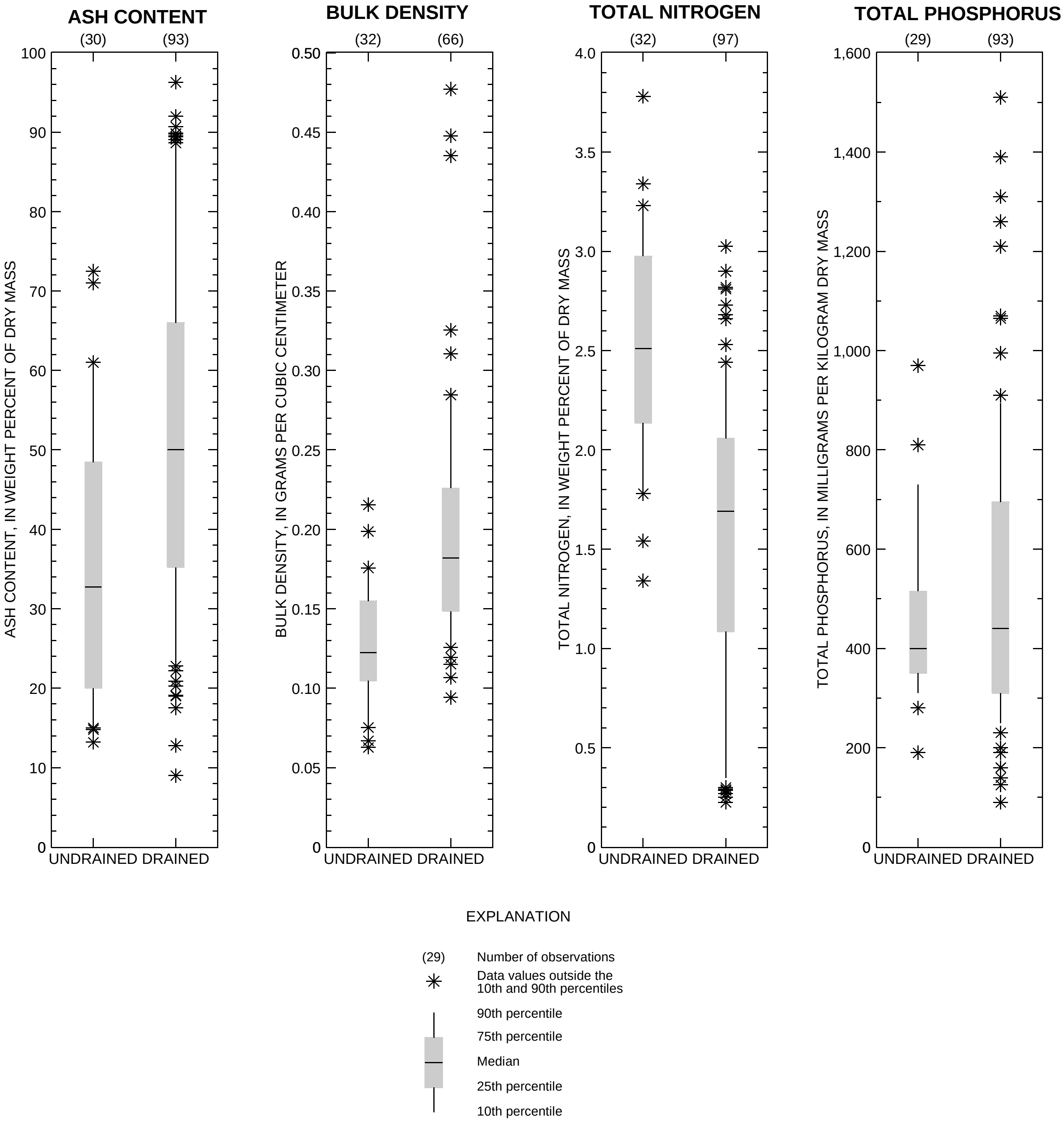


Figure 7. Statistical summaries of physical and chemical properties of samples from undrained and drained peat soils.

For some areas, only a range of possible dates for the conversion from undrained to drained wetlands could be identified (table 4). For purposes of calculation in this report, the mean date of initial drainage was used. Figure 8 summarizes the relation between the cumulative area of drained wetlands adjacent to Upper Klamath Lake and time.

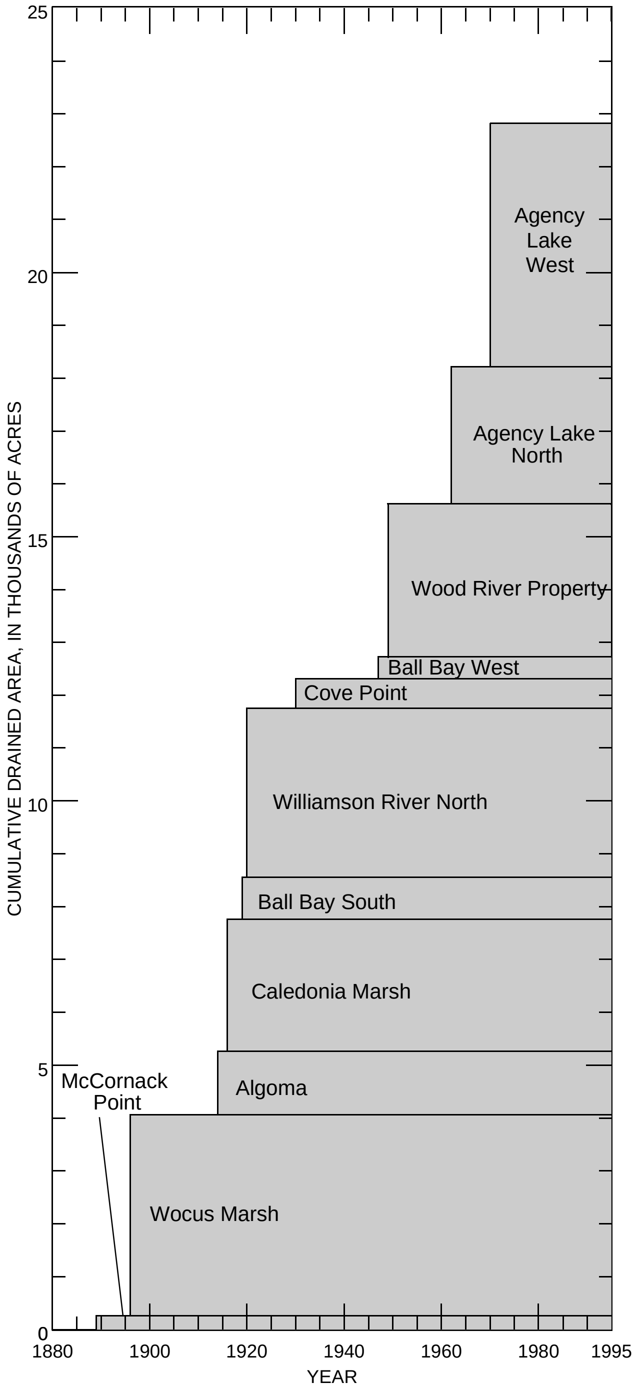


Figure 8. Cumulative area of drained wetlands adjacent to Upper Klamath Lake over time. (This area excludes about 8,200 acres of drained wetlands that were not considered in this study.)

NUTRIENT LOADING FROM DRAINED WETLANDS

Nutrient loading from drained wetlands was estimated using two independent techniques. The first method involved the measurement of the quantity and quality of water discharged by pumps draining the wetlands. This approach integrates all the nutrient inputs and outputs to the drained wetlands, some of which are a result of the drainage and utilization of the wetlands and some of which are the result of naturally occurring processes. The second method estimated the loss of nutrient mass due to peat decomposition in drained wetlands. Not all the nutrients released by the peat soils were pumped into the lake; some were lost to the atmosphere or incorporated in crops and forage. A comparison of the results from these two techniques is presented to further identify the effects of drainage and agricultural utilization of the wetlands on the nutrient loading of Upper Klamath Lake.

Discussion of Nutrient Loads and Yields from Pump Discharge

The nutrient concentrations measured at the pumping stations are shown in table 9. These concentrations all fell within the ranges of total nitrogen and total phosphorus given by Miller and Tash (1967) for Upper Klamath Lake and agricultural drains around the lake (table 10). As another comparison, these concentrations are consistent with concentrations reported for Agency Lake in 1990 (Kann, 1993a), to which three of the six pumping stations discharge, either directly or indirectly. Table 10 also shows that the concentrations measured at the flowing artesian wells are elevated in relation to the concentrations measured at the pumping stations.

Instantaneous loads were calculated for the days when the discharge measurements were made (table 11). These instantaneous loads provide a “snapshot” of the nutrient input to the lake for one point in time and are not necessarily representative of the nutrient loading during other time periods. This look at daily nutrient loading is information that cannot be extracted from the annual-loading estimates because of the limitations imposed by the intermittent pumping schedules.The Williamson River North pumping station is noteworthy because the total nitrogen load is greater than the loads from the other five pumping stations combined and the total phosphorus load is about 75 percent of the sum of the other five loads.

Table 9. Summary of nutrient data from water-quality samples collected at selected pumping stations and flowing artesian wells adjacent to Upper Klamath Lake, Oregon, 1993–95

[All concentrations reported are from filtered-water samples, unless otherwise stated. All concentrations are reported as nitrogen or phosphorus. See table 2 for methods used and minimum reporting levels. <, less than]

Sample description			Nitrogen (milligrams per liter)					Phosphorus (milligrams per liter)		
Station name	**Date**	**Time**	**Ammonia**	**Ammonia plus organic nitrogen**	**Ammonia plus organic nitrogen, unfiltered**	**Nitrite**	**Nitrite plus nitrate**	**Phosphorus, unfiltered**	**Phosphorus**	**Orthophosphate**
Pumping stations										
Wocus Marsh	04–07–93	1245	0.15	<0.2	3.3	0.01	0.16	0.17	<0.01	0.04
Wocus Marsh	05–14–93	0915	.07	2.6	3.7	<.01	.028	.28	.16	.10
Wocus Marsh	04–06–94	0900	.60	4.6	6.2	.03	.012	.29	.14	.12
Wocus Marsh	04–20–94	1000	.13	2.9	4.8	.02	.010	.31	.05	.03
Wocus Marsh	05–05–94	0920	.08	2.2	3.3	<.01	.012	.32	.11	.10
Wocus Marsh	05–24–94	1145	.08	2.1	2.9	<.01	.007	.21	.10	.07
Wocus Marsh	03–16–95	1340	.15	4.0	4.3	.02	.41	.10	.06	.02
Wocus Marsh	04–04–95	0830	.03	4.1	4.5	<.01	<.005	.11	.04	.02
Wocus Marsh	04–19–95	0830	.14	4.4	4.8	<.01	.029	.08	.05	.01
East Caledonia Marsh	04–07–93	1710	.16	2.2	2.9	.01	.094	.14	.05	.02
East Caledonia Marsh	05–14–93	1930	.29	3.4	4.1	.02	.084	.15	.10	.07
East Caledonia Marsh	05–05–94	1130	.05	3.9	5.5	<.01	.008	.44	.15	.15
Williamson River North	04–08–93	1315	.83	1.9	2.3	.03	.32	.57	.45	.39
Williamson River North	04–06–94	1345	2.7	3.5	3.9	.03	.040	1.4	.91	.93
Williamson River North	04–20–94	1300	2.0	2.3	2.8	.01	.033	1.7	1.2	1.2
Williamson River North	05–06–94	0845	4.3	5.2	6.2	<.01	.066	1.2	.71	.75
Williamson River North	03–15–95	1530	1.5	2.7	2.7	.02	.43	.70	.50	.49
Williamson River North	04–04–95	1100	1.6	3.4	3.9	.02	.11	1.0	.80	.64
Williamson River North	04–19–95	1140	2.6	3.8	4.4	.02	.15	.92	.52	.50
Williamson River North	05–24–95	0815	2.9	3.7	3.6	.02	.046	.85	.75	.77
Williamson River North	08–17–95	1330	1.1	1.8	1.8	.07	.30	.89	.80	.77
Northwest Agency Lake	04–08–93	1620	.04	1.1	1.5	<.01	<.005	.21	.15	.10
Northwest Agency Lake	05–14–93	1645	.03	1.3	2.5	<.01	<.005	.39	.20	.19
Northwest Agency Lake	04–06–94	1530	.67	2.4	3.9	.04	.051	.58	.41	.38

Table 9. Summary of nutrient data from water-quality samples collected at selected pumping stations and flowing artesian wells adjacent to Upper Klamath Lake, Oregon, 1993–95—Continued

Sample description			Nitrogen (milligrams per liter)					Phosphorus (milligrams per liter)		
Station name	Date	Time	Ammonia	Ammonia plus organic nitrogen	Ammonia plus organic nitrogen, unfiltered	Nitrite	Nitrite plus nitrate	Phosphorus, unfiltered	Phosphorus	Orthophosphate
Pumping stations—Continued										
Northwest Agency Lake	05–06–94	1240	<0.01	0.4	0.6	<0.01	0.005	0.21	0.13	0.14
Northwest Agency Lake	03–16–95	0930	.05	1.1	1.2	<.01	<.005	.13	.10	.08
Northwest Agency Lake	04–04–95	1400	.02	.4	.5	<.01	<.005	.07	.05	.04
Northwest Agency Lake	04–19–95	1330	.42	2.2	2.6	.01	.033	.30	.22	.19
Northwest Agency Lake	05–24–95	1500	.03	.4	.5	<.01	<.005	.11	.09	.09
Wood River Property (Seven Mile Canal)	04–06–93	0950	.12	2.0	2.5	.02	.17	.56	.52	.40
Wood River Property (Seven Mile Canal)	05–14–93	1545	.04	2.4	3.0	<.01	.052	.75	.63	.55
Wood River Property (Seven Mile Canal)	04–07–94	0830	.23	1.9	2.8	.03	.016	1.2	1.0	.96
Wood River Property (Seven Mile Canal)	04–13–94	1345	.67	3.4	4.8	.03	.025	1.1	.87	.76
Wood River Property (Seven Mile Canal)	05–06–94	1420	1.3	3.5	3.9	.02	.058	1.2	1.0	.96
Wood River Property (Seven Mile Canal)	06–23–95	1215	.05	2.4	2.6	.02	<.005	.79	.75	.70
Wood River Property (Corral)	04–06–93	1255	.04	2.1	2.2	<.01	.006	.76	.68	.55
Wood River Property (Corral)	05–14–93	1430	.21	2.4	3.4	<.01	.037	1.0	.78	.76
Wood River Property (Corral)	04–07–94	1410	.27	3.0	4.4	.04	.022	1.6	1.3	1.3
Wood River Property (Corral)	05–05–94	1540	.15	1.0	1.0	<.01	.013	.53	.39	.36
Wood River Property (Corral)	05–24–95	1245	.17	2.2	2.3	.07	.12	.99	.96	.97
Wood River Property (Corral)	06–23–95	1330	<.015	2.2	2.9	.02	<.005	1.0	.82	.82
Flowing artesian wells										
Flowing artesian well #1	07–13–93	0830	5.5	5.8	6.0	<.01	<.005	6.4	6.7	6.2
Flowing artesian well #1	04–07–94	1215	5.5	6.3	7.0	.03	<.005	7.3	6.5	6.8
Flowing artesian well #1	05–24–95	1045	5.7	5.7	5.6	<.01	<.005	6.4	6.8	6.6
Flowing artesian well #2	05–24–95	1410	7.8	8.7	8.7	<.01	<.005	2.0	1.9	1.7
Flowing artesian well #3	08–17–95	1100	6.1	7.1	7.0	<.01	<.005	7.2	7.5	7.1

Table 10. Concentration ranges of total nitrogen and total phosphorus from the Upper Klamath Lake area, Oregon
[mg/L, milligrams per liter]

Water source	Total nitrogen concentrations	Total phosphorus concentrations	Reference
Upper Klamath Lake	0.0 to 10.6 mg/L	0.03 to 2.0 mg/L	Miller and Tash, 1967
Agricultural drains around Upper Klamath Lake	0.0 to 8.8 mg/L	0.08 to 2.0 mg/L	Miller and Tash, 1967
Agency Lake	0.3 to 8.8 mg/L	0.06 to 0.65 mg/L	Kann, 1993a
Wetland pumping stations	0.5 to 6.3 mg/L	0.07 to 1.7 mg/L	This study
Flowing artesian wells on Wood River Property	5.6 to 8.7 mg/L	2.0 to 7.3 mg/L	This study

Table 11. Instantaneous loads for pumping stations adjacent to Upper Klamath Lake, Oregon, May 5–6, 1994
[Total nitrogen, ammonia plus organic nitrogen in unfiltered water plus nitrite plus nitrate in filtered water; total phosphorus, phosphorus in unfiltered water; lbs/day, pounds per day; see table 9 for concentrations and table 3 for discharge values]

Pumping station	Date	Total nitrogen load (lbs/day)	Total phosphorus load (lbs/day)
Wocus Marsh	05–05–94	280	27
East Caledonia Marsh	05–05–94	25	2.0
Williamson River North	05–06–94	880	170
Northwest Agency Lake	05–06–94	330	110
Wood River Property (Seven Mile Canal)	05–06–94	92	28
Wood River Property (Corral)	[1]05–05–94	79	41

[1] Water-quality samples collected 05–05–94, but discharge measured 05–06-94.

This most likely is due to the elevated concentrations measured at this pumping station on May 6, 1994 (table 9). Although the instantaneous loads for the Williamson River North pumping station are large in relation to the other stations (table 11), the annual loads are comparable to those of the other stations (fig. 9).

Miller and Tash (1967, p. 9), in their nutrient budget for Upper Klamath Lake from March 1965 to April 1966, estimate the total input from agricultural drains for five drained wetlands to be 241 tons of nitrogen and 133 tons of total phosphorus over the 14-month study. These values are about 3 and 9 times, respectively, larger than the sum of the annual loads of nitrogen and phosphorus calculated for each of the pumping stations in 1995 (80 tons and 15 tons, respectively) (fig. 9). It is not surprising that these values would differ because Miller and Tash considered a larger number of drained areas than the present study, and their study encompassed a 14-month, instead of a 12-month, period.

When comparing the annual median concentrations, volume of water pumped, loads, and yields among pumping stations for total nitrogen, the Northwest Agency Lake pumping station stands out (fig. 9). Although the concentration is much lower than those of the other stations, the volume of water pumped is much larger due to the area and the 600-horsepower pumping station (which is greater than the horsepower for the other five pumping stations combined). Thus, the load is larger. When normalized for the drained area, however, the yield is actually the smallest for all of the pumping stations in 1995 because of the large area drained. Additionally, there is little variation in the total nitrogen yields among sites for a given year or among years for a given site.

There was, however, much more variation among sites for the annual total phosphorus yields (fig. 9). Wocus Marsh and Northwest Agency Lake pumping stations had median total phosphorus concentrations that were more than four times smaller than the median concentrations for the Williamson River North and Wood River Property pumping stations. This same pattern was repeated in the load and yield values for Wocus Marsh. For the Northwest Agency Lake pumping station, however, the load was in the same range as the other two stations because the volume of water pumped was so large. Wood River Property total phosphorus concentrations, loads, and yields may be larger due to ground-water inputs as indicated by the high concentrations of phosphorus in the samples from the flowing artesian wells (table 9). One possible reason why the Williamson River North pumping station has higher total phosphorus concentrations could be from fertilizers applied to the cultivated crops grown in the drained area.

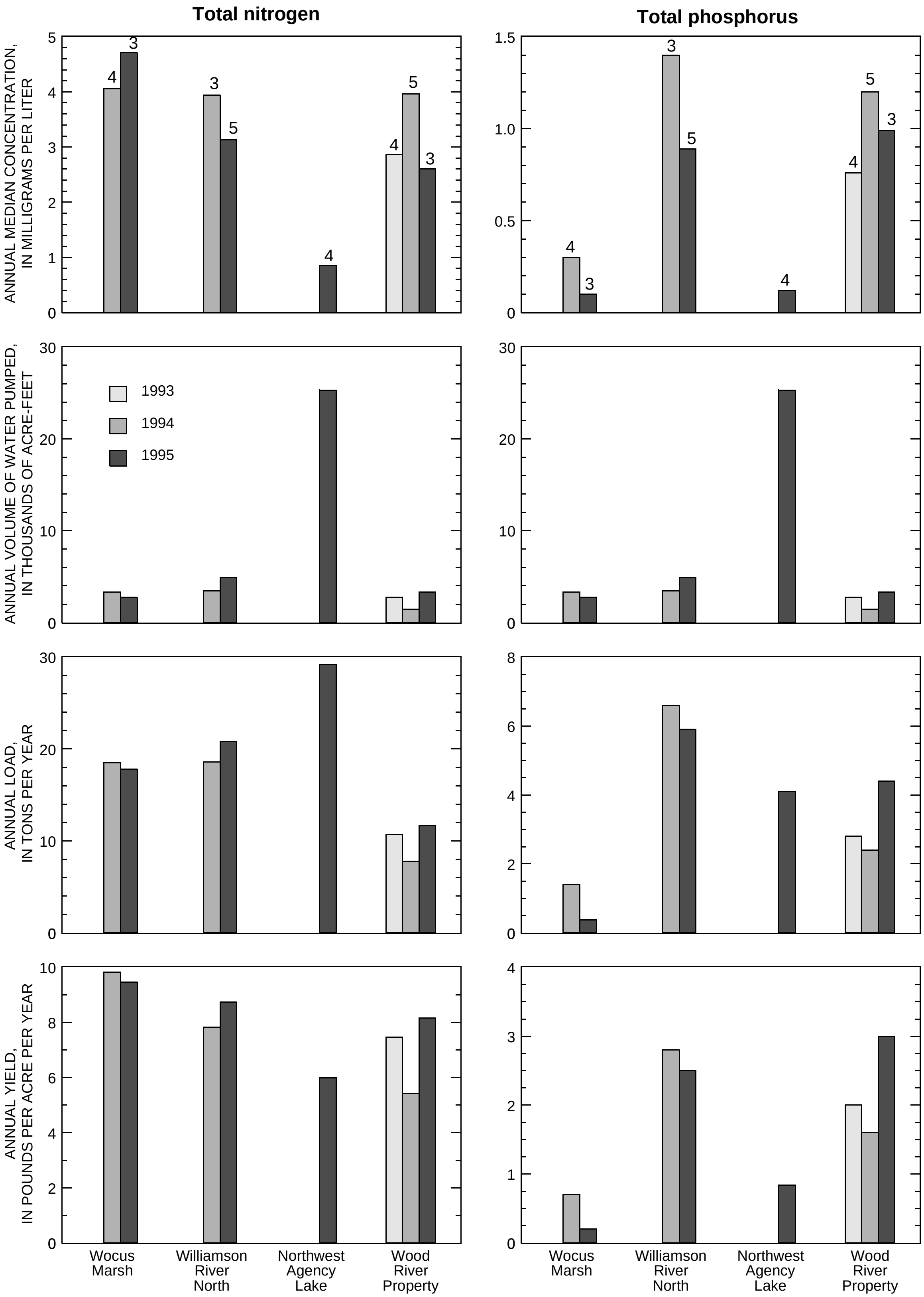


Figure 9. Annual median concentrations, volume of water pumped, load, and yield of total nitrogen and total phosphorus for selected pumping stations adjacent to Upper Klamath Lake, Oregon, 1993–95 water years. (Number over bar indicates the number of determinations used in the calculation of the median.)

