WATER QUALITY OF THE KALAMALKA-WOOD LAKE BASIN

prepared for

THE WATER INVESTIGATIONS BRANCH

WATER RESOURCES SERVICE

DEPARTMENT OF LANDS FORESTS AND WATER RESOURCES

by

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A. INTRODUCTION

The report describes studies of water quality in lakes and surface waters of the Kalamalka-Wood Lake basin, that were carried out between March 1972 - August 1973.

Main aspects of the study were to:-

1. Describe the quality of surface waters.
2. Measure the movement of nutrients in surface waters to and from Ellison, Wood and Kalamalka lakes.
3. Examine limnological aspects of Oyama, Swalwell, Ellison, Wood and Kalamalka lakes.
4. Describe the trophic condition of each lake.
5. Assess the effects of Hiram-Walker distillery cooling water discharge upon water quality in the Kalamalka- Wood Lake basin.
6. Obtain an understanding of water quality in the Kalamalka-Wood Lake basin as an aid to water management decisions.

Results of water quality analyses and physical measurements related to groundwater, fisheries and land use studies are not reported here.

The raw data print-out containing all the analytical results for this study and the other investigations of the Kalamalka-Wood Lake basin are held at B. C. Research under library call number TD 380.H6.

B. SUMMARY

1. Chemical Composition of Surface Waters.

a. Tables of the annual mean concentrations and the range of monthly average values are provided for water quality variables at nine sampling sites throughout the Kalamalka-Wood Lake basin. Seasonal changes; monthly values and the results from individual samples are described where appropriate.

b. Nitrogen and phosphorus concentrations were generally lowest in samples collected from the outlet of Kalamalka lake and from Oyama Canal. Low concentrations for most water quality variables were measured at the inflow and exit of Ellison Lake, in the distillery cooling water and in the Oyama Canal between Wood and Kalamalka Lakes.

c. Winfield Creek is a surface flow of groundwater characterised by consistent flows and a high nitrate concentration of 1.263 ± 0.541 mg N/1.

d. High nitrate concentrations (1.280 ± 0.534 mg/1) which originated as a result of land use practice within the watershed, were measured in lower Coldstream Creek.

e. There is an increase in nutrient concentration, notably soluble phosphorus and nitrate, in Vernon Creek between Ellison and Wood Lakes.

2. Quantities of Nutrients in Surface Waters.

a. Average monthly nutrient quantities transferred at each surface water sampling site were computed using average daily flows and nutrient concentrations. These data were then used to calculate annual nutrient loadings (lb/yr) for total, total soluble and orthophosphate phosphorus, TKN and nitrate nitrogen, calcium, magnesium, organic carbon and suspended solids.

b. Nutrient loadings at each sample site were computed for one wet year (1972); one dry year (1973) and also averaged. The loadings are discussed in relation to the ratio of average water flows between the two years.

c. The monthly variation in nutrient loading is described and illustrated by figures .

d. Loadings of suspended solids and nutrients were exceptionally high during the high spring run-off of 1972. In consequence, the annual loadings of these variables was elevated by a factor greater than the ratio of flows between the two years.

e. Between Ellison and Wood Lakes the mean of the annual loadings of nutrients increased in Vernon Creek from 21,910 lb nitrogen and 3,175 lb phosphorus at the outlet from Ellison Lake to 24,715 lb nitrogen and 6,525 lb phosphorus above Wood Lake.

f. Urban development and land use practices caused a large nutrient increase in Vernon Creek waters between Kalamalka Lake and Okanagan Lake. The annual transfer of total phosphorus increased in 1972 from 2,210 lb to 44,080 lb between the two lakes; soluble phosphorus from 610 lb to 28,690 lb, TKN from 26,290 lb to 110,900 lb and nitrate nitrogen from 6,810 lb to 57,500 lb.

g. Water management which would reduce the transfer of nutrients within the Kalamalka-Wood Lake basin would have very little effect upon nutrient loading to the Vernon Arm of Okanagan Lake.

3. Loadings of Nutrients to Ellison, Wood and Kalamalka Lakes.

a. Annual loadings of nitrogen and phosphorus were calculated from the sum of nutrients entering through surface waters together with estimates of input from direct drainage, dustfall and groundwater.

b. Annual loadings in lb/yr were as follows:-

	1972	1973	Mean
Ellison Lake			
nitrogen	39,360	13,390	26,380
phosphorus	15,550	1,050	8,290
Wood Lake			
nitrogen	59,350	43,200	51,300
phosphorus	8,970	2,700	5,830
Kalamalka Lake			
nitrogen	169,420	77,920	123,700
phosphorus	23,710	5,110	14,400

c. The relative contribution of nutrients from surface waters was calculated for each lake. In Ellison Lake 84% of the nitrogen and 85% of the phosphorus entered from Vernon Creek, Wood Lake received 15% nitrogen, 6% phosphorus from Winfield Creek and 51% nitrogen and 87% phosphorus from Vernon Creek. In Kalamalka Lake 56% nitrogen and 52% phosphorus entered from Coldstream Creek. Wood Lake water flowing through Oyama Canal added 20% nitrogen and 29% phosphorus into Kalamalka Lake.

d. Surface area loadings ($g/m^2/yr$) of nitrogen and phosphorus were used as an index of lake trophic conditions.

	1972	1973	Mean
Ellison Lake			
nitrogen	8.58	2.92	5.75
phosphorus	3.39	0.23	1.81
Wood Lake			
nitrogen	2.90	2.11	2.50
phosphorus	0.44	0.13	0.28
Kalamalka Lake			
nitrogen	2.96	1.36	2.16
phosphorus	0.41	0.08	0.24

e. Using the surface area loadings, Ellison Lake is classified as eutrophic with respect to both nitrogen and phosphorus. Kalamâlka Lake is oligotrophic.

f. Surface area loadings in Wood Lake differed between years. For 1972 the phosphorus loading classified the lake as eutrophic while for 1973 it was within the oligotrophic range. Nitrogen concentrations for both years classified Wood Lake within the oligo-mesotrophic range.

4. <u>Theoretical Lake Flushing Times</u>.

a. The theoretical lake water replacement times were 1.4 yr for Ellison Lake, 14 yr Wood Lake and 42 yr in Kalamalka Lake based on average water flows during the study period.

5. <u>The Effects of Distillery Cooling Water on Water Quality and Movement in the Basin</u>.

a. Water quality characteristics of the cooling water discharge from the distillery were monitored regularly.

b. The average annual quantities of nutrients discharged by the distillery were 205 lb/yr total phosphorus, 190 lb/yr soluble phosphorus, 2,020 lb/yr TKN and 550 lb/yr nitrate nitrogen. These quantities were approximately 13% of the nitrogen and 25% of the soluble phosphorus entering Ellison Lake via Vernon Creek on an annual basis.

c. Excluding the distillery input of 5 cfs flow from the Kalamalka-Wood Lake basin, there would be an increase in the theoretical replacement time of the lakes to 2.1 yr for Ellison Lake, 18 yr for Wood Lake and 48 yr for Kalamalka Lake.

d. Distillery cooling water augments water flow through the basin. Removal of this water could cause a reduction in nutrient transfer of 15% nitrogen and 23% phosphorus to Wood Lake and 5% nitrogen, 6% phosphorus into Kalamalka Lake. Considering only the transfer of Wood Lake water through Oyama Canal to Kalamalka Lake the reduction in nutrient transfer could be 31% nitrogen and 32% phosphorus.

e. The relationship of the distillery cooling water to water quality in the Kalamalka-Wood Lake basin is complex. The water is of good quality, yet the consequent increase in Vernon Creek flow results in a significant increase in nutrient transfer during the summer from Ellison Lake to Wood Lake, and thus to Kalamalka lake.

f. Any increased loading of nutrients to Wood Lake will favour the production of algal blooms.

g. Kalamalka lake responds to innoculation with Wood lake water by increased algal productivity (Appendix 1). Augmented flow into Kalamalka through Oyama canal, particularly during summer will provide additional nutrients that are readily available for phytoplankton growth in Kalamalka lake.

h. If algal blooms occur in Wood lake surface waters they can be transported into surface waters of the south end of Kalamalka lake. The extent to which such blooms are transported to Kalamalka lake depends on water flow through the canal.

6. Lake Nutrient Concentrations.

a. Mean nutrient concentrations were calculated for spring turnover during 1972 and 1973 in Ellison, Wood and Kalamalka lakes; these data were used as indicators of trophic conditions in the lakes.

b. Total phosphorus concentrations in Ellison lake were 63 and 66 mg/m^3 in 1972 and 1973 respectively; corresponding nitrogen concentrations were 409 and 499 mg/m^3. These concentrations classify Ellison lake as eutrophic.

c. Total phosphorus concentrations in Wood lake were 87 and 61 mg/m^3 and for nitrogen 538 and 546 mg/m^3. This lake also is classified as eutrophic.

d. Kalamalka lake is oligotrophic. In 1972 phosphorus concentrations were 9 mg/m^3 and nitrogen 195 mg/m^3.

e. Ellison lake is frequently mixed by the wind; data for nutrient concentrations were pooled for all depths at all stations and plotted to show seasonal patterns.

f. Wood lake is persistently stratified in summer. There were negligible differences in nutrient concentrations between stations. However, there were pronounced concentration differences between the epilimnion and hypolimnion which were typical of an eutrophic dimictic lake. The data were analysed with respect to depth and seasonal variation.

g. Nutrient concentrations in Kalamalka lake differed insignificantly between stations, seasonally and with depth.

7. Headwater Lakes.

Limited physical and chemical analyses were carried out on Oyama and Swalwell lakes. Tables of mean concentrations are given for various water quality variables, and these data are discussed in relation to the lake physical structure. The lakes were classified as mesotrophic with moderate to severe oxygen depletion throughout much of the summer.

8. Water Movements in Ellison and Kalamalka Lakes.

a. Dye and drogue studies were carried out to assess general patterns of water dispersal entering Ellison and Kalamalka lakes.

b. Vernon Creek water frequently short circuits the main water mass of Ellison Lake by travelling along the north shore. At times of short circuiting, the residence time of inflowing water is related to the Vernon Creek inflow rate. The minimum residence time of inflowing water was 1.2 hr when Vernon Creek entered Ellison Lake at 80 cfs, and was only 5 hr when the inflow rate was 4.1 cfs.

c. Wind direction and water temperature affect the extent to which Vernon Creek water mixes with the main body of Ellison Lake.

d. A gravel bar at the mouth of Vernon Creek deflects water into Ellison Lake; erosion or accretion of sediments on the bar affect the diversion of water flow within the lake.

e. During winter,an ice-free zone is maintained along the north shore of Ellison Lake as a result of the input of warm distillery cooling water. At such times short circuiting of Vernon Creek water is predicted.

f. The net flow of water through Oyama Canal is northward from Wood Lake to Kalamalka Lake. Wind action and lake seiching frequently cause oscillations of flow through Oyama Canal. In the late summer and particularly during dry years, there is a net southerly flow of water from Kalamalka Lake to Wood Lake.

g. Dye and drogue studies carried out during summer stratification showed that Wood Lake water entering Kalamalka Lake mixes slowly with the epilimnion of Kalamalka Lake. Dispersion of this nutrient-rich Wood Lake water is largely dependent on the wind.

h. Nutrient-rich water enters Kalamalka Lake from Coldstream Creek. Temperature differences between the creek water and Kalamalka Lake surface waters cause the incoming Coldstream Creek water to plunge below the epilimnion of Kalamalka Lake during summer. Consequently, nutrients within Coldstream Creek waters may not be readily available to phytoplankton growth. Thus their effect on the trophic condition of Kalamalka Lake is less than if the nutrients were dispersed into surface waters of the lake.

i. To illustrate gross patterns of water movement during the high spring runoff in 1972 aerial photographs were taken of the suspended solids transported into Wood and Kalamalka Lakes.

j. Groundwater entering along the east shore of Wood Lake maintained an ice-free zone during the winter.

9. Lake Thermal Structure.

a. Seasonal variation in thermal structure was illustrated for Ellison, Wood and Kalamalka Lakes.

b. Wind action prevents persistant thermal stratification of Ellison ake.

c. Temperature profiles for Wood and Kalamalka Lake during summer stratification, spring and fall overturn are discussed.

d. Maximum summer temperatures within the lakes were; Ellison 1972 25 C, 1973 24C ; Wood 1972 23 C, 1973 23 C; and Kalamalka 1972 21 C, 1973 21 C.

e. Summer heat incomes (cal/cm^2) were as follows:-

	1972	1973
Ellison	5,000	4,900
Wood	20,500	21,800
Kalamalka	24,500	27,500

These data are discussed in relation to the differences in climate between the two years and the findings of the Okanagan Basin study.

f. Epilimnion heating rates in ^{o}C/month were:-

	1972	1973
Ellison (Lake total)	4.25	4.02
Wood	4.05	4.83
Kalamalka	3.80	5.40

g. Corresponding heating rates in the hypolimnion were:

	1972	1973
Wood	1.30	1.20
Kalamalka	0.43	0.40

10. Oxygen.

a. Oxygen profiles were obtained for Ellison, Wood and Kalamalka lakes.

b. There was no constant stratification of Ellison Lake due to wind action, consequently there was no persistent oxygen reduction.

c. Dissolved oxygen profiles in Wood Lake were different between 1972 and 1973. During summer stratification in both years epilimnion dissolved oxygen values were close to saturation while there was a progressive decrease in dissolved oxygen within the hypolimnion.

d. A clinograde dissolved oxygen curve, characteristic of eutrophic lakes was recorded in Wood Lake at the height of summer stratification during 1972.

e. In August 1973, dissolved oxygen concentrations at the thermocline level in Wood Lake were elevated above saturation due to photosynthetic activity of algal populations at this depth. The dissolved oxygen profile at this time is described as a positive heterograde curve. Prior to August 1973 a clinograde curve was present.

f. Only limited measurements were made in Kalamalka Lake but these were sufficient to characterise the dissolved oxygen curve as orthograde; typical of oligotrophic lakes.

g. The areal hypolimnetic oxygen utilisation (mg $O_2/cm^2/day$) was calculated for Wood and Kalamalka Lakes. The following values were obtained.

	1972	1973
Wood	0.121	0.148
Kalamalka	0.044	0.034

h. The hypolimnetic oxygen utilisation rates were in the oligo-mesotrophic range for Kalamalka Lake; for Wood, they were in the eutrophic range.

11. Metal Contents

Metal contents were determined in samples collected from surface waters and the lakes of the system. No anomalous or high values were recorded at any location.

12. Appendix 1, submitted separately from this report, describes the results for algal taxonomy and algal bioassay investigations.

13. Appendix 2, submitted separately from this report, reports studies of fossil pollen and diatom assemblages in sediment cores from Ellison, Wood and Kalamalka Lakes.

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5. Drafting

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D. MATERIALS AND METHODS

1. Sample Collection

a. Water Samples

Clear plastic 32 oz. capacity bottles purchased from J & C Manufacturing, Vancouver were used to collect routine surface water samples. Each sample was collected using a new bottle thoroughly pre-rinsed on site before being filled with the final sample. No detectable contamination by any of the measured characteristics of routine water quality occurred when the sample bottles were filled with distilled water that was subsequently analysed for water quality characteristics.

A 2-litre capacity Van Dorne acrylic plexiglass sampler was used to obtain water from the various depths sampled in each lake.

Lake and surface water samples were cooled to approximately 4C by refrigeration packs, placed in insulated containers and shipped to our Vancouver laboratory by an overnight truck service. Samples were invariably received the day following sample collection.

b. Routine Sediment Samples

Sediment cores of 10 cm length and 20 cm^2 in area were collected using a plexiglass hand corer by SCUBA divers. Each core was extruded into a plastic "whirlpak" bag and forwarded to our Vancouver laboratory.

c. Other Samples

Samples for fluorometry, algal bioassay, palynology and algal taxonomy were collected by procedures described separately in Appendix 1 and Appendix 2 to this report.

2. Analysis of Water Samples

a. Field Analyses

i. Dissolved oxygen and temperature were measured in the field using a Yellow Springs Instrument Company Model 54 polarographic oxygen analyser and thermistor. Frequent checks of dissolved oxygen values measured with this instrument were carried out in the field by performing Winkler titrations on samples preserved at the time of collection by the addition of manganous sulphate and alkaline potassium iodide/sodium azide solutions.

ii. pH. A Metrohm Model E488 portable pH meter equipped with a heavy duty glass/silver chloride electrode was used to measure the pH of water samples at the time of collection. The meter was standardised regularly throughout each day of sampling with buffer solutions of pH 4.0, 7.0 and 10.0.

iii. Alkalinity was measured by potentiometric titration of an aliquot of sample to pH 4.5 immediately on collection.

iv. Dissolved carbon dioxide was calculated from the equation:-

$$CO_2 \text{ in mg/l} = 1.60 \times 10^{(6.0-pH)} \times mgHCO_3^{-1}/l$$

where the bicarbonate concentration is given by the bicarbonate alkalinity of the sample (Brown, *et al.*, 1971).

v. Dye dispersal and dilution were monitored aboard the sampling boat using a Turner Model III fluorometer fitted with a flow-through cell.

b. Laboratory Analyses of Water Samples

Procedures for the analysis of most characteristics of water quality were based on those described in "Standard Methods for the Examination of Water and Wastewater", 13th edition, (1971), published by the American Public Health Association. Page numbers from this text are given for each analytical characteristic measured.

Analysis of nutrients in water samples were always completed on the day after sample collection. Other analyses were routinely completed within one week of sample collection. For colorimetric determinations, solution absorbance was measured using a Zeiss PMQ II or PMQ 3 spectrophotometer. Calibration curves for each analysis were made daily.

Analytical consistency was assessed on the basis of duplicate analyses of random samples and also by comparison of the results of split samples processed by our laboratory and by the Water Resources laboratory of the Water Resources Service. Analytical procedures were compared further by processing reference samples obtained from the Environmental Protection Agency of the U.S.; good agreement was achieved for all measured characteristics.

i. Suspended Solids. An aliquot of sample was passed through a tared, pre-washed Millipore cellulose-acetate filter of 0.45 μ pore size. Material retained on the filter was dried at 105C and weighed (Standard Methods, page 291). Dissolved constituents in the sample were analysed on the filtrate.

ii. Volatile Suspended Solids were determined as the difference in weight of material retained by a Whatman GF/A filter paper before and after incineration at 550C (Standard Methods, page 292).

iii. Orthophosphate was determined colorimetrically by the reaction of a filtered aliquot of sample with ammonium molybdate and potassium antimonyl tartrate to give phosphomolybdic acid which was then reduced to molybdenum blue by ascorbic acid (Standard Methods, page 532).

iv. Dissolved phosphorus was measured colorimetrically as orthophosphate on a filtered aliquot of sample after digestion with persulphate in an autoclave (Standard Methods, page 526).

v. Total phosphorus was measured as orthophosphate on a well mixed, unfiltered aliquot after persulphate digestion (Standard Methods, page 526).

vi. Nitrate and nitrite. The sample was evaporated to dryness in the presence of hydrogen peroxide. Nitrites were thus converted to nitrates which were analysed colorimetrically by the phenoldisulphonic acid procedure (Standard Methods, page 234).

vii. Ammonia was analysed colorimetrically on unfiltered samples using the phenol-hypochlorite technique of Harwood and Kuhn (1968).

viii. Total Kjeldahl nitrogen (TKN). Unfiltered samples were processed by a micro-Kjeldahl digestion using sulphuric acid and a Hengar granule. The digested solution was neutralised and the ammonia concentration measured colorimetrically as above.

ix. Total organic carbon was measured as the difference between total carbon and inorganic carbon using a Beckman model 915 TOC analyser.

x. Metal analyses were carried out by atomic absorption spectrophotometry (AAS) using a Perkin-Elmer model 303 instrument.

xi. Calcium and magnesium were determined by conventional AAS on filtered and well-mixed unfiltered samples that had been treated with lanthanum chloride to eliminate phosphate interference.

xii. Silicon was measured on filtered samples by conventional AAS.

xiii. Trace Metals. Dissolved copper, zinc, manganese, iron, cobalt and nickel were analysed on filtered, acidified samples by flameless AAS using a Perkin-Elmer HGA 70 heated graphite atomiser. Deuterium background correction was used to compensate for broadband absorption. The technique of "standard additions" was used to determine the concentration of each metal.

xiv. Turbidity was determined using a Hellige turbidimeter. Readings were compared with calibration curves produced by formazin standards (Standard Methods, page 350).

xv. Chlorophyll a and phaeophytin a were measured using the procedure of Strickland and Parsons (1968). The water sample was filtered through a bed of magnesium carbonate on a Whatman GF/A filter. Retained material was ground in a Van Potter tissue homogeniser with 90% acetone. The extract was centrifuged and the absorbance of the supernatant measured at 630, 645, 665, and 750 mμ and again at 665 and 750 mμ after acidification. Concentrations of chlorophyll a and phaeophytin a were determined nomographically.

3. Analysis of Routine Sediment Samples

All sediment samples were dried at 105C before analysis.

a. Total Kjeldahl Nitrogen. A portion of the sediment (1-2 g) was carried through a micro-Kjeldahl digestion. Ammonia in the digest was distilled at pH 7.4 into boric acid solution and measured by titration.

b. Phosphorus. Sediment samples were digested with sulphuric acid/ammonium persulphate, the resulting solution was filtered and analysed colorimetrically for orthophosphate.

c. Organic Carbon. The sample was treated with hydrochloric acid at room temperature to remove carbonate and bicarbonate and dried at 60C under reduced pressure in a vacuum oven. The sample was then analysed for carbon content by ignition in a Leco induction furnace. The carbon dioxide produced by ignition was measured volumetrically.

4. Sample Sites - Surface Waters

The locations of sites at which surface water samples were collected are shown in Figure 1.

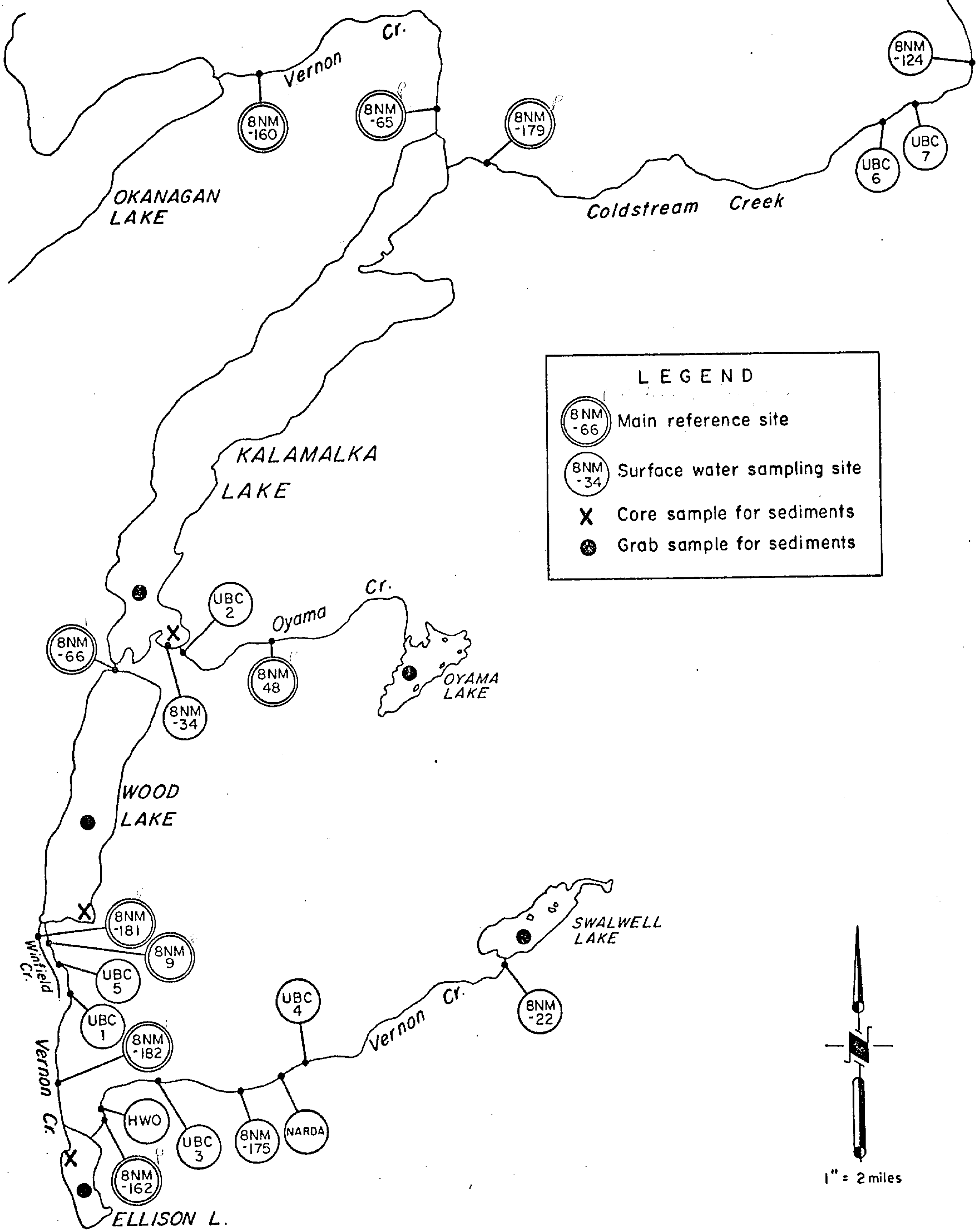
At each location, measurements were made of dissolved oxygen, temperature, alkalinity, analytically free carbon dioxide, temperature and pH. Water flow was measured by recording or staff gauges. Each routine water sample collected was analysed for general water quality characteristics.

a. Swalwell Lake - Ellison Lake

i. 8NM-22

This station is located on Vernon Creek approximately 200 yards

Figure 1
SAMPLING LOCATIONS - SURFACE WATERS AND SEDIMENTS



downstream of the Swalwell Lake Dam. Surface water samples were collected for analysis every two weeks during the period April 20 - November 27, 1972 giving a total of 17 samples.

ii. UBC-4

A total of 9 samples were collected at weekly intervals during the period June 29, 1972 to August 23, 1972 from a sample site located where Vernon Creek enters the storage behind the new ARDA diversion.

iii. N-ARDA

This sample site was located at the new ARDA diversion but no staff gauge was available to measure water flow. A total of 15 samples was collected at weekly intervals from May 28 - September 5, 1972.

iv. 8NM-175

This station is located on Vernon Creek about 3/4 mile below the new ARDA diversion. Flow measurements were made using recordings and staff gauges operated with an artificial control at a partial rock dam. Samples were collected weekly from May 28 - September 5, 1972 and at 2-week intervals from September 5, 1972 to November 27 for a total of 18 samples.

v. UBC-3

A total of 22 samples were collected weekly during the period from April 19 - September 4, 1972 and each month from September 5 to November 27, 1972 from a station located on Vernon Creek 100 yards downstream from the confluence of Clark and Vernon Creeks.

vi. Hiram Walker Outfall

The distillery outfall enters Vernon Creek approximately 300 yards above Ellison Lake at the southeast corner of the company property. Flow data were provided by Hiram Walker personnel and were analysed on a weekly and monthly basis. For practical purposes the flow was 5 cfs. A total of 24 samples were collected weekly from March 17, 1972 to November 27, 1972.

vii. 8NM-162

This was a main sampling station on Vernon Creek approximately 200 yards above Ellison Lake and 100 yards below the distillery outfall. The location of the sample site was such that the water from the distillery outfall was well mixed with the

Vernon Creek flow. Flow was measured by recording and staff gauges. Samples were collected weekly from March 17 to September 25, 1972, every two weeks from October 2, 1972 to April 8, 1973 and again weekly from April 16 to July 11, 1973 for a total of 46 samples. From April 19 - November 27, 1972, additional samples were collected at this site for the determination of chlorophyll a and phaeophytin a.

b. Ellison Lake - Wood Lake

i. 8NM-182

This station is located on Vernon Creek approximately 3/4 mile downstream from the exit of Ellison Lake. Flow measurements were made using recording and staff gauges. Water samples were collected weekly from March 17 - September 25, 1972 and every two weeks from October 2, 1972 to April 8, 1973. The 48 samples collected at this site were made up by weekly samples obtained from April 16 to July 11, 1973. Additional samples were taken and analysed for chlorophyll a and phaeophytin a during the period April 19, 1972 to November 27, 1972.

ii. UBC-1

This site is located on Vernon Creek where it crosses Wood Lake Road approximately 150 yards south of Perry Road. Flow measurements were made by staff gauge and 39 samples were collected as follows: weekly from March 19 to September 25, 1972, at 2-week intervals from October 2, 1972 to November 27, 1972 and again weekly from April 16, 1973 to July 11, 1973.

iii. UBC-5

This station is on Vernon Creek approximately 3/4 mile above Wood Lake. No gauge was available to measure flow. Only 8 samples were collected and these were obtained at weekly intervals from September 5 - September 25, 1972 and every 2 weeks from October 2 to November 22, 1972.

iv. 8NM-9

This is a main reference station located on Vernon Creek 1/4 mile above Wood Lake. Flow measurements were made using recording and staff gauges and a total of 51 samples were collected. The samples were collected weekly from April 19 to September 25, 1972, every 2 weeks from October 2, 1972 to April 8, 1973 and weekly from April 16 to July 11, 1973. Additional samples were collected during the period of April 19 to November 27, 1972 and were analysed for chlorophyll a and phaeophytin a content.

v. 8NM-181

This main reference site is located on Winfield Creek approximately 1/4 mile above Wood Lake. Flow was measured by staff gauge. Samples were collected weekly from March 3, 1972 to September 25, 1972, every 2 weeks from October 3, 1972 to April 8, 1973 and weekly from April 16, 1973 to July 11 for a total of 44 samples. Chlorophyll a and phaeophytin a samples were taken between April 19, 1972 and November 27, 1972.

c. Oyama Canal

i. 8NM-66

Measurements of flow through the Oyama Canal were monitored at Station 8NM-66 at the southerly end of the canal under the railway bridge, using recording, staff gauges and a Savonius Q9 direct reading current meter mounted in the canal. Flow information on net transfer was obtained from Mr. H. Coulson (Water Investigation Branch) on the basis of his interpretation of all the available flow information. A total of 44 samples was collected; weekly from March 17 to September 25, 1972, every 2 weeks from October 3, 1972 to April 8, 1973 and weekly from April 16 to July 11, 1973. Additional samples were taken and analysed for chlorophyll a and phaeophytin a during the period April 19 - November 27, 1972.

d. Oyama Creek Area

i. 8NM-48

The main reference station for Oyama Creek is located above the Wood Lake irrigation intake and about 1 1/2 miles above Kalamalka Lake. Flow measurements were made by recording and staff gauges. A total of 19 samples was collected every 2 weeks from April 20, 1972 to February 13, 1973. Additional samples were taken for chlorophyll a and phaeophytin a analysis between April 19 and November 27, 1972.

ii. UBC-2

This station is on Oyama Creek 1/4 mile above Kalamalka Lake and flow measurements were made using a staff gauge. A total of 29 samples was collected weekly from May 14 to August 28, 1972 and from April 8 to July 11, 1973.

iii. 8NM-34

This site included the drainage from a feed lot area south of

Oyama Creek. No flow measurements were made. A total of 17 samples was collected every 2 weeks during the period April 19 to November 26, 1972.

e. Coldstream Creek

i. 8NM-124

The headwater sample of Coldstream Creek is located approximately 9 miles from the mouth and about 1/2 mile north of the Vernon-Lumby Highway. Flow measurements were made using a staff gauge. General water quality characteristics were measured on a total of 15 samples collected at 2-week intervals from May 15, 1972 to November 26, 1972.

ii. UBC-7

The sample site is located on Coldstream Creek approximately 1 mile below 8NM-124. No flow measurements were made at this site and samples were collected on only 2 occasions, September 4, 1972 and September 18, 1972.

iii. UBC-6

No measurement of flow was made at this site. Seven samples were collected between September 4, 1972 and November 26, 1972 at a point on Coldstream Creek approximately 1/2 mile below UBC-7.

iv. 8NM-179

The main reference site on Coldstream Creek is located approximately 400 yards above the mouth of the creek and slightly above the point where the Kalavista diversion occurs. Flow measurements were made using staff gauge. Samples were collected every two weeks from March 17, 1972 to April 8, 1973 and weekly from April 16 to July 3, 1973; a total of 36 samples. From April 17 to November 27, 1972 the samples were also analysed for chlorophyll a and phaeophytin a concentrations.

f. Kalamalka to Okanagan Lake

i. 8NM-65

This site was located at the B.C. Hydro bridge approximately 1/2 mile below the outlet of Kalamalka Lake. Flow measurements were made by recording and staff gauges with 36 samples collected every 2 weeks from March 17, 1972 to April 8, 1973 and weekly from April 16 to July 11, 1973. Additional samples were collected between April 19 and November 27, 1972 for chlorophyll a and phaeophytin a analysis.

ii. 8NM-160

This site is located on Vernon Creek 3/4 mile upstream of the entry of Vernon Creek into Okanagan Lake. No staff gauge was available at this site and flow data were provided by Mr. H. Coulson; 23 samples were collected every 2 weeks from March 17, 1972 to April 8, 1973.

5. Surface Water Supplementary Site Samples

a. Comparison of Test Methods Between Laboratories

Duplicate sets of samples were collected on July 16 and August 28, 1972 and were tested for water quality characteristics by the Water Quality Group at B.C. Research and by the Water Resource Services laboratory in Vancouver. The sites sampled were as follows:- UBC-1, UBC-3, 8NM-9, 8NM-66, 8NM-162, 8NM-175, 8NM-181, 8NM-182, N-ARDA and the distillery outfall.

b. Low Level Metal Analyses

On five occasions, samples were collected at the same time as regular surface water samples and were analysed by flameless atomic absorption spectrophotometry. These samples were collected in acid-washed bottles and at the time of sample collection were adjusted to pH 2. The metals analysed were: copper, zinc, nickel, iron, cobalt, manganese, calcium, magnesium, sodium and potassium. The sample series were as follows.

October 10, 1972

Sites:	8NM-9, 8NM-162, 8NM-62, 8NM-175, 8NM-182, distillery outfall, UBC-3
Analysis:	Copper, zinc, calcium

October 15, 1972

Sites:	8NM-48, 8NM-65, 8NM-34, 8NM-66, 8NM-124, 8NM-179, 8NM-160, 8NM-181, UBC-6.
Analysis:	Copper, zinc, nickel, iron, cobalt, manganese, calcium

October 16, 1972

Sites:	8NM-9, 8NM-22, 8NM-182
Analysis:	Copper, zinc, iron, cobalt, nickel, manganese, calcium, sodium, potassium

November 14, 1972

Sites:	8NM-34, 8NM-65, 8NM-160, 8NM-179, 8NM-181, 8NM-182, 8NM-48, 8NM-66, UBC-6
Analysis:	Copper, zinc, nickel, iron, cobalt, manganese, sodium, potassium.

November 15, 1972
Sites: 8NM-22, 8NM-162
Analysis: Zinc, nickel, iron, cobalt, manganese, sodium, potassium

6. Sample Sites - Lake Structure

The location of the sample sites for lake structure is shown in Figure 2. At each sample site, measurements were made in the field for temperature, pH, alkalinity, carbon dioxide, and dissolved oxygen. Measurements were made of transparency using a 16-cm diameter Secchi disc. Samples were also collected at selected depths and preserved for chlorophyll a, phaeophytin a analysis and algal taxonomy.

Site locations were as follows.

a. Swalwell Lake

Sampled in June, July, August and October 1972

Site 1 Location: 50° 02' 50"N, 119° 14' 15"W.

Depths sampled: 0, 2.5, 5.0, 7.5, 10.0, 12.5 and 15 meters

Chlorophyll a, phaeophytin a and algal samples at: 0, 2.5, 5.0, and 7.5 meters

b. Ellison Lake

Sampled monthly from April to November, 1972 and bimonthly from January to May, 1973.

Site 1 Location: 50° 00' 05"N, 119° 23' 30"W

Depths sampled: 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 meters

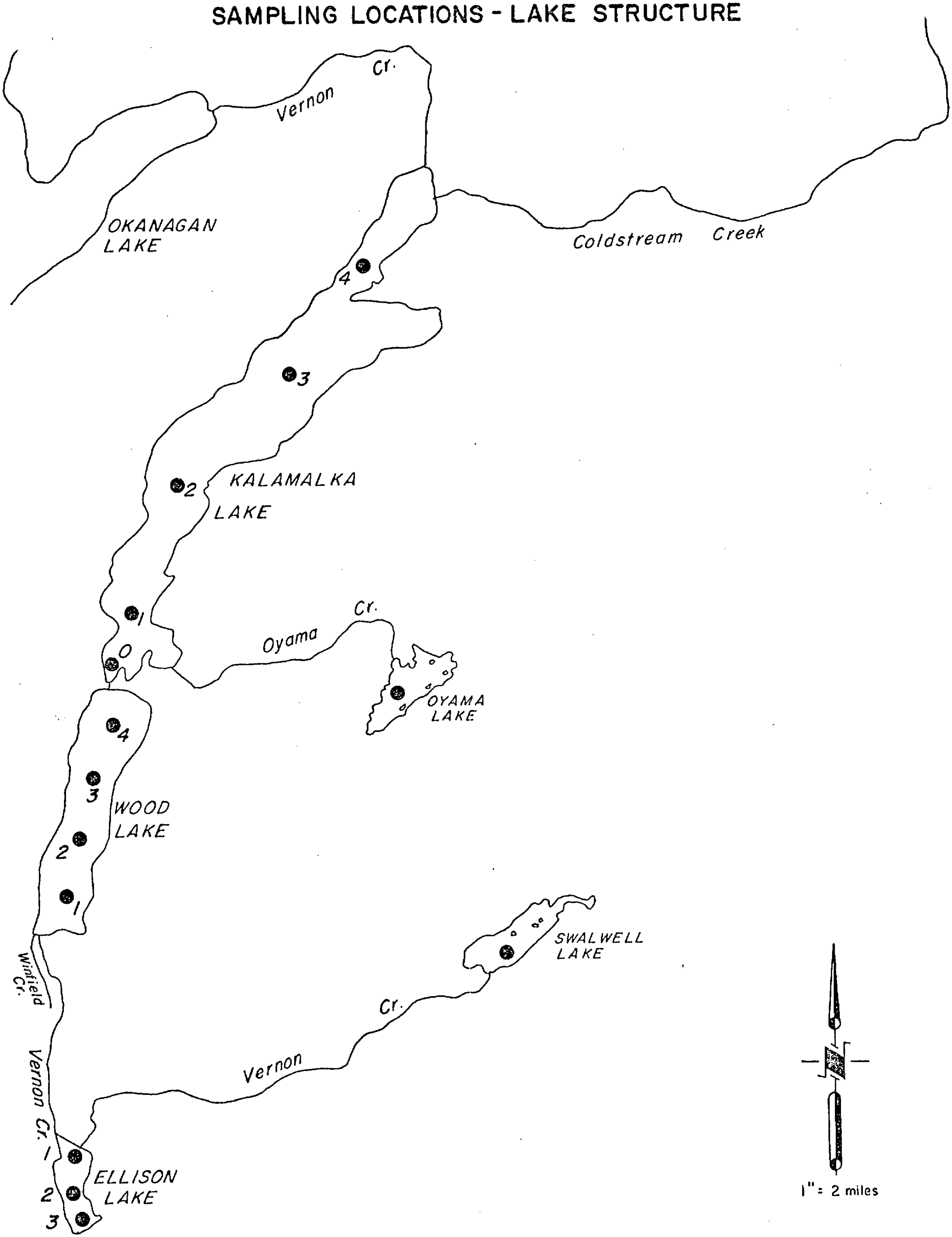
Chlorophyll a, phaeophytin a and algal samples at: 0 and 2.5 meters

Site 2 Location: 49° 59' 20"N, 119° 23' 40"W

Depths sampled: 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 meters

Chlorophyll a, phaeophytin a and algal samples at: 0, 0.5, 1.5, 2.5 and 3.0 meters

Figure 2
SAMPLING LOCATIONS - LAKE STRUCTURE



Site 3 Location: 49° 59' 20"N, 119° 23' 35"W

Depths sampled: 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 meters

Chlorophyll *a*, phaeophytin *a* and algal samples at: 0 and 2.5 meters.

c. Wood Lake

Sampled monthly from April to November 1972 and bimonthly from January to May, 1973.

Site 1 Location: 50° 03' 30"N, 119° 23' 50"W

Chlorophyll *a*, phaeophytin *a* and algal samples at: 0 and 5.0 meters.

Site 2 Location: 50° 04' 25"N, 119° 23' 35"W

Depths sampled: 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 20.0 and 25.5 meters

Chlorophyll *a*, phaeophytin *a* and algal samples at: 0, 2.0, 5.0, 10.0, 15.0 meters.

Site 3 Location: 50° 05' 25"N, 119° 23' 10"W.

Depths sampled: 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 20.0 and 25 meters.

Chlorophyll *a*, phaeophytin *a* and algal samples at: 0 and 5.0 meters.

Site 5 Location: 50° 06' 10"N, 119° 22' 40"W

Depths sampled: 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 20 meters.

Chlorophyll *a*, phaeophytin *a* and algal samples at: 0, 2.5 5.0, 10.0, 15.0 meters.

d. Kalamalka Lake

Sampled every two months from April to October, 1972.

Site 0 Location: 50° 06' 45"N, 119° 22' 45"W

Samples for chlorophyll a, phaeophytin a and algal identification samples taken at all depths.

Site 1 Location: 50° 07' 35"N, 119° 22' 20"W

Depths sampled: 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0 and 20 meters.

Chlorophyll a, phaeophytin a and algal samples at: 0, 2.5, 5.0, 15 meters.

Site 2 Location: 50° 08' 50"N,119° 21' 40"W

Depths sampled: 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 20.0 and 50.0 meters.

Chlorophyll a, phaeophytin a and algal samples at: 0, 2.5, 5.0 and 10.0 meters

Site 3 Location: 50° 10' 35"N, 119° 19' 20"W

Depths sampled: 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 20.0 and 75.0 meters.

Chlorophyll a, phaeophytin a and algal samples at: 0, 2.5, 5.0, and 15.0 meters.

Site 4 Location: 50° 12' 45"N, 119° 17' 10"W

Depths sampled: 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0 and 20.0 meters.

Chlorophyll a, phaeophytin a and algal samples at: 0 and 5.0 meters.

e. Oyama Lake

Sampled in July, August and October, 1972.

Site 1 Location: 50° 06' 20"N, 119° 16' 40"W

Depths sampled: 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0 and 20.0 meters.

Chlorophyll a,
phaeophytin a and
algal samples at: 0, 2.5, 5.0, and 7.5 meters.

7. Lake Structure - Supplementary Samples

To supplement the program of lake structure, additional measurements and samples were collected. Weekly dissolved oxygen and temperature profiles were measured at Site 4 in Wood Lake, Site 0 in Kalamalka Lake and Site 2 in Ellison Lake. At the same time, samples were also collected to monitor the abundance and species composition of phytoplankton. In July and October, 1972 supplementary samples were taken in conjunction with regular lake water sampling and were analysed by flameless atomic absorption spectrophotometry for copper, zinc, nickel, iron, cobalt, manganese, calcium, magnesium, sodium and potassium. These samples were collected at all depths and from all stations.

8. Lake Structure - Sediment Samples

Core samples for sediment and pollen analyses were taken from Wood, Kalamalka and Ellison Lakes in July 1972 by SCUBA divers. The location of these sediment samples is shown in Figure 2.

9. Physical Structure of Kalamalka, Wood and Ellison Lakes

Physical data were collected during 1972 and 1973 for Ellison, Wood and Kalamalka Lakes in conjunction with the regular sampling for water quality analyses. In the three lakes, physical data were collected more extensively during the summer months and the measurements made have been listed in Section 5 of the Materials and Methods section of this report.

Lake structure data were not obtained from Kalamalka Lake at depths greater than about 75 meters and on most occasions were obtained only to a depth of 25 meters. This was considered adequate for the purposes of comparison with Wood Lake which has a maximum depth of 34 meters and a mean depth of 22 meters.

The data obtained from the sampling of Ellison, Wood and Kalamalka Lakes were used to follow seasonal changes within each lake and to allow comparative assessments to be made of the physical structure of each. In this context, annual thermal changes were calculated for each lake and epilimnion and hypolimnion heating were plotted for Wood and Kalamalka Lake during periods of stratification, while heating of Ellison Lake was also monitored. Heat income for each lake was calculated from the temperature profiles collected on each sampling occasion. Normally the data collected at each station within a lake was averaged and weighted by an area of influence. From the averaged temperature profile of each lake on each occasion, representative temperature profiles were constructed. Hypsometric curves for Wood and Kalamalka Lake (Blanton and Ng, 1972) were used to estimate the volumes of the epilimnion, thermocline and hypolimnion. The point of separation of epilimnion from the thermocline was established as the depth of maximum change in vertical temperature gradient above the thermocline. The separation of the thermocline from the hypolimnion corresponded to the depth of maximum rate of thermal change below the thermocline. Heat content of each lake for each sampling occasion was calculated using the following equation:-

$$Q = \frac{Cp^P}{Ao} \{Vh(Th-4) + Vm(Tm-4) + Ve(Te-4)\}$$

where Q is the heat content in calories/cm^2, c_p is the specific heat of water, p is the water density, and A∘ is the surface area of the lake. V_h,V_m and V_e are the volumes of the hypolimnion, metalimnion (thermocline) and epilimnion respectively and T_h,T_m and T_e is the temperature of the hypolimnion, metalimnion and epilimnion (Blanton and Ng, 1972). The product $C_p{}^P$ was taken as 1. The maximum value of Q is the summer heat income as described by Hutchinson (1957). Temporal changes in the dissolved oxygen content of the lakes were calculated and the oxygen uptake within the hypolimnion of Wood and Kalamalka Lake was obtained to indicate the state of eutrophication in the lakes. The method employed to determine the hypolimnetic oxygen deficit was that described by Hutchinson (1957). Briefly it involves the determination of the hypolimnion level within each lake from the measured temperature profiles for each sampling occasion and location whereby the average oxygen concentration within the hypolimnion was rated with respect to the volume of water enclosed within the hypolimnion. The volume of the hypolimnion as deduced from hypsometric curves was used to calculate the total oxygen content within the hypolimnion of the lake on each sampling occasion. From hypsometric curves the surface area of the hypolimnion was determined and division of the total oxygen content of the hypolimnion by this area gives a figure representing the areal oxygen content. By plotting the temporal variation in areal oxygen content, the rate of change of hypolimnetic oxygen expressed in relation to area was determined and is termed the hypolimnetic oxygen deficit. Insufficient data were available to apply this procedure directly to Kalamalka Lake and hypolimnetic oxygen concentrations were determined using proportioning methods related to the hypsometric curve for this lake. Due to the frequent mixing and the break down of stratification in Ellison Lake waters, hypolimnetic oxygen deficits could not be calculated. The actual oxygen deficit of the water at any point in the lake is defined as the difference between the saturation value at the temperature of the water at the pressure of the lake surface. "The relative deficit expressed per unit of the hypoliminon surface between spring circulation and the height of summer stratification, or better the relative areal deficit acquired during this period per unit time appears to give a fair indication of the hypolimnetic productivity of the lake" (Hutchinson, 1957).

