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CHARACTERISTICS OF THE WATER OF FINNISH MAN-MADE LAKES

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The artificial lakes included in the study are mainly located on peatlands and strongly regulated. The article discusses the characteristics of their water, the trends revealed by the chemical water analysis and their connections with the physical characteristics of the reservoirs. The man-made lakes have lower values than the natural lakes for oxygen content and pH, but higher values for chemical oxygen demand, suspended solids, total phosphorus, total nitrogen, iron and colour. The trends for oxygen concentration were always positive whereas negative trends were found in electrolytical conductivity, suspended solids and chloride concentration. Most of the trends shown by iron were positive, whereas of the trends for colour, total nitrogen and total phosphorus, six were positive and 17 were negative. With the aid of factor analysis, 17 variables of the chemical properties of the inflowing water and the physical features of the reservois were condensed into eight factors. The regression analysis of outflowing water, using these factors as independent variable, gave the result that for both the oxygen saturation percentage and the total iron and phosphorus concentration the most important variable was the suspended solids factor. For COD, the first variable was nitrogen factor, for chloride the electrolyte factor and for colour, the oxygen deficit factor.

Index words: Man-made lakes, water quality, reservoirs.

1. INTRODUCTION

Numerous artificial lakes were constructed in Finland in the 1960s and 1970s, mainly in Ostrobothnia and Lapland, which are poor in lakes (Fig. 1). They were built for the purposes of power development and flood control, and for water-supply systems.

Most of the lakes had to be built in fairly flat, forested or boggy country. In some cases it was possible to use swampy lakes, where attempts had earlier been made to drain the land for agriculture. For these reasons Finnish artificial lakes are generally very shallow. At the maximum water level, the mean depth of the deepest reservoir is 7 m and that of the shallowest is only 1 m. The mean depth of the artificial lakes studied here is 2.9 m (Table 1). The majority of the reservoirs are regulated according to the requirements of power-supply systems and flood control. Exceptions in this study are Lohijärvi, which was built for purposes of recreation, and the Hintsa and Haapajärvi reservoirs, which are used for water supply purposes.

The amplitude of regulation permitted by the water court is generally considerably greater than the mean depth of the reservoir (Table 1). During the time of the ice cover, which lasts till late April, the reservoirs are drawn down till they are almost empty. After they have been filled by the spring floods, an attempt is made to keep the water level high until the beginning of the following year, though the regulation instructions allow very considerable fluctuation in the water level. Except in the case of Haapajärvi, Lokka and Porttipahta, the theoretical residence time in the artificial lakes is less than one year. In practice, however, the water is completely renewed in the spring and accordingly replenishment is slower than the theoretical value at other times of the year.

In a considerable number of the artificial lakes the bottom consists of peat (Table 1). Rafts of peat that have risen to the surface have occurred extensively in the reservoirs Kivi- and Levalampi, Liikapuro, Vissavesi, Kortteinen, Haapajärvi and Lokka, and to a smaller extent in Varpula, Patana, Venetjoki and Uljua (Vogt 1971).

The artificial lakes in Finland are differentiated from the natural lakes by the wide seasonal fluctuation in their level in relation to the total depth, their small volume and surface area when they are drawn down to the regulation minimum, and their short residence time. These exceptional properties affect their stratification and biology (Vogt 1971).

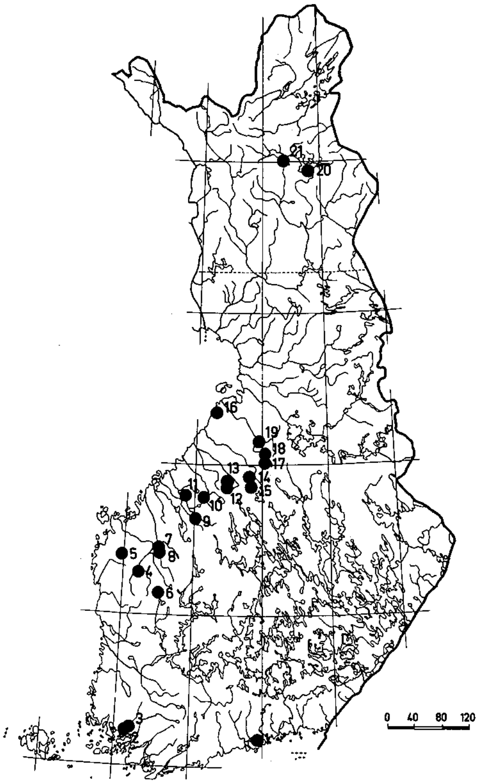

Fig. 1. The sampling stations of the investigated man-made lakes.

Table 1. General characteristics of artificial lakes.

No	Lake	Year of filling	Area km^2	Volume 10^6m^3	Mean depth m	Max. amplitude of regulation m	Theor. residence time days	Percentage of peat soils of bottom area %
1.	Lohijärvi	1968	0.16	0.45	2.5	0.6	364	70
2.	Hintsa-Lähteenmäki	1963	0.15	0.45	3.0	3.5	-	0
3.	Hintsan vesilaitos	1960	0.05	0.20	4.0	2.8	-	0
4.	Pitkämö	1971	1.05	7.0	7.0	10.0	4	0
5.	Kivi- ja Levalampi	1964	3.65	4.8	1.3	2.5	188	-
6.	Liikapuro	1967	3.10	4.5	1.5	3.0	296	75
7.	Hirvijärvi	1973	13.50	29.4	2.2	4.0	122	40
8.	Varpula	1963	3.67	5.6	1.6	3.0	181	73
9.	Patana	1967	11.2	53.5	4.8	11.5	194	32
10.	Venetjärvi	1965	17.50	28.0	1.6	3.5	204	58
11.	Vissavesi	1965	3.67	6.6	1.8	4.5	256	52
12.	Korpinen	1964	3.06	5.4	1.8	4.5	266	47
13.	Juurikkajärvi	1964	1.80	3.8	2.1	1.3	256	19
14.	Settijärvi	1970	4.20	10.2	2.4	2.5	52	59
15.	Kuonanallas	1968	5.40	10.3	1.9	2.1	57	0
16.	Haapajärvi	1967	5.10	15.5	3.0	5.0	445	38
17.	Vähä-Lamu	1967	3.10	3.0	1.0	0.5	168	0
18.	Kortteinen	1968	7.00	9.0	1.3	2.0	-	45
19.	Uljua	1970	28.00	146.0	5.2	8.0	153	48
20.	Lokka	1968	417.00	1 563.0	3.7	5.0	711	90
21.	Porttipahta	1970	214.00	1 353.0	6.3	11.0	573	48

