VESIENTUTKIMUSLAITOKSEN JULKAISUJA
PUBLICATIONS OF THE WATER RESEARCH INSTITUTE **69**

VESI- JA YMPÄRISTÖHALLITUS—
NATIONAL BOARD OF WATERS AND ENVIRONMENT, FINLAND
Helsinki 1986

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ISBN 951-47-0864-4
ISSN 0355-0982

Helsinki 1987. Valtion painatuskeskus

QUALITY OF LAKE WATER AND SEDIMENTS AND FACTORS AFFECTING THESE IN THE KUUSAMO UPLANDS, NORTH-EAST FINLAND

Urpo Myllymaa

MYLLYMAA, U. 1987. Quality of lake waters and sediments and factors affecting these in the Kuusamo uplands, north-east Finland. Publications of the Water Research Institute, National Board of Waters and Environment, Finland, no. 69.

The area of Kuusamo consists of four main river basins, the waters of the Rivers Koutajoki and Kemjoki flowing towards the White Sea and the Rivers Iijoki and Oulujoki towards the Bothnian Bay.

The water of the Koutajoki and Kemjoki river basins differed in quality from that of the Oulujoki and Iijoki basins in its higher salinity and alkalinity. The calcium and magnesium concentrations were here particularly high because of the alkaline rocks, whereas the Iijoki and Oulujoki river basins posses more mires and less lakes, so that the water was somewhat browner and more acid. The highest mean concentrations of trace metals were in the lakes of the Iijoki watercourse, and the lowest in the Kemjoki system. The waters in Kuusamo are mostly pure and very clear. Where the water has been polluted by human activity, sewage treatment has led to marked improvements. The fish farms, loading some larger lakes, are capable of adjusting their feeding regimes and use of water and intensifying the removal of sludge.

The most important factors affecting the concentrations in sediments were the pH and Eh values and the organic matter content. In the lake Kitkajärvi the most important reasons were sedimentation variations resulting from stratification of the lake water and regional differences in flow rates. In some areas an upflow of ground water and the resulting precipitation of an iron-manganese complex affected the material balance. Calcium concentrations gave the clearest indication of the location of the original source.

Some anomalous high concentrations of metals in small lakes were indicative of mineral deposits, which should be studied for prospecting purposes. Human influence was evident in an increase in metals towards the surface in some cores. Atmospheric fallout was one probable cause of the increase of concentrations in some lakes, but as a rule the enrichment factor was fairly low. The correlations between the water and sediment variables were very weak due to e.g. factors such as the high buffer capacity.

Index words: quality, nutrients, metals, lake, water, sediment

1. INTRODUCTION

This work includes a summary of the papers of Myllymaa (1985, 1987), Piispanen and Myllymaa (1982), Myllymaa et al. (1985) and Myllymaa and Murtoniemi (1987). These provide studies of water quality in almost all lakes over 0.1 km^2 in area and the bottom sediments of 41 small lakes in the Koutajoki river basin in Kuusamo and the Kitkajärvi chain of lakes. Results have also been presented previously by Heinonen and Myllymaa (1974) and Myllymaa and Ylitolonen (1980). The morphology and depth of the lakes were first studied by Hänninen (1915) and since 1972 by the Water District Office of Oulu. The natural environment of Kuusamo, the area covered by this study (Fig. 1) has been comprehensively studied at the University of Oulu (see Viramo 1978).

The aim of the work, in addition to improving our knowledge of this geologically, climatologically and botanically interesting area, is also to investigate factors affecting water quality and sediments. Special interest is focused on metals. Most of the lakes are virtually in a natural state, but some atmospheric pollution and influence from agriculture, forestry and other human activities is possible. The influence of mineral deposits is also discussed with a view to geochemical prospecting.

2. RESEARCH AREA

2.1 Physical features

The Kuusamo area (Figs. 1—2) belongs geologically and lithologically to two contrasting regions, thus paving the way for a comparison of the lake water chemistry of contrasting river basins (Piispanen and Myllymaa 1982). The southern part of the area belongs to the Archaean Presvekokarelidic basement gneiss complex of eastern Finland, which is dominated by felsic rocks of more than 2.5 Ga in age. The main deformation in the area took place 2.7—2.8 Ga ago (Simonen 1980). Petrographically the rocks of the basement complex consist mainly of migmatitic and other silicic rocks. Trondhjemitic, granodioritic and granitic gneisses are the most common. Next to these there are subparallel diabase dykes, which occur in swarms and are fairly common in places. These dykes vary in width from 1 to 20 meters and in length from tens of meters to 2—3 kilometers.

The northern parts of the area form part of the Karelidic belt of eastern and northern Finland (Simonen 1980), in which conglomerates, quartzites, slates and mica schists are abundant among the sediment rocks. Occasional dolomites and limestones are also encountered, and the sediment schists interspersed with numerous sills, dykes, lava beds and shallow intrusions of spilitic rocks and low-grade greenschists.

Physiographically, the area is markedly elevated the highest peaks of the hills rising to approximately 400 m (Piispanen and Myllymaa 1982). There are large areas of mire in the south part, but less in the north. This obviously enhances the composition of the lake water in the southern part, i.e. in the Iijoki river basin.

The total lake area in Kuusamo is 768 km^2, which represents 13.9 % of the total area of the commune (Piispanen and Myllymaa 1982). There are 94 lakes larger than 1 km^2 in area and 87 between 0.50 and 0.99 km^2 in area (Myllymaa and Ylitolonen 1980). The watershed of Maanselkä distributes the waters in two opposing directions, westwards to the Bothnian Bay via the Oulujoki and Iijoki watercourses and a minor part of the Kemijoki watercourse and eastwards to the White Sea via the Kemjoki (Vienan Kemi) and Koutajoki watercourses (Fig. 2). The lakes are usually shallow, but there are also some deep lakes and bays formed by faults in the bedrock. The rivers are young, with many rapids. The river Oulankajoki runs part of its course in a valley filled by glacial till with assorted soils.

The location and the form of the lakes within the area is mainly regulated by the tectonics of the bedrock in the northern part and by the glacial fluting and bedrock in the south. The lakes in the south are mainly parallel and subparallel, elongated and narrow, and situated between glacigenic drumlins (Aario et al. 1974, Aario and Forsström 1979) with their longest axes in a direction WNE-ESE, which is parallel to the direction of the continental ice-sheet movements during the last glaciation. In the northern part, the lakes are not as regular in shape and vary in their direction of elongation. This area was in a supra-aquatic position during the glacial retreat, which has left it with a small proportion of assorted soils, the origins of which probably lie in glacial meltwater streams (Aario 1965, Rankama 1964).

Kuusamo has a climate characterized by wet winters and short summers in which less than four months have a mean temperature over 10°C (cf. Aario 1965), the mean annual temperature being 0°C. Precipitation is slightly below the average for the whole country, varying in the range 510—535 mm a^{-1} from one part of the area to another

