LIMNOLOGICAL STUDY AND MANAGEMENT PLAN FOR UPPER AND LOWER TWIN LAKES KOOTENAI COUNTY, IDAHO

by
C.M. Falter
D. Hallock
Department of Fish and Wildlife
College of Forestry, Wildlife and Range Sciences

Submitted to
Twin Lakes Improvement Association

WATER for IDAHO
Idaho Water Resources Research Institute
University of Idaho
Moscow, Idaho 83843

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AKNOWLEDGEMENTS

As is usual in a project of this scope, a number of people contributed to the final product and deserve special recognition and thanks: Chet Park collected precipitation and provided answers to a myriad of miscellaneous questions. Orland Pupo read outlet and lake level gages, rain or shine. The Schenks surrendered the use of their garage for sample work-up after collection. Molly Spayde donated several long weekends to help with the field work. The McMillions placed their small boat and motor at our disposal and, perhaps more importantly, provided the occasional home-baked goodie which field researchers need to survive.

Finally, we would like to recognize the Idaho Water Resources Research Institute and the College of Forestry, Wildlife, and Range Sciences, which have funded other limnological projects in the Twin Lakes watershed. These results augment and are partially incorporated into this report.

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ABSTRACT

A water quality study of Twin Lakes was conducted by the University of Idaho from April, 1985 through August, 1986 with three objectives: 1) to estimate nutient loading and partition loading to major sources, 2) to define the present trophic state of Upper and Lower Twin Lakes, and 3) to formulate a lake and watershed management plan with the goal of protecting or improving water quality.

Phosphorus loading was estimated to be 0.33 g P/m^2/yr to the upper lake and 0.34 g P/m^2/yr to the lower lake in Water Year 1986. Tributaries were responsible for the majority of the nutrient load (76% and 61% in the upper and lower lake, respectively). Unnatural inputs directly contributed an estimated 109 kg P (16.6% of the total) to the upper lake from grazing and logging in the watershed and wastewater system leaching. The only significant direct nutrient loading from human activity to the lower lake was 61 kg P (11% of the total) from wastewater leaching. The effects of human activity in the upper lake watershed on Lower Twin Lake are attenuated because of nutrient processing by the upper lake prior to discharge to the lower lake.

Twin Lakes are moderately productive, bicarbonate waters. Chlorophyll *a* ranged from 1.50 to 9.54 ug/l and averaged 3.03 ug/l. Temperatures reached a maximum of 25.2 C; both lakes are usually ice-covered in winter. PH was near neutral.

Both Upper and Lower Twin Lakes are oligo-mesotrophic to mesotrophic based on annual nutrient loads, in-lake phosphorus and chlorophyll *a* concentrations, secchi depths, hypolimnetic oxygen

depletion, algal biovolume and species, benthic fauna, and macrophyte cover. Extensive macrophyte growth and the short hydraulic retention time (0.29 yrs) serve to ameliorate some of the effects of the moderately high phosphorus load to the upper lake.

Management alternatives recommended for immediate implementation include rehabilitation and closing of degraded roads in the watershed, inspection and upgrading of wastewater treatment systems, education of lake users, and implementation of a cattle grazing plan in keeping with water quality concerns.

INTRODUCTION

Public awareness of, and concern for water quality in North Idaho is growing. Since 1985, representatives from eight regional lake associations have met regularly as the North Idaho Lake Association Coalition (NILAC) to discuss lake management problems of mutual concern and to enhance the legislative power of individual associations. To date, four of the lake associations in NILAC (Spirit, Twin, Cocolalla, and Hayden) have independently funded water quality studies. Several other studies have been funded by state or federal agencies.

The Twin Lakes Improvement Association (TLIA) is a non-profit organization founded in 1957 to defend the water rights of lake users. The original purpose of the TLIA, which currently has over 200 members, has evolved to include the general management of the lake's use and protection of the lake as a resource. This study was funded primarily by the TLIA through membership fees, fund raising projects, and a grant from the Idaho Department of Water Resources.

The residents of Twin Lakes have been concerned about a perceived decline in water quality in recent years. Increased macrophyte coverage, decreased water clarity and lake shallowing have all been reported. The University of Idaho contracted in April 1985 to investigate the limnology of Twin Lakes. The purpose of the study was to collect baseline limnological data and to propose a management plan based on that data. Our specific objectives were as follows:

a) to define the present trophic status of Twin Lakes,

b) to estimate nutrient loading to Twin Lakes and to partition loading to major sources, and

c) to formulate a lake management plan suggesting optimal ways to reduce nutrient loading and the in-lake manifestations of loading.

Two other studies of note have been conducted on Twin Lakes. The National Eutrophication Survey (NES) included Upper and Lower Twin Lakes as two of the thirteen Idaho study lakes (NES 1977). The Idaho Department of Health and Welfare studied the nutrient, mineral, and bacteriological loading to Twin Lakes (Trial 1978). The former study was not conducted in depth and is useful primarily as a comparative survey of Idaho lakes. The latter study contains very little information on lake water quality but is of interest from the public health viewpoint. These studies will be referred to later in this report.

We have endeavored to present the following information in a form that would be of interest to the homeowner, yet be technically complete and accurate. Towards this end, we have separated the more detailed methods and results into appendices, specifically: hydrology, nutrient loading, general limnology, and a homeowner's survey. Readers interested in a specific aspect are encouraged to refer to the appropriate appendix. In addition, we have included a glossary of technical terms used in this report.

STUDY AREA

Twin Lakes is located in Kootenai County, North Idaho, 27 km northwest of the city of Coeur d' Alene. The lake was formed when Fish Creek was dammed by a glacial moraine 10,000 years ago. In 1906, a dam was built on the outlet (Rathdrum Creek) to provide irrigation storage for downstream water rights holders. Area soils to the north and east are glacial outwash mantled with volcanic ash and loess (Kootenai-Bonner series); soils to the south and west are primarily volcanic ash and loess over weathered granite (Vasser series) and are relatively nutrient-poor (Weisel 1981).

Twin Lakes receives runoff from an 81 km^2 watershed which extends westward to Mt. Spokane State Park. The watershed is 83% forested and has been periodically logged since the early 1900's. Four percent of the watershed is the lake itself, 5% is pasture/meadow, and 8% is in residential lots, roads, etc. The Inland Empire Paper Company is the largest landowner in the area (66%). There is one cattle ranch in the watershed adjacent to the west end of the upper basin.

The climate at Twin Lakes is considered to be "modified maritime" with predominant weather systems from the west. Annual precipitation, about 84 cm (33 in), occurs mostly in early spring and late fall; average snowpack in the upper watershed approaches 1.0 m (Chet Park, pers. comm.). Both summer and winter temperatures are moderate.

MORPHOLOGY

Introduction

The basin shape (morphometry) of a lake is an important element in determining trophic state. For example, a shallow lake has more bottom area exposed to light (littoral area) and hence a greater propensity to develop macrophyte problems. A deeper lake, on the other hand, is more likely to stratify and experience hypolimnial oxygen depletion and associated phosphorus release. The remainder of this section will address the morphometry of Twin Lakes and its relationship to trophic status.

Methods

A morphometric map of Twin Lakes was developed from 1977 1:12,500 scale aerial photographs (courtesy of Inland Empire Paper Company) and a series of transects where the depth along each transect was measured by a recording fathometer.

Depths were then plotted on an outline map drawn from the aerial photographs and contours were drawn in. Areas and volumes of contour segments were determined by digital planimetry. Field data was collected 28 July, 1985, when the lake level was 8.0 ft. on the dam staff gage (elev. 2310.01 msl). Morphometric maps and parameters are based on that level. The lake level generally drops through the summer from a high of 10+ ft. to a low of 6+ ft.

Results

Twin Lakes consists of two distinct basins separated by a channel *ca*. 680 m long and 3 to 200 m wide. These basins have very different morphometries and therefore will be analyzed separately throughout this report. We have considered Upper Twin Lake to be separated from Lower Twin Lake at the narrowest point (the upper end) of the channel between the two lakes.

The upper basin, although slightly larger than the lower basin in surface area, is relatively shallow (mean depth 3.25 m) and somewhat saucer-shaped (Figure 1). The lower basin, on the other hand, has a mean depth of 6.91 m and a more varied shape with underwater cliffs and shelves (Figure 2). As a result, volume, relative depth, morphoedaphic index, and measures of water residence time are greater for the lower basin (Table 1). In addition, Lower Twin Lake has a longer shoreline and a higher shoreline development index.

Discussion

The morphometry of a lake can dramatically affect its trophic state. A lake's response to the addition of a given quantity of nutrients will depend in large part on the lake's volume. In other words, a given nutrient load to a shallow lake will usually result in greater plant production than the same nutrient load would in a deeper lake with the same surface area (dilution is greater in the deeper lake). Likewise, the consequence of a nutrient addition is affected by the following morphometric parameters:

Mean Depth: In addition to indicating a low lake volume, a shallow mean depth (such as in Upper Twin Lake) results in a greater littoral area. This usually results in greater macrophyte cover which may, in turn, reduce phytoplankton quantities by binding essential nutrients in rooted plant biomass. Shallow lakes are also less

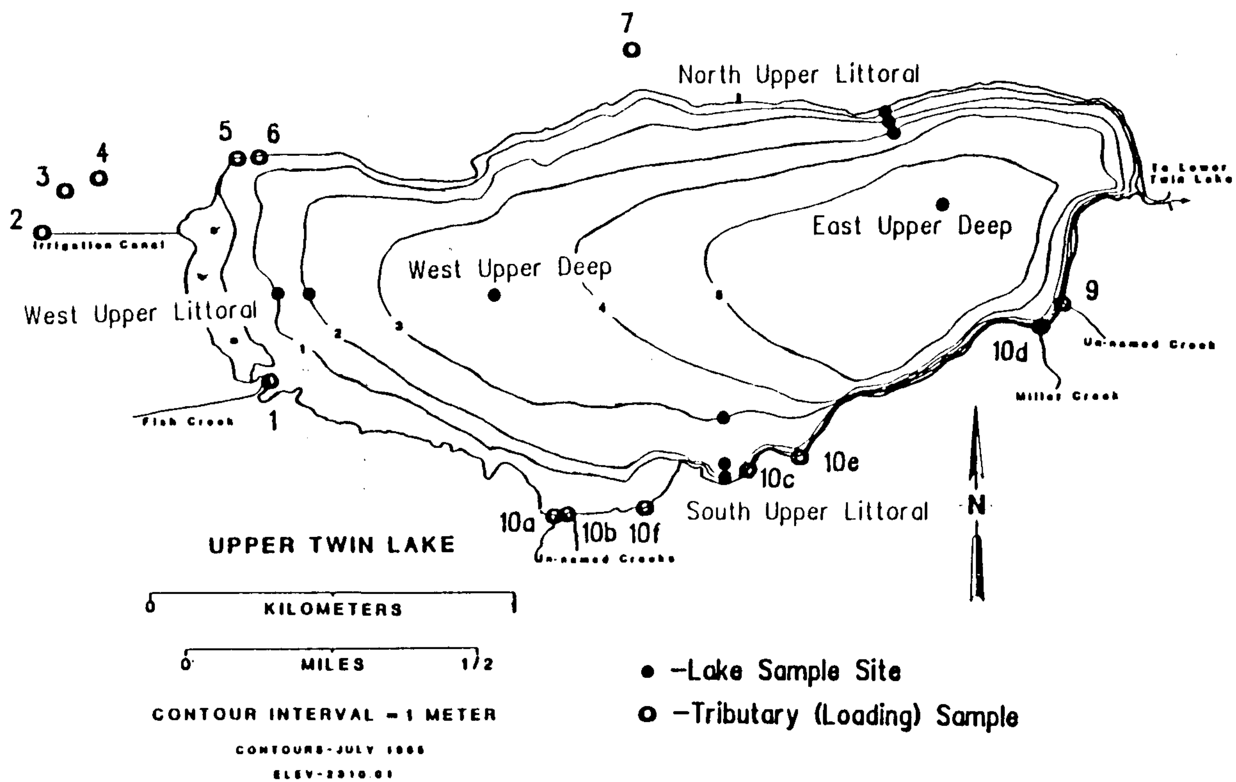


Figure 1. Morphometric map of Upper Twin Lake, Idaho, with tributary and lake sampling stations. (Based on lake elevation of 8.0 ft.).

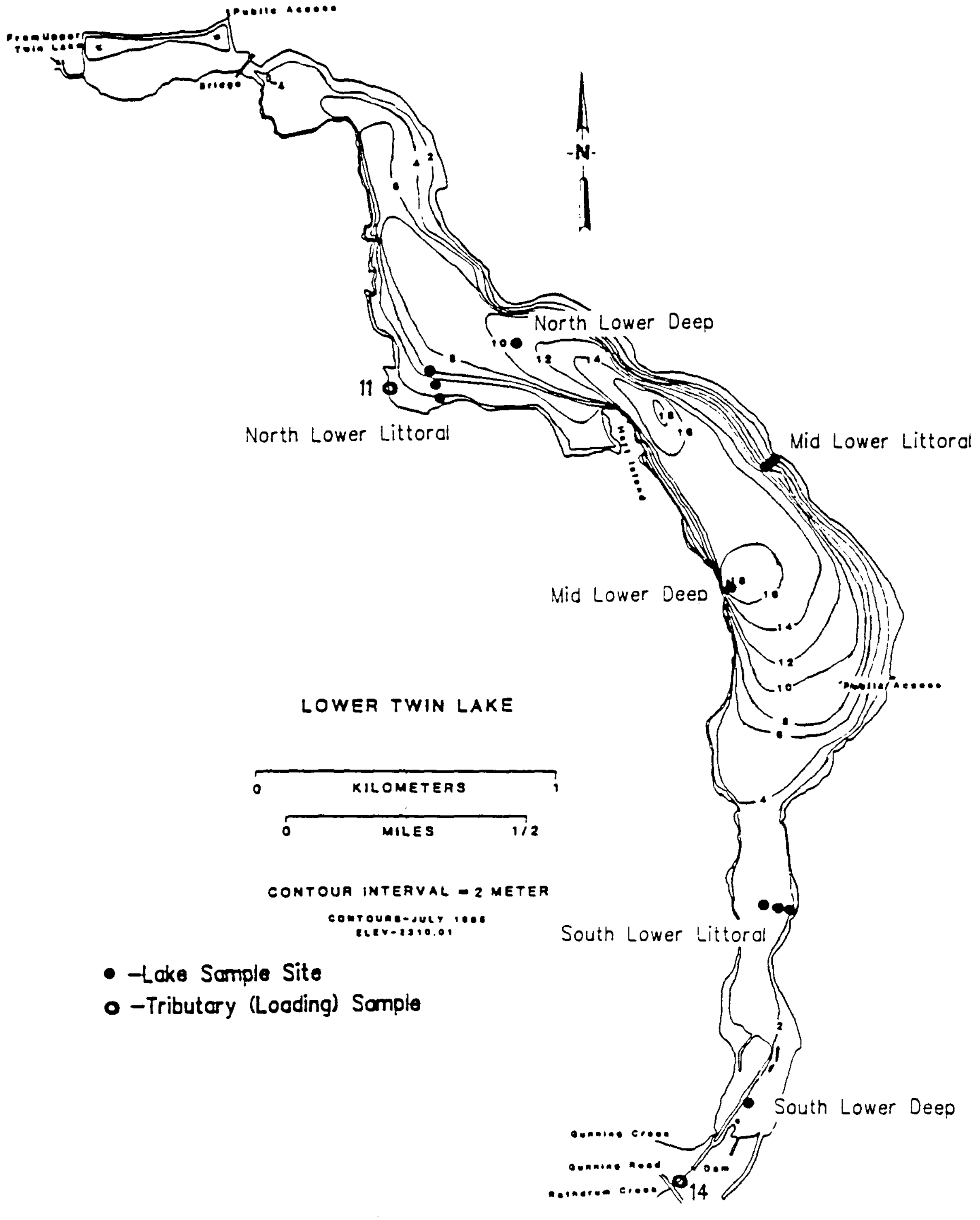


Figure 2. Morphometric map of Lower Twin Lake, Idaho, with tributary and lake sampling stations. (Based on lake elevation of 8.0 ft.)

Table 1. Morphometric data for Twin Lakes, Kootenai County, Idaho. Measurements taken July 1985.

	Symbol	Whole Lake	Upper Basin	Lower Basin	Formulation
Maximum length (km)	l	6.02	2.54	4.28	
Maximum width (km)	b	3.04	1.10	0.68	
Mean width (km)	b	0.59	1.30	0.37	SA/l
Surface area (ha)	SA	353.7	195.6	158.1	
Shoreline length (km)	L	22.13	7.20	14.93	
Maximum depth (m)	Z_m	19.1	5.1	19.1	
Mean depth (m)	Z	4.89	3.25	6.91	V/SA
Volume ($m^3 x 10^6$)	V	17.28	6.36	10.92	
Shoreline development	D_L	3.32	1.45	3.35	L/2 SA
Relative depth	Z_r	0.90	0.32	1.05	$88.6 x Z_m /$ SA
Volume development	D_V	0.77	1.91	1.09	$3(Z/Z_m)$
Morpho-edaphic index	MEI	2.70	4.06	1.91	TDS/Z
Hydraulic residence time	T_w	0.42	0.29	0.57	V/annual inflow
Flushing time (yr)	p	0.80	0.30	0.51	V/annual outflow
Areal water loading	q_s	8.22	14.84	15.11	Annual inflow/SA
Effective Watershed Area (km^2)	WA	81.37	73.69	81.37	
Watershed:Surface Area Ratio		23.0	37.7	51.5	WA:SA

likely to stratify in the summer resulting in less near-bottom oxygen depletion and less anoxic phosphorus release from sediments. Conversely, shallow lakes are more likely to become oxygen deficient under winter ice cover because of their lower volume.

Hydraulic Residence Time: Hydraulic residence time, or simply residence time, the time required for all the lake's volume to flow out its outlet, affects the length of time nutrients will be available before being flushed from the system. The residence times for both Upper and Lower Twin Lakes are comparatively low (0.29 and 0.57 years, respectively). The lakes are flushed relatively quickly.

Shoreline Development Index: The shoreline development index (SDI) is a measure of how circular a lake's shoreline is; a perfect circle has an SDI of 1.0. The higher the SDI, the more convoluted the shoreline. Lower Twin Lake has a high SDI (3.35) while Upper Twin Lake's SDI is quite low (1.45). As a result, the land-water interface is greater and more shoreline development is possible on the lower basin. Nutrient loading from urban runoff or wastewater drainage per unit surface area is therefore likely to be greater on the lower lake.

Watershed Area to Lake Surface Area Ratio: A high ratio projects a high nutrient load from tributaries. Upper Twin Lake's ratio of 38 is relatively high (Spirit Lake has a ratio of 21, for example (Soltero and Hall 1985)). This ratio should not be applied to the lower basin because the upper basin processes nutrients prior to discharge into the lower basin.

The above morphometric parameters and others will be discussed further in other sections of this report.

The morphometric data reported in NES (1977) is incorrect. The reported mean depth is one-half the actual mean depth and reported surface area is 4x too high. As a result, volume and retention time are both over-estimated.

HYDROLOGY

Introduction

The hydrology of a lake is comprised of several major components: surface inflows and outflows, precipitation and evaporation, changes in storage, and groundwater inflows and outflows.

A complete and accurate knowledge of a lake's hydrology is useful for several reasons:

1) The volume of water entering or leaving the lake, in conjunction with measures of nutrient concentration, is necessary to determine the mass of nutrients annually entering a lake.
2) In Twin Lakes and other lakes where the water level is controlled, there are often conflicts among lake users (who may want the lake level high for better dock access or low for greater beach area (see Appendix D, "Homeowner's Survey")) and between lake users and downstream water users with priority water rights to a given volume of water. Knowledge of hydrology is essential to mediate between factions. (A task beyond the scope of our study).
3) Lake drawdown is often used as a control technique for aquatic macrophytes. A hydrologic analysis is needed to adequately evaluate this and other management alternatives.

Methods

The methods used to quantify water volumes entering the lake from various sources are presented in detail along with additional results in Appendix A. Briefly, surface inflow and outflow volumes were determined by extrapolating measured flow measurements to the shape of the annual hydrograph from USGS data from Blanchard Creek. Precipitation was measured at a point near Rathdrum Creek using a plastic wedge-shape rain gage issued by the National Weather Service. Evaporation was estimated based on Molnau and Kpordze (1986). Storage changes were determined from depth-volume curves and lake level records. Finally, groundwater losses were determined by differences between measured inflows and outflows.

Results

Thirteen surface inflows were gaged during the course of the study (Figures 1 and 2). All but six of the inflows (#1, 10a, 10b, 10c, 10d, and 11) were dry by late summer, and all but one of the inflows entered the upper basin. Fish Creek (#1) was by far the most important tributary with an annual flow of 19.3 x 10^6 m^3 in Water Year (WY) 1986. (Water Years begin October 1^{st}.) Total annual inflow volumes (all tributaries) were 21.8 x 10^6 m^3 (Table 2). Flows measured at Blanchard Creek, Kootenai County, Idaho, were 70% of normal in WY 1986, based on six years of data. Peak runoff occurred between 25 February and 5 April when flows in Fish Creek were *ca.* 1.6 m^3/s (summer flows were *ca.* 0.28 m^3/s) (Figure 3).

Twin Lakes discharges at the southern end of the lower basin via Rathdrum Creek. In WY 1986, Rathdrum Creek discharged 8.9 x 10^6 m^3 of water (41% of the tributary inflow volumes) and peak flow occurred between 15 March and 5 April, when flows were *ca.* 1.0 m^3/s (summer flows were *ca.* 0.22 m^3/s) (Figure 4).

Total precipitation was 81.1 cm and 83.6 cm in WY 1985 and 1986, respectively. Mean annual precipitation at Twin Lakes based on four

Table 2. Hydrologic loading to Twin Lakes, Idaho, in WY 1986.

Source	Volume ($m^3 \times 10^6$)	Percent of Total Loading
<u>Inflows</u>		
Tributaries	21.79	88.0
Precipitation	2.96	12.0
TOTAL	24.75	100.0
<u>Outflows</u>		
Rathdrum Creek	8.93	34.9
Evaporation	2.86	11.2
Loss to Groundwater	13.42	52.3
Withdrawals	0.40	1.6
TOTAL	25.61	100.0
<u>Change in Storage</u>	-0.38	

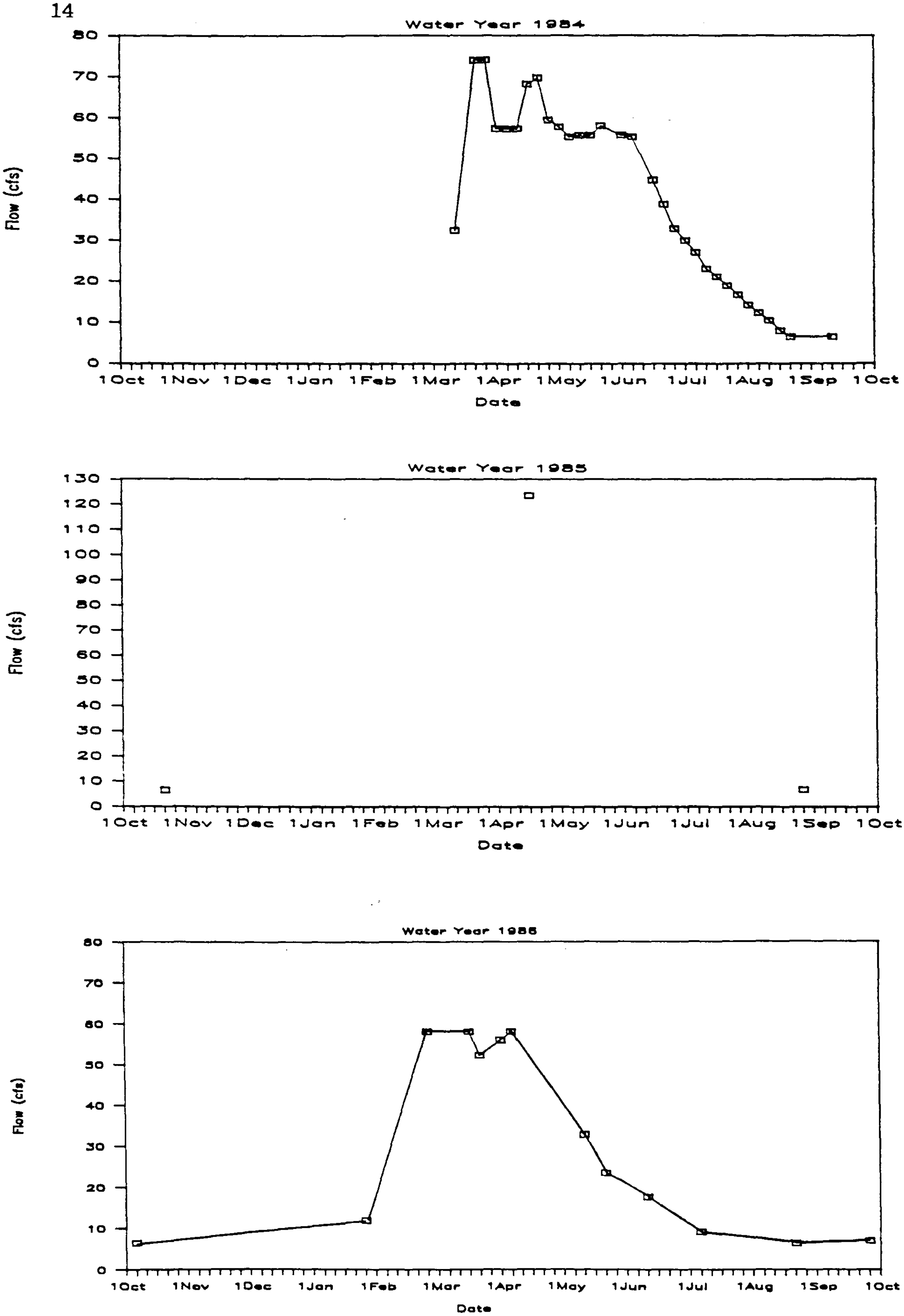


Figure 3. Fish Creek flows in Water Years 1984-1986.

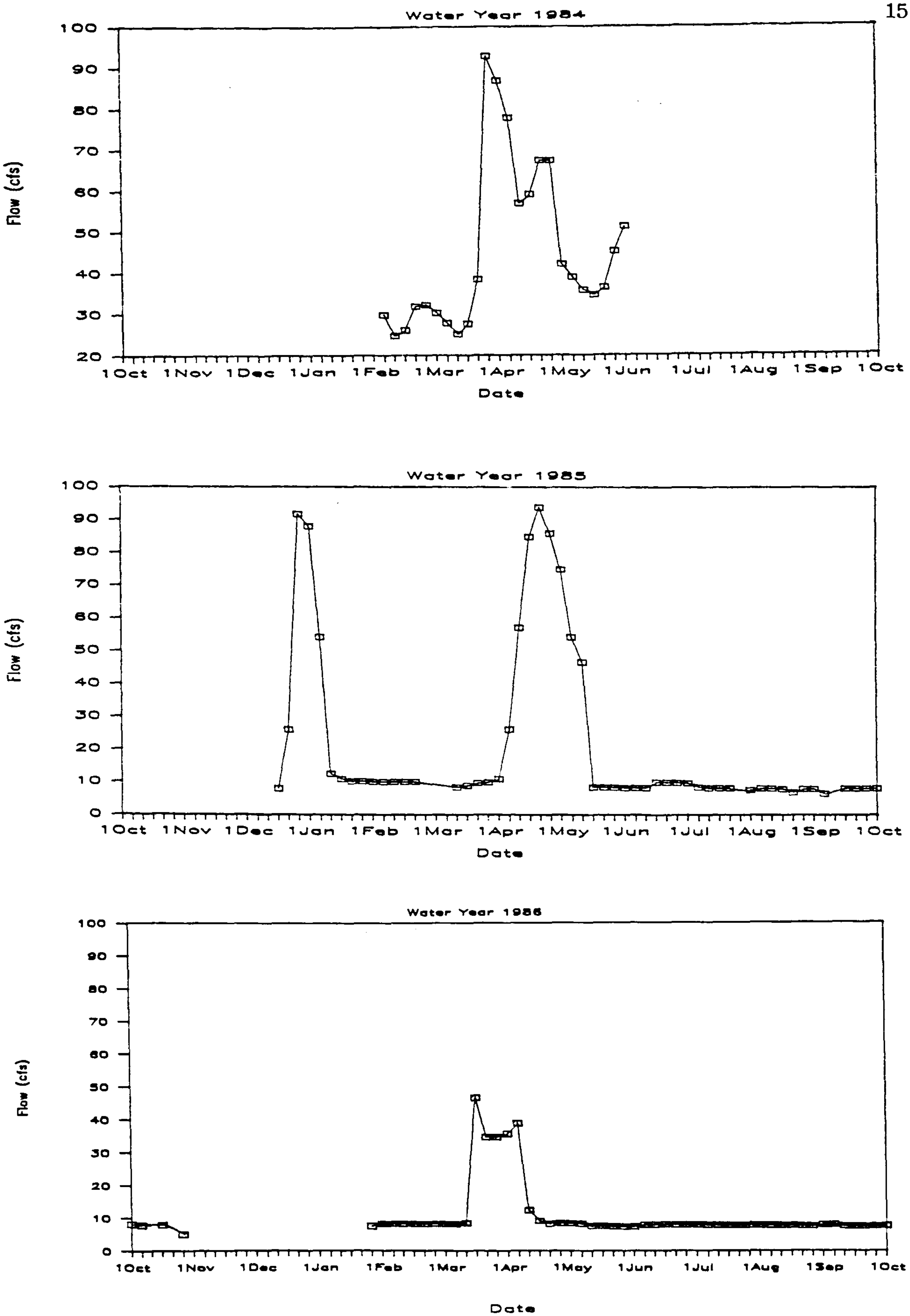


Figure 4. Rathdrum Creek flows in Water Years 1984-1986.

years of data is 91.7 cm. (Park, unpub. data). This volume of rainfall equates to 3.24 x 10^6 m^3 of water annually entering Twin Lakes directly as precipitation (12% of the total). Twin Lakes consistently received about 130% greater rainfall than did the Coeur d' Alene station. This is undoubtedly due to the influence of Twin Lake's nearby mountains and location downwind of metropolitan Spokane area. The correlation coefficient (r) between the two stations was 0.95. Evaporation was estimated to be 81 cm/yr.

In WY 1984-1986, lake levels ranged from a low of 6.00 ft (Sept. 20, 1986) to a high of 10.52 ft (May 25, 1984) on the outlet staff gage. Differences between years, however, were small (Figure 5). Lake levels peaked between mid-March and early June. The lake was low between early September and early February.

Withdrawals by lakewater users were a small fraction of Twin Lakes outflows. The largest water user, Twin Lakes Village golf course, has water rights to roughly 0.2 x 10^6 m^3/yr (Bob Haynes, Dept of Water Resources, pers. comm.). Altogether, withdrawals probably account for less than 0.4 x 10^6 m^3/yr or an average 0.013 m^3/s (1.6% of all outflows)(Table 2).

The average annual loss to groundwater was 0.37 m^3/s (11.59 x 10^6 m^3/yr) and 0.43 m^3/s (13.42 x 10^6 m^3/yr) in WY 1985 and 1986, respectively. These volumes are approximately 50% greater than surface outflows. Because the Spokane Valley-Rathdrum Prairie Aquafer is 91 m below the surface of Twin Lake (Drost and Seitz 1977), ground water inflows were assumed to be negligible, particularly when compared to losses. Several underwater springs have been reported by homeowners, however.

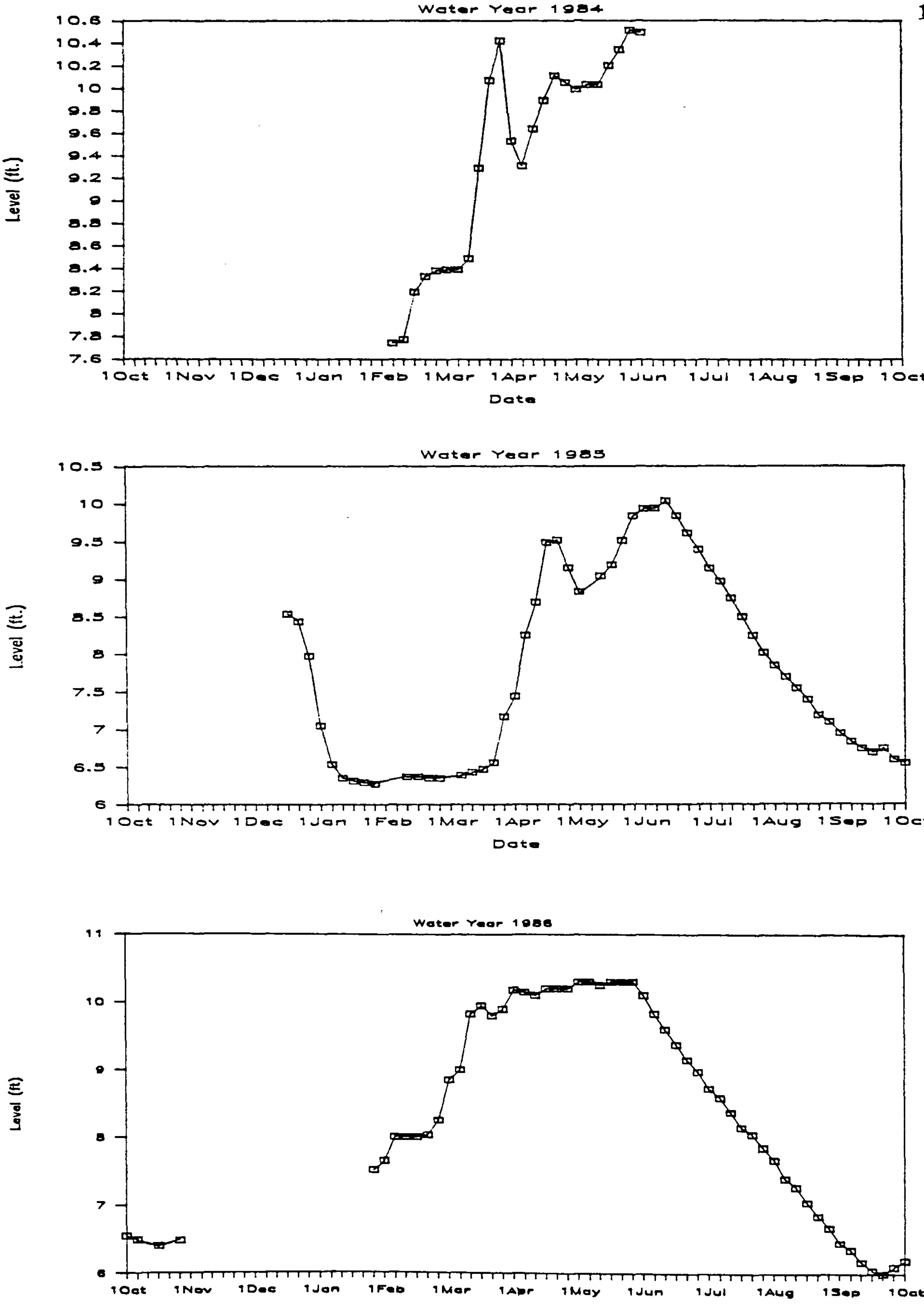


Figure 5. Lake levels in Water Years 1984-1986 as measured at the Rathdrum Creek dam staff gage.

Most of the groundwater loss occurred during the spring when the lake level was high. From late February through June, groundwater loss averaged 0.84 m^3/s; otherwise, the loss averaged 0.25 m^3/s (Table 2).

Discussion

While our study indicates a groundwater loss of *ca.* 0.43 m^3/s (11,003 acre-feet), the USGS reported a loss to the Rathdrum Aquifer from Twin Lakes of 2.4 m^3/s (62,054 acre-feet)(Drost and Seitz 1977). Even though this latter figure is most likely an over-estimate, it is clear that most of the water entering Twin Lakes exits to the aquifer. This is because of the porous nature of the glacial till comprising the north and east boundaries of the lakes.

It is reasonable to expect loss to groundwater to be greatest around the shallow lake margins, in part because the fine sediment debris accumulated in the profundal zone have sealed the deeper interstitial (pore) spaces. This explains the greater loss rate during the period when the lake level is highest. This phenomenon implies that water storage in basins other than Twin Lakes would be a more efficient way to store water for downstream users.

NUTRIENT LOADING

Introduction

There is an ecological principle, the "law of the minimum", which states that the substance that is least abundant in relation to the needs of an organism will control the yield of that organism (Wetzel 1983). This substance can be sulfur, silicon, carbon, or a host of other compounds essential for growth, but in temperate aquatic systems it is almost always either nitrogen or phosphorus (Mason 1981). Considerable effort, therefore, is allotted to measuring the influx of these two elements. Phosphorus is generally more often limiting than nitrogen. N:P ratios in Twin Lakes furthermore suggest phosphorus limitation. Phosphorus input is also easier to control through lake and watershed management (Jones and Lee 1982), in part because significant proportions of available nitrogen may be fixed in the lake from the atmosphere.

Because lakes act as collection points, or sumps, for anything that can be moved downhill by water, phosphorus and nitrogen are continually transported to lakes by natural weathering processes. Nutrient loading to a water body is increased by watershed disturbances such as road building and use, logging, grazing, and agriculture. In addition, residential development adds nutrients through septic drainage and suburban runoff from lawns, roof tops, parking lots, and road surfaces. These sources are called "non-point sources" (NPS) of nutrients and they are the biggest cause of cultural eutrophication (human-enhanced nutrient loading) in Idaho lakes (Milligan et al. 1983).

Nutrients can enter a lake via a number of routes. By far the largest percentage of nutrients enter a lake *via* its tributaries. Other important pathways of entry are precipitation, septic drainage, and the release of bound phosphorus from the lake sediments (internal loading).

An accurate and complete knowledge of nutrient sources is essential for several reasons. Perhaps the foremost reason for collecting loading data is lake management. The knowledge of nutrient quantity and sources is essential to control nutrient input. Present and future nutrient loading rates can be compared to past loading rates as a measure of management effectiveness (or ineffectiveness). Finally, nutrient and sediment loading rates can be a predictor of a lake's trophic future.

Methods

The methods used to determine nutrient loading are presented in detail in Appendix B. Briefly: tributary and precipitation loading were determined by multiplying concentrations by volumes; septic loading was determined by multiplying per capita loading from the literature by lake use figures; internal loading was determined by several methods, the results from a combination of methods are presented here; and finally, loading from powerboat exhausts was determined from a series of *in situ* experiments (Hallock and Falter 1986).

Results

Upper Twin Lake generally received a greater nutrient load than did Lower Twin Lake (Tables 3 and 4). When expressed as mass of nutrients per unit surface area, however, WY 1986 nutrient loads to the two basins were quite similar. Nutrient loads were fairly consistent between the

Table 3. Nutrient sources to Upper Twin Lakes, Water Years 1985 and 1986.

Source	Total Nitrogen (kg)	Percent of Total TN Loading	Total Phosphorus (kg)	Percent of Total TP Loading
1985				
Tributaries	5,965	73.3%	640	78.0%
Precipitation	1,755	21.6%	88	10.7%
Wastewater	158	1.9%	30	3.7%
Grazing[a]	240	2.9%	39	4.8%
Internal	--	--	23	2.8%
Motorboats	25	0.3%	0.1	~0.0%
TOTAL	8,143 kg ($4.16\ g/m^2/yr$)		820 kg ($0.42\ g/m^2/yr$)	
1986				
Tributaries	4,634	72.9%	495	75.6%
Precipitation	1,286	20.2%	66	10.1%
Wastewater	170	2.7%	32	4.9%
Grazing[a]	240	3.8%	39	6.0%
Internal	--	--	23	3.5%
Motorboats	25	0.4%	0.1	~0.0%
TOTAL	6,355 kg ($3.25\ g/m^2/yr$)		655 kg ($0.33\ g/m^2/yr$)	

[a]Does not include loading from grazing entering via tributaries.

Table 4. Nutrient sources to Lower Twin Lakes, Water Years 1985 and 1986.

Source	Total Nitrogen (kg)	Percent of Total TN Loading	Total Phosphorus (kg)	Percent of Total TP Loading
1985				
Tributaries	6,525	78.7%	271	54.3%
Precipitation	1,419	17.11	71	14.2%
Wastewater	305	3.7%	56	11.2%
Internal	--	--	101	20.2%
Motorboats	43	0.5%	0.1	0.0%
TOTAL	8,292 kg (5.24 $g/m^2/yr$)		499 kg (0.32 $g/m^2/yr$)	
1986				
Tributaries	4,361	75.5%	339	61.1%
Precipitation	1,040	18.0%	54	9.7%
Wastewater	329	5.7%	61	11.0%
Internal	--	--	101	18.2%
Motorboats	43	0.8%	0.1	~0.0%
TOTAL	5,773 kg (3.65 $g/m^2/yr$)		555 kg (0.35 $g/m^2/yr$)	

two water years as well, especially considering the differences in runoff volumes. Total phosphorus (TP) loading ranged from 0.32 to 0.42 $g/m^2/yr$ and total nitrogen (TN) loading from 3.25 to 5.24 $g/m^2/yr$.

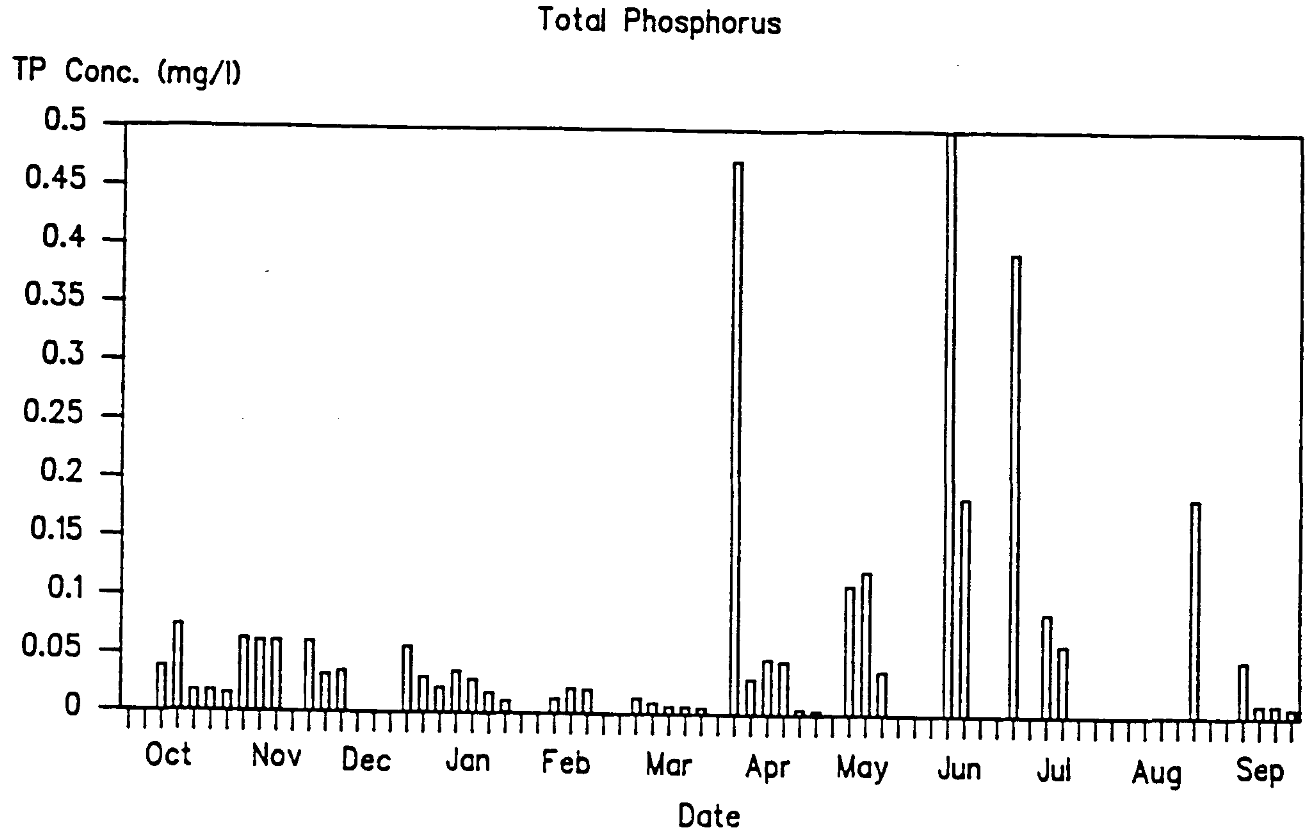
Tributaries accounted for the highest percentage of nutrients entering each basin but they also accounted for the greatest water volume. Actually, nutrient concentrations in tributary streams were quite low. A corollary to this phenomenon is that a watershed disturbance which causes only a slight increase in nutrient concentrations (perhaps an increase even considered insignificant) <u>can</u> result in significant increases in nutrient loading to a lake.

Sediment deltas were noted at the mouths of several streams, notably #1 (Fish Creek), 10a and 10b. The upper lake has been reported to be very turbid after some major storm events. An exploration of Upper Twin Lake's watershed revealed that much of the sediment entering the lake originates from abandoned or poorly maintained logging roads and skid trails rather than from logging sites themselves. This phenomenon is well documented (eg: Packer 1967). In some places, currently eroding gullies nearly two meters deep were found running across old abandoned roads.

There are three major disturbances in the watershed that contribute to accelerated nutrient loading: logging, roads, and grazing. A rough estimate of the nutrient contribution from logging is 22 kg/yr TP and 203 kg/yr TN, or 4.4% of the total annual loading of each nutrient to Twin Lakes from tributaries. Almost all of these nutrients enter the upper lake because tributary flow volumes entering the lower lake are so small. These figures do not include the effects of roads outside the logged areas. Although the scientific basis for estimating the impact of logging and roads on a nutrient budget in North Idaho is incomplete at present, we feel these are reasonable figures. A discussion of our methods and its shortcomings can be found in Appendix B.

About 120 cattle were counted at the west end of the upper lake in each of the two study years. Cattle were present from July or August through October and were often observed belly-deep in the shallow marshes at the west end of Upper Twin Lake. The estimated phosphorus contribution from livestock adjacent to the upper lake was 55.4 kg, or 8.5% of total loading to Upper Twin Lake in WY 1986. The nitrogen load from cattle was 343 kg or 5.4% of TN loading to Upper Twin Lake.

Precipitation contributed about 10% of the annual TP load and 20% of the annual TN load to each basin in WY 1986. Nutrient concentrations of precipitation were highest during the summer. Total phosphorus concentrations ranged from <0.002 to 0.504 and total nitrogen from 0.21 to 4.04 mg/l in WY 1986 (Figure 6). Volume-weighted summer mean phosphorus concentration was 0.147 mg/l. This was higher than any other season, despite total nutrient loading from precipitation being highest during the spring because of the greater rainfall volume (Table 5). Electrical conductivity of rainfall samples ranged from 1 to 72 umhos with a mean of 37 umhos; pH ranged from 4.7 to 7.6 with an average of pH units of 6.52 and a volume-weighted average of 6.36. Phosphorus concentration was correlated with days since the last rainfall event ($r=0.47$, $P<0.005$), and amount of rainfall ($r=-0.34$, $P<0.025$), but not with conductivity. Total nitrogen concentration was correlated with days since the last rainfall event ($r=0.50$, $P<0.005$), amount of rainfall ($r=-0.49$, $P<0.005$), and conductivity ($r=0.35$, $P<0.025$). In other words, precipitation nutrient concentrations are likely to be higher when the



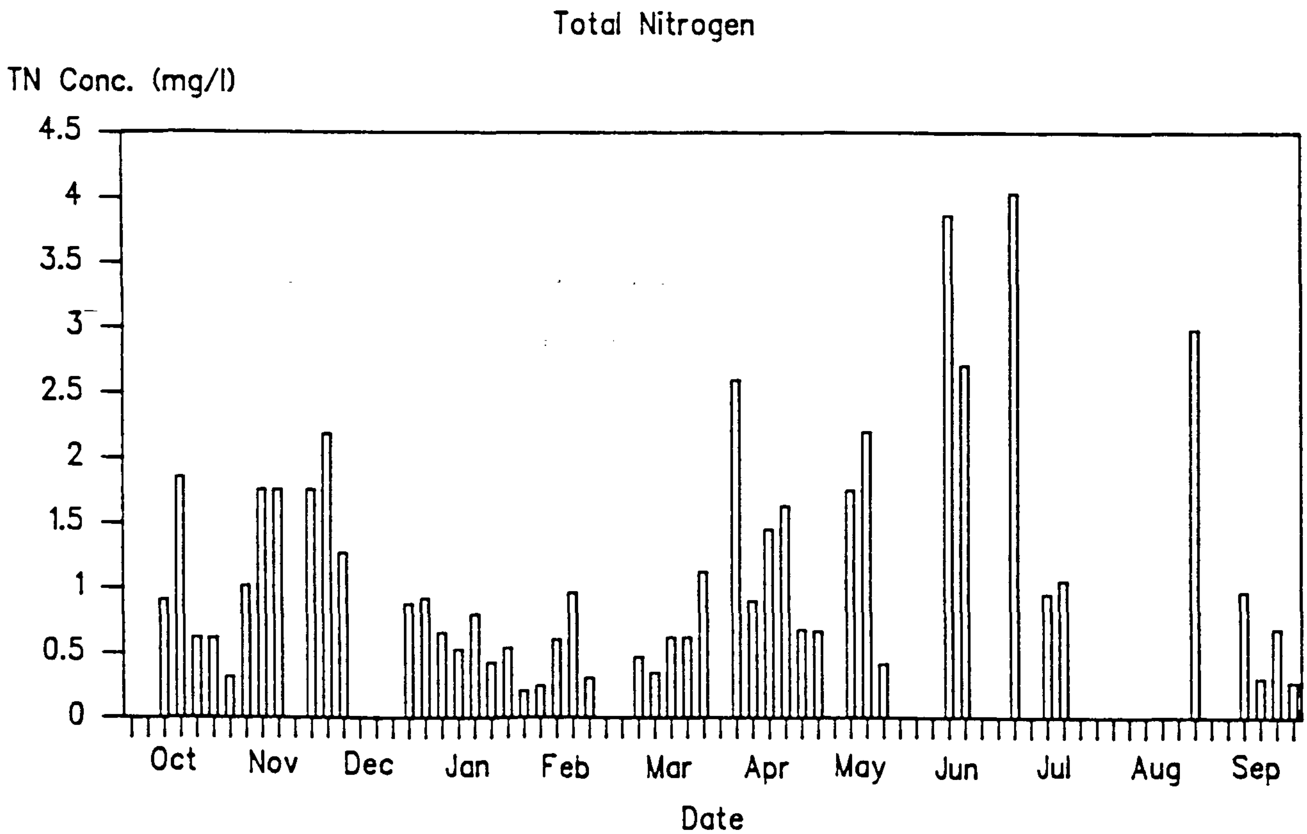


Figure 6. Phosphorus and nitrogen concentrations in rainfall in Water Year 1986 (means of five-day periods).

