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Seasonal Fluctuations of Physical and Chemical Parameters of a Weir Basin in a Regulated West Norwegian River

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Both before (1967-69) and after (1976-78) the regulation of the river Ekso in western Norway, physical and chemical analyses were made of the river water. After the regulation water samples for chemical analyses were taken at the inlet and outlet of a weir basin 375 m long which had recently been built to maintain the previous water level.

The reduced water discharges and the increased water temperatures which followed the regulation presumably increased the amount and the quality of food available to detritusfeeding animals.

The O_2 content of the water was slightly reduced after the regulation. The pH was in the same range. Specific conductance (κ_{20}) and the concentrations of major ions before the regulation (Ca^{2+}, Cl^-, NO_3^--N, PO_4^{3-}-P) and after the regulation (Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^--N. NH_4^+-N, PO_4^{3-}-P) were also in the same range, but a distinct seasonal variation appeared after the regulation.

These variations were thought to have three main reasons:
1) water discharge, 2) biological production, 3) nonspecified physicochemical relationships.

Ionic fluxes through the weir basin were highest during the autumn. Only small differences were found between the inlet and outlet of the weir basin.

Regression analyses based on the concentrations of major ions and water discharge after the regulation were made separatly for the summer and the winter season. κ_{20} and SO_4^{2-}-concentrations were not correlated to water discharge, Cl^--concentrations were positively correlated, whereas Ca^{2+} showed a negative correlation. Mg^{2+} and NO_3^--N were not correlated to water discharge during the summer season, but showed a significant negative correlation during the winter.

Introduction

In Norway many rivers are subject to hydroelectric exploitation. A general feature of many of these rivers is the reduced water discharges. In some regulated rivers weirs have been built in order to maintain the previous water levels. In 1975 a research project, The Weir Project, was started in order to clarify the biological effects of small impoundments in rivers (Mellquist 1976). The main part of the research were carried out in the river Ekso, western Norway.

A weir basin can be considered an open ecosystem with a number of inputs and outputs. Besides the biological investigations of the weir basin ecosystem, physical and chemical measurements were carried out simultaneously. The purposes of this work were to describe the physical and chemical properties in the river Ekso and to produce a balance sheet which illustrates, on a gross scale, the chemical dynamics of the weir basin ecosystem. We would also look at the changes in chemical composition of the river water and compare these to physical changes caused by the regulation and, since abiotic and biotic factors are closely linked together, to biological changes in the river ecosystem.

Study Area

The river Ekso originates in high altitude lakes some 800 m a.s.l. (Fig. 1). It drains a V-shaped valley and runs into the sea about 42 km from the origin. The river course is characterized by slowflowing stretches interrupted by steep falls in a steplike manner.

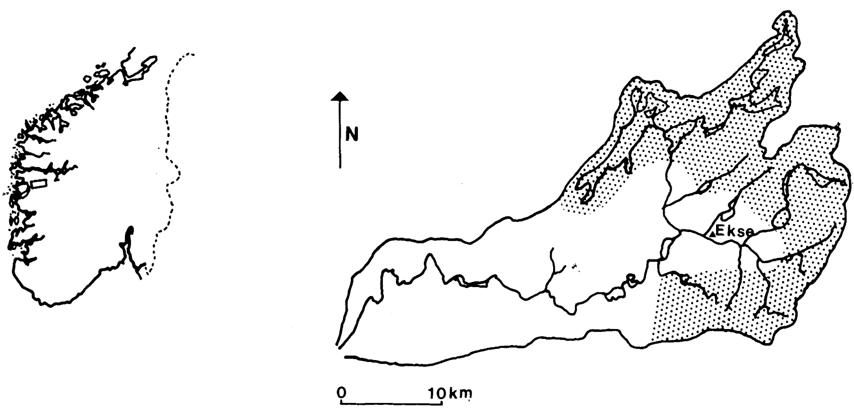

Fig. 1. The Eksingedalen valley and its geographical position in Norway. Shaded area denotes the regulated chatchment area.

