Sediment in Ice-Block Lakes in Intensively Cultivated Watersheds of Southern Minnesota

J. F. Cummins
R. O. Paulson
R. H. Rust
S. E. Gruenhagen

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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ABSTRACT

Basin sediment was studied from 20 ice-block lakes associated with nutrient-rich, intensively cultivated soils on landscapes with poorly integrated drainage in southern Minnesota. This sediment is placed in the coprogenous earth class of limnic materials. Rice and Hall Lakes were investigated in detail because of the contrast in size and relief of their watersheds. Bulk density, mineral content, and total phosphorus and potassium were measured in cores taken from the lakes.

A core from Rice Lake was sampled at selected depths for radiocarbon dating, examination of minerals, and pollen and diatom content with a petrographic microscope and X-ray analysis of the 2- to 20-micron size particles. Bulk density of the sediments increased from 0.07 g/cm^3 in the layers part to 0.36 g/cm^3 in the lower. Between 5.4 and 14.5 m, the bulk density fluctuated between 0.25 g/cm^3 and 0.30 g/cm^3. In Rice Lake, a peaty layer near 4.45 m had a much lower bulk density. Content of phosphorus and potassium increased to a depth of 10 m, then decreased slightly with depth to the basin floor. Petrographic microscopic examination and X-ray analysis of the sediment identified only quartz and calcite in appreciable amounts. Crystalline silicates in the sediment are like those in nearby upland soils formed in the calcareous gray glacial drift. Diatomaceous forms and opalized plant remains were abundant.

Radiocarbon date and pollen dominance were determined at depths of 4 to 5 m and 14.5 m. The layer at 14.5 m was dated at 9675 ± 144 years before present (B.P.) and spruce pollen was dominant. The peaty layer at 4 to 5 m was dated at 1835 ± 80 B.P.

Sediment from Hall Lake had a higher bulk density, more total phosphorus, and more total potassium and mineral material than sediment from Rice Lake. These higher values probably reflect the larger amounts of upland sediment from the larger watershed and the shorter distance from the sample site to an incoming stream. Nevertheless, upland mineral types were present only in trace amounts and in sizes commonly transported by wind. Also, soil surveys located most sediment eroded from hillslopes at the foot slope. We conclude that most of the sediment was generated in the lakes themselves from dissolved nutrients.

AUTHORS

J.F. Cummins is a retired soil scientist, U.S.D.A., Soil Conservation Service. **R.O. Paulson** is a soil scientist, U.S.D.A. Soil Conservation Service. **R.H. Rust** is Professor of Soils, and **S.E. Gruenhagen** is a Junior Scientist, Soil Science Department, University of Minnesota. Special credit is due **Dr. H.E. Wright, Jr.** for his contributions to the sampling of Rice Lake, including pollen analysis of selected samples and advice on carbon 14 analysis.

INTRODUCTION

Within the last 25 years, studies have clearly outlined the history of ice-block lakes within and near southern Minnesota (Swain 1956, Jelgersma 1962, Clayton 1967, Watts and Bright 1968, Florin 1970, Latterell et al. 1971, Wright 1972).

This paper deals specifically with the nature and origin of post-glacial sediments in such lakes. Excluded are sediments in mill ponds and reservoirs that are often classified as "lakes". Some river lakes were sampled for data comparison. Lake water quality was not a part of this study.

The Late Wisconsin gray till plain is a region of disordered relief forms only slightly modified since glacial deposition (Matsch et al. 1972). Few first- and second-order streams are present. The drainage net is none to weakly integrated (De Koster et al. 1959). The energy of hillslope runoff is absorbed by the low-gradient base slopes and depressions. Engineering designs of drainage systems affirm that the land surface away from hillslopes commonly has average gradients ranging from 0.05 to near 1 percent. This seemingly "level" land surface has numerous small depressions within a complex, convex-concave micro-relief. Soil surveys indicate that most organic soils in depressions below hillslopes commonly lack visual evidence of upland sediment. The gray-surfaced Alboll soils (Soil Survey Staff 1975) in the shallow depressions on the level glacial-lake plains commonly lack sediments from the adjacent, slightly higher, dark colored soils. Thus, little evidence exists for long-range transport of sediment in this area. However, the filling of lakes is attributed to the transport of sediment from cultivated soils. The purpose of this study was to compare the lake basin sediment with upland sediment to establish the extent to which lake sediments originated from surrounding lands.

Mineral sediment from soils formed in the calcareous Wisconsin drift is composed chiefly of both primary and secondary silicate minerals, the crystalline structure of which is identifiable by petrographic microscope, differential thermal analysis, or X-ray analysis (Arneman et al. 1958). Lake sediment collected for this study is within the coprogenous earth category of limnic material (Soil Survey Staff 1975). Limnic production by aquatic organisms was sustained by nutrients entering the lake from the watershed. Such organisms included plants, which were subsequently digested by aquatic animals. Coprogenous earth (gyttja) is a limnic material that contains many fecal pellets a few hundredths to a few tenths of a millimeter in diameter.

Soils developed in soil materials surrounding the lakes have properties diagnostic for suborders of Histosols and Entisols (Soil Survey Staff 1975). The Blue Earth and Urness series are examples of Entisols and occupy desiccated or drained basins (Finney et al. 1972).

In this study area, the limnic material has a moist Munsell color value less than 5; forms a slightly viscous suspension in water; is slightly plastic when wet or shrinks on drying to form clods that are difficult to re-wet and tend to crack along horizontal lines; and yields saturated sodium pyrophosphate extracts that have a Munsell color value higher than 7 and chroma lower than 3. This material has a range in particle size and carbon-nitrogen ratio (12-20) that is consistent with advanced decomposition. The exchange capacity (80 to 100 meq/100 g of organic matter, measured by loss on ignition) indicates little decomposition influenced by exposure to air (Soil Survey Staff 1975).

INVESTIGATION PROCEDURE

Preliminary Studies

Basin sediment was classified in 20 lakes located in southern Minnesota (Table 1, Figure 1). Transects or selected drilling sites included areas near major inflow and near the center and deeper part of the lakes. Initial sampling was done with a Giddings soil sampler with either a 7.62 cm diameter tube or a 7.62 cm diameter flight auger. All material sampled was classified within the coprogenous earth category of limnic sediment (Soil Survey Staff 1975). The transect in Minnesota Lake revealed two layers of limnic sediment separated by about 2 m of black clayey sediment. The sediments sampled in Big Stone, Gun Club, Pepin, and Snelling Lakes which are river lakes was also in the nature of coprogenous earth. The transects of Creamery Lake, Kandiyohi County, had limnic sediment composed mostly of submergent aquatic vegetation. Rice and Hall Lakes were selected for detailed study because of their contrasting watersheds. Rice Lake is astride a regional watershed divide with low relief whose land-to-water ratio is 4.7 to 1. The Hall Lake watershed has higher hillslope relief and nutrient contributions from the City of Fairmont, the land-to-water ratio of which is about 37 to 1.

Table 1. Minnesota lakes and counties included in the sediment study.