Table 5. Nutrient loading from precipitation, by season[a].

Season	Total Phosphorus (kg)	Mean TP Conc. (mg/l)	Total Nitrogen (kg)	Mean TN Conc. (mg/l)	Volume ($m^3 \times 10^5$)
Fall	21.45	0.044	565.42	1.15	4.90
Winter	16.11	0.018	483.59	0.54	9.03
Spring	44.44	0.087	664.99	1.31	5.08
Summer	34.91	0.147	472.10	1.98	2.38
TOTAL/ MEAN	116.91	0.055	2186.10	1.02	21.39

[a] This table is not based on water year, so nutrient and hydraulic loading is different than that used in other calculations.

amount of rainfall is low, conductivity is high, and when it has not rained recently.

In WY 1986, residential wastewater contributed an estimated 4.9% of the total phosphorus load to the upper basin and 11.0% to the lower basin. We estimated capita-years within 300 feet of the lake to be 143 for the upper basin and 277 for the lower basin. We assumed that a relatively high percentage of nutrients in septic effluent reaches the lake (15% of phosphorus and 25% of nitrogen) because of the age and poor condition of the average septic tank, the proximity of wastewater systems to the lakes, and because of the high proportion of cesspools and drywells (Panhandle Health District 1 1977, Cantor and Knox 1985). In addition, area soils in many places are inadequate for septic drainage (ie. too gravelly or sandy, shallow soil depth, and steep slope).

Approximately 3.5% of Upper Twin Lake's phosphorus load and 18.2% of Lower Twin Lake's originated as internal loading from lake sediments in WY 1986.

Powerboat exhausts accounted for less than 1% of both nitrogen and phosphorus annual loading to Twin Lakes. We include powerboats as a nutrient source because a specific investigation of powerboat effects was ancillary to this study (Hallock and Falter 1986).

Discussion

Phosphorus loading per unit surface area to both Upper and Lower Twin Lakes was similar to the loading received by Liberty Lake, Washington prior to restoration (0.37 g $P/m^2/yr$)(Michael Kennedy Consulting Engineers 1985), and greater than that received by Spirit

Lake (est. 0.22 g P/m^2/yr) (Soltero and Hall 1985). Twin Lake's nutrient load was similar to Spirit Lake's if both basins are considered together. The importance of this magnitude of loading to Twin Lake's trophic structure and management is a function of hydraulic residence time. This will be discussed in later sections of this report.

Logging

The effect of logging on aquatic systems in Idaho is highly controversial. In fact, recently proposed legislation that may affect the manner in which logging operations are conducted and will almost certainly affect water quality regulations and enforcement is being hotly debated (Idahonian 29 Sept., 1986; Id. Dept. of Health and Welfare and Id. Dept. of Lands 1986). A water quality study in North Idaho would be remiss without addressing the estimated impacts of logging and most have done so (Soltero and Hall 1985, Soltero et al. 1986, this study). Arguably the best data available for predicting the specific effects of logging on nutrient budgets in this area is from studies conducted in Northwest coastal forests (Fredriksen 1971, Brown et al. 1973, Cole and Gessel 1965) where slopes were steeper, rainfall was higher, and 100% of the drainage was clearcut. Furthermore, adverse impacts were calculated for the first three years only, and did not include long-term effects, particularly from road use and continuing deterioration. We are studying the effects of logging on stream water quality in the Twin Lakes watershed but results are several years away.

Although difficult to quantify accurately at present, it is clear that logging does have an impact on Twin Lakes. We estimated annual nutrient export attributable to contemporary logging to be 22 kg of phosphorus and 203 kg of nitrogen.

The high sediment loads carried by several streams draining logged areas are indicative of a watershed disturbance. Off-road vehicles exacerbate the problem. Sediment not only accelerates lake shallowing, but also carries sediment-bound phosphorus. Observations of watershed erosion and sediment deltas lend credence to the contention by long-time residents that Upper Twin Lake is shallowing relatively rapidly.

Grazing

The small number of cattle seen during the study period would not normally be important in a lake's overall nutrient budget. However, all cattle were confined to an area adjacent to the west end of Upper Twin Lake and along Fish Creek. Part of this area is innundated each spring when the lake levels are high, and so a high percentage of nutrient loading from cattle (in a soluble form and therefore exceptionally available to aquatic plants) can be expected to enter the water column. As the cattle wade in the lake and lower streams, they also resuspend sediments and associated nutrients. We estimated the direct annual contribution of nutrients from livestock to be 55 kg phosphorus and 343 kg of nitrogen.

Precipitation

Nutrient loading from precipitation, 0.034 g P/m^2/yr and 0.66 g N/m^2/yr, was higher than what might be expected in the inland northwest (Uttormark et al. 1974). One reason for this is that Twin Lakes is immediately downwind from metropolitan Spokane with its associated industry, woodburning stoves, and vehicular traffic. The Spokane airport and Fairchild Air Force Base also contribute to pollution from atmospheric fallout. A second reason for high precipitation loading may be grassfield burning on the Rathdrum Prairie during August. At these times the Twin Lakes area becomes literally enveloped in smoke and nutrient concentrations in rainfall are higher than the summer average.

Wastewater

The estimated contribution of nutrients by wastewater systems was not high, but, with the exception of grazing, wastewater systems were the only significant source attributable solely to the activities of man. A large majority of all other loading sources is a result of natural processes. From a management point of view, one should not compare septic loading to tributary loading *per se* but rather to that fraction of tributary nutrient loading attributable to man's activities.

Calculating the quantity of nutrients entering a lake's septic systems is straightforward but determining phosphorus transport from septic drainfields to surface or groundwater is a complicated process. The proportion of phosphorus entering a lake from a drainfield is a function of a many factors, among them distance and slope to the drainfield, age of the drainfield and quantity of clays and oxides in the soil (which affect phosphorus binding sites available), waste and hydraulic loading rate, particle size, soil porosity, drainfield design, and type and condition of the system (Jones and Lee 1977, Cantor and Knox 1985). Generally, phosphorus from septic systems is not considered to be a water pollution problem (Scalf 1977), but at Twin Lakes, many of the factors listed above facilitate transport of phosphorus from wastewater systems to the lake (see Appendix B).

Internal

Internal phosphorus loading refers to the release of phosphorus from sediments into the water column. Not all lakes experience internal loading; many lake sediments serve as net phosphorus sinks rather than as phosphorus sources (Premazzi and Provini 1985). Holdren and Armstrong (1980) concluded that aerobic sediments can contribute significant phosphorus in some lakes. Internal loading, however, is most common and most pronounced during anoxic periods when the redox potential at the sediment water interface is low (McKean 1986). Most internal loading in Lower Twin Lake occurred during the period of anoxia in mid-summer. In the upper basin, which never became anoxic, internal loading would occur by active transport of nutrients from the sediments by rooted aquatic macrophytes, macrophyte decomposition (Moore et al 1984), disturbance of sediments by burrowing benthic organisms (bioturbation), and mixing from powerboats.

Internal loading can be particularly important for several reasons:

1) Phosphorus released during anoxic conditions becomes concentrated in the deep hypolimnion during the summer and fall stratification period. High concentrations of dissolved phosphorus then become suddenly available for plant growth upon fall overturn, a time when external loading is low (Riley and Prepas 1984).
2) Internally released phosphorus contains a higher percentage of soluble reactive phosphorus (up to 61%), a readily usable form, than does phosphorus from other sources (Nurnberg et al. 1986).

3) Finally, internal phosphorus loading can reduce the effectiveness of restoration projects by continuing to release algal nutrients even after external loading sources have been curtailed. This is one reason lakes need to be carefully managed before they become eutrophic.

As a result of 1) and 2), above, algae blooms often occur after fall overturn.

Earlier studies of Twin Lakes estimated total nutrient loading to be higher than our estimates. The National Eutrophication Survey (NES 1977) estimated external phosphorus loading to be 1,910 kg to both lakes and Trial (1978), in a very low flow year, estimated 939 kg. This compares to the 924 kg in 1985 and 747 kg in 1986 to both lakes determined by our study. Because neither Trial nor NES sampled tributaries other than Fish Creek, they calculated loading based on total watershed area including large areas to the north and east that produce little runoff. As a result, while their Fish Creek loadings are similar to ours, their calculated loading from other tributaries is over-estimated.

Our measured tributary loading in WY 1986 was lower than might be expected in a normal water year. Because flows were 70% of the six-year normal (based on nearby Blanchard Creek) tributary loading would normally have contributed a higher proportion of total nutrients. Flow is not considered in calculations of nutrient loading from cattle, logging, and septic systems, so those sources would contribute a smaller proportion of the total nutrient loading in normal (higher) flow years.

As a check of our phosphorus loading estimates, we back-calculated loading based on in-lake phosphorus concentrations, mean depth and flushing time (Larsen and Mercier 1976). (Note that the flushing time term accounts for deviations from normal flow years.) Calculated in this manner, phosphorus loading was 0.20 and 0.33 $g/m^2/yr$ in the upper and lower lake, respectively. These are very close to the 0.33 $g/m^2/yr$ in the upper lake and 0.35 $g/m^2/yr$ in the lower lake determined empirically. The difference between calculated and measured loading in Upper Twin Lake may be caused by unmeasured uptake of phosphorus by aquatic macrophytes resulting in a decrease in water phosphorus concentrations.

GENERAL LIMNOLOGY

Introduction

Basic limnology -- the physical, chemical, and biological characteristics of a lake -- is the core of any lake study. This information is used to determine a lake's trophic state. It is this basic lake data that provides the baseline against which future analyses will be compared. Finally, an understanding of a lake's general limnology can be used, in conjunction with the information discussed in previous sections, to predict the lake's trophic future.

Methods

Physical/Chemical Limnology

Both Upper and Lower Twin Lake were sampled ten times between 3 May 1985 and 18 August 1986. Seven of the sample trips took place in 1985, most intensely when the lower lake was stratified. The lakes were sampled once through the ice on January 28, 1986. In addition, we sampled twice in the summer of 1986 to ensure that conditions encountered in the first year were not anomalous.

Eleven sampling stations were established, five in the upper lake and six in the lower lake (Figs. 1 and 2). Six of the stations, three in each basin, were littoral transects consisting of a shallow (1 m deep), mid (2 m deep), and deep (4-5 m deep) sample point. Two open water (deep) stations were sampled in the upper lake and three in the lower lake. Each station was designated by a three letter code: the first letter indicates direction (for example, N for north, M for mid), the second indicates the basin (U for upper, L for lower), and the third differentiates between littoral (L) and deep (D) stations. Stations were chosen to be representative of the lake. For example, each basin was assigned a transect adjacent to a developed (NUL and MLL) and a less developed (SUL and NLL) section of shoreline. Deep stations were placed at the deepest point in each basin or sub-basin.

Water samples were collected from each site with a Kemmerer bottle from depths of 1 and 4 m and from 1 m above the bottom. Samples were placed in acid-washed polyethylene bottles. At the end of each sample day, one set of samples was analyzed for pH (Sargent-Welch meter with glass electrode), turbidity (Hach 2100A meter), alkalinity and carbon dioxide (titration), and hardness (Hach kit). Another set of samples was frozen for later analysis of total phosphorus (stannous chloride method with persulfate digestion), nitrate-nitrogen (spectrophotometric screening method), kjeldahl nitrogen (micro-kjeldahl), and chloride (argentometric method). Wet chemistries were conducted according to APHA (1985). Spectrophotometric analyses were conducted with a Beckman DU-8 spectrophotometer.

Temperature, oxygen, and conductivity were measured at 1 to 2 meter intervals to the bottom with YSI model 57 oxygen/temperature meter, and a YSI conductivity meter or with a Martek Mark V Water Quality Analyzer. Oxygen depletion in the hypolimnion was calculated according to Wetzel (1983). Secchi disk transparency was measured at each deep station and compensation point depth calculated from secchi depth.

Sediment samples were collected from three points in each basin on 25 October 1985, and dried for later analysis for total nitrogen and total phosphorus.

Biological Limnology

Measures of phytoplankton and zooplankton were collected in conjunction with physical/chemical water samples. At the end of each sample day, one set of samples was filtered through 1.2 um glass-fiber filters which were then frozen for later analysis of phaeophytin and trichromatic and monochromatic chlorophyll *a* (APHA 1985), and percent organic matter (based on loss on ignition at 550 C). A second set of samples was preserved in Lugol's solution for later counting, measuring, and identification of algae using an inverted microscope (Lund 1958; Prescott 1962, Smith 1950, Vinyard 1974, Palmer 1962). Zooplankton samples were collected from depths of 1 and 4 m and from 1m above the bottom with a modified Schindler box and preserved in alcohol for later identification (Pennak 1978, Ward and Whipple 1959).

Substrate samples were collected at each sample point with a Ponar dredge. An aloquat was taken for analysis of wet, dry, and organic weights. The remainder was sieved through a #30 mesh wash bucket and the benthic organisms and detrital matter preserved in FAA for later sorting and identification (Merritt and Cummins 1984, Simpson and Bode 1980, and Mason 1968). Shannon-Weaver diversity and equitability was calculated according to Weber (1973).

Water samples for bacteria determination were collected from twelve different sites, six in each basin, on 8 September, 1985. Samples were filtered and cultured within 24 hrs for total coliform, fecal coliform, and fecal streptococci bacteria according to Ehlke (1977).

Macrophytes were collected and identified, distribution was mapped, standing crops were determined, and production estimated. Quantitative macrophyte samples were collected in triplicate in late August with a Peterson dredge (eleven sites) and by SCUBA diving and harvesting all plants within a 0.25 m area (eight sites). These samples were sorted to species, identified (Hitchcock and Cronquist 1981), and dried and weighed. Plant distribution was determined from a) the quantitative samples discussed above, b) fourteen qualitative samples collected with a thrown, weighted rake, c) aerial photographs, and d) interpretation of depth sounder records made during morphometric mapping. Production in Upper Twin Lake was calculated from the difference in standing crop (dry weight) determined from 10 samples collected from site EUD on 8 May, 1986 and again on 18 August. The determination of nutrient content in Twin Lake's macrophytes was based on standing crop and a literature review (Boyd and Goodyear 1971, Gerloff and Krombholz 1966, and Mitchell 1974).

Information presented in this report on the Twin Lakes fishery is based on unpublished, informal data from Idaho Fish and Game stocking records and fish sampling records.

Results

Physical/Chemical Limnology

Means and ranges of physical and chemical parameters were very similar between basins and between sites within basins (Tables 6 and 7). There were a few exceptions, however: The upper basin was cooler,

Table 6. Ranges and Means of selected water quality parameters for Upper Twin Lakes, Idaho. Based on seven sample periods from May through October, 1985.

Parameter	EUD	WUD	NUL	WUL	SUL
Temperature	15.4	15.2	16.2	15.7	17.0
(C)	7.3-24.9	7.3-23.8	7.3-24.4	6.4-23.0	6.9-24.6
Oxygen	9.38	9.18	9.29	9.24	9.19
(mg/l)	8.10-11.05	7.00-10.70	8.00-11.00	7.80-10.70	8.00-11.10
Pct. O2 Sat.	102	99	102	100	103
(%)	90-12	81-107	93-120	94-107	94-125
Conductivity	23	24	23	22	23
(umhos)	19-28	19-37	19-28	19-26	19-27
pH	7.04	6.99	6.87	6.93	6.99
(units)	6.71-7.71	6.74-7.35	6.20-7.39	5.95-7.39	6.50-7.40
Turbidity	1.4	1.1	1.4	1.3	1.1
(NTU)	0.4-2.9	0.7-1.7	0.8-2.4	0.8-2.6	0.6-2.2
Total Nitrogen	0.29	0.23	0.24	0.26	0.28
(mg/l)	0.20-0.36	0.18-0.30	0.18-0.32	0.24-0.30	0.20-0.38
Total Phosphorus	0.021	0.019	0.011	0.011	0.010
(mg/l)	<.002-0.083	<.002-0.056	<.002-0.036	<.002-0.025	<.002-0.043
Chlorophyll *a*	2.89	2.79	3.03	3.09	3.46
(ug/l)	1.69-3.76	1.70-4.21	1.77-4.62	1.91-4.58	1.50-8.92
Pct. Org. Matter	58	50	53	58	58
(%)	43-92	37-71	30-90	35-99	38-95
Methyl-Orange Alk.	13.8	14.3	13.5	14.5	14.2
(mg/l)	11.5-16	12-18	10-19	12-18	12-18

Table 7. Ranges and Means of selected water quality parameters for Lower Twin Lakes (epilimnion), Idaho. Based on seven sample periods from May through October, 1985.

Parameter	NLD	MLD	SLD	NLL	MLL	SLL
Temperature (C)	16.4 8.7-24.1	15.6 7.9-23.3	16.0 8.6-22.9	16.7 8.7-25.2	16.2 8.7-23.2	16.8 8.8-23.0
Oxygen (mg/l)	8.57 7.40-9.70	8.90 7.80-9.60	9.21 7.65-10.60	8.65 7.25-9.70	8.69 7.50-9.70	8.94 7.30-10.30
Pct. O2 Sat. (%)	97 91-111	97 88-108	101 98-106	97 91-113	93 89-106	100 93-120
Conductivity (umhos)	23 21-28	23 20-29	23 18-27	23 20-28	23 20-28	22 19-27
pH (units)	6.78 6.30-7.18	6.82 6.34-7.28	6.96 6.72-7.21	6.77 6.30-7.12	6.85 6.20-7.27	6.89 6.20-7.28
Turbidity (NTU)	1.2 0.8-1.8	1.2 0.7-2.0	1.7 0.9-2.4	1.3 0.8-2.7	1.5 0.2-2.9	1.5 0.7-3.4
Total Nitrogen (mg/l)	0.24 0.22-0.32	0.29 0.22-0.35	0.27 0.22-0.33	0.23 0.16-0.27	0.27 0.20-0.50	0.24 0.20-0.26
Total Phosphorus (mg/l)	0.025 <.003-0.182	0.012 <.002-0.016	0.026 0.005-0.080	0.011 <.002-0.029	0.017 <.002-0.115	0.007 <.002-0.025
Chlorophyll *a* (ug/l)	4.11 1.57-9.54	2.76 1.51-5.64	2.79 2.38-3.95	2.82 1.89-6.10	3.06 1.53-6.25	2.52 1.76-4.11
Org. Matter (%)	55 45-69	60 44-90	49 33-56	58 40-66	58 39-89	71 48-87
Methyl-Orange Alk. (mg/l)	13.8 12-17	13.8 11.5-16	13.5 12-16	14.1 12-17	14.1 12-19	13.5 12-20

overall, than the lower basin and had higher oxygen concentrations due, in part, to the higher saturation concentrations at cooler temperatures. More interesting was the fact that percent oxygen saturation in the upper basin was typically higher than in the lower basin, often exceeding 100%. This is probably indicative of the higher photosynthetic activity from the rooted aquatic macrophytes. The averaged of pH units at the different sample sites were also slightly but consistently higher in Upper Twin Lake, again suggesting high photosynthetic activity in Upper Twin Lake.

Upper Twin Lake began to stratify in early May 1985, and again in late July, but stratification soon disappeared in the shallow water column (Figure 7). Oxygen profiles at EUD indicate some oxygen depletion near the bottom. More pronounced, however, were the high oxygen levels just above the bottom -- often exceeding saturation -- during the height of the summer. Oxygen depletion was evident on 28 January when the mean oxygen concentration was only 5.3 mg/l, 33% of saturation (Table 8). At that time, ice depth was 48 cm and there was 10 cm of snow on top of the ice.

Lower Twin Lake was strongly stratified by late June and remained stratified into October when overturn occurred (Figure 8). Hypolimnetic oxygen depletion appears pronounced in Figure 8. Because the hypolimnion volume was small, however, actual oxygen consumption was a relatively low 0.017 $mg/cm^2/day$. Nevertheless, hypolimnetic oxygen concentrations precluded fish through most of the summer in the waters below about 10 m. In addition, high temperatures (>21 C) probably

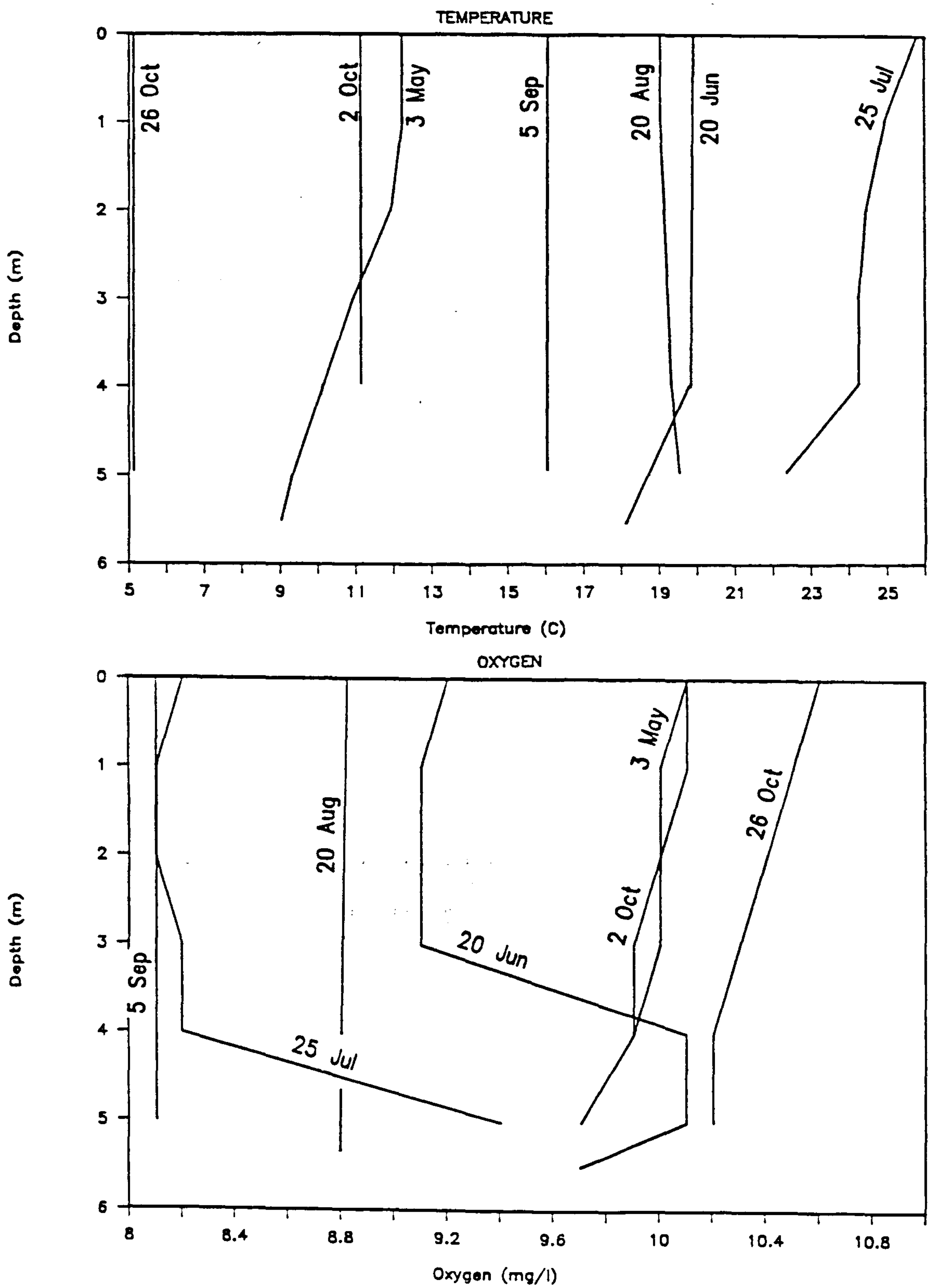


Figure 7. Temperature and oxygen profiles from Upper Twin Lake at station East Upper Deep (sample year 1985).

Table 8. Means of selected water quality variables for Upper Twin Lake, Idaho (May 1985-August 1986).

Date	Temp (C)	Pct Sat	O2 (mg/l)	pH	TN (mg/l)	TP (mg/l)	Chl *a* (ug/l)
Deep Sites							
03May85	11.2	99.1	9.95	6.84	0.28	0.074	3.17
20Jun85	19.6	108.8	9.10	6.74		0.005	2.86
25Jul85	23.0	101.6	7.90	7.32	0.26	0.030	3.42
20Aug85	18.1	105.3	9.10	6.85		0.010	2.55
05Sep85	15.7	91.3	8.27	6.98	0.28	0.026	2.29
02Oct85	10.6	100.1	10.20	7.33		0.008	2.03
26Oct85	7.3	98.3	10.83	7.07	0.24	0.014	3.86
28Jan86	1.2	33.1	5.30			0.019	
08May86	10.6		10.13	6.34		0.017	2.32
18Aug86	22.1			7.38		0.020	2.12
Littoral Sites							
03May85							
20Jun85	20.5	108.2	8.87	6.75		0.003	2.60
25Jul85	24.1	109.2	8.10	7.05	0.25	0.021	3.39
20Aug85	18.4			6.42		0.009	3.93
05Sep85	15.9	96.4	8.72	7.10	0.25	0.014	2.68
02Oct85	11.0	97.4	9.81	7.29		0.030	2.27
26Oct85	7.1	97.7	10.81	7.04	0.28	0.012	4.36
08May86	11.6		10.09	6.91		0.012	2.09
18Aug86	23.0			7.63		0.018	1.92
All Sites							
03May85	11.2	99.1	9.95	6.84	0.28	0.074	3.17
20Jun85	20.3	108.3	8.94	6.75		0.003	2.67
25Jul85	23.8	107.0	8.05	7.13	0.25	0.024	3.40
20Aug85	18.3	105.3	9.10	6.54		0.009	3.53
05Sep85	15.8	94.8	8.58	7.06	0.26	0.018	2.56
02Oct85	10.9	98.3	9.93	7.30		0.008	2.21
26Oct85	7.1	97.9	10.82	7.05	0.27	0.012	4.23
28Jan86	1.2	33.1	5.30			0.010	
08May86	11.6		10.12	6.82		0.012	2.07
18Aug86	22.8			7.56		0.019	2.01

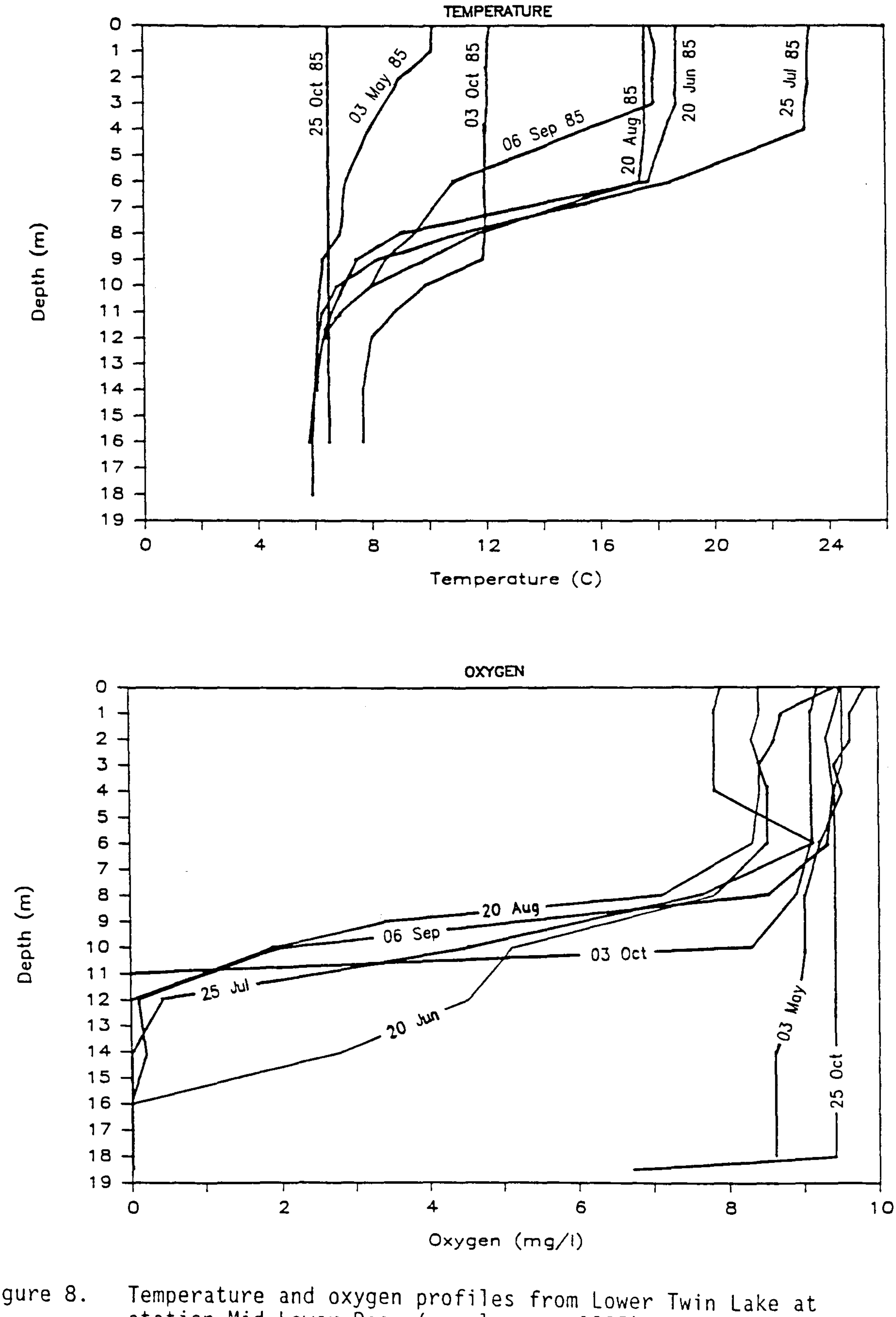


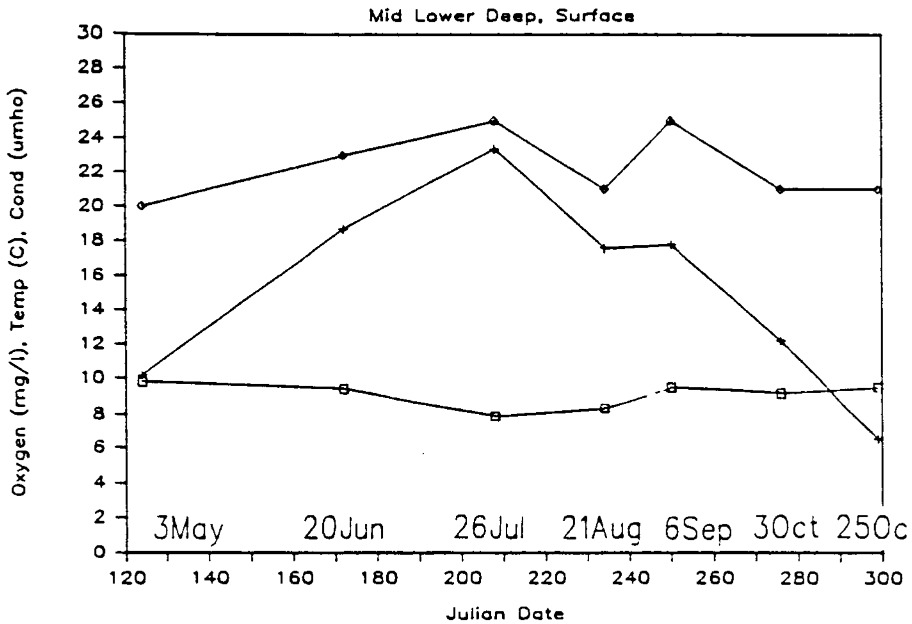
Figure 8. Temperature and oxygen profiles from Lower Twin Lake at station Mid Lower Deep (sample year 1985).

excluded trout above about 5 m during July (Scott and Crossman 1973). Seasonal changes in oxygen and temperature are shown in Figure 9. Mid-winter oxygen concentrations near the surface of Lower Twin Lake were 12.3 mg/l; the lake was anoxic near the bottom at that time (Table 9).

Carbon dioxide concentrations were typically 2 to 3 mg/l and pH was near neutral in both basins. There were two notable exceptions to this: 1) lower basin deep sites had high carbon dioxide concentrations (14-20 mg/l) and correspondingly low pH levels (5.8-6.2) during stratification, and 2) several upper lake stations, most notably NUL, had carbon dioxide concentrations under 1 mg/l during the 25 July sample period.

Alkalinity, hardness, and conductivity varied little during the study. There was no phenolphthalein alkalinity except for a single sample (WUL, 25 July) when carbon dioxide was 0.0 mg/l and phenolphthalein alkalinity was 2 mg/l. Methyl-orange alkalinity was between 12 and 19 mg/l. Hardness varied from 6 to 11 mg/l as $CaCO_3$ indicating exceptionally soft water. Average conductivity was a relatively low 23 umhos.

Total phosphorus concentrations ranged from below detection limits (<0.004 mg/l) to 0.190 mg/l. Phosphorus concentrations in the hypolimnion of the lower basin were above 0.040 mg/l during most of the stratified period (Table 9, Figure 10). Epilimnion phosphorus concentrations averaged over all dates and stations in 1985 were 0.014 and 0.016 mg/l in the upper and lower basins, respectively. The deep stations in both basins, with the exception of MLD, had slightly higher mean phosphorus concentrations in the epilimnion than did the shallow stations (Tables 5 and 6).



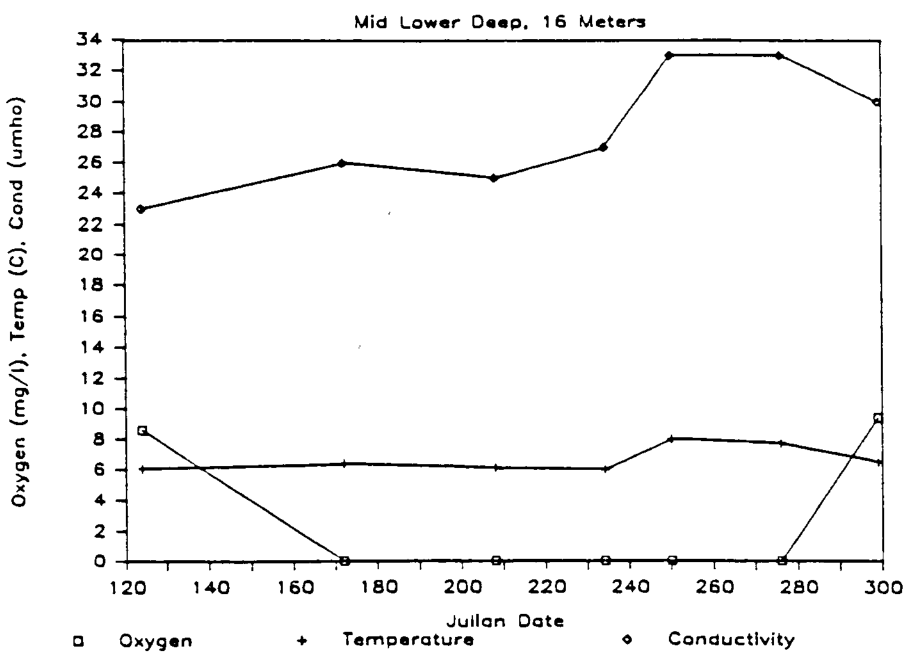


Figure 9. Seasonal patterns of oxygen, temperature, and conductivity in surface and hypolimnion samples from Lower Twin Lake at station Mid Lower Deep during 1985.

Table 9. Means of selected water quality variables from Lower Twin Lake, Idaho (May 1985-August 1986).

Date	Temp (C)	Pct Sat	O2 (mg/l)	pH	TN (mg/l)	TP (mg/l)	Chl *a* (ug/l)
Deep Sites -- Epilimnion							
23Feb85	1.7	80.4	10.25	6.33			
03May85	10.0	92.6	9.55	6.69	0.29	0.119	2.99
20Jun85	19.4	101.4	8.52	6.50		0.008	1.99
26Jul85	23.3	100.9	7.61	6.89	0.27	0.063	3.51
21Aug85	18.7	97.6	8.32	6.60		0.007	3.63
06Sep85	16.2	102.3	9.21	7.09	0.28	0.017	2.50
03Oct85	11.9	93.8	9.27	7.18		0.007	2.87
25Oct85	8.7	91.5	9.78	6.83	0.24	0.031	5.26
28Jan86	1.5	95.8	12.30				
08May86	9.7		9.51	6.84	0.19	0.015	5.97
18Aug86	18.4		4.97	6.35		0.042	1.73
Littoral Sites							
03May85	10.5			6.98	0.22	0.074	
20Jun85	19.8	106.2	8.86	6.43		0.003	2.06
26Jul85	23.5	98.0	7.53	7.00	0.24	0.022	2.06
21Aug85	19.0	98.1	8.31	5.93		0.004	2.88
06Sep85	15.8	97.0	8.79	7.06	0.25	0.016	2.70
03Oct85	12.0	94.5	9.30	7.16		0.008	2.50
25Oct85	8.8	92.3	9.81	6.82	0.26	0.015	4.80
08May86	10.8		10.85	7.30	0.17	0.009	4.61
18Aug86	21.7		7.58	6.52		0.019	1.65
All Sites -- Epilimnion							
03May85	10.2	92.6	9.55	6.79	0.27	0.104	2.99
20Jun85	19.7	104.8	8.76	6.45		0.003	2.04
26Jul85	23.4	98.9	7.56	6.97	0.25	0.027	2.49
21Aug85	18.9	98.0	8.31	6.54		0.004	3.11
06Sep85	15.9	98.8	8.93	7.07	0.26	0.016	2.63
03Oct85	12.0	94.3	9.29	7.16		0.008	2.62
25Oct85	8.8	92.1	9.80	6.82	0.26	0.020	4.94
28Jan86	1.5	95.8	12.30				
08May86	10.8		10.84	7.23	0.17	0.011	4.75
18Aug86	21.8		7.51	6.55		0.018	1.68
Deep Sites -- Hypolimnion							
03May85	6.1	75.7	8.60	6.20	0.18	0.067	4.88
20Jun85	8.1	17.5	1.80	5.88		0.018	4.56
26Jul85	7.1	17.1	1.85	5.98	0.41	0.115	4.41
21Aug85	7.4	0.0	0.00	6.16		0.045	4.77
06Sep85	7.6	0.0	0.00	6.50	0.30	0.045	4.30
03Oct85	9.4	20.6	2.08	6.73		0.044	3.01
25Oct85	8.7	89.1	9.50	6.76	0.23	0.033	5.36
28Jan86	3.5	0.0	0.00		2.00	0.737	
08May86	7.0		6.25	6.35	0.19	0.015	8.26

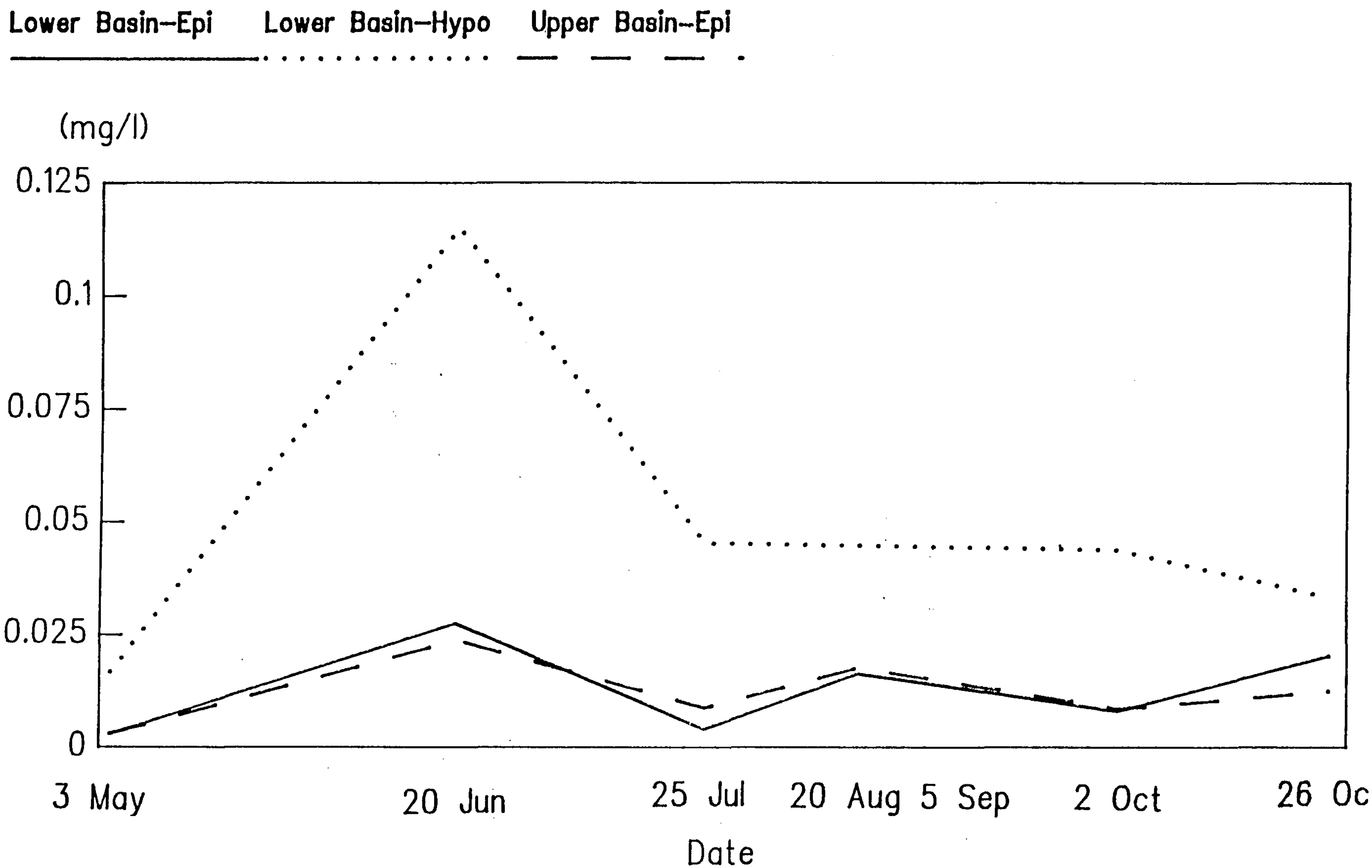


Figure 10. Phosphorus concentration means in epilimnion and hypolimnion samples during 1985.

Total nitrogen (nitrate+kjeldahl nitrogen) ranged from 0.14 to 0.60 mg/l, and epilimnion nitrogen concentration means over all dates and stations was 0.26 mg/l in both basins. There were no apparent differences between stations or basins. Total nitrogen to total phosphorus ratios were 19 in Upper Twin Lake and 16 in Lower Twin Lake (epilimnion) (averaged over all dates). After fall overturn in Lower Twin Lake, the N:P ratio dropped to 13.

Turbidity in the epilimnion was never over 4 NTU's. Secchi depths were less than 3 m in the spring of 1985 but by 20 June had increased to 5.2 m in the upper lake and 7.0 m in the lower lake (Figure 11). In May of 1986, secchi depths were 4.0 m and 5.75 m in the upper and lower lake, respectively. The compensation point ranged from 7.2 to 12.5 m in Lower Twin Lakes during the summer. Light easily penetrated to the bottom throughout the upper lake.

Deep station sediments from both basins contained 78-91% water and 14-20% of the solid material was organic matter (Table 10). For comparative purposes, sediments in the more eutrophic Liberty Lake were 90% water and 33% organic matter (Michael Kennedy Engineers 1985). Bottom sediments from MLD in late summer smelled of hydrogen sulfide, indicating reducing, anaerobic conditions. Organic matter content in littoral transect sediments varied from 1% to 21%. Stations NUL, SLL, and MLL were particularly sandy and had low organic content. Sediment phosphorus content was 1.07 mg/g (std. err.=0.096) in Upper Twin Lake and 1.13 mg/g (std. err.=0.126) in Lower Twin Lake. Total nitrogen was 10.1 mg/g (std. err.=0.473) and 6.9 mg/g (std. err.=1.417) in upper and

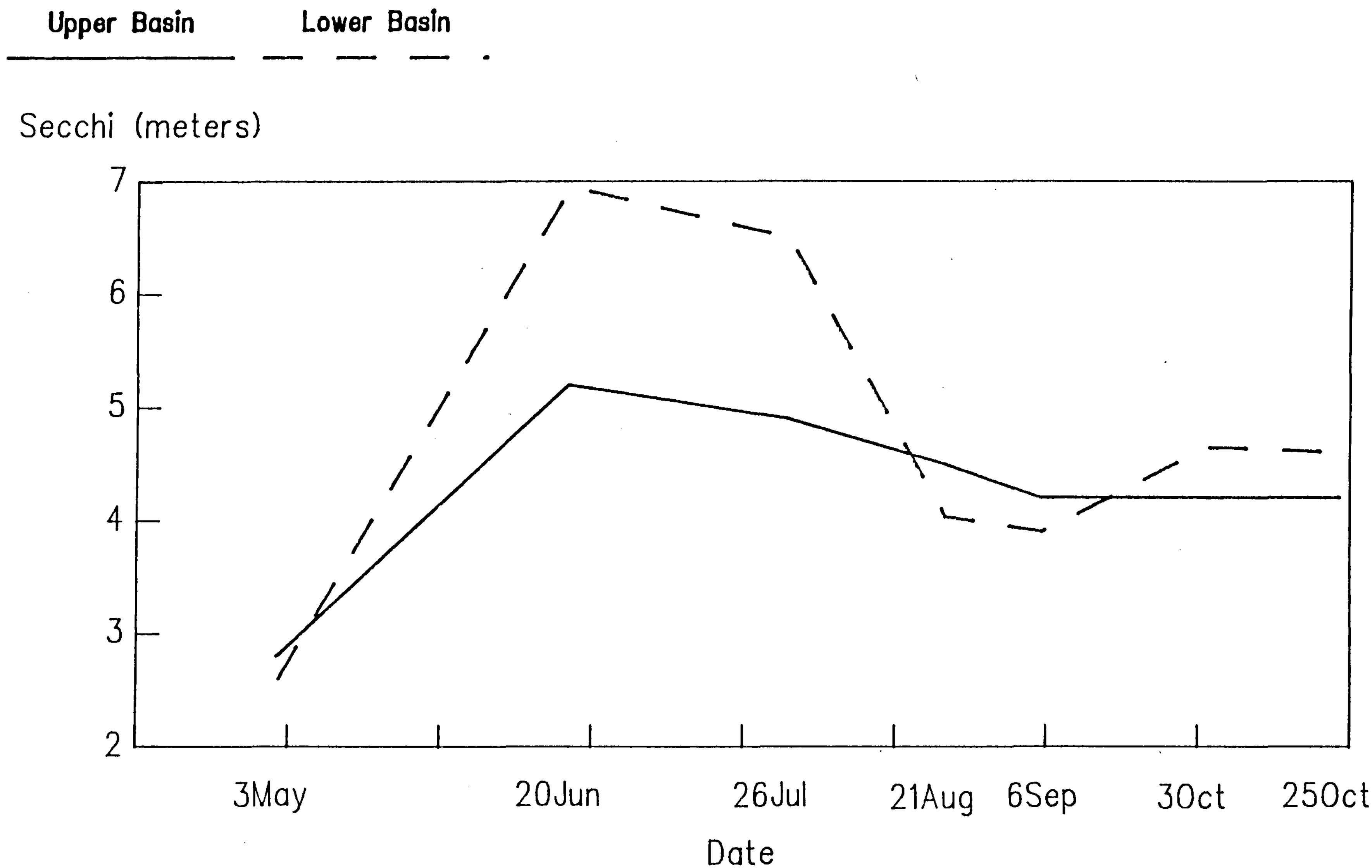


Figure 11. Seasonal patterns in secchi depth in Upper and Lower Twin Lakes.

