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PHOSPHORUS AND NITROGEN BALANCE OF THE EUTROPHIC LAKE TUUSULANJÄRVI

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Phosphorus and nitrogen balances of the highly eutrophic Lake Tuusulanjärvi are calculated for the years 1974—1977. The data was comprised of monthly water quality observations. Nutrient input is calculated as the sum of terrestrial and aeolian diffuse load and of sewage. Output through the outlet, net sedimentation and changes in nutrient concentrations are also calculated. Furthermore denitrification is estimated.

Index words: Plant nutrients, phosphorus balance, nitrogen balance, eutrofication, sedimentation, denitrification.

1. INTRODUCTION

Lake Tuusulanjärvi is located in southern Finland about 30 km north of Helsinki. It is the largest lake in the river basin of Vantaa. The lake's most important hydrological and morphological characteristics are:

Surface area	6 km^2
Volume	$18.6 \cdot 10^6 m^3$
Maximum depth	10 m
Mean depth	3.1 m
Maximum length	8.1 km
Maximum width	1.5 km
Theoretical retention time	220 d
Drainage area	92 km^2
Lake percentage	8.4 %
Percentage of cultivated land	40 %

Two towns, Järvenpää and Tuusula, are located in the catchment area. The population of the area has grown from about 7 500 in 1910 to more than 40 000 in 1977. Both towns discharged their domestic sewage to Lake Tuusulanjärvi until 1973, when sewage from Tuusula was led to the River Tuusulanjoki. The sewage of Järvenpää (mostly domestic) was treated in a tertiary sewage works before discharging to the lake. From 1979 the sewage has been led to the Gulf of Finland off Helsinki.

Much intensive farming is carried out in the drainage area. Thus agriculture has been the other activity loading the lake. After sewage diversion in 1979 agriculture has become the most important nutrient source of Lake Tuusulanjärvi.

Tuusulanjärvi was originally a slightly brown humus lake. The eutrophication process was slow until the mid 1950's, since when blooms of blue-green algae and late winter oxygen deficit have frequently occurred. Since the winter of 1972—1973 the lake has been aerated during the ice-covered period (Lemmelä et al. 1974).

The purpose of this study was to illustrate the nutrient dynamics of Lake Tuusulanjärvi, by calculating the phosphorus and nitrogen balance of the lake in 1974—1977. The results help in estimating the effects of sewage diversion on the lake.

2. MATERIAL AND METHODS

2.1 Material

The Helsinki Water District Office took water samples once a month in the main deep, the outflow and two of the inflowing brooks, Mäyränoja and Sarsalanoja. Samples from all the brooks were taken six times to check how well the two largest brooks represent the total inflow. For sampling sites see Fig. 1.

The lake was sampled at five depths from 1 to 9 meters, the outlet and the brooks near the surface. The analytical methods used were those presented by Erkomaa et al. 1977.

The daily water level and the discharge at the outlet were observed by Helsinki City Water Works, the precipitation and the evaporation by the Hydrological Office and the sewage load by the Water Protection Association of Vantaa River and Helsinki Region. The discharge used in calculations is the sum and the water level the mean of daily values for the period in question. Both precipitation and evaporation were measured at some distance from Lake Tuusulanjärvi. The evaporation was corrected by multiplying the evaporation at the two nearby stations by the ratio between the evaporation at Lake Tuusulanjärvi and at the two stations in 1973 and 1974.

The discharge of the eight largest brooks flowing into Lake Tuusulanjärvi was only measured six times, in 1976 and 1977. Thus the inflow was calculated from the water balance equation (1)

$$\frac{ds}{dt} = Q_I - Q_O + P - E \qquad (1)$$

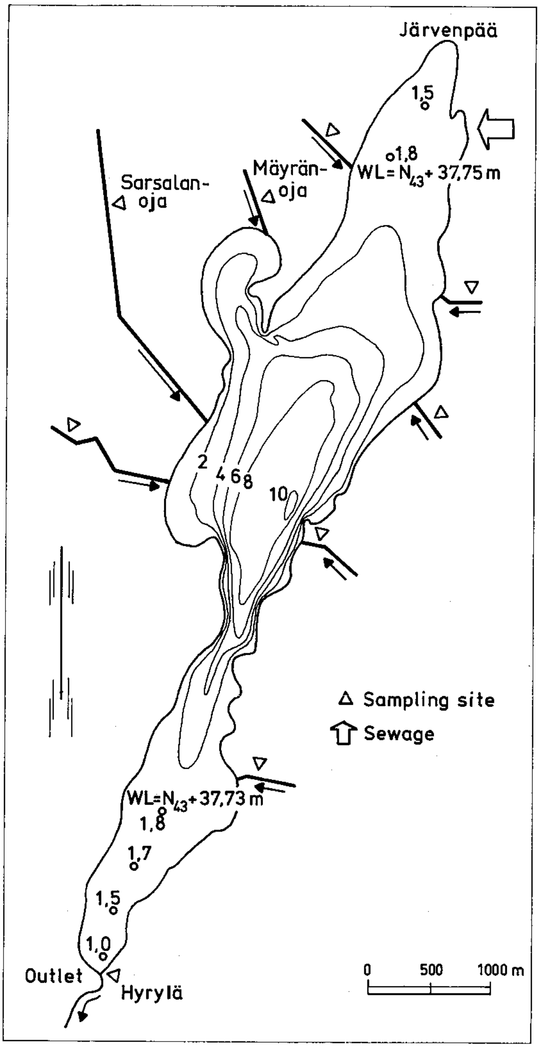

Fig. 1. Map of Lake Tuusulanjärvi.

$\frac{ds}{dt}$ = change in lake water volume
Q_I = inflow
Q_O = outflow
P = precipitation
E = evaporation

The fallout was measured at two stations at some distance from the lake (Haapala 1977). The median of the monthly values multiplied by 12 was used as the annual fallout.

2.2 Methods

The nutrient balance was calculated for each month. The annual values were then obtained by summation.

The mass balance equation used was (2)

$$\frac{dm}{dt} = I - O - S \qquad (2)$$

$\frac{dm}{dt}$ = change in the amount of nutrient in the total water volume
I = input
O = output
S = net sedimentation

The input or the total load was calculated as the sum of the sewage load and both the terrestrial and aeolian diffuse load. Thus the internal load, i.e. the nutrients released from the bottom sediments, is not included in the total load. The terrestrial diffuse load for each period is the product of the inflow (calculated from equation 1) and the mean of the concentrations in the two brooks sampled. By analogy the output is the product of the concentration and the discharge measured at the outlet.

