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Sediments and Sediment-Water Nutrient Interchange In Upper Klamath Lake, Oregon

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SEDIMENTS AND SEDIMENT-WATER NUTRIENT INTERCHANGE IN UPPER KLAMATH LAKE, OREGON

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PREFACE

Upper Klamath Lake, a very large and seemingly naturally eutrophic Oregon lake, has been the subject of a number of studies by various researchers over the years. Work on that lake was carried on intermittently by this laboratory from 1965 to 1970. This report summarizes results of studies begun in 1967 which were oriented principally toward sediment-water nutrient interchange.

The cooperation of W. E. Miller, Pacific Northwest Environmental Research Laboratory, in assisting in measurement of sediment thickness, and in permitting use of his unpublished data, and of Julie A. Searcy, also of PNERL, in the analysis of samples is gratefully acknowledged. We also wish to thank R. E. Wildung and R. L. Schmidt, of Battelle-Northwest Laboratories, for continued cooperation and helpful suggestions.

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SECTION I
INTRODUCTION

In 1965 studies were initiated by the Pacific Northwest Water Laboratory, U. S. Public Health Service (now Pacific Northwest Environmental Research Laboratory, EPA), to investigate the causes for regularly occurring nuisance algal blooms in Upper Klamath Lake, Oregon, and to gather information relative to their possible control. From March 1965 to April 1966 studies were directed principally toward the hydrologic and nutrient budgets of the lake. Additionally, laboratory and *in situ* algal assay experiments were carried out in an effort to identify algal growth-limiting nutrients. This work has been reported by Miller and Tash[1]. Since 1967 work by this laboratory on Upper Klamath Lake has been carried out principally by the present authors together with agency-sponsored extramural research at Oregon State University by Morita[2] and at Battelle-Northwest by Wildung and Schmidt.[3] Preliminary results have been reported by Gahler.[4] Emphasis during this phase has been on problems involving sediment-water nutrient interchange, rather than on overall eutrophication problems.

SECTION II
SUMMARY

Upper Klamath Lake, a very large, shallow lake in south-central Oregon, has a history of nuisance blue-green algae blooms, predominantly *Aphanizomenon flos-aquae*. Lake water and sediment interstitial water chemistry were monitored during 1968 and 1969, and for a short time in 1970. Nutrient concentrations in interstitital water of sediment exposed to direct agricultural drainage were several orders of magnitude greater than in cases where sediments were not so located. Nutrient concentrations showed considerable seasonal variation in both interstitial and lake waters. Variations in lake and interstitital waters frequently, but not always, exhibited inverse relationships. The larger fluctuations appeared to correlate with density of *A. flos-aquae*.

Although strong evidence of biological uptake of sedimentary nutrients was found, dredging of the lake would probably not be effective as a restorative measure because of the high nutrient concentrations present at depth in the sediment.

SECTION III
CONCLUSIONS

1. Unconsolidated sediments occur in Upper Klamath Lake to a depth of 32.6 m (107 ft) below the lake bottom. Radiocarbon dating indicates that sedimentation rates have increased greatly in recent time. This could be the result of changes in the watershed and in the trophic status of the lake.

2. Concentrations of nutrients in the sediment interstitial water from Howard Bay were up to several orders of magnitude greater than at other sampling sites in the lake. Proximity to agricultural drainage may account for the high levels in Howard Bay. Ammonia and total Kjeldahl nitrogen concentrations tended to increase with sediment depth at all sampling locations. This was also frequently the case with ortho- and total phosphorus, but not consistently so.

3. In Howard Bay, comparison of lake water chemistry with chemistry of interstitial water from surficial sediments showed a definite tendency for inverse relationships in concentrations of total Kjeldahl nitrogen, phosphorus, and soluble organic carbon in the two media. Further, lowered P, N, and C in the interstitial water usually coincided with heavy *Aphanizomenon flos-aquae* growths in the adjacent lake water. Such relationships in other parts of the lake were not clearly defined.

4. Restoration of Upper Klamath Lake to a less eutrophic condition would be difficult to achieve by dredging. Although the evidence in support of biological utilization of sedimentary nutrients appears to argue in favor of dredging, at least in some areas, deeper sediments

which would thereby be exposed contain nutrient concentrations at least as high as those in the surficial sediments. Further, the very large size of the lake system makes such an operation economically and logistically impractical, and dredging would do nothing to limit the large nutrient input from outside sources.

SECTION IV
RECOMMENDATIONS

There is at the present time no obvious practical means for eliminating the regularly-occurring nuisance blue-green algae blooms in the Upper Klamath Lake system. Nutrients enter the lake primarily from a variety of non-point sources, particularly from springs and agricultural drainage. The present studies, and those of Miller and Tash,[1] have shown that nutrient concentrations in the bottom sediments are very large. Therefore, a program of restoration for the lake would have to include both control of nutrient flux from the watershed and exchange of nutrients between sediments and lake water. Neither of these appears possible at present. Dredging of sediment would be of dubious value because nutrient concentrations generally increase with distance into the sediment. Conversely, however, the deepening of the lake as a result of dredging would likely be of benefit, since the ratio of sediment area to lake volume would thereby be decreased. Because of the very large size of the lake, however, a dredging program would be difficult to justify unless it was also intended to serve other purposes, such as obtaining a larger holding capacity to increase hydroelectric generating potential.

SECTION V
DESCRIPTION OF LAKE SYSTEM AND WATERSHED

Upper Klamath Lake is a natural body located in the structural valley, the Klamath Graben, in southern Oregon east of the Cascade Mountains (Figure 1). Its area (combined with that of the smaller Agency Lake, considered an integral part of the system) is about 31,000 ha (120 sq. mi), one of the largest water areas in the western United States. Water level is regulated by a dam constructed in 1917, which maintains the surface elevation between 1261 and 1264 m, with a mean lake depth of 2.44 m. The watershed is about 985,000 ha (3800 square miles), much of which is located in mountainous volcanic areas or rolling regions covered with volcanic pumice deposits derived from formation of the Crater Lake caldera. Principal inflows to the lake are the Williamson and Wood Rivers. Upper Klamath Lake discharges into the Klamath River which eventually enters the Pacific Ocean in northern California.

The lakes are used extensively by waterfowl during the fall and spring migrations in the Pacific Flyway.[5] Rainbow trout (*Salmo gairdneri*) are common in the lake in early spring but later migrate into the tributaries and spring areas. Two genera of Cyprinidae, blue chub (*Gila bicolor*) and tui chub (*Siphateles bicolor*), constitute 90 percent of the total fish population.[6]

The elevation of the watershed varies generally from approximately 1281 m to 2440 m with some of the higher peaks reaching elevations greater than 2745 m. The Cascade Mountain Range borders the watershed to the west and creates a rain shadow over much of the area. Precipitation varies with location in the watershed; the sheltered, lower elevations receive 25-76 cm annually and the higher regions up to 152 cm. Most precipitation occurs between October and March.

Vegetation varies with the mountainous regions having forests of douglas fir, ponderosa pine, lodgepole pine and true firs, and the open flatlands associated with large pumice deposits occupied by grass-shrub communities. Marshes are extensive in parts of the watershed. The Sycan and Klamath marshes cover the basins of former Pleistocene Lakes and extensive marsh areas surround much of the present Upper Klamath and Agency Lakes. Since World War I large sections of marsh have been reclaimed for agricultural use. The flora associated with the marsh area is a typical sedge-reed community.

SECTION VI
METHODS

Three primary sampling sites for lake water and sediment were utilized in the present study (Figure 1). They were located (a) near the inner (southern) end of Howard Bay, (b) just south of Buck Island, and (c) near the lake outlet. In the text they are referred to as Howard Bay, Buck Island, and the Outlet, respectively. Seven other stations were visited solely to obtain sediment cores, and are designated stations D through J.

Water samples were obtained with a Van Dorn type PVC sampler from the surface and near bottom, and surficial sediment samples, unless otherwise noted, with an Eckman grab. Cores were taken with a modified corer described by Livingstone[7] which utilizes filament tape in the core barrel to reduce compaction.

Interstitial water was separated from sediment following the method of Gahler.[8] Samples were centrifuged at 13,000 rpm in 250 ml polycarbonate bottles in a refrigerated (4°C) centrifuge, and the supernatant interstitial water filtered through a 0.45 μ membrane filter.

Laboratory and field analytical procedures were the same as described by Gahler[4], and are listed in the appendix.

SECTION VII
CHARACTERIZATION OF SEDIMENTS

THICKNESS OF RECENT SEDIMENTS

A survey to determine the thickness of the very soft, fine-grained recent sediments in Agency and Upper Klamath Lakes was carried out in June 1968, utilizing a 8.5 KHz, 1500 watt high energy recording sonar and a 100 cycle, 16 joule Pulser system. The first horizon having significant continuity occurs at depths of 14.6 to 32.6 m below the lake surface and is believed to represent the approximate base of recent, unconsolidated lake deposits. The depth of this horizon is shown on the map in Figure 2. Several shallower reflecting horizons (not shown) are discontinuous and are believed to represent geologic structure within the recent lacustrine deposits. During this study the lake depth ranged between 2.1 and 2.4 m with occasional localized holes to 11.3 m.

SEDIMENTATION RATES

Cores were taken at site G in mid-lake, at Buck Island, and at the Outlet for radiocarbon dating. Sections were removed at points ± 5 cm on both sides of the 15, 30, 60, and 90-cm depths of the core for dating by the Radioisotopes and Radiations Laboratory, Washington State University. Results are summarized in Table 1.