County	Lake	Fig. 1 Map Number
Big Stone	Big Stone	1
Brown	Hanska	2
	Sleepy Eye	3
Dakota	Gun Club	4
Faribault	Minnesota	5
Freeborn	Albert Lea	6
	Fountain	7
	Geneva	8
Hennepin	Snelling	9
Jackson	Loon	10
Kandiyohi	Creamery	11
	Eagle	12
Martin	Hall	13
Murray	Shetek	14
Sibley	Titlow	15
Steele	Beaver	16
	Rice	17
	Oak Glen	18
Wabasha	Pepin	19
Waseca	Elysian	20

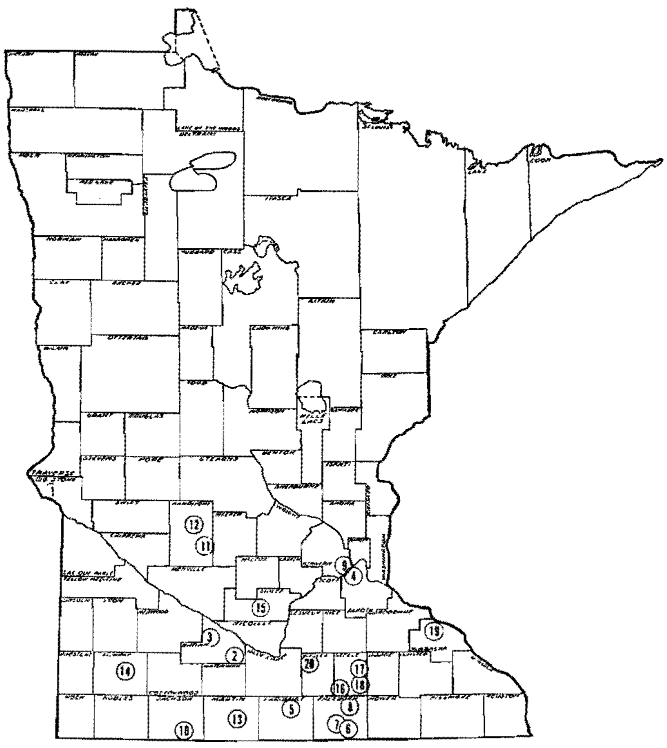

Figure 1. Lakes in southern and southwestern Minnesota sampled for basin sediments.

Field Investigation

The Macauley peat sampler was used to collect undisturbed samples from Hall and Elysian Lakes along transects from the deltas of major inflows toward the centers. Rice and Hall Lakes were sampled parallel to the longest axis. The Macauley peat sampler is a cylinder 50 cm long and 5 cm in diameter. Samples were placed in plastic bags and refrigerated until analysis. In Lake Elysian additional samples were collected for volumetric and percent moisture measurements on wet and oven dry weight basis. Additional samples from Rice and Hall Lakes were taken with the Livingstone peat sampler, with which undisturbed cores 1 m long and 3.8 cm in diameter were collected. Each core was wrapped in plastic film and aluminum foil and labeled. Samples were refrigerated until analysis.

Description of Rice Lake Watershed

Rice Lake is a 360 ha ice-block lake on a watershed divide and adjacent to a glacial meltwater channel (Figure 2). It is near the outer fringe of the Des Moines Lobe of the Late Wisconsin Glaciation. The water level is controlled at 377 m above mean sea level (AMSL). The meltwater channel north of the lake is now occupied by the sluggish, peat-filled, permanently flowing Maple Creek, which enters the Straight River to the west. An earth-and-concrete dam at 377 m AMSL controls the flow of Maple Creek from the northwest "outlet". But prolonged rainfall and strong southeast winds cause a small amount of outflow over this control structure. A possible northeast "outlet" grades to Maple Creek, but gravel pits and other disturbances have largely obliterated clear evidence of aboveground flow. The nearby boggy Maple Creek channel and the gravelly substrata in that area, however, suggest a weak subsurface flowage of lake water to creek flow. Most surface outflow at this time is to the east. A dredged ditch breaches an ice rampart and continues easterly through a large marsh. The peat marsh and ditch extend for about 2 km and join a branch of the easterly flowing Zumbro River.

The regional water table and the lake level are maintained by an average annual precipitation of 71 inches. The watershed includes small subwatersheds with areas of full-canopy deciduous woods and cropland along the north and southeast shorelines and two larger subwatersheds that are mostly cropland. One larger watershed of about 700 ha adjoins the southeast corner of the lake and contains a shallow dredged ditch with a maximum grade of 0.02 percent. This ditch extends about 1 km south from the lake's edge. Seventy-five percent of this subwatershed is composed of high-water-table soils in the Aquoll suborder. Surface gradients are less than 0.5 percent. Closed depressions make up 25 to 30 percent of the Aquoll surfaces. Knolls with 1.5 to 4.5 m relief have short, complex hillslopes and soils in the Mollisol and Alfisol orders and Typic and Aquic subgroups. Udoll soils on knolls are bounded by or intermingled with Aquolls. Sediment transport is very limited. Several subwatersheds, totalling 200 ha in area, contribute runoff from the lake's west side. Here, Aquolls make up about 35 percent of the land surface, principally as broad, poorly defined drainage nets. Knoll slopes are short and complex, with 1.5 to 4.5 m of relief. Knoll soils are

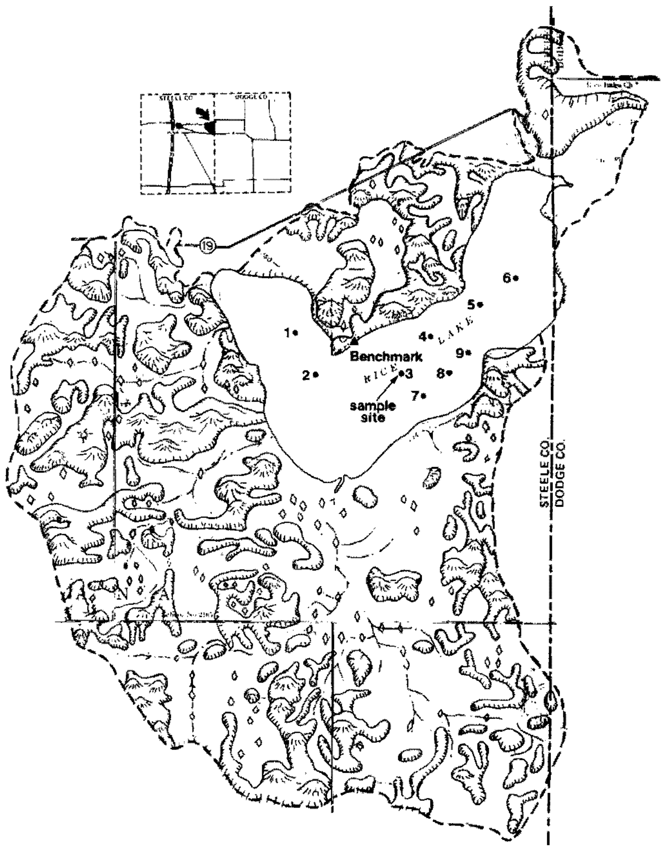

Figure 2. Approximate boundary of Rice Lake watershed in Steele and Dodge Counties and sampling sites within the lake.