The weir basin is located at Ekse (60°50'N, 6°15'E) in the upper part of the valley, 560 m a.s.l. within the subalpine birch woodland belt. Prior to the regulation the catchment area at Ekse was 81.1 km^2. After the regulation it has been reduced by 75%. The predominating bedrocks of the catchment area are quartzite, granulite, and phyllite. The mean annual precipitation is about 1,800 mm.

The weir basin is 375 m long and about 28 m wide. At low water discharge (0.2 m^3s^{-1}), the depth in the downstream part is about 1.5 m gradually decreasing to about 0.4 m in the upstream part. The substrate in the deepest parts consists of fine sand and organic matter, whereas in the shallow upstreams end gravel and stones predominate.

The predominating trees are birch (*Betula pubescens* Ehrh.) and willows (*Salix* spp.). The aquatic vegetation comprises algae, mostly diatoms, and scattered patches of mosses (Baekken et al. in press). The most common animal groups of the river are chironomids, oligochaets, mayflies, and stoneflies. The only fish species is brown trout (*Salmo trutta* L.).

Methods

During the period of investigation preceding the regulation and weir building, water samples for chemical analyses were taken regulary from April to December every year. Water temperatures were measured simultaneously and water discharge was continuously registered at a station about 8 km below Ekse (Fig. 1). The following analytical methods were used: EDTA-titration (Ca^{2+}), Potensiometry (Cl^-), the Kjeldahl method (NO_3^--N), and Colorimetry (ortho-PO_4^{3-}-P) (American Public Health Association 1965). pH and specific conductance were measured by ordinary equipments and the oxygen contents were determined by the Winkler titration method.

After the regulation and the weir building, the water samples for chemical analyses were taken regulary every fortnight from November 1975 to September 1978. The oxygen content, the pH, and the specific conductance of the river water were measured both at the in- and outlet of the basin during the first year. The analyses of ions at the inlet were made every year, whereas at the outlet the analyses started in February 1977. The concentrations of different ions were found using the following analytical methods:

Perkin-Elmer Atomic Absorption Spectrophotometer (Ca^{2+}, Mg^{2+}), the Thorin method (SO_4^{2-}), and Colorimetry (Cl^-, NO_3^--N, NH_4^+-N, ortho-PO_4^{3-}-P). pH, specific conductance, and oxygen contents were measured as before the regulation. Water discharge during 1976, 1977, and 1978, and water temperature during 1976 and 1977 were continuously registered by a limnigraph and a termograph respectively, both situated in the upstream part of the weir basin.

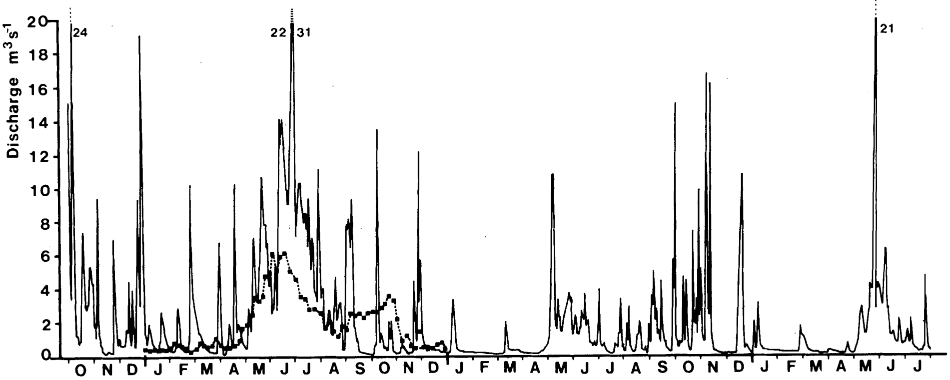

Fig. 2. Water discharge at Ekse from Oct. 75 to July 78 (daily means) and at a station 8 km below Ekse during 1967 (5 days means as black squares). The actual values during 1967 are ten times those shown on the graph.

Results

Water Discharge, Runoff, and Water Temperature

The water discharge at Ekse after the regulation and the discharge found about 8 km downstream Ekse before the regulation are shown in Fig. 2. The discharge pattern in 1976 looked quite similar to that found before the regulation. During the May – August period 1976, the discharge was very high compared to those found during the same months the successive two years as also demonstrated by the runoff (Table 1).