A certain number of studies, mainly arranged by the water authorities, have been made on the condition of the strongly regulated reservoirs built on peat soils. According to Kleemola (1967), typical features of such waters are high values for colour (200–1 000 mg/l Pt) and $KMnO_4$- consumption (ca. 100 mg/l $KMnO_4$), a fairly high content of iron (1–2 mg/l), and low values for electrolytic conductivity (20–35 µS/cm) and pH (4.2–6.0). During the open-water period, the oxygen saturation value is 60–80 %. During the time of the ice cover, in late winter, oxygen may become completely exhausted in the recently constructed reservoirs and even in older basins the oxygen content falls to near zero (Kleemola 1967). The reservoirs studied by Kleemola (op. cit.) were also examined by Vogt (1971), but 4–5 years later. According to Vogt the oxygen content of the reservoirs is low in winter, most often being less than 10 % of saturation, even in the surface layer. In the summer thermal stratification of even short duration often gives rise to an oxygen deficiency in the hypolimnion. The oxygen concentrations are highest at the time of the overturn, but, at least in the first years, remain 10–30 % lower than the saturation value. The concentration of total nitrogen in the reservoirs is 0.7–1.3 mg/l, of which about 30 % is generally in the form of ammonium nitrogen. In the epilimnion the concentration of total phosphorus is generally 0.04–0.07 mg/l. In the deoxygenated hypolimnion the concentration of orthophosphate can rise to 0.3 mg/l. According to Vogt (op. cit.), at least on the basis of their absolute nutrient concentrations, Finnish reservoirs may be classified as eutrophic.

In the reservoirs built on peatlands the water is of poor quality, due to the high contents of humus and iron, and in many cases is unsuitable for the water-supply systems. According to Kleemola (1967), the reservoirs built for stream regulation on peat soil in Ostrobothnia have no advantage from the point of view of water supply and conservation beyond reducing the fluctuations in stream discharge. Kleemola (op. cit.) points out that the content of dissolved and suspended organic matter, which is already high, is further increased by the rafts of floating peat. In most cases, however, the amount of floating turf has decreased considerably as the reservoirs age.

In the reservoirs built on mires considerable leaching and decomposition of terrestrial material occurs during the first 2–3 years. This stage is characterized by a small oxygen content and high values for CO_2, colour and $KMnO_4$-consumption. This is followed by a stage in which the oxygen concentration is higher and the values for colour $KMnO_4$-consumption are lower. The annual variation is great, however, and, according to Vogt (1971), the changes at this stage do not yet show any clear trend. The rate of aging of reservoirs built on peatlands is so far unknown.

The aim of the study was to provide a general view of the condition of the artificial lakes and to examine the properties of the water and the changes occurring in them during residence in relation to the structural characteristics, the nature of the bottom and the age of the reservoirs.

2. MATERIAL AND METHODS

The study is based on the analyses of water samples taken from the reservoirs by the National Board of Waters. The most recent observations are from March 1974, the oldest from 1963.

The study comprises 21 reservoirs, 16 of which are located in Ostrobothnia (Fig. 1). The results of only one sampling time (March 1971) were included for the Lokka and Porttipahta reservoirs, because a separate study had been made of them (Heinonen and Airaksinen 1974).

The study included analyses of the water entering and leaving the reservoir as well as results for the water in the reservoir itself. The data on the lake water comprised the analyses of samples taken at 1 m depth and at the greatest sampling depth, which was generally 1 m above the bottom.

The number of analyses made of the samples varied to some extent, depending on such circumstances as the facilities at the laboratory where the samples were examined. In order to achieve a uniform treatment of the artificial lakes, the analyses included in this study were restricted to those which are most commonly determined: temperature (t^o, C), oxygen concentration (mg/l O_2), oxygen saturation percentage (%O_2), electrolytic conductivity ($\varkappa_{20}$, µS/cm), suspended solids (mg/l), pH-value, colour (mg/l Pt), chemical oxygen demand ($KMnO_4$-comsumption, mg/l), and the concentration of total nitrogen (µg/l N), total phosphorus (µg/l P), chloride (mg/l) and iron (mg/l). The analyses were made by the methods used by the National Board of Waters (Erkomaa et al. 1977).

The analysis results were obtained from the water quality register of the National Board of Waters, which is kept at the State Computer Centre. The statistical treatment of the results was carried out at the State Computer Centre, mainly using the library programmes of the computing centre of Helsinki University (HYLPS programmes).

The following computations were made:

- the means and their standard deviations for each artificial lake in three different periods (March-April, July-August and October-November).
- the relative differences in the water variables between samples taken on the same day from the inflowing and outflowing water; the correlations of these differences with the physical properties of the reservoir and stepwise regression analysis of these relationships
- stepwise regression analysis in which the chemical properties of the outflowing water were explained by factors formed by the properties of the inflowing water and the physical properties of the reservoir
- the trends revealed in the different seasons and depth zones by the water entering, leaving and residing in the reservoir.

3. RESULTS AND DISCUSSION

3.1 Condition of the artificial lakes in different seasons

The quality of the water in late winter is of great interest from the point of view both the ecology and the utilization of the water resources. It is then that information can be obtained on the minimum level reached by dissolved oxygen, which occupies such a key position in the processes of a lake, and on the consequences of the decline in the oxygen content. It may be noted that reservoirs built for flood control or hydropower generation are generally drawn down to their minimum level before the beginning of the spring floods in April. In most cases the water is withdrawn from the epilimnion, which increases the proportion of the hypolimnion poor in oxygen in the total water mass.

The mean values of the quality characteristics of artificial lakes in late winter differ statistically significantly from those of the lake deep observation stations of large lakes (Table 2). Only the values for chloride and electrolytical conductivity at the maximum depths do not differ significantly, mainly owing to the great deviation of the mean values of the lakes. Comparison of the mean values shows that, as a group, the artificial lakes differ clearly from natural lakes. The water entering the reservoirs has higher contents of organic matter and iron. In contrast to the situation in natural lakes, interception of substances does not appear to be general in artificial lakes (Laaksonen 1972, p. 12). Strong biological consumption of oxygen is caused by the high content of organic matter in the water entering the reservoir and the organic substances of terrestrial origin present in the bottom. This exhausts the oxygen in the water layer overlying the bottom and allows large amounts of iron and phosphorus to pass into solution from the bottom.

