Pertti Seuna: Long-term influence of forestry drainage on the hydrology of an open bog in Finland

Veli Hyvärinen & Bertel Vehviläinen: The effects of climatic fluctuations and man on discharge in Finnish river basins

Kaarle Kenttämies: The effects on water quality of forest drainage and fertilization in peatlands

Pertti Seuna & Lea Kauppi: Influence of sub-drainage on water quantity and quality in a cultivated area in Finland
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THE EFFECTS ON WATER QUALITY OF FOREST DRAINAGE AND FERTILIZATION IN PEATLANDS

Kaarle Kenttämites

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A small peat drainage basin was drained and fertilized after first being monitored for four years. Suspended solids concentration after drainage, expressed as the two-year mean, was six times higher than before. Organic carbon concentration immediately after the drainage was a little lower than before. After fertilization with PK-fertilizer, the phosphorus content in runoff increased from 18 µg l⁻¹P to a mean value of 128 µg l⁻¹P. The highest monthly mean was 300 µg l⁻¹P. The share of phosphate phosphorus of the total phosphorus doubled to 60 per cent. Potassium concentrations increased after fertilization by a factor of about four. Suspended solids and organic carbon concentrations are on the same level in old (20—40 years) drained and afforested peatlands as in natural peatlands. The effects of phosphorus fertilization on runoff water quality can be detected for at least 5—10 years, while the effects of potassium fertilization disappear in 1—2 years.

Index words: water quality, forest drainage, fertilization, peatlands

1. INTRODUCTION

Finland is one of the leading countries in the utilization of peatlands for forestry. The area of drained peatlands in Finland is today over 5 × 10⁶ ha, about 15 per cent of the total land area. A total of 150—200 000 ha of forest land are fertilized annually, of which about 50 per cent is peatland. Peatlands are fertilized in Finland with phosphate and potassium fertilizers. Because Finnish peatlands are mostly acidic in nature, the less soluble rock phosphate is preferred to superphosphate to assure a long-lasting effect. Potassium, however, is given as a water soluble chloride. It is planned to fertilize nutrient-poor peatlands every 8—15th year.

Widespread forest management operations in drainage basins influence water courses mainly in two ways: they may cause eutrophication of lakes and rivers through rising plant nutrient loads, or oxygen depletion by increasing the content of biodegradable organic substances. Although observed in some cases, the massive erosion of ditches is rare in the conditions prevailing in Finland.

In Finland, situated in the area of northern coniferous forests, most lakes represent the oligotrophic production type. The minimum nutrient is very often phosphorus but nitrogen resources are also scant. The brown colour of the water, caused by dissolved humic substances from the peat, is very characteristic. The humic substances constitute a natural organic pollution load that strictly limits the capacity of a lake to receive additional nutrient of organic load.

There has been much interest in the environmental effects of modern forestry methods al
through little research has been carried out so far. The hydrological effects of drainage have been treated in the works of Mustonen and Seuna (1971), Ahti (1977), Heikurinen et al. (1978) and Hyvärinen and Vehviläinen (1978). The effects of drainage and fertilization on waters have been considered by Särkkä (1970), Karsisto and Ravela (1971), Kenttämies (1977) and Heikurainen et al. (1978).

The primary aim of the study reported here was to obtain information concerning the effects of drainage on the discharge of organic matter from peatlands. Both the immediate and the long-term effects were studied, as was the washing-out of phosphorus and potassium fertilizers.

2. METHODS

This study was carried out in cooperation between the Department of Peatland Forestry, University of Helsinki and the Water Research Office of the Water Research Institute. The hydrological field of 'Lyly 5', located in the parish of Juupajoki (61° 55'N, 24° 20'E) was founded and managed by the Department of Peatland Forestry. The basin, of area 16.9 ha, consisted of ordinary sedge bog and dwarf-shrub pine swamp. The field was partly surrounded by an old ditch, in which the measuring weir, equipped with a pluviograph, was installed. The basin constituted one of the water balance study fields of the Department of Peatland Forestry. The hydrological study has been explained in more detail by Heikurainen (1974) and Heikurainen et al. (1978). The field was untouched until June 1977 when it was drained. In June 1978 the drained field was fertilized with phosphorus-potassium (PK) fertilizer, 500 kg/ha. The phosphate was in the form of fine-grained rock phosphate and the potassium as KCl. The phosphorus and potassium contents of the fertilizer were 9 and 17 per cent respectively. The fertilizer was applied by aerial spreading.