Successful dating of all the core segments was not accomplished. However, with the exception of the 60 cm depth at the mid-lake location, the age of the sediments in each core increased with depth. There is no ready explanation for the apparent age anomaly at the mid-lake location, unless some sort of translocation of sediments occurred in the geologic past. The oldest indicated sediment was at 90 cm in the Buck Island core [4110 ± 210 years BP (before present)], although its age differed but little from that at the same depth in the Outlet core. Sediment at 90 cm at the mid-lake location was roughly 1700 to 1900 years younger than at the other two sites.

It is difficult to relate these data to those pertaining to apparent thickness of recent unconsolidated deposits. If it is assumed that the average age of about 4200 years at the 90-cm depth in the Buck Island Outlet cores is representative for sediments in that region of the lake, then the deepest sediments there (about 18 m) are approximately 84,000 years old. However, the indicated ages at the 30 and 60 cm depths in the Outlet core show an accelerated rate of sedimentation in more recent years, possibly related to changes in the watershed and in the trophic status of the lake. The difference in age between the 60 and 90 cm depths is about 3,000 years, whereas that between 30 and 60 cm is only about 100 years. The overall average rate of deposition at the Outlet is approximately 0.22 mm per year, but it is obvious that actual rates have fluctuated greatly.

PHYSICAL AND CHEMICAL CHARACTERISTICS

The sediments at the primary sites: Howard Bay, the Outlet and Buck Island, were composed of diatom frustules, organic matter, and mineralogical components consisting of feldspar, chlorite, vermiculite, and mica (Wildung, Blaylock, Routson, and Gahler).[9] Sediment samples from

Howard Bay and Buck Island were characterized as silty clay (Table 2). The cation exchange capacity of these sediments ranged between 30 and 55 meq/100 g.

The water content of the sediments throughout the entire lake system was high, 88 to 92 percent at the water interface and 80 to 88 percent at 1.2 m below the interface, as indicated by core samples. At Station H and the Outlet the water content decreased to 55 to 65 percent at 1.2 m. A layer of pumice-like material occurred at this level in both locations.

Surficial sediment pH varied from 6.1 to 7.8, and E_h from -0.1 to +0.3 volt. The odor of hydrogen sulfide was thought to be detected only once or twice. Undisturbed sediment surface samples taken with a Jenkins corer (Mortimer[10]) did not reveal oxidized surface and reduced black subsurface layers.

Total phosphorus (total-P) varied in surface sediment samples from 0.022 to 0.12 percent on a dry weight basis. The total-P content in surficial sediment did not increase appreciably with depth of water. Samples taken along transects where deeper holes occur in the lake (near Bare Island) showed no significant increase in phosphorus: 0.072 percent P at 3 m to 0.075 percent P at 8 m along a transect north of the island, and 0.062 percent P at 4 m to 0.073 percent at 15 m along a transect south of the island.

The total carbon content varied from 3.7 to 10.0 percent, with the highest values in Howard Bay. No carbonate occurred in the surface sediments indicating that all carbon was present as organic matter. Total-N content was 0.46 to 1.3 percent.

Vertical Distribution of Nutrients in Interstitial Water

Cores were obtained at Howard Bay, Buck Island, the Outlet, and several other locations to determine the distribution of nutrients with respect to sediment depth. Analyses of interstitial water were performed at standard core depths as indicated. Data are summarized in Table 3.

Considering the primary sampling sites at Howard Bay, Buck Island, and the Outlet, both orthophosphate-phosphorus (ortho-P) and total soluble phosphorus (TSP) were as much as several orders of magnitude greater in the interstitial sediment water from Howard Bay. Ortho-P and TSP doubled between the 0-30 and 60-90 cm core segments, and remained constant to the 120-150 cm depth. Some increase in phosphorus with sediment depth was evident at the other two locations, but values never exceeded a fraction of a milligram per liter at any depth.

Similarly, ammonia nitrogen in the interstitial water was much greater at Howard Bay, ranging between 85.0 and 146.0 mg/l there as opposed to 8.5 to 17.0 at Buck Island and 22.0 to 47.0 at the Outlet. Ammonia concentration increased with core depth at all three sites. Total Kjeldahl nitrogen (TKN) values differed little from ammonia-N. Oxidized N forms were negligible.

Conductivity was very high in the Howard Bay sediment, and at all three stations conductivity increased with core depth. Hardness was also greatest in Howard Bay and appeared to increase significantly with depth at that location only.

Soluble silica was of the same order of concentration at all three sites, and did not exhibit major changes in concentration with sediment depth.

Comparisons of the Howard Bay, Buck Island, and Outlet cores with those taken at other locations in the lake (Stations D thru J) indicate that nutrient levels in the sediment of inner Howard Bay were unusually high and not typical of the lake as a whole. P values at Howard Bay ranged to 18.2 mg/l and TKN to 122.0; at all other locations phosphorus was always less than 1.0 mg/l and TKN was well below 25 mg/l. Stations D, E, and F were also located in Howard Bay but were more typical of the lake stations than of the inner bay. The very high chemical concentrations there may be causally related to drainage water from an adjacent ranch, as noted previously by Gahler (1969). Analyses of this discharge made in 1968 showed ortho-P concentrations of 0.20 mg/l, and total P, 0.46 mg/l. However, nitrogen levels were not unusually high, with ammonia-N <0.1 and TKN 3.2 mg/l.

SECTION VIII

INTERRELATIONSHIPS OF SEDIMENT CHEMISTRY AND LIMNOLOGICAL CONDITIONS

Water chemistry data for Howard Bay and the Outlet for the period July 1967 - March 1969 were reported by Gahler.[4] More recently collected data, together with Gahler's, for the Howard Bay, Buck Island, and Outlet stations are presented in Table 4.

Data designed to show temporal variation of interstitial water chemistry of surficial sediments at the primary sampling sites were collected from June 1968 to July 1970. These data appear in Table 5.

Temporal variation of lake surface water and sediment interstitial water values for TKN, total-P, ortho-P or TSP, and soluble non-volatile organic carbon (SNOC) from the Howard Bay, Outlet, and Buck Island stations are presented graphically in Figures 3, 4, and 5, utilizing data from Tables 4 and 5 for surface water. Multiple data for a given month have been averaged to yield a single data point. Secchi disc transparency and visual observations of phytoplankton growth are also noted on the graphs. The time spans covered by these data at the three stations were selected, for the most part, to coincide with periods for which sediment chemistry data existed for those same stations, to compare temporal variation of nutrients in water with sediment interstitial nutrients.

HOWARD BAY (Figure 3)

In January 1968 the lake was ice-covered. TKN was at the somewhat elevated level of 3.5 mg/l; SNOC measured 9 mg/l. Shortly after ice-out in March, TKN had shown little change, but SNOC had doubled, coinciding with the onset of the spring diatom bloom. Both ortho-P and total-P were relatively high. TKN, SNOC, and total-P decreased sharply in April and May, while secchi disc transparency increased to 115 cm. Aphanizomenon flos-aquae growth began in late May, corresponding to the increases in TKN and total-P which attained maximum values in late summer and fall. Data on SNOC are lacking for that period. The highest observed TKN for the season at this station occurred in October (5.5 mg/l). This does not agree with the decreased total-P, the much higher secchi disc transparency, and the visual observation that some A. flos-aquae was present. However, TKN at the Outlet station was also high at that time.

Chemical data on surficial sediments from Howard Bay in 1968 are available only for June, August, and October. Sedimentary TKN and TSP levels showed sharp increases in August over June, paralleling the increases in these parameters observed in the overlying water. By October TKN and TSP had declined somewhat although, as already pointed out, TKN in the water attained a maximum at that time.

Data on lake water were not obtained for the 1968-69 winter period at Howard Bay. TKN was at an intermediate level (5.3 mg/l) in June, 1969, the first month that observations were made that year, and increased to an extreme high of 14.6 mg/l in July. Growth of A. flos-aquae was described as "very heavy." SNOC peaked sharply with the TKN on this occasion and minimal secchi disc values of 15 cm were observed. TKN declined sharply in August but rose again somewhat in September. SNOC decreased steadily after August, and water clarity increased.

Low midsummer sedimentary N and P levels in 1969 corresponded to the very sharp August rise in TKN and SNOC in the lake water, associated with very heavy A. flos-aquae growth (discussed above). Sediment N and P concentrations rose in September and October (TKN peaked at 690 mg/l) as the algal bloom declined and were accompanied by falling levels of N and P in the water.

THE OUTLET (Figure 4)

At the Outlet the sequence was similar to that described for Howard Bay. High 1967-68 winter values for TKN in the lake water fell to lows of about 1.0 mg/l in April and May, corresponding to increased secchi disc transparency ranging from about 40 to 105 cm. Total-P also decreased, but a similar trend was not found for SNOC. TKN increased greatly in late summer and early fall, reaching the high for that year of 8.5 mg/l in October. Total-P was high also, and secchi disc transparency stabilized at 55-70 cm after the high of 105 cm in May. The increases in TKN and total-P paralleled an A. flos-aquae bloom which began in late May, as was also noted for Howard Bay.

The very few data on sediment chemistry obtained for this station in 1968 preclude any discussion of trends there, or comparisons with water chemistry, for that year.

Data were obtained a month earlier in 1969 (May) than at Howard Bay. Lowest TKN values (0.6 mg/l) for the two-year sampling period were found at that time, and SNOC was likewise quite low. Secchi disc data are lacking for May and June, but decreasing transparency from July through September corresponded to increases in TKN, SNOC, and total-P, and visual observations of very heavy A. flos-aquae growths occurring through late summer and early fall.

