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LEACHING IN THE MATERIAL BALANCE OF PEATLANDS — PRELIMINARY RESULTS

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The hydrology and hydrochemistry of Lakkasuo (Orivesi, central Finland) was studied for a 12-month period (September 1991–August 1992). Results from four monitored catchments in Lakkasuo are presented. The catchments represent a bog and a fen, both in the natural state and as drained for forestry 30 years ago. In the relatively wet study period (runoff 414 mm for the undrained bog), the catchments released 8.0–16.6 g m^{-2} of organic carbon (mainly dissolved) into runoff waters. All the catchments retained total N and sulphate provided by deposition or groundwater very effectively (65–80% and 52–72%, respectively); undrained catchments retained also total P. The net output rates of all the elements except H+ were greater from the drained catchments compared with the undrained ones. The leaching rates of Mg and Ca from the drained catchments were great compared with the pool of these elements in the surface peat, whereas the K pool is more effectively retained and added to by deposition.

Keywords: Bog, fen, hydrochemistry, hydrology

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INTRODUCTION

Mires in the natural state acquire their carbon and, to a lesser extent, also their nitrogen, by fixing atmospheric gases. In the case of inorganic elements, peatlands rely upon inputs carried by water or by dry deposition.

Peatlands do not accumulate only organic material, but also inorganic elements ("ash"). Accumulation is a process which competes with leaching. Peatlands may be regarded as primary sources of organic carbon or nitrogen in runoff waters, since these may originate from large atmospheric reservoir. With respect to inorganic elements, a mire ecosystem is not a primary source, but rather a sink, for these elements.

Ditching of a mire changes the material balance both abruptly and in the long run. Ditches cut off the waters originating in the uplands, thus preventing them from entering the acrotelm of the mire. The aeration of the peat is improved and the mobilization of the nutrients from the peat is increased. Biomass reacts to the altered conditions. The changes are reflected in the runoff water quality and quantity, too. However, the quality of the water of different natural mires and both the immediate and, especially, the long-term effects of peatland drainage for the leaching process are still inadequately understood.

AIM OF STUDY

The main objectives of this subproject of SUOSILMU are to determine:

- the role of leaching and retention in the long-term material balance of mires
- the primary regulators in the leaching process
- the manner in which climatic change affects the rates of leaching from peatlands.

This report describes the hydrology and hydrochemistry of Lakkasuo, one of the main research sites of SUOSILMU, based on monitoring for 12 months.

MATERIAL AND METHODS

There have been 6 runoff-water quality monitoring sites in Lakkasuo, two of which are gauged. In addition, water samples have been collected from 12 wells installed in Transects 1–6, with each transect representing the same mire-site type both in the natural state and as drained for foresty 30 years ago.

The monitoring programme includes also deposition quality and quantity, water quality and quantity monitoring in the main inlets from the esker feeding the mire and water-level monitoring in the esker (Table 1, Fig. 1).

The esker has a perched and rather stable water table, ranging from about 158 m above sea level in E1 to 157 m in E9. The situation is made possible because of moraines with poor hydraulic conductivity surrounding the central area of highly permeable sand. The main direction of water flow in the esker is from south to north; a sharp water divide is situated close to ES, and a bedrock threshold near EN serves to control the water level. The sizes of the minerotrophic catchments have been calculated on the basis that the border of the catchment against the esker is at the same altitude as the average water level in the esker. The water inputs to the minerotrophic catchment originating outside the assumed border of the catchment have been calculated from the water balance, using the ombrotrophic catchment as a reference catchment for estimating evaporation.

Water samples have been analyzed for pH, alkalinity, conductivity, inorganic and organic carbon, N, nitrate, ammonium, P, Na, K, Ca, Mg, Al, Fe, Zn, Mn, S, Si, chloride and sulphate.

The material fluxes carried by water for each monitoring site can be calculated or estimated. Catchment 2 has been used as representative of a minerotrophic catchment, assuming the same specific runoff rate as in the gauged Catchment 1. For the drained catchments (Catchments 5 and 6) the runoff data from a nearby gauged forest drained catchment (Lyly 5) have been used to calculate the output rates of elements.