In summer the hydrology of the artificial lakes is more similar to that in natural lakes, but thermal stratification does not become established in the majority of the artificial lakes. According to the present observations, the reservoirs that become stratified are Lohijärvi, Pitkämö, Vissavesi, Haapajärvi and Uljua. According to the material treated by Heinonen and Airaksinen (1974), Porttipahta and Lokka also belong to this group, but summer stratification is not stable in these reservoirs and often disappears as early as July, depending on the weather conditions. Nor does a proper homothermic hypolimnion occur in these waters. In the water layer close to the bottom the temperature is well above 4 ^{0}C, too.

The variables used in this study do not include direct determinations of primary production or production capacity. Judged from their total contents of the most important plant nutrients, phosphorus and nitrogen, the reservoirs are notably rich in nutrients. The mean concentrations of phosphorus and nitrogen in July-August (85 μg/l and 877 μg/l, respectively) clearly exceed the corresponding values recorded at the natural lake deep observation stations (Laaksonen 1972). However, the physico-chemical variables used here do not suggest that the primary production reaches a level indicative of eutrophy. In the surface water (1 m deep) the oxygen saturation values never rise above 100 % and the pH remains below the level indicating

Table 2. The means of some chemical parameters of water in artificial and large natural lakes (Laaksonen 1972) in March-April. The t-values and significance of difference between reservoirs and lakes.

	Artificial lakes						Natural lakes						t-values	
	1 m depth			max. depth^{x}			1 m depth			max. depth^{x}			1 m	max. depth^{x}
	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n		
Oxygen, mg/l	5.3	3.7	20	2.5	3.8	17								
Oxygen, satur. %	38	27	20	21	28	16	83	13	727	37	24	725	7.42***	2.27*
COD_{Mn}, mg/l	34	15	18	37	12	14	10.6	8	641	13.9	15.9	642	6.59***	7.07***
Susp.solids, mg/l	19.0	11.9	19	18.9	14.4	14	1.6	2	561	6.0	10	567	6.37***	3.33**
Chloride, mg/l	5.2	2.7	19	5.3	3.2	13	3.6	2.3	727	4.2	3.1	727	2.56*	1.23
Tot.phosphorus, µg/l P	107	51	21	189	100	16	19	42	699	75	146	706	7.83***	4.45***
Tot.nitrogen, µg/l N	1 274	382	21	1 529	439	16	500	400	714	800	1 000	719	9.14***	6.29***
$\varkappa_{20}$, µS/cm	64	39	19	78	56	16	46	24	727	60	40	727	2.00*	1.28
pH	5.77	0.61	19	5.83	0.53	16	6.6	0.4	721	6.4	0.4	721	5.90***	4.27***
Fe, µg/l	3 498	2 679	19	4 593	3 372	14	300	400	574	1 800	3 400	649	5.20***	3.07**
Colour, mg/l Pt	277	133	21	350	140	16	49	36	725	89	95	711	7.85***	7.42***

x = sampled 1 m above bottom
$\bar{x}$ = arithmetic mean
s = standard deviation
n = number of observations

$\star$ = indicates 95 % confidence level
$\star\star$ = indicates 99 % confidence level
$\star\star\star$ = indicates 99.9 % confidence level

vigorous assimilation of carbon dioxide. On the other hand, even in summer extensive oxygen consumption is apparent in the oxygen concentrations; the mean value of the surface water is only 70 % of saturation. Thus heterotrophic production predominates in summer as well. Autotrophic production is strongly limited by the poor transmission of light; the mean colour is 238 mg/l Pt and the maximum is 380 mg/l Pt (Vissavesi reservoir).

The comparatively high oxygen saturation value for the maximum depth, 48 %, is due to the general absence of thermal stratification. In the basins that are thermally stratified, for even a brief period, the mean oxygen values in the maximum depth are much lower, e.g. Haapajärvi 0 %, Uljua 26 % and Lohijärvi 9 %. Other properties whose mean values differed between the two sampling depths in the reservoirs are suspended solids, total phosphorus and colour; their mean values at the maximum depth were, respectively, 53, 57 and 23 % higher than at a depth of 1 m. Statistically, however, the confidence level is only 90 %. The mean values for COD, chloride, total nitrogen, electrolytic conductivity and iron are also higher at the maximum depth than at 1 m. Although the differences are not statistically significant, they all support the conclusion that in most of the reservoirs the high biological oxygen consumption in the water and the bottom keep the redox potential at the surface of the bottom sufficiently low, even in the summertime, to permit the release of phosphorus and iron from the bottom and to prevent sedimentation of ferriphosphate from the upper layers.

In the autumn material (October-November; Table 4), t-tests showed that only the mean values for the oxygen concentration differed significantly between the different sampling depths (1 m = 10.56 mg/l O_2, maximum depth = 9.08 mg/l O_2). The mean values for the other variables did not differ between the two depths.

Comparison of the mean values for October-November with those for March-April (Table 2) and July-August (Table 3) shows that suspended solids, total phosphorus, electrolytic conductivity and iron have their minima in the autumn and that oxygen has its maximum. In October-November both the oxygen concentration and the oxygen saturation percentage are significantly higher than in July-August in both depth zones. In the 1-m zone, which represents the surface layer, the values for COD, chloride and colour are all of the same order as in the summer, but total nitrogen is ca. 17 % higher at the maximum depth. COD, chloride and colour also have their minima in October-November. The means for suspended solids and iron are significantly smaller than in summer and the mean for

Table 3. The means of some chemical parameters of water in artificial lakes in July-August. The t-values and significance of difference derived from studen's t-test for the two sampling depths.

		Means of reservoir mean values						t-values
		1 m			Max. depth			
		x̄	s	n	x̄	s	n	|t|
Oxygen	mg/l	6.36	1.29	16	4.00	2.55	12	3.20★★
Oxygen satur.	%	69.86	15.82	16	48.38	26.29	12	2.69★
COD$_{Mn}$	mg/l	25.57	7.39	15	29.77	10.47	13	1.24
Susp. solids	mg/l	8.01	4.44	16	12.26	7.82	13	1.83^{o}
Chloride	mg/l	3.27	1.13	15	3.46	1.33	10	0:37
Tot. phosphorus	µg/l P	84.99	52.95	16	133.46	78.36	12	1.95^{o}
Tot. nitrogen	µg/l N	877.00	364.06	16	1 077.56	466.15	13	1.29
Temperature	^{o}C	19.84	2.45	16	14.92	3.88	13	4.15★★★
$\varkappa_{20}$	µS/cm	36.68	20.06	16	38.37	29.24	13	0.17
pH		5.98	0.50	16	5.82	0.46	13	0.90
Fe	µg/l	2 070.8	1 183.50	16	3 209.30	2 362.20	13	1.68
Colour	mg/l Pt	237.70	72.11	16	292.88	91.75	13	1.81^{o}

x̄ = arithmetic mean
s = standard deviation
n = number of observations

o = 90 % confidence level
★ = 95 % confidence level
★★ = 99 % confidence level
★★★ = 99.9 % confidence level

Table 4. The means of some chemical parameters of water in artificial lakes in October-November. The t-values for sampling depths and for the mean values of July-August (Table 3).