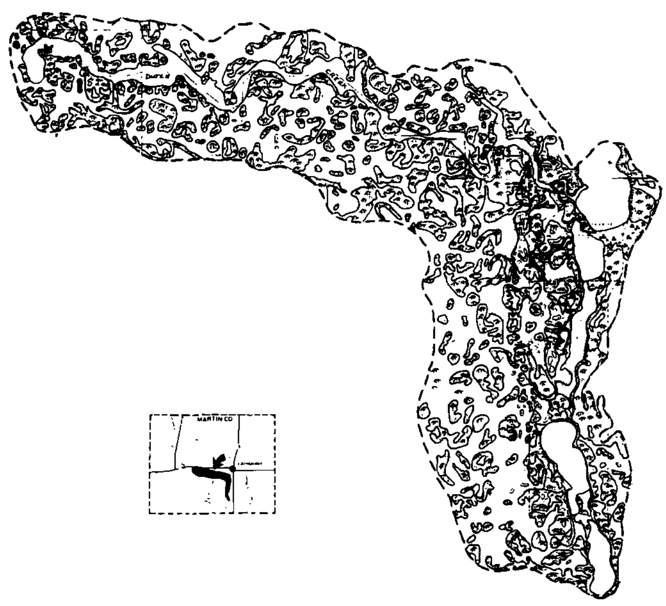

Figure 3. Approximate boundary of Hall Lake watershed in Martin County.

bounded by low-gradient draws and broad low concave and convex relief. Most of the Aquolls used as cropland are tile-drained. Grass waterways have been constructed in the lower reaches of the outlets. Surface gradients range from 0.3 to 0.5 percent.

Nine sampling sites were selected along a west-to-east transect of Rice Lake (Figure 2). The west bay ranged from 3 to 6 m in depth of water and limnic sediments above a glacial drift. In the eastern part, the glacial drift was commonly 14 m below the lake surface in the deepest part. The study site was selected because the limnic sediments overlie a dark mineral layer.

Description of Hall Lake Watershed

Hall Lake is a 223 ha ice-block basin lying within a north-south-trending partially filled glacial channel. This channel was crossed by an easterly trending meltwater channel that extends from Fox Lake to Dutch Creek, across the south edge of Hall Lake and southeasterly and easterly to the South Creek drainage. Soils occupying this second channel developed in outwash sands and gravels. The watershed includes the major subwatershed, small fringe subwatersheds, and inflow from Amber Lake-County Ditch #28 and Amber Lake, Mud Creek, Wilmert Lake, and North Silver Lake. The water flows out of Hall Lake by way of two box culverts into Budd Lake and others before flowing into Center Creek. The cumulative watersheds are 8,206 ha of which 4,178 ha are in Dutch Creek watershed (Figure 3).

The land surface of the Hall Lake watershed differs from that of the Rice Lake area by having smoothly contoured to irregular hillslopes with relief of 4.5 to 9 m. Sideslope soils are in Udoll and Orthent subgroups. Typic Orthents and Entic Udolls are commonly on the upper convex slope segments. Typical and Entic Udolls occupy the middle slopes. They are bounded by broad "flats" of Aquolls. Relief is commonly less than 1 m and more commonly less than 0.5 m, with closed depressions. Soils on the hill summits are Udolls and Orthents bounded by or intermingled with Aquolls with less than 0.5 percent gradient. The Aquolls also occupy numerous shallow and deep closed depressions. The surfaces of some closed depressions are mantled with organic soils of the Histosol order.

Dutch Creek has a channel dredged to 5.6 km from the Hall Lake inlet. The channel berm controls water entry into the constructed channel except at road crossings or a constructed access. The undredged area is a typical meandering stream with a broad, low alluvial bottom deeply inset among the glacial knolls. Bank caving and sloughing is active in parts of the dredged ditch, and streambank cutting is active along the natural stream meanders. This streambed is cut in the buried sandy and gravelly deposits of the glacial meltwater channel.

Bottom sediment was sampled in Hall Lake along a transect near the Dutch Creek delta. Sampling started (Site 1, Figure 4) above a sand bar about 120 m east of the shoreline and continued to the southwest. At site 1, the water was 1.5 to 3.3 m deep over the sand bar, which was underlain by an unoxidized glacial till of high bulk density. Sediment between the water and glacial drift was classified as limnic coprogenous earth. At a point about 110 m due east of the delta of Dutch Creek (Site 8, Figure 4), 1.8 m of water overlies 12.8 m of limnic sediment. Further drilling to the east indicated that the bottom sloped upward to the sand bar described above. A deep, small basin existed between the delta and the sand bar, a natural settling basin filled with limnic sediment. Site Number 8, selected for detailed measurement, is located about 105 m east of the Dutch Creek delta. The Livingstone sampler was used.

Three additional sites were sampled with the Macauley peat sampler. They were located near the Hall Lake-Budd Lake channel and southward (Sites 1N, 2N, and 3N, Figure 4).

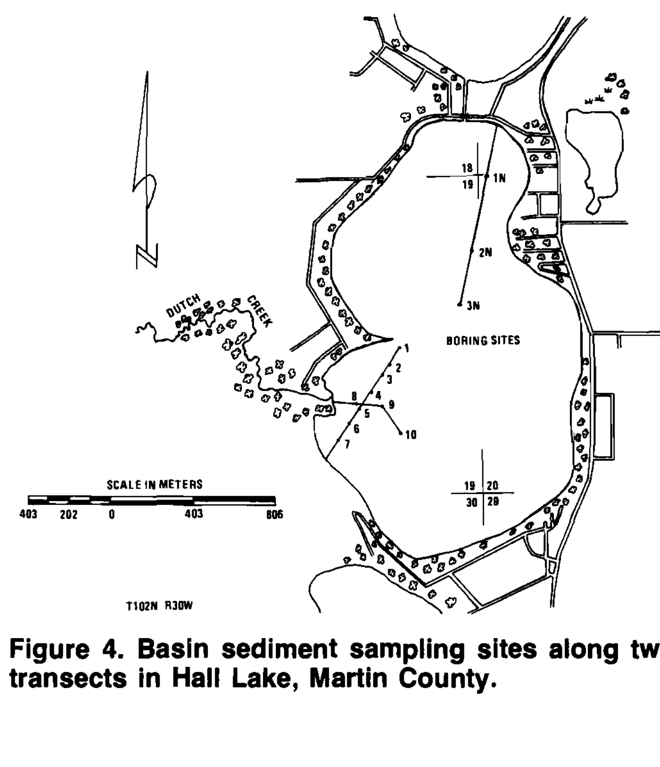

Figure 4. Basin sediment sampling sites along two transects in Hall Lake, Martin County.