This paper is a preliminary one. For example, combining the results with other monitoring data from Lakkasuo is a task for the future. Especially important for this project are the dated peat profiles, which enable the long-term accumulation rates (annual retention) of elements to be determined.

RESULTS

Precipitation in the study area over a 12-month period (September 1991–August 1992) was 835 mm, which is about 150 mm more than the average annual precipitation in Hyytiälä (5 km north). The ombrotrophic catchment (Catchment 4) produced 414 mm of runoff, which is also about 150 mm more than the long-term mean value for a forested catchment 14 km south of Lakkasuo (Fig. 2).

The minerotrophic catchment, the size of which has been calculated excluding the esker, produced 645 mm of runoff during the same period. Assuming the same evaporation rate and same change in water storage for the bog and the fen, the fen catchment would have received 231 mm of water inputs from the esker, which yields a mean value of about 3.1 l s^{-1}. The figure is reasonable; the size of the groundwater-forming area of the esker is about 70 ha, which would form about 6–9 l s^{-1} of groundwater as an annual mean in average weather conditions. Part of this groundwater is discharged west of the esker, and part flows north over a bedrock threshold near EN (Fig. 1).

A greater part of the groundwater flow from the esker enters the mire as channel runoff origi-

Table 1. The runoff-water monitoring sites of Lakkasuo.

Catchment	Size, ha	Peatland, %	Remarks
1	>42	<75	Natural minerotrophic, gauged
2	>30	<75	Natural minerotrophic
3	>10	<95	Natural minerotrophic
4	29	100	Natural ombrotrophic, gauged
5	2	100	Drained minerotrophic
6	2	100	Drained ombrotrophic

nating in springs or man-made ditches, which are situated up to several meters higher than the minerotrophic part of the mire. Inlet R (Fig. 1) alone brings about half of the excess minerotrophic inputs.

Due to the high water table and relatively steep slope, the minerotrophic mire responds to rain very quickly also after dry periods. Therefore, the summer peak flows are far greater from the natural fen catchment than from the bog catchment.

Water quality in different sampling points of the mire is determined largely by the ratio of minerotrophic inputs and rainwater, which have a huge difference in their concentrations (Table 2). The minerotrophic water is particularly en-

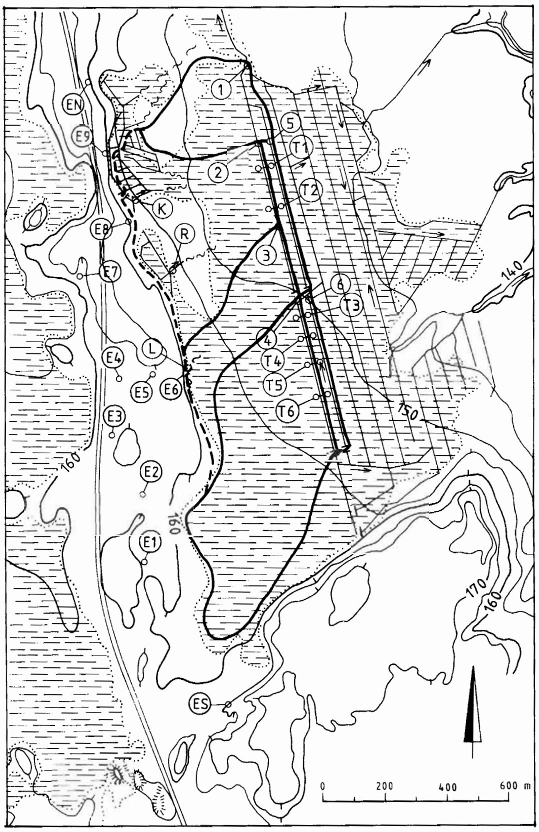

Fig. 1 (Right). The monitoring sites at Lakkasuo: 1–6 = Runoff water quality. T1–T6 = Transects (peatland groundwater wells for water quality monitoring). K, R, L = Inlets for water quality monitoring. E1–E9, EN, ES = Groundwater level monitoring wells in the esker.

Fig. 2 (Below). Monthly precipitation and runoff at Lakkasuo during the study period and long-term (1961–1980) data for a nearby site.