Prior to the regulation, in 1967 and 1968, the water temperatures were 0°C from December to May when ice covered the river. The highest temperature was found in July 1968 with 10°C (Fig. 3). After the regulation, during 1976 and 1977, the water temperatures were 0°C from medio November to May. Ice covered the river during the same period. In general, the water temperatures were higher in the regulated river than they were before the regulation.

Table 1 – Runoff values from January 76 to July 78 based on the catchment area at Ekse before the regulation. The unit is $ls^{-1}km^{-2}$.

	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1976	12.7	18.4	17.4	19.3	60.5	126.2	89.6	25.8	29.1	14.6	18.1	4.9	36.4
1977	7.0	1.5	4.1	2.0	35.0	18.8	9.2	10.0	28.3	26.6	25.5	18.2	15.5
1978	7.4	3.3	2.8	2.1	43.6	25.3	9.7						

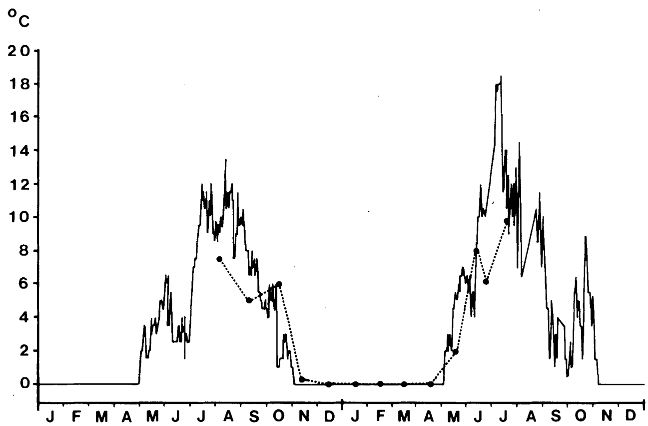

Fig. 3. Water temperature at Ekse during 1976 and 77 (solid line) and from Aug. 67 to July 68 (stippled line).

Oxygen, pH, and Specific Conductance

The river water was always supersaturated with oxygen during the 1967-1969 period, whereas after the regulation there was a slight subsaturation except for some periods in the summer and the autumn (Table 2). Differences between the inlet and the outlet were most pronounced in the autumn and the winter, usually with the largest values at the inlet.

The water was slightly acid both before and after the regulation, values ranging between 5.7-6.8 and 5.8-6.8, respectively (Table 2). There were only minor differences between the pH values at the inlet and the outlet of the basin.

Prior to the regulation the specific conductance (H_{20}) ranged from 7 to 48 μScm^{-1} having the highest peak in August/September each year. After the regulation the conductance was in the same range. However, a more distinct seasonal variation appeared showing high values during the winter and low during the summer. Except for one sample in July 1976, there were only minor differences of conductance between the inlet and the outlet of the weir basin (Table 2).

Concentrations and Fluxes of Different Ions

The concentrations of ions from before (Ca^{2+}, Cl^-, NO_3^--N) and after (Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-, NO_3^--N) the regulation are shown in Fig. 4. During the 1967-1969 period there was no seasonal pattern in the variation of the concentrations. The concentrations were lower in 1967 than in the following two years. The amount of phosphate-phosphorus was less than 2 μgl^{-1}. After the regulation the concentrations of ions showed a regular seasonal pattern except for the amonium-nitrogen and phosphate-phosphorus. The highest rate of change in the concentrations occurred about May and September. The concentrations of ammonium-nitrogen