Table 10. Description of sediments collected from Twin Lakes, Idaho, on 20 August, 1985.

Site		Approx. Phi Scale[a]	Percent Water	Percent Organic Matter
Deep Sites				
East Upper Deep		6	88.46%	19.35%
West Upper Deep		6[b]	88.92%	20.30%
North Lower Deep		6	87.20%	14.22%
Mid Lower Deep		6	91.20%	15.24%
South Lower Deep		5,6	77.67%	17.15%
Littoral Sites				
NUL	Shallow	3,1	24.66%	1.14%
	Mid	6	71.77%	8.59%
	Deep	6[b]	84.33%	15.88%
WUL	Shallow	6	84.79%	14.44%
	Mid	6	83.59%	14.27%
SUL	Shallow	5,1	53.28%	5.02%
	Mid	6	86.24%	19.46%
	Deep	6	87.83%	18.82%
NLL	Shallow	5[b]	64.68%	9.03%
	Mid	6,1	79.38%	13.26%
	Deep	6,1	43.52%	3.09%
MLL	Shallow	Sandy/gravel substrate.		
	Mid	too hard-packed to sample.		
	Deep	5[b]	78.66%	10.56%
SLL	Shallow	1	31.56%	3.70%
	Mid	5,1	62.26%	9.35%
	Deep	6	88.68%	20.74%

[a] Phi scale is a measure of particle size: 1=coarse sand, 6=silt.

[b] Much decomposing macrophytes in sample.

lower lake sediments, respectively. WUL and NLD sediments had the highest phosphorus content in each basin.

Appendix C contains physical and chemical data in unabridged form.

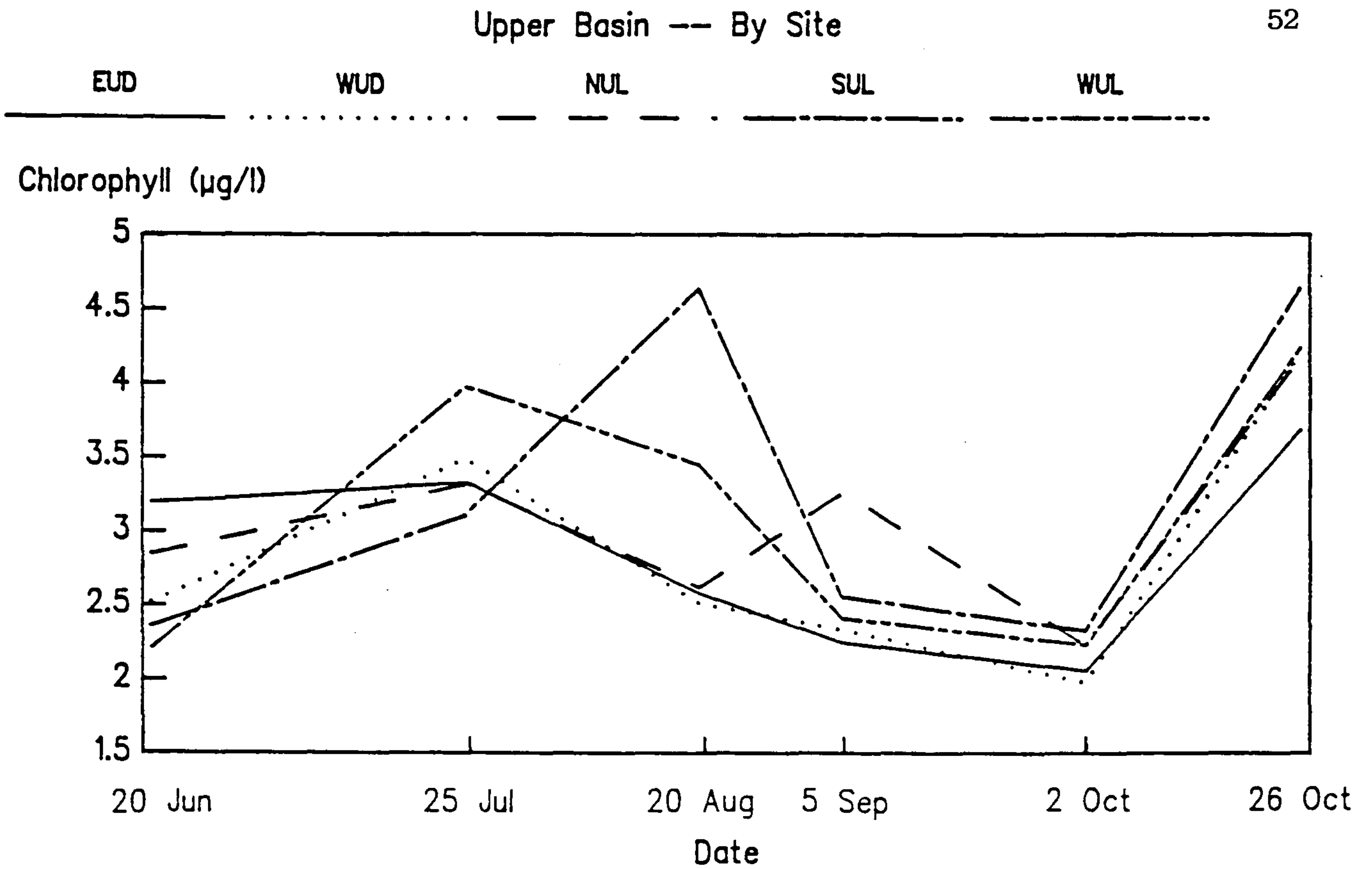
Biological Limnology

Phytoplankton

Upper Twin Lake chlorophyll *a* levels ranged from 1.50 to 8.92 ug/l and averaged 3.05 ug/l during 1985 (Table 6). Stations SUL and WUL had slightly higher chlorophyll *a* levels than other stations (Figure 12) and upper basin littoral sites overall, had slightly higher values than deep sites (Table 6, Figure 13). There was generally 1 to 3 mg/l of non-filterable residue in the water -- 55% of which was organic matter -- with little variability between sites (Table 6). Autotrophic indices in the upper lake averaged 289.

Lower Twin Lake chlorophyll *a* levels ranged from 0.89 to 9.54 ug/l. All lower lake sites together averaged 3.01 ug/l (Table 7). Measures of algae were especially high in hypolimnion samples from MLD and NLD. Station NLD had consistently higher chlorophyll *a* values than any other station (Figure 12). Chlorophyll *a* increased in both basins between the 2 October and 26 October sampling trips. The average percent organic matter in non-filterable residue was as follows: littoral sites-61%; deep sites - epilimnion-55% and hypolimnion-64%. Average autotrophic indices were highest in littoral site samples (461) and lowest in deep site (epilimnion) samples (400).

Algae counts and biovolumes were similar at all sample stations in both basins with the exceptions of WUD and NLD (Figure 14). The late spring biovolume peak at WUD was primarily due to a large and abundant



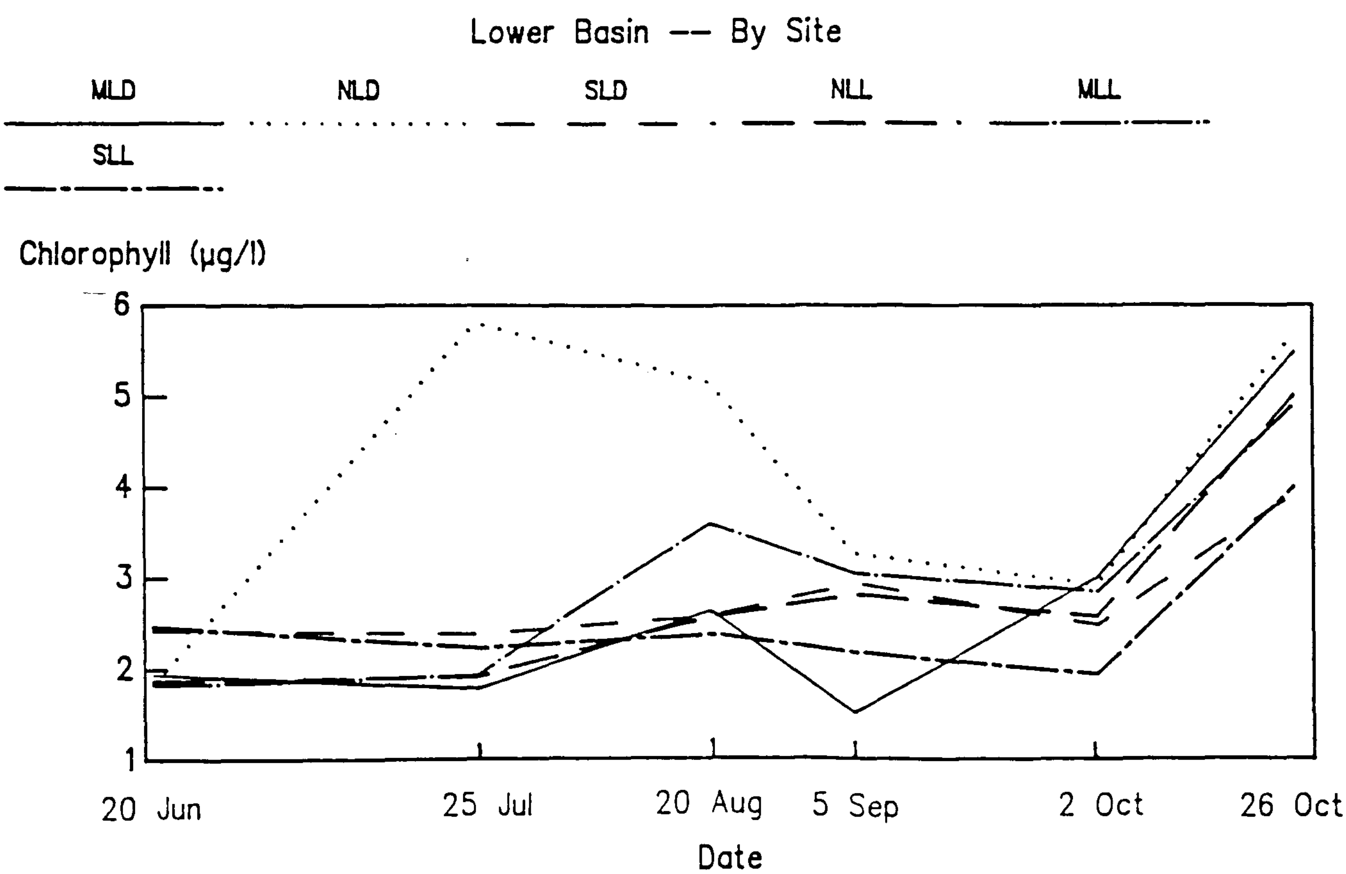


Figure 12. Chlorophyll "a" concentrations in Upper and Lower Twin Lakes in 1985 (means of epilimnion samples).

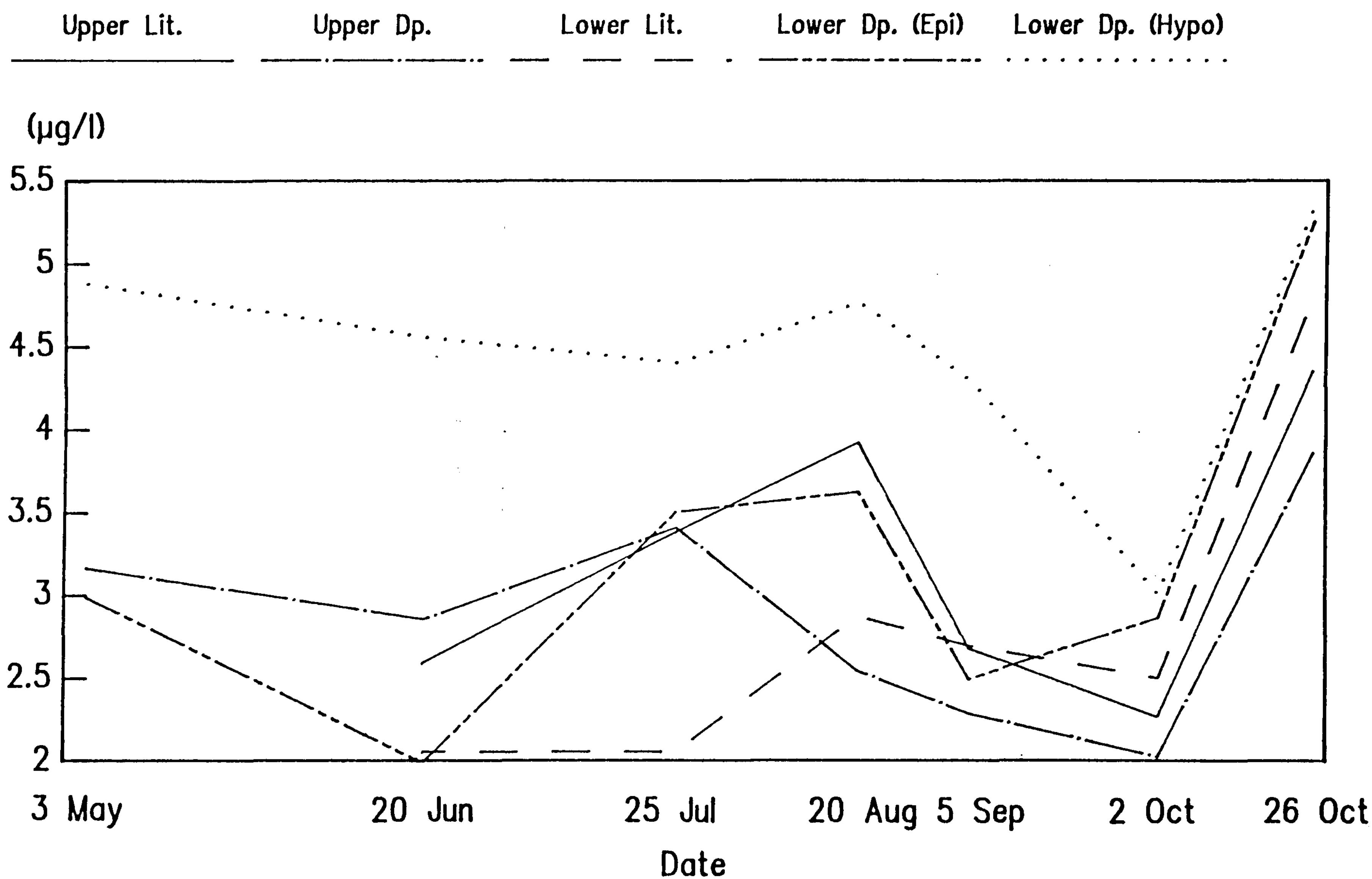
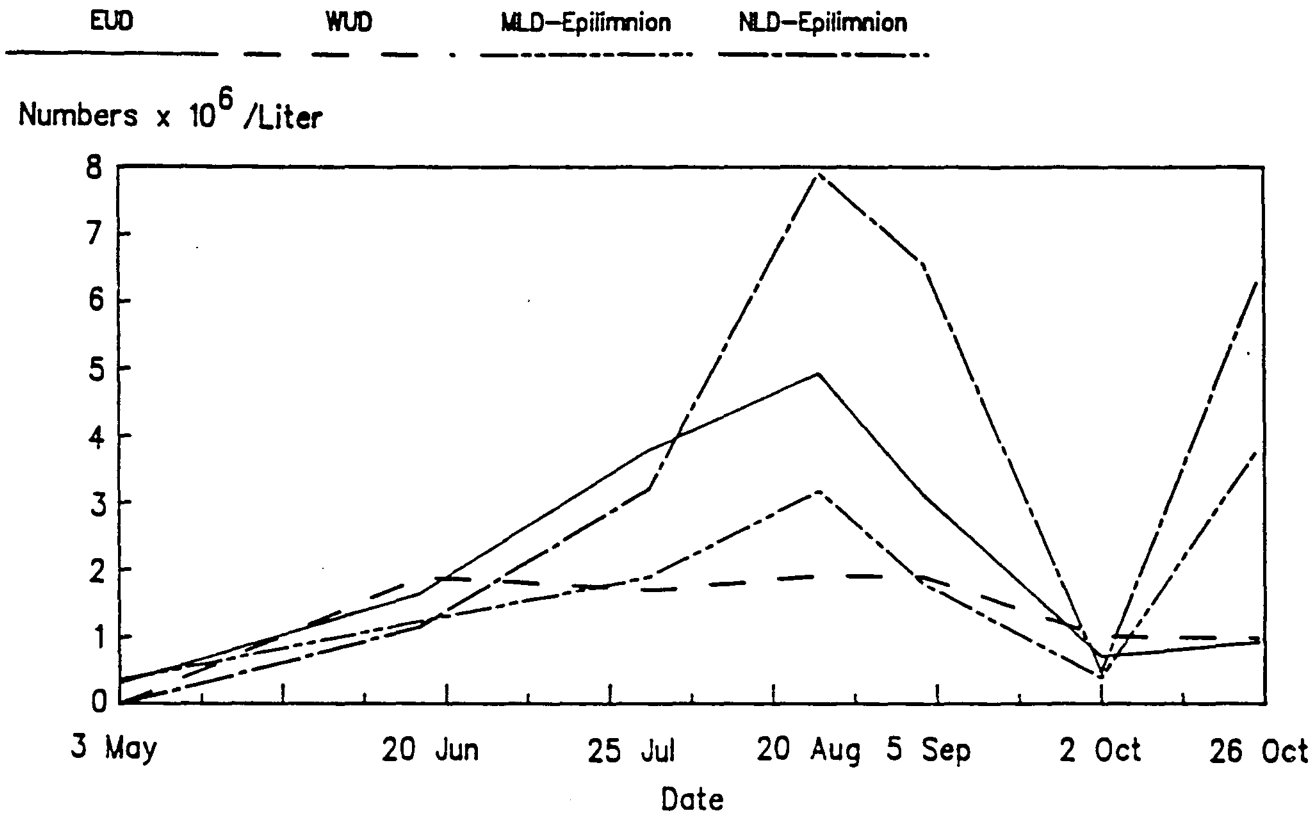


Figure 13. Chlorophyll "a" concentrations in littoral and deep stations in 1985. Deep stations are separated into epilimnion and hypolimnion sample means.



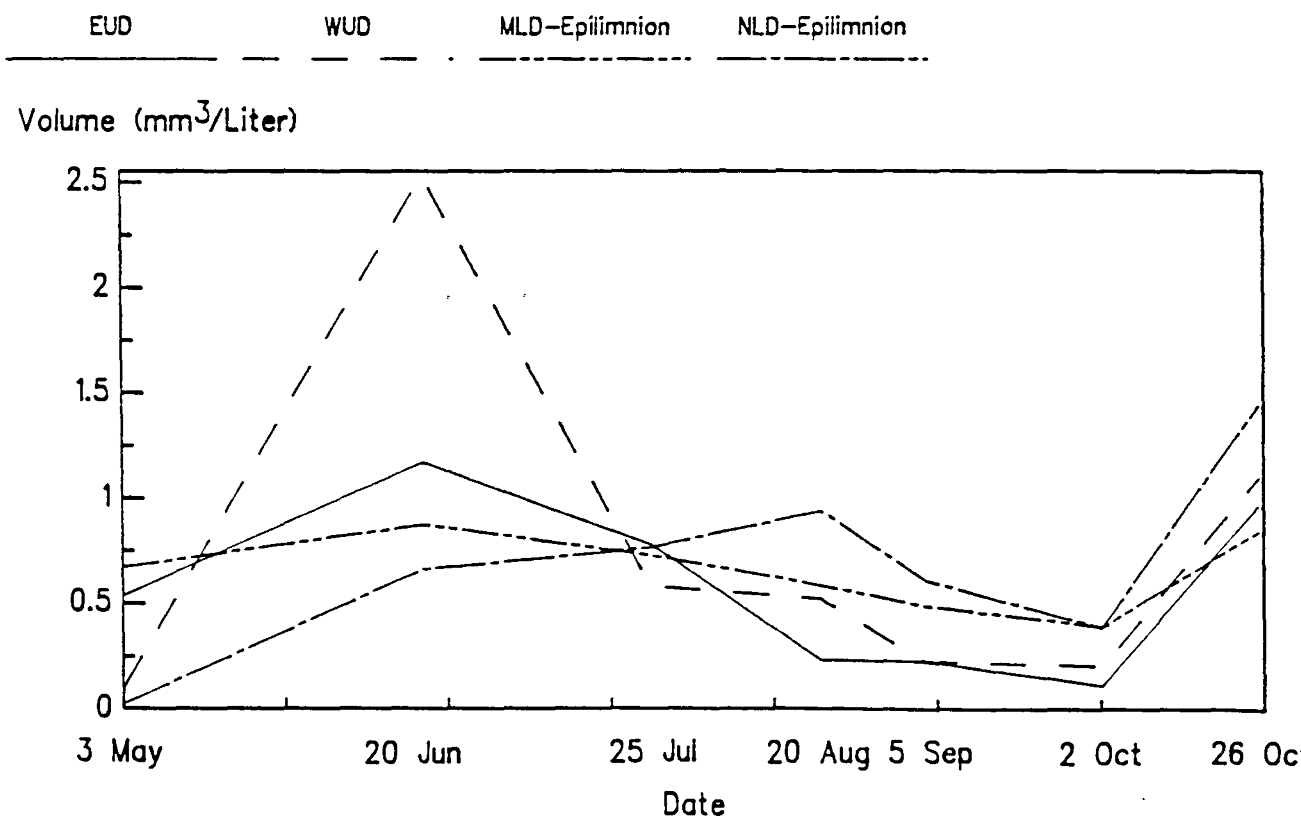


Figure 14. Numbers and biovolume of algae cells from deep stations in 1985. WUD and NLD were not sampled in May.

Cryptomonas sp. The August-September pulse in numbers that was most evident at NLD was due to the tiny blue-green algae *Agmenellum* and *Microcystis*. Both numbers and biovolumes increased in late October at most stations, especially in the lower basin. This pulse was due to Chrysophyta in both basins -- *Dinobryon* in the Upper Twin Lake and *Melosira* in Lower Twin Lake. Cyanophyta (blue-green algae) was by far the dominant division, particularly during the warmer summer months (Figure 15). In terms of biovolume, however, the Cyanophyta pulsed in both basins in late July during a light *Gloeotrichia* bloom, but the Crysophyta were more consistently dominant (Figure 16). May, 1986, phytoplankton measures differed from the previous year in that NLD and MLD had high biovolumes of *Peridinium* (1.92 and 2.73 mm^3/liter, respectively). All stations had higher chlorophyll *a* in 1986 spring samples than in 1985 spring samples.

The algal community in Twin Lakes was diverse (Table 11). Numbers and biovolumes of the five most abundant species of algae for each date and site are in Appendix C.

Zooplankton and Benthos

Zooplankton populations peaked in late June in both basins, were low in August, and had increased again by early October (Figure 17). Cladocera were generally more abundant than copepods. Copepod nauplii, though abundant in the spring samples, were otherwise only a minor fraction of the zooplankton. Rotifer populations were stable throughout the study. The rotifer *Polyarthra vulgaris*, the copepod *Diacyclops bicuspidatus thomasi*, and the Cladocerans *Bosmina longirostris*, and *Daphnia thorata* were the dominant zooplankters (see Appendix C.).

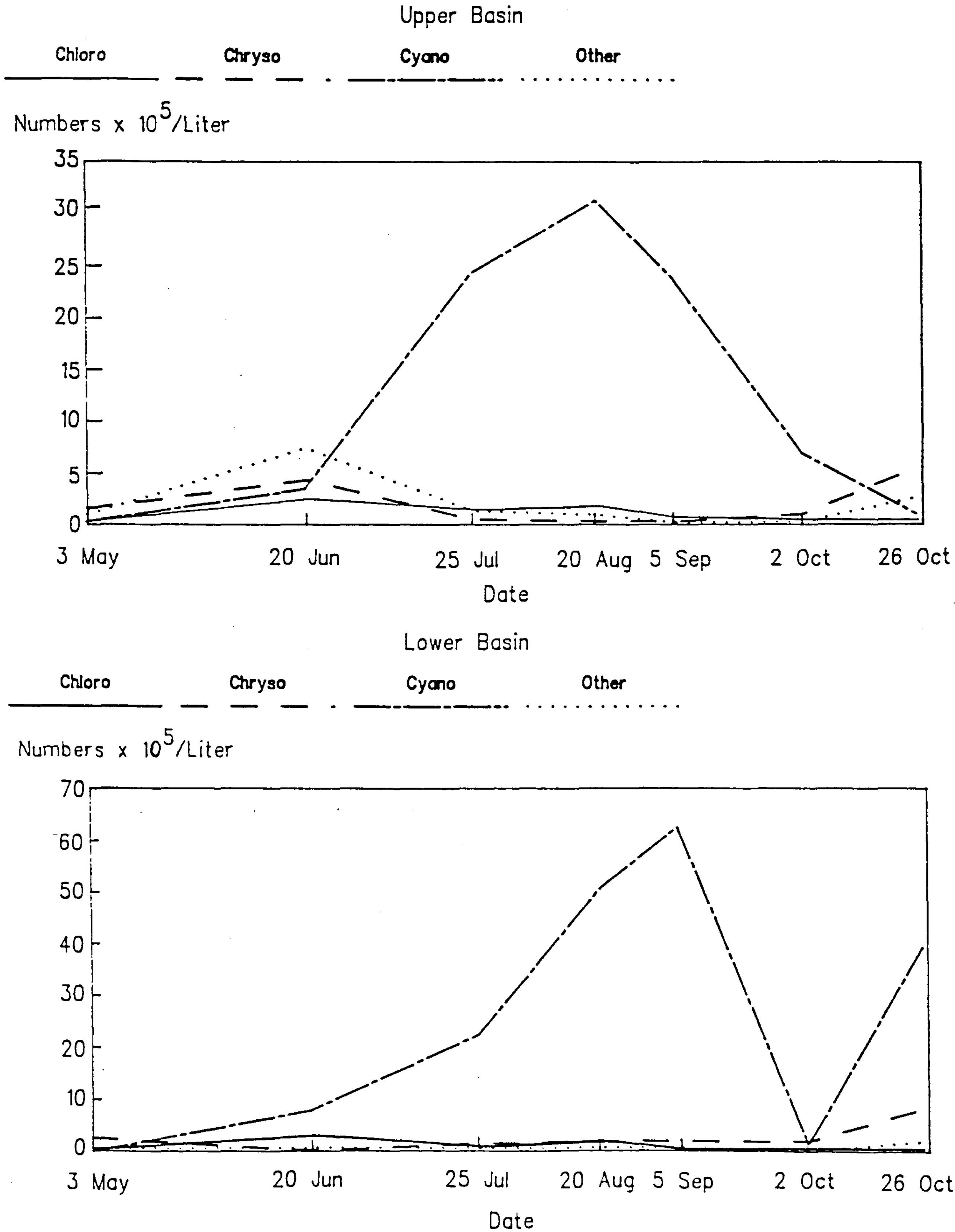
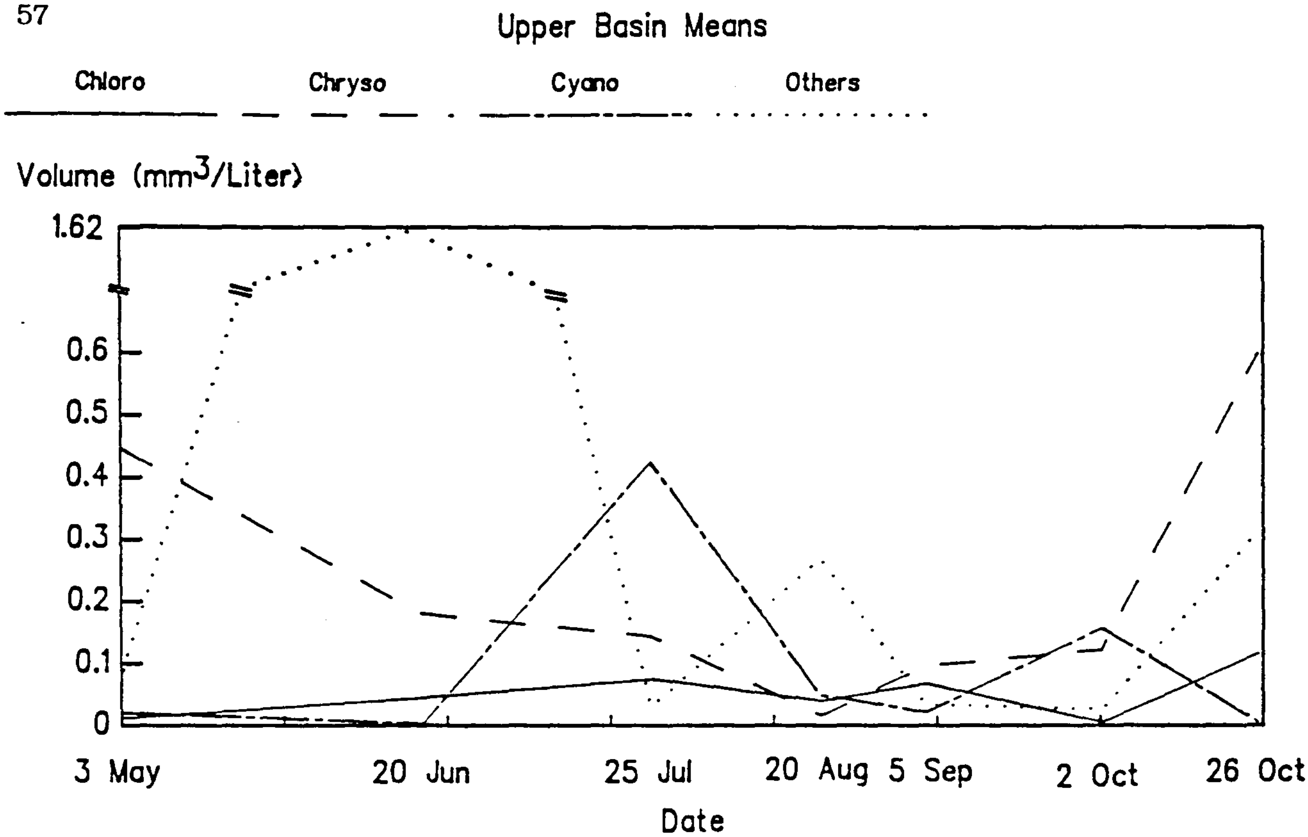


Figure 15. Numbers of algae cells in Upper and Lower Twin Lakes (epilimnion only) in 1985. (Chloro=Chlorophyta, Chryso=Chrysophyta, Cyano=Cyanophyta, and Other= Euglenophyta+Pyrrhophyta+Cryptophyta).



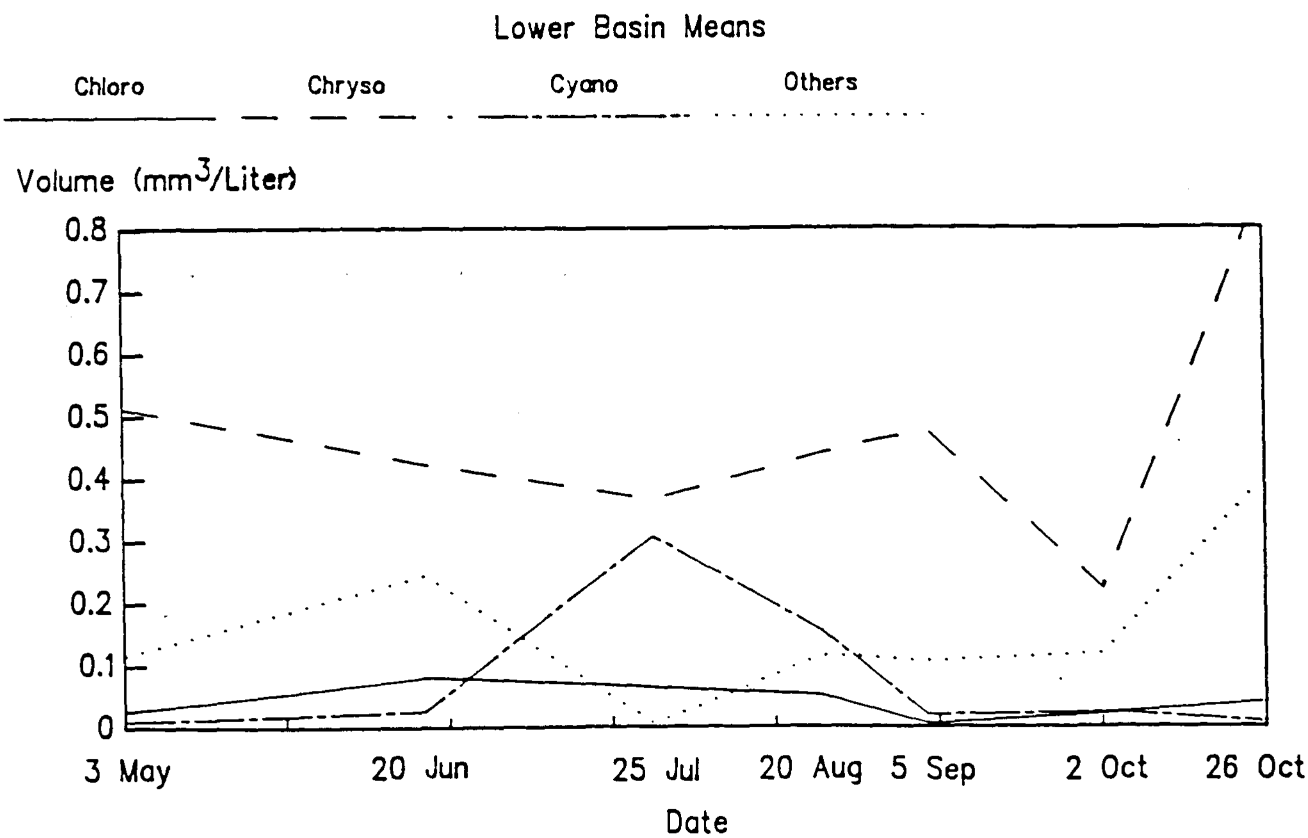


Figure 16. Biovolume of algae cells in Upper and Lower Twin Lakes (epilimnion only) in 1985. (Chloro=Chlorophyta, Chryso=Chrysophyta, Cyano=Cyanophyta, and Other= Euglenophyta+Pyrrhophyta+Cryptophyta).

Table 11. Phytoplankton genera collected in 1985 from Twin Lakes, Idaho.

Division: CHLOROPHYTA

Class: Chlorophyceae

Acanthosphaera (?)	*Mougeotia*
Ankistrodesmus	*Oocycstis*
Chlamydomonus	*Pandorina*
Closteriopsis	*Pediastrum* (2 sp.)
Closterium	*Quadrigula*
Coelastrum (?)	*Scenedesmus*
Crucigenia (2 sp.)	*Sphaerocystis*
Eudorina	*Spondylosium*
Gloeocystis	*Staurastrum*
Micrasterias	*Tetraedron*
	Ulothrix

Division: CHRYSOPHYTA

Class: Chrysophyceae

Dinobryon

Class: Diatomaceae

Amphora	*Fragilaria*
Asterionella	*Melosira* (3 sp.)
Caloneis	*Meridion*
Ceratoneis	*Navicula* (3 sp.)
Cocconeis	*Nitzschia*
Cyclotella	*Synedra* (3 sp.)
Cymbella	*Tabellaria*

Division: CRYPTOPHYTA

Class: Cryptophyceae

Cryptomonas (2 sp.)

Division: CYANOPHYTA

Class: Cyanophyceae

Agmenellum	*Gloeotrichia*
Anacystis	*Microcystis*
Aphanocapsa	*Nostoc*
Chroococcus (2 sp.)	*Oscillatoria*
Coelosphaerium	*Synechocystis*
Gloeocapsa	

Division: EUGLENOPHYTA

Phacus	*Trachelomonas*

Division: PYRRHOPHYTA

Class: Dinophyceae

Ceratium	*Peridinium*

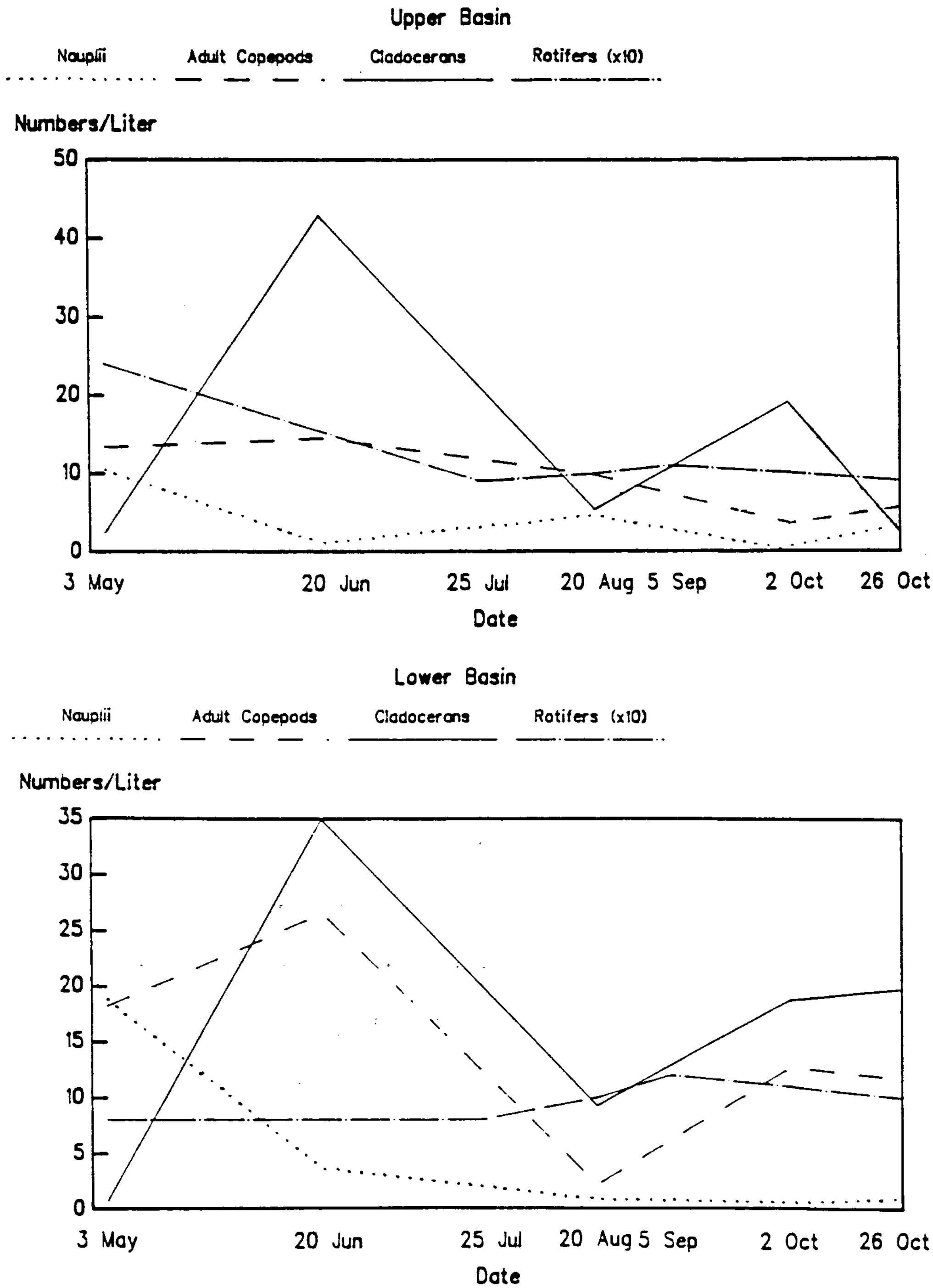


Figure 17. Numbers of zooplankton in Upper and Lower Twin Lakes (epilimnion only) in 1985.

Numbers and species of benthic organisms were highly variable, both between stations and between samples within stations (Table 12). Chironomids were abundant except at NUL-shallow, which had a relatively sandy substrate, and MLD, which was anoxic for a long period. Over 95%of the organisms collected at MLD were oligochaetes (aquatic earthworms). Oligochaetes were also abundant at WUL-mid. The Shannon-Weaver diversity index for insect genera was lowest at MLD (1.22). Equitability, a measure of evenness of distribution, was lowest at NUL-deep (0.38), primarily due to a plethora of *Chironomus*. Equitability was also low at WUL-shallow (0.85) and WUL-mid (0.84). Numerous floating chironomid exuviae (cast skins) were seen on the surface of Twin Lakes on several occasions, indicating large insect hatches.

Bacteria

Bacteria counts were well below recommended levels (500 colonies/100ml in any given sample (Idaho Department of Health and Welfare)) for primary contact recreation waters at all stations at the time of sampling. Bacteria counts greater than one were obtained at only three sites: WUL-deep, WUL-shallow, and from a site where homeowners had reported a submerged barrel suspected of receiving septic waste (Table 13). Because these counts are from a single sample date rather than a geometric mean of several samples, they should be used for comparative purposes only. Trial (1978) found low fecal bacteria counts at 25 different in-lake stations in September. However, he did find indications of fecal contamination of tributary streams, presumably from cattle.

Table 12. Benthic organisms per square meter from selected sites (mean of three samples), collected 20 June, 1985.

Organism	EUD	NUL Shall	NUL Deep	WUL Shall	WUL Mid	MLL Deep	MLD
OLIGOCHAETA							
Tubificidae or Naididae		272	63	21	1839	111	1602
Lumbriculidae						56	
PELYCOPODA							
Sphaeriidae				63	125		
AMPHIPODA							
Hyallela azteca				84			
HYDRACARINA							
Forelia					42		
TURBELLARIA							
Planaria	84					28	
EPHEMEROPTERA							
Caenis				21			
ODONATA							
Perithemis						28	
TRICOPTERA (cases)			272	125	188	14	14
DIPTERA							
Chaoborus	84						84
Ceratopogonus				42		14	
CHIRONOMIDAE							
Procladius				185	564		14
Chironomus	602		4128	21	21	14	28
Paratanytarsus	117		42			35	
Dicrotendipes	602		403	165	42	70	
Psectrocladius	242	21	84			14	
Microtendipes	602		193	115	42		
Thienemanimyia gp.	242		297	456		28	
Polypedilum				489	355		
Tanytarsus	359	21	128	94	125	14	
Parachironomus						14	
Cladopelma				21	188		
Ablabesmyia			130			14	
Labrundinia			65				
Tribe Tanytarsini	359						
Alotanypus	117						
Paratendipes					63		
Cryptochinomus					21		
Cricotopus						14	
Nanocladius						14	
Unknown		42				14	
TOTAL CHIRONOMIDS	3242	84	5470	1546	1421	245	42
GENUS DIVERSITY OF INSECTS	3.06	1.50	1.46	2.63	2.47	3.43	1.22
Equitability	1.18	1.19	0.38	0.85	0.84	1.19	0.95

Table 13. Bacteria counts (colonies/100 ml) from Twin Lakes, Idaho, for samples collected 8 September, 1985. All counts are estimates based on non-ideal colony counts.

Site	Total Coliform	Fecal Coliform	Fecal Streptococci
West Upper Deep, Surface	<1	1	1
East Upper Deep, Surface	<1	<1	<1
North Upper Littoral, Shallow	<1	<1	<1
North Upper Littoral Deep	<1	1	<1
West Upper Littoral Mid	5	18	1
West Upper Littoral Shallow	15	9	8
South Lower Deep, Surface	<1	<1	<1
Mid Lower Deep, Surface	<1	<1	<1
North Lower Deep, Surface	<1	<1	<1
Mid Lower Littoral Shallow	<1	<1	<1
Mid Lower Littoral Deep	<1	<1	<1
Adjacent to Percy Cochran	<1	14	<1

Rooted Aquatic Macrophytes

Macrophytes covered 89% of Upper Twin Lake bottom area and 35% of Lower Twin Lake (Table 14 and Figures 18 and 19). The pondweed *Potamogeton robbinsii* accounted for 97.5% of the estimated 298,649 kg dry weight of total macrophyte standing crop in the upper basin and 87.3% of the 45,470 kg in the lower basin. Although macrophyte coverage was extensive, submerged macrophytes were not troublesome to most boaters (see Appendix D.) and extended to the surface only in a few places, most notably the extreme western end of the upper basin. These latter communities were predominately *Elodea canadensis* and *P. amplifolius*. The floating-leaved macrophyte *Nuphar polysepalum* (water lilies) must be cleared occasionally from the channel to maintain boat access between basins.

Macrophyte biomass in the upper lake contains 466 kg of phosphorus and 6,659 kg of nitrogen -- 71% of the total annual phosphorus loading to the lake (Table 15)! Lower lake macrophytes contain a reservoir of 75 and 1,057 kg of phosphorus and nitrogen, respectively.

Production of *P. robbinsii* in Upper Twin Lake was approximately 1.32 g dry weight/m^2/day during the growing season. Because production was calculated from the change in standing crop during the summer, any plant biomass that was cropped or died between sample periods would be lost from the production estimate. Hence 1.32 g/m^2/day is a conservative estimate. *P. robbinsii* appeared green and healthy when sampled in late January.

Fish

From 1979 through 1984, Upper Twin Lake was stocked with an average of 11,900 rainbow trout (*Salmo gairdneri*) each year. In addition, a

Table 14. Twin Lakes macrophyte communities (see Figures 18 and 19).

Symbol	Species	Dry Weight ($g/m^2 \pm$ 1SD(n)) Peterson Dredge	Diving Sample	Area (ha)	Total Dry Wt[a] (kg)
		LOWER BASIN			
	*Potamogeton robbinsii*	31 ± 17(3)	75 ± 17(3)	---	12,833
	Elodea canadensis	0.8 ± 1.4	0.05 ± 0.09	17.11	8.6
	*P. robbinsii*	92 ± 23(3)	80 ± 19(3)		6,784
	P. amplifolius	17 ± 30	none	8.48	2,909
	*P. robbinsii* (40%)[b]	---	---		2,599
	P. amplifolius (5%)[b]	---	---	6.59	560
	E. canadensis (5%)[b]	---	---		3.8
	*P. robbinsii*	140 ± 127(4)	166 ± 25(3)		10,375
	E. canadensis	none	0,4 ± 0.5	6.25	25
	Ceratophyllum demersum	none	0.07 ± 0.12		4.4
	*P. robbinsii*	22 ± 6(3)	35 ± 16(3)	6.11	2,139
	E. canadensis	none	3.0 ± 1.9		183
	*Nuphar* (80%)[b]	---	---	4.38	2,542
	*P. robbinsii*	30 ± 13(3)	137 ± 41(3)	3.00	4,110
	*P. berchtoldii* (80%)	---	---	2.31	33
	*P. robbinsii* (70%)[b]	---	---		863
	P. amplifolius (1%)[b]	---	---		2.1
	E. canadensis (1%)[b]	---	---	1.25	0.10
	P. berchtoldii (1%)[b]	---	---		.23
		TOTAL		55.48 (35% of basin)	45,470

Table 14. (continued).

Symbol	Species	Dry Weight (g/m^2 ± 1SD(n)) Peterson Dredge	Diving Sample	Area (ha)	Total Dry Wt[a] (kg)
		UPPER BASIN			
	Potamogeton robbinsii	110 ± 51(3)	275 ± 92(3)	93.89	258,198
	P. robbinsii	61 ± 15	---	39.08	23,839
	Nuphar polysepalum (80%)[b]	---	---	11.88	6,896
	P. robbinsii (50%)b	---	---	11.24	8,020
	Elodea canadensis (25%)b	---	---		31
	Najas guadalupensis	2 ± 1(3)	---		186
	E. canadensis	0.7 ± 1.2	---	9.32	65
	P. robbinsii	0.4 ± 0.7	---		37
	P. berchtoldii	0.1 ± 0.2	---		9.3
	P. robbinsii	14 ± 22(4)	---		743
	E. canadensis	0.5 ± 0.9	---	5.31	27
	Isoetes echinospora	0.4 ± 0.9	---		21
	Chara sp.	0.3 ± 0.4	---		16
	P. robbinsii	---	10.4 ± 17.4(3)		426
	P. berchtoldii	---	1.8 ± 3.0		74
	E. canadensis	---	1.1 ± 1.2	4.10	45
	Chara sp.	---	0.2 ± 0.3		8.2
	I. echinospora	---	0.2 ± 0.3		8.2
		TOTAL:		175.81 (89% of basin)	298,649

[a] Area x Dry Weight of diving sample, where available, otherwise peterson sample dry weight was used.
[b] Percentages were subjectively determined for communities where no samples were taken. Total Dry Weight = Percent x Area x Mean of diving sample dry weights for that species (for *Nuphar*, average dry weights were obtained from the literature).