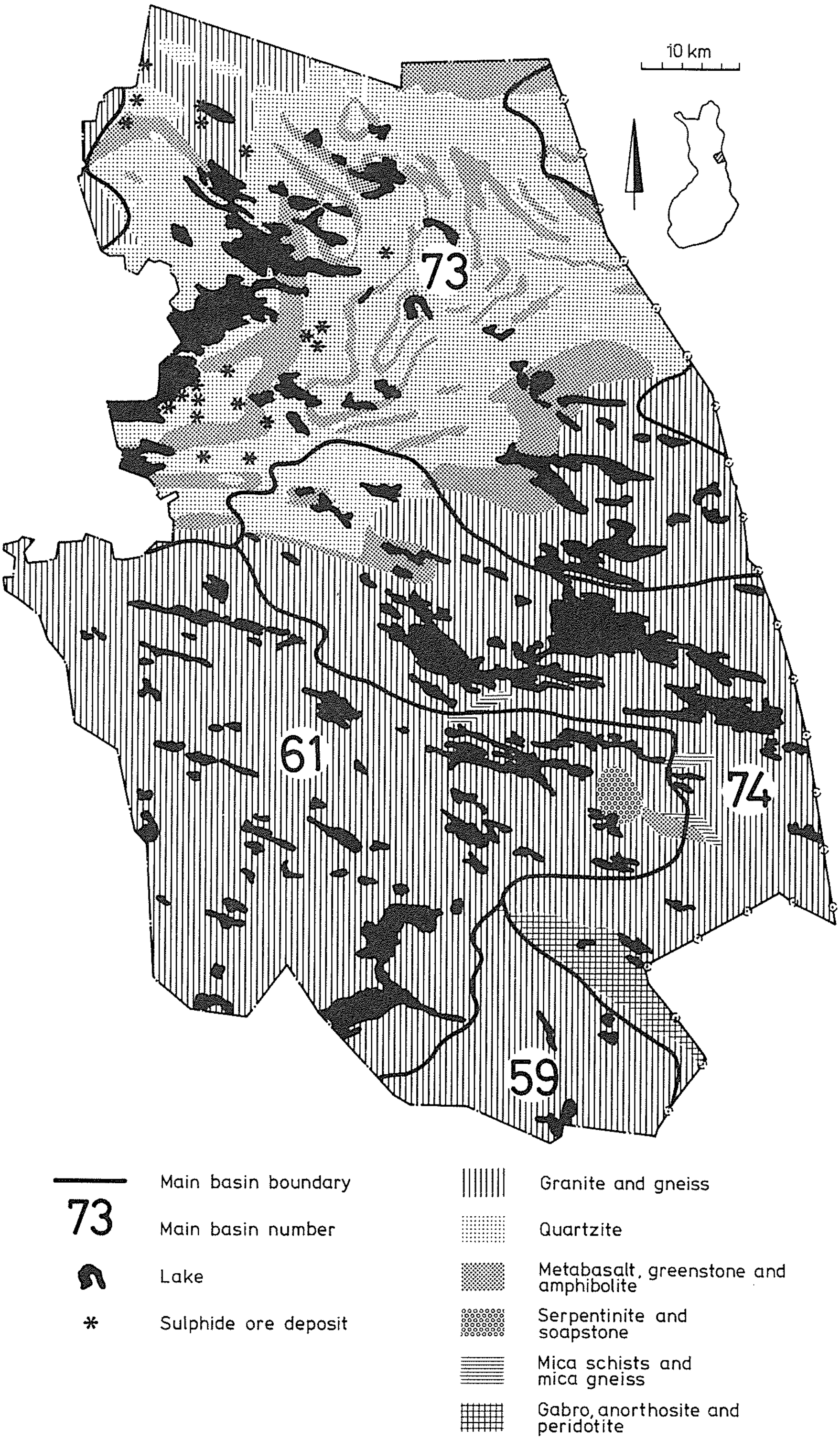

Fig. 1. Research area and bedrock after the Prequaternary rocks of Finland (1980).

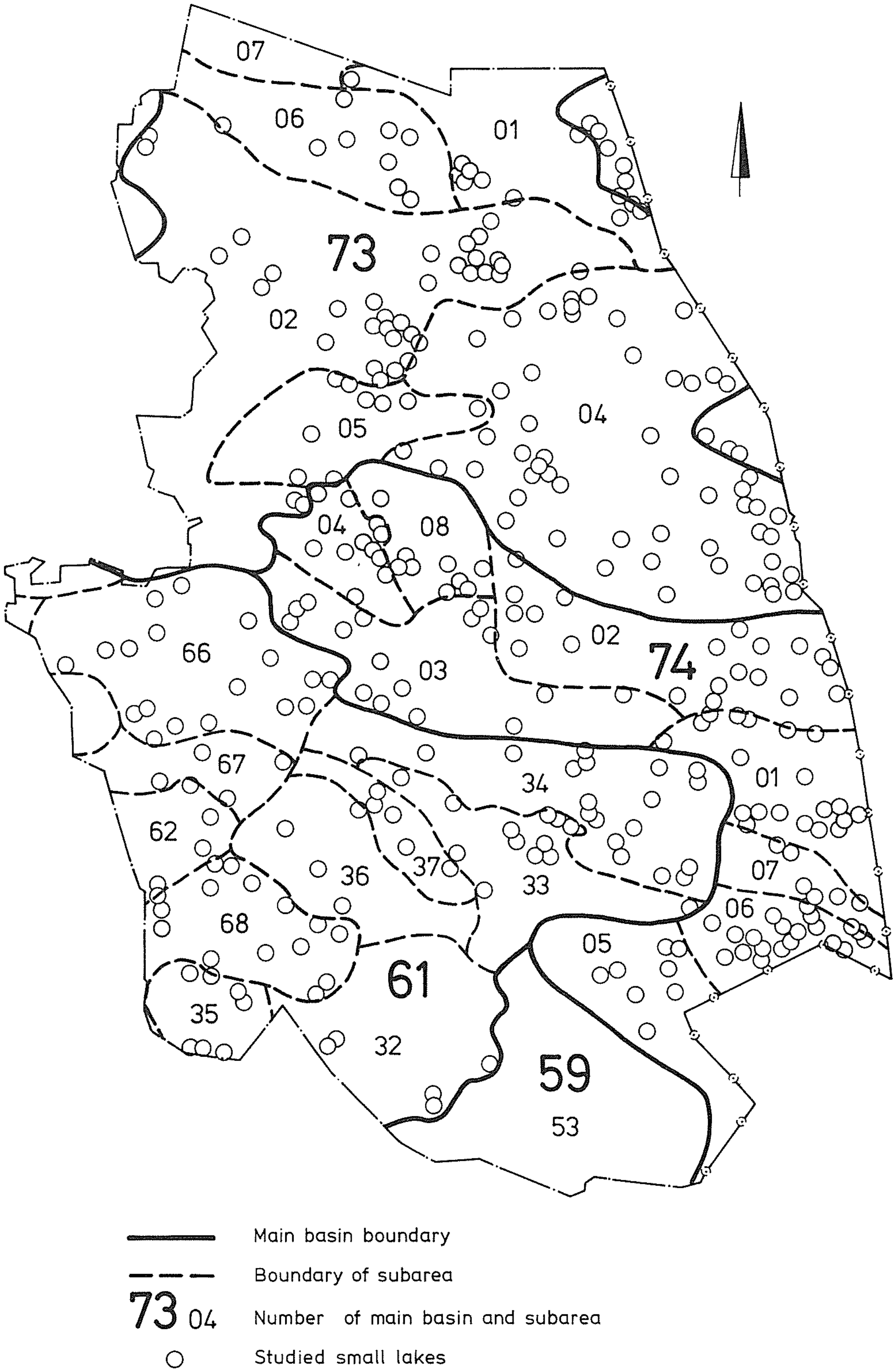

Fig. 2. River basins and location of the small lakes 0.1—0.49 km² studied in Kuusamo commune.

(Helimäki 1966). Although Kuusamo is one of the most snowy areas in the country, there are also places with quite small accumulation of snow. This is a consequence of pronounced microclimatic variation, the effect of which is accentuated in winter.

The vegetation in the northern Kuusamo is very special, including numerous copses (Ilvessalo 1960), whereas the southern forests are drier and poorly productive. There is a high incidence of mires in the area, mostly pine bogs, although there are also some spruce swamps and also bogs and fens, especially in the northern part (Ilvessalo 1960, Rankama 1964, Aario 1965). Northern Kuusamo in particular has some rare species of plants of both southern and northern origin.

2.2 Human influence

Myllymaa (1978), reporting on the state of the watercourses in Kuusamo, notes that the quality of the waters has been altered by agriculture, forestry and the scattered settlements. Sewage from built-up areas has affected the water of Lakes Torankijärvi and Kuusamojärvi and the River Kesäjoki. The River Nilojoki and Lake Kuusamojärvi are loaded by industrial sewage from a dairy. Loading from domestic and industrial sewage can be reduced by the construction of sewage plants. Substantial loading comes from fish farms, mainly during four summer months in the year. Rainbow trout production in Kuusamo in 1978 was 400 000 kg, the nutrient loading being equivalent to that from a settlement of 6 000 people. The fish farms are capable of adjusting their feeding regimes and use of water and intensifying the removal of sludge. Tables 1—2 show the total nutrient loading of the waters of the Kuusamo area and the proportion attributable of factors (Water District Office of Oulu 1984).

3. MATERIAL AND METHODS

The material was collected by the Water District Office of Oulu during 1973—1982. The large lakes (>1 km^2 in area) were studied in 1973 (Heinonen and Myllymaa 1974) and the lakes 0.5—0.99 km^2 in 1977 (Myllymaa and Ylitolonen 1980, Piispanen and Myllymaa 1982). Sediments in Kitkajärvi chain of lakes were studied in 1979 and 1982 (Myllymaa et al. 1985) and in the small lakes of Koutajoki river system in 1983 (Myllymaa 1987, Myllymaa and Murtoniemi 1987).

Water samples were collected and conserved in winter and in summer using the methods described by the National Board of Waters (1984). Sediments were taken using a Kajak sampler modified by Hakala (Hakala 1971) and in the hard bottoms of the Kitkajärvi lakes also an Ekman sampler. Analyses of the water samples were carried out at the laboratory of the Water District Office of Oulu. Physical properties of these sediments analysed at the Oulanka Biological Station are reported by Saarelainen (1980) and Hyvönen (1983). The cores of sediment profiles (0—10, 10—20 and 20—26 cm from surface) of the small lakes were analysed at the laboratories of the Geological Survey of Finland in Rovaniemi (metals), the National Board of Waters (Hg), the Department of Water Technology at the University of Oulu (Cd) and the Water District Office of Oulu (pH, residue and loss on ignition, N and P). Methods are in more detail described by Myllymaa and Murtoniemi (1987).

