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The Effect of Thinning, Clear Cutting, and Fertilization on the Hydrology of Peatland Drained for Forestry

Harvennuksen, avohakkuun ja lannoituksen vaikutus ojitetun suon vesiloihin

Leo Heikurainen & Juhani Päivänen

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THE EFFECT OF THINNING, CLEAR CUTTING, AND FERTILIZATION ON THE HYDROLOGY OF PEATLAND DRAINED FOR FORESTRY

HARVENNUKSEN, AVOHAKKUUN JA LANNOITUKSEN VAIKUTUS OJITETUN SUON VESIOLOIHIN

LEO HEIKURAINEN & JUHANI PÄIVÄNEN

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PREFACE

This paper is a continuation of the authors' research series dealing with the possible hydrological changes in drained peatland influenced by silvicultural treatments. Mr. Päivänen, the co-author, was responsible for the throughfall experiment. He was also primarily responsible for the description of the tree stands growing on the sample plots. All other parts of the study were carried out by myself.

I have the pleasure of thanking all the field workers and assistants who have collaborated with me during this study. In particular I wish to express my thanks to Dr. Kustaa Seppälä and Mr. Hannu Mannerkoski, B.For., who have helped me with the treatment of the data collected.

The work was financed by the National Research Council for Agriculture and Forestry and the manuscript proofread by Mr. Karl-Johan Ahlsved, B.For., and Mr. Robert Goebel.

March, 1970

Leo Heikurainen

CONTENTS

1. AIMS OF THE STUDY

At the moment there are over three million hectares of peatland drained for forestry in Finland, and this area will be increased by about 300.000 hectares annually. It has been estimated that in 15 years there will be about 6.5 million hectares drained for forestry in our country.

Viewed against this background, it is understandable that the question of the effect of silvicultural treatments on the hydrology of drained areas is of great importance. This kind of knowledge enables us to choose the right methods of maintaining the large, drained areas.

The authors have previously published some papers on the same subject (Heikurainen 1966, 1967, Päivänen 1966). According to these studies, clear cutting significantly raises the level of the ground water, and thinning seems to have the same effect, though to a lesser degree. The changes in interception and throughfall resulting from cutting probably are the most important factors contributing to a rise in the level of the ground water.

The aim of this study is to assess the effect of cutting of different intensities. Special interest was paid to the effect of fertilization on the hydrology. As the studies referred to above, this study, too, was concerned with measuring changes in the ground water level, throughfall, and snow cover. Measurement of runoff, a factor previously omitted, is of particular interest here.

This study focusses on the phenomena that occur during the growing season. On the other hand, the hydrology of the winter season, too, has an important effect on the conditions during the growing season (cf. Yli-Vakkuri 1960). For this reason some measurements were also carried out in the winter.

2. LAYOUT AND DATA SAMPLING

21. Study area and measurements

The study was carried out in Central Finland (61°50′ N, 24°20′ E). The altitude of the study area is about 150 metres above sea level. The annual mean temperature in the region in question is +3°C and the mean temperature for the month of July, +17°C. The annual rainfall is about 600 mm and that of the summer months (June-September), about 300 mm. The depth of the snow cover is about 55 cm. The evapotranspiration is about 300 mm annually.

In 1966 seven sample plots were marked off in an area which had been drained about 50 years earlier and where a satisfactory Scots pine stand of uniform age is presently growing. The size of the sample plots is 30 × 40 m. Each sample plot was provided with a runoff drain made out of perforated plastic pipe, 5 cm in diameter, eight ground water wells, twenty rain gauges, and three snow depth rods. These constructions are described in more detail in Fig. 1.

Measurement of throughfall, depth of the ground water table, and runoff was begun in the summer of 1966, when the set-up in the sample area was ready. These measurements were continued in the following winter, and the snow depth was also recorded. In the next summer the same readings were taken except for the snow cover measurings. This period (1966—67) forms the calibration period.

In the winter of 1968 all the cuttings in the various sample plots were carried out, and in the early spring, just after thaw, two sample plots were fertilized. 600 kg/ha of mixed fertilizer ($N-P_2O_5-K_2O$, 14—18—10) was applied. The following treatments were used:

