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FATE OF CLAY PARTICLES INPUT TO SKINNER LAKE, INDIANA FROM AGRICULTURAL DRAINAGE

presented by

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has been accepted towards fulfillment of the requirements for

M.S. degree in LIMNOLOGY

C. D. McNabb
Major professor

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FATE OF CLAY PARTICLES INPUT TO SKINNER LAKE, INDIANA FROM AGRICULTURAL DRAINAGE

By

John Michael McCabe

A THESIS

Submitted to
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ABSTRACT

FATE OF CLAY PARTICLES INPUT TO SKINNER
LAKE, INDIANA FROM AGRICULTURAL DRAINAGE

By

John M. McCabe

A mass balance budget for clay particles was developed for Skinner Lake, Indiana, for the period 3/14/78-4/2/79 in order to ascertain the fate of clay particles input to the lake from agricultural drainage. Of 5.4×10^5 kg of clay input to the lake during the study period, 54 % was deposited at the mouth of the input channel, forming a delta. Forty percent was exported through the lake outlet, and the remaining 6% was apparently deposited in lake sediments. Relationships between clay and phosphorus in Skinner Lake were considered.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

One of the primary concerns in the drainage of agricultural systems is the input of particulate matter into the waters draining these systems (Iwamoto, *et al.*, 1978). Of the different sized particles present in the soil matrix, clay is of special importance because of its susceptibility to rainfall and runoff erosion (Massey and Jackson, 1952; Ryden, *et al.*, 1973). The limnological importance of clay stems from its physical effects in fresh water, including increased turbidity and geomorphological changes due to increased erosion and deposition, and chemical and biological effects due to the release of adsorbed substances, including phosphorus (Mortimer, 1941) and various pesticides (Bailey, *et al.*, 1974). The turbidity caused by agriculturally introduced clay concentrations in natural waters also has adverse biological impacts. Deleterious effects on fish (Cordone and Kelley, 1961), arthropods (Rosenberg and Wiens, 1975), and aquatic flora, due to the attenuation of light available for photosynthesis (Meyer and Heritage, 1941), have all been observed.

The role of clay in the transport and release of phosphorus is fairly well understood. Cations of iron and aluminum on the particle surface function in binding orthophosphate (PO_4^{3-}) to clay particles. Soil clay tends to adsorb or release this orthophosphate until an equilibrium with the concentration in the soil water is established (Stoltenberg and White, 1953; Bigger and Corey, 1969; Mattingly, 1975; Mansell, *et al.*, 1977). The faculty for adsorption differs depending on the mineral composition of the clay (Edzwald, 1977). Phosphorus adsorption and release dynamics are particularly important in the case of agricultural lands where orthophosphate compounds are routinely added to the soil as fertilizers. When clay enters the aquatic system in runoff or streambank erosion, it tends to carry its adsorbed phosphorus with it (Barrows and Kilmer, 1963; Massey and Jackson, 1952). The limnological importance of phosphorus as a nutrient is well documented (Vollenweider, 1968; Porter, 1975). Helfrich and Kevern (1973) have shown that phosphorus adsorbed to clay is available to the planktonic algae.

In a situation where a lake is fed by agricultural drainage, it is of some interest to determine the fate of clay input to the lake from that drainage. For example, those particles remaining in the water column, as well as serving as an available source of phosphorus, have an effect on light availability. Those deposited in the sediments are a potential source of phosphorus for the growth of macrophytes, planktonic algae, and bacteria.

In looking at the deposition patterns of clay input from agricultural drainage, it is helpful to use a mass balance approach. This method considers sources and sinks of the material of interest, in this case clay particles, to determine the net gain or loss to the system over some interval of time.

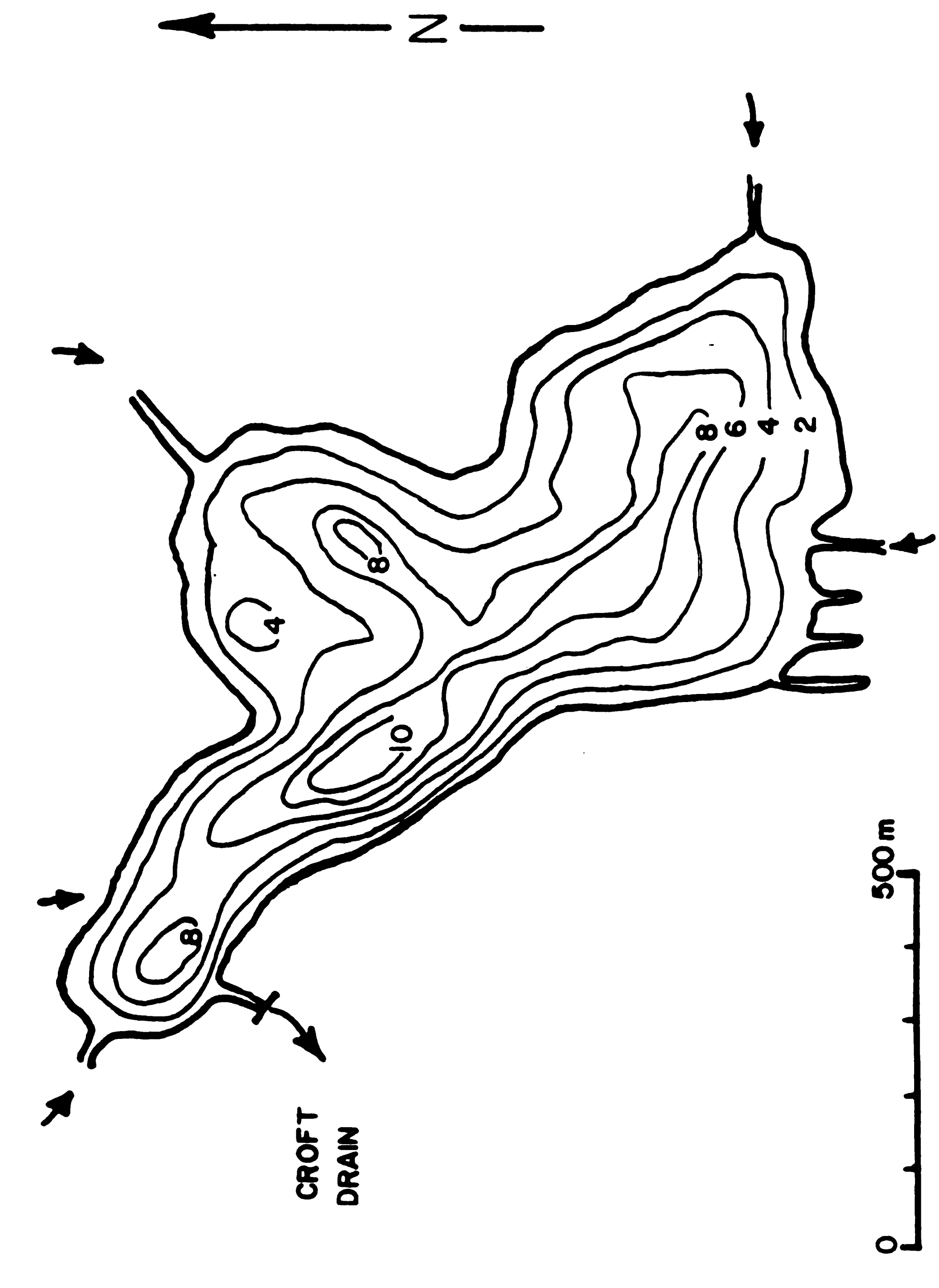
The purpose of this work was to determine the clay budget of a small midwestern lake. Elucidation of patterns in the process of clay deposition can lead to a greater understanding of impacts on receiving waters, both the physical aspects of erosion, deposition, and increased turbidity, and the chemical and biological aspects of clay as a source of nutrients.