The sediment profiles of Lakes Yli-Heikinjärvi and Särkijärvi (nos. 90 and 94 in Myllymaa 1987) were divided into 2 cm sections for chemical analyses and 1 cm sections for Pb-210 dating. Mercury was analysed at the Research Laboratory of the National Board of Waters, other metals at the laboratory of Pohjois-Suomen Vesientutkimustoimisto in Oulu and the rest variables at the Water District Office of Oulu. The samples for dating were freeze-dried and homogenised and the Pb activity present at each depth, the age of the sediment and the sedimentation rate were determined at the Reactory Laboratory of the Technical Research Centre of Finland by methods described by Rekolainen et al. (1986a).

The location of sulphide ore deposits have been determined for prospecting purposes by the Geological Survey of Finland and Pohjois-Suomen Malminetsintä Oy. The bedrock of the area was grouped into three classes according to chemical composition (see Myllymaa 1985): silicious (class 1), basic (class 2) and intermediate (class 3; cf. Huang 1962, Lahermo 1970, Rönkä et al. 1980 and Rönkä 1983). The soil classes were: sand or gravel (class 1), till (class 2), till with mires (class 3) and mires in the main catchment basin (class 4).

Table 1. Nitrogen loading of watercourses in Kuusamo (Sum) and separate watercourses (1 = Oulujoki, 2 = upper part of Iijoki, 3 = Korpuanjoki, 4 = Kuusinkijoki, 5 = Kitkajoki, 6 = Kemjoki. Y = annual loading kg a^{-1}, S = loading in summer kg $(92\ d)^{-1}$. + minor loading, – no loading.

	Years	1		2		3		4		5		6		Sum	
		Y	S	Y	S	Y	S	Y	S	Y	S	Y	S	Y	S
Fish farming	1981	1800	1300	8300	6000	1200	900	11200	8000	80	60	1700	1200	24280	17460
	1983	1500	1000	8500	6100	1800	1300	9600	6900	70	50	3000	2100	24470	17450
Built-up areas	1981	—	—	—	—	—	—	—	—	2400	460	28900	7400	31300	7860
Industry	1981	—	—	—	—	—	—	—	—	—	—	950	270	950	270
Scattered settlements	1980	50	10	470	120	320	80	530	130	960	240	510	130	2840	710
Weekend cottages	1981	5	5	35	25	10	10	30	20	85	60	100	70	265	190
Separate plants	1981—1982	+	+	10	+	5	+	10	+	20	+	+	+	45	+
Tourism	1980	+	+	5	5	+	+	5	5	40	30	30	30	80	70
Farming	1981	1500	+	19900	100	11200	50	22300	100	5400	150	28100	130	118400	530
Silage	1981	+	+	55	55	35	35	60	60	100	100	70	70	320	360
Fur farms	1981—1982	120	20	130	25	—	—	1080	200	200	40	1230	225	2760	510
Forest fertilization	1981	10	+	270	30	—	—	130	10	280	30	740	75	1430	145

Table 2. Phosphorus loading of watercourses in Kuusamo (Sum) and separate watercourses. For explanations, see Table 1.

	Years	1		2		3		4		5		6		Sum	
		Y	S	Y	S	Y	S	Y	S	Y	S	Y	S	Y	S
Fish farming	1981	540	280	2400	1300	350	180	3300	1700	20	10	500	270	7110	3740
	1983	330	180	1900	990	410	220	2100	1100	15	10	660	350	5405	2850
Built-up areas	1981	—	—	—	—	—	—	—	—	75	15	2170	560	2245	575
Industry	1981	—	—	—	—	—	—	—	—	—	—	195	55	195	55
Scattered settlements	1980	20	5	190	50	130	30	210	50	390	100	200	50	1140	285
Weekend cottages	1981	+	+	15	10	5	5	10	5	35	25	40	30	105	75
Separate plants	1981—1982	+	+	5	+	5	+	5	+	5	+	+	+	20	+
Tourism	1980	+	+	+	+	+	+	5	5	15	15	15	10	35	30
Farming	1981	70	+	900	15	510	10	1000	15	1600	20	1300	20	5380	80
Silage	1981	+	+	5	5	5	5	5	5	10	10	5	5	30	30
Fur farms	1981—1982	15	+	15	+	—	—	115	20	20	5	130	20	295	45
Forest fertilization	1981	5	+	10	+	60	10	90	10	90	10	50	5	305	35

4. RESULTS

4.1 Spatial variation and correlations in water quality

Table 3 shows significant differences between the three main watercourses in the water quality in small lakes. The values for oxygen, conductivity, alkalinity, pH, phosphorus, manganese, potassium, magnesium and calcium were lowest in the Iijoki watercourse indicating a poverty of minerals, resulting from the bedrock, and also slight acidity due to humic substances. The concentrations of lead, copper, zinc and cadmium were highest here, some values being exceptionally high and suggesting an anomaly in the bedrock. The highest values for conductivity, alkalinity, pH, sulphate, mercury, manganese, potassium, magnesium and calcium were recorded in the Koutajoki watercourse, the catchment basin of which has a high incidence of mafic and basic rocks and also sulphide minerals, leading to high values for certain metals. There are also magmatic carbonate-bearing veins associated with the spilitic rocks (cf. Piispanen and Myllymaa 1982). The lakes of the Kemjoki watercourse are intermediate due to the wide variation in the bedrock (Fig. 1).

The differences in geological and physiographic properties between the main watercourses clearly affected the water quality. The bedrock greatly affected the pH, alkalinity and metals, and the proportion of lakes and mires affected the colour and humic content of the rivers (Myllymaa 1978). The river water probably reflected the water quality of the large lakes in the area (cf. Heinonen and Myllymaa 1974), for the rivers flow through these in many cases. The rivers of the Koutajoki river basin vary in their percentages of lakes, and consequently the River Kitkajoki was very clear in contrast to the River Oulankajoki. The same difference existed between the Rivers Iijoki, Kemjoki, Kitkajoki and Oulankajoki. Comparison of the water quality of lakes 0.5—0.99 km^2 in area showed the same differences between the Iijoki and Koutajoki watercourses (Piispanen and Myllymaa 1982).

According to Piispanen and Myllymaa (1982), the electrolyte content of both rivers and lakes of middle size in Kuusamo is on average nearly the same as in Finland in general and also in Scandinavian river basins and the river basins of the Barents Sea and the White Sea (cf. Livingstone 1963, Landström and Wenner 1965, Zverev 1971, Laaksonen 1972 and Salbu et al. 1979). Exceptionally high concentrations of calcium and magnesium were found in the Koutajoki river system. Myllymaa (1985) also reports high mercury concentrations in the waters of some small lakes in the Koutajoki river basin which corresponded to the ground water concentrations in some mining areas (cf. Hyyppä 1981). Due to the unprecision of the assay method of mercury in natural waters, we have to consider the values inaccurate, but they probably indicated the spatial variation.

All selenium values, measured from the Iijoki and Kemjoki watercourses, were smaller than the detection limit of the method used, 0.1—1 $\mu g\ l^{-1}$.

Table 4 shows the correlations with a significance over 90 % in the small lakes in the Iijoki, Koutajoki and Kemjoki watercourses considering both winter and summer values. The regression lines and scatter of some variables are described in Figs. 3—5. Oxygen correlated negatively with all the variables measured except pH, sulphate and chlorophyll *a* while turbidity correlated with all except pH, sulphate and trace metals. Conductivity, indicating soluble minerals, showed a close correlation with alkalinity, manganese, potassium, magnesium and calcium, but a negligible correlation with zinc and cadmium and only a slight one with the other metals. Alkalinity showed the same correlation pattern as conductivity. pH correlated negatively with colour, silica and some metals and positively with oxygen and conductivity. Nitrogen correlated with variables indicating humic matter and with some metals, and markedly with phosphorus, iron and chlorophyll *a*. Its correlations were the opposite of those of oxygen. Sulphate correlated with potassium, sodium, magnesium and calcium which were intercorrelated and with conductivity and alkalinity while lead, zinc and cadmium were intercorrelated and correlated with silica.

The data for the Koutajoki watercourse (Myllymaa 1985) showed correlations which were in general equal to those in the whole data. Some seasonal and vertical differences were due to variations in primary production and redox potential.

4.2 Correlations between water quality and physiographic variables

Oxygen showed a highly significant negative correlation with total depth in the hypolimnion of the small lakes studied by Myllymaa (1985), while the corresponding wintertime correlation in the epilimnion was positive. The main factor contributing to this was oxygen consumption in deep lakes. Oxygen had a marginal negative correlation with the percentage of mires in the drainage basin.