TKN and TSP concentrations in the sediment at the outlet in 1969 were much lower than at Howard Bay. The highest TKN concentration, 1.0 mg/l, occurred in May coincident with the very low value of 0.6 mg/l found in the overlying water that month. The TSP level in the sediment was also maximal in May. Both TKN and TSP fluctuated through

June and July, but stabilized at low levels in August, September, and October coincident with a heavy late summer-fall _A. flos-aquae_ bloom and high TKN levels in the lake water.

BUCK ISLAND (Figure 5)

The Buck Island station was not sampled as frequently as Howard Bay or the Outlet. Data obtained from May to October, 1969, afford the only continuous record of water and sediment chemistry. The interstitial water chemistry from 1968, however, is interesting to compare with the concurrent visual observations of phytoplankton. As noted on Figure 5, the weather in August was abnormally cold and rainy. Phytoplankton growth was much less than normal, and this is reflected in the high levels of interstitial TKN and ammonia-nitrogen. The sharp rise in TSP in October is difficult to explain, but the decrease in interstitial TKN and ammonia-N through September and October appears to correspond with the late _A. flos-aquae_ bloom.

As at the other two sites in 1969, TKN in the lake water increased strongly through the summer and early fall coincident with very heavy production of _A. flos-aquae._ TKN rose from 0.8 mg/l in May to 4.2 mg/l in September, falling to 2.6 mg/l in October. SNOC rose to 9.0 in July, falling to 7 mg/l in August; it was not determined beyond that time. A peak in total-P coincided with the September TKN maximum.

TKN levels in the interstitial water exhibited two peaks, one in May (5.5 mg/l), and a second in September (5.2 mg/l), the latter coinciding with the TKN peak in the lake water. Interstitial total-P also showed a bimodal distribution, with the lowest value occurring in July when the TKN low was observed. SNOC measurements were not made on interstitial water except in April.

SECTION IX

DISCUSSION

The problem of sediment-water nutrient interchange and, in particular, the question of ultimate availability to algae of nutrients released from lake sediments, may never be completely resolved. The present study has emphasized nutrients present in solution in the interstitial water of the sediments, since such dissolved nutrients would be expected to be most readily transferrable to the overlying lake water through physical, chemical, or biological mechanisms.

Harriss[11] has stated, "The composition of interstitial waters from river and lake sediments is controlled by a complex interaction of the ground water recharge system, mineralogical dissolution and precipitation reactions, biological activity, and the degree of physical interaction between the sediment and overlying water." Other investigators have measured soluble constituents in interstitial water for the purpose of studying mineral-water equilibria and mineral transformations (Sutherland, et al[12]). Gorham[13] suggested that ions would diffuse from the interstitial water to the overlying water, particularly during stormy periods. Sullivan[14] has shown that orthophosphate in the sediment interstitial water from Lake Bloomington increases during stratification and decreases following turnover. Lee[15] has pointed out that in lakes the hydrodynamics of the system are often the rate-controlling step in exchange reactions, and that currents in the overlying waters tend to transport leached materials away from the sediments and thereby allow concentration-dependent exchange reactions to proceed.

There is little doubt that in a large shallow lake such as Upper Klamath Lake, turbulent mixing frequently extends to the bottom. Disturbance of the fine, flocculent sediment must often result, with consequent mixing of interstitial and lake water. The inverse relation between nutrient concentrations in interstitial water and overlying lake water which were observed at the three primary stations, particularly Howard Bay, may be an indication of uptake of sediment-contained nutrients by photosynthetic organisms.

Wildung and Schmidt[3] also noted variations in sediment and water phosphorus chemistry which appeared to be related to biological activity. Decreases in total and inorganic P in Howard Bay sediments in the early summer of 1969 were related to the exponential growth of A. flos-aquae. The following year reductions in sediment P in Howard Bay in April and August coincided with an extensive increase in diatom numbers and a delayed A. flos-aquae bloom. Therefore, they suggested that considerable quantities of sediment P were released at times of maximum production in Howard Bay, but that because of algal uptake these losses from the sediments were not reflected in increased concentrations of dissolved P in the water. In comparisions of SNOC in the water with sediment inorganic P in Howard Bay, a significant inverse correlation was found, a further indication of utilization of sedimentary nutrients in biological production.

Further evidence favoring the likelihood of biological utilization of sedimentary nutrients has been provided by Morita[2], who has shown that bacteria isolated from Upper Klamath Lake sediment have the ability to solubilize phosphate precipitates through the production of necessary organic acids. However, in order for the soluble phosphate to become available for algae, there must be an interchange between the sediment and the overlying water. He suggested that for shallow Upper Klamath Lake wind stress could result in physical suspension of sediment and consequent mixing of the soluble phosphorus with the lake water. Such suspension and mixing appear to be a distinct possibility according to Bond, et al,[6] who concluded that resuspension of sediments in Upper Klamath Lake occurs when water mass movement exceeds 0.005 m/sec (0.02 ft/sec), which would be expected to occur in response to wind speeds of 0.9 - 2.2 m/sec (2-5 mph).

During this study a different sediment-water exchange mechanism was observed. In 1968 and 1970, the blue-green alga *Oscillatoria princeps*, which grew as a mat on the sediment, produced and collected sufficient gas to cause sections to be lifted to the lake surface. As the algal mass rose, it brought with it attached sediment in pieces 30 cm or more in breadth and from 15 to 30 cm thick. Such clumps were found floating throughout the lake in June 1968, throughout Howard Bay in September 1968, and in the northern area of the lake in August 1970. When the floating sediment broke apart, the soluble nutrients in the interstitial water were dispersed, as evidenced by increased concentrations in the water. Between August and September 1968, the average concentrations of nutrients in the water in Howard Bay increased as follows: from 0.4 to 1.1 mg/l total-P, from 0.15 to 1.2 mg/l ammonia-N, and from 5.2 to 8 mg/l TKN. Conductivity increased from 125 to 190 μ-mhos/cm, and dissolved oxygen decreased from 6 to 3 mg/l. The water at the Outlet and Buck Island stations, where an *A. flos-aquae* bloom was occurring but where *O. princeps* was undetected on the lake surface, contained levels of 0.25 mg/l total-P, <0.1 mg/l ammonia-N, 5.5 mg/l TKN, 7.5 mg/l dissolved oxygen, and conductivity of 122 μ-mhos/cm.

Data from the present study, however, appear to support sediment-water nutrient interchange more strongly in Howard Bay than in other parts of the lake. As already pointed out, phosphorus concentration in Howard Bay sediment was several orders of magnitude higher than in Buck Island or Outlet sediment samples. Further, variations in nutrient concentration in Howard Bay sediment were quite large in comparision with those at Buck Island and the Outlet, with TKN and ammonia-N fluctuating over a range in excess of 50 mg/l. At the Outlet and Buck Island, fluctuations were less than 10 mg/l, and were much more likely to represent random variations.

The earlier data of Miller and Tash[1] and of Miller[16] likewise suggest that sediment-water interchange is of greater importance to the nutrient budget of Howard Bay than to that of the rest of the lake. Measurements made by them between March 1965 and April 1966 showed that the Wood and Williamson Rivers contributed 43 to 79 percent of all nutrients entering Upper Klamath lake, with the remainder coming from pristine streams, agricultural drainage, canals, and springs. No significant point sources were found. Average concentrations of most nutrients in lake water and tributary water for the period March 1965 to April 1966 were quite similar. Total phosphorus was higher in the inflow water (0.17 vs 0.11 mg/l). Nitrogen concentration in the lake, on the other hand, averaged over three times that in the tributaries, possibly as a result of biological fixation. Boron, calcium, chloride, iron, magnesium, potassium, silica, sodium, and sulfate showed little difference between lake and influent water. However, significant exchange of these substances between sediment and water probably would not be expected.

SECTION X
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SECTION XI
Appendix
METHODS OF ANALYSIS
A. Laboratory

Determination	Units	Method	Reference
Alkalinity, Total	mg $CaCO_3/\ell$	Titrimetric with sulfuric acid	SMEWW*
Conductivity	micromhos/cm	Conductimetric measurement	SMEWW
Carbon, Total	mg C/ℓ	Combustion, infrared detection in Beckman Carbonaceous Analyzer	ASTM (D 2579)
Carbon, soluble non-volatile organic	mg C/ℓ	Acidification of sample, volatilization of CO_2 with nitrogen gas, determination in Beckman Carbonaceous Analyzer	
Hardness, Ca	mg $CaCO_3/\ell$	Titrimetric with EDTA, Hydroxy Naphthol Blue indicator	SMEWW
Hardness, Total	mg $CaCO_3/\ell$	Titrimetric with EDTA, Calmagite indicator	SMEWW
Nitrogen-Ammonia	mg N/ℓ	Distillation, Spectrophotometric measurement	Technicon Auto analyzer
Nitrogen-Nitrate	mg N/ℓ	Spectrophotometric measurement	Technicon Auto analyzer
Nitrogen-Nitrite	mg N/ℓ	Spectrophotometric measurement	Technicon Auto analyzer, SMEWW
Nitrogen-Total Kjeldahl	mg N/ℓ	Digestion, distillation, spectrophotometric measurement	Aminco digestion, semi-micro distillation apparatus, SMEWW
pH	pH	Beckman Electromate and other portable pH meters	
Phosphorus, ortho	mg P/ℓ	Millipore filtration, spectrophotometric determination	Strickland, FWPCA**
Phosphorus, total	mg P/ℓ	Digestion in acid solution with persulfate, spectrophotometric determination	Strickland, FWPCA
Silica, Soluble	mgSiO_2/ℓ	Spectrophotometric determination	Technicon Auto analyzer, SMEWW
Sodium	mg Na/ℓ	Flame photometric or atomic absorption spectrophotometric determination	SMEWW
Potassium	mg K/ℓ	Flame photometric or atomic absorption spectrophotometric determination	SMEWW
Chloride	mg Cl/ℓ	Titrimetric with mercuric nitrate	SMEWW
Sulfate	mg SO_4/ℓ	Turbidimetric measurement	SMEWW