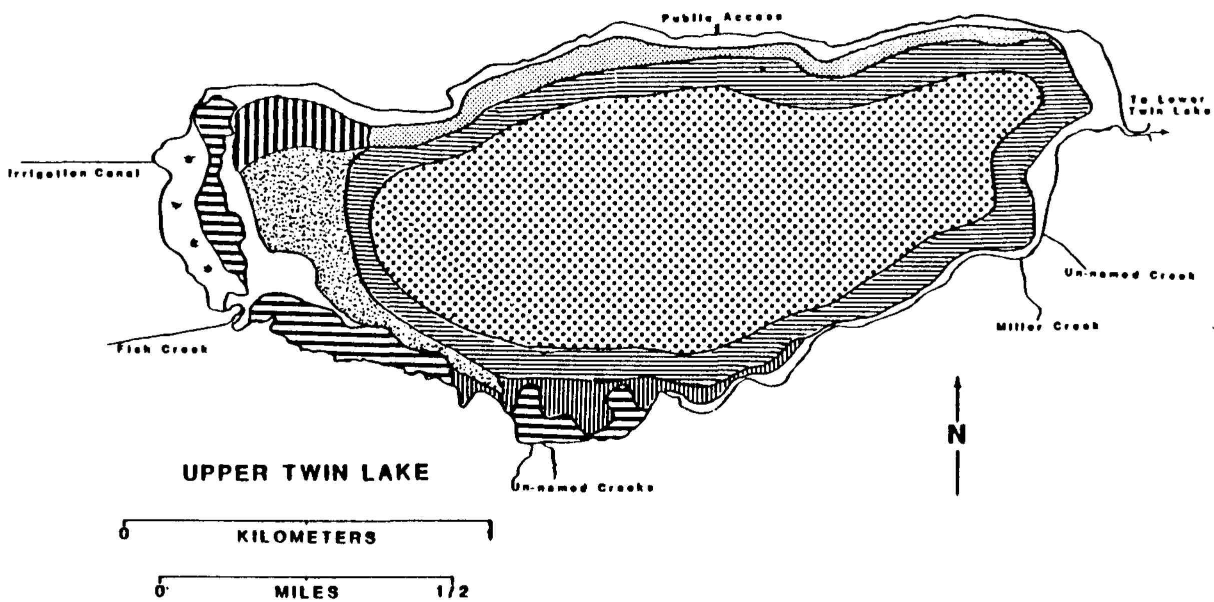


Figure 18. Macrophyte communities in Upper Twin Lakes. See Table 13 for key to community species composition and standing crop.

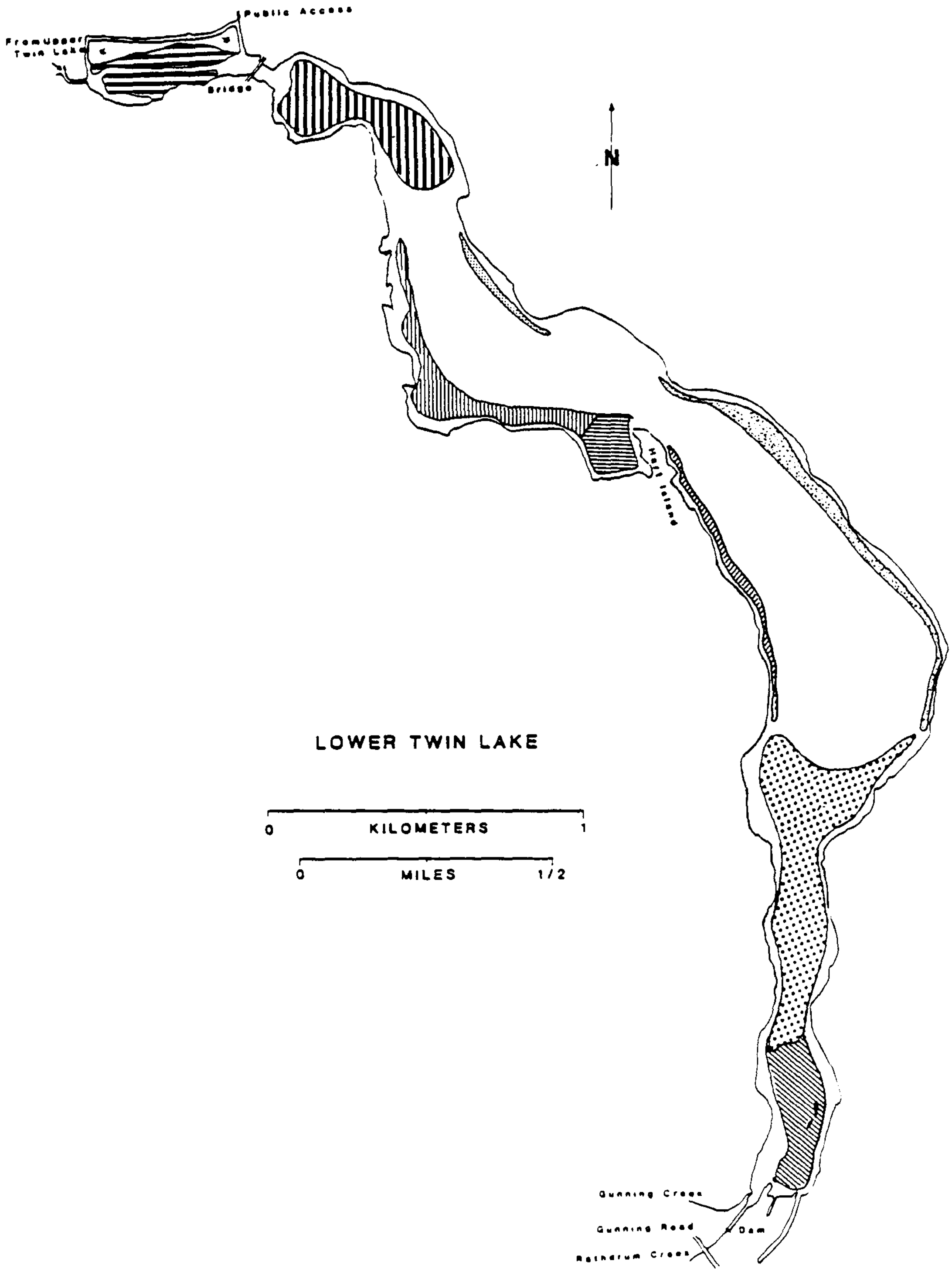


Figure 19. Macrophyte communities in Lower Twin Lakes. See Table 13 for key to community species composition and standing crop.

Table 15. Nutrient content in Twin Lakes macrophytes.

Species	Total Dry Weight (kg)	Phosphorus (% of dry Weight)	Nitrogen (% of Dry Weight)	Total Phosphorus (kg)	Total Nitrogen (kg)
			UPPER BASIN MACROPHYTES		
Potamogeton robbinsii	291,263	0.15[b]	2.20[b]	437	6,408
Nuphar polysepalum	6,896[c,e]	0.40[a]	3.46[a,d]	28	239
Najas quadalupensis	186	0.15[a]	2.30[a,d]	0.3	4.28
Elodea canadensis[e]	168	0.18[b]	2.51[b]	0.3	4.22
P. berchtoldii[e]	83	0.45[b]	3.59[b]	0.4	2.98
Isoetes echinospora	29	N/A	N/A	N/A	N/A
Chara sp.	24	0.25[c]	2.44[c]	0.06	0.6
TOTAL	298,649			466	6,659
			LOWER BASIN MACROPHYTES		
Potamogeton robbinsii	39,703	0.15[b]	2.20[b]	59	873
P. amplifolius	2,967	0.19[b]	2.99[b]	5.6	89
Nuphar polysepalum[e]	2,542[c,e]	0.40[a]	3.46[a,d]	10.2	88
Elodea canadensis[e]	221	0.18[b]	2.51[b]	0.4	5.5
P. berchtoldii[e]	33	0.45[b]	3.59[b]	0.15	1.2
Ceratophyllum demersum	4.4	0.26[a]	2.74[a,d]	0.01	0.12
TOTAL	45,470			75	1057

[a] Boyd and Goodyear, 1971
[b] Gerloff and Krombholz, 1966. Mean of 3-4 sample dates.
[c] Mitchell, 1974
[d] Protein/6.25
[e] Nutrient concentration based on different or unknown species within the listed genera.

total of 12,100 kokanee (*Oncorhynchus nerka*), kamloops (*Salmo gairdneri*), and brook trout (*Salvelinus fontinalis*) were stocked in this six-year period. The lower lake was stocked with an annual average of 8,700 rainbow trout and an annual average of 14,900 kokanee, kamloops, brown trout (*Salmo trutta*), and brook trout. There are no plans to change this general stocking strategy (Horner, Id. F. & G., pers. comm.). Net samples of the upper lake collected rainbow trout, cutthroat trout (*S. clarki*), largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), black crappie (*Pomoxis nigromaculatus*), bullheads (*Ictalurus* sp.), sunfish (*Lepomis* sp.), suckers (*Catostomus* sp.), and tench (*Tinca tinca*). Lower lake net collections included all of the above with the exception of cutthroat trout, bullheads, and suckers. The only gamefish native to Twin Lakes is the cutthroat trout.

Discussion

Both total phosphorus and total nitrogen were relatively low -- 0.014 and 0.016 in the upper and lower lake, respectively. Overall mean phosphorus concentrations were slightly higher at the deep stations, perhaps because of sediment release or release by decomposing macrophytes. However, this difference was small and inconsistent with time and station. NES (1977) found similar total phosphorus concentrations in Twin Lakes.

Twin Lakes is phosphorus limited, that is, an increase in phosphorus concentration would result in increased plant yield, an increase in nitrogen would not. Plant tissues contain nitrogen to phosphorus atoms in the ratio of about 16N:1P. By weight, this ratio is

7.2N:1P. In practice, the boundary between nitrogen and phosphorus limitation depends on the biological availability of phosphorus, the degree of nitrogen fixation and perhaps other factors. Most limnologists consider phosphorus to be limiting at TN:TP ratios above 10 to 17 by weight (OECD 1982). In any case, the lowest N:P ratio in Twin Lakes, which occurred after fall overturn when high hypolimnetic phosphorus concentrations were released into the water column, was well within this range. Phosphorus is clearly indicated as the controlling nutrient. Phosphorus control is, therefore, the key to eutrophication control.

Although phosphorus loading was about 20% greater to the upper basin than to the lower basin, in-lake phosphorus concentrations were 13% lower in the upper lake. One reason for this phenomenon is that the upper lake flushes twice as quickly as the lower lake. Rast and Lee (1978) graphically present a method of checking the reasonableness of loading estimates by comparing in-lake phosphorus concentration, influent phosphorus concentration, and flushing time. Mathematically, this relationship can be expressed as a ratio:

$$(\text{Lake P} / \text{Influent P}) / \{1 + (T_w)^{0.5}\}^{-1}$$

where T_w is the hydraulic residence time. If this ratio falls between 0.5 and 2.0, estimates are considered reasonable. The ratio was 0.74 in Upper Twin Lake and 1.18 in Lower Twin Lake. Hence the relationship between the three parameters in both Twin Lakes is similar to that found in the many lakes used to test this model. In other words, flushing time explains most of the disparity between phosphorus loading and in-lake phosphorus in the two basins.

A second explanation for low phosphorus concentrations compared to loading in the upper basin is the abundance of macrophytes. Although rooted macrophytes obtain most of their nutrients by uptake from the sediments, many species are capable of direct uptake from the water (Boyd 1971, Moore et al. 1984). Without macrophytes, water column phosphorus concentrations could be expected to be higher and the ratio described above would have been even closer to the model's theoretical norm of 1.0 in the upper lake. Also, more phosphorus would have been available for phytoplankton growth. NES (1977) attribute their low phosphorus concentrations in Upper Twin Lake to the presence of aquatic macrophytes.

Aquatic macrophytes were responsible for most of the plant production in the upper basin. Macrophyte production was conservatively estimated to be 1.32 $g/m^2/day$. Although we did not measure phytoplankton productivity, it was almost certainly less than 0.6 $g/m^2/day$ (Wetzel 1983). Macrophyte productivity in the upper lake is likely the cause of high summer pH levels and low CO_2 concentrations, in addition to high oxygen concentrations and percent oxygen saturations. These conditions were not found to the same degree in Lower Twin Lake, despite similar average chlorophyll *a* concentrations (a measure of algae biomass) in both lakes.

The contribution of aquatic macrophytes to the ecology of the upper lake is a complex issue. Boyd (1968) states that the relation of macrophytes to overall productivity can be either positive or negative. Many macrophytes and all associated epiphytes (attached algae) obtain some phosphorus from surrounding water and may thereby reduce water column phosphorus concentrations (Howard-Williams 1981). On the other hand, phosphorus (much of which was obtained from sediments) is released into the water column during senescence as the plant decays. These processes may be concurrent but one is usually dominant at a given time. Early in the growing season macrophytes probably will be a net sink of phosphorus while during fall dieback, macrophytes contribute significantly to internal phosphorus loading. In general, macrophytes are a net phosphorus sink in oligotrophic lakes and a net phosphorus source in eutrophic lakes (Carpenter 1983).

In Upper Twin Lake, macrophytes may be responsible for lower summer phytoplankton standing crops through nutrient competition. Canfield et al. (1983) report that Lake Baldwin (Florida) chlorophyll *a* concentrations increased from <3 ug/l to 20 ug/l when submerged macrophytes were removed by grass carp (*Ctenopharyngodon idella*). Note that in that situation, nutrients were not removed from the lake, but just reprocessed into other system components. Canfield et al. (1984) found an inverse relationship between chlorophyll *a* and percent macrophyte cover. They proposed the following reasons: a) release and uptake of nutrients by macrophytes, b) reduced nutrient cycling because of reduced mixing, and c) increased algae sedimentation because of reduced turbulence.

On the other hand, decomposition and subsequent nutrient release from those plants that die back in the fall and winter may be responsible for the increase in chlorophyll *a* in late October, 1985, in the upper lake. Phosphorus release from decomposing macrophytes was probably also responsible, at least in part, for high under-ice phosphorus concentrations. Gladyshev and Kogan (1977) report annual turnover rates of three *Potamogeton* spp. to be 1.00 to 1.60 times in a mesotrophic Russian lake. This means that as much as 1 to 1.6 times 466 kg P, our estimate of phosphorus contained in upper lake macrophytes, may be released during a year by senescing macrophytes. Some of this phosphorus is re-absorbed by living macrophytes, some precipitates to the sediments, some is taken up by algae, and some will be exported to Lower Twin Lake. It is possible that the phosphorus export to Lower Twin Lake after release from aquatic macrophytes in the upper lake is a significant contributor to Lower Twin Lake nutrient loading for the following year.

Secchi disk transparency is roughly the depth to which a 20-cm black and white disk may be lowered and still be visible. Secchi depth is a function of all suspended particulates in the water column, but when non-algae particulates are low, secchi depth is a reasonable index of phytoplankton density (Wetzel 1983). Secchi depth measurements are not only easy to collect but are one of the few water quality measures that can be visualized: it is simply a measure of water clarity. Secchi depths in Twin Lakes were generally commensurate with chlorophyll *a* concentration. The annual low readings in the spring were below 3 m in both basins because of inorganic sediment, not because of organic production. As the amount of sediment entering the lake decreased with decreasing inflow volumes, secchi depths increased.

Obviously, secchi depth is correlated with light penetration and therefore with compensation level, the depth at which light is just sufficient to allow photosynthesis to balance respiration (about 1% of incident light). Light penetrates to the bottom in Upper Twin Lake in sufficient intensity to permit macrophyte growth throughout the lake. In the lower lake, the maximum compensation level was 12.5 m in early summer. The compensation level averaged 7.6 m in the late summer and fall. As a result, macrophytes were not found below 12 m and were rare below 8 m. This also explains the high algae biomass in the hypolimnion. Because light penetrated into the hypolimnion, and because nutrient levels were high, chlorophyll *a* concentrations were high. Futhermore, the oxygen produced by algae in the hypolimnion would result in an underestimation of oxygen depletion rates. Fulthorpe and Paloheimo (1985) found that in lakes where the upper zones of the hypolimnion had light intensities greater than 1% of surface light, productivity was not stongly correlated with hypolimnetic depletion rates because oxygen production interfered with depletion rate measurements.

There was little summer oxygen depletion in the upper lake, even near the sediment surface, because of the lake's extensive cover of oxygen-producing macrophytes. In fact, during June and July, oxygen was supersaturated within the macrophyte beds near the bottom of the upper lake. Depletion was evident, however, in January under ice cover. Although *P. robbinsii* does not die back in the winter, under thick ice and snow cover low light levels slowed oxygen production and oxygen depletion did occur from both microbial and plant respiration.

In the lower lake, oxygen depletion occurred in both summer and winter. The sediment-water interface was anoxic for almost the entire stratified period in summer and undoubtedly for several months in winter as well.

Oxygen depletion is significant for several reasons:

1) The rate of depletion is a function of the organic matter fixed in the photic zone that rains down into the hypolimnion. This organic matter and the organic matter remaining from previous years is then decomposed by oxygen-consuming bacteria, mostly at the sediment surface. Hence, the rate of oxygen consumption can indicate past productivity.
2) A thick ice-cover or heavy snowfall can reduce light penetration and thereby reduce oxygen production by phytoplankton or submerged macrophytes. If this condition persists long enough or if the oxygen consumption rate is high enough, a winter fish kill can occur in shallow lakes due to low oxygen levels in late winter. Water volume in Upper Twin Lake is low enough that this event could well occur, particularly during an exceptionally long winter with early, heavy, and persistent snow cover. (Twenty-six cm of snow on top of 41 cm of ice will block 99% of incident light (Wright 1964)).
3) Under aerobic conditions, dissolved phosphorus combines with iron to form a precipitate that settles to the lake bottom. Under anaerobic conditions, the phosphorus is released back into the water column. During stratification, phosphorus concentrations increase in the hypolimnion and are available for release into the water column at spring and fall overturn. As a result, phytoplankton have a sudden supply of phosphorus in an especially available form. Spring and fall phytoplankton blooms often result. Hypolimnetic phosphorus concentrations in the lower lake were high in both winter and summer and chlorophyll *a* increased after summer overturn.
4) Finally, anoxic conditions result in high CO_2 levels, low pH, and H_2S release, all of which can be detrimental to fish.

Sediment nutrient concentrations in both lakes exceeded 1.0 mg P/kg. Sediments in the eutrophic Liberty Lake, Washington, and Black Lake, Idaho contained about 0.57 mg P/g (Funk et al. 1975) and 1.34 mg P/g (Kann, unpub. data), respectively. High sediment nutrients are not related to plant growth and may not indicate trophic state (Boyd 1968). Nor is the degree of internal loading necessarily related to sediment nutrient concentration. Not all of the nutrients in sediment are available for plant growth and the fraction that is available is variable. Sediment nutrient concentration does allude to historical organic and nutrient loading. WUD had the highest sediment phosphorus concentration in Upper Twin Lake, a fact possibly explained by the proximity of that station to the marsh and cattle pasture. NLD had the highest sediment phosphorus concentration in Lower Twin Lake. There is other evidence to suggest that NLD was the most nutrient-rich of our sample stations.

NLD had 34% higher mean chlorophyll *a* concentrations than the next highest station in the lower lake. In addition, NLD had higher phytoplankton numbers during the late summer and fall and higher mean phosphorus concentrations than all stations but SLD. Excluding hypolimnion samples, there were very few differences in measures of water quality between other stations within each lake. Nor were there differences between littoral and deep stations taken together. Whether this is because of horizontal mixing within the lake or because chemical inputs to the lake were evenly distributed is not clear. Mean chlorophyll *a* concentrations in 1977 were 2.3 ug/l in Lower Twin Lake and 5.0 ug/l in Upper Twin Lake (NES 1977) as compared to 3.01 and 3.05 ug/l, respectively, from our study.

The algae response was fairly typical of northern temperate lakes. The spring *Cryptomonas* peak in the upper lake, particularly at WUD, may be a function of a) cold water from runoff entering at Fish Creek, b) peak lake water levels bringing in nutrients from the west-end marsh/pasture, and c) a population already established from winter. *Cryptomonas* is capable of surviving very low light levels and temperatures and is often dominant under thick ice cover (Wright 1964).

The Crysophyta (diatoms) declined in the upper basin with the onset of high epilimnial temperatures (above 25 C by late July). Lower lake temperatures were moderated by its greater volume. As a result, Crysophyta did not decline to the same degree as in the upper lake. The diatoms increased in both basins after fall overturn when temperatures declined and nutrient concentrations increased.

Cyanophyta (blue-green algae) were dominant in both basins from July through September. Blue-green algae are not as palatable to zooplankton as are other algae types (Arnold 1971, Moss 1980). Because of physiological adaptations such as the ability to fix nitrogen and regulate their buoyancy, the blue-green algae are also more likely to cause visible blooms. The late July *Gloeotrichia* bloom was readily visible to the naked eye. The spherical, yellowish colonies have the potential to produce toxins that cause skin irritations to swimmers (Gentile 1971). Although homeowners had reported these problems in the past, we know of no cases during our study.

The benthic community cannot be correlated with lake productivity with confidence, but some generalizations can be made. Well oxygenated profundal communities usually consist of *Chironomus*, *Tanytarsus*, pelycopods and perhaps other insect larvae, but few oligochaetes.

Anaerobic sediments, on the other hand, often consist of one or two detritivore species (eg: *Chironomus anthracinus*) and large numbers of oligochaete worms (Moss 1980, Wetzel 1983). Oligochaetes are the major group associated commonly with high organic loading (Wetzel 1983). The benthic organisms at MLD are likely a result of the anaerobic conditions present at that station. The large number of oligochaetes at WUL-Mid mirrors the high organic content in the sediments. The fact that these organisms are not found at other stations with high organic content (Table 11) may be attributable to detrital particle size. The organic matter at most other stations consisted to a large degree of decaying macrophyte parts which were too large for oligochaetes to ingest.

TROPHIC STATE

Introduction

Technically, the trophic state of a lake refers to the nutrient supply to the lake (Goldman and Horne 1983). However, the term has evolved and now refers loosely to the productivity of the lake: an oligotrophic lake is infertile and a eutrophic lake is fertile (Moss 1980). Clearly, a continuum exists between these terms. In addition, the terms are not defined in a way that permits the objective classification of water bodies. A number of classification methodologies have been developed to describe a lake's trophic condition, but there is no concensus among limnologists as to which method is best, nor do limnologists agree as to what parameter or combination of parameters should be used to classify lakes. The classification of lakes is not a purely academic exercise. Public Law 92-500, section 314-A, requires states to classify their lakes and to initiate control measures in "excessively fertile" lakes (Rast and Lee 1978).

The ideal trophic state index should be objective, simple to compute, easy to collect data for, appropriate for comparing many different types of lakes, and easy to understand. In addition, it should correlated with phosphorus loading so that it can be used to predict the effects of phosphorus loading changes on trophic state, ie, for management. Most classification schemes use either nutrients or some biological expression of nutrients such as chlorophyll *a*, productivity, or secchi depth (Table 16).

Table 16. Some key water quality indexes for Upper and Lower Twin Lakes in 1985-1986.

Water Quality Characteristic	Upper Twin Lake	Lower Twin Lake
Mean[a] Chlorophyll *a* (mg/m^3)	3.05	3.01
Maximum Chlorophyll *a* (mg/m^3)	8.92	9.54
Mean Tributary TP Concentration (mg/l)	0.023	0.018
Mean Tributary TN Concentration (mg/l)	0.21	0.23
Mean Inflow[b] TP Concentration (mg/l)	0.029	0.024
Mean Inflow[b] TN Concentration (mg/l)	0.30	0.30
Annual P Loading ($g/m^2/yr$)	0.33	0.35
Mean[a] In-lake TP Concentration (mg/l)	0.014	0.016
Mean[a] In-lake TN Concentration (mg/l)	0.26	0.26
Mean TP:TN Ratio	18.6	16.3
Mean[a] Secchi Depth (m)	4.3	4.8
Minimum Secchi Depth (m)	2.8	2.6
Oxygen Depletion Rate ($mg/m^2/day$)	N/A	0.017
Epilimnion:Euphotic Zone Ratio	N/A	0.81
Hydraulic Residence Time, 1986 (T_w)	0.29	0.57

[a] Means of all stations and all dates.
[b] Includes all loading sources except internal.

In this section, we will classify Twin Lakes according to trophic state by several methods and discuss advantages and disadvantages of each.

Methodologies Based On In-Lake Conditions

The most straightforward way to classify lakes is to compare in-lake conditions. Twin Lakes' chlorophyll *a* and average in-lake phosphorus concentrations indicate mesotrophy while secchi depths indicate oligo-mesotrophy (Table 17). These descriptors are useful in a general way but are too vague to rank lakes according to management priority or to determine the degree of phosphorus control necessary to restore a lake to a pre-specified condition.

Carlson (1977) used linear transformations to convert secchi depth, total phosphorus, and chlorophyll *a* to scales of 0 to 100 with higher values indicating greater eutrophication. Each major division (10, 20, 30, etc.) corresponds to a doubling of the variable used in the index. Upper Twin Lake trophic state indices (TSI's) were 39, 38, and 42 for secchi depth, phosphorus, and chlorophyll *a*, respectively (mean=39.7); Lower Twin Lake TSI's were 37, 40, and 41 (mean=39.3). Canfield (1984) proposed adding the phosphorus contained in macrophyte biomass to in-lake phosphorus before calculating TSI. This yields TSI's for Upper and Lower Twin Lakes of 64 and 45, respectively. These latter values may indicate the trophic condition of Twin Lake if macrophytes were destroyed without removing them and their contained nutrients from the system.

Table 17. Limnological classification of Twin Lakes, Idaho.

Classification	Chlorophyll a (mg/m^3)	Secchi Depth (m)	Total Phosphorus (ug/l)
From Jones and Lee (1982)			
Oligotrophic	<2.0	>4.6	<7.9
Oligo-mesotrophic	2.1-2.9	4.5-3.8	8-11
Mesotrophic	3.0-6.9	3.7-2.4	12-27
Meso-Eutrophic	7.0-9.9	2.3-1.8	28-39
Eutrophic	>10	<1.7	>40
From OECD (1982)			
Oligotrophic	0.3-4.5	5.4-28.3	3.0-17.7
Mesotrophic	3.0-11	1.5-8.1	10.9-95.6
Eutrophic	2.7-38	0.8-7.0	16.2-386
Upper Twin Lake	3.05	4.3	14
Lower Twin Lake	3.01	4.8	16

The agreement between the three Carlson indices for Twin Lakes is quite good. There is often considerable variability between indices as a result of regional variations in the relationship between chlorophyll *a* and phosphorus or secchi depth as compared to those relationships in the data used to develop the indices (Osgood 1982). This agreement between Carlson's TSI's corroborates our use of predictive equations to relate loading rate to in-lake chlorophyll *a*, phosphorus, and secchi depths in order to predict the effects of loading changes on lake condition (see Hern et al. 1981).

Carlson's trophic index has been criticized as ambiguous and misleading because it does not consider light attenuation by substances other than algae (Lorenzen 1980, Megard et al. 1980). Secchi depth is a good predictor of algal biomass only at intermediate chlorophyll *a* concentrations, and then only if non-algal interference is small.

Phosphorus Loading - Trophic State Models

Vollenwieder (OECD 1971) quantified the relationship between phosphorus loading and trophic condition. Initially, his model consisted of a graph of areal phosphorus loading vs. mean depth. When the data from different water bodies were plotted, the points tended to be grouped on the graph according to trophic state. Lines were added representing the boundaries between oligotrophic, mesotrophic, and eutrophic zones. These lines, which can also refer to "dangerous" and "excessive" loading zones, were derived theoretically from Sawyer's (1947) eutrophic:mesotrophic:oligotrophic boundary criteria of 0.01 and 0.02 mg/l in-lake total phosphorus concentration. The original diagram has gone through several modifications, including the addition of a hydraulic residence time term and the modification of the boundary lines (Vollenweider 1975, Dillon 1974). (The above discussion is based on Rast and Lee (1978).)

Although the diagram has been developed with mathematical rigor, one should remember that the boundary conditions are still based, almost by convention, on Sawyer's original somewhat arbitrary criteria. In addition, the discontinuity between permissible and excessive loading which may be inferred by a casual review of the diagram, does not exist. The boundary lines do not define sharp zones which may be approached but not crossed, but provide a general guide only. Nevertheless, Vollenweider's relationship and Sawyer's criteria have been widely tested and have held up remarkably well.

Both Upper and Lower Twin Lakes plot well above the "permissible loading" line on Vollenweider's modified phosphorus loading diagram (Figure 20). If Twin Lakes are in a steady state, this indicates mesotrophy. It also indicates that management of phosphorus loading may be necessary to prevent Twin Lake's trophic condition from changing for the worse.

This nutrient loading:trophic state relationship is not a true index. There are no numbers to assign with which lakes can be ranked. While it is relatively objective, simple to compute, and useful for comparing different lakes, the data are difficult to collect and the diagram is difficult to understand completely. The advantage of this method of data presentation is that it can be used, in conjunction with equations predicting steady state in-lake phosphorus and chlorophyll *a*

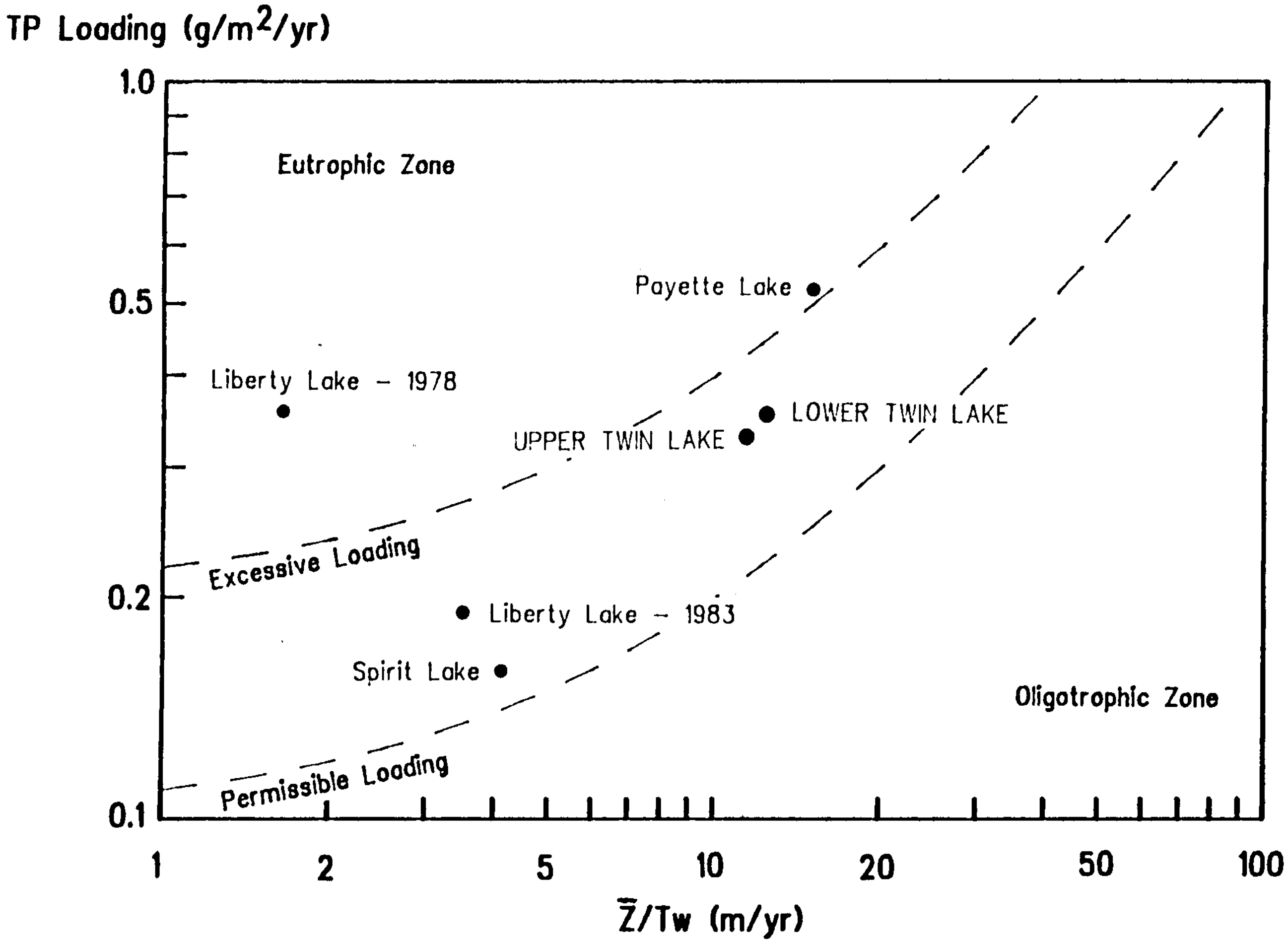


Figure 20. Phosphorus loading and mean depth/hydraulic residence time relationship in Upper and Lower Twin Lakes. Other lakes are plotted for comparative purposes and are approximations only. Liberty Lake is plotted for before (1978) and after (1983) rehabilitation.

concentrations given phosphorus loading, to graphically demonstrate the approximate effectiveness of different management alternatives.

The "Clean Lakes" Study

Milligan et al. (1983) inventoried over 1,300 lakes in Idaho and chose an 85-lake subsample, including both Upper and Lower Twin Lakes, to evaluate further. These 85 lakes were evaluated according to geomorphological, limnological, and socio-economic aspects. Each lake was assigned a TSI (not related to Carlson's (1974) index) and a priority classification. The lakes were then ranked according to management priority.

The TSI was based on 11 water quality/lake condition variables. TSI's ranged from 7.6 to 59.6 in the 85 lakes with oligotrophic lakes receiving lower values. Upper Twin Lake received a 9.3 and Lower Twin Lake a 10.0 (Spirit Lake TSI was 9.2); both lakes were considered to be oligotrophic (11.0 was the borderline between oligotrophic and oligo-mesotrophic). Milligan et al. felt that Twin Lakes received falsely low TSI ratings due to their late sampling of Twin Lakes and unseasonably cool temperatures prior to their sampling in September, 1981.

The priority classification was determined from a formula that considered TSI, the nutrient loading intensity, management potential, and importance of the lake. Loading intensity is an index of nutrient loading developed from land use and mean depth and is indicative of the rate TSI is likely to worsen; management potential was subjectively assigned as high, intermediate or low; and importance was a function of lake area and nearby population sizes. Both Twin Lakes were assigned very high indices of loading intensity, high management potential, and moderate lake use potential. Both were given a priority classification of 3. (Priority 1 lakes require immediate management consideration, priority 5 lakes are those with low use potential.) Had the lakes received a TSI even two points higher, as they perhaps should have, they would have been rated Priority 2. (Coeur d' Alene and Hayden Lakes were two of the six Priority 1 lakes in that study.)

Milligan et al. were not able to study any single lake in detail. Their ranking system was necessarily general and had poor resolution compared to a detailed lake study. Nevertheless, their data for Twin Lakes appear to be valid and, with the exception of a somewhat low TSI value, we concur with their conclusions.

Summary

The above models indicated that Twin Lakes are mesotrophic, or at best, oligo-mesotrophic. Considering both nutrient loading and internal physical, chemical and biological characteristics, we feel that Carlson's TSI of 39 on a scale of 1 to 100 accurately reflects Twin Lakes' current trophic condition.

MANAGEMENT ALTERNATIVES

A number of management alternatives are presented in the following section. The alternatives should be carefully reviewed and a lake preservation/restoration strategy should be developed that includes a combination of economically feasible options. We have included approximate costs for most of the management alternatives discussed that are averages of costs found in the literature. Cooke, et al. (1986) review many of the alternatives listed below and discuss case studies of each alternative.

Harvest of Rooted Aquatic Macrophytes in the Upper Basin

By late summer, the standing crop of rooted aquatic macrophytes in the shallow Upper Twin Lakes basin is at the maximal level of the year. This mass of plants is estimated to contain 477 kg of total phosphorus, an amount equivalent to 87% the total annual total phosphorus loading to the upper lake basin. The literature is in general agreement that little soluble phosphorus is released to the water column during the growing season by living aquatic macrophyte shoots. As these plants senesce and die, however, much of the total phosphorus reservoir is released to the water column and is instantly available for uptake by planktonic algae. This subsequent release of TP is available not just to Upper Twin Lake, but also to Lower Twin Lake after loading to that latter basin during the fall-winter-spring period of high water loading. It is quite likely that very heavy macrophyte growths in Upper Twin one year would produce heavy algae growths in Lower Twin the following year.

The upper basin has about 133 ha. (essentially 100% coverage) by mixed beds of rooted aquatic vegetation, mostly the pondweed *Potomogeton robbinsii*. At an average biomass of 61 - 110 g/m^2, this plant community represents a standing crop of 204,600 kg dry weight by late summer. These plants grow up from the bottom (*ca*. 4 m depth) to within 2 m of the surface throughout most of the shallow basin. Cutting and removal from the lake of the top 1m of these plants would remove approximately 150 kg total phosphorus each fall. Since the lower basin receives an annual loading of 527 kg total phosphorus, the assumption of a partial dieback and removal of perhaps 100 kg from Lower Twin's TP budget, could result in up to a 19% reduction of annual loading to the lower basin. Areal loading of total phosphorus into the lower basin could then decline from 0.335 to 0.27 g total phosphorus/m^2/yr. Macrophyte harvest could decrease total phosphorus loading to the lower basin from the "dangerous" level to nearer the "permissable" range in the relationship which considers total phosphorus loading in light of mean depth and hydraulic residence time (Rast and Lee 1978).

After harvest of these water plants, the material would have to be removed from the lake to avoid algae blooms occurring from the weeds releasing nutrients. Disposal could be economically realized through production of silage, or utilization of the nutrient- and organic-rich plant material after composting as a soil conditioner on the prairie where soil nutrients and humus are often in short supply.

The effect of this removal of *ca*. 150 kg total phosphorus/yr from the Upper Twin Lake should be a 10 to 20% reduction of planktonic algae in the lower basin as a result of less soluble P as loading to the lower lake. This would probably result in a projected mean chlorophyll *a* in the Lower Lake of *ca*. 2.5 mg/m^3 compared to the current 3.0 mg/m^3. Upper lake TP loading should decline by up to 40% (based upon regional experience in other lakes) with even greater reduction in summer fall algae blooms, especially if harvest occurred earlier in the growing season.

This management action would likely result in immediate improvement in water quality of the Lower Lake the following year by attenuation of algae blooms and improvement in lake color and transparency. Average water transparency should increase 10 to 20% in the lower basin and 15 to 25% in the north end of the lower basin. The north end of the lower basin consistently had higher chlorophyll *a* levels during this study, reflecting the proximity to nutrients coming into the lower basin from the upper basin.

In the United, States, aquatic plant harvesting has been running about $400/ha harvested. Total costs would be $53,200/year. Harvesting is generally more effective than herbicide treatments since it controls both aquatic vegetation and alage blooms (Cooke, *et al* 1986).

Grazing Control in the Upper Basin Watershed

We estimated that 8.5% of the total phosphorus loading and 5.4% of the TN loading to Upper Twin Lake is contributed by cattle grazing on the marshy meadows around the mouth of Fish Creek. The bulk of this loading is coming in from the livestock use of that part of the meadow which lies between the contours of full early summer lake level and minimum late summer level. Cattle concentrate in that area and their wastes are much more available to the lake since the meadow is either under water or will be the following spring. A solution would be to permanently restrict grazing animals from the meadow below full pool level by fencing (most of which already seems to be in place). Most of the grass production from that area could be utilized by cutting followed by removal in mid- and late-summer. This action would result in a reduction in total phosphorus loading to the Upper Lake of up to 40 kg/yr. This management action would also be especially significant to the lake since a high percentage of the grazing contribution is soluble, readily available phosphorus.

Management of the Forested Watershed for Nutrient and Sediment Control

Approximately 77% of the total phosphorus loading to Upper Twin Lake is coming in *via* tributaries which, in the Upper Twin Lakes watershed, translates to the forested lands as the ultimate source. In this report, we have been careful to not blanketly attribute this nutrient loading to forest management activities. Closer on-site inspection of these watersheds revealed that most of the sediments and nutrient loading seems to be derived from abandoned and eroding cuts, fills, and road beds over the entire upper watershed. Throughout the watershed, it is common for first and second order streams (the smallest and next smallest streams) to be cutting through and eroding their fine sediment banks. These deposits probably are bank storage deposits created by deposition of eroded sediments following the more damaging logging acitivities earlier in this century. These deposits will continue to be eroded and to move downstream to the lake basin unless stabilized.

Unregulated use of these watershed roads during all seasons of the year is a continual source of degradation. Falter and Reininger (1982) found similar conditions in the Craig Mountain watershed of Sweetwater and Webb Creeks south of Lewiston, Idaho. Following that study with its identification of the sediment and nutrient sources, land owners and management agencies cooperated to regulate both road and ORV use on upland streams since resulting road deterioration was judged to be the principal source of sediment and phosphorus to area lakes. In the Twin Lakes watershed, use could likewise be more restricted during wet seasons, or minimized on southwest sides of the basin where slopes are steeper and runoff has less distance to travel before intercepting the lake. North side tributaries drop much of their sediment load to bank storage along the low gradient meadows before reaching the lake. Such watershed use regulation would be comparatively easy in the Twin Lakes watershed since fewer land owners are involved than in the Craig Mountain watershed. Inland Empire Paper Co. is moving in this direction with some road closures and even removal or permanent putting to rest old, unneeded roads. Our study points out the value of these actions and strongly supports them.

We further recommend a survey effort in the Twin Lakes watershed to inventory and rate these continuing sources of sediment and nutrients. A priority action plan could then be initiated to set a plan of remedial action. The worst sources could be physically stabilized with lower priority sources simply re-vegetated to reduce downslope transport of sediments and nutrients.

This management action should be given top priority since the watershed contributes such a high percentage of the total nutrients to the lake. We cannot separate nutrient loading of natural runoff from the non-point loading from downslope, road, and stream erosion, but even a moderate reduction of the tributaries' contribution would be very significant to the lake. Watershed management offers the most cost-effective nutrient control action in the Twin Lakes management program.

Remedial Action on Domestic Wastewater Sources

Septic systems are presently contributing 4.3% of the total phosphorus and 2.3% of the TN to Upper Twin Lake and 11.1% of the total phosphorus and 4.7% of the TN to Lower Twin Lake. These phosphorus values are higher than septic estimates for some other lakes in the area (septic systems in Spirit Lake account for 7.6% of the total phosphorus; 5% of the total phosphorus and 14% of the TN in Hayden Lake; and 4% of the total phosphorus in Black Lake). Twin Lakes septic systems on average, are old, underdesigned, undersized, set too close to the lake, and located in soils of insufficient depth and nutrient absorptive capacity. Improvement of the generally antiquated systems around Twin Lakes margins would result in significant control of algae blooms and improved water transparency and color.

A likely initial step would be to target the most poorly functioning systems *via* a coordinated system survey and estimates of system functioning by dye and towed fluorimeter studies. Poorly functioning drainfields can have binders worked into their absorption areas; they can be relocated and rebuilt; In cases of no drainfields (such as with cesspools or buried absorption tanks), drainfields can be constructed for the first time. Many lots are deep enough to permit construction of new drainfields on the front, or top side of the lot, with wastes moved there by pump-up systems from a storage tank below each septic tank. Pump-up technology is well-proven and suitable for even the smallest, seasonal systems, but economies of scale are achieved by pooling of resources (and effluent) to create small scale community waste storage facilities or drainfields. This pooling would permit siting of drainfields further away from the lake. Most total phosphorus removal from wastes would be achieved by a 300′ travel distance from the lake if soil characteristics were suitable.

Pump-up systems should be seriously considered where cabins and homes are sited on bedrock ledges. A drainfield below the house in such a situation is ludicrous since it scarcely slows the effluent on the way to lake. In such situations, use of composting or incinerating toilets (*Clivus multrum* or Ecolets, respectively) should be seriously considered, especially where seasonal use is the norm.

The above alternatives would achieve significant reduction in total phosphorus loading to both lakes, but more significantly to Lower Twin Lake. Effectiveness would vary, but total phosphorus reduction in total loading would be proportional to the number of systems rebuilt. Elimination of the full 11.1% of the Lower Twin total phosphorus loading from septic systems (4.3% for Upper Twin) would, of course, be achieved by sewering of the lakes. We would assume mandatory pump-up systems to community drainfields far above the lake for those isolated subdivisions such as the south shore of Upper Twin Lake. Treated wastes could be pumped to the Rathdrum Prairie where they would be in high demand as pasture irrigation water. Complete sewering would result in a direct reduction of 69 kg total phosphorus from the upper basin's annual budgent and a 95 kg reduction from the lower basin's total phosphorus budget. The lower basin would realize a further reduction benefit since its major nutrient loading through the channel from the upper basin would further be reduced because of the removal of septic sources from the upper basin's total phosphorus budget. The lower basin should realize a total reduction of about 15% in total phosphorus loading. This should bring its total phosphorus loading from 0.335 to 0.29 g total phosphorus/m^2/yr.

Sediment Removal in Channel

The channel area between Upper and Lower Twin Lakes (water area between the bridge and the narrows) comprises *ca*. 8.8 ha. The area is extremely shallow, averaging 1 to 2 m depth. With high light intensity at the sediment surface throughout the summer, the presently very heavy growths of *Nuphar* (yellow water lily) will assuredly continue. Boat passage through this channel with large props inches off the bottom agitates the sediment surface and brings large quantities of nutrients into the water column even at low boat speeds. There is a large enough reservoir of phosphorus in these channel sediments to supply needs of Lower Twin algae populations for many years.

Vaccuum dredging of these surface channel sediments down to 2.25 m would deepen the channel enough to reduce the heavy growths of *Nuphar*, greatly retard sediment resuspension by boat wakes, and remove a large reservoir of phosphorus from the system. Removed sediment spoil could be pumped to a temporary drying basin back from the lake, then trucked to sites further removed for use as a needed soil conditioner. Ultimate nutrient control in the channel would be achieved by spreading a thin (*ca*. 4 mil thickness) plastic film over the winter ice cover of the channel. The plastic would blanket the sediments after dredging, effectively sealing plant nutrients in the sediments and retarding rooted plant growth. Fiberglass window screening material similarly applied is nearly as effective, lasts longer than the thin plastic sheeting, but is twice as expensive. The material costs are high, but this technique will provide control for 4-7 years. Application can be by a TLIA organized effort.

Our limnology study did not obtain the data necessary to calculate the nutrient contribution from this channel area so we cannot predict nutrient reduction from dredging this area. Improvement should be significant especially in the north end of the lower basin where algae populations were higher than in the rest of the lake, presumably since the north end first receives nutrients from the upper basin and from the channel area.

Approximately 90,000 m^3 of sediment removal would deepen the channel area to 2.25 m with some slope to in-shore areas. Nine dredging studies reported in the literature averaged sediment removal costs of \$2.25/m^3 of sediment removed and deposited in spoil areas. (0.3 - 110 ha areas). On that basis, this proposed dredging would cost \$202,000. Adjusting upward 20% for inflation, gives an estimate of \$243,000.

This estimate could be reduced by local participation by a highly organized lake association. Local participation and subsequent cost reduction could be especially significant where dredging is not used. Instead, material would be bulldozed from the dried sediments over the winter after a fall drawdown. This method of removal is much cheaper than dredging and more amenable to coordinated volunteer labor. Twin Lakes could be lowered 1-2 m below the natural low lake level by installation of temporary siphons at the outlet to permit channel sediments to adequately dry.

A major drawback to this lake lowering over winter is the reduction in oxygenated water volume to carry fish populations over the low oxygen period under winter ice cover. Some fish mortality is a strong possibility. Lake benthos and zooplankton population would also be negatively impacted, but would recover fully the following growing season with normal lake levels. Some turbidity could result the following spring when the lake is raised, but speeding up the fill cycle would reduce that to a minimum. There are several advantages of this lake drawdown:

1. Sediment removal would be cheaper and faster.
2. Less turbidity would result since the work would be done in the dry.
3. At the same time, sediment removal could also be occurring in other shallow regions of the Lakes.
4. Membrane or screen placement is cheaper and more effective in the dry.

We have not provided a cost estimate to this technique as earth removal contractors could provide an estimate more realistic than ours.

Sediment Removal from the Shallow Area of Lower Twin Lake Above Outlet

The same treatment recommended in the channel area would work well for the shallow reach of Lower Twin Lake just lakeward of the Rathdrum Creek outlet. The benefits from such action, however, would be largely restricted to that immediate area of the lake with little nutrient reduction to the rest of the lake's nutrient budget. Costs would still be about \$2.25/m^3 of sediment removed, but the benefits to the whole lake would be much less since the area is just above the lake outlet.