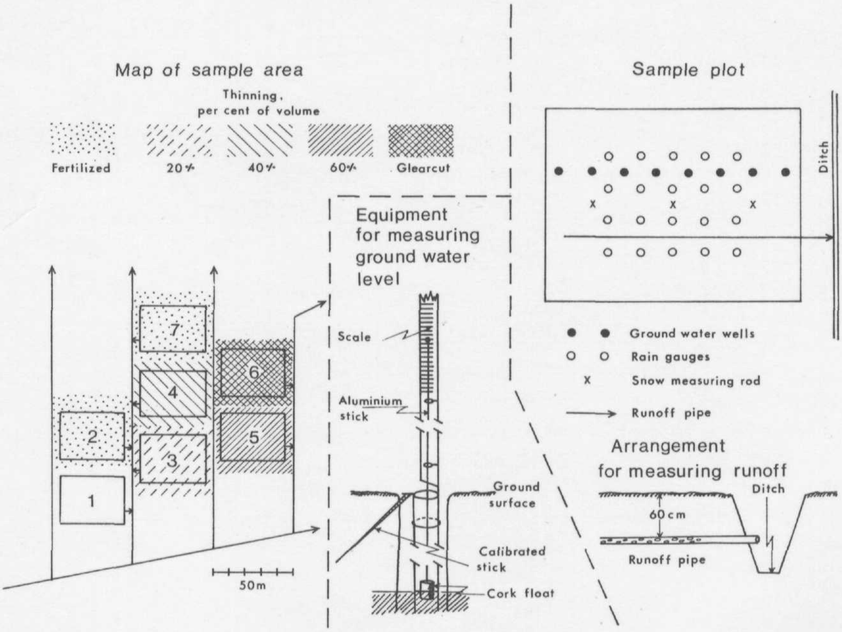

Figure 1. Layout of the study area and the constructions of the sample plots.

Sample plot	Treatment
1	Control
2	Fertilized, May 4, 1968
3	Thinned in January 1968, 20 per cent of the volume
4	Thinned in January 1968, 40 per cent of the volume
5	Thinned in January 1968, 60 per cent of the volume
6	Clear-cut in January 1968
7	Fertilized, May 4, 1968

In the summer of 1968 and 1969 and in the intervening winter all the measurements were continued in the same way as during the calibration period, besides in the winter 1970 the depth of snow cower was measured once more.

During the period 1966—69, throughfall measurements were carried out all summer long, from about May 15 to September 15. The only exception is sample plot 7, where measurements were not performed during the summer of 1966.

The measurement periods for the ground water level, runoff and snow depth in all sample plots were as follows:

Summer periods	Winter periods
1966, Sept. 7-Oct. 29	1966—67, Nov. 15-May 10
1967, May 18-Sept. 30	
1968, May 7-Oct. 13	1968—69, Oct. 31-Apr. 29
1969, May 14-Sept. 12	1970, Febr. 27

Throughfall was measured during the summer periods on every rainy day with twenty rain gauges systematically placed on each sample plot. The 100 sq. cm sampling area of the rain gauges was about 60 cm above the ground surface. In 1968 some measurements of the interception caused by logging waste were made on sample plot 6. Gross precipitation was also measured in the open for the same period using a Lambrecht recording rain gauge. More details concerning the rain gauges may be found in Päivänen (1966).

The measurements of the depth of the ground water table and runoff were usually made three times a week except during the winter when measurements were performed only once every ten days. After rain the measurements were delayed for 24 hours if precipitation was less than 10 mm and for 48 hours if it was more than 10 mm.

The depth of the ground water table was measured with a precision of two millimeters with the equipment shown in Fig. 1. During the winter the measurements were done with a tape measure after the snow covering the wells had been removed. After measuring, the well was once again covered with snow.

Especially during the winter there was a danger that the calibration sticks in the ground water wells (cf. Fig. 1) might be inadvertently moved when the snow was removed. There was also the possibility that the ground frost might move the calibration sticks. Therefore, two height levellings were done, first in the spring of 1967 and then in the spring of 1969. According to these levellings and after careful comparison of several wells, 19 wells were rejected from the material. The number of wells for final treatment in each sample plot are as follows:

Sample plot	1	2	3	4	5	6	7
Final number of wells	5	6	6	5	6	5	4

Measuring runoff was done with a measuring glass at the end of the runoff pipes. Usually the amount of water discharged from the pipes during one minute was measured, but if runoff was copious, shorter periods of measurement were used.

The tree stands growing on the sample plots were measured in the fall of 1966. The measuring methods used here are of the kind ordinarily used in Finland and in many other countries. Crown closure was measured in per cents both before and after treatment with the equipment developed by Cajanus (cf. Sarvas 1953). Some data on the tree stands is given below.