METHODS OF ANALYSIS
B. Field

Determination	Units	Instrument
Conductivity	micromhos/cm	Beckman RB3 - 327 Solu Bridge
Oxygen	mg O/ℓ	Electronic Instruments Limited Model 15A dissolved oxygen meter and probe
pH	pH	Beckman portable pH meters
Transparency	cm	Secchi disc
Temperature	^{o}C	Electronic Instruments Limited

* Standard Methods for the Examination of Water and Waste Water, Twelfth Ed., 1965

** FWPCA Official Interim Methods for Chemical Analysis of Surface Waters, Sept. 1968

Table 1. Age of Sediments as Determined by Carbon-14 Dating

Core depth (cm)	Age (Years B. P.)* Mid-Lake	Buck Island	Outlet
15	2060 ± 270	----	Modern
30	----	1940 ± 220	1260 ± 200
60	4040 ± 570	----	1350 ± 180
90	2425 ± 375	4110 ± 210	4370 ± 220

*Before Present

Table 2. Physical Properties of Upper Klamath Lake Sediments*
(Dry basis, except as noted)

Sediment	Organic Matter	Water**	Texture			Textural Description
	%	%	Sand %	Silt %	Clay %	--
			2.0-0.05 mm	0.05-0.002 mm	<0.002 mm	--
Howard Bay	18.4	91.3	3.1	40.6	56.3	Silty Clay
Buck Island	14.2	91.1	4.9	52.3	42.9	Silty Clay

*Data obtained via personal communication from V. Volk, Oregon State University.
**Wet Basis

Table 3
Interstitial Water Chemistry
(Sediment Cores)
A. Primary Stations

	Howard Bay 8-20-68			Howard Bay 10-23-68		
Depth-cm	0-45	45-90	90-135	0-30	60-90	120-150
Constituent						
Cond	1076	1297	1474	1022	1363	1659
pH	8.1		8.2	7.7	7.8	7.8
P-ortho	10.5	14.5	12.0	8.5	16.5	17.5
P-total sol	10.5	14.8	12.0	8.5	17.0	18.2
$N-NH_3$	86	107	126	85	119	146
N-TKN	86	102	122			
$N-NO_3$				<0.03	<0.03	<0.03
$N-NO_2$				<0.02	<0.02	<0.02
Hardness, T	141		177	189	246	264
Silica, sol	91	92	86	56	60	58

Notes: Constituents expressed in mg/l.
Conductivity expressed in micromhos/cm @ 25°C.

Table 3 (Cont'd)
A. Primary Stations

	Buck Island 9-24-68						Outlet 8-27-68			
Depth-cm	0-30	30-60	60-90	90-120	120-150	150-155	0-30	30-60	60-90	90-120
Constituent										
Cond	191	231	266	298	306	211	221	364	417	472
pH	6.9	6.8	6.9	7.4	7.1	7.0	8.1	7.8	7.9	8.2
P-ortho	.07	.11	.08	.05	.03	.04	(a).03	.14	.31	.10
P-total sol	.17	.22	.27	.17	.19	.19	(a).05	.24	.44	.24
$N-NH_3$	8.5	12	14.5	16	17	12.5	22	37	42	47
N-TKN	10.4	15	19.3	21.2	21.8	17.5	22	37	46	56
$N-NO_3$	0.1	.08	<.03	<.03	<.03	.03				
$N-NO_2$										
Hardness, T	37	36	41	47	51	30	9	42	33	38
Silica, sol	49	49	49	43	41	42	78	81	76	50

(a) Data for Outlet for ortho-P and total soluble-P taken 9-24-68.

Table 3 (Cont'd)
B. Secondary Stations

	Sta. D 10-23-68			Sta. E 10-23-68			Sta. F 10-23-68		
Depth-cm	0-30	60-90	120-150	0-30	60-90	120-150	0-30	60-90	120-150
Constituent									
Cond.	240	329	389	264	335	381	293	321	334
pH	7.2	7.9	7.2	7.0	7.2	7.1	7.2	7.2	7.1
P-ortho	.43	.59	.28	.44	.24	.20	.40	.70	.53
P-total sol	.53	.73	.49	.57	.40	.38	.47	.83	.63
$N-NH_3$	11	16.8	19.2	12.4	16	17.4	16.8	16.8	16.2
N-TKN	12.5	.9.7	22.6	12.5	19.1	20.3	15.5	18.5	17.9
$N-NO_3$	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03
$N-NO_2$	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	.08
Hardness, T	66	66	85	57	113	104	57	66	85
Silica, sol	50	54	54	60	60	55	54	58	59

Table 3 (Cont'd)
B. Secondary Stations

	Sta. G 11-7-68			Sta. H 11-7-68				
Depth-cm	0-30	60-90	120-150	0-30	30-60	60-90	90-120	120-150
Constituent								
Cond	195	255	349	153	217	248	262	281
pH	8.0	8.0	8.2	7.9	8.0	8.1	8.1	8.1
P-ortho	.14	.11	.25	.04	.45	.09	.08	.06
P-total sol	.18	.19	.34	.15	.59	.23	.23	.25
$N-NH_3$	7.2	10.8	14.8	4.2	7.8	10.1	10.6	11
N-total Kjel	7.4	11		5.7	9.5	12.8		15.5
$N-NO_3$	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03
$N-NO_2$	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Hardness, T				57	62	79	76	72
Silica, Sol.	50	56	10.5?	44	52	51	42	40

Table 3 (Cont'd)
B. Secondary Stations

	Sta. I 11-20-68						Sta. J 11-7-68				
Depth-cm	0-30	30-60	60-90	90-120	120-150	150-160	0-30	30-60	60-90	90-120	120-150
Constituent											
Cond	208	236	245	250	268	234	230	288	314	309	300
pH	8.0	8.1	8.1	8.1	8.1	8.0	8.0	8.0	8.1	8.2	8.2
P-ortho	.41	.43	.18	.05	.03	.03	.09	.15	.15	.25	.11
P-total sol.	.57	.63	.29	.22	.21	.14	.15	.21	.25	.34	.21
$N-NH_3$	9.3	10.9	12	12.6	13.4	11.8	11.4	15.9	17.1	17.1	16.8
N-total Kjel.	13.8	17.8	16.2	17.8	17.0	16.2	12.8	14.9	17.3	19.1	18.2
$N-NO_3$	.10	.05	.05	<.03	<.03	<.03	<.03	<.03	<.03	<.03	.06
$N-NO_2$	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Hardness, T	37	43	42	41	43	35	57	62	79	76	72
Silica, sol	53	56	52	50	48	46	46	52	49	8	42

Table 4
Lake Water Chemistry
at Primary Stations
A. Howard Bay

Date of Collection	Depth	T.Alk.	Cond.	Carbon Total	Carbon SNOC	Hardness Ca	Hardness Total	$N-NH_3$	$N-NO_3$	$N-NO_2$	TKN	P Ortho	P Total	Silica Soluble	Na	K	Cl	SO_4	pH
9-15-67	s	55	109	23	10	33	37	< .1	.05		2.5	.07	.08	27.8	12.0	2.1			8.8
10-12-67	s	61	141	31	10	34	37					.22	.36	31.4	14.0	2.8		<10	7.6
11-16-67	s	59	128	24	8	31	55	1.4	.12		3.0	.05	.15	31.4	11.3	2.6	<5	<10	8.2
	b	58	130	24	6	29	42	2.0	.11		2.9	.05	.16	31.4	10.2	2.4	<5	<10	8.2
12-12-67	s	61	139	22	7	29	39		.02			.02	.15	32.8	11.6	2.2			8.8
12-13-67	s	59	138	22	10	32	38	1.5	.09		8.4	.03	.18	32.8	11.6	2.2			8.1
	b	59	139	22	8	35	40	1.8	.06		2.8	.03	.21	29.3	11.6	2.3			7.6
1-18-68	s	69	181	29	9	43	58	2.3	.13	.01	3.1	.13	.32	30.0	13.0	3.2	<5	15	7.7
	b	84	263	37	13	66	88	2.6	.12	.02	3.5	.25	.49	28.6	15.0	4.4	<5	27	6.5
1-31-68	s	75	169	28	9	42	48	1.8	.06	<.01	3.9	.12	.36	34.0	12.0	2.8		10	7.3
	b	113	367	62	31	110	126	1.7	.05	.02	4.4	.43	.65	32.9	28.0	4.4		32	7.0
3-02-68	s	70	296	43	18	102	106	< .1	.30	.01	3.4	.02	.29	18.3	19.0	3.0	<5	31	8.4
	b	75	355	43	21	128	133	< .1	.35	.01	3.9	.02	.37	15.1	23.0	3.2	<5	20	7.3
4-04-68	s	84	105	19		26	31	< .1	.01	<.01	1.2	<.01	.08	10.3					8.6
	b	78	105	20		22	33	< .1	.02	<.01	1.1	.01	.07	10.7					7.9
5-08-68	s	45	105		8	22	30	< .1	.02		0.8	<.01	.04	9.6	8.8	2.1		<10	7.7
	b	45	115		12	23	32	< .1	.02		0.8	.01	.05	9.6	8.8	1.9		<10	6.8
6-12-68	s	45	112					< .1	<.01		1.0	<.01	.08						8.2
	b	43	105					< .1	<.01		1.4	.03	.08	12.4					8.2
6-25-68	b	50	110			28	61	.59	<.01	<.01				15.2	9.9	2.0			9.2(L)
7-09-68	s	50	120					.24	<.01		1.8	.02	.09	22.0					9.6
	b	51	125					.34	.017		1.7	.04	.10	22.0					9.7
8-14-68	s	58	126	38		67	78	.14	.11	.01	4.6	.05	.53	41.5	9.3	3.2	<5	11	9.4(L)
	b	58	126	36		65	77	.15	.08	<.01	5.8	.01	.34	42.1	9.0	3.1	<5	10	9.4(L)
9-11-68	s	75	185			33	44	1.2	<.01	<.01	4.0	.02	.99	49.0					7.9
	b	75	197			38	47	1.1	<.01	<.01	12.2	.03	1.20	48.0					
10-22-68	s	73	180	30	6	28	39	0.50	<.01	<.01	5.5	.22	.30	37.8	12.0	2.8	<5	<10	6.9

b - bottom
Cl - chloride
Cond. - conductivity (micromhos/cm)
K - potassium
(L) - laboratory measurments