Hypolimnetic Aeration (Lower Twin Lake)

Lower Twin Lake undergoes pronounced thermal stratification from mid summer through early fall and again as an inverse stratification in winter under ice cover. At these times, the water column below *ca.* 10 m either is anoxic, or approaches anoxia.

During these low oxygen periods, internal loading of phosphorus (as detailed in this report, mostly regeneration of soluble phosphorus to the water column from the sediments when under an anoxic hypolimnion) is substantial, amounting to 19.2% of the total phosphorus annual loading to the lake. Raising the oxidation-reduction potential at the sediment-water interface below the 10 m contour would greatly attenuate exchange of P from sediments to the water column.

Increased oxygen over these deep sediments can be achieved by two general approaches:

1) Pumping of warm surface water into the hypolimnion, thereby destabilizing the cold, deep layers and reoxygenating them at the same time. The end result is a water column undergoing continual mixing top to bottom through the otherwise stratified periods. Phosphorus tends to be reduced at the elevated oxygen levels resulting from the mixing. Surface algae blooms are correspondingly reduced. The resulting overall warmer water column may, however, become undesireable for salmonids in the summer.

2) Pumping of either compressed air or oxygen into the stratified hypolimnion. The result is reoxygenation of deep, anoxic layers, raising the oxidation-reduction potential, and retarding the transfer of phosphorus to the water column. If the air or oxygen volume pumped is carefully controlled to ensure complete solution of bubbles before they ascend up through the metalimnion and thereby destroy stratification, the result can be reoxygenation of deep waters while still containing them in the deep, dark, non-productive depths. Any tendency of fertilizing summer surface algae populations with nutrient-rich deep water is avoided. Maintenance of cold temperatures over the bottom muds through the summer period also reduces the nutrient supply eventually delivered to surface waters at fall overturn by retardation of the diffusion process. Fall algae blooms are thus reduced.

The second method, pumping of air or oxygen to the hypolimnion, is preferred for the stated algae production reasons, and also because that method provides optimal salmonid habitat through the otherwise limiting warm months. Rainbow trout and kokanee salmon are presently forced to spend much of the summer months "squeezed" in the 5-10m water layer as they must go at least to a depth of 5m to obtain their cooler preferred water temperatures and yet remain shallower than 10m to obtain their oxygen requirements. Aeration would effectively give them more useable habitat for feeding and growth. Air or oxygen pumping is also best in the winter for salmonid habitat enhancement, another stressful period in Twin Lake limiting fish yield. It should improve holdover of these fish during the winter.

This air or oxygen pumping method is also cheaper to incorporate than water circulation. Two aeration devices are recommended for Lower

Twin Lake....one set on the bottom in each of the two deep holes at depths of 18 m. Each would be supplied compressed air or oxygen *via* a single hose running from an on-shore compressor. It would be sized to run continuously from late June to mid-September, delivering enough air to the hypolimnion to oxygenate, but not overturn the deep layer. Air delivery rates of 1.17 m^3/minute maintained through the 117 day summer stratification period would keep hypolimnion waters at 40-70% saturation. Some under-ice aeration may be required as well. Installation costs would be about $172,000 and operating costs would be about $23/day.

Incorporation of this alternative could be expected to reduce hypolimnetic total phosphorus during stratification periods by 30 to 70%. Planktonic algae in the overturn periods following stratification will be much reduced, but aeration must continue during subsequent stratifications because of high phosphorus reserves in the sediments. Algae populations are further reduced because of the enhanced zooplankton populations and subsequent intensive grazing (esp. by *Daphnia*). Salmonid populations nearly always show dramatically increased growth after hypolimnetic aeration because they can then forage deeper into the formerly anaerobic layers and because of the improved zooplankton food supply.

Deep Water Dredging in Lower Twin Lake

Considering the high contribution of total phosphorus to the water column by internal loading, deep dredging for nutrient-rich sediment removal is a possibility. Dredging is expensive, however, and exceptionally expensive when considered in waters deeper than 8 m. We feel that little would be gained over the results achieved by the above-described deep water aeration. Deep water dredging in Lower Twin Lake is not a cost-effective option.

Shallow Water Dredging in Lower Twin Lake

In the course of our SCUBA diving and sediment sampling around Lower Twin Lake, we observed the sand-rubble shorelines disappearing beneath a layer of flocculant organic ooze beginning at a depth of about 1m. Proceeding lakeward, the ooze deepens (*ca*. 0.4m thickness at 6m depth and becoming progressively deeper into the profundal zone). This is a normal phenomenon associated with lake aging....lakes undergoing more accelerated eutrophication such as Twin Lakes simply have acquired this ooze layer at a more rapid pace in the last 60 years. These sediments are a source of several problems in mesotrophic, heavily used lakes such as Twin Lakes:

1. A nutrient supply to the productive shallow waters around the lake margin;
2. A rooting medium for rooted aquatic macrophytes with their accompanying problems of nutrient supply and esthetic considerations in heavier densities at the shoreline;
3. A source of turbidity in the wave-washed shallows;
4. Covers the cobbles of littoral areas precluding spawning by lake whitefish, kokanee, and rainbow trout; and,
5. Not esthetically pleasing to swimmers.

Vaccuum dredging can effectively remove the top 0.5 to 1.0m of these flocculant, nutrient rich sediments from the lake, leaving the clean cobble substrate which historically was a feature of Twin Lakes and other north Idaho lake shorelines.

The natural shape of the Upper Twin Lake basin renders dredging an unfeasible alternative in the upper basin....too many factors are working to keep that basin shallow and its shorelines gradual.

Lower Twin Lake, however, does offer some excellent possibilities for sediment removal from shallower depth contours, *ca.* from the 1-4 m depth contours. The depth of 4 m was selected because it is approximately the depth at which the lake bottom slope steepens and leaves the littoral zone. Sediment removal from the shallow bands around Lower Twin Lake should be approached cautiously, however, so as not to increase water loss to groundwater by excessive disruption of the sediment seal on the lake bottom. We do believe that most loss to groundwater at present occurs from these shallower contours around the lake, especially on the north and east margins of the lower basin.

Approximately 440,000 m^2 of shallow sediment in this in-shore band could be dredged, mostly on the N, NE, and E shore of Lower Twin Lake. We estimate approximately 250,000 m^3 of littoral bottom sediments in Lower Twin Lake would benefit from this treatment for a total cost of *ca.* $ 500,000. Phosphorus reduction accruing from this action is difficult to calculate since we did not estimate nutrient supply from this source. We would approximate only a 20 kg reduction of total phosphorus a year from this source in Lower Twin Lake.

Lake Level Control

Lake level manipulation is sometimes used to achieve reduction of rooted aquatic plants by summer dessication and winter freezing. The technique offers little to Twin Lakes for the following reasons:

1. Most of the rooted aquatic plants controllable by drawdown are deeper than 2m, the area of routinely feasible drawdown. The plants that are in heavy abundance in the 0 - 2 m zone are primarily emergents and floating leaved varieties which are little affected by sporadic drying and freezing.
2. Summer lake levels are largely controlled by downstream irrigation needs.
3. Drawdown would reduce the volume of high oxygen living space for fish, crowding them into central areas of the lake.
4. Recreation use would suffer from summer drawdown.
5. A smaller summer water volume would undoubtedly exacerbate algae blooms by providing less dilution for summer nutrient loading. Any summer water removal is undesireable because the mean depth/T_w ratio (T_w is the hydraulic residence time) will become smaller, hence rapidly putting the relationship of total phosphorus loading:mean depth/T_w further to the left and into the "dangerous" and "excessive" zone (see Figure 20).

Chemical Treatment

A feasible chemical treatment is dosing the lake with alum (aluminum sulfate) which forms a floc when added to lake water. This sinks to the bottom carrying with it most suspended matter and total phosphorus in the water column. The phosphorus is for all practical purposes, permanently bound in the sediments. With no further control of nutrient inputs, recovery to former total phosphorus levels is a function of the T_{90} (time for nutrient levels to decline to within 90% of average inflow concentrations), but slowed somewhat as the floc continues to absorb total phosphorus. Reduction of total phosphorus concentration and algae would be dramatic, probably to levels 10 - 20% of pre-treatment levels. Internal loading of total phosphorus would be reduced by 50 - 70%. Transparency could be expected to increase to 7 - 10 m in the first year after treatment, declining closer to pre-treatment levels each year. Further treatment would probably be required by year 4. Alum treatment would be ineffective in the upper basin since it does not offer total phosphorus control in lakes shallower than *ca.* 3 m. After alum treatment, some restriction of powerboat speed in shallow waters would be necessary to prevent resuspension of the phosphorus-rich sediments.

Treatment costs for comparable water volumes have run \$2,435/million m^3. Allowing a 20% inflationary increase, the lower basin could be treated for approximately \$40,000. Liberty Lake alum treatment costs were \$5,730/million m^3, making the lower basin estimate *ca.* \$94,000.

Individual Property Owner Action

* Update sewage disposal systems that are antiquated, clogged, or with drain fields sited closer than 300 feet to the lakeshore. Small scale "community" approaches might work where several landowners might jointly acquire and develop a drainfield easement

on a site set well back from the lake shore.
An "antiquated system", for example, is a buried 55 gallon drum with holes punched in it.

* Don't use detergents containing significant (> 0.5%) amounts of phosphorus. The following detergents contain little or no (< 0.5%) phosphorus:
  Laundry detergents: ERA Plus, YES, Dynamo, Tide liquid, All, Purex, Arm and Hammer liquid, Trend, Wisk, Purex, and Sun.
  Dish Washing Detergents: Palmolive, Dawn, Ivory, Joy, Sunlight, Lux, and Sweetheart. Most automatic dishwasher detergents contain high phosphorus.
  Cleansers: 409, Fantastic, and Bon Ami.
  If your detergent is not on this list, check its label for phosphorus content. Some detergents contain up to 5 - 8% of phosphorus (Dash, Fab, Bold, Oxydol, and Cheer).

* Don't wash dogs, horses, car, and boats, etc. at the lake shore. This direct loading of the dirt, soaps, and chelating agents of even low phosphorus detergents to the lake will be significant.

* Don't burn trash and slash on the beach, or at least carry the ashes away for upland disposal. These ashes are readily soluble nutrients, effectively instant fertilizer for the lake. Springtime beach burning makes great fertilizer for the beachfront attached algae and water weeds later in the summer.

* Water in moderation and use lawn and garden fertilizer sparingly. Any used in excess of plants' immediate requirements may well end up fertilizing the lake.

* Consider converting lawns adjacent to the lake to natural areas which control runoff and yet don't require fertilizer and water.

* Minimize overland runoff to the lake from roads, drives, rooftops, patios, livestock yarding areas, and construction areas. Consider small stormwater containment areas which might double as ornamental ponds toward the bottom of your property.

* Be especially vigilant with construction activities adjacent to the lake. Any ground-disturbing action will supply nutrients and sediment to the lake during following storms.

* Restrict direct pet and livestock use of the immediate lake shoreline to reduce bottom churning and direct nutrient additions.

* Boat usage:
    - Avoid boat bilge pumping into the lake.
    - Consider control of maximum engine size on the lake.
    - Encourage use of well-tuned boat engines.
    - Encourage use of electric trolling motors.
    - Encourage use of 4-cycle rather than 2-cycle engines. They are more than twice as efficent in gasoline consumption.
    - Consider no-wake zones and no-speedboat zones in shallows

(Many of the above will reduce nutrient loading from shorelines and shallow bottom sediments.)

* See that public toilets are provided at ramps and public swimming areas.

* After cleaning fish, keep the remains out of the lake.

Each of the above is a small contribution, but in aggregate, will be significant to the lake's health.

A number of management alternatives have been described above (summarized in Table 18). Presumably, some combination of lake restoration/protection methods will be implemented in Twin Lakes in the next few years. Lake response to the various methods employed can be predicted from relationships presented in Rast and Lee (1978) between nutrient loading and chlorophyll *a* (Figure 21) and chlorophyll *a* and secchi depth (Figure 22). (The lines of best fit on these diagrams are based on a regression of data from dozens of different lakes; when plotted on the original graphs, Twin Lakes falls well within the range of data points from other lakes.) The original condition should be plotted and the predicted response determined by moving parallel to the line of best fit. For example, the following actions might reduce total phosphorus loading to Lower Twin Lake by the listed percentages: grazing control (4.5%), wastewater system upgrading (6%), watershed management (4%), miscellaneous individual actions (2%), and hypolimnetic aeration (10%). The total reduction in phosphorus loading would be 26% and the new loading rate would be 0.25 $mg/m^2/yr$. (Caution: not all actions are additive; for example, hypolimnetic aeration and alum treatment would both affect internal loading.) From Figure 21, the new equilibrium chlorophyll *a* level would be 2.39 ug/l (down from 3.01) and, from Figure 22, the new secchi depth would be 5.35 m (up from 4.80). Because

Table 18. Summary of management alternatives. Priority 1=should be implemented; priority 2=options; priority 3=not recommended. Nutrient loading reductions and costs are approximate.

Action	Basin	Priority	Reduction in Annual P Loading	Cost to TLIA[a] $
Macrophyte Removal	Upper	2	<19%	53,200 annually
Grazing Control	Upper	1	<6%	0
Watershed Management	Both	1	Indef. (0-10%?)	0
Wastewater Management				
Upgrade	Both	1	up to 8%	0
Sewering	Both	2	up to 15%	?
Channel Dredging	--	2	Not Determined	243,000
Hypolimnetic Aeration	Lower	2	10%	172,000 (+3100 Annually)
Deep Water Dredging	Lower	3		
Shallow Water Dredging	Lower	3		
Lake Level Control	Both	3		
Chemical Treatment[b]	Lower	2	11%	50,000-94,000
Misc. Individ. Action	Both	1	Indef. (0-5%?)	0

[a] Assumes volunteer organizational labor by TLIA

[b] In-lake TP temporarily reduced 80-90%.

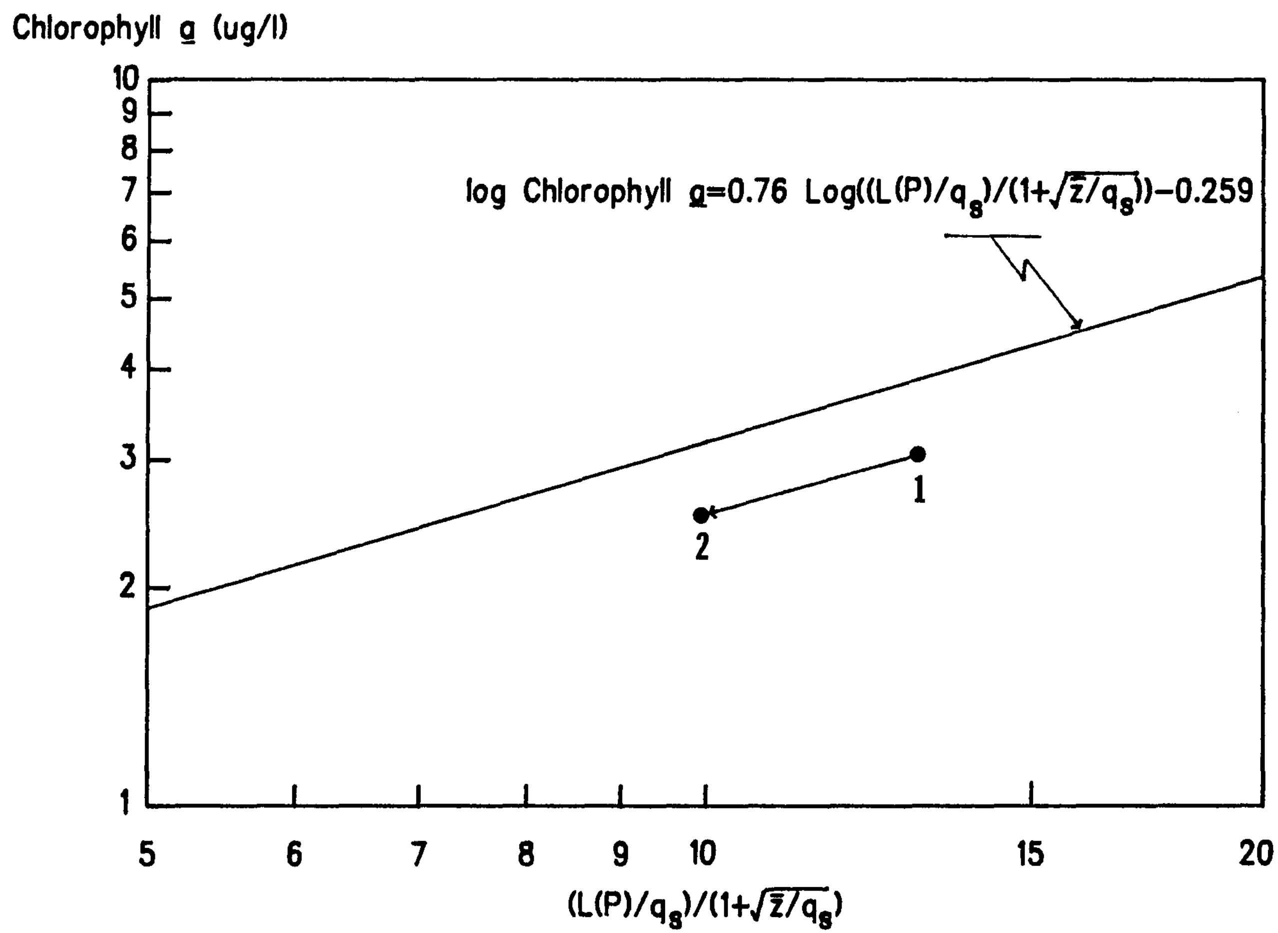


Figure 21. Phosphorus loading - mean chlorophyll *a* relationship (after Rast and Lee 1978). L(P)=phosphorus load ($mg/m^2/yr$); q_s=areal water load (m); z=mean depth (m). Point 1 refers to Lower Twin Lake in WY 1986. Point 2 is after hypothetical 26% reduction in phosphorus loading. See text.

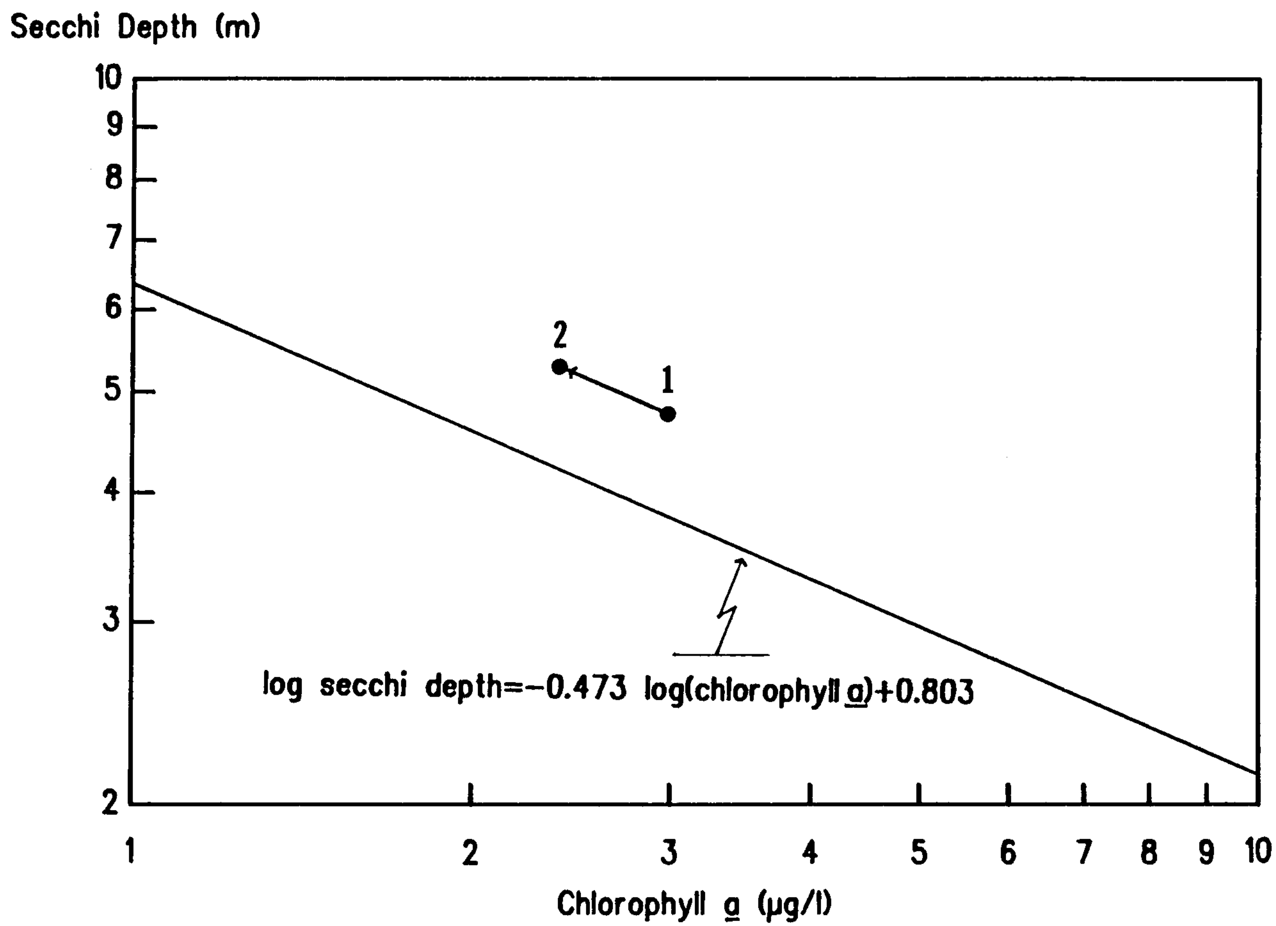


Figure 22. Mean chlorophyll *a* - secchi depth relationship (after Rast and Lee 1978). Point 1 refers to Lower Twin Lake in WY 1986. Point 2 is after hypothetical 26% reduction in phosphorus loading. See text.

nutrient loading varies with different hydrologic regimes and because the relationships for Twin Lakes are based on only one year of data, this method may not predict *absolute* chlorophyll *a* concentrations and secchi depths. However, the *relative* improvement attributable to different lake management strategies can still be evaluated.

After any package of nutrient reduction actions have been taken, lake response should be fairly rapid. The time required to achieve a reduction in lake nutrient concentration to a level 90% of the average inflow concentration can be approximated by the relationship T_{90} = ln (10/hydraulic flushing rate). For the upper basin, T_{90} is estimated at 1.1 years while T_{90} for the lower basin is 1.7 years. In other words, 1.7 years after remedial action in the lower basin, nutrient content of lower basin lake water should have dropped down to a new equilibrium value which would be within 90% of average inflow nutrient concentrations. T_{90} is less for the upper basin because the upper basin flushes more rapidly.

A few years after the implementation of an agressive and comprehensive lake and watershed management strategy as outlined above, lake users could experience lower chlorophyll a levels, shorter and less severe algae blooms, slower macrophyte growth, less beach debris, and increased cold-water fish yield. At the very least, more management than at present is required to prevent a further decline in water quality and recreational enjoyment in Twin Lakes.

CONCLUSIONS

1. Upper Twin Lake had a mean depth of 3.3 m, a surface area of 195.6 ha, and a volume of 6.4 x $10^6 m^3$ at a lake level of 8 ft on the Rathdrum dam staff gage. Lower Twin Lake had a mean depth of 6.9 m, a surface area of 158.1 ha, and a volume of 10.9 x $10^6 m^3$.

2. Surface inflow volumes plus precipitation to Twin Lakes totaled 24.75 x 10^6 m^3 in Water Year 1986. Surface outflow volumes plus evaporation totaled 11.79 x 10^6 m^3. Accounting for withdrawals (0.4 x 10^6 m^3) and changes in storage, annual subsurface discharges to groundwater of 13.42 x 10^6 m^3 (11,003 acre-feet) were calculated by difference between inflow and outflow volumes.

3. Total phosphorus loading to the upper lake in WY 1986 was 655 kg (0.33 $g/m^2/yr$). Tributaries were responsible for 75.6%. At most, 3.4% was from logging, excluding roads. Cattle were responsible/ for 8.5% of the total, 10.1% came from precipitation, 4.9% from wastewater systems, and 3.5% from internal sources.

4. Total phosphorus loading was 555 kg (0.34 $g/m^2/yr$) to the lower lake. Tributaries and the discharge from the upper lake were responsible for 61.1%, 9.7% came from precipitation, 11% from wastewater systems, and 18.2% from internal sources.

5. Upper Twin Lake has extensive macrophyte cover (89% of the bottom area) of predominantly *P. robbinsii*. Late August macrophyte standing crop was 298,649 kg (dry weight). Upper lake macrophytes contained 466 kg of phosphorus at late August densities.

6. Upper Twin Lake water column mean phosphorus concentration was 14 mg/m^3, chlorophyll *a* was 3.05 mg/m^3, and secchi depth was 4.3 m. These factors and others indicate that the upper lake is mesotrophic to oligo-mesotrophic.

7. Lower Twin Lake water column mean phosphorus concentration was 16 mg/m^3, chlorophyll *a* was 3.01 mg/m^3, and secchi depth was 4.8 m. The lower lake was stratified from early June until mid-October and hypolimnetic oxygen depletion was pronounced. Lower Twin Lake is mesotrophic to oligo-mesotrophic.

8. Both lakes exhibited a *Gloeotrichia* (a planktonic blue-green algae) bloom in late July.

9. Phosphorus is the nutrient limiting plant yield in Twin Lakes. Hence phosphorus control is the key to an effective management strategy.

10. Management alternatives recommended for immediate implementation include rehabilitation and/or closing of selected roads in the watershed, inspection and upgrading of wastewater treatment systems, education of lake users, and implementation of a cattle

grazing plan in keeping with water quality concerns. Recommendations for later implementation include macrophyte harvest and removal from Upper Twin Lake, dredging of the shallow channel area between the upper and lower basins, and hypolimnetic aeration in Lower Twin Lake.

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GLOSSARY

Where possible, these definitions were taken from the American Heritage Dictionary or the Institute of Ecology (1973). Some definitions are simplified or defined only in the context in which we used them.

Aerobic - Air or free oxygen is present.

Aloquat - A measured sub-sample.

Anaerobic - Air or free oxygen is absent.

Autotrophic Index - Organic weight divided by chlorophyll *a*. A measure of the portion of organic matter that is photosynthetic.

Benthic - Of the bottom of lakes

Biomass - The weight of matter in living and dead organisms.

Bioturbation - The disturbance of sediments by organisms.

Capita Year - Number of people times number of days per year per person.

Chironomid - The larvae of midges.

Chlorophyll *a* - The green, photosynthetic pigment in plants.

Cladocera - A tiny (<3 mm long) crustacean; often called "water fleas".

Coliform - A bacteria from vertebrate intenstine or bacteria resembling intestinal bacteria.

Compensation Level (or point) - Depth of a water body where light available is just sufficient for photosynthesis to balance respiration.

Copepod - A tiny (<3 mm long) crustacean; somewhat torpedo-shaped.

Diversity Index - eg: "Shannon-Weaver"; A measure of the numbers of species of organisms and the distribution among the species.

Epilimnion - The water layer in a lake above the horizontal plane marked by the maximum temperature and density gradient.

Equitability - A statistical measure of the evenness of the distribution of organisms among species.

Eutrophic - Literally, "nutrient rich". Generally refers to a fertile water body.

Eutrophication - The natural process of becoming eutrophic. Cultural eutrophication refers to man-caused contributions to the eutrophication process.

Export Coefficient - The mass of a substance (generally nitrogen or phosphorus) per unit area of watershed per unit time leaving that watershed in surface runoff.

Exuviae - The cast of skin coverings of various animals. Generally refers to the molted exoskeletons of insects.

Flushing Time - The time required for all a lake's water to go out the outflow.

Hydraulic Residence Time (or Retention Time) - The time required to fill the lake if it were empty.

Hydrograph - A graph of flow volume per unit time versus time, generally one year.

Hypolimnion - The water layer in a lake below the horizontal plane marked by the maximum temperature and density gradient.

In Situ - In its original place. In the field as opposed to in the lab.

Internal Loading - The release of lake sediment-associated nutrients into the water column.

Limnology - The study of the biological, chemical, and physical features of inland water.

Littoral - Of the shoreward region of a water body where light penetrates to the bottom.

Loess Soil - A fine-grained, calcareous silt or clay, thought to be a deposit of wind-blown dust.

Macrophyte - Non-microscopic aquatic plants.

Mean Depth - The lake's volume divided by surface area.

Mesotrophic - Literally, "moderate nutrients". Generally refers to a moderately fertile water body.

Metalimnion - The zone over which temperature drops relatively rapidly with depth.

Morphoedaphic Index - An index combining mean depth and total dissolved solids thought to be indicative of fish yield.

Morphometry - Of or pertaining to shape, ie, the form of the lake basin.

Nauplii - Immature copepods.

Nutrient Loading - The addition of nutrients, usually nitrogen and phosphorus, to a lake; often expressed as g per m^2 of lake surface per year.

Oligochaete - Aquatic earthworms. May range from several millimeters in length to the size of the common garden variety or larger.

Oligotrophic - Literally, "nutrient poor". Generally refers to an infertile water body.

Overturn - The complete circulation or mixing of upper and lower layers of water when temperatures (and densities) are similar.

Phaeophytin - A degradation product of chlorophyll.

Phytoplankton - Small, microscopic plants floating in the water column.

Planimeter - A device used to measure the area of a plane figure.

Profundal - The deeper portion of a body of water below the area of plant growth.

Redox - Reduction-Oxidation; Reactions between molecules involving the gain and loss of electrons.

Relative Depth (Z_r) - A relationship between mean depth and surface area of a lake; $Z_r > 4\%$ indicates high nutrient absorbtion capacity.

Rotifer - A phylum of mostly freshwater microscopic organisms that feed on small organic particles and algae.

Secchi Depth - The average of the depths at which a 20-cm black and white disk lowered into the water is no longer visible and becomes visible again when raised.

Senescent - Aging, growing old.

Shoreline Development Index (SDI) - A measure of how circular a lake's shoreline is; SDI for a perfect circle = 1.0.

Stratification - The division of water into non-mixing layers of different temperatures and densities as a result of differential heating of the water column.

Transect - A line through a community.

Trophic - Of nurishment or feeding. See eutrophic and oligotrophic.

Turbidity - Condition of water resulting from suspended matter; water is turbid when suspended material is conspicuous.

Water Year - October 1st to September 30th.

Zooplankton - Small, non-vertebrate animals floating in the water column (usually refers to rotifers, cladocera and copepods).

APPENDIX A. HYDROLOGY

The reader is cautioned not to use flow volume data presented here for applications other than those discussed in this report. Water-use planning requires more intensive sampling than was economically feasible in our study.

TRIBUTARIES

Tributary flow volumes were measured by one or more of following methods:

1) Larger streams were gaged by summing the product of cross-sectional areas and flow velocities measured at six inch to two foot intervals across the stream (depending on stream size). Flow velocities were measured with a Marsh-McBirney electromagnetic flow meter.

2) Shallow streams were sometimes gaged by the product of flow velocities measured with flourescent dye and total stream cross-sectional area.

3) Where possible, flow rates in small streams were determined by timing the filling of a bucket.

Prior to April 1985, the beginning of the study, Fish Creek flow data were calculated from staff gage records collected by Meckel Engineering (unpublished data) at a staff gage at the bridge on the Easterday Ranch. We calibrated this gage and applied a correction factor to convert flows at this point to flows at the creek mouth, 1.9 km downstream. Flows during WY 1986 were monitored most frequently during periods of high runoff. Annual flows in Fish Creek, the major inlet to Twin Lakes, were determined as follows:

1) A linear regression was performed between measured Fish Creek flows (n=12) and corresponding five-day mean flows from Blanchard Creek, the nearest USGS gaged station (Blanchard Creek's headwaters are only a few miles from the headwaters of Fish Creek). The equation for WY 1986 was

$$\text{Fish Flow} = 5.25 + 1.224\ (\text{Blanchard Flow}) \quad (r^2=0.89).$$

2) The regression equation above was used to calculate Fish Creek flows from five-day means of the Blanchard Creek data (Figure A.1).

3) The resulting hydrograph was divided into sections with each section containing a flow volume measurement. Total flow volume and flow volume in each section was then determined by planimetry.

Flows (Q) in each hydrograph section for the i^{th} tributary stream were determined from the following equation:

$$Q_{ith\ stream} = Q_{Fish}(\text{Measured Flow}_{ith\ stream}/\text{Measured Flow}_{Fish})$$

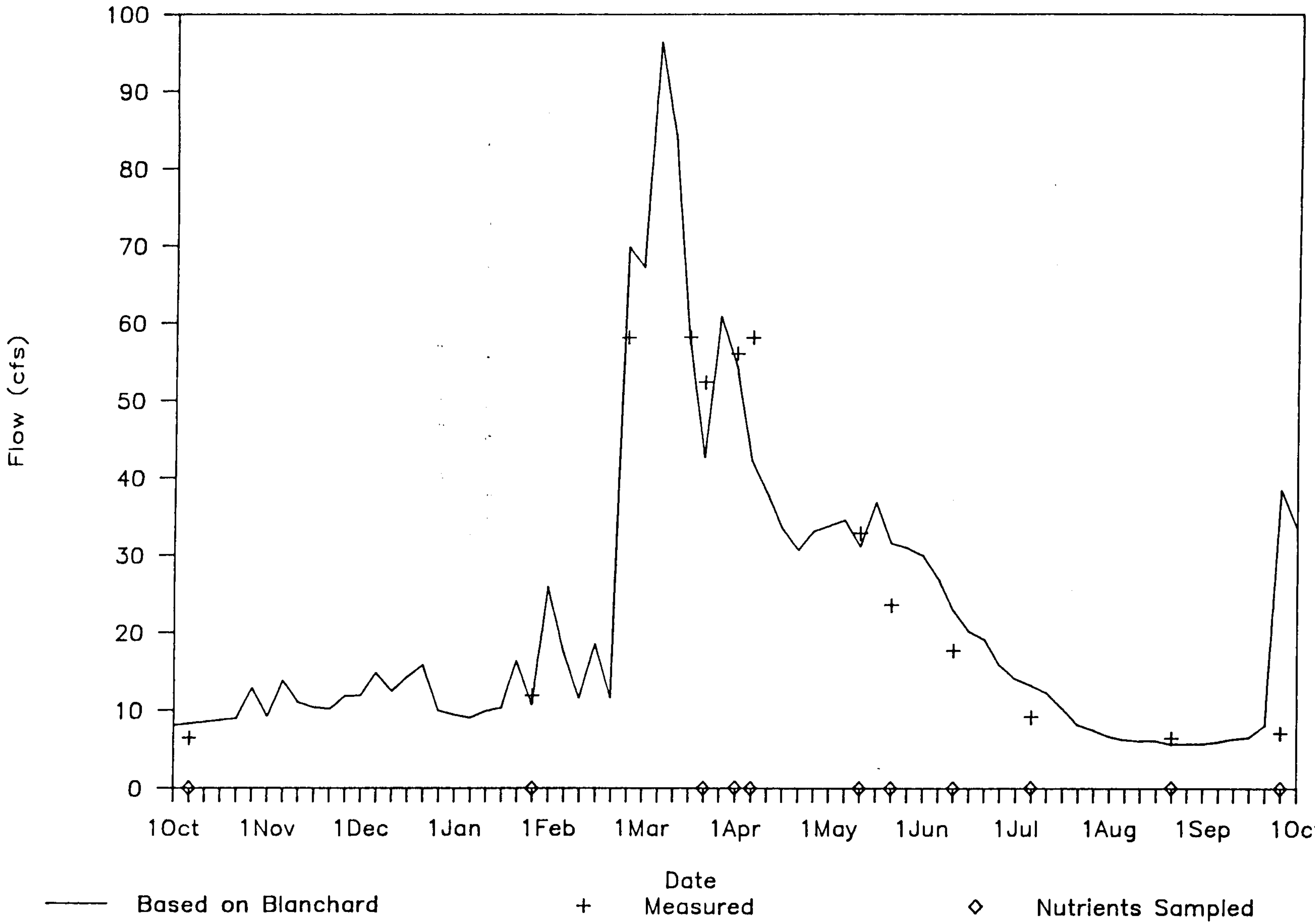


Figure A.1. Fish Creek flows in WY 1986 based on five-day means of Blanchard Creek flow data.

The staff gage at Rathdrum Creek, the only surface outflow from Twin Lakes, was read daily in WY 1986, with the exception of the early winter months (Figure 6). Staff gage readings were calibrated from flow measurements taken as described above. Rathdrum Creek and lake level data from before April 1985 were provided by the county commissioners office (unpublished data).

Table A.1 lists data collected from tributary monitoring.

STORAGE

During the study period, the lake level varied from 6.00 ft on the staff gage to 10.52 ft. Based on depth-volume curves (Figure A.2), this range corresponds to a storage capability of 4.8×10^6 m^3 (4000 acre-ft).

Tables A.1 and A.2 list data collected from tributary and lake level monitoring.

PRECIPITATION

Precipitation volume was recorded daily. Table A.3 lists monthly totals for 1982 through 1986. Total precipitation in WY 1986 in five-day periods is shown graphically in Figure A.3.

Evaporation is rarely measured, but can be estimated from regional evaporation isopleths. We estimated average annual evaportation to be 81 cm/yr (32 in/yr), with 51% occuring during June through August (Molnau and Kpordze 1986).

GROUNDWATER

Groundwater flows are difficult to determine directly. We determined net subsurface flows in a given period by the following equation:

$$GW=(Tribs+Precip)-(Outflow+Evap)\pm Storage\ Change$$

This method does not separate direct overland runoff, which we assume to be minimal, or lake withdrawals from groundwater flows.

Lake withdrawals were roughly estimated from existing water rights. Twin Lakes Village has water rights to about 210,000 m^3/yr, Twinlow Church Camp has rights to about 97,600 m^3/yr and Twin Echo Resort to about 12,200 m^3/yr. About 260 other water rights are held on Twin Lakes to a total of about 76,000 m^3/yr. Even if full rights were exercised, which is unlikely, withdrawals only explain a small fraction of the "unaccounted for" water. It is clear that most of the water leaving Twin Lakes is discharged to groundwater.

Table A.1. Nutrient loading to Twin Lakes from tributaries.

Site	Number	Date	Flow (cfs)	Flow (m3/s)	Temp (C)	Cond (umhos)	Time	Cl- (mg/l)	NO3-N (mg/l)	TKN (mg/l)	TP (mg/l)
Fish Creek at Mouth	1b	17Apr85	122.8	3.4384	6	15	820	<0.5	<0.02	0.12	0.019
		23Aug85	6.93	0.19404	10.5	28	940	0.5	<0.02	0.14	0.035
		03Oct85	6.48	0.18144	4.6	20	940	<0.5	<0.02	0.14	0.028
		28Jan86	11.95	0.3346	NA	NA	NA	NA	0.04	0.19	0.024
		20Mar86	52.34	1.46552	5.1	14	1621		0.06	0.16	0.023
		29Mar86	56.07	1.56996					0.20	0.30	0.030
		3Apr86	58.14	1.62792					0.04	0.12	0.027
		10May86	32.86	0.92008					<0.02	0.13	0.009
		22May86	23.58	0.66024	7.3	14	1655		0.06	0.13	0.013
		12Jun86	17.72	0.49616					<0.02	NA	0.025
		3Jul86	9.2	0.2576	9	19	1140		<0.02	0.14	0.024
		20Aug86	6.51	0.18228	17.9	12	1515		<0.02	0.26	0.044
		25Sep86	7.2	0.2016					<0.02	0.18	0.025
Irrigation Canal	2	17Apr85	7.98	0.22344	6.5	20	800	<0.5	<0.02	0.14	0.016
		23Aug85	Dry								
		03Oct85	Dry								
		20Mar86	3.65	0.1022	4.1	12	1720		<0.02	0.10	0.014
		3Apr86	2.59	0.07252	6.4	19	1500		<0.02	0.10	0.013
		10May86	0.6658	0.0186424	8.7	20	1628		<0.02	0.08	0.008
		22May86	0.3207	0.0089796	9.3	24	1725		0.04	0.12	0.008
		3Jul86	0.0552	0.0015456	17	27	1215		<0.02	0.20	0.023
		20Aug86	Dry								
Seep	3	17Apr85	0.08	0.00224	7	23	900	<0.5	<0.02	0.14	0.020
		23Aug85	Dry								
		03Oct85	Dry								
		20Mar86	0.08	0.00224	6.1	18	1745		<0.02	0.24	0.064
		3Apr86	0.064	0.001792	10	27	1635		<0.02	0.14	0.023
		10May86	0.0106	0.0002968	10	31	1645		<0.02	0.22	<0.004
		22May86	0.0089	0.0002492	11.9	32	1740		0.05	0.12	<0.004
		3Jul86	Dry								
		20Aug86	Dry								
Seep	4	17Apr85	0.112	0.003136	6	20	915	<0.5	<0.02	0.16	0.050
		23Aug85	Dry								
		03Oct85	Dry								
		20Mar86	0.093	0.002604	4.4	19	1740		<0.02	0.12	0.019
		3Apr86	0.0396	0.0011088	8.2	23	1646		<0.02	0.14	0.023
		10May86	0.0104	0.0002912	7.6	24	1656		0.02	0.14	0.016
		22May86	0.012	0.000336	9	32	1745		<0.02	0.14	<0.004
		12Jun86	Dry								
		3Jul86	Dry								
		20Aug86	Dry								

Table A.1. (continued).

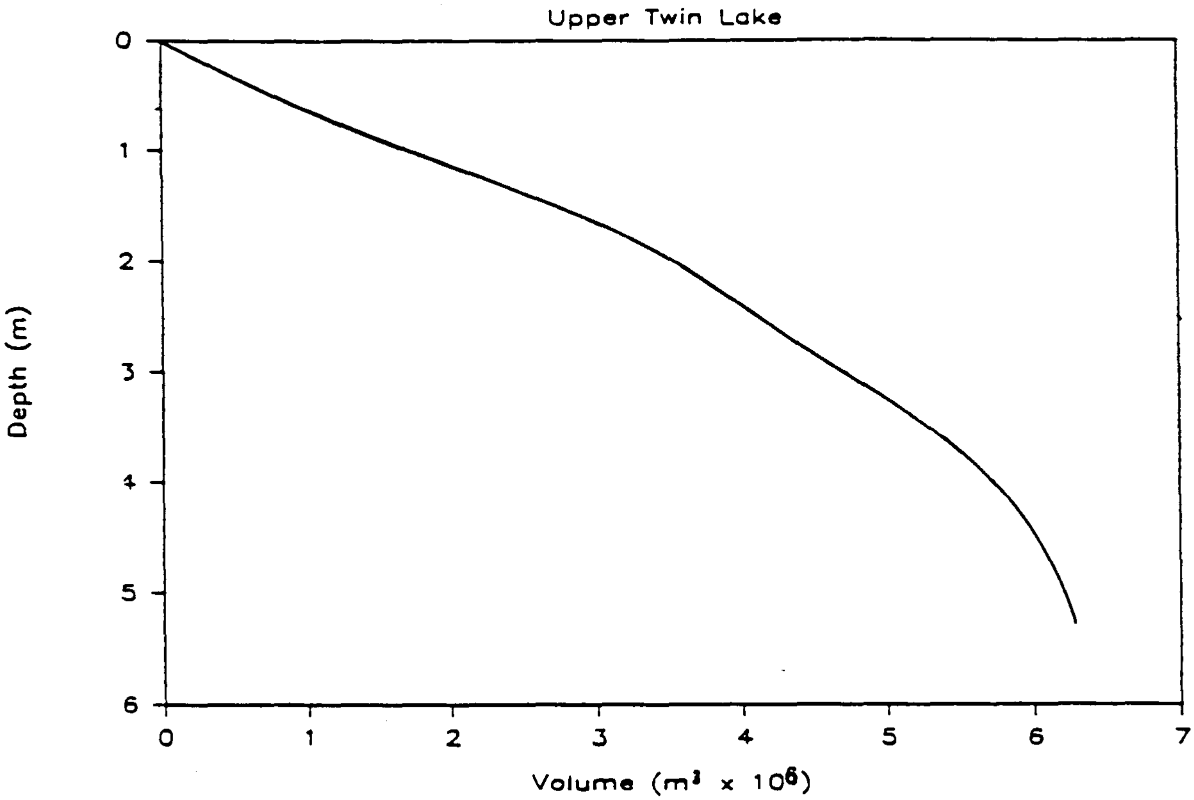
Site	Number	Date	Flow (cfs)	Flow (m3/s)	Temp (C)	Cond (umhos)	Time	Cl- (mg/l)	NO3-N (mg/l)	TKN (mg/l)	TP (mg/l)
Stream	5	17Apr85	0.287	0.008036	6	49	930	<0.5	<0.02	0.20	0.014
		23Aug85	Dry								
		03Oct85	Dry								
		20Mar86	0.318	0.008904	3.9	21	1800		<0.02	0.16	0.012
		3Apr86	0.126	0.003528	5.6	20	1700		<0.02	0.12	0.012
		10May86	0.0079	0.0002212	8.9	21	1705		<0.02	0.10	0.012
		22May86	0.0295	0.000826	9.5	28	1754		0.04	0.10	0.004
		12Jun86	Dry								
		3Jul86	Dry								
		20Aug86	Dry								
Drainage Canal	6	17Apr85	2.57	0.07196	5	35	1015	<0.5	<0.02	0.14	0.014
		23Aug85	Dry								
		03Oct85	Dry								
		20Mar86	1.88	0.05264	3.5	23	1800		0.07	0.30	0.034
		3Apr86	0.545	0.01526	4.4	20	1700		0.08	0.12	0.026
		10May86	0.2895	0.008106	6.5	24	1715		0.15	0.12	<0.004
		22May86	0.1989	0.0055692	7.1	12	1803		0.18	0.08	<0.004
		12Jun86	Dry								
		3Jul86	Dry								
		20Aug86	Dry								
Stream	7	17Apr85	0.675	0.0189	5	24	1045	<0.5	<0.02	0.26	0.014
		23Aug85	Dry								
		03Oct85	Dry								
		20Mar86	0.584	0.016352	3.1	21	1820		<0.02	0.16	0.012
		3Apr86	0.2203	0.0061684	3.9	22	1712		<0.02	0.16	0.012
		10May86	Dry								
		22May86	Dry								
		12Jun86	Dry								
		3Jul86	Dry								
		20Aug86	Dry								
Seep	9	17Apr85	0.3	0.0084	5	12	1215	<0.5	<0.02	0.06	0.018
		23Aug85	Dry								
		03Oct85	Dry								
		20Mar86	0.0213	0.0005964					NA	NA	NA
		3Apr86	0.0237	0.0006636	3.8	8	1052		0.25	0.12	0.019
		10May86	0.0241	0.0006748	5.1	13	915		0.02	0.06	<0.004
		22May86	0.017	0.000476					NA	NA	NA
		12Jun86	0.013	0.000364					NA	NA	NA
		3Jul86	Dry								
		20Aug86	Dry								

Table A.1. (continued).

Site	Number	Date	Flow (cfs)	Flow (m3/s)	Temp (C)	Cond (umhos)	Time	Cl- (mg/l)	NO3-N (mg/l)	TKN (mg/l)	TP (mg/l)
Seep	10a	17Apr85	Not	Sampled							
		23Aug85	0.23	0.00644	10	19	1040	<0.5	0.09	0.12	0.047
		03Oct85	0.13	0.00364	5	16	1006	<0.5	<0.02	0.10	0.016
		20Mar86	1.146	0.032088					NA	NA	NA
		3Apr86	1.273	0.035644	5.8	13	1207		0.25	0.12	0.019
		10May86	0.5468	0.0153104	5.1	11	1045		0.17	0.06	<0.004
		22May86	0.3924	0.0109872					NA	NA	NA
		12Jun86	0.2949	0.0082572					NA	NA	NA
		3Jul86	0.1783	0.0049924	11.9	15	1343		0.22	0.09	0.023
		20Aug86	0.1246	0.0034888			1140		0.08	0.12	0.014
Stream	10b	17Apr85	Not	Sampled							
		23Aug85	0.19	0.00532	10	24	1115		0.09	0.12	0.047
		03Oct85	0.13	0.00364	5	20	1032	0.75	0.12	0.12	0.050
		20Mar86	1.309	0.036652					NA	NA	NA
		3Apr86	1.454	0.040712	3.7	15	1145		0.43	0.08	0.012
		10May86	0.8021	0.0224588	5.1	11	1031		0.25	0.14	0.010
		22May86	0.5746	0.0160888					NA	NA	NA
		12Jun86	0.4325	0.01211					NA	NA	NA
		3Jul86	0.3031	0.0084868	12.5	19	1355		0.14	0.24	0.018
		20Aug86	0.0488	0.0013664			850		0.15	0.14	0.046
Seep	10c	17Apr85	Not	Sampled							
		23Aug85	0.00055	0.0000154	7.5	42	1200	1	0.04	0.06	0.048
		03Oct85	0.0003	0.0000084	7.2		1105	<0.5	<0.02	0.02	0.042
		20Mar86	0.0003	0.0000084					<0.02	0.02	0.042
		3Apr86	0.0003	0.0000084					<0.02	0.02	0.042
		10May86	0.0003	0.0000084					<0.02	0.02	0.042
		22May86	0.0003	0.0000084					<0.02	0.02	0.042
		12Jun86	0.0003	0.0000084					<0.02	0.02	0.042
		3Jul86	0.0003	0.0000084					<0.02	0.02	0.042
		20Aug86	0.0003	0.0000084					<0.02	0.02	0.042
Miller Creek	10d	17Apr85	Not	Sampled							
		23Aug85	0.057	0.001596	10.5	27	1213	<0.5	0.08	0.14	0.044
		03Oct85	0.039	0.001092	5.2		1130	<0.5	0.03	0.12	0.027
		20Mar86	0.3916	0.0109648					NA	NA	NA
		3Apr86	0.435	0.01218	3.3	17	1030		0.50	0.10	0.020
		10May86	0.1357	0.0037996	5.8	18	900		0.22	0.14	0.032
		22May86	0.0974	0.0027272					NA	NA	NA
		12Jun86	0.0732	0.0020496					NA	NA	NA
		3Jul86	0.04953	0.00138684	12.7	21	1313		0.11	0.20	0.050
		20Aug86	0.035	0.00098			1052		0.08	0.17	0.034

Table A.1. (continued).

