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LARS LUNDIN

Abstract

Peatlands are used in agriculture and forestry for vegetational growth and in peat-winning for soil improvement, horticulture production and as fuel. A prerequisite in peatland use is drainage, with influences on water conditions in the peatland and in its surroundings. Environmental effects from such peatland use have been investigated at a sedge fen in central Sweden. Groundwater, runoff, water chemistry and streamwater biology were studied during almost 14 years. This period started with a virgin undrained peatland, later being drained for forest production and after a period of seven years intensively drained for peat-winning and with peat harvesting going on for another seven year period with hydrological investigations. Results show a lowered groundwater level, increased runoff and both higher concentrations of most elements and higher leaching from the drained peatland. Biomass and number of individuals of the benthic fauna in streamwater also increased.

Introduction

Peatland activities, such as forestry, agriculture and peat-winning require drainage to lower the groundwater level and water content in the peat. Consequences are a change from a growing organic storage to a substrate in decomposition (Sallantaus, 1989). Peatland preparation at peat-winning and ongoing peat harvesting furnishes additional influences on the chemical compounds.

At forest drainage, lowering of the groundwater level and changed water pathways influence hydrology and hydrochemistry (Lundin, 1988 & 1994). Impacts on the water environment have, however, been investigated only to a limited extent. Presented results have been somewhat contradictory (Verry & Boelter, 1978) but influences are known to appear (Sallantaus, 1984; Olofsson, 1989). Further investigations on hydrology and hydrochemistry have been performed on a sedge fen in central Sweden.

Site description

A large sedge fen catchment, including several subcatchments, was investigated concerning hydrology and water chemistry during 14 years. Influences were investigated from drainage for forestry and peat-winning and during a period with peat harvesting going on. The catchment was located at 350 m a.m.s.l., i.e. above the highest coast line, in central Sweden at N 62°57'; E 15°42' (Fig. 1). Peatlands of tall sedge fen type with a top two metres dominated by Sphagnum peat above Carex peat had developed on calcareous till on granitic bedrock. At the control peat had partly been formed directly on the bedrock. Mean peat thickness was 3.2 m with a largest depth of 10 m.

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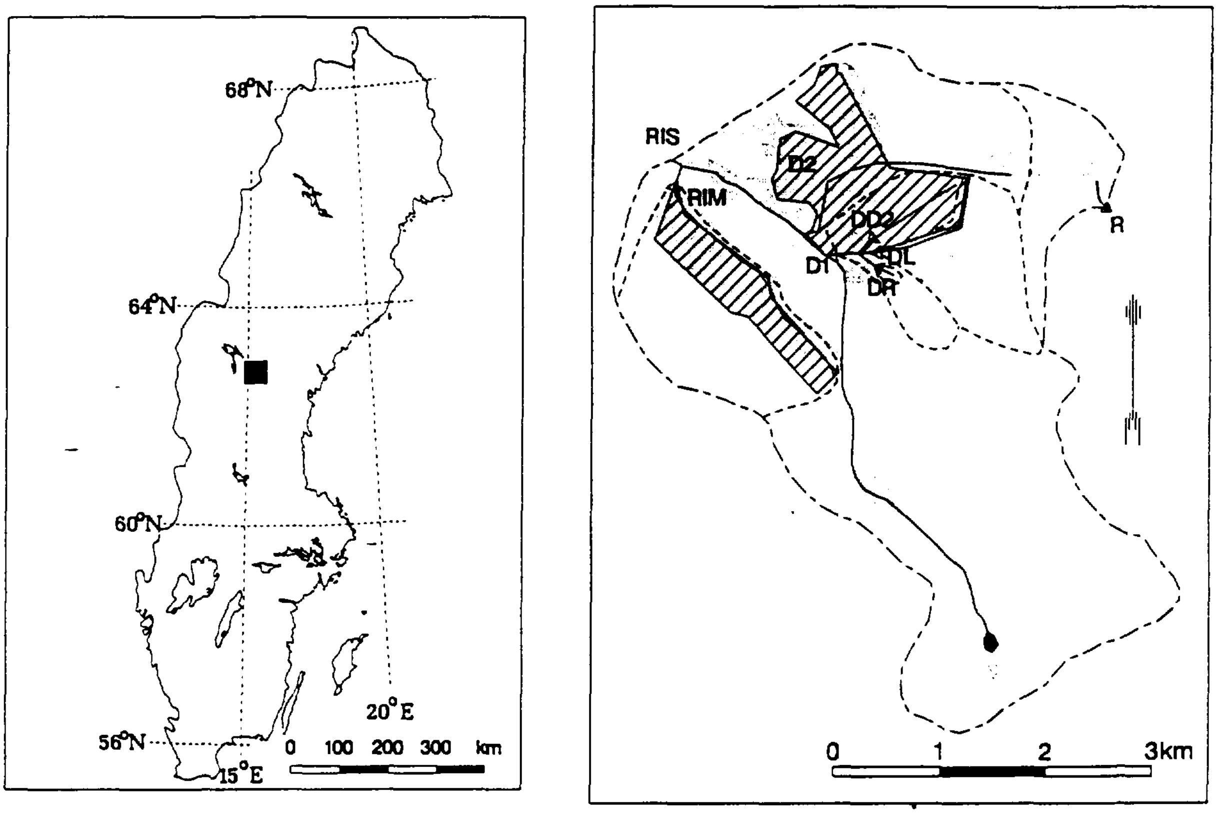