Na - sodium
$N-NH_3$ - nitrogen-ammonia
$N-NO_2$ - nitrogen-nitrite
$N-NO_3$ - nitrogen-nitrate
s - surface

SNOC - soluble non-volatile organic carbon
SO_4 - sulfate
T.Alk. - total alkalinity, mg $CaCO_3$/1
TKN - total Kjeldahl nitrogen
Silica (soluble) expressed as mgSiO_2/1
Concentrations espressed in mg/1

Table 4 (cont'd)
A. Howard Bay

Date of Collection	Depth	T.Alk.	Cond.	Carbon Total	Carbon SNOC	Hardness Ca	Hardness Total	$N\text{-}NH_3$	$N\text{-}NO_3$	$N\text{-}NO_2$	TKN	P Ortho	P Total	Silica Soluble	Na	K	Cl	SO_4	pH
05-07-69	b	42	98	14	4	29	30	.05	<.01	<.01	.8	<.01	.16	21	7.8	1.9	<5	<10	7.0
06-03-69	s	42	110	35	10	31	37	2.7	.01	<.01	5.3	<.01	.20	23					9.5
06-03-69	b	43	108	22	7	29	49	1.8	<.01	<.01	3.6	<.01	.14	23					
07-16-69	s	70	105	35	23	31	36	11.0	.09	.01	14.6	<.01							8.4
07-16-69	b	46	102	25	8	30	33	1.2	<.01	<.01	3.5	<.01	.16						8.7
08-04-69	s	49	110					1.7			3.4		.20	39					9.1
08-04-69	b	48	114					1.6			3.7		.18	39					
08-28-69	s	47	115	25	7		44	1.3	.03	.01	3.3			40				<10	9.4
08-28-69	b	46		25	7		46	1.2	.04	.01	3.4			44				<10	
09-09-69	s		117	20	6		46	.31	.03	<.01	2.6		.05	40				<10	8.9
09-09-69	b		117	20	7		46	.21	<.01	<.01	2.9		.48	40				<10	9.1
09-30-69	s	66	172	31			50	1.8	.02	.01	5.0	.23	.37	44				10	7.9
09-30-69	b	64	178	38			45	1.8	<.01	<.01	5.6	.17	.31	44				11	8.1
10-20-69	s	48	135				36	.7			3.2		.23	44	9.0	1.8		<10	8.3
10-20-69	b	52	148				38	1.0			3.0		.22	44	9.9	1.8		10	7.9
01-13-70	s	54	145	21	7		31	0.5	.35		1.9	<.01	.14	31					7.5
01-13-70	b	88	338	39	14		35	0.8	.35		3.5	.03	.24	35					7.3

Table 4 (cont'd)
B. Outlet

Date of Collection	Depth	T.Alk.	Cond.	Carbon Total	Carbon SNOC	Hardness Ca	Hardness Total	$N\text{-}NH_3$	$N\text{-}NO_3$	$N\text{-}NO_2$	TKN	P Ortho	P Total	Silica Soluble	Na	K	Cl	SO_4	pH
10-11-67	s		108	27	13	32	34					.03	.15	32.0	13.5	2.3		<10	9.4
11-16-67	s	58	138	23	7	30	48	2.0	.08		2.9	.07	.13	33.0			<5	<10	7.7
1-18-68	s	63	137	25	8	34	39	1.9	.20	.02	2.7	.12	.18	33.5	11.0	2.7	<5	<10	7.0
	b	65	141	26	6	33	41	2.0	.32	<.01	3.4	.11	.21	34.1	11.0	2.7	<5	<10	7.3
1-31-68	s	64	137	23	7	31	40	1.8	.13	<.01	2.8	.11	.31	35.3	10.0	2.5			7.4
	b	64	139	23	8	32	40	1.8	.13	<.01	2.8	.10	.16	35.4	10.0	2.5			7.7
3-02-68	s	48	110	24	9	30	31	<.1	.13	<.01		<.01	.28	19.4	10.0	1.9	<5	<10	9.8
	b	51	107	22	9	32	32	<.1	.12	<.01	2.1	<.01	.15	20.3	10.0	2.0	<5	<10	9.6
4-04-68	s	43	105	20		18	32	<.1	.02	<.01	1.1	.01	.08	11.7					8.4
	b	42	105	20		19	30	<.1	.02	<.01	1.2	.01	.07	11.7					8.1
5-08-68	s	45	108		9	25	33	<.1	.01		0.9	.02	.06	9.7	8.8	1.9		<10	8.1
	b	46	105		9	23	38	<.1	.01		1.0	.01	.08	10.0	9.3	2.1		<10	8.1
6-12-68	s	47	110					<.1	<.01		1.3	.01	.09						8.6
	b	47	109					<.1	<.01		1.6	.01	.12						8.6
6-25-68	b	50	110			33	51	.56	<.01	<.01				14.7	10.0	2.0			9.9(L)
7-09-68	s		145																
	b		133																
8-14-68	s	54	113	29		64	68	<.1	.03	<.01		.11	.37	40.8	9.8	2.7	<5	<10	9.1(L)
	b	54	114	26		64	76	<.1	.03	<.01	3.6	.07	.27	41.0	9.0	2.7	<5	<10	9.2(L)
9-11-68	s	52	122			34	35	0.1	<.01	<.01	3.5	.09	.24	48.0					9.8
	b	52	123			29	38	<.1	<.01	<.01	3.6	.10	.29	49.0					
10-23-68	s	61	150	26	7	27	38	.55	.06	.01	8.5	.10	.39	39.2	12.0	2.6	<5	<10	
	b		152																
2-06-69	s	53	150	23		24	37	.15	.12	<.01	2.7	.08	.24	29.3	9.9	2.4		<10	8.0(L)

Table 4 (cont'd)
B. Outlet

Date of Collection	Depth	T.Alk.	Cond.	Carbon Total	Carbon SNOC	Hardness Ca	Hardness Total	$N\text{-}NH_3$	$N\text{-}NO_3$	$N\text{-}NO_2$	TKN	P Ortho	P Total	Silica Soluble	Na	K	Cl	SO_4	pH
05-06-69	s	41	98	14	4	26	30	.03	<.01	<.01	.6	<.01	.26	21	7.9	1.9	<5	<10	6.4
06-03-69	s	43		21	4	36	38	.52	<.01	<.01	1.6	<.01	.08	23					
06-03-69	b	42		21	5	30	34	.78	<.01	<.01	1.9	<.01	.08	23					
07-16-69	s	45	112	22	7	29	32	.23	<.01	<.01	2.8	<.01	.16						9.6
07-16-69	b	44	109	20	8	30	31	.18	<.01	<.01	2.7	<.01	.14						9.5
08-04-69	s	46	108					1.0			4.5		.22	38					9.7
08-04-69	b	49	108					.90			4.0		.20	37					9.7
08-28-69	s	47	115	22	6		36	.72	<.01	<.01	2.9			40				<10	9.7
09-09-69	s		118	27	7			.06	<.01	<.01	4.2		.36	40				<10	9.3
09-09-69	b		112	23	7			.07	.02	<.01	3.3		.46	40				<10	9.2
09-30-69	s	48	118	27			32	.10	.02	.01	4.3	.05	.33	44				<10	9.6
09-30-69	b	48	118	26			31	.09	<.01	<.01	4.2	.04	.28	44				<10	9.7
10-21-69	s	49					35	.04			3.8		.32	44	9.7	1.6			8.3
10-21-69	b	49					33	.04			2.4		.23	45	9.5	1.6			8.3
01-13-70	s	59	113	19	4		33	1.1	.15		2.4	.02	.11	38					7.3
01-13-70	b	51	113	21	4		33	1.1	.15		2.4	.02	.16	39					7.3