		Means of reservoir mean values						t-values		
		1 m			Max. depth			1m/max depth	1m July-August/ October-November	max.depth July-August/ October-November
		x̄	s	n	x̄	s	n			
Oxygen	mg/l	10.56	0.77	15	9.08	2.19	14	2.39★	11.08★★★	5.40★★
Oxygen satur.	%	79.65	6.17	15	69.81	17.09	14	2.03	2.29★	2.41★
COD$_{Mn}$	mg/l	25.77	9.18	15	25.90	9.06	14	0.03	0.06	1.02
Susp.solids	mg/l	6.93	2.97	15	6.14	3.41	13	0.64	0.80	2.58★
Chloride	mg/l	3.30	1.05	15	2.77	0.67	11	1.56	0.07	1.47
Tot. phosphorus	µg/l P	78.58	55.39	15	77.50	62.65	13	0.04	0.32	1.96^{o}
Tot. nitrogen	µg/l N	1 026.44	333.65	15	934.05	430.88	13	0.62	1.18	0.44
Temperature	^{o}C	2.33	1.24	15	3.11	1.28	14	1.66	25.33★★★	10.45★★★
$\varkappa_{20}$	µS/cm	32.77	14.68	15	31.76	14.15	14	0.18	0.62	0.73
pH		5.88	0.66	15	5.76	0.73	14	0.46	0.47	0.25
Fe	µg/l	1 700.89	944.50	15	1 711.35	940.75	13	0.02	0.51	2.12★
Colour	mg/l Pt	238.25	76.91	15	238.24	76.79	14	0.00	0.02	1.67

x̄ = arithmetic mean
s = standard deviation
n = number of observation

o = 90 % confidence level
★ = 95 % confidence level
★★ = 99 % confidence level
★★★ = 99.9 % conficende level

phosphorus is almost significantly (90 % confidence level) smaller.

If stratification occurs, it does not last beyond late summer, owing to the high temperature of the hypolimnion. The long duration of the turnover, the lower loading than in spring and the decreasing temperature, particularly the latter, all contribute to make the quality of the water better in autumn than in the other seasons. On the other hand, the mean oxygen deficit of 20–30 % is evidence of vigorous decomposition of organic matter, and the values for COD do not decline from the summer level.

Thus, although the reservoirs are comparatively rich in oxygen in autumn, there is clear evidence that a strong oxygen deficit develops during the time of the ice cover.

3.2 Effect of residence in the artificial lakes on water characteristics

Lakes typically intercept suspended solids and many dissolved substances in the water that passes through them (e.g. Laaksonen 1972).

According to the observations made to date, however, the changes occurring in the water of peat-bottomed regulated reservoirs do not always follow the pattern characteristic of lakes (Vogt 1972). In this connection, the effect of the reservoir on the water characteristics was examined qualitatively, without taking account of the amounts of water involved. In the investigation the inflowing water is considered to represent the condition in which it would remain in the water system in question if it did not pass through the reservoir. If at any given moment some property differs between the inflowing and outflowing water, this difference is considered to be due to residence in the reservoir. In order to clarify the influence of the reservoirs, the relative changes in the properties of the water were calculated for the following correlation analysis according to the formula:

$$\frac{\text{inflowing water} - \text{outflowing water}}{\text{inflowing water}} \cdot 100.$$

These values were calculated for 12 reservoirs.

An increase in the percentage means an increase in the interception of substances in the reservoir and a decrease in the oxygen content and the pH. Conversely, a decrease in the value means poorer interception or even an increase in dissolved and suspended substances during residence in the reservoir.

The coefficients of the correlation between the relative changes in the concentrations and the physical properties of the reservoirs (Table 5) show that the changes in chloride, total nitrogen, electrolytic conductivity and pH correlate positively with the surface areas of the reservoirs. Thus interception of substances appears to be stronger and pH evidently decreases more in large reservoirs than in basins with a smaller surface area. The decrease in pH also seems to be more pronounced in basins with a greater volume. The mean depth of the reservoir correlates negatively with the changes in COD, chloride, total nitrogen

Table 5. The significant correlation coefficients of the relative changes in the properties of the water $(\frac{\text{inflowing water} - \text{outflowing water}}{\text{inflowing water}} \cdot 100)$ with the physical characteristics of the artificial lakes.

	Area	Volume	Mean depth	Max. amplitude of regulation	Theor. residence	Percentage of peat soils	Relative amplitude of regulation	Degrees of freedom
Oxygen	..	..	..	..	..	-0.260^{**}	..	120
Oxygen satur. %	..	..	..	..	..	-0.249^{**}	..	119
COD_{Mn}	..	..	-0.559^{***}	-0.255^{**}	0.272^{**}	-	..	117
Susp.solids	..	..	..	..	..	..	..	120
Chloride	0.301^{**}	..	-0.747^{***}	..	0.546^{***}	0.377^{***}	..	99
Tot. phosphorus	..	..	..	..	-0.281^{**}	..	..	115
Tot. nitrogen	0.259^{**}	..	0.285^{**}	..	..	..	..	117
Temperature	..	..	..	..	..	..	..	122
κ_{20}	0.292^{**}	..	-0.307^{***}	..	0.220^{**}	..	..	123
pH	0.376^{***}	0.292^{**}	..	..	..	..	..	122
Fe	..	..	..	..	..	..	..	119
Colour	..	..	..	..	..	..	..	122

** = statistically significant (99.0 % prob.)

*** = statistically highly significant (99.9 % prob.)

and electrolytical conductivity. Thus an increase in the mean depth of the reservoirs evidently weakens interception in respect of the substances in question.

There is also a negative correlation between COD and the regulation amplitude i.e. an increase in the regulation amplitude will weaken the interception of organic substances in the reservoir. The residence time correlates positively with the values for COD, chloride and electrolytical conductivity, and negatively with total phosphorus. The poorer interception of total phosphorus in basins with a longer residence time suggests that differences occur in the oxygen concentrations which are not evident in the correlations, however.