The turbidity of the epilimnion correlated

Table 3. Water quality in three main watercourses and the significant differences between them according to T-test (—<90 %, ○ 90 %, *95 %, **99 %, ***99.9 %). Sampling depth of lead, copper, zinc, cadmium and mercury is 1 m.

		1. Iijoki			2. Koutajoki			3. Kemjoki			Differences		
		Mean	s	Range	Mean	s	Range	Mean	s	Range	1/2	1/3	2/3
Oxygen	mg l^{-1}	7.7	2.3	0 — 12	7.0	3.3	0 — 13	8.2	2.9	0 — 13	**	*	***
Turbidity	FTU	1.1	2.0	0.3 — 20	1.4	2.5	0.1 — 23	1.2	1.4	0.2 — 9	—	—	—
Conductivity	mS m^{-1}	3.0	1.6	1 — 12	8.5	5.5	0.9 — 44	4.5	3.6	1 — 35	***	***	***
Alkalinity	mmol l^{-1}	0.16	0.14	0 — 0.9	0.67	0.45	0 — 3	0.31	0.29	0 — 2	***	***	***
pH		6.4	0.35	5 — 7	6.9	0.52	6 — 10	6.6	0.47	5 — 8	***	***	***
Colour		77.1	74.8	5 — 900	45.1	69.5	4 — 1000	68.0	71.6	5 — 700	***	—	***
Nitrogen	μg l^{-1}	399.8	252.2	30 — 2500	444.0	431.7	61 — 5500	412.0	248.4	90 — 2200	—	—	—
Phosphorus	μg l^{-1}	11.2	12.5	2 — 120	16.3	30.9	1 — 530	20.0	45.9	3 — 650	**	**	—
SiO_2	mg l^{-1}	5.0	4.3	0.3 — 19	4.6	3.0	0.2 — 14	4.8	3.3	0.05 — 18	—	—	—
Sulphate	mg l^{-1}	3.5	1.1	0.3 — 6	4.7	4.1	0 — 31	3.0	1.5	0.5 — 16	***	**	***
Lead	μg l^{-1}	1.7	2.8	0 — 16	0.9	2.7	0 — 33	0.7	1.5	0 — 9	*	***	—
Copper	μg l^{-1}	7.1	40.3	0 — 425	2.1	2.5	0 — 19	1.3	2.1	0 — 12	—	—	**
Zinc	μg l^{-1}	14.3	28.2	0 — 260	4.2	7.2	0 — 60	3.4	3.9	0 — 25	***	***	—
Cadmium	μg l^{-1}	0.16	0.43	0 — 3	0.01	0.15	0 — 1	0.025	0.08	0 — 0.3	**	**	—
Mercury	μg l^{-1}	0.056	0.13	0 — 0.6	0.26	2.2	0 — 19	0.014	0.08	0 — 0.5	—	○	—
Iron	μg l^{-1}	732.3	2360.3	27 — 29000	781.7	2568.4	0 — 38000	788.0	2061.5	26 — 22000	—	—	—
Manganese	μg l^{-1}	76.0	128.8	2 — 900	296.2	1053.2	0 — 13000	86.0	177.8	0 — 1500	**	—	**
Natrium	mg l^{-1}	1.3	0.63	0 — 5	1.3	0.49	0.4 — 3	1.4	0.59	0.4 — 4	—	—	*
Potassium	mg l^{-1}	0.51	0.43	0 — 3	1.0	0.40	0.3 — 3	0.72	0.38	0 — 3	***	***	***
Magnesium	mg l^{-1}	0.93	0.52	0.3 — 3.4	3.0	3.1	0.3 — 46	1.2	1.2	0.2 — 9	***	***	***
Calcium	mg l^{-1}	2.8	1.6	0.6 — 10	8.6	5.9	0.1 — 51	3.9	3.0	0 — 20	***	***	***
Chloroph. *a*	μg l^{-1}	4.8	10.4	0.7 — 75	4.0	7.3	0.6 — 45	6.7	10.7	1 — 75	—	—	○

Table 4. Correlations between water quality variables. Statistical significance: —<90 %, ○90 %, *95 %, **99 %, ***99.9 %.

	O_2	Turb.	Cond.	Alk.	pH	Colour	N	P	SiO_2	SO_4	Pb	Zn	Cd	Fe	Mn	Na	K	Mg
Turb.	—.40 ***																	
Cond.	—.34 ***	.16 ***																
Alk.	—.37 ***	.19 ***	.88 ***															
pH	.34 ***	—	.30 ***	.38 ***														
Colour	—.37 ***	.54 ***	—	.08 ○	—.24 ***													
N	—.34 ***	.38 ***	.15 ***	.21 ***	—	.49 ***												
P	—.23 ***	.27 ***	.11 *	.14 **	—	.23 ***	.41 ***											
SiO_2	—.41 ***	.34 ***	.38 ***	.45 ***	—.16 **	.32 ***	.17 ***	.14 **										
SO_4	—	—	.36 ***	.27 ***	.11 *	—.09 ○	—	—	—									
Pb	—.16 **	—	.11 *	.11 *	—.22 ***	—	.08 ○	—	.29 ***	—								
Zn	—.23 ***	—	—	—	—.23 ***	.11 *	.09 ○	—	.27 ***	—	.33 ***							
Cd	—.40 ***	—	—	—	—.20 **	.18 *	.24 ***	—	.31 ***	—	.46 ***	.76 ***						
Fe	—.42 ***	.53 ***	.17 ***	.23 ***	—.15 ***	.90 ***	.51 ***	.22 ***	.34 ***	—	—	—	.13 ○					
Mn	—.36 ***	.24 ***	.38 ***	.48 ***	—	.21 ***	.33 ***	.09 *	.35 ***	—	—	.12 *	.23 **	.26 ***				
Na	—.30 ***	.26 ***	.27 ***	.28 ***	—.15 **	.26 ***	.22 ***	.17 ***	.68 ***	.11 *	.19 ***	.19 ***	.20 **	.24 ***	.18 ***			
K	—.26 ***	.23 ***	.61 ***	.70 ***	.29 ***	—	.23 ***	.35 ***	.34 ***	.25 ***	—	—	—	.19 ***	.21 ***	.46 ***		
Mg	—.26 ***	.13 **	.59 ***	.67 ***	.20 ***	.10 *	.37 ***	.11 *	.24 ***	.23 ***	—	—	—	.22 ***	.19 ***	.19 ***	.48 ***	
Ca	—.25 ***	.10 *	.79 ***	.89 ***	.33 ***	—	.09 ○	.10 *	.33 ***	.38 ***	.09 ○	—	—	—	.24 ***	.25 ***	.65 ***	.63 ***
Chlor.	—	.86 ***	—	—	—	—	.55 ***	.49 ***	—	.31 *	—	—	—	—	.44 **	.26 ○	.40 **	—

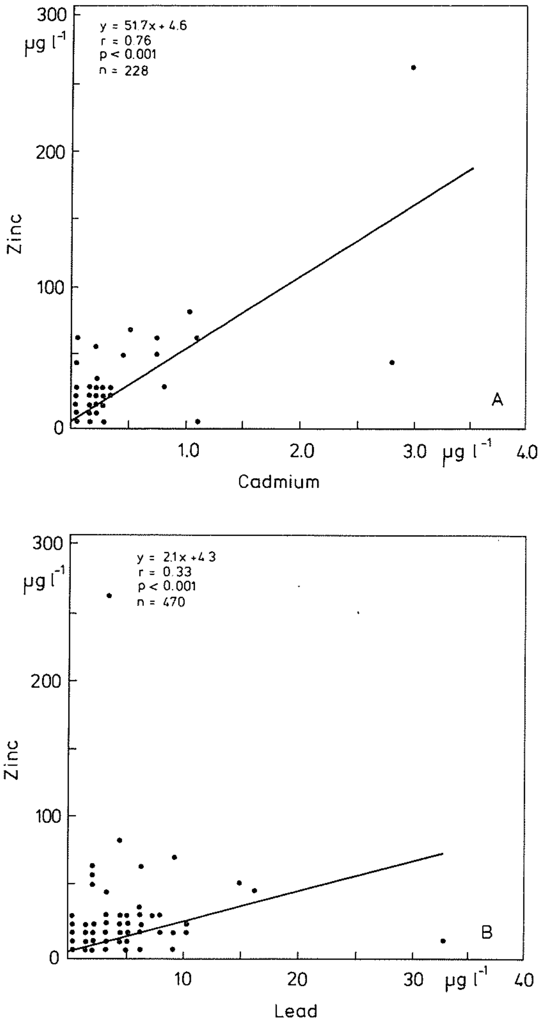

Fig. 3. Regression lines for zinc/cadmium (A) and zinc/lead (B) and the scatter of the values.