10. Water Movement in Ellison, Wood and Kalamalka Lake

Dispersion patterns of the incoming creek waters were monitored on a number of occasions in Ellison, Wood and Kalamalka Lakes. Fluorescent dye and drogues were used in these studies. General patterns of water movement were monitored using 2-ft diameter surface drogues or fixed-depth vane drogues. The latter consisted of a color-coded polystyrene float connected to aluminum vanes positioned at fixed depths. Vane drogues were constructed with a high surface area ratio between vane and float. Approximate wind speed and direction were recorded regularly throughout each study. Rhodamine WT (20% solution) was used in dye studies because of its low toxicity, high sensitivity to fluorometry and its low adsorption on particulate material, which is important in turbid waters, such as Ellison Lake. During each study the dye was added from 5-gal containers at a constant flow-rate, for a period which varied according to the requirement of the study. Dye concentrations were monitored fluorometrically to a detection limit of 0.1 μg/l. Dispersal patterns were mapped on a grid system set up using landmarks on the shore. Aerial photography was used to supplement the fluorometric recordings of dye dispersal. Aerial photography proved very effective when the dye was dispersed throughout surface water of a lake or when it became mixed with clear water as in Kalamalka Lake.

Water movements during a high runoff period were observed during spring 1972 by aerial photography of silt patterns in Kalamalka and Wood Lakes near the entry points of Coldstream and Vernon Creeks.

11. <u>Algal Studies</u>

Methods used in the analysis of algal bioassays and algal taxonomy are reported in Appendix 1.

12. <u>Palynology</u>

Studies of fossil pollen and diatom populations from core samples are reported in Appendix 2.

13. <u>Supporting Data</u>

Information concerning such aspects of the study as lake volumes and surface area were obtained from the reports of the Okanagan Basin Agreement. Flow data were obtained from the Water Survey of Canada and are shown in Table 1. Meteorological records were collected from Environment Canada at the Kelowna airport. Dustfall loadings and direct drainage loadings were supplied by Dr. G. Kennedy and Mr. C. Purpora from the land-use section of the Kalamalka-Wood Lake Basin Study. Mr. G.A. LeBreton, Water Resources Branch provided information which was used to assess the transfer of nutrients through direct groundwater inputs to the lakes.

Table 1

WATER FLOWS AT REFERENCE SITES IN THE KALAMALKA-WOOD LAKE BASIN
(DATA SUPPLIED AS MEAN DAILY FLOWS BY THE WATER SURVEY OF CANADA)

	STATION 8NM -			(flows in cfs)				
	162	182	9	66	48	179	65	160
1972								
April	43.0	47.7	44.1	35.4	8.1	22.3	66.5	122.0
May	82.8	56.2	53.1	33.8	52.4	196.0	117.0	186.0
June	76.1	79.0	76.8	73.7	22.2	60.9	163.0	270.0
July	13.8	33.4	32.6	38.2	16.2	33.5	138.0	166.0
Aug.	6.9	8.6	9.9	15.6	14.4	23.9	80.8	96.5
Sept.	12.3	7.3	8.5	14.0	7.5	20.0	40.9	60.8
Oct.	8.2	5.5	7.6	15.0	1.9	12.3	19.6	41.8
Nov.	9.5	6.3	7.6	16.9	2.0	9.7	1.0	17.8
Dec.	6.7	5.5	6.5	20.3	1.6	8.9	0.2	14.0
1973								
Jan.	6.4	4.8	5.0	-1.6	1.7	8.0	13.6	31.0
Feb.	5.4	3.7	4.9	13.9	1.4	9.0	25.6	36.0
Mar.	2.4	1.6	4.0	6.5	1.4	13.0	17.4	37.0
April	34.3	14.8	15.7	5.6	3.7	13.5	14.6	
May	12.2	16.7	18.7	5.0	15.1	38.3	60.3	
June	12.1	6.5	7.3	-1.0	12.2	11.1	12.3	
July	8.3	3.8	3.9	-7.3	12.4	6.6	3.8	
1972 Freshet Year	22.8 ±28.5	21.6 ±26.0	21.8 ±24.2	23.5 ±19.7	10.9 ±14.8	23.0 ±23.3	57.0 ±56.0	89.9 ±80.8
1973 Freshet Year	10.4 ±8.1	7.0 ±4.5	8.3 ±4.6	8.6 ±8.7	6.3 ±5.7	11.6 ±8.7	24.2 ±24.7	
Ratio 1972:1973	2.2	3.1	2.6	2.7	1.7	2.0	2.3	

B.C. RESEARCH - FIELD DATA								
1972 Freshet Year	17.6	21.6	21.1	23.5	12.1	65.8	59.8	
1973 Freshet Year	7.6	7.6	8.1	8.6		49.5	24.5	
Ratio 1972-1973	2.3	2.8	2.6	2.7		1.3	2.4	

E. RESULTS

1. Surface Waters

In this section analytical results are given for surface water from routinely sampled stations along Vernon Creek. The data are initially presented in terms of general water quality, identifying mean values and the range of values for each parameter with comments upon significant differences in concentration for the various characteristics measured. Subsequently the data are presented as loadings for the more important nutrients and suspended solids from surface waters into Ellison, Wood and Kalamalka Lakes. Measurement of the direct input of nutrients from the distillery outfall and the effect of this cooling water flow upon the translocation of nutrients throughout the Kalamalka-Wood Lake Basin are considered separately.

The investigation included two spring runoff periods. To maximize the information obtained, the data are converted to terms of "freshet years". The period April 1, 1972 to March 31, 1973, characterized by a high spring runoff, is termed freshet year 1972. Data gathered between August 1, 1972 and July 31, 1973, a period in which the spring runoff was very low, are included in freshet year 1973. Mean values for concentration and overall loadings were taken as the average of these two freshet years. Flow data are treated similarly.

a. Concentration of Water Quality Constituents in Surface Waters

i. Swalwell Lake to Ellison Lake

Table 2 lists overall and annual mean values, together with standard deviations, of pH and the concentrations of nitrogen, phosphorus, calcium and magnesium in samples from Station 8NM-162. Monthly maxima and minima are also cited. At this site, Vernon Creek contains cooling water from the Hiram Walker distillery. With the exception of total phosphorus, for which mean concentrations in 1972 and 1973 were 0.129 ± 0.263 and 0.041 ± 0.047 mg P/1 respectively, there were no major differences between the mean concentrations of any constituent in 1972 and 1973 freshet years. Average daily flows, on the other hand, differed by a factor of 2.2 between freshet years, being 22.8 cfs during 1972 and only 10.4 cfs during 1973.

The water in Vernon Creek above Ellison Lake was alkaline with a mean pH 8.1 ± 0.4 and a range of pH between 7.3 and 8.5. Alkalinity was 74 - 86 mg $CaCO_3$/1 with calcium and magnesium concentrations of 24.0 ± 7.3 and 7.8 ± 2.9 mg/1 respectively. Silicon ranged from 5.0 to 20 and total organic carbon concentration was between 3 and 20 mg/1.

TKN concentration tended to increase as water flow increased, particularly during the 1972 spring runoff. The highest mean monthly value for TKN was 1.4 mg N/1 measured during May 1972. A sample collected May 22, 1972 had the highest individual TKN concentration (3.50 mg N/1) measured in a highly turbid sample (150 APHA units) that also contained the highest concentration of total phosphorus (2.27 mg P/1). By contrast in 1973, maximum TKN concentrations were 0.450 - 0.460 mg N/1, measured between March 25 and April 30.

One sample collected in December 1972 had a nitrate concentration of 0.400 mg N/1. In general however, nitrate levels were highest during spring runoff with mean monthly concentrations between 0.122 and 0.230 mg N/1 during the 1972 and 1973 runoff periods.

The concentrations of particulate phosphorus increased during times of high water flow. The maximum mean monthly value of 0.952 mg P/1 measured in May, 1972 was 5-10 fold higher than at other times of the year. The elevation of the mean monthly content of particulate phosphorus was due largely to the value 2.27 mg/1 in the single sample collected May 22. Soluble phosphorus concentrations were more consistent throughout the year, with highest mean monthly values of 0.058 and 0.033 mg P/1 measured during May and June 1972. Orthophosphate accounted for 90% of the total soluble phosphorus in samples collected above Ellison Lake.

The concentrations of chlorophyll <u>a</u> and phaeophytin <u>a</u> ranged between 0 and 2.0 mg/1 and 0 and 1.6 mg/1, respectively, in samples collected between April and November 1972. Highest values for both these indicators of algal productivity were measured between April and November 1972 as shown in the plot of mean monthly values in Figure 3

ii. <u>Ellison Lake to Wood Lake</u>

Water quality in Vernon Creek near the exit from Ellison Lake was monitored at Station 8NM-182. The data obtained were compared with those from Station 8NM-162 above Ellison Lake and also with results from Station 8NM-9, downstream on Middle Vernon Creek above Wood Lake. Values for nitrogen, phosphorus, calcium, magnesium and pH at Station 8NM-182 are shown in Table 3 as the overall, 1972 and 1973 freshet year averages with standard deviations, the monthly maximum and minimum concentrations.

There were no significant differences between freshet years 1972 and 1973 in the concentrations of the major water quality characteristics listed for Station 8NM-182 in Table 3. Calcium and magnesium concentrations - 16.8 ± 3.0 and 5.7 ± 1.0 mg/1, respectively, were significantly lower at the exit from Ellison Lake than upstream of the lake at Station 8NM-162. pH was essentially unchanged. The alkalinity of water leaving Ellison Lake ranged between 59 and 73 mg $CaCO_3$/1 in individual samples and the concentration of silicon was between 5 and 10 mg/1.

The overall concentrations of most of the major nutrients in water leaving Ellison Lake were comparable with those in Vernon Creek above the lake. Mean nitrate concentrations were identical (0.111 ± 0.063 mg N/1). Total phosphorus and total soluble phosphorus concentrations were very similar to the corresponding values at 8NM-162 and the difference in orthophosphate was not significant.

There was, however, substantial change in the overall concentration of TKN in Vernon Creek below Ellison Lake compared with the concentration at the entrance to the lake. Mean values were 0.843 ± 0.383 mg N/1 and 0.370 ± 0.317 mg N/1 respectively. Below Ellison Lake, individual samples containing TKN concentrations above 1.00 mg N/1 were measured periodically throughout the sampling period.

The concentration of total phosphorus leaving Ellison Lake during freshet year 1973 (0.103 ± 0.064 mg P/1) was significantly higher than the mean value in Vernon Creek entering Ellison Lake (0.041 ± 0.047 mg P/1). The difference was due to an increase in particulate phosphorus and high concentrations were measured in a sample collected on May 28, 1972 (0.331 mg P/1). High particulate phosphorus levels were also measured from the end of July to the middle of September 1972 (0.110-0.312 mg P/1) and on a single sample collected February 25, 1973, in which the concentration was 0.292 mg P/1.

Results plotted in Figure 3 show that the concentration of chlorophyll a increased progressively throughout the summer of 1972, reaching the highest monthly values of 13.4-21.1 mg/1 between July and October. The highest individual concentration of chlorophyll a was 38.9 mg/1 found in a sample collected October 15, 1972. Phaeophytin a concentrations varied widely, with monthly mean values ranging between 0.2-12.7 mg/1. Although the concentrations of phaeophytin a tended to follow the chlorophyll a pattern, the relationship was not consistent.

Water enters Wood Lake from Vernon Creek near Station 8NM-9. The concentrations of nutrients in Vernon Creek above the point of entry to Wood Lake are shown in Table 4. Comparison of the concentrations at this site with those at the exit from Ellison Lake can be used to assess the effects of land use practices upon surface water quality in Middle Vernon Creek. The data are discussed in relation to the overall averages because differences were small between the two freshet years in nitrogen and phosphorus concentrations at the lower end of Middle Vernon Creek.

As water passed through Middle Vernon Creek from Ellison to Wood Lake, the nitrate concentration increased more than 3-fold, from 0.111 ± 0.063 to 0.382 ± 0.201 mg N/1. TKN concentration was reduced from 0.843 ± 0.383 to 0.547 ± 0.199 mg N/1. The difference may be due to settlement of particulate material along Middle Vernon Creek. However, concentrations of total and soluble phosphorus increased slightly in this section of the creek; total soluble phosphorus increased from 0.019 ± 0.016 to 0.030 ± 0.019 mg P/1 and orthophosphate concentration to 0.024 ± 0.017 mg P/1 from 0.010 ± 0.008 mg/1.

Calcium and magnesium concentrations in Vernon Creek at the entrance to Wood Lake increased by approximately 50% over the values recorded at the exit from Ellison Lake. Alkalinity was determined on only four samples from Station 8NM-9 and declined from 133 mg/1 in March 1972 to 66 mg/1 on April 30, 1972. pH was 7.7 ± 0.3, slightly reduced from the upstream station despite the increase in calcium and magnesium concentrations. Silicon content was 5 mg/1 with mean monthly averages ranging between 6 and 10 mg/1. Organic carbon was between 5 and 20 mg/1 with the highest values recorded during June.

Chlorophyll a and phaeophytin a concentrations are plotted in Figure 3. Similar values were obtained at Station 8NM-9 to those for the upstream station 8NM-182. Mean monthly values for chlorophyll a ranged between 3.2 and 12.2 mg/1, reaching their maximum in August. Phaeophytin a values ranged between 0.7 and 6.1 mg/1.

Winfield Creek had a steady flow and consistent water quality. The analytical data for this station is shown in Table 5.

Although the alkalinity of Winfield Creek was measured only between March - June 1972, there was a substantial increase from 68 mg/1 in March to approximately 200 mg/1 subsequently. Samples collected between April and November 1972 contained concentrations of chlorophyll a and phaeophytin a in ranges 1.1 to 4.6 and 0 to 1.8 mg/1 as shown in Figure 3.

iii. Wood Lake - Kalamalka Lake

Care was taken at all times to ensure that samples were collected from Oyama Canal (Station 8NM-66) only when water was passing from Wood Lake to Kalamalka Lake. There is, of course, no assurance that these samples were not Kalamalka water being repassed through the canal.

Results presented in Table 6 show mean values for pH and for concentrations of nutrients, magnesium and calcium at Station 8NM-66. Except for TKN, the concentrations of nutrients were lower in water entering Kalamalka Lake through the Oyama Canal from Wood Lake than in water at most upstream Vernon Creek locations, including Station 8NM-9 at the entrance to Wood Lake and also Station 8NM-162 above Ellison Lake, where the flow of Vernon Creek was augmented by low-nutrient water discharged as distillery cooling effluent. Oyama Canal samples contained slightly higher magnesium and orthophosphate concentrations (0.015 mg P/l) than samples from Station 8NM-182 at the exit from Ellison Lake (0.010 mg P/l). Differences in the concentrations of nutrients, calcium and magnesium were minimal from freshet year 1972 to freshet year 1973, despite the large change in total water flow in these periods. Even so, monthly maxima and minima showed that there was a considerable range of concentrations throughout the year.

The data indicate the role of Wood Lake as a sink for some nutrients. However, as will be discussed later, nutrient accumulation does not occur in Wood Lake for all constituents.

Turbidity and concentrations of suspended solids were low in samples collected from the Oyama Canal, with values ranging between 1.2 and 4.5 APHA turbidity units and 1 to 6 mg/l respectively. This excludes suspended solids concentrations of 25 and 8 mg/l during maximum runoff months of 1972 and 1973. Silicon concentration was constant at 5 mg/l, while alkalinity ranged between 123 and 148 mg/l. Chlorophyll a values were between 1.2 and 17.1 mg/l and are plotted in Figure 3, together with concentrations of phaeophytin a (0 to 1.1 mg/l).

iv. Oyama Lake to Kalamalka Lake

Samples were collected from April 1972 to February 1973 at Station 8NM-48 to monitor water quality at the downstream end of Oyama Creek. Concentrations of nitrogen, phosphorus, calcium and magnesium are reported in Table 7.

Nutrient levels were low in comparison with values measured elsewhere in the study area. Calcium and magnesium contents were also low and were reflected in low alkalinities of between 28 and 33 mg/l. Silicon concentration was 5 mg/l.

Concentrations of chlorophyll a and phaeophytin a were low, ranging between 0.1 and 0.8 mg/l and 0 to 0.8 mg/l, respectively.

Monthly values are plotted in Figure 3.

v. Coldstream Creek to Kalamalka Lake

Results given in Table 8 show the concentrations and mean standard deviations, together with the monthly ranges for nitrogen, phosphorus, calcium, magnesium and pH in Coldstream Creek above its point of entry to Kalamalka Lake. The results are separated for freshet years 1972 and 1973.

Overall, there were no significant differences in water quality between the two freshet years. The downstream end of Coldstream Creek contained very similar concentrations of nutrients, calcium and magnesium to Winfield Creek which originates as groundwater. Nitrate concentrations were much higher in Coldstream Creek than other surface water sites, with a mean overall value of 1.280 ± 0.534 mg N/1, which is the same as the nitrate level in Winfield Creek. The average TKN concentration of 0.406 ± 0.212 mg N/1 was also similar to that in Winfield Creek. This is lower than the values recorded for most other surface waters with the exceptions of Station 8NM-48 on Oyama Creek and Station 8NM-162 on Vernon Creek above Ellison Lake. The concentration of orthophosphate was relatively high at 0.024 ± 0.016 mg P/1, corresponding to 85% of total soluble phosphorus.

Calcium and magnesium concentrations were high with average values of 57.1 ± 13.9 and 17.9 ± 4.8 mg/1 respectively. Alkalinity ranged between 154 and 271 mg/1 and pH was 8.1 ± 0.3. Concentrations of chlorophyll a and phaeophytin a in the water samples were low with values from 0.5 to 7.5 mg/1 and 0.2 to 2.4 mg/1, respectively, as shown in Figure 3.

vi. Kalamalka Lake to Okanagan Lake

Samples collected at Station 8NM-65 were used to monitor water quality in Vernon Creek leaving Kalamalka Lake before any significant input of nutrients could occur.

Table 9 lists mean values together with a standard deviation for concentrations of nitrogen, phosphorus, calcium, magnesium and for pH.

The water is characterised by low concentrations of nitrogen and phosphorus with little or no overall difference between freshet years 1972 and 1973. Similarly, calcium, magnesium and pH values were almost constant. Differences between monthly maxima and minima for some characteristics are appreciable, however. The results are compatible with the description of Kalamalka Lake as a stable oligotrophic water body.

Table 2

CONCENTRATIONS OF WATER QUALITY CHARACTERISTICS AT

STATION 8NM 162 - INFLOW TO ELLISON LAKE

(values as mg/1 ± one standard deviation)

	OVERALL	1972	1973	Range of Monthly Averages	
				Maximum	Minimum
Nitrate, Nitrite N	0.111 ± 0.088	0.107 ± 0.098	0.120 ± 0.104	0.400	0.033
TKN	0.370 ± 0.317	0.410 ± 0.370	0.298 ± 0.198	1.409	0.129
Total P	0.105 ± 0.223	0.129 ± 0.263	0.041 ± 0.047	0.952	0.003
Total soluble P	0.020 ± 0.016	0.025 ± 0.018	0.016 ± 0.015	0.058	0.003
Orthophosphate (P)	0.018 ± 0.014	0.019 ± 0.016	0.013 ± 0.014	0.029	0.003
Total calcium	24.0 ± 7.3	24.6 ± 8.4	27.4 ± 4.6	31.5	9.0
Total magnesium	7.8 ± 2.9	7.9 3.4	7.6 ± 2.8	16.9	3.2
pH	8.1 ± 0.4	8.2 ± 0.2	8.1 ± 0.4	8.5	7.3
Flow [1]		22.8	10.4	82.8	5.4

[1] Average value in cfs

Table 3

CONCENTRATIONS OF WATER QUALITY CHARACTERISTICS AT

STATION 8NM 182 - EXIT FROM ELLISON LAKE

(value as mg/l ± one standard deviation)

	OVERALL	1972	1973	RANGE OF MONTHLY AVERAGES	
				MAXIMUM	MINIMUM
Nitrate, nitrite N	0.111 ± 0.063	0.116 ± 0.07	0.110 ± 0.07	0.305	0.045
TKN	0.843 ± 0.383	0.832 ± 0.416	0.880 ± 0.415	1.615	0.410
Total P	0.102 ± 0.058	0.113 ± 0.065	0.103 ± 0.064	0.230	0.005
Total soluble P	0.019 ± 0.016	0.024 ± 0.018	0.019 ± 0.019	0.067	0.003
Orthophosphate (P)	0.010 ± 0.008	0.012 ± 0.008	0.010 ± 0.009	0.032	0.003
Total calcium	16.8 ± 3.0	16.0 ± 3.0	17.7 ± 2.2	21.5	12.1
Total magnesium	5.7 ± 1.0	5.5 ± 1.1	6.0 ± 0.8	7.5	4.3
pH	8.1 ± 0.5	8.2 ± 0.5	8.0 ± 0.6	9.1	7.2
Flow[1]		21.6	7.1	79.0	1.6

[1] Average value in cfs.

Table 4

CONCENTRATION OF WATER QUALITY CHARACTERISTICS AT
STATION 8NM 9 (VERNON CREEK) INFLOW TO WOOD LAKE

(values as mg/1 ± one standard deviation)

	OVERALL	1972	1973	RANGE OF MONTHLY AVERAGES	
				MAXIMUM	MINIMUM
Nitrate, nitrite N	0.382 ± 0.201	0.389 ± 0.220	0.447 ± 0.179	0.800	0.113
TKN	0.547 ± 0.199	0.503 ± 0.145	0.539 ± 0.238	1.119	0.260
Total P	0.134 ± 0.078	0.142 ± 0.090	0.112 ± 0.075	0.321	0.039
Total soluble P	0.030 ± 0.019	0.035 ± 0.020	0.031 ± 0.021	0.058	0.007
Orthophosphate (P)	0.024 ± 0.017	0.027 ± 0.017	0.022 ± 0.017	0.053	0.003
Total calcium	22.6 ± 6.2	21.7 ± 6.3	24.1 ± 4.5	35.5	13.4
Total magnesium	8.9 ± 3.2	8.4 ± 3.2	9.5 ± 2.6	16.7	4.8
pH	7.7 ± 0.3	7.8 ± 0.3	7.6 ± 0.2	8.4	7.3
Flow[1]		22.7	9.3	76.9	3.9

[1] Average value in cfs.

Table 5

CONCENTRATION OF WATER QUALITY CHARACTERISTICS AT

STATION 8NM 181 (WINFIELD CREEK) INFLOW TO WOOD LAKE

(values as mg/l ± one standard deviation)

	OVERALL	1972	1973	RANGE OF MONTHLY AVERAGES	
				MAXIMUM	MINIMUM
Nitrate, nitrite N	1.263 ± 0.541	1.292 ± 0.600	1.272 ± 0.572	1.925	0.144
TKN	0.349 ± 0.200	0.380 ± 0.234	0.357 ± 0.230	0.492	0.171
Total P	0,085 ± 0.078	0.101 ± 0.088	0.078 ± 0.083	0.334	0.029
Total soluble P	0.028 ± 0.028	0,032 ± 0.032	0.021 ± 0.009	0.126	0.012
Orthophosphate (P)	0,020 ± 0.025	0.024 ± 0.030	0.013 ± 0.007	0.114	0.003
Total calcium	55.1 ± 6,1	56.9 ± 2.3	56.0 ± 3.2	60.5	34.0
Total magnesium	15.8 ± 0.5	16.0 ± 0.3	15.9 ± 0.2	16.4	14.0
pH	8.0 ± 0.4	8,1 ± 0,2	7.9 ± 0.3	8.3	7.1
Flow[1]		2.4	2.5	3.3	2.0

[1] Average value in cfs.

Table 6

CONCENTRATION OF WATER QUALITY CHARACTERISTICS

AT STATION 8NM 66 - OYAMA CANAL

(value as mg/1 ± one standard deviation)

	OVERALL	1972	1973	RANGE OF MONTHLY AVERAGES MAXIMUM	MINIMUM
Nitrate, nitrite N	0.083 ± 0.035	0.084 ± 0.039	0.089 ± 0.032	0.144	0.024
TKN	0.500 ± 0.122	0.511 ± 0.132	0.501 ± 0.120	0.744	0.320
Total P	0.049 ± 0.029	0.054 ± 0.031	0.039 ± 0.020	0.127	0.013
Total soluble P	0.018 ± 0.014	0.020 ± 0.016	0.016 ± 0.013	0.049	0.005
Orthophosphate (P)	0.015 ± 0.020	0.017 ± 0.021	0.011 ± 0.020	0.073	0.003
Total Calcium	24.9 ± 2.9	24.0 ± 2.3	24.9 ± 3.0	31.7	19.8
Total magnesium	17.0 ± 0.4	17.0 ± 0.5	16.9 ± 0.3	18.0	16.4
pH	8.6 ± 0.5	8.8 ± 0.2	8.5 ± 0.4	9.2	7.6
Flow[1]		23.5	8.6	73.7	-7.3

1 Average value in cfs.

Table 7

CONCENTRATION AND LOADINGS OF WATER QUALITY CHARACTERISTICS IN

OYAMA CREEK ENTERING KALAMALKA LAKE (STATION 8NM 48)

Samples collected April 1972 - Feb. 1973 inclusive

	CONCENTRATIONS (mg/l)			LOADING (lb/year)
	MEAN	MAXIMUM	MINIMUM	Estimated values incl. for March 1973
Nitrate N	0.149 ± 0.080	0.271	0.052	2700
TKN	0.295 ± 0.080	0.410	0.130	6700
Total nitrogen[1]				
Total P	0.024 ± 0.014	0.048	0.003	700
Total soluble P	0.013 ± 0.010	0.038	0.003	385
Orthophosphate (P)[2]	0.009 ± 0.008	0.030	0.003	230
Total calcium	6.57 ± 2.9	15.0	4.75	112,000
Total magnesium	2.38 ± 1.2	6.0	1.75	39,500
Suspended solids				281,000
Organic carbon				279,000
pH	7.5 ± 0.3	8.0	7.0	
Flow (average cfs)	12.8	52.4	1.4	

1 By addition

2 By difference

Table 8

CONCENTRATIONS OF SELECTED WATER QUALITY CHARACTERISTICS IN COLDSTREAM CREEK JUST ABOVE KALAMALKA LAKE (STATION 8NM 179)

(concentration as mg/l ± one standard deviation)

	OVERALL	1972	1973	RANGE OF MONTHLY AVERAGES	
				MAXIMUM	MINIMUM
Nitrate N	1.280 ± 0.534	1.414 ± 0.493	1.316 ± 0.457	2.390	0.382
TKN	0.406 ± 0.212	0.420 ± 0.236	0.340 ± 0.132	1.02	0.115
Total P	0.090 ± 0.110	0.098 ± 0.126	0.060 ± 0.030	0.487	0.023
Total soluble P	0.028 ± 0.014	0.028 ± 0.015	0.029 ± 0.015	0.073	0.011
Orthophosphate (P)	0.024 ± 0.016	0.024 ± 0.018	0.022 ± 0.015	0.056	0.003
Total calcium	57.1 ± 13.9	58.9 ± 14.5	57.4 ± 15.2	81.0	32.0
Total magnesium	17.9 ± 4.8	18.3 ± 5.1	18.8 ± 4.4	25.5	10.3
pH	8.1 ± 0.3	8.3 ± 0.2	8.1 ± 0.4	8.6	7.4
Flow[1]		34.8	14.5	196.0	8.9

1 Average value in cfs.

Table 9

CONCENTRATIONS OF WATER QUALITY CHARACTERISTICS AT STATION 8NM-65, EXIT FROM KALAMALKA LAKE

(values as mg/l ± one standard deviation)

	Overall	1972	1973	Range of Monthly Averages	
				Maximum	Minimum
Nitrate N	0.086 ± 0.053	0.086 ± 0.048	0.094 ± 0.058	0.197	0.025
TKN	0.245 ± 0.084	0.242 ± 0.084	0.294 ± 0.085	0.413	0.082
Total P	0.013 ± 0.010	0.014 ± 0.011	0.011 ± 0.005	0.044	0.003
Total soluble P	0.005 ± 0.002	0.005 ± 0.002	0.005 ± 0.002	0.012	0.003
Orthophosphate (P)	0.004 ± 0.002	0.004 ± 0.002	0.004 ± 0.002	0.010	0.001
Total calcium	35.8 ± 1.6	35.8 ± 1.1	35.9 ± 1.3	40.0	30.0
Total magnesium	17.0 ± 0.3	17.0 ± 0.3	17.0 ± 0.3		
pH	8.2 ± 0.3	8.4 ± 0.1	8.2 ± 0.4	8.5	7.4
Flow [1]		57.0	24.7	179.1	1.8

1 Average value in cfs.

Table 10

CONCENTRATIONS OF WATER QUALITY CHARACTERISTICS AT STATION 8NM-160,
JUST ABOVE OKANAGAN LAKE

(values as mg/l ± one standard deviation)

	Overall	1972	1973	Range of Monthly Averages	
				Maximum	Minimum
Nitrate N	0.536 ± 0.398	0.506 ± 0.433	0.678 ± 0.457	1.625	0.117
TKN	0.916 ± 0.523	0.910 ± 0.563	1.087 ± 0.579	2.290	0.037
Total P	0.394 ± 0.228	0.384 ± 0.245	0.463 ± 0.238	0.789	0.113
Total soluble P	0.328 ± 0.224	0.313 ± 0.256	0.393 ± 0.243	0.737	0.053
Orthophosphate (P)	0.290 ± 0.212	0.274 ± 0.229	0.346 ± 0.230	0.652	0.050
Total calcium	48.3 ± 7.9	47.3 ± 7.8	50.4 ± 7.2	59	38
Total magnesium	19.8 ± 1.4	19.1 ± 1.8	19.9 ± 1.3		
pH	8.1 ± 0.2	8.1 ± 0.2	8.0 ± 0.2	8.4	7.4
Flow [1]		89.9			

1 Average value in cfs.

Chlorophyll a and phaeophytin a mean monthly values are plotted in Figure 3.

Results from Station 8NM-160 are more complex. Data reported in Table 10 illustrate the massive accumulation of nitrate, TKN and soluble phosphorus that occurs as Vernon Creek passes from Kalamalka to Okanagan Lake. These results are not described further here because no data were obtained in this study on the input of nutrients to Vernon Creek in this region nor on water quality of tributary creeks such as BX Creek. Loading values are provided later and discussed in terms of the net input to Okanagan Lake from the Kalamalka-Wood Lake basin.

b. Quantities of Selected Nutrients in Surface Waters

i. Swalwell Lake to Ellison Lake

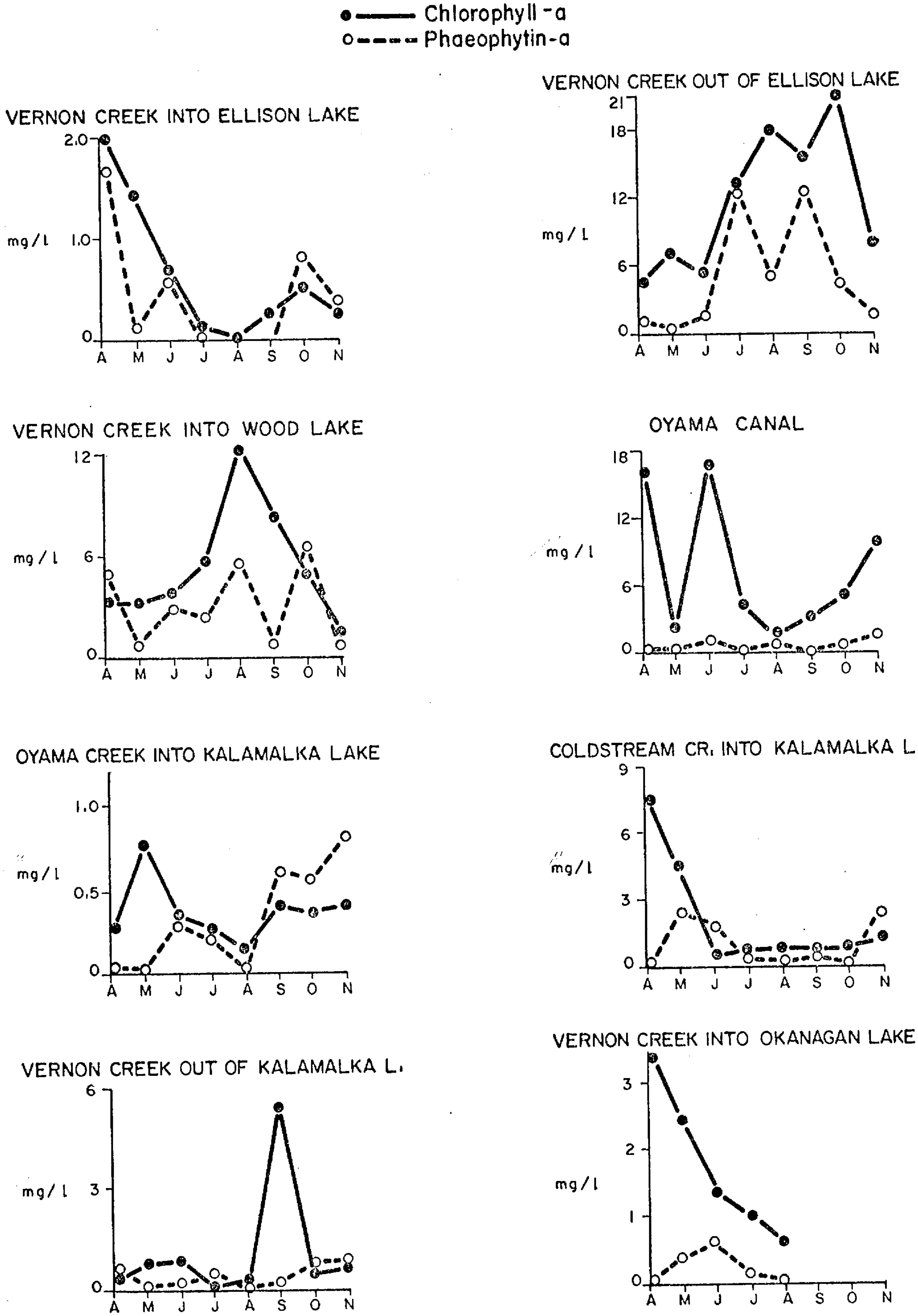
The ratio of flow for the 1972 and 1973 freshet years at Station 8NM-162 above Ellison Lake was 2.2. Results reported in Table 11 show the loadings (lb/yr) to Ellison Lake of nitrogen, phosphorus, organic carbon, calcium, magnesium and suspended solids, together with the ratio of loadings for each constituent between 1972 and 1973 freshet years. TKN loading was 30,660 lb for freshet year 1972, which was 4.5 times higher than the 6,760 lb transported into the lake during 1973. The ratio of nitrate loadings was slightly less than the flow ratio in the two years, with values of 5,040 lb for 1972 and 2,970 lb for 1973.

The massive input of suspended matter during the spring runoff of 1972 resulted in a 20.6-fold difference in the total phosphorus loading to Ellison Lake compared with freshet year 1973; the 1972 value was 15,260 lb compared with only 740 lb during 1973. Much of this was particulate phosphorus during spring runoff. Soluble phosphorus and orthophosphate were 3.4 and 4.5 times higher in the 1972 freshet year than in the 1973 freshet year mainly because of their elevated concentrations during the high water flow period in May and early June, 1972. Approximately 80% of the soluble phosphorus was present in the form of orthophosphate during 1973, and all of the measured total soluble phosphorus was present as orthophosphate in 1972. Organic carbon was 4.3 times higher in 1972 than in 1973, with respective loadings of 661,400 lb and 153,400 lb.

Suspended solids loadings were 16 times higher in 1972. Calcium and magnesium loadings were higher in 1972 than in 1973 but the ratio of these constituents was only 1.4 in each case.

Figure 3

MEAN MONTHLY CONCENTRATIONS OF CHLOROPHYLL-a AND PHAEOPHYTIN-a FOR 1972



ii. Ellison Lake to Wood Lake

Table 12 shows the loadings for nutrients in water leaving Ellison Lake measured at Station 8NM-182. Flows during the 1972 freshet year were 21.6 cfs, 3 times higher than in 1973. The 1972:1973 ratios of loadings of nitrogen, phosphorus, carbon, calcium and suspended solids were not widely different from the ratio of flows in the two years. Nitrate and soluble phosphorus loading ratios were very close to the ratio of average daily flows; calcium and magnesium were slightly lower in ratio. Organic carbon had the highest loading ratio, being 4.5 times greater in the 1972 freshet year.

Results in Table 13 refer to the input of nutrients to Wood Lake measured at Station 8NM-9, at the lower end of Middle Vernon Creek, and at Station 8NM-181, on Winfield Creek. As expected for a stream that originates from groundwater, the flow and chemical composition of Winfield Creek was very similar in both years, apart from slightly higher soluble and particulate phosphorus loadings in the 1972 freshet year. The ratio of average daily flows of Vernon Creek in 1972 and 1973 was 2.4. Loadings ratios of nitrate and soluble phosphorus were 1.3 and 1.7 respectively. TKN was 2.5 higher in 1972 (24,720 lb) than in the 1973 freshet year (9,950 lb). Particulate phosphorus was 5.6 times higher in 1972; much of this phosphorus was carried in the high suspended solids loading during spring runoff. The suspended solids ratio was 6.9 for the two freshet years.

The quantities of nutrients change along Middle Vernon Creek between Ellison and Wood Lakes. Results in Table 14 show that the accumulations of total nitrogen, calcium and magnesium and soluble phosphorus are relatively independent of flow. Nitrate loadings increased by 6,770 lb during 1972 freshet year and by 7,080 lb during 1973. There was a general reduction of TKN in both years, 2,500 lb being lost in 1972, possibly by settlement of particulate material, and 1,440 lb in 1973. Soluble phosphorus accumulation was remarkably consistent along Middle Vernon Creek in the two freshet years; 480 lb of soluble phosphorus were picked up between Ellison and Wood Lakes in 1972 and 470 lb in 1973, while 590 lb orthophosphate accumulated during 1972 and 410 lb in 1973. Changes in the quantity of particulate phosphorus transferred along the creek fell from 2,720 lb in 1972 to 30 lb in 1973.

Suspended solids increased by 876,000 lb along Middle Vernon Creek in 1972, a high runoff year. However, in 1973 with below-average runoff, 49,800 lb settled out in the same stretch of creek. There was a greater accumulation of organic carbon during 1973 than in 1972 with values of 69,400 lb and 38,900 lb respectively.

Calcium and magnesium increased independently of water flow; in each year approximately 200,000 lb of calcium and 100,000 lb of magnesium, in addition to amounts leaving Ellison Lake, were transported to Wood Lake through Middle Vernon Creek.

iii. Oyama Canal Between Wood and Kalamalka Lake

Loadings of nitrogen, phosphorus, carbon, suspended solids, magnesium and calcium from Wood Lake to Kalamalka Lake are given in Table 15. The calculated ratio of flows in 1972 and 1973 freshet years was 2.7.

Considerable quantities of nutrients were transferred through the Oyama Canal. The ratios of nitrate and TKN loadings in 1972 and 1973 freshet years were 2.3 and 2.6, similar to the flow ratio. The nitrate loading was 3,470 lb in 1972 and 1,530 lb in 1973. For TKN, the values were 25,200 lb during 1972 and 9,570 lb in 1973.

Soluble phosphorus, suspended solids and organic carbon ratios in the two years were greater than the ratio of annual mean flows. Total phosphorus loading averaged 2,465 lb/year, the value of 3,420 lb in 1972 being 2.3 times higher than the 1973 loading. The average quantity of soluble phosphorus transferred to Kalamalka Lake through the Oyama Canal was 690 lb/yr and consisted almost entirely of orthophosphate.

Suspended solids loadings were low compared with inputs to Ellison and Wood Lakes. The figures for freshet years 1972 and 1973 were 332,000 lb and 82,000 lb respectively. Organic carbon was transferred at a rate of 500,700 lb/year in 1972 and 133,600 lb/year in 1973.

Ratios of calcium and magnesium loadings in the two years corresponded closely to flow ratios . During the 1972 freshet year 1,172,500 lb of calcium and 814,000 lb of magnesium passed through the canal into Kalamalka Lake.

iv. Oyama Lake to Kalamalka Lake

Nutrient input to Kalamalka Lake from Oyama Creek was measured only in freshet year 1972. The results are reported in Table 16. Compared with the Oyama Canal, Oyama Creek contributed approximatley one-fifth as much orthophosphate and one-third as much nitrogen to Kalamalka Lake in 1972.

v. Input to Kalamalka Lake from Coldstream Creek

Results in Table 17 show nutrient loadings to Kalamalka Lake from Coldstream Creek. The flow ratio of Coldstream Creek in freshet years 1972 and 1973 was 2.4 individual values being 34.8 and 14.5 cfs.

The dominant feature of nutrient input from Coldstream Creek was the extremely high level of nitrate. The values for 1972 and 1973 freshet years were 68,380 lb and 32,210 lb, respectively. (Table 17). The loadings ratios of suspended solids and all forms of phosphorus from Coldstream Creek to Kalamalka Lake in freshet years 1972 and 1973 were lower than the loading ratios from Vernon Creek into Ellison Lake (cf.Table 11). The particulate phosphorus loading from Coldstream Creek in freshet year 1972 was 16,650 lb compared with the 1973 value of 1,190 lb; suspended solids differed by a factor of 15.5 and TKN by a factor of 4.4 in the two years.

vi. Kalamalka to Okanagan Lake

Results in Table 18 show the quantities of nutrients and suspended solids leaving Kalamalka Lake along Vernon Creek as measured at Station 8NM-65. The flows were 57.0 and 24.2 cfs in freshet years 1972 and 1973. Except for particulate phosphorus, the ratios of individual nutrients and solids transported from Kalamalka Lake were similar to the flow ratios in the two years. The quantities of particulate phosphorus leaving Kalamalka Lake were low; 1,600 lb in freshet year 1972 and 230 lb in freshet year 1973.