METHODS AND STUDY SITE

Skinner Lake is located in Noble County in northwestern Indiana and is part of the Elkhart River drainage basin. Lake area is 49.4 ha and it drains a predominantly agricultural watershed of 3636 ha. Direct inputs to the lake come from five drainage streams (Figure 1). The lake is drained by an outlet passing over a concrete dam. A U.S. Geologic Survey stage height recording gauge is located immediately lakeward of the dam and records stage height once per hour. The most important inlet to the lake is the Rimmell system which drains 68% of the watershed and contributes 77% of the annual discharge (1979 estimate) to the lake. The Rimmell receives discharge from three drains along its course, the Bauman, the Becker, and the Knafel-Hill. These systems drain soils that are primarily silty clay loam, planted in row crops. Because of the dominant role played by the Rimmell in the hydrologic budget of the lake, this study concentrated on that stream.

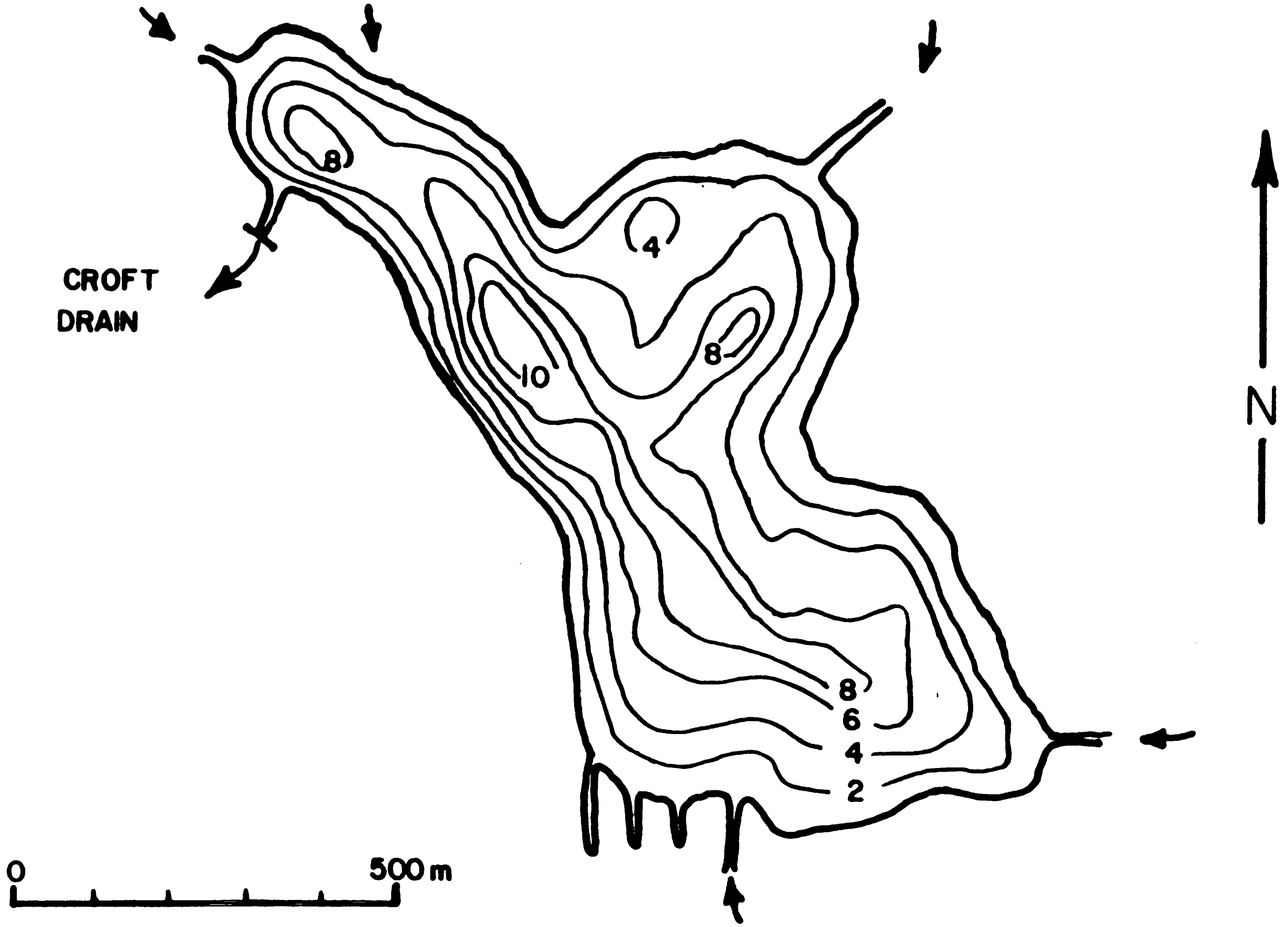
Since 1977, the Skinner Lake drainage basin has been subject to erosion control land management practices as part of an ongoing water quality improvement program sponsored by the U.S. EPA Clean Lakes Program. These practices include construction of settling basins, contour plowing,

Figure 1. Map of Skinner Lake showing depth contours, inlets, and outlet. Depth contours are in meters.



SKINNER LAKE, INDIANA

Figure 1. Map of Skinner Lake showing depth contours, inlets, and outlet. Depth contours are in meters.



SKINNER LAKE, INDIANA

minimum tillage, and a variety of other methods of erosion control.

In the autumn of 1977, the Rimmell channel was excavated from lakeside to a distance of 1.6 km upstream in order to improve its ability to drain cropland. A dragline was used; erosion control practices were largely ignored.

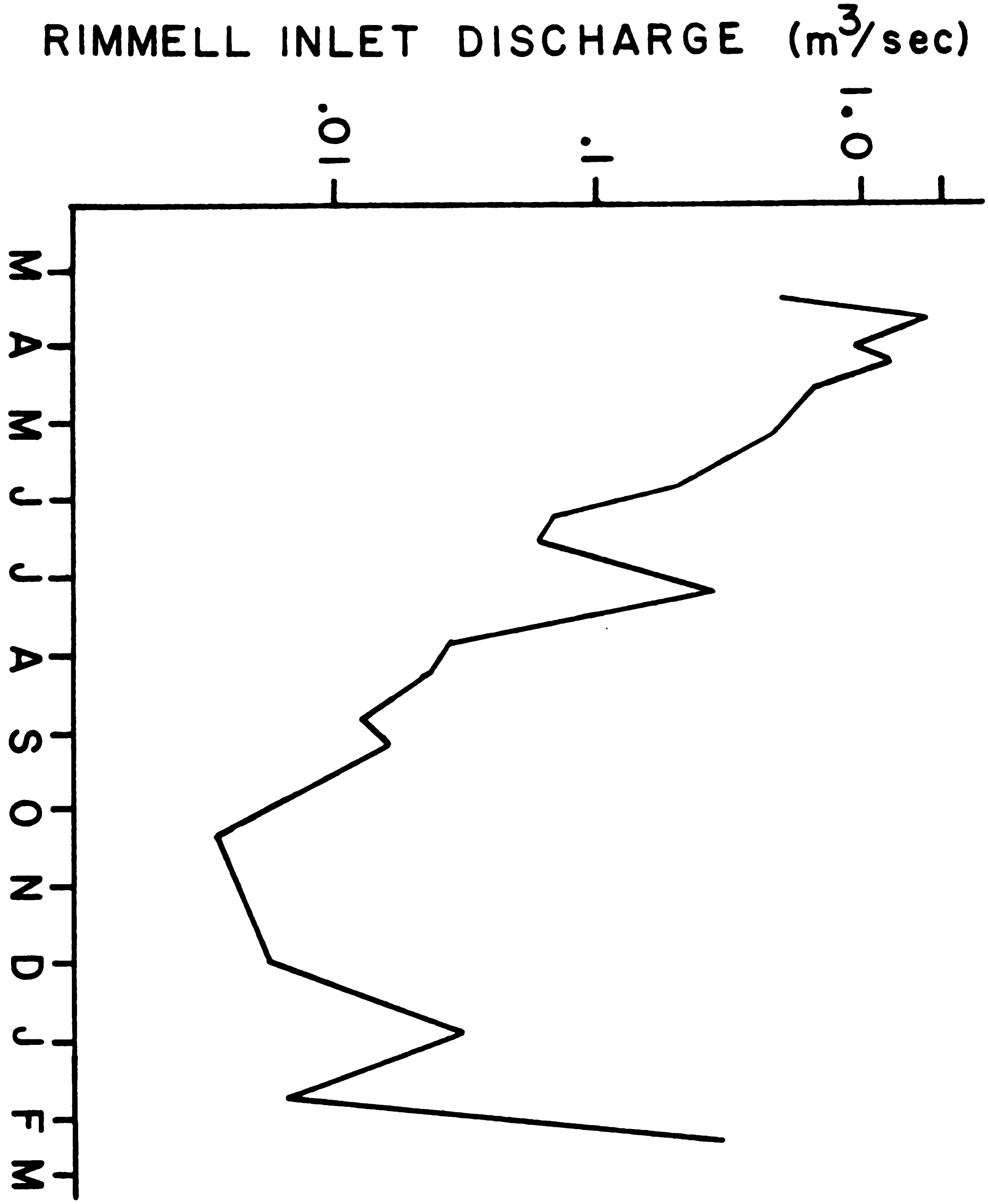
In the spring of 1978, an unusually high input discharge occured from the Rimmell system (Figure 2). This event was responsible for excessive erosion in the freshly dug Rimmell channel and the formation of a delta in the lake at the mouth of the channel.