The proportion of peat soil present in the bottom correlates positively with the value for chloride, but negatively with the values for oxygen concentration and the oxygen saturation percentage. The negative correlations seem to indicate that the decrease in oxygen occurring in the reservoirs becomes less pronounced as the proportion of peat soil increases. The positive correlation suggests that the interception of chloride ions increases with the proportion of peat soil.

Stepwise regression analysis was used to elucidate the connections between certain physical characteristics of the reservoirs and the relative changes occurring in the chemical properties of the water. The physical background factors chosen as independent variables were: the year in which the reservoir was filled, (1960 = 0, 1961 = 1, etc.), the surface area, volume, mean depth, regulation amplitude, residence time and percentage of peat soil in the bottom area of the reservoir.

The regression models giving the best solutions are presented in Appendix 1.

Oxygen saturation percentage: The independent variable best explaining the relative change was the peat soil percentage (proportion explained 6.27 %). The proportion explained rose to 9.4 % with the inclusion of mean depth, to 13.6 % with residence time, and to 17.3 % with volume. Together, the remaining three independent variables only raised the percentage to 19.5 %, and thus they do not appear to be significant.

pH value. The most important independent variable, surface area, explained 14.1 % of the change in pH. The following variables were residence time (21 %), year of filling (23.6 %), volume (25.6 %), regulation amplitude (27.2 %) and mean depth (30.4 %). The contribution of the last independent variable, the percentage of peat soil, was not significant.

Chemical oxygen demand. The most important independent variable was the mean depth (31.2 %). The following variables were: year of filling (35.2 %) and residence time (36.2 %). After this, there was practically no improvement in the model, since even after inclusion of the 7th independent variable the proportion explained was only 36.6. %.

Chloride concentration. The most important independent variable was mean depth (55.8 %). The next most important were the regulation amplitude (63.8 %) and residence time, after which inclusion of the remaining variables failed to cause any notable increase, the final explanation value being 67.7 %.

Phosphorus concentration. The chief independent variable was residence time (7.9 %). Volume raised the explanation level to 11.0 %, filling year to 17.7 % and surface area to 19.7 %. The last three variables, regulation amplitude, mean depth and peat soil percentage, together raised the explanation level to only 21.9 %, and none of them were significant.

3.3 Influence of inflowing water and properties of the reservoir on outflowing water

The properties of the water leaving the reservoir are chiefly determined by the properties of the inflowing water and the reservoir, and the changes occurring during residence. Attempts to relate the properties of the outflowing water to the properties of the reservoir and the inflowing water with the aid of stepwise regression analysis are hampered by the strong correlations between the independent variables. In order to decrease the disturbance caused by this, factor analysis was used to condense a group of altogether 17 variables to eight new mutually uncorrelated factors. Temperature was excluded from the factor analysis and the regulation height was replaced with the relative regulation amplitude (regulation amplitude/mean depth).

The factor matrix, rotated by the Varimax method, is shown in Appendix 2. The factors were named according to their greatest loadings:

- F_1 – oxygen deficit factor
- F_2 – clear water or colour factor
- F_3 – basin size factor
- F_4 – electrolyte factor
- F_5 – suspended solids factor
- F_6 – mire reservoir factor
- F_7 – river reservoir factor
- F_8 – nitrogen factor

Factors F_1, F_2, F_4, F_5 and F_8 have their highest loadings, those responsible for their names, for the chemical properties of the water entering the reservoirs. Factors F_3 and F_6 have their highest loadings for the physical properties of the reservoir. Only F_7, the river reservoir factor, has high loadings in both groups of variables.

The regression models with the factors as independent variables are presented in Appendix 3.

The most important factor for the **oxygen saturation percentage** of the outflowing water is F_5, the suspended solids factor, which explains 15 % of the variation. The inclusion of all the seven following variables raises the percentage very little – to only 18.6. In view of the small percentage explanation, the influence of the suspended matter factor is chiefly remarkable because it shows the significance of the properties of the inflowing water.

The **chemical oxygen demand** is best explained by the nitrogen factor (F_8), which accounts for 10.5 % of the variation. The river reservoir factor (F_7) raises the value to 18.5 %, the electrolyte factor (F_2) to 27.7 % and the basin size factor (F_3) to 30.2 %. When all eight factors are included the value is 32.6 %. The position of the nitrogen factor as that best explaining the variation in COD is somewhat surprising, but the correlation between COD and F_8 (0.325) is clearly greatest. A rather close connection between COD and nitrogen is also shown by the significant correlation between the nitrogen concentration of the inflowing water and COD (0.495***). The second most important factor is the river reservoir factor (F_7), which has a negative correlation with COD (–0.263). Together these two factors account for 18.5 % of the variation. Thus, in this material the typical features of the reservoirs constructed across rivers are inversely connected with the COD of the outflowing water. The percentage explanation given by the following factors (electrolyte, clear water and basin size factors) is very small, but the direction of their influence is as would be expected. There is a positive correlation between the electrolyte factor and COD, whereas the clear water and basin size factors are negatively correlated.

The **chloride concentration** is best explained by the electrolyte factor (F_4), which accounts for 31.7 % of the variation. Inclusion of the mire reservoir factor (F_6) raises the percentage to 62.7. One of the two most important factors thus contains the properties of the inflowing water and the other the properties of the reservoir basin. The mire reservoir factor correlates negatively with the chloride concentration. The clear water factor (F_2) raises the percentage to 67.7, the basin size factor (F_3) to 71.4, the nitrogen factor (F_8) to 72.4 and the river reservoir factor (F_7) to 73.3. The total percentage explanation for chloride, 73.6, is the highest in the whole analysis.

The leading position of the electrolyte factor was to be expected. This factor has its chief loadings for the chloride concentration and electrolytic conductivity, and these two variables are strongly correlated with each other. The chloride concentration, which depends on the geochemistry of the region, remains fairly constant in the reservoirs, as in inland waters in general, owing to the high solubility of chloride and its low biochemical activity.

Total phosphorus concentration. The suspended solids factor (F_5) accounts for 12.2 % of the variation, and the percentage is raised to 15.5 by the electrolyte factor. After this, the increase is very slight, the value obtained after inclusion of all eight factors being only 18.5 %.

The analysis shows that the only important factor for the phosphorus concentration of the outflowing water is the suspended solids factor, which has its chief loadings for the phosphorus, suspended solids and iron concentrations of the inflowing water. This naturally does not mean that the reservoir has no influence on the phosphorus concentration, but the analysis does not provide any further explanation for the general increase in the phosphorus concentration in the reservoir.

The **iron concentration** of the outflowing water is chiefly explained by the suspended solids factor (32 %). The river reservoir factor raises the value very little – to only 37.9 %. The contributions of the other factors are negligible, the total percentage being only 40.2.