In calculating the concentration and the amount of each nutrient in the water volume the lake was divided into five horizontal slices two meters thick. The equations used were

$$c = \frac{\sum_{i=1}^{5} V_i c_i}{V} \qquad (3)$$

$$m = \sum_{i=1}^{5} V_i c_i \qquad (4)$$

c = concentration in the water mass (mg m^{-3})
c_i = concentration in the slice i (mg m^{-3})
m = amount of the nutrient in the water mass (kg)
V = lake volume ($10^6 m^3$)
V_i = volume of the slice i ($10^6 m^3$)

3. RESULTS

3.1 Nutrient supplies to Lake Tuusulanjärvi

In 1974—1977 the most important phosphorus source of Lake Tuusulanjärvi was sewage, contributing 58 % of the total phosphorus load. Terrestrial diffuse load came second with 41 % of total. Nitrogen had the reverse order, with terrestrial diffuse load contributing 57 % and sewage 39 % of the total load. Aeolian load was less important, its proportion being only 1 % of phosphorus and 4 % of nitrogen load (Table 1).

Total load of both nitrogen and phosphorus varied from year to year, the greatest values being approximately twice the smallest (Tables 2 and 3). Differences between years were due mostly to variation in terrestrial diffuse load, which in turn followed changes in precipitation:

	nitrogen $kg km^{-2} a^{-1}$	phosphorus $kg km^{-2} a^{-1}$	precipitation $mm a^{-1}$
1974	1 280	73	940
1975	320	26	515
1976	340	18	505
1977	1 380	88	861

Both phosphorus ($r = 0.94^{o}$) and nitrogen ($r = 0.97^{\star}$) leaching correlates positively with precipitation. The small number of research years (4) and the lack of years with normal precipitation (years 1974 and 1977 were wetter and 1975 and 1976 drier than normal) lessen the reliability of the results.

Diffuse load varied not only between but also within years, being smallest in summer and largest in spring (Figures 2 and 3). The proportion of terrestrial diffuse load arriving in the lake during the spring flood (month of april) was:

	nitrogen	phosphorus
1974	32 %	18 %
1975	32 %	25 %
1976	36 %	55 %
1977	37 %	40 %

Table 1. Relative importance of nutrient sources to Lake Tuusulanjärvi (% of total load).

Year	Nitrogen load			Phosphorus load		
	diffuse		sewage	diffuse		sewage
	terrestrial	aeolian		terrestrial	aeolian	
1974	69.6	3.8	26.6	53.0	1.0	46.0
1975	34.6	4.5	60.9	21.8	1.3	76.9
1976	35.6	5.3	59.1	24.4	1.3	74.3
1977	65.8	2.8	31.4	51.4	0.7	47.9
1974–1977	57.1	3.8	39.1	40.9	1.0	58.1

Table 2. Annual inputs of phosphorus to Lake Tuusulanjärvi in 1974–1977 (g m^{-2} a^{-1} = g per square meter of lake surface and year).

Year	Diffuse load				Sewage		Total load	
	terrestrial		aeolian					
	kg a^{-1}	g m^{-2} a^{-1}	kg a^{-1}	g m^{-2} a^{-1}	kg a^{-1}	g m^{-2} a^{-1}	kg a^{-1}	g m^{-2} a^{-1}
1974	6 740	1.1	130	0.022	5 830	1.0	12 700	2.1
1975	2 360	0.4	144	0.024	8 310	1.4	10 810	1.8
1976	1 700	0.3	94	0.016	5 170	0.9	6 960	1.2
1977	8 140	1.4	112	0.019	7 580	1.3	15 830	2.7

Table 3. Annual inputs of nitrogen to Lake Tuusulanjärvi in 1974–1977 (g m^{-2} a^{-1} = g per square meter of lake surface and year).

Year	Diffuse load				Sewage		Total load	
	terrestrial		aeolian					
	kg a^{-1}	g m^{-2} a^{-1}	kg a^{-1}	g m^{-2} a^{-1}	kg a^{-1}	g m^{-2} a^{-1}	kg a^{-1}	g m^{-2} a^{-1}
1974	118 000	19.7	6 300	1.1	45 100	7.5	169 400	28.3
1975	29 400	4.9	4 070	0.7	51 800	8.6	85 270	14.2
1976	31 500	5.3	4 970	0.8	52 200	8.7	88 670	14.8
1977	127 300	21.2	5 470	0.9	60 800	10.1	193 570	32.2

The proportion of the total diffuse load contributed by the atmosphere varied from year to year:

	nitrogen	phosphorus
1974	5.1 %	1.9 %
1975	12.2 %	5.8 %
1976	13.6 %	5.2 %
1977	4.1 %	1.4 %

This variation is due to changes in terrestrial diffuse load, the aeolian load having varied less and in the opposite direction. Aeolian load was smaller in the dry years 1975 and 1976 (except phosphorus in 1975). Nothing can be said about differences between seasons, for the values used in calculations are annual medians of monthly fallout.

Sewage load did not change significantly during the research period. Even monthly variations were small, the only exception being the unusually large phosphorus load during the first third of 1975 (Fig. 2). This was due to repairs at the sewage works.