Site	Number	Date	Flow (cfs)	Flow (m3/s)	Temp (C)	Cond (umhos)	Time	Cl- (mg/l)	NO3-N (mg/l)	TKN (mg/l)	TP (mg/l)
Unnamed	10e	20Mar86	0.1065	0.002982					NA	NA	NA
		3Apr86	0.1183	0.0033124	3.7	18	1101		0.17	0.14	0.010
		10May86	0.0499	0.0013972	5.1	16	945		0.03	0.08	0.011
		22May86	0.0358	0.0010024					NA	NA	NA
		12Jun86	0.0269	0.0007532					NA	NA	NA
		3Jul86	Dry								
		20Aug86	Dry								
Unnamed	10f	20Mar86	0.0887	0.0024836					NA	NA	NA
		3Apr86	0.0985	0.002758	3.9	18	1130		0.53	0.15	0.010
		10May86	0.0439	0.0012292	5	18	1009		0.17	0.18	<0.004
		22May86	0.0315	0.000882					NA	NA	NA
		12Jun86	0.0237	0.0006636					NA	NA	NA
		3Jul86	Dry								
		20Aug86	Dry								
Stream	11	17Apr85	Not Sampled								
		23Aug85	0.011	0.000308	12.5	22	1350	1.25	0.04	0.06	0.008
		03Oct85	0.004	0.000112	6.5		1300	<0.5	<0.02	0.62	0.014
		20Mar86	0.0932	0.0026096					NA	NA	NA
		3Apr86	0.1035	0.002898	4.6	14	1345		0.34	0.12	<0.004
		10May86	0.0711	0.0019908	5.5	14	1304		0.23	0.12	0.011
		22May86	0.051	0.001428					NA	NA	NA
		12Jun86	0.0383	0.0010724					NA	NA	NA
		3Jul86	0.0205	0.000574	10	14	1500		0.09	0.21	0.028
		20Aug86	0.00354	0.00009912			1405		0.04	0.06	0.007
Rathdrum Creek (outlet)	14	17Apr85a	94	2.632	6	37	1515	<0.5	0.04	0.32	0.102
		17Apr85b	94	2.632	6	37	1515	<0.5	0.02	0.44	0.054
		17Apr85c	94	2.632	6	37	1515	<0.5	0.02	0.44	0.059
		23Aug85	6.9	0.1932	19.8	22	1545	<0.5	<0.02	0.25	0.011
		03Oct85	7.76	0.21728	12.5	21	1645	<0.5	<0.02	0.30	0.016
		28Jan86	7.5	0.21	NA	NA	NA	NA	0.02	0.34	0.005
		20Mar86	34.8	0.9744	6.9	13	1450		<0.02	0.18	0.006
		3Apr86	39	1.092	7.4	16	1735		0.07	0.20	0.009
		10May86	7.6	0.2128	11	19	1745		<0.02	0.28	0.020
		22May86	7.45	0.2086			1825		0.06	0.20	0.004
		3Jul86	7.84	0.21952	20.8	20	1048		0.03	0.23	0.014
		20Aug86	7.6	0.2128	20.5	18	1157		<0.02	0.26	0.012
Channel		3Jul86	NA						<0.02	0.28	0.028
		20Aug86	NA						<0.02	0.30	0.010



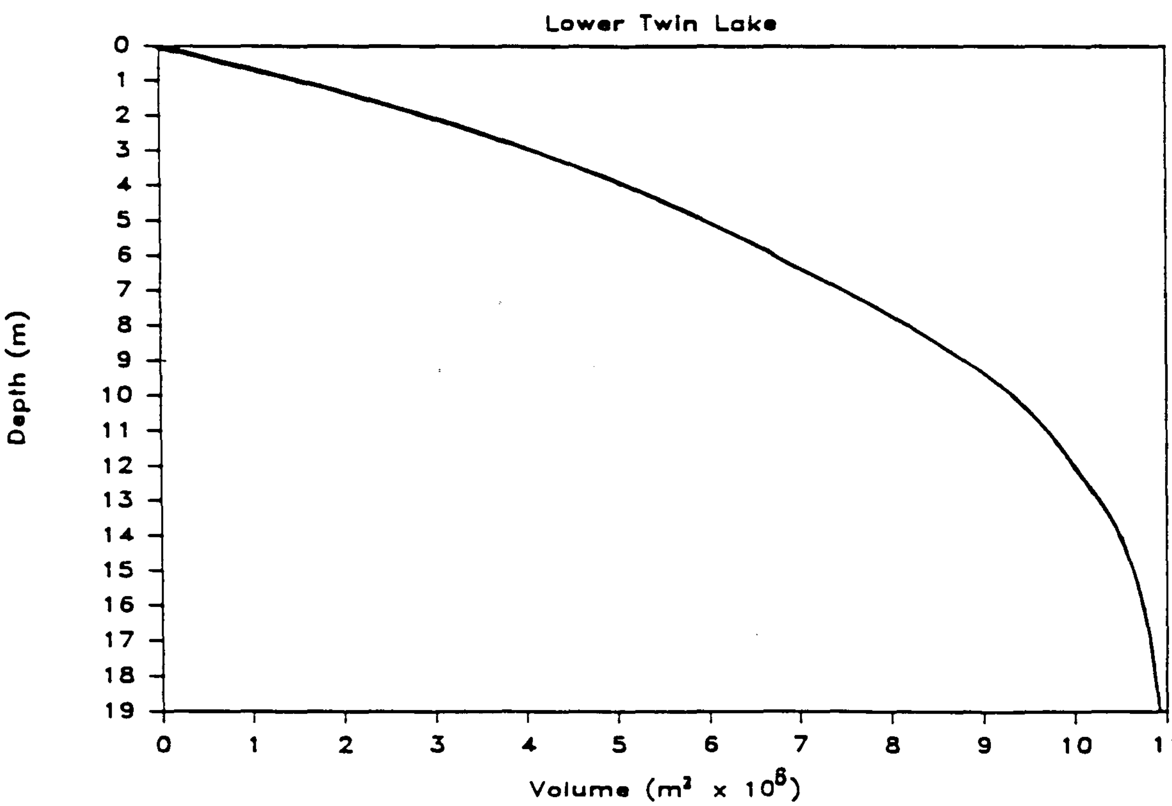


Figure A.2. Depth-volume curve for Upper and Lower Twin Lake (gives volume above selected depth strata).

Table A.2 Fish Creek and Rathdrum Creek flows and Twin Lakes lake level as measured at the outlet dam for water years 1984 through 1986. Data listed under "Fish Creek 1986a" was estimated from Blanchard Creek flows.

Date	Rathdrum Creek (cfs)			Fish Creek (cfs)				Lake Level (ft)		
	1984	1985	1986	1984	1985	1986	1986a	1984	1985	1986
Oct 1			8.10				8.06			6.550
Oct 5			7.76			6.48	8.38			6.490
Oct 10							8.60			
Oct 15			7.90				8.80			6.400
Oct 20					6.73		9.07			
Oct 25			5.00				12.89			6.480
Oct 30							9.26			
Nov 5							13.84			
Nov 10							11.00			
Nov 15							10.36			
Nov 20							10.14			
Nov 25							11.86			
Nov 30							11.98			
Dec 5							14.84			
Dec 10							12.45			
Dec 15		8.10					14.31		8.540	
Dec 20		26.20					15.82		8.440	
Dec 25		91.85					10.00		7.980	
Dec 30		88.20					9.43		7.060	
Jan 5		54.40					9.07		6.540	
Jan 10		12.60					9.95		6.360	
Jan 15		11.00					10.41		6.320	
Jan 20		10.30					16.39		6.300	
Jan 25		10.30	7.50			11.95	10.78		6.280	7.510
Jan 30		10.10	8.20				26.03			7.650
Feb 5	30.00	10.10	8.20				17.64	7.750		8.000
Feb 10	24.84	10.10	8.20				11.61	7.780	6.380	8.000
Feb 15	26.20	10.10	8.20				18.59	8.200	6.380	8.000
Feb 20	31.96	10.10	8.20				11.66	8.340	6.360	8.030
Feb 25	32.30		8.20			58.14	69.88	8.390	6.360	8.250
Feb 30	30.40		8.20				67.27	8.400		8.850
Mar 5	27.90		8.20				96.32	8.400	6.400	9.000
Mar 10	25.20	8.50	8.54	32.60			84.33	8.500	6.440	9.830
Mar 15	27.70	9.00	46.80			58.14	57.64	9.300	6.480	9.950
Mar 20	38.50	9.80	34.80	74.20		52.34	42.71	10.080	6.570	9.800
Mar 25	93.00	10.00	34.80	74.20			60.82	10.430	7.180	9.900
Mar 30	87.00	11.00	35.80	57.40		56.07	54.42	9.540	7.450	10.180
Apr 5	78.00	26.20	39.00	57.40		58.14	42.22	9.320	8.260	10.150
Apr 10	57.10	57.20	12.40	57.40			38.05	9.650	8.700	10.100
Apr 15	59.30	85.00	9.19	68.30	122.8		33.40	9.900	9.500	10.200
Apr 20	67.50	94.00	8.30	69.90			30.71	10.120	9.530	10.200
Apr 25	67.50	86.00	8.50	59.50			33.16	10.060	9.160	10.200
Apr 30	42.20	75.00	8.50	57.80			33.89	10.000	8.840	10.300
May 5	39.00	54.40	8.30	55.40			34.63	10.040		10.300

Table A.2. (continued).

Date	Rathdrum Creek 1984	Rathdrum Creek 1985 (cfs)	Rathdrum Creek 1986.00	Fish Creek 1984	Fish Creek 1985	Fish Creek 1986 (cfs)	Fish Creek 1986a	Lake Level 1984	Lake Level 1985 (ft)	Lake Level 1986
May 10	35.80	46.80	7.60	55.80		32.86	31.20	10.040	9.050	10.250
May 15	34.60	8.50	7.60	55.80			36.83	10.210	9.200	10.300
May 20	36.50	8.50	7.45	58.14		23.58	31.57	10.350	9.525	10.300
May 25	45.30	8.45	7.40				30.95	10.520	9.850	10.300
May 30	51.40	8.33	7.40	55.80			29.94	10.500	9.945	10.100
Jun 5		8.33	7.90	55.40			27.04		9.950	9.830
Jun 10		8.33	8.00			17.72	22.87		10.050	9.600
Jun 15		10.00	8.10	44.80			20.18		9.850	9.375
Jun 20		10.00	7.90	38.90			19.13		9.625	9.150
Jun 25		9.84	7.90	33.00			15.77		9.400	8.975
Jun 30		9.65	7.90	30.10			14.06		9.150	8.725
Jul 5		8.50	7.84	27.20		9.2	13.20		8.975	8.590
Jul 10		8.20	7.75	23.20			12.22		8.750	8.375
Jul 15		8.20	7.75	21.30			10.27		8.500	8.150
Jul 20		8.20	7.75	19.00			8.19		8.250	8.050
Jul 25			7.82	16.80			7.45		8.020	7.850
Jul 30		7.60	7.75	14.30			6.70		7.850	7.675
Aug 5		8.10	7.75	12.40			6.25		7.700	7.400
Aug 10		8.10	7.75	10.50			6.05		7.550	7.275
Aug 15		7.90	7.75	8.00			6.11		7.400	7.050
Aug 20		6.90	7.60	6.56		6.44	5.67		7.190	6.850
Aug 25		7.90	7.60		6.93		5.68		7.100	6.675
Aug 30		7.90	8.10				5.71		6.950	6.450
Sept 5		6.50	8.10				6.02		6.840	6.350
Sept 10			7.60	6.56			6.42		6.750	6.175
Sept 15		8.10	7.60				6.62		6.700	6.050
Sept 20		8.10	7.60				8.16		6.750	6.000
Sept 25		8.10	7.60			7.12	38.54		6.600	6.100
Sept 30		8.10	7.75				33.68		6.550	6.200

Table A.3. Monthly total precipitation (inches) south of Twin Lakes, Idaho (T52N R4W sec 21) (Chet Park, unpublished data).

Month	1982	1983	1984	1985	1986	Mean
January	2.63	1.74	3.37	0.39	5.19	2.66
February	4.15	1.24	3.46	2.67	2.74	2.85
March	4.55	7.13	4.70	3.44	3.34	4.63
April	4.41	1.55	2.63	1.32	2.17	2.42
May	0.83	1.61	3.72	1.92	2.28	2.07
June	0.90	4.51	3.69	1.47	0.75	2.26
July	1.44	5.37	0.52	0.78	1.11	1.84
August	0.66	1.39	0.35	0.36	0.26	0.60
September	2.04	1.02	1.28	2.38	5.33	2.41
October	3.29	2.04	1.00	3.27	1.02	2.12
November	5.56	10.42	8.15	4.85	6.00	7.00
December	4.83	4.19	7.04	1.62	1.91	3.92
TOTAL	35.29	42.21	39.91	24.47	32.10	34.78
AVERAGE	2.94	3.52	3.33	2.04	2.68	2.90

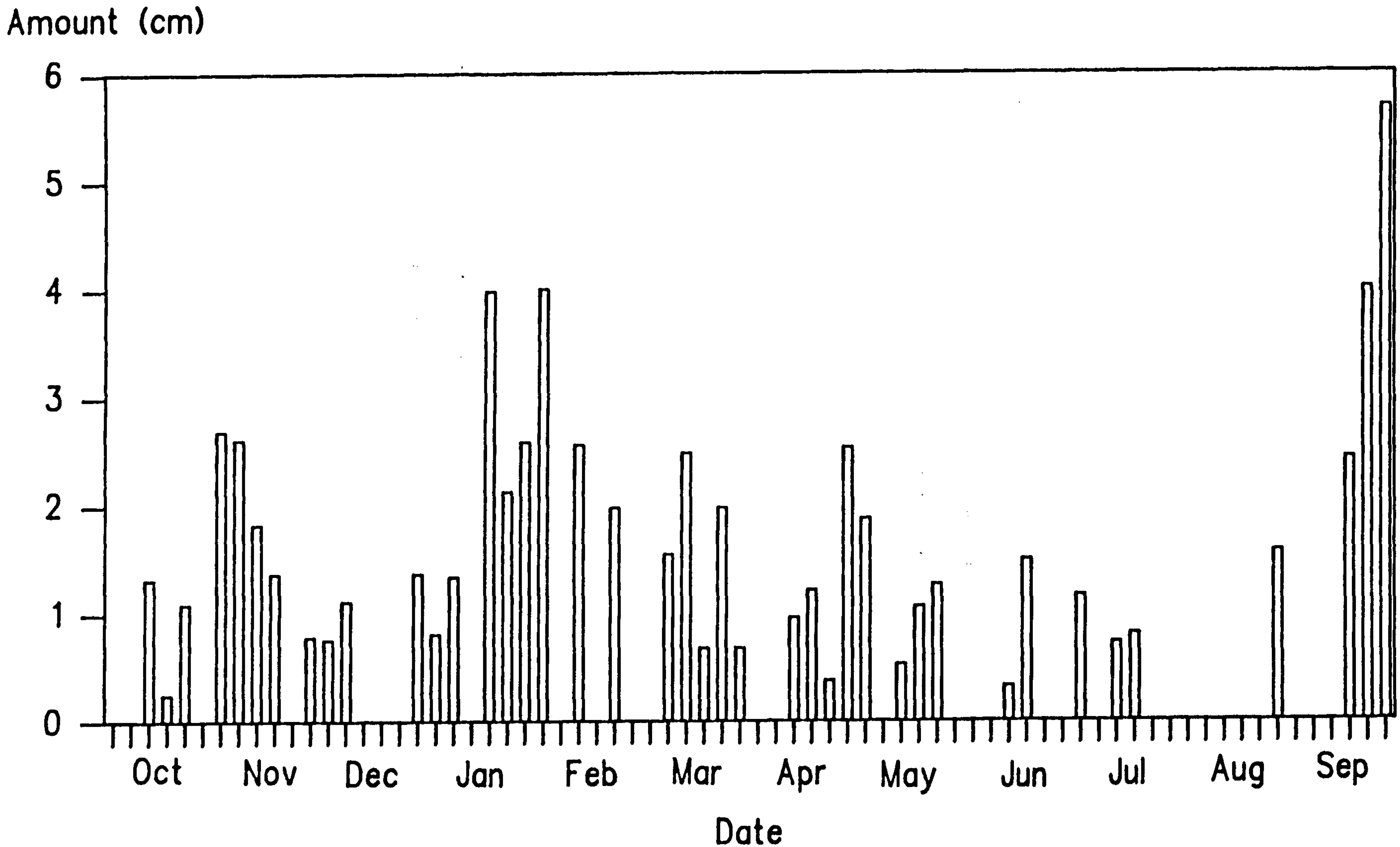


Figure A.3. Five-day precipitation volumes at Twin Lakes during WY 1986.

Although a number of underwater springs were reported by homeowners, it is unlikely that subsurface inflows are a major source of water to Twin Lakes because of the soil type and the depth of the aquifer in the Twin Lakes area (about 91 m below the lake surface (USGS 1977)).

UPPER TWIN LAKES OUTLET

Upper basin outlet (=lower basin inlet) flow volumes could not be gaged because the flow rates were often too slow for accurate measurements. Instead, between-basin flows were estimated by calculating all other inflows and outflows for each basin (assuming 20% of ground water loss originated in the upper basin based on the percent of shoreline bordering glacial till) and back calculating flow from the groundwater equation, above. We estimate that 87% of upper basin tributary inflows ultimately flow into the lower basin.

APPENDIX B. NUTRIENT LOADING

Plant nutrients enter Twin Lakes from a number of sources: tributaries, precipitation and dryfall, wastewater leaching, release from internal sediments, overland runoff, and powerboat exhaust. Overland runoff was not determined directly, but is probably small compared to other sources. Overland runoff becomes important when the permeability of a large percentage of shoreline area is greatly reduced by urban development (eg: parking lots, large or many buildings, etc.).

Nutrient loading from other sources was calculated as described below.

POWERBOAT EXHAUST

The importance of powerboat exhaust as a nutrient source was unknown, but potentially high enough that we applied for and received funding from the Idaho Water Resources Research Institute to investigate this aspect of nutrient loading as a separate study. Our conclusions were as follows:

1. In 1986, motorboats were run 18,000 hours on Twin Lakes (50 hrs/ha) in a four-month season. Fuel consumption was 230,000 liters. At the peak of the season, boat density reached 0.24 boats/ha on weekends and 0.08 boats/ha on weekdays.

2. Phosphorus loading from outboard engine exhaust is insignificant (*ca*. 1 mg P per liter fuel consumed for an annual loading to the lake of 0.23 kg).

3. Nitrogen loading will be insignificant in northern latitude lakes with short boating seasons, but may be near 0.15 $g/m^2/yr$ in high-use, long-season lakes (due to a full year of use).

4. Large quantities of inorganic carbon are added by motorboats (>8,600 mg CO_2/liter fuel consumed....over 1,980 kg each year to Twin Lakes).

5. The biological response in our test enclosures was moderate. Considering the concentrated nature of our tests, it is unlikely that even high boat use will affect Twin Lakes' biota in the short-term. The effects of long-term powerboat use is unknown.

Powerboats can have other effects not discussed here. For example, motor wash is capable of resuspending lake bottom sediments at depths of 5 m. We refer the reader to Hallock and Falter (1986) and Jackivicz and Kuzminski (1973) for a more detailed discussion of the effects of powerboats.

TRIBUTARIES

Nutrient loading from tributaries was determined from the hydrology of surface inflows (Appendix A) and nutrient analyses of tributary water (Table A.1). The hydrograph was divided into sections with each section containing a nutrient concentration datum. Total nutrient loading was determined from the sum of the products of flows x concentration (Table B.1). Sampling was more intensive in WY 1986 than in WY 1985. Samples were collected in acid-washed polyethylene bottles and frozen for later analysis for total phosphorus (stannous chloride method with persulfate digestion), nitrate nitrogen (spectrophotometric screening method), and total kjeldahl nitrogen (micro-kjeldahl technique) according to APHA (1985). Some smaller tributaries were not sampled as often as Fish Creek because of access difficulties. In these cases, a missing concentration datum was approximated by taking the mean of samples collected before and after the missing sample. Also, nutrient samples were not collected from the channel between basins until late in the study. Missing channel concentration data were approximated from open lake samples collected at sample point East Upper Deep.

Logging

The effect logging has on the nutrient load to Twin Lakes is of great concern to lake users, state agencies and the timber companies themselves. The effects are difficult to accurately assess.

Nutrient export from watersheds is often expressed as an export coefficient (loading per unit area of the watershed). Expression of the data in this manner allows a comparison of export from tributaries of different sizes. Tributaries #1(Fish Creek), 10a, 10b, and 10d all have high export coefficients of both nitrogen and phosphorus (Table B.2 and B.3). All of these tributaries except 10a drain areas that have been recently logged. But this evidence of logging impacts is non-quantitative and circumstantial, at best.

A quantitative way of assessing logging impacts is to assume that logging triples the export coefficient of a watershed for the first year. The factor of three is based on a studies by Fredriksen (1971), Fredriksen et al. (1973), and Cole and Gessel (1965) as cited in Cooper (1969) following logging and slash burning. There are significant drawbacks to this method:

1) The factor of three is only a "best-guess". These studies were conducted in coastal forests where soils, rainfall, slope, etc., are different than in northern Idaho. Fredriksen's treatment watershed was not roaded and was 100% clearcut without buffer strips. In addition, neither study was conducted with the specific objective of determining the effects of logging on nutrient loading to surface waters. Finally, the baseline data were obtained after, not before, logging.

Table B.1. Spreadsheet for calculating nutrient loading from tributaries.

Hydrograph Section	1	2	3	4	5	6	7	8	9	10	11	TOTAL
Days in Section	60	85	30	7	21	24	16	20	34	42	26	WY 1986
Date Sampled	3 Oct	28 Jan	20 Mar	29 Mar	3 Apr	10 May	22 May	12 Jun	3 Jul	20 Aug	25 Sep	
FISH CREEK												
Measured Flow(cfs)	6.480	11.950	52.000	56.000	58.000	33.000	24.000	17.700	9.200	6.510	7.200	
Total Flow (m3)	1558929	3170259	5161497	1048020	1912636	1834034	1152822	1257624	995619	615712	641912	19349063
TP (mg/l)	0.028	0.024	0.023	0.030	0.027	0.009	0.013	0.025	0.024	0.044	0.025	
TN (mg/l)	0.140	0.230	0.220	0.500	0.160	0.130	0.190	0.165	0.140	0.260	0.180	
TP (kg)	43.650	76.086	118.714	31.441	51.641	16.506	14.987	31.441	23.895	27.091	16.048	451.50
TN (kg)	218.25	729.16	1135.53	524.01	306.02	238.42	219.04	207.51	139.39	160.09	115.54	3992.95
STREAM 2+3+4												
Measured Flow	Dry	0.879	3.823	3.318	2.694	0.687	0.342	0.212	0.055	Dry	Dry	
Total Flow		233075	379469	62087	88825	38170	16408	15031	5974			839040
TP (mg/l)		0.015	0.015	0.014	0.013	0.008	0.008	0.015	0.023			
TN (mg/l)		0.103	0.103	0.102	0.102	0.083	0.160	0.180	0.200			
TP (kg)		3.535	5.756	0.886	1.189	0.306	0.125	0.230	0.137			12.17
TN (kg)		24.104	39.243	6.362	9.019	3.182	2.618	2.702	1.195			88.43
STREAM 5												
Measured Flow	Dry	0.073	0.318	0.226	0.126	0.008	0.030	Dry	Dry	Dry	Dry	
Total Flow		19387	31565	4230	4155	439	1417					61193.19
TP (mg/l)		0.012	0.012	0.012	0.012	0.012	0.004					
TN (mg/l)		0.160	0.160	0.140	0.120	0.100	0.140					
TP (kg)		0.233	0.379	0.051	0.050	0.005	0.006					0.72
TN (kg)		3.102	5.050	0.592	0.499	0.044	0.198					9.49
STREAM 6												
Measured Flow	Dry	0.432	1.880	1.235	0.545	0.290	0.199	Dry	Dry	Dry	Dry	
Total Flow		114617	186608	23104	17972	16089	9554					367944.8
TP (mg/l)		0.034	0.034	0.030	0.026	0.002	0.002					
TN (mg/l)		0.370	0.370	0.285	0.200	0.270	0.260					
TP (kg)		3.897	6.345	0.693	0.467	0.032	0.019					11.45
TN (kg)		42.408	69.045	6.585	3.594	4.344	2.484					128.46
STREAM 7												
Measured Flow	Dry	0.134	0.584	0.409	0.220	Dry	Dry	Dry	Dry	Dry	Dry	
Total Flow		35604.5	57967.6	7662.9	7264.7							108499.7
TP (mg/l)		0.012	0.012	0.012	0.012							
TN (mg/l)		0.160	0.160	0.160	0.160							
TP (kg)		0.427	0.696	0.092	0.087							1.30
TN (kg)		5.697	9.275	1.226	1.162							17.36

Table B.1. (continued).

Hydrograph Section	1	2	3	4	5	6	7	8	9	10	11	TOTAL
Days in Section	60	85	30	7	21	24	16	20	34	42	26	WY 1986
Date Sampled	3 Oct	28 Jan	20 Mar	29 Mar	3 Apr	10 May	22 May	12 Jun	3 Jul	20 Aug	25 Sep	
STREAM 9												
Measured Flow	Dry	0.005	0.021	0.023	0.024	0.024	0.017	0.013	Dry	Dry	Dry	
Total Flow		1298.59	2114.23	428.74	781.54	1339.40	816.58	923.68				7702.75
TP (mg/l)		0.019	0.019	0.019	0.019	0.002	0.002	0.002				
TN (mg/l)		0.370	0.370	0.370	0.370	0.080	0.080	0.080				
TP (kg)		0.025	0.040	0.008	0.015	0.003	0.002	0.002				0.09
TN (kg)		0.480	0.782	0.159	0.289	0.107	0.065	0.074				1.96
STREAM 10a												
Measured Flow	0.130	0.263	1.146	1.231	1.273	0.547	0.392	0.295	0.178	0.125	Dry	
Total Flow	31275	69868	113751	23047	41979	30389	18849	20953	19296	11785		381191
TP (mg/l)	0.016	0.019	0.019	0.019	0.019	0.002	0.002	0.023	0.023	0.014		
TN (mg/l)	0.100	0.370	0.370	0.370	0.370	0.230	0.230	0.310	0.310	0.200		
TP (kg)	0.500	1.327	2.161	0.438	0.798	0.061	0.038	0.482	0.444	0.165		6.41
TN (kg)	3.127	25.851	42.088	8.527	15.532	6.990	4.335	6.496	5.982	2.357		121.28
STREAM 10b												
Measured Flow	0.130	0.301	1.309	1.407	1.454	0.802	0.575	0.433	0.303	0.049	Dry	
Total Flow	31275	79805	129931	26324	47948	44578	27600	30730	32801	4615		455608
TP (mg/l)	0.050	0.012	0.012	0.012	0.012	0.010	0.010	0.018	0.018	0.046		
TN (mg/l)	0.240	0.510	0.510	0.510	0.510	0.390	0.390	0.380	0.380	0.290		
TP (kg)	1.564	0.958	1.559	0.316	0.575	0.446	0.276	0.553	0.590	0.212		7.05
TN (kg)	7.506	40.701	66.265	13.425	24.453	17.385	10.764	11.677	12.464	1.338		205.98
STREAM 10c												
Measured Flow	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	
Total Flow	72.173	79.588	29.778	5.614	9.893	16.673	14.410	21.316	32.466	28.374	26.746	337.03
TP (mg/l)	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	
TN (mg/l)	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	
TP (kg)	0.003	0.003	0.001	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.01
TN (kg)	0.001	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.01
STREAM 10d												
Measured Flow	0.039	0.090	0.392	0.421	0.435	0.136	0.097	0.073	0.050	0.035	0.039	
Total Flow	9382.4	23874.5	38870.0	7875.4	14344.8	7541.8	4678.5	5201.0	5360.1	3310.3	3451.1	123890.0
TP (mg/l)	0.027	0.027	0.024	0.020	0.020	0.032	0.032	0.050	0.050	0.034	0.034	
TN (mg/l)	0.150	0.150	0.375	0.600	0.600	0.360	0.360	0.310	0.310	0.250	0.250	
TP (kg)	0.253	0.645	0.913	0.158	0.287	0.241	0.150	0.260	0.268	0.113	0.117	3.40
TN (kg)	1.407	3.581	14.576	4.725	8.607	2.715	1.684	1.612	1.662	0.828	0.863	42.26
STREAM 10e												
Measured Flow	0.011	0.024	0.107	0.114	0.118	0.050	0.036	0.027	Dry	Dry	Dry	
Total Flow	2551.7	6492.9	10571.1	2141.8	3901.1	2773.3	1719.6	1911.3				32062.8
TP (mg/l)	0.010	0.010	0.010	0.010	0.010	0.011	0.011	0.011				
TN (mg/l)	0.310	0.310	0.310	0.310	0.310	0.110	0.110	0.110				
TP (kg)	0.026	0.065	0.106	0.021	0.039	0.031	0.019	0.021				0.33
TN (kg)	0.791	2.013	3.277	0.664	1.209	0.305	0.189	0.210				8.66

Table B.1. (continued).

Hydrograph Section	1	2	3	4	5	6	7	8	9	10	11	TOTAL
Days in Section	60	85	30	7	21	24	16	20	34	42	26	WY 1986
Date Sampled	3 Oct	28 Jan	20 Mar	29 Mar	3 Apr	10 May	22 May	12 Jun	3 Jul	20 Aug	25 Sep	
STREAM 10f												
Measured Flow	0.009	0.020	0.089	0.095	0.099	0.044	0.031	0.024	Dry	Dry	Dry	
Total Flow	2125.2	5407.7	8804.3	1783.5	3248.2	2439.8	1513.1	1683.9				27005.8
TP (mg/l)	0.010	0.010	0.010	0.010	0.010	0.002	0.002	0.002				
TN (mg/l)	0.680	0.680	0.680	0.680	0.680	0.350	0.350	0.350				
TP (kg)	0.021	0.054	0.088	0.018	0.032	0.005	0.003	0.003				0.22
TN (kg)	1.445	3.677	5.987	1.213	2.209	0.854	0.530	0.589				16.50
STREAM 11												
Measured Flow	0.004	0.021	0.093	0.100	0.104	0.071	0.051	0.038	0.021	0.004	0.004	
Total Flow	962.30	5682.08	9250.99	1874.05	3413.07	3951.51	2449.75	2721.30	2218.50	334.81	349.06	33207.41
TP (mg/l)	0.014	0.014	0.009	0.003	0.003	0.011	0.011	0.028	0.028	0.007	0.007	
TN (mg/l)	0.620	0.620	0.540	0.460	0.460	0.350	0.350	0.300	0.300	0.100	0.100	
TP (kg)	0.013	0.080	0.079	0.006	0.010	0.043	0.027	0.076	0.062	0.002	0.002	0.40
TN (kg)	0.597	3.523	4.996	0.862	1.570	1.383	0.857	0.816	0.666	0.033	0.035	15.34
RATHDRUM												
Measured Flow	7.760	7.500	34.800	35.800	39.000	7.600	7.450	8.000	7.840	7.600	7.600	
Total Flow	1143874	1590234	1643537	630214	854176	486828	271851	402762	650147	789001	464448	8927073
TP (mg/l)	0.016	0.005	0.006	0.008	0.009	0.020	0.004	0.009	0.014	0.012	0.012	
TN (mg/l)	0.300	0.360	0.180	0.225	0.270	0.280	0.260	0.260	0.260	0.260	0.260	
TP (kg)	18.302	7.951	9.861	4.727	7.688	9.737	1.087	3.625	9.102	9.468	5.573	87.12
TN (kg)	343.162	572.484	295.837	141.798	230.627	136.312	70.681	104.718	169.038	205.140	120.757	2390.56
CHANNEL												
Total Flow	1181254	3116099	5894000	1153702	1984041	1796069	1114231	1182627	801613	317401	448502	18989539
TP (mg/l)	0.009	0.010	0.020	0.020	0.020	0.020	0.020	0.024	0.028	0.010	0.010	
TN (mg/l)	0.240	0.230	0.210	0.210	0.210	0.210	0.210	0.240	0.280	0.300	0.300	
TP (kg)	10.631	31.161	117.880	23.074	39.681	35.921	22.285	28.383	22.445	3.174	4.485	339.12
TN (kg)	283.50	716.70	1237.74	242.28	416.65	377.17	233.99	283.83	224.45	95.22	134.55	4246.09

Table B.2. Tributary nutrient loading to Twin Lakes, Idaho, water year 1985.

Tributary	Total Flow (m^3)	Drainage Area (ha)	Total Phosphorus (kg)	TP per Drainage Area (kg/ha/yr)	Total Nitrogen (kg/yr)	TN per Drainage Area (kg/ha/yr)
Fish (#1)	25,355,267	5126	560	0.109	5105	0.996
2+3+4	1,534,952	456	44.0	0.097	225	0.494
5	45,868	64	0.64	0.010	9.2	0.144
6	412,957	341	5.8	0.017	58	0.169
7	108,646	112	1.5	0.014	28	0.251
9	48,263	14.9	0.87	0.058	2.9	0.195
10a	574,732	118	9.8	0.082	156	1.318
10b	622,269	160	11.3	0.071	250	1.566
10c	376	9.9	0.02	0.002	0.03	0.003
10d	223,255	49	6.3	0.130	96	1.971
10e	49,737	17.3	0.52	0.030	10	0.602
10f	46,545	23	0.23	0.010	24	1.052
11	41,279	50	0.300	0.006	16	0.312
TOTAL	29,064,146	6540	641	0.098	5981	0.915

Table B.3. Tributary nutrient loading to Twin Lakes, Idaho, water year 1986.

Tributary	Total Flow (m^3)	Drainage Area (ha)	Total Phosphorus (kg)	TP per Drainage Area (kg/ha/yr)	Total Nitrogen (kg/yr)	TN per Drainage Area (kg/ha/yr)
Fish (#1)	19,349,063	5126	452	0.088	3993	0.779
2+3+4	839,040	456	12	0.027	88	0.194
5	61,193	64	0.72	0.011	9.5	0.149
6	367,945	341	11.5	0.034	128	0.377
7	108,500	112	1.3	0.012	17	0.154
9	7,703	14.9	0.09	0.006	2.0	0.132
10a	381,191	118	6.4	0.054	121	1.025
10b	455,608	160	7.1	0.044	206	1.290
10c	337	9.9	0.01	0.001	0.01	0.001
10d	123,890	49	3.4	0.069	42	0.866
10e	32,063	17.3	0.33	0.019	8.7	0.500
10f	27,006	23	0.22	0.010	17	0.724
11	33,207	50	0.40	0.008	15	0.308
TOTAL	21,786,745	6540	495	0.076	4649	0.711

2) This method does not account for continuing nutrient loading after the first year, nor does it account for roads in the watershed.

All things considered, it is likely that 3 times background loading is a high estimate.

By this method, background export (X_b) can be determined from the following equation:

$$X_b = N/\{3(\text{area logged annually}) + \text{area not logged}\}$$

where N is the total mass of nutrient entering the lake from tributaries. The area logged annually (1.5 km^2) is an average of the area logged in the last 10 years on Inland Empire Paper Company land (Dennis Parent, IEPC, pers. comm.) plus an approximation of annual logging on land not owned by IEPC. In the case of Twin Lakes, X_b was 0.072 kg/ha/yr for phosphorus and 0.680 kg/ha/yr for nitrogen. By this method, logging was directly responsible for 22 kg of phosphorus and 203 kg of nitrogen in 1986, or 4.4% of the tributary loading of each nutrient to Upper Twin Lake. The direct impact of logging on Lower Twin Lake is negligible. The effects of logging in the upper lake's watershed on the lower lake are attenuated by nutrient processing in the upper lake prior to discharge to the lower lake.

A more significant problem than the direct effects of logging is the erosion from both new and old logging roads in the watershed. The "background" export coefficient of 0.073 kgP/ha/yr, is high. This coefficient includes the nutrient export from roads in the watershed.

We are continuing to study the effects of logging in the Twin Lakes watershed with a MacIntire-Stennis grant through the College of Forestry, Wildlife and Range Sciences, University of Idaho.

<u>Grazing</u>

The Twin Lakes watershed sustains a small amount of grazing. About 120 cattle were counted during each year of the study, although considerably higher numbers had been pastured in the watershed in the past, according to homeowners and Trial (1978). Cattle were primarily seen in the pastures at the western end of the upper basin from late July or early August and through October. The nutrient load from these cattle is particularly important because they are pastured so close to the lake and Fish Creek -- they were often seen wading in both -- and because much of the pasture later becomes flooded when the lake level raises in summer. As a result, there is little opportunity for nutrient uptake and removal by terrestrial flora. A high percentage of these nutrients, therefore, can be expected to enter the lake.

Export coefficients, as discussed above, are one method of determining nutrient load from pasture land. Reckhow et al. (1980) report phosphorus export coefficients of 0.20 to 0.84 kg/ha/yr and nitrogen export of 1.48 to 1.73 kg/ha/yr for unfertilized rotation grazing, based on a literature review. Means of these figures (0.52 kg P/ha/yr and 1.61 kg N/ha/yr) will be used in the following calculations because, while these studies were conducted in small, relatively intensively grazed mid-western pastures, it is unlikely that the pastures were in such close proximity to a lake as is the case at Twin Lakes. Therefore, assuming 100 ha of pasture land is used annually, 52 kg of phosphorus and 161 kg of nitrogen loading to Twin Lakes can be attributed to cattle. This method does not consider number of cattle or time in pasture. These important factors were not discussed by the authors of the studies from which the above export coefficients were derived.

A second method of calculating the nutrient load from cattle is to multiply the effects of one animal by the total number of animals and by some scaling factor to account for that portion of nutrients that do not reach the lake. Each adult cow excretes 0.022 kg phosphorus and 0.136 kg nitrogen each day (Viets 1971). Typical export from pasture land is estimated at 1 to 5% (OECD 1971). However, because of the marshy nature and periodic flooding of the pasture at the west end of Upper Twin Lake, we estimate that 20 to 30% of the nutrients were transported to the lake, but because not all of the cattle were adults, our calculations are based on the lower figure. Therefore, phosphorus loading would be

$$(0.022 \text{ kg/cow/day})(120 \text{ cows})(105 \text{ days})(0.20) = 55.4 \text{ kg}.$$

Similarly, nitrogen loading from grazing was 342.7 kg. These figures equate to 8.5% of the total phosphorus loading and 5.4% of nitrogen loading to Upper Twin Lake in WY 1986. Results from the two methods are similar; we feel that the second method is more appropriate to this situation.

Of this loading, perhaps 30% enters Fish Creek and is included in tributary loading estimates. The other 70% (38.8 kg TP and 239.9 kg TN) enter Upper Twin Lake directly.

PRECIPITATION

Precipitation and dryfall was collected and analyzed for total phosphorus, nitrate and kjeldahl nitrogen (APHA 1985), pH (Markson ph meter), and conductivity (YSI meter) from August 1985 to October 1986. Precipitation was collected from a site about 1 km south of Twin Lakes in a 34.4 cm x 43.2 cm acid-washed plastic pan mounted 1.5 m above the ground. Samples for analysis were usually collected after each major event or series of events, pH was measured and the sample was then frozen for later nutrient analyses.

Table B.4 contains precipitation data.

Table B.4. Precipitation chemistry and nutrient loading to Twin Lakes, Idaho in WY 1986.

Event Start	Event Stop	Amount (in)	Days Since Last Event	pH	Conductivity (umhos)	Nutrient Concentrations TP (mg/l)	NO3 (mg/l)	TKN (mg/l)	Nutrient Load to Twin Lakes TP (kg)	TN (kg)
1-Aug-85	1-Aug-85	0.78	NA	6.3	NA	0.031	0.09	0.32	2.17	28.73
4-Aug-85	3-Sep-85	0.35	3	6.8	NA		1.97	2.60	0.00	143.70
5-Sep-85	5-Sep-85	0.13	2	7.2	NA	0.624	0.83	2.52	7.29	39.13
7-Sep-85	8-Sep-85	0.16	2	6.3	NA	0.684	0.42	0.68	9.83	15.81
10-Sep-85	11-Sep-85	0.15	2	6.3	NA	0.137	0.25	0.70	1.85	12.80
11-Sep-85	11-Sep-85	0.12	0	5.8	NA	0.158	0.73	1.10	1.70	19.73
16-Sep-85	17-Sep-85	0.69	5	5.7	NA	0.051	1.25	0.68	3.16	119.64
17-Sep-85	18-Sep-85	0.57	0	5.6	NA	0.030	0.16	0.42	1.54	29.70
18-Sep-85	19-Sep-85	0.28	0	5.9	NA	0.020	0.13	0.42	0.50	13.84
11-Oct-85	13-Oct-85	0.52	22	4.7	NA	0.039	0.26	0.65	1.82	42.51
19-Oct-85	20-Oct-85	0.10	6	7.5	NA	0.074	0.43	1.42	0.66	16.62
20-Oct-85	1-Nov-85	0.43	0	NA	NA	0.018	0.18	0.44	0.70	23.95
3-Nov-85	4-Nov-85	1.06	2	6.1	NA	0.016	0.11	0.21	1.52	30.47
5-Nov-85	10-Nov-85	1.03	1	6.4	NA	0.063	0.24	0.78	5.83	94.39
14-Nov-85	16-Nov-85	0.72	4	5.5	NA	0.061	0.20	1.56	3.95	113.84
17-Nov-85	18-Nov-85	0.54	1	7.0	NA	0.061	0.20	1.56	2.96	85.38
25-Nov-85	28-Nov-85	0.31	7	6.7	28	0.061	0.20	1.56	1.70	49.02
2-Dec-85	2-Dec-85	0.30	4	6.9	24	0.033	0.15	2.04	0.89	59.02
6-Dec-85	7-Dec-85	0.44	4	6.8	63	0.036	0.17	1.10	1.42	50.20
31-Dec-85	1-Jan-86	0.54	24	6.2	8	0.057	0.32	0.56	2.77	42.69
1-Jan-86	3-Jan-86	0.32	0	5.6	23	0.031	0.16	0.76	0.89	26.45
5-Jan-86	6-Jan-86	0.53	2	6.8	9	0.022	0.10	0.56	1.05	31.43
15-Jan-86	16-Jan-86	0.52	9	6.0	16	0.036	0.21	0.32	1.68	24.76
16-Jan-86	17-Jan-86	0.50	0	5.3	29	0.029	0.05	0.75	1.30	35.94
17-Jan-86	19-Jan-86	0.55	0	5.8	11	0.018	0.03	0.40	0.89	21.25
22-Jan-86	24-Jan-86	0.84	3	6.2	12	0.011	0.08	0.46	0.83	40.75
27-Jan-86	29-Jan-86	1.02	3	5.9	1	<0.004	0.05	0.16	0.00	19.24
30-Jan-86	2-Feb-86	0.78	1	5.8	1	<0.004	0.07	0.18	0.00	17.52
2-Feb-86	6-Feb-86	0.80	0	5.8	3	0.013	0.10	0.50	0.93	43.12
14-Feb-86	16-Feb-86	1.01	8	6.6	4	0.022	0.06	0.90	2.00	87.11
21-Feb-86	24-Feb-86	0.78	5	6.7	2	0.021	0.11	0.20	1.47	21.72
6-Mar-86	8-Mar-86	0.61	10	7.7	3	0.014	0.13	0.34	0.77	25.76
9-Mar-86	12-Mar-86	0.98	1	6.7	3	0.010	0.11	0.24	0.88	30.82
16-Mar-86	16-Mar-86	0.27	4	7.3	3	0.007	0.24	0.38	0.17	15.04
23-Mar-86	23-Mar-86	0.78	7	7.3	2	0.007	0.24	0.38	0.49	43.45
29-Mar-86	30-Mar-86	0.27	6	6.7	72	0.006	0.24	0.88	0.15	27.17
11-Apr-86	12-Apr-86	0.38	11	6.5	11	0.474	0.02	2.60	16.18	88.76
15-Apr-86	16-Apr-86	0.48	3	6.5	32	0.031	0.19	0.71	1.34	38.81
22-Apr-86	23-Apr-86	0.15	6	7.0	8	0.048	0.47	0.98	0.65	19.54
25-Apr-86	26-Apr-86	0.20	2	NA	11	0.046	0.41	1.22	0.83	29.29
26-Apr-86	30-Apr-86	0.80	0	7.6	3	0.005	0.16	0.52	0.36	49.02
2-May-86	4-May-86	0.74	2	7.0	5	0.004	0.27	0.40	0.27	44.54

Table B.4. (continued).

Event Start	Event Stop	Amount (in)	Days Since Last Event	pH	Conductivity (umhos)	Nutrient Concentrations TP (mg/l)	NO3 (mg/l)	TKN (mg/l)	Nutrient Load to Twin Lakes TP (kg)	TN (kg)
10-May-86	12-May-86	0.21	6	6.5	17	0.111	0.49	1.26	2.09	33.02
19-May-86	21-May-86	0.42	7	6.0	11	0.123	0.30	1.9	4.64	83.01
21-May-86	22-May-86	0.50	0	6.1	3	0.038	0.12	0.3	1.71	18.87
14-Jun-86	15-Jun-86	0.13	23	6.6	24	0.504	1.19	2.68	5.89	45.20
15-Jun-86	20-Jun-86	0.59	0	6.9	10	0.186	0.49	2.22	9.86	143.64
3-Jul-86	6-Jul-86	0.46	13	7.0	28	0.396	0.94	3.1	16.37	166.96
10-Jul-86	11-Jul-86	0.29	4	7.2	9	0.088	0.29	0.66	2.29	24.75
16-Jul-86	17-Jul-86	0.32	5	6.0	10	0.061	0.31	0.74	1.75	30.19
29-Aug-86	2-Sep-86	0.62	43	6.7	27	0.186	0.83	2.16	10.36	166.55
14-Sep-86	21-Sep-86	0.96	12	7.1	11	0.048	0.41	0.56	4.14	83.66
23-Sep-86	24-Sep-86	1.58	2	6.8	5	0.011	0.13	0.18	1.56	44.00
26-Sep-86	29-Sep-86	1.10	2	7.2	8	0.011	0.27	0.42	1.09	68.19
29-Sep-86	30-Sep-86	1.14	0	6.3	4	0.008	0.11	0.17	0.82	28.68
Annual Sum		27.62				3.145	11.822	42.070	119.900	2326.28
Event Mean		0.60				0.068	0.257	0.915	2.607	50.571
Standard Deviation		0.32				0.112	0.231	0.744	3.650	37.202

WASTEWATER SYSTEMS

Septic loading is more difficult to determine directly than rainfall or tributary loading; estimating wastewater loading requires some important assumptions:

1) Only sewage systems within 91 m (300 ft) have the potential to affect the lake. This is the zone surveyed by the Panhandle Health District (Panhandle Health District 1 1977).

2) Per capita nutrient delivery to the sewage system is 1.48 kg phosphorus and 4.75 kg nitrogen per year (Rast and Lee 1978). These figures are based on a mean of 10 studies.