The suspended solids factor, loading chiefly for the iron, phosphorus and suspended solids concentrations of the inflowing water, makes by far the greatest contribution to the explanation value. As in the discussion of phosphorus in the preceding section, it should be added that this result does not disagree with the general increase in the iron concentration observed in the reservoirs. The position of the river reservoir factor as the second most important factor may indicate that this effect of residence in the reservoirs mainly involves iron present in insoluble form.

Colour. The oxygen deficit factor accounts for 13.2 % of the variation. The suspended solids factor raises the value to 20 % and the clear water factor brings it up to 24.5 %. The contributions of the remaining five factors are small, the final value being 27.3 %.

The fact that the colour of the outflowing water is best explained by the factor loading for the oxygen deficit of the inflowing water is somewhat unexpected, since this factor did not play a significant role in explaining the oxygen saturation percentage of the outflowing water. An oxygen deficit in the inflowing water is a sign of strong biological oxygen consumption, whose reducing effect in the reservoir leads to an increase in colour, chiefly by raising the amount of iron. The position of the suspended solids factor in second place is evidence of the connection between colour and iron. The fact that the clear water factor takes only third place is unexpected, since this factor had its highest loadings for the colour and COD of the inflowing water. The changes affecting water colour during residence in the reservoirs appear to be so dominant in this case that the most important factors do not have any direct dependence on the corresponding property of the inflowing water. In this respect the behaviour of colour is the same as that of COD.

3.4 Changes in the chemical properties of the water with aging of the artificial lakes

Using automatic data processing, trends were determined for the 1 m and maximum depths in the reservoirs, and for the inflowing and outflowing water as well. The data for each reservoir were first divided into three groups representing the conditions in different seasons. The first series scanned comprises March-April (months 3–4), the second July-August (months 7–8) and the third October-November (months 10–11) (Table 6).

The data for the reservoir proper revealed 61 trends; the inflowing water had 14 and the outflowing water 8. The changes are thus clearly concentrated in the water of the reservoirs. The reservoir data for late winter (months 3–4) revealed only 12 trends, but those for late summer (months 7–8) and autumn (months 10–11) 24 and 25, respectively. The trends for reservoir oxygen are always positive, while those for electrolytical conductivity, suspended solids and chloride are negative. The other parameters show both positive and negative trends. Of the trends for colour, total nitrogen and total phosphorus, six are positive and 17 are negative.

The oxygen concentration in the open-water period shows a rising trend in five reservoirs. As the basins age, a decrease presumably occurs in the oxygen-consuming heterotrophic microbial production, with a consequent increase in oxygen. Other trends reflecting this course of events and connected with the rise in oxygen are the falling values for electrolytical conductivity, chloride, colour, suspended solids, nitrogen and phosphorus. However, the scarcity of trends for COD and the predominantly positive trends for iron show that the development in this direction is still very slight.

4. SUMMARY

In the 1960s and 1970s, numerous artificial lakes were built in Finland, for flood control, hydropower production and of recreation. The reservoirs are generally very shallow and strongly regulated. A notable proportion of their bottoms consists of peat soil.

The study treats analysis results for the 1960s and 1970s obtained by the National Board of Waters from 21 artificial lakes. According to the means for March-April, the reservoirs differ significantly in several of their properties from the natural lake deep observation stations. They have lower values than the natural lakes for oxygen content and pH, but higher values for chemical oxygen demand (COD), suspended solids, total phosphorus, total nitrogen, iron and colour. Even in July-August the oxygen content of the surface water is 30 % below the saturation value. In reservoirs with even brief thermal stratification in summer, a large oxygen deficit develops in the

Table 6. The number of statistically significant trends (95 % probability level) in artificial lakes.

	Period*	O_2mg/l				O_2%				ϑ20				pH				Colour				COD			
		1m		max. dep.		1m		max. dep.		1m		max. dep.		1m		max. dep.		1m		max. dep.		1m		max. dep.	
		+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–
Inflowing water	I	1	1			1	1				2				1										
	II																								
	III																						1		
Lake	I										2					1			2	1					
	II	3		1		3		1					1	1	1			2	2			1			
	III	3				3					1		3						1		1		1		
Outflowing water	I		1				1																		
	II										1				1										
	III																								
Sum of trends		7	2	1		7	2	1			6		4	1	3	1		2	5	1	1	1	2		

	Period*	Susp.solids				Tot.N				Tot.P				Fe				Cl				Sum of trends
		1m		max. dep.		1m		max. dep.		1m		max. dep.		1m		max. dep.		1m		max. dep.		
		+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	
Inflowing water	I		1								1			1					1			11
	II																					
	III						1								1							3
Lake	I						1		1					2	1				1		1	13
	II					1				1	2			2		1						23
	III						3		2		2		1	2					1		1	25
Outflowing water	I													1	1							4
	II														1				1			4
	III																					
Sum of trends			1			1	5		3	1	5		1	8	4	1			4		2	83

* I = March-April
II = July-August
III = October-November

hypolimnion. In October-November minima are recorded for suspended solids, total phosphorus, electrolytical conductivity and iron, and a maximum for oxygen.

Stepwise regression analysis was used in an attempt to find connections between the relative changes in the water properties caused by residence in the reservoirs and the physical characteristics of the reservoirs. In most cases the proportion of the variation explained was very small. It was highest in the case of the chloride content, for which the most important independent variables were mean depth (R^2 = 55.8 %) and regulation amplitude R^2 = 63.8 %), the proportion of the variation explained after the seventh step being 67.7 %. Mean depth was also the most important independent variable for COD (R^2 = 31.2 %), but the total proportion of the variation explained was only 36.6 %.

Stepwise regression analysis was also used to examine the influence on the outflowing water of the chemical properties of the inflowing water and the physical properties of the reservoir. With the aid of factor analysis, 17 independent variables, some of which correlated with each other, were condensed into eight new mutually uncorrelated factors (oxygen deficit factor, clear water factor, basin size factor, electrolyte factor, suspended solids factor, mire reservoir factor, river reservoir factor, nitrogen factor). The proportions of the variation explained for the oxygen saturation percentage and the total phosphorus concentration were under 20 %. The most important independent variable for both of them was the suspended solids factor. In the case of the chemical oxygen demand the proportion of the variation explained was 32.6 % and the most important independent variables were the nitrogen factor and the river reservoir factor. The explained proportion for the chloride concentration was 73.6 % and the chief independent variable was the electrolyte factor. The iron concentration was best explained by the suspended solids factor, which accounted for 32 % of the variation (total proportion explained 40.2 %). In the case of colour the eight factors explained only 27.3 % of the variation, the most important of them being the oxygen deficit and the suspended matter factors.