Implications of Nutrient Loading from Ground Water

Three flowing artesian wells on the Wood River Property (fig. 2) were sampled during this study in an attempt to estimate nutrient loading from ground water. These wells flow continuously onto the land surface and were used for watering livestock. The occurrence of artesian conditions for these wells is probably the result of confining units consisting of the alluvial fill materials in the Wood River Valley. Newcomb and Hart (1958) located more than 20 wells between Fort Klamath and the Wood River Property that were all completed in artesian aquifers and that ranged in depth from 90 to 360 ft having heads as much as 20 ft above the land surface. The three wells sampled in this study are probably similar to the wells located by Newcomb and Hart. Because Upper Klamath Lake and the adjacent drained wetlands, including the Wood River Property, form the lowest part of the Upper Klamath Basin, these areas are expected to be the discharge area for the regional ground-water flow system in the Upper Klamath Lake basin. As a result, the water flowing from the artesian wells is probably from the regional ground-water flow system and is assumed to have little variation in concentration or discharge over the period 1993–95.

Nutrient loads for these three flowing artesian wells were calculated in the same general way as for the pumping stations. The median concentrations measured at the flowing artesian wells in the Wood River Property area and the estimated annual loads are given in table 12. The wells represent an annual (1995) total load that could account for 1 and 3 percent of the total nitrogen and phosphorus loads, respectively, from the Wood River Property area for the 1995 water year. Although this contribution is small, it does indicate that total nutrient loading to Upper Klamath Lake from the discharge of ground water could be significant. Further study of the quantity and nutrient concentration of discharge from regional ground-water flow system is needed to quantify the nutrient loading to Upper Klamath Lake and the adjacent wetlands.

Discussion of Nutrient Loss and Yields from Peat Soils

The loss of nutrients from the drained wetlands was calculated as the change in nutrient mass during several 1-year periods and as the cumulative loss since drainage. About 26 percent (8,200 acres) of the drained wetlands adjacent to Upper Klamath Lake were not sampled as part of this study and, therefore, are not included in these calculations. Differences in the time since drainage began, the frequency and duration of flooding, land use, and cultivation practices prohibited extrapolating from sampled drained wetlands that were near these unsampled wetlands. In addition, the Ball Bay South drained wetland (800 acres) is also not included in the above totals owing to the lack of data.

On an annual basis for the 1994–95 period, the estimated TN mass loss ranged from about 4 to 860 tons and totaled 3,000 tons for all drained wetlands that were sampled (table 13). During this period the estimated TP mass loss ranged from about 0 to 21 tons and totaled 60 tons for all drained wetlands that were sampled (table 13). The Williamson River North and the Agency Lake North drained wetlands had the largest annual loss of TN and TP mass during 1994–95.

Table 12. Estimated discharge, nutrient concentrations, and annual loads for flowing artesian wells adjacent to Upper Klamath Lake, Oregon, 1993–95

[Total nitrogen, ammonia plus organic nitrogen in unfiltered water plus nitrite plus nitrate in filtered water; total phosphorus, phosphorus in unfiltered water; ft^3/s, cubic feet per second; mg/L, milligrams per liter; see figure 2 for location of flowing artesian wells]

Well number	Date	Estimated discharge (10^{-3} ft^3/s)	Total nitrogen		Total phosphorus	
			Concentration (mg/L)	Annual load (pounds)	Concentration (mg/L)	Annual load (pounds)
1	07–13–93	6.3	6.0	75	6.4	80
1	04–07–94	6.3	7.0	88	7.3	91
1	05–24–95	6.3	5.6	68	6.4	79
2	05–24–95	5.8	8.7	99	2.0	22
3	08–17–95	13	7.0	176	7.2	181

Table 13. Parameters and estimates for estimation of annual loss and yield of total nitrogen and total phosphorus from drained areas using a first-order rate law

[See section “Calculation of Decay Rates and Annual Estimates of Peat and Nutrient Loss” for method of calculation. Symbols in brackets refer to variables used in the equation of the first-order rate law. Values for individual drained wetlands are presented using two significant figures. Sums were calculated using masses for individual areas are rounded to the nearest 10,000 and 100 tons for initial mass and annual loss, respectively, for total nitrogen, and 100 and 1 tons for initial mass and annual loss, respectively, for total phosphorus. Initial mass, mass prior to drainage of a wetland for agricultural use; mass, in tons; yield, in pounds per acre; --, not applicable]

Drained wetland	Area (acres)	Year drained[1]	Rate constant[2] [k] (percent per year)	Initial mass [A] (tons)	Annual loss (tons)				Annual yield (pounds/acre)			
					1965–66	1992–93	1993–94	1994–95	1965–66	1992–93	1993–94	1994–95
TOTAL NITROGEN												
Land use—crop cultivation												
McCornack Point	260	1889	2.38	1,800	7.1	3.7	3.6	3.5	54	28	28	27
Algoma	1,200	1914	1.67	20,000	140	91	89	88	240	150	150	150
Caledonia Marsh	2,500	1916	.46	82,000	310	270	270	270	250	220	220	220
Williamson River North	3,200	1920	1.32	170,000	1,300	880	870	860	780	550	540	540
Cove Point	550	1919–40	1.63	15,000	130	86	85	83	490	310	310	300
Land use—crop cultivation and cattle grazing												
Wocus Marsh	3,800	1896	.63	86,000	350	300	290	290	190	160	160	160
Land use—cattle grazing												
Ball Bay West	410	1946–47	.13	6,100	7.8	7.5	7.5	7.5	38	36	36	36
Wood River Property	2,900	1940–57	.75	88,000	580	470	470	470	400	330	330	330
Agency Lake North	2,600	1962	.55	130,000	710	610	610	600	550	470	470	470
Agency Lake West	4,600	1968–71	.11	210,000	(3) --	230	230	230	(3) --	100	100	100
Total	22,020	--	--	820,000	3,500	3,000	3,000	3,000	--	--	--	--
TOTAL PHOSPHORUS												
Land use—crop cultivation												
McCornack Point	260	1889	.951	50	.22	.17	.17	.17	1.7	1.3	1.3	1.3
Algoma	1,200	1914	.166	610	.93	.89	.89	.89	1.5	1.5	1.5	1.5
Caledonia Marsh	2,500	1916	.291	2,000	5.0	4.6	4.6	4.6	4.0	3.7	3.7	3.7
Williamson River North	3,200	1920	.702	5,000	25	21	21	21	16	13	13	13
Cove Point	550	1919–40	.796	430	2.6	2.1	2.1	2.0	9.4	7.5	7.5	7.4
Land use—crop cultivation and cattle grazing												
Wocus Marsh	3,800	1896	.054	2,700	1.4	1.4	1.4	1.4	.74	.73	.72	.72
Land use—cattle grazing												
Ball Bay West	410	1946–47	.055	160	.086	.084	.084	.084	.41	.41	.41	.41
Wood River Property	2,900	1940–57	.641	2,100	12	10	10	10	8.3	7.0	7.0	6.9
Agency Lake North	2,600	1962	.981	2,700	26	20	20	20	20	15	15	15
Agency Lake West	4,600	1968–71	0	3,400	(3) --	0	0	0	(3) --	0	0	0
Total	22,020	--	--	19,200	73	60	60	60	--	--	--	--

[1] If the year drained is only known as a range, then the mean was used in determining the time since drainage for use in the first-order rate law equation.

[2] The rate constant, as presented in the table, is expressed as a percentage and must be divided by 100 before use in the first-order rate law equation.

[3] Area not yet drained during this period.

McCornack Point and Ball Bay West had the smallest annual loss of TN mass and Agency Lake West and Ball Bay West had the smallest annual loss of TP mass. A comparison of the estimated annual yields of TN and TP is useful in removing the influence of the areal size of the drained wetland and shows no apparent trends with regard to land use or the time since drainage (table 13, figs. 10A and 11A).

The total cumulative nutrient loss from the drained wetlands was calculated as the sum of the cumulative nutrient losses from each drained wetland where soil samples were collected (table 14). Since being drained, the peat soils of the drained wetlands are estimated to have cumulatively lost 250,000 tons and 4,300 tons of TN and TP, respectively. Using table 14, comparisons can be made of the cumulative mass of peat, TN, and TP lost from the individual drained wetlands. The drained wetland that has the largest cumulative loss of peat, TN, and TP since being drained is the Williamson River North area which has lost more than twice the mass of these constituents than any other drained wetland. The Agency Lake West and Ball Bay West drained wetlands have had little or no cumulative loss of peat, TN, or TP mass since being drained.

Estimated yields of cumulative mass lost for peat, TN, and TP are presented in table 14 and figures 10B and 11B. The Williamson River North drained wetland has the largest cumulative loss of peat, TN, and TP per unit area, nearly twice that of any other drained wetland. There appears to be a relation between land use and the cumulative losses of peat and TN per unit area (table 14, fig. 10B). The cumulative loss of peat and TN per unit area for drained wetlands used for cultivation of crops are larger than for wetlands used for the grazing of cattle. The cumulative loss of TP per unit area does not show this relation (fig. 11B). However, these comparisons do not account for the differences due to the length of time since drainage and variations in the initial mass of peat, TN, and TP. Comparison of the drained wetlands using the relation between the amount of time elapsed since drainage began and the percentage of initial TN or TP mass still present can help to account for the differences in the initial mass of peat, TN, or TP. Land use, time since drainage, or both appear to be correlated to the cumulative TN loss; however, this is not evident for TP (figs. 10C and 11C). The cumulative TN loss as a percentage of the initial TN is greater for cultivated land use and older drained wetlands; however, this trend is not evident for TP.

It would be expected that older drained wetlands would have a greater cumulative nutrient loss as measured by the percentage of the initial nutrient mass. However, because the data set is small and unevenly distributed with regard to time since drainage (most of the drained areas used for grazing were drained more recently than those used for cultivation), it is difficult to determine whether land use has any affect on nutrient loss. To aid in this determination, the rate constants calculated for the estimation of annual TN and TP loss based on a first-order rate law (see section "Calculation of Decay Rates and Annual Estimates of Peat and Nutrient Loss") were used for comparison. The rate constants for TN and TP are characteristic of a particular drained wetland under consideration but are independent of both the time since drainage and the quantity of initial nutrient mass at a drained wetland. Many of the conditions that may influence the rate constants are related to land use as discussed in the section "Drainage of Wetlands and Effects of Land Use." The drained areas used for the cultivation of crops generally have larger rate constants for TN (and thereby a greater percentage of TN loss per year) than the areas used for cattle grazing (fig. 12). This relation is not evident for TP (fig. 12). The apparent relation between loss of nitrogen and land use may be the result of tillage of the cultivated lands, which would accelerate decomposition of peat soils, and compaction of the grazed lands by cattle, which would retard decomposition of the peat soils. However, there are other factors that could influence the rates of nutrient loss that have not been fully considered, such as temperature and the length and frequency of inundation by water. These factors may be especially important because the rate constants for individual drained wetlands were not determined for identical time periods owing to differences of when drainage began. Therefore, although land use and larger rate constants for annual TN loss appear correlated, the apparent relation is not necessarily causal.

Given the current data, the estimates of nutrient loss from the decomposition of peat soils contained in the drained wetlands may place an upper limit on the actual nutrient loads contributed to Upper Klamath Lake from this source. Possible outputs for the nutrients lost from the peat soils of the drained wetlands include drainage to the lake, the harvesting of crops or grazing by cattle (Farnham, 1976), wind loss, erosion, and fire. Nitrogen also can be lost as a gas by denitrification and the volatilization of ammonia (Farnham, 1976) or by sorption of ammonia.

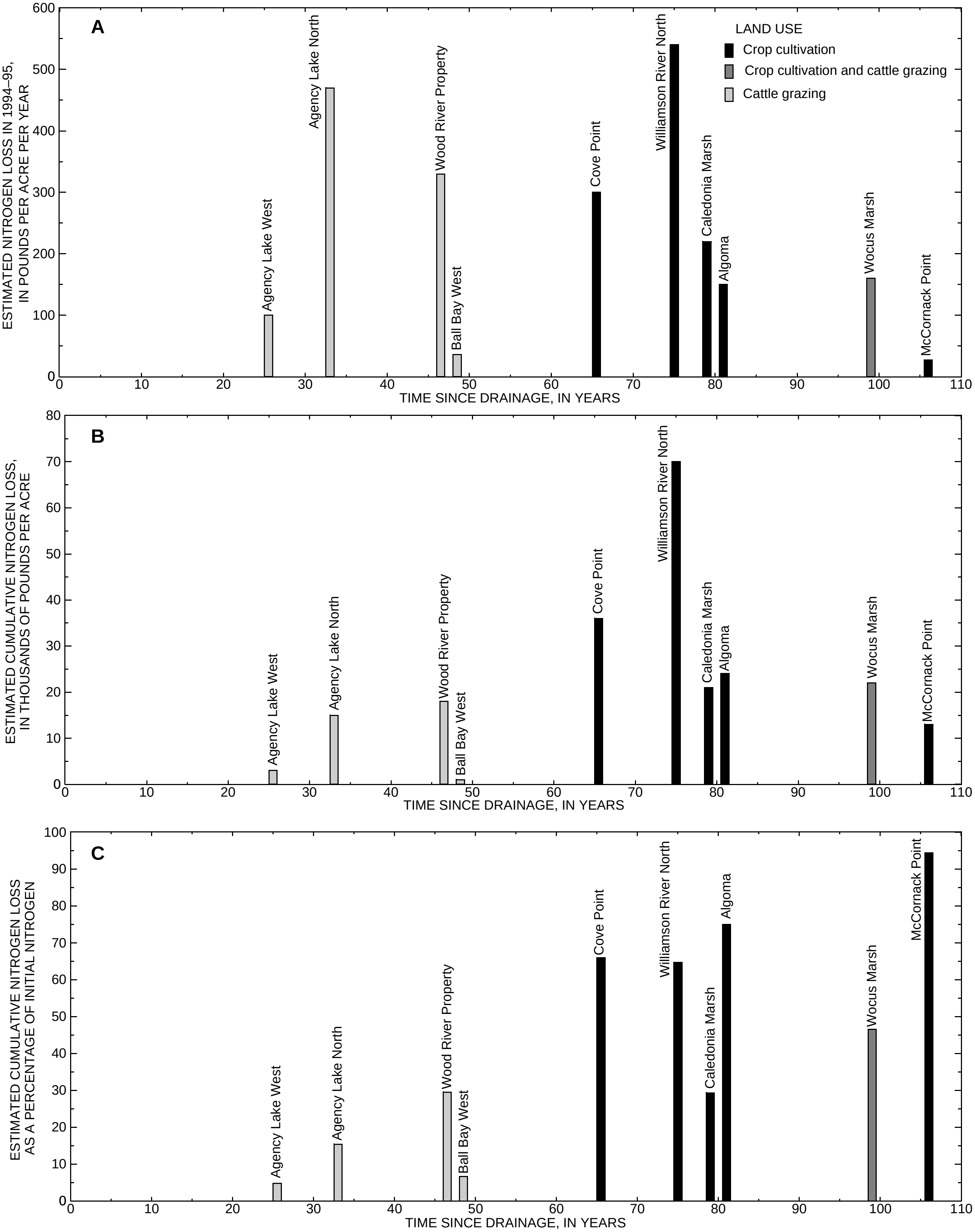


Figure 10. Nitrogen loss in drained wetlands, Upper Klamath Lake, Oregon:
A. Estimated annual nitrogen loss in 1994–95 per unit area at each drained wetland.
B. Estimated cumulative nitrogen loss per unit area at each drained wetland.
C. Estimated cumulative nitrogen loss as a percentage of initial nitrogen at each drained wetland.

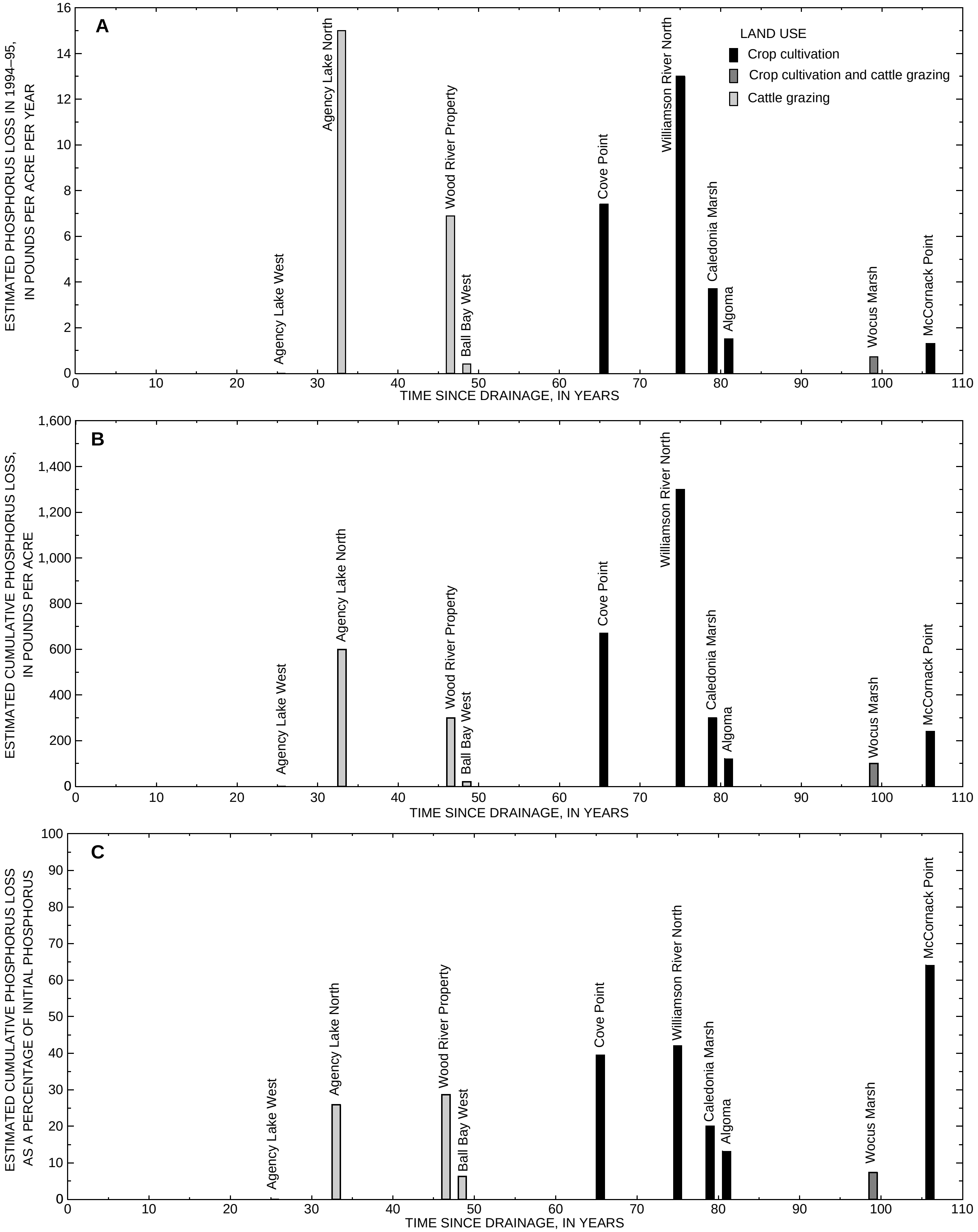


Figure 11. Phosphorus loss in drained wetlands, Upper Klamath Lake, Oregon:
A. Estimated annual phosphorus loss in 1994–95 per unit area at each drained wetland.
B. Estimated cumulative phosphorus loss per unit area at each drained wetland.
C. Estimated cumulative phosphorus loss as a percentage of initial phosphorus at each drained wetland.