In early 1978, the Limnological Research Laboratory at Michigan State University was contracted, under the authority of the Clean Lakes Program, to assess the impacts of land management techniques on water quality of the lake. Stream flows, evaporation and precipitation, and changes in lake level were measured to obtain an estimate of the annual hydrologic budget. Suspended and dissolved solids, nitrogen, and phosphorus were measured in the lake and in the inputs and output. Temperature and oxygen depth profiles were developed for the lake for the different seasons of the year.

To develop a mass balance budget for clay particles in Skinner Lake, atmospheric inputs were assumed to be negligible. The input of clay from the Rimmell system was the target of the study.

Estimates of particulate and dissolved solids

Figure 2. Hydrograph of Rimmell inlet discharge for the period 3/14/78-3/2/79.


RIMMELL INLET DISCHARGE (m3/sec)
.01
.1
1.0
M
A
M
J
J
A
S
O
N
D
J
F
M

input to the lake for the period 4/14/78-4/2/79 were made. Samples were taken by lowering acid-washed 1 liter Nalgene bottles to mid-depth in the stream. Bottles were rinsed once with stream water, and refilled. Within 24 hours the samples were returned to the laboratory for analysis. Sampling was carried out at two week intervals during the spring and summer months and less frequently from September to February.

At the laboratory, the samples were partitioned in two equal portions, one of which was passed through a Reeve Angel 984 H glass fiber filter. One hundred milliliter aliquots were then taken from filtered and unfiltered portions. These aliquots were placed in acid-washed crucibles of known weight and evaporated to dryness at 90° C in a Blue-M Stabil-Therm forced air oven. They were then heated at 180° C in the same oven for 24 hours to drive off the water of hydration. The crucibles were kept covered during heating to avoid contamination. The crucibles were cooled for one hour in a dessicator and weighed to the nearest 0.1 mg on a Mettler electro-balance. The weight of material remaining in the crucible containing the unfiltered sample was taken as the total solids or total residue per 100 ml of sample; that in the crucible containing the filtered portion of the sample, as the total dissolved residue. The difference between these two values was taken as the total non-filterable residue, equivalent to the total suspended particulates.

Following weighing, the crucibles were ignited at 550° C in a muffle furnace for one hour to drive off organics. They were then cooled and weighed as above. The difference between the first and second weighings of the crucibles containing unfiltered water was taken as the total volatile residue per 100 ml of sample. The weight of the material remaining in the crucibles after ignition was the total fixed residue. Likewise, the difference between the first and second weighing of the crucibles containing filtered samples was taken as the dissolved volatile residue; the material remaining in the crucible after ignition as the dissolved fixed residue. Values determined in this fashion were reported in mg/l.

In determining the amount of clay input to Skinner Lake, the particulate inorganic fraction of the stream discharge was of concern. By subtracting the value of the dissolved fixed residue from that of the total fixed residue, the non-filterable fixed residue was obtained. This fraction was taken to represent clay particles. When non-filterable fixed residue (NFF) concentration in inlet water was multiplied by inlet discharge over the sampling period, the total clay input to the lake over this sampling period was estimated. The contribution of non-filterable inorganic salts to the total non-filterable fixed residue is ignored by this method; the error is thought to be small.

Stream discharge was measured at the same time water samples were taken using a Gurley pygmy current meter. Toward the end of the sampling period, a weir was constructed on the Rimmell drain and discharge was estimated using the stage height of the channel upstream from the weir and a rating curve of stage height versus discharge. The values obtained by these methods were instantaneous discharges. In order to obtain total discharge estimates for the sampling period in question, discharge estimates for consecutive sampling dates were considered. Figure 3 illustrates this procedure for obtaining the best estimate of discharge for an interval. The shaded area represents the total discharge estimated. Times (T_s) were sample collection dates. Discharges (Q_s) were stream discharges measured on those dates. The volume of water discharged between $\frac{T_1 - T_0}{2}$ and $\frac{T_2 - T_1}{2}$, represented by the sample taken at T_1, was calculated by:

$$V = \frac{Q_0 + 3Q_1}{8} (T_1 - T_0) + \frac{3Q_1 + Q_2}{8} (T_2 - T_1)$$

where: V = volume of water (m^3) discharged in the period represented by the sample taken at T_1;

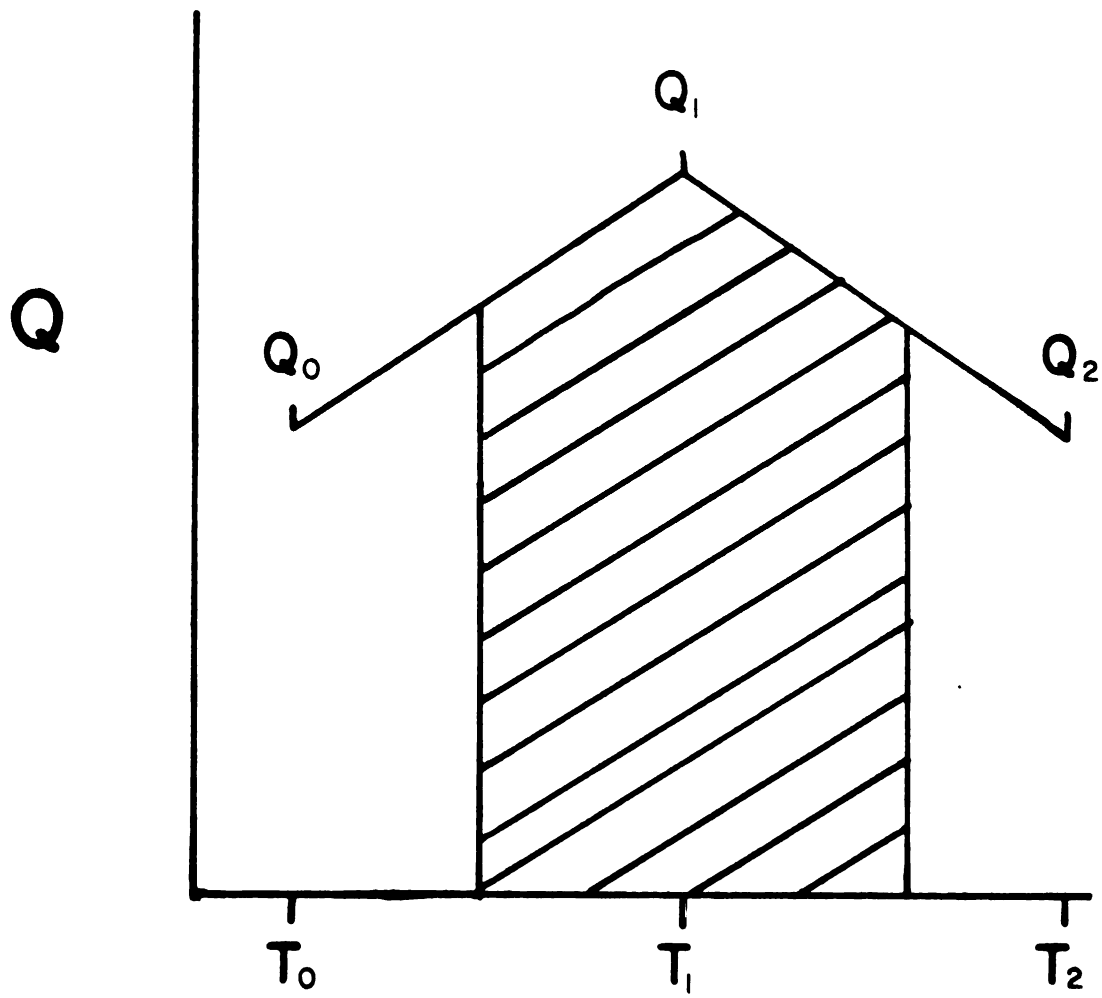
Q = discharge rates (m^3/day) at T_0, T_1, and T_2;