Table 4 (cont'd)
C. Buck Island

Date of Collection	Depth	T.Alk.	Cond.	Carbon Total	Carbon SNOC	Hardness Ca	Hardness Total	$N-NH_3$	$N-NO_3$	$N-NO_2$	TKN	P Ortho	P Total	Silica Soluble	Na	K	Cl	SO_4	pH
05-07-69	s	42	110	14	4	28	32	.06	<.01	<.01	.8	<.01	.16	20	7.6	1.9	<5	<10	8.5
05-07-69	b	42	110	14	4	29	31	.05	.01	<.01	.9	<.01	.14	20	7.8	1.9	<5	<10	7.8
06-02-69	s	42	108	18	5	30	40	.47	<.01	<.01	1.4	<.01	.07	23					9.2
06-02-69	b	42	102	18	4	30	33	.24	.01	<.01	1.0	<.01	.07	23					
07-16-69	s	43	109	19	9	30	33	.08	<.01	<.01	2.0	<.01	.10						9.4
07-16-69	b	44	109	23	8	30	31	.09	<.01	<.01	2.9	<.01	.15						9.2
08-04-69	s	45	108					.7			3.8		.20	37					9.7
08-04-69	b	45	108					.5			4.5		.28	37					9.7
08-28-69	s	47	115	22	7		36	.4	<.01	<.01	2.3			40				<10	9.7
08-28-69	b	46	117	22	7		34	.5	<.01	.02	3.2			40				<10	9.7
09-09-69	s		112	31	7			.06	<.01	<.01	5.4		.94	40				<10	9.2
09-09-69	b		114	20	7			.04	<.01	<.01	2.0		.88	39					9.1
09-30-69	s	48	118	25			38	.1	.05	<.01	3.0		.24	44					9.6
09-30-69	b	48	118	22			33	.06	.62	.017	3.2		.26	44					9.6
10-21-69	s	49	128				31	.07			2.6		.16	44	9.7	1.3		<10	8.8
10-21-69	b	48	128				36	.05			1.8		.20	44	9.5	1.4			8.3

Table 5
Interstitial Water Chemistry
at Primary Stations
(Surficial Sediment Grab Samples)
A. Howard Bay

Date	Ortho-P	TSP	Cond	N-NH_3	N-TKjel	Alk.	Total Hardness	Sol. Silica	Total Carbon	SNOC*	pH	Total Fe % dry wt	Total P % dry wt
June 12, 1968	2.9	3.1	525	30	30	234	155	46	59	10	7.5	1.29	.088
June 25, 1968	6.2	6.2	704	46		325	144	54	75	11	7.4		
July 10, 1968	6.2	6.2	658	39				57		15	7.8		
Aug. 14, 1968	9.0	9.0	893	54	63	452	189	96	117		7.7		
Aug. 20, 1968	10.5	10.5	1076	86	86	559	203	91	141	19	8.1	1.10	.058
Aug. 27, 1968	9.5	9.5	939	67	123	450	207	97			7.9		
Sept.11, 1968	8.5	9.0	1008								8.1		
Sept.25, 1968	7.0	7.2	889								7.7		
Oct. 23, 1968	8.5	8.5	1022	85	72		189	63			7.7	1.20	.064
Dec. 10, 1968	7.9		726	48							8.0		
Apr. 2, 1969	7.1	11.2	944	64	66			42	106	12	7.2	1.45	.116
May 7, 1969	.72	1.4	386	4.0		165	128	38			7.7		064
June 3, 1969	.32	.40	188	2.3	3.9	85	60	31			8.0		
June 12, 1969	6.0	6.0	775	38.5	40.8	362	192	56			7.9		
July 16, 1969	.30	.45	148	3.6	6.1	65		37			7.9		
Aug. 5, 1969	.64	.64	244	8.8	8.2	88		29			7.9		
Aug. 27, 1969	1.8	1.8	426								7.7	1.40	.076
Sept. 9, 1969	2.6	8.0	462	22	27	209		48			7.5	1.35	.064
Sept.30, 1969	4.6	4.6	596	30	35	288		50			7.5		
Oct. 21, 1969	6.4	6.4	761	58	69			48			7.2		
Jan. 13, 1970	1.3	1.5	457	16	17	189		43	53	13	7.2		
Mar. 26, 1970	3.0	3.2	511	20	19	255		46	72	20	6.8		
Apr. 27, 1970	5.5	5.3	648	40	38	319	126	50			7.1		
June 3, 1970	4.0	4.0	469	20	22	231	123	48			7.3		
July 7, 1970	4.0		562								7.7		

Note: Concentrations expressed in mg/l.
Total Fe and P determined on dried sample.

Table 5 (Cont'd)
B. Outlet

Date	Ortho-P	TSP	Cond	$N-NH_3$	N-TKjel	Alk.	Total Hardness	Sol. Silica	Total Carbon	SNOC	pH	Total Fe % dry wt	Total P % dry wt
June 25, 1968	.06	.16	138	24		60	40	27	19	6	7.4	1.35	.045
Aug. 27, 1968			221	22	22	102	9	78	37	7	8.1		
Sept.24, 1968	.03	.05	209				14				7.8	1.3	.040
Feb. 6, 1969	1.8	1.9	317								7.3		.080
Apr. 2, 1969	.45	.45	204	5.5	7.8			40	27	6	6.7	1.70	.072
May 7, 1969	.52	1.0	211	8.1	9.9	95	50	40			7.7		
June 3, 1969	.12	.18	107	2.1	3.2	44	35	33			8.2		
July 16, 1969	.53	.55	165	6.6	8.9	71		44			7.9		
Aug. 5, 1969	.20	.26	130	5.0	5.0	55		36			7.8		
Aug. 28, 1969	.26	.41	129								7.8	1.50	.070
Sept. 9, 1969	.21	.32	134		6	57	39				7.9	1.55	.052
Sept.30, 1969	.23	.26	149	1.9	4.8	50		48			8.1		
Oct. 21, 1969	.10	.20	145	2.3	5.4			42			7.5		
Jan. 13, 1970	1.3	1.3	398	23	3.3	164		44	60	11	7.0	1.60	.086
Feb. 24, 1970	.06	.10	121	2.6	3.9	56		33	.34	6	6.4		
Mar. 26, 1970	.04	.14	124	1.9	3.1	61		31	22	7	6.7		
Apr. 27, 1970	.05	.13	121	1.7	3.1	56	33	26			7.3		
June 3, 1970	.11	.21	139	1.76	3.7	64	39	25			6.6		
July 7, 1970	.10		156								8.0		

Table 5 (Cont'd)
C. Buck Island

Date	Ortho-P	TSP	Cond	$N-NH_3$	N-TKjel	Alk.	Total Hardness	Sol. Silica	Total Carbon	SNOC	pH	Total Fe % dry wt	Total P % dry wt
June 12, 1968												.98	.033
June 25, 1968	.07	.15	124	1.6		56	35	26	22	6	6.7		
Aug. 20, 1968	.11	.27	191	9	10.7	79	47	72	37	13	7.4		
Sept.11, 1968	.08	.21	133										
Sept.24, 1968	.07	.17	191	8.5	10.4	82	37	49			6.9	.90	.026
Oct. 23, 1968	.75	.75	276	6.2	9.6	97	76	51	26	19	7.4	1.22	.060
Nov. 6, 1968	.58	.62		5.2	5.4		65	55	33	6			
Nov. 19, 1968	.31	.37	178								8.2		
Apr. 2, 1969	.06	.12	187	2.3	4.4			34	31	11	6.4	1.35	.065
May 7, 1969	.14	.36	132	2.0	5.5	60	38	36			7.7		
June 3, 1969	.12	.21	137	2.4	4.5	58	38	36			7.7		
June 12, 1969	.30	.36	134	2.2	3.9	62	50	38			7.8		
July 16, 1969	.13	.21	116	1.8	4.1	49		8			7.8		
Aug. 5, 1969	.18	.24	122	2.8	4.8	54		36			7.9		
Aug. 27, 1969	.21	.40	117								7.9	1.25	.062
Sept. 9, 1969	.16	.37	118	2.0	4.4	46		40			7.9	1.35	.058
Sept.30, 1969	.26	.59	121	1.9	6.0	54		44			8.2		
Oct. 21, 1969	.10	.21	129	1.3	3.7			40			7.4		
Feb. 24, 1970	.08	.16	120	1.9	3.5	61		33			6.6		
Mar. 26, 1970	.04	.14	124	1.4	2.5	60		33	20	5	6.6		
Apr. 27, 1970	.05	.07	120	1.3	2.6	57	34	27			7.7		
June 3, 1970	.08	.22	135	1.4	3.2	64	42	28			7.4		
July 7, 1970	.02		147								7.2		