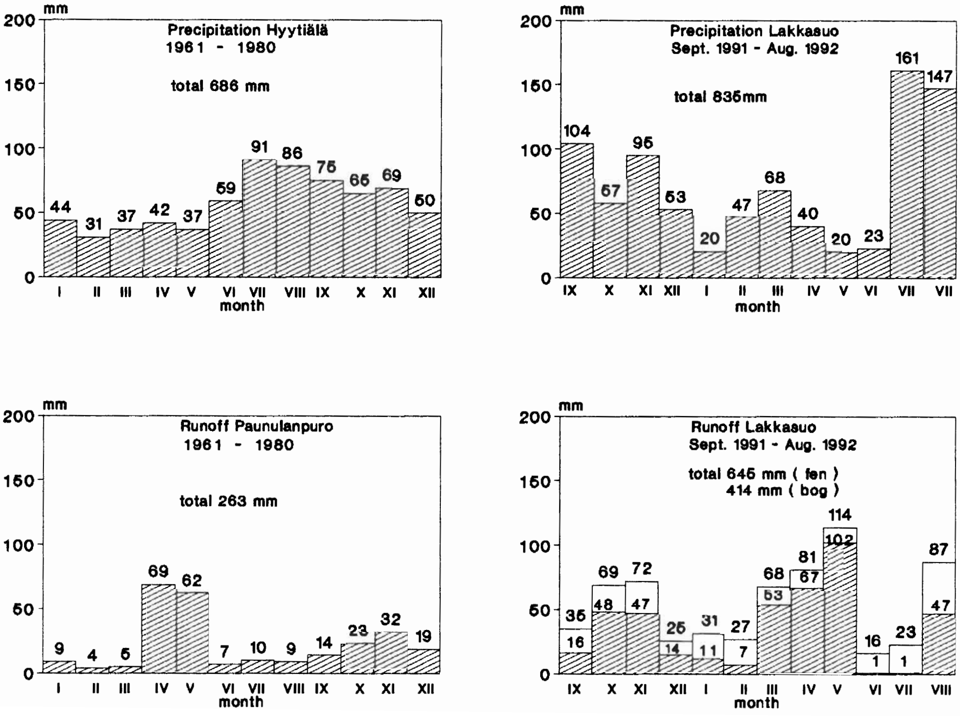

Table 2. Mean concentrations (Sept. 1991–Aug. 1992) in deposition, in the main inlet to the mire from the esker, in Catchments 2 and 5 (natural and drained fen) and in Catchments 4 and 6 (natural and drained bog). Values for Inlet R are from August 1992 only.

	Org. C, mg/l	Ca, mg/l	Mg, mg/l	Na, mg/l	K, mg/l	Cl, mg/l	SO_4, mg/l	N, µg/l	P, µg/l
Deposition	3.6	0.14	0.07	0.23	0.10	0.35	2.50	860	14
Inlet R	2.9	5.00	1.40	2.80	0.93	9.70	4.70	40	4
Catchment 2	12.4	1.69	0.55	1.57	0.61	2.43	2.57	219	6
Catchment 5	30.6	2.97	0.70	1.36	0.33	0.90	1.89	547	24
Catchment 4	30.0	0.41	0.18	0.50	0.19	0.47	1.42	343	10
Catchment 6	36.0	1.44	0.39	1.03	0.26	0.69	2.05	460	30

riched in chloride and sodium, due to spreading of salt on the roads in winter. Chloride enrichment can be seen in the undrained minerotrophic sites only.

The output rates of DOC vary from 8.0–16.6 g m^{-2}. The outputs are lower from the natural catchments compared with the drained ones (8.0 *versus* 14.1 g m^{-2} for the fen catchments, 12.4 *versus* 16.6 g m^{-2} for bog catchments, respectively). However, if expressed per peatland area of the catchments, the variation is only from 10.7–16.6 g m^{-2}.

The output rates of all the inorganic elements, too, are higher in the drained bog compared with the natural bog; in the fen catchments, the output rates of Mg, K, chloride and sulphate are higher in the undrained site. However, if a preliminary balance for the elements is constructed, it can be seen that the larger outputs are explained by inputs from the esker (Fig. 3).