Figure 1. The Docksmyren mire catchment and subcatchments with topographic water divides —, peatland areas (shaded) and peat-winning areas (hatched).

A rather high altitude and northerly location implied a cold climate, with annual mean temperature of + 1 °C and a fairly low precipitation, 612 mm. In the first 6 year period there was ordinary cold winters with concentrated and dominating water turnover at spring snowmelt but during the last 7- year period there were smaller water content in the snow and snowmelt occurred at several times during the winter months. Ordinary snow-covered period was 180 days and mean water content in the snow at before snowmelt was 155 mm. In 1992, water content in the snow was only 47 mm.

Methods

The investigations were performed on catchment level, using the control basin and calibration period technique. This means comparisons between catchments before and after treatment, i.e. drainage and peat harvesting. During the calibration period and the period after forest drainage there was one main treatment peatland (D1) included in a catchment, i.e. both mineral soil uplands and peatlands. There was also a small peatland area (DD) cut off from the surroundings by ditches but with discharging groundwater from the uplands. Such discharge is a natural condition at a fen. Both these areas were compared to control areas, R and DR. After drainage for peat-winning also other subcatchments were included but without calibration period. A mineral soil upland lagg catchment (DL) was mainly composed of mineral soils and one additional and separate peat-winning area (RIM) was a replicate to D1. All subcachments were included in a combined total outlet, RIS (Table 1).

Table 1. Catchment and peatland areas at the Docksmyren mire.

Catchment	Catchment area, ha	Peatland area, ha & %
Main Docksmyren mire, D1	212	65 , 37
Mineral soil uplands, lagg, DL	129	15 , 12
Small peat-winning area, DD	1.3	1.3 , 100
Control, R	91	38 , 42
Small control area, DR	2.3	2.3 , 100
Peat-winning catchment RIM	241	94 , 39
Total catchment outlet, RIS	1411	504 , 36

Investigations were performed during a control period of two years (1979-80), one 4-year period after forest drainage (1981-84) and a 7-year period after drainage for peat-winning (1988-94). Measurements concerned precipitation, peat surface subsidence, groundwater level, runoff and chemical composition of groundwater and surface water. Runoff was measured continuously and sampling of streamwater was made monthly. Analysis were mainly performed according to Swedish standards (SIS, 1986).