Table 14. Initial, present-day, and cumulative loss of peat and nutrients from drained wetlands by land use, expressed as mass and yield

[Initial is prior to the beginning of drainage of a wetland for agricultural use. Present day is 1995. Cumulative loss is the difference between initial and present day. MASS, in tons; YIELD, in pounds per acre. Values for individual drained wetlands are presented using two significant figures. Sums were calculated using masses for individual areas and are rounded to the nearest 100,000, 10,000, and 100 tons for peat, total nitrogen, and total phosphorus, respectively. See section “Estimation of Nutrient Loss Using Change in Nutrient Mass of Drained Wetland Soils” for method of calculation]

MASS

			Peat (tons)			Total nitrogen (tons)			Total phosphorus (tons)		
Drained wetland	**Area (acres)**	**Year drained**	**Initial**	**Present day**	**Cumulative loss**	**Initial**	**Present day**	**Cumulative loss**	**Initial**	**Present day**	**Cumulative loss**
Land use—crop cultivation											
McCornack Point	260	1889	78,000	45,000	33,000	1,800	150	1,700	50	18	32
Algoma	1,200	1914	860,000	600,000	260,000	20,000	5,200	15,000	610	530	80
Caledonia Marsh	2,500	1916	3,800,000	3,400,000	400,000	82,000	58,000	24,000	2,000	1,600	400
Williamson River North	3,200	1920	7,900,000	5,900,000	2,000,000	170,000	64,000	110,000	5,000	2,900	2,100
Cove Point	550	1919–40	630,000	460,000	170,000	15,000	5,100	9,900	430	260	170
Land use—crop cultivation and cattle grazing											
Wocus Marsh	3,800	1896	3,700,000	3,000,000	700,000	86,000	46,000	40,000	2,700	2,500	200
Land Use—cattle grazing											
Ball Bay West	410	1946–47	260,000	250,000	10,000	6,100	5,700	400	160	150	10
Wood River Property	2,900	1940–57	4,000,000	3,600,000	400,000	88,000	62,000	26,000	2,100	1,500	600
Agency Lake North	2,600	1962	6,800,000	6,600,000	200,000	130,000	110,000	20,000	2,700	2,000	700
Agency Lake West	4,600	1968–71	9,500,000	9,500,000	0	210,000	200,000	10,000	3,400	3,400	0
Total	22,020	--	37,600,000	33,400,000	4,200,000	820,000	570,000	250,000	19,200	14,900	4,300

YIELD

			Peat (pounds/acre)			Total nitrogen (pounds/acre)			Total phosphorus (pounds/acre)		
Drained Wetland	**Area (acres)**	**Year drained**	**Initial**	**Present day**	**Cumulative loss**	**Initial**	**Present day**	**Cumulative loss**	**Initial**	**Present day**	**Cumulative loss**
Land use—crop cultivation											
McCornack Point	260	1889	590,000	340,000	250,000	14,000	1,100	13,000	370	130	240
Algoma	1,200	1914	1,400,000	980,000	420,000	33,000	8,600	24,000	1,000	880	120
Caledonia Marsh	2,500	1916	3,000,000	2,700,000	300,000	67,000	46,000	21,000	1,600	1,300	300
Williamson River North	3,200	1920	4,900,000	3,700,000	1,200,000	110,000	40,000	70,000	3,100	1,800	1,300
Cove Point	550	1919–40	2,300,000	1,700,000	600,000	54,000	18,000	36,000	1,600	930	670
Land use—crop cultivation and cattle grazing											
Wocus Marsh	3,800	1896	2,000,000	1,600,000	400,000	46,000	24,000	22,000	1,400	1,300	100
Land use—cattle grazing											
Ball Bay West	410	1946–47	1,300,000	1,200,000	100,000	29,000	28,000	1,000	760	740	20
Wood River Property	2,900	1940–57	2,800,000	2,500,000	300,000	61,000	43,000	18,000	1,400	1,100	300
Agency Lake North	2,600	1962	5,300,000	5,100,000	200,000	100,000	85,000	15,000	2,100	1,500	600
Agency Lake West	4,600	1968–71	4,200,000	4,100,000	100,000	91,000	88,000	3,000	1,500	1,500	0

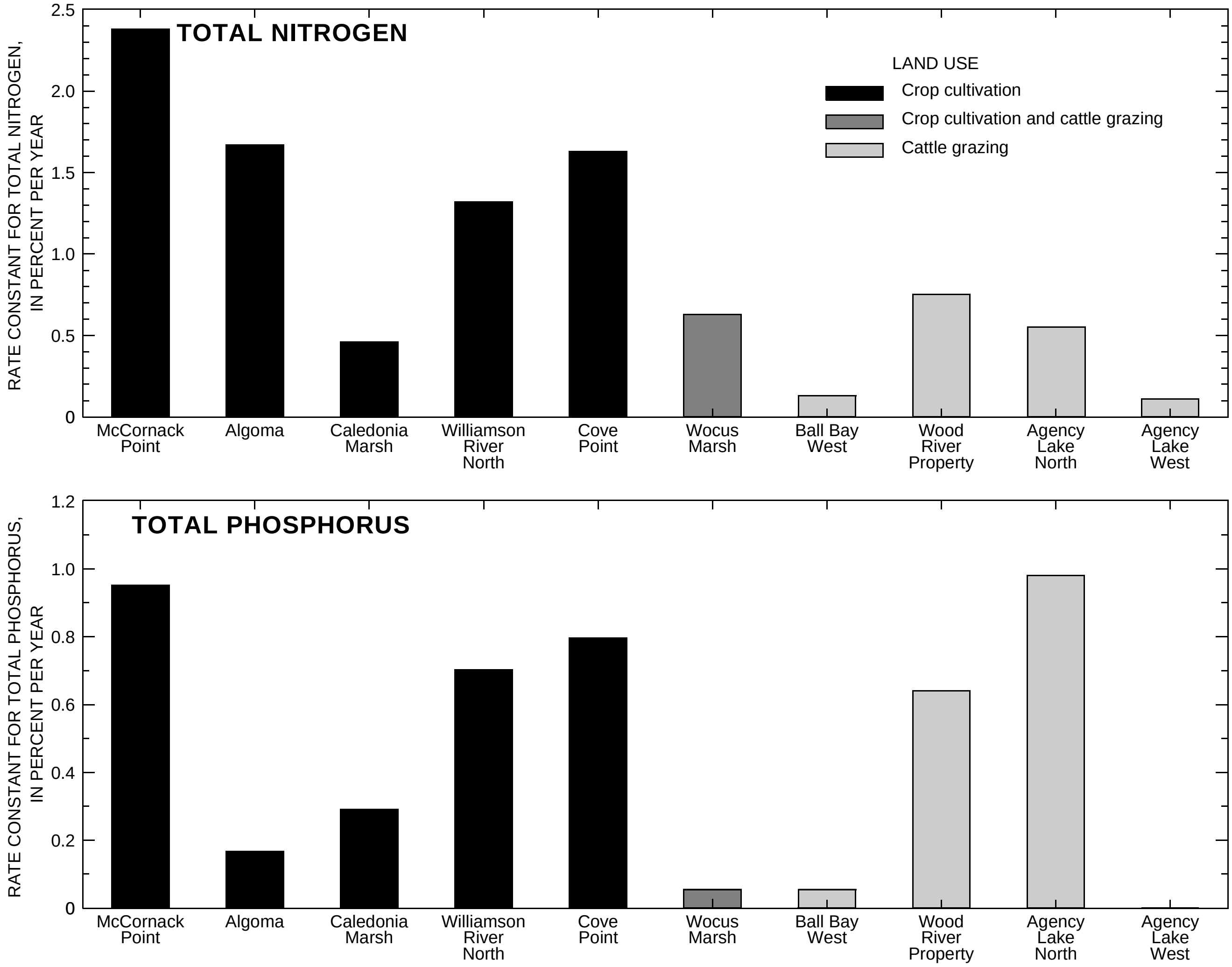


Figure 12. Rate constants for estimation of nutrient loss using a first-order rate law for each drained area by land use. (The rate constant is the fraction of the nutrient mass that is lost on an annual basis and, as present in this figure, is expressed as a percentage and must be divided by 100 before use in the first-order rate law equation.)

Phosphorus can become stored by adsorption or exchanged within adjacent soil layers or the sediments of irrigation ditches.

Comparison of Estimates of Nutrient Loads

Nutrient Loads from Peat Soils and Discharge Pumps

A comparison was made of the annual nutrient yields for the drained wetlands calculated by the two approaches used in this study. The estimates determined using the change in nutrient mass of the peat soils are substantially larger than the estimates made by analysis of the pump discharge. The mean of the annual yields of TN for the 1993–95 water years was calculated by nutrient loss from the soils. It ranged from about 16 to 65 times the mean of the annual yields of TN calculated using pump discharge over the same period for individual drained areas. The mean of the annual yields of TP for the 1993–95 water years calculated by nutrient loss from soils ranged from about 1.6 to 7 times the mean of the annual yields of TP calculated for individual drained areas using pump discharge over the same period.

There are several reasons for these large differences. The nutrient yields calculated using nutrient loss from soils do not account for other possible outputs of nutrients from the soils. These outputs can include volatilization of nitrogen gas and ammonia, uptake by crops or forage, and the adsorption or exchange of phosphorus or ammonia with adjacent soils or sediments. In addition, the soil-loss estimates represent time-averaged contributions to the lake estimated on the basis of the entire time since drainage began, which may be quite different from measurements made in any particular year. In contrast, the pump discharge integrates all inputs and outputs for nutrients and are subject to year-specific variations due to temperature, land use, frequency and length of inundation, and other factors. Such estimates are particularly useful for comparisons with same-year loading estimates from other sources.

Nutrient Loads from Peat Soils and Estimates by Miller and Tash

The preliminary nutrient budget prepared by Miller and Tash (1967, p. 9) for Upper Klamath Lake for a 14-month period during 1965–66 estimated nutrient loads from agricultural drainage to be 241 tons of nitrogen and 133 tons of phosphorus. The values of the annual loss of nitrogen and phosphorus calculated for all the drained areas existing during the period 1965–66 that were sampled in this study (3,500 tons and 73 tons, respectively) are about 15 times larger and about 0.55 times smaller, respectively, than the values determined by Miller and Tash. As discussed above in the section “Nutrient Loads from Peat Soils and Discharge Pumps,” there are several reasons that might explain the differences between these estimates. In addition, Miller and Tash used the agricultural drainage from five pumping stations representing about 9,300 acres of drained wetlands, whereas the present study considered agricultural nutrient loss from nine drained wetlands that were present during the 1965–66 period, totalling about 17,400 acres. The difference in the size of drained area considered for each study makes an evaluation of the estimates difficult. Unfortunately, Miller and Tash provided only a sum total of agricultural drainage, thereby prohibiting direct comparison between nutrient loads for individual drained areas examined in both studies. It should also be noted that the 14-month period of study used by Miller and Tash complicates comparisons to annual estimates of nutrient loading.

Nutrient Loss from Upper Klamath Lake Peat Soils and Estimates for Other Wetlands

Comparisons were attempted between the nutrient loss calculated for the peat soils within the drained wetlands adjacent to Upper Klamath Lake and peat soils from other wetlands. Data on nutrient loss from wetlands are scarce, although values have been reported by Pollett (1972), Reddy (1982), Karlovski and Brezgunov (1988), Okruszko and others, (1988), Walbridge (1991), and Otabbong and Linden (1992). However, because of differences in land use, time since drainage, mean annual temperatures, and especially the thickness of soils and their proximity to the surface, these studies were unsuitable for comparison. It is of special interest to note that these studies typically estimated losses based on changes only in the plow layer (about the top 6–12 inches) rather than the entire affected soil profile as was done in the present study.

IMPLICATIONS AND SUGGESTIONS FOR FURTHER STUDY

The results of this study could be useful in helping to prioritize which drained wetlands might provide the greatest benefits with regard to reducing nutrient loads to the lake if restoration or land-use modifications are instituted. If the water table rises to predrainage levels, the peat soils might become inundated most of the year. This inundation could result in the continued long-term storage of nutrients already present within the peat soils by reducing the aerobic decomposition of these soils that occurs when they are exposed to air or oxygenated water. The results from the present study can be used to identify the drained wetlands having the greatest nutrient yields and stores, information which could be included in a cost-benefit analysis for restoration activities. Such activities have already begun as evidenced by the recent acquisition of drained wetland areas at the Wood River and Williamson River North properties. Planned restoration at these sites could produce significant reduction in the quantity of nutrients released by the decomposition of peat soils of these areas. The maximum benefit, in terms of decreasing potential nutrient loss due to peat decomposition, could be the reduction of TN and TP loss to about one-half that of the 1994–95 annual loss estimated for all the drained wetlands sampled for this study. In addition, nitrogen and phosphorus contained in tributary waters that are routed through the restored wetlands might become sequestered in wetland plant material. This sequestration could result in additional reductions in nutrient loading to Upper Klamath Lake.

One implication of the present study results relates to the intentional lowering of Upper Klamath Lake and the possible subsequent increase in nutrient loading from undrained wetlands. Because of the shallowness of Upper Klamath Lake, lower lake levels can expose as much as 30,000 acres (table 1) of lake bottom to oxygen in the air. Much of the area that becomes uncovered consists of submerged wetlands

(Hubbard, 1970) and may contain substantial quantities of organic soils. Therefore, lowering the lake level could increase the aerobic decomposition of these soils that occurs when they are exposed to air or oxygenated water. This decomposition could result in the release of nitrogen and phosphorus into the lake from the undrained wetlands.

The results of this study could also have implications related to the possible effects on water quality resulting from rotating between flooded wetlands and agricultural cropland as has been proposed for parts of the nearby Tule and Lower Klamath Lakes National Wildlife Refuges. If the soils in these areas behave in a manner similar to the soils examined in this study, then draining these previously undisturbed wetland areas even temporarily could result in a release of nutrients to the receiving water bodies unless water and crops can be managed to avoid this effect.

Suggestions for further study include:

1. Collect soil, water quality, and discharge data for the areas undergoing wetland restoration. The present study provides baseline data on initial conditions within the drained wetlands; the effectiveness of restoration activities can be monitored by comparing later conditions to the baseline data.
2. Continue to sample drained wetlands areas where past land use has remained unchanged. This could be useful for comparison with restored wetlands by removing effects such as weather patterns. Additional sampling of previously unsampled drained wetlands could help to refine the relationship between land use and nutrient loss.
3. Evaluate nutrient loading from ground water to Upper Klamath Lake.
4. Estimate the possible nutrient loading from undrained wetlands as a result of lowering lake levels at Upper Klamath Lake.
5. Collect baseline data on present-day nutrient mass within the organic soils of the flooded wetlands and agricultural cropland proposed for rotation at Tule and Lower Klamath Lakes National Wildlife Refuges.
6. Collect additional data on nutrient inputs and outputs such as irrigation, ground-water seepage, fertilizer application, cattle, waterfowl, and crops, to develop a detailed nutrient budget for the wetlands.

SUMMARY

Upper Klamath Lake and the connecting Agency Lake constitute a large, shallow lake in south-central Oregon that the historical record indicates has likely been eutrophic since its discovery by non-Native Americans. In recent decades, however, the lake has had annual occurrences of near-monoculture blooms of the blue-green alga *Aphanizomenon flos-aquae* that are thought to be a result of accelerated eutrophication. In 1988, two sucker species endemic to the lake, the Lost River sucker (*Deltistes luxatus*) and the shortnose sucker (*Chasmistes brevirostris*), were listed as endangered by the U.S. Fish and Wildlife Service, and it has been proposed that their decline is due to the poor water quality associated with extremely long and productive algal blooms. It has also been proposed that the effluent drained from wetlands has contributed to worsening water quality (Bortleson and Fretwell, 1993).

Since the turn of century, most of the wetlands adjacent to Upper Klamath Lake have been drained for agriculture—cultivation of crops and grazing of cattle. Wetland areas were reclaimed from the lake by building dikes to isolate them from the lake, constructing a series of drainage ditches, and installing pumps to drain the water and maintain a lowered water table. A consequence of lowering the water table is the increased ability of air and oxygenated water to move through the subsurface and facilitate the rapid aerobic decomposition of the peat soils. Nutrients, nitrogen and phosphorus, are then liberated, leach into adjacent ditches, and are subsequently pumped to the lake or its tributaries. The rate of peat decomposition may be related to the time since drainage and the type of agricultural land use. On lands cultivated for crops, farming practices, such as disking and furrowing, could enhance the movement of air and oxygenated water, resulting in rapid rate of decomposition. In contrast, on grazed lands, the compaction of soils by cattle probably inhibits the movement of air and oxygenated water and results in a slower rate of decomposition relative to drained wetlands used for the cultivation of crops.

This report presents the results of a cooperative study between the U.S. Geological Survey and the Bureau of Reclamation to estimate the nutrient loading to Upper Klamath Lake from adjacent drained wetlands. Nutrient loading from drained wetlands was estimated using two independent techniques. The first method involved the measurement of the quantity and quality of water discharged by pumps draining the wetlands. The second method estimated the initial (prior to drainage) and present-day nutrient mass of the organic soils within the drained wetlands and calculated the change (or loss) in nutrient mass.

In an effort to estimate the nutrient loading from the water pumped off selected drained wetlands adjacent to Upper Klamath Lake, nutrient concentrations were measured during 1993–95, and the electrical meters associated with the pumping stations were monitored to determine the annual volume of water pumped based on the power consumption. Annual loads and yields of total nitrogen and total phosphorus were estimated from concentration data and the volume of water pumped during the water year. Because of the possible error associated with the method used to estimate the annual volume of water pumped, these loading estimates are only an indication of the order of magnitude of nutrient contributions from these areas.

The annual nutrient loads and yields calculated for the water discharged from six pumping stations represent an integration of many factors, including land use, the time since drainage of the wetlands, and multiple sources of inputs and outputs. Although there was apparent variation in the nutrient concentrations measured, there was little variation in the annual total nitrogen loads or yields (medians of about 18 tons/yr [tons per year] and about 8 lbs/acre/yr [pounds per acre per year], respectively) among sites for a given year or among years for a given site. There was, however, much more variation among sites in the total phosphorus loads and yields (medians of about 3 tons/yr and about 2 lbs/acre/yr, respectively). The sum of the annual loads of nitrogen and phosphorus calculated for each of the pumping stations in 1995 was 80 tons/yr and 15 tons/yr, respectively.

In 1995, soil-coring was done to ascertain the nature and extent of the organic soils in the drained and undrained wetlands. This effort included description of the soil stratigraphy and collection of soil samples for physical and chemical analysis. Eleven drained and 5 undrained wetland areas were selected for coring and sampling. The 11 drained wetland areas represent about 74 percent of the approximately 31,000 acres of drained wetlands adjacent to Upper Klamath Lake. The five undrained wetlands represent nearly all of the 17,400 acres of undrained wetlands around the lake. Sixty-one soil cores with an average length of about 9 ft were described and photographically documented. A total of 229 soil samples were collected, of which 181 were analyzed for physical and chemical characteristics, including nutrient content.

The present-day soil nutrient mass was calculated for each drained wetland using the nutrient content and the present-day peat mass as determined from the bulk density, thickness of the organic soil layers, and area of the wetland. The initial nutrient mass prior to drainage was calculated for each drained wetland by estimating the initial nutrient content and peat mass. The initial nutrient content was estimated by using data from the undrained wetlands. The initial peat mass was estimated using the bulk density from the undrained wetlands and an estimate of the amount of decomposition that had occurred since drainage, derived by comparing present-day ash content with that of the undrained wetlands. The cumulative loss of nutrient mass since drainage was calculated as the change between initial and present-day nutrient mass for each drained area.

The cumulative yield of total nitrogen and total phosphorus loss from the organic soils of individual wetlands since drainage ranged from 3,000 to 70,000 lbs/acre and from 0 to 1,300 lbs/acre, respectively. For all the drained wetlands sampled, the cumulative loss of nitrogen and phosphorus since drainage totaled 250,000 tons and 4,300 tons, respectively. This loss represents about 30 percent and 22 percent of the mass of nitrogen and phosphorus, respectively, that initially existed in the organic soils. The loss of nutrients from the drained wetlands is considered to be a maximum estimate of the possible contribution of nutrients to Upper Klamath Lake from the peat soils of the drained wetlands sampled. However, not all the nutrients released by the soils are discharged to the lake. Nutrients lost from the peat soils of the drained wetlands may have been taken up by crops and harvested or consumed by grazing cattle. In addition, nitrogen can be lost to the atmosphere by denitrification and the volatilization of ammonia; phosphorus may be bound to adjacent soil layers by adsorption.

The annual nutrient loss for the period 1994–95 was calculated using a first-order rate law to describe nutrient loss since drainage began. For individual drained wetlands, the yield of nitrogen and phosphorus lost from the organic soils for the period 1994–95 ranged from 27 to 540 lbs/acre/yr and from 0 to 15 lbs/acre/yr, respectively. The total mass of nitrogen and phosphorus loss during this period was 3,000 tons/yr and 60 tons/yr, respectively, for all drained wetlands that were sampled. The yield and mass of nutrient loss determined in this fashion reflect what might be expected on the basis of time-averaged or long-term contributions of nutrients to the lake and do not reflect the specific conditions existing during the period 1994–95.

Implications resulting from this study include (1) low stages of Upper Klamath Lake could result in increased decomposition of peat soils of exposed wetlands within the lake's perimeter, resulting in the release of nitrogen and phosphorus, and (2) the rotation between flooded wetlands and agricultural cropland as proposed for parts of the nearby Tule and Lower Klamath Lakes National Wildlife Refuges could result in a release of nutrients to the receiving water bodies.

The results of this study could be useful in helping to prioritize which drained wetlands could provide the greatest benefits with regard to reducing nutrient loads to the lake if restoration or land-use modifications are instituted. Recent acquisition and planned restoration of drained wetland areas at the Wood River and Williamson River North properties could produce significant reduction in the quantity of nutrients released by the decomposition of peat soils of these areas. If the water table rises to predrainage levels, the peats soils could become inundated most of the year, resulting in the continued long-term storage of nutrients within the peat soils by reducing aerobic decomposition. The maximum benefit, in terms of decreasing potential nutrient loss due to peat decomposition, could be the reduction of total nitrogen and total phosphorus loss to about one-half that of the 1994–95 annual loss estimated for all the drained wetlands sampled for this study.

SELECTED REFERENCES

Adam, D.P., Bradbury, J.P., Carter, Claire, Dean, W.E., Hakala, Kathryn, McGann, Mary, Reynolds, R.L., Rieck, H.J., Roberts, Andrew, Rosenbaum, J.G., Sarna-Wojcicki, A.M., Schiller, Karen, and Whitlock, Cathy, 1995, Status report on cores taken in 1991–1992 in the Upper Klamath Basin and vicinity, Oregon and California, *in* Adam, D.P., Bradbury, J.P., Dean, W.E., Gardner, J.V., and Sarna-Wojcicki, A.M., eds., Report of 1994 workshop on the correlation of marine and terrestrial records of climate changes in the western United States: U.S. Geological Survey Open-File Report 95–34, p. 13–29.

Adam, D.P., Rieck, H.J., McGann, Mary, Schiller, Karen, Sarna-Wojcicki, A.M., and Trimble, D.A., 1994, Lithologic description of sediment cores from Wocus Marsh, Klamath County, Oregon: U.S. Geological Survey Open-File Report 94–189, 65 p.

Akins, Glenn J., 1970, The effects of land use and land management on the wetlands of the Upper Klamath Basin: Bellingham, Washington, Western Washington State College, M.S. thesis, 122 p.

American Public Health Association, American Public Water Works Association, and Water Pollution Control Federation, 1989, Standard methods for the examination of water and wastewater (17th ed.): Washington, D.C., American Public Health Association, 1527 p.

Bacon, C.R., and Lanphere, M.A., 1990, The geologic setting of Crater Lake, Oregon, *in* Drake, E.T., Larson, G.L., Dymond, Jack, and Collier, Robert, eds., Crater Lake—An ecosystem study: Sixty-Ninth Annual Meeting of the Pacific Division/American Association for the Advancement of Science, Oregon State University, Corvallis, Oregon, June 18–22, 1988, p. 19–27.

Bartels, Rüdiger, and Scheffer, Bernard, 1996, Nitrate enrichment in fenland soils on meadows after ploughing: Proceedings of the 10th International Peat Congress, Volume 4, Bremen, Germany, May 27–June 2, 1996, p. 43–48.

Bartholomay, R.C., and Williams, L.M., 1996, Evaluation of preservation methods for selected nutrients in ground water, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 96–4260, 16 p.

Belanger, T.V., and Van Vonderen, S.D., 1984, Water quality characteristics of agricultural pumpage in the Upper St. Johns River, Florida: Water Resources Bulletin, v. 20, no. 3, p. 349–358.

Berglund, K., 1992, Subsidence of cultivated peat soils—Two case studies in Sweden: Proceedings of the 9th International Peat Congress, Volume 3, Uppsala, Sweden, June 22–26, 1992, p. 251.