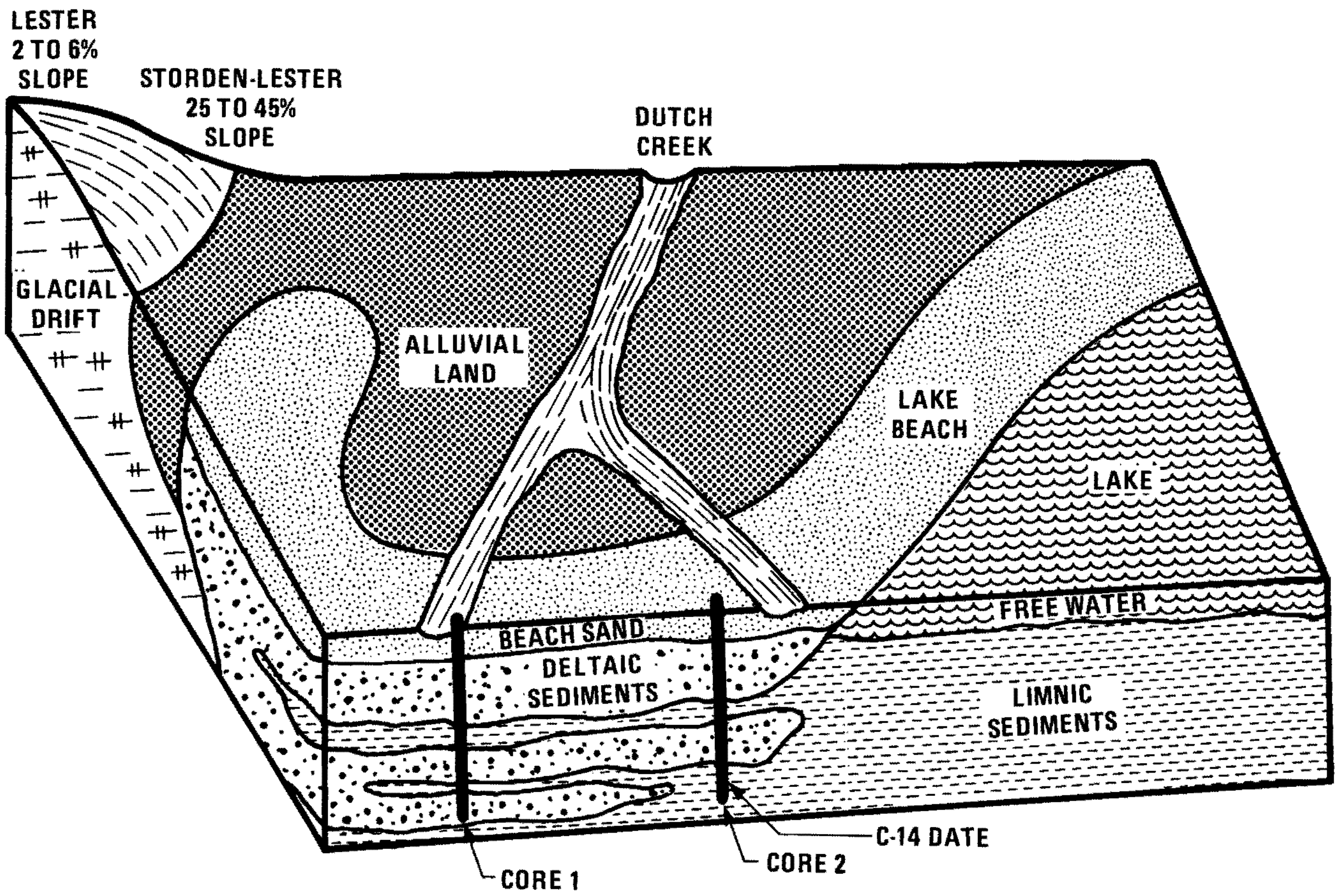

Figure 5. Probable stratigraphy of Dutch Creek delta sediments, Hall Lake, Martin County.

Two borings were made through the deltaic sediments at the mouth of Dutch Creek (Figure 5). The first boring (Core 1) was in the channel abandoned between 1968 and 1974 when the outlet to Dutch Creek moved about 61 m north. Core 1 had about 5.8 m of material stratified with mucky sandy loam, mucky loamy sand, and coarse sand overlying limnic sediment. There were two layers of typical limnic sediment 5 cm thick, at depths of about 3 m and 4.6 m. The second boring (Core 2) was about 30 m northeast of the first boring. Core 2 had about 3.8 m of stratified mucky sandy loam, mucky loamy sand, sand, and coarse sand overlying limnic sediments. There was a coarse sandy layer 15 cm thick at the 2.1 m depth with limnic sediments 5 cm thick both above and below it. The limnic sediment from the 3.6 to 3.7 m depth was sampled for carbon-14 dating.

LABORATORY PROCEDURES

The following data were obtained in the laboratory:

1. Dry bulk density was determined on a 100 cm^3 volume.
2. Mineral content was determined on a 50 cm^3 aliquot ashed in muffle furnace at 500° C and weighed.
3. Total phosphorus was measured by nitric-percholoric acid digestion and acid-free vanadate-molybdate reagent (Jackson, 1958).
4. Exchangeable potassium was extracted with neutral 1 N ammonium acetate and analyzed by atomic absorption (Jackson, 1958).
5. Wet-dry volume and water content were measured on Lake Elysian sediments.
   a. Volumetric measurements were used to determine percent shrinkage on drying.
   b. Water content was determined on jar samples, oven dried.
6. Carbon dating was determined on samples submitted to Geochron Laboratories Division, Krueger Enterprises, Inc. Cambridge, Ma.
7. X-ray analyses were made on slide oriented specimens using a GE XRD-5 diffractometer according to procedures outlined by Jackson (1956).

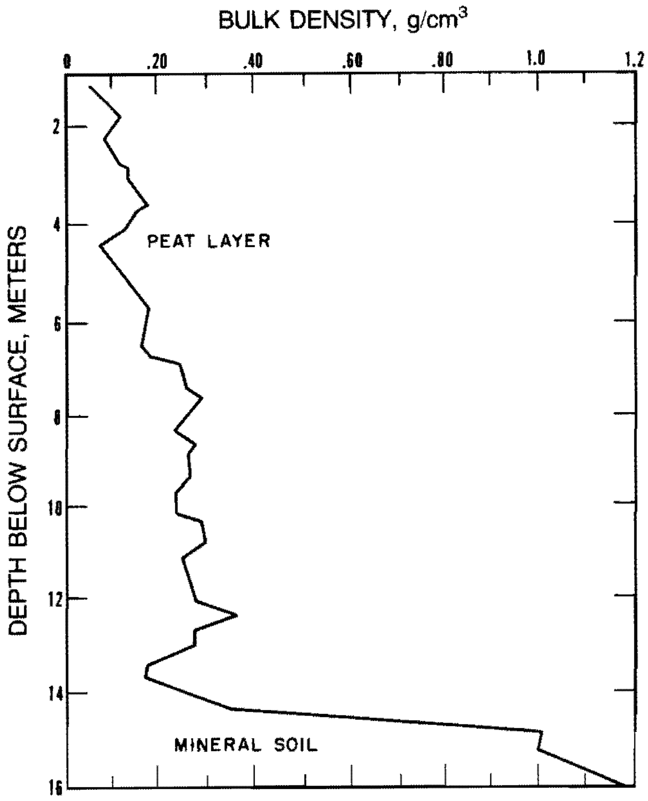

Figure 6. Bulk density of sediment in Rice Lake, Steele County, by depth.