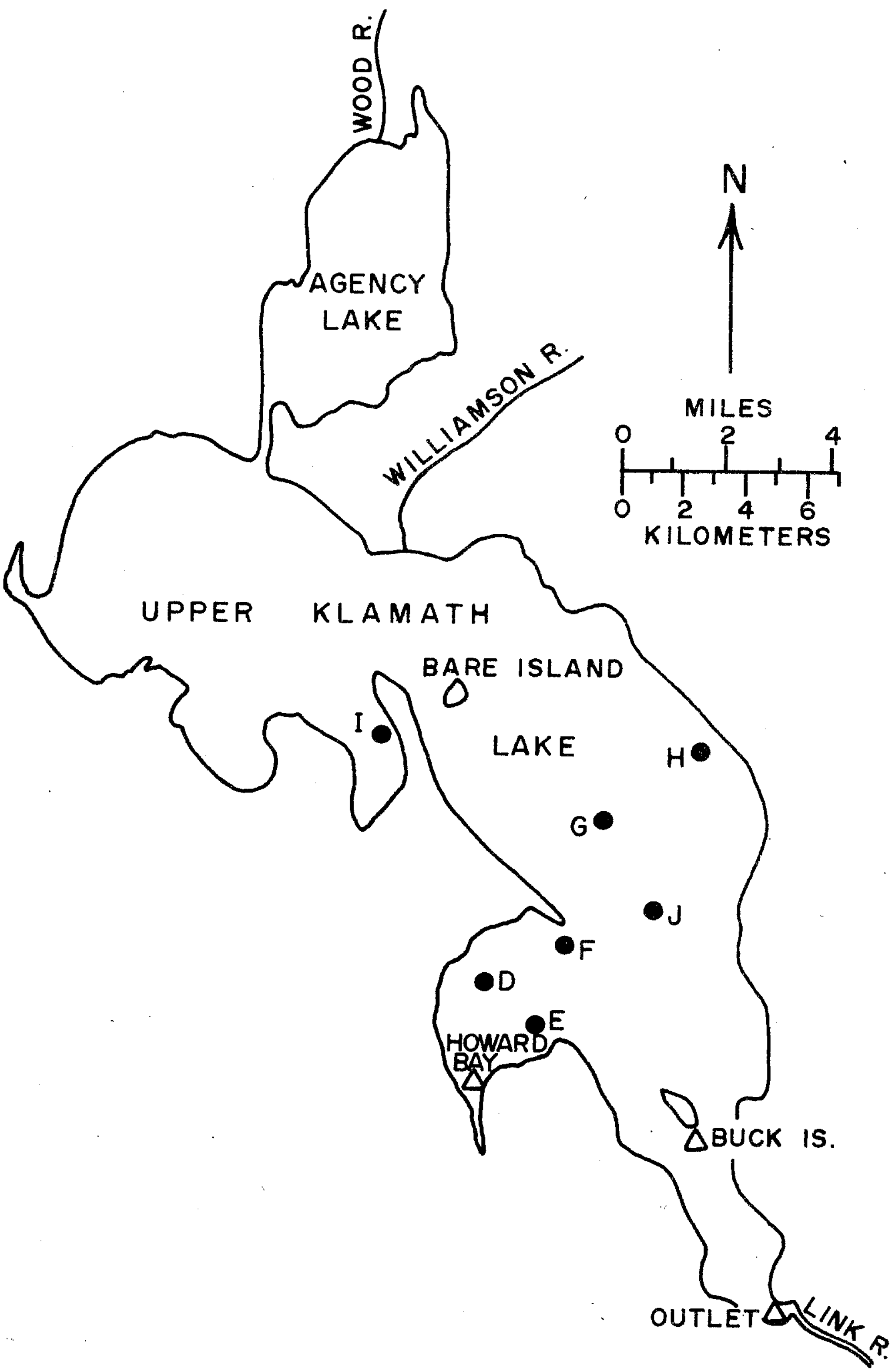

Figure 1. Upper Klamath Lake and Station Locations

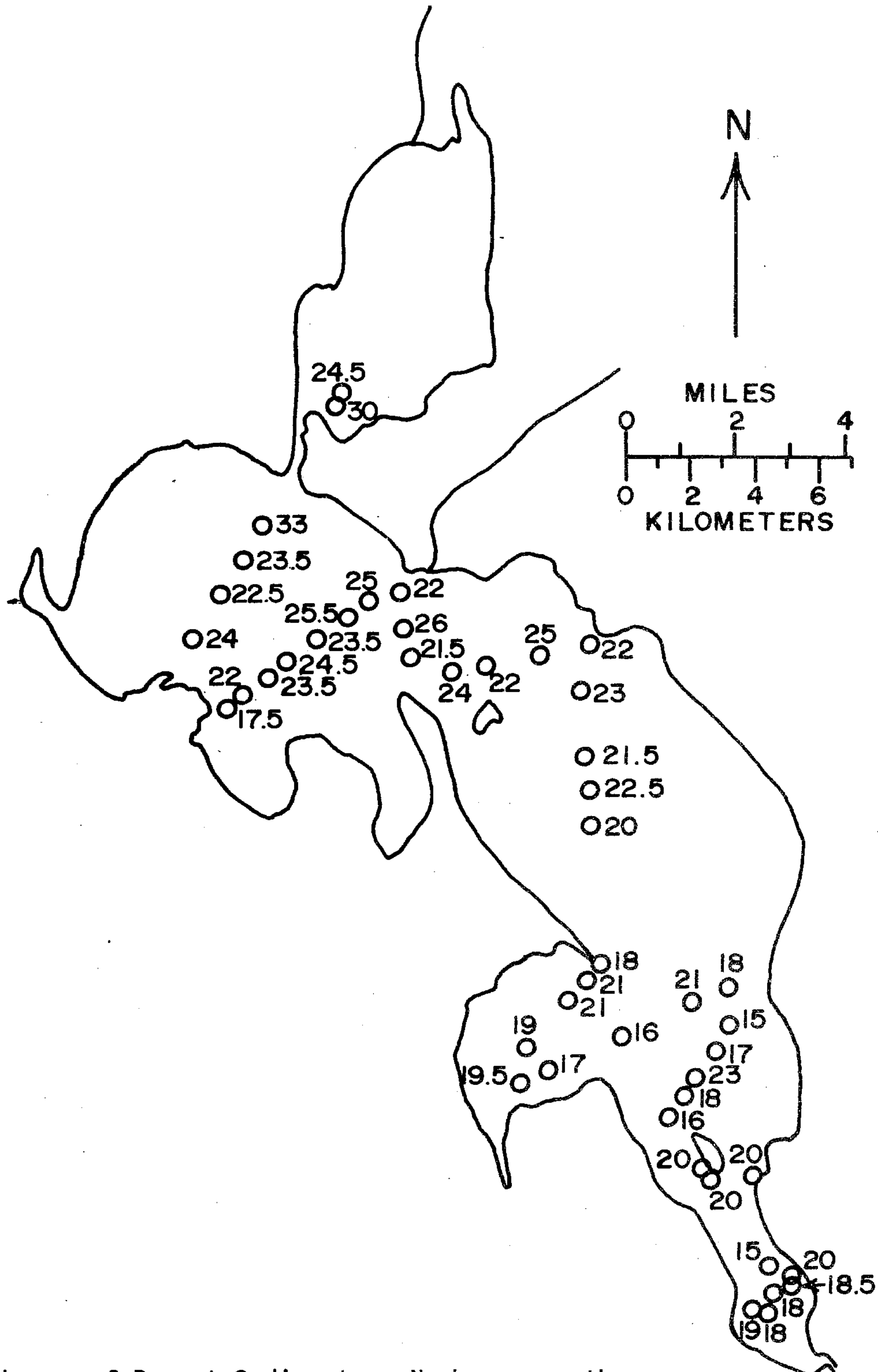

Figure 2. Thickness of Recent Sediments. Numbers are the distance in meters from the lake surface to the bottom of the unconsolidated layer.

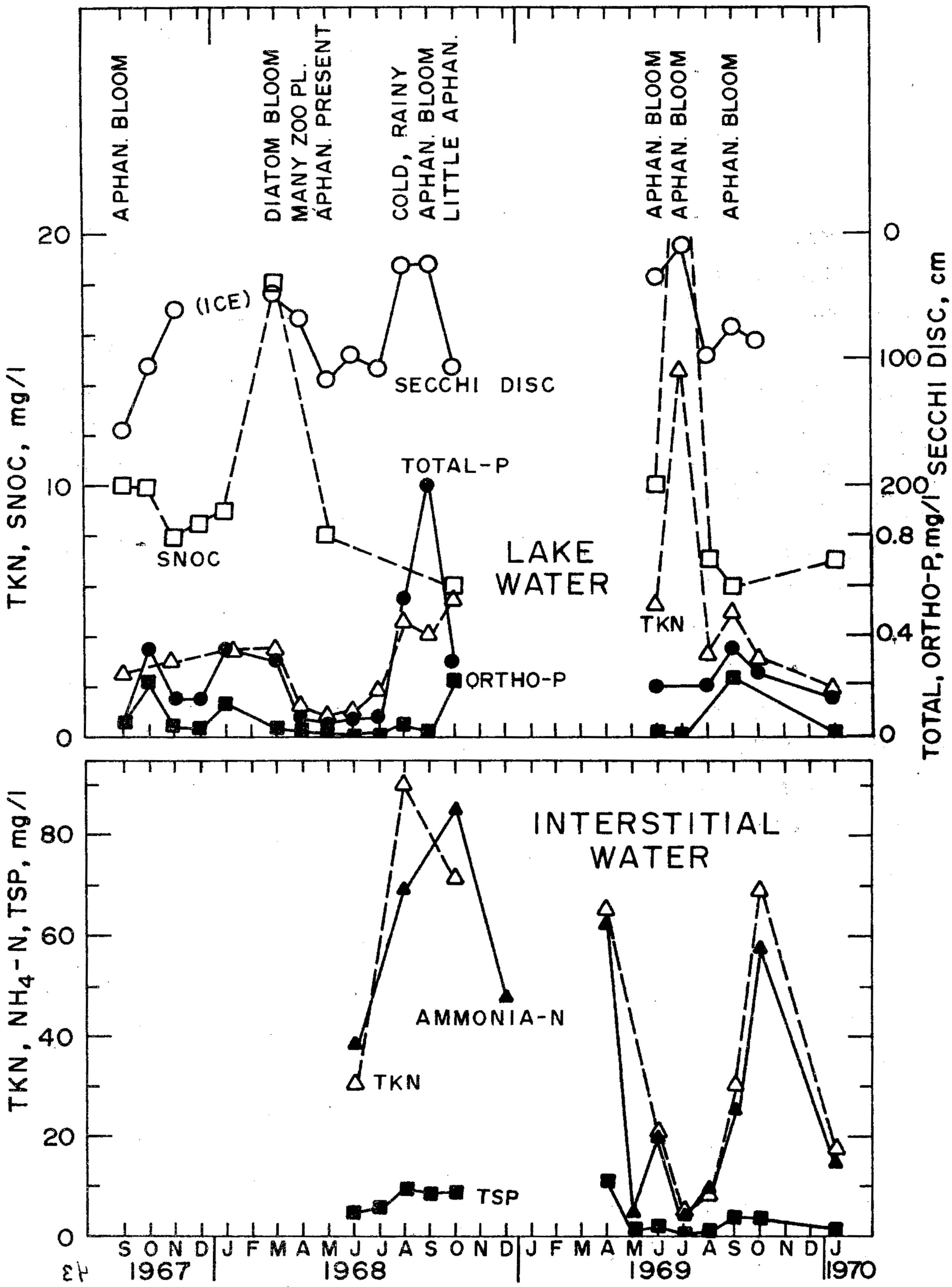

Figure 3. Chemistry of Lake Water and Interstitial Water, 1968-69.