3) Fifteen percent of the phosphorus and 25% of the nitrogen entering sewage systems is transported to the lake. These percentages are relatively high, but even so may be conservative estimates for Twin Lakes. (More commonly, 5-10% is used for phosphorus transport.) We felt justified in using 15% for several reasons: a) the average disposal site is only 22 m from the shoreline and on a 11.5 degree slope; b) the majority of systems are quite antiquated, "older systems close to the water's edge are the rule rather than the exception"; c) 72% of the wastewater systems are cesspools and drywells; and d) nearly 20% of the lots have significant subsurface rock (Panhandle Health District 1 1977). In addition, soils in many areas around both basins are gravelly and sandy *ie*. less than ideal for septic system drainfields (Table B.5).

We calculated septic nutrient loading by multiplying per-capita loading rates and percent transported as described above by per-capita use. Per-capita use was determined from a homeowner's survey (Appendix D) which determined number of people per residence and lengths of stay on the lake for each party responding to the survey. These figures times the number of lots with homes within 91 m of Twin Lakes (419 homes at the time of the shoreline survey plus 44 new homes based on our homeowner's survey) yields a total of 420.5 person-years (143.3 for the upper lake and 277.2 for the lower lake). Phosphorus loading to both basins is then

$$420.5 \text{ person-yrs} \times 1.48 \text{ kg P/person-yr} \times 0.15 = 93.2 \text{ kg per year}$$

to the lakes. Nitrogen loading from septic tanks calculated in the same manner is 499.3 kg per year to the lakes.

INTERNAL LOADING

Internal nutrient loading, like septic nutrient loading, is difficult to determine directly. We calculated internal loading to Twin Lakes by three different methods -- hypolimnetic increase, estimated sediment release rates, and a loading - retention time model.

Table B.5. Major soil types at Twin Lakes, Idaho.

Unit No	Soil Type	Shoreline Length (km)	Slope (%)	Permiability	Rooting Depth (inches)	Location/Remarks
Upper Basin						
149	McGuire-Marble assoc.	0.52	0-7	rap.-v. rapid	60+	Eastern-most end, north of channel
159	Pywell muck	1.70	0-2		60+	West end marsh/high water table
164	Rubson-Mokins complex	0.97	0-20	slow	60+	Western Lake Forest/perched water table
174	Selle fine sandy loam	1.49	0-7	mod. rapid	60+	Eastern Lake Forest
184	Spokane loam	0.59	30-65	mod. rapid	20-40	Pioneer Park to channel
199	Vassar silt loam	1.93	30-65	mod. rapid	60+	Swan Beach to Pioneer Park
Lower Basin						
126	Kootenai gravelly silt loam	1.33	0-7	v. rapid	60+	Gunning
127	Kootenai silt loam	2.32	20-45	v. rapid	60+	Pinehurst to Dellar Beach
144	Lenz complex	1.77	35-65	mod.	20-40	Echo Cliff/shallow soil
145	Lenz-Spokane-Rock outcrop assoc.	2.36	30-55	rapid	20-40	Hart Island to Gunning/rocky, shallow soil
149	McGuire-Marble assoc.	4.52	0-7	rap.-v. rapid	60+	Dellar Beach to Lakeview
184	Spokane loam	1.30	30-65	mod. rapid	20-40	Lakeview Addition
198	Vassar silt loam	1.33	5-30	mod. rapid	60+	Springwater, Excelsior Beach/seepage

Hypolimnetic Increase.

Sediment-bound phosphorus is released primarily under anaerobic conditions. Because there is little exchange between the hypolimnion and epilimnion, hypolimnetic phosphorus concentrations increase as an anaeobic hypolimnion accumulates dissolved phosphorus. This increase can be measured and converted to a loading rate.

Hypolimnetic phosphorus increase during the period of summer stratification in Lower Twin Lake in 1985 was measured (the upper lake did not stratify). Mean hypolimnion concentrations increased from 0.0165 mg/l on 20 June to 0.043 mg/l on 2 October. Given the volume of the hypolimnion (2.47×10^6 m^3), 0.6288 kg P were released each day of the measured stratification period. The period of stratification was 122 days so if the release during the measured period was representative of the entire period, total phosphorus release in the lower basin was 77 kg to the hypolimnion.

This method cannot account for aerobic phosphorus release. Twin Lakes is likely to have some aerobic internal loading because of the extensive macrophyte growth, which can release nutrients by living foliage pumping phosphorus from sediments to the water column and by decomposition of senescent plants (Moore et al. 1984). We consider 77 kg to be a lower limit for internal phosphorus loading in the lower basin. Because the upper lake did not stratify, this method could not be applied to Upper Twin Lake.

Laboratory-Measured Sediment Release Rate.

If the phosphorus release rate from sediments is known under aerobic and anaerobic conditions, total phosphorus release can be calculated. In practice, actual release rates are difficult to determine accurately because release rates vary with time and location as a function of a number of factors such as temperature, oxygen, and bioturbation (Holdren and Armstrong 1980, Bates and Neafus 1980).

We used release rates determined for nearby Liberty Lake by Mawson et al. (1983) of 127 ug $P/m^2/hr$ for anaerobic sediments and 1.86 ug $P/m^2/hr$ for aerobic sediments. We calculated the anaerobic release for different depth strata separately by calculating the sediment surface area of each strata and the time that strata was anaerobic in 1985 and then summing over all strata. Calculated in this manner, anaerobic phosphorus release in Lower Twin Lake was 101 kg P/yr. Similarly, aerobic release to the lower basin was 24 kg P (125 kg total) and 32 kg P/yr in the upper basin.

Mass Balance.

Internal phosphorus loading can be calculated from the following model:

$$L_{internal}=-L_{external}(R_{observed}-R_{predicted})$$

where

$$R_{observed}=1-(P_{out}/P_{in}) \quad \text{and} \quad R_{predicted}=10/(10+q_s)$$

where L is loading, R is retention, P is total inflow or outflow phosphorus, and q_s is the areal water loading rate. The reader is refered to Nurnberg (1984) for a discussion of the methodology. Using this method, internal loading to Upper Twin Lakes was 117 kg in 1985 and 48 kg in 1986. Internal loading to Lower Twin Lakes was 172 kg and 71 kg in 1985 and 1986, respectively.

There are major disadvantages to this method:

1) It is heavily dependent on inflow and outflow concentration and flow measurement.

2) Phosphorus leaving the lake in groundwater flow had to be estimated because no groundwater samples were taken.

3) Internal loading calculated in this manner will include any phosphorus sources that were not included in the $L_{external}$ variable. In Twin Lakes, these sources could include overland runoff, cattle waste entering the lake directly, rather than through Fish Creek, and errors in calculations of other sources. A major potential source not included in other methods is phosphorus release from macrophyte decomposition (1-1.6 x the average phosphorus content of summer standing crop).

All of these methods have advantages and disadvantages. Ultimately, we decided to use a combination of the first two methods to estimate internal loading to Twin Lakes. Phosphorus released under aerobic conditions was determined by the sediment release rate method and anaerobic release in the lower basin by the hypolimnetic release method. Internal loading to the upper basin was therefore 32 kg and loading to the lower basin was 77+24=101 kg. These loading rates were determined for 1985 only because insufficient data was collected in 1986 to determine hypolimnetic release.

APPENDIX C. GENERAL LIMNOLOGY

Table C.1. Physical/chemical data for Lower Twin Lake. Sorted by date and by depth. (Pct Sat=percent oxygen saturation, EC=electrical conductivity, Turb=turbidity, Alk=methyl-orange alkalinity, Hard=hardness, Chl=trichromatic chlorophyll "a", Pheao=pheaophytin, and LOI=loss on ignition.)

Site	Depth (m)	Date	Temp (C)	Pct Sat	O2 (mg/l)	EC (umhos)	pH	Turb (NTU)	Alk	CO2	Hard	Cl-	NO3-N	TKN	TP	Time	Chl (ug/l)	Phaeo (ug/l)	Dry Wt (mg/l)	LOI (mg/l)
									-----------	(mg/l)	-----------									
MLD	18	28Jan86	3.5	0.0	0.0								0.06	1.94	0.737					
MLD	4	28Jan86	1.9	92.9	11.8	6							<0.02		0.016					
MLD	1	28Jan86	1.1	98.6	12.8	9							<0.02							
MLD	18	26Jul85	6.0	0.0	0.0	28	6.00	9.1	16.0	14.0		<0.5	<0.02	0.60	0.190	0815	7.06	1.13	10.00	5.89
NLD	11	26Jul85	8.1	34.2	3.7	24	5.96	1.5	14.0	6.5		<0.5	<0.02	0.22	0.040	1413	1.75	0.79	1.04	0.85
MLD	4	26Jul85	23.2	100.3	7.8	27	7.00	0.8	13.0	3.0		<0.5	0.02	0.20	<0.002	0815	1.82	0.73	1.09	0.68
NLD	4	26Jul85	23.1	95.0	7.4	28	6.70	1.2	14.0	1.5		<0.5	0.12	0.20	<0.002	1414	2.07	1.21	1.31	0.89
MLD	1	26Jul85	23.3	100.4	7.8	25	7.05	0.7	12.0	2.0		<0.5	<0.02	0.34	<0.002	0815	1.74	0.61	1.60	1.44
SLD	1	26Jul85	22.9	97.8	7.7	27	7.10	1.5	15.0	2.0		<0.5	0.05	0.22	0.025	1054	2.38	0.74	2.09	1.10
NLD	1	26Jul85	24.1	111.3	7.4	27	6.61	0.8	15.0	2.0		<0.5	<0.02	0.22	0.182	1414	9.54	1.58	3.38	2.34
NLL	Shl 1	26Jul85	25.2	110.8	8.3	26	6.71	1.8	15.0	1.5		<0.5	0.05	0.18	0.016	1515	1.96	0.46	3.40	1.96
MLL	Shl 1	26Jul85	23.1	97.6	7.6	26	7.05	0.8	13.0	3.0		0.7	0.02	0.44	<0.002	0915	1.67	0.29	0.90	0.80
SLL	Shl 1	26Jul85	22.9	94.0	7.4	27	7.20	1.0	12.0	2.0		<0.5	0.03	0.22	<0.002	1013	2.25	1.11	1.23	0.59
SLL	Mid 1	26Jul85	22.9	93.4	7.3	26	7.20	0.9	13.0	2.0		<0.5	<0.02	0.20	<0.002	1023	2.09	1.15	0.92	0.74
MLL	Mid 1	26Jul85	23.2	97.0	7.6	26	7.10	0.8	13.0	2.0		<0.5	<0.02	0.20	<0.002	0927	2.21	0.78	1.80	0.91
NLL	Mid 1	26Jul85	24.4	100.4	7.6	27	6.60	1.0	14.0	2.0		0.5	<0.02	0.18	0.008	1530	1.65	0.69	1.23	0.82
SLL	Dp 4	26Jul85	23.0	94.9	7.4	26	7.25	0.8	13.0	2.0		<0.5	<0.02	0.22	<0.002	1033	2.34	0.79	0.85	0.74
MLL	Dp 4	26Jul85	23.2	104.4	7.6	28	7.20	0.7	13.0	1.5		<0.5	0.02	0.22	0.115	0940	1.94	0.46	1.25	0.73
NLL	Dp 4	26Jul85	23.3	93.3	7.3	27	6.60	1.0	13.0	0.5	8	<0.5	<0.02	0.16	0.011	1545	2.35	1.49	1.80	1.16
SLL	Dp 1	26Jul85	23.0	94.9	7.4	26	7.20	0.8	13.0	2.0		0.5	<0.02	0.22	0.025	1033	2.34	0.89	1.19	0.89
NLL	Dp 1	26Jul85	24.2	98.8	7.6	28	6.78	1.1	12.0	3.0	8	<0.5	0.05	0.22	0.038	1545	1.95	0.53	2.23	1.43
MLL	Dp 1	26Jul85	23.2	96.4	7.5	27	7.15	0.8	13.0	1.5		<0.5	<0.02	0.20	0.046	0940	1.95	0.69	1.05	0.80
MLD	18	25Oct85	8.7	88.2	9.4	21	6.74	1.6	16.0	4.0		1.0	<0.02	0.22	0.053	0830	5.74	12.08	2.64	1.04
NLD	11	25Oct85	8.7	90.1	9.6	29	6.78	1.3	14.0	3.0		1.0	<0.02	0.24	0.013	1100	4.98	2.09	2.35	1.14
MLD	4	25Oct85	8.7	87.7	9.4	22	6.78	1.3	13.0	4.0	9	0.5	<0.02	0.24	0.009	0830	5.33	6.39	2.03	1.06
NLD	4	25Oct85	8.7	91.0	9.7	22	6.78	1.5	12.0	2.5	9	0.8	<0.02	0.24	0.018	1100	6.10	5.25	1.83	1.16
NLD	1	25Oct85	8.7	91.0	9.7	20	6.78	1.8	14.0	3.0		0.8	<0.02	0.24	0.030	1100	5.29	4.86	2.69	1.36
SLD	1	25Oct85	8.6	99.2	10.6	18	6.99	2.2	12.0	2.5	9	0.5	<0.02	0.22	0.080	1523	3.94	3.02	2.77	0.92
MLD	1	25Oct85	8.7	88.6	9.5	21	6.81	2.0	16.0	5.5		0.5	<0.02	0.26	0.019	0830	5.64	4.15	1.75	1.08

Table C.1. (continued).

Site	Depth (m)	Date	Temp (C)	Pct Sat	O2 (mg/l)	EC (umhos)	pH	Turb (NTU)	Alk	CO2	Hard	Cl-	NO3-N	TKN	TP	Time	Chl (ug/l)	Phaeo (ug/l)	Dry Wt (mg/l)	LOI (mg/l)
									----	----	----	(mg/l)	----	----	----					
NLL	Shl 1	25Oct85	9.0	93.2	9.9	20	6.80	2.6	13.0	3.0		1.0	<0.02	0.24	0.014	1200	4.94	3.51	1.76	1.04
SLL	Shl 1	25Oct85	9.2	97.8	10.3	19	6.90	2.7	14.0	3.0		1.0	<0.02	0.26	0.005	1415	4.11	2.45	1.35	1.01
MLL	Shl 1	25Oct85	8.7	91.0	9.7	21	6.74	2.6	19.0	2.5		1.0	<0.02	0.24	0.015	0940	4.10	3.41	2.92	1.46
SLL	Mid 1	25Oct85	8.8	96.1	10.2	19	6.89	1.9	13.0	2.5	8	0.8	<0.02	0.24	0.005	1445	3.87	3.02	1.63	1.10
MLL	Mid 1	25Oct85	8.7	89.1	9.5	21	6.74	2.9	15.0	3.0	9	1.0	<0.02	0.24	0.036	1006	4.87	4.05	2.61	1.24
NLL	Mid 1	25Oct85	8.7	91.0	9.7	21	6.84	2.7	13.0	3.0	9	1.0	<0.02	0.24	0.025	1224	4.86	3.20	2.40	0.96
NLL	Dp 4	25Oct85	8.6	90.7	9.7	21	6.79	2.1	13.0	2.5		1.0	<0.02	0.26	0.027	1230	6.10	4.46	2.29	1.37
MLL	Dp 4	25Oct85	8.7	89.1	9.5	23	6.75	2.9	13.0	2.5		1.0	<0.02	0.50	0.011	1026	5.30	4.36	2.64	1.04
SLL	Dp 1	25Oct85	8.8	97.1	10.3	19	6.99	2.8	16.0	2.5		0.8	<0.02	0.20	0.006	1500	4.03	2.50	1.45	0.82
NLL	Dp 1	25Oct85	8.7	91.0	9.7	20	6.86	2.2	14.0	3.0		1.0	<0.02	0.22	0.010	1230	4.35	1.82	1.75	1.00
MLL	Dp 1	25Oct85	8.8	89.4	9.5	21	6.73	2.2	14.0	3.0		1.0	<0.02	0.24	0.013	1026	6.25	6.27	1.75	0.99
MLD	18	23Feb85	4.3	0.0	0.0		6.11		38.0	18.0										
MLD	4	23Feb85	3.0	84.4	10.4		6.26		16.0	11.5										
MLD	1	23Feb85	0.4	76.3	10.1		6.40		16.0	10.5										
MLD	18	21Aug85	6.8	0.0	0.0	29	6.13	4.8	22.0	14.0	11	<0.5	0.09		0.017	0850	5.12	3.90	4.52	2.82
NLD	11	21Aug85	7.9	0.0	0.0	25	6.18	2.4	16.0	6.0	8	<0.5	0.09		0.012	1120	4.42	1.05	2.75	2.03
NLD	4	21Aug85	18.9	95.4	8.1	23	6.65	1.0	13.0	2.0		<0.5	0.04		0.010	1120	3.00	0.00	2.37	1.06
MLD	4	21Aug85	18.5	98.1	8.4	23	6.68	0.8	13.0	2.0		<0.5	<0.02		0.003	0850	2.76	2.71	2.20	1.11
SLD	1	21Aug85	18.4	101.5	8.7	23	6.72	2.4	13.0	2.0	6	<0.5	0.09		0.010	1600	2.58	1.79	2.09	1.15
MLD	1	21Aug85	18.5	98.2	8.4	21	6.34	0.9	14.0	3.0		<0.5	0.03		0.006	0850	2.51	1.09	2.41	1.07
NLD	1	21Aug85	19.1	94.7	8.0	23	6.59	1.1	12.0	2.0	6	<0.5	<0.02		0.005	1120	7.31	4.52	2.54	1.19
MLL	Shl 1	21Aug85	18.8	98.9	8.4	22	6.50	1.7	13.0	2.0		<0.5	0.04		<0.002	1000	4.52	3.01	1.57	0.88
SLL	Shl 1	21Aug85	18.9	100.0	8.5	22	6.49	1.5	14.0	2.0		<0.5	<0.02		<0.002	1435	2.82	0.95	0.91	1.25
NLL	Shl 1	21Aug85	19.1	100.0	8.5	22	6.73	1.3	14.0	2.0	2	<0.5	0.11		0.010	1400	2.34	2.15	1.88	1.10
MLL	Mid 1	21Aug85	18.8	98.4	8.4	21	6.46	1.5	14.0	2.0		<0.5	0.02		0.009	1025	2.78	1.22	1.00	1.04
NLL	Mid 1	21Aug85	19.4	96.5	8.1	22	6.38	1.2	14.0	2.0		<0.5	0.02		<0.002	1335	2.81	1.67	2.38	1.49
SLL	Mid 1	21Aug85	18.9	100.1	8.5	22	6.54	1.2	13.0	2.0		<0.5	<0.02		<0.002	1500	2.22	0.84	2.31	1.30
MLL	Dp 4	21Aug85	18.9	98.0	8.3	23	6.43	0.9	15.0	2.0	8	<0.5	0.05		<0.002	1045	4.22	3.20	1.80	1.13
NLL	Dp 4	21Aug85	19.0	94.6	8.0	23	6.61	1.0	13.0	2.0	8	<0.5	0.05		<0.002	1255	2.78	0.22	2.63	1.35
SLL	Dp 1	21Aug85	18.8	97.5	8.3	23	6.41	0.8	13.0	3.0	8	<0.5	0.03		<0.002	1530	2.08	1.14	2.03	1.17
NLL	Dp 1	21Aug85	19.6	96.3	8.1	22	6.63	1.0	14.0	2.0		<0.5	<0.02		<0.002	1255	2.29	0.61	2.41	1.25
MLL	Dp 1	21Aug85	18.8	98.9	8.4	21	0.00	2.3	14.0	2.0		<0.5	0.02		0.010	1045	2.80	0.95	2.23	1.04
MLD	18	20Jun85	6.4	0.0	0.0	26	5.80	8.2	14.0	19.0	8	1.0	0.05		0.033	0830	3.86	1.82		
NLD	11	20Jun85	9.7	35.1	3.6	24	5.95	1.6	10.0	13.0	8	1.5	0.12		<0.002	1007	5.26	3.07		
NLD	4	20Jun85	19.4	100.1	8.4	24	6.60	1.1	12.0	12.0	8	2.0	0.02		0.005	1007	2.10	2.13		
MLD	4	20Jun85	18.3	99.0	8.5	25	6.40	0.9	14.0	12.0	8	1.0	<0.02		0.004	0830	1.55	2.45		
SLD	1	20Jun85	20.7	106.2	8.7	25	6.80	1.0	12.0	11.0	8	1.0	0.04		0.010	1440	2.42	4.35		
MLD	1	20Jun85	19.7	102.0	8.7	23	6.39	1.0	12.0	12.0	8	1.0	<0.02		<0.002	0830	2.32	1.03		
NLD	1	20Jun85	19.9	99.8	8.3	23	6.30	1.8	12.0	12.0	8	1.5	0.10		<0.002	1007	1.57	2.31		

Table C.1. (continued).

Site	Depth (m)	Date	Temp (C)	Pct Sat	O2 (mg/l)	EC (umhos)	pH	Turb (NTU)	Alk	CO2	Hard	Cl-	NO3-N	TKN	TP	Time	Chl (ug/l)	Phaeo (ug/l)	Dry Wt (mg/l)	LOI (mg/l)
									-------------	(mg/l)	-------------									
NLL	Shl 1	20Jun85	20.0	113.3	9.4	23	6.30	1.2	12.0	11.0	7	<0.5	0.02		0.004	1215	1.77	2.49		
SLL	Shl 1	20Jun85	19.8	105.5	8.8	23	6.30	1.3	14.0	12.0	7	0.5	<0.02		0.004	1623	2.62	1.08		
MLL	Shl 1	20Jun85	19.9	104.6	8.7	22	6.61	1.4	14.0	9.0	7		0.08		<0.002	1458	1.93	1.89		
SLL	Mid 1	20Jun85	19.8	106.7	8.9	24	6.50	1.4	14.0	10.0	7	1.0	<0.02		0.002	1623	2.25	1.52		
NLL	Mid 1	20Jun85	20.6	104.9	8.6	23	6.58	0.6	12.0	10.0	7	<0.5	<0.02		0.007	1215	2.08	1.05		
MLL	Mid 1	20Jun85	19.8	103.1	8.6	23	6.68	0.7	16.0	13.0	8	1.5	<0.02		<0.002	1458	1.53	0.42		
MLL	Dp 4	20Jun85	19.6	102.6	8.6	25	6.20	0.9	12.0	11.0	8	2.0	<0.02		<0.002	1458	2.19	1.60		
NLL	Dp 4	20Jun85	19.7	101.7	8.5	25	6.58	0.7	12.0	6.0	6		0.05		0.002	1215	2.62	3.62		
SLL	Dp 4	20Jun85	18.8	119.9	10.2	23	6.20	0.8	12.0	10.0	8	1.0	0.08		<0.002	1623	3.25	1.68		
MLL	Dp 1	20Jun85	19.9	105.8	8.8	23	6.05	1.0	12.0	11.0	8	1.0	0.04		0.003	1458	1.82	1.30		
NLL	Dp 1	20Jun85	20.0	102.4	8.5	23	6.52	0.8	14.0	11.0	6	<0.5	0.06		0.002	1215	0.89	0.88		
SLL	Dp 1	20Jun85	19.8	104.3	8.7	22	6.65	0.7	20.0	11.0	6	1.5	0.02		0.006	1623	1.78	1.76		
MLD	18	06Sep85	8.0	0.0	0.0	33	6.49	2.1	19.0	8.0	8	<0.5	<0.02	0.38	0.068	1445	2.43			
NLD	11	06Sep85	7.2	0.0	0.0	25	6.51	2.2	16.0	7.0	6	<0.5	<0.02	0.22	0.021	0750	6.17	1.05	3.21	2.32
MLD	4	06Sep85	17.9	108.4	9.4	29	7.09	1.6	13.0	2.0		0.5	<0.02	0.30	0.012	1445	1.51			
NLD	4	06Sep85	15.4	94.7	8.8	23	7.00	1.4	13.0	3.0		<0.5	<0.02	0.22	0.015	0750	4.14	1.54	3.60	1.68
MLD	1	06Sep85	17.9	108.4	9.4	26	7.17	1.1	16.0	2.0		<0.5	0.08	0.27	0.015	1445	1.51			
SLD	1	06Sep85	14.3	102.0	9.5	23	7.21	2.1	16.0	2.5	8	<0.5	0.09	0.24	0.023	1433	2.94	1.63	2.36	1.33
NLD	1	06Sep85	15.7	98.1	8.9	22	6.99	1.4	17.0	3.0	6	<0.5	<0.02	0.22	0.022	0750	2.39	1.52	4.10	1.96
SLL	Shl 1	06Sep85	15.5	101.0	9.2	22	7.17	3.4	15.0	2.0		<0.5	0.02	0.24	0.017	1356	2.08	0.39	3.99	2.78
NLL	Shl 1	06Sep85	15.8	92.7	8.4	22	7.02	1.5	16.0	3.0		<0.5	<0.02	0.24	0.010	0837	2.80	2.32	3.41	1.77
SLL	Mid 1	06Sep85	15.3	98.6	9.1	22	7.20	1.7	16.0	2.0	8	1.0	0.04	0.26	0.022	1407	2.39	1.87	2.60	1.64
MLL	Mid 1	06Sep85	16.1	100.7	9.1	22	7.16	2.4	15.0	2.0	8	<0.5	<0.02	0.22	0.009	1505	3.30	4.11	3.96	1.64
NLL	Mid 1	06Sep85	15.9	93.0	8.4	22	6.85	1.3	16.0	3.0	8	<0.5	<0.02	0.26	0.010	0846	3.11	1.67	3.19	1.73
NLL	Dp 4	06Sep85	16.0	92.5	8.3	23	6.90	1.4	16.0	3.0		<0.5	<0.02	0.24	0.011	0854	2.95	1.66	3.86	2.47
MLL	Dp 4	06Sep85	16.0	98.2	8.9	24	7.14	2.0	13.0	2.5		<0.5	0.03	0.26	0.024	1520	3.06	2.32	3.24	1.27
NLL	Dp 1	06Sep85	16.0	93.2	8.4	22	6.88	1.4	17.0	3.0		<0.5	<0.02	0.24	0.029	0854	2.70	0.25	2.39	1.40
SLL	Dp 1	06Sep85	15.3	100.3	9.2	24	7.12	1.9	15.0	2.0		<0.5	<0.02	0.24	0.013	1417	2.05	0.71	4.37	2.14
MLL	Dp 1	06Sep85	16.1	100.1	9.0	22	7.11	1.6	15.0	2.5		<0.5	<0.02	0.22	0.012	1520	2.53	0.60	3.43	1.91
MLD	18	03Oct85	7.7	0.0	0.0	32	6.45	2.3	24.0	14.0	10	<0.5	0.02		0.080	1245	2.51	1.61		
NLD	11	03Oct85	11.1	41.3	4.2	23	7.01	0.9	15.0	7.0	8	<0.5	<0.02		0.007	0800	3.51	1.18		
NLD	4	03Oct85	12.1	92.1	9.1	21	7.18	0.9	17.0	3.0		<0.5	<0.02		0.006	0800	2.59	1.02		
MLD	4	03Oct85	12.0	91.9	9.1	22	7.28	1.1	15.0	3.0		<0.5	0.03		0.011	1245	2.82	0.61		
MLD	1	03Oct85	12.1	92.6	9.1	21	7.11	1.0	14.0	3.0	9	<0.5	0.02		0.006	1245	3.20	1.32		
NLD	1	03Oct85	12.1	1096.4	9.1	20	7.13	0.9	15.0	3.0	8	<0.5	<0.02		0.009	0800	3.25	2.50		
SLD	1	03Oct85	11.1	99.9	10.1			0.9	13.0	2.0		<0.5	<0.02		0.005	1622	2.48	2.39		

Table C.1. (continued).

Site	Depth (m)	Date	Temp (C)	Pct Sat	O2 (mg/l)	EC (umhos)	pH	Turb (NTU)	Alk	CO2	Hard	Cl-	NO3-N	TKN	TP	Time	Chl (ug/l)	Phaeo (ug/l)	Dry Wt (mg/l)	LOI (mg/l)
									-------------	(mg/l)	-------------									
NLL	Shl	103Oct85	12.1	93.6	9.2	20	7.11	1.0	16.0	2.5		<0.5	<0.02		0.014	0900	2.51	1.07		
SLL	Shl	103Oct85	12.1	97.7	9.6	22	7.05	1.3	16.0	3.0		0.7	0.04		0.005	1530	1.76	1.70		
MLL	Shl	103Oct85	12.0	93.9	9.3	21	7.27	1.2	15.0	3.0		0.5	0.06		0.006	0940	2.80	1.23		
SLL	Mid	103Oct85	11.8	99.1	9.8	19	7.20	1.5	14.0	3.0	9	<0.5	<0.02		0.015	1550	1.79	0.72		
NLL	Mid	103Oct85	12.1	93.6	9.2	20	7.11	1.0	16.0	2.5	9	<0.5	0.02		0.008	0907	2.57	0.79		
MLL	Mid	103Oct85	12.0	92.4	9.1	21	7.18	0.9	16.0	3.0	7	<0.5	0.03		0.007	0950	2.84	0.74		
MLL	Dp 4	03Oct85	12.0	91.4	9.0	22	7.14	0.9	13.0	3.0		<0.5	0.04		0.005	1005	2.71	1.51		
NLL	Dp 4	03Oct85	12.2	93.8	9.2	21	7.18	1.0	15.0	2.5		<0.5	0.10		0.006	0920	2.62	0.99		
NLL	Dp 1	03Oct85	12.2	93.3	9.2	20	7.12	0.9	14.0	2.5		<0.5	<0.02		0.008	0920	2.61	0.89		
SLL	Dp 1	03Oct85	11.8	99.1	9.8	19	7.28	1.1	14.0	3.0		<0.5	<0.02		0.008	1606	2.25	0.96		
MLL	Dp 1	03Oct85	12.1	92.1	9.1	20	7.10	1.1	16.0	3.0		0.5	0.04		0.007	1005	3.08	1.07		
MLD	18	03May85	6.1	75.7	8.6	23	6.20	2.7	12.0		6	<0.5	<0.02	0.18	0.067	1300	4.88			
MLD	4	03May85	7.9	87.5	9.5	20	6.63	1.6	11.5		6	<0.5	<0.02	0.32	0.168	1300	3.71			
MLD	1	03May85	12.1	97.7	9.6	20	6.75	1.8	12.0		6	<0.5	<0.02	0.26	0.069	1300	2.27			
MLL	Shl	103May85	10.5				6.98	2.0	12.5		6	<0.5	<0.02	0.22	0.074	1430				
MLD	18	08May86	6.5		5.2	24	5.44		14.0	7.5			<0.02	0.22	0.008		14.40	11.43		
NLD	11	08May86	7.5		7.3	25	7.25	0.7	14.0	7.0			<0.02	0.16	0.021		2.12	1.55	2.09	2.058
NLD	4	08May86	10.8		10.8	26	7.38	0.5	14.0	2.5			<0.02	0.19	0.014		6.00	3.05	1.99	1.99
MLD	4	08May86	10.3		10.8	26	6.59	0.5	14.0	2.0			<0.02	0.18	0.013		5.17	3.33		
SLD	1	08May86	11.5		10.8	27	7.25	0.7	14.0	2.0			0.03	0.18	0.020		4.29	2.00		
MLD	1	08May86	10.5		10.9	26	6.60	0.6	14.0	2.0			<0.02	0.20	0.022		4.62	1.59		
NLD	1	08May86	10.9		10.8	26	7.36	0.5	13.0	2.0			<0.02	0.14	0.006		5.18	1.76		
MLL	4Dp	08May86	10.6		10.9	26	7.25	0.7	14.0	2.0			0.03	0.16	0.005		4.21	1.76	2.23	2.23
NLL	4Dp	08May86	11.0		10.8	26	7.38	0.6	13.0	2.0			<0.02	0.17	0.014		6.03	1.81	2.31	2.31
SLL	4Dp	08May86	10.4		10.6	26	7.28													
NLL	1Shl	08May86	11.2		10.8	26	7.30	0.6	12.0	2.0			0.02	0.15	0.008		4.81	1.88	1.69	1.69
SLL	1Shl	08May86	10.5		10.8	26	7.26	0.6	13.0	2.0			<0.02	0.16	0.009		3.57	1.46		
MLL	1Shl	08May86	11.0		11.2	26	7.36	0.7	13.0	2.0					0.017		3.29	3.00		
NLL	1Mid	08May86	10.9		10.8	26	7.30	0.8	14.0	2.0			<0.02		0.010		5.44	1.95	2.53	2.14
MLL	1Mid	08May86	11.0		11.1	26	7.36	0.7	14.0	2.0			<0.02		0.005		5.07	1.87	2.57	2.19
SLL	1Mid	08May86	10.5		10.8	26	7.28	0.8	13.0	2.0			0.03		0.010		4.55	1.44		
NLL	1Dp	08May86	11.1		10.8	26	7.38	0.8	14.0	2.0			<0.02	0.14	0.002		4.70	2.24	2.067	2.05
MLL	1Dp	08May86	10.7		11.0	26	7.25	0.6	13.0	2.0			<0.02	0.16	0.003		4.36	1.86	2.15	2.03
SLL	1Dp	08May86	10.6		10.6	26	7.25	0.8	14.0	2.0			<0.02	0.18	0.011		4.64	3.04		
MLD	18	18Aug86	8.9		0.0	26	5.71	2.6	18.5	18.5			0.15		0.176					
NLD	11	18Aug86	10.3		0.0	27	5.73	3.1	13.5	13.5			<0.02		0.032					

Table C.1. (continued).

Site	Depth (m)	Date	Temp (C)	Pct Sat	O2 (mg/l)	EC (umhos)	pH	Turb (NTU)	Alk	CO2	Hard	Cl-	NO3-N	TKN	TP	Time	Chl (ug/l)	Phaeo (ug/l)	Dry Wt (mg/l)	LOI (mg/l)
									---(mg/l)						---					
NLD	4	18Aug86	22.2		7.4	21	6.59	1.4	13.5				<0.02		0.015					
MLD	4	18Aug86	22.1		7.4	21	6.61	1.3	14.5				<0.02		0.013		1.46	0.75		
SLD	1	18Aug86	20.2			18	6.63	1.2	15.0				<0.02		0.024		2.43	0.90		
MLD	1	18Aug86	22.6		7.5	19	6.61	1.7	13.5	4.0			0.02		0.022		1.28	0.32		
NLD	1	18Aug86	22.5		7.5	20	6.60	1.3	13.5	4.0			<0.02		0.012		1.75	0.56		
MLL	4Dp	18Aug86	22.4		7.5	21	6.69		12.5				0.03		0.012					
NLL	4Dp	18Aug86	21.6			20	6.41	0.8	15.0				<0.02		0.023					
NLL	1Shl	18Aug86	21.9			18	6.42	1.3	15.0				0.03		0.022		2.29	0.99		
SLL	1Shl	18Aug86	20.7			19	6.44	0.8	15.0				<0.02		0.023					
MLL	1Shl	18Aug86	22.7		7.7	19	6.69	1.2	13.0				0.03		0.015		1.36	0.59		
NLL	1Mid	18Aug86	21.6			19	6.33	0.8	15.0				0.03		0.020		1.20	0.18		
MLL	1Mid	18Aug86	22.6		7.6	20	6.64	1.2	13.0				0.02		0.011					
SLL	1Mid	18Aug86	20.5			19	6.40	0.8	15.0				<0.02		0.021					
NLL	1Dp	18Aug86	21.5			19	6.42	0.8	15.0				0.03		0.024		1.56	0.66		
MLL	1Dp	18Aug86	22.6		7.5	20	6.68	0.8	13.0				0.02		0.015		1.10	0.33		
SLL	1Dp	18Aug86	20.5			19	6.57	0.6	15.0				0.03		0.023		2.37	3.34		

Table C.2. Physical/chemical data for Upper Twin Lake. Sorted by date and by depth. (Pct Sat=percent saturation, EC=electrical conductivity, Turb=turbidity, Alk=methyl-orange alkalinity, Hard=hardness, Chl=trichromatic chlorophyll "a", Pheao=pheaophytin, and LOI=loss on ignition.)

Site	Depth (m)	Date	Temp (C)	Pct Sat	O2 (mg/l)	EC (umhos)	pH	Turb (NTU	Alk ----	CO2 ----	Hard ----	Cl- (mg/l	NO3-N ----	TKN ----	TP ----	Time	Chl (ug/l)	Phaeo (ug/l)	Dry Wt (mg/l)	LOI (mg/l)
WUD	4	28Jan86	2.9	14.57	1.8	40							0.04		0.019					
WUD	1	28Jan86	0.6	66.11	8.7	27														
EUD	4	26Oct85	7.3	99.00	10.9	21	7.10	1.4	16	2.0	8	0.8	<0.02	0.24	0.007	0830	3.76	1.26	1.24	0.75
WUD	4	26Oct85	7.3	95.37	10.5	20														
EUD	1	26Oct85	7.3	101.82	11.2	19	7.09	2.0	15	2.0		0.8	<0.02	0.24	<0.004	0830	3.61	1.30	1.52	0.72
WUD	1	26Oct85	7.3	97.18	10.7	20	7.02	1.7	15	2.0		<0.5	<0.02	0.24	0.034	1055	4.21	3.01	1.38	0.79
SUL	Shl 1	26Oct85	6.9	97.56	10.8	20	7.06	2.2	14	2.5		0.5	<0.02	0.24	<0.004	1130	4.62	1.98	2.23	0.86
NUL	Shl 1	26Oct85	6.8	98.57	11.0	19	6.99	2.2	16	2.5		1.0	<0.02	0.26	0.017	0910	4.24	2.02	2.86	0.85
WUL	Shl 1	26Oct85	6.4	94.94	10.7	20	7.00	2.6	15	2.5		0.8	<0.02	0.30	0.011	1020	4.54	3.21	2.66	0.98
WUL	Mid 1	26Oct85	6.8	95.88	10.7	20	7.06	1.7	15	2.0	8	0.5	<0.02	0.24	0.021	1048	3.94	2.11	1.68	0.73
SUL	Mid 1	26Oct85	7.4	101.09	11.1	20	7.01	2.1	14	2.0	8	0.8	<0.02	0.38	0.022	1200	4.83	11.04	1.84	0.98
NUL	Mid 1	26Oct85	7.3	98.09	10.8	20	7.03	1.7	14	2.5	8	0.5	<0.02	0.32	0.014	0935	4.06	1.59	2.54	0.94
NUL	Dp 4	26Oct85	7.3	96.28	10.6	21	7.06	1.4	15	2.0		0.5	<0.02	0.22	0.006	0945	4.04	2.23	1.39	0.83
SUL	Dp 1	26Oct85	7.4	98.36	10.8	19	7.10	1.6	16	2.5		0.8	<0.02	0.34	0.010	1215	4.48	1.89	1.60	0.82
NUL	Dp 1	26Oct85	7.3	98.09	10.8	20	7.04	1.8	14	2.0		0.8	<0.02	0.24	0.005	0945	4.45	12.39	1.95	0.90
EUD	4	25Jul85	24.2	107.33	8.2	28	7.71	0.4	12	0.5		<0.5	<0.02	0.20	<0.004	1226	3.01	0.23	1.20	1.11
WUD	4	25Jul85	19.2	80.66	6.8	26	6.70	1.6	18	1.5	8		<0.02	0.30	0.037	1040	4.08	2.64	2.90	1.06
WUD	1	25Jul85	23.8	110.68	8.5	27	7.52	0.9	15	0.5	8	<0.5	<0.02	0.18	0.016	1040	2.91	0.89	1.05	0.75
EUD	1	25Jul85	24.9	107.71	8.1	27	7.35	0.7	13	0.5		<0.5	0.10	0.26	0.065	1226	3.66	0.31	2.13	1.44
WUL	Shl 1	25Jul85	23	99.36	7.8	26	6.90	1.1	14	3.0		<0.5	<0.02	0.28	0.025	1004	3.38	1.49	2.00	1.05
SUL	Shl 1	25Jul85	24.6	105.30	8.0	27	7.09	0.8	14	1.0		<0.5	<0.02	0.30	0.025	1109	2.91	1.01	1.20	0.80
NUL	Shl 1	25Jul85	24.3	108.13	8.3	28	6.59	1.6	14	0.5		0.5	<0.02	0.27	0.036	0857	3.26	0.74	1.33	0.93
WUL	Mid 1	25Jul85	23	101.28	7.9	25	6.70	1.2	15	0.0	8	<0.5	<0.02	0.24	<0.004	1015	4.58	0.97	1.27	1.00
NUL	Mid 1	25Jul85	24.2	120.48	8.0	27	6.88	1.4	13	0.5		<0.5	<0.02	0.24	<0.004	0914	3.33	0.80	1.87	1.57
SUL	Mid 1	25Jul85	24.6	107.28	8.1	26	7.25	1.2	13	1.0		<0.5	<0.44	0.20	0.016	1130	3.21	0.90	1.12	0.84
NUL	Dp 4	25Jul85	24	107.05	8.2	27	7.18	0.8	13	0.5	8	0.5	0.04	0.18	0.029	0930	3.34	0.94	0.92	0.83
SUL	Dp 4	25Jul85	24.1	124.66	8.3	27	7.40	0.7	13	1.0	8	<0.5	0.03	0.24	0.016	1148	3.31	0.54	1.51	0.91
SUL	Dp 1	25Jul85	24.5	109.79	8.3	26	7.38	1.5	14	0.5	8	<0.5	0.03	0.23	0.043	1148	3.13	0.34	0.79	0.84
NUL	Dp 1	25Jul85	24.4	108.92	8.3	27	7.10	1.1	13	0.5	7	0.5	<0.02	0.18	0.020	0930	3.43	0.17	1.05	0.94
EUD	4	20Jun85	19.1	119.53	10.1	23	6.71	1.1	12	13.0	6	2.0	0.04		<0.004	0913	2.75	1.90		
WUD	4	20Jun85	18.8	101.06	8.6	25	6.71	1.0	12	13.0	6	1.0	0.05		0.012	1210	2.55	1.30		
EUD	1	20Jun85	19.8	109.24	9.1	22	6.79	0.8	12	13.0	8	1.0	<0.02		<0.004	0913	3.64	3.02		
WUD	1	20Jun85	20.8	105.26	8.6	23	6.76	0.8	12	12.0	8	1.0	<0.02		<0.004	1210	2.49	0.54		

Table C.2. (continued).

Site	Depth (m)	Date	Temp (C)	Pct Sat	O2 (mg/l)	EC (umhos)	pH	Turb (NTU	Alk	CO2	Hard	Cl- (mg/l	NO3-N	TKN	TP	Time	Chl (ug/l)	Phaeo (ug/l)	Dry Wt (mg/l)	LOI (mg/l)
NUL	Shl 1	20Jun85	20.5	109.49	9.0	22	6.50	0.8	14	13.0	7	1.0	<0.02		<0.004	1011	2.25	2.05		
SUL	Shl 1	20Jun85	21.3	109.05	8.8	23	6.78	0.7	12	9.0	6	1.0	<0.02		<0.004	1315	1.50	1.08		
WUL	Shl 1	20Jun85	20.8	106.49	8.7	22	6.80	1.0	14	9.0	8	1.0	<0.02		<0.004	1124	1.99	0.66		
WUL	Mid 1	20Jun85	20.8	107.71	8.8	23	6.85	0.8	12	9.0	7	1.0	<0.02		<0.004	1124	2.43	1.13		
NUL	Mid 1	20Jun85	20.3	108.01	8.9	23	6.65	0.9	12	12.0	6	1.0	0.05		<0.004	1011	3.00	0.29		
SUL	Mid 1	20Jun85	20.5	110.71	9.1	23	6.82	0.8	12	9.0	7	1.5	<0.02		<0.004	1315	2.88	1.71		
SUL	Dp 4	20Jun85	19.7	102.87	8.6	25	6.85	0.8	12	9.0	8	1.0	<0.02		0.004	1315	3.01	2.03		
NUL	Dp 4	20Jun85	19.9	108.17	9.0	25	6.72	0.9	14	11.0		1.0	<0.02		<0.004	1011	3.91	4.09		
SUL	Dp 1	20Jun85	20.8	108.94	8.9	23	6.85	0.7	14	13.0	8	1.0	0.03		0.007	1315	2.37	1.00		
NUL	Dp 1	20Jun85	20.7	110.29	8.9	23	6.65	1.6	10	14.0	7	1.0	<0.02		<0.004	1011	2.67	0.01		
EUD	4	20Aug85	18.8	103.41	8.8	25	6.73	0.9	15	3.0	8	<0.5	0.03		<0.004	1345	2.36	0.00	1.78	0.81
WUD	4	20Aug85	17.2	106.94	9.4	37	6.89	0.9	13	2.0	10	<0.5	0.05		0.008	1030	2.63	0.00	1.62	0.69
WUD	1	20Aug85	17.7	107.92	9.4	25	7.00	0.7	14	3.0		<0.5	0.02		0.011	1030	2.40	1.39	1.43	0.69
EUD	1	20Aug85	18.5	102.80	8.8	23	6.90	0.8	14	3.0		<0.5	0.03		0.018	1345	2.80	1.20	1.35	0.73
SUL	Shl 1	20Aug85	18.4			23	6.50	0.9	14	3.0		<0.5	<0.02		0.014	1200	2.66	1.68	1.10	0.65
NUL	Shl 1	20Aug85	19.2			23	6.20	1.6	16	3.0		<0.5	<0.02		0.010	0840	2.98	2.65	1.92	0.67
WUL	Shl 1	20Aug85	18.1			23	5.95	1.4	12	5.0	10	<0.5	<0.02		0.009	1110	4.21	1.83	1.98	
WUL	Mid 1	20Aug85	17.8			23	6.70	1.2	16	4.0		<0.5	0.02		0.011	1130	2.69	1.37	1.54	0.64
NUL	Mid 1	20Aug85	19.1			23	6.32	1.4	14	2.0		<0.5	0.05		0.009	0910	2.42	1.01	1.61	0.62
SUL	Mid 1	20Aug85	18.5			23	6.57	0.7	14	3.0		<0.5	0.03		0.010	1300	3.15	1.91	1.47	0.72
SUL	Dp 4	20Aug85	18.6			24	6.55	0.9	14	3.0	10	<0.5	0.02		<0.004	1315	8.92	0.71	1.65	1.03
NUL	Dp 4	20Aug85	18.5			24	6.35	1.0	14	3.0	10	<0.5	0.02		0.006	0930	2.49	0.86	1.55	0.70
SUL	Dp 1	20Aug85	18.5			23	6.60	0.8	14	3.0		<0.5	0.03		0.011	1315	7.32	3.07	1.94	0.98
NUL	Dp 1	20Aug85	18.5			23	6.41	0.8	16	3.0		<0.5	0.02		0.004	0930	2.44	1.34	1.07	0.49
WUD	4	05Sep85	15.2	92.15	8.5	22	7.00	1.1	15	3.0		<0.5	<0.02	0.20	0.056	1008	2.97	2.34	2.41	0.96
EUD	4	05Sep85	16.1	91.11	8.1	26	6.98	2.9	16	3.0		<0.5	0.03	0.24	0.025	0842	2.80	3.29	2.40	1.04
EUD	1	05Sep85	16.1	90.00	8.1	25	6.95	1.4	14	3.0	8	<0.5	<0.02	0.44	0.012	0842	1.69	0.95	1.37	0.72
WUD	1	05Sep85	15.2	91.82	8.4	22	6.98	1.3	16	3.0	7	<0.5	<0.02	0.22	0.011	1008	1.70	0.68	1.50	0.84
SUL	Shl 1	05Sep85	16.3	94.97	8.5	22	7.03	1.4	17	2.5		<0.5	<0.02	0.36	0.009	1105	2.58	2.14	1.90	0.93
WUL	Shl 1	05Sep85	15.1	99.02	9.1	22	7.05	1.8	18	2.0	8	<0.5	<0.02	0.24	0.021	1030	2.91	2.21	2.67	1.14
NUL	Mid 1	05Sep85	15.4	92.57	8.6	27	7.00	1.8	14	2.0	8	<0.5	<0.02	0.24	<0.004	0910	4.62	2.95	2.51	0.99
SUL	Mid 1	05Sep85	16.6	102.13	9.1	23	7.09	1.6	15	2.0	8	<0.5	<0.02	0.20	0.014	1156	1.93	1.20	2.05	0.82
WUL	Mid 1	05Sep85	15.6	100.11	9.1	22	7.40	1.4	14	2.0		<0.5	0.02	0.24	0.013	1044	1.91	1.11	3.51	1.22
SUL	Dp 4	05Sep85	16.4	96.30	8.6	26	7.15	1.6	15	2.0		<0.5	<0.02	0.22	0.014	1210	4.43	3.12	2.53	1.42
NUL	Dp 4	05Sep85	15.7	94.82	8.6	24	7.02	1.5	15	2.0		<0.5	0.03	0.26	0.018	0930	1.77	0.84	2.40	1.01
NUL	Dp 1	05Sep85	15.7	93.72	8.5	22	7.02	2.4	14	2.0		<0.5	<0.02	0.18	0.026	0930	2.07	1.06	1.32	0.59
SUL	Dp 1	05Sep85	16.5	94.28	8.4	25	7.11	1.2	14	2.0	8	<0.5	<0.02	0.26	0.009	1210	1.91	0.80	1.73	0.82
EUD	4	03May85	10.1	96.12	9.9	21	6.75	2.1	12		6	<0.5	<0.02	0.24	0.083	1022	3.35			
EUD	1	03May85	12.2	102.04	10.0	21	6.93	2.5	11.5		6	<0.5	<0.02	0.32	0.065	1022	2.98			

Table C.2. (continued).