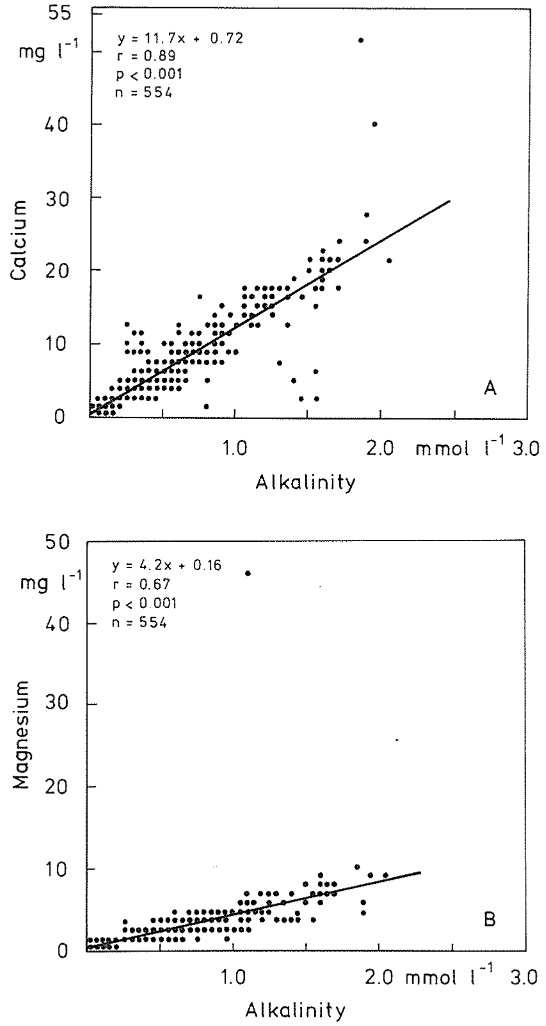

Fig. 4. Regression lines for calcium/alkalinity (A) and magnesium/alkalinity (B) and the scatter of the values.

negatively with total depth in winter and with the percentage of mires in the catchment basin in summer, while that of the hypolimnion correlated positively with the percentage of mires in summer. This effect was probably due to sedimentation and the accumulation of allochthonous material in the hypolimnion. Humus seemed to diminish turbidity in the epilimnion, perhaps due to inhibition of the algal growth.

Colour and COD correlated positively with the percentage of mires in the catchment area, but negatively with lake depth owing to increased dilution at greater volumes.

A negative correlation with total depth emerged for nutrients in the epilimnion and for phosphorus in both the epilimnion and hypolimnion, because the sedimentation of these is dependent on the mean depth of the lake.

Conductivity correlated negatively with the percentage of lakes in the drainage basin, due to the sedimentation that occurs while the water is in the lake. The same was suggested by its weak correlation with lake area.

pH in the epilimnion in summer had a negative correlation with the percentage of mires in the drainage basin, a positive correlation with total depth and a negative correlation with the percentage of lakes. The pH and alkalinity values were hence influenced by the increase in sedimentation as a function of the retardation in flow.

Silica showed a minor positive correlation with the percentage of mires and a negative one with the

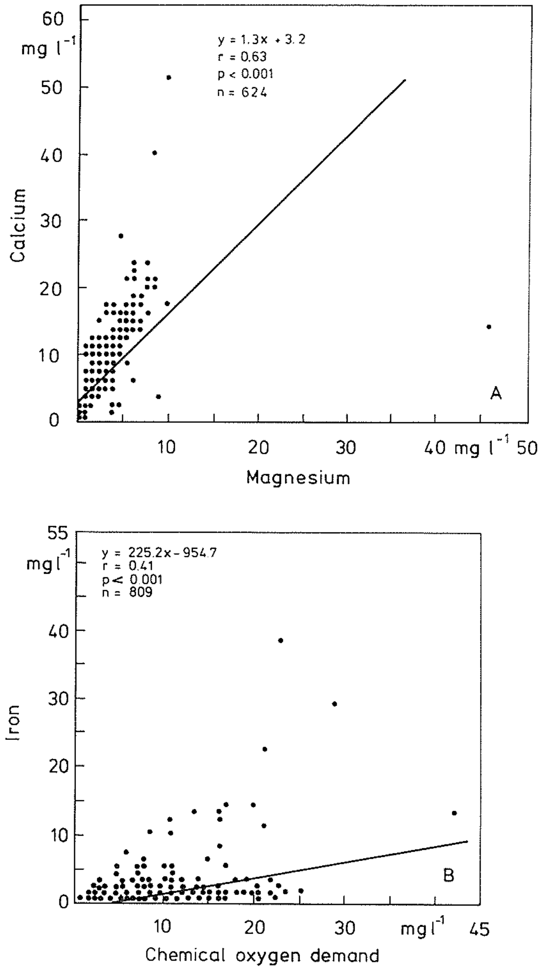

Fig. 5. Regression lines for calcium/magnesium (A) and iron/COD (B) and the scatter of the values.

area of the lake concerned and the percentage of lakes in the drainage basin. Sulphate in the epilimnion showed slight correlations with the area of the lake and the percentage of lakes, while in the hypolimnion it was correlated with the area of the drainage basin.

Epilimnic iron was correlated negatively with total depth, which was related to sedimentation and the exchance of material between the water and the sediments. There was a highly significant summertime correlation with the percentage of mires in the drainage basin. There were no summertime observations regarding manganese, but in winter it showed correlations similar to those of iron.

Sodium showed a negative correlation with the total depth of the lake and a positive one with the percentage of mires, particularly in winter. The correlations between potassium and the physiographic factors were weak. Increasing percentage of lakes seemed to reduce potassium concentrations slightly. Both calcium and magnesium in the epilimnion correlated negatively in summer with the percentage of lakes.

There were no significant correlations between heavy metals and the physiographic factors, one reason for this being that observations were only made in the epilimnion, where the concentrations are generally lower than in the hypolimnion. The concentrations are low in waters in a natural state, being near or below the detection limit for some metals. Possible anomalies also increased dispersion and detracted from the statistical significance of the results (Fig. 3).

4.3 Effect of bedrock and soil

The composition of the bedrock seemed to affect the iron, potassium, calcium and copper concentrations, the highest values except for iron being in the areas of alkaline bedrock. Correspondingly, the soil affected the concentrations of iron, manganese, sodium, calcium and magnesium in that the highest concentrations of the first two were found in the catchment areas with a high incidence of mires and those of the latter two in till areas. The lowest sodium concentrations were in the areas with assorted soils. The lead and zinc concentrations depended on the nature of the soil within the rock classes.

The pH, conductivity and alkalinity values, which denote electrolyte content and buffer capacity, were dependent on both the bedrock and the soil, while the colour and COD values, which are related to humus concentrations, generally varied in accordance with the soil.

Special features of the bedrock of the area are its calcitic and dolomitic limestones and sulphidic minerals, which have been also studied for prospecting purposes. These rock types also affect the water in the lakes (Piispanen and Myllymaa 1982, Myllymaa 1985). Anomalous high concentrations of heavy metals in some lakes detracted from the significance of the differences between rock classes and also the intercorrelations between the metals. High copper and zinc concentrations were observed in the same areas in many cases, suggesting the presence of sulphidic mineral deposits, and also near known deposits. Since the metals are generally precipitated at different velocities, high concentrations did not always occur in the same lakes.

4.4 Intercorrelations between the sediment variables

Intercorrelations between variables for the sediments of the Kitkajärvi lakes (Myllymaa et al. 1985) and the small lakes (Myllymaa and Murtoniemi 1987) are composed in Table 5. The loss on ignition, which indicates the organic matter content of the sample, was in the Kitkajärvi lakes clearly correlated with nitrogen, phosphorus, calcium, lead, copper, zinc and mercury. The pH value of the sediments was correlated with the concentrations of nitrogen, phosphorus, copper, cadmium (negatively) and iron.

Loss on ignition in the small lakes described by Myllymaa and Murtoniemi (1987) correlated positively with pH, nitrogen, lead, zinc, cadmium and the Fe/Mn ratio, negatively with phosphorus, manganese and nickel and almost significantly negatively with mercury. The correlations with phosphorus and mercury were in contrast to those in the Kitkajärvi lakes. About 30 % of the lakes in the material of Myllymaa and Murtoniemi (1987) suffered from an oxygen deficit, which had released phosphorus and mercury from the bottom which may explain these differences.

The pH in the small lakes correlated positively with phosphorus, zinc, mercury and manganese, and negatively with nitrogen and the Fe/Mn ratio. Here the correlation with nitrogen was in contrast to that in the Kitkajärvi lakes. This difference is probably caused by the fact that the sediments of small lakes contain of more allochthonous humic substances.

Lead was correlated with zinc, cadmium and the Fe/Mn ratio in the study of Myllymaa and Murtoniemi (1987), and copper with mercury, cobalt and nickel.