Data were available only in freshet year 1972 for the quantities of nutrients entering Okanagan Lake from Vernon Creek measured at Station 8NM-160. The results, shown in Table 19, are discussed later in the report in relation to findings of the Okanagan Basin Agreement study. No information was obtained in the present investigation on water entering Vernon Creek between the exit from Kalamalka Lake and subsequent entry to Okanagan Lake. Nutrient loadings are characterised by massive inputs of total nitrogen, which in 1972 reached 168,400 lb and large inputs of soluble phosphorus (28,690 lb) and particulate phosphorus (15,390 lb)

c. Total Nutrient Loadings to Ellison, Wood and Kalamalka Lakes

Estimates of the trophic condition of lakes were obtained by investigators in the Okanagan Basin Agreement study using procedures developed by Vollenweider (1970), i.e. nutrient loading per unit surface area with reference to water depth and residence time. In the present study, annual inputs were calculated for total nitrogen and for total and soluble phosphorus in Ellison, Wood and Kalamalka

Table 11

INPUT OF SELECTED NUTRIENTS INTO ELLISON LAKE (STN. 8NM-162)

(loadings in lb/year)

	1972 FRESHET YEAR (April 1972-March 1973 inc)	1973 FRESHET YEAR (Aug.1972-July 1973 inc)	RATIO (1972:1973)
Nitrate, nitrite N	5,040	2,970	1.7
TKN	30,660	6,760	4.5
Total nitrogen [1]	35,700	9,730	3.7
Total soluble P	1,200	350	3.4
Orthophosphate (P)	1,210	270	4.5
Total P	15,260	740	20.6
Particulate P [2]	14,060	390	36.1
Suspended solids	2,195,000	136,700	16.1
Organic carbon	661,400	153,400	4.3
Total calcium	713,400	520,200	1.4
Total magnesium	238,700	164,900	1.4
Flow (average cfs)	23.0	10.6	2.2

1 by addition

2 by subtraction

Table 12

OUTFLOW OF SELECTED NUTRIENTS FROM ELLISON LAKE (STN. 8NM-182)

(loading in lb/yr)

	1972 FRESHET YEAR (Apr.1972-March 1973 inc)	1973 FRESHET YEAR (Aug.1972-July 1973 inc)	RATIO (1972:1973)
Nitrate, nitrite N	3,980	1,330	3.0
TKN	27,220	11,390	2.4
Total nitrogen [1]	31,200	12,720	2.5
Total soluble P	750	260	2.9
Orthophosphate (P)	500	130	3.8
Total P	4,870	1,480	3.3
Particulate P [2]	4,120	1,220	3.4
Suspended solids	1,265,000	358,500	3.5
Organic carbon	604,800	135,700	4.5
Total calcium	579,800	240,200	2.4
Total magnesium	199,500	81,500	2.4
Flow (average cfs)	21.6	7.1	3.0

1 by addition

2 by subtraction

Table 13

INPUT OF SELECTED NUTRIENTS TO WOOD LAKE - MEASURED AT STATION 8NM-9 (VERNON CREEK) AND 8NM-181 (WINFIELD CREEK)

(loadings in lb/year)

	1972 FRESHET YEAR (April 1972-March 1973 inc)			1973 FRESHET YEAR (August 1972-July 1973 inc)			RATIO 1972:1973		
	Vernon Creek	Winfield Creek	Total	Vernon Creek	Winfield Creek	Total	Vernon Creek	Winfield Creek	Combined Input
Nitrate, nitrite N	10,750	5,950	16,700	8,410	6,000	14,410	1.3	1.0	1.2
TKN	24,720	1,850	26,570	9,950	1,800	11,750	2.5	1.0	2.3
Total nitrogen [1]	35,470	7,800	43,270	18,360	7,800	26,160	1.9	1.0	1.7
Total soluble P	1,230	135	1,365	730	95	825	1.7	1.4	1.7
Orthophosphate (P)	1,090	105	1,195	540	60	600	2.0	1.8	2.0
Total P	8,170	345	8,515	1,980	250	2,230	4.1	1.3	3.8
Particulate P [2]	6,940	210	7,150	1,250	160	1,410	5.6	1.3	5.1
Suspended solids	2,141,000	62,000	2,203,000	308,700	56,500	365,200	6.9	1.1	6.0
Organic carbon	653,700	28,500	682,200	205,100	29,500	234,600	3.2	1.0	2.9
Total calcium	790,200	267,500	1,057,700	441,400	271,500	712,900	1.8	1.0	1.5
Total magnesium	299,400	75,500	374,900	177,000	77,000	254,000	1.7	1.0	1.5
Flow (average cfs)	22.7	2.4	25.1	9.3	2.5	11.8	2.4	1.0	2.1

1 by addition

2 by subtraction

Table 14

ACCUMULATION OF NUTRIENTS IN VERNON CREEK (ONLY) BETWEEN ELLISON LAKE AND WOOD LAKE

(lb/year)

	1972 FRESHET YEAR (April 1972-March 1973 inc)	1973 FRESHET YEAR (Aug.1972-July 1973 inc)
Nitrate, and nitrite nitrogen	6,770	7,080
TKN	-2,500	-1,440
Total nitrogen [1]	4,270	5,640
Total soluble P	480	470
Orthophosphate (P)	590	410
Total P	3,300	500
Particulate P [2]	2,720	30
Suspended solids	876,000	-49,800
Organic carbon	38,900	69,400
Total calcium	210,400	201,200
Total magnesium	99,900	95,500
Flow (average cfs)	1.1	2.2
(average % change in flow)	5.1	30.1

1 by addition

2 by subtraction

Table 15

INPUT OF SELECTED NUTRIENTS TO KALAMALKA LAKE FROM WOOD LAKE AS SURFACE WATER THROUGH THE OYAMA CANAL (STATION 8NM-66)

(loadings as lb/year)

	1972 FRESHET YEAR (April1972-March1973)	1973 FRESHET YEAR (August 1972-July 1973)	RATIO 1972:1973
Nitrate, nitrite N	3,470	1,530	2.3
TKN	25,200	9,570	2.6
Total nitrogen [1]	28,500	11,000	2.6
Total soluble P	1,130	295	3.8
Orthophosphate (P)	1,140	245	4.7
Total P	3,420	1,510	2.3
Particulate P [2]	1,150	970	1.2
Suspended solids	332,000	82,000	4.1
Organic carbon	500,750	133,600	3.7
Total calcium	1,172,500	402,500	2.9
Total magnesium	814,000	294,000	2.8
Flow (average cfs)	23.5	8.6	2.7

1 By addition

2 By difference

Table 16

CONCENTRATION AND LOADINGS OF WATER QUALITY CHARACTERISTICS IN OYAMA CREEK ENTERING KALAMALKA LAKE (STATION 8NM-48)

Samples collected April 1972 - February 1973 inclusive

	CONCENTRATIONS (mg/l)			LOADING (lb/yr)
	Mean	Maximum	Minimum	
Nitrate, nitrite N	0.149 ± 0.080	0.271	0.052	2,800
TKN	0.295 ± 0.080	0.410	0.130	6,800
Total nitrogen [1]				9,600
Total P	0.024 ± 0.014	0.048	0.003	700
Total soluble P	0.013 ± 0.010	0.038	0.003	350
Orthophosphate (P)	0.009 ± 0.008	0.030	0.003	200
Particulate P [2]				350
Total calcium	6.57 ± 2.9	15.0	4.75	125,000
Total magnesium	2.38 ± 1.2	6.0	1.75	43,000
Suspended solids				233,000
Organic carbon				300,000
pH	7.5 ± 0.3	8.0	7.0	
Flow (average cfs)	12.8	52.4	1.4	

1 by addition

2 by difference

Table 17

LOADINGS OF SELECTED NUTRIENTS TO KALAMALKA LAKE - MEASURED
AT STATION 8NM-179 AT LOWER END OF COLDSTREAM CREEK

(loadings in lb/year)

	1972 FRESHET YEAR (Apr.1972-March 1973 inc)	1973 FRESEHT YEAR (Aug.1972-July 1973 inc)	RATIO (1972:1973)
Nitrate, nitrite N	68,380	32,210	2.1
TKN	48,400	10,960	4.4
Total nitrogen [1]	116,780	43,170	2.7
Total soluble P	1,810	820	2.2
Orthophosphate (P)	2,670	650	4.1
Total P	18,650	2,010	9.2
Particulate P [2]	16,650	1,190	14.0
Suspended solids	8,238,000	533,000	15.5
Organic carbon	704,200	177,400	4.0
Total calcium	3,533,000	1,497,000	2.4
Total magnesium	900,500	477,100	1.9
Flow (average cfs)	34.8	14.5	2.4

1 by addition

2 by subtraction

Table 18

OUTFLOW OF SELECTED NUTRIENTS FROM KALAMALKA LAKE (STATION 8NM-65)

(loadings in lb/year)

	1972 FRESHET YEAR (April 1972-March 1973 inc)	1973 FRESHET YEAR (Aug.1972-July 1973 inc)	RATIO 1972:1973
Nitrite, nitrate N	6,810	3,190	2.1
TKN	26,290	12,690	2.1
Total nitrogen [1]	33,100	15,880	2.1
Total soluble P	610	260	2.3
Orthophosphate (P)	460	200	2.3
Total P	2,210	490	4.5
Particulate P [2]	1,600	230	7.0
Suspended solids	424,000	126,000	3.4
Organic carbon	725,800	250,400	2.9
Total calcium	4,094,000	1,709,000	2.4
Total magnesium	1,918,000	814,200	2.4
Flow (average cfs)	57.0	24.2	2.4

1 by addition

2 by subtraction

Table 19

INPUT OF SELECTED NUTRIENTS INTO OKANAGAN LAKE FROM VERNON CREEK (STATION 8NM-160)

(loadings in lb/year)

	1972 FRESHET YEAR (April 1972 - March 1973 inc.)
Nitrite, nitrate N	57,500
TKN	110,900
Total nitrogen [1]	168,400
Total soluble P	28,690
Orthophosphate (P)	27,960
Total P	44,080
Particulate P [2]	15,390
Suspended solids	3,998,000
Organic carbon	1,657,000
Total calcium	7,565,000
Total magnesium	3,165,000
Flow (average cfs)	90.2

1 by addition

2 by subtraction

Lakes. Annual input in lb/year (kg/year) and area loadings in $g/m^2/yr$ were calculated as the sum of surface water input together with direct surface drainage, dustfall and direct groundwater inflow.

The theoretical time for complete water replacement in each lake was calculated by dividing the lake volume by the water outflow. The results for 1972, 1973 and mean values are reported in Table 20. For Ellison Lake the calculated residence time was 1.4 yr compared with 14 yr for Wood Lake and 42 yr for Kalamalka Lake. These values are in close agreement with the data published in the final report for the Okanagan Basin Agreement study (see Table 20). Differences between the two studies in estimating the influence of nutrient addition on the trophic conditions of lakes are therefore due to differences in nutrient loading measurements rather than to differences in water flows.

Assuming a steady 5 cfs input of distillery cooling water, it is possible to recalculate theoretical replacement times for water in the lakes in the absence of the distillery. Residence times would be increased to 48 yr for Kalamalka Lake, 18 yr for Wood Lake and 2.1 yr for Ellison Lake.

i. Nutrient Loadings to Ellison Lake

Results in Table 21 show the nutrient loadings to Ellison Lake for 1972 and 1973, together with mean values and area loadings. Mean annual loading of nitrogen was 26,340 lb (12,000 kg) of which 84% originated from surface flow via Vernon Creek. The nitrogen input in the 1972 freshet year was 39,360 lb and in 1973 the input was 13,390 lb. Area loadings of nitrogen were high; 8.58 g/m^2 in 1972, and 2.92 g/m^2 in 1973, giving a mean of 5.75 $g/m^2/yr$.

High phosphorus loads averaging 1.81 $g/m^2/yr$. More than 90% originated from Vernon Creek. The mean input of total phosphorus was 8,290 lb/year (3770 kg). An average load of 770 lb (350 kg) for soluble phosphorus entering Ellison Lake from Vernon Creek together with that proportion of the dustfall and direct drainage phosphorus loading present as soluble phosphorus.

ii. Nutrient Loadings to Wood Lake

Nutrient loadings to Wood Lake are shown in Table 22. The input of nitrogen was 59,350 lb in freshet year 1972 and 43,200 lb in 1973, giving a mean value of 51,300 lb (23,300 kg). Mean loading was nearly twice the value calculated for 1969-71 during the Okanagan Basin Agreement study.

In contrast, the mean input of total phosphorus to Wood Lake measured in the present study was 5,830 lb (2,650 kg), compared

Table 20

ANNUAL OUTFLOW AND THEORETICAL WATER REPLACEMENT TIMES (YR)

	Annual Outflow ($10^6 m^3/yr$)			Residence Times (Years)			Residence Times From 1969-1971 Okanagan Basin Study (years)	Residence Times With Distillery Cooling Water Removed From the System
	1972	1973	Mean	1972	1973	Mean		
Kalamalka Lake	50.9	21.6	36.3	29.8	70.3	42.0	45.0	48.0
Wood Lake	21.0	7.7	14.3	9.5	26.0	14.0	14.0	18.0
Ellison Lake	19.3	6.3	12.8	0.9	2.8	1.4	-	2.1

Table 21

NUTRIENT LOADINGS TO ELLISON LAKE

Total Nitrogen

	1972		1973		Mean	
	lb/yr	%	lb/yr	%	lb/yr	%
Vernon Creek	35,700	91	9,730	73	22,720	84
Direct Drainage	2,805	7	2,805	21	2,805	
Dustfall	855	2	855	6	855	
Groundwater	-		-		-	
Total (lb/yr)	39,360		13,390		26,380	
Total (kg/yr)					(10,610)	
Area Loading ($g/m^2/yr$)	8.58		2.92		5.75	

Total Phosphorus

	1972 lb/yr	%	1973 lb/yr	%	Mean lb/yr	%
Vernon Creek	15,260	98	740	72		
Direct Drainage	240	2	240	23		
Dustfall	50	<1	50	5		
Groundwater	-	-	-	-		
Total (lb/yr)	15,550		1,050		8,290	
Total (kg/yr)					(3,770)	
Area Loading ($g/m^2/yr$)	3.39		0.23		1.81	

Soluble Phosphorus

	1972	1973	Mean
Total (lb/yr)	1,200	350	770
Total (kg/yr)			(350)
Area Loading ($g/m^2/yr$)	0.29	0.11	0.20

Table 22

NUTRIENT LOADINGS TO WOOD LAKE

Total Nitrogen

	1972		1973		Mean		Okanagan Basin Study
	lb/yr	%	lb/yr	%	lb/yr	%	
Vernon Creek	35,400	60	18,400	42	26,900		
Winfield Creek	7,800	13	7,800	18	7,800		
Oyama Canal	150		1,000	2	600		
Direct drainage } Dustfall	5,000	8	5,000	12	5,000		
Groundwater	11,000	19	11,000	26	11,000		
Total (lb/yr)	59,350		43,200		51,300		
Total (kg/yr)					(23,300)		(13,354)
Area Loading (g/m²/yr)	2.90		2.11		2.50		1.4

Total Phosphorus

	1972 lb/yr	%	1973 lb/yr	%	Mean lb/yr	%	Okanagan Basin Study
Vernon Creek	8,170	91	1,980	74	5,070	87	
Winfield Creek	350	4	250	9	300		
Oyama Canal	15	<1	35	1	25		
Direct Drainage } Dustfall	350	4	350	9	350		
Groundwater	85	1	85	3	85		
Total (lb/yr)	8,970		2,700		5,830		
Total (kg/yr)					(2,650)		(4,650)
Area Loading (g/m²/yr)	0.44		0.13		0.28		0.50

Soluble Phosphorus

	1972	1973	Mean	Okanagan Basin Study
Total (lb/yr)	1,650	1,105	1,380	
Total (kg/yr)			(625)	
Area Loading (g/m²/yr)[1]	0.08	0.05	0.06	

1 Only from surface water.

Table 23

NUTRIENT LOADINGS TO KALAMALKA LAKE

Total Nitrogen

	1972		1973		Mean		Okanagan Basin Study
	lb/yr	%	lb/yr	%	lb/yr	%	
Coldstream Creek	117,000	69	43,000	55	80,000	65	
Oyama Canal	28,500	17	11,000	14	19,750	16	
Oyama Creek	9,600	6	9,600	12	9,600	8	
Direct Drainage	820	1	820	1	820	1	
Dustfall	10,700	6	10,700	16	10,700	9	
Groundwater	2,800	2	2,800	4	2,800	2	
Total (lb/yr)	169,420		77,920		123,670		16,550
Total (kg/yr)					(56,110)		(7,511)
Area Loading (g/m²/yr)	2.96		1.36		2.16		(0.29)

Total Phosphorus

	1972		1973		Mean		Okanagan Basin Study
Coldstream Creek	18,700	79	2,010	39	10,350	72	
Oyama Canal	3,420	14	1,510	30	2,460	17	
Oyama Creek	660	3	660	13	660	5	
Direct Drainage	60		60		60		
Dustfall	640	3	640	13	640	4	
Groundwater	230	1	230	5	230	2	
Total (lb/yr)	23,710		5,110		14,400		5,770
Total (kg/yr)					(6,530)		(2,625)
Area Loading (g/m²/yr)	0.41		0.08		0.24		(0.10)

Soluble Phosphorus

	1972	1973	Mean	Okanagan Basin Study
Total (lb/yr)	3,280	1,460	2,370	
Total (kg/yr)			(1,080)	
Area Loading (g/m²/yr)	0.05	0.03	0.04	

with 4,650 kg reported by investigators in the Okanagan Basin Agreement study. Area loadings for total phosphorus averaged 0.28 $g/m^2/yr$ (0.4 g/m^2 in 1972 and 0.13 g/m^2 in 1973 compared with 0.50 $g/m^2/yr$ for 1969-71). By far the main source of phosphorus to Wood Lake was the surface flow from Vernon Creek, which contributed an average of 87% of the total phosphorus loading.

iii. Nutrient Loadings to Kalamalka Lake

Annual and mean loadings of total nitrogen and total and soluble phosphorus to Kalamalka Lake are shown in Table 23 for freshet years 1972 and 1973.

The mean loading of nitrogen was 123,670 lb/yr (56,110 kg/yr). This value was 7.5 times higher than the value of 7,511 kg/yr contained in the final report of the Okanagan Basin Agreement. However in Table 36 of Technical Report No. 4 from that study the total input of nitrogen into Kalamalka Lake in 1971 was estimated at 98,400 lb/year. In the present study, the area loading was calculated to be 2.16 g/m^2, markedly higher than the value of 0.29 $g/m^2/yr$ reported in the Okanagan Basin Agreement study.

Total phosphorus loads calculated in the two studies were in better agreement. The mean loading in this study was 14,400 lb/yr (6,530 kg/yr) and the corresponding value from the Okanagan Basin Agreement study was 2,625 kg/yr. Area loadings of phosphorus were similar; 0.24 $g/m^2/yr$ in this study compared with 0.10 $g/m^2/yr$ calculated by the Okanagan Basin investigators.

Between 81% and 92% of the nitrogen loading and 82% to 96% of the phosphorus loading to Kalamalka Lake originated as surface input from Coldstream Creek, Oyama Canal and Oyama Creek.

d. Input of Nutrients from the Hiram Walker Distillery

Cooling water discharged from the distillery is obtained from the hypolimnion in Okanagan Lake. Chemical composition of the cooling water is therefore relatively constant, as shown by the results in Table 24. The cooling water had a low nutrient content. Total phosphorus concentration was 0.021 ± 0.018 mg/l, of which 95% was present in the soluble form and 60% as orthophosphate. The TKN concentration was 0.205 ± 0.065 mg/l and the nitrate level 0.056 ± 0.023 mg N/l.

In general, the composition of cooling water from the distillery was comparable with Vernon Creek during low flow periods. The nitrate concentration was the only factor substantially lower in

Table 24

MEAN CONCENTRATIONS AND CALCULATED NUTRIENT LOADINGS FROM HIRAM WALKER OUTFALL

BASED ON AN AVERAGE FLOW OF 5 cfs (MARCH 1972 - NOVEMBER 1972)

	lb/year
Nitrate, nitrite N	550
TKN	2,020
Total nitrogen[1]	2,570
Total soluble P	190
Orthophosphate (P)	120
Total P	205
Particulate P[2]	15
Organic carbon	52,250
Flow (average cfs)	5.0

CONCENTRATIONS OF WATER QUALITY CHARACTERISTICS OF HIRAM WALKER OUTFALL

(mg/l ± one standard deviation)

	Mean	Range	
		Maximum	Minimum
Nitrate, nitrite N	.056 ± .023	.102	.025
TKN	.205 ± .065	.306	.094
Total P	.021 ± .018	.066	.009
Total soluble P	.019 ± .018	.057	.006
Orthophosphate (P)	.012 ± .015	.050	.003
Total calcium	32.9 ± .9	34.5	31.2
Total magnesium	8.4 ± .5	9.5	7.5
pH	8.2 ± .2	8.6	7.8

1 by addition

2 by subtraction

the cooling water outfall. Calcium concentration (32.9 ± 0.9 mg/1) and magnesium concentration (8.4 ± 0.5 mg/1) were somewhat higher in the cooling water than in Vernon Creek.

Also shown in Table 24 are the calculated annual loadings of nutrients entering the Kalamalka-Wood Lake Basin through the distillery outfall. The calculations are based upon 5 cfs average flow and mean concentrations measured in the period March to November 1972. This procedure was adopted because effluent samples were not taken on all occasions under conditions of normal plant operation. For some nutrients, input from the distillery cooling water was not insignificant, as shown by comparison of the results in Tables 24 and 25. Assuming that the chemical composition of the cooling water remains constant, in freshet year 1973, 1/4 of the total nitrogen and more than 50% of the soluble phosphorus entering Ellison Lake originated from the distillery. In freshet year 1972, the relative contribution from the outfall was substantially less and the corresponding values are 8% and 16%, respectively.

e. Nutrient Loadings Throughout the Kalamalka-Wood Lake Basin, Excluding the Distillery Outfall

An objective of the study was to estimate effects of the distillery discharge on water quality in the Kalamalka-Wood Lake Basin caused by hydraulic displacement of nutrient-rich water north through Ellison and Wood Lakes into Kalamalka Lake. Accordingly, nutrient loadings to Wood and Kalamalka Lakes were recalculated to exclude the 5 cfs cooling water. The assumption was made that the concentrations of nutrients are unchanged in surface water transferred to and from Wood Lake. The results are reported in Table 26 for Wood Lake and in Table 27 for Kalamalka Lake. Calculations for other major water constituents are in the data print-out for the investigation

The input of nitrogen to Wood Lake would theoretically be reduced by 15% (8,025 lb) if Hiram Walker cooling water was excluded from the Kalamalka-Wood Lake basin. A greater effect would occur in the case of total phosphorus with a 23% reduction, from 5,830 lb to 4,460 lb. There would also be a greater nutrient input to Wood Lake from Kalamalka Lake because of an increase in southward flow of water through the Oyama Canal. Increases in nutrient input by this route could reach 2,400 lb of nitrogen and 110 lb of phosphorus in a low-flow year such as 1973.

Eliminating the distillery cooling water would also affect the nutrient loading to Kalamalka Lake. The mean nitrogen loading would be reduced by 6,130 lb, i.e. 5% of the total nitrogen input. Total phosphorus would be reduced by 6%, since 800 lb less each year would be transferred through the Oyama Canal into Kalamalka Lake. When the data are considered in relation to the Oyama Canal only, the differences are much more pronounced. The 6,130 lb of

Table 25

CALCULATED INPUT OF SELECTED NUTRIENTS INTO ELLISON LAKE,
EXCLUDING HIRAM WALDER LOADING

(Loading in lb/year)

	1972 FRESHET YEAR (April 1972-March 1972 inc)	1973 FRESHET YEAR Aug.1972-July 1973 inc)	RATIO 1972:1973
Nitrate, nitrite N	4,490	2,420	1.9
TKN	28,650	4,740	6.0
Total nitrogen [1]	33,140	7,160	4.6
Total soluble P	1,010	160	6.3
Orthophosphate (P)	1,090	150	7.3
Total P	15,060	535	28.1
Particulate P [2]	14,050	375	37.5
Organic carbon	609,000	101,000	6.0
Flow (average cfs)	18.0	5.6	3.2

1 by addition

2 by subtraction

Table 26

NUTRIENT LOADINGS TO WOOD LAKE - DISTILLERY COOLING WATER REMOVED

Total Nitrogen

	1972		1973		Mean		Change *	
	lb/yr	%	lb/yr	%	lb/yr	%	lb/yr	%
Vernon Creek	27,660	53	8,490	24	18,075	41		
Winfield Creek	7,800	15	7,800	22	7,800	18		
Oyama Canal	400	<1	2,400	6	1,400	3		
Direct drainage	5,000		5,000		5,000			
Dustfall		30		45		36		
Groundwater	11,000		11,000		11,000			
Total (lb/yr)	51,860		34,690		43,275		-8,025	-15
Total (kg/yr)					(19,670)		(3,650)	
Area loading (g/m²/yr)					2.12			

Total Phosphorus

	1972		1973		Mean		Change *	
Vernon Creek	6,370	88	915	53	3,640	81		
Winfield Creek	345	4	250	14	300	6		
Oyama Canal	60	<1	110	6	85	1		
Direct drainage	350		350		350			
Dustfall		6		25		9		
Groundwater	85		85		85			
Total (lb/yr)	7,210		1,710		4,460		-1,370	-23
Total (kg/yr)					(2,025)		(620)	
Area loading (g/m²/yr)					0.21			

* Difference from existing conditions caused by removing 5 cfs flow.

Table 27

NUTRIENT LOADINGS TO KALAMALKA LAKE - DISTILLERY COOLING WATER REMOVED

Total Nitrogen

	1972		1973		Mean		Change *	
	lb/yr	%	lb/yr	%	lb/yr	%	lb/yr	%
Oyama Canal	22,370	18	4,870	7	13,620	14		
All other sources (see Table 23)	140,920		66,920		103,900			
Total (lb/yr)	163,300		71,800		117,600		-6,130	-5
Area loading ($g/m^2/yr$)	2.85		1.25		2.05			

Total Phosphorus

Oyama Canal	2,620	24	710	16	1,660	21		
All other sources (see Table 23)	20,300		3,600		12,000			
Total (lb/yr)	22,900		4,310		13,700		-800	-6
Area loading ($g/m^2/yr$)	0.40		0.08		0.24			

* Difference from existing conditions caused by removing 5 cfs flow.

Reduction in Loadings through Oyama Canal Only

Total Nitrogen: 6,130 lb/yr - 31%

Total Phosphorus: 800 lb/yr - 32%

nitrogen and 800 lb of phosphorus then represent a 31% and 32% reduction, respectively, in the quantities of these nutrients entering Kalamalka Lake through the Oyama Canal. As is discussed later, it may be that this nitrogen and phosphorus is in a form directly assimilable by phytoplankton in Kalamalka Lake and that an estimate of the effects of excluding the distillery discharge in terms of nutrient transfer would approach the 31 and 32% reduction described.

f. Retention of Nutrients in Ellison, Wood and Kalamalka Lakes

i. Ellison Lake

Ellison Lake has been thought of as a pollution sink. However, as shown by the results in Table 28, retention of total nitrogen and of total and soluble phosphorus varies depending upon water throughput. In a high-flow year such as 1972, 21% of the total nitrogen, 69% of the total phosphorus and 38% of the soluble phosphorus entering Vernon Creek were retained in the lake. In freshet year 1973, however, only 5% of the total nitrogen and 26% of the soluble phosphorus were retained. A net loss of total phosphorus from Ellison Lake to Middle Vernon Creek occurred in the low-flow year; equivalent to 44% of the sources.

ii. Wood Lake

There was a difference in the retention of total nitrogen and total and soluble phosphorus in Wood Lake between 1972 and 1973 freshet years, as shown by the data in Table 29. In 1972, 51% of the incoming total nitrogen and 62% of the total phosphorus were retained. Only 17% of incoming soluble phosphorus was retained in the lake. In 1973, 72% of the total nitrogen and 43% of the total phosphorus were retained, together with 63% of the soluble phosphorus.

iii. Kalamalka Lake

Retentions of total nitrogen, total phosphorus and total soluble phosphorus in Kalamalka Lake were fairly constant as shown in Table 30. In freshet years 1972 and 1973, there was a high retention of total nitrogen and total phosphorus, 80% and 79% of the total nitrogen and 91% and 90% of the total phosphorus were held within Kalamalka Lake in freshet years 1972 and 1973. Retentions of soluble phosphorus were 81% for 1972 and 1973.

Table 28

RETENTION OF SELECTED NUTRIENTS IN ELLISON LAKE FOR 1972 AND 1973 FRESHET YEARS

	1972 Freshet Year			1973 Freshet Year		
	Total N (lb/yr)	Total P (lb/yr)	Total Soluble P (lb/yr)	Total N (lb/yr)	Total P (lb/yr)	Total Soluble P (lb/yr)
Sources						
Vernon Creek	35,700	15,260	1,200	9,730	740	350
Direct Drainage	2,800	240		2,800	240	
Dustfall	860	50		860	50	
Groundwater	-	-	-	-	-	-
Total	39,360	15,550		13,390	1,030	
Losses						
Vernon Creek	31,200	4,870	750	12,720	1,480	260
Retention (lb/yr)	8,160	10,680	450	670	-450	
Retention (%)	21	69	[38][1]	5	-44	[26][1]

[1] No data available for direct drainage, dustfall, or groundwater.

Table 29

RETENTION OF SELECTED NUTRIENTS IN WOOD LAKE FOR 1972 AND 1973 FRESHET YEARS

	1972 Freshet Year			1973 Freshet Year		
	Total N (lb/yr)	Total P (lb/yr)	Total Soluble P (lb/yr)	Total N (lb/yr)	Total P (lb/yr)	Total Soluble P (lb/yr)
Sources						
Vernon Creek	35,500	8,170	1,230	18,400	1,980	730
Winfield Creek	7,800	350	135	7,800	250	95
Oyama Canal	150	10	10	1,000	30	20
Direct Drainage	1,200	120		1,200	120	
Dustfall	3,850	230		3,800	230	
Groundwater	11,000	90		11,000	90	
Total	58,500	9,020		43,200	2,700	
Losses						
Oyama Canal	28,800	3,400	1,140	12,100	1,550	310
Retention	29,700	6,620	230	31,100	1,150	535
% Retention	51	62	[17][1]	72	43	[63][1]

[1] No data available for direct drainage, dustfall or groundwater.

Table 30

RETENTION OF SELECTED NUTRIENTS IN KALAMALKA LAKE FOR 1972 AND 1973 FRESHET YEARS

	1972 Freshet Year			1973 Freshet Year		
	Total N (lb/yr)	Total P (lb/yr)	Total Soluble P (lb/yr)	Total N (lb/yr)	Total P (lb/yr)	Total Soluble P (lb/yr)
Sources						
Coldstream Creek	117,000	18,700	1,810	43,000	2,010	820
Oyama Canal	28,800	3,430	1,140	12,100	1,550	315
Oyama Creek	9,600	660	340	9,600	660	340
Direct Drainage	800	60		800	60	
Dustfall	10,700	640		10,700	640	
Groundwater	2,800	230		2,800	230	
Total	169,400	23,710	3,290	79,000	5,150	1,475
Losses						
Vernon Creek	33,100	2,210	610	15,900	490	260
Oyama Canal	150	15	15	1,000	30	20
Total	33,250	2,225	625	16,900	520	280
Retention	136,200	21,480	2,660	62,100	4,630	1,200
% Retention	80	91	[81][1]	79	90	[81][1]

[1] No data available for direct drainage, dustfall, or groundwater.

2. Lake Waters

a. Concentration of Nutrients in Ellison, Wood and Kalamalka Lake

i. Ellison Lake

There were no appreciable differences in the concentrations of nutrients between stations or at different depths on each sampling occasion in Ellison Lake. Wind mixing prevents stratification and there is no spring or fall overturn in the lake. Mean concentrations of nitrogen and phosphorus in April 1972 and 1973 are listed below to illustrate the consistency of the values prior to the onset of phytoplankton growth.

	1972		1973	
	Mean	Range	Mean	Range
Total phosphorus (mg/l)	0.063	0.061-0.066	0.066	0.056-0.078
Total soluble phosphorus (mg/l)	0.016	0.013-0.020	0.016	0.010-0.024
Orthophosphate P (mg/l)	0.002	0.001-0.004	0.003	0.003-0.003
TKN (mg/l)	0.332	0.297-0.370	0.416	0.384-0.485
Nitrate N (mg/l)	0.079	0.072-0.090	0.083	0.079-0.096

Figure 4 plots monthly concentrations of nitrogen and phosphorus for all stations and depths in Ellison Lake for the periods April - November 1972; January 1973 and March - May 1973

ii. Wood Lake

Mean concentrations of nitrogen and phosphorus at spring overturn in Wood Lake were very similar for 1972 and 1973 as shown in the table below. The range in these characteristics was large particularly for TKN in both years and for total phosphorus and nitrate in 1973. Highest values were recorded in the lower depths of the hypolimnion.

With the exception of nitrate, all the characteristics measured were higher in Wood Lake than in Ellison Lake. For phosphorus, minimum values in Wood Lake were higher than the mean values for Ellison

There were no consistent differences in concentrations of nitrogen or phosphorus between stations; data from all stations were pooled for each depth. Seasonally, the concentration of nutrients varied in a pattern associated with eutrophic dimictic

Figure 4

MEAN PHOSPHORUS AND NITROGEN CONCENTRATIONS IN ELLISON LAKE

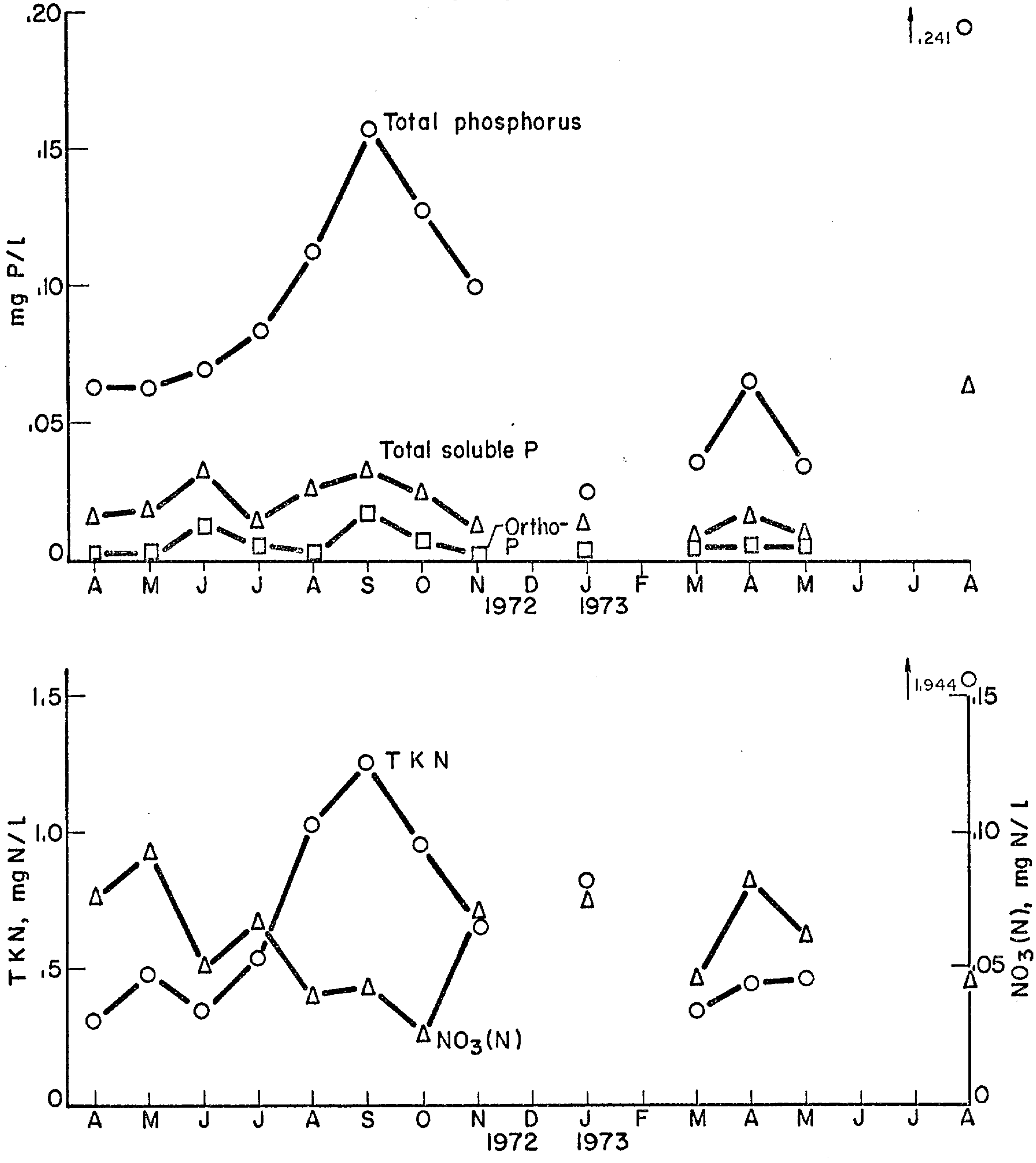


Figure 5

DEPTH PROFILES FOR TOTAL PHOSPHORUS AND TOTAL SOLUBLE PHOSPHORUS IN WOOD LAKE

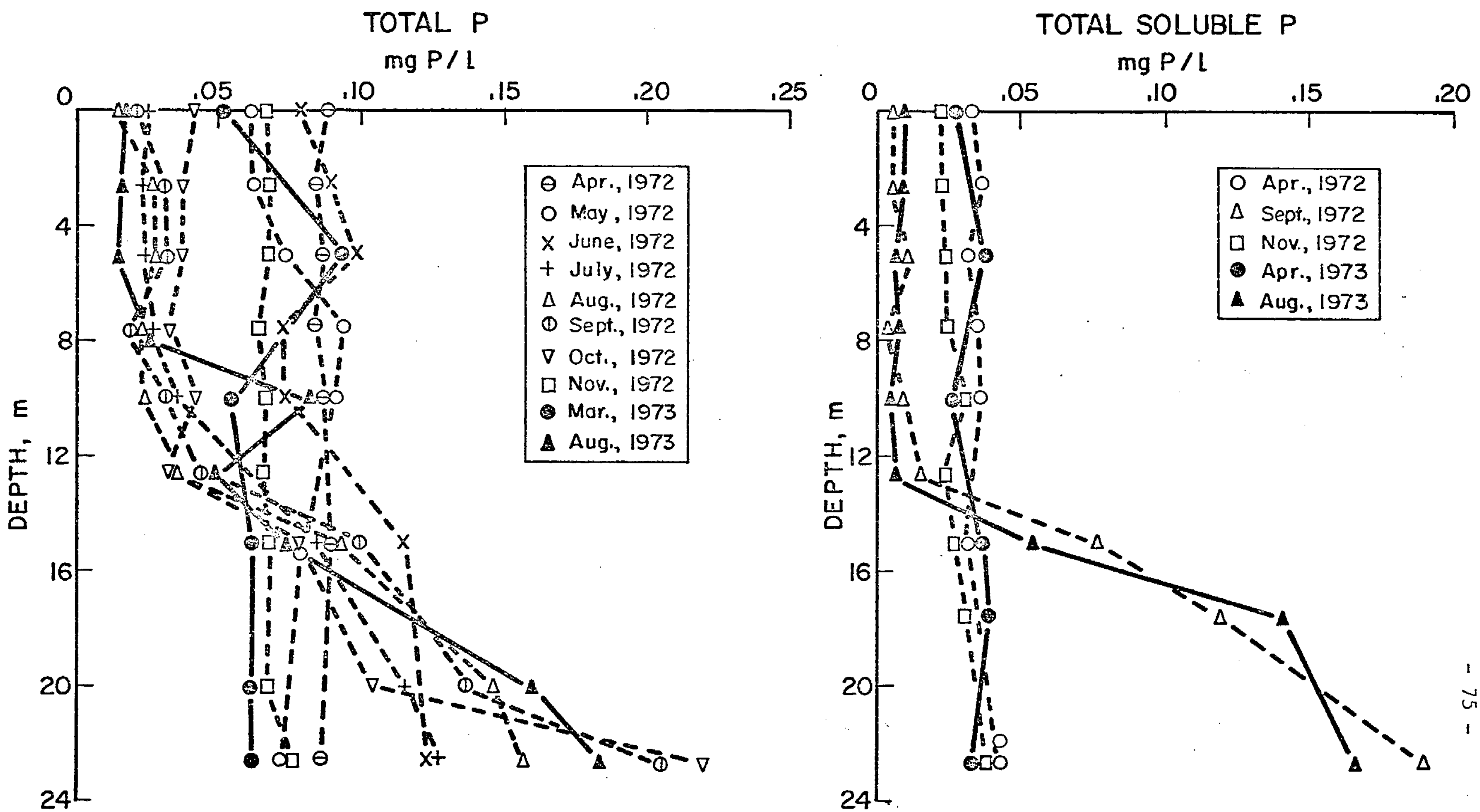
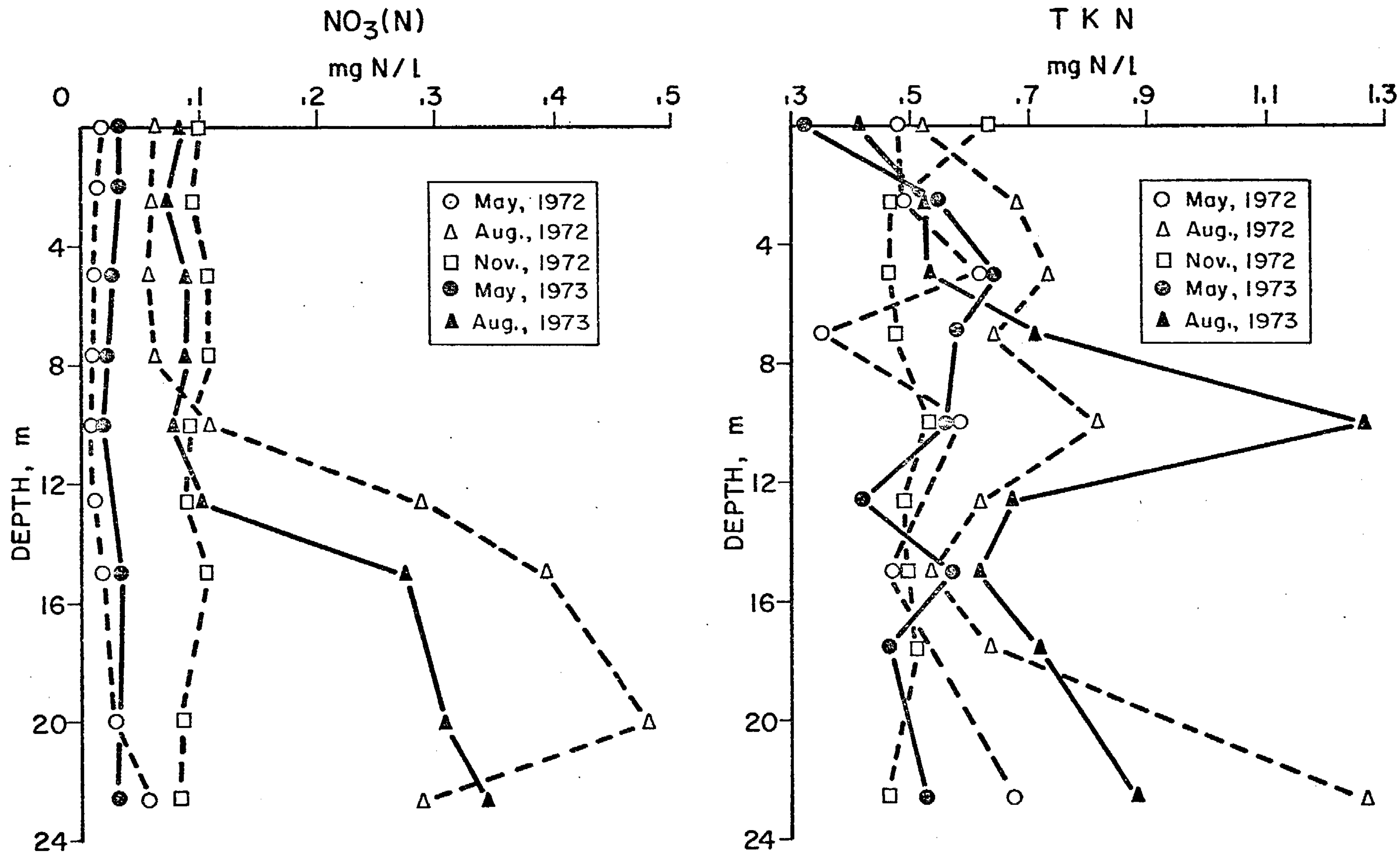


Figure 6
DEPTH PROFILES FOR NITRATE AND T K N IN WOOD LAKE



lakes as shown in Figures 5 and 6.

	1972		1973	
	Mean	Range	Mean	Range
Total Phosphorus (mg/l)	0.087	0.085-0.088	0.061	0.043-0.081
Total Soluble Phosphorus (mg/l)	0.034	0.030-0.042	0.032	0.025-0.034
Orthophosphate P (mg/l)	0.030	0.027-0.034	0.023	0.014-0.031
TKN (mg/l)	0.511	0.350-0.670	0.520	0.326-0.642
Nitrate N (mg/l)	0.027	0.022-0.030	0.026	0.014-0.057

Concentrations of total phosphorus (Figure 5) were relatively consistent at all depths during spring and fall periods. Throughout the summer period of vegetative growth, epilimnion concentrations were reduced but in the hypolimnion there was a progressive increase in total phosphorus concentration. Maximum increases in phosphorus concentration occurred at times of maximum oxygen reduction in the hypolimnion. A similar pattern of reduced concentration in the epilimnion and progressive increase in the hypolimnion also occurred for soluble phosphorus (Fig. 5) which made up the bulk of the total phosphorus load in the hypolimnion.

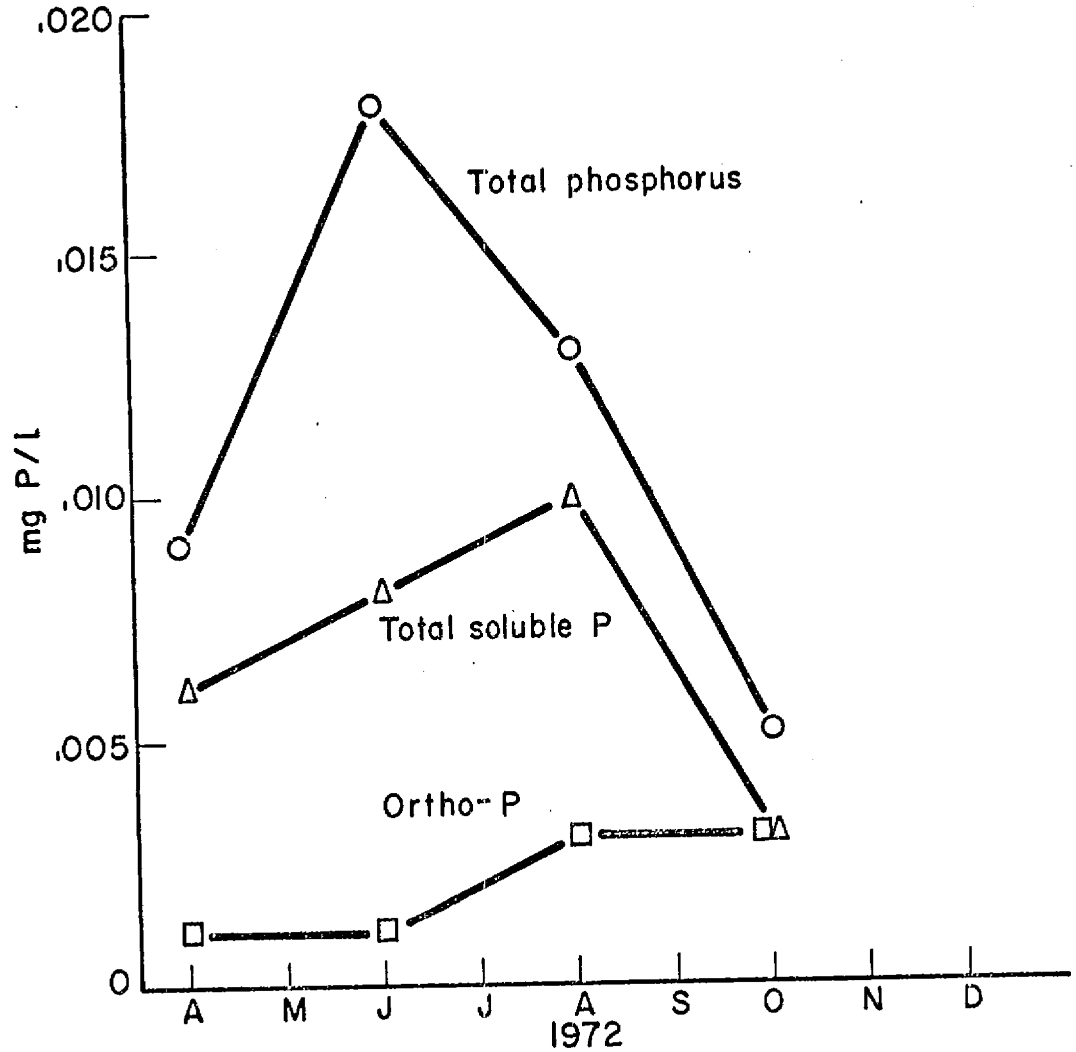
Nitrate concentrations followed a similar pattern to that described for phosphorus (Fig. 6). TKN concentrations were more variable as shown in Figure 6. A feature of the results is the increase in TKN that occurred in August 1973 at the thermocline level. As described earlier the lake at this time was strongly stratified; epiliminon transparency was high and the dissolved oxygen profile was of the positive heterograde type characterised by supersaturation at the thermocline as a result of algal photosynthesis. The high TKN concentrations result from this algal population. A similar peak was observed in Figure 5 for total phosphorus but not in Figure 5 for soluble phosphorus. Again, the peak in total phosphorus is attributed to algal biomass.