Results

Subsidence and Groundwater level

The peat surface level was influenced by snow weight and water content in the peat. During dry periods the surface was lowered a few cm and snow compacted the peat 4-12 cm. Forest drainage lowered the peat surface by c. 0.2 m. The more intense drainage for peat-winning lowered the surface another 0.1-0.5 m and after start of peat harvesting there was an annual subsidence of c. 0.1 m. The total subsidence until 1994 was c. 0.9 m.

The groundwater levels occurred in undrained conditions at mean detph of 0.06-0.1 m. Forest drainage lowered the water level to 0.4-0.6 m. Mean lowering during the first three years after drainage for peat-winning was one metre. Later during the years 4-6, the groundwater level was another 0.35 m lower, with variations in total lowering between 1.0 m at high levels and 1.65 m at low levels (Fig. 2). The change was as a mean 1.3 m. At the other peat-winning area (RIM) lowering was smaller with c. 0.9 m. Distance from the peat surface to the groundwater was c. 0.5 m.

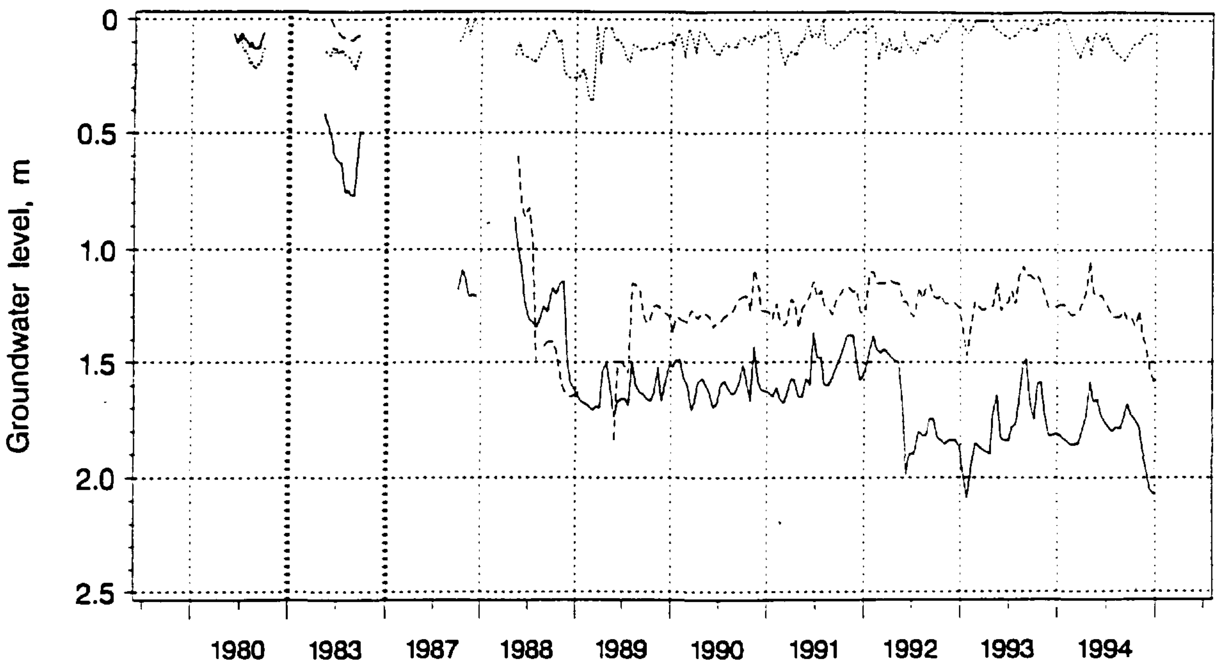

Figure 2. Groundwater levels at three locations, i.e. at mire D1 ——, at mire RIM – – and at the control ----.

Streamwater discharge

Runoff from the control was as a mean for the total investigation period 299 mm with spring snowmelt period making up 60-80% of annual flow. In the last five year period with snowmelt in the winter period the spring proportion was down at 50%. The highest runoff was 452 mm and the lowest 241 mm. Runoff from the small peatland catchments were higher with 600-2000 mm when calculated only on peatland area. This shows a considerable groundwater inflow to these areas. Runoff from the lagg subcatchment was comparably low with 200-300 mm. Part of the groundwater flow passes beneath the lagg and forms surface water further out on the peatland.