Bulk Density

Bulk density was measured to compare upland soils with limnic sediment. Silicate clay minerals commonly have a dry density near 2.6 g/cm^3, silt particles range from 2.6 to 2.7 g/cm^3, and sands are near 2.8 g/cm^3. Typical topsoil, which is a mixture of sand, silt, clay, and organic matter, ranges in dry density from about 1.35 g/cm^3 in an uncultivated prairie surface with 5 to 7 percent organic matter to 1.45 to 1.55 g/cm^3 in the cultivated surface horizons. In many soils, the bulk density increases with depth because of decreases in organic matter and pore space. Lake sediment commonly has a dry density considerably lower than the density of water. Vertical variations in bulk densities of limnic sediments from Rice and Hall Lakes are shown in Figures 6 and 7, respectively.

The limnic sediment at water-sediment interface in the Rice Lake core at the 1.2 m depth has a dry bulk density value of 0.06 g/cm^3 which increases to 0.11 g/cm^3 at the 2 m depth (Figure 6). Density was irregularly related to depth, exceeding 0.30 g/cm^3 in only two samples. A peaty layer about 30 cm thick at the 4.5 m depth could represent a dry period during which the lake developed into a reed-sedge marsh or a reed-sedge lake fringe that was loosened and coincidentally sank at the sampling site. This sinking could result from lowering of the regional water table caused by the climatic shift. The density of this peaty layer was 0.09 g/cm^3. The data for limnic sediment are further supported by the volumetric and gravimetric water contents on similar limnic sediment in Lake Elysian (Table 2). These sediments ranged from 54 to 80 percent water by weight.

The mineral soil bulk density values for Rice Lake were 1.1 g/cm^3 in the surface layer, increasing to 1.2 g/cm^3 at the 16 m depth. The dark colored sample at the base was above a gravelly layer. By constrast, the core samples from Hall Lake had higher bulk densities (Figure 7). The limnic sediment was underlain at the 13 m depth by an unoxidized glacial till with a high bulk density, about 1.8 g/cm^3.

Table 2. Volumetric moisture analysis of basin sediments in Lake Elysian, Waseca County.

Depth (cm)[a]	Wet Weight (gms)	Dry Weight (gms)	Water (%)	Shrinkage (%)
0-229	Water	Water	Water	Water
229-254	258.1	52.2	79.8	82
254-305	260.3	53.5	79.4	81
305-356	260.3	54.6	79.0	82
356-406	260.4	61.1	76.5	80
406-457	282.5	99.2	64.9	56
457-508	282.0	102.0	63.8	66
508-551[b]	315.8	155.3	50.8	46
551-584	306.9	141.4	53.9	54
584-602[b]	301.5	208.8	30.7	1
602-607[c]	100.3	41.9	58.2	82

[a]Except as noted, sample core lengths of about 50 cm were taken.
[b]Thin layers of sand present.
[c]Marl and plant detritus.

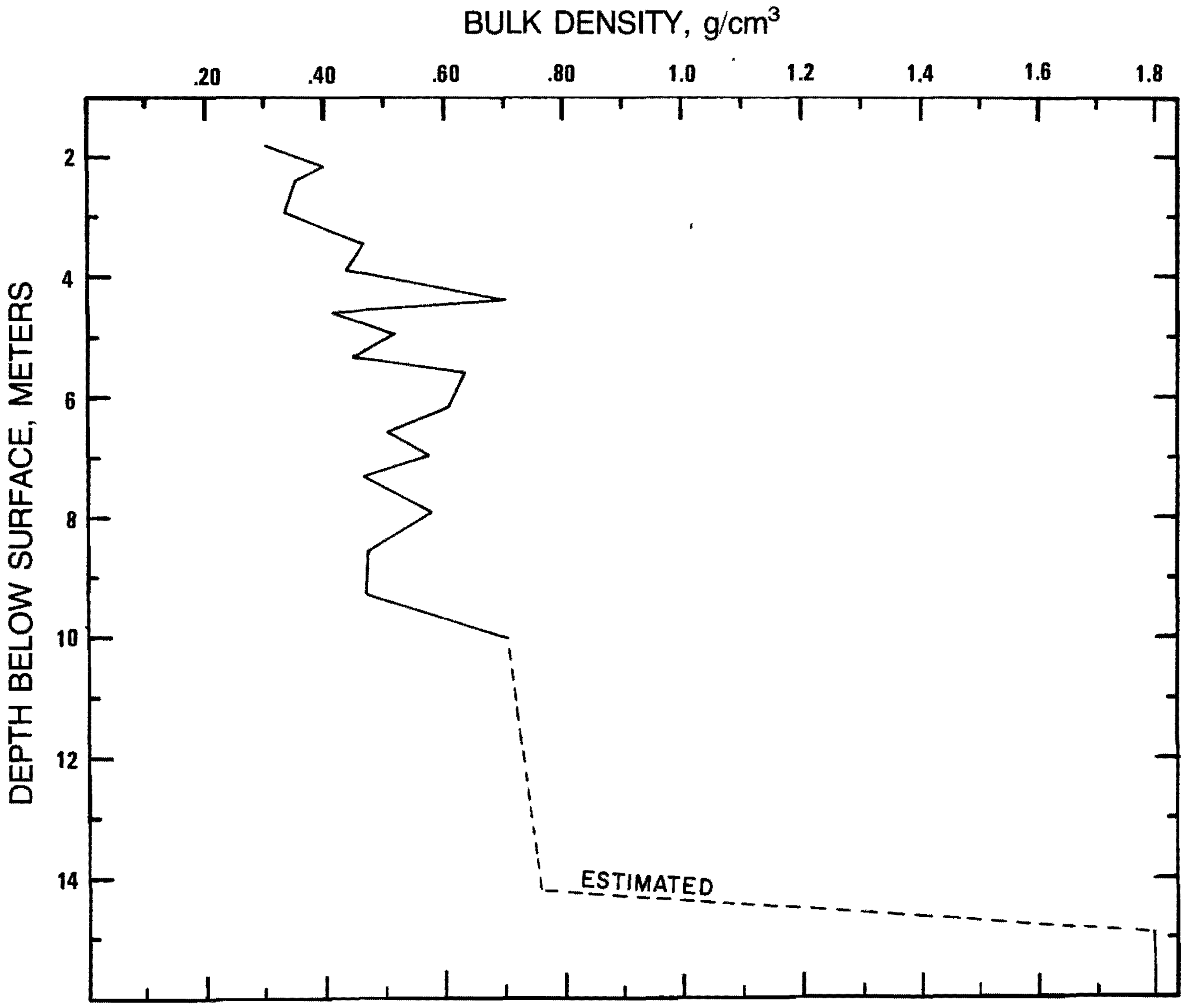

Figure 7. Bulk density of sediment in Hall Lake, Martin County, by depth.

Ash Content

The ash (mineral matter) content was much less above the peat layer than below it (Figure 8). The ash content varied widely above the peaty layer, but was more constant below it. The mineral soil at the base, 15 to 16 m, had a mineral content between 93 and 97 percent. By contrast, the core sample of the limnic sediment from Hall Lake generally had a higher mineral content (Figure 9).