Of the trends revealed by the changes in the water properties, those for oxygen were always positive, whereas negative trends were shown by electrolytical conductivity, suspended solids and chloride. Of the trends for colour, total nitrogen and total phosphorus, six were positive and 17 were negative. However, most of the trends shown by iron were positive. This and the general scarcity of trends indicate that the "aging" of the reservoirs is slow.

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Kaarle Kenttämies

LOPPUTIIVISTELMÄ

1960- ja 1970-luvuilla on Suomeen rakennettu lukuisia tekoaltaita tulvasuojelua, voimataloutta ja virkistyskäyttöä varten. Altaat ovat yleensä hyvin matalia ja tehokkaasti säännösteltyjä. Huomattava osa allaspohjista on turvemaita.

Tutkimuksessa käsiteltiin vesihallinnon 1960- ja 1970-luvuilla 21 tekoaltaasta keräämää analyysimateriaalia. Maalis-huhtikuun allaskeskiarvojen mukaan eroavat tekoaltaat useimpien ominaisuuksiensa kohdalla merkittävästi "luonnonjärvien" ns. valtakunnallisista syvännehavaintopaikoista. Altaiden happipitoisuus ja pH ovat pienempiä, mutta COD, kiintoaine, kokonaisfosfori, kokonaistyppi, rauta ja väri suurempia kuin järvisyvänteillä. Heinä-elokuussakin jää pintaveden happipitoisuus 30 % kyllästysarvon alapuolelle. Altaissa, joissa on edes tilapäistä kesäkerrostuneisuutta, on alusvedessä tällöin suuri hapenvajaus. Loka-marraskuussa ovat kiintoaine, kokonaisfosfori, sähkönjohtavuus ja rauta minimissään ja happi maksimissaan.

Valikoivan, askeltavan regressioanalyysin avulla etsittiin allastuksen aiheuttamien veden ominaisuuksien suhteellisten muutosten ja altaiden teknillisten ominaisuuksien välisiä yhteyksiä. Selitysasteet jäivät useimmissa tapauksissa sangen pieniksi. Parhaiten selittyi kloridipitoisuuden muutos, jonka tärkeimmät selittäjät olivat keskisyvyys (osuus 55,8 %) ja säännöstelykorkeus (63,8 %) selitysasteen ollessa 7. askeleen jälkeen 67,7 %. Myös COD:n ensimmäinen selittäjä oli keskisyvyys (osuus 31,2 %), mutta koko mallin selitysaste jäi 36,6 prosenttiin.

Altaaseen tulevan veden kemiallisten ominaisuuksien ja altaan fysikaalisten ominaisuuksien vaikutusta lähtevään veteen tutkittiin myös valikoivalla askeltavalla regressioanalyysillä. Yhteensä 17 selittäjästä, jotka osin korreloivat keskenään, muodostettiin faktorianalyysiä käyttäen kahdeksan uuden, keskenään korreloimattoman faktorin selittäjäjoukko (happivajausfaktori, kirkasvetisyysfaktori, altaan suuruusfaktori, elektrolyyttifaktori, kiintoainefaktori, suoallasfaktori, jokiallasfaktori, typpifaktori). Happiprosentin ja kokonaisfosforipitoisuuden selitysaste oli alle 20 %. Ensimmäinen selittäjä oli kummallakin kiintoainefaktori. Kemiallisen hapentarpeen selitysaste oli 32,6 % ja tärkeimmät selittäjät olivat typpifaktori ja jokiallasfaktori. Kloridipitoisuuden selitysaste oli 73,6 % ja tärkein selittäjä elektrolyyttifaktori. Rautapitoisuuden tärkein selittäjä oli kiintoainefaktori, jonka osuus (32 %) oli hallitseva kokonaisselitysasteesta (40,2 %). Värin selitysaste oli 8. selittäjänkin jälkeen vain 27,3 %. Tärkeimmät selittäjät olivat happivajausfaktori ja kiintoainefaktori.

Veden ominaisuuksien muutostrendit olivat hapen osalta aina positiivisia, sähkönjohtavuuden, kiintoaineen ja kloridin osalta taas negatiivisia. Värin, kokonaistypen ja kokonaisfosforin trendeistä oli 6 positiivista ja 17 negatiivista. Raudalla esiintyi kuitenkin enimmäkseen positiivisia trendejä. Tämä sekä yleensäkin trendien vähäisyys viittaavat tekoaltaiden "vanhenemisen" hitauteen.

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Appendix 1. The most explanatory regression models of the relative change ($\frac{\text{inlet-outlet}}{\text{inlet}} . 100$) of some chemical characteristics in reservoirs.

The independent variables:

3 filling year of the reservoir (1961= 1, 1962 = 2)
4 area at high stage ($10^4 m^2$)
5 volume at high stage ($10^4 m^3$)
6 mean depth at high stage ($10^{-1} m$)
7 regulation amplitude ($10^{-1} m$)
8 theoretical residence time (days)
9 percentage of peatland

A. The relative change in the oxygen saturation

Step 4. F = 6.25, R = 0.415, degrees of freedom = 120

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value
9	−0.48	0.17	−2.92
6	−0.08	0.03	−2.87
8	−0.13	0.05	−2.59
5	−0.002	0.0008	2.30

Constant term 63.51

B. The relative change of pH

Step 6. F = 8.60, R = 0.55, degrees of freedom = 118

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value
4	0.01	0.002	4.68
8	−0.08	0.02	−5.02
3	−0.94	0.33	−2.89
5	−0.001	0.0005	−2.90
7	0.101	0.04	2.74
6	−2.02	0.007	−2.34

Constant term 13.40

C. The relative change of COD

Step 2. F = 33.12, R = 0.593, degrees of freedom = 122

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value
6	−0.35	0.05	−6.93
3	−5.85	2.14	−2.73

Constant term 28.81

D. The relative change of Cl⁻ concentration

Step 3. F = 78.61, R = 0.813, degrees of freedom = 121

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value
6	−0.25	0.02	−11.04
7	0.34	0.09	3.76
8	0.12	0.04	2.83

Constant term −19.62

E. The relative change of tot. P concentration

Step 3. F = 8.66, R = 0.420, degrees of freedom = 121

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value
8	−1.93	0.41	−4.75
5	0.02	0.006	3.23
3	−28.92	9.25	−3.13

Constant term 272.42

Appendix 2. Rotated factor matrix (varimax solution) of the chemical characteristics of inlet water and reservoirs'technical features.