T = time (days).

This procedure avoids the error inherent in using instantaneous discharge to represent total discharge over a period by allowing for varying discharge with time. By increasing the frequency of T, the accuracy could be increased.

The estimates of NFF residue for an interval were multiplied by their respective discharge estimates. These values were used to determine the clay input to the lake by the Rimmell during each sample period.

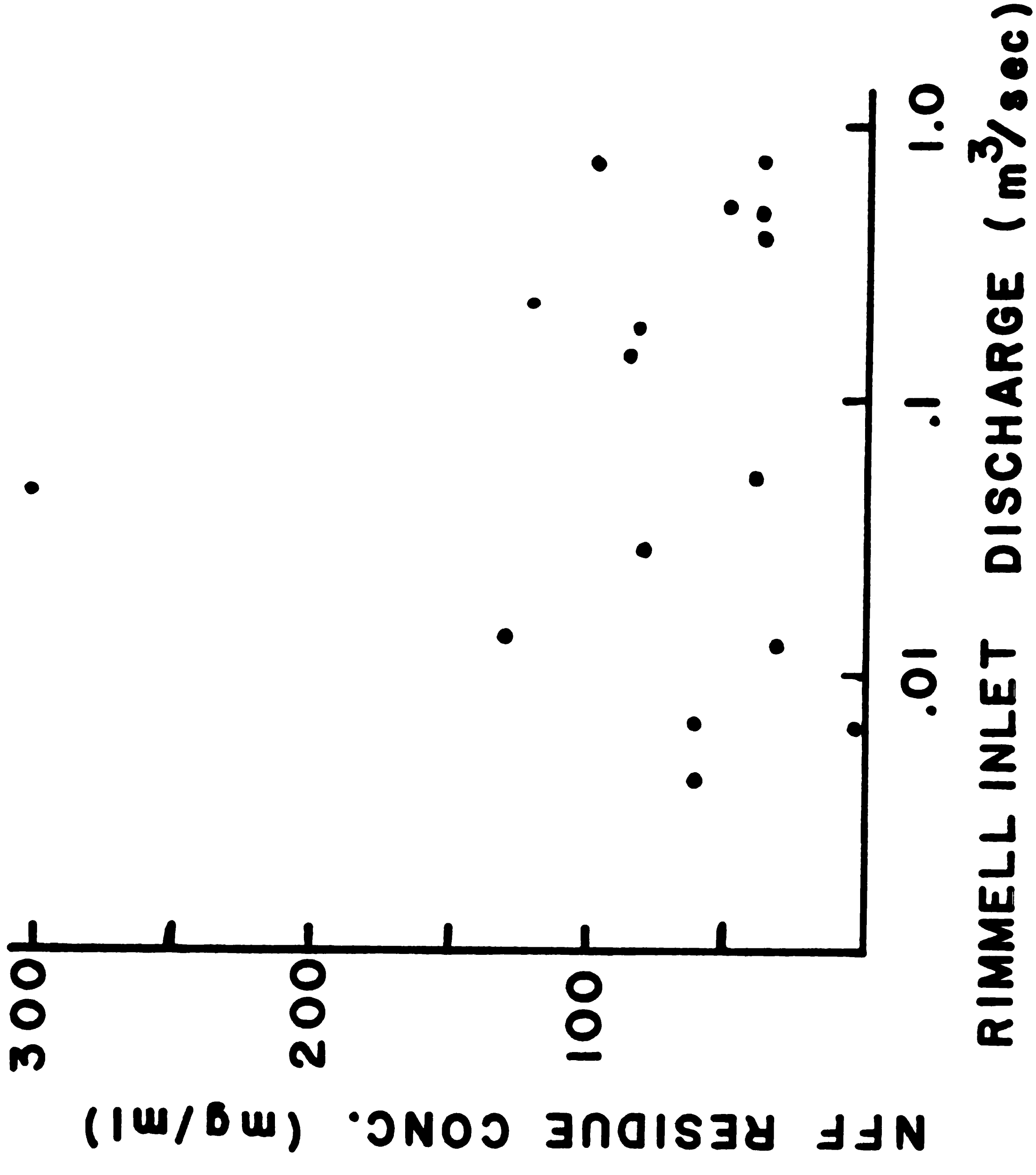
Figure 3. Illustration of the procedure used to obtain discharge estimates over an interval of time.


Q
Q1
Q0
Q2
T0
T1
T2

The schedule of sampling at Skinner Lake and the principle springtime interval of clay transport in 1978 did not coincide. However, an estimate of clay discharged during the spring of 1978 was of interest for this study. The USGS gauge at the outfall indicated that lake discharge for the year began on 3/14/78, after the winter period of no discharge. This date was taken as the initiation of spring discharge from the watershed. Sampling at the lake began on 4/13/78. An estimate of NFF residue discharged during late March and early April was made by the following procedure. Regression of instantaneous inlet discharges on outlet discharges for the period 4/14/78-4/2/79 indicated a linear relationship described by the equation $y = 0.565x - 0.003$ ($s_{y \cdot x} = 0.233$) where x is outlet discharge and y is inlet discharge. Using the average outlet discharge for a given date (determined from outlet stage height recordings for that date) as the x value, Rimmell inlet discharge was estimated for each of the 31 days in question.

In observing the relationship between inlet discharge and solids loads over the period in which the sampling was carried out (Figure 4), no clear pattern was indicated. Since the values of NFF residue varied within a relatively small range at higher discharge levels, the average value of NFF residue concentration at discharge levels greater than 0.1 m^3/sec was taken to represent NFF residue concentration during the spring period of high discharge. This average value (67 mg/l $\pm$ 29.9 mg/l) was multiplied by

Figure 4. The relationship between discharge level and non-filterable fixed residue concentration in Rimmell Inlet discharge.


NFF RESIDUE CONC. (mg/ml)
300
200
100
RIMMELL INLET DISCHARGE (m^3/sec)
.01
.1
1.0

the total discharge estimated for the period 3/14/78-4/13/78. The result was an estimate of the total NFF residue input to Skinner Lake from the Rimmell during the period when residue measurements were lacking. When added to the values determined by sampling, the total NFF residue input to the lake for the period 3/14/78-4/2/79 was estimated. Thus the annual Rimmell input of clay was approximated.