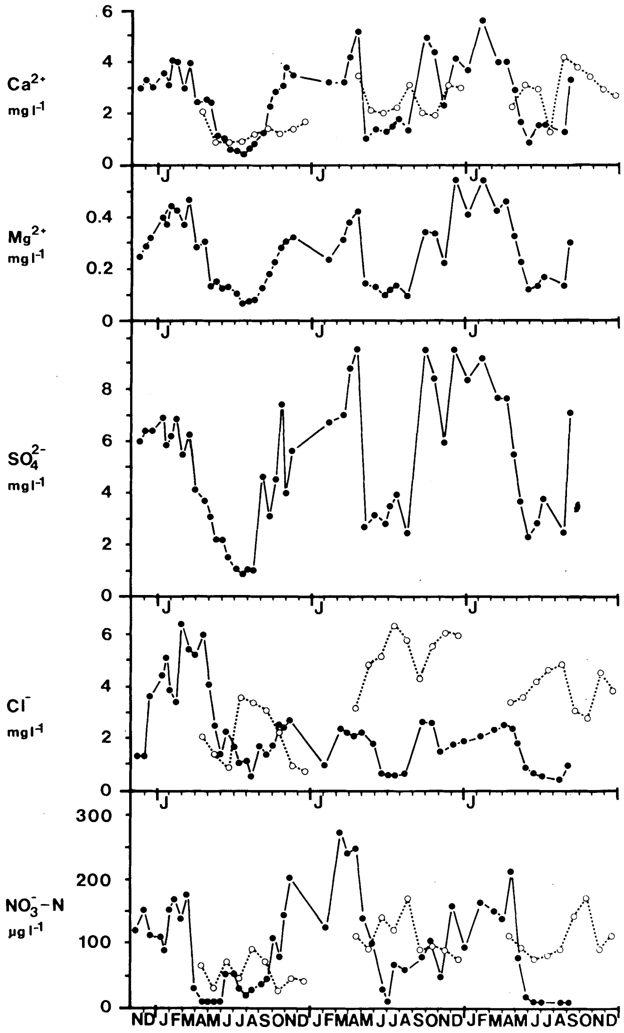

Fig. 4. Concentrations of major ions at the inlet of the weir basin at Ekse from Nov. 75 to Sep. 78. Open circles denote concentrations found at Ekse during 1967, 68, and 69.

were mostly less than 10 µgl^{-1}. However, in some periods, particularly in the autumn, the values were higher. The concentrations of phosphate-phosphorus were mostly less than 2 µgl^{-1}.

The ionic fluxes through the weir basin were highest during the autumn (Sept.-Dec.) showing a mean sulphate flux of about 43 tons a month. The other ions had lower values (Table 3). Flux-differences between the inlet and outlet were small.

Table 2 – Oxygen saturation, pH, and specific conductance ($\varkappa_{20}$) in the river water at Ekse before the regulation (1967-69) and after the regulation (1976). »In« and »Out« refers to the inlet and outlet of the weir basin.

			J	F	M	A	M	J	J	A	S	O	N	D
	1967													
% 0_2	1968						>100							
	1969													
	1976	In	92	97	94	93	97	97	97	92	93	99	97	96
		Out	88	95	92	91	99	96	98	93	91	97	87	93
	1967					6.4	6.1	6.2	6.5	6.8	6.2	6.4	6.5	6.7
pH	1968					6.5	6.3	6.0	6.1	5.9	6.2	6.3	6.4	6.2
	1969					6.0	6.2	5.9	5.7	5.8	6.1	6.2	6.4	6.0
	1976	In	6.1	6.4	6.3	6.2	6.3	6.4	5.9	6.6	6.5	6.8	6.3	6.2
		Out	6.0	6.3	6.2	6.2	6.2	6.2	5.9	6.3	6.2	6.7	6.2	6.2
	1967					19	10	7	15	22	35	12	20	18
$\varkappa_{20}$	1968					19	25	30	35	38	10	15	19	18
	1969					15	22	17	35	48	20	11	9	17
	1976	In	42	49	47	38	30	18	23	12	23	32	38	34
		Out	40	49	44	37	28	17	12	10	23	37	38	34

Table 3 – Mean ionic fluxes per month into and out of the weir basin at Ekse from March 1977 to July 1978. The unit is $kg.month^{-1}$.