Boelter, D.H., 1969, Physical properties of peats as related to their degree of decomposition: Soil Science Society of America Proceedings, v. 33, no. 4, p. 606–609.

Bortleson, G.C., and Fretwell, M.O., 1993, A review of possible causes of nutrient enrichment and decline of endangered sucker populations in Upper Klamath Lake, Oregon: U.S. Geological Survey Water-Resources Investigations Report 93–4087, 24 p.

Broadbent, F.E., 1960, Factors influencing the decomposition of organic soils of the California Delta: Hilgardia, v. 29, no. 13, p. 587–612.

Brown, J.L., and Farnham, R.S., 1976, The mineral content of peat and the degree of decomposition: Proceedings of the 5th International Peat Congress, Volume II, Poznan, Poland, August 21–25, 1976, p. 246–253.

Brown, J.L., Malterer, Thomas, and Farnham, R.S., 1984, Surface and subsurface sampling of organic soils: Proceedings of the 7th International Peat Congress, Volume 1, Dublin, Ireland, June 18–23, 1984, p. 54–67.

Brownell, D.L., and Rinallo, M.R., 1995, A selected bibliography of water related research in the Upper Klamath Basin, Oregon: U.S. Geological Survey Open-File Report 95–285, 23 p.

Bureau of Land Management, 1994, Draft resource management plan—Environmental impact statement for the Upper Klamath Basin: Klamath Falls, Oregon, [unknown pagination].

———1995, Proposed resource management plan—Final Environmental impact statement for the Upper Klamath Basin: Klamath Falls, Oregon, [unknown pagination].

Cahoon, J.S., 1985, Soil survey of Klamath County, Oregon, southern part: U.S. Department of Agriculture Soil Conservation Service in cooperation with Oregon Agriculture Experiment Station, 269 p., 106 soil map sheets.

Cameron, C.C., 1970, Peat resources of the unglaciated uplands along the Allegheny structural front in West Virginia, Maryland, and Pennsylvania: U.S. Geological Survey Professional Paper 700–D, p. 153–161.

———1973, Peat *in* Brobst, D.A., and Pratt, W.P., eds, 1973, United States mineral resources: U.S. Geological Survey Professional Paper 820, p. 505–513.

———1975, Some peat deposits in Washington and southeastern Aroostook Counties, Maine: U.S. Geological Bulletin 1317–6., 40 p.

———1989, Peat and its occurrence as a resource in Maine: Studies in Maine Geology, v. 5, p. 125–146.

Cameron, C.C., and Anderson, W.A., 1980, Peat resources of the Great Heath, Washington County, Maine: U.S. Geological Survey Open-File Report 80–39, 10 p.

Cameron, C.C., Esterle, J.S., Palmer, C.A., 1989, The geology, botany and chemistry of selected peat-forming environments from temperate and tropical latitudes: International Journal of Coal Geology, v. 12, p. 105–156.

Campbell, S.G., ed., 1993a, Environmental research in the Klamath Basin, Oregon—1991 annual report: Denver, Colorado, Bureau of Reclamation, Research and Laboratory Services Division, Report No. R–93–13, 212 p.

———1993b, Environmental research in the Klamath Basin, Oregon—1992 annual report: Denver, Colorado, Bureau of Reclamation, Research and Laboratory Services Division, Report No. R–93–16, 341 p.

Campbell, S.G., and Ehinger, W.J., 1993, Wood River hydrology and water quality study, *in* Campbell, S.G., ed., Environmental research in the Klamath Basin, Oregon—1991 annual report: Denver, Colorado, Bureau of Reclamation Report No. R–93–13, p. 7–79.

Campbell, S.G., and Ehinger, W.J., and Kann, Jacob, 1993, Wood River hydrology and water quality study, *in* Campbell, S.G., ed., Environmental research in the Klamath Basin, Oregon—1992 annual report: Denver, Colorado, Bureau of Reclamation Report No. R–93–16, p. 9–90.

Canning, S.P., Fazio, P.C., Fisher, Donna, Gutman, E.L., Hsia, C.T., Kauffman, S.L., Kramer, Joanne, Lane, Marianne, Leinweber, C.M., and McGee, P.A., eds., 1991, 1991 Annual book of ASTM standards—Section 4 construction—Volume 04.08 soil and rock; Dimension Stone; Geosynthetics: Philadelphia, Pennsylvania, American Society for Testing and Materials, 1182 p.

Carlson, J.R., 1993, The evaluation of wetland changes around Upper Klamath Lake, Oregon, using multitemporal remote sensing techniques, *in* Campbell, S.G., ed., Environmental research in the Klamath Basin, Oregon—1991 annual report: Denver, Colorado, Bureau of Reclamation Report No. R–93–13, p. 197–202.

CH2M Hill, 1996, Feasibility review—Williamson River restoration—The Nature Conservancy: Corvallis, Oregon, CH2M Hill, March, 13 p.

Chason, D.B., and Siegel, D.I., 1986, Hydraulic conductivity and related physical properties of peat, Lost River Peatland, Northern Minnesota: Soil Science, v. 142, no. 2, p. 91–99.

Chow, V.T., ed., 1964, Handbook of applied hydrology: New York, McGraw-Hill, 1418 p.

Cowardin, L.M., Carter, Virginia, Golet, F.C., and Laroe, E.T., 1979, Classification of wetlands and deepwater habitats of the United States: U.S. Fish and Wildlife Service, FWS/OBS–79/31, 103 p.

Crowley, S.S., Dufek, D.A., Stanton, R.W., and Ryer, T.A., 1994, The effects of volcanic ash disturbances on a peat-forming environment—Environmental disruption and taphonomic consequences: PALAIOS, v. 9, p. 158–174.

Dicken, S.N., 1980, Pluvial Lake Modoc, Klamath County, Oregon, and Modoc and Siskiyou Counties, California: Oregon Geology, v. 42, no. 11, p. 179–187.

Dicken, S.N., and Dicken, E.F., 1985, The legacy of ancient Lake Modoc-A historical geography of the Klamath Lakes Basin: Eugene, University of Oregon, 166 p.

Dileanis, P.D., Schwarzbach, S.E., and Bennett, Jewel, 1996, Detailed study of water quality, bottom sediment, and biota associated with irrigation drainage in the Klamath Basin, California and Oregon, 1990–92: U.S. Geological Survey Water-Resources Investigations Report 95–4232, 68 p.

Efimov, V.N., and Lunina, N.F., 1988, Evolution of bog soils in the European part of the USSR due to their agricultural use: Proceedings of the 8th International Peat Congress, Volume 3, Leningrad, USSR, August 14–21, 1988, p. 71–78.

Eggelsmann, R., 1976, Peat consumption under influence of climate, soil condition and utilization: Proceedings of the 5th International Peat Congress, Volume I, Poznan, Poland, August 21–25, 1976, p. 233–247.

Farnham, R.S., 1976, Influence of intensive agriculture on water quality in peatlands: Proceedings of the 5th International Peat Congress, Volume I, Poznan, Poland, August 21–25, 1976, p. 107–117.

Federal Register, 1988, Endangered and threatened wildlife and plants—Determination of endangered status for the shortnose sucker and Lost River sucker: Department of Interior, Fish and Wildlife Service, July 18, 1988, v. 53, no. 137, p. 27130–27134.

Finney, H.R., Gross, E.R., and Farnham, R.S., 1974, Limnic materials in peatlands of Minnesota, *in* Aandahl, A.R., Buol, S.W., Hill, D.E., and Bailey, H.H., eds., Histosols—Their characteristics, classification, and use: Madison, Wisconsin, Soil Science Society of America, Special Publication Series no. 6, p. 21–31.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93–125, 217 p.

Fretwell, J.D., Williams, J.S., and Redman, P.J., comps., 1996, National water summary on wetland resources: U.S. Geological Survey Water-Supply Paper 2425, 431 p.

Gallagher, J.L., 1978, Decomposition processes—Summary and recommendations, *in* Good, R.E., Whigham, D.F., and Simpson, R.L., eds., 1978, Freshwater wetlands—Ecological processes and management potential: New York, Academic Press, p. 145–151.

Gearheart, R.A., Anderson, J.K., Forbes, M.G., Osburn, Mark, and Oros, Daniel, 1995a, Watershed strategies for improving water quality in Upper Klamath Lake, Oregon—Volume I: Arcata, California, Humboldt State University, 42 p.

———1995b, Watershed strategies for improving water quality in Upper Klamath Lake, Oregon—Volume II: Arcata, California, Humboldt State University, 270 p., plus references and appendixes.

———1995c, Watershed strategies for improving water quality in Upper Klamath Lake, Oregon—Volume III: Arcata, California, Humboldt State University, [unknown pagination].

Geitgey, R.P., 1992, Pumice in Oregon: Oregon Department of Geology and Mineral Industries Special Paper 25, 26 p.

Goode, D.A., Marsan, A.A., and Michaud, J.-R., 1977, Water resources *in* Radforth, N.W., and Brawner, C.O., eds., Muskeg and the northern environment of Canada: University of Toronto Press, p. 299–331.

Gore, A.J.P., 1983, Introduction, *in* Gore, A.J.P., ed., Ecosystems of the world 4A, Mires—swamp, bog, fen, and moor—General studies: New York, Elsevier, p. 1–34.

Hubbard, L.L., 1970, Water budget of Upper Klamath Lake, southwestern Oregon: U.S. Geological Survey Hydrologic Investigations Atlas HA–351, scale 1:250,000.

Hurr, R.T., and Litke, D.W., 1989, Estimating pumping time and ground-water withdrawals using energy-consumption data: U.S. Geological Survey Water-Resources Investigation 89–4107, 27 p.

Illian, J.R., 1970, Interim report on the ground water in the Klamath Basin, Oregon: Salem, Oregon State Engineer, 110 p.

Johnson, D.M., Peterson, R.R., Lycan, D.R., Sweet, J.W., and Neuhaus, M.E., 1985, Atlas of Oregon lakes: Corvallis, Oregon State University Press, 317 p.

Kaffka, S.R., Lu, T.X., and Carlson, H.L., 1995, An assessment of the effects of agriculture on water quality in the Tulelake region of California: Tulelake, California, University of California, Intermountain Research and Extension Center, Research Progress Report 108, 85 p.

Kann, Jacob, 1993a, Agency Lake limnology, 1990–91, *in* Campbell, S.G., ed., Environmental research in the Klamath Basin, Oregon—1991 annual report: Bureau of Reclamation Technical Report R–93–13., p. 103–187.

———1993b, Agency Lake limnology, 1992, *in* Campbell, S.G., ed., Environmental research in the Klamath Basin, Oregon—1992 annual report: Bureau of Reclamation Technical Report R–93–16, p. 91–137.

Karlovski, V.F., and Brezgunov, V.S., 1988, Peat soil liquid body transformation: Proceedings of the 8th International Peat Congress, Volume 4, Leningrad, USSR, August 14–21, 1988, p. 11–18.

Kaunisto, Seppo, 1976, Aspects of nitrogen mobilization in peat: Proceedings of the 5th International Peat Congress, Volume II, Poznan, Poland, August 21–25, 1976, p. 295–305.

Klamath Consulting Service, Inc., 1983, The Upper Klamath Lake, EPA–314 Clean Lakes Program 1981 to 1983—Phase 1, diagnostic and feasibility study: Klamath Falls, Oregon, 145 p.

Kuntze, H., 1984, The risks of water pollution by agricultural utilization of peatlands and practical defenses: Proceedings of the 7th International Peat Congress, Volume 1, Dublin, Ireland, June 18–23, 1984, p. 246–267.

———1992, Peat losses by liming and fertilizing of peatland used as grassland: Proceedings of the 9th International Peat Congress, Volume 2, Uppsala, Sweden, June 22–26, 1992, p. 306–314.

Laenen, Antonius, and LeTourneau, A.P., 1996, Upper Klamath Basin nutrient-loading study—Estimate of wind-induced resuspension of bed sediment during periods of low lake elevation: U.S. Geological Survey Open-File Report 95–414, 11 p.

Laine, J., Vasander, H., and Puhalainen, A., 1992, Effect of forest drainage on the carbon balance of mire ecosystems: Proceedings of the 9th International Peat Congress, Volume 1, Uppsala, Sweden, June 22–26, 1992, p. 170–181.

Lee, Gerhard B., and Manoch, Bamrung, 1974, Macromorphology and micromorphology of a Wisconsin saprist, *in* Aandahl, A.R., Buol, S.W., Hill, D.E., and Bailey, H.H., eds., Histosols—Their characteristics, classification, and use: Madison, Wisconsin, Soil Science Society of America, Special Publication Series no. 6, p. 47–62.

Leonard, A.R., and Harris, A.B., 1974, Ground water in selected areas in the Klamath Basin, Oregon: Oregon State Engineer Ground Water Report No. 21, 104 p.

Levanon, D., Levin, I., Kipnis, T., and Cohen, U., 1987, The effect of high yielding perennial herbage crops on biological degradation and nitrate accumulations in peat soil: Experimental Agriculture, v. 23, p. 69–74.

Lévesque, M.P., and Mathur, S.P., 1979, A comparison of various means of measuring the degree of decomposition of virgin peat materials in the context of their relative biodegradability: Canadian Journal of Soil Science, v. 59, p. 397–400.

Linsley, R.K., Jr., Kohler, M.A., and Paulhus, J.L.H., 1982, Hydrology for engineers (3d ed.):New York, McGraw-Hill, 508 p.

Lucas, R.E., 1982, Organic soils (histosols)—Formation, distribution, physical and chemical properties and management for crop production: East Lansing, Michigan State University Agricultural Experiment Station, Research Report v. 435 Farm Science, 77 p.

Lynn, W.C., McKinzie, W.E., and Grossman, R.B., 1974, Field laboratory tests for characterization of histosols, *in* Aandahl, A.R., Buol, S.W., Hill, D.E., and Bailey, H.H., eds., Histosols—Their characteristics, classification, and use: Madison, Wisconsin, Soil Science Society of America, Special Publication Series no. 6, p. 11–20.

McDonnell, J.G., and Farrell, E.P., 1984, An evaluation of techniques for the measurement of decomposition in peat: Proceedings of the 7th International Peat Congress, Volume 4, Dublin, Ireland, June 18–23, 1984, p. 358–382.

Maciak, Franciszek, 1972, Effect of fertilization and tillage on content of organic forms of nitrogen in peat soil and its humus fractions: Proceedings of the 4th International Peat Congress, Volume IV, Otaniemi, Finland, June 25–30, 1972, p. 105–120.

Mathur, S.P., and Farnham, R.S., 1985, Geochemistry of humic substances in natural and cultivated peatlands, *in* Aiken, G.R., McKnight, D.M., Wershaw, R.L., and MacCarthy, Patrick, eds., Humic substances in soil, sediment, and water: New York, Wiley-Interscience, p. 53–85.

Miller, W.E., and Tash, J.C., 1967, Interim report, Upper Klamath Lake studies, Oregon: Corvallis, Oregon, Federal Water Pollution Control Administration, Pacific Northwest Laboratory, Water Pollution Control Research Series, Paper WP–20–8, 37 p.

Montedoro-Whitney Corporation, 1984, Instruction manual for PVM-2A portable velocity meter: San Luis Obispo, California, 21 p. [Available from Montedoro-Whitney Corporation, 2741E McMillan Road, San Luis Obispo, California 93401.]

Mulqueen, J., 1986, Hydrology and drainage of peatland: Environmental Geology and Water Sciences, v. 9, no. 1, p. 15–22.

National Oceanic and Atmospheric Administration, 1994, Climatological Data, Oregon: Asheville, North Carolina, National Climatic Data Center.

———1995, Climatological Data, Oregon: Asheville, North Carolina, National Climatic Data Center.

———1996, Climatological Data, Oregon: Asheville, North Carolina, National Climatic Data Center.

Nesterenko, I.M., 1976, Subsidence and wearing out of peat soils as a result of reclamation and agricultural utilization of marshlands: Proceedings of the 5th International Peat Congress, Volume I, Poznan, Poland, August 21–25, 1976, p. 218–232.

Newcomb, R.C., and Hart, D.H., 1958, Preliminary report on the ground water resources of the Klamath River Basin, Oregon: U.S. Geological Survey Open-File Report [unnumbered], 248 p.

Okruszko, H., Sapek, B., and Szuniewicz, J., 1988, Balance of mineral components in peat soil utilized for a grassland over 24 years: Proceedings of the 8th International Peat Congress, Volume 3, Leningrad, USSR, August 14–21, 1988, p. 226–233.

Oregon Water Resources Department, 1978, Land use—Klamath drainage basin, Oregon: Salem, Oregon, scale 1:260,000, 1 sheet.

Otabbong, E., and Linden, B., 1992, Nitrogen dynamics and control in organic soils—A review: Proceedings of the 9th International Peat Congress, Volume 3, Uppsala, Sweden, June 22–26, 1992, p. 250.

Page, A.L., Miller, R.H., and Keeney, D.R., eds., 1982, Methods of soil analysis—Part 2—Chemical and microbiological properties, (2d ed.): Madison, WI, American Society of Agronomy, Inc. and Soil Science Society of America, Inc., 1159 p.

Patton, C.J., and Truitt, E.P., 1992, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of total phosphorus by a kjeldahl digestion method and an automated colorimetric finish that includes dialysis: U.S. Geological Survey Open-File Report 92–146, 39 p.

Peterson, N.V., and McIntyre, J.R., 1970, The reconnaissance geology and mineral resources of eastern Klamath County and western Lake County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 66, 70 p.

Petukhova, N.N., 1988, On the reclamation-provoked geochemical transformation of peatland in the Byelorussian SSR: Proceedings of the 8th International Peat Congress, Volume 4, Leningrad, USSR, August 14–21, 1988, p. 3–10.

Phinney, H.K., and Peek, C.A., 1961, Klamath Lake—An instance of natural enrichment, *in* Transcript of 1960 seminar on Algae and metropolitan wastes: Cincinnati, Ohio, R.A. Taft Sanitary Engineering Center, p. 22–27.

Pollett, F.C., 1972, Nutrient contents of peat soils in Newfoundland: Proceedings of the 4th International Peat Congress, Volume III, Otaniemi, Finland, June 25–30, 1972, p. 461–468.

Reddy, K.R., 1982, Mineralization of nitrogen in organic soils: Soil Science Society of America Journal, v. 46, no. 3, p. 561–566.

Rosenbaum, J.G., Reynolds, R.L., Adam, D.P., Sarna-Wojcicki, A.M., Whitney, C.G., Kerwin, M.W., and Fitzmaurice, P., 1995, Climate records from Quaternary sediment, Buck Lake and Caledonia Marsh, southern Oregon—Comparison of magnetic and pollen data, *in* Adam, D.P., Bradbury, J.P., Dean, W.E., Gardner, J.V., and Sarna-Wojcicki, A.M., eds., Report of 1994 Workshop on the correlation of marine and terrestrial records of climate changes in the western United States: U.S. Geological Survey Open-File Report 95–34, p. 30–35.

Sartoris, J.J., and Sisneros, D., 1993, Upper Klamath Lake wetlands study, *in* Campbell, S.G., ed., Environmental research in the Klamath Basin, Oregon—1991 annual report: Bureau of Reclamation Technical Report R–93–13., p. 189–196.

Sartoris, J.J., Sisneros, D., and Campbell, S.G., 1993, Upper Klamath Lake wetlands study, *in* Campbell, S.G., ed., Environmental research in the Klamath Basin, Oregon—1992 annual report: Bureau of Reclamation Technical Report R–93–16., p. 189–222.

Schalitz, Gisbert, Scholz, Anton, Fischer, Andreas, and Kaiser, Thomas, 1996, Function of large-area extensive pasture on shallow undulated low-moor: Proceedings of the 10th International Peat Congress, Volume 2, Bremen, Germany, May 27–June 2, 1996, p. 184–197.

Segeberg, H., 1962, Vorausberechnung der auf Moorkulturen durch den Schwund von Torfsubstanz zu erwartenden Höhenverluste: Z.f. Kulturtechnik, v. 3, p. 336–367.

Sherrod, D.R., 1993, Historic and prehistoric earthquakes near Klamath Falls, Oregon: Earthquakes and Volcanoes, v. 24, no. 3, p. 106–120.

Sherrod, D.R., and Pickthorn, L.G., 1992, Geologic map of the west half of the Klamath Falls 1° by 2° Quadrangle, south-central Oregon: U.S. Geological Survey Miscellaneous Investigations Series, Map I-2182, scale 1:250,000.

Smith, James G., 1988, Geologic map of the Pelican Butte Quadrangle, Klamath County, Oregon: U.S. Geological Survey Geologic Quadrangle Map 1653, scale 1:62,500, 1 sheet.

Smith, James G., Page, N.J., Johnson, M.G., Moring, B.C., and Gray, Floyd, 1982, Preliminary geologic map of the Medford 1° by 2° Quadrangle, Oregon and California: U.S. Geological Survey Open-File Report 82–955, scale 1:250,000.

Sorenson, S.K., and Schwarzbach, S.E., 1991, Reconnaissance investigations of water quality, bottom sediment, and biota associated with irrigation drainage in the Klamath Basin California and Oregon, 1988–89: U.S. Geological Survey Water-Resources Investigations Report 90–4203, 64 p.

Stephens, J.C., 1956, Subsidence of organic soils in the Florida Everglades, Soil Science Society of America Proceedings, v. 20, p. 77–80.

U.S. Army Corp of Engineers, 1979, Klamath River Basin—Oregon—Reconnaissance report: San Francisco, California, U.S. Army Corps of Engineers, 175 p.

———1982, Potential eutrophication control measures for Upper Klamath Lake, Oregon—Data evaluation and experimental design: San Francisco, California, 200 p.

U.S. Department of Agriculture, 1975, Soil taxonomy—A basic system of soil classification for making and interpreting soil surveys: Soil Conservation Service Agriculture Handbook no. 436, 754 p.

———1991, Soil Survey Laboratory Methods Manual: Lincoln, Nebraska, National Soil Survey Center, Soil Conservation Service Soil Survey Investigations Report No. 42 Version 1.0, 603 p.

———1996, Soil Survey Laboratory Methods Manual: Lincoln, Nebraska, National Soil Survey Center, Natural Resources Conservation Service Soil Survey Investigations Report No. 42 Version 3.0, 693 p.

Voznjuk, S.T., Olinevich, V.A., and Lyko, D.V., 1988, The rational use of peat soils in agricultural production: Proceedings of the 8th International Peat Congress, Volume 3, Leningrad, USSR, August 14–21, 1988, p. 18–24.

Walbridge, M.R., 1991, Phosphorus availability in acid organic soils of the lower North Carolina coastal plain: Ecology, v. 72, no. 6, p. 2083–2100.