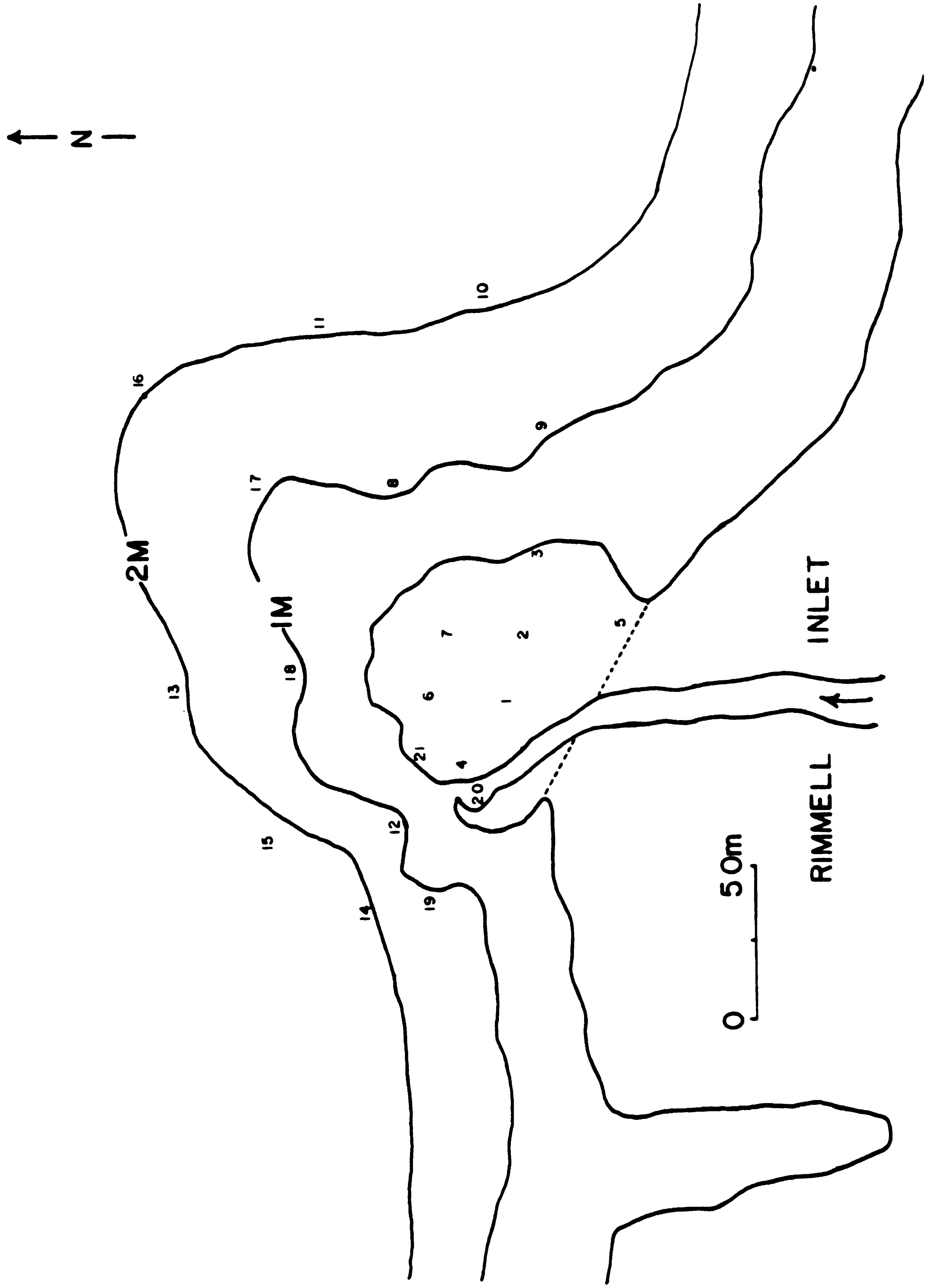
In terms of a mass balance budget, one of the sinks for clay particles in the Skinner Lake system was discharge by the outlet. Suspended and dissolved solids sampling on the outlet was conducted from 4/14/78-4/2/79 in the same manner as described for the inlet. Discharge was measured using the recording stage height gauge and USGS weir discharge calculations (USDI, 1967). For the period 3/14/78-4/13/78, an average value for outlet NFF residue concentration at flow greater than 0.1 m^3/sec was determined using the discharge and NFF residue data obtained during 4/14/78-4/2/79. This average (19.55 mg/l $\pm$ 21.0) was multiplied by the total outlet discharge over the period 3/14/78-4/13/78. The result was an estimate of the total NFF residue exported from the lake by the outlet for the period 3/14/78-4/13/78. Added to the observational values for the rest of the study period, the value of NFF residue exported from the lake during the period 3/14/78-4/2/79 was estimated.

The delta formed at the mouth of the Rimmell inlet and surrounding littoral sediments constitute a sink for clay particles through deposition. In June of 1979, twenty-one core samples were taken from this area in order to estimate clay deposition for the period 3/14/78-4/2/79. Sample stations are shown in Figure 5. A 2.54 cm inner diameter piston-type corer was used. Determination of the depth of material deposited was facilitated by the presence of rooted aquatic vegetation, primarily *Nuphar advena*, at the mouth of the Rimmell channel prior to delta formation in the spring of 1978. The presence of a heavy layer of decomposing plant parts in cores indicated the depth to which new material had been layed down.

The individual core samples were treated by particle size separation procedures in order to determine their clay content. Samples were oven-dried at 90° C for 24 hours. Fifty cubic centimeters of sample were taken, crushed with a mortar and pestle to break up aggregations of soil particles, and passed through a 0.5 mm screen to remove larger pieces of sand and rock. Seven hundred milliliters of distilled water were then added to the sample along with 125 ml of a 10% solution of $NaPO_3$ brought to a pH of 8.3 with $NaCO_3$. This preparation is known commercially as Calgon and was used to prevent the reformation of particle aggregations. The mixture was then agitated at high speed for three minutes in a Waring blender, decanted into a 1000 ml beaker, covered, and stored in a dark laboratory cabinet until analyzed.

The removal of particles in the clay size range (less than 0.4μm) required the use of particle settling-velocity techniques. Stokes' law describes the velocity of a particle

Figure 5. Map of the delta formed by the Rimmell Inlet showing sediment core sample stations.


N
2M
1M
RIMMELL INLET
0
50m

of given size settling in quiescent water. A form of that law giving the time needed for a particle of given size to settle through a given depth of water is:

$$t = \frac{18nh}{g} (p_s - p_1) x^2$$

where: t = time needed for particles to settle a given distance;

n = viscosity of water (temperature dependent);

h = depth of water particle is falling through;

p_s = particle density (2.68 for clay soil particles);

p_1 = liquid density (1.00 for water);

g = acceleration due to gravity (978 cm/sec^2);

x = particle diameter.

Using this equation, the time needed for all particles larger than 0.4µm diameter to settle through 8 cm of water was calculated for ambient laboratory temperature. At the end of this period, all water above 8 cm depth in the beaker containing the sample was siphoned off, evaporated at 90° C, and the residue weighed. The water removed from the sample beaker was replaced with fresh distilled water, the samples agitated, and the procedure repeated. When the yield of dry material for a given extraction fell below 0.05 g, the clay was considered removed from the sample. The extracted material was then ignited at 550° C for one hour, in order to remove organics, and weighed. In this way the mass of clay per 50 cc of sample was determined.

The values estimated for the depth of deposition of material in the delta and those for the clay content of core samples were used to determine the clay content of the delta. Using isopleth techniques to join estimates for depth of material deposition on a map of the delta surface, a series of depth of deposition contours was developed (Figure 6). With delta area known, the volume of material deposited was estimated in this fashion. Isopleth techniques were also used to join values for estimated clay concentrations on a map of the delta surface. This resulted in a series of clay concentration contours (Figure 7). These two contour maps were then integrated by planimetry to determine the concentration of clay in a known volume of delta sediment.