To study the representativeness of the research basin and the long-term effects of drainage, 38 peatland basins, both drained and in the natural state, were studied in 1974—1975. Water samples were collected and analysed four to five times during the two-year period without flow measurements. The drained fields were mainly 20—40 years old (oldest 60 years) afforested areas. About half of the fields were situated near the 'Lyly 5' field, and the other half in northern Finland near the town of Oulu.

The water samples were taken mostly at monthly intervals from the overflow of the weir. In the summers of 1977 and 1978 the sampling frequency was once a week and in June 1977, when the excavation work was being carried out, twice a day. The analyses were carried out according to the standard methods of the National Board of Waters (Erkomaa et al. 1977). Of the analyses discussed in this paper, 'suspended solids' is a measure of the dry weight of all suspended material filtered out with a glass fibre filter of pore size 1 μm. Organic carbon is the weight of all carbon, in suspended and dissolved material, degrading to carbon dioxide in a high-temperature analyser. Total phosphorus was analysed by wet burning the sample with sulphuric acid and peroxide and then analysing phosphate by the ammonium molybdate method. Potassium was analysed by flame photometry.

The other analyses, not treated in this paper, were as follows: electrolytical conductivity, pH, colour, chemical oxygen demand (KMnO₄-method), total nitrogen, nitrate, nitrite, ammonium, chloride, total iron, calcium and turbidity.

The monthly loads were calculated as the product of the concentration and the total runoff per hectare per month. For many reasons, the most prominent of which was the freezing of the weir and the ditches, this study lacks winter runoff measurements.

3. RESULTS

The concentrations and discharges of suspended solids, organic carbon, phosphorus and potassium are presented in Figs 1—4, respectively. The arithmetic means and t-values of concentrations for the periods before and after the drainage and the fertilization of the field 'Lyly 5' are presented in Table 1. Because there are significant differences between the variances ($s^2$), the results of t-statistics are only approximate. In this case, the n-value of the smaller datum in the t-test may be regarded as a 'safe' value of degrees of freedom (Lindgren 1976, p. 352).

3.1 Suspended solids

The suspended solids concentration rose drastically after the drainage. This phenomenon has been con-
Fig. 1. The concentration and load of suspended solids in water from 'Lyly 5' field.

Fig. 2. The concentration and load of organic carbon in water from 'Lyly 5' field.
Table 1. The arithmetic means, standard deviations and t-values of periods before and after drainage and fertilization of 'Lyly 5' field

<table>
<thead>
<tr>
<th></th>
<th>I</th>
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<th>III</th>
<th>IV</th>
<th>t-value</th>
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<tbody>
<tr>
<td><strong>Susp. solids (mg l⁻¹)</strong></td>
<td>1.45</td>
<td>9.31</td>
<td>3Q7xx</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td><strong>Org. carbon (mg l⁻¹)</strong></td>
<td>33.42</td>
<td>27.75</td>
<td>2.52x</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td><strong>Tot. phosphorus (µg l⁻¹)</strong></td>
<td>17.83</td>
<td>128.48</td>
<td>2.84x</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td><strong>Potassium (mg l⁻¹)</strong></td>
<td>0.29</td>
<td>0.33</td>
<td>0.87</td>
<td>0.22</td>
<td></td>
</tr>
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</table>

Fig. 3. The concentration and load of total phosphorus and the content of phosphate phosphorus in water from 'Lyly 5' field.

Table 1. The arithmetic means, standard deviations and t-values of periods before and after drainage and fertilization of 'Lyly 5' field

<table>
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<td>0.22</td>
<td></td>
</tr>
</tbody>
</table>

I Before drainage and fertilization 1.1.73—1.6.77
II Before fertilization 1.1.73—1.6.78
III After drainage 1.6.77—31.12.78
IV After drainage and fertilization 1.6.78—31.12.78
considered in more detail by Heikurainen et al. (1978) and Kytövuori (1978). Higher concentrations were also observed in the second year after the drainage. The six-fold level in mean concentration after drainage gave rise to a statistically significant difference between the periods. (Table 1).