Walker, G.W., 1951, Pumice deposits of the Klamath Indian Reservation Klamath County, Oregon: U.S. Geological Survey Circular 128, 6 p.

Williams, Howell, 1965, The geology of Crater Lake National Park, Oregon, *in* Peterson, N.V., and Groh, E.A., eds., State of Oregon lunar geological field conference guide book: Oregon Department of Geology and Mineral Industries Bulletin 57, p. 39–51.

Wood, T.M., Fuhrer, G.J., and Morace, J.L., 1996, Relation between selected water-quality variables and lake level in Upper Klamath and Agency Lakes, Oregon: U.S. Geological Survey Water-Resources Investigations Report 96–4079, 57 p.

APPENDIX I

QUALITY ASSURANCE

APPENDIX I. QUALITY ASSURANCE

Quality assurance of the collection, preparation, and analysis of soil and water samples was accomplished with the use of replicate split samples. Replicate split samples are prepared by dividing a single sample into a pair of identical samples (replicates) at the time and place of sampling. The replicate samples are processed and preserved in the same manner. The purpose of analyzing replicate samples was to assess analytical precision—assuming no contamination or other differences caused by sample processing, preservation, or transport. The relative percent difference (RPD) was used as a measure of how well the analyses of the split samples compared:

$$RPD = \left| \frac{(Sample1 - Sample2)}{(Sample1 + Sample2)/2} \times 100 \right|$$

where:

RPD = relative percent difference (dimensionless),

Sample 1 = the constituent concentration or other measurement for the first sample of a replicate pair, and

Sample 2 = the constituent concentration or other measurement for the second sample of a replicate pair.

Water-Quality Samples

Quality-assurance data were used, to the degree possible, to quantify precision in the water-quality samples collected during this study for the analysis of nutrients. By collecting replicate split samples from the churn splitter, the results give an indication of the precision involved in the splitting of the samples, the handling and processing of the samples, and the laboratory analyses run on the samples. Because the quality-assurance data for this study are few in number, a comprehensive analysis was precluded. Statistics generated from the quality-assurance data were used, however, in the interpretation of the data and should be consulted by other users.

The RPD was calculated for all replicate split samples as an indicator of precision (table I–A). Twenty-five percent of the quality-assurance data had an RPD of 0 percent, indicating that both samples had the same constituent concentration. In general, the RPDs were less than 20 percent, with over three-fourths of the differences less than 10 percent. All constituents, except phosphorus in unfiltered water and nitrite in filtered water, appear to follow the commonly occurring pattern of decreasing RPD as concentration is increasing. In general, however, the absolute differences are approximately constant. For phosphorus and ammonia plus organic nitrogen in unfiltered water, there is no apparent pattern, but the differences could partly reflect how well the churn was able to split particulates in samples. Also, both of these analyses involve digestions that typically contribute to analytical error. For nitrite in filtered water, all RPD values for detectable concentrations were zero, indicating good precision across the concentration range. Overall, these replicate data show that sampling and analytical variation were not great enough to affect the conclusions of this report.

Soil Samples

The Colorado State University Soil, Water and Plant Testing Laboratory used for physical and chemical analyses was reviewed by the USGS Branch of Technical Development and Quality Systems and was rated as satisfactory (L.J. Schroder, U.S. Geological Survey, written commun., 1996). About 11 percent of the soil samples submitted and analyzed for this study were for quality assurance and consisted of 22 replicate split samples. The RPD was calculated to examine the magnitude of the difference between concentrations and other measurements in the sample pairs (table I–B).

With the exception of the analyses for total carbon and nitrite plus nitrate, the mean RPD for all analyses was less than 10 percent. The total carbon and nitrite plus nitrate analyses had mean RPDs of 15.8 and 30.7 percent respectively, however, these analyses were not used in the interpretations for this report.

Obtaining identical samples from splitting of soil materials is difficult because of the heterogeneous nature of the soil and clumping. In addition, some chemical species may not be evenly distributed within the soil. However, overall, these replicate data show that sampling and analytical variation were not great enough to affect the conclusions of this report.

Table I–A. Quality-assurance data for nutrients in water-quality samples collected at pumping stations and a flowing artesian well adjacent to Upper Klamath Lake, Oregon, 1993–95

[All concentrations reported are from filtered-water samples, unless otherwise stated. Concentrations are reported as nitrogen or phosphorus. Relative percent difference, absolute value of the difference between the split samples divided by the mean and multiplied by 100. *, both concentrations were below the minimum reporting level. <, less than]

Sample description			Nitrogen (milligrams per liter)					Phosphorus (milligrams per liter)		
Pumping station	Date	Time	Ammonia	Ammonia plus organic nitrogen	Ammonia plus organic nitrogen, unfiltered	Nitrite	Nitrite plus nitrate	Phosphorus, unfiltered	Phosphorus	Orthophosphate
Pumping stations										
Wocus Marsh	03-16-95	1340	0.15	4.0	4.3	0.020	0.41	0.10	0.060	0.020
Wocus Marsh	03-16-95	1330	.15	4.1	4.1	.020	.42	.10	.050	.020
Relative percent difference			0	2.5	4.8	0	2.4	0	18	0
Williamson River North	04-04-95	1100	1.6	3.4	4.9	.020	.11	1.0	.80	.64
Williamson River North	04-04-95	1115	1.9	3.2	4.0	.020	.10	.80	.79	.63
Relative percent difference			17	6.1	20	0	9.5	22	1.2	1.6
Northwest Agency Lake	05-14-93	1645	.030	1.3	2.5	<.010	<.005	.39	.20	.19
Northwest Agency Lake	05-14-93	1645	.030	1.5	2.5	<.010	<.005	.38	.23	.19
Relative percent difference			0	14	0	*	*	2.6	14	0
Northwest Agency Lake	04-19-95	1330	.42	2.2	2.6	.010	.033	.30	.22	.19
Northwest Agency Lake	04-19-95	1350	.49	2.3	3.2	.010	.029	.35	.23	.20
Relative percent difference			15	4.4	21	0	13	15	4.4	5.1
Wood River Property (Corral)	06-23-95	1330	<.015	2.2	2.9	.020	<.005	1.0	.82	.82
Wood River Property (Corral)	06-23-95	1345	<.015	2.2	2.5	.020	<.005	.97	.83	.83
Relative percent difference			*	0	15	0	*	3.0	1.2	1.2
Flowing artesian well										
Flowing artesian well #1	05-24-95	1045	5.7	5.7	5.6	<.010	<.005	6.4	6.8	6.6
Flowing artesian well #1	05-24-95	1120	5.8	5.6	5.7	<.010	<.005	6.4	6.5	6.3
Relative percent difference			1.7	1.8	1.8	*	*	0	4.5	4.6

Table I–B. Quality-assurance data for analyses of soil samples collected from wetlands adjacent to Upper Klamath Lake, Oregon, August 1995

[Relative percent difference, absolute value of the difference between split samples divided by the mean and multiplied by 100. *, both concentrations were below the minimum reporting level. --, not analyzed or not applicable; <, less than; see plates 1 and 2 for sample locations]

Abbreviations used in sample name:

ALW	Agency Lake West
BBS	Ball Bay South
CAM	Caledonia Marsh
COV	Cove Point
HNK	Hanks Marsh Unit—Upper Klamath National Wildlife Refuge
MCC	McCornack Point
PUD	Replicate Split Sample
WOC	Wocus Marsh
WRN	Williamson River North
WRR	Wood River Property

Sample name	Percent ash	Total carbon (as percent dry mass)	Inorganic carbon (as percent dry mass)	Total nitrogen (as percent dry mass)	Nitrite plus nitrate as N (mg/kg)	Total phosphorus (mg/kg)
ALW-03C	35.5	35.3	--	1.87	289	240
PUD-08B	39.1	34.1	--	1.81	128	260
Relative percent difference	9.7	3.5	--	3.3	77.2	8.0
ALW-04A	27.4	38.3	--	2.63	250	910
PUD-09A	27.4	39.2	--	2.83	127	1,080
Relative percent difference	.0	2.3	--	7.3	65.3	17.1
BBS-01B	86.4	3.8	--	.50	23	310
PUD-09G	86.4	3.7	--	.49	21	310
Relative percent difference	.0	2.7	--	2.0	9.1	.0
CAM-01C	9.2	52.5	--	2.06	23	300
PUD-07E	8.8	53.0	--	2.05	20	310
Relative percent difference	4.4	.9	--	.5	14.0	3.3
CAM-01F	76.7	11.1	--	1.00	200	210
PUD-07A	76.2	11.8	--	1.09	273	230
Relative percent difference	.7	6.1	--	8.6	30.9	9.1
CAM-02A	82.4	5.7	<.01	.56	33	340
PUD-02A	82.7	5.2	<.01	.61	27	370
Relative percent difference	.4	9.2	*	8.5	20.0	8.5
CAM-02B	88.1	4.0	<.01	.29	25	120
PUD-02B	89.2	3.4	<.01	.28	20	130
Relative percent difference	1.2	16.2	*	3.5	22.2	8.0
CAM-03A	33.3	36.5	--	1.74	53	480
PUD-05C	35.0	34.3	<.01	1.69	42	390
PUD-09B	35.9	38.1	--	1.93	59	510
Relative percent difference	2.8	3.7	--	5.3	12.1	10.1
CAM-03B	21.5	42.0	--	3.00	36	470
PUD-08C	20.3	44.2	--	3.05	29	500
Relative percent difference	5.7	5.1	--	1.7	21.5	6.2
CAM-03C	75.5	11.8	--	1.07	29	150
PUD-07C	74.9	12.8	--	1.13	28	180
Relative percent difference	.8	8.1	--	5.5	3.5	18.2

Table I–B. Quality-assurance data for analyses of soil samples collected from wetlands adjacent to Upper Klamath Lake, Oregon, August 1995—Continued

Sample name	Percent ash	Total carbon (as percent dry mass)	Inorganic carbon (as percent dry mass)	Total nitrogen (as percent dry mass)	Nitrite plus nitrate as N (mg/kg)	Total phosphorus (mg/kg)
CAM-04A	63.5	16.7	0.02	1.06	66	870
PUD-05B	63.4	17.6	.02	.89	83	830
Relative percent difference	.2	5.2	.0	17.4	22.8	4.7
CAM-04D	93.7	.9	<.01	.06	7	270
PUD-05A	94.0	.6	<.01	.05	22	320
Relative percent difference	.3	40.0	*	18.2	103.4	16.9
COV-01A	72.3	13.5	--	1.02	34	410
PUD-09D	71.3	13.7	--	.95	27	470
Relative percent difference	1.4	1.5	--	7.1	23.0	13.6
COV-02B	38.4	35.0	--	2.17	104	390
PUD-08E	36.1	35.7	--	2.18	100	440
Relative percent difference	6.2	2.0	--	.5	3.9	12.0
HNK-03B	25.7	41.9	--	2.82	34	490
PUD-09E	26.6	40.1	--	2.65	31	500
Relative percent difference	3.4	4.4	--	6.2	9.2	2.0
MCC-01A	89.7	2.6	<.01	.25	13	200
PUD-02D	89.0	3.1	<.01	.25	11	220
Relative percent difference	.8	17.5	*	.0	16.7	9.5
WOC-02A	63.1	14.0	<.01	1.48	301	770
PUD-06B	62.0	16.3	<.01	1.37	314	780
Relative percent difference	1.8	15.2	*	7.7	4.2	1.3
WOC-07C	97.8	.0	.15	.01	17	130
PUD-06D	99.1	.2	.17	.01	7	150
Relative percent difference	1.3	181.0	12.5	.0	83.3	14.3
WRN-01A	53.3	24.4	--	1.84	71	1070
WRN-01B	52.8	24.3	--	1.83	95	1060
Relative percent difference	.9	.4		.5	28.9	.9
WRN-01C	57.3	17.8	<.01	1.53	129	640
PUD-02C	62.4	15.5	<.01	1.45	109	590
Relative percent difference	8.5	13.8	*	5.4	16.8	8.1
WRN-03C	89.5	2.71	--	.22	6	420
PUD-09C	90.2	2.9	--	.23	5	400
Relative percent difference	.8	7.1	--	4.4	18.2	4.9
WRR-05B	66.2	18.3	--	1.46	29	740
PUD-09H	64.9	18.7	--	1.42	14	780
Relative percent difference	2.0	2.2	--	2.8	69.8	5.3
Mean relative percent difference	2.4	15.8	6.3	5.3	30.7	8.3

APPENDIX II

LOCATION AND DEPTH OF SOIL CORES

Appendix II. Location and depth of soil cores

[Longitude and latitude for 1993 cores are approximate and were determined from U.S. Geological Survey 1:24,000 scale topographic maps; longitude and latitude for 1995 cores were determined using a high precision Global Positioning System (GPS) and are accurate to about +/- 50 feet; datum is the 1927 North American Datum]

Abbreviations used in sample name:

ALG	Algoma
ALN	Agency Lake North
ALW	Agency Lake West
BBS	Ball Bay South
BBW	Ball Bay West
CAM	Caledonia Marsh
COV	Cove Point
HNK	Hanks Marsh Unit—Upper Klamath National Wildlife Refuge
MCC	McCornack Point
NWR	Northwest Upper Klamath Lake—Upper Klamath National Wildlife Refuge
SHO	Shoalwater Bay Wildlife Area
SQW	Squaw Point Wildlife Area
WOC	Wocus Marsh
WRM	Wood River Marsh
WRN	Williamson River North
WRR	Wood River Property

1993 Cores

Core name	Total depth (feet)	Longitude	Latitude
ALW-A1	13.08	121°58'47"	42°33'53"
CAM-A1	14.00	121°54'19"	42°18'43"
CAM-A2	14.00	121°54'04"	42°17'49"
CAM-A3	13.50	121°53'49"	42°17'25"
NWR-A1	21.67	122°04'19"	42°27'60"
NWR-A2	22.33	122°04'38"	42°28'03"
WOC-A1	18.00	121°55'34"	42°16'47"
WOC-A2	5.67	121°53'09"	42°15'23"
WRN-A1	5.33	121°57'22"	42°30'01"
WRN-A2	5.58	121°57'45"	42°30'01"
WRN-A3	5.67	121°58'46"	42°29'60"
WRR-A1	12.17	121°58'04"	42°35'04"
WRR-A2	12.83	121°58'10"	42°35'04"
WRR-A3	5.50	121°57'24"	42°36'15"
WRR-A4	2.00	121°58'12"	42°37'13"

1995 Cores

Core Name	Total depth (feet)	Longitude	Latitude
ALG-01	6.10	121°49'10"	42°20'53"
ALG-02	7.80	121°49'09"	42°21'46"
ALG-03	10.20	121°48'39"	42°22'50"
ALG-04	6.80	121°48'19"	42°22'06"
ALG-05	4.00	121°48'29"	42°21'24"
ALN-01	13.60	121°58'27"	42°34'52"
ALN-02	13.60	121°59'24"	42°34'38"
ALN-03	10.20	122°00'26"	42°34'41"
ALN-04	11.90	121°59'46"	42°36'04"
ALW-01	13.60	122°00'49"	42°31'59"
ALW-02	10.20	121°58'36"	42°32'48"
ALW-03	10.20	121°59'51"	42°33'34"
ALW-04	11.90	121°59'45"	42°32'59"
BBS-01	4.00	122°00'13"	42°23'02"
BBS-02	4.80	122°00'11"	42°23'33"
BBW-01	4.50	122°02'51"	42°24'24"
BBW-02	13.60	122°02'12"	42°24'33"
CAM-01	10.20	121°55'12"	42°18'33"
CAM-02	10.00	121°53'41"	42°18'52"
CAM-03	6.80	121°53’31"	42°18’15"
CAM-04	3.00	121°52’50"	42°17’30"
CAM-05	3.40	121°53’22"	42°17’04"
CAM-06	11.90	121°55’28"	42°17’43"
CAM-07	6.80	121°54’42"	42°17’13"
CAM-08	18.70	121°55’27"	42°17’05"
COV-01	9.40	121°49’37"	42°17’36"
COV-02	7.40	121°49’04"	42°17’35"
HNK-01	18.80	121°49’14"	42°18’11"
HNK-02	11.90	121°49’40"	42°18’11"
HNK-03	11.20	121°49’20"	42°19’38"
MCC-01	3.40	121°50’39"	42°15’19"
MCC-02	2.30	121°51’03"	42°15’58"
MCC-03	2.60	121°51’17"	42°15’30"
NWR-01	18.70	122°00’31"	42°31’47"
NWR-02	17.00	122°02’23"	42°31’47"
NWR-03	11.90	122°02’56"	42°26’01"
SHO-01	14.20	121°57’33"	42°23’38"
SQW-01	9.70	121°54’34"	42°21’04"
WOC-01	3.50	121°53’03"	42°16’02"
WOC-02	5.10	121°54’02"	42°16’18"
WOC-03	6.80	121°54’49"	42°15’56"
WOC-04	6.80	121°53’56"	42°15’21"
WOC-05	5.30	121°53’04"	42°14’44"
WOC-06	3.90	121°52’05"	42°14’45"
WOC-07	2.00	121°52’03"	42°13’60"
WOC-08	3.50	121°51’45"	42°15’10"
WRM-01	10.60	121°56’11"	42°34’52"
WRM-02	12.20	121°56’18"	42°35’13"
WRN-01	10.20	121°58’31"	42°28’58"
WRN-02	6.30	121°57’26"	42°28’50"
WRN-03	8.20	121°57’03"	42°29’34"
WRR-01	6.40	121°56’47"	42°35’55"
WRR-02	7.90	121°56’50"	42°35’01"
WRR-03	18.30	121°58’58"	42°35’42"
WRR-04	11.20	121°59’53"	42°36’29"
WRR-05	5.40	121°58’58"	42°36’51"
WRR-06	2.80	121°58’07"	42°37’11"
WRR-07	2.00	121°57’28"	42°36’31"
WRR-08	10.00	121°57’50"	42°36’12"
WRR-09	11.90	121°58’08"	42°35’04"
WRR-10	11.70	121°57’22"	42°35’31"

APPENDIX III

DESCRIPTION OF SOIL SAMPLES

AND

SUMMARY OF PHYSICAL AND CHEMICAL ANALYSES

Appendix III. Description of soil samples and summary of physical and chemical analyses

[-, not available; D, Davis soil auger; L, large Macaulay peat sampler; S, small Macaulay peat sampler; ft, feet; cm, centimeter; mL, milliliters; g, grams; mg, milligrams; kg, kilogram]

Abbreviations used in sample name:

ALG	Algoma	COV	Cove Point	SHO	Shoalwater Bay Wildlife Area
ALN	Agency Lake North	HNK	Hanks Marsh Unit-- Upper Klamath National Wildlife Refuge	SQW	Squaw Point Wildlife Area
ALW	Agency Lake West			WOC	Wocus Marsh
BBS	Ball Bay South	MCC	McCornack Point	WRM	Wood River Marsh
BBW	Ball Bay West	NWR	Northwest Upper Klamath Lake-- Upper Klamath National Wildlife Refuge	WRN	Williamson River North
CAM	Caledonia Marsh			WRR	Wood River Property

Sample name	Sample depth (ft) Top	Sample depth (ft) Bottom	Length of sample interval (ft)	Volume (mL)	Sample method	Soil material	Sample weight as received (g)	Sample weight dry (g)	Bulk density (g per cubic cm)	Percent moisture, as percentage of total mass	Percent dry matter, as percentage of total mass	Percent ash content, as percentage of oven-dried mass	Soil pH (standard pH units)	Total carbon, as percentage of oven-dried mass as carbon	Inorganic carbon, as percentage of oven-dried mass as carbon	Total nitrogen, as percentage of oven-dried mass as nitrogen	Nitrite plus nitrate, as mg nitrogen per kg of oven-dried mass	Total inorganic phosphorus, as mg phosphorus per kg of oven-dried mass	Total phosphorus, as mg phosphorus per kg of oven-dried mass
ALG-01A	0.30	0.60	0.30	-	D	SAPRIC PEAT	85.8	58.8	-	31.5	68.5	89.5	-	4.5	-	0.27	14	-	540
ALG-01B	0.70	0.90	0.20	-	D	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
ALG-01C	1.10	1.30	0.20	-	D	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
ALG-01D	2.00	2.30	0.30	-	D	SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
ALG-01E	4.00	4.30	0.30	-	D	SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
ALG-02A	0.00	0.70	0.70	-	D	SAPRIC PEAT	68.8	36.6	-	46.8	53.2	70.4	-	16.8	-	1.06	38	-	830
ALG-02B	6.00	6.30	0.30	47.8	L	CLAY WITH SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
ALG-03A	0.70	1.20	0.50	-	D	SAPRIC PEAT	74.9	34.9	-	53.4	46.6	80.1	-	10.9	-	0.91	46	-	560
ALG-03B	5.50	5.80	0.30	20.6	S	PUMICE SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
ALG-03C	9.40	9.70	0.30	47.8	L	CLAY WITH PUMICE SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
ALG-04A	0.70	1.10	0.40	-	D	SAPRIC PEAT	69.8	41.2	-	40.9	59.1	65.9	-	19.5	-	1.00	24	-	1,260
ALG-05A	0.70	1.10	0.40	-	D	SAPRIC PEAT	79.9	49.2	-	38.5	61.5	85.0	-	7.7	-	0.49	70	-	1,070
ALN-01A	2.10	2.40	0.30	47.8	L	HEMIC PEAT	49.6	8.8	0.1832	82.3	17.7	58.0	-	22.5	-	1.44	74	-	300
ALN-01B	6.20	6.50	0.30	47.8	L	HEMIC PEAT	49.1	6.0	0.1250	87.8	12.2	36.3	-	36.2	-	1.98	149	-	310
ALN-01C	8.00	8.30	0.30	47.8	L	HEMIC PEAT	45.9	8.9	0.1856	80.7	19.3	57.1	-	24.7	-	1.60	167	-	190
ALN-02A	2.50	2.80	0.30	47.8	L	HEMIC PEAT	54.5	8.9	0.1860	83.7	16.3	48.9	-	28.1	-	1.51	409	-	230
ALN-02B	7.50	7.80	0.30	47.8	L	HEMIC PEAT	51.1	9.3	0.1951	81.8	18.2	65.7	-	17.9	-	0.94	241	-	160
ALN-02C	10.75	11.05	0.30	47.8	L	HEMIC PEAT	49.3	7.1	0.1490	85.6	14.4	34.0	-	36.6	-	1.69	266	-	560
ALN-03A	2.10	2.40	0.30	47.8	L	HEMIC PEAT	51.0	12.3	0.2570	75.9	24.1	32.7	-	27.5	-	1.62	55	-	300
ALN-03B	3.80	4.10	0.30	47.8	L	HEMIC PEAT	54.5	6.8	0.1433	87.4	12.6	12.8	-	48.2	-	2.16	79	-	310
ALN-03C	8.90	9.20	0.30	47.8	L	HEMIC PEAT	49.9	6.3	0.1319	87.4	12.6	31.7	-	36.3	-	1.60	163	-	320
ALN-04A	2.60	2.90	0.30	47.8	L	HEMIC PEAT	49.2	10.2	0.2134	79.2	20.8	37.8	5.4	28.8	<0.01	1.86	39	-	-
ALN-04B	2.90	3.20	0.30	47.8	L	HEMIC PEAT	45.9	10.7	0.2239	76.6	23.4	-	5.5	33.4	-	2.10	19	-	390
ALN-04C	7.40	7.70	0.30	47.8	L	HEMIC/SAPRIC PEAT	48.5	7.2	0.1509	85.1	14.9	45.5	-	28.7	-	1.38	171	-	450
ALN-04D	10.80	11.10	0.30	47.8	L	HEMIC/SAPRIC PEAT	49.4	8.0	0.1677	83.8	16.2	43.5	-	31.1	-	1.80	5	-	250
ALW-01A	1.00	1.30	0.30	47.8	L	HEMIC PEAT	49.6	8.8	0.1841	82.3	17.7	-	5.9	29.9	-	2.09	-	107.3	-
ALW-01B	4.60	4.90	0.30	47.8	L	HEMIC PEAT	46.6	6.4	0.1347	86.1	13.9	42.9	-	31.9	-	2.21	170	-	310
ALW-01C	7.00	7.30	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
ALW-01D	11.40	11.70	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
ALW-01E	13.10	13.40	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
ALW-02A	0.00	0.25	0.25	-	D	SAPRIC PEAT	56.7	23.1	-	59.3	40.7	53.6	-	23.8	-	1.71	123	-	850
ALW-02B	4.30	4.60	0.30	47.8	L	HEMIC PEAT	52.0	5.7	0.1193	89.0	11.0	19.1	-	46.6	-	2.43	178	-	290
ALW-02C	9.50	9.80	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
ALW-03A	1.00	1.30	0.30	47.8	L	HEMIC PEAT	49.7	10.8	0.2260	78.4	21.6	46.3	5.9	22.8	<0.01	1.98	47	-	360
ALW-03B	4.60	4.90	0.30	47.8	L	HEMIC PEAT	49.7	6.1	0.1282	87.7	12.3	25.1	-	43.2	-	2.42	206	-	310
ALW-03C	7.60	7.90	0.30	47.8	L	HEMIC PEAT	25.4	3.8	0.0797	85.0	15.0	35.5	-	35.3	-	1.87	289	-	240
ALW-04A	0.00	0.30	0.30	-	D	HEMIC PEAT	24.6	13.2	-	46.3	53.7	27.4	-	38.3	-	2.63	250	-	910
ALW-04B	1.20	1.50	0.30	47.8	L	HEMIC PEAT	37.0	6.2	0.1297	83.2	16.8	-	5.6	24.5	<0.01	2.82	84	-	630