An estimate of the amount of clay originating in the Rimmell system during the interval 3/14/78-4/2/79 and sedimenting in the littoral outside the delta and in the hypolimnetic portions of the basin during that interval was made from the relationship:

$$c_s = c_i - (c_o + c_d + c_w)$$

where: c_s = clay sedimenting in portions of the lake other than the delta;

c_i = clay input from Rimmell discharge;

c_o = clay exported by the output;

c_d = clay deposited in the delta and surrounding littoral;

c_w = clay loss in the water column.

The amount of clay lost from the water column during the interval was estimated from lake volume and NFF residue determined at the beginning and end of the interval. Upper

Figure 6. Map of the delta formed by the Rimmell Inlet with contours showing the depth of deposition of material from inlet discharge. Depth of deposition contours are in mm.

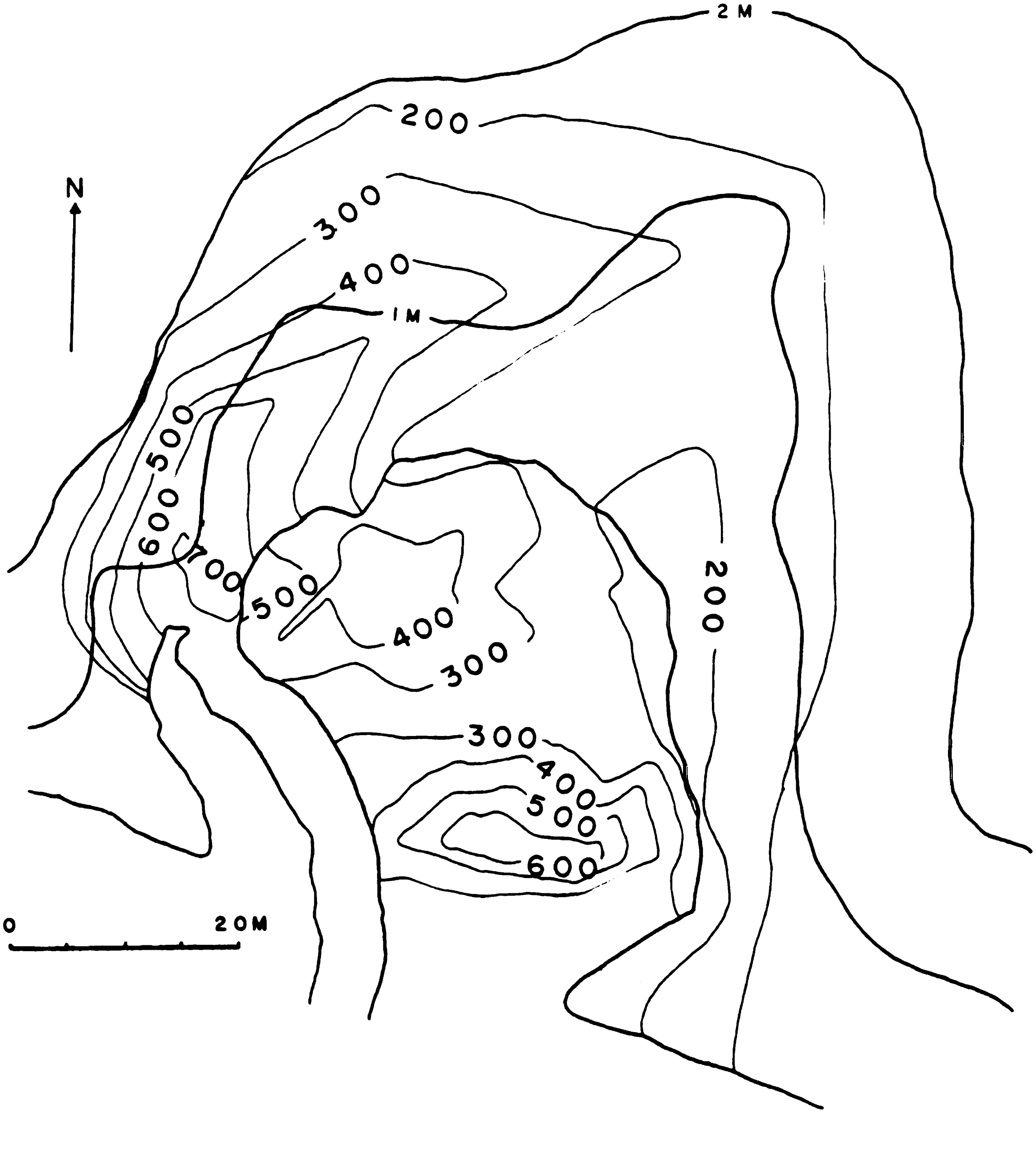

2 M
200
300
400
1 M
500
600
700
500
400
300
200
300
400
500
600
N
0
20M

Figure 7. Map of the delta formed by the Rimmell Inlet with contours showing the concentration of clay in the material deposited from inlet discharge. Clay concentration contours are in g clay/cc deposited material.

pelagial water samples were taken at the surface, 1.5, and 2.5 m depths at four locations in the lake. Samples were taken with a Kemmerer bottle and composited into a single upper pelagial water sample. Hypolimnetic water was sampled at the same four stations. Samples were taken at 3.5, 4.5, 5.5, 6.5, and 7.5 m depths. The samples were composited according to a depth proportional compositing scheme which allowed for the decreasing volume represented by samples taken at each descending depth. NFF residue was determined on the composites as previously described. Values of NFF residue in the upper and lower pelagial zones for the spring of 1978 were compared with those for the spring of 1979 to determine if there had been a net change in NFF residue in either zone.

RESULTS

The estimated daily discharge of the Rimmell inlet for the period 3/14/78-4/13/78 is found in Appendix Table A-1 and the numerical estimates of discharge for the remainder of the sampling period in Appendix Table A-2. The measurements of instantaneous discharge used to determine total discharge over individual sampling periods are found in Appendix Table A-3. The results of the NFF residue analyses (Appendix Table A-4) were multiplied by the appropriate discharge value to obtain an estimate of total NFF residue input by the Rimmell over the sampling period. These NFF residue values are found in Table 1. In like fashion, the NFF residue concentration of the outlet water was multiplied by outlet discharge to determine the NFF residue removed from the lake by outlet discharge. Because the Rimmell was not the only inlet to the lake, the values determined in this fashion are an overestimate of the amount of NFF residue entering the lake from the Rimmell and lost through the outlet. Since NFF residue was measured for all input streams during this study, the percentage of the Rimmell contribution to the total NFF residue input to the lake could be calculated for each sampling period. The NFF residue output from the lake for each period was multiplied by the corresponding percentage to estimate the NFF residue

Table 1. Non-filterable fixed (NFF) residue input to Skinner Lake by the Rimmell inlet during the period 3/14/78-4/2/79.

Season	Period of Observation	NFF Residue Input (kg)
Spring	3/14/78-4/13/78	118,797[1]
	4/14/78-5/ 2/78	26,482
	5/ 3/78-5/16/78	86,615
	5/17/78-5/30/78	16,822
		248,716
Summer	5/31/78-6/13/78	2,548
	6/14/78-6/26/78	14,776
	6/27/78-7/10/78	2,168
	7/11/78-7/24/78	2,787
	7/25/78-8/ 7/78	1,626[2]
	8/ 8/78-8/21/78	465
		24,370
Fall	8/22/78-9/ 6/78	2,725
	9/ 7/78-10/16/78	954
	10/17/78-11/ 6/78	13
	11/ 7/78-11/27/78	7,643
		11,335
Winter	11/28/78-12/13/78	15,274
	12/14/78-1/16/79	1,232
	1/17/79-2/ 6/79	48,220
	2/ 7/79-3/ 6/79	64,633
		129,359
Spring	3/ 7/79-3/19/79	62,550[2]
	3/20/79-4/ 2/79	60,467
		123,017
Total		536,796 kg

1. Estimated as shown in Appendix Table A-1.
2. Means of estimates for adjacent intervals.

input by the Rimmell that was carried through the outlet in each sampling period. The values of output NFF residue, percentage correction factors, and estimated Rimmell inlet contributions to outlet NFF residue discharge are found in Table 2. Since measurements for the correction factor for the period 3/14/78-4/13/78 were not available, an average of all the percentage correction factors was taken as the correction for this period.