Actually, all the catchments retain nitrogen and sulphate very effectively. Part of the sulphur entering the mire as sulphate leaves it as organic sulphur. This reduces the overall retention of S; for example, in the undrained bog, sulphate retention was 72%, but retention of total S only 52%.

Undrained catchments retain also phosphorus. Inputs nearly equal outputs in the undrained catchments for Ca, Mg, Na and K. The small discrepancies can be explained by the short study period. Indicated net outputs for, e.g., Ca and Mg for the natural bog may still make long-term net accumulation possible. However, the drained catchments obviously loose Ca, Mg, Na and also K at a rate which is high compared with the inputs from deposition.

The water quality results from the groundwater wells in Transects 1–6 (results not shown) give basically the same picture as runoff water monitoring. However, when comparing the values, it becomes certain that the quality of runoff water of Catchment 6 (drained bog) is slightly influenced by minerotrophic peat layers, which reach up to less than one meter in depth in this catchment. Although the surface vegetation is almost totally ombrotrophic, runoff-water quality shows some minerogenic influence.

Another clear difference in the quality of runoff-water and peatland groundwater is in the high concentrations of ammonium in the groundwater wells of the drained sites (up to more than 1 mg l^{-1} in Transect 1), especially when the groundwater level is deep down. Ammonium concentrations in runoff are highest in wintertime low-flow periods (up to 0.3 mg l^{-1} in Catchment 5).

DISCUSSION AND CONCLUSIONS

The observed leaching rates of organic carbon are of the same magnitude or slightly less than the long-term mean accumulation rates of organic carbon in natural mires in Finland (Tolonen et al. 1992). The relatively high leaching rate of organic matter has several important consequences for runoff water quality; organic matter is acidic in character and affects the leaching behaviour of cationic elements. The acid-base chemistry of natural and drained mires will be discussed in forthcoming papers. Nitrogen, phosphorus and also sulphur are leached to a considerable degree in organic form. Iron and aluminium form complexes with organic matter. These phenomena are not discussed in this preliminary paper.

From previous studies in Finnish conditions we know that N and P are effectively retained