Appendix III. Description of soil samples and summary of physical and chemical analyses—Continued

Sample name	Sample depth (ft) Top	Sample depth (ft) Bottom	Length of sample interval (ft)	Volume (mL)	Sample method	Soil material	Sample weight as received (g)	Sample weight dry (g)	Bulk density (g per cubic cm)	Percent moisture, as percentage of total mass	Percent dry matter, as percentage of total mass	Percent ash content, as percentage of oven-dried mass	Soil pH (standard pH units)	Total carbon, as percentage of oven-dried mass as carbon	Inorganic carbon, as percentage of oven-dried mass as carbon	Total nitrogen, as percentage of oven-dried mass as nitrogen	Nitrite plus nitrate, as mg nitrogen per kg of oven-dried mass	Total inorganic phosphorus, as mg phosphorus per kg of oven-dried mass	Total phosphorus, as mg phosphorus per kg of oven-dried mass
ALW-04C	4.50	4.80	0.30	47.8	L	HEMIC PEAT	51.4	6.6	0.1381	87.2	12.8	34.3	5.8	3.6	<0.01	2.53	81	-	270
ALW-04D	7.50	7.80	0.30	47.8	L	HEMIC PEAT	51.9	7.3	0.1527	85.9	14.1	41.5	5.7	2.1	<0.01	1.83	101	-	250
ALW-04E	7.80	8.10	0.30	47.8	L	HEMIC PEAT	50.5	7.0	0.1465	86.2	13.8	46.5	5.7	2.7	<0.01	1.62	90	-	200
BBS-01A	0.40	0.70	0.30	-	D	SAPRIC PEAT WITH MINERAL SOIL	60.6	30.3	-	50.0	50.0	85.3	-	5.6	-	0.71	27	-	320
BBS-01B	0.80	1.10	0.30	-	D	SAPRIC PEAT WITH CLAY	67.2	38.8	-	42.2	57.8	86.4	-	3.8	-	0.50	23	-	310
BBS-01C	2.00	2.40	0.40	-	D	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
BBS-01D	3.60	4.00	0.40	-	D	CLAY WITH SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
BBS-02A	2.80	3.10	0.30	47.8	L	CLAY WITH PEBBLES	-	-	-	-	-	-	-	-	-	-	-	-	-
BBW-01A	0.40	1.30	0.90	-	D	SAPRIC PEAT WITH CLAY	96.2	38.8	-	59.7	40.3	63.0	-	17.70	-	1.50	46	-	820
BBW-01B	1.50	1.80	0.30	47.8	L	SAPRIC PEAT WITH CLAY	55.4	21.4	0.4482	61.3	38.7	80.6	-	8.08	-	0.64	8	-	310
BBW-01C	2.90	3.20	0.30	47.8	L	CLAY	53.6	15.0	0.3139	72.1	27.9	88.4	7.3	3.9	0.01	0.30	12	-	160
BBW-02A	0.60	0.90	0.30	47.8	L	HEMIC/SAPRIC PEAT	34.2	7.7	0.1611	77.5	22.5	43.6	5.8	23.7	<0.01	2.11	88	-	770
BBW-02B	2.10	2.40	0.30	47.8	L	HEMIC/SAPRIC PEAT	49.9	8.2	0.1705	83.7	16.3	20.3	-	44.00	-	2.90	39	-	540
BBW-02C	2.90	3.20	0.30	47.8	L	SAPRIC PEAT WITH CLAY	51.3	13.2	0.2767	74.2	25.8	69.0	-	17.10	-	1.37	25	-	470
BBW-02D	8.00	8.30	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
BBW-02E	9.70	10.00	0.30	47.8	L	HEMIC/SAPRIC PEAT	51.0	7.1	0.1496	86.0	14.0	25.0	-	42.90	-	2.02	4	-	470
BBW-02F	11.00	11.30	0.30	47.8	L	HEMIC PEAT WITH CLAY	54.7	9.3	0.1938	83.1	16.9	69.4	-	16.80	-	1.46	17	-	320
CAM-01A	0.70	1.30	0.60	-	D	SAPRIC PEAT	83.0	38.5	-	53.6	46.4	64.7	-	16.2	-	1.03	136	-	430
CAM-01B	2.70	3.00	0.30	47.8	L	SAPRIC PEAT	39.8	10.1	0.2118	74.6	25.4	30.0	-	38.6	-	1.96	47	-	280
CAM-01C	4.20	4.50	0.30	47.8	L	HEMIC PEAT	24.5	3.8	0.0787	84.7	15.3	9.2	-	52.5	-	2.06	23	-	300
CAM-01D	8.00	8.30	0.30	47.8	L	HEMIC PEAT	48.7	6.6	0.1375	86.5	13.5	25.0	-	42.7	-	2.19	124	-	320
CAM-01E	9.30	9.60	0.30	47.8	L	CLAY WITH HEMIC PEAT	53.3	12.3	0.2575	76.9	23.1	77.9	-	10.4	-	0.87	209	-	220
CAM-01F	9.60	9.90	0.30	47.8	L	CLAY WITH HEMIC PEAT	25.5	5.4	0.1135	78.7	21.3	76.7	-	11.1	-	1.00	200	-	210
CAM-02A	1.70	2.00	0.30	-	D	SAPRIC PEAT WITH ASH?	51.6	2.2	-	95.7	4.3	82.4	6.0	5.7	<0.01	0.56	33	-	340
CAM-02B	2.90	3.20	0.30	-	D	SAPRIC PEAT	81.1	30.7	-	62.2	37.8	88.1	6.1	4.0	<0.01	0.29	25	119.1	120
CAM-02C	4.10	4.40	0.30	20.6	S	SAPRIC PEAT	17.0	6.4	0.3108	62.6	37.4	86.1	6.0	3.4	<0.01	0.37	25	-	140
CAM-02D	4.40	4.70	0.30	20.6	S	SAPRIC PEAT	18.0	6.7	0.3254	62.9	37.1	-	6.0	4.2	-	0.30	18	-	160
CAM-02E	6.30	6.70	0.40	27.5	S	SAPRIC PEAT WITH CLAY	25.1	9.4	0.3424	62.5	37.5	82.2	5.4	6.3	<0.01	0.40	28	-	240
CAM-02F	7.50	7.80	0.30	20.6	S	HEMIC PEAT WITH CLAY	17.1	3.6	0.1748	78.8	21.2	-	3.2	14.5	-	1.05	22	-	-
CAM-03A	0.80	1.70	0.90	-	D	SAPRIC PEAT	21.4	10.3	-	52.1	47.9	33.3	-	36.5	-	1.74	53	-	480
CAM-03B	2.80	3.20	0.40	-	D	HEMIC PEAT	28.6	6.9	-	75.8	24.2	21.5	-	42.0	-	3.00	36	-	470
CAM-03C	4.10	4.40	0.30	47.8	L	HEMIC PEAT WITH CLAY	26.2	5.3	0.1108	79.8	20.2	75.5	-	11.8	-	1.07	29	-	150
CAM-03D	6.40	6.70	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
CAM-04A	0.00	0.70	0.70	-	D	SAPRIC PEAT	87.1	53.3	-	38.8	61.2	63.5	7.6	16.7	0.02	1.06	66	-	870
CAM-04B	1.50	1.80	0.30	20.6	S	CLAY WITH HEMIC PEAT	17.7	6.5	0.3156	63.5	36.5	80.2	7.4	7.5	<0.01	0.53	54	-	320
CAM-04C	1.80	2.10	0.30	20.6	S	CLAY WITH HEMIC PEAT	16.8	5.3	0.2574	68.1	31.9	-	6.7	5.4	<0.01	0.43	14	-	210
CAM-04D	2.90	3.00	0.10	-	D	CLAY WITH SAND	83.5	58.0	-	30.5	69.5	93.7	5.2	0.9	<0.01	0.06	7	-	270
CAM-05A	0.40	0.70	0.30	47.8	L	SAPRIC PEAT	51.2	22.8	0.4760	55.6	44.4	61.7	-	19.3	-	1.11	54	-	910
CAM-05B	0.70	1.00	0.30	47.8	L	SAPRIC PEAT	52.5	20.8	0.4352	60.4	39.6	56.1	7.5	20.3	0.03	1.13	54	-	730
CAM-06A	0.20	1.20	1.00	-	D	SAPRIC PEAT	73.4	42.4	-	42.2	57.8	66.0	-	16.7	-	1.32	41	-	690
CAM-06B	3.70	4.00	0.30	47.8	L	SAPRIC PEAT WITH CLAY	37.2	8.6	0.1799	76.8	23.2	52.9	5.3	21.8	<0.01	1.47	128	-	580
CAM-06C	4.00	4.30	0.30	47.8	L	HEMIC/SAPRIC PEAT	45.4	8.6	0.1795	81.1	18.9	43.4	-	30.6	-	1.77	59	-	500
CAM-06D	5.80	6.10	0.30	47.8	L	HEMIC PEAT	49.5	7.3	0.1527	85.3	14.7	22.8	-	42.7	-	2.34	132	-	490
CAM-07A	0.70	1.20	0.50	-	D	SAPRIC PEAT	83.8	38.6	-	54.0	46.0	45.8	-	28.7	-	1.87	98	-	560
CAM-07B	2.30	2.60	0.30	47.8	L	HEMIC/SAPRIC PEAT	44.3	10.3	0.2147	76.8	23.2	26.7	-	40.3	-	2.44	51	-	330
CAM-07C	4.10	4.40	0.30	47.8	L	CLAY WITH HEMIC PEAT	46.6	9.4	0.1957	79.9	20.1	63.1	-	18.3	-	1.45	71	-	240
CAM-07D	6.20	6.50	0.30	47.8	L	CLAY WITH SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
CAM-08A	0.40	0.70	0.30	47.8	L	SAPRIC PEAT	45.0	13.6	0.2846	69.7	30.3	39.7	6.0	25.4	-	2.43	-	-	-
CAM-08B	0.70	1.00	0.30	47.8	L	SAPRIC PEAT	45.8	11.6	0.2427	74.7	25.3	37.6	5.6	29.0	<0.01	2.66	109	-	1,510

Appendix III. Description of soil samples and summary of physical and chemical analyses—Continued

Sample name	Sample depth (ft)		Length of sample interval (ft)	Volume (mL)	Sample method	Soil material	Sample weight as received (g)	Sample weight dry (g)	Bulk density (g per cubic cm)	Percent moisture, as percentage of total mass	Percent dry matter, as percentage of total mass	Percent ash content, as percentage of oven-dried mass	Soil pH (standard pH units)	Total carbon, as percentage of oven-dried mass as carbon	Inorganic carbon, as percentage of oven-dried mass as carbon	Total nitrogen, as percentage of oven-dried mass as nitrogen	Nitrite plus nitrate, as mg nitrogen per kg of oven-dried mass	Total inorganic phosphorus, as mg phosphorus per kg of oven-dried mass	Total phosphorus, as mg phosphorus per kg of oven-dried mass
	Top	Bottom																	
CAM-08C	2.60	2.90	0.30	47.8	L	CLAY	49.9	6.6	0.1381	86.8	13.2	65.8	5.0	13.4	<0.01	1.28	72	-	490
CAM-08D	8.00	8.30	0.30	47.8	L	HEMIC PEAT	43.1	4.5	0.0951	89.5	10.5	31.5	-	38.3	-	2.02	243	-	350
CAM-08E	11.40	11.70	0.30	47.8	L	CLAY WITH HEMIC PEAT	47.6	7.1	0.1486	85.0	15.0	76.3	5.2	8.4	<0.01	0.96	106	-	200
CAM-08F	17.80	18.10	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
CAM-08G	18.10	18.40	0.30	47.8	L	CLAY	65.0	32.2	0.6733	50.5	49.5	95.1	-	0.5	-	0.14	8	-	770
COV-01A	0.90	1.40	0.50	-	D	SAPRIC PEAT	41.8	17.4	-	58.3	41.7	72.3	-	13.5	-	1.02	34	-	410
COV-01B	2.20	2.50	0.30	-	D	SAPRIC PEAT WITH CLAY	77.7	34.6	-	55.4	44.6	87.1	-	6.0	-	0.45	13	-	140
COV-01C	3.10	3.40	0.30	-	D	SAPRIC PEAT	85.5	36.9	-	56.8	43.2	96.3	-	6.0	-	0.36	6	-	90
COV-01D	4.10	4.20	0.10	-	D	PUMICE SAND	30.2	22.0	-	27.4	72.6	94.5	-	1.7	-	0.09	3	-	330
COV-01E	5.00	5.40	0.40	-	D	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
COV-01F	5.40	6.00	0.60	41.2	S	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
COV-02A	0.70	1.20	0.50	-	D	SAPRIC PEAT	75.1	42.9	-	42.8	57.2	57.7	-	23.7	-	1.57	51	-	870
COV-02B	2.80	3.10	0.30	-	D	HEMIC PEAT WITH CLAY	41.5	8.6	-	79.3	20.7	38.4	-	35.0	-	2.17	104	-	390
HNK-01A	2.30	2.60	0.30	47.8	L	HEMIC PEAT	51.0	7.5	0.1569	85.3	14.7	34.0	-	38.4	-	3.04	18	-	480
HNK-01B	2.60	2.90	0.30	47.8	L	HEMIC PEAT	45.9	5.0	0.1046	89.0	11.0	14.8	6.2	38.2	-	3.78	-	-	-
HNK-01C	4.60	4.90	0.30	47.8	L	SAPRIC PEAT	47.6	7.0	0.1472	85.2	14.8	23.9	-	46.4	-	2.40	22	-	340
HNK-01D	6.20	6.50	0.30	47.8	L	MUCK WITH SAPRIC PEAT	48.2	8.5	0.1779	82.4	17.6	71.7	6.5	12.7	<0.01	0.86	17	164.0	-
HNK-01E	7.90	8.20	0.30	47.8	L	HEMIC PEAT	49.3	9.5	0.1981	80.8	19.2	72.5	-	15.2	-	1.34	7	-	190
HNK-01F	9.50	9.80	0.30	47.8	L	CLAY WITH HEMIC PEAT	52.7	11.0	0.2295	79.2	20.8	83.5	-	8.0	-	0.81	13	-	190
HNK-01G	12.90	13.20	0.30	47.8	L	CLAY WITH SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
HNK-01H	17.70	18.00	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
HNK-02A	2.60	2.90	0.30	47.8	L	HEMIC PEAT	46.7	8.2	0.1722	82.4	17.6	51.9	-	28.0	-	2.17	26	-	530
HNK-02B	2.90	3.20	0.30	47.8	L	HEMIC PEAT	44.4	5.9	0.1235	86.7	13.3	-	6.1	33.1	-	2.72	-	-	350
HNK-02C	4.60	4.90	0.30	47.8	L	SAPRIC PEAT	46.3	8.4	0.1767	81.8	18.2	47.3	-	30.4	-	1.81	29	-	330
HNK-02D	7.40	7.70	0.30	47.8	L	SAPRIC PEAT	48.5	8.3	0.1731	82.9	17.1	52.6	-	27.6	-	1.87	46	-	340
HNK-02E	8.00	8.30	0.30	47.8	L	HEMIC PEAT	44.8	5.4	0.1134	87.9	12.1	20.3	-	48.3	-	2.13	27	-	390
HNK-02F	9.20	9.50	0.30	47.8	L	HEMIC PEAT WITH CLAY	49.7	8.9	0.1870	82.0	18.0	76.9	-	12.0	-	1.07	49	-	240
HNK-02G	10.60	10.90	0.30	47.8	L	CLAY WITH HEMIC PEAT	51.6	13.9	0.2908	73.1	26.9	84.8	5.3	5.0	<0.01	0.63	22	-	370
HNK-02H	11.40	11.70	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
HNK-03A	2.30	2.60	0.30	47.8	L	HEMIC/SAPRIC PEAT	50.0	7.7	0.1618	84.5	15.5	41.8	-	32.6	-	2.15	25	-	500
HNK-03B	2.90	3.20	0.30	47.8	L	HEMIC/SAPRIC PEAT	22.0	3.2	0.0665	85.6	14.4	25.7	-	41.9	-	2.82	34	-	490
HNK-03C	6.10	6.40	0.30	47.8	L	HEMIC PEAT	42.8	6.6	0.1387	84.5	15.5	29.2	-	41.9	-	2.26	76	-	350
HNK-03D	7.70	8.00	0.30	47.8	L	SAPRIC PEAT WITH CLAY	52.4	14.2	0.2980	72.8	27.2	64.3	-	21.5	-	1.29	79	-	1,570
MCC-01A	0.80	1.20	0.40	-	D	MINERAL SOIL	85.9	52.7	-	38.7	61.3	89.7	6.4	2.6	<0.01	0.25	13	-	200
MCC-01B	1.30	1.40	0.10	-	D	MINERAL SOIL	56.2	32.2	-	42.7	57.3	93.2	-	1.7	-	0.14	15	-	170
MCC-01C	1.40	1.70	0.30	-	D	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
MCC-01D	2.90	3.20	0.30	-	D	SAND WITH CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
MCC-02A	0.00	0.70	0.70	-	D	SAPRIC PEAT	114.5	71.8	-	37.3	62.7	90.7	-	3.0	-	0.27	12	-	380
MCC-03A	0.00	0.70	0.70	-	D	SAPRIC PEAT	82.0	54.8	-	33.1	66.9	89.1	-	4.6	-	0.37	12	-	400
MCC-03B	1.30	1.70	0.40	-	D	ASH? CLAY WITH SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
NWR-01A	0.50	0.80	0.30	47.8	L	MUCK WITH CLAY	35.4	4.5	0.0948	87.2	12.8	51.5	-	26.8	-	2.45	10	-	760
NWR-01B	2.50	2.80	0.30	47.8	L	HEMIC PEAT	45.4	3.6	0.0753	92.1	7.9	19.3	4.2	38.1	-	2.90	-	-	-
NWR-01C	2.80	3.10	0.30	47.8	L	HEMIC PEAT	42.4	3.0	0.0628	92.9	7.1	-	5.6	34.6	-	2.91	-	-	-
NWR-01D	4.60	4.90	0.30	47.8	L	HEMIC PEAT	47.3	3.7	0.0783	92.1	7.9	13.2	-	50.3	-	3.14	117	-	510
NWR-01E	6.00	6.30	0.30	47.8	L	HEMIC PEAT	47.1	4.8	0.1010	89.7	10.3	25.0	-	41.9	-	2.74	167	-	370
NWR-01F	7.70	8.00	0.30	47.8	L	HEMIC PEAT	48.5	5.2	0.1082	89.3	10.7	27.9	-	41.3	-	2.73	249	-	370
NWR-01G	10.90	11.20	0.30	47.8	L	CLAY	47.1	10.0	0.2092	78.8	21.2	82.6	5.4	6.2	<0.01	0.67	14	-	110
NWR-01H	11.20	11.50	0.30	47.8	L	CLAY	49.3	10.0	0.2092	79.8	20.2	82.8	5.6	4.7	<0.01	0.67	28	50.0	120
NWR-01I	12.90	13.20	0.30	47.8	L	HEMIC PEAT	46.9	5.0	0.1055	89.2	10.8	33.0	-	37.7	-	2.20	289	-	280

Appendix III. Description of soil samples and summary of physical and chemical analyses—Continued