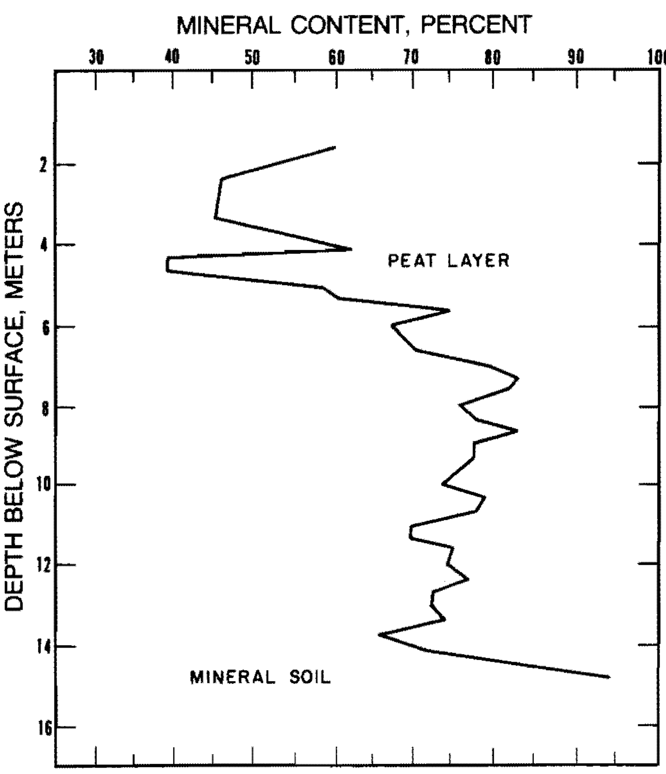

Figure 8. Percent mineral matter in Rice Lake, Steele County, by depth.

Mineralogy

X-ray analysis of the Rice Lake mineral sediment ranging from 2 to 20 micron and from depths of 2-3 m and 5-6 m indicated that the only minerals present in identifiable amounts were quartz and calcite. There was no appreciable difference in minerals between the two sampled depths. This finding was verified by examination with the petrographic microscope, which also showed an abundance of diatomaceous forms and opalized plant remains. Limnic sediments at a depth of 2 m had a bulk density of 0.10 to 0.15 g/cm^3, so the weight of these sediments is 10 to 15 kg, with about half mineral ash. This ash was estimated to be less than 5 percent quartz plus calcite or 0.25 to 0.35 kg/m^3 with an eolian delivery source likely.

For Hall Lake sediment, petrographic analysis showed about 15 percent quartz at the 0.25 m, 24 percent at the 2 m, and 36 percent at the 5 m depths. The higher values for quartz in Hall Lake sediment probably reflect the larger contributing watershed and the closeness of the sampling site to the inlet.

Radiocarbon Dating and Pollen Analysis

Samples from depths of 4 to 5 m and 11 to 14.5 m in Rice Lake were analyzed for radiocarbon date and pollen dominance. The 4 to 5 m depth included the peaty layer and the 11 to 14.5 m layer included the dark colored mineral soil at the basin bottom. The radiocarbon date for the 4 to 5 m zone was 1835±80 B.P. (before present). The dominant pollen was principally oak and herbaceous types, indicating a climate similar to that at the time of the European settlement in the mid-nineteenth century. The radiocarbon date for the 11 to 14.5 m zone was 9675 ± 144 B.P. The dominant pollen was spruce, correlating with data for other lakes for the same time or earlier. The date is near the time when a rapid shift in climate forced an abrupt change in dominance from spruce forest to deciduous forest.

The Hall Lake sample from the 3.6 to 3.7 m depth had a radiocarbon date of 3730 ± 135 B.P. This date is near the time when the delta of Dutch Creek began covering the limnic sediment at the sampling point (Figure 3). Most of the Dutch Creek delta was probably a result of the landscape erosional cycle during a drier period, when the water level was lower.

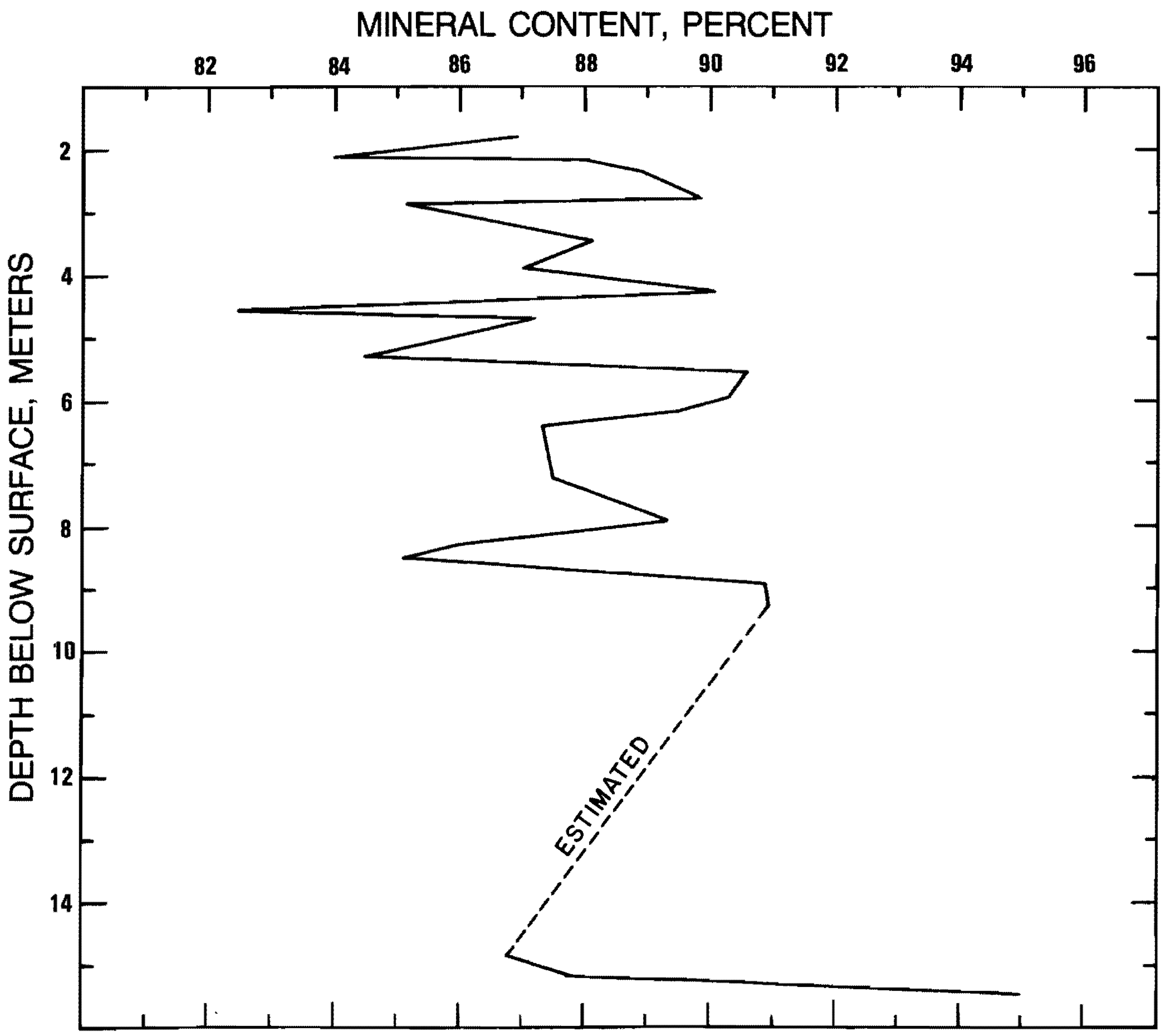

Figure 9. Percent mineral matter in Hall Lake, Martin County, by depth.