Howard Bay

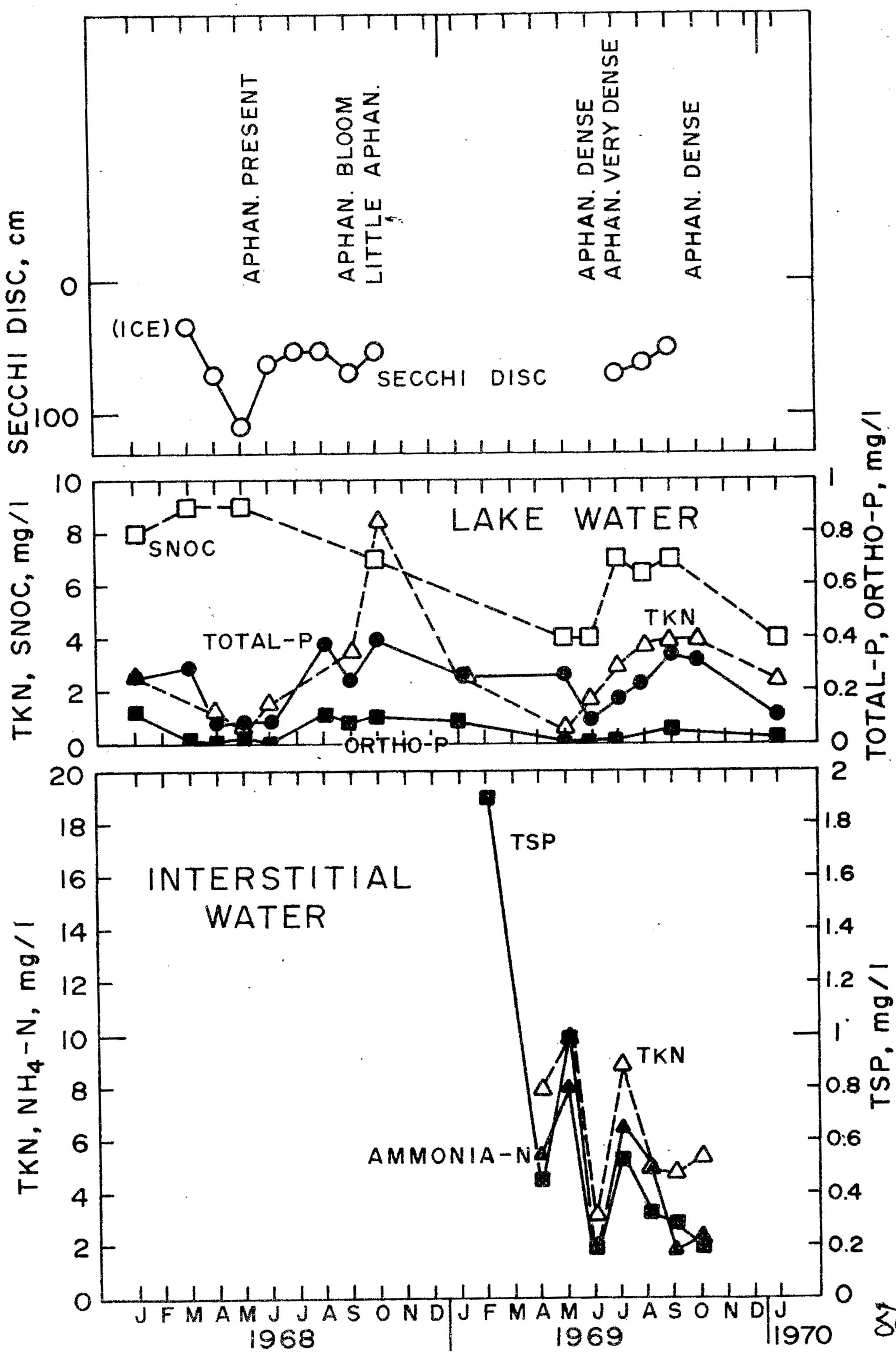

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Figure 4. Chemistry of Lake Water and Interstitial Water, 1968-69, the Outlet

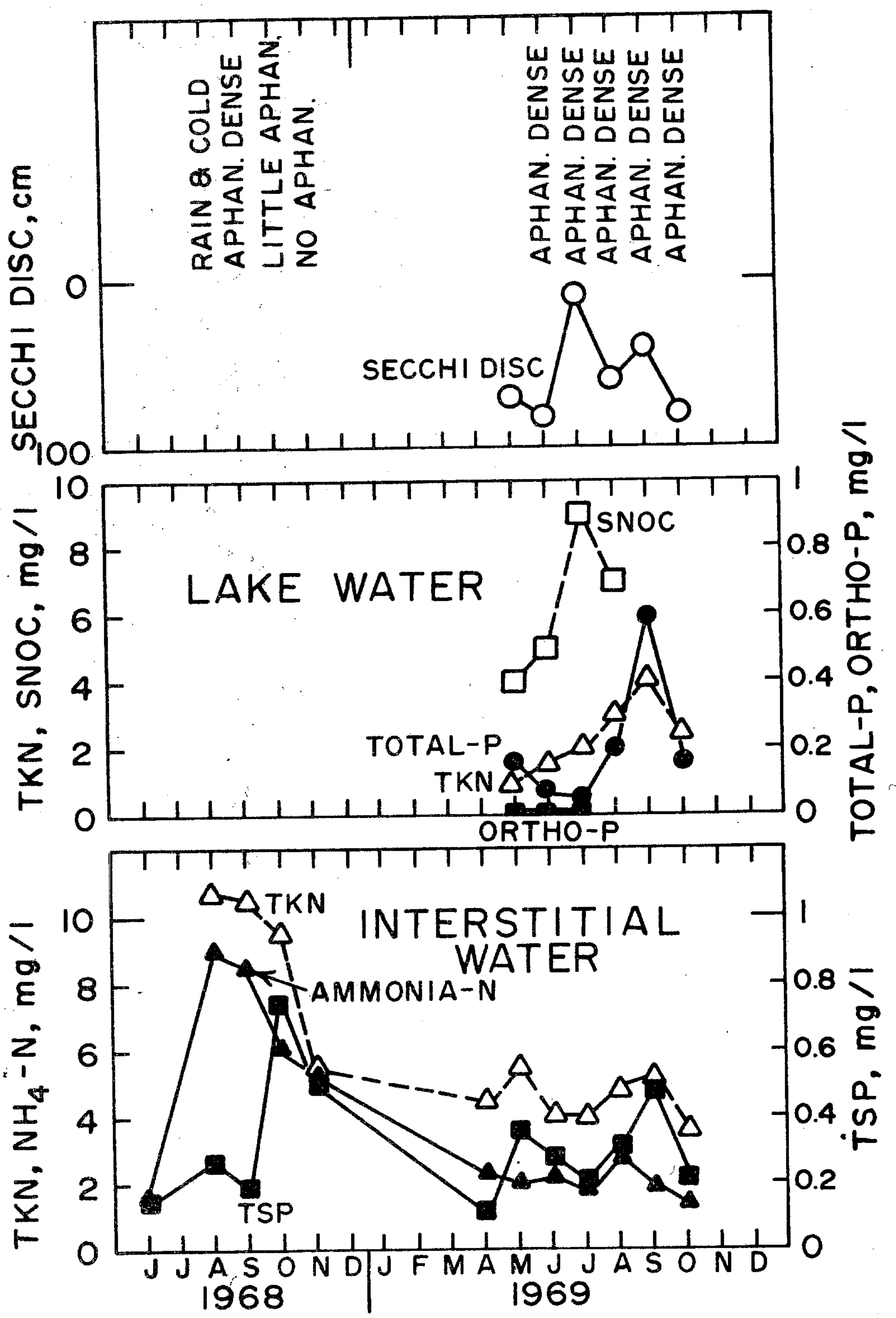

Figure 5. Chemistry of Lake Water and Interstitial Water, 1968-69, Buck Island

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16. Abstract

Upper Klamath Lake, a very large, shallow lake in south-central Oregon, has a history of nuisance blue-green algae blooms, predominantly Aphanizomenon flos-aquae. Lake water and sediment interstitial water chemistry were monitored during 1968 and 1969, and for a short time in 1970. Nutrient concentrations in interstitial water of sediment exposed to direct agricultural drainage were several orders of magnitude greater than in cases where sediments were not so located. Nutrient concentrations showed considerable seasonal variation in both interstitial and lake waters. Variations in lake and interstitial waters frequently, but not always, exhibited inverse relationships. The larger fluctuations appeared to correlate with density of A. flos-aquae.

Although strong evidence of biological uptake of sedimentary nutrients was found, dredging of the lake would probably not be effective as a restorative measure because of the high nutrient concentrations present at depth in the sediment.

17a. Descriptors
*sediments, *nutrients, algal blooms, water quality, eutrophication, agricultural chemicals.

17b. Identifiers
*Upper Klamath Lake

17c. COWRR Field & Group 05C

18. Availability

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