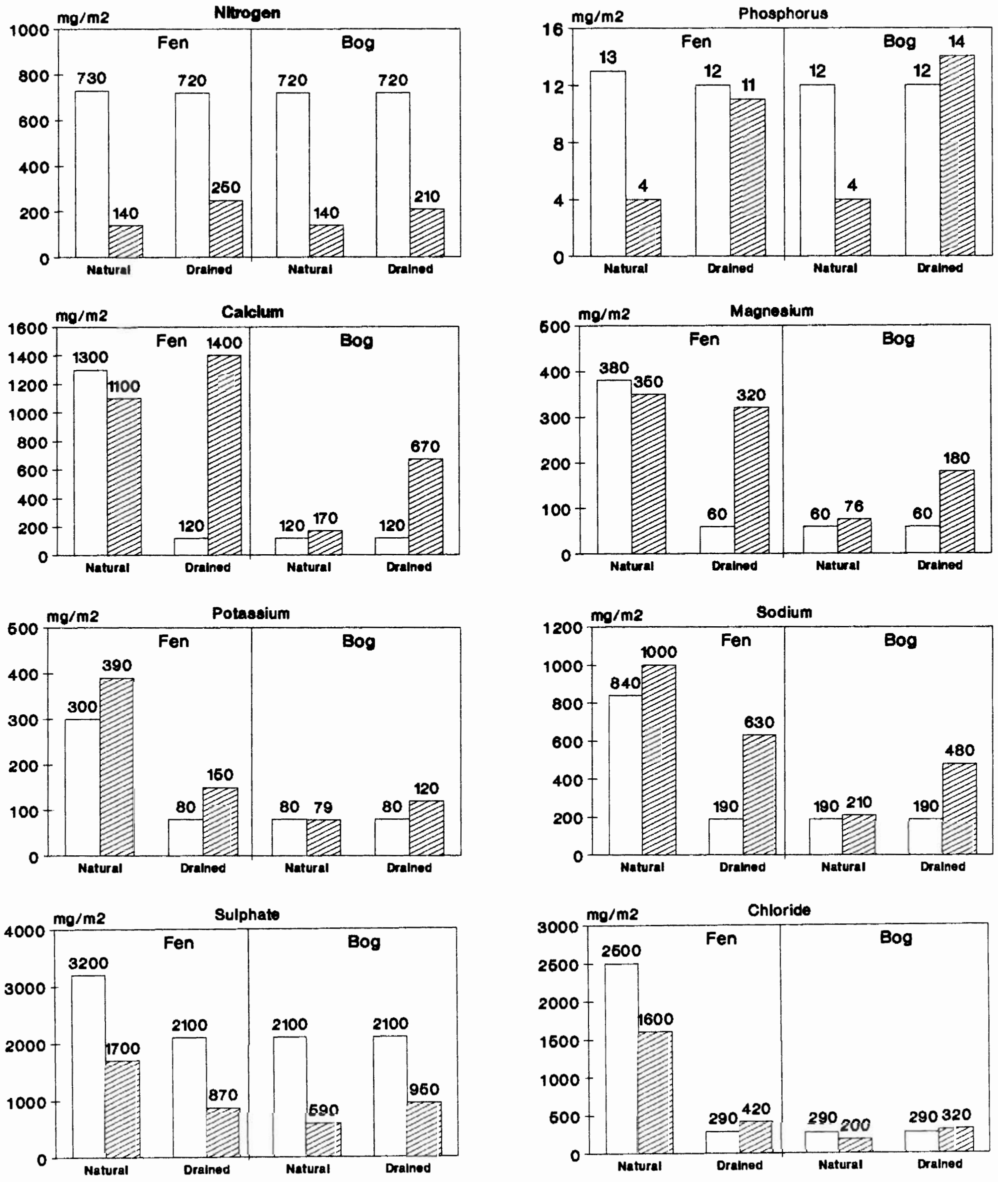

Fig. 3. A preliminary input–output balance of major water quality constituents in Lakkasuo.

in bogs, while Ca and Mg are retained less effectively and K very poorly (e.g. Pakarinen 1982). The retention rates of elements in minerotrophic mires, compared with inputs or outputs, have not been documented so far. From the point of view of leaching, very little is known about the actual changes in the material balance due to forest drainage.

The most obvious results of this study so far concern the balance of Mg and Ca in drained peatlands; these are leached in amounts which are far greater than the amounts provided by deposition. The stores of these elements in a 20-cm surface layer in the same region for tall sedge or herb-rich sedge pine fens (Laiho & Laine 1990) are only 50–60 times greater than the measured net output rates for the drained minerotrophic catchment. The corresponding figure for K is more than two times higher, indicating tighter biocycling.

Due to the magnitude of the net output rates, and since large quantities of these plant nutrients are bound in the growing tree biomass, the stores of especially Mg and Ca in the surface peat of these kind of forest drainage areas should be rapidly diminishing already during the first rotation period. This would have important consequences for, e.g., runoff water acidity, due to reduced availability of base cations for leaching, or even tree growth. However, Laiho and Laine (1990) did not observe any greater change in the nutrient stores of the surface peat layers up to 55 years from drainage; actually, the K stores were growing. The authors concluded, that nutrient availability will not restrict tree growth at least during the first rotation period.

The findings are partly contradictory. A partial explanation lies in the subsidence of the peat layer, which concentrates dry matter in the top 20-cm layer and facilitates the nutrient uptake of trees from layers below 20 cm. Perhaps a great part of the leached elements may also originate in deeper layers. Net loss of organic matter in the peat layer could preserve the ratio between nutrients and carbon. The results concerning the carbon balance in drained peatlands are still contradictory. The increase in the ratio of K to Ca or Mg in the surface peat as well as the lowering of pH as functions of the time since drainage (Laiho & Laine 1990) are in agreement with the results of this study.

These preliminary results clearly indicate that, from the point of view of the long-term behaviour of mire ecosystems, the carbon balance and the balance of mineral nutrients, controlling both production and decay, must be considered together. To be able to predict the future changes both in the mire ecosystems and in the recipient watercourses also in changing climatic conditions, it is essential to understand the processes regulating the retention and release of elements in mire ecosystems. The integrated results being collected in SUOSILMU are a big step forward in understanding the overall biogeochemistry of natural and managed mire ecosystems.

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