There were strong correlations between the metals bound to organic matter. The correlations were generally closer in the Kitkajärvi lakes than in the small lakes, probably due to the unchanged and quite similar conditions in the separate parts of the bottom.

4.5 Effect of drainage basin variables and lake physiography on sediments

The concentrations of metallic elements did not reflect very accurately the variations in the bedrock of the bottom and the drainage basin of the largest lakes of the area, the Kitkajärvi chain (Myllymaa et al. 1985). Explanation of the reasons for the observed variations would require more detailed investigation of the bedrock. The copper concentrations in particular suggested a dependence on albite diabase deposits in some places. The observed differences in sediment calcium and magnesium concentrations in the area of the Kitkajärvi lakes were presumably dependent on variations in bedrock type and on the distribution of chalk and dolomite in the bedrock and also on the total depth, the incidence of streams and the proximity of the shoreline.

In the small lakes discussed by Myllymaa and Murtoniemi (1987) the loss on ignition and nitrogen concentration were correlated negatively with the total depth and the drainage area and the former showed a marginal positive correlation with the percentages of mires and lakes. pH correlated very significantly with the drainage area, and the differences between the soil classes were almost significant, the highest values being recorded in the areas with till soils and basic rocks. Phosphorus was correlated with total depth, and there was also a significant difference in phosphorus concentration between the soil classes, the highest values being found in the areas with till soils.

Lead was correlated negatively with the area of the drainage basin, due to its dependence on organic matter. The highest copper concentrations were in the rock class containing basic rocks, but the difference between the classes was not significant, due to a high range and exceptionally high concentrations accompanied by high values for cobalt, zinc and mercury. The copper values varied greatly, the high values being accompanied by corresponding levels of cobalt in some lakes, but high values for zinc and mercury in Lake Ruoppilampi (Fig. 6).

The presence of copper with zinc, mercury and cobalt suggested that these metals had all been mobilised from local rocks containing sulphide minerals. The highest zinc concentrations were found in lakes with a drainage basin comprising till and mires, while the highest concentrations of cadmium were in till areas. Its occurrence with high concetrations of mercury, zinc and copper also suggested the presence of sulphide minerals. Cadmium had an almost significant difference in its concentration between the soil classes, the highest mean values being in areas consisting of till and mires.

Iron was correlated with the percentage of lakes, and manganese with total depth. Cobalt differed between assorted and unassorted soils, the lowest value being in the former and the highest in the latter.

Table 5. Correlations between variables for the sediments of the Kitkajärvi Lakes (upper) and small lakes (lower). Statistical significance: —<90 %, ○90 %, *95 %, **99 %, ***99.9 %, · · no observations.

	LOI	pH	N	P	Ca	Mg	Pb	Cu	Zn	Cd	Hg	Fe	Mn	Mo	Co
pH	—														
	.39**														
N	.93***	.64***													
	.52***	—.42**													
P	.71***	.56***	.73***												
	—.44**	.32**	—.43**												
Ca	.58***	—	.88***	.41*											
	· ·	· ·	· ·	· ·											
Mg	.20○	—	.39**	.34○	.39***										
	· ·	· ·	·	· ·	· ·										
Pb	.52***	—	.80***	.79***	.37***	.29**									
	.63***	—	—	—	· ·	· ·									
Cu	.47***	.78***	.84***	.60***	.43***	.41***	.48***								
	—	—	—	—	· ·	· ·	—								
Zn	.64***	.23○	.90***	.81***	.54***	.36**	.78***	.66***							
	.40**	.32*	—	—	· ·	· ·	.49***	—							
Cd	—	—.37**	· ·	· ·	—	—	.42***	.34*	.53***						
	.54***	—	—	—	· ·	· ·	.66***	—	.67***						
Hg	.49***	—	.63***	.45*	.39***	.37***	.63***	.20○	.47***	—					
	—.27○	.45***	—.41○	.58*	· ·	· ·	—	.85***	—	—					
Fe	.22○	.30***	.54**	.82***	—	—	.44***	.23**	.37***	—	.32**				
	—	—	—	—	· ·	· ·	—	.27○	—	—	—				
Mn	—	—	.63***	.71***	—	—	—	—	—	—	—	.59***			
	—.36*	.44**	—.38*	.62***	· ·	· ·	—	—	—	—	—	—			
Fe/	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·		
Mn	.69***	—.36*	—	.41**	· ·	· ·	.55***	—	—	—	—	—	—.37*		
Mo	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	
	—	.29○	—.32*	.40**	· ·	· ·	—	—	.33*	—	—	—	—	—	
Co	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	
	—	—	—	.28○	· ·	· ·	—	.94***	—	—	.85***	.36*	—	.43**	
Ni	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·	· ·
	—.36*	—	—	.29○	· ·	· ·	—	.52***	.56***	.49***	.65**	—	—	.32*	.50***

Fig. 6. Lake Ruoppilampi, which contains high concentrations of metals in its water and sediments, is surrounded by steep hills composed of till and has a bedrock which includes metabasalts and greenstones.

4.6 Vertical variation in sediments

The vertical variation in organic matter in the total data (Myllymaa and Murtoniemi 1987) was usually small. Two small lakes (nos. 90 and 94 in Myllymaa 1987), Yli-Heikinjärvi and Särkijärvi, studied in detail had sedimentation rates averaging 15—17 mg cm^{-2} a^{-1}. Sedimentation had been fastest 50 years ago in the former (24 mg cm^{-2} a^{-1}) and 65 years ago in the latter (17 mg cm^{-2} a^{-1}). The structures of their sediments were similar. A small decrease in sedimentation could be seen towards the surface in both lakes, with no increase during the forest drainage carried out in 1969—1978.

Although the total data showed a marked increase in lead upwards in the sediment cores, the maximum in Lake Yli-Heikinjärvi, at 4—6 cm, was followed by a sharp decrease. The background value in both lakes seemed to be below 10 mg kg^{-1}. The increase towards the surface may be caused by precipitation of lead into the oxidated level, although the maximum cannot be explained in this way, but may be caused by forest drainage, as reflected in its position in the core. The rise in the uppermost part of the curve for Särkijärvi may be caused by drainage carried out 10 years before dating. The accumulation of lead did not depend on the sedimentation rate, but on the concentration. The concentration of lead in the sediment of Lake Yli-Heikinjärvi was high, averaging 45 mg kg^{-1}.

Copper concentrations did not vary vertically, the curves being equivalent to those depicting sedimentation rate. A rise in accumulation was seen only at a depth of 0—4 cm. The total data showed concentrations to increase upwards, which could not be explained by redox potential in every case. The vertical distribution of zinc equalled that of copper in both lakes. In the total data (Myllymaa and Murtoniemi 1987) zinc concentrations usually increased towards the surface, where the variation was large.

Cadmium increased towards the surface as lead, but no reduction was in the uppermost layer in Lake Yli-Heikinjärvi. The minimum occurred at a depth of 14—16 cm, representing an age of 70—80 years. The vertical distribution of the concentration was quite similar in both lakes and seemed to be correlated with accumulation. Mercury concentrations also increased towards the surface of the sediments, but reached a maximum at a depth of 6—8 cm, which was followed by a decline in both lakes. The maximum concentrations occurred 30 years before dating in Lake Yli-Heikinjärvi and 40 years before in Lake Särkijärvi. Concentration and accumulation did not depend on sedimentation rate.

Aluminium concentrations decreased slightly towards the surface in Lake Yli-Heikinjärvi, in contrast to Lake Särkijärvi. This may be caused by diminished leaching from the drainage basin. Its accumulation also decreased from around 1960 onwards. The recent trend in iron concentrations in Lake Yli-Heikinjärvi was again opposite to that in Lake Särkijärvi, the former featuring a strong maximum at a depth of 4—6 cm, as in the curves for lead and nickel. This may be caused by forest drainage, but the accumulation was not highest at this point in time. The curve for manganese paralleled that for iron in Särkijärvi, in which the concentration was low. In both lakes the increase towards the uppermost layers was obviously caused by mobilisation towards a higher redox potential.

The Fe/Mn ratio in the total data (Myllymaa and Murtoniemi 1987) was almost unchanged vertically, suggesting that the redox potential had remained fairly constant. This relation was affected by the organic matter content, and the correlation between the Fe/Mn ratio and loss on ignition was highly significant. Iron and manganese had as a rule been enriched in the uppermost layer.

The molybdenum concentration did not usually vary vertically, although it was high in the uppermost layer in Lakes Jorvanjärvi and Särkijärvi (nos. 69 and 94 in Myllymaa 1987) like that of manganese (Myllymaa and Murtoniemi 1987). Nickel behaved like iron in Lakes Yli-Heikinjärvi and Särkijärvi (Myllymaa 1987), with its maximum at a depth of 4—6 cm. The nickel concentration in the total data generally increased towards the surface, but some of the lakes in which the concentrations were greatest showed the opposite gradient (Myllymaa and Murtoniemi 1987).