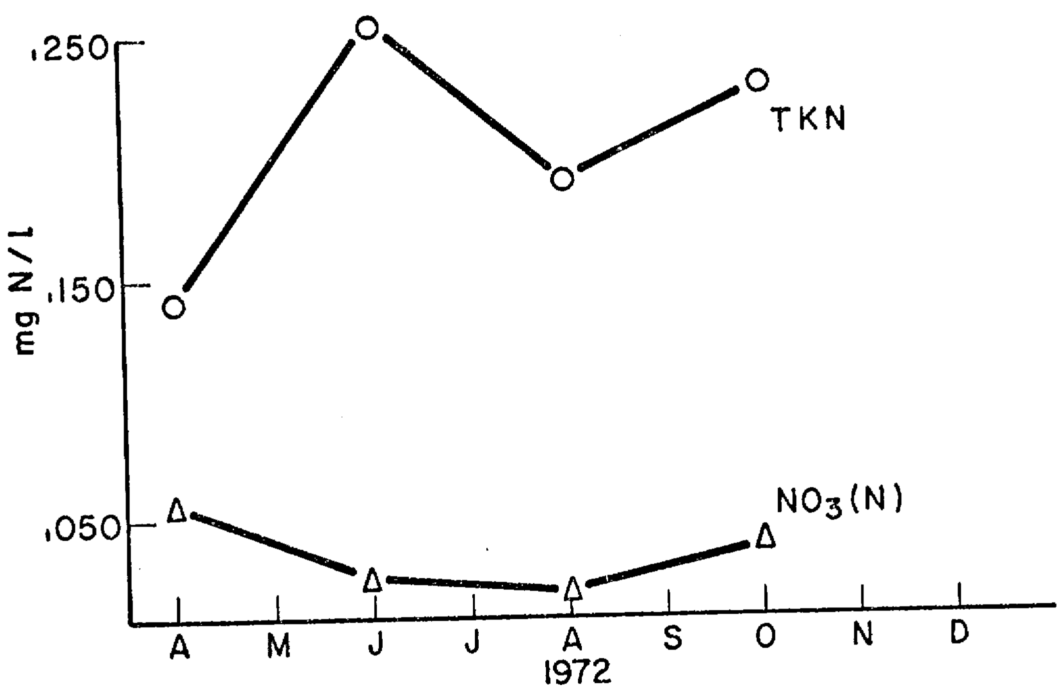
iii. Kalamalka Lake

There were no consistent differences of nutrient concentrations in Kalamalka Lake between stations or at different depths. The plots in Figure 7 illustrate pooled mean values for all stations and depths at the times the lake was sampled between April and November 1972. The concentrations of each characteristic

Figure 7

MEAN PHOSPHORUS AND NITROGEN CONCENTRATIONS IN KALAMALKA LAKE





changed very little throuhgout the year.

Mean concentrations and the range of values for nitrogen and phosphorus at spring overturn in 1972 are shown below.

	1972	
	Mean	Range
Total Phosphorus (mg/l)	0.009	0.008-0.011
Total Soluble Phosphorus (mg/l)	0.006	0.005-0.009
Orthophosphate P (mg/l)	0.001	-
TKN (mg/l)	0.138	0.110-0.205
Nitrate N (mg/l)	0.057	0.052-0.063

b. Limnology of Oyama and Swalwell Lakes

i. Oyama Lake

Water quality determinations were carried out in July, August and October 1972.

Persistent lake stratification occurred in summer and in July and August the thermocline was at 6 m depth. The maximum surface water temperature was 17.5C and the average epilimnion temperature was 16C in August. At this time the average hypolimnion temperature was 7.8C. Fall turnover occurred in October, and at the time of sampling, water temperatures ranged between 6C at the surface and 5.5C at depth.

During summer stratification dissolved oxygen concentrations varied with depth. In August the average epilimnion dissolved oxygen concentration was 6.7 mg/l (70% saturation). A more pronounced oxygen deficit occurred in the hypolimnion where the average dissolved oxygen concentration was 3.1 mg/l (30% saturation). At fall turnover the average dissolved oxygen concentration was 8.2 mg/l (65% saturation).

During summer stratification nitrogen and phosphorus values varied between the epilimnion and hypolimnion. Within the epilimnion the average TKN concentration was 0.303 mg N/l and in the hypolimnion 0.170 mg N/l. TKN concentrations increased to 0.340 mg N/l at fall turnover. In contrast to the vertical variation of TKN in the lake waters during the summer, average nitrate concentrations were 0.021 mg N/l in the epilimnion, increasing to 0.067 mg N/l in the hypolimnion. At fall turnover the average nitrate concentration was 0.070 mg N/l. Phosphate concentrations similarly differed between the epilimnion and hypolimnion. In August the average total phosphorus, total soluble phosphorus and orthophosphate concentrations were 0.020, 0.012 and 0.003 mg P/l and in the hypolimnion the same variables were at concentrations of 0.048, 0.030 and 0.017 mg P/l respectively. At fall turnover all phosphorus concentrations decreased; total phosphorus to 0.026 mg P/l, total soluble phosphorus to 0.013 mg P/l and orthophosphate to 0.003 mg P/l.

During the summer, other water quality variables changed only slightly with depth and time. In August turbidity values were low, 1-2 APHA units. Total suspended solids concentrations were also low and the highest value was 4.8 mg/l at fall turnover at 17.5 m depth. TOC concentrations were stable at about 9 mg/l. Free CO_2 and NH_3 did not increase significantly within the hypolimnion during summer stratification despite hypolimnetic oxygen reduction. However, at fall turnover free ammonia concentrations were elevated to 0.022 mg/l, but free CO_2 concentrations were similar to those recorded in August at 3 mg/l. Hypolimnetic water had a lowered pH (6.5) in August which increased to 6.9 at fall turnover. Alkalinity was 17 mg $CaCO_3$/l during the study period. Similarly, total magnesium, calcium and silicon remained constant at 1.5, 4 and <5 mg/l respectively.

Secchi disc recordings of water transparency were low and varied between 4.01 and 2.7 m August to October. The highest chlorophyll a concentrations, 1.7 mg/m^3 were recorded within 5 m of the lake surface in August. At fall turnover, chlorophyll a concentrations were lower overall and varied with depth. Phaeophytin a concentrations, as expected were low in summer and increased at fall turnover to 2.3 mg/m^3.

ii. Swalwell Lake

The lake stratified during the summer months. In June the epilimnion was shallow with the thermocline at 3 m depth. The epilimnion thickened in July, and the thermocline lowered to 6 m until August. The maximum surface water temperature 16C was recorded in August while the average temperatures of the epilimnion and hypolimnion were 15 and 6.6C respectively. In general, Swalwell lake temperatures were lower than those of Oyama Lake during summer stratification. Swalwell Lake waters were isothermal at 5C in October.

Dissolved oxygen concentrations varied with depth and time during summer stratification. In August the average dissolved oxygen in the epilimnion was 6.3 mg/l (65% saturation) and 3.8 mg/l (30% saturation) in the hypolimnion. Oxygen concentrations decreased within the hypolimnion between June and August, but at fall turnover dissolved oxygen levels were at 9.4 mg/l 75% saturation). Although this level of dissolved oxygen was low, surface water layers and those at 2.5 m depth had much higher dissolved oxygen levels at 11.5 mg/l (90% saturation). High chlorophyll a concentrations occurred in these upper water layers at fall turnover.

During summer stratification, between June and August, nitrate and orthophosphate concentrations in the hypolimnion varied only a little, but in the epilimnion nitrate concentrations decreased. Hypolimnion TKN concentrations decreased markedly between June and August but total phosphorus and total soluble phosphorus concentrations decreased only slightly. Similar trends in the variation in TKN, total phosphorus and total soluble phosphorus concentrations occurred within the epilimnion.

In August, the average epilimnion TKN and nitrate concentrations were 0.298 and 0.026 mg/l respectively. Total phosphorus, total soluble phosphorus and orthophosphate concentrations in the epilimnion in August were 0.019, 0.015 and 0.003 mg/l respectively, and 0.015, 0.012 and 0.005 mg/l in the hypolimnion. At fall turnover, the average concentrations of nitrate plus nitrite, total phosphorus, total soluble phosphorus and orthophosphate all decreased from the values recorded in August to 0.056, 0.008, 0.004 and 0.003 mg/l respectively. TKN concentrations increased overall to 0.337 mg/l.

Turbidity varied between 0.1 and 2 APHA units during summer stratification, the highest value being recorded in the thermocline in August. Total suspended solids were generally low, between 1 and 2 mg/l but in July and August TOC concentrations decreased from 12 to 6.5 mg/l but at fall turnover were at 15 mg/l. Alkalinity was stable at about 21 mg $CaCO_3$/l. Although pH levels were constant at 7.5 in epilimnion waters and throughout the water column at fall turnover, reduction in pH to 6.4 occurred in the hypolimnion in August. Associated with the changes in pH, free carbon dioxide increased in the hypolimnion to between 10.5 and 19.2 mg/l in August. Prior to August, and at turnover free carbon dioxide values were between 0.3 and 2.2 mg/l. In contrast free ammonia did not increase in the hypolimnion during summer stratification or at fall turnover and remained generally low at about 0.015 mg/l. Calcium, magnesium and silicon concentrations remained stable over the study period at 6, 1.5 and <5 mg/l respectively.

Secchi disc recordings ranged from a minimum of 2.5 m in August to 3.4 m in June compared with 4.0 m in Oyama Lake at this time. Chlorophyll a concentrations were higher in Swalwell Lake than in Oyama Lake. 3.0 mg/m^3 was the maximum value recorded in surface waters in October. During summer, chlorophyll _a_ concentrations ranged between 1.1 and 2.5 mg/m^3 within 5 m of the lake surface. Phaeophytin _a_ concentrations were only detectable at 0.3 mg/m^3 at 2.5 m in August. At fall turnover phaeophytin _a_ concentrations were between 0 and 2.1 mg/m^3.

c. Seasonal Changes in Thermal Structure of Lakes in the Kalamalka-Wood Lake Basin

Seasonal trends in temperature are influenced by lake morphometry. Table 31 illustrates differences between the structure of the major lakes within the Kalamalka-Wood Lake Basin.

i. Ellison Lake

Ellison Lake is thermally unstable; heating and cooling are greatly influenced by the wind. Average monthly temperatures are plotted for the period April 1972 to August 1973 in Figure 8. Although stratification occurred periodically throughout the summer, the lake became mixed by strong wind action at all times. Ice cover was well established by December 1972, and throughout the winter persistent inverse stratification occurred. This condition prevailed until March 1973 when the ice began to melt on Ellison Lake. Periodically, there was a variation in the water temperature at the south and north end of the lake. During the freshets of 1972 and 1973 water at the north end of Ellison Lake was cooler than at the south. This situation reversed on occasions during the summer when northerly winds cooled the southern region of Ellison Lake.

ii. Wood Lake

Persistent summer stratification occurs in Wood Lake. Seasonal temperature data are plotted in Figure 9 for Station 2 in the lake; temperatures at this station were generally intermediate between those of Station 1 and Station 4 at the south and north end of Wood Lake, respectively.

During spring of 1972 the lake was not stratified and temperatures ranged between 4.9 C at the surface to 4.1 C at depth. After April, heating was rapid and lake stratification developed. By June, thermal stratification was apparent and the epilimnion extended from the surface to approximately 7.5 m depth. Weather conditions during June 1972 caused a reduction of surface temperatures from 20 C at the beginning of the month to 18.5 C at the beginning of July. Subsequently, water temperatures increased and by August maximum temperatures between 22 C and 23°C were recorded in surface waters. In general, warmer waters were found at the southern end of Wood Lake during the spring, but during the summer, northerly winds tended to decrease the

Figure 8

SEASONAL CHANGES IN THE THERMAL STRUCTURE OF ELLISON LAKE

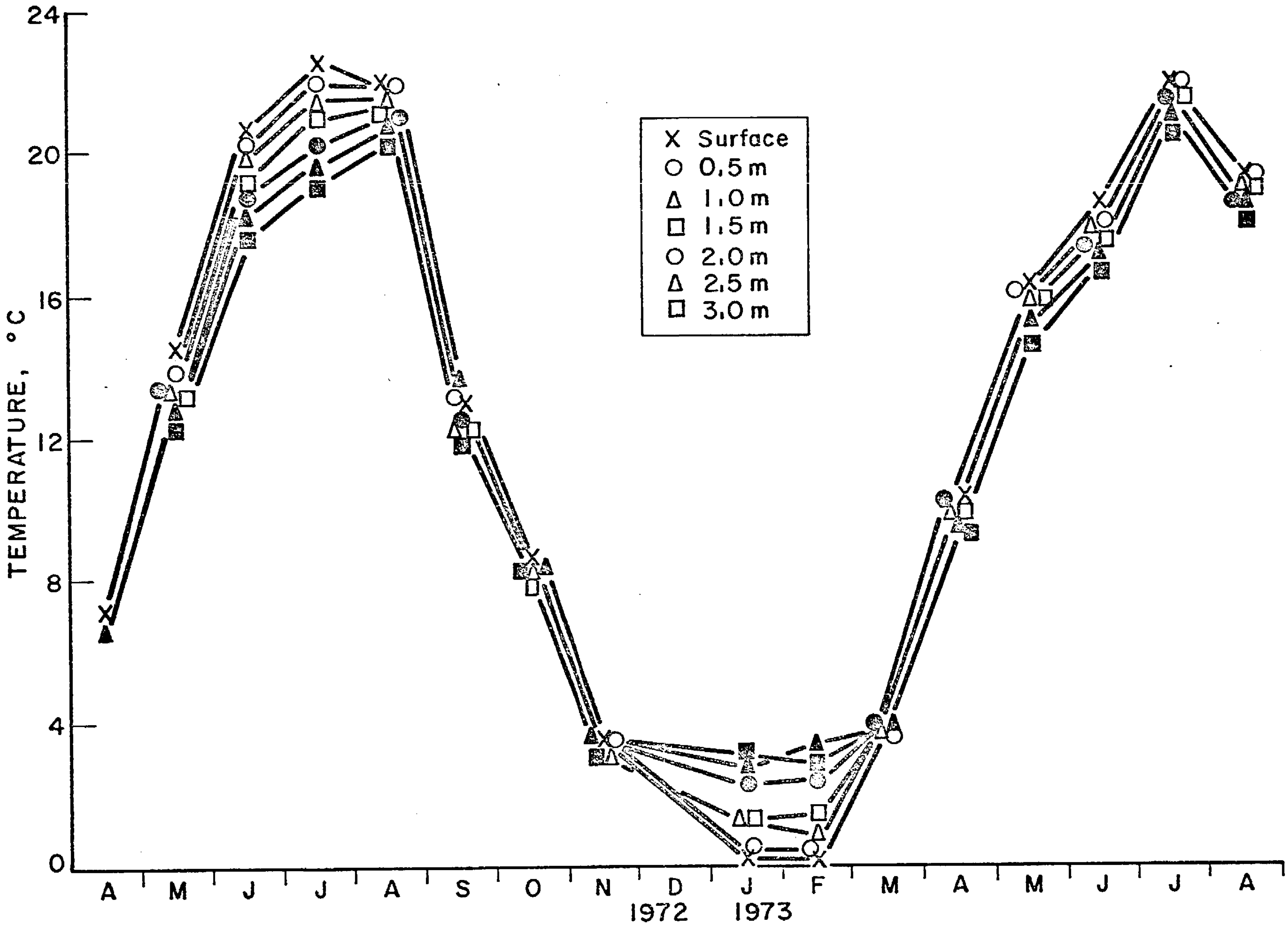


Figure 9

SEASONAL CHANGES IN THE THERMAL STRUCTURE OF WOOD LAKE SITE No. 2

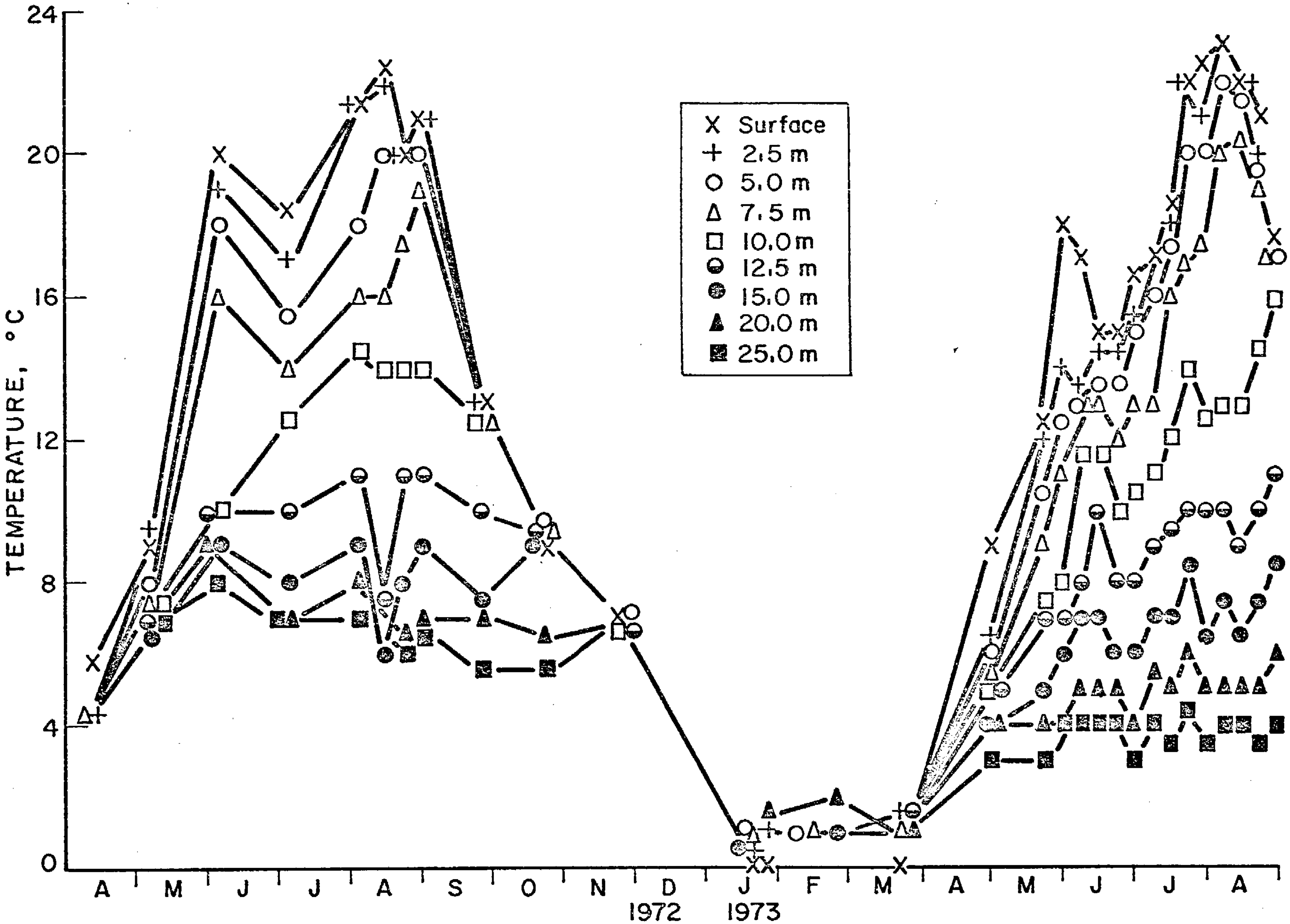


TABLE 31

LAKE MORPHOMETRY DATA

Lake		Volume ($10^6 m^3$)	Surface Area ($10^6 m^2$)	Depths (m) Mean	Depths (m) Maximum	Maximum Length (km)	Maximum Width (km)	Perimeter (km)
Wood[a]		200	9.3	22	34	6.60[b]	1.70[b]	16.7[b]
Kalamalka[a]		1520	25.9	59	142	16.0[b]	2.30[b]	42.4[b]
Ellison[a] (Duck)		5.4	2.08	2.6	4.3	2.7	1.2	7.1
Swalwell[cd]	Max.	26.0	3.1	8.4	31.6	4.5	1.1	-
(Beaver)	Min.	14.2	1.7	8.4	26.1	2.8	0.8	-
Oyama[cd]	Max.	17.4	2.6	6.7	22.5	3.1	1.4	-
	Min.	11.3	1.8	6.3	19.8	2.9	1.2	-

a Data compiled from charts of the Fish and Wildlife Branch, Department of Recreation and Conversation, B.C.

b Data compiled from maps of the Canadian Topographic System, 1960. Scale 1:126,720.

c Data compiled from maps of the Water Investigations Branch, B.C. Dwgs. 4567-9-A, 4567-1-A.

d Max is level at crest of spillway, Min is at level of invert of culvert.

surface water temperatures in the southern, more exposed parts of the lake relative to those at the north end of the lake. Marked stratification occurred by August and the level of the thermocline progressively lowered as the epilimnion thickened. Cooling of the lake began during late August and early September 1972 and accelerated throughout September. Fall turnover of the lake waters was complete in November 1972 at 6-7C.

As a result of strong winds, Wood Lake did not become permanently frozen until mid January 1973 when lake water temperatures dropped below the maximum density temperature of 4C. Between January and March 1973 lake water temperatures varied little and were generally between 1 and 2C at all depths. By late April 1973, stratification had commenced but the temperature structure was different from that of the same period in 1972. Again in 1973, the epilimnion thickened in depth during the period of summer stratification, particularly after maximum lake temperatures had been attained in early August and cooling began in late summer. The thermocline was more stable in depth during the summer of 1973. More rapid cooling of Wood Lake surface waters occurred in August 1973 than in August 1972 when there was only a slight decrease in surface water temperatures.

iii. <u>Kalamalka Lake</u>

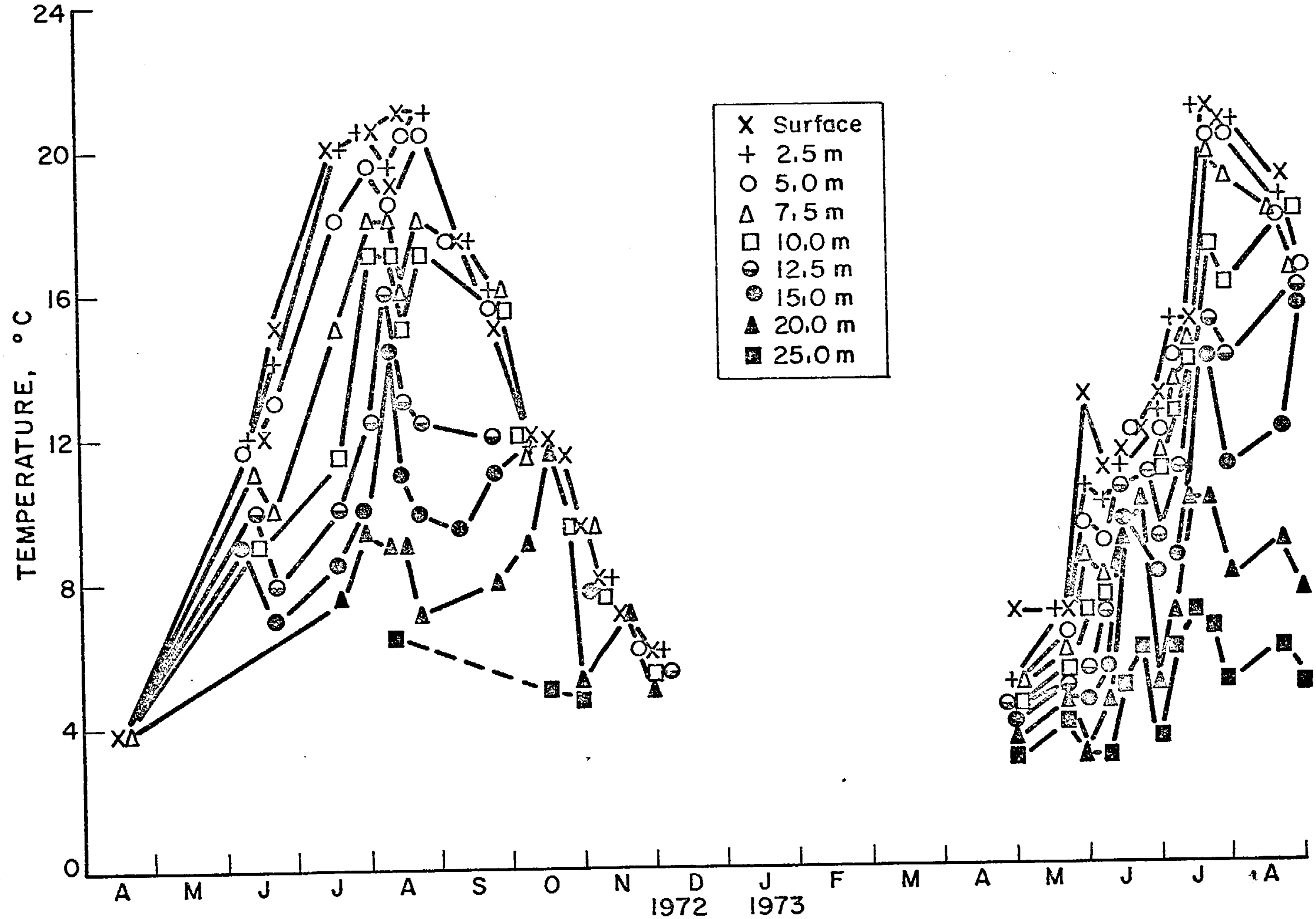
Temperature data for Site 1 at the southern end of Kalamalka Lake are shown in Figure 10. In April 1972 Kalamalka Lake was unstratified, with a water temperature of approximately 3.4C. No further measurements were made until early June, by which time lake stratification was apparent and surface water temperatures had increased to approximately 12C. Maximum water temperatures were recorded during August of 1972.

Surface water temperatures varied over the length of the lake. Close to Oyama Canal they reached a maximum of 21C by late August while the same temperature was recorded at the north end of Kalamalka Lake earlier in the month. At Station 1 a temperature of 21C was recorded between the 15th and 28th of August 1972. In contrast to this, surface water at the center of the lake (Stations 2 and 3) attained its maximum temperature of 20C between the period of July 18 to August 25, 1972. The variation in surface water temperature may be related to the northerly winds which allowed higher temperatures to be reached in sheltered surface waters at the northerly end of Kalamalka Lake and also to the influx of warmer water from Wood Lake.

During September 1972 the water of Kalamalka Lake started to cool rapidly and by October there was little variation between

Figure 10

SEASONAL CHANGES IN THE THERMAL STRUCTURE OF KALAMALKA LAKE
SITE No. 1



water temperature at the surface and at 15 m depth. Mixing continued and by late October 1972 the lake was unstratified to a depth of 20 m at a temperature of about 11°C. The time of the fall turnover in Kalamalka Lake was not precisely determined but probably occurred during November of 1972.

During 1973, the thermal structure of Kalamalka Lake was monitored from May to August as shown in Figure 10; in May, although the lake was not clearly stratified, temperatures at surface and depth were about 7 C and 4 C, respectively. The temperature of the surface waters and those at depth increased slowly during May and, with minor fluctuations, the maximum rate of heating occurred during June and July. Maximum surface temperatures were recorded in July and were comparable with those measured during 1972. Strong wind action at the beginning of August resulted in coolings of surface waters to a depth of about 7.5 m, the epilimnion thickened and on termination of thermal structure measurements in late August 1973 the temperature variation between surface and 15 m depth was only from 16.5 C to 15.5 C.

d. Thermal Changes in the Epilimnion and Hypolimnion of Ellison, Wood and Kalamalka Lakes

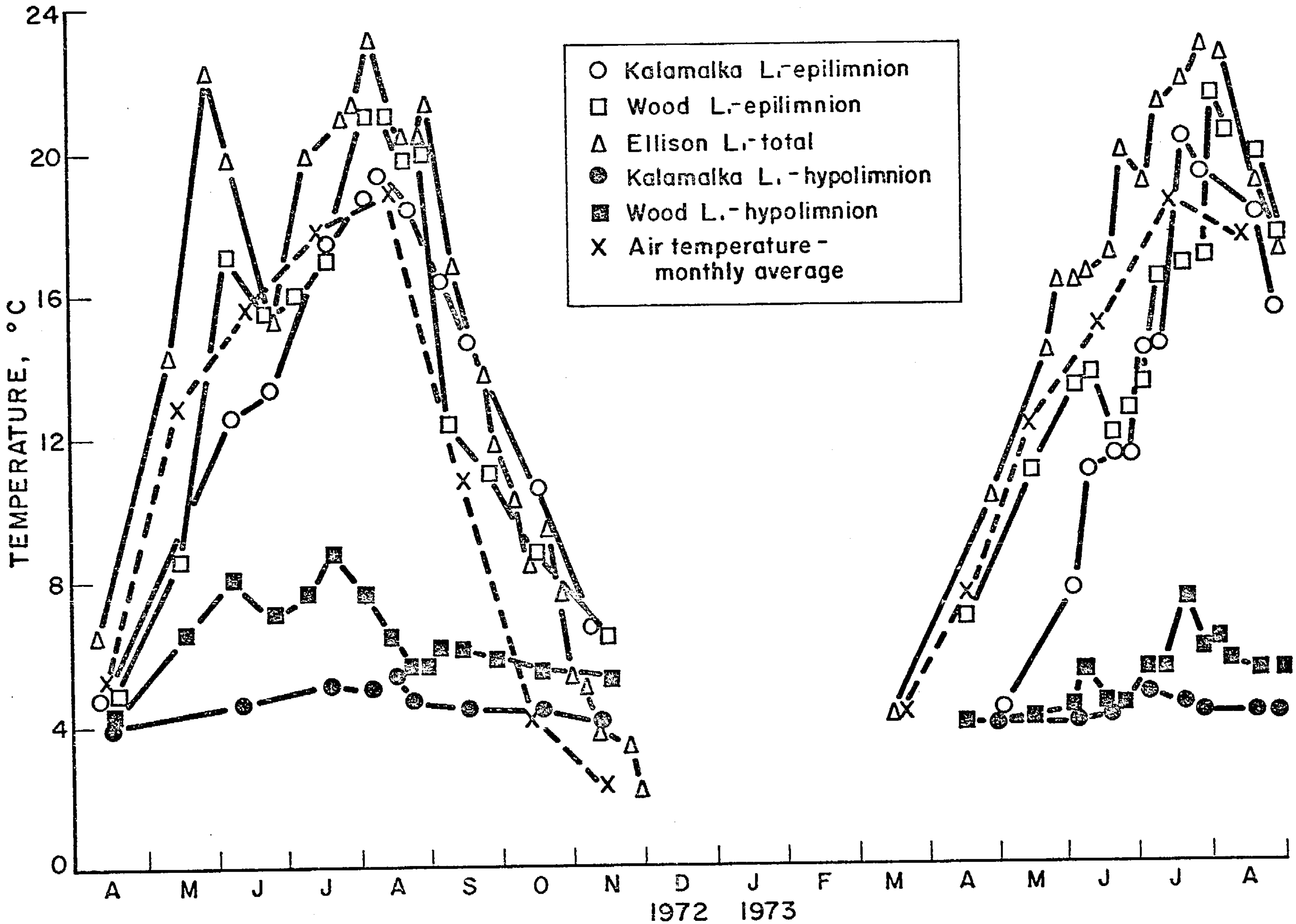
Average temperatures of the epilimnion and hypolimnion of Kalamalka and Wood Lake are plotted in Figure 11 for each sampling occasion during 1972 and 1973. Average temperatures for all depths of Ellison Lake are also plotted, together with the monthly average air temperature at Kelowna. Changes in heating rate were influenced by weather conditions. In August 1972 when air temperatures reached their maximum value, Ellison Lake was at least 2 C warmer than the epilimnion of Wood Lake which in turn was approximately 2 C warmer than the epilimnion of Kalamalka Lake. Considerable differences were noted in the rate of warming of the hypolimnion between the lakes, with Wood Lake reaching a maximum temperature in the hypolimnion of 9 C in July 1972 while the hypolimnion temperature in Kalamalka changed only slightly from the level of maximum water density.

Mean epilimnion monthly heating rates were calculated for each lake. The temperature between April and August 1972, in Ellison Lake increased at an average rate of 4.25 C/month; in Wood Lake the rate was 4.05 C/month and in Kalamalka Lake, 3.8 C/month. Hypolimnion heating rates were 1.3 C/month for Wood Lake and 0.43 C/month for Kalamalka Lake. Maximum hypolimnion temperatures in both Wood and Kalamalka Lakes were measured during July.

Epilimnion and hypolimnion heating rates were different in 1973 from 1972, as shown in Figure 11. The temperature of Ellison Lake increased by approximately 4.02 C/month, while the temperature of epilimnion waters in Wood Lake increased at a rate of 4.83 C/month. In Kalamalka, the temperature of the epilimnion increased 5.4 C/month.

Figure 11

SEASONAL CHANGES IN THE TEMPERATURE OF ELLISON LAKE AND THE EPILIMNION AND HYPOLIMNION OF WOOD AND KALAMALKA LAKES



Temperatures of hypolimnion waters in Wood and Kalamalka Lakes increased at rates of 1.2 C and 0.4 C/month, respectively, during 1973. Maximum hypolimnion temperatures were recorded in July.

e. Heat Content of Ellison, Wood and Kalamalka Lakes

Seasonal changes in lake thermal structure may be described by temperature-depth curves. A capacity factor relating to the amount of water heated in the lake can also be used for this purpose. A summary of data for a large number of lakes is provided by Hutchinson (1957), who termed the amount of heat needed to raise the lake from an isothermal condition at 4 C to the highest observed temperature, "the summer heat income". On the occasions that samples were collected, the total heat content of each lake was calculated. The results are presented in Figure 12.

Stratification and lake morphometry greatly influenced the values of summer heat income. Ellison Lake heated at a lower rate than Wood or Kalamalka Lake and there was a negligible increase in the heat content of Ellison Lake during July and August 1972.

The summer heat income of Kalamalka Lake was 24,500 cal/cm^2 on August 15 1972. For Wood Lake the summer heat income for 1972 was 20,500 cal/cm^2, measured on August 2, 1972. The summer heat income for Ellison Lake, recorded August 8, 1972, was 5,000 cal/cm^2.

Following the time of maximum heat content, decreasing air temperatures, wind and other factors rapidly reduced the thermal content of all three lakes. Heat loss rates in Wood and Kalamalka Lakes were similar and slightly higher than in Ellison Lake. Under Hutchinson's definition, the differential heat content above 4 C of each lake approached zero after fall turnover. The heat budgets of Ellison, Wood and Kalamalka Lakes in 1973 were different from those measured in 1972, as shown in Figure 12. Heat contents of the three lakes increased at different rates from those recorded for 1972 and the summer heat incomes were higher in 1973 for Wood and Kalamalka Lakes. The summer heat income of Kalamalka Lake was 27,500 cal/cm^2 on July 29, 1973. For Wood Lake the summer heat content was 21,800 cal/cm^2 on August 2 and for Ellison Lake it was 4,900 cal/cm^2 on July 31. In 1972, the lake heat contents did not begin to decrease markedly until about September; however in 1973, the heat content decreased from the end of July, following the trend in air temperatures. The study was terminated in late August 1973, at which time the heat contents of all lakes were decreasing.

f. Lake Water Transparency

Secchi disc readings were made in each lake when water samples were collected. Where possible, Secchi disc readings were made at mid-day. Transparency data are plotted for each lake and sampling occasion in Figure 13. Kalamalka Lake had the highest transparency. After an

Figure 12

SEASONAL CHANGES IN THE HEAT CONTENT OF KALAMALKA, WOOD AND ELLISON LAKES

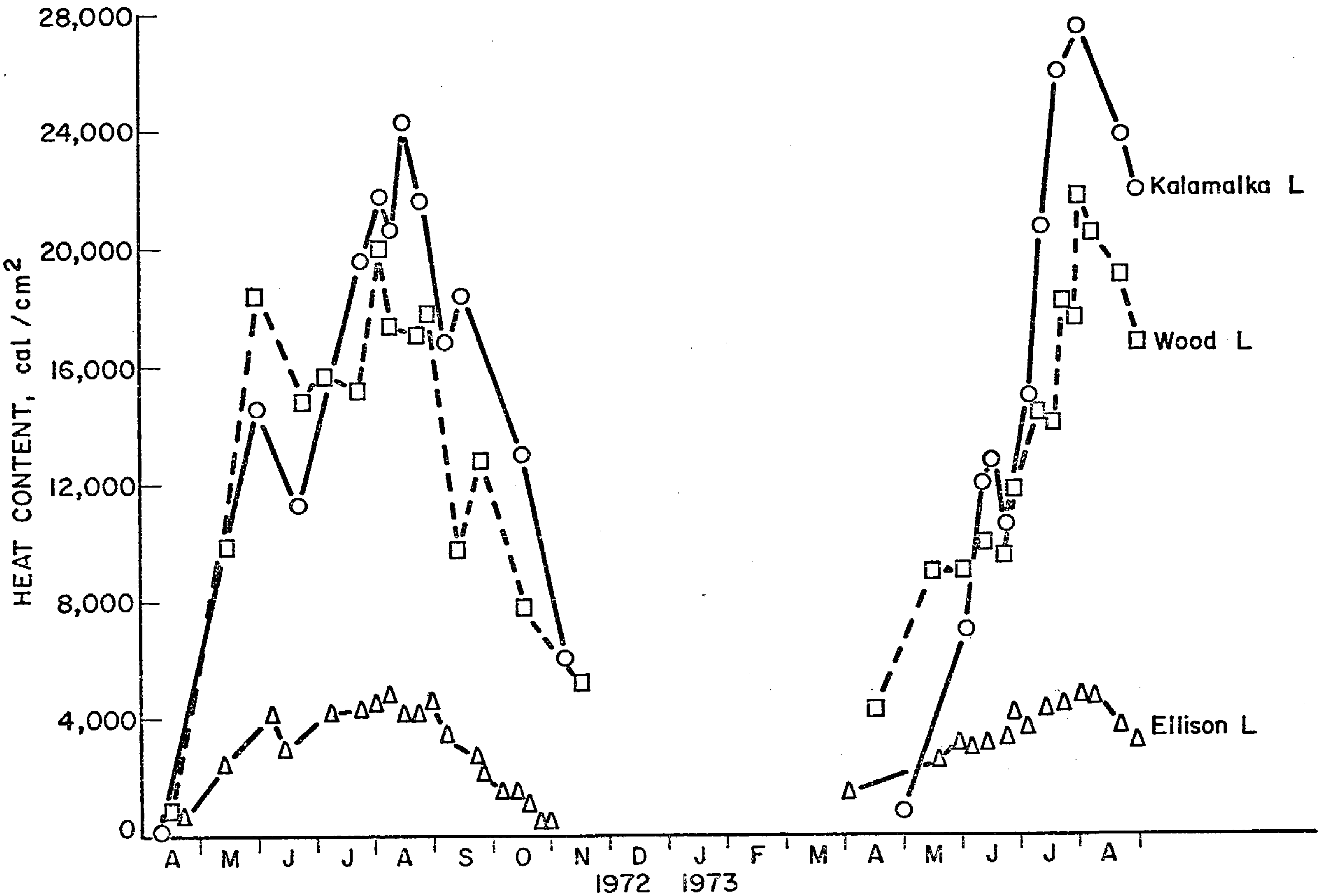
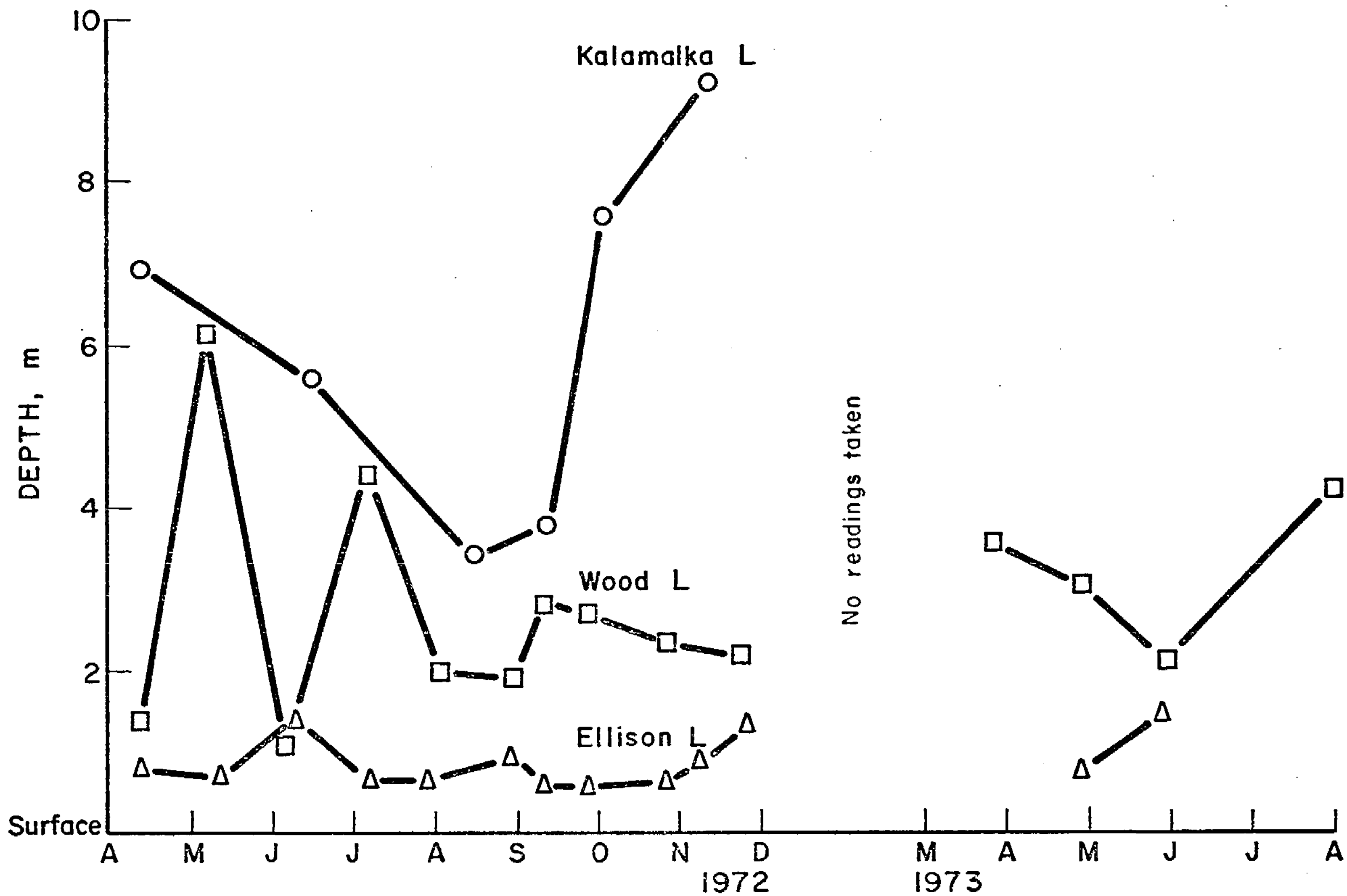


Figure 13

SECCHI DISC-WATER TRANSPARENCY VALUES



initial Secchi disc reading of 6.9 m in April 1972, the water transparency values decreased markedly throughout the summer period to a reading of approximately 3.4 m in August. Subsequently the transparency increased again and in November the Secchi value had reached 9.3 m when fall turnover occurred.

Water transparency in Wood Lake fluctuated throughout 1972, with an April reading of 1.4 m, which increased in May to 6.1 m. Subsequently the transparency decreased to a minimum Secchi reading of 1.1 m in June and then increased again to 4.4 m in July. By August Secchi disc readings were about 1.9 m and remained between 2-3 m for the rest of the year.

Measurements of water transparency in Wood Lake were also made during 1973. In April and May the values were similar to those recorded in the same period of 1972. Light transmission through the waters of Wood Lake was much greater during 1973 and by August, Secchi disc readings were 4.7 m (higher than recorded in August 1972 for Kalamalka Lake). The improvement in water transparency of Wood Lake during 1973 was obvious both in the Secchi disc readings and from other field observations. The improved transparency persisted throughout the whole summer period.

Lowest light transmission readings were obtained in Ellison Lake with Secchi values, ranging between 0.6 and 1.5 m.

g. Oxygen In Ellison, Wood and Kalamalka Lake

Data are reported in Figures 14, 15 and 16 for dissolved oxygen profiles for Ellison, Wood and Kalamalka lakes during periods of stratification and turnover in 1972 and 1973. The seasonal variation of dissolved oxygen in Wood Lake was examined in more detail as shown in Figure 16.

i. Ellison Lake

Seasonal variations in dissolved oxygen concentration and temperature of Ellison Lake are shown in Figure 15 for 1972 and 1973. Winds caused periodic breakdown of stratification in this shallow lake during the summer months. In general, there was no indication of persistent oxygen reduction in bottom waters.

ii. Wood Lake

Wood Lake at spring turnover of 1972 was isothermal and approximately 90% saturated with oxygen at all depths. During the spring and summer, dissolved oxygen values remained relatively constant in the epilimnion but progressively decreased at greater depths in the lake.