Sample plot	Number of stems per hectare	Volume cu.m/ha	Increment cu.m/ha/ year	Crown closure per cent
1	1533	97.0	3.6	53
2	1959	77.6	2.6	48
3	1473	122.4	3.4	49
4	1573	77.5	3.0	49
5	1128	113.2	4.4	52
6	1218	60.6	3.2	41
7	2199	63.7	2.7	55

We can see that stands differ markedly from plot to plot. The research method used, however, does not require uniform tree stands on each sample plot. In this respect similarity of tree stands on the sample plots is satisfactory. Also, the crown closure indicates satisfactory similarity of the tree stands on different sample plots. The tree stands are, furthermore, of uniform age, about 45 years old, and they are composed exclusively of Scots pine.

The sample plots are relatively small (30 × 40 m), but the treated areas overlap them such that similarly treated areas cover about 1/4 hectare, as shown in Fig. 1.

22. Effect of treatments on the tree stand

Owing to the importance of thinning intensity in this study, it is necessary to survey the thinnings used more closely. We said before that 20 per cent of the volume was cut on sample plot 3, 40 per cent on sample plot 4, and 60 per cent on sample plot 5, whereas sample plot 6 was clear cut. The changes in stem number and especially in crown closure, are hydrologically more important than the changes in volume. Following figures show the thinning intensities in these respects.

Sample plot	Stem number removed per hectare	Stem number removed per cent	Crown closure, per cent 1967	Crown closure, per cent 1969	Crown closure, per cent change
3	493	33	49	44	−10.2
4	773	49	49	42	−14.3
5	613	54	52	33	−36.5
6	1218	100	41	0	−100.0

We found that thinnings on sample plots 3 and 4 did not have a very different effect, especially on the crown closure, but that the diminishing of it was of about the same magnitude on both sample plots. The effect of thinning on the crown closure on sample plot 5 was much heavier. We can consider that the effect of thinnings of 20 (sample plot 3) and 40 per cent (sample plot 4) is roughly the same, but that the 60 per cent thinning (sample plot 5) differs markedly from these.

It is well known that the first response of trees to fertilization is an increase in needle length. This is observable from the first growing season after fertilizing. The increase in diameter growth and shoot growth of Finnish pine stands does not become evident until the second, third, or even fourth growing season after fertilizer application (Viro 1965, Paarlahti 1967). For this reason it made no sense to study the effect of fertilization on the increase in diameter or shoot growth but only on the length of needles. Needle samples were accordingly collected in August 1969 from five medium-sized trees on each sample plot. The needles were systematically collected from the south side of the same whorl or branches. The results, which are arithmetic means of 200 measurements for each sample plot, are given below.

Sample plot	Treatment	Length of needles, mm 1967	1968	1969
1	Control	35.0 ± 0.7	33.9 ± 0.5	34.0 ± 0.7
2	Fertilized	33.5 ± 0.9	47.9 ± 0.5	47.3 ± 0.7
7	Fertilized	33.4 ± 0.6	49.1 ± 0.7	47.3 ± 0.8

Crown closure on the fertilized sample plots is roughly the same as on the control plot, as is shown below.

Sample plot	Crown closure, per cent 1967	1969	change
1	53	54	+ 1.9
2	48	49	+ 2.1
7	55	56	+ 1.8

We can consider that during the period of this study the only marked response to fertilization is an increase in needle length; this is only later followed by other responses such as increase in growth and crown closure. It is also very likely that the amount of needles fastened to the shoots will increase only after the period of this study. Therefore the results presented here are not final.

3. RESULTS

31. Precipitation

311. Throughfall

Throughfall on the sample plots was determined as the arithmetic mean of the quantities measured after each individual shower by 20 rain gauges with a precision of 0.1 mm. Because stemflow is almost negligible in pine stands during normal showers (PÄIVÄNEN 1966), it was not measured in this study.

The usual way to survey the throughfall and its possible changes is to describe it as a function of gross precipitation (cf. e.g. ROGERSON 1968). This method was tried using a regression analysis in which gross precipitation before and after treatments was the independent and the corresponding throughfall on the control plot, the dependent variable. The difference between the regression coefficients was found to be significant at the 5 % level ($t = 2.04^*$ and $t_{5\,\%} = 1.99$). The fact that the ratio of gross precipitation to throughfall is not constant may be caused by the variation in the direction of the prevailing wind, the average intensity of the precipitation, and the needle mass annually produced in the stand. In any event the possibility of changes in the ratio of gross precipitation to throughfall means that it is more reliable to study the effect of treatments on the throughfall with regression analyses in which the control sample plot is an independent and the thinned, clear-cut, and fertilized sample plots are dependent variables. The method is in principle the same as the one we shall use to study the problem of ground water table. This method is all the more suitable because the difference between the regression equations will show directly the possible effect of the treatment on the amount of throughfall reaching the ground. The regression between throughfall and gross precipitation is not linear because the canopy saturation phenomenon bends the point cluster (see e.g. LEYTON *et al.* 1966).