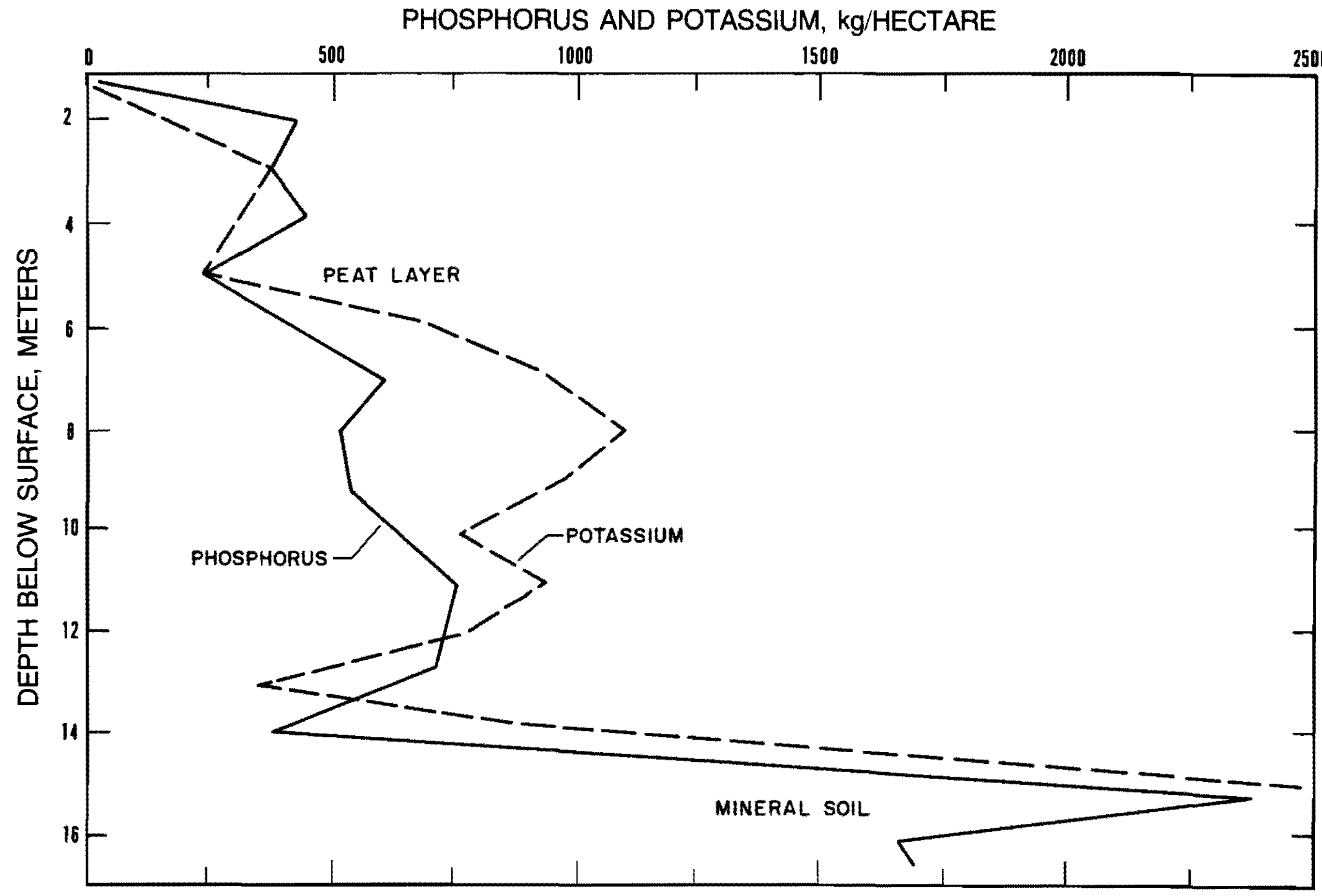

Figure 10. Total phosphorous and exchangeable potassium in Rice Lake, Steele County, by depth.

Phosphorus and Potassium Measurement

Total phosphorus and potassium levels measured represent a time span with widely varying climate and its associated vegetative responses. Data were reduced to dry weight to convert parts per million to kilograms per hectare. Phosphorus and potassium values increased with depth in both lakes. In Rice Lake the highest potassium values were at a depth of 8 m (Figure 10). The phosphorus level of the dark colored mineral soil at the 14.8 m depth was within the range of levels in upland surface soils.

The phosphorus and potassium levels in the Hall Lake sediment were consistently higher than those in Rice Lake (Figure 11). The higher values in the Hall Lake sediment reflect the larger contributing watershed and closeness of the sampling site to the inlet.

SUMMARY

Late Wisconsin glacial landscapes lack integrated drainage nets and have many shallow and deep closed basins. These features control the yields of upland sediment beyond the micro-watersheds. Main streams are underfit and flow in channels developed by glacial torrents. Even the largest floods are confined to the flood plains. First- and second-order streams are few or nonexistent over wide areas. The landscape retains much disordered terrain inherited from the wasting ice sheet. The lack of a drainage net resulted from the irregular melting of drift-buried ice for several thousand years after the exposed ice sheet was melted (Florin and Wright 1969). Landscape inversion from late melting of buried, ice-formed knolls as isolated rises emplaced on and intermingled with a low-gradient base level (Clayton 1967). Slopes are a complex of convex and concave forms. Soil erosion is most active on the lower part of the convex slopes (Meyer and Kramer 1969, Young and Mutchler 1969). This erosion is commonly observed and described in detailed soil surveys in counties of southern Minnesota (Waseca County 1965).

Peat began filling depressions about 3,000 to 5,000 years ago. The peat is seldom mantled with upland sediment (Finney et al. 1973). In many deeper depressions a peat has mantled layers of limnic sediment, indicating a stable pond at some stage. The thickness of limnic sediment under peat ranges from a few centimeters to more than 15 meters. In some depressions, dark mineral soil is intact below the peat and limnic sediment (Cvancara et al. 1971, Walker 1966). Some of the dark soil probably formed in drift mantling the buried ice block. Small ponds developed in ice-block depressions.

The limnic sediment began accumulating with increased precipitation following the dry period between 4,000 and 8,000 years ago. Coincident with the dry period were several cycles of depressions by several tiers of buried soil or combinations of buried mineral soil and organic soil and limnic sediment. Many depressions are covered with reed-sedge peat over limnic sediment or soil.

Lakes are primarily filled by accumulations of algae and other biota whose growth is sustained by dissolved nutrients supplied by the watershed (Latterel et al. 1971). Rice Lake phosphorus and potassium values were higher before 1835 ± 80 B.P. The sharp irregularities on the graphs (Figures 10 and 11) probably outline short-term shifts in weather patterns during the past 1,835 years.