Sample name	Sample depth (ft)		Length of sample interval (ft)	Volume (mL)	Sample method	Soil material	Sample weight as received (g)	Sample weight dry (g)	Bulk density (g per cubic cm)	Percent moisture, as percentage of total mass	Percent dry matter, as percentage of total mass	Percent ash content, as percentage of oven-dried mass	Soil pH (standard pH units)	Total carbon, as percentage of oven-dried mass as carbon	Inorganic carbon, as percentage of oven-dried mass as carbon	Total nitrogen, as percentage of oven-dried mass as nitrogen	Nitrite plus nitrate, as mg nitrogen per kg of oven-dried mass	Total inorganic phosphorus, as mg phosphorus per kg of oven-dried mass	Total phosphorus, as mg phosphorus per kg of oven-dried mass
	Top	Bottom																	
NWR-01J	16.40	16.70	0.30	47.8	L	HEMIC PEAT WITH CLAY	42.0	4.3	0.0904	89.7	10.3	26.6	-	41.5	-	2.25	61	-	280
NWR-02A	1.20	1.50	0.30	47.8	L	HEMIC PEAT	40.5	3.2	0.0672	92.1	7.9	71.0	-	48.2	-	3.23	15	-	460
NWR-02B	2.50	2.80	0.30	47.8	L	HEMIC PEAT	41.7	5.0	0.1052	87.9	12.1	32.5	-	37.9	-	3.21	14	-	380
NWR-02C	6.00	6.30	0.30	47.8	L	HEMIC PEAT	48.0	5.1	0.1067	89.4	10.6	37.8	-	34.9	-	2.27	5	-	400
NWR-02D	7.80	8.10	0.30	47.8	L	HEMIC PEAT	46.0	4.0	0.0839	91.3	8.7	18.1	-	47.5	-	2.93	15	-	480
NWR-02E	11.10	11.40	0.30	47.8	L	HEMIC PEAT	46.4	5.2	0.1092	90.1	9.9	38.6	-	37.0	-	2.23	122	-	310
NWR-02F	16.30	16.60	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
NWR-03A	1.00	1.30	0.30	47.8	L	HEMIC PEAT	43.0	4.9	0.1026	88.6	11.4	20.2	-	43.5	-	3.19	56	-	970
NWR-03B	2.80	3.10	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
NWR-03C	11.40	11.70	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
SHO-01A	2.20	2.50	0.30	47.8	L	HEMIC PEAT	47.5	5.2	0.1091	89.0	11.0	15.0	-	46.7	-	3.34	238	-	520
SHO-01B	4.30	4.60	0.30	47.8	L	HEMIC PEAT	49.1	7.1	0.1488	85.5	14.5	33.1	-	38.0	-	2.33	226	-	350
SHO-01C	7.30	7.60	0.30	47.8	L	SAPRIC PEAT	38.8	6.9	0.1438	82.3	17.7	33.9	-	38.3	-	1.90	162	-	500
SHO-01D	9.10	9.40	0.30	47.8	L	HEMIC PEAT	52.1	6.9	0.1444	86.8	13.2	19.1	-	45.4	-	2.99	22	-	360
SHO-01E	12.60	12.90	0.30	47.8	L	HEMIC PEAT WITH CLAY	52.1	9.8	0.2057	81.1	18.9	78.4	-	10.3	-	0.95	20	-	130
SHO-01F	13.80	14.10	0.30	20.6	S	SAND WITH CLAY?	-	-	-	-	-	-	-	-	-	-	-	-	-
SQW-01A	0.80	1.10	0.30	47.8	L	MUCK	40.1	8.0	0.1674	80.0	20.0	69.8	5.5	11.6	<0.01	1.27	73	-	660
SQW-01B	1.90	2.20	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
SQW-01C	2.40	2.70	0.30	47.8	L	SAPRIC PEAT	42.7	10.3	0.2146	76.1	23.9	55.6	-	24.1	-	1.87	95	-	810
SQW-01D	2.90	3.20	0.30	47.8	L	HEMIC PEAT	45.4	6.1	0.1285	86.5	13.5	15.6	-	48.2	-	2.62	99	-	620
SQW-01E	4.30	4.60	0.30	47.8	L	HEMIC PEAT WITH CLAY	46.6	5.7	0.1194	87.7	12.3	80.9	-	8.8	-	1.11	123	-	310
SQW-01F	9.30	9.60	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
WOC-01A	0.30	0.90	0.60	-	D	SAPRIC PEAT	71.6	42.6	-	40.4	59.6	57.9	-	23.80	-	1.73	71	-	720
WOC-01B	1.70	2.00	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
WOC-01C	2.40	2.70	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
WOC-02A	0.70	1.70	1.00	-	D	SAPRIC PEAT	84.8	33.4	-	60.6	39.4	63.1	5.8	14.0	<0.01	1.48	301	-	770
WOC-02B	4.50	4.80	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
WOC-03A	0.60	0.90	0.30	47.8	L	SAPRIC PEAT	34.0	13.1	0.2744	61.4	38.6	68.0	-	16.90	-	1.48	76	-	510
WOC-03B	1.20	1.50	0.30	47.8	L	CLAY WITH HEMIC PEAT	37.5	11.0	0.2311	70.5	29.5	76.1	-	10.50	-	1.12	74	-	230
WOC-03C	3.60	3.90	0.30	47.8	L	HEMIC/SAPRIC PEAT	47.1	9.4	0.1967	80.0	20.0	46.8	5.2	21.2	<0.01	2.06	26	-	300
WOC-03D	4.70	5.00	0.30	47.8	L	HEMIC PEAT WITH CLAY	50.4	7.0	0.1472	86.0	14.0	53.4	-	23.90	-	1.57	12	-	210
WOC-03E	5.70	6.00	0.30	47.8	L	HEMIC PEAT WITH CLAY	54.2	12.9	0.2701	76.2	23.8	78.3	-	10.90	-	0.89	46	-	280
WOC-03F	6.30	6.60	0.30	47.8	L	CLAY WITH SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
WOC-04A	1.80	2.10	0.30	47.8	L	SAPRIC PEAT	41.0	12.2	0.2553	70.3	29.7	44.1	4.6	26.3	<0.01	2.01	90	-	470
WOC-04B	2.10	2.40	0.30	47.8	L	SAPRIC PEAT	43.6	10.2	0.2134	76.5	23.5	27.9	5.6	21.5	<0.01	2.81	55	-	320
WOC-04C	2.90	3.20	0.30	47.8	L	HEMIC PEAT WITH CLAY	50.3	10.4	0.2176	79.4	20.6	67.4	6.0	11.6	<0.01	1.23	55	-	170
WOC-05A	2.60	2.90	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
WOC-06A	0.40	0.70	0.30	47.8	L	SAPRIC PEAT	50.6	21.4	0.4487	57.6	42.4	67.8	-	19.00	-	1.32	95	-	1,310
WOC-06B	1.10	1.40	0.30	47.8	L	SAPRIC PEAT	35.2	10.0	0.2100	70.5	29.5	35.7	-	34.70	-	2.23	85	-	570
WOC-07A	0.70	1.30	0.60	-	D	SAPRIC PEAT	100.1	70.2	-	29.9	70.1	89.4	-	3.75	-	0.29	3	-	830
WOC-07B	1.50	1.70	0.20	-	D	MINERAL SOIL WITH SAND	80.2	50.5	-	37.1	62.9	91.7	-	5.15	-	0.11	5	-	560
WOC-07C	1.80	2.00	0.20	-	D	SAND	78.4	68.3	-	12.9	87.1	97.8	9.3	<0.01	0.15	<0.01	17	-	130
WOC-08A	0.20	0.60	0.40	-	D	SAPRIC PEAT	93.5	55.2	-	40.9	59.1	73.7	-	17.60	-	0.89	38	-	1,390
WRM-02A	1.20	1.50	0.30	47.8	L	HEMIC PEAT	42.0	5.8	0.1210	86.2	13.8	61.0	-	19.7	-	1.54	11	-	690
WRM-02B	2.90	3.20	0.30	47.8	L	CLAY WITH SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
WRM-02C	4.60	4.90	0.30	47.8	L	CLAY WITH SAPRIC PEAT	47.4	9.1	0.1904	80.7	19.3	74.6	4.7	9.2	<0.01	1.08	17	-	330
WRM-02D	6.30	6.60	0.30	47.8	L	SAPRIC PEAT	45.9	7.5	0.1563	83.7	16.3	60.0	-	21.4	-	1.78	28	-	730
WRM-02E	9.70	10.00	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
WRM-02F	12.00	12.20	0.20	-	D	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-

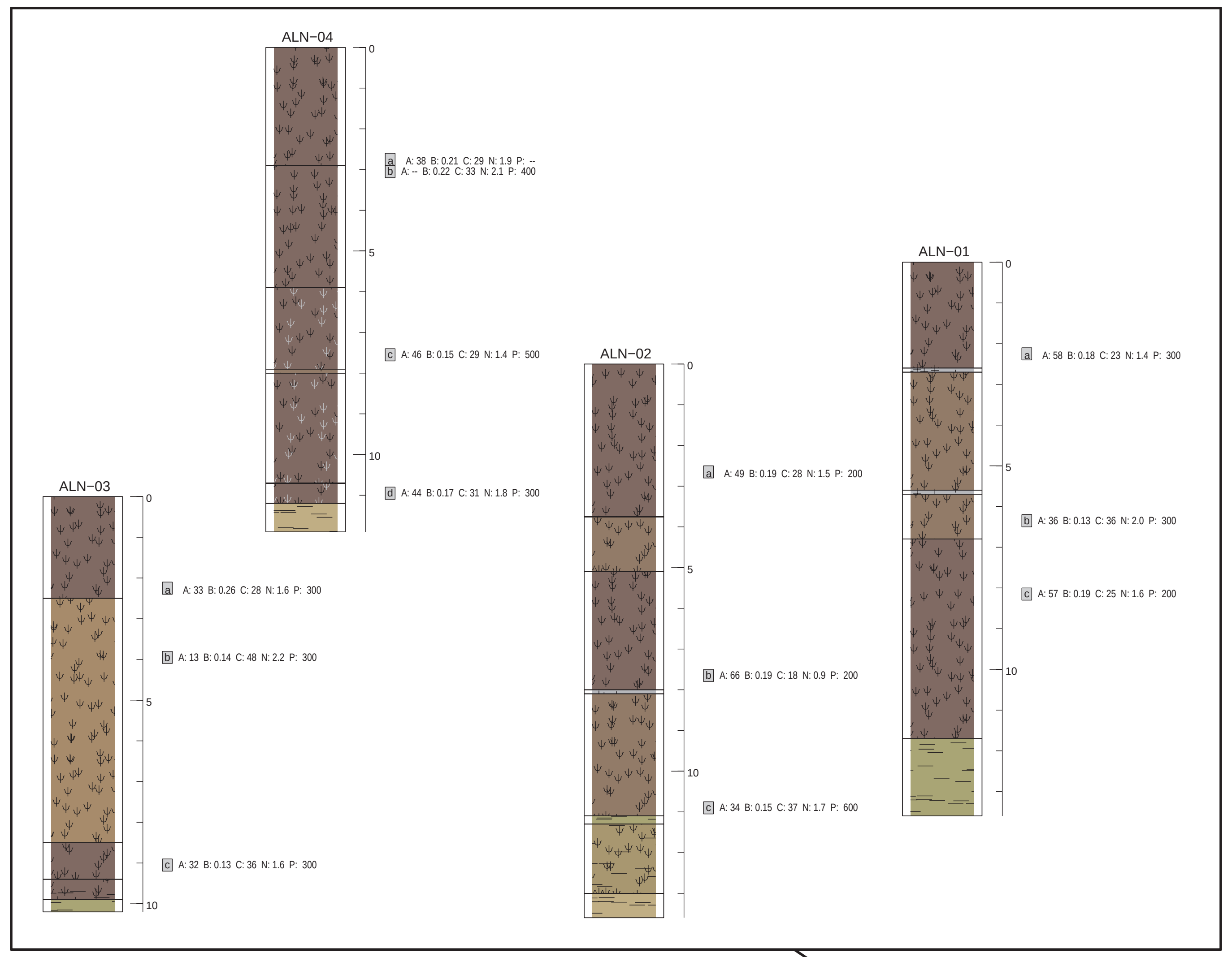
Appendix III. Description of soil samples and summary of physical and chemical analyses—Continued

Sample name	Sample depth (ft) Top	Sample depth (ft) Bottom	Length of sample interval (ft)	Volume (mL)	Sample method	Soil material	Sample weight as received (g)	Sample weight dry (g)	Bulk density (g per cubic cm)	Percent moisture, as percentage of total mass	Percent dry matter, as percentage of total mass	Percent ash content, as percentage of oven-dried mass	Soil pH (standard pH units)	Total carbon, as percentage of oven-dried mass as carbon	Inorganic carbon, as percentage of oven-dried mass as carbon	Total nitrogen, as percentage of oven-dried mass as nitrogen	Nitrite plus nitrate, as mg nitrogen per kg of oven-dried mass	Total inorganic phosphorus, as mg phosphorus per kg of oven-dried mass	Total phosphorus, as mg phosphorus per kg of oven-dried mass
WRN-01A	0.70	1.10	0.40	-	D	SAPRIC PEAT	75.5	40.8	-	46.0	54.0	53.3	-	24.4	-	1.84	71	-	1,070
WRN-01B	0.70	1.10	0.40	-	D	SAPRIC PEAT	99.3	56.6	-	43.1	56.9	52.8	-	24.3	-	1.83	95	-	1,060
WRN-01C	1.10	1.70	0.60	-	D	HEMIC/SAPRIC PEAT	64.5	22.0	-	66.0	34.0	57.3	5.4	17.8	<0.01	1.53	129	-	640
WRN-01D	2.70	3.00	0.30	47.8	L	SAPRIC PEAT	51.6	11.7	0.2442	77.4	22.6	49.5	-	27.4	-	1.85	52	-	740
WRN-01E	3.00	3.30	0.30	47.8	L	SAPRIC PEAT	49.0	11.4	0.2385	76.8	23.2	56.9	-	22.70	-	1.59	46	-	590
WRN-01F	6.00	6.30	0.30	47.8	L	HEMIC/SAPRIC PEAT	52.0	8.6	0.1799	83.5	16.5	42.5	5.7	23.9	<0.01	1.72	299	-	400
WRN-01G	7.10	7.40	0.30	47.8	L	SAPRIC PEAT	52.1	12.7	0.2659	75.6	24.4	49.4	-	26.30	-	1.95	168	-	700
WRN-01H	8.00	8.30	0.30	47.8	L	HEMIC PEAT WITH CLAY	49.1	8.1	0.1699	83.5	16.5	59.5	-	20.80	-	1.65	369	-	370
WRN-02A	1.80	2.30	0.50	-	D	SAPRIC PEAT	93.0	50.9	-	45.2	54.8	89.8	-	3.24	-	0.27	3	-	300
WRN-02B	4.30	4.60	0.30	47.8	L	CLAY	60.7	20.0	0.4185	67.1	32.9	82.7	5.6	5.7	<0.01	0.49	19	-	270
WRN-02C	5.80	6.10	0.30	47.8	L	CLAY WITH PUMICE SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
WRN-03A	0.70	1.30	0.60	-	D	SAPRIC PEAT WITH PUMICE SAND	88.7	69.4	-	21.7	78.3	92.0	-	2.75	-	0.27	13	-	1,210
WRN-03B	2.90	3.40	0.50	-	D	SAPRIC PEAT	64.3	38.0	-	40.9	59.1	88.6	-	3.30	-	0.25	13	-	270
WRN-03C	4.60	5.00	0.40	-	D	SAPRIC PEAT	91.4	47.2	-	48.4	51.6	89.5	-	2.71	-	0.22	6	-	420
WRN-03D	5.90	6.20	0.30	47.8	L	SAPRIC PEAT WITH CLAY	68.8	30.0	0.6268	56.5	43.5	91.8	-	2.47	-	0.24	5	-	340
WRN-03E	6.20	6.50	0.30	47.8	L	SAPRIC PEAT WITH CLAY	71.6	30.4	0.6369	57.5	42.5	89.6	-	2.86	-	0.24	6	-	340
WRR-01A	1.20	1.80	0.60	-	D	PUMICE GRAVEL	-	-	-	-	-	-	-	-	-	-	-	-	-
WRR-01B	3.00	3.20	0.20	31.9	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
WRR-02A	1.20	1.50	0.30	47.8	L	HEMIC PEAT WITH CLAY	49.3	11.3	0.2364	77.1	22.9	72.6	-	13.2	-	1.12	73	-	490
WRR-02B	2.70	3.00	0.30	47.8	L	HEMIC PEAT	47.4	8.5	0.1772	82.1	17.9	63.8	-	19.8	-	1.61	30	-	300
WRR-02C	7.00	7.30	0.30	47.8	L	SAPRIC PEAT WITH CLAY	43.0	9.5	0.1988	77.8	22.2	77.1	5.3	8.7	<0.01	0.78	42	-	180
WRR-03A	0.30	0.60	0.30	47.8	L	HEMIC PEAT	40.0	7.3	0.1526	81.8	18.2	19.0	-	42.8	-	2.68	156	-	700
WRR-03B	2.10	2.40	0.30	47.8	L	HEMIC PEAT	47.6	6.1	0.1276	87.3	12.7	33.9	4.7	26.3	<0.01	2.17	57	-	440
WRR-03C	2.40	2.70	0.30	47.8	L	HEMIC PEAT	47.9	7.9	0.1653	83.5	16.5	41.9	4.6	25.0	<0.01	2.12	13	-	350
WRR-03D	7.40	7.70	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
WRR-03E	12.90	13.20	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-
WRR-03F	14.90	15.20	0.30	47.8	L	CLAY WITH PUMICE SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
WRR-04A	0.80	1.10	0.30	47.8	L	HEMIC PEAT	45.3	5.5	0.1156	87.8	12.2	22.2	-	43.5	-	2.02	112	-	480
WRR-04B	7.60	7.90	0.30	47.8	L	HEMIC/SAPRIC PEAT	49.9	7.4	0.1539	85.3	14.7	50.0	-	27.3	-	1.22	10	-	420
WRR-05A	2.80	3.10	0.30	47.8	L	SAPRIC PEAT	40.1	8.4	0.1752	79.1	20.9	54.1	-	25.3	-	1.96	37	-	690
WRR-05B	3.10	3.40	0.30	47.8	L	SAPRIC PEAT	19.8	5.1	0.1072	74.1	25.9	66.2	-	18.3	-	1.46	29	-	740
WRR-05C	5.00	5.30	0.30	20.6	S	PUMICE SAND	-	-	-	-	-	-	-	-	-	-	-	-	-
WRR-08A	1.00	1.30	0.30	47.8	L	HEMIC PEAT	46.2	7.3	0.1527	84.3	15.7	60.2	5.2	15.0	<0.01	1.85	48	-	480
WRR-08B	1.30	1.60	0.30	47.8	L	HEMIC PEAT	42.9	7.0	0.1465	83.8	16.2	66.8	5.1	12.0	<0.01	1.43	55	-	390
WRR-08C	7.50	7.80	0.30	47.8	L	SAPRIC PEAT	50.3	10.8	0.2260	78.5	21.5	66.0	4.4	14.1	<0.01	1.15	27	-	310
WRR-08D	7.90	8.20	0.30	47.8	L	ASH CLAY	34.0	9.2	0.1934	72.8	27.2	95.3	-	0.9	-	0.16	91	-	70
WRR-09A	0.60	0.90	0.30	47.8	L	SAPRIC PEAT	47.3	13.3	0.2783	71.8	28.2	56.7	5.5	17.6	<0.01	1.69	54	-	750
WRR-09B	0.90	1.20	0.30	47.8	L	SAPRIC PEAT	46.1	11.3	0.2364	75.5	24.5	40.2	4.1	17.3	<0.01	1.59	82	-	620
WRR-09C	2.00	2.30	0.30	47.8	L	HEMIC PEAT	51.5	9.7	0.2033	81.1	18.9	54.3	-	23.1	-	1.62	85	-	400
WRR-09D	7.90	8.20	0.30	47.8	L	HEMIC PEAT	-	-	-	-	-	-	-	-	-	-	-	-	-
WRR-10A	1.10	1.40	0.30	47.8	L	HEMIC PEAT	47.7	10.3	0.2146	78.5	21.5	64.8	-	18.1	-	1.37	54	-	560
WRR-10B	3.80	4.10	0.30	47.8	L	CLAY WITH HEMIC PEAT	55.0	17.7	0.3693	67.9	32.1	83.3	-	8.0	-	0.62	17	-	390
WRR-10C	9.80	10.10	0.30	47.8	L	SAPRIC PEAT	46.2	10.4	0.2176	77.5	22.5	66.6	5.7	14.7	<0.01	1.05	58	257.7	390
WRR-10D	11.00	11.30	0.30	47.8	L	CLAY	-	-	-	-	-	-	-	-	-	-	-	-	-

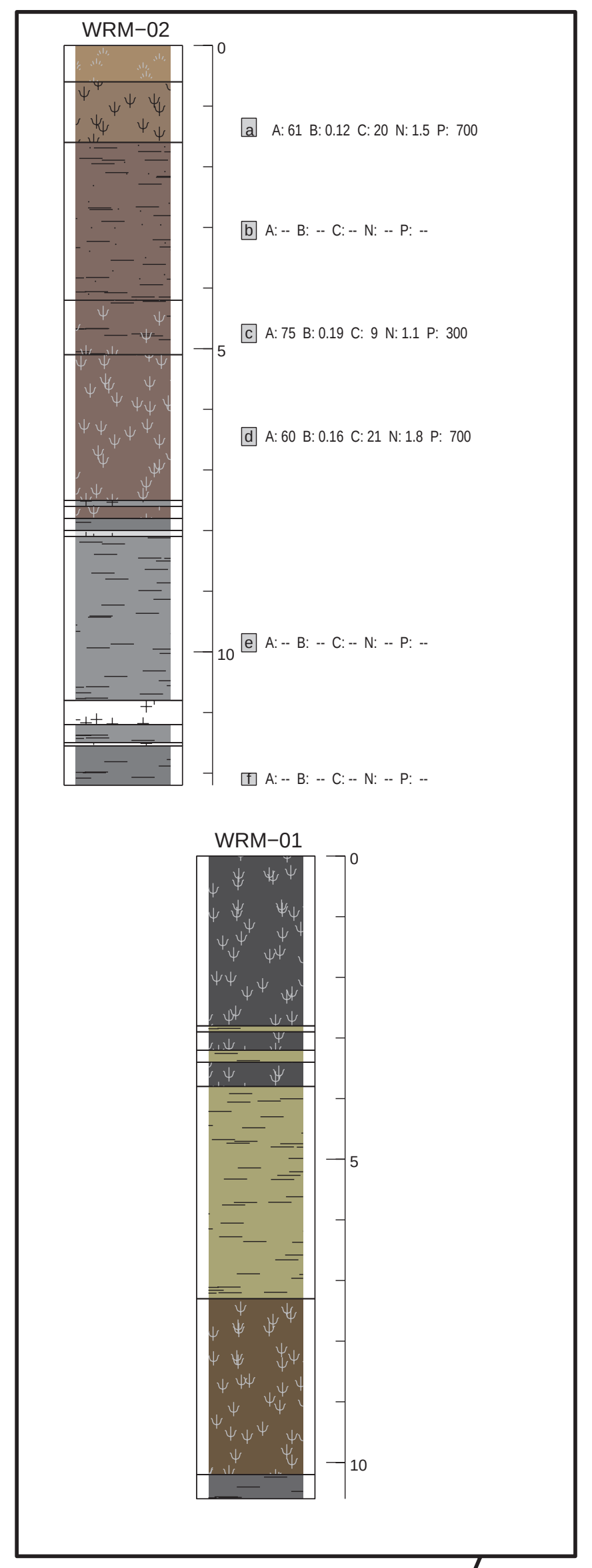
Prepared in cooperation with the
BUREAU OF RECLAMATION