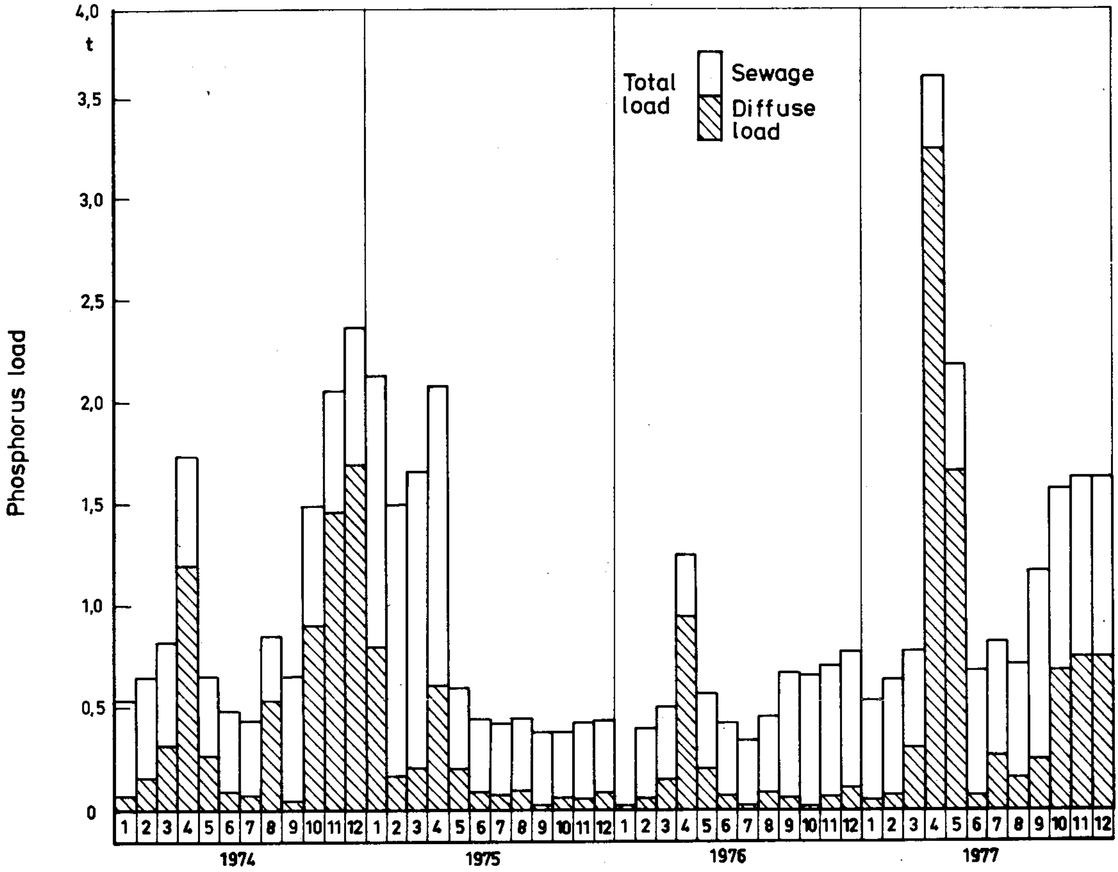

Fig. 2. Sewage, diffuse and total load of phosphorus to Lake Tuusulanjärvi in 1974—1977.

3.2 Retention and output of nutrients

Varying fractions of the total load left Lake Tuusulanjärvi through the outlet (Tables 4 and 5). Both nitrogen and phosphorus output followed the water outflow, changes in nutrient concentrations being less significant:

	outflow of water ($m^3 a^{-1}$)	annual average ($mg\,m^{-3}$) N	P
1974	$48 \cdot 10^6$	2 220	114
1975	$18 \cdot 10^6$	2 390	140
1976	$12 \cdot 10^6$	2 040	85
1977	$37 \cdot 10^6$	2 440	116

Nitrogen output was 30—66 % of input, phosphorus output only 14—43 % (Tables 4 and 5). Seasonal rhythm, however, was similiar for each nutrient and followed the rhythm of nutrient input, having maximum values in spring. In rainy years another maximum occurred in the autumn (Figures 4 and 5).

More than half of the phosphorus input was retained in the lake, net load being 57—86 % of total load (Table 4). Nitrogen net load was less, between 34 and 70 % of total (Table 5).

Nutrient content of the water mass varied regularly in one respect. In summer nitrogen content decreased and phosphorus content increased (Figures 4 and 5). The cause of this was variation of nutrient concentration, not of water volume. Nitrogen (both total and inorganic) had its minimum in summer, when phosphorus had its maximum (Figures 6 and 7). Except in 1976 phosphorus had another maximum in early spring at the time of the oxygen minimum (Fig. 8).

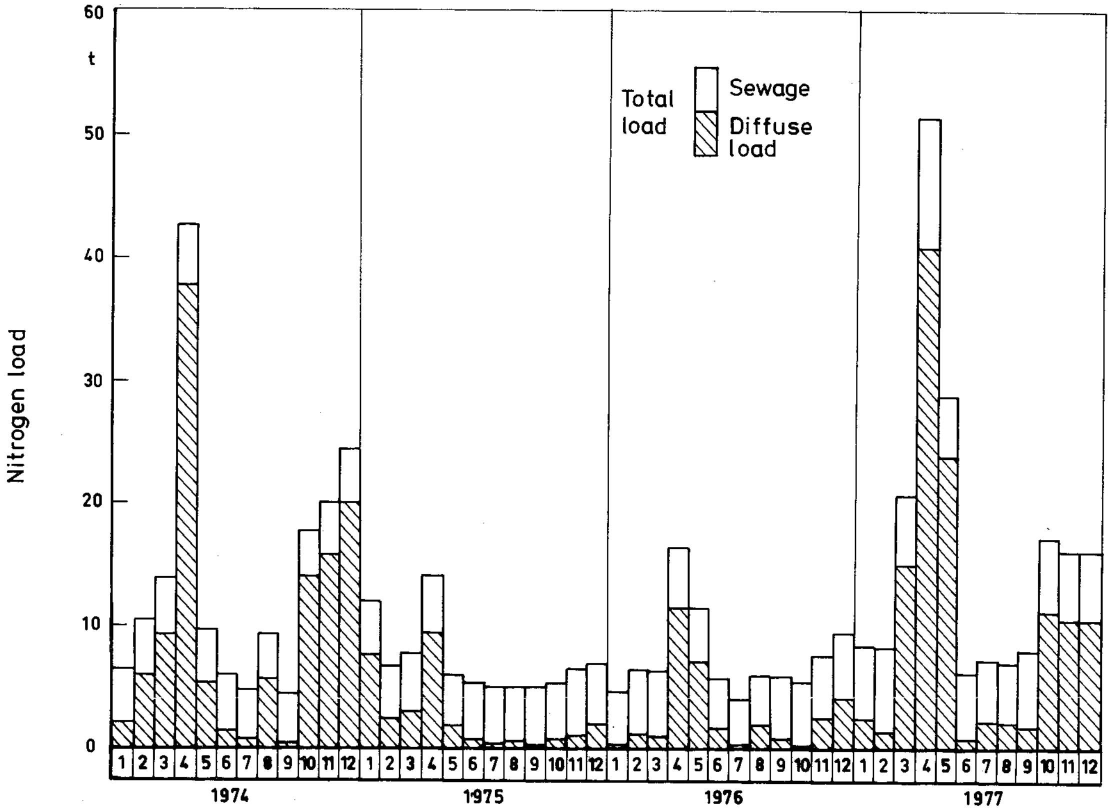

Fig. 3. Sewage, diffuse and total load of nitrogen to Lake Tuusulanjärvi in 1974—1977.

Table 4. Phosphorus net load to and output from Lake Tuusulanjärvi, and change in the phosphorus content of water and sediment.

Year	Output		Net load			Phosphorus content	
	kg a^{-1}	% of total	kg a^{-1}	g m^{-2} a^{-1}	% of total	water mass kg a^{-1}	sediment kg a^{-1}
1974	5 460	43.0	7 240	1.2	57.0	+ 2 010	+ 5 230
1975	2 590	24.0	8 220	1.4	76.0	− 2 430	+ 10 650
1976	950	13.6	6 010	1.0	86.4	− 120	+ 6 130
1977	3 910	24.7	11 910	2.0	75.3	+ 1 260	+ 10 650

Table 5. Nitrogen net load to and output from Lake Tuusulanjärvi, and change in the nitrogen content of water and sediment.