The lower yields indicated for the recent past are probably related to retention of these nutrients on the silicate clay complex of the weathered upland mineral soil. Also, much of the erosional sediment is trapped for lack of a delivery system. When upland sediment with attached phosphorus reaches the lakes, either by wind or water, it is absorbed by the bottom sediments.

Dissolved nutrients enter lakes over frozen fields and marshes during the spring melt (Boelter and Verry 1977, Latterell et al. 1971). Runoff associated with high-intensity storms overwhelms most natural and engineered sediment-retention structures. The data indicate a supply of nutrients adequate for lake eutrophication over the past 10,000 years. Further, shallow water is subject to stirring by wind. This stirring brings up, for example, available phosphates to the water column from the water-sediment interface, where anaerobic conditions sustain phosphate availability.

We emphasize that this study deals with but one aspect of lake eutrophication—upland mineral sediment. The data show that this sediment is a very small part of the total volume of limnic sediment.

Unanswered are the questions: Are lakes to be left to their natural course toward extinction? Are there alternatives other than extinction or occasional deepening by dredging? Would a combination of engineering and hydrologic managing of irrigation slurry contribute some nutrients to crops? Would deepening the lakes and possibly changing the water characteristics be a useful management approach?

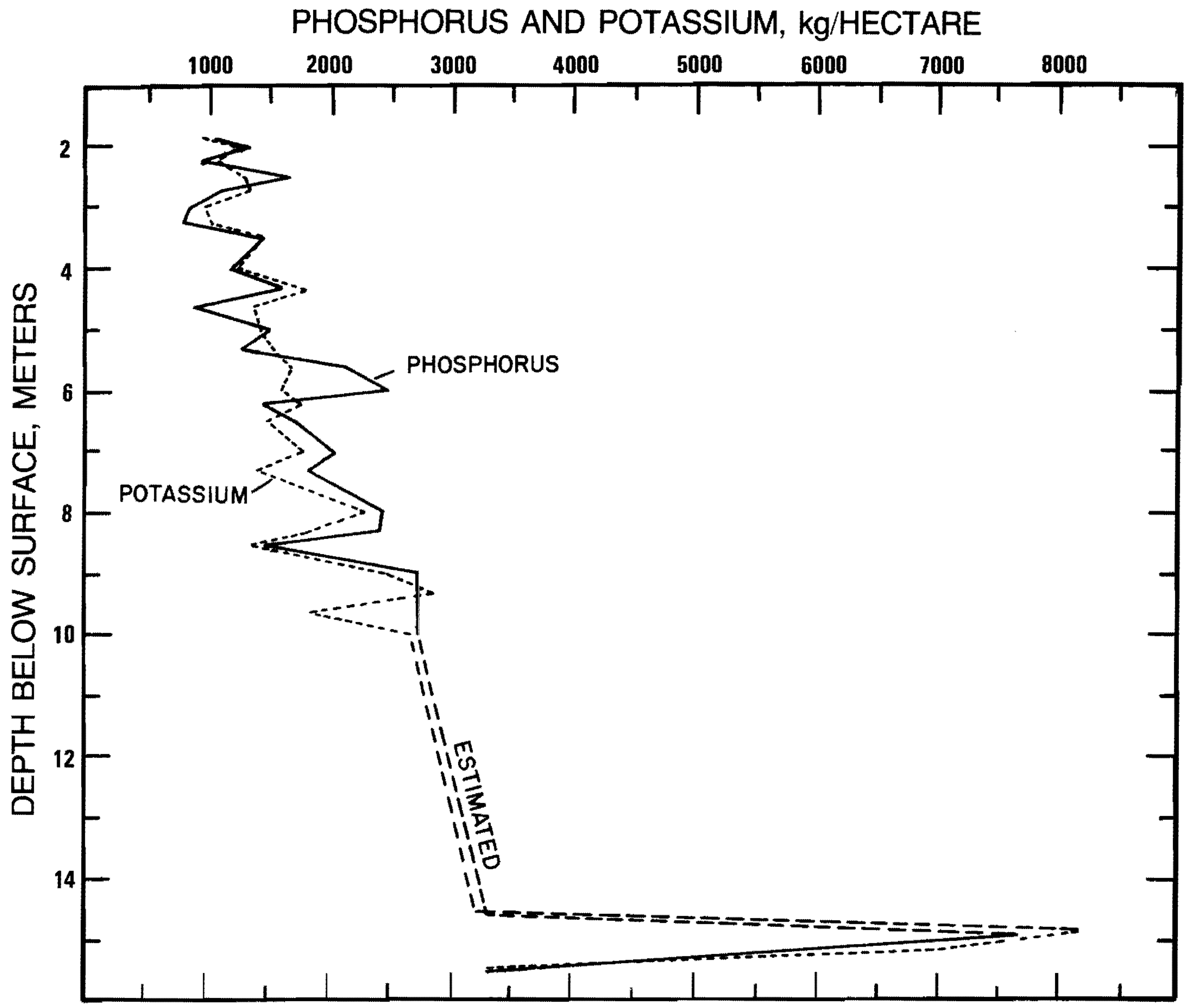

Figure 11. Total phosphorous and exchangeable potassium in Hall Lake, Martin County, by depth.

GLOSSARY

Albolls: Mollisols having a grayish subsurface horizon and commonly a B horizon of clay accumulation.
Alfisols: Soils with gray to brown surface horizons, medium to high supply of bases, and B horizons of clay accumulation.
Aquic: Soil moisture regime indicating frequent or sustained periods of saturation.
Biota: The flora (plants) and fauna (animals) of a region.
Calcareous: Material having a high percentage of lime carbonate.
Carbon-nitrogen Ratio: The ratio of the weights of C to N in organic forms in soils or in organic material.
Coprogenous: A form of limnic materials, relatively high in organic matter, containing many fecal pellets.
Detritus: Matter worn from rocks by mechanical means, alluvial deposits generally.
Diatomaceous: Deposit of fine, grayish siliceous material composed chiefly of the remains of diatoms.
Diatoms: Algae having siliceous cell walls that persist as a skeleton after death. Occur abundantly in fresh and salt waters.
Entic: Soil development approaching the condition of Entisols, i.e., with no diagnostic horizons.
Entisols: Soils that have no diagnostic horizons, as on fans and floodplains where recently eroded materials are deposited.
Eutrophication: A means of aging of lakes whereby aquatic plants are abundant and waters are deficient in oxygen.
Gyttja: Sedimentary peat consisting mainly of plant and animal residues precipitated from standing water.
Histosols: Soils formed from organic soil materials.
Ice-Block Lake: A lake formed in an ice-block basin commonly occurring on outwash plains formed by retreating glaciers.
Limnic: Generally including materials of both organic and inorganic form deposited in water by precipitation or action of aquatic organisms.
Marl: An earthy, unconsolidated deposit consisting chiefly of calcium carbonate mixed with clay.
Mollisols: Soils with nearly black, organic-rich surface horizons and high supply of bases.
Opalized: Relating to the development of hydrated amorphous silica commonly of organic origin and found in lake muds.
Orthents: Entisols with loamy or clayey textures.
Udolls: Mollisols in moist, warm-temperate climates.

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