Snyder, D.T. and Morace, J.L., 1997, Nitrogen and phosphorus loading from
drained wetlands adjacent to Upper Klamath and Agency Lakes, Oregon

AGENCY LAKE NORTH



WOOD RIVER MARSH



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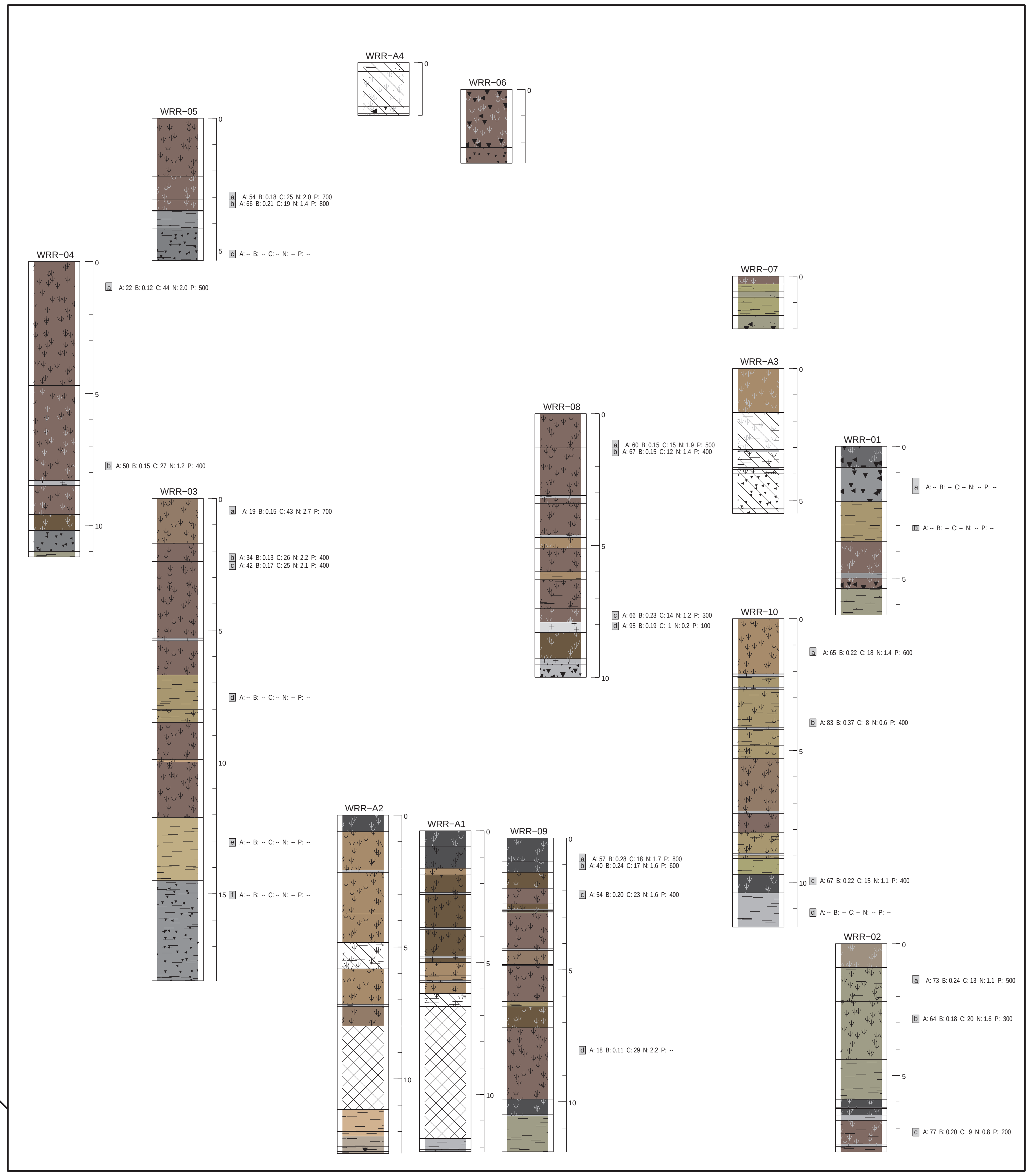

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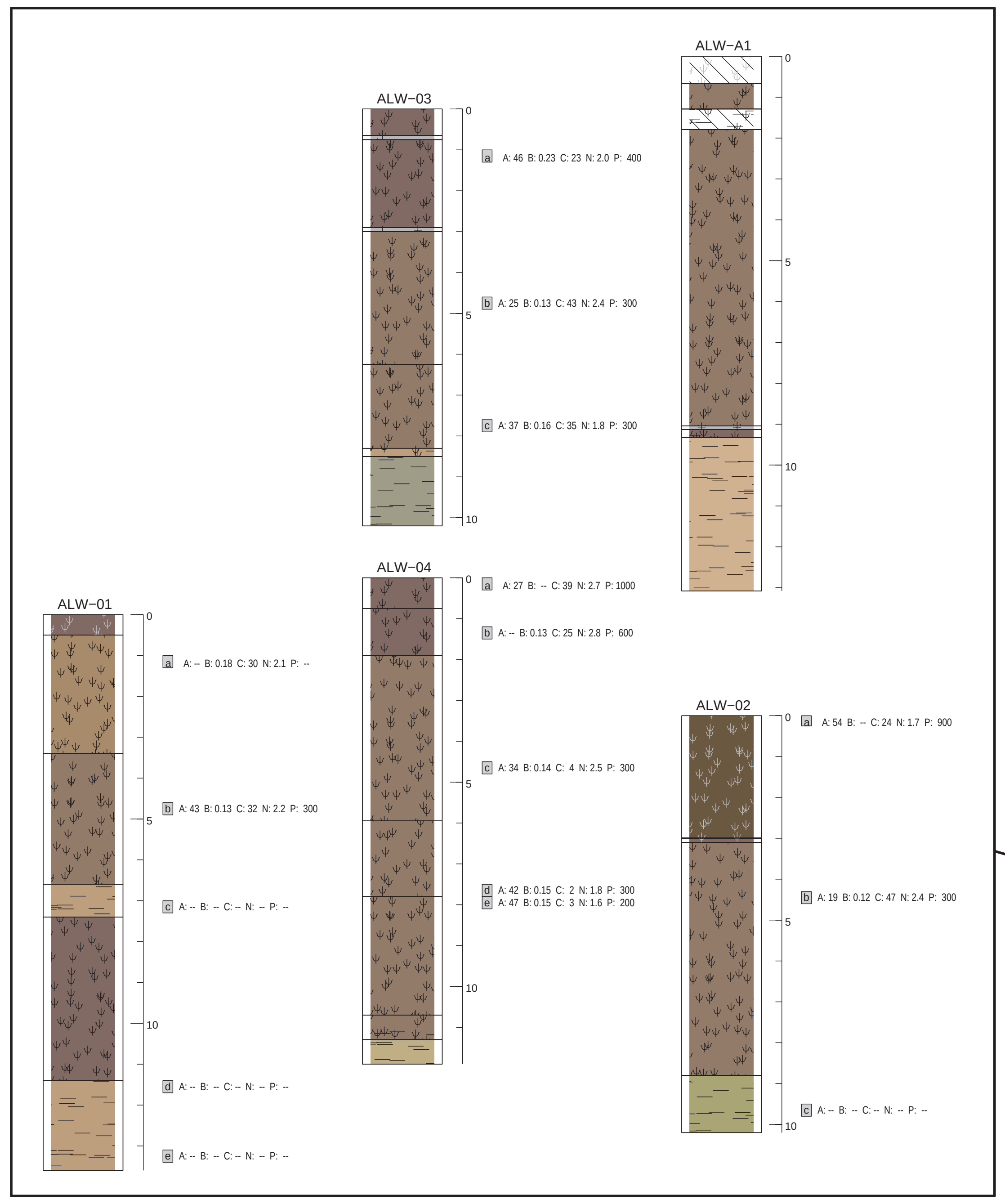
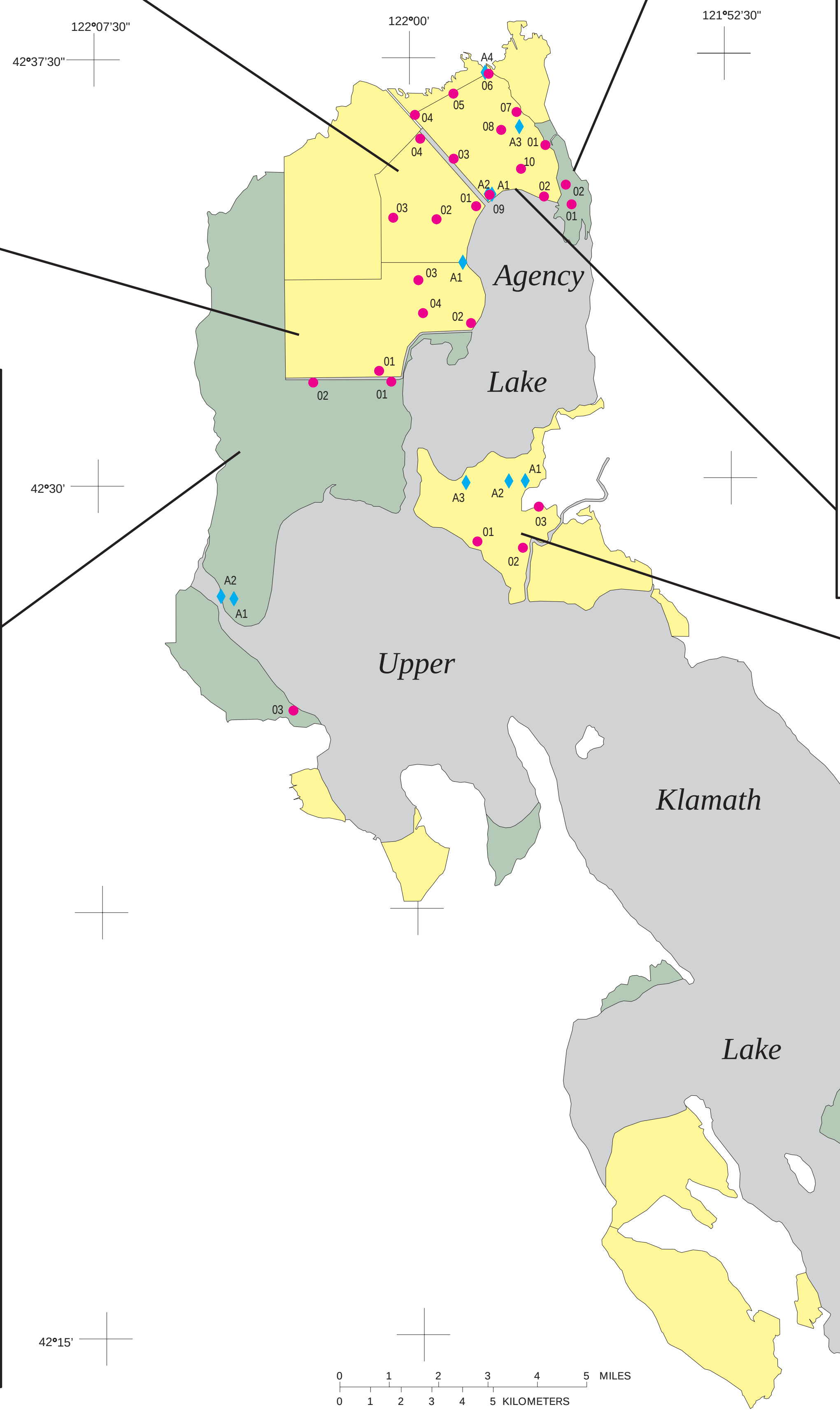




EXPLANATION

🟨 Wetlands drained for agriculture

🟩 Undrained wetlands

● 03 1995 cores and ID number

◆ A1 1993 cores and ID number

Sample location, designation, and analyses

b A: 57 B: 0.28 C: 18 N: −− P: 800

where:
A = Ash Content, in percent dry matter
B = Bulk Density, in g/cubic cm
C = Total Carbon, in percent dry matter
N = Total Nitrogen, in percent dry matter
P = Total Phosphorus, in mg/kg
−− = analysis not available

PRIMARY LITHOLOGIC COMPONENT

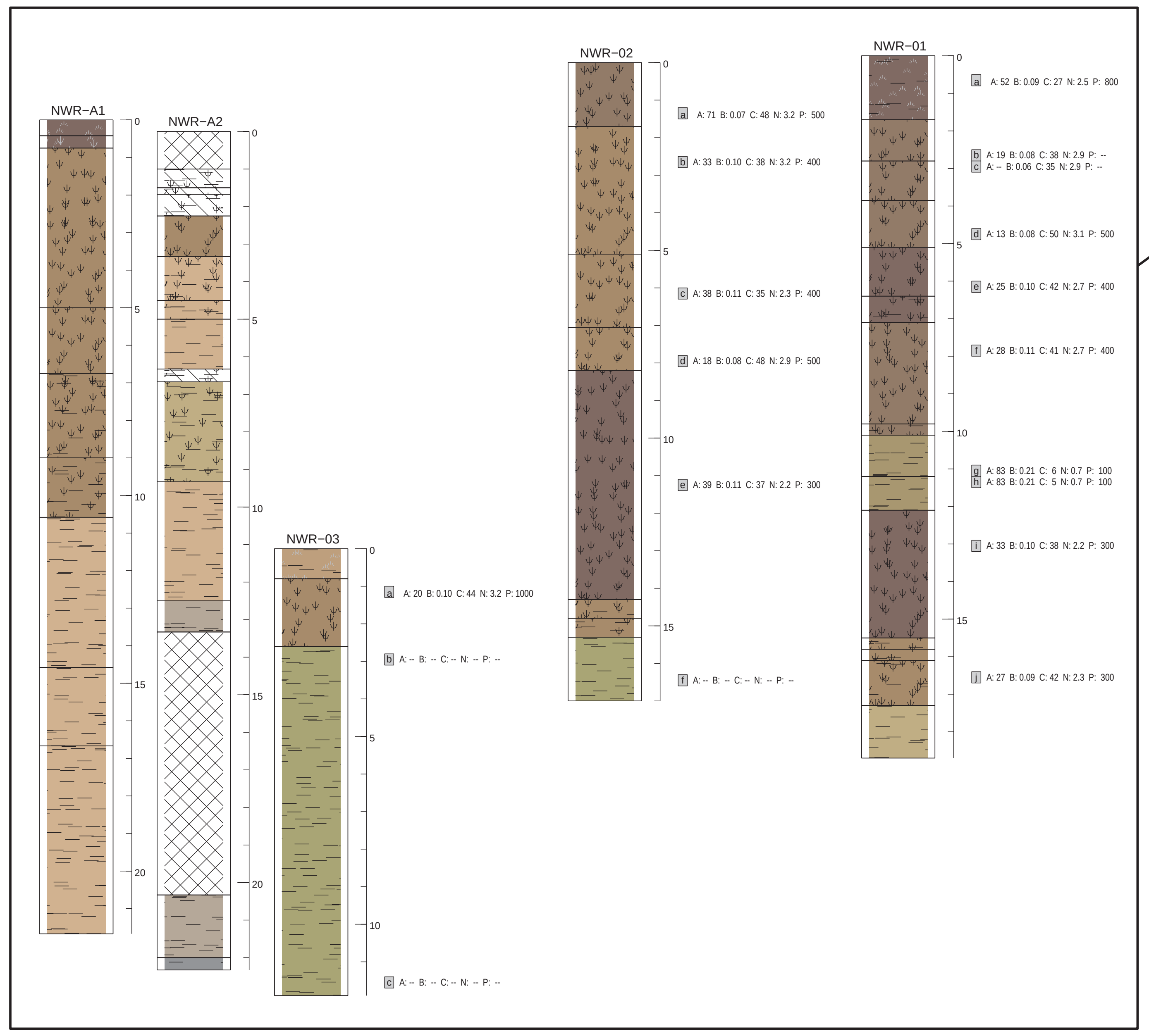
SECONDARY LITHOLOGIC COMPONENT	Hemic peat	Hemic/ Sapric peat	Sapric peat	Muck	Mineral soil	Clay	Sand	Volcanic ash	Pumice sand	Pumice gravel
No secondary component	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Hemic peat						▨				
Sapric peat				▨		▨				
Mineral soil			▨							
Clay	▨	▨	▨	▨			▨	▨	▨	
Sand			▨		▨	▨				
Gravel						▨	▨			
Pumice sand			▨			▨		▨		
Pumice gravel			▨			▨	▨		▨	

NOTE:
Colors closely represent those observed in the field

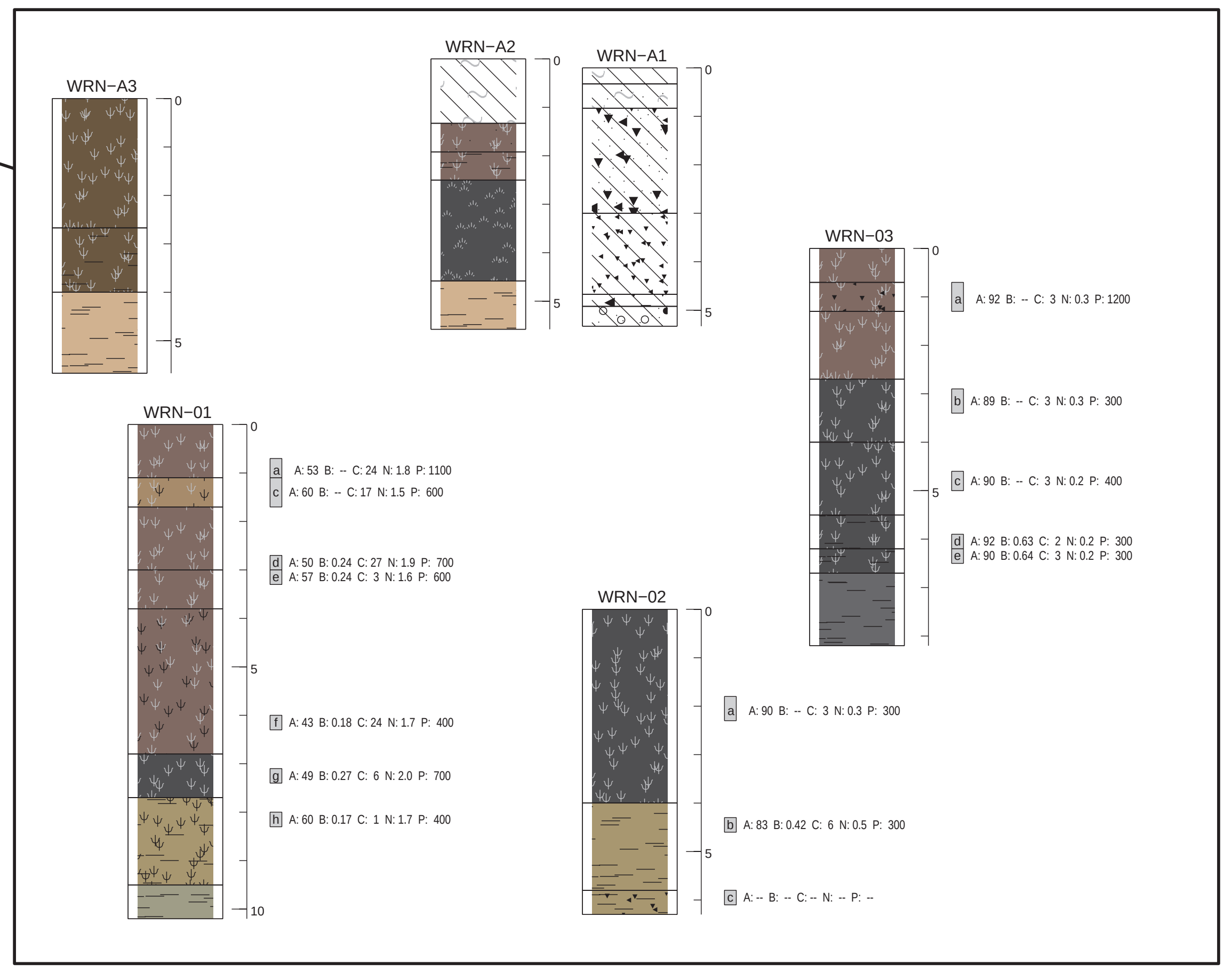
▨ Missing lithology information

▨ Missing color information

NORTHWEST UPPER KLAMATH LAKE—UPPER KLAMATH NATIONAL WILDLIFE REFUGE



WILLIAMSON RIVER NORTH



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LOCATION AND LITHOLOGY OF SOIL CORES EXAMINED FROM DRAINED AND UNDRAINED WETLANDS ADJACENT TO UPPER KLAMATH AND AGENCY LAKES, OREGON—NORTHERN PART

By

Daniel T. Snyder, Kenneth A. Skach, and Donita J. Parker

1997

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
BUREAU OF RECLAMATION

WATER-RESOURCES INVESTIGATIONS REPORT 97-4059
PLATE 2
Location and lithology of soil cores near Upper Klamath and Agengy Lakes, Oregon-Southern part
Snyder, D.T. and Morace, J.L., 1997, Nitrogen and phosphorus loading from
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EXPLANATION

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P = Total Phosphorus, in mg/kg
–– = analysis not available

PRIMARY LITHOLOGIC COMPONENT

SECONDARY LITHOLOGIC COMPONENT	Hemic peat	Hemic/ Sapric peat	Sapric peat	Muck	Mineral soil	Clay	Sand	Volcanic ash	Pumice sand	Pumice gravel
No secondary component	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Hemic peat						▨				
Sapric peat				▨		▨				
Mineral soil			▨							
Clay	▨	▨	▨	▨			▨	▨	▨	
Sand			▨		▨	▨				
Gravel						▨	▨			
Pumice sand			▨			▨		▨		
Pumice gravel			▨			▨	▨		▨	

NOTE:
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Digital Line Graphs published
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LOCATION AND LITHOLOGY OF SOIL CORES EXAMINED FROM DRAINED AND UNDRAINED WETLANDS ADJACENT TO UPPER KLAMATH AND AGENCY LAKES, OREGON—SOUTHERN PART

By

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1997