Year	Output		Net load			Nitrogen content	
	kg a^{-1}	% of total	kg a^{-1}	g m^{-2} a^{-1}	% of total	water mass kg a^{-1}	*sediment kg a^{-1}
1974	111 400	65.7	58 100	9.7	34.3	+ 4 000	+ 54 100
1975	45 800	53.9	39 200	6.5	46.1	− 10 300	+ 49 500
1976	26 700	30.2	61 700	10.3	69.8	+ 7 950	+ 53 750
1977	96 900	50.1	96 700	16.1	49.9	+ 3 350	+ 93 350

* denitrification included

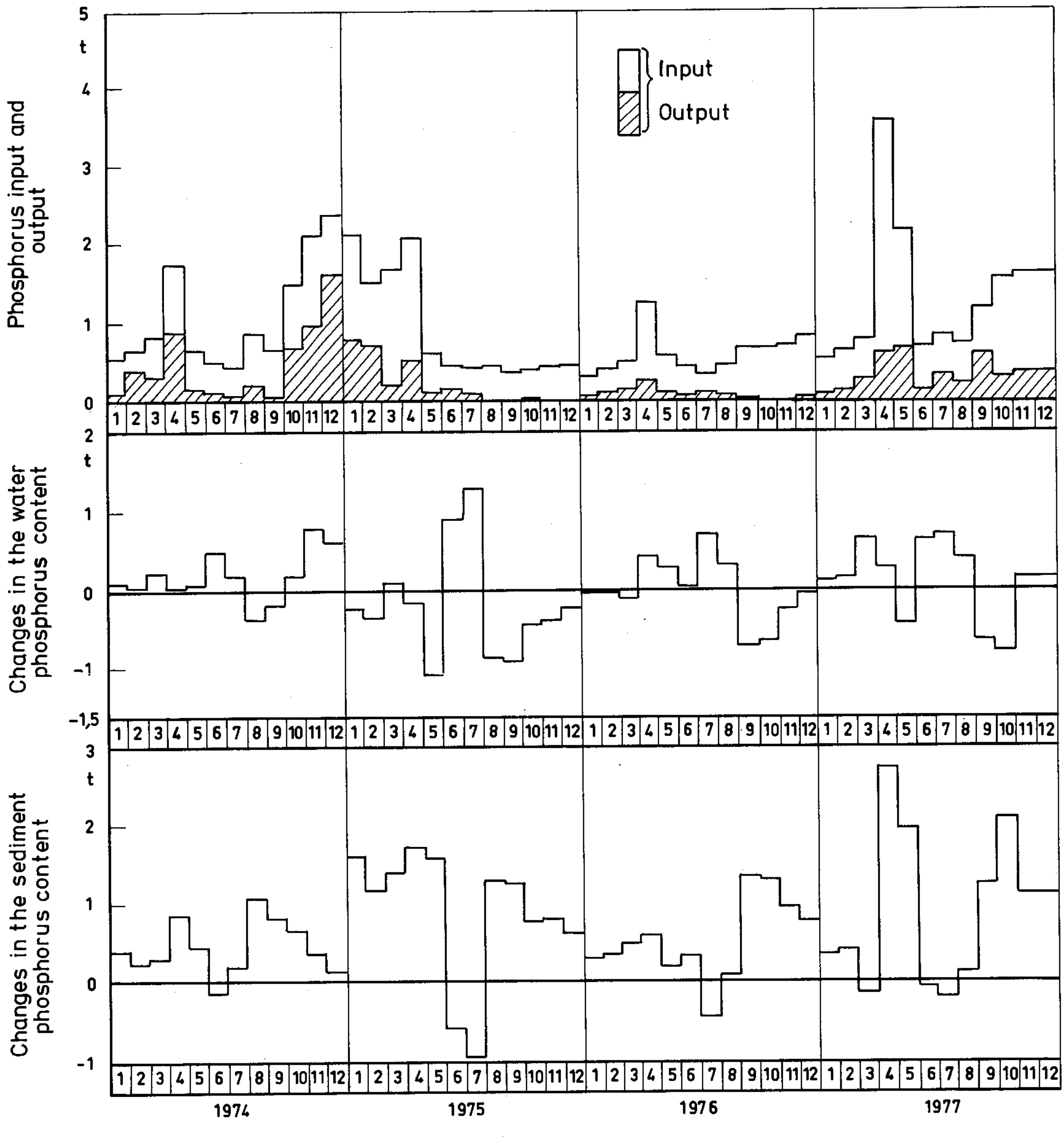

Fig. 4. Phosphorus balance of Lake Tuusulanjärvi in 1974—1977; input, output and change in the phosphorus content of the water mass and of the sediment.

Most of the retained phosphorus sedimented. Net sedimentation, i.e. the difference between phosphorus sedimented and that released from sediment, varied from 72 to 130 % of net load (Table 4). The greatest net sedimentation, 130 %, was for 1975, when sedimentation was greater then retention. Thus some of the phosphorus sedimented had arrived in the lake during previous years.

Seasonal variation of phosphorus sedimentation was quite regular. Net sedimentation was positive at all other times but in summer, when more phosphorus was released than sedimented (Fig. 4).

It is rather difficult to interpret the calculated net sedimentation of nitrogen, for denitrification