Forest drainage changed discharge and as a mean there was a decrease by 25 mm, 8%, but with an increase in one of the years. Annual runoff pattern influenced the change and in the year with a very high spring flow, the increase was observed. At the small peatland subcatchments there was a mean increase of 13%.

After drainage for peat-winning, runoff from the main catchment D1 increased by 48-161 mm, 14-61%. Mean increase in the last 3-year period was 130 mm, 40% (Fig. 3). Partly, this increase could be a result of uncertainty about the water divide but this only change the magnitude of the increase from 38% to 12% for the whole 7 year period and not the fact there was an increase. At the peat-winning area RIM, the specific discharge was higher than at both the control and the D1 catchment, i.e.

indicating increased runoff. Changes at the small peatland area showed mainly decreases with as a mean during the last 3 year period by 810 mm, 54%.

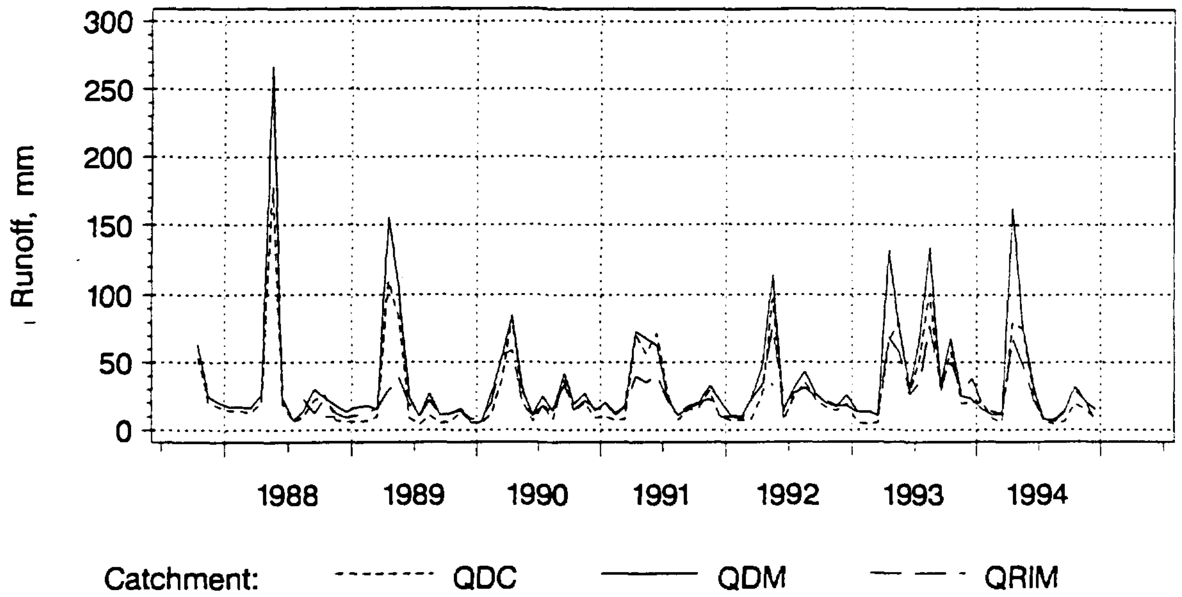

Figure 3. Measured runoff from the two peat-winning catchments D1 (QDM) and RIM (QRIM) and calculated runoff from D1 as undrained (QDC) during the period 1987-1994.

Drainage for peat-winning mainly increased low and mean discharges. Low discharge increased 3-5 times the calculated undrained discharge. Also after forest drainage low discharge increased, by 3 times. Mean daily very high discharges (> 200 l/s • km^2) increased by c. 50% after forest drainage and by 60-70% after drainage for peat-winning.