		1977 March-April	May-Aug.	Sept.-Dec.	1978 Jan.-April	May-June
	in	3545	4898	20693	3378	7123
Ca^{2+}	out	3135	4990	25328	3168	6937
	in	620	905	3658	723	1727
Mg^{2+}	out	585	955	4208	670	1700
	in	7020	11133	43645	6715	16730
SO_4^{2-}	out	6485	11273	43083	6500	15623
	in	1775	4928	11358	1735	5830
Cl^-	out	1845	4658	11328	1760	5660
	in	206	305	493	107	162
NO_3^--N	out	189	281	396	100	169
Water discharge $10^{-3}m^3 \cdot month^{-1}$		809	3839	5274	823	5599

Discussion

A rough estimate shows that about 60% of the water discharge at Ekse during 1976 was derived from the regulated catchment area; i.e. released from the water power basin (Table 4). The large release was due to improvement works on the dam. During 1977 only about 8% of the water discharge was derived from the regulated catchment area, reflecting the common situation in regulated rivers.

Generally, in cases of reduced water discharge, the rate at which organic and inorganic matter are carried down the river and ultimately washed to the sea is also reduced. The rate of transport is in addition strongly affected by the topography of the watercourse and is artificially reduced by the building of weirs. The retention time of dead organic matter (detritus) in the river is then prolonged increasing the amount available to detritivors. The rise of water temperature which followed the regulation will certainly increase the microbial activity of the detritus and increase its nutritional quality (Hynes and Kaushik 1969, Iversen 1973, Ward and Cummins 1979).

Most of the energy to this weir basin is of allochthonous origin (Baekken et al. in press) and the oxygen demand is high compared to the oxygen production. This is reflected by the lower oxygen content of the outlet water during most of the year.

A marked acidification has been observed in southern Norway during the last decade (Semb 1976, Wright et al. 1976). In the river Ekso there was, however, not observed any acidification indicating the presence of effective buffering mechanisms of the drainage area.

Most rivers in mountain areas and along the western coast of Norway are characterized by low concentration of major ions. The river Ekso fits this pattern. Higher conductivity are associated with rivers draining more or less polluted, lowland, urban areas, and areas with sedimentary rocks (Salbu et al. 1979).

The postregulation data for the concentration of different ions can be divided into two separate data populations; high concentration during the winter and low during the summer which coincide with low and high water discharge, low and high biological production, and low and high temperature, respectively. The use of nitrate-nitrogen in primary- and secondary production presumably accounts for

Table 4 – The mean annual runoff at Ekse based on the catchment area after the regulation. The precipitation is estimated to 1800 mm a year. WPB-release, Water Power Basin-release, indicate the amount of water derived from the regulated catchment area. The unit is $ls^{-1}km^{-2}$.

	Runoff	Precipitation	WPB-release (%)
1976	145.6	57.1	88.5 (61%)
1977	62.0	57.1	4.9 (8%)

its low concentrations during summer. Minimum concentrations of nitrate during the high-productive season are also found elsewhere (Johnson et al. 1969, Owens et al. 1972). Phosphate is readily taken up by plants and micro-organisms and was only occasionally (probably a pollution effect) found in significant amounts during this study. The other ions are less associated with biological production (Johnson et al. 1969, Whittaker et al. 1979) and their low summer concentrations are probably caused by dilution at high summer discharge or by other, maybe temperature dependent factors e.g. physicochemical relationships.

In order to examine the effect of water discharge on the concentration of ions, the inlet data of each ion from 1976, 1977 and 1978, where put together. A regression analysis was made separately for each of the two seasons using a model of logarithmic transformed water discharge on the abscissa and a linear scale of concentrations on the ordinate. Summer season is defined as the time from the most rapid decrease of concentrations to the most rapid increase of concentrations, winter season is the remaining part of the year.

There was no significant relationship between specific conductance and discharge or between sulphate concentration and discharge (Fig. 5). Much of the sulphate is derived from the atmosphere (Nordø 1976). Førland (1973) showed that precipitation falling from air masses that have passed over strongly industrialized areas have higher concentrations of sulphate ions than precipitation from other air masses. This may cause an irregular sulphate supply to the drainage area and affect the sulphate concentrations of the river water in the same way.