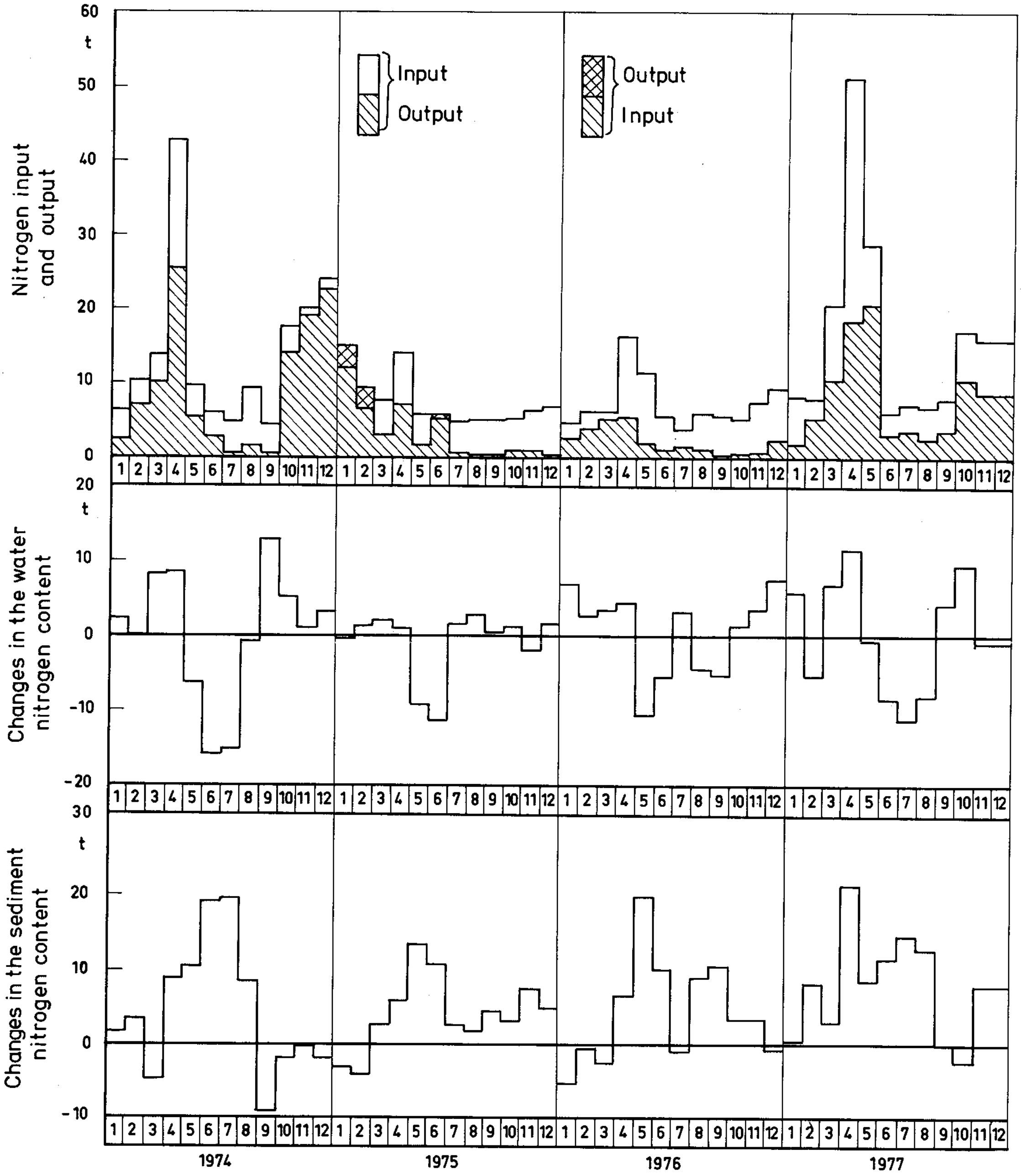

Fig. 5. Nitrogen balance of Lake Tuusulanjärvi in 1974—1977; input, output and change in the nitrogen content of the water mass and of the sediment.

is included in this part of the balance. Therefore annual denitrification was estimated to get some idea of its importance. The estimation is based on nutrient analyses from the bottom sediment, which gave concentrations of 4.7 mg nitrogen and 1.6 mg phosphorus per gram dried surface sediment (Vesihallitus 1971). Thus nitrogen sedimentation was estimated by multiplying the phosphorus sedimentation by 2.9. The part of the net load which neither sediments nor remains

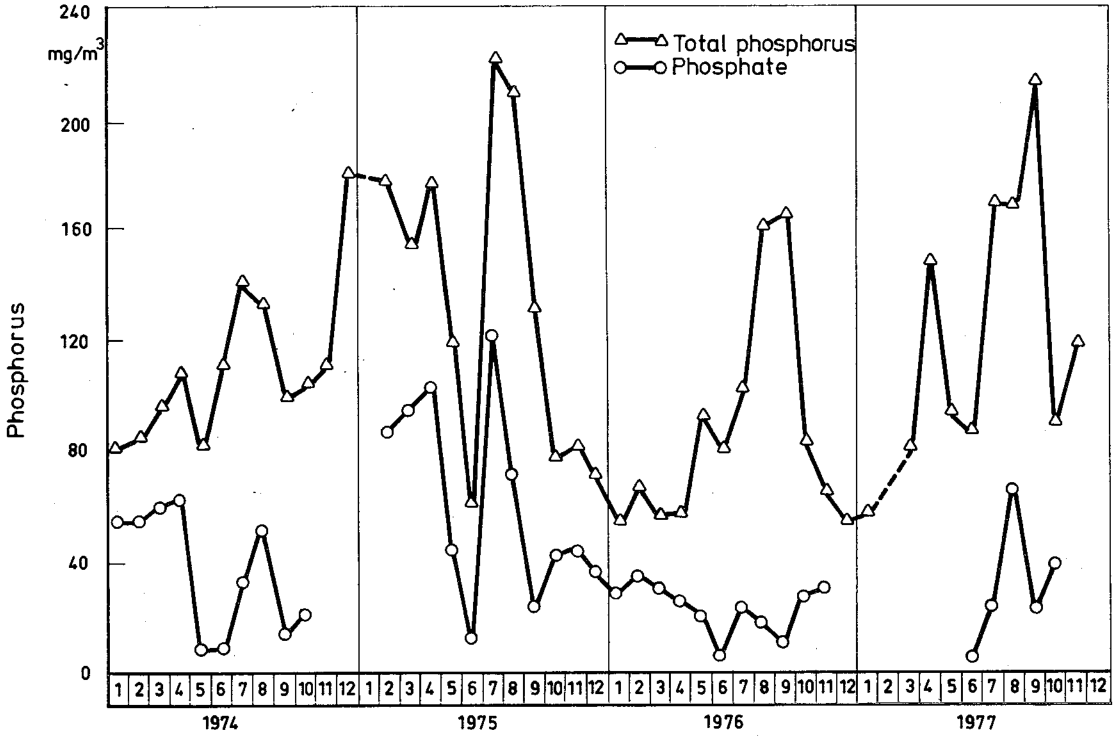

Fig. 6. Concentration (mean weighted by volume) of total phosphorus and of phosphate phosphorus in the main deep of Lake Tuusulanjärvi in 1974—1977.

in the water is presumed to go to the atmosphere as the result of denitrification (Table 6). Denitrification was an important output for nitrogen, having removed from 20 to 40 % of the total and up to 70 % of the net load of nitrogen.

4. DISCUSSION

4.1 Diffuse load

The mean for the terrestrial diffuse load to Lake Tuusulanjärvi in 1974—1977, 51 kg km^{-2} a^{-1} phosphorus (range of variation from 18 to 88) and 830 kg km^{-2} a^{-1} nitrogen (range of variation from 320 to 1380), is larger than the mean for leaching in southern Finland calculated by Särkkä (1972). This author arrived at values of 27 kg km^{-2} a^{-1} phosphorus and 400 kg km^{-2} a^{-1} nitrogen.

The results of this study are also greater than those calculated from the equations developed for small drainage basins by Kauppi (1979), which were 26 kg km^{-2} a^{-1} phosphorus and 570 kg km^{-2} a^{-1} nitrogen for the drainage basin of Lake Tuusulanjärvi. The values solved from the equations are, however, within the range of variation in 1974—1977.

The large variation in annual leaching is explained by differences in precipitation. Two of the research years were exceptionally rainy, resulting in high values of diffuse load. The observation period, however, was too short for the results to be used for expressing the terrestrial diffuse load as a function of precipitation.

The seasonal rhythm of diffuse load is mostly explained by the inflow of water. More than one third of nitrogen and from one fifth to a half of phosphorus diffuse load entered the lake during the spring flood. This is the time of the snow melt. Another maximum of diffuse load is during the wet season of autumn.