Water chemistry

The mineral soil underlying the peat, influenced the chemical composition of the peatland waters. This is an inevitable consequence of the predominating water pathways in fens. The mineral soil at the Docksmyren mire, originates from formations of Cambro-Silurian character which has resulted in peat waters with pH 6-7 being 0.5-1 unit higher in deep groundwater compared to the upper peat layers. Concentrations of alkalinity and base cations were also higher in deeper peat layers and with streamwater concentrations of 50-100 mg/l and 20-30 mg/l, respectively. Nitrogen contents were 0.4-0.7 mg/l with equal shares of NH_4-N and Org-N in deep peat layers but with 70-90% Org-N in the upper peat groundwater and in surface water. Phosphorus concentrations were low in the upper peat groundwater and in streamwater (0.01-0.02 mg/l) and higher in deeper peat layers (0.15 mg/l). Phosphate portion increased from 20-30% in the upper peat layers to over 50% in deeper layers. Organic carbon content was comparably low with 4-10 mg/l.

Changes after drainage in chemical composition of the groundwater were reflected in the streamwater chemistry. After forest drainage, concentrations of most elements increased apart from hydrogen, Fe, Cu and possibly also dissolved organic carbon showing decreased concentrations. Unchanged concentrations were observed in Ca, Cl and Tot-P (Lundin, 1988).

After drainage for peat-winning and with peat harvesting, changes in streamwater quality continued in mostly the same fashion as after forest drainage. The overall change was increased concentrations of most elements apart from hydrogen.

During the four year period after forest drainage, pH was mainly 0.2 units higher than expected undrained. At two months in autumn 1983, however, pH dropped to very low values, below 4. This occurred in a period with increasing discharge after a fairly dry summer period. At these low pH-values, DOC and Org-N increased considerably, 200% and 90%, respectively. After the two months, pH was back to normal again.

After drainage for peat-winning there also was higher pH as compared to estimated undrained conditions. The mean pH, at D1, during the first three year period was 7.0 which was an increase by 0.4 units. Higher pH was also observed in the following five year period when mean pH was 7.3, an increase by 0.7 (Fig. 4). Runoff from the small peatland subarea increased with 0.1-0.2 units to pH between 6.9 and 7.3.

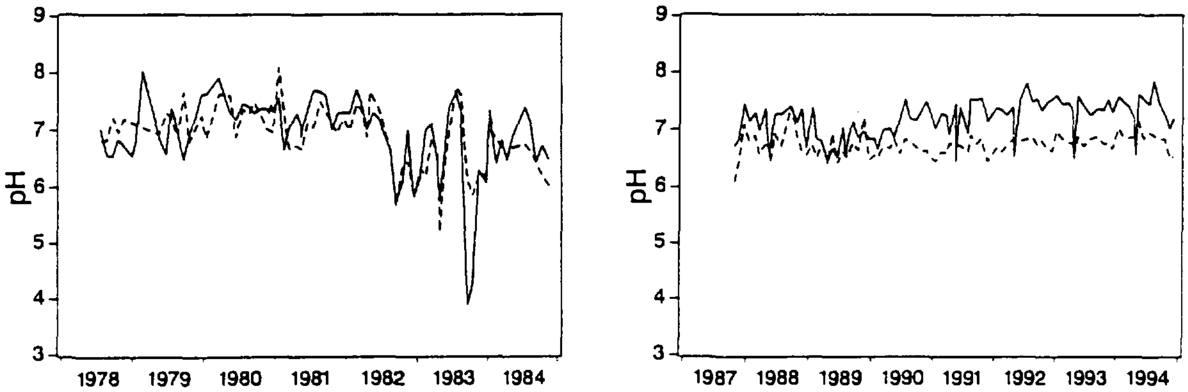

Figure 4. Monthly pH at the main catchment D1 during the undrained period 1978-80, after forest drainage 1981-84 and after drainage for peat-winning 1987-94. Measured pH —— and estimated undrained pH ---.