A preliminary graphical examination showed that there were no marked differences in the ratio between the throughfall on the control plot and on the treated plots during the two growing seasons, either before or after the treatments. For this reason the material was analyzed only for the groups of the calibration period and the period after treatments.

The method described above yields the following equations correlating the throughfall on the control plot with that on the thinned and clear-cut sample plots (see also Fig. 2). Included below are also testings of the differences in the regression coefficients before and after treatments.

Sample plot	Treatment		Function and correlation coefficient	Testing $t\,(b_c - b_a)$
3	Thinning,	c:[1]	$y = 0.1 + 1.035x, \quad r = 0.998$	5.09***
	20 per cent	a:	$y = 0.2 + 1.084x, \quad r = 0.999$	
4	Thinning,	c:	$y = 0.1 + 1.012x, \quad r = 0.997$	5.21***
	40 per cent	a:	$y = 0.2 + 1.069x, \quad r = 0.999$	
5	Thinning,	c:	$y = 1.027x, \quad r = 0.998$	4.10***
	60 per cent	a:	$y = 0.2 + 1.101x, \quad r = 0.993$	
6	Clear	c:	$y = 0.994x, \quad r = 0.997$	12.34***
	cutting	a:	$y = 0.5 + 1.175x, \quad r = 0.997$	

[1] c (before the function and as an index) indicates the calibration period and a, the period after treatment.

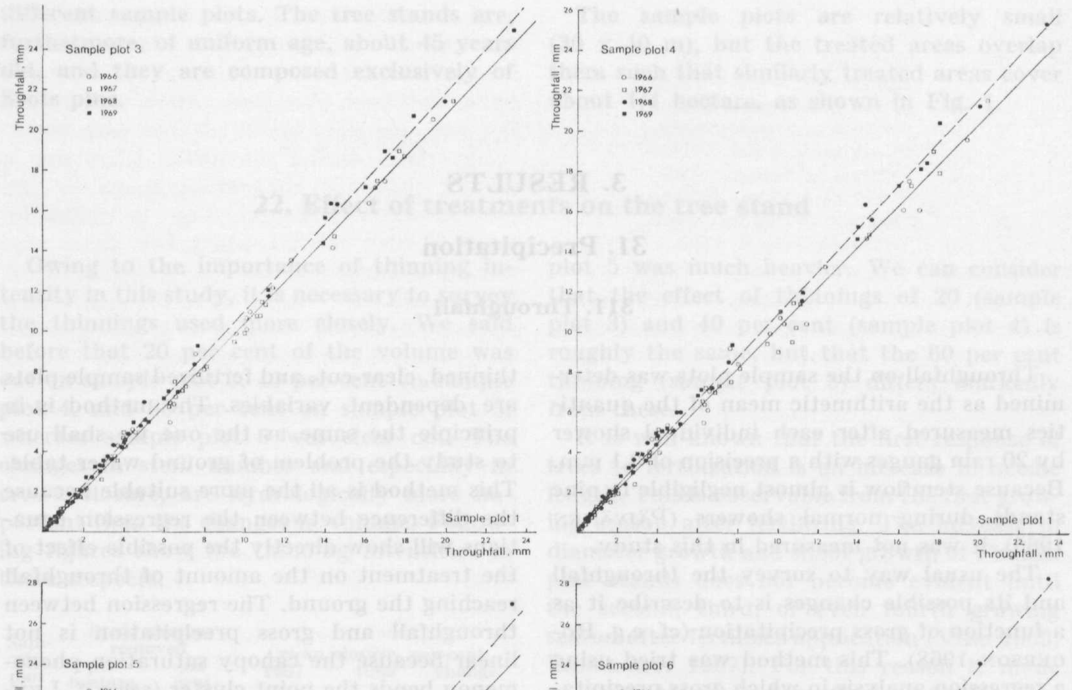

Figure 2. Effect of thinning and clear cutting on throughfall. (Unbroken line = before treatment, broken line = after treatment.)

Even the lightest thinning clearly increased the difference between the regression coefficients to a highly significant degree.

Using the equations above we calculated the following increase in the throughfall when the throughfall varies on the control plot.

Sample plot	Treatment	Throughfall on the control plot, mm 5	10	15	20
		Increase in throughfall, mm			
3	Thinning, 20 per cent	0.4	0.6	0.9	1.2
4	Thinning, 40 per cent	0.4	0.6	0.9	1.3
5	Thinning, 60 per cent	0.6	0.9	1.3	1.7
6	Clear cutting	1.4 (0.9)	2.3 (1.5)	3.2 (2.0)	4.1 (2.5)

As cutting becomes heavier, throughfall also increases. The difference between the effect of the two lightest thinnings seems to be almost negligible.