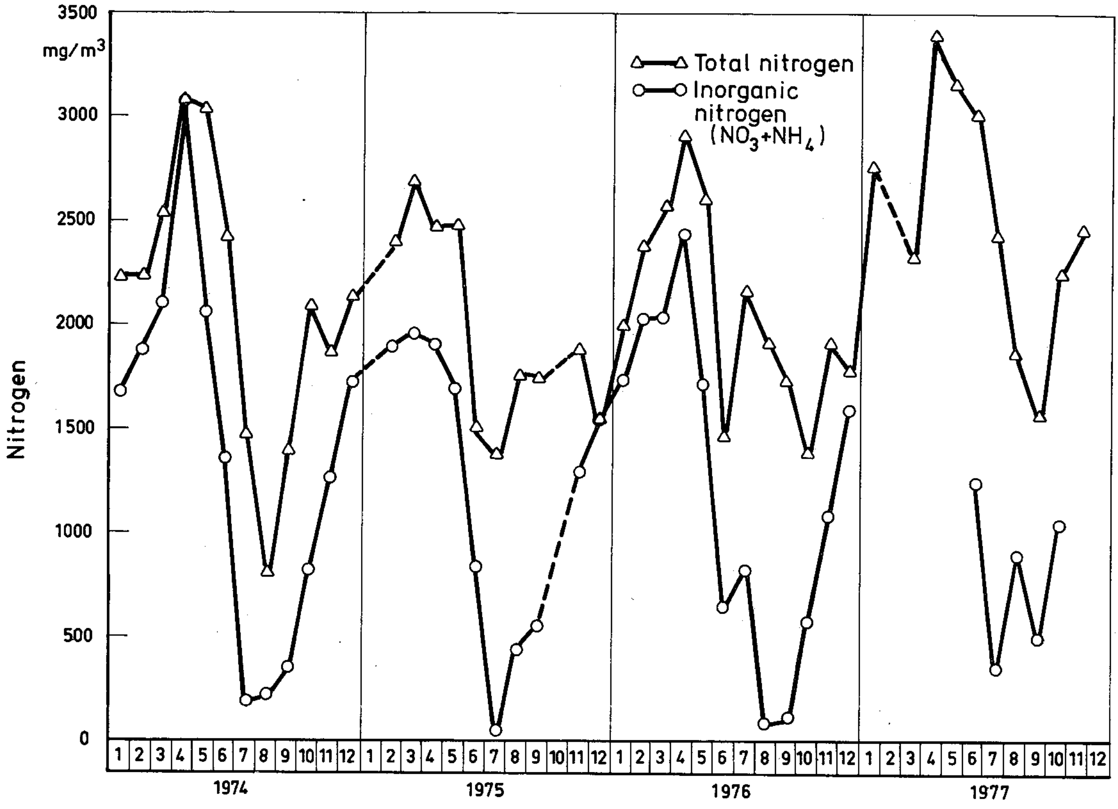

Fig. 7. Concentration (mean weighted by volume) of total nitrogen and of inorganic nitrogen in the main deep of lake Tuusulanjärvi in 1974–1977.

4.2 Total load

The most important source of phosphorus was sewage (mean 58 % of total) and that of nitrogen terrestrial diffuse load (mean 57 % of total). The relative importance of these sources varied, however. The most important source of both nutrients was the terrestrial diffuse load in rainy years and sewage in dry years.

Various parts of the nutrient load to Lake Tuusulanjärvi, especially that of phosphorus, have been estimated during the last decade (Anttila 1968, Oy Suunnittelukeskus-MKR 1969, Kangas 1970, Harjula 1970 and 1971). The estimates of the total phosphorus load vary between 6 600 and 15 000 kg a^{-1} for different rescarchers. These well correspond to the results of this study, which are 6 960–15 830 kg a^{-1}.

Both the nitrogen and phosphorus surface loads were very high, being 1.2–2.7 g of phosphorus and 14–32 g of nitrogen per square metre of lake surface per year. These values are much higher than those regarded permissible by Vollenweider (1970). The town of Järvenpää stopped leading sewage to Lake Tuusulanjärvi in 1979. Since then the only nutrient source of the lake is the aeolian and terrestrial diffuse load. During the research period even this load was greater than the permissable values given by Vollenweider (1970). This indicates that the sewage diversion will not be sufficient for the lake to recover. The diffuse load should also be lessened.

The aeolian load was very small compared with the other parts of the total load. However, it has become more significant since Järvenpää stopped using the lake as a recipient for sewage. In 1974–1977 the aeolian load varied from 4 to 14 % of nitrogen and from 1 to 6 % of phosphorus diffuse load. After sewage diversion the

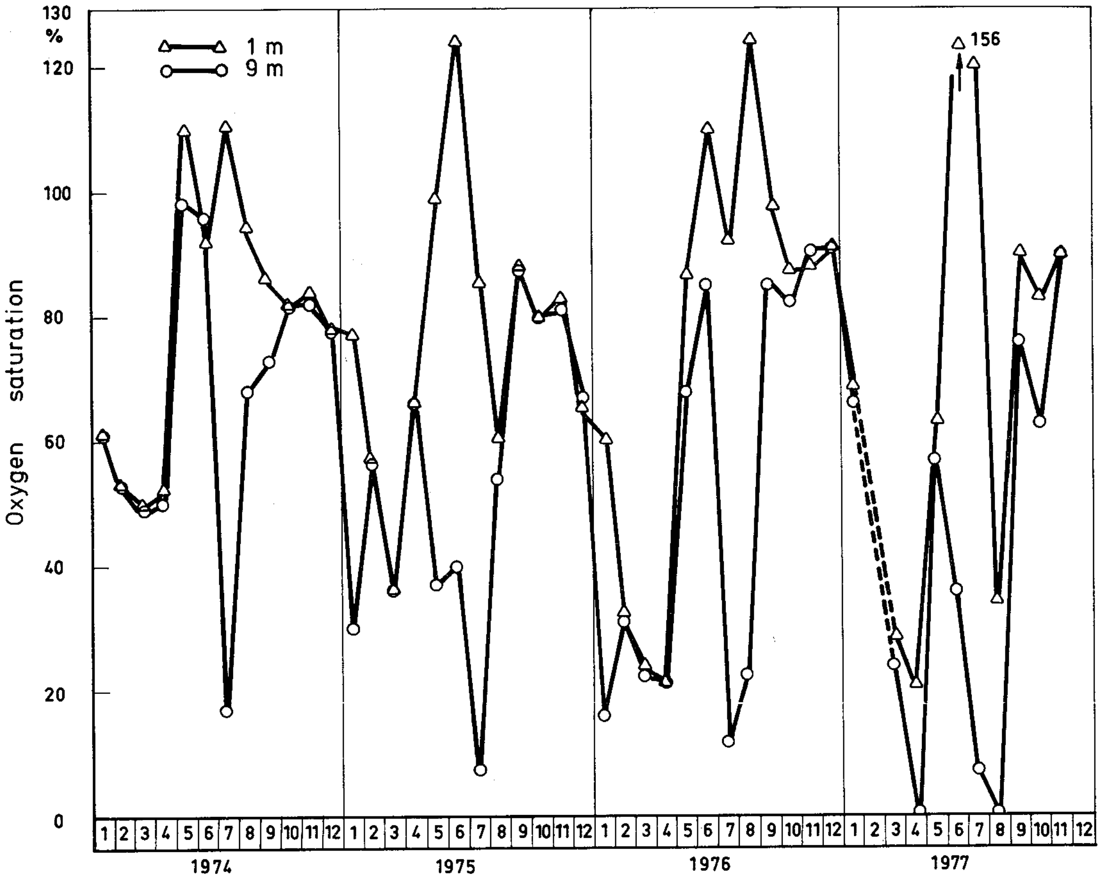

Fig. 8. Oxygen saturation in the main deep of Lake Tuusulanjärvi at depths of 1 m and 9 m in 1974—1977.