Alkalinity and base cation concentrations increased slightly after forest drainage with larger increases after drainage for peat-winning. Mean Ca increase, at D1, during the first three years after peat-winning drainage was 30% and during the following four years 60% (Fig. 5).

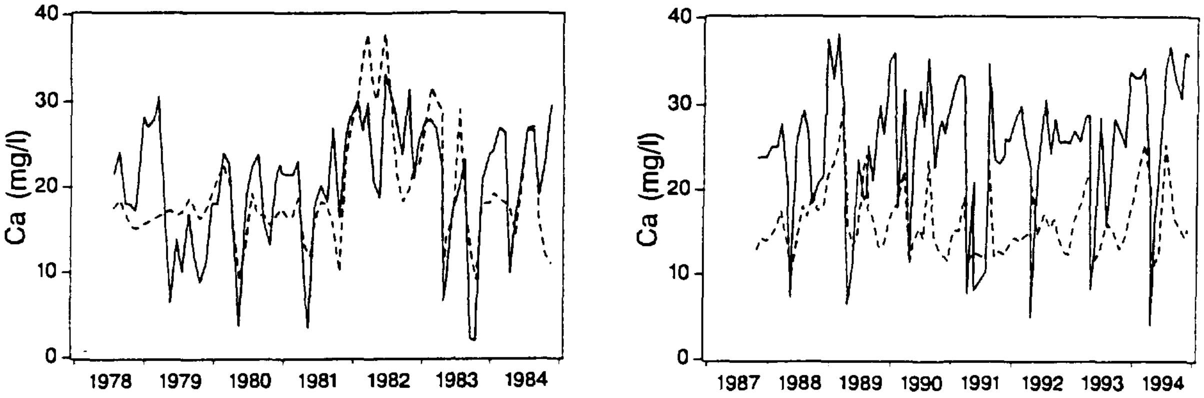

Figure 5. Monthly Ca concentrations at the main catchment D1 during the undrained period 1978-80, after forest drainage 1981-84 and after drainage for peat-winning 1987-94. Measured Ca conc. — and calculated undrained Ca conc —.

Phosphorus concentrations were higher after drainage which especially concerned phosphate-P. Increases in Tot-P at the outlet from the total catchment was 0.01 mg/l, 15% . Concentrations of metals, such as Fe, Al and Cu, were generally low at mire Docksmyren and changes after drainage mainly decreases.

Organic carbon concentrations (DOC) were fairly low. After forest drainage and during the three first years following drainage for peat-winning almost unchanged concentrations were observed. During the three year period 1990-92, concentrations were slightly lower than expected undrained. In the last two year period (1993-94), however, increased concentrations occurred both at the main peat-winning area and at the peatland strip (Fig. 6).

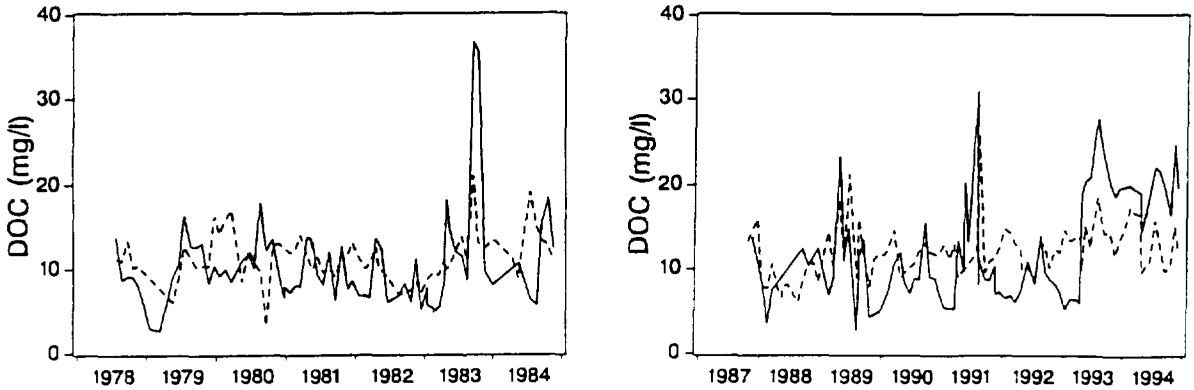

Figure 6. Monthly organic carbon concentrations (DOC) at D1 during the undrained period 1978-80, after forest drainage 1981-84 and after drainage for peat-winning 1987-94. Measured DOC — and calculated undrained DOC —.