Figure 14

AVERAGED DISSOLVED OXYGEN-TEMPERATURE PROFILES FOR ELLISON LAKE

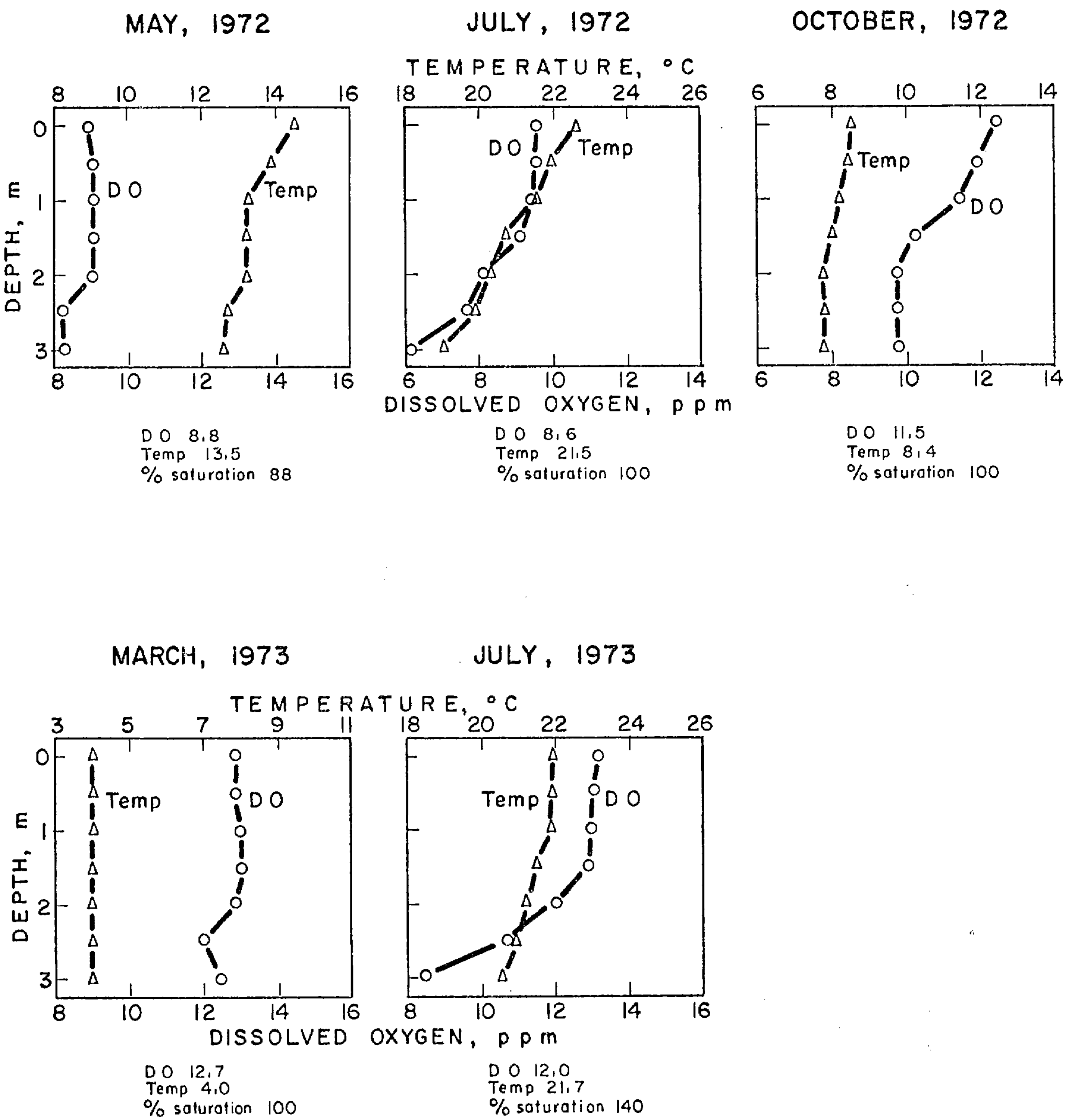
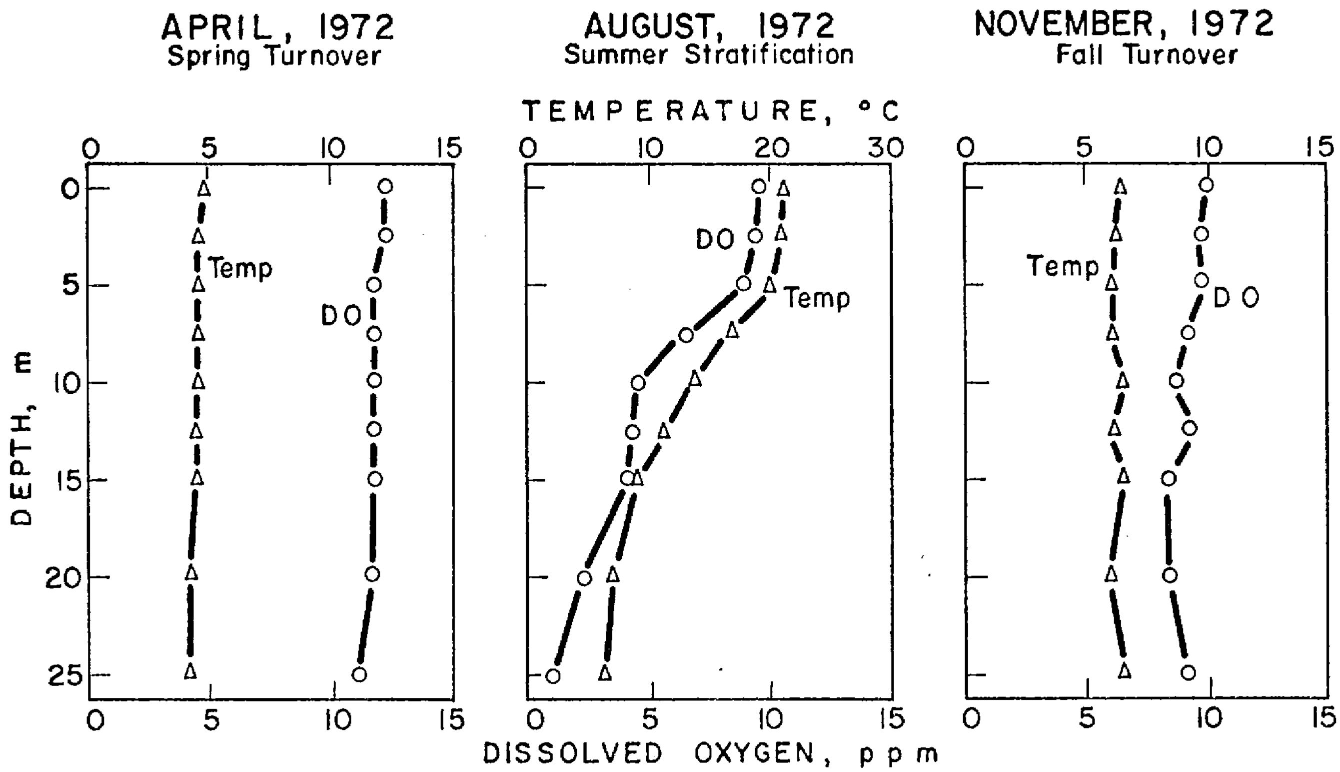


Figure 15
AVERAGED DISSOLVED OXYGEN-TEMPERATURE PROFILES FOR WOOD LAKE

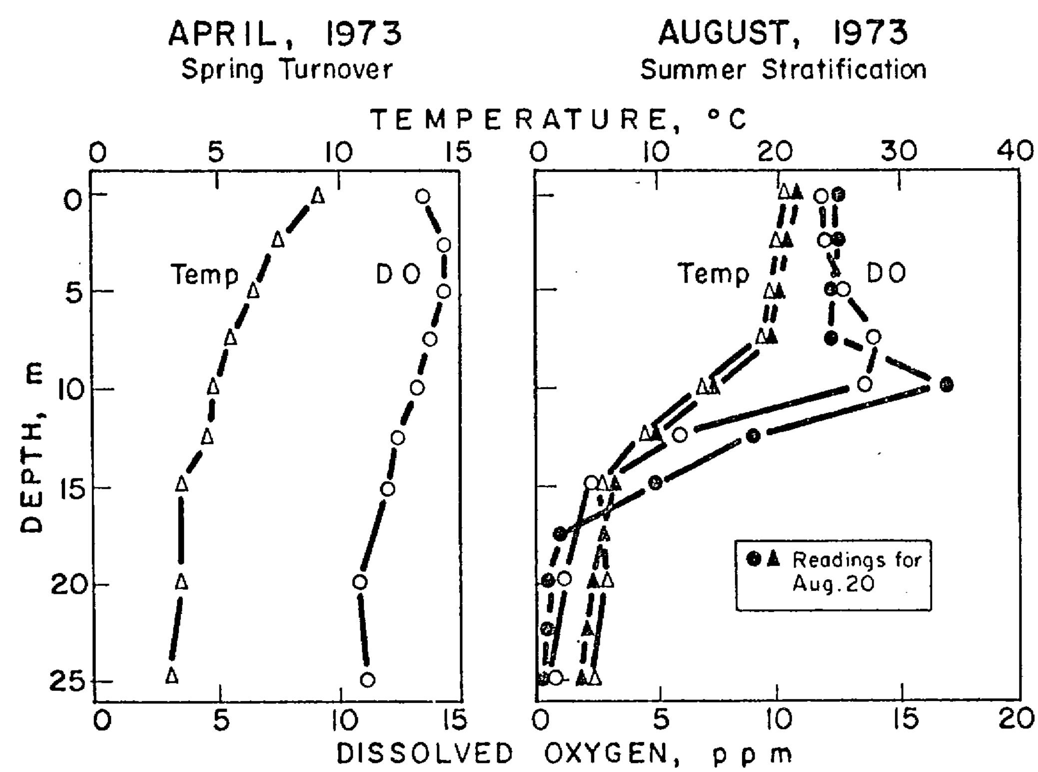


	Above 10m	Below 10m

DO 11.8
Temp 4.4
% saturation 90

	Above 10m	Below 10m
DO	7.8	2.9
Temp	18.6	8.3
% saturation	83	24

DO 9.3
Temp 7.3
% saturation 74

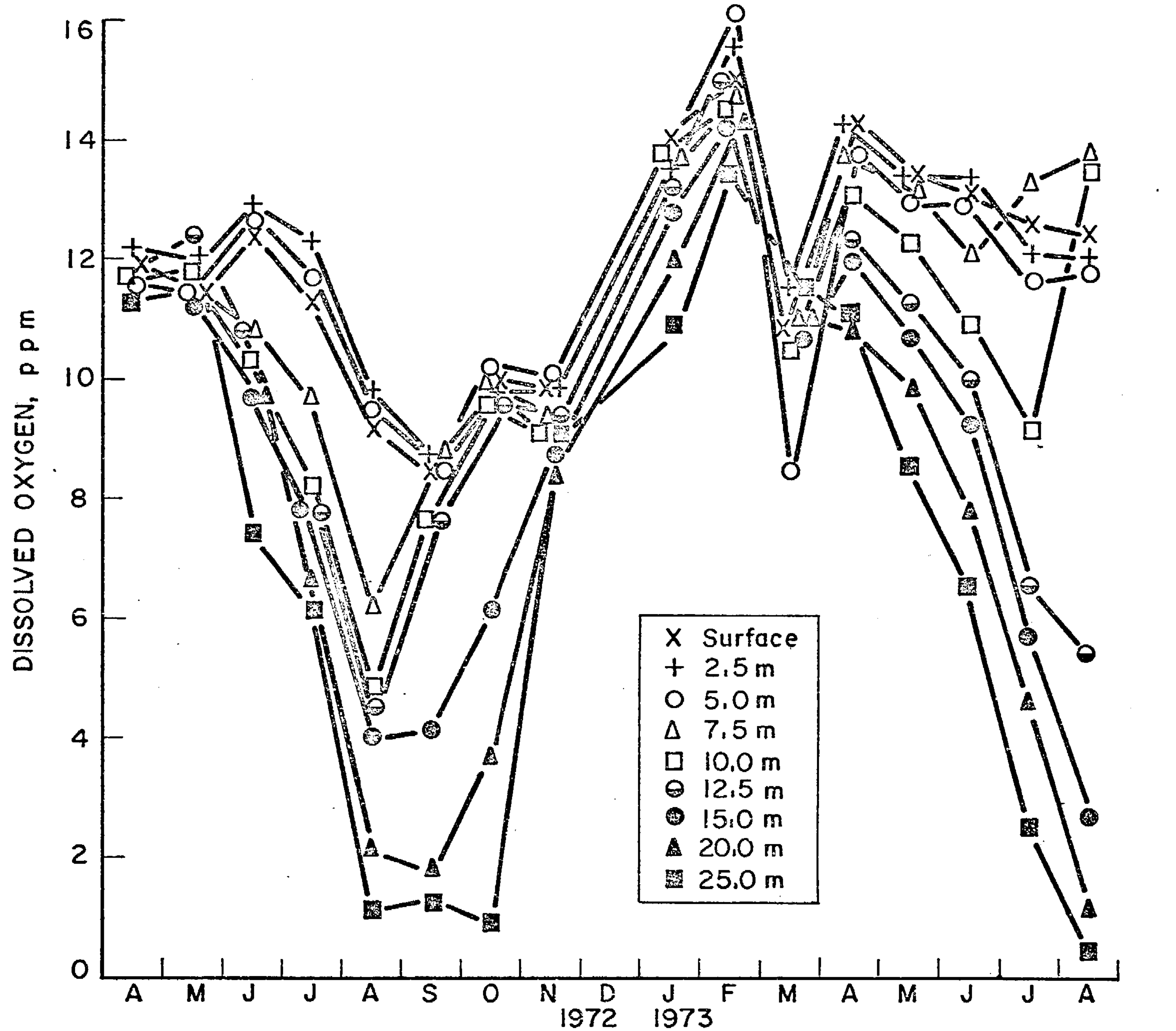


DO 12.8
Temp 5.4
% saturation 100

	Above 10m	Below 10m
DO	12.7	2.4
Temp	18.5	6.4
% saturation	135	19

Figure 16

SEASONAL VARIATION IN DISSOLVED OXYGEN IN WOOD LAKE (Averaged data)



Figures 15 and 16 illustrate the changes in dissolved oxygen with respect to water layers in Wood Lake during 1972 and 1973. The lake stratified during summer and dissolved oxygen levels in the epilimnion were close to saturation while dissolved oxygen values in the hypolimnion decreased. Very low values were measured in the hypolimnion between August and October, 1972. Dissolved oxygen content of the water above approximately 10 meters depth in August was 80% of saturation while in deeper waters the average was only 25% of saturation. The type of oxygen/depth curve recorded for the summer period in Figure 11 is typical of eutrophic lakes and is described as a clinograde curve characterised by marked oxygen reduction within the hypolimnion layers. At fall turnover, which occurred during November in 1972, Wood Lake temperature was approximately 6.2 C. Dissolved oxygen values were relatively low, at about 70% of air saturation.

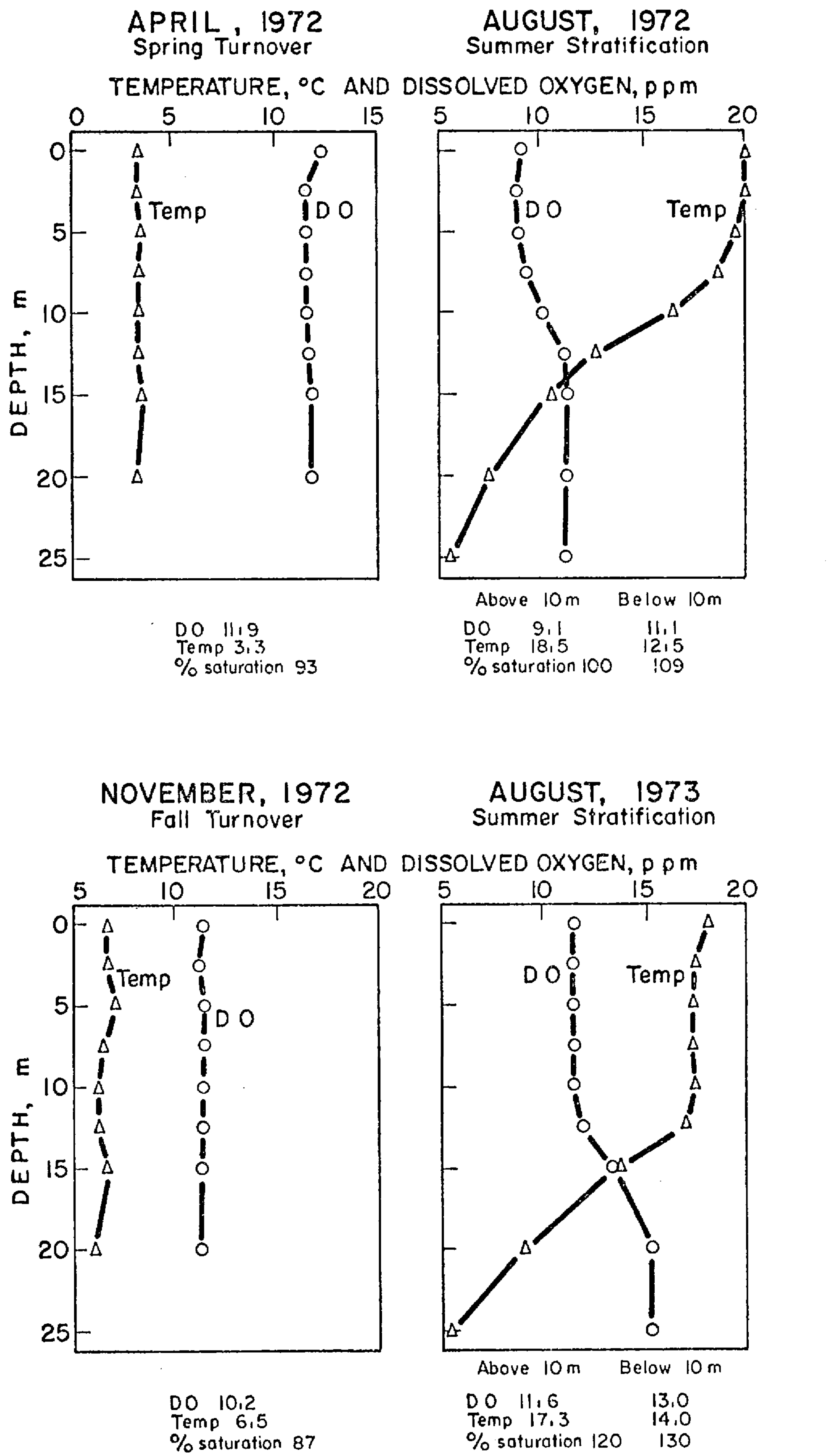
Data in Figures 15 and 16 show that during the 1973 spring turnover Wood Lake was saturated with respect to dissolved oxygen at all depths. Stratification occurred during the summer and there were substantial differences in the pattern of dissolved oxygen concentrations in late summer. By August, the dissolved oxygen content at the level of the thermocline increased markedly and this highly oxygenated water overlaid the hypolimnion in which oxygen reduction was occurring. The monthly average data for dissolved oxygen during August 1973 indicated a slight peak in dissolved oxygen concentration close to the thermocline level and partially within it. An extreme example of this situation is given by the data for August 20, 1973 (as shown in Fig. 15). Here, dissolved oxygen values increased to approximately 160% of saturation close to the thermocline and then rapidly decreased in deeper waters to a minimum of 0.3 mg/l at 25 m. Thus in 1973 the production of oxygen by phytoplankton within the thermocline region caused a positive heterograde curve which persisted throughout August. The high water transparency readings measured in Wood Lake during 1973 probably aided this situation. Light transmission was greater in 1973 than in 1972 allowing algal photosynthesis in deeper waters. Oxygen supersaturation occurred in the thermocline region, with average dissolved oxygen values in August of 135% saturation at depths above 10 m.

iii. Kalamalka Lake

Dissolved oxygen and temperature profiles for Kalamalka Lake are shown in Figure 17. The data for dissolved oxygen at times of summer stratification represent an orthograde distribution of oxygen (Hutchinson, 1957) characteristic of oligotrophic lakes.

Figure 17

AVERAGED DISSOLVED OXYGEN-TEMPERATURE PROFILES FOR KALAMALKA LAKE



Although the orthograde condition of Kalamalka Lake is not exceptionally marked, it differs sufficiently from the clinograde curve of Wood Lake to permit a differentiation in trophic classification between the two lakes.

h. Oxygen Reduction in the Hypolimnion of Wood and Kalamalka Lakes

The difference between areal oxygen deficits in the hypolimnion in the period between spring circulation and the height of summer stratification expressed per unit of time gives an indication of the biological productivity of a lake. The volumes of hypolimnion waters in Wood and Kalamalka Lakes were calculated using data from temperature/depth curves and hypsometric curves (Blanton and Ng 1973). Knowing the average dissolved oxygen concentration within the hypolimnion, the total oxygen content of the hypolimnion in each lake was then calculated. This value was divided by the hypolimnion surface area to give the value of oxygen per unit area of the hypolimnion, expressed as mg/cm^2.

Calculations were made for the periods of summer stratification of Wood and Kalamalka Lakes during 1972 and 1973 and results are shown in Figures 18 and 19 respectively. The rate of oxygen utilisation within the hypolimnion of Wood Lake ranged between 0.121 $mg/cm^2/day$ for 1972 and 0.148 $mg/cm^2/day$ in 1973. Oxygen utilisation rates within the hypolimnion of Kalamalka Lake were much lower; 0.044 $mg/cm^2/day$ in 1972 and 0.034 $mg/cm^2/day$ in 1973. In both lakes the dissolved oxygen concentration within the hypolimnion decreased faster during 1973 than during 1972.

Hypolimnetic oxygen utilisation rates calculated for this study confirmed that Kalamalka Lake waters can be described as oligotrophic to mesotrophic whereas those of Wood Lake are eutrophic.

i. Water Movement in Ellison, Wood and Kalamalka Lakes

i. Ellison Lake

Studies of water movement were carried out in Ellison Lake to determine if inflowing Vernon Creek water short-circuited across the north shore to the outflow from the lake.

The first study was carried out on May 18, 1972. Between 09:30 hr and 09:50 hr, 5 gal 20% Rhodamine WT were added to Vernon Creek water entering Ellison Lake. At the time of the study the temperature of Vernon Creek was 5C and the flow was 80.7 cfs, Ellison Lake was slightly stratified with surface temperatures of 14C declining to 12C at 3 m depth. The prevailing southerly winds pushed dye in surface waters onto the shallow, flooded region of the north shore of the lake and after 40 min the dye could not be seen from the air. Fluorometric measurements

Figure 18

CHANGES IN THE HYPOLIMNION OXYGEN DEFICITS IN WOOD LAKE

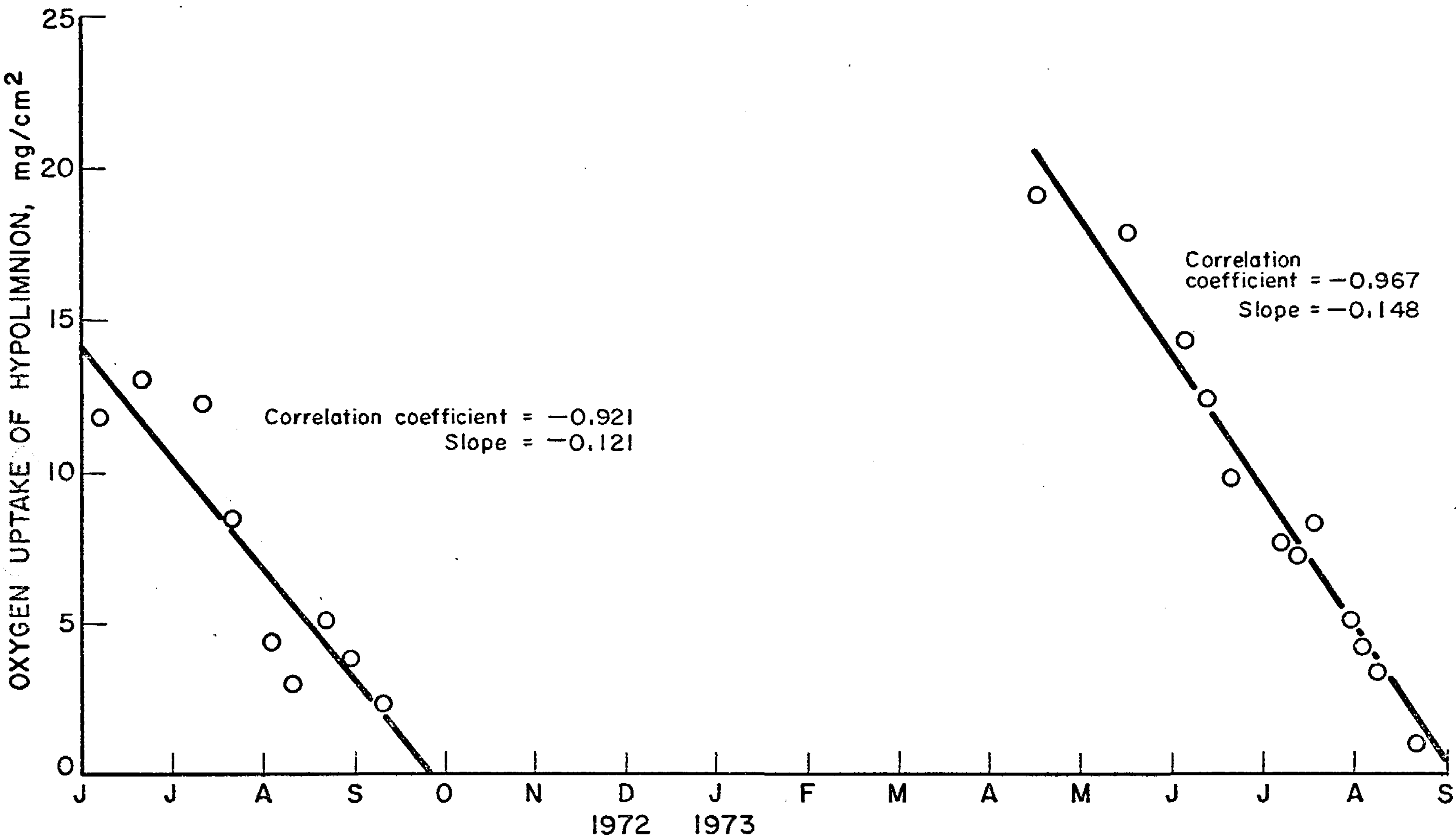
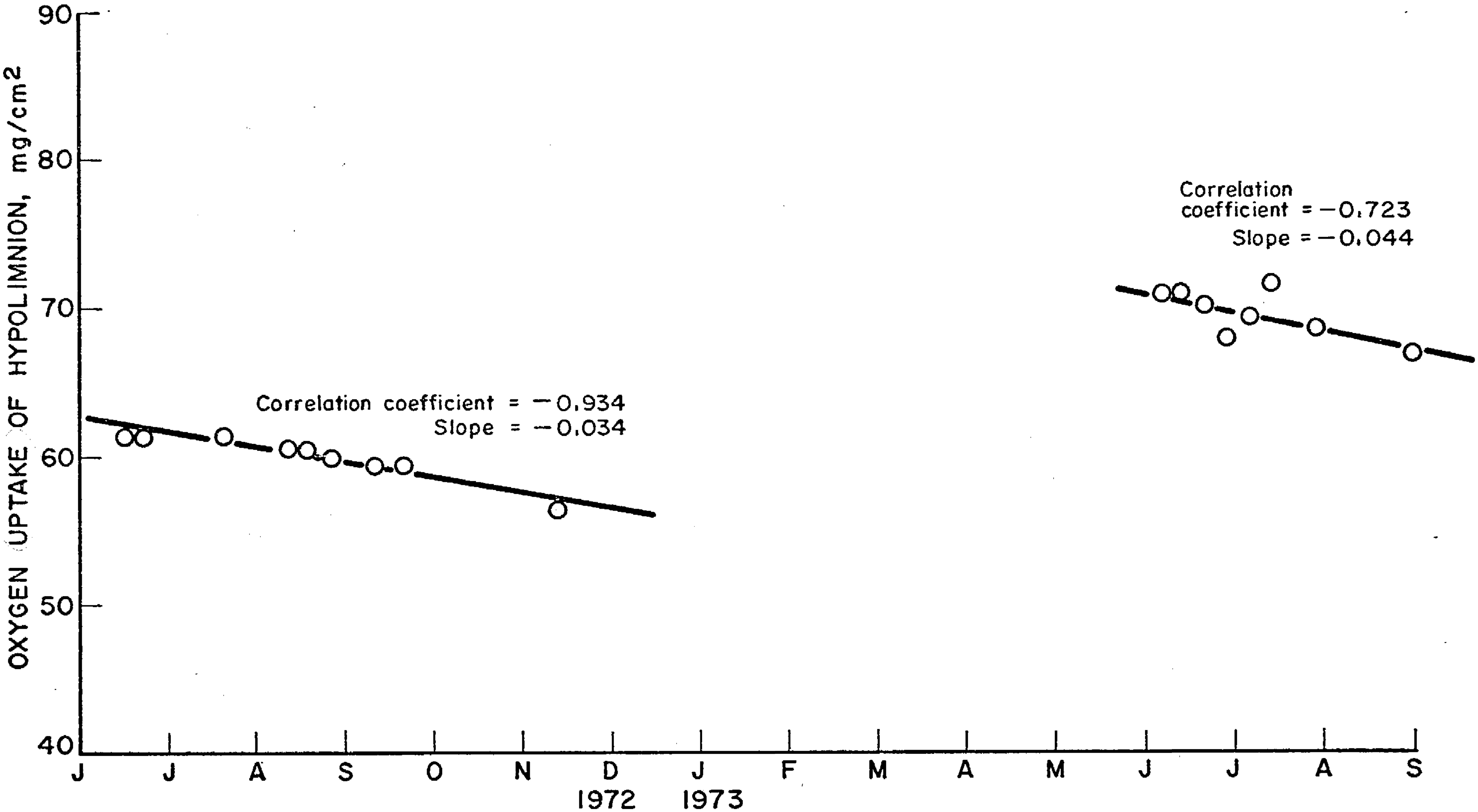


Figure 19

CHANGES IN THE HYPOLIMNION OXYGEN DEFICITS IN KALAMALKA LAKE



of dye concentration showed that it was moving along the north shore of the lake although the precise path could not be determined. Samples were taken at the outlet of Ellison Lake to determine if short-circuiting of Vernon Creek water was occurring. Within 6 hr the dye had traversed the north end of Ellison Lake as shown below.

Time of Recording	Time from Dye Input	Dye Concentration at Outlet of Ellison Lake (ppb)		
		Surface	0.5 m	1.0 m
10:00 hr	0.6 hr	0	0	0
10:30 hr	1.2 hr	0	10	
11:30 hr	2.2 hr	0	9	12
13:30 hr	4.2 hr		7	
16:00 hr	6.3 hr		7	
20:00 hr	10.3 hr		0	

A second study was carried out on July 18, 1972. At this time the distillery was discharging the minimum of cooling water. Inflowing Vernon Creek water had a temperature of 15C and Ellison Lake was isothermal at a temperature of 18.5C. Between 10:20 hr and 10:45 hr, 2.5 gal 20% Rhodamine WT was added to the inflowing creek water and its dispersal was monitored by fluorometry. The cold, inflowing water travelled below the surface of Ellison Lake and within 1 hr, dye was detected along the north shore, with only a minor component moving south into the main body of the lake. The results obtained are shown in Figures 20-23. The dye plume became visible at the surface and aerial photographs taken 6 hr after dye addition showed that the plume was close to the outlet from Ellison Lake (Fig. 29). By 15:00 hr dye was detected at the outflow from the lake. Lateral and vertical spreading had also occurred. This water movement took place despite northerly winds. In addition, Vernon Creek water, as a result of the gravel delta produced during the 1972 freshet, was deflected into the main body of Ellison Lake rather than along the north shore as was the case in the earlier study. The mean rate of water movement was approximately 350 ft/hr at a time when the inflow of Vernon Creek was 4.1 cfs. This contrasted with the rate of movement of approximately 200-1200 ft/hr measured on May 18, 1972 when the inflow of Vernon Creek was 80.7 cfs. No appreciable dye concentrations remained in Ellison Lake on July 19, 1972, as shown in Figure 22.

Figure 20
MAIN PATHS OF DYE IN ELLISON LAKE
JULY 18, 1972

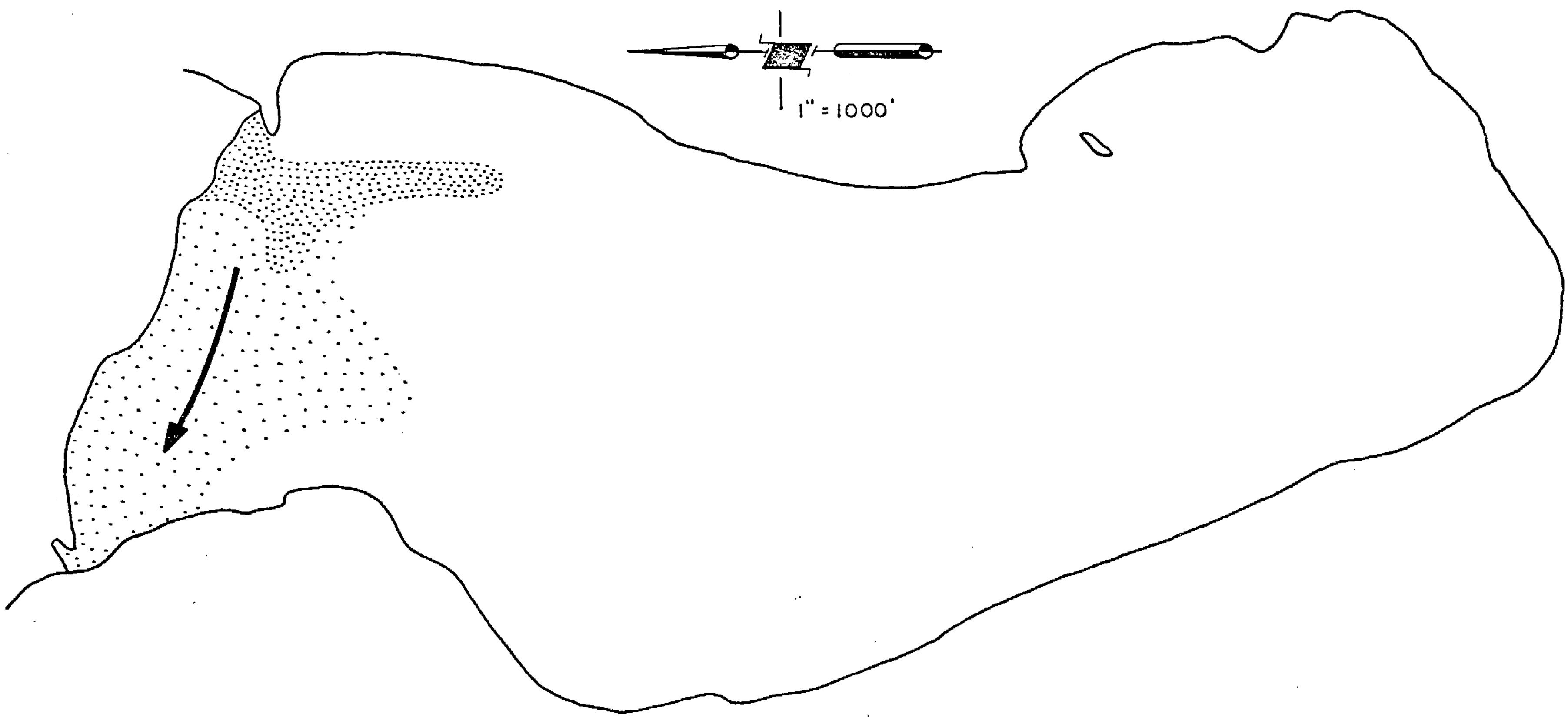


Figure 21
DYE CONCENTRATIONS (ppb) IN ELLISON LAKE
JULY 18, 1972

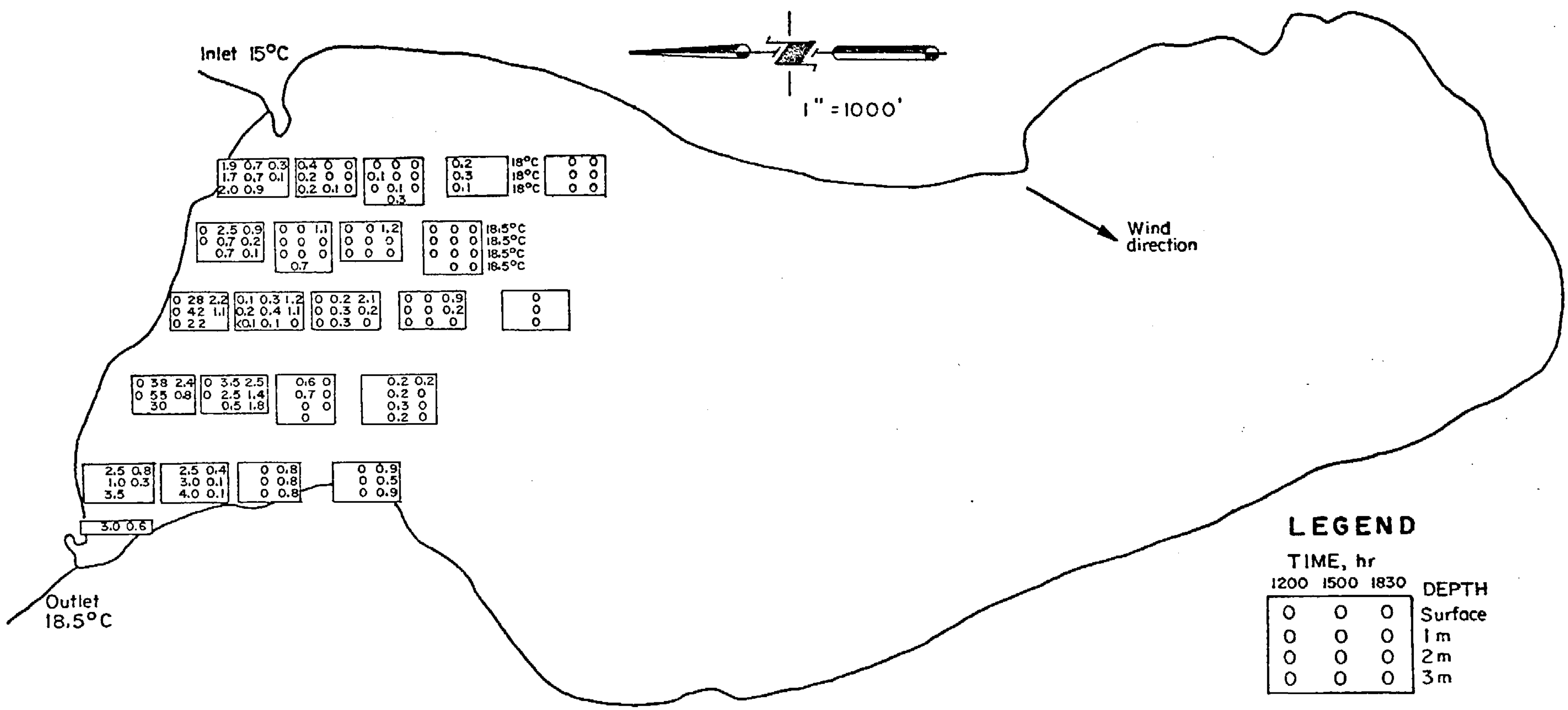


Figure 22
DYE CONCENTRATIONS (ppb) IN ELLISON LAKE
JULY 19, 1973
1200 hr

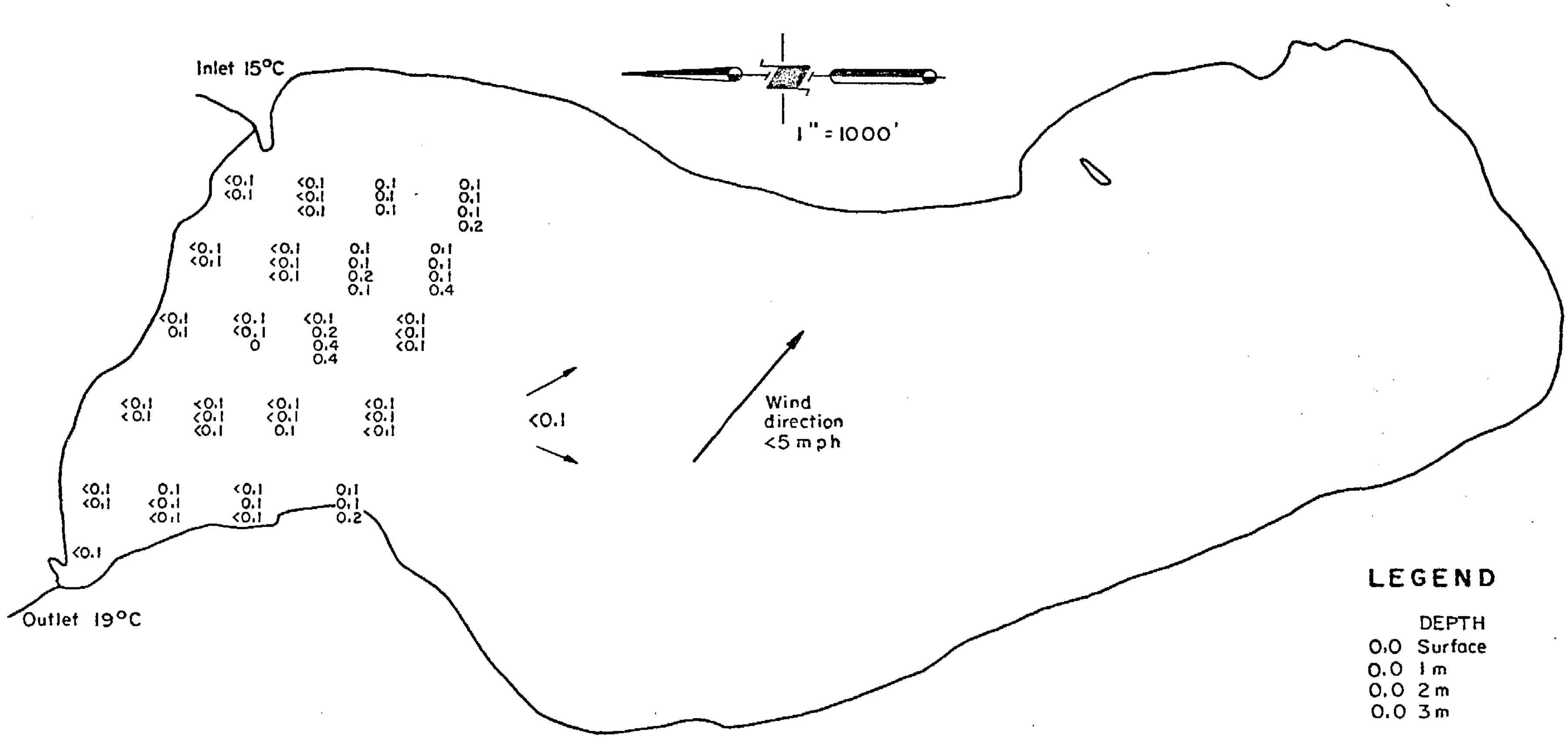
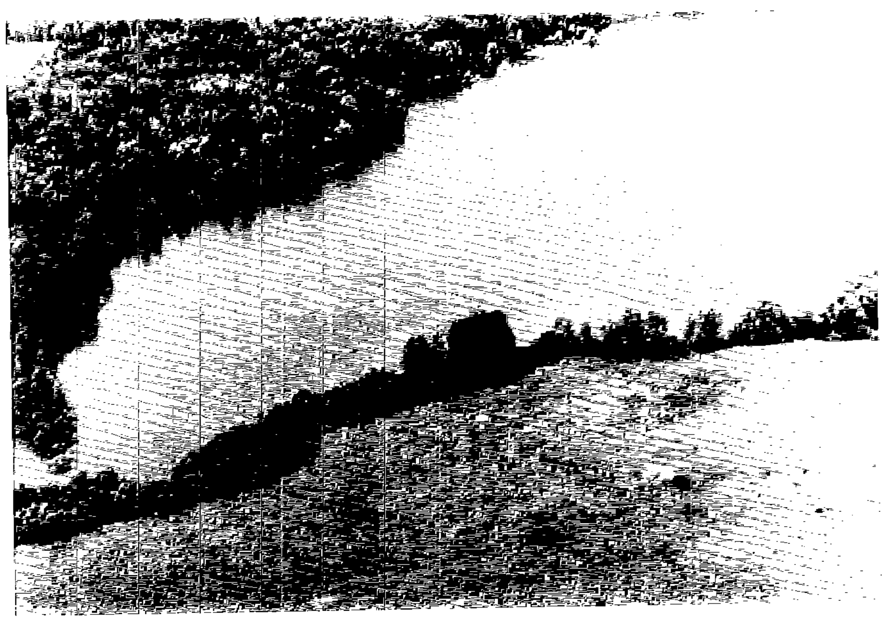


FIGURE 23



Dye Position, North End of Ellison Lake Six hr after Introduction at Vernon Creek Inlet to Lake, July 18, 1972