Variables	Factors								Communality after 8 factors
	1	2	3	4	5	6	7	8	
Oxygen concentration	−0.732	0.178	0.040	−0.041	−0.034	−0.080	0.064	0.094	0.58
Oxygen saturation	−0.714	0.154	0.102	−0.149	−0.025	−0.002	0.207	−0.119	0.58
Chemical oxygen demand	0.169	−0.723	−0.259	0.146	−0.130	0.112	−0.321	0.180	0.73
Suspended solids	−0.020	0.067	0.076	0.035	0.698	0.008	0.134	0.092	0.49
Chloride	0.052	−0.096	−0.007	0.726	0.041	0.047	−0.095	0.021	0.51
Total phosphorus	−0.016	−0.047	−0.005	0.102	0.699	−0.091	0.039	−0.013	0.49
Total nitrogen	−0.016	−0.119	0.017	0.298	0.160	0.212	−0.020	0.467	0.33
Electrolytic conductivity	0.182	0.053	0.023	0.636	0.278	−0.093	0.161	0.197	0.51
pH	−0.251	0.339	0.151	0.166	0.255	0.058	0.601	−0.161	0.60
Iron	0.334	−0.107	0.003	0.226	0.579	0.024	0.300	0.060	0.48
Colour	0.341	−0.767	−0.096	0.028	0.166	0.125	−0.166	−0.025	0.73
Area	−0.097	0.157	0.910	0.010	0.041	0.180	−0.053	0.077	0.89
Volyme	−0.048	0.077	0.945	0.004	0.039	0.011	0.006	−0.053	0.89
Average depth	0.062	0.146	−0.049	−0.123	−0.057	−0.699	0.188	−0.007	0.56
Relative amplitude of regulation	0.130	−0.207	0.112	0.130	−0.134	0.506	−0.756	−0.062	0.91
Residence time	0.160	−0.187	0.104	0.024	−0.254	0.399	−0.791	−0.028	0.91
Peatlands %	0.156	0.029	0.112	−0.157	−0.139	0.561	−0.107	0.181	0.39
Eigenvalues	**3.843**	**2.465**	**2.114**	**0.920**	**0.752**	**0.573**	**0.399**	**0.283**	

Appendix 3. The most explanatory regression models of outflowing water characteristics with the factors of inflowing water and reservoirs' physical features as independent variables. (The factor-score variables were formed to correspond to the accepted factor solutions (Appendix 2) using the method of Lederman.)

The independent variables:

1. Oxygen deficit factor
2. Clear water or colour factor
3. Basin size factor
4. Electrolyte factor
5. Suspended solids factor
6. Mire reservoir factor
7. River reservoir factor
8. Nitrogen factor

A. Oxygen saturation percentage

Step 8. F = 4.39, R = 0.186, degrees of freedom = 117

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value	Included in multiple correlation squared
5	−0.013	0.003	−4.92	0.147
8	0.006	0.003	2.13	0.023
1	−0.004	0.003	−1.62	0.004
3	−0.002	0.003	−0.89	0.004
2	−0.002	0.003	−0.89	0.002
4	0.001	0.003	0.43	0.002
6	−0.001	0.003	−0.32	0.0004
7	−0.00008	0.003	−0.03	0.0001

Constant term = 15.19

B. The chemical oxygen demand (COD)

Step 8. F = 7.07, R = 0.326, df = 117

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value	Included in multiple correlation squared
8	0.032	0.008	3.92	0.089
7	−0.030	0.009	−3.51	0.071
4	0.023	0.008	2.82	0.046
2	−0.020	0.008	−2.41	0.033
3	−0.017	0.008	−2.05	0.024
1	0.014	0.008	1.73	0.017
6	−0.006	0.008	−0.72	0.003
5	0.006	0.008	0.71	0.003

Constant term = 28.73

C. Suspended solids

Step 8. F = 3.314, R = 0.185, df = 117

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value	Included in multiple correlation squared
5	0.023	0.008	2.91	0.059
7	0.014	0.008	1.71	0.020
4	0.014	0.008	1.80	0.023
2	0.013	0.008	1.72	0.021
6	−0.014	0.008	−1.79	0.022
1	−0.007	0.008	−0.92	0.005
8	0.004	0.008	0.57	0.002
3	0.003	0.008	0.45	0.001

Constant term = −14.20

D. Chloride

Step 8. F = 40.81, R = 0.736, df = 117

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value	Included in multiple correlation squared
4	0.009	0.0008	12.02	0.326
6	−0.009	0.0008	−10.85	0.265
2	0.004	0.0008	4.91	0.054
3	−0.003	0.0008	−4.06	0.037
8	−0.002	0.0008	2.00	0.009
7	0.002	0.0008	2.07	0.010
1	0.001	0.0008	1.10	0.003
5	−0.002	0.0008	−0.23	0.0001

Constant term = 0.82

E. Total phosphorus

Step 8. F = 3.32, R = 0.185, df = 117

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value	Included in multiple correlation squared
5	0.277	0.070	3.93	0.108
4	0.155	0.070	2.22	0.034
1	0.095	0.070	1.36	0.013
8	−0.077	0.069	−1.12	0.009
6	−0.052	0.071	−0.74	0.004
7	−0.043	0.072	−0.59	0.002
3	−0.036	0.070	−0.52	0.002
2	0.007	0.069	−0.10	0.00007

Constant term = −37.53

F. Iron concentration

Step 8. F = 9.83, R = 0.402, df = 117

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value	Included in multiple correlation squared
5	12.657	1.781	7.11	0.258
7	6.336	1.818	3.49	0.062
1	2.941	1.766	1.66	0.014
2	1.568	1.739	0.90	0.004
4	1.357	1.761	0.77	0.003
8	−0.864	1.746	−0.49	0.001
6	−0.696	1.786	0.39	0.0008
3	−0.617	1.762	−0.35	0.0006

Constant term = −9079.17

G. Colour

Step 8. F = 5.48, R = 0.273, df = 117

Independent variable	Regression coefficient	Standard deviation of regression coefficient	t-value	Included in multiple correlation squared
1	0.325	0.079	4.08	0.104
5	0.270	0.080	3.36	0.070
2	−0.196	0.079	−2.50	0.039
6	0.096	0.080	1.19	0.008
7	−0.083	0.082	−1.01	0.006
3	−0.076	0.080	−0.96	0.006
8	0.067	0.079	0.84	0.004
4	−0.037	0.079	−0.46	0.001

Constant term = 100.8