Planimetry of the depth of deposition contours of Figure 6 led to an estimate of 3916 m^3 of material deposited in the delta and surrounding littoral during 1978 and early 1979. Of this material, 1138 m^3 was in the above water portion of the delta when the lake surface was at its normal summer elevation; the remaining 2778 m^3 was in the surrounding littoral during the summer. Heaviest deposition was found at the stream mouth. Deposition contours of Figure 6 indicate that the stream current swung eastward after entering the lake. The area of relatively low deposition in the center of the above water portion indicates the location of a scoured stream channel formed during high water of the spring of 1978.

The results of the clay separation procedures on sediment core samples are given in Appendix Table A-5. Using the clay concentration contours developed from these concentration values (Figure 7) and integrating with the depth of deposition contours by planimetry, a value of 287,681 kg of clay material was estimated to have been deposited in the

Table 2. Estimates of non-filterable fixed (NFF) residue input by the Rimmell and lost through the lake outlet during the period 3/14/78-4/2/79.

Season	Period of Observation	Output NFF Residue (kg)	% of Outlet Discharge Attributable to Rimmell Inlet Discharge	NFF Residue Input by the Rimmell and Lost Through the Outlet (kg)
Spring	3/14/78-4/13/78	98,111	70.4[1]	69,070
	4/14/78-5/ 2/78	26,183	37	9,688
	5/ 3/78-5/16/78	12,302	96	11,809
	5/17/78-5/30/78			
		136,596		90,567
Summer	5/31/78-6/13/78			
	6/14/78-6/26/78	3,901	28	1,092
	6/27/78-7/10/78	13,674	79	10,802
	7/11/78-7/24/78	336	81	272
	7/25/78-8/ 7/78	3,122		2,198[2]
	8/ 8/78-8/21/78	204	73	149
		21,237		14,513
Fall[3]	8/22/78-9/ 6/78	0		0
	9/ 7/78-10/16/78	0		0
	10/17/78-11/ 6/78	0		0
	11/ 7/78-11/27/78	0		0
		0		0

Table 2. (cont'd.).

Season	Period of Observation	Output NFF Residue (kg)	% of Outlet Discharge Attributable to Rimmell Inlet Discharge	NFF Residue Input by the Rimmell and Lost Through the Outlet (kg)
Winter	11/28/78-12/14/78	0		0
	12/15/78-1/16/79	1,502		1,057[2]
	1/17/79-2/ 6/79	40,050	97	38,849
	2/ 7/79-3/ 6/79	155,278	92	142,856
		196,830		182,762
Spring	3/ 7/79-3/19/79			
	3/20/79-4/ 2/79	20,079	70	14,055
		20,079		14,055
Totals		374,742 kg		301,897 kg

1. Average annual value.
2. Average annual percent contribution used for these intervals.
3. The lake did not discharge during this interval.

delta during the period 3/14/78-4/2/79.

Examination of the NFF residue values for the upper and lower pelagial zones for the spring of 1978 and the spring of 1979 (Appendix Table 6) indicated a slight change in NFF residue contained in the upper pelagial zone and a net loss of 15,106 kg from the lower pelagial.

With the above results, an annual mass balance was calculated for clay discharged to Skinner Lake by the Rimmell drain. The output of NFF residue attributable to the Rimmell in various intervals of the year was subtracted from the Rimmell input during those intervals. The results are given in Table 3. The procedures used here yield an estimate of 322,238 kg of clay trapped in the lake in the interval 3/14/78-4/2/79. If the estimate of clay deposited in the Rimmell delta is subtracted from this, an estimated 34,557 kg of material remains elsewhere in the lake basin. Since it has been suggested from estimates made above that the water column of the lake did not gain NFF residue between the beginning and end of the study, the unaccounted for material was apparently sedimented.

Table 3. Estimates of non-filterable fixed (NFF) residue discharged by the Rimmell Drain and remaining in Skinner Lake during the period 3/14/78-4/2/79.

Season	Period of Observation	NFF Residue Remaining in Lake (kg)
Spring	3/14/78-4/13/78	49,727
	4/14/78-5/ 2/78	16,794
	5/ 3/78-5/16/78	74,806
	5/17/78-5/30/78	16,822
		158,149
Summer	5/31/78-6/13/78	2,548
	6/14/78-6/26/78	13,684
	6/27/78-7/10/78	0
	7/11/78-7/24/78	2,515
	7/25/78-8/ 7/78	0
	8/ 8/78-8/21/78	316
		19,063
Fall	8/22/78-9/ 6/78	2,725
	9/ 7/78-10/16/78	954
	10/17/78-11/ 6/78	13
	11/ 7/78-11/27/78	7,643
		11,335
Winter	11/28/78-12/13/78	15,274
	12/14/78-1/16/79	165
	1/17/79-2/ 6/79	9,371
	2/ 7/79-3/ 6/79	0
		24,810
Spring	3/ 7/79-3/19/79	62,550
	3/20/79-4/ 2/79	46,331
		108,881
Total		322,238 kg

DISCUSSION

The results of the clay mass balance study are useful in indicating patterns of depositon. By the procedures used in this study, an estimated 5.4 x 10^5 kg of clay (as NFF residue) was discharged to the lake from the Rimmell drain in the interval 3/14/78-4/2/79. Fifty-four percent (2.9 x 10^5 kg) was deposited at or near the mouth of the Rimmell channel, there contributing to the formation of a delta. Forty percent (2.1 x 10^5 kg) passed through the lake outlet, and 6% (3.5 x 10^4 kg) was apparently deposited in lake sediments away from the channel mouth. The deposition of so large an amount of material at the mouth of the Rimmell inlet over the duration of the study period is a matter of some concern. While it reduced lake surface area by only 0.3%, 1700 m^2 of that surface area are nonetheless gone. Emergent vegetation growing on newly created shoreline sites such as this contribute to an accelerated rate of filling the lake. Lake filling by soil particles and refractory plant parts can occur at a rate that substantially reduces the lifespans of small lakes that have large watersheds.

There are a number of points to be made from the perspective of clay as a vehicle for phosphorus transport and release. Imevbore and Adeniyi (1977) indicated that suspended material, primarily clay, levels were associated with increased PO_4 levels and subsequent increased biomass in Lake Kainji, Nigeria. Samsel (1973) also reported increased PO_4 with increasing suspended sediment concentration in a small American impoundment but noticed a decrease in productivity at high turbidity levels. A discussion of chlorophyll *a*, secchi disk, and phosphorus relationships in Skinner Lake in 1979 by Wilson (1980) suggests that soil particle turbidity does not severely depress algal standing crops in the lake. She found algal standing crops at densities predicted by phosphorus concentration, where the predictions were made from studies on lakes not heavily impacted by agricultural drainage.

Comparison of NFF residue concentrations and particulate phosphorus levels in Rimmell inlet discharge (Progress Report to EPA) indicated a high correlation ($r = 0.76$). Using the linear estimate of this relationship ($y = 0.0033 + 0.0014x$), the amount of phosphorus associated with clay input by Rimmell discharge over the study period was calculated. The 5.4×10^5 kg of NFF residue input over the study period was estimated in this fashion to be carrying 751.5 kg of phosphorus. Forty percent of this (300.4 kg) passed through the lake outlet and 54% was deposited in the delta and surrounding littoral, to be slowly released through equilibrium reactions and rooted plant uptake. The remaining 6% (48.3 kg) was deposited in lake sediments away from the mouth of the Rimmell channel. This corresponds to a phosphorus loading of 0.098 $g/m^2/yr$. With a mean lake depth of 4.6 m, this value falls between the permissible (0.07 $g/m^2/yr$) and dangerous (0.13 $g/m^2/yr$) loading levels developed by Vollenweider (1968). These levels do not take lake residence times into consideration and must be interperted with caution. Assuming slow release of phosphorus from aerobic sediments, however, loading of this magnitude need not be a problem.