Lake Outlet is in Left Foreground

Figure 24
DYE CONCENTRATIONS (ppb) IN ELLISON LAKE
JULY 27, 1972

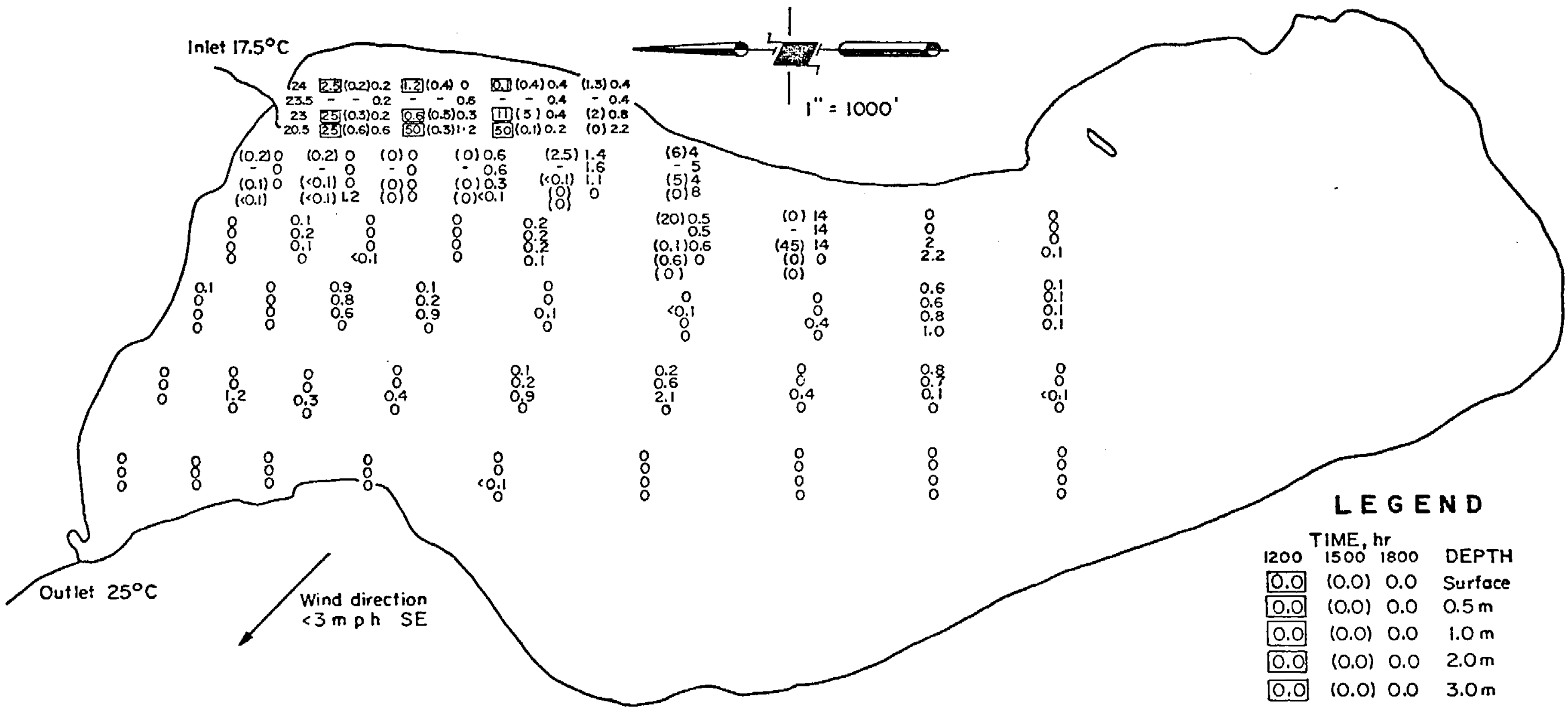
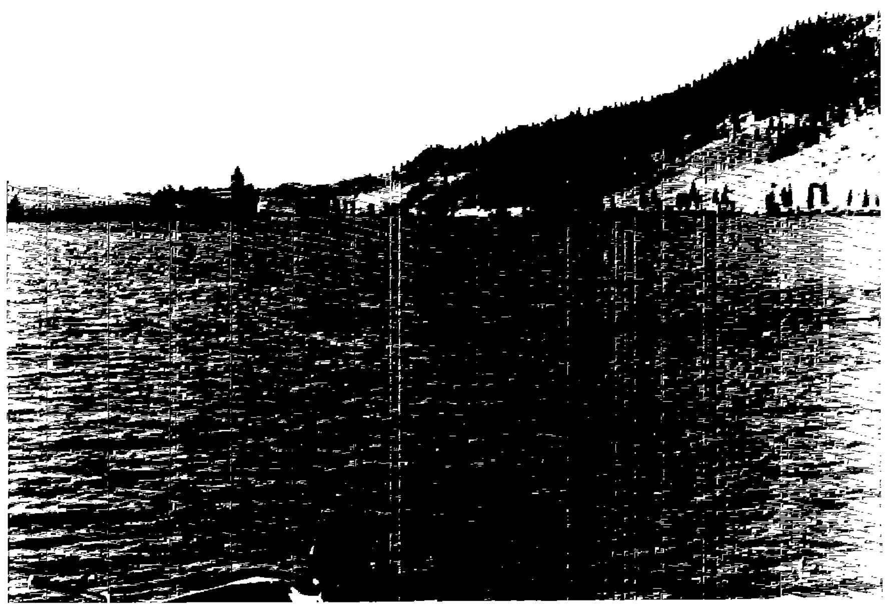


FIGURE 25

(a)

(b)

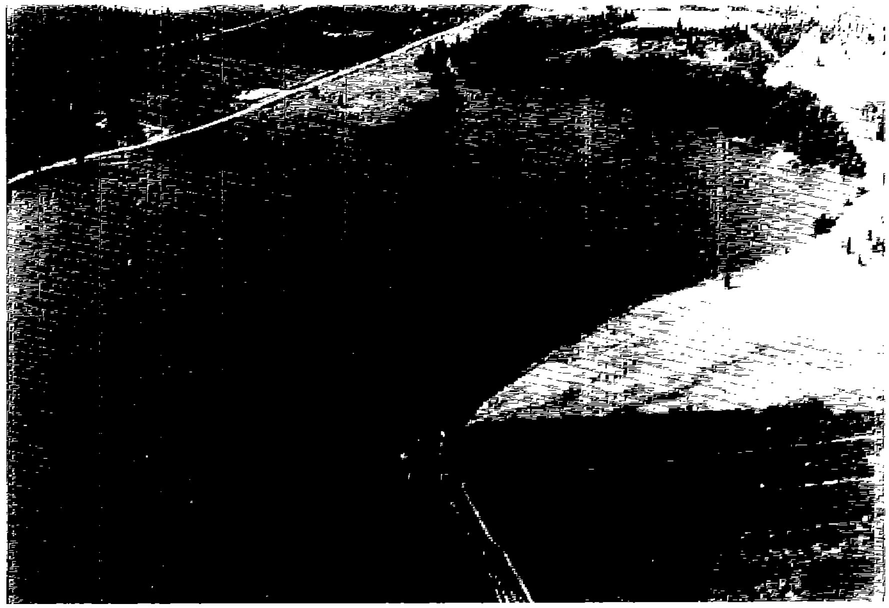


Narrow Dye Plume at the North End of Ellison Lake
Immediately after Introduction at Lake Inlet, July 27, 1972

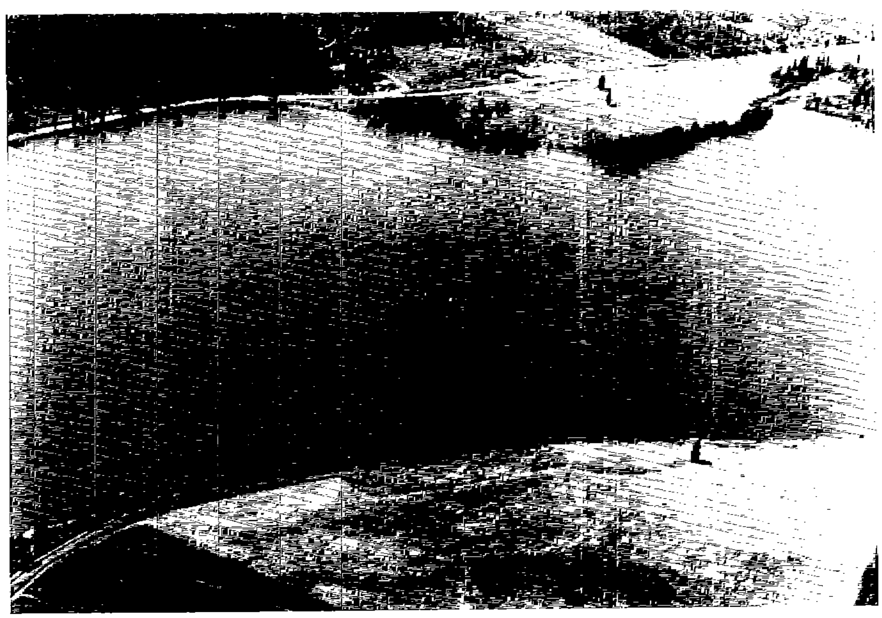
(a) View West from Inlet
(b) View South from Inlet

FIGURE 26

(a)



(b)



Dye Plume Along the East Shore of Ellison Lake,
Six hr after Introduction at Inlet

(a) Outlet in Upper Right Corner
(b) Outlet Top Center

Figure 27
DYE CONCENTRATIONS (ppb) IN ELLISON LAKE
JULY 28, 1972
1200 hr

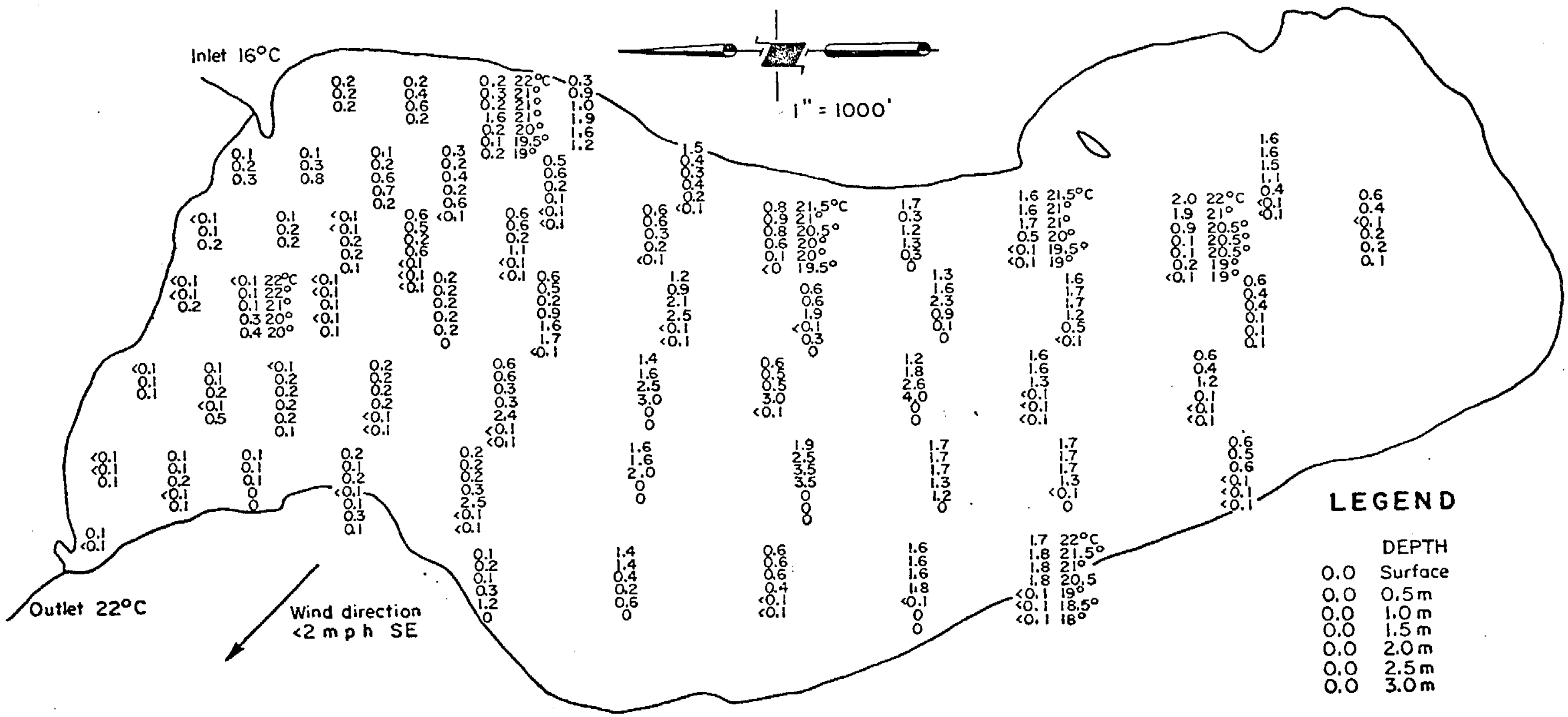


Figure 28
MAIN PATHS OF DYE IN ELLISON LAKE
JULY 27 AND JULY 28, 1972

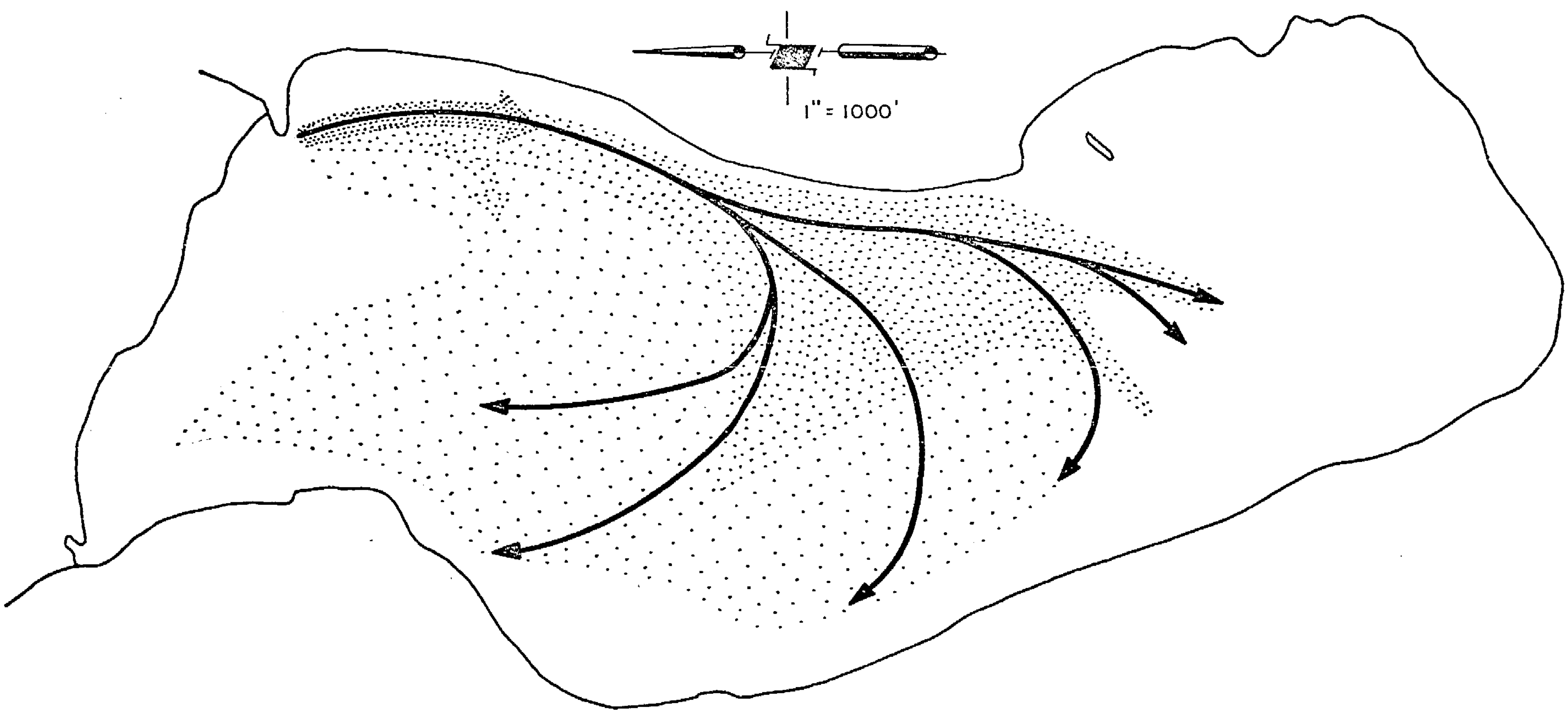
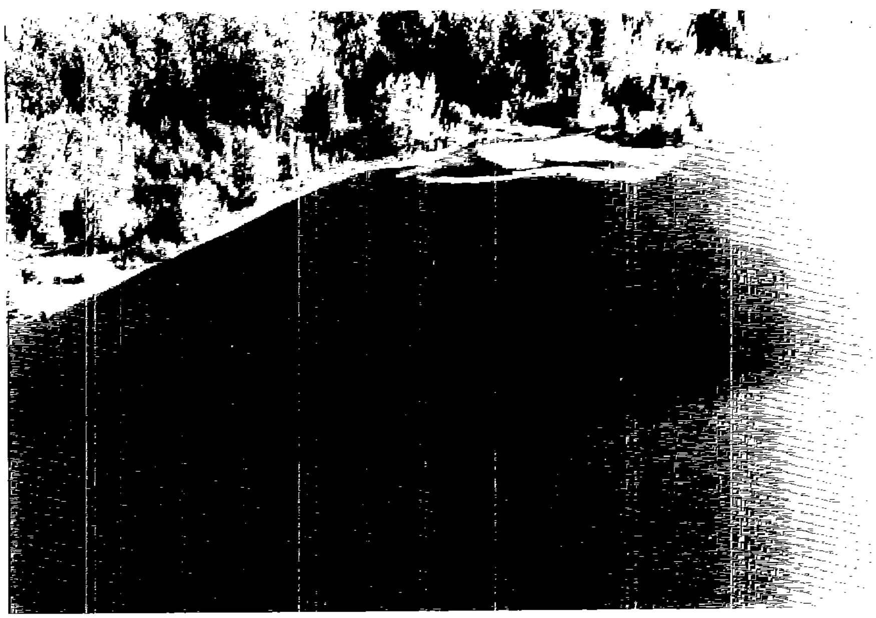


FIGURE 29

(a)

(b)



Dye Plume at Vernon Creek Inlet to Ellison Lake, October 4, 1972

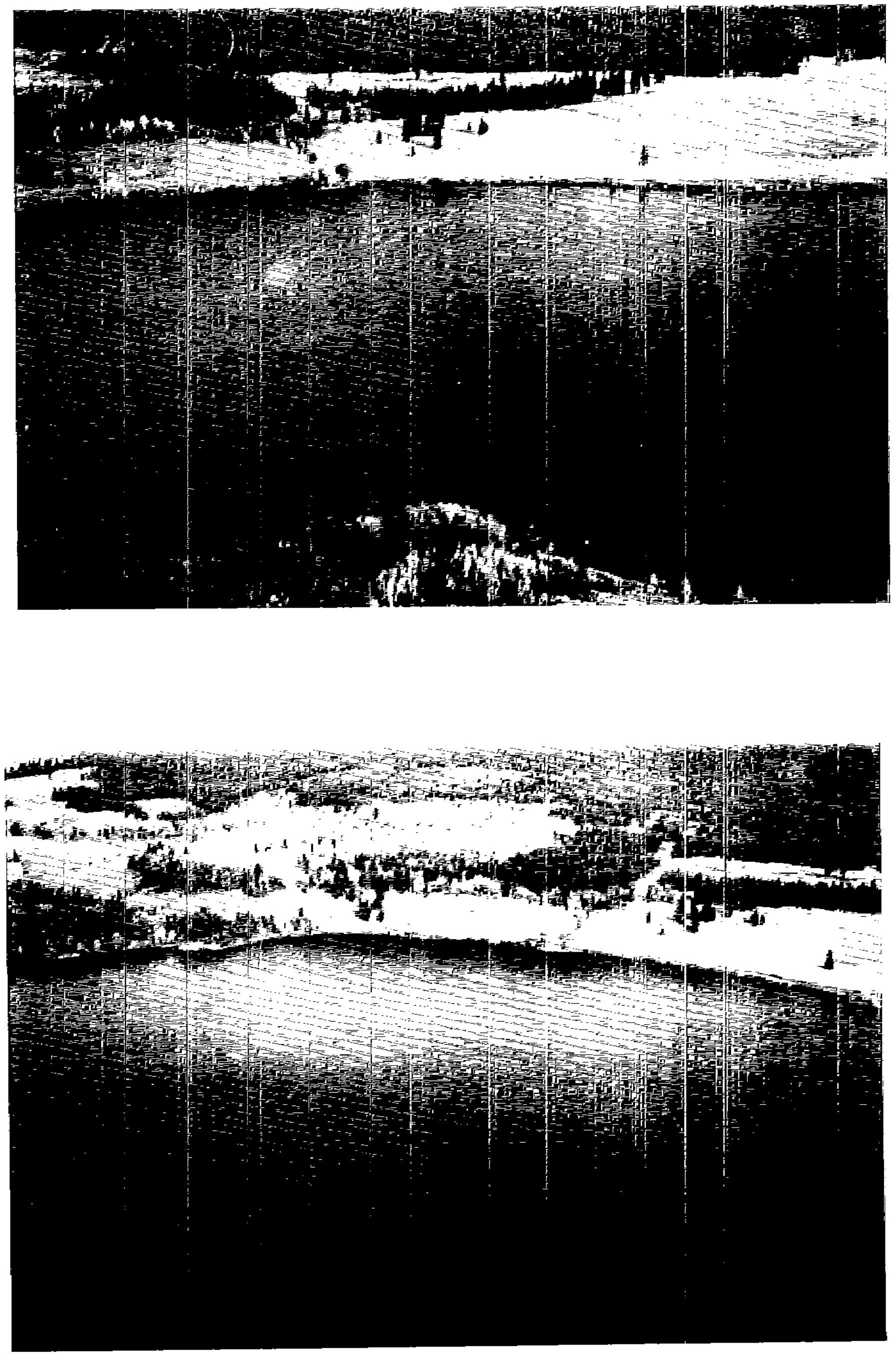
(a) 20 Minutes after Introduction
(b) 70 Minutes after Introduction

Different conditions prevailed during the next dye study carried out on July 27, 1972. The distillery was operating and the flow of Vernon Creek water entering Ellison Lake was 6.4 cfs. Between 09:20 hr and 09:40 hr, the temperature of Vernon Creek was 17.5C while Ellison Lake had temperatures at the surface of 24-25C declining to 19.2C at depth. The temperature of the water flowing out of Ellison Lake was 25C. Dye movements were traced fluorometrically 2 1/2 hr after addition. The dye did not disperse laterally but veered along the east shore of the lake in a narrow path. Concentrations fo the dye were higher at depth due to the colder, dense inflowing water moving beneath Ellison Lake water. The dye moved at a speed of about 500 ft/hr. Results of fluorometric measurements are shown in Figure 24 and the photographs in Figure 25 illustrate the narrow path taken by the dye. Further observations were carried out at 15:00 hr when the dye was more dispersed as shown in Figure 24. A minor component moved along the north shore; the major component tracked along the eastern shore of Ellison Lake and at distance from the inlet tended to rise towards the surface. Aerial photographs taken at this time (Figure 26) show the dye dispersal and the tendency to track in the center of Ellison Lake. Movement of water away from the eastern lakeshore was probably aided by the slight southeast wind. By 18:00 hr the dye was far more dispersed than previously recorded and measurable concentrations were found about 4500 ft from the inlet. Considerable lateral dispersion of the dye had taken place by this time.

Additional fluorometric measurements were carried out at 12:00 hr the following day. The results are shown in Figure 27. The dye was extensively distributed and although the highest concentrations were found well into Ellison Lake, measurable concentrations were also found close to the lake outlet. On this occasion the main movement of Vernon Creek water entering Ellison Lake was to the south of the lake. However, a small volume of the inflowing water left the lake within 24 hr. The main dye paths recorded between July 27 and 28, 1972 are shown in Figure 28.

A dye study was carried out on the 4th October, 1972, when Ellison Lake was isothermal at 11C; inflowing Vernon Creek water was 17C and entering at a rate of 9.9 cfs. Between 10:20 hr and 10:45 hr, 5 gal 20% Rhodamine WT were added to inflowing Vernon Creek water. At this time, configuration of the delta where Vernon Creek enters Ellison Lake deflected the inflowing water along the north shore. The warmer inflowing creek water flowed on the surface of Ellison Lake and a series of aerial photographs were taken to illustrate the movement of the dye (see Figures 29 and 30). A relatively strong northeasterly wind (15-20 mph) affected dye migration and

FIGURE 30



Dye Plume Parallel to the East Shore in the North End of Ellison Lake
Four hr after Introduction at Inlet, October 5, 1972

Figure 31
DYE CONCENTRATIONS (ppb) IN ELLISON LAKE
OCTOBER 4, 1972
1430 hr

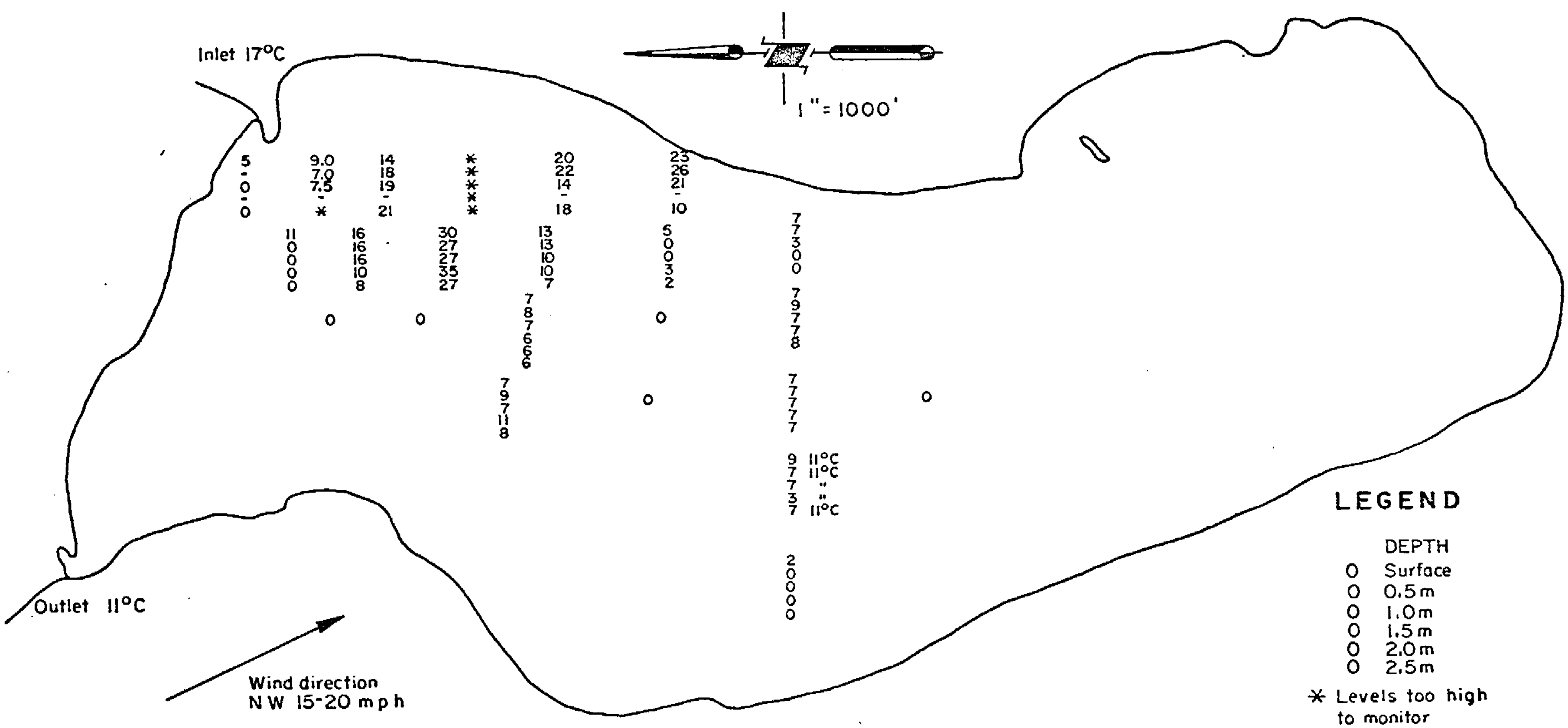
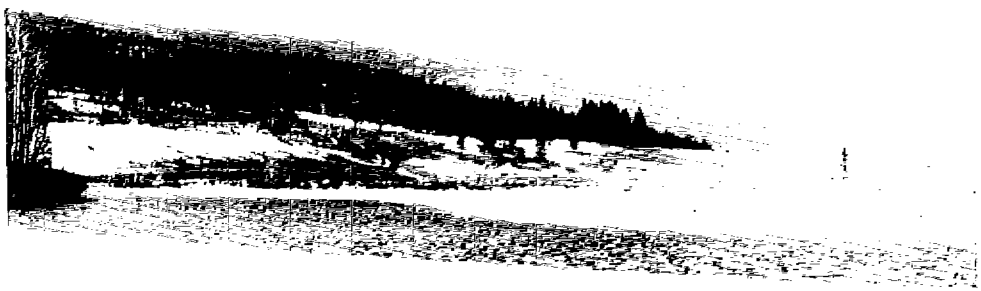


FIGURE 32



(a)

(b)

The Effect of Vernon Creek and the Distillery on Ice Cover of Ellison Lake.

(a) January 1972
(b) January 1973

Inlet Bottom Center
Outlet Upper Right

promoted general water movement to the south of Ellison Lake. Fluorometric measurements were started approximately 5 hr after dye addition. The results are shown in Figure 31. Dye movement and dispersal was rapid and confined in general to the upper layers. The wind aided rapid dispersion and dye travelled at a mean speed of approximately 850 ft/hr for 4 hr after input. There was only limited dye movement along the north shore. By October 5, the inflowing water had mixed with the main body of Ellison Lake and low dye concentrations were observed in the southeast corner of the lake.

Drogue studies were carried out on a number of occasions to trace the approximate path of Vernon Creek water in Ellison Lake. Drogue depths were 0, 0.5, 1.0, 1.5 and 2.0 m. The results of these tests showed that Vernon Creek water occasionally passes along the north shore of Ellison Lake. Surface waters in Ellison Lake were always subject to wind action and this greatly affected water movements. Southerly winds tended to move surface drogues along the north shore of the lake, while the wind did not influence the movement of subsurface drogues to the same extent. Short-circuiting of Vernon Creek water was often indicated when Vernon Creek temperature was lower than that of the lake water.

Drogue studies were carried out to determine the pattern of water movement in an arc 200 yards from the outlet of Ellison Lake. A series of drogues were released along this arc and in each case the drogues moved towards the lake outlet.

Ellison Lake is ice-covered to a depth of about 2 ft for approximately four months in winter. During this time, Vernon Creek is at a markedly higher temperature than the lake, due to the content of cooling water from the distillery. Before ice cover the incoming water therefore flows on the surface of Ellison Lake and is readily dispersed along the north side of the lake by the prevailing southerly winter winds. Photographs taken during the winters of 1972 and 1973 (Figure 32) shows how the thermal input from Vernon Creek maintains an ice-free zone from the inlet along the north shore of Ellison Lake. The western part of the ice-free area lies within 600 ft of the outlet from Ellison Lake. Short-circuiting of Vernon Creek water probably occurs during most of the winter period

ii. Kalamalka Lake

The passage of water from Wood Lake into Kalamalka Lake through the Oyama Canal was studied on June 21, 1972; between 10:45 hr and 11:30 hr 3.5 gal 20% Rhodamine WT were added to the Oyama Canal. Throughout the test, water flowed northward through the canal at a rate between 0.5 and 2.0 ft/sec. The wind was SE-SW at less than 5 mph. Thermal conditions in Kalamalka Lake, Wood Lake and the Oyama Canal are listed in the following table.

Depth (m)	Temperature (°C)		
	Kalamalka Lake Station 1	Wood Lake Station 4	Oyama Canal
Surface	15	16	16
2.5	14	16	
5	12	15.5	
7.5	10	12	
10	9	9	
12.5	8	8.5	
15	7	8	

The dye was traced fluorometrically and by aerial photography. The results are shown in Figures 33-38. Lateral dispersion of the inflowing water from Wood Lake into Kalamalka Lake was very limited initially and the dye travelled in a narrow band north into Kalamalka Lake. Vertical dispersion within the lake was limited and the highest dye concentrations were recorded in the upper water layers. The dye moved at a rate of approximately 500 ft/hr, assisted by southerly winds. A weaker component of the dye plume moved west from Oyama Canal but the main passage of water was northeast.

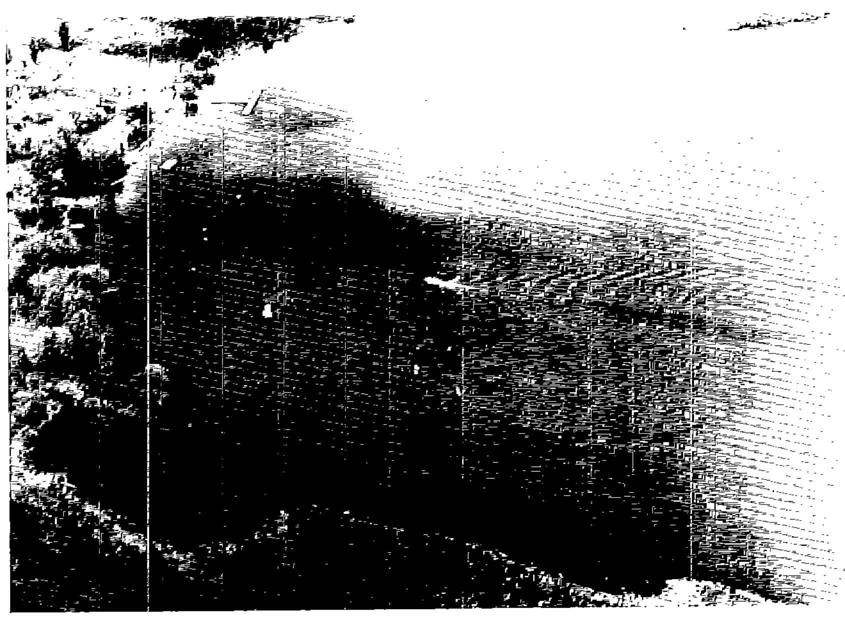
Aerial photographs taken at 15:30 hr showed that the dye was moving around the first point at the southeast end of Kalamalka Lake (see Figure 34). There was still northward movement at about 500 ft/hr and lateral dispersion of the dye plume was apparent. Dye concentrations measured again at 18:30 hr showed that water movement was still N/NE. Vertical and lateral mixing of the water was occurring and high dye concentrations were found at depth as well as at the surface stations. At 18:30 hr marked residence of dye at 1 m depth was noted at many sites close to Oyama Canal; eight hours after addition, the dye had travelled distances up to 1 mile.

On June 22 fluorometric measurements and aerial photographs of the dye plume were again taken. The results are shown in Figures 37-38. Between June 21 and 22, the wind became northerly. Extensive lateral and vertical mixing had occurred 24 hr after dye addition. Throughout this period, the dye moved at a mean

FIGURE 33

(a)

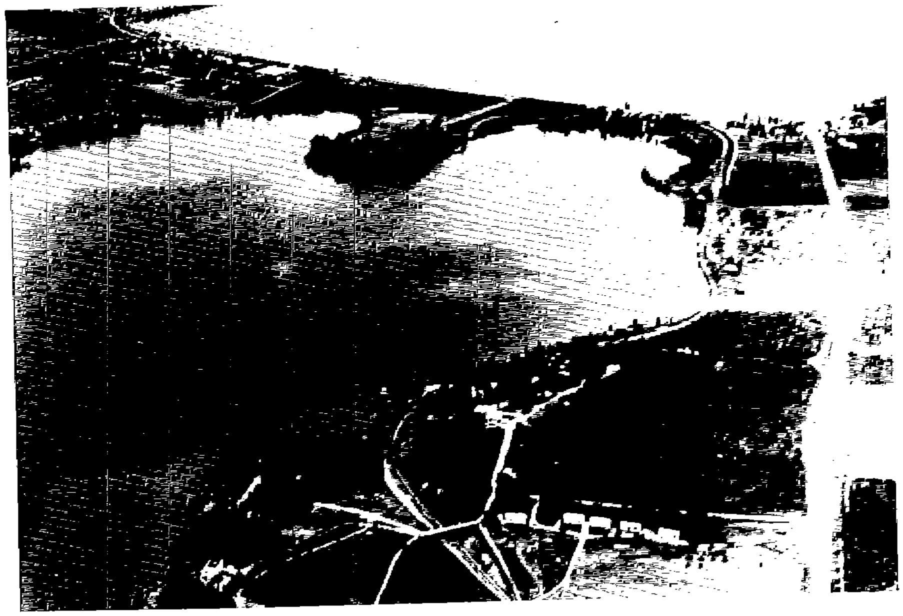
(b)

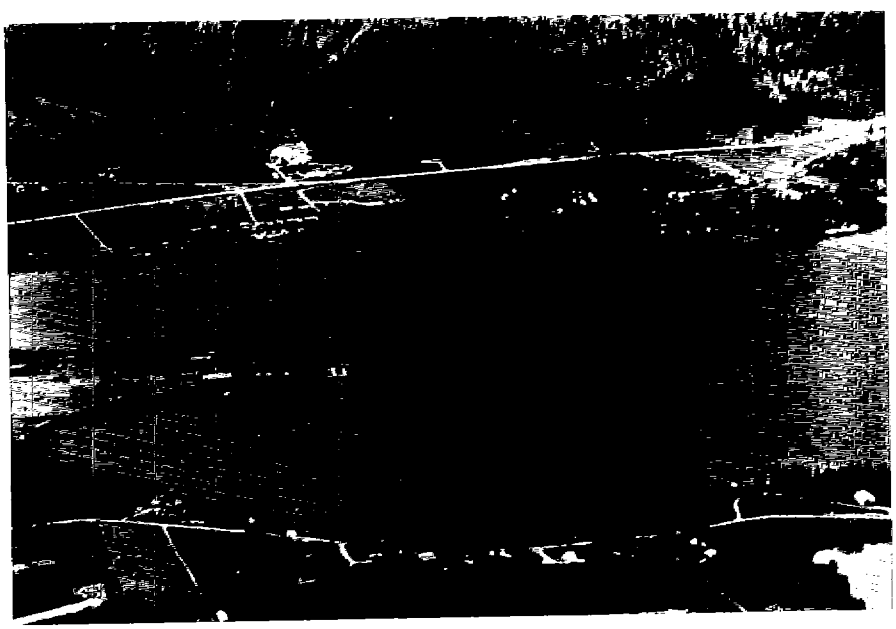


Dye Movement in the South End of Kalamalka Lake after Introduction in Oyama Canal. Plume is Moving North, June 21, 1972

(a) 20 Minutes after Introduction
(b) 30 Minutes after Introduction

FIGURE 34





Dye Movement in the South End of Kalamalka Lake
5 hr after Introduction in Oyama Canal, June 21, 1972

Figure 35

DYE CONCENTRATIONS (ppb) IN KALAMALKA LAKE JUNE 21, 1972

1330 hr

LEGEND

DEPTH
00 Surface
00 1m
00 2m
00 3m
* Levels too high to monitor

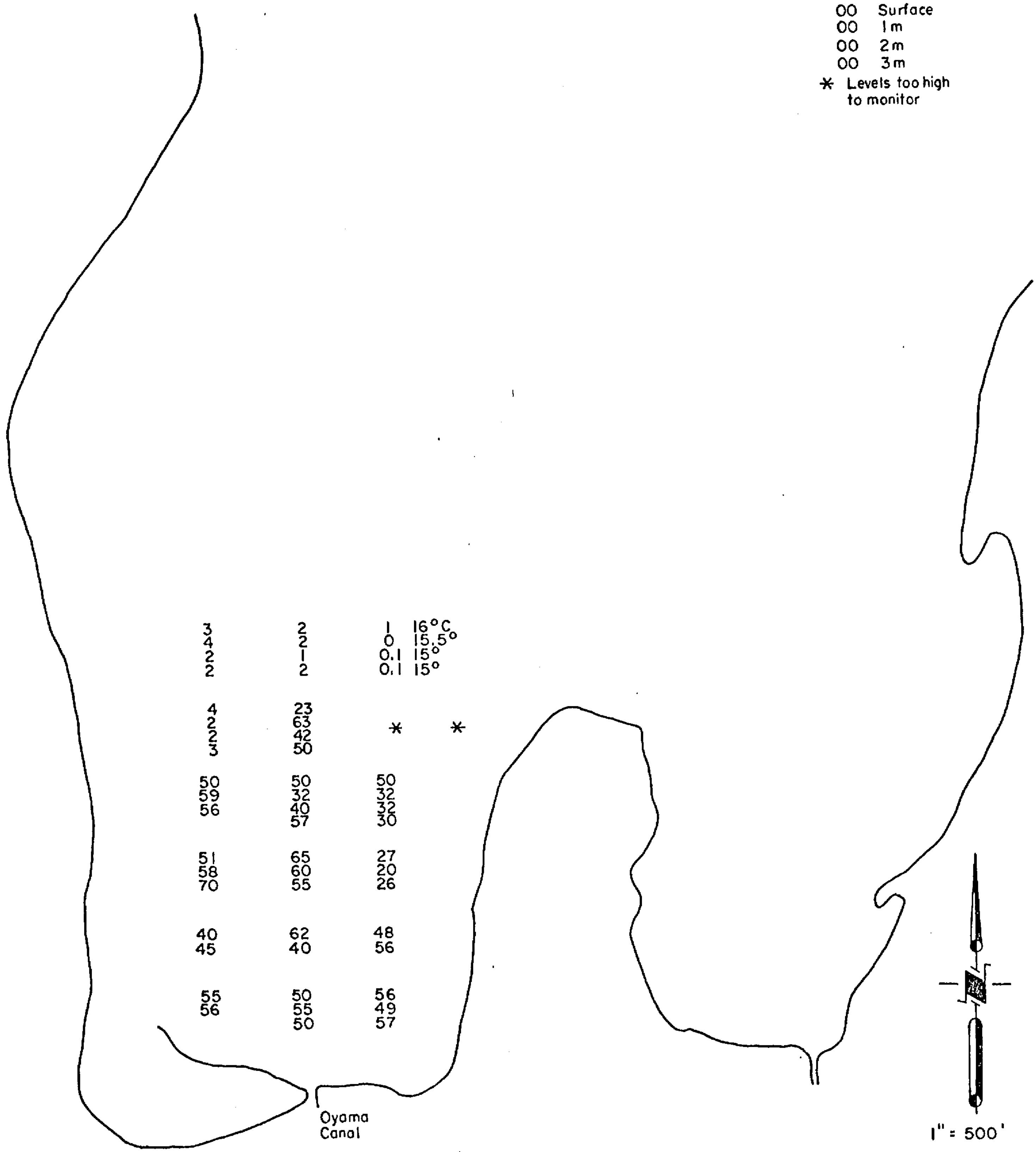


Figure 36
DYE CONCENTRATIONS (ppb) IN KALAMALKA LAKE
JUNE 21, 1972
1830 hr

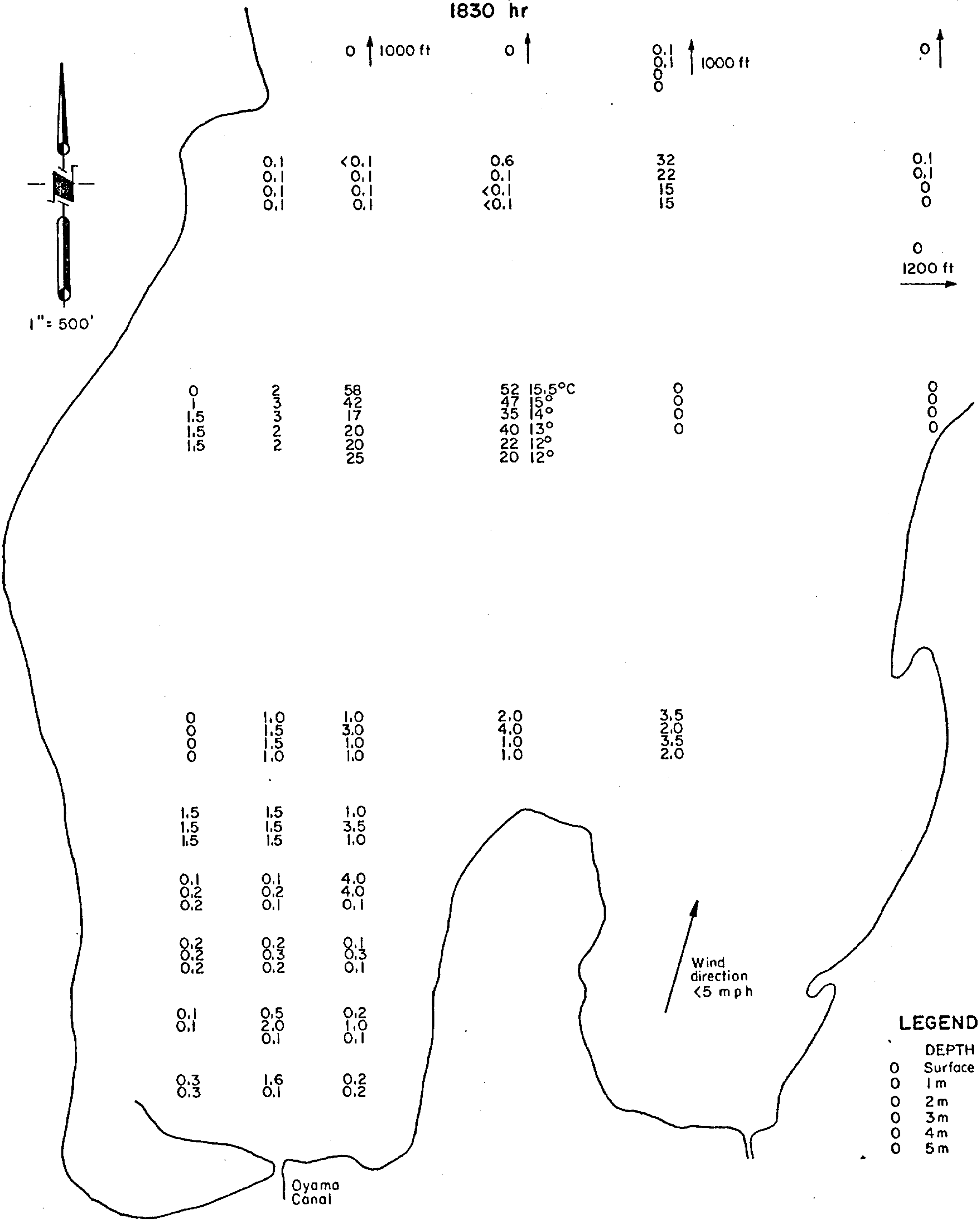


Figure 37
DYE CONCENTRATIONS (ppb) IN KALAMALKA LAKE JUNE 22 AND 23, 1972

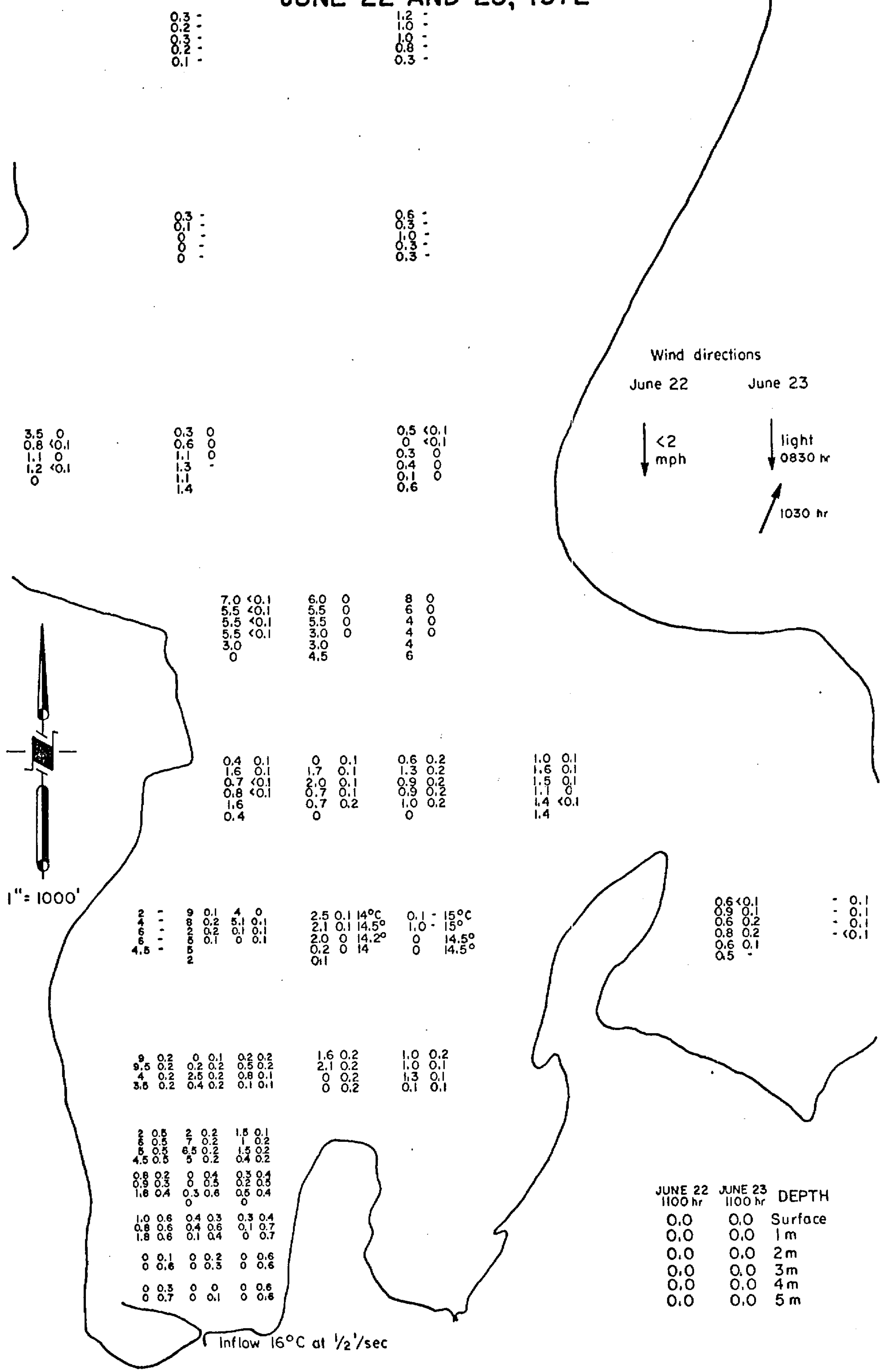


FIGURE 38

Dye Movement in the South End of Kalamalka Lake
22 hr after Introduction in Oyama Canal, June 22, 1972

rate of approximately 350 ft/hr into the lake.