The high concentration peak observed in August 1975 had its origin in the high concentration of coagulated ferric hydroxide (total Fe = 10 mg l⁻¹). High concentrations of iron are very common in peatland waters at low flow times. There were no significant correlations between the suspended solids mean concentrations or loads and runoff monthly means after the drainage. However, it was observed that torrential rainfalls caused considerable increases in the concentration and discharge of suspended solids derived from the sides and the bottom of the ditches.

3.2 Organic carbon

A slight decrease in concentrations of organic carbon was observed after the drainage. The statistical significance of the decrease was only slight, but as this result was rather unexpected, there is a need for further studies of this phenomenon. The loads remained on the same level as before the drainage. Organic carbon load is a typical runoff-dependent variable, as changes in the concentrations are quite small. The monthly means of the runoff and of the organic carbon load values had a linear correlation coefficient value of r = 0.94xxx before the drainage and r = 0.67xxx after the drainage.

3.3 Phosphorus

Significant increase in the phosphorus concentration took place after the fertilization of the 'Lyly
5' field in June 1978. The concentrations were at first 10—15 times greater than before the fertilization. The difference of means was statistically significant (Table 1). The concentration of phosphate-phosphorus can also be seen in Fig. 3. The phosphate-phosphorus concentration increased relatively more than that of total phosphorus after the fertilization. Before the fertilization, the share of phosphate-phosphorus was only 33 per cent of the total phosphorus, while after the fertilization it was 60 per cent. As in the case of iron, phosphorus concentrations tend to increase in natural peatlands during dry periods. Thus the high phosphorus concentration peak in August 1975 had practically no load effect.

3.4 Potassium
Potassium concentration increased significantly after the fertilization in 1978 (Fig. 4 and Table 1). However, a smaller rise was also observed in summer 1977, after the drainage. The fluctuations in potassium concentrations before fertilization and drainage were quite large. This may be partly due to the fact that the concentrations were near to the lower limit of detection of the analysing method. The precision of results was lower in the earlier years than in 1977—1978.

3.5 Long-term effects of drainage
The means and t-values of the data from drained, afforested peatlands and natural peatland basins are presented in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>Natural peatland</th>
<th>Drained peatland*</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susp. solids (mg l⁻¹)</td>
<td>6.26</td>
<td>7.58</td>
<td>0.62</td>
</tr>
<tr>
<td>SD</td>
<td>7.30</td>
<td>6.04</td>
<td></td>
</tr>
<tr>
<td>Org. carbon (mg l⁻¹)</td>
<td>23.48</td>
<td>20.95</td>
<td>0.61</td>
</tr>
<tr>
<td>SD</td>
<td>9.58</td>
<td>9.82</td>
<td></td>
</tr>
<tr>
<td>Tot. phosphorus (µg l⁻¹)</td>
<td>21.64</td>
<td>74.63</td>
<td>3.79**</td>
</tr>
<tr>
<td>SD</td>
<td>29.35</td>
<td>86.00</td>
<td></td>
</tr>
<tr>
<td>Potassium (mg l⁻¹)</td>
<td>0.42</td>
<td>0.69</td>
<td>2.18*</td>
</tr>
<tr>
<td>SD</td>
<td>0.75</td>
<td>0.51</td>
<td></td>
</tr>
</tbody>
</table>

* Includes fertilized areas.

4. DISCUSSION
Only one basin was monitored in this study. Obviously, this is not a sufficient basis for comparison, but the opportunity to study the effects of the drainage and fertilization in the 'Lyly 5' field arose after the field had served for four years as its own control in the researches of the Department of Forestry (Heikurainen 1974). The fact that the drainage of peatlands increases the concentration of suspended solids is well known in practice in Finland. Ponds and small lakes in the outflowing water course detain the greatest part of suspended sediments. It is clear that sediment concentration and nutrient loading are very dependent on local conditions, such as the slope of ditches and peat quality. Thus the results in this paper may give only qualitative indications of changes in solids' concentrations. The lack of spring flood flow measurements is a serious
deficiency because a considerable part of the annual material transport takes place in spring (Särkkä 1972; Kauppi 1979).