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APPENDIX

Table A-1. Estimated discharge (Q) of the Rimmell inlet and calculated non-filterable fixed (NFF) residue for the period 3/14/78-4/13/78.

Date	Outlet Q (m^3/sec)	Total Daily Outlet Q (m^3)	Rimmell Q[1] (m^3/sec)	Total Daily Inlet Q (m^3)
3/14/78	0.9062	78,295.0	0.5087	43,957.7
3/15/78	0.9062	78,295.0	0.5087	43,957.7
3/16/78	0.9062	78,295.0	0.5087	43,957.7
3/17/78	0.9062	78,295.0	0.5087	43,957.7
3/18/78	0.9345	80,740.8	0.5247	45,334.1
3/19/78	1.1045	95,428.8	0.6207	53,628.5
3/20/78	1.3877	166,381.5	0.7806	67,443.8
3/21/78	3.0303	261,817.9	1.7080	147,571.2
3/22/78	3.1719	274,052.2	1.7890	154,569.6
3/23/78	3.1719	274,052.2	1.7890	154,569.6
3/24/78	3.0586	264,263.0	1.7329	148,944.9
3/25/78	2.8320	244,684.0	1.5959	137,885.8
3/26/78	2.2789	205,537.0	1.3402	115,793.3
3/27/78	2.1240	183,513.6	1.1963	103,360.3
3/28/78	2.0208	173,733.1	1.3223	97,830.7
3/29/78	2.0208	173,733.1	1.3223	97,830.7
3/30/78	1.9541	168,834.2	1.1003	95,065.9
3/31/78	1.5859	137,021.8	0.8925	77,112.0
4/ 1/78	1.5859	137,021.8	0.8925	77,112.0
4/ 2/78	1.4160	122,342.4	0.7966	68,826.2
4/ 3/78	1.5576	134,576.6	0.8765	75,729.6
4/ 4/78	1.8691	161,490.2	1.0524	90,927.4

Table A-1 (cont'd.).

Date	Outlet Q (m^3/sec)	Total Daily Outlet Q (m^3)	Rimmell Q (m^3/sec)	Total Daily Inlet Q (m^3)
4/ 5/78	2.3789	205,537.0	1.3402	115,793.3
4/ 6/78	2.3789	205,537.0	1.3402	115,793.3
4/ 7/78	2.5205	217,771.2	1.4201	122,696.6
4/ 8/78	2.2656	195,747.8	1.2762	110,263.7
4/ 9/78	1.7275	149,256.0	0.9724	84,015.4
4/10/78	1.3877	166,381.5	0.7806	67,443.8
4/11/78	1.3027	112,553.3	0.7326	63,296.6
4/12/78	1.2177	105,209.3	0.6846	59,149.4
4/13/78	1.0195	88,084.8	0.5727	49,481.3
		5,018,482.9		1,773,098.4

1,773,098.4 m^3 x 67 g/m^3 = 118,797,000 g or 118,797 kg $\pm$ 47,342 kg (80% confidence) of NFF residue input by the Rimmell during the period 3/14/78-4/13/78.

5,018,482.9 m^3 x 19.55 g/m^3 = 98,111,341 g or 98,111 kg $\pm$ 107,970 kg (80% confidence) of NFF residue output from Skinner Lake during the period 3/14/78-4/13/78.

1. Values estimated from regression of inlet discharge on outlet discharge.

Table A-2. Observed Rimmell inlet discharges during the period 3/14/78-4/2/79.

Season	Period of Observation	Total Q (m^3)
Spring	3/14/78-4/13/78	1,773,098[1]
	4/14/78-4/23/78	450,424
	4/24/78-5/ 9/78	715,723
	5/10/78-5/23/78	962,942
		3,902,187
Summer	5/24/78-6/ 6/78	207,603
	6/ 7/78-6/20/78	63,686
	6/21/78-7/ 3/78	178,023
	7/ 4/78-7/17/78	58,575
	7/18/78-7/31/78	34,837
	8/ 1/78-8/14/78	26,006
	8/15/78-8/29/78	15,023
	8/30/78-9/27/78	20,963
		604,786
Fall	9/28/78-10/27/78	15,390
	10/28/78-11/17/78	12,247
	11/18/78-12/ 6/78	23,331
		50,868
Winter	12/ 7/78-12/31/78	50,576
	1/ 1/79-1/27/79	19,861
	1/28/79-2/23/79	8,424
		78,861
Spring	2/24/79-3/12/79	1,795,349
	3/13/79-4/ 2/79	625,905
		2,421,254
Total		7,057,956 m^3

1. Estimated as shown in Appendix Table A-1.

Table A-3. Estimates of instantaneous discharge (Q) from the Rimmell inlet for the period 4/13/78-4/2/79.

Sample Date	Rimmell Inlet Q (m^3/sec)
4/13/78	0.5567
5/ 2/78	0.4152
5/16/78	0.9133
5/30/78	0.0722
6/13/78	0.0270
6/26/78	0.1870
7/10/78	0.0284
7/24/78	0.0300
8/ 7/78	0.0220
8/21/78	0.0100
9/ 6/78	0.0090
10/16/78	0.0050
11/ 6/78	0.0060
11/27/78	0.0130
12/14/78	0.0280
1/16/79	0.0050
2/ 6/79	0.0050
3/ 6/79	1.3100
3/19/79	0.3820
4/ 2/79	0.7130

Table A-4. Results of non-filterable fixed (NFF) residue analyses.

Sample Date	Input NFF Residue Concentration (mg/l)	Output NFF Residue Concentration (mg/l)
4/13/78	47.0	8.7
5/ 2/78	37.0	24.0
5/16/78	96.0	8.0
5/30/78	81.0	
6/13/78	40.0	0.0
6/26/78	83.0	15.0
7/10/78	37.0	19.0
7/24/78	80.0	2.0
8/ 7/78		59.0
8/21/78	31.0	45.0
9/16/78	130.0	0.0[1]
10/16/78	62.0	0.0
11/ 6/78	1.0	0.0
12/14/78	302.0	0.0
1/16/79	61.0	76.0
2/ 6/79	119.0	43.0
3/ 6/79	36.0	38.0
3/19/79		0.0
4/ 2/79	67.0	15.0

1. The outlet did not discharge between 9/16 and 12/14, 1978.

Table A-5. Results of clay particle separation procedures.

Sample Site #	Sample Volume (cc)	Weight of Extracted Material (g)	Weight of Clay (g)	Density of Clay (g/cc)
1	50	16.102	14.053	0.281
2	20	8.544	7.662	0.383
3	25	7.310	6.737	0.269
4	50	19.566	19.093	0.362
5	30	10.549	9.807	0.327
6	50	15.160	13.646	0.273
7	50	18.298	16.883	0.338
8	50	23.593	11.655	0.233
9	50	30.472	17.612	0.352
10	50	30.755	17.966	0.359
11	50	27.442	9.341	0.187
12	50	29.193	25.553	0.511
13	50	9.646	8.935	0.179
14	50	17.411	12.536	0.251
15	50	18.649	16.989	0.339
16	50	6.478	6.195	0.124
17	50	7.186	6.733	0.135
18	50	10.262	7.261	0.145
19	50	7.607	7.073	0.142
20	50	8.888	8.472	0.169
21	50	15.599	14.442	0.289

Table A-6. Estimates of non-filterable fixed (NFF) residue in the upper and lower pelagial zones of Skinner Lake for the spring of 1978 and the spring of 1979.

Sampling Date	NFF Residue in Upper Pelagial (kg)	NFF Residue in Lower Pelagial (kg)
5/ 2/78	0	15,106
5/16/78	632	7,753
5/30/78	0	
4/23/79	0	0
5/ 7/79	0	0