Aerial photographs taken at 11:00 hr on June 22 (Figure 38) showed that dye concentration was greatest close to the southwest shore of Kalamalka Lake. Fluorometric measurements shown in Figure 37 support the observation. On June 23, at 11:00 hr additional fluorometric measurements were made when the dye was no longer visible from the air. A gale-force north wind had blown overnight but at the time of dye measurement the wind was light and variable. The results, shown in Figure 37 contrast with those obtained the previous day, showing the effect of the north wind on dye dispersion. The dye front was no longer at its previous location but had moved south towards Wood Lake. Water temperatures were lower due to water mixing by the north wind. Significant quantities of dye were present near to the Oyama Canal particularly at the 1 m level on June 23, in contrast to the situation on the previous day.

The observed pattern of water movement substantiated deductions from drogue studies on June 20. Results of these studies are shown in Figures 39 and 40. Surface, 1.0, 1.5 and 2 m vane drogues were released close to Oyama Canal. The paths of these drogues were plotted when Wood Lake water was entering Kalamalka Lake at a rate of about 0.5 ft/sec. The wind varied from SE to SW. Surface drogues moved in the direction of the wind at a rate between 400 and 800 ft/hr. Vane drogues at depths of 1, 1.5 and 2 m did not move with the wind but travelled around the Oyama Canal inlet as if in an eddy system (see Figure 36). Only the surface water entering Kalamalka Lake moved into the main body of the lake and the pattern of this movement was directly related to wind action.

A single dye study was carried out to monitor the path of Coldstream Creek water in Kalamalka Lake. On October 12, 1972 5 gal 20% Rhodamine WT were added at the mouth of the creek. The surface water in Kalamalka Lake was much warmer than the incoming creekwater which plunged deep into the lake. The dye was not detected by fluorometry. The situation appears to be constant under these conditions. In April, lake temperatures are generally lower than those of inflowing Coldstream Creek water and at such times the creek water would be expected to mix with Kalamalka Lake surface waters. However from May to October lake surface water temperatures are generally higher than those of Coldstream Creek.

Drogue studies showed that Coldstream Creek water enters Kalamalka Lake and plunges to a level of similar temperature.

On one occasion the inflowing water temperature was 10C. Drogues were placed around the inlet area and only the surface drogues

Figure 39
DROGUE MOVEMENTS IN KALAMALKA LAKE
JUNE 20, 1972

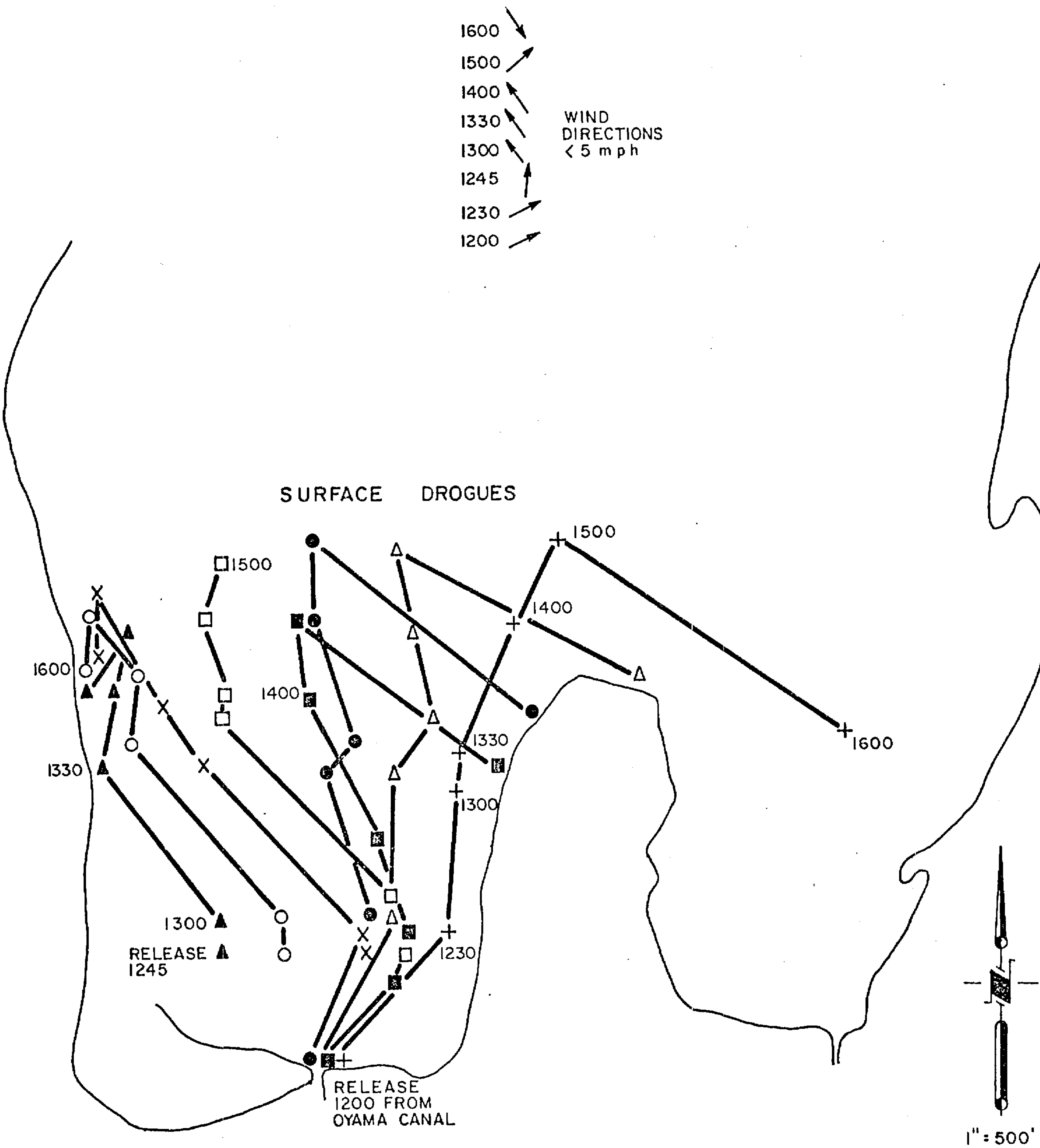


Figure 40
DROGUE MOVEMENTS IN KALAMALKA LAKE
JUNE 20, 1972
1200 to 1600 hr

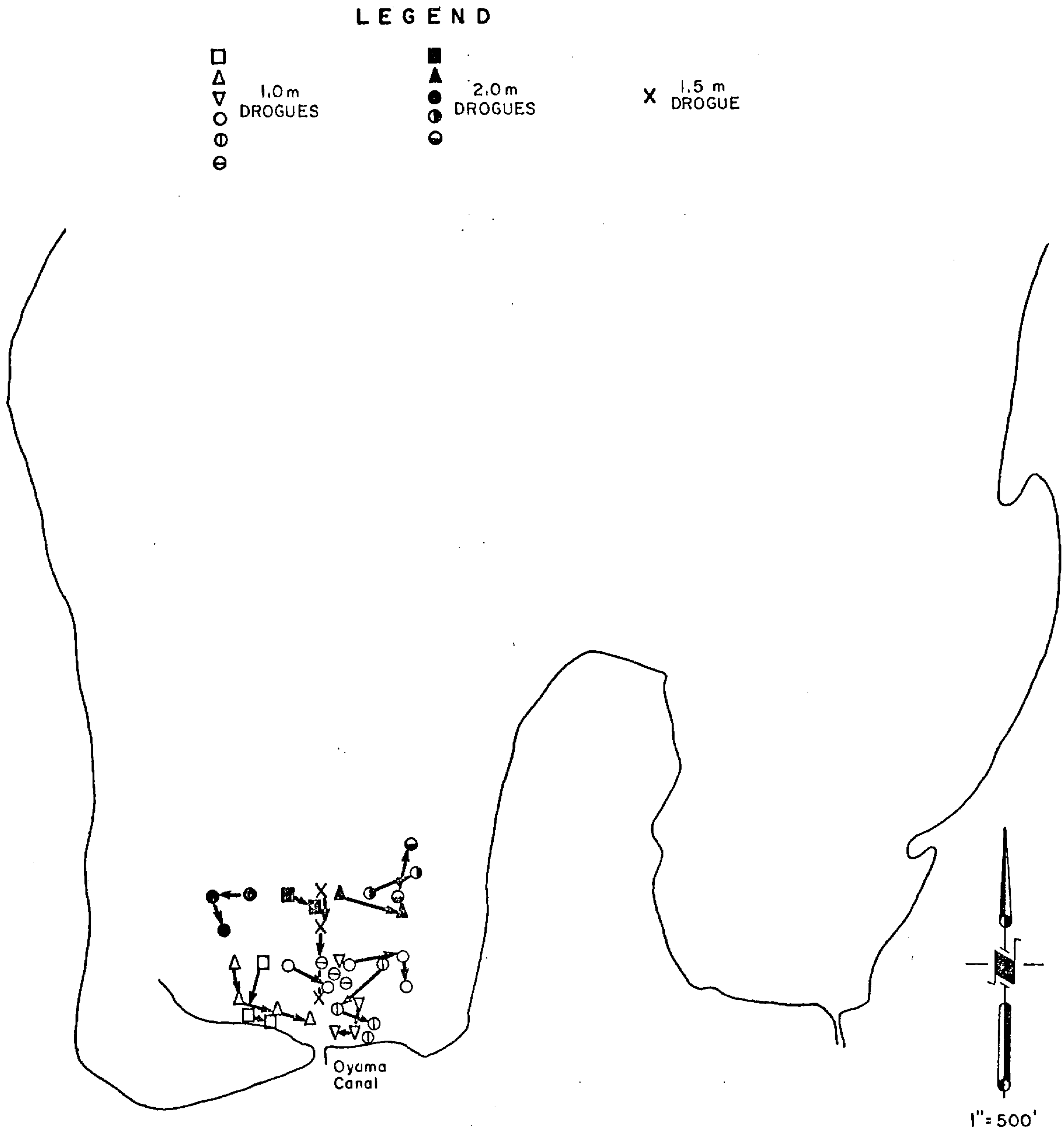
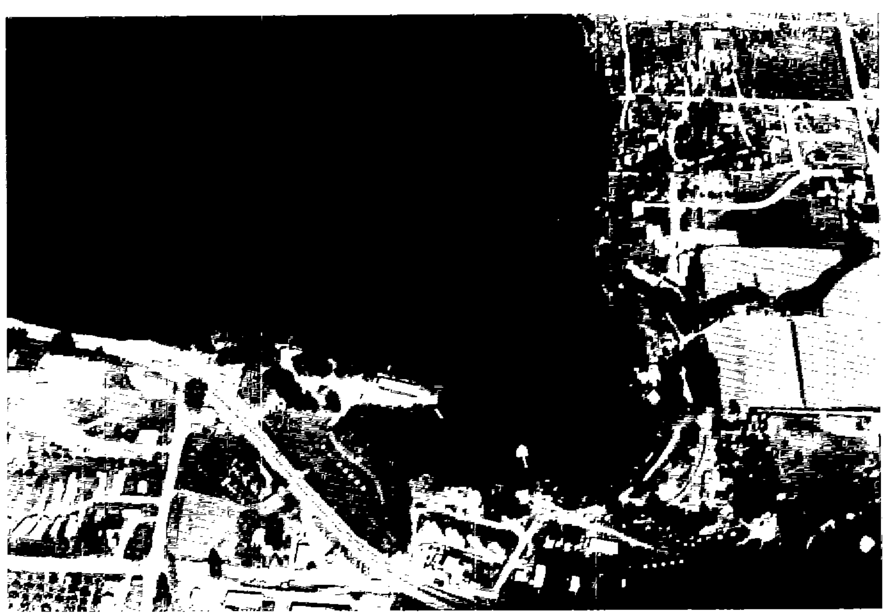


FIGURE 41



Solids Transport into the South End of Wood Lake by Vernon Creek
June 1, 1972

FIGURE 42

Solids Transport into the South End of Wood Lake by Vernon Creek
June 22, 1972

FIGURE 43

(a)

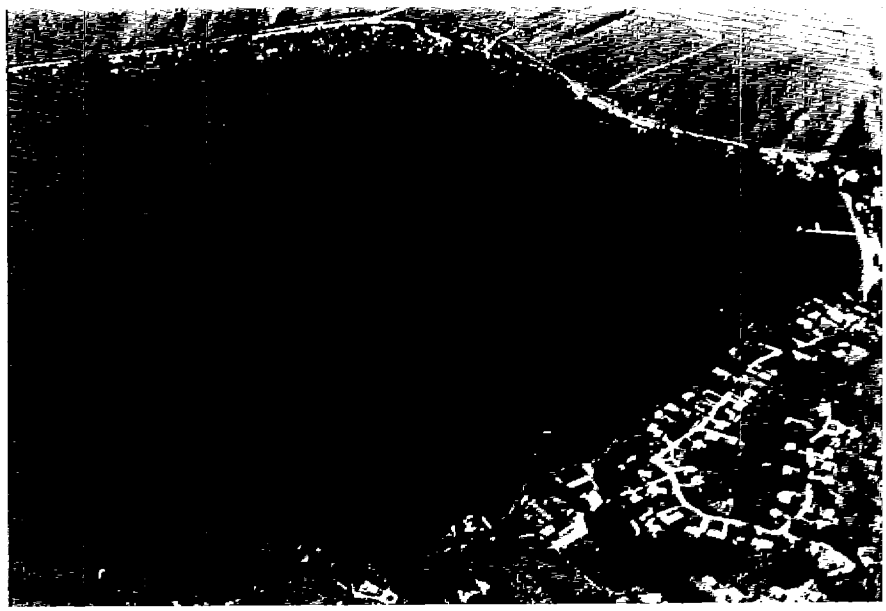
Solids Transport into the North End of Kalamalka Lake by Coldstream Creek

(a) May 18, 1972
(b) June 1, 1972

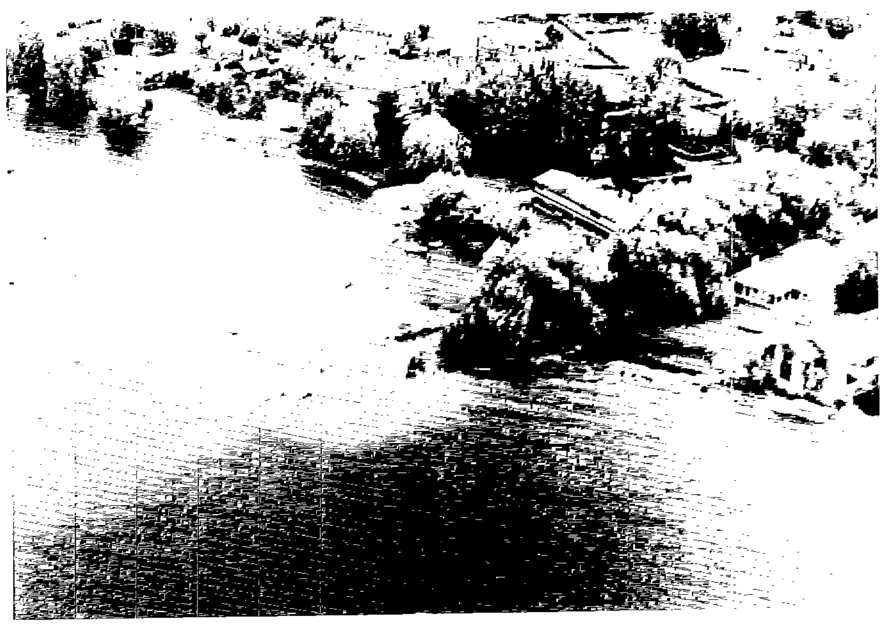
(b)

FIGURE 44

(a)



(b)



Solids Transport into the North End of Kalamalka Lake by Coldstream Creek

(a) June 1, 1972
(b) June 1, 1972

remained stationary and the 7 m depth vane drogues moved during the day. At this depth the temperature in Kalamalka Lake was 10C. Movement of the 7 m depth drogues was along the east side of the lake.

Water from Coldstream Creek does mix with the main water body in Kalamalka Lake on some occasions as shown by observations of suspended solids movements.

j. Water Movement Monitored by Solids Transport During Spring Runoff

Aerial photographs of solids transport into Wood Lake from Vernon Creek were taken on June 1 and June 22 (Figure 41 and 42). On the first date water movement was towards the west side of the lake and solids accumulated in the southwest corner. On June 22 Vernon Creek flow was lower than on June 1 and the plume of suspended matter moved towards the middle of Wood Lake.

Figure 43 and 44 show the input of suspended solids to Kalamalka Lake from Coldstream Creek during spring runoff. A component of the water moved south into the main body of the lake, but water movement also proceeded east and west of the inlet.

The photographs indicate tendencies in solids deposition at the mouth of the creek. This may be a major factor with respect to weed growth around the Vernon Arm of Kalamalka Lake. The area is used extensively for recreation.

3. Trace Metal Concentrations in Lakes and Surface Waters

During October and November, 1972 creek and lake sites were sampled for analysis of their metal content. The samples were acidified immediately on collection, before filtration, to minimise metal losses through adsorption onto the container. Only total metal concentrations were measured, therefore. Earlier measurements showed negligible differences between total and dissolved calcium or magnesium. The samples were collected at a low-flow period of the year when dissolved metal concentrations are probably highest.

a. Creek Samples

Sites on Vernon, Winfield, Coldstream and Oyama Creeks, Hiram Walker outfall and the Oyama Canal were sampled up to three times for heavy metal determinations. Individual values or ranges of values, where appropriate, are shown in Table 32. Calcium, magnesium, sodium and potassium concentrations are also given.

Overall concentrations of copper, zinc, manganese, cobalt and nickel were low, as expected for moderately hard water. Comparatively high iron concentrations were detected at some sites.

Table 32

TOTAL CONCENTRATIONS OF SELECTED METALS IN CREEKS, OCTOBER - NOVEMBER, 1972

Site Number 8NM-	Copper (μg/1)	Zinc (μg/1)	Iron (μg/1)	Manganese (mg/1)	Calcium (mg/1)	Magnesium (mg/1)	Sodium (mg/1)	Potassium (mg/1)
22	1.0	5 - 8	150	7.5 - 14	6.1	2.0	1.0 - 1.7	1.0
Hiram Walker outfall	7.0	7 - 13	120	0.5	33	8.0	7.9	2.4
162	6.0	7 - 21	18	4.5	30	8.0	7.7	2.3
182	1.0 - 3.0	4 - 8	40	7 - 20	16.6	5.2	2.6	1.8
9	3.0 - 7.0	6 - 10	54	20 - 50	23.5	8.8	3.8 - 6.9	2.2
181	0.8 - 1.5	11 - 13	22 - 33	14 - 16	57	15.8	15.0	3.5
66	1.5	4 - 6	9 - 40	1.0	24	16.9	17.0	4.3
48	2.0	4 - 14	28 - 280	1.0	6.1	2.0	2.1	1.1
124	1.5	6	9	2.0	74	14.5	-	-
179	1.6 - 6.0	6 - 13	22 - 23	6 - 11	65	21.7	26.5	6.3
65	1.0 - 4.5	5 - 13	15 - 18	1.0	35	16.5	17.0	4.8
160	2.0 - 4.4	10 - 18	19 - 82	14 - 17	65	21.7	26.5	6.3

Cobalt <0.5 μg/1 at all sites.

Nickel <2 μg/1 at all sites.

Copper concentrations were between 0.0008 mg/l and 0.007 mg/l. The lowest value was found in Winfield Creek, a stream originating as groundwater. The highest copper level was detected in the cooling water outfall from Hiram Walker distillery and on one occasion at Station 8NM-9, where Vernon Creek enters Wood Lake. Zinc concentrations were in the range 0.004-0.021 mg/l. Higher values were generally found at the entrances to lakes. Iron and manganese concentrations were more varied than other metals. Iron levels were between 0.009 mg/l and 0.280 mg/l and manganese concentrations were 0.0005-0.050 mg/l. Cobalt and nickel concentrations were below detection limits. Sodium and potassium levels ranged from 1.0-26.5 mg/l and 1.0-6.3 mg/l, respectively.

b. Swalwell and Oyama Lakes

Metal concentrations at various depths in these lakes are shown in Table 33. In Swalwell Lake, the concentrations of all metals were low and varied only slightly or not at all with depth. In Oyama Lake, the concentrations of zinc and magnanese were comparatively high (0.013-0.024 mg/l and 0.022-0.027 mg/l, respectively). Iron was not measured. The concentration of copper decreased noticeably with increasing depth in Oyama Lake, from 0.0032 mg/l at the surface to 0.0005 mg/l at 20 m.

c. Ellison and Wood Lakes

Heavy metal concentrations except for iron were low, especially in Wood Lake as shown in Table 34. There was little difference between surface and bottom readings in Ellison Lake. However, at Site 4 in Wood Lake, copper concentration decreased from 0.0014 mg/l at the surface to 0.0004 mg/l at 20 m depth. At Site 3 the copper value increased from 0.0005 mg/l at 5 m to 0.0018 at 15 m. Iron reached a maximum value of 0.070 mg/l at 10 m depth at Site 4, compared with 0.016 mg/l at 2.5 m and 0.022 mg/l at 20 m. Other metals showed little or no variation with depth or location in Wood Lake.

d. Kalamalka Lake

Concentrations of heavy metals shown in Table 35 were generally lower in Kalamalka Lake than in the other lakes. There was a slight trend towards decreasing concentrations of copper, zinc, and manganese with increasing depth. Copper values ranged from 0.0003-0.0024 mg/l, zinc was between 0.002 mg/l and 0.012 mg/l, iron ranged from 0.007 mg/l to 0.028 mg/l and manganese from 0.0002 mg/l to 0.0009 mg/l. Sodium, potassium, calcium and magnesium figures were essentially constant.

Table 33

TOTAL CONCENTRATIONS OF SELECTED METALS IN SWALWELL AND OYAMA LAKES, OCTOBER, 1972

Lake	Depth (M)	Copper (μg/1)	Zinc (μg/1)	Iron (μg/1)	Manganese (mg/1)	Calcium (mg/1)	Magnesium (mg/1)	Sodium (mg/1)	Potassium (mg/1)
Swalwell	0	2.4	1.2	80	6	6.0	1.6	1.8	1.0
	2.5	2.4	4.2	90	8	6.0	1.5	1.8	1.0
	5	1.1	-	90	6	6.0	1.6	1.8	1.0
	7.5	0.5	7.4	90	-	6.0	1.6	1.8	1.0
	10	-	4.6	90	6	6.0	1.6	1.8	1.0
	12.5	1.3	4.6	90	7	6.0	1.6	1.8	1.0
	15	1.6	4.6	90	-	6.1	1.6	1.8	1.0
Oyama	0	3.2	-	-	22	4.1	1.5	1.9	1.1
	2.5	2.2	-	-	22	4.1	1.5	1.9	0.9
	5	0.8	24	-	26	4.1	1.5	1.9	1.0
	7.5	0.8	24	-	26	4.1	1.5	1.9	1.0
	10	0.6	-	-	25	4.1	1.5	1.9	1.0
	12.5	0.3	11	-	26	4.1	1.5	1.9	1.0
	15	0.7	-	-	24	4.1	1.5	1.9	1.0
	20	0.5	13	-	27	4.1	1.5	1.9	1.0

Cobalt <0.2 μg/1 at all sites.

Nickel <1 μg/1 at all sites.

Table 34

TOTAL CONCENTRATIONS OF SELECTED METALS IN WOOD AND ELLISON LAKES, OCTOBER, 1972

Lake and Site Number	Depth (M)	Copper (µg/l)	Zinc (µg/l)	Iron (µg/l)	Manganese (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)
Wood 1	0	1.1	5	17	0.5	24.5	17.5	17.0	4.2
	5	1.2	2	14	-	24.5	17.5	17.0	4.2
	15	1.1	2	17	0.4	24.5	17.5	17.0	4.5
Wood 3	0	0.5	2	20	0.4	24.5	17.0	17.0	4.2
	5	0.5	2	15	0.4	24.5	17.0	17.0	4.2
	15	1.8	2	19	0.4	24.5	17.0	17.0	4.2
Wood 4	0	1.4	3	26	0.4	24.5	17.5	16.5	4.3
	2.5	0.9	3	16	0.4	24.5	17.5	16.5	4.2
	5	0.6	3	16	0.6	24.5	17.5	16.5	4.2
	7.5	0.6	3	25	0.4	24.5	17.5	16.5	4.2
	10	0.6	3	70	0.4	24.5	17.5	16.5	4.2
	12.5	0.5	4	46	0.5	24.5	17.5	16.5	4.2
	15	0.6	3	36	0.4	24.5	17.5	18.0	4.2
	20	0.4	2	22	0.4	24.5	17.5	18.0	4.2
Ellison 1	0	4.0	5	40	7.5	15.8	4.9	4.9	1.8
	1.5	4.5	6	51	3.0	-	-	4.7	1.8
	2.5	5.5	5	37	9.0	-	-	4.7	1.8
	3.0	4.0	2	48	9.0	16.9	5.4	4.7	1.8

Cobalt <0.5 µg/l at all sites.

Nickel <2 µg/l at all sites.

Table 35

TOTAL CONCENTRATIONS OF SELECTED METALS IN KALAMALKA LAKE, OCTOBER, 1972

Site Number	Depth (M)	Copper (µg/1)	Zinc (µg/1)	Iron (µg/1)	Manganese (mg/1)	Calcium (mg/1)	Magnesium (mg/1)	Sodium (mg/1)	Potassium (mg/1)
0	0	0.5	8	28	0.4	36.5	17.0	15.8	4.8
	1	1.0	8	12	0.4	36.5	17.0	15.8	4.8
	2	0.75	6	14	0.4	36.5	17.0	15.8	4.8
	3	-	4	15	0.4	36.5	17.0	15.8	4.8
1	0	0.8	3	12	0.8	37.0	17.5	16.5	5.0
	2.5	0.8	10	13	0.9	37.0	17.5	16.5	5.0
	5	0.4	10	10	0.8	37.0	17.5	16.5	5.0
	15	0.4	5	8	0.8	37.0	17.5	16.5	5.0
2	0	0.4	14	8	0.8	36.5	17.5	16.5	5.0
	2.5	0.6	4	8	0.8	36.5	17.5	16.5	5.0
	5	-	10	8	0.8	36.5	17.5	16.5	5.0
	10	0.6	12	8	0.6	37.0	17.5	16.5	5.0
	15	0.3	5	8	-	36.5	17.5	16.5	5.0
	20	0.3	4	8	0.6	38.0	17.5	16.5	5.0
	50	0.3	4	8	0.5	38.5	17.5	16.5	5.0
3	0	0.8	2	7	0.8	37.0	17.5	15.9	5.0
	2.5	2.4	7	-	-	36.5	17.5	15.9	5.0
	5	-	7	-	-	36.5	17.5	15.9	5.0
	10	2.4	5	-	-	36.0	17.5	15.9	5.0
	15	1.4	4	-	-	36.5	17.5	15.9	5.0
	20	1.6	5	8	0.4	38.0	17.5	15.9	5.0
	75	0.8	5	14	0.2	38.5	17.5	15.9	5.2
4	0	1.0	4	-	0.5	36.5	17.0	15.9	5.2
	5	0.8	5	9	0.5	36.5	17.0	15.9	5.2
	15	0.6	4	-	0.4	36.5	18.0	15.9	5.2

Cobalt <0.5 µg/1 at all sites. Nickel <2 µg/1 at all sites.

Table 36

CONCENTRATIONS (DRY WT.) OF SELECTED NUTRIENTS IN LAKE SEDIMENT

Lake	Site	Depth (M)	Kjeldahl Nitrogen (g/Kg)	Phosphorus (g/Kg)	Carbon (g/Kg)
Swalwell	1	15	10.7	1.8	10.0
Oyama	1	20	14.0	1.2	13.5
Ellison	2	3.5	3.8	1.9	2.6
Wood	4	22	8.2	1.4	6.0
Kalamalka	1	80	1.6	0.8	1.8

4. Sediment Analyses

Values for TKN, phosphorus and organic carbon of bottom sediments in Swalwell, Oyama, Ellison, Wood and Kalamalka Lakes are shown in Table 36.

Highest values of TKN in bottom sediments were present in headwater lakes; the concentration of TKN in Oyama Lake was 14.0 g/kg, for Swalwell 10.7 g/kg. The headwater lakes also had the highest organic content; 13.5 g/kg in Oyama and 10.0 g/1 in Swalwell Lake.

In the Valley lakes, Wood had the highest values for sediment TKN (8.2 g/kg) and carbon (6.0 g/kg) followed by Ellison (TKN 3.8 g/kg, carbon 2.6 g/kg). The low productivity of Kalamalka Lake was reflected in the values of 1.6 g/kg TKN and 1.8 g/kg organic carbon.

Sediment phosphorus concentrations ranged from 0.8 g/kg in Kalamalka Lake to 1.8 g/kg in Swalwell and 1.9 g/kg in Ellison Lake.

The sediment measurements undertaken in this study were a minor part of the investigation and are not discussed further pending release of the technical report by St. John and co-workers from the Okanagan Basin Study.

F. DISCUSSION

1. Characteristics of Surface Waters

Mean values for the important nutrient characteristics of water quality in the Kalamalka-Wood Lake basin were compared for reference stations.

Nitrate nitrogen concentrations between stations varied widely and the following list tabulates the mean concentrations:-

Station	Location	Mean Concentration (mg/1)
8NM-66	Oyama Canal	0.083
8NM-65	Exit from Kalamalka Lake	0.086
8NM-162	Inflow to Ellison Lake	0.111
8NM-182	Exit from Ellison Lake	0.111
8NM-48	Oyama Creek	0.149
8NM-9	Inflow to Wood Lake	0.382
8NM-160	Inflow to Okanagan Lake	0.536
8NM-181	Winfield Creek	1.263
8NM-179	Coldstream Creek	1.280

Relatively low concentrations of between 0.083 and 0.149 mg/l of nitrate nitrogen were measured at Stations 8NM-66, 65, 182 and 48. A significant elevation to 0.382 mg/l occurred in the mean value for nitrate concentrations in Middle Vernon Creek compared with the upstream reference value of 0.111 mg/l at the exit from Ellison Lake. Nitrate concentrations at Station 8NM-160, the inflow to Okanagan Lake, were elevated by about 6-fold over values measured in Vernon Creek for water leaving Kalamalka Lake.

High values (1.263 mg/l) were measured at Winfield Creek, which is a known groundwater source. Coldstream Creek also had a value of 1.280 mg/l.

This high value for Coldstream Creek can be compared to concentrations measured at upstream stations. Headwater stations on Coldstream Creek (8NM-124) were 0.033 and 0.158 mg/l nitrate during May and November 1972. Lower down the creek, supplementary stations at UBC-7 and UBC-6 assessed land use effects, and results from these stations show that the input of nitrate nitrogen was associated with land-use practices along the creek. A single sample from UBC 7 in September had a concentrations of 0.022 mg/l while at UBC 6 values were 0.970, 2.037 and 1.912 mg/l in September, October and November 1972.

A graded series for mean concentrations of TKN is shown below. There were no sharp jumps in mean values between stations but the highest values of 0.843 and 0.916 mg/l of TKN were recorded at the exit of Ellison Lake and in Vernon Creek above the point of entry to Okanagan Lake.

Station	Location	Mean Concentration (mg/l)
8NM-65	Exit from Kalamalka Lake	0.245
8NM-48	Oyama Creek	0.295
8NM-181	Winfield Creek	0.349
8NM-162	Inflow to Ellison Lake	0.370
8NM-179	Coldstream Creek	0.406
8NM-66	Oyama Canal	0.500
8NM-9	Inflow to Wood Lake	0.547
8NM-182	Exit from Ellison Lake	0.843
8NM-160	Inflow to Okanagan Lake	0.916

Very low concentrations of total phosphorus were measured from the exit of Kalamalka Lake (0.013 mg/l) and at Oyama Creek and Oyama Canal with mean concentrations of 0.024 and 0.049 mg/l respectively. Values between 0.085 and 0.134 mg/l included all but one of the remaining sites and this range corresponded to the difference in concentration between water leaving Ellison Lake (0.085 mg/l) by Vernon Creek and that entering Wood Lake, the bottom end of Middle Vernon Creek (0.134 mg/l). Again, the concentration of phosphorus was highest just above Okanagan Lake at Station 8NM-160 where total soluble phosphorus concentration was elevated to 0.394 mg/l from the value of 0.013 mg/l at the exit of Kalamalka Lake.

The picture for soluble phosphorus was very similar to that for the total phosphorus. Lowest values were observed at the exit of lakes and also in Oyama Creek. Soluble phosphorus content increased from 0.019 - 0.043 mg/l along Middle Vernon Creek and the highest concentration (0.328 mg/l); seven times higher than at any other location was just above the entry of Vernon Creek to Okanagan Lake.

Throughout much of the system, the concentration of water quality characteristics is low. Coldstream Creek has high nitrate nitrogen values, associated with land-use practices within that water shed. Water quality in Vernon Creek just above Okanagan Lake was poor with high concentrations of total phosphorus, total soluble phosphorus and TKN. Although it is not within the terms of reference of this study to examine water quality downstream of the exit of Kalamalka Lake, it is apparent that land-use activities are contributing to the degradation of general water quality between Kalamalka and Okanagan Lakes.

The quantity of nutrients transferred through the Kalamalka-Wood Lake system have been described earlier, in relation to the mean annual rate of transfer through the system and the ratio of nutrient movement to flow in wet and dry years. These data do not require further discussion.

2. Annual Loadings of Nutrients to Ellison, Wood and Kalamalka Lakes

Differences in annual loadings between wet and dry years are greatly influenced by the input of nutrients during freshet. Figures 45, 46 and 47 illustrate the input of total nitorgen and total phosphorus to Ellison, Wood and Kalamalka lakes throughout the study period and illustrate that for each station the massive loading of nutrients, mainly in the particulate form during the spring runoff of 1972 was responsible for the increase in loadings for that year.

The following table summarises the pattern of translocation for total nitrogen, nitrate nitrogen, total phosphorus and soluble phosphorus through the Kalamalka-Wood Lake basin.

Figure 45

CUMULATIVE MONTHLY LOADING OF TOTAL PHOSPHORUS AND TOTAL NITROGEN

Ellison Lake

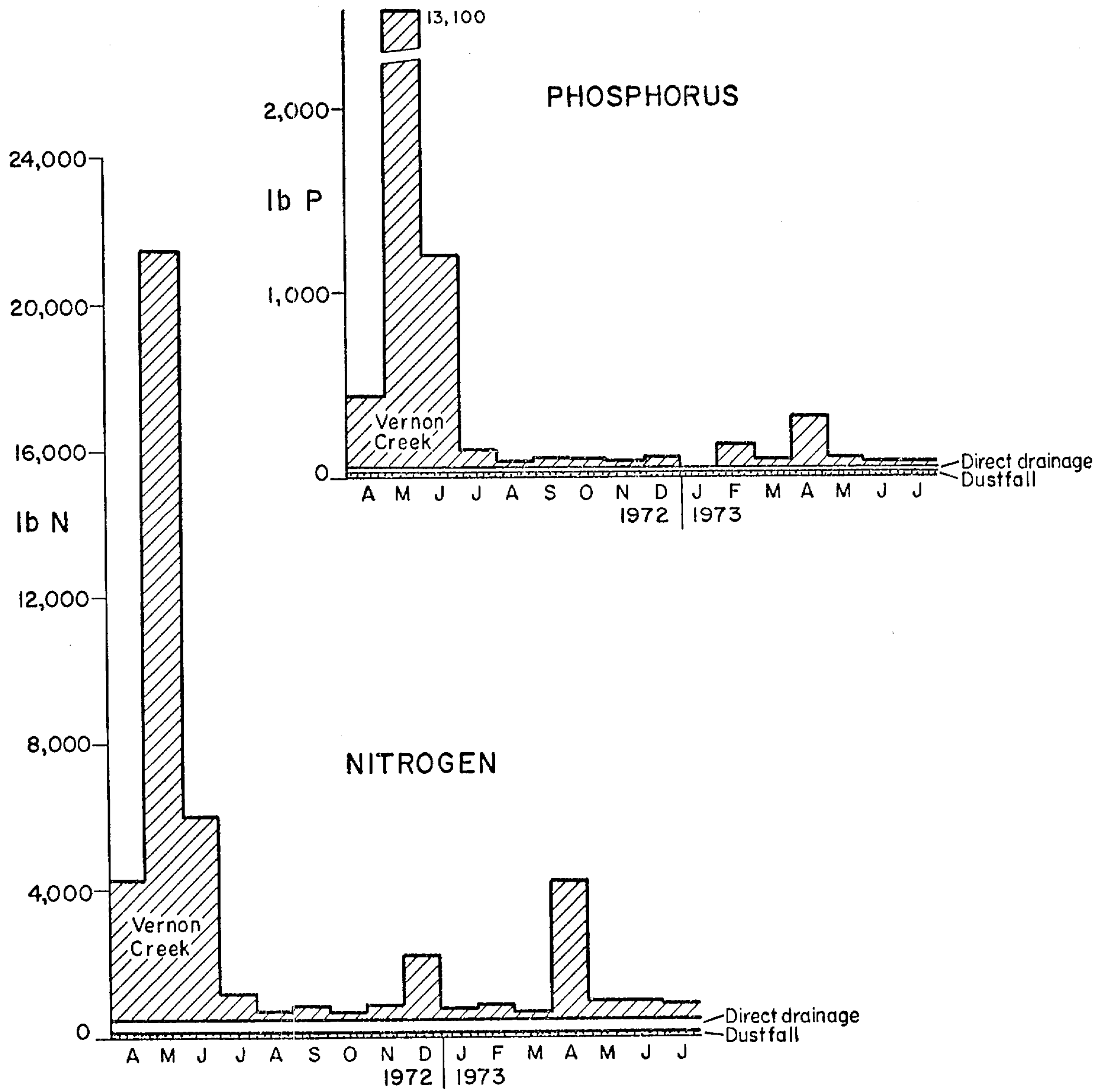


Figure 46
CUMULATIVE MONTHLY LOADING OF TOTAL PHOSPHORUS AND TOTAL NITROGEN
Wood Lake

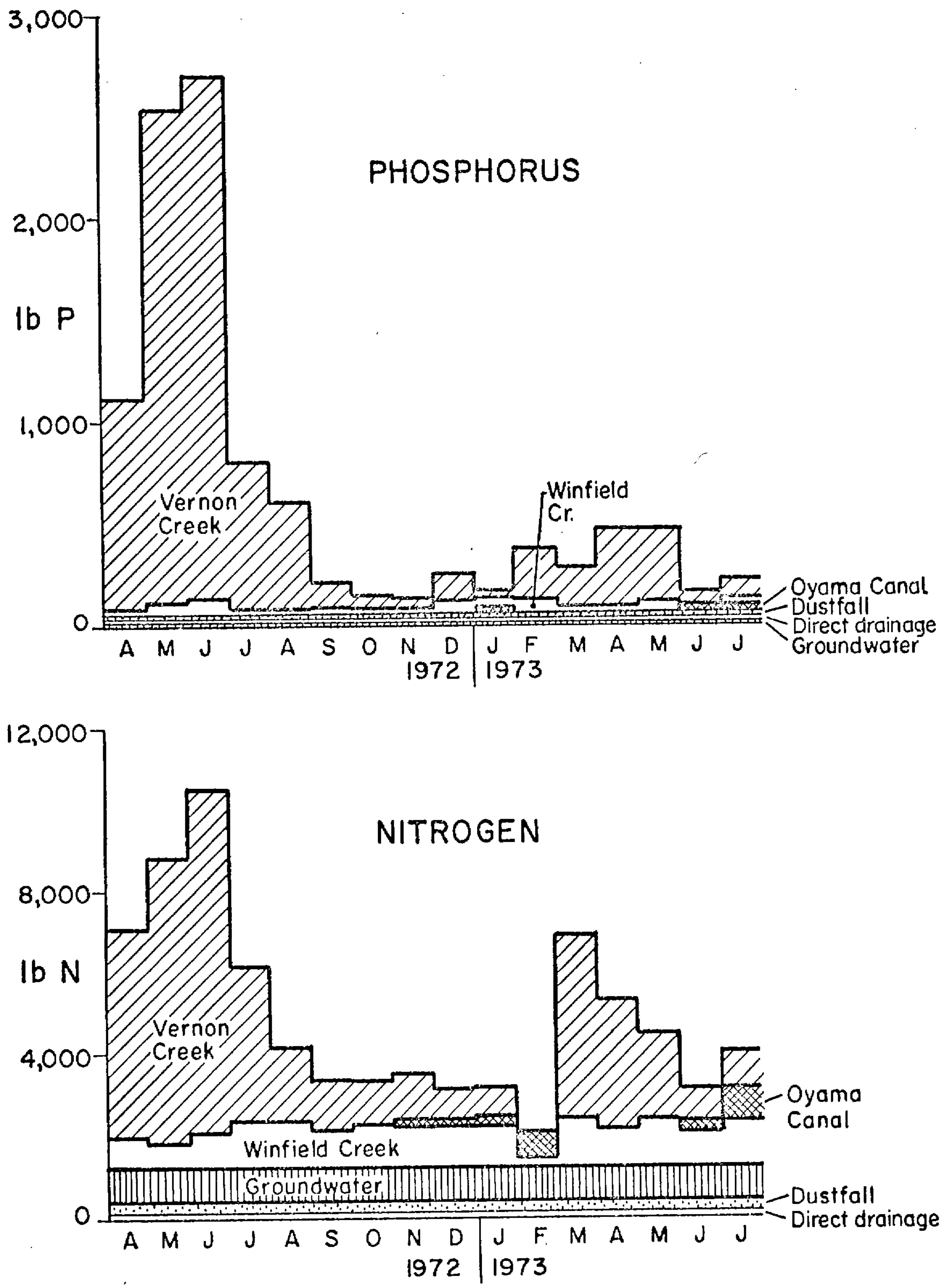
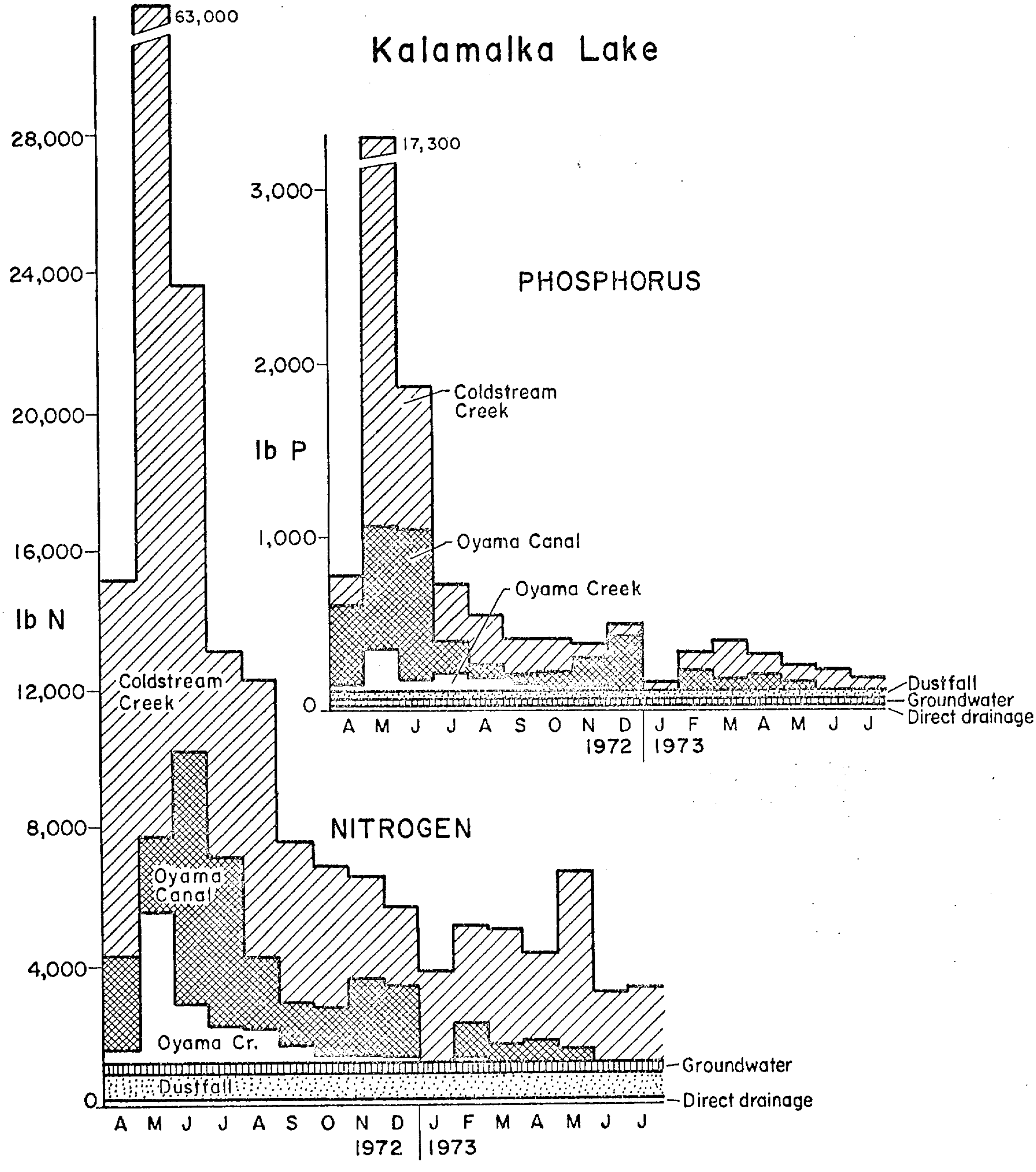


Figure 47

CUMULATIVE MONTHLY LOADING OF TOTAL PHOSPHORUS AND TOTAL NITROGEN



	Total N	Nitrate[1] N	Total P	Soluble[1] P
To Ellison Lake	26,340	4,000	8,290	350
From Ellison Lake	22,000	2,650	3,180	260
% Change	(-16.5)	(-23.7)	(-61.6)	(-25.7)
To Wood Lake	51,700	16,600	5,830	1,380
From Wood Lake	20,500	2,500	2,500	710
% Change	(-60.0)	(-84.9)	(-57.2)	(-48.6)
To Kalamalka Lake	123,670	14,600	14,400	2,370
From Kalamalka Lake	24,500	5,000	1,350	335
% Change	(-80.2)	(-65.8)	(-90.6)	(-85.9)
To Okanagan Lake	168,400	40,000[2]	44,000	28,700
% Change	(+687)	(+800)	(+3,259)	(+8,567)

1 Surface waters only

2 Includes estimated value for 1973

Within Ellison Lake there was a high retention (61.6%) of total phosphorus while the retentions of total nitrogen, nitrate nitrogen and soluble phosphorus ranged between 16.5 and 25.7%. Wood Lake was a more effective pollution sink retaining 60% of the total nitrogen, 84.9% nitrate nitrogen, 57% of total phosphorus and 48.6% of soluble phosphorus. Similarly, Kalamalka Lake was effective in retaining large quantities of inflowing nutrients and between 65 and 90% of nitrogen and phosphorus were held in the lake. Massive accumulations of nitrogen and phosphorus occurred during the passage of water from lower Vernon Creek between Kalamalka and Okanagan lake.