Table 6. Denitrification and change in the nitrogen content of water and sediment. Change in the nitrogen content of sediment is obtained by multiplying change in the phosphorus content of sediment by an experimental factor. Denitrification is calculated as the difference between net load and changes in the nitrogen content of water and sediment.

Year	Change in the nitrogen content of		Denitrification		
	water kg a^{-1}	sediment kg a^{-1}	kg a^{-1}	% of net load	% of total load
1974	+ 4 000	+ 15 000	39 100	67	23
1975	− 10 300	+ 30 000	19 500	50	23
1976	+ 7 950	+ 18 000	35 750	58	41
1977	+ 3 350	+ 31 000	62 350	64	32

aeolian load will contribute a correspondingly larger proportion of the total load. This will however still be less than the proportion of the total nutrient load carried to Finnish lakes through the atmosphere, which is 18 % for phosphorus (Haapala 1972). The atmospheric contribution will be relatively higher in dry years, for the diffuse load is then small.

4.3 Net load and sedimentation

Lake Tuusulanjärvi retained nutrients during all but some periods in 1975, when nitrogen output was greater than input. Annual net load of both phosphorus and nitrogen was always positive.

Phosphorus retention was greater than nitrogen retention, for most of the phosphorus coming into the lake is attached to organic or inorganic particles, for example clay, which quickly sediment. Nitrogen was mostly present in soluble forms and therefore stayed in the water mass, leaving the lake through the outlet. The difference between the behaviour of phosphorus and nitrogen can be especially well seen in the spring and autumn, at the times of large input and output.

Almost all of the nutrient net load sedimented, changes from year to year in the nutrient content of the water being small. The sediment thus acted as a sink for nutrients (for nitrogen see 4.5). It will be interesting to see whether the role of sediment will change after the sewage diversion in 1979. Large reserves of nutrients have been stored in the bottom sediments of the lake during the years it has been used as a recipient of sewage. The lake might now enter a phase in which sediment acts as a nutrient source.

Net sedimentation of phosphorus was negative in summer, the sediment releasing more phosphorus than it retained. A corresponding phenomenon has been detected in many other shallow, eutrophic lakes (e.g. Andersen 1974, Ryding and Forsberg 1977, Stevens and Gibson 1977). According to Andersen (1974) the release is due to high temperature, high values of pH and low values of redox potential.

4.4 Nitrogen and phosphorus concentrations

The rhythm of total nitrogen and total phosphorus concentrations in Lake Tuusulanjärvi followed changes in inorganic nitrogen (NO_3+NH_4) and phosphate phosphorus. Almost all nitrogen is in inorganic form in winter at the time of the nitrogen maximum, whereas the proportion of organic nitrogen is many times that of inorganic in summer at the time of minimum concentration.

Phosphorus concentration had two maxima, one in late winter and another in summer. The maxima appear at the time of oxygen minima in the bottom layers of water. In addition to poor oxygen levels phosphorus release from the bottom sediments in summer may be accelerated by the action of wind. The lake is shallow and its longitudinal axis lies from north to south, which is the direction of the prevailing winds in the region. Thus the lake seldom stratifies in summer. The hypothesis concerning the effect of wind on phosphorus release from the sediment has not been tested. A similar phenomenon has, however, been detected in Lake Uttran in Sweden, where nutrient concentrations and algal biomass were greater in years with strong winds in the direction of the axis of the lake (Ryding and Forsberg 1977).

Phosphorus load cannot be the cause of phosphorus summer maxima, for both total and net load were smaller in summer than in other seasons.

4.5 Denitrification

The estimated denitrification in Lake Tuusulanjärvi was 3—10 g m^{-2} a^{-1}. This is smaller than denitrification in some other shallow, eutrophic lakes, which has been 20—47 g m^{-2} a^{-1} (Andersen 1974, Jörgensen et al. 1973). According to Ahl (1973) denitrification is the greater the more heavily a lake is loaded.

Denitrification has been an important sink for nitrogen in Lake Tuusulanjärvi. Between 50 and 70 % of nitrogen net load was denitrified. Denitrification has thus reduced the amount of nitrogen stored in the bottom sediments.

The proportion of total nitrogen load leaving the lake through denitrification varied from 20 to 40 %. These values are smaller than those obtained for lakes Glaningen, Ramsjön and Ryssbysjön by Ryding and Forsberg (1977), which were 35—60 % of total load. Brezonik (1972) reported denitrification to be 11—15 % of total load in some Swiss lakes, which in turn is smaller than in Lake Tuusulanjärvi.

SUMMARY

The purpose of this study was to evaluate the nutrient dynamics of the highly eutrophic Lake Tuusulanjärvi by calculating the phosphorus and nitrogen balances. The data comprised monthly water quality and sewage observations and daily hydrological observations in 1974—1977.

Most of the phosphorus load, approx. 58 % was contributed by sewage, whereas diffuse load was the most important nitrogen source contributing approx. 57 % of total load. Compared with other nutrient sources aeolian load has been of minor importance. Its significance has grown, however, since sewage diversion in 1979.

Both annual and seasonal variation of total load is mainly due to changes in diffuse load. Variation was between 320 and 1 380 kg m^{-2} a^{-1} nitrogen and 18—88 kg m^{-2} a^{-1} phosphorus. Diffuse load was greatest in the years 1974 and 1977, which were exceptionally rainy. Approximately one third of the diffuse load came in one month during the spring flood.

About half of the nitrogen and over two thirds of the phosphorus load was retained in the lake. Almost all of the phosphorus retained was sedimented. The net sedimentation was, however, negative in summer. Less phosphorus was then sedimented than released from the sediment.

The summer phosphorus released by bottom sediments gave rise to a maximum of phosphorus concentration in the lake water. Another maximum occurred in late winter at the time of oxygen deficit. Nitrogen behaved differently, having a minimum in summer and a maximum in winter.

From 50 to 70 % of nitrogen retained in the lake left as a result of denitrification. The importance of denitrification to the nitrogen balance of the lake can be clearly seen when compared with the output through the outlet, which is only two times the size of denitrification.

Further nutrient balance calculations for lake Tuusulanjärvi should be carried out to estimate the significance of the 1979 sewage diversion for the lake.