Total nitrogen concentrations were c. 0.04 mg/l and composed of 70-90% organic - N. After drainage tot-N increased by 20-100% with increased shares of inorganic-N, that at the peatland strip constituted up to half of tot-N. At the main catchment, D1, there were 10-20% higher concentrations of org-N and at the outlet from the total peat-winning area (RIS) the increase was c. 30%. Inorg-N, i.e. NH_4-N and NO_3-N, increased after drainage from 0.1 mg/l to 0.2-0.6 mg/l, more at the small peatland strip and less at the main catchment and the total outlet. The strongest increases were observed in NO_3-N with at the main subcatchment 77% after forest drainage and c. 700% during 3-8 years after drainage for peat-winning (Fig 7). Corresponding increases at the peat-cutting strip were 71% and c. 500%, respectively.

At the mineral soil lagg subcatchment, DL, inorg-N concentrations after drainage were low, c. 0.1 mg/l with equal shares of NH_4-N and NO_3-N. Such proportions also occurred at the total outlet, where the concentration was c. 0.3 mg/l.

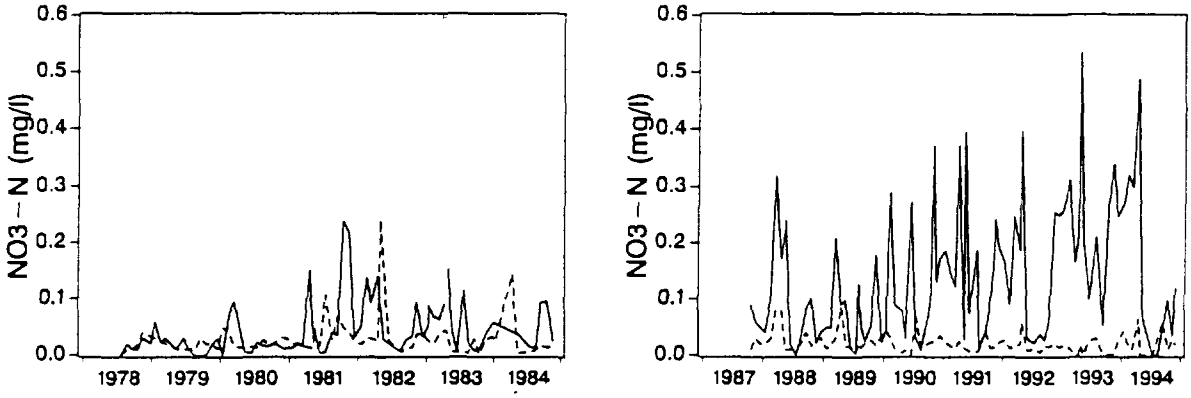

Figure 7. Monthly nitrate-N concentrations at the main catchment D1 during the undrained period 1978-80, after forest drainage 1981-84 and after drainage for peat-winning 1987-94. Measured NO_3-N — and estimated undrained NO_3-N ---.

Element leaching

Element flows before drainage were mostly higher from the Docksmyren peatlands than from the control and the mineral soil uplands. Hydrogen, Fe, Al and sulphate were among the elements showing opposite conditions. A more acid water at the control agrees with the poorer peatland type. This could also be observed in the comparably low leaching of alkalinity and base cations. Also phosphorus flow was lower with c. 1 mg/m^2-year but with about six times higher flow from the catchment D1 which could be considered an ordinary magnitude. Flow of organic carbon (DOC) and nitrogen from the different catchments were of the same sizes.