Site	Depth (m)	Date	Temp (C)	Pct Sat	O2 (mg/l)	EC (umhos)	pH	Turb (NTU)	Alk	CO2	Hard	Cl-	NO3-N	TKN	TP	Time	Chl (ug/l)	Phaeo (ug/l)	Dry Wt (mg/l)	LOI (mg/l)
									------------	------------	------------ (mg/l	------------	------------	------------	------------					
WUD	4	02Oct85	9.2	101.33	10.7	21														
EUD	4	02Oct85	11.1	98.41	9.9	19	7.22	0.9	15	2.0		<0.5	0.06		0.005	0900	2.00	1.13		
WUD	1	02Oct85	10.9	100.99	10.2	19	7.35	0.8	13	2.5	10	0.7	0.03		0.008	1055	1.98	1.12		
EUD	1	02Oct85	11.1	99.80	10.1	19	7.41	1.3	15	2.0	8	<0.5	0.03		0.012	0900	2.11	0.62		
WUL	Shl 1	02Oct85	10.6	94.49	9.6	19	7.31	1.1	16	2.0	9	<0.5	0.05		0.005	1017	2.34	1.02		
SUL	Shl 1	02Oct85	10.8	95.85	9.7	19	7.20	1.1	14	2.0		0.7	0.03		<0.004	1110	2.44	0.73		
NUL	Shl 1	02Oct85	11	98.71	10.0	19	7.30	1.1	14	2.0		<0.5	0.04		0.010	0920	2.50	1.93		
NUL	Mid 1	02Oct85	11.2	97.61	9.8	19	7.25	1.9	14	2.5	8	<0.5	0.08		0.009	0930	1.86	0.75		
WUL	Mid 1	02Oct85	11	99.21	10.0	19	7.39	0.8	13	2.0		<0.5	0.10		0.009	1040	2.12	0.98		
SUL	Mid 1	02Oct85	11	99.21	10.0	19	7.20	0.8	15	2.0	9	<0.5	<0.02		<0.004	1150	2.12	0.46		
NUL	Dp 4	02Oct85	11.2	96.61	9.7	20	7.30	0.8	13	2.0		<0.5	0.03		0.007	0950	2.73	1.45		
SUL	Dp 1	02Oct85	11.3	98.30	9.9	19	7.23	0.6	18	2.0		<0.5	0.06		<0.004	1200	2.42	0.91		
NUL	Dp 1	02Oct85	11.3	96.81	9.7	19	7.39	1.0	19	2.0		<0.5	<0.02		0.030	0950	1.90	0.65		
EUD	4	08May86	10.8		10.2	25	6.46	0.8	12	2.0			<0.02	0.18	0.017		2.29	2.06		
WUD	4	08May86	8.8		9.8	25	6.18	1.2	12	2.5			<0.02	0.26	0.019		3.05	2.30		
EUD	1	08May86	11.0		10.3	25	6.53	0.4	12	3.0	8		<0.02	0.24	0.024		1.89	2.33		
WUD	1	08May86	11.8		10.2	25	6.19	0.8	12	2.5			<0.02	0.18	0.009		2.03	1.36		
SUL	Dp 4	08May86	11.2		10.1	24	6.44	0.7	12	2.5			<0.02		0.017		1.84	2.04	1.38	1.32
NUL	Dp 4	08May86	11.0		10.1	25	6.93	0.6	12	2.0			<0.02	0.14	0.010		1.71	0.47	1.42	1.32
NUL	Shl 1	08May86	11.2		10.2	26	7.06	0.8	12	3.0			<0.02		0.008		2.89	1.96		
SUL	Shl 1	08May86	12.5		9.9	27	6.70	0.9	12	2.5			0.05	0.16	0.028		1.86	2.10	1.41	1.22
WUL	Shl 1	08May86	11.3		10.3		7.12	0.6	12	2.5			<0.02	0.22	0.013		2.33	1.80	1.52	1.34
NUL	Mid 1	08May86	11.2		10.2	27	7.15	0.6	12	3.0			<0.02	0.14	0.006		2.28	1.71	1.91	1.39
WUL	Mid 1	08May86	11.4		10.3	25	7.16	0.8		2.5			<0.02	0.14	0.007		3.38	2.46	1.32	1.32
SUL	Mid 1	08May86	12.5		9.9	26	6.93	0.6	12	2.5			0.06	0.16	0.015		1.31	0.94		
SUL	Dp 1	08May86	12.5		9.7	25	6.39	0.6	12	2.5			0.02	0.14	<0.004		1.58	1.43	1.17	1.17
NUL	Dp 1	08May86	11.1		10.2	27	7.18	0.7	13	2.5			0.02	0.02	0.008		1.76	1.16		
EUD	4	18Aug86	23.3			21	7.73	1.1	14.5	2.5			<0.02		0.015		1.96	0.43		
WUD	4	18Aug86	19.6			22	6.73	1.2	14.5	4.0			<0.02		0.023		2.62	0.96		
EUD	1	18Aug86	23.4			21	7.47	0.7	14.5	2.0			0.02		0.021		1.83	0.53		
WUD	1	18Aug86	22.2			21	7.60	1.4	16.0	2.5			<0.02		0.020		2.05	0.48		
SUL	4Dp	18Aug86	22.9			22	7.89	0.9	14.5				<0.02		0.013					
NUL	4Dp	18Aug86	23.1			22	7.70	1.4	14.0				<0.02		0.016		2.34	0.66		
NUL	1Shl	18Aug86	23.2			21	7.62	1.3	14.0				<0.02		0.018		2.04	0.39		
SUL	1Shl	18Aug86	23.2			21	7.50	1.2	14.5				<0.02		0.024					
WUL	1Shl	18Aug86	22.1			21	6.68	2.1	14.5	4.5			<0.02		0.025					
NUL	1Mid	18Aug86	23.2			21	7.87	1.2	14.5				0.03		0.015					
WUL	1Mid	18Aug86	22.3			21	7.43	1.3	14.5	3.0			<0.02		0.017					
SUL	1Mid	18Aug86	23.5			21	7.79	0.8	14.5				<0.02		0.019		2.38	0.95		
SUL	1Dp	18Aug86	23.3			22	7.97	0.7	14.5				0.07		0.018		1.20	0.39		
NUL	1Dp	18Aug86	23.4			21	7.89	1.1	14.0				<0.02		0.015		1.65	0.54		

Table C.3. Upper and Lower Twin Lake temperature, oxygen, and conductivity profiles.

Mid Lower Deep

Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time	Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time
	03May85					20Jun85			
0	10.2	9.8	20	1300	0	18.7	9.4	23	0830
1	10.1	9.6	20		1	18.7	8.7	23	
2	9	9.6	20		2	18.7	8.6	24	
3	8.5	9.4	20		3	18.7	8.4	25	
4	7.9	9.5	20		4	18.3	8.5	25	
6	7.1	9.2	21		6	17.7	8.5	24	
8	6.9	9	21		8	9	7.8	23	
9	NA	NA	NA		9	NA	NA	NA	
10	6.3	9	21		10	7.5	5.1	23	
11	NA	NA	NA		12	7	4.5	24	
12	6.2	8.9	23		14	6.6	2.8	26	
14	6.1	8.6	23		16	6.4	0	NA	
16	6.1	8.6	NA		18	NA	NA	NA	
18	6.1	8.6	NA		18.5	NA	NA	NA	
18.5	NA	NA	NA						
	26Jul85					21Aug85			
0	23.4	7.9	25	0815	0	17.6	8.4	21	0850
1	23.3	7.8	25		1	17.6	8.4	21	
2	23.3	7.8	26		2	17.6	8.3	21	
3	23.2	7.8	27		3	17.6	8.4	22	
4	23.2	7.8	27		4	17.6	8.4	23	
6	18.5	9.1	26		6	17.4	8.3	23	
8	11.1	7.6	23		8	11.7	7.1	23	
10	8.2	4.5	23		9	9.9	3.4	NA	
12	6.8	0.4	24		10	8	1.9	22	
14	6.3	0	25		11	NA	NA	NA	
16	6.1	0	NA		12	6.9	0	23	
18	6	0	28		14	6.3	0	27	
18.5	5.8	0	NA		16	6	0	NA	
					18	5.9	0	29	
					18.5	5.9	0	NA	

Table C.3. (continued).

Mid Lower Deep

Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time	Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time
06Sep85					02Oct85				
0	17.8	9.5	25	1445	0	12.2	9.2	21	1245
2	18	9.3	28		1	12.1	9.1	21	
4	17.9	9.4	29		2	12.1	9.1	21	
6	17.9	9.3	29		3	12.1	9.1	21	
8	15.5	8.5	29		4	12	9.1	22	
9	NA	NA	NA		6	12	9.1	23	
10	10.9	2	28		8	12	8.9	24	
11	NA	NA	NA		9	NA	NA	NA	
12	9.5	0.1	29		10	11.9	8.3	26	
14	8.5	0.2	33		11	9.9	0	NA	
16	8	0	NA		12	8.8	0	30	
18	NA	NA	NA		14	8	0	33	
18.5	NA	NA	NA		16	7.7	0	NA	
					18	7.7	0	32	
					18.5	NA	NA	NA	
25Oct85					28Jan86				
0	6.5	9.5	21	0830	0	0	13.5	11	1100
1	6.5	9.5	21		1	1.1	12.8	9	
2	6.5	9.5	21		2	1.5	11.9	9	
3	6.5	9.5	21		4	1.9	11.8	6	
4	6.5	9.4	22		6	2.6	9	7	
6	6.5	9.4	28		8	2.4	8.5	8	
8	6.5	9.4	29		10	2.4	7.1	9	
10	6.5	9.4	29		12	2.6	6.2	9	
12	6.5	9.4	29		14	2.8	4.7	10	
14	6.5	9.4	30		16	3.2	0.1	NA	
16	6.5	9.4	NA		18	3.5	0	NA	
18	6.5	9.4	21		18.5	3.6	0	NA	
18.5	6.5	6.7	NA						

Table C.3. (continued).

North Lower Deep

Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time	Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time
03May85					20Jun85				
Surf	Not sampled				Surf	20	8.3	23	1007
1					1	19.9	8.3	23	
2					2	19.9	8.4	24	
3					3	19.7	8.4	24	
4					4	19.4	8.4	24	
6					6	17.9	8.5	25	
8					8	14	7.6	24	
9					9	NA	NA	NA	
10					10	10.8	6	23	
10.5					10.5	NA	NA	NA	
11					11	9.7	3.6	24	
12					12	8.7	2	25	
25Jul85					21Aug85				
Surf	24.8	7.5	27	1414	Surf	18.2	8.1	22	1120
1	24.1	7.4	27		1	18.2	8	23	
2	23.5	7.5	27		2	18.1	8.1	23	
3	23.2	7.5	27		3	18	8.1	23	
4	23.1	7.4	28		4	18	8.1	23	
6	20	8.7	27		6	18	8	24	
8	11.8	6.8	24		8	17.4	8.1	24	
9	9.5	NA	NA		9	11.7	4	23	
10	8.1	3.7	24		10	9.1	1.3	23	
10.5	NA	NA	NA		10.5	NA	NA	NA	
11	7.9	0	28		11	7.2	0	25	
12	NA	NA	NA		12	NA	NA	NA	
06Sep85					03Oct85				
Surf	15.8	9	22	0750	Surf	12.1	9.1	19	0800
1	15.7	8.9	22		1	12.1	9.1	20	
2	15.6	8.9	22		2	12.1	9.1	20	
3	15.4	8.8	22		3	12.1	9.1	21	
4	15.4	8.8	23		4	12.1	9.1	21	
6	15.3	8.7	24		6	12.1	9.1	21	
8	14.9	8.4	26		8	12.1	9	22	
9	11.2	5.3	25		9	12	8.3	NA	
10	7.2	0	25		10	11.1	4.2	23	
10.5	NA	NA	NA		10.5	NA	NA	NA	
11	7	0	29		11	9.9	0	28	
12	NA	NA	NA		12	NA	NA	NA	

Table C.3. (continued).

North Lower Deep

Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time	Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time
25Oct85					29Jan86				
Surf	6.5	9.7	20	1100	Surf	Not sampled			
1	6.5	9.7	20		1				
2	6.5	9.7	20		2				
3	6.5	9.7	21		3				
4	6.5	9.7	22		4				
6	6.5	9.6	28		6				
8	6.5	9.6	29		8				
10	6.5	9.6	29		10				
10.5	6.5	9.6	29		10.5				
11	NA	NA	NA		11				
12	NA	NA	NA		12				

West Upper Deep

Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time	Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time
03May85					21Jun85				
Surf	Not sampled				Surf	20.8	8.7	23	1210
1					1	20.8	8.6	23	
2					2	20.8	8.6	24	
3					3	19.8	8.6	24	
3.5					3.5	NA	NA	NA	
4					4	18.8	8.6	25	
25Jul85					20Aug85				
Surf	24.3	8.6	27	1040	Surf	18.2	9.4	24	1030
1	23.8	8.5	27		1	18.2	NA	25	
2	23.1	8.2	26		2	18.2	NA	25	
3	21.8	7.6	27		3	18.2	NA	28	
3.5	19.2	6.8	26		3.5	17.7	9.4	37	
4	NA	NA	NA		4	NA	NA	NA	
05Sep85					02Oct85				
Surf	15.2	8.5	22	1008	Surf	10.9	10.3	19	1030
1	15.2	8.4	22		1	10.9	10.2	19	
2	15.2	8.4	22		2	10.5	10.4	19	
3	15.2	8.5	22		3	9.2	10.7	21	
3.5	NA	NA	NA		3.5	NA	NA	NA	
4	NA	NA	NA		4	NA	NA	NA	

Table C.3. (continued).

Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time	Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time
West Upper Deep									
26Oct85					28Jan86				
Surf	5.1	10	19	1055	Surf	0	10.6	27	1600
1	5.1	10	20		1	0.6	8.7	27	
2	5.1	10.1	20		2	2.6	5.6	28	
3	5.1	9.8	20		3	2.9	2.3	30	
3.5	NA	NA	NA		3.5	2.9	1.8	40	
4	NA	NA	NA						
East Upper Deep									
03May85					21Jun85				
Surf	12.2	10.1	21	1022	Surf	19.8	9.2	22	0913
1	12.2	10	21		1	19.8	9.1	22	
2	11.9	10	20		2	19.8	9.1	23	
3	10.9	10	20		3	19.8	9.1	23	
4	10.1	9.9	21		4	19.1	10.1	23	
5	9.3	9.7	21		5	18.8	10.1	23	
5.5	9	NA	21		5.5	18.6	9.7	24	
25Jul85					20Aug85				
0	25.8	8.1	26	1226	Surf	19	NA	22	1345
1	24.9	8.1	27		1	19	8.8	23	
2	24.4	8.1	27		2	19.1	NA	24	
3	24.2	8.2	28		3	19.2	NA	24	
4	24.2	8.2	28		4	19.3	8.8	25	
5	22.3	9.4	34		5	19.5	NA	25	
5.5	NA	NA	NA		5.5	NA	NA	NA	
05Sep85					02Oct85				
Surf	16.1	8.2	24	0842	Surf	11.1	10.1	19	0900
1	16.1	8.1	25		1	11.1	10.1	19	
2	16.1	8.1	25		2	11.1	10	19	
3	16.1	8.1	25		3	11.1	9.9	19	
4	16.1	8.1	26		4	11.1	9.9	20	
5	16.1	8.1	26		5	NA	NA	NA	
5.5	NA	NA	NA		5.5	NA	NA	NA	

Table C.3. (continued).

Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time		Depth	Temp (C)	O2 (mg/l)	EC (umhos)	Time
				West Upper Deep						
0	5.1	10.6	18	0830	¦	0	Not sampled			
1	5.1	10.5	19		¦	1				
2	5.1	10.4	20		¦	2				
3	5.1	10.3	20		¦	3				
4	5.1	10.2	21		¦	4				
5	5.1	10.2	21		¦	5				
5.5	NA	NA	NA			5.5				

Table C.4. Numbers/liter and biovolume (mm3/l) of the five most abunant genera of phytoplankton collected from Twin Lakes. 3 May, 1985.

Algae	East Upper Deep	Mid Lower Deep Epilimnion	Mid Lower Deep Hypolimnion
Ankistrodesmus		24,550 (0.002)	
Aphanocapsa	21,300 (0.001)		
Asterionella		23,450 (0.012)	64,000 (0.031)
Cryptomonas 1	21,300 (0.014)	33,000 (0.002)	
Cryptomonas 2	73,600 (0.008)		162,000 (0.020)
Dinobryon	41,300 (0.065)	70,350 (0.112)	36,200 (0.057)
Nostoc			61,800 (0.120)
Synedra 1	52,750 (0.129)	112,950 (0.277)	121,500 (0.298)
Synedra 2	30,150 (0.148)		

Table C.4. (continued). 20 June, 1985.

Algae Genera	East Upper Deep	West Upper Deep	North Lower Deep Epilimnion	North Lower Deep Hypolimnion	Mid Lower Deep Epilimnion	Mid Lower Deep Hypolimnion
Nostoc			111930 (0.023)			
Trachelamonas		119925 (0.565)				
Oocystis	77285 (0.026)					
Ankistrodesmus		63960 (0.001)				
Asterionella	463710 (0.165)	333125 (0.119)	157235 (0.056)	868790 (0.309)	223860 (0.080)	71995 (0.026)
Crucigenia	95940 (0.010)				85280 (0.009)	
Cryptomonas 1						63960 (1.017)
Cryptomonas 2	154570 (0.191)	1068665 (1.325)				66625 (0.083)
Melosira 1			157235 (0.241)	101270 (0.155)	162565 (0.249)	37310 (0.057)
Microcystis	626275 (0.003)	319800 (0.002)	277160 (0.001)	306475 (0.001)		5303350 (0.025)
Fragillaria				69290 (0.028)		
Aphanocapsa				421070 (0.001)	138580 (0.001)	
Gleocystis			151905 (0.031)		138580 (0.028)	

Table C.4. (continued). 25 July, 1985.

Algae Genera	East Upper Deep	West Upper Deep	Mid Lower Deep Epilimnion	Mid Lower Deep Hypolimnion	North Lower Deep Epilimnion	North Lower Deep Hypolimnion
Agmenellum			295,800 (0.001)		373,100 (0.002)	
Anacystis	612,100 (0.002)			119,900 (0.001)	173,200 (0.0004)	
Ankistrodesmus		58,600 (0.005)				
Aphanocapsa		80,000 (0.003)	594,300 (0.020)		1,825,500 (0.070)	1,225,800 (0.048)
Asterionella				394,400 (0.191)		565,000 (0.274)
Chroococcus	68,800 (0.005)		151,900 (0.010)		125,300 (0.009)	
Coelastrum				383,800 (0.001)		
Coelosphaerium				549,000 (0.005)		1,918,800 (0.016)
Cryptomonas 1		58,600 (0.004)				
Cryptomonas 2		162,600 (0.020)				
Gloeocapsa	56,700 (0.007)			4,935,600 (0.057)		
Gloeotrichia	2,750,000 (0.340)	1,000,000 (0.125)	250,000 (0.030)			
Melosira 1						410,400 (1.044)
Nostoc	144,400 (0.280)					
Pediastrum						255,800 (0.004)
Synechocystis		125,300 (0.080)	247,800 (0.150)		213,200 (0.132)	

Table C.4. (continued). 20 August, 1985.

Algae Genera	East Upper Deep	West Upper Deep	Mid Lower Deep Epilimnion	Mid Lower Deep Hypolimnion	North Lower Deep Epilimnion	North Lower Deep Hypolimnion
Anacystis	245180 (0.010)					
Crucigenia					63960 (0.002)	63960 (0.009)
Gleocystis		53300 (0.002)	162565 (0.006)	247845 (0.009)		
Pediastrum		63960 (0.003)				
Aphanocapsa	359775 (0.001)	165230 (0.001)	170560 (0.001)			
Agmenellum			1148615 (0.002)	42640 (0.001)	3261960 (0.006)	418405 (0.001)
Fragillaria						
Cryptomonas 1		58630 (0.052)				
Gleocystis	82615 (0.003)					
Microcystis	4064125 (0.003)	1348490 (0.001)	1284530 (0.001)	1367145 (0.001)	4205370 (0.003)	5468580 (0.004)
Melosira 1			191880 (0.449)	207870 (0.486)	175890 (0.412)	213200 (0.499)
Astarionella				34645 (0.013)		101270 (0.039)
Chrococcus					90610 (0.288)	
Scenedesmus	45305 (0.005)					

Table C.4. (continued). 6 September, 1985.

Algae Genera	East Upper Deep	West Upper Deep	North Lower Deep Epilimnion	North Lower Deep Hypolimnion
Agmenellum			1,673,000 (0.003)	882,100 (0.002)
Anacystis	277,200 (0.006)	32,000 (0.001)		
Ankistrodesmus	34,700 (0.004)	26,700 (0.003)		
Aphanocapsa	16,000 (0.001)		391,800 (0.003)	461,000 (0.004)
Asterionella				103,900 (0.087)
Chlamydomonas	29,399 (0.004)			
Cryptomonas 2		34,700 (0.063)	53,300 (0.097)	
Melosira 1			165,200 (0.390)	109,300 (0.256)
Microcystis	2,694,300 (0.002)	1,663,000 (0.001)	4,098,800 (0.003)	10,985,100 (0.008
Nostoc		66,700 (0.011)		

Table C.4. (continued). 2 October, 1985.

Algae Genera	East Upper Deep	West Upper Deep	Mid Lower Deep Epilimnion	Mid Lower Deep Hypolimnion	North Lower Deep Epilimnion	North Lower Deep Hypolimnion
Trachelamonas	18655 (0.003)					18655 (0.003)
Asterionella	53300 (0.041)		23985 (0.019)	47970 (0.037)	50635 (0.039)	53300 (0.041)
Cryptomonas 1						
Unknown Bl-Gr		533000 (0.002)		21320 (0.002)		
Pediastrum	37300 (0.001)					
Fragillaria		58630 (0.058)				
Melosira 1		42640 (0.045)	154570 (0.164)	45305 (0.048)	154570 (0.164)	111930 (0.119)
Scenedesmus		26650 (0.002)				
Microcystis	533000 (0.001)	266500 (0.001)		1345825 (0.001)	79950 (0.001)	
Oocystis			55965 (0.024)		42640 (0.018)	29315 (0.012)
Chrococcus			87945 (0.014)	479700 (0.078)		
Nostoc			29315 (0.006)		55965 (0.011)	39975 (0.008)
Anacystis	37300 (0.001)					

Table C.4. (continued). 25 October, 1985.

Algae Genera	East Upper Deep	West Upper Deep	Mid Lower Deep Epilimnion	Mid Lower Deep Hypolimnion	North Lower Deep Epilimnion	North Lower Deep Hypolimnion
Anacystis	133,200 (0.003)					
Asterionella	229,200 (0.057)	205,200 (0.051)	269,200 (0.067)	948,700 (0.234)	743,500 (0.184)	740,900 (0.183)
Cryptomonas 1	64,000 (0.207)	72,000 (0.232)		72,000 (0.233)		
Cryptomonas 2	143,900 (0.032)	237,200 (0.052)	109,300 (0.024)		178,600 (0.039)	130,600 (0.029)
Dinobryon	255,800 (0.404)	303,800 (0.480)				
Fragillaria			173,200 (0.171)			
Melosira 1			122,600 (0.325)	226,500 (0.600)	159,900 (0.424)	101,270 (0.267)
Melosira 2				125,300 (0.086)	127,900 (0.088)	154,600 (0.107)
Microcystis			2,939,500 (0.002)	6,364,000 (0.004)	4,892,900 (0.003)	5,314,000 (0.004)
Navicula		32,000 (0.014)				

Table C.4. (continued). 28 January, 1986.

Algae Genera	West Upper Deep	Mid Lower Deep Hypolimnion
Fragillaria		79950 (0.079)
Microcystis	482365 (0.001)	74620 (0.001)
Asterionella	63960 (0.089)	
Cryptomonas 1	45305 (0.082)	
Melosira 2		154570 (0.295)
Chrococcus		258505 (0.034)
Melosira 1		39975 (0.036)
Navicula	18655 (0.003)	
Trachelamonas	37310 (0.046)	

Table C.4. (continued). 8 May, 1986.

Algae Genera	East Upper Deep	West Upper Deep	Mid Lower Deep Epilimnion	Mid Lower Deep Hypolimnion	North Lower Deep Epilimnion	North Lower Deep Hypolimnion
Dinobryon	130585 (0.283)	165230 (0.359)	167895 (0.364)			
Quadrigula	21320 (0.005)	34645 (0.008)				
Trachelamonas	21320 (0.025)	26650 (0.031)				
Gleocapsa	114595 (0.002)				34645 (0.001)	
Nostoc	42640 (0.003)					
Eudornea	39975 (0.036)					
Cryptomonas 1		138580 (0.331)				
Chrococcus		18655 (0.030)				
Gleocystis		18655 (0.001)	109265 (0.001)			
Astarionella			61295 (0.082)	362440 (0.482)	50635 (0.067)	106600 (0.142)
Cryptomonas 2			37310 (0.032)		58630 (0.051)	55965 (0.048)
Microcystis			79950 (0.001)			
Peridinium				151905 (5.104)	82615 (2.78)	31980 (1.064)
Fragillaria				101270 (0.031)		31980 (0.010)
Melosira 1				277160 (0.267)	21320 (0.021)	71955 (0.069)
Melosira 2				165230 (0.105)		

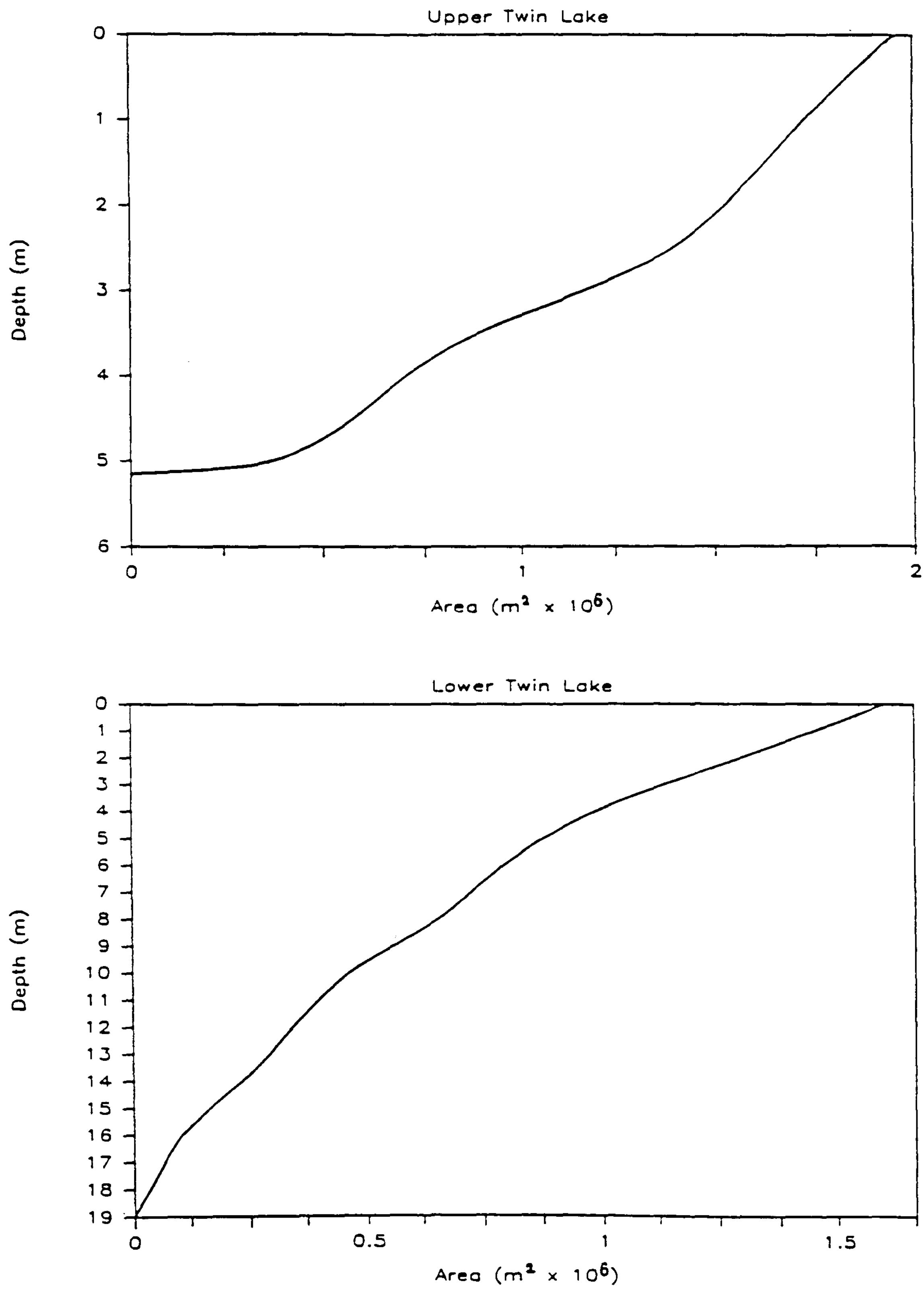


Figure C.1. Hypsographic curve for Upper and Lower Twin Lake (gives surface area of selected depth strata).

Table C.5. Zooplankton species (number/liter) collected from Twin Lakes between 5 May and 26 October, 1985.

Station	Date	Nauplii	Diacyclops bicuspidatus thomasi	Diaptomus	Epischura	Unknown Harpacticoid	Bosmina longirostris	Polyphemus pediculus	Leptodora kindtii	Ceriodaphnia reticulata	Daphnia thorata	Daphnia rosea	Sida crystalina	Holopedium gibberum	Daphnia schrodleri
MLD-Hypo	03May85	6.900	8.15								0.005				
	20Jun85	2.950	32.75				56.850	0.001		1.400	6.200				0.20
	21Aug85	Sample dried out													
	02Oct85	0.100	2.95								2.000	0.50			
	25Oct85	4.750	14.30				1.100				8.250			1.850	
NLD-Epi	03May85	Not sampled													
	20Jun85	0.38	5.60				0.00			15.90	8.02				
	20Aug86	0.500	2.22				0.825				4.125			3.300	
	03Oct85	0.250	9.38						2.677		16.060				
	25Oct85	0.300	9.95				6.050				13.848			5.350	0.277
NLD_Hypo	03May85	Not sampled													
	20Jun85	1.800	12.45				0.002		0.001	4.500	9.850				
	21Aug85	7.800	12.75								7.300				
	03Oct85	0.150	5.90				2.256				6.767	1.13			
	25Oct85	0.300	9.95				0.900				11.900			4.500	

Table C.5. Zooplankton species (number/liter) collected from Twin Lakes between 5 May and 26 October, 1985.

Station	Date	Nauplii	Diacyclops bicuspidatus thomasi	Diap-tomus	Epi-schura	Unknown Harpac-ticoid	Bosmina longi-rostris	Poly-phemus pediculus	Lepto-dora kindtii	Cerio-daphnia reticulata	Daphnia thorata	Daphnia rosea	Sida crystal-ina	Holo-pedium gibberum	Daphnia schrod-leri
EUD	03May85	10.350	13.35				0.963				1.153			0.275	
	20Jun85	1.200	11.40				0.004				25.500				
	20Aug86	2.600	5.40				0.485	1.455			0.485				
	02Oct85	0.000	2.63					2.419			1.613	1.61			
	26Oct85	6.800	7.88				0.200				3.125				
WUD	03May85	Not sampled													
	20Jun85	0.001	6.20				0.001			8.225	26.575				
	20Aug86	4.050	7.64	1.09			1.175	0.588			4.113				
	02Oct85	0.250	2.00				2.246				13.475	4.49	6.738		
	26Oct85	1.425	3.98				0.400				4.250				
SLD	03May85	Not sampled													
	20Jun85	1.750	20.55				7.250	0.001		3.450	6.000				
	20Aug86	Sample dried out													
	01Oct85	0.350	3.25						0.567		1.133				
	25Oct85	0.200	24.60				0.550				2.411			0.950	0.689
MLD-Epi	03May85	18.850	18.20								0.700				
	20Jun85	1.775	4.15		0.000		0.500	0.001	0.001	3.175	6.600				
	20Aug86	0.700	0.00		1.425		0.589				4.121			1.766	
	02Oct85	0.125	5.58			0.797			2.417		8.458				
	26Oct85	0.250	11.08				1.300				11.096			1.750	0.579

Table C.6. Sediment nutrient content in samples collected 25 October, 1985.

Station	Depth (m)	Nitrate Nitrogen (mg/g)	Kjeldahl Nitrogen (mg/kg)	Total Phosphorus (mg/kg)
<u>Upper Basin</u>				
SUL - mid site	1.9	2.0	10,000	990
EUD	4.8	0.9	11,000	972
WUL - shallow site	2.3	0.4	9,375	1,269
MEAN		1.1	10,125	1,077
Standard Error		0.47	473	96
<u>Lower Basin</u>				
MLD	18.9	0.0	4,063	880
MLL - mid site	2.5	1.0	8,250	1,198
NLD	11.0	0.7	8,375	1,300
MEAN		0.6	6,896	1,126
Standard Error		0.30	1,417	126

APPENDIX D. HOMEOWNER'S SURVEY

Input from homeowners was required to determine nutrient loading to wastewater treatment systems, powerboat use (for a separate study), and to determine what lake problems homeowners were most concerned with. In addition, some of the demographic information collected may be of interest to the Twin Lakes Improvement Association. We decided that the most efficient way to collect this information was with the use of a mailed questionnaire.

Survey forms (Figure D.1) were mailed to about 800 residences around the lakes in May, 1986 as part of the annual TLIA newsletter. By the end of October, 108 responses (13.5%) had been received. This return rate was disappointingly low, particularly considering the salience of the survey to the respondents. In a study of nearly 100 surveys, Heberlein and Baumgartner (1978) found an average 48% return rate. One reason for our low return rate may have been the inability (due to financial constraints) to include a stamped, self-addressed envelope. A second reason may have been that, although we intended this survey to be anonymous, the mailing label was inadvertantly placed on the back of the survey form. Where necessary, survey results were converted to whole lake results by applying a correction factor to account for the percent responding.

The following is a summary of the results, some of which are presented in more detail in Table D.1:

1) Forty-nine (45.4%) of the respondents were from Spokane. Twenty-one were from Rathdrum/Twin Lakes and twelve were from Washington, other than Spokane. Five were from Idaho, four from California, and one from each of six different states.

2) 19.4% were full-year residents. The figure was over twice as high as previous estimates (Department of Health and Welfare 1974). It is possible that full-year residents were more likely to return the survey.

3) For the 108 respondents, the sum of the number of people per residence times length of stay (capita-years) was 99.8.

4) Lower lake residents returned 74 surveys, 31 surveys came from residents of the upper lake, and 3 from the channel. Lake Park and Lake Park Addition residents returned the most surveys (18), Excelsior Beach was runner-up with 14, followed by Percy Cochran (12) and Lake Forest (11).

5) We estimate that 10.2% of the respondents have built homes since 1974. This was a poorly worded question, however. Many respondents had built additions or rebuilt existing homes. The purpose of this question was to determine the number of previously empty lots built on since the 1977 shoreline survey (Panhandle Health District 1 1977).

Mail to: David Hallock
Dept. of Fish & Wildlife
University of Idaho
Moscow, ID 83843

TWIN LAKES HOMEOWNERS SURVEY

Please circle the appropriate answers or fill in the blanks.

1. Are you a full-year resident of Twin Lakes? (YES/NO)
2. On an average, how many people stay in your Twin Lakes home and for how many weeks a year? ________________________________
3. What subdivision do you live in (e.g., Gunning, Pinehurst, Firgrove, etc.)? ________________________________
4. Is your house on the upper lake, lower lake, or channel?
5. Was your home built after 1975? (YES/NO). If so, when? _______
6. About how many hours per year do you run a motor boat engine on Twin Lakes? ________ What size (horsepower) engine is it? _____ Two- or four-cycle? __________ Inboard or outboard? _________
7. Is the lake your sole source of drinking water? (YES/NO) If yes, do you pre-treat the water? ______ If yes, how? __________
8. Rank the following lake-wide concerns in order of decreasing importance to you (i.e., #1 indicates that you are most concerned about that factor). Line through factors that you do not consider to be a problem.
   - ____open water plants (pondweed, etc.)
   - ____shoreline plants (cattail, rushes, etc.)
   - ____beach debris
   - ____skiers and boats too close to dock
   - ____poor swimming conditions (specify __________)
   - ____inadequate fish numbers
   - ____lake level (specify ______________)
   - ____fish species (specify ______________)
   - ____boat speed
   - ____boat congestion
   - ____water odors
   - ____water color/clarity
   - ____drinking water availability
   - ____other (specify ____)
9. Use this space and the back to comment further about those factors ranked #1, #2, and #3 in question #8, and for any other remarks you may have. ________________________________

____

____

Figure D.1. Survey form mailed to homeowners.

Table D.1. Results of homeowner's survey conducted during the summer of 1986. Numbers in columns 5 through 17 are rankings by the respondent of water quality concerns from greatest to least. (NA=not available, ie, no response.)

Respondent	No. of People	Length of Stay (Wks)	Upper or Lower Lake	Open Water Plants	Shoreline Plants	Beach Debris	Boats Close to Dock	Poor Swimming	Fish (#'s)	Lake Level	Fish (Spp)	Boat Speed	Boat Congestion	Water Odors	Water Color	Drinking Water Avail
1	3	52	u	6	7	8	9	14	5	1	11	14	2	4	3	10
2	4	52	u	3	6	7	11	2	9	4	8	13	12	5	1	14
3	5	6	l	2	1	14	14	14	3	14	14	14	14	14	14	14
4	4	52	u	1	2	3	11	8	10	4	14	9	12	7	6	14
5	6	26	l	2	14	14	1	14	14	14	14	14	14	14	14	14
6	3	6	l	1	5	6	10	14	7	2	8	9	11	4	3	14
7	2	13	l	1	1	2	1	2	2	3	2	1	1	1	14	14
8	2	NA		2	1	14	3	4	14	14	14	14	14	14	14	14
9	6	3	u	4	14	14	14	14	14	14	14	14	14	3	2	1
10	NA	7	l	14	14	14	4	1	3	1	14	14	14	14	2	14
11	2	35	u	14	14	14	14	14	14	2	14	14	14	14	1	14
12	2	12	u	5	5	11	10	4	12	6	9	8	7	2	3	1
13	5	17	l	6	7	14	14	14	14	3	14	5	4	2	1	14
14	4	12	l	14	14	14	1	7	14	4	14	2	3	14	5	6
15	3	52	l	4	5	6	8	7	12	1	11	9	10	2	3	13
16	2	26	l	5	6	8	7	4	14	1	14	9	10	3	2	14
17	2	52	l	14	14	14	1	14	14	14	14	1	1	14	14	14
18	4	4	u	5	9	4	14	8	6	3	7	14	14	2	1	14
19	2	44	l	1	14	14	14	1	1	1	1	14	14	1	14	1
20	NA	NA		14	14	14	14	14	14	14	14	1	14	14	14	14
21	2	26	u	14	14	2	14	14	4	1	14	3	14	14	14	14
22	2	NA	l	1	14	14	14	14	1	1	14	14	14	14	14	14
23	4	2	u	2	3	14	14	14	4	1	14	14	14	14	14	4
24	4	10	l	14	4	14	3	14	14	1	14	2	6	7	5	14
25	2.5	6	l	14	14	5	14	14	14	14	14	14	6	3	2	14
26	2	12	u	3	2	10	1	14	4	5	7	9	11	8	6	14
27	6	NA	u	14	14	14	14	14	14	1	14	14	14	14	14	14
28	2.5	3.5	l	14	14	14	1	14	14	2	14	14	14	14	14	14
29	2	4	l	6	5	7	4	14	2	1	14	3	8	14	14	14
30	2	20	u	5	5	5	3	14	14	1	14	6	14	14	2	14
31	NA	NA		14	14	14	14	14	14	14	14	14	14	14	14	14
32	4	6	l	1	14	14	2	3	14	14	14	14	4	14	5	14
33	3	12	u	14	14	14	14	14	14	2	14	3	14	14	1	14
34	3.1	8	c	14	14	14	1	14	14	14	14	1	1	14	14	14
35	4	12	l	14	6	5	2	3	14	14	14	7	8	4	1	14
36	1.2	20	l	3	14	14	14	1	14	14	14	2	2	2	2	14
37	3	6	u	14	3	14	2	4	8	1	8	5	6	7	14	14
38	2	20	l	2	14	14	3	14	14	1	14	14	14	14	14	14
39	2	52	c	1	3	3	3	1	1	1	1	2	2	2	2	3
40	2	52	l	2	9	5	4	14	6	1	14	3	14	8	7	10

Table D. 1. (continued).

Respondent	No. of People	Length of Stay (Wks)	Upper or Lower Lake	Open Water Plants	Shoreline Plants	Beach Debris	Boats Close to Dock	Poor Swimming	Fish (#'s)	Lake Level	Fish (Spp)	Boat Speed	Boat Congestion	Water Odors	Water Color	Drinking Water Avail
41	4	4	l	14	14	14	3	14	5	4	14	14	14	14	2	14
42	2	10	l	4	3	5	2	14	14	1	14	14	14	14	14	14
43	3	10	l	14	14	14	1	14	14	14	14	2	3	14	4	14
44	3	3	l	14	14	14	14	14	14	1	14	3	2	14	14	14
45	2	18	l	1	2	9	8	4	14	6	14	14	7	3	5	14
46	2	52	u	14	14	14	1	2	4	5	14	3	14	14	6	14
46	3.5	20	l	11	12	3	4	5	6	7	10	8	1	9	2	13
48	4	4	l	2	14	14	14	14	4	6	5	7	8	3	1	14
49	3	7	u	14	14	14	2	14	5	1	14	3	4	14	14	14
50	2	12	l	14	14	14	14	14	14	3	14	2	1	14	14	14
51	5	4	u	1	1	1	14	14	14	14	14	14	14	14	1	14
52	NA	NA	l	1	2	3	4	14	14	14	14	14	14	14	14	14
53	2	16	l	14	14	14	2	3	1	14	14	14	14	14	14	14
54	4	3	l	14	14	14	3	14	1	2	14	14	14	14	14	14
55	6	10	u	14	14	14	1	14	14	14	14	14	14	14	14	14
56	4	6	u	14	14	14	2	14	14	1	14	14	14	14	3	14
57	4	4	l	6	7	5	4	10	9	8	12	3	11	13	2	1
58	3.5	8	l	3	14	14	14	14	1	5	4	14	14	14	2	14
59	4	14	l	1	11	10	5	4	14	8	14	6	7	3	2	9
60	5	4	l	3	6	14	14	2	14	5	14	14	14	14	4	14
61	2.5	6	u	5	14	6	14	2	4	3	7	14	14	8	1	14
62	2	52	u	2	3	14	4	14	14	1	14	14	14	14	14	14
63	4	13	c	14	14	14	14	2	14	1	14	3	14	14	3	14
64	2	3	l	7	14	14	8	14	14	4	14	14	14	5	3	6
65	4	1	u	2	1	8	5	7	3	12	14	9	11	10	4	6
66	4	14	u	14	14	14	14	14	14	3	14	14	14	2	1	14
67	3	52	l	6	6	6	7	7	4	2	5	7	7	3	3	1
68	3	52	l	14	14	3	14	5	2	14	14	1	4	14	14	14
69	2	40	l	14	14	14	1	14	14	14	14	2	14	14	14	14
70	4	5	l	2	14	14	4	14	6	14	14	3	5	14	1	14
71	3.5	16	l	14	14	2	1	14	14	14	14	3	4	14	14	14
72	2	9	l	14	14	14	14	3	14	2	14	14	14	14	1	14
73	4	8	l	14	14	14	14	14	14	3	14	2	4	5	1	14
74	5	2	u	1	2	14	14	4	14	14	3	14	14	14	14	14
75	2	52	l	10	11	12	5	7	1	13	8	6	4	2	3	9
76	2	52	l	14	14	14	14	14	14	14	14	14	14	14	14	14
77	3	20	u	14	1	3	14	1	14	14	14	14	14	14	14	14
78	2	3	u	3	12	7	11	6	4	1	5	10	13	8	2	9
79	5	8	l	3	2	6	9	7	14	1	14	14	8	14	5	4
80	3	52	u	1	2	7	14	14	6	3	14	14	14	5	4	14
81	0	0	l	14	14	14	6	14	7	4	5	2	1	14	14	3
82	3	52	u	14	14	14	14	2	14	3	14	14	14	14	1	14
83	2.5	3.5	l	1	14	2	3	9	10	8	7	6	14	5	4	11
84	2	13.5	l	14	14	14	14	14	4	1	3	14	14	14	2	14
85	3	52	l	1	1	7	5	14	14	4	14	14	8	9	3	6

Table D. 1. (continued).

Respondent	No. of People	Length of Stay (Wks)	Upper or Lower Lake	Open Water Plants	Shoreline Plants	Beach Debris	Boats Close to Dock	Poor Swimming	Fish (#'s)	Lake Level	Fish (Spp)	Boat Speed	Boat Congestion	Water Odors	Water Color	Drinking Water Avail
86	2	4	1	5	14	14	1	4	6	14	14	2	3	14	14	14
87	2	12	1	14	14	14	14	14	14	14	14	14	14	14	14	14
88	5	16	1	14	14	14	1	14	3	4	5	14	2	14	14	14
89	2	10	u	3	2	14	14	14	14	1	14	14	14	14	4	14
90	0	0	1	3	2	5	6	14	4	14	14	7	14	14	14	14
91	2	10	1	14	14	14	3	14	14	1	6	3	3	14	4	5
92	2	52	1	4	6	7	14	5	14	1	14	14	14	3	2	14
93	1	120	1	14	14	14	14	14	14	1	14	4	14	3	2	14
94	2	39	1	2	10	3	5	4	6	1	9	8	7	3	1	14
95	5	9	1	14	14	4	1	1	14	14	5	2	3	14	14	14
96	6	3	1	2	14	14	3	14	14	5	4	14	14	14	1	6
97	0	0	1	14	14	14	14	14	14	14	14	14	14	14	14	14
98	7	9	1	4	3	14	14	14	14	1	14	14	14	5	2	14
99	3	4	u	14	14	3	14	14	2	1	14	14	14	14	14	14
100	2	52	u	14	14	14	14	14	5	1	14	14	14	4	3	14
101	4	3	1	14	14	6	2	14	5	4	14	3	7	14	14	14
102	4.5	7	1	1	2	3	14	6	4	5	14	14	14	14	14	14
103	2	13	1	4	6	14	8	14	3	1	7	14	2	14	5	14
104	3	3	1	8	7	14	14	3	14	14	6	4	5	14	2	14
105	9	5	1	14	14	14	2	14	3	14	14	1	4	14	5	14
106	2	52	1	4	14	14	6	14	1	2	14	5	14	14	14	14
107	2	52	1	14	14	3	9	7	6	14	8	1	4	14	5	14
108	2	12	1	14	14	14	14	14	14	1	2	4	3	14	14	14
		Sum		877	1072	1132	880	1092	1033	666	1263	976	1067	1126	794	1328
		Overall Rank		3	8	11	4	9	6	1	12	5	7	10	2	13

6) The mean horsepower of boats owned by respondents was 67.6. Twenty-six (24.1%) of the respondents had inboards and 17 (15.7%) had more than one boat. Powerboat information, including results from a census conducted by homeowner volunteers, are presented in more detail in Hallock and Falter (1986).

7) Of the 108 respondents, only 2 (1.9%) said that the lake was their sole source of water (one of the two did not treat their water). Homeowner's concerns (question 8, Figure D.1) were evaluated by assigning the number 14 to items unranked by respondents (excluding the "other" category which was evaluated separately, there were 13 choices) and summing the ranks for a given choice over all respondents. Totals were then converted to an index ((1512-sum)/1404) so that 1.00 would indicate the greatest possible concern (first choice of all respondents) and 0.00 would indicate last place. This technique is not statistically valid, but its results are adequate for comparative purposes. The following are in order of concern to the responding homeowners, with the index in parentheses: lake level (too low - 32 respondents, too high - 5 respondents)(0.60), water color (0.51)(many considered this category to mean "general water quality"), excessive open water plants (0.45), boat traffic too close to dock (0.45), boat speed (0.38), low fish numbers (0.34), boat congestion (0.32), excessive shoreline plants (0.31), poor swimming (0.30), water odors (0.27), beach debris (0.27), undesirable fish species (0.18), and poor quality drinking water (0.13).

A number of people listed "other" as one of their top concerns. Among the items listed were population density (1 person), water quality (4 people), cattle on the upper lake (1), boat access (1), boat related problems such as noise (4), security (1), sanitary facilities (1), field burning (1), clearcut logging (4) and dogs (2).