The slight decrease in organic carbon concentration after drainage agrees well with the observations of Korpiaakkio and Pheneey (1976) and Ferda (1976). According to the observations of Heikurainen et al. (1978), the peatland type may have a greater influence on the concentration and load of organic carbon than the drainage. In the long-term monitoring results of larger lakes and rivers in Finland (Laaksonen 1975), no rising trends in organic matter (measured as KMnO₄-consumption) were observed in the river observations made in 1962—1973 in central and northern Finland, although the area of drained peatlands in Finland doubled in the 1960s decade.

It is obvious that suspended organic sediments in runoff are more abundant and also are a more harmful factor in the drainage of peatlands than dissolved humic substances. Where sedimentation basins (natural or man-made) are lacking, washed-out sediments have in some cases severely disturbed water quality, fish and crayfish in creeks. If ditches have been dug in mineral ground, erosion is possible. The extent of ditch erosion is uncertain and may depend very much on local conditions. However, ditch cleaning and redrainage every 30—50 years may produce a new loss of sediments.

In natural peatlands, phosphorus concentration in runoff water is usually very low, about 20μg L⁻¹. The increase in phosphorus content observed in this investigation after fertilization was at first 15—20 fold. Similar observations were made by Kenttämies (1977) in north Karelia. According to Karsisto and Ravela (1971) the phosphorus concentration may double after drainage and fertilization. In their research, in the first summer after PK-fertilization an additional loss of 66 g ha⁻¹ P was observed. In the present investigation the total loss of phosphorus from 'Lyly 5' during the first four months was 154 g ha⁻¹ P. If the three-year mean of 6—9 months, representing the natural state (21 g ha⁻¹ P), is subtracted from this value the remainder, 133 g ha⁻¹ P, may describe the effects of drainage and fertilization on phosphorus loss.

Särkkä (1970) found that the mean increase in concentration of phosphorus was 70 μg L⁻¹ during the first year after fertilization. Using a yearly runoff mean, Särkkä arrived at an approximate phosphorus discharge value of 200 g ha⁻¹ year⁻¹ P. In north Karelia a loss of 470 g ha⁻¹ year⁻¹ P was observed during the first year after fertilization (Kenttämies, 1977). However, the washing-out of phosphorus after fertilization is negligible if it is compared with the amount applied during the course of these researches (45—52 kg ha⁻¹). The concentration increase in runoff after fertilization is however so great that it may alter the trophic state of the recipient water body if a considerable part of the drainage basin is fertilized at the same time.

Gibson (1976) has observed a substantial phosphate increase in water after the fertilization of peatland in Ireland.

The long-term effects of fertilization are not seen in the results from the 'Lyly 5' field. According to Karsisto (1970) (ref. Karsisto and Ravela (1971)) the effects of phosphorus fertilization on runoff water last one year. However, the results from old drained and fertilized peatlands reveal significantly higher phosphorus concentrations compared with unfertilized areas. Thus it is obvious that the effect of fertilization on phosphorus discharge lasts at least 5—10 years.

The increase in potassium content was smaller than that observed by Särkkä (1970) and by Karsisto and Ravela (1971). The effects of potassium fertilization on the potassium discharge have been found to be quite short-lived, only 1—2 years (Särkkä 1970; Kenttämies 1977). Potassium concentration is of less importance because potassium is regarded as an insignificant factor in water quality.

ACKNOWLEDGEMENTS
This study was carried out in co-operation between the Water Research Institute and the Department of Peatland Forestry, University of Helsinki. My best thanks to the staff of the Department of Peatland Forestry, and especially to professor Leo Heikurainen, the initiator of this research. I am likewise grateful to the personnel of the Tampere Water District Office and the laboratory and research office of the Water Research Institute.

Helsinki, December 1980
Kaarle Kenttämies

Orgaanisen hiilen konsentraatioissa havaittiin ojituksen jälkeen lievää laskua. Kuormat pysyivät samalla tasolla kuin luonnontilaisena käytetyn.  


Tutkittaessa ojituksen pitkäaikaisia vaikutuksia vertaamalla vanhoja (20—40 v.) ojitusalueita luonnontilaisiin ja luonnontilaisiin, havaittiin, että niin kiintoaineen kuin orgaanisen hiilenkin pitoisuudet olivat samalla tasolla kummassakin ryhmässä. Kokonaisfosfori- ja kaliumpitoisuudet olivat merkittävästi suurempia sellaisilla ojitetuilla soilla joita oli lannoitettu. Fosforilannoituksen vaikutus näkyi valunnassa ainakin 5—10 vuotta.