Changes in element leaching after drainage show mainly increased outflows. Only hydrogen and phosphorus differ from this. Hydrogen flow decreased most of the time but the low pH in autumn 1983 caused an increased leaching during the total period after forest drainage. Apart from these two months, there was a decreased flow both after forest and peat-winning drainage. Phosphorus leaching decreased after forest drainage but increased after drainage for peat-winning (Table 2). The increase during the last 3-year period was, however, small and uncertain.

Table 2. Mean annual element leaching from the main catchment D1 after forest drainage (1981-84) and during two periods after drainage for peat-winning (1988-91 and 1992-94). Changes compared to undrained conditions are presented as amounts and in % of undrained leaching.

Period	Leach.	Change, %	Leach.	Change, %	Leach.	Change, %
	H^+, mg/m^2·year		HCO_3, g/m^2·year		DOC, g/m^2·year	
1981-84	1.65	+1.41, 580	20	+ 1, 5	3.9	+ 0.4, 11
1988-91	0.06	- 0.04, 41	23	+ 7, 42	5.1	+ 1.6, 45
1992-94	0.05	- 0.02, 27	28	+ 12, 69	7.9	+ 3.6, 84
	K, g/m^2·year		Ca, g/m^2·year		Al, mg/m^2·year	
1981-84	0.29	+ 0.08, 38	4.9	+ 0.5, 11	47	+ 8, 21
1988-91	0.39	+ 0.23, 167	7.6	+ 4.0, 108	35	+ 12, 81
1992-94	0.40	+ 0.27, 209	9.0	+ 5.1, 130	94	+ 43, 84
	NO_3-N, mg/m^2·year		NH_4-N, mg/m^2·year		ORG-N, mg/m^2·year	
1981-84	29	+ 18, 164	34	+ 10, 43	180	+ 9, 5
1988-91	51	+ 42, 529	33	+ 27, 465	178	+ 93, 107
1992-94	106	+ 100, c. 800	50	+ 35, 232	182	+ 69, 61
	TOT-N, mg/m^2·year		TOT-P, mg/m^2·year		SO4, g/m^2·year	
1981-84	243	+ 37, 18	8.0	- 1.7, 18	0.82	+ 0.32, 64
1988-91	272	+ 150, 128	12.0	+ 4.6, 63	0.88	+ 0.51, 142
1992-94	339	+ 185, 120	12.3	+ 2.1, 21	0.86	+ 0.67, 353

Cations, bicarbonate alkalinity and Al showed higher outflow and continuing increases with time after drainage. Flow of organic carbon, being comparably low before drainage, continued to increase throughout the investigation period and was doubled at the end.

Nitrogen, being the most obvious element in change, increased considerably from an undrained background value of c. 2 kg/ha • year to 3.4 kg/ha • year at the end of the investigation period. Both organic and inorganic nitrogen increased but nitrate change was largest. Total-N composition changed from c. 80% org-N in virgin conditions to a mean of 54% in the period 1992-94. NO_3-N constituted 31% and NH_4-N 15% (Table 2). At the small peat-cutting strip, org-N share was only 38% which should be compared with 77% at the small peatland control DR.

Conclusions

Drainage caused impacts on hydrology and hydrochemistry of the peatland waters. Influences were caused by changed water pathways, i.e. decreased surface runoff and increased groundwater discharge. The lowered groundwater level provided increased possibilities to store precipitation in the unsaturated peat and increased the

evaporation which in warm periods was emphasised by the black peat surface. This could be noticed in decreased discharge from the peatland area. Lowered groundwater level also increased water infiltration and percolation passing both a decomposing peat layer and in the lagg underlying mineral soil layers.

These conditions increased leaching of stored elements in the peat and base cations from the mineral soil. A major change was the increase in nitrogen leaching and the larger part inorganic-N. In the outlet from the whole peat-winning catchment RIS, changes were smaller than close to the peat-winning subareas. Anyhow, influences were found on the benthic invertebrate fauna which increased both in biomass and numbers of individuals.

Acknowledgement

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