4.7 Correlations between water and sediments

The correlations between the water and sediment values depend on water quality, sedimentation and the remobilisation of precipitated material. The deeper the lake and the larger the drainage basin, the greater is the sedimentation. Thus there were some positive and some negative correlations in the small lakes reported by Myllymaa (1987). Organic matter in sediments, expressed by loss on ignition, correlated negatively with oxygen and the pH of the water and positively with COD, nitrogen, iron and manganese. As sediment pH is governed by the ion concentration, it correlated with alkalinity, calcium and magnesium and also with the pH of the water.

Nitrogen in the sediments correlated with COD in water and negatively with water colour in winter, while phosphorus correlated positively with oxygen and the pH of the water in winter, due to immobilisation at high redox potentials, but correlated negatively with some other variables.

Lead in sediments correlated positively with nitrogen and negatively with SiO_2 in water due to binding to organic matter. Copper correlated with pH, perhaps due to immobilisation at high pH values, while zinc correlated with water colour, COD and calcium content, and cadmium negatively with sodium. The mercury content of the sediments correlated in winter with the oxygen content and pH of the water, since mercury is maintained at a high level in sediments with high pH and Eh values.

Iron correlated only with phosphorus (negatively), whereas manganese correlated with oxygen, sodium, potassium, zinc and copper in the water. The Fe/Mn ratio, indicative of redox potential, correlated negatively with oxygen and positively with phosphorus, sodium, potassium and chlorophyll *a*.

There were no intercorrelations between any of the water and sediment variables in the data reported by Myllymaa (1987), and thus we cannot assess any variable by reference to that in the water. This situation results from the very complex reactions both in water and in sediments and from the instability of the water quality.

5. DISCUSSION

The water of the lakes studied here differed from one drainage basin to another due to variations in bedrock and soil (Myllymaa 1978, Piispanen and Myllymaa 1982, Myllymaa 1987). The influence of industrial and domestic sewage and of fish farming was seen in many lakes (Myllymaa 1978, Water

District Office of Oulu 1984). Some of the lakes still in a quite natural state were perhaps also loaded by scattered settlements, forestry, agriculture and other activities (Tables 1—2). The lakes in a natural state in this sense were on the average clear, low in humic substances and rich in alkaline earth metals in the Koutajoki river basin, and their buffer capacity, measured in terms of pH and alkalinity, was high (Table 3). There was an oxygen deficit in the hypolimnion in a third of the small lakes of the Koutajoki watercourse (Myllymaa 1987), due to the high organic content of the sediments. The heavy metal concentrations in some lakes in winter, as reported by Myllymaa (1985) and detailed in Table 3 suggested the presence of metals in the bedrock, and these would therefore be worth studying for prospecting purposes. The presence of lead and cadmium in some lakes suggested an anthropogenic influence. The highest concentrations of trace metals were in the Iijoki watercourse and the lowest in the Kemjoki watercourse due to variation in the bedrock and the binding capacity of the sediments.

All selenium values, measured from the Iijoki and Kemjoki watercourses, were under the detection limit of the analysis method, 0.1—1 $\mu g\ l^{-1}$. Selenium concentrations of Finnish surface waters have not been studied earlier, but in Canada the concentrations are usually smaller than 0.2 $\mu g\ l^{-1}$ (Leskinen 1984).

Organic matter affected the pH and the concentrations of nitrogen and lead in the sediments, but not that of phosphorus (Myllymaa 1987, Myllymaa and Murtoniemi 1987). Cadmium and manganese usually increased towards the surface, whereas nitrogen, phosphorus, copper, zinc and the Fe/Mn ratio did not. Gorham and Swaine (1965) report that lead in particular, and also zinc and cobalt, are enriched in oxidized sediments, while nickel and copper favour reduced sediments. Tenhola (1983) reports that under increasingly reduced conditions in a small lake, zinc, nickel and cobalt, and to some extent also lead and copper, are enriched in the uppermost layer of the sediment with a decrease in iron and manganese and an increase in the Fe/Mn ratio towards the surface. According to Gorham and Swaine (1965) and Tenhola (1983) we can postulate in accordance with the above that some of the lakes studied here had a low redox potential. The water analyses showed this to apply to 14 lakes described by Myllymaa (1987), although these did not differ from the others in any other way except that in Lake Kokkojärvi (no. 39 in Myllymaa 1987) the oxygen concentration was very low and hence large amounts of phosphorus and manganese had leached into the water. According to Boström (1982) there is no close relationship between total phosphorus and the trophic level of the lake due to the dependence of phosphorus on pH or redox potential, for instance.

The sediments with a high proportion of iron and aluminium-bound phosphorus released the largest amounts of phosphorus, a process which was strongly favoured by a low redox potential and a high pH level (Boström 1982). Phosphorus bound to iron and aluminium can be released into aerobic water when the pH is high due to a ligand exchange mechanism in which hydroxide ions replace phosphate. In calcareous eutrophic lakes the phosphorus-retaining capacity of the sediments can be increased at higher pH levels.

Myllymaa and Murtoniemi (1987) postulate that the human effect may have caused an increase in lead, zinc, cadmium and mercury in some of these lakes. The spatial distribution showed that these metals were usually enriched in lakes with a high organic content in their sediments. An accumulation curve for lead like that found in Lake Yli-Heikinjärvi is attributed by Davis et al. (1982) and Dillon and Evans (1982) to an anthropogenic effect, e.g. traffic or atmospheric pollution. The increase in Lakes Yli-Heikinjärvi and Särkijärvi had taken place during the periods of forest drainage, but accumulation did not follow the sedimentation rate.

No clear conclusions can be drawn from comparing the concentrations of metals and the drainage of peatlands within the catchment areas in all the 161 lakes (Myllymaa 1987). 40—50 % of the lakes which were in natural state in this sense were among those in which the metal concentrations were high (90 % fractiles), and the possible influence of drainage was obscured by the effects of other human activity, atmospheric pollution and chemical effects in the bottom mud itself.

Atmospheric inputs have been observed to play a very important role in the increase in lead, zinc, cadmium, copper and mercury in some lakes in Canada and western Europe (Kemp and Thomas 1976, Galloway and Likens 1979, Hamilton-Taylor 1979, Rippey et al. 1981), and though their import may not be marked in the Kuusamo area, they must be taken into consideration as constituting one of the major factors. About 15—40 % of the annual precipitation in Finland falls as snow (Soveri 1985) and in Kuusamo over 30 % (Koutaniemi 1978). Materials in the snow cover reflect the degree and nature of atmospheric loading. After melting and infiltration through the soil, they eventually affect the groundwater and surface waters.

The mean background concentrations of copper, lead, manganese and zinc measured in snow during the years 1976—1981 were usually low, and regional variation was slight (Soveri 1985). Concentrations of copper were slightly higher in Northern Finland than in the south of the country, while lead concentrations were markedly higher in the south than in the north. The major factor affecting lead concentrations and their regional variation in Finland is the density of road traffic (Salmi 1969), although mining and certain industries that use lead also release considerable amounts (Soveri 1985). Some regional variation in manganese was also recorded, the concentrations again being higher in the south of the country than in the north. The concentrations of copper and zinc in the snow at the observation station at Kuusamo were slightly higher than the means for the whole country, but the lead content was only 38 % of the mean (see Soveri 1985). In the snow at Riisitunturi near this area, metal concentrations have been very high. Also the low pH indicated atmospheric pollution (Havas 1986).

It has been estimated that approximately 20 % of the mercury in the atmosphere is derived from anthropogenic emissions (e.g. Watson 1979, Brosset 1983a, b). The mercury concentration in rainwater has been found to be higher in urban than in rural areas in southern Finland, whereas no clear differences were found between southern and northern Finland. The highest values in the snow in 1983 (20—50 ng l^{-1}) were measured in Northern Karelia, Kainuu and Kuusamo (see Rekolainen et al. 1986b).

Mercury is a well studied example of anthropogenic effects on the environment. Because its presence at higher concentrations in rural areas is often found to be the result of airborne effects, it may also serve as an indicator for certain other airborne materials, e.g. heavy metals. The background mercury levels in the sediments of the three largest lakes in Sweden are 0.03—0.095 mg kg^{-1} (Håkanson 1977), and according to Särkkä et al. (1978), Häkkilä (1980) and Lodenius (1980) the background values in Finland are at the same level. The higher base level concentration in the sediment of Lake Polvijärvi (about 0.25 mg kg^{-1}) is obviously a consequence of the low mineral content (Simola and Lodenius 1982). When calculated on the basis of organic matter in the sediment the concentrations are equivalent.