ACKNOWLEDGEMENTS

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Helsinki, September 1979

Titta Ojanen

LOPPUTIIVISTELMÄ

Tämän tutkimuksen tarkoituksena on ollut tarkastella hyvin rehevän Tuusulanjärven ravinnetaloutta. Päämäärään on pyritty laskemalla fosfori- ja typpitase vuosina 1974—1977. Käytettävissä on ollut vuosilta 1974—1977 kuukausittaiset vedenlaatu- ja jätevesihavainnot sekä päivittäiset hydrologiset havainnot.

Tärkein fosforikuormittaja on ollut Järvenpään jätevedenpuhdistamo, jonka jätevesi on muodostanut keskimäärin 58 % kokonaiskuormasta. Sen sijaan tärkein typen lähde on ollut valuma-alueelta tuleva hajakuormitus, jonka osuus kokonaiskuormasta on ollut keskimäärin 57 %. Ilmakehän kautta tulevan laskeuman osuus on ollut pieni muihin ravinnelähteisiin verrattuna. Sen merkitys on kuitenkin kasvanut sen jälkeen, kun jätevesien lasku Tuusulanjärveen lopetettiin vuonna 1979.

Vuosien ja vuodenaikojen väliset kokonaiskuormituksen vaihtelut ovat johtuneet pääasiassa huuhtoutumasta, joka on vaihdellut välillä 320 — 1 380 kg km^{-2} a^{-1} typpeä ja 18—88 kg km^{-2} a^{-1} fosforia. Huuhtouma on ollut suurimmillaan vuosina 1974 ja 1977, jotka olivat poikkeuksellisen sateisia. Vuosittaisesta hajakuormasta kolmasosa on tullut yhden kuukauden aikana keväällä lumen sulaessa.

Noin puolet typen ja kaksi kolmasosaa fosforin kokonaiskuormasta on pidättynyt järveen. Fosforin nettokuorma on sedimentoitunut lähes kokonaan. Kesäisin sedimentistä on kuitenkin vapautunut enemmän fosforia kuin mitä siihen on pidättynyt. Fosforin nettokuorma on silloin ollut negatiivinen.

Kesäinen fosforin vapautuminen sedimentistä on aiheuttanut samanaikaiset fosforipitoisuuden maksimit. Toinen maksimi on esiintynyt lopputalvesta pohjanläheisten vesikerrosten ollessa vähähappisia. Typen vuosirytmi on ollut toisenlainen. Sen maksimiarvot on havaittu talvisin ja minimiarvot kesäisin.

Järveen pidättyneestä typestä yli puolet — 50—70 % — on poistunut ilmakehään denitrifikaation seurauksena. Denitrifikaatiolla on ollut suuri merkitys järven typpitaloudelle, onhan sen seurauksena poistunut järvestä suunnilleen puolet siitä typpimäärästä, mikä on poistunut lähtövirtaaman mukana luusuan kautta.

Jotta Tuusulanjärven tilan kehitystä jätevesien laskun loputtua voitaisiin arvioida, on edelleen jatkettava näytteenotto-ohjelmaa, jonka tulosten avulla voidaan laskea typpi- ja fosforitase.

REFERENCES

Ahl, T. 1973. Mälarens belastning och vattenkvalitet. Summary: Lake Mälaren, loading and water quality. Scripta Limnologica Upsaliensia 332. 76 p.

Andersen, J.M. 1974. Nitrogen and phosphorus budgets and the role of sediments in six shallow Danish lakes. Arch. Hydrobiol. 74:528—550.

Anttila, R. 1968. Tuusulanjärven likaajista. Tuusulanjärven vesiensuojeluyhdistys ry. Monistettuja julkaisuja 14 p.

Brezonik, P.L. 1972. Nitrogen: Sources and transformations in natural waters. Allen, H.E. & Kramer, J.R. (eds.). Nutrients in natural waters. Series environmental science and technology: 1—50. New York.

Erkomaa, K., Mäkinen, I. & Sandman, O. 1977. Vesiviranomaisten ja julkisen valvonnan alaisten vesientutkimuslaitosten fysikaaliset ja kemialliset analyysimenetelmät. Vesihallituksen tiedotus 121. 54 p.

Haapala, K. 1972. Sadeveden laatu Suomessa vuonna 1971. Summary: The quality of rainwater in Finland according to observations made during 1971. Vesihallituksen tiedotus 26. 49 p.

Haapala, K. 1977. Vattenstyrelsens observationer 1971—1976. Diffuse vannenforurensningen. Nordforsk. Miljövårdssekretariatet. Publ. 1977, 1:151—160.

Harjula, H. 1970. Hiidenveden rehevöitymisen kehitys vertailevan pohjasedimenttitutkimuksen perusteella. Pro gradu. Helsingin yliopiston limnologian laitos. 134 p. Helsinki.

Harjula, H. 1971. Talvisesta happitilanteesta Tuusulanjärvessä sekä järven restauraatiotoimenpiteistä. Tuusulanjärven vesiensuojeluyhdistys ry. Monistettuja julkaisuja 35 p.

Jörgensen, S.E., Jacobson, O.S. & Høi, I. 1973. A prognosis for a lake. Vatten 29:382—404.

Kangas, I. 1970. Selvitys jätevesien käsittelystä ja johtamisesta Tuusulanjoen ja Keravanjoen vesistöalueilla. Tuusulanjärveä koskeva erillisselvitys. Oy Suunnittelukeskus-MKR:1—11. Helsinki.

Kauppi, L. 1979. Effect of drainage basin characteristics of the diffuse load of phosphorus and nitrogen. Publications of the Water Research Institute, National Board of Waters, Finland, No. 30:21—41.

Lemmelä, R., Numminen, S. & Seppänen, P. 1974. Aeration tests at Lake Tuusulanjärvi. Vannet i Norden 4:12—20.

Oy Suunnittelukeskus-MKR 1969. Selvitys jätevesien käsittelystä ja johtamisesta Tuusulanjoen ja Keravanjoen vesistöalueella. Yhteenveto perusselvityksistä. 50 p. Helsinki.

Ryding, S.-O. & Forsberg, C. 1977. Sediments as a nutrient source in shallow polluted lakes. Golterman, H.L. (ed.). Interactions between sediments and fresh water. Amsterdam, Sept. 6—10. 1976:227—234. Hague.

Stevens, R.J. & Gibson, C.E. 1977. Sediment release of phosphorus in Lough Neagh, Northern Ireland. Golterman, H.L. (ed.). Interactions between sediments and fresh water. Amsterdam Sept. 6—10. 1976:343—347. Hague.

Särkkä, M. 1972. The washing out of nutrients in the watersheds. Aqua Fennica 1972:88—103.

Vesihallitus 1971. Pohjalietteen analyysituloksia valtakunnallisilta syvännepaikoilta. Vesihallituksen tiedotus 7. 2 p.

Vollenweider, R.A. 1970. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. OECD. 159 p.