The precipitation also accounts for most of the input of chloride to the river. When extrapolating the data of Skartveit and Førland (1976), we expect the concentrations of chloride in the precipitation in this area to be in the range 2.5 – 3.5 mgl^{-1}, which is somewhat above the concentrations found in the water during high summer discharges (and heavy rain). The significant positive correlation found between water discharge and chloride concentrations during the summer (Fig. 5) might therefore have been caused by rain water (high chloride content) which has a successively larger part of the river water at increasing discharges. In periods of snowmelt during winter, chloride ions are released from the snowpack (Skartveit and Gjessing 1979). This may explain the apparent positive correlation between water discharge and chloride concentration during the wintertime.

The atmospheric input of calcium is low. Thus the calcium source is to be found within the drainage area itself. This was also indicated by the dilution of calcium ions with increasing discharges (Fig. 5). A similar situation was found for magnesium and nitrogen during the winter. During the summer, however, there was not detected any significant relationship between water discharge and the concentration of magnesium and nitrogen.

To summarize it is evident, although we lack some data, that the regulation has changed the chemical conditions of the river water with respect to seasonal variations. Factors regulating these variations may be 1) water discharge, 2) biological

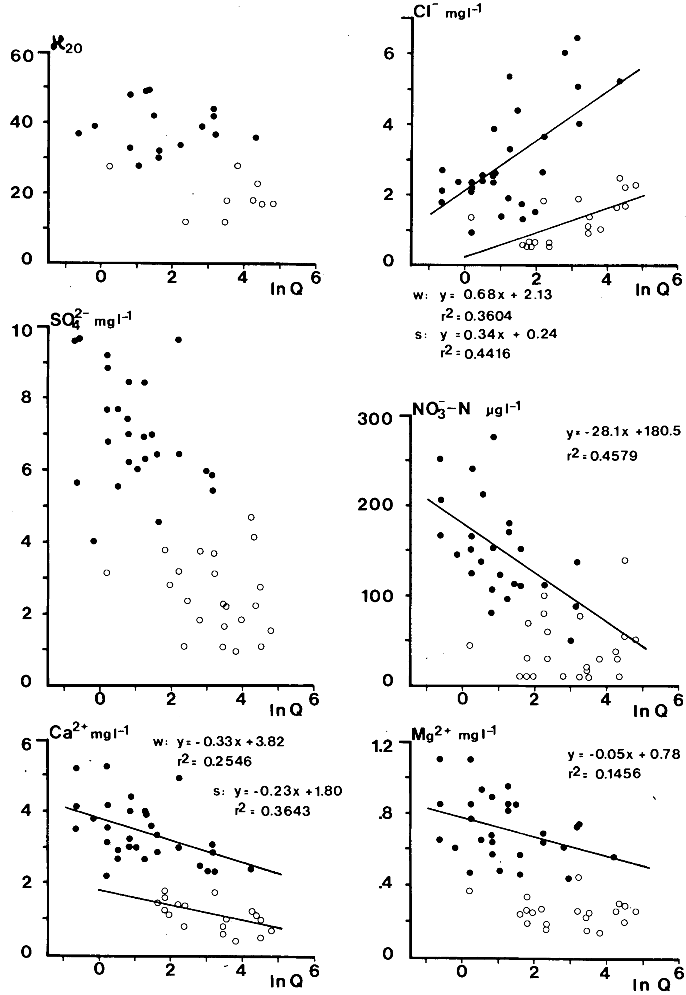

Fig. 5. The relation between specific conductance, concentrations of major ions and the water discharge. Only significant regression lines are drawn ($p < 0.05$). s and open circles denote summer season, whereas w and black circles denote winter season. Q is the water discharge.

activity 3) nonspecified physicochemical factors.

With regard to plant nutrients, primarily nitrate-nitrogen, the second factor is the most important. Although we are well aware that the other ions are also more or less used in biological production e.g. magnesium is essential in the chlorophyll, we presume that the biological factors is of minor importance relative to factors 1) and 2), maybe particularly the water discharge. Also within the two seasons (summer and winter) we have demonstrated that the water discharge is of prime importance in regulating the concentration of some ions whereas for other ions no relation could be found.

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