The background values in Lakes Yli-Heikinjärvi and Särkijärvi were about 0.15 mg kg^{-1} (Myllymaa 1987), which is also the average background value for the other small lakes in the area according to Myllymaa and Murtoniemi (1987). The variation in mercury content was evidently a consequence of fluctuations in both the sedimentation of organic matter and the atmospheric fallout of mercury. In most other lakes the vertical distribution of mercury was suggestive of atmospheric origin. The average concentration of mercury in the surface sediments of the Kitkajärvi chain of lakes was only 0.04—0.05 mg kg^{-1} (Myllymaa et al. 1985), and loss on ignition was only 16 %, whereas it was 43 % on average in the smaller lakes described by Myllymaa (1987). Organic matter binds mercury originating from any source and transfers it into water and sediments. At high pH values, as in northern Kuusamo, mercury is largely maintained in the sediments.

Increases in mercury towards the surface sediments in lakes without any direct mercury pollution are recorded by Vernet and Thomas (1972), Björklund and Norling (1979), Johansson (1980, 1985), Björklund et al. (1982), Simola and Lodenius (1982), Quellet and Jones (1983) and Tolonen and Jaakkola (1983). The possible causes are the increased atmospheric deposition and the human activities, which have increased the leaching of mercury from drainage areas (Rekolainen et al. 1986a). The beginning of the distinct increase in mercury content in sediments has been placed at around 1910—1940 in northern Europe and Canada (Johansson 1980, 1985, Björklund et al. 1982, Quellet and Jones 1983), but slight increases are also observed in earlier sediments (Aston et al. 1973).

The concentrations of sulphate, copper and lead, all materials of mainly atmospheric origin, in the ground water are greater in coarse and assorted soil types than in unassorted ones (Soveri 1985), whereas the concentrations of the typical products of weathering, namely calcium, potassium, magnesium, sodium and aluminium, are very much greater in unassorted soils than in assorted ones. Myllymaa (1985) reports that metal concentrations were lowest and the sulphate concentration highest in those lakes, whose catchment areas contained mainly assorted soils. The sulphate may thus be largely of atmospheric origin, as in groundwater. The concentrations of metals in surface water are usually smaller than in groundwater, due to dilution, changes in pressure, oxidation and chemical and biochemical reactions (Hartikainen 1976).

Changes in pH, and to a larger extent in buffer capacity affect the distribution of trace metals over the dissolved and particulate phase (Salomons and Förstner 1984). With an increase in pH the dissolved metal concentrations in water decrease and the sediment concentrations increase, the reduction being greater for lead than for zinc.

Salomons and Mook (1980) also report that an increase of 0.5 pH unit caused an almost complete removal of dissolved cadmium from river water entering a lake. The reverse may be expected in acidifying lakes (Salomons and Förstner 1984). pH thus explains the fact that the mean concentration of lead, copper, zinc and cadmium was smallest in the lake waters of the Iijoki watercourse (Table 1). These metals in water are increased by acidification in Iijoki watercourse more than in northern Kuusamo because of the smaller buffer capacity.

The high buffer capacity in the lakes of northern Kuusamo explained the negligible intercorrelations between the metal concentrations in the water and sediments. Epilimnic water samples were taken at the ends of stagnation periods, when a long sedimentation time had elapsed since the spring or autumn runoff period. The concentrations were usually higher in the hypolimnion than in the epilimnion, due to sedimentation and mobilisation from the bottom. The correlations between copper, mercury, manganese, cobalt and nickel in the sediments and pH in the water evidently followed the variation in buffer capacity. Furthermore, the decrease in metals towards the surface in some lakes, as recorded by Myllymaa and Murtoniemi (1987), was a consequence of a lowering in the pH.

According to Soveri (1985), Rekolainen et al. (1986b) and Havas (1986), airborne inputs have affected the quality of lake water in this area, but in practice it is impossible here to separate this effect from those of human activity, the bedrock and the soil. According to Kämäri (1984) no significant acidification has occurred in this area. It is nevertheless possible that acid rain may have affected sediments over a longer period.

Metals originating from sulphidic minerals also serve to increase the concentrations measured here. Sandberg (1976, 1978) reports that mineral deposits of copper lying under lakes are reflected in higher than usual concentrations in the sediments, while according to Tuokko (1980), nickel, copper, zinc and lead deposits can be manifested in increased concentrations in lake sediments. It is uncertain whether mineral deposits can be discovered by means of water data, because the deposits occur often in narrow veins and the metals do not move long distances in high concentrations. High metal concentrations in sediments are thus worth closer study in connection with prospecting.

The average concentrations of lead, copper and zinc in the Koutajoki watercourse were usually comparable to those found in eastern Finland (Tanskanen 1979, Tenhola and Lummaa 1979), whereas the cadmium concentration was much lower than that found in central Finland by Tummavuori and Aho (1978), and the mercury content was lower than in southern and western Finland (Rekolainen et al. 1986b). The mean concentration of iron was much higher than that in eastern Finland (Tenhola and Lummaa 1979), and the cobalt concentration was higher than in the lakes of northern Karelia but the nickel concentration lower (Tanskanen 1979, Tenhola and Lummaa 1979).

The area examined here is in much more of a natural state than most parts of southern Finland. When choosing reference stations for the monitoring of water quality e.g. in an integrated study of air, soil and water, it is important to examine the recent history and possible special features of the lakes, especially the influence of the bedrock in this area. The use of sediments as indicators of metal loading caused by human activities also requires precise dating. It also is important to study the present state of the lakes, the quality of both water and sediments, as reference for comparison with some later state possibly involving alteration by human agency.

TIIVISTELMÄ

Tutkimuksessa selvitettiin Kuusamon ylänköalueen järvien veden laadun ja sedimenttien alueellisia eroja, niihin vaikuttavia tekijöitä sekä veden, sedimentin ja valuma-alueen vuorovaikutusta ja ihmistoimintojen vaikutusta. Tutkittujen järvien veden laatuun vaikuttivat järven koko ja syvyys, soiden ja järvien osuus valuma-alueesta sekä valuma-alueen kallio- ja maaperän geokemialliset ominaisuudet. Alueen pohjoisosan kallioperälle oli tyypillistä emäksisten kivilajien suuri osuus, ja siellä vedet olivat yleensä kirkkaita sekä hyvin puskuroituja. Kolmasosassa Koutajoen vesistöalueen pieniä järviä esiintyi talvella alusveden hapettomuutta, mikä vapautti sedimentistä ravinteita ja metalleja.

Kuusamon kalankasvatusta koskevassa vesiensuojelusuunnitelmassa on arvioitu eri kuormituslähteiden osuus kokovuotisesta ja kesäaikaisesta vesistökuormituksesta. Kalankasvatus on todettu suurimmaksi reittivesistöjen rehevöitymistä aiheuttavaksi tekijäksi, koska kuormitus on suuri ja muodostuu pääasiassa kesäaikana.

Hajakuormitus voi aiheuttaa rehevöitymistä ja hapen kulumista sekä siitä johtuvia muita vaikutuksia pienissä järvissä. Tämän tutkimuksen pienet järvet olivat suhteellisen luonnontilaisia vailla jäte-

vesikuormitusta, mutta ilman kautta tapahtuva kuormitus sekä maa- ja metsätalouden, virkistyskäytön sekä muun ihmistoiminnan vaikutus olivat mahdollisia.

Tässä tutkimuksessa ei voitu erottaa erilaisten ihmistoimintojen vaikutusta vesistöjen metallipitoisuuksiin luonnollisista ilmiöistä. On kuitenkin ilmeistä, että lyijyn, kadmiumin ja elohopean merkittävä lisääntyminen sedimentin pintaa kohti johtui osittain ihmistoiminnasta ja ilman kautta tapahtuvasta leviämisestä. Sedimenttien käyttö ihmisen vaikutuksen ilmentäjänä vaatisi enemmän sedimenttien iän määritystä. Veden korkea pH lisäsi metallien sitoutumista orgaanisiin sedimentteihin ja vähensi pitoisuuksia vedessä, erityisesti Pohjois-Kuusamossa. Sedimenttien korkeisiin metallipitoisuuksiin oli syynä myös kallioperä, joka koostui paljolti helposti rapautuvista emäksisistä kivilajeista sekä sulfidimineraaleista. Joidenkin Iijoen ja Koutajoen vesistöalueen järvien valuma-alueiden kallioperää tulisi lähemmin tutkia malminetsinnässä.

Alue on suhteellisen luonnontilainen Etelä-Suomeen verrattuna. Etsittäessä vertailuvesistöjä esimerkiksi ilman, maaperän ja vesistöjen yhdennetyssä seurannassa tulisi selvittää niiden tähänastinen kehitys sekä mahdolliset erikoispiirteet, tällä alueella erityisesti kallioperän ominaisuudet. Järvien veden ja sedimenttien laatu tulisi kartoittaa nopeasti tulevien muutosten selvittämisen pohjaksi.

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