Considering only the net nutrient translocation through the Kalamalka-Wood Lake basin the data illustrate that the system is essentially in balance for the input of nutrients from above Ellison Lake with those leaving Kalamalka Lake or, viewed another way, that the overall retention of nutrients in the Kalamalka Lake basin corresponds roughly to the total of inputs from Coldstream Creek, Oayma Creek, groundwater and direct drainage. Loadings to Okanagan Lake can be considered to mainly originate between the exit of Kalamalka Lake and the north arm of Okanagan Lake. Improvements to water quality within the Kalamalka-Wood Lake basin would not therefore affect Okanagan Lake to any substantial extent.

Vollenweider (1970) plotted surface annual loadings for total phosphorus and total nitrogen in g/m /yr against mean depth for numerous lakes and defines loading levels which corresponded to eutrophic, mesotrophic and oligotrophic loading conditions. Vollenweider stressed that the scheme was simplistic but nonetheless it does provide a procedure to categorize the trophic levels of lakes relative to the input of main nutrients. Interpretation of the data should be carried out with caution. This classification scheme was adopted by investigators under the Okanagan basin study and has also been followed here.

Figure 48 plots annual phosphorus loadings for 1972, 1973 and the mean value for Ellison, Wood and Kalamalka Lakes against mean depth of the lake. No corresponding values for this lake were obtained by the Okanagan Basin study. All values for Ellison Lake fell into the strongly eutrophic range. A similar plot for total nitrogen in Figure 49 shows again that 1972 and 1973 and mean values for Ellison Lake were well into the eutrophic range.

Data for Wood Lake are plotted for nitrogen on Figure 48 and for phosphorus on Figure 49 together with the value reported by the Okanagan study investigators. In our investigations, Wood Lake in terms of nitrogen fell at the lower end of the mesotrophic range but nitrogen loadings were substantially higher than the Okanagan study results which placed Wood Lake in the oligotrophic range. For phosphorus our mean values of surface area loadings were towards the upper end of the mesotrophic range. In 1972 it was within the eutrophic range and in 1973 in the oligotrophic range. The categorisation of the lake agrees quite well with the observed physical and biological conditions that prevailed in these two years. Conditions in 1972 had high nutrient input with low lake transparency and incipient algal blooms occurred. During 1973 in contrast, Wood Lake was relatively clear and the only algal blooms that occurred were in the thermocline and were made up predominantly of green algae (see Appendix 1). Mean values for the Okanagan Basin study were slightly above our 1972 values.

The mean for Kalamalka Lake fell into the oligotrophic range but was more productive than indicated by values reported by the Okanagan Basin Study. Values of phosphorus loading for 1972 were in the mesotrophic range.

Although the classification scheme may have severe limitations, it provides data which corresponded well with observed conditions in the field. One problem relates to the availability of nutrients.

Particularly for Kalamalka Lake many of the nutrients entering may not be readily available for utilisation by phytoplankton. Nutrients entering Kalamalka Lake during the late spring and summer months through Coldstream Creek pass below the epilimnion layer and thus may not be utilised; passive settlement to the bottom coupled with the co-precipitation mechanism proposed by investigators of the Okanagan basin study for the removal of phosphorus from waters in this lake may remove these nutrients

Figure 48

ANNUAL PHOSPHORUS LOADING VERSUS MEAN DEPTH

(From Vollenweider, 1970)

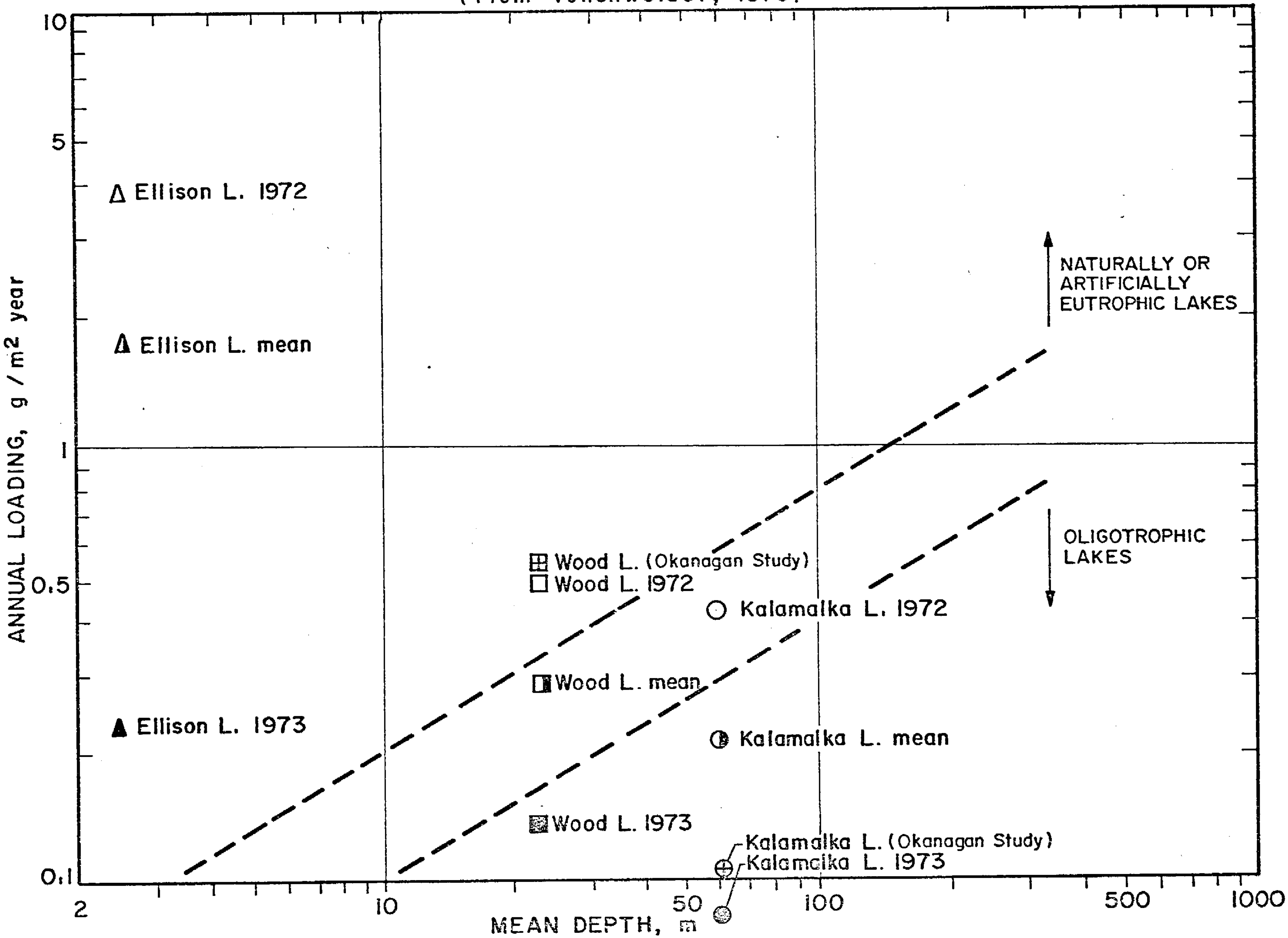
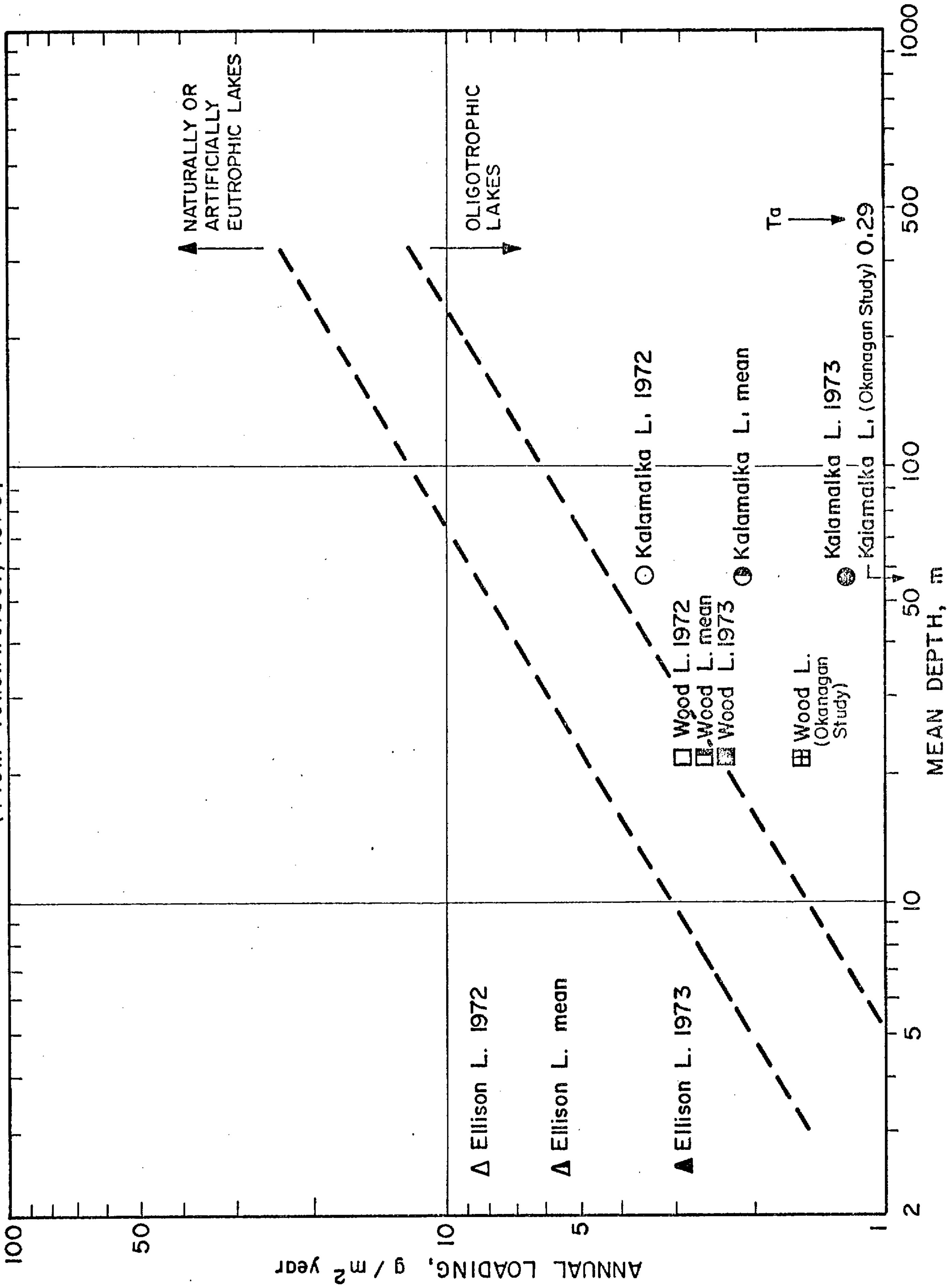


Figure 49
ANNUAL NITROGEN LOADING VERSUS MEAN DEPTH
(From Vollenweider, 1970)



from the system. In this connection the relatively small quantities of nitrogen and phosphorus entering the south end of Kalamalka Lake through the Oyama Canal become more important since these enter directly into the epilimnion and thus should be readily utilised by phytoplankton in the south end of Kalamalka Lake. The impact of the distillery cooling water could be enhanced since the extra nutrients passed from Wood to Kalamalka Lake as a result of the hydraulic loading from the distillery are readily assimilated. In the subsequent general discussion the classification of trophic conditions in each of the lakes in the Kalamalka-Wood Lake basin based on annual loading of nutrients will be compared with results obtained using other classification schemes such as that of Hutchinson (1957).

3. Water Movements in Ellison, Wood and Kalamalka Lakes

i. Ellison Lake

Although Ellison Lake is ice covered for much of the winter, the input of cooling water from the distillery at temperatures above ambient lake temperature maintains an ice-free zone along the north shore. Photographs taken during the winters of 1971-2 and 1972-3 clearly show this effect (see figure 32). There is a strong inference that water entering Ellison Lake during the winter passes along the north shore of the lake. Similarly, just before and after ice cover when inflowing water temperatures are higher than ambient lake temperatures and when southerly winds predominate, water movement will be along the north shore.

There were high flow conditions during freshet 1972 with a peak flow of approximately 173 cfs in Vernon Creek entering Ellison Lake on June 1. The only dye study carried out during the freshet period was on May 18, 1972 when there was a high inflow of Vernon Creek water at 80.7 cfs. AT this time short-circuiting by inflowing Vernon Creek water occurred and the residence time of the inflowing water was approximately 1 hr. In contrast, on July 18, 1972 there was a substantial reduction in the flow of water entering Ellison Lake (4.1 cfs) due to minimum flows of cooling water augmenting the natural water flow in Vernon Creek. Short-circuiting occurred but the residence time was increased to approximately 5 hr. Wind conditions differed between May 18 and July 18, and did not affect dye dispersal primarily due to the temperature of inflowing Vernon Creek water which was lower than that of Ellison Lake and thus travelled beneath the warmer lake waters.

The direction of inflowing Vernon Creek water was dictated in part by the nature of the Vernon Creek inlet area. A delta area is produced at freshet each year and the course of inflowing water over this area changes throughout the year depending on the configuration of this delta. Short-circuiting of Ellison Lake by inflowing Vernon Creek water would probably have persisted during most of the 1972 freshet period and also at those times when inflowing Vernon Creek water had a temperature below ambient lake temperatures; when the inflowing creek waters were directed along the north shore by the inlet delta. Erosion of the delta area occurred during July and August 1972, and Vernon Creek water was directed south towards the main body of Ellison Lake. A dye study carried out on July 27, 1972 showed how the delta area affected water movement and also how water movement is affected by wind action. On this occasion the delta deflected Vernon Creek water entering Ellison Lake to the south beneath the warmer lake waters. The dye travelled along the eastern side of Ellison Lake within the shelter of the eastern hillside. The southeast wind did not affect the travel of the dye until the water moved away from the sheltered area. Wind action then turned the dye towards the center of Ellison Lake and although mixing of the inflowing Vernon Creek water with Ellison Lake occurred, a minor portion of the inflowing water reached the outlet area within approximately 24 hr. Thus short-circuiting at this time was related to wind action.

On October 4, 1972 inflowing Vernon Creek temperatures were higher than ambient lake temperatures and the dye study carried out on this day clearly indicated the influence of wind action on the dispersion of surface water. Water dispersion of the inflowing creek waters which overlay the colder lake waters was rapid and mixing of inflowing water with Ellison Lake occurred due to the strong northerly winds. During the winter months when southerly winds predominate, both before and after ice cover, inflowing Vernon Creek water will move along the north shore of Ellison Lake.

A variety of conditions affect the dispersion of Vernon Creek water flowing into Ellison Lake. Stratification of lake waters affects the transport of inflowing water but even under nonstratified conditions when inflowing water is colder than lake water, transport of inflowing water beneath the lake waters is rapid. The nature of the inlet area affects the initial path of inflowing Vernon Creek water. The delta area directed water along the north shore prior to freshet 1972 and from summer onwards to freshet 1973. When inflowing Vernon Creek water travelled south into Ellison Lake, mixing of the waters occurred. Even when the temperature of the inflowing Vernon Creek was much lower than that of lake waters the cooler inflowing water did not reside in a pool beneath the more eutrophic lake waters. (This contrasts with the preliminary data presented by Stockner and Koshinsky, 1971). The shallow depth of Ellison Lake promotes mixing of the lake waters due to wind action. At times when short-circuiting was not occurring it is suggested that water mixing occurs within short periods of time between Vernon Creek water and the main water mass of Ellison Lake.

The flow rate of Vernon Creek is a major factor affecting the residence time of water entering Ellison Lake. On May 18, 1972 when 80.7 cfs of Vernon Creek water entered Ellison Lake, short-circuiting occurred in 1.2 hr. In contrast to this situation 4.1 cfs flowed into Ellison Lake on July 18, 1972 and short-circuiting again occurred but the duration for this was 5 hr. There was a 20 times reduction in flow rate between May 18 and July 18 but only a 5 times increase in the residence time of inflowing Vernon Creek water.

Depending upon the proposed developments for this area, it would be possible to affect the mixing of Ellison Lake waters with inflowing Vernon Creek waters by modification of the inlet area. Under the present situation inflowing Vernon Creek water frequently short circuits Ellison Lake and the main body of Ellison Lake is subjected to circulation patterns effected by wind action. It must be stressed that strong southerly winds, although promoting short circuiting of Ellison Lake by Vernon Creek water, will also promote the movement of eutrophic lake waters towards the outlet of Ellison Lake. Water quality of Vernon Creek below Ellison Lake would be enhanced by permanent short-circuiting of Ellison Lake. However this situation would be detremental to the water quality of Ellison Lake.

ii. Wood Lake

Lake stratification and inflowing creek temperature data imply that water flowing into Wood Lake from Vernon Creek will mix in the epilimnion waters during the summer period. The following table serves to illustrate this effect.

Date	Temperature (°C)	
	Inlet	Thermocline
April	9.5	4.5*
May	14.6	7 *
June	17.7	14
July	18.7	12
August	18.4	14
September	12.9	12
October	6.5	9
November	4	6 *

* No thermocline

Water entering Wood Lake will travel into and above the thermocline region during spring and summer, and only in the fall will it travel beneath the thermocline level. Nutrients carried into Wood Lake will become available for algal growth in the epilimnion waters. Wood Lake is relatively turbid and under normal conditions, light transmission is limited. Algal growth is generally restricted to the epilimnion waters and utilisation of inflowing nutrients will be enhanced during the spring and summer period.

During the main algal growth period in Wood Lake, nutrients transported from Vernon Creek will be available for growth. Wind action will tend to distribute these nutrients within the epilimnion as a result of lake circulation patterns. However, the persistence of northerly winds in the summer will tend to retain inflowing creek waters at the south end of Wood Lake and prevent rapid movement of inflowing waters throughout the epilimnion. Throughout September and into October lake temperatures decrease rapidly and it is expected that inflowing Vernon Creek water will mix with the main water column in Wood Lake.

iii. Kalamalka Lake

The dye study carried out at Oyama Canal when Wood Lake water was flowing into Kalamalka Lake indicated how wind action affects the dispersion of inflowing waters into the southern part of Kalamalka Lake. Wood Lake is generally warmer than Kalamalka Lake and consequently water flowing from Wood Lake to Kalamalka Lake will flow over the surface of the colder Kalamalka Lake water around the region of Oyama Canal. The drogue studies carried out on July 20, 1972 and the dye study of July 21, 1972 clearly indicated this situation. With increased distance from Oyama Canal, inflowing Wood Lake water was progressively mixed within the epilimnion of Kalamalka Lake. Water movement was rapid and assisted by southerly winds. It has been mentioned that northerly winds predominate during the summer period, and it may be expected that the more eutrophic waters of Wood Lake will be prevented from rapid movement into the main body of Kalamalka Lake in the summer. Water quality within the southern region of Kalamalka Lake will be affected by the inflow of Wood Lake water and its retention in the environs of Oyama Canal. However observation of water quality data does not reveal any significant differences attributed to the influx of Wood Lake water into Kalamalka Lake. Because the inflowing Wood Lake water resides in the surface layers of Kalamalka Lake, the availability of nutrients for algal growth will be enhanced. Southerly movement of Kalamalka Lake waters through Oyama Canal into Wood Lake is promoted by northerly winds and natural seiching. The net effect will be to temporarily improve the water quality of Wood Lake waters around Oyama Canal but any improvement will be transient. The transport of water to Wood Lake from Kalamalka Lake will of course be promoted by the distillery cooling water which enters the basin water system above Ellison Lake. As a result of these augmented flows from the distillery, more eutrophic Wood Lake water will be pushed into Kalamalka Lake than was previously carried through when the distillery was not in operation. Even though water quality data do not show the effect of nutrient input from Wood Lake to any significant extent, algal concentrations illustrate the effect of Wood Lake water entering Kalamalka Lake. High concentrations of algae occurred in the upper layers close to Oyama Canal and algal concentrations declined further into Kalamalka Lake (see Appendix 1).

Dye and drogue studies carried out at the inlet of Coldstream Creek into Kalamalka Lake indicated that colder Coldstream Creek water will travel deep into Kalamalka Lake during times of summer stratification. Coldstream Creek remains cold and the majority of the nutrients within this water will be unavailable for algal growth during summer stratification as shown by the following table.

Month (1972)	Temperature (°C)			
	Inlet of Coldstream Creek into Kalamalka Lake	Surface	Thermo-cline	20 Meter Level
April	7	3.3	-	3.3
May	8.7	9	-	-
June	9.7	14.6	11	6.8
July	11.5	19.6	11	6.5
Aug.	13	20	17	7.6
Sept.	9.7	14.9	15.5	9.0
Oct.	6.2	10.8	11	8.4
Nov.	5	6.6	-	6.0

Coldstream Creek water will tend to flow deep into Kalamalka Lake particularly during the summer period. However during April and May most of the inflowing Coldstream Creek water will mix with the lake waters. In April 1972 the lake temperature was lower than that of Coldstream Creek water and at freshet, during May and the beginning of June, mixing of inflowing Coldstream Creek water probably occurred with surface waters of Kalamalka Lake. Aerial photographs taken during this time (see Figs. 43 and 44) illustrate that mixing of lake and creek waters occurred in the upper lake water layers.

Although drogue studies indicated that most of the water movement of Coldstream Creek proceeds along the eastern shore of Kalamalka Lake during summer stratification during periods of high runoff, water movement proceeded east, west and south of the inlet of Coldstream Creek. Nutrients in the water and trapped in solids transported down the creek may be utilised by rooted aquatic weeds which, as discussed separately in a report by R.J. Buchanan (1974) are becoming an increasing problem in the area.

Land development at the mouth of Coldstream Creek has affected the settlement of suspended material entering Kalamalka Lake with the result that large quantities of suspended materials enter the lake at this point.

4. Temperature

Lake morphometry and climate greatly affect seasonal trends of temperature for any lake. Ellison Lake is shallow and greatly affected by wind, consequently it is not consistently stratified during the summer while Wood and Kalamalka Lakes follow conventional patterns of dimictic lakes. Thermal patterns in Wood and Kalamalka Lakes were different between 1972 and 1973. One noteable feature was that prior to winter ice cover which commenced in January 1972, Wood Lake water temperatures throughout the lake decreased to about 1C. This situation where lake water temperatures decrease to levels below the temperature of maximum density prior to freezing has been reported for a number of dimictic lakes.

For 1972 average maximum temperatures of epilimnion waters in Kalamalka, Wood and Ellison Lakes were 19.5, 21 and 23C respectively. Although the volume of water in Kalamalka Lake is much greater than the volume of Wood Lake the small difference in heat between Wood and Kalamalka Lakes was assigned to the lower heat absorbance associated with the clear waters of Kalamalka Lake when compared with Wood Lake.

Epilimnion heating rates for 1972 were 3.8C per month for Kalamalka Lake, 4.05C per month for Wood Lake and 4.25C per month for Ellison Lake. Hypolimnion heating rates were 1.3C per month in Wood Lake compared with 0.43C per month for Kalamalka. During 1973, heating rates were different, the epilimnion waters of Kalamalka Lake increased faster in temperature than those of Wood and Ellison Lake at rates of 5.4, 4.83 and 4.02C per month respecitvely. The epilimnion of Kalamalka Lake was shallower in 1973 than in 1972 and consequently the rate of heating of these waters was greater in 1973. In contrast, the epilimnion for Wood Lake was thicker in 1973 than that in Kalamalka and the rate of heating of the larger volume of epilimnion water in Wood Lake was reflected by the lower value obtained. The heating rate of Ellison Lake is greatly influenced by water mixing due to wind action and the loss of heat due to evaporation and back radiation. Consequently the differences between 4.25 during 1972 and 4.02 in 1973 are not noteworthy.

Hypolimnion heating rates for Wood and Kalamalka Lakes were similar in 1972 and 1973. For Wood Lake, hypolimnion waters increased at 1.2C per month while for Kalamalka Lake the value was 0.4C per month. The maximum hypolimnion mean temperature was 7.6 in 1973 compared with 8.2 C in 1972. Hypolimnion heating rates in Kalamalka Lake in 1972 and 1973 were similar, due to the large volume of low temperature water within the hypolimnion. The hypolimnion heating rates measured during this study were considerably different to those measured during the Okanagan Basin investigation where Blanton and Ng (1973) recorded values of 0.26C per month and 0.18C per month for hypolimnetic warming rates of Wood and Kalamalka Lakes respectively. They suggested that the low warming rate for the hypolimnion waters of Wood Lake could be linked to an influx of groundwater. The data presented in this report does not substantiate such a large influx of groundwater entering Wood Lake.

The seasonal variation in lake heat content followed the pattern of seasonal air temperatures, attaining maximum values somewhat later than the time at which maximum air temperatures were recorded. Summer heat incomes for Kalamalka, Wood and Ellison Lakes were determined and differences were apparent in the measurements between 1972 and 1973, due in part to the different climatic conditions between these years. The summer heat income for Kalamalka Lake for 1972 was approximately 24,500 cal/cm^2 and for 1973 27,500 cal/cm^2; for Wood Lake 1972 20,500 cal/cm^2 and for 1973 21,800 cal/cm^2 and for Ellison Lake 1972 5,000 cal/cm^2, 1973 4,900 cal/cm^2.

Blanton and Ng (1973) measured maximum heat contents for Kalamalka Lake at 25,100 cal/cm^2 and for Wood Lake at 18,100 cal/cm^2 in August of 1971. These workers considered that the maximum summer heat content of Wood Lake was abnormal for lakes with this morphometry. By plotting the maximum heat content in cal/cm^2 against the cube root of the volume for each lake they studied, a linear regression line was drawn through the data. The summer heat content for Wood Lake was below the regression line and considered to be anomalous. In contrast, the present studies placed the maximum heat content close to the theoretical regression line predicted by Blanton and Ng (1973). It is suggested that the differences in recorded maximum heat contents are not so great as to fall outside the naturally encountered variation. For example Hutchinson (1957) reports that in Green Lake, Wisconsin the average maximum heat content was 34,200 cal/cm^2 but between years ranged between 32,300 to 36,400 cal/cm^2. Another explanation for the differences between our results for Wood Lake and those of Blanton and Ng (1973) may be related to the fact that their temperature profiles were taken less frequently than those in our studies which show that the rate of temperature increase is by no means constant throughout the heating period of the year. Thus it is possible that the maximum heat content in 1971 was not recorded precisely.

However there are indications that there is some influx of cold groundwater into the hypolimnion of Wood Lake since hypolimnion water temperatures achieved a maximum in June and then tended to decline even though epilimnion water temperatures were substantially elevated above those of the hypolimnion and the lake was still stratified. (See Fig. 11).

Only limited thermal data was obtained for Kalamalka Lake and the mean value of 26,000 cal/cm^2 for maximum heat content is only slightly higher than the value obtained by the joint Okanagan Basin Study group of 25,100 cal/cm^2 (Blanton and Ng 1973).

5. Dissolved Oxygen

During summer stratification the nature of the dissolved oxygen depth profile, the areal relative oxygen deficits in the hypolimnion, and hypolimnetic oxygen uptake rates have been used to characterise the trophic condition of lakes (Hutchinson, 1957). A similar classification scheme has been adopted here for Wood and Kalamalka Lakes but not for Ellison Lake which does not remain persistently stratified during the summer period. Data from Kalamalka Lake are not sufficiently detailed to permit unequivocal statements concerning its classification under this scheme, however information for Wood Lake is sufficiently detailed and is discussed here in relation to differences between 1972 and 1973 and the mean situation

i. Ellison Lake

Except for the winter period of ice cover, wind effects did not permit any peristent stratification in this shallow lake during 1972 and 1973. On occasions dissolved oxygen content diminished with depth in the summer period, however, overall the water was usually 100% air saturated and in the summer of 1973 became supersaturated, due to algal phtosynthesis in the upper water layers. Water transparency in Ellison Lake was very low and high summer oxygen concentrations in Ellison Lake resulted from the utilisation by phytoplankton of the available light penetrating into the surface water layers of the lake.

Oxygen deficits were observed in Ellison Lake during winter ice cover and dissolved oxygen concentration was reduced to the level of 6.5 mg/l at depths below 1.5 m. Anaerobic conditions did not occur during ice cover.

According to the classification developed by Hutchinson (1957) Ellison Lake is a grade 3 lake, eutrophic and highly turbid.

ii. Kalamalka Lake

Kalamalka Lake exhibited an orthograde dissolved oxygen profile during the summer stratification period. During spring and fall turnovers the waters were essentially oxygen saturated.

The hypolimnetic oxygen deficit for Kalamalka Lake during 1972 and 1973 was 0.043 $mg/cm^2/day$. The areal relative oxygen deficit in the hypolimnion corresponds to the difference in dissolved oxygen between the value at spring turnover and that measured during the height of summer stratification expressed per unit of hypolimnion surface area; for Kalamalka Lake the areal relative oxygen deficit after approximately 120 days stagnation was 5.5 mg/cm^2. These data can be compared with results reported for Black Oak Lake which had a mean depth of 26 meters; a hypolimnion oxygen deficit of 0.043 $mg/cm^2/day$ and areal relative deficit of 4.3 mg/cm^2 (Hutchinson, 1957). The results between this lake and Kalamalka Lake are very comparable, although the comparison may be criticised since they refer to the oxygen utilisation for biochemical oxidation of organic matter and not necessarily productivity.

Oligotrophic lakes in Norway and Sweden with mean depths of approximately 53 meters had oxygen deficits between 0.004 and 0.013 $mg/cm^2/day$ (Hutchinson, 1957), lower than the value of 0.043 $mg/cm^2/day$ measured for Kalamalka Lake in the present investigation. Hutchinson considered oligotrophic lakes to be those losing hypolimnetic oxygen at a rate of 0.004 to 0.033 $mg/cm^2/day$ and eutrophic lakes to be those losing oxygen from the hypolimnion at a rate of between 0.05 to 0.14 $mg/cm^2/day$; lakes intermediate between these ranges would reasonably be termed mesotrophic. According to Hutchinson (1957), Mortimer suggested rather different limits at 0.025 $mg/cm^2/day$ as the lower limit for eutrophic lakes. For the purpose of the present study either classification would place Kalamalka Lake in terms of oxygen utilisation rate as a moderately productive water body within the lower part of the mesotrophic range. Thus considering the values for oxygen deficits in the hypolimnion, Kalamalka Lake may be described as within the oligotrophic-mesotrophic range.

iii. Wood Lake

The hypolimnion oxygen deficit for Wood Lake was 0.134 $mg/cm^2/day$; the value for 1972 being 0.12 $mg/cm^2/day$ and that for 1973 0.15 $mg/cm^2/day$. The relative areal deficit of oxygen was 10 mg/cm^2. Under the classification adopted above, Wood Lake is eutrophic and comparable with Green Lake, Wisconsin where the hypolimnion oxygen was lost at a rate of 0.14 $mg/cm^2/day$ and the areal relative oxygen deficit 13.8 mg/cm^2 (Hutchinson 1957).

There were differences in oxygen utilisation and the nature of oxygen depth profiles for Wood Lake between 1972 and 1973.

During 1972 at spring turnover the lake waters in Wood Lake were at 90% saturation. At thermal stratification the hypolimnion waters progressively lost dissolved oxygen while epilimnion waters remained oxygenated. Epilimnion waters were turbid with Secchi disc recordings during August at about 2 m depth. Photosynthesis during 1972 was thus largely restricted to the upper layers of the epilimnion; the distribution of oxygen within the water of Wood Lake during August 1972 is termed clinograde, a condition typical of eutrophic lakes where biochemical oxidation of organic matter in the hypolimnion causes a severe oxygen reduction in the hypolimnion. At the fall turnover, the oxygen content of the water column was close to saturation. Oxygen levels increased prior to ice cover and no major reduction of dissolved oxygen occurred during the period of ice cover.

At spring turnover during 1973 the lake waters were at 100% saturation in terms of dissolved oxygen. During the summer of 1973 thermal stratification again occurred and initially resulted in the development of a clinograde oxygen curve. Dissolved oxygen concentrations in the hypolimnion were lower than those found during 1972 but at mid summer dissolved oxygen levels above saturation were recorded at the thermocline level. Dissolved oxygen levels above 10 m depth were at 135% air saturation, while hypolimnion waters were only 20% saturated. Secchi disc readings in August of 1973 showed that the water of Wood Lake was much clearer than in the corresponding period of 1972 and the measured values were greater than those recorded by the Okanagan Basin study during August 1971. Due to the increased clarity of the water during 1973, photosynthetic activity proceeded to a greater depth and as a result dissolved oxygen levels in the metalimnion or thermocline region of the lake were greatly elevated. When oxygen is produced well below the surface, for example in excess of 4 meters depth the extra pressure of water causes it to dissolve rather than to form bubbles and super saturation relative to the lake surface pressure may occasionally be recorded although the absolute saturation is not exceeded (Hutchinson 1957). During summer stratification of 1973 the clinograde oxygen curve developed into a positive heterograde curve in which metalimnion oxygen concentrations exceeded saturation values. As an example on August 20, 1973, a maximum dissolved oxygen level corresponding to 160% saturation occurred at 10 m depth. Below the thermocline reduction of dissolved oxygen took place following the pattern noted during

1972. This condition has been reported by a number of workers (see Hutchinson 1957). In some Japanese eutrophic lakes oxygen levels in the metalimnion were recorded at 380% saturation.

The improved water transparency in Wood Lake during 1973 greatly affected the distribution of algae. During 1972 algal concentrations in August were high and values of 20,000 cells/ml were recorded in late August in the upper surface layers in Wood Lake. In August 1972 lake water transparency was reduced and the Secchi disc recording was approximately 2 m depth. During August 1973 algae were less abundant and on the 6th of August 1973 only 260 cells/ml were found. The distribution of algae was vertically marked, increasing towards the thermocline where at a level of 10 m, 3,500 cells/ml were recorded. The following table serves to illustrate the variation in chlorophyll a and algal density versus depth between years. For 1972 oxygen/depth profiles followed a clinograde curve, while in April 1973 there was a positive heterograde distribution pattern for oxygen and greatly increased epilimnion water transparency.

Depth	Wood Lake Station 4 3/8/72		Wood Lake Station 4 6/8/73	
	Algal conc. (cells/ml)	Chlorophyll a (mg/m^3)	Algal conc. (cells/ml)	Chlorophyll a (mg/m^3)
0.0 m	27,000	2.7	260	0.4
5 m	22,000	3	720	0.3
7.5 m	-	-	860	0.5
10 m	2,340	1.1	3,500	3.0
12.5 m	-	1.3	-	-
15 m	-	0.5	-	-

6. Concentration of Nutrients in Ellison, Wood and Kalamalka Lakes

Lake morphometry, water transparency and a range of chemical and physical factors affect the productivity of lakes. Measurements of nutrient concentration during overturn describe the potential productivity in a lake and a number of workers have developed schemes to classify the trophic condition of a lake on the basis of nitrogen and phosphorus at spring or fall overturn. Vollenweider (1970) reviewed these schemes, and presented ranges of concentration for total phosphorus and inorganic nitrogen that described the trophic characteristics of lakes as follows.

		Total P (mg/m^3)	N (mg/m^3)
1.	Ultra-oligotrophic	<5	<200
2.	Oligo-mesotrophic	5-10	200-400
3.	Meso-eutrophic	10-30	300-650
4.	Eu-polytrophic	30-100	500-1500
5.	Polytrophic	100	1500

Using this classification Ellison Lake with total phosphorus concentrations of 63-66 mg/m^3 and nitrogen concentrations of 79-83 mg/m^3 is highly eutrophic for phosphorus (eupolytrophic); Wood Lake (61-87 mg/m^3 phosphorus; 511-520 mg/m^3) is also classified as eutrophic. Kalamalka Lake is oligotrophic, with concentrations of 9 mg/m^3 phosphorus and 57 mg/m^3 nitrogen.

These data can be compared with results for earlier investigations of nutrient concentration at spring overturn during the period 1969-1971.

For Wood Lake, total phosphorus concentrations as total orthophosphate were as follows:

1969:	150 mg/m^3	(Stein, J.R. and T.L. Coulthard, 1971)
1970:	213 mg/m^3	(B.C. Research-Okanagan basin study)
1971:	240 mg/m^3	(Williams- Okanagan basin study, Task 118)
1972:	263 mg/m^3	present data
1973:	183 mg/m^3	present data

These data all place Wood Lake in the same trophic category in terms of overturn phosphorus content. At least during 1972 and 1973 there was no indication of internal nutrient loading during winter ice cover. Concentrations of 0.057 - 0.076 mg/l of total phosphorus were measured at Station 2 in Wood Lake under the ice during January 1973 when lake water temperatures ranged between 0-1.3C; oxygen was close to saturation at all depths ranging from 13.5 mg/l at the surface to 10.9 mg/l at the bottom. Similarly at the end of the ice cover in March 1973 temperature ranged from 0-1.0C; dissolved oxygen from 8.4 mg/l at the surface to 11.6 mg/l at the bottom while phosphorus concentrations were relatively consistent between 0.052-0.069 mg/l.

Although our measurements of nutrient concentration at overturn placed Kalamalka Lake in the oligotrophic category, the values measured were higher than those reported in earlier studies which were expressed as total orthophosphate:

1969: 20 mg/m^3
1970: 14 mg/m^3
1971: 7 mg/m^3
1972: 27 mg/m^3

Considering the problems of measuring phosphorus concentrations in the range of 0.003-0.008 mg/l these differences are probably not overly significant.

Seasonal patterns in nutrient concentration in Ellison Lake were greatly affected by wind action and water transparency. Similarly, the seasonal patterns in Kalamalka Lake showed only slight variation in concentration of the various nutrients (see Fig. 6) and the limited depth sampled prevents any detailed analysis of the results.

In Wood Lake the pattern of seasonal variation and differences in concentration of nutrients between various water depths during summer stratification were typical of a eutrophic, dimictic lake. Increase of nitrogen and phosphorus in the hypolimnion occurred during the period of summer stratification as oxygen concentrations declined. A similar pattern for this lake was described earlier by Williams (1973).

7. Limnology of Oyama and Swalwell Lakes

Swalwell and Oyama Lakes are above 4,000 ft. elevations and are ice covered for a minimum of six months. Both lakes are relatively shallow but maximum surface water temperatures are lower than in these valley lakes due to the relatively short ice-free period and their high elevation. Both Swalwell and Oyama Lake are dimictic. They stratify during the summer and temperatures in Oyama Lake are slightly higher than in Swalwell Lake.

The lakes exhibited clinograde oxygen curves, typical of eutrophic lakes and similar to those recorded in Wood Lake 1972. Although hypolimnion dissolved oxygen concentrations decreased during summer stratification, anaerobic conditions were not attained. Epilimnion dissolved oxygen concentrations were also low at 70% saturation during August indicating relatively low photosynthetic activity. Chlorophyll *a* concentrations reflected algal population studies (R.J. Buchanan 1974). Although algal populations were low and restricted to the upper water layers in both lakes, they were five times higher in Swalwell Lake than in Oyama Lake. Secchi disc recordings of light transmission were low in both lakes but in August Oyama Lake waters were more transparent. The low water transparency is probably related to the decay of pine needles which impart a brown colour to the lake waters. Low suspended solids and turbidity indicate that factors other than suspended material are responsible for the poor light transmission which relates directly to the recorded low photosynthetic activity of small populations of algae in the surface water layers.

At fall turnover the pH of Swalwell Lake was higher than that of Oyama Lake, and is consistent with the higher calcium and alkalinity values obtained for Swalwell Lake. However both lakes had lower pH values than the valley lakes. During summer stratification the pH shift in the hypolimnion of Swalwell Lake was from 7.5 to 6.4, much greater than that in Oyama Lake (6.9 to 6.5). This is probably associated with the large increases in carbon dioxide within the hypolimnion of Swalwell Lake.

Nitrogen and phosphorus concentrations in Swalwell and Oyama Lake were similar during summer stratification. However, at fall turnover TKN, nitrate, total phosphorus and total soluble phosphorus were slightly higher in Oyama than in Swalwell Lake. Orthophosphate recordings for both lakes were low at fall turnover (0.003 mg/l).

According to Vollenweider's classification of the trophic condition of lakes (reported in section 6), with respect to nitrogen, Oyama Lake contains 410 mg/m^3 and Swalwell Lake 391 mg/m^3 at fall turnover. According to this classification both lakes are meso-eutrophic with respect to their nitrogen content . At fall turnover Oyama Lake has a total phosphorus concentration of 26 mg/m^3 and Swalwell 8 mg/m^3. These values also place these lakes in the meso-eutrophic range.

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