The throughfall measured 60 cm above ground surface does not show the whole amount of rain reaching the ground because of the interception of the logging waste especially on the clear-cut sample plot (cf. e.g. GOODEL 1952). Therefore, the throughfall was also measured during the first growing season after treatments with ten rain gauges systematically placed on flush with the ground surface in the clear-cut sample plot. Owing to the small number of rain gauges the measured values are not strictly reliable, but according to these measurements the average interception of the logging waste was 9 per cent. This amount of interception seemed to decrease with the shedding of needles during the late summer. During the next growing season these measurements were not continued, but it is likely that the interception of the logging waste would then have been almost negligible. The preceding table gives in parentheses the increase of throughfall when the effect of the logging waste has been taken into consideration (in sample plot 6). It is obvious that on other sample plots, too, the increase in throughfall would be a bit smaller if the interception of logging waste were included.

The following equations give the throughfall on the fertilized sample plots before and after treatment as functions of the throughfall on the control plot.

Sample plot	Function and correlation coefficient	Testing t ($b_c - b_a$)
2	c: $y = -0.1 + 1.063\,x$, $r = 0.998$	3.01**
	a: $y = -0.1 + 1.035\,x$, $r = 0.999$	
7	c: $y = 0.1 + 1.029\,x$, $r = 0.995$	1.64
	a: $y = 0.998\,x$, $r = 0.999$	

The result is not so clear as with thinning. The difference between regression coefficients before and after fertilization is significant only for sample plot 2. On sample plot 7 the variation is so great, especially before fertilization (see Fig. 3), that the difference does not reach a significant level. One reason for this is that sample plot 7 is the only one for which the calibration period is exclusively based on material from 1967. It is nevertheless very likely that fertilization has the effect of diminishing the throughfall on sample plot 7, too.

The decrease in throughfall caused by fertilization is shown below.

Sample plot	Throughfall on the control plot, mm 5	10	15	20
	Decrease in throughfall, mm			
2	0.1	0.2	0.4	0.6
7	0.2	0.3	0.5	0.7

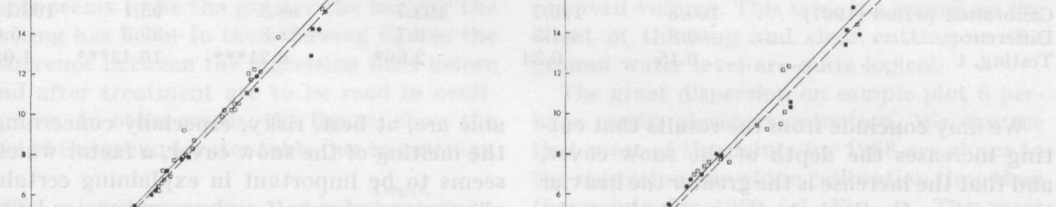

Figure 3. Effect of fertilization on throughfall. (Unbroken line = before treatment, broken line = after treatment.)

The decrease in the throughfall is quite small, yet we must bear in mind that the period of investigation was restricted to the first two years after fertilizing and that the main effects of fertilization on the tree stand will be evident only after three or four years, as stated above (cf. p. 8).

It may be worth while to express in per cents the mean change in throughfall brought about on different sample plots by the various treatments. The figure in parentheses indicates the change in throughfall during the first summer after cutting (cf. p. 11).

Sample plot	Treatment	Change in throughfall, per cent
3	Thinning, 20 per cent	+ 7.3
4	Thinning, 40 per cent	+ 7.9
5	Thinning, 60 per cent	+ 11.6
6	Clear cutting	+ 28.5 (+ 19.5)
2	Fertilizing	− 5.8
7	Fertilizing	− 4.0

It is clear that these changes, including the rather small ones caused by fertilization, must be important in determining the water conditions of the soil.

312. Snow cover

The depth of the snow cover was recorded using the simple expedient of three permanent snow depth rods on each sample plot. In the final phase of data gathering only midwinter recordings were included because the snow cover in the fall and during the spring thaw was very changeable. The final calculations were made from only six measurements for the calibration period and seven for the period after treatments. The figures for the depth of the snow cover, in centimetres, were converted into relative figures in the following manner: The figures for the control plot were assigned the value of 100 and all the others were calculated in accordance with them. The results based on these calculations are given below.

Sample plot	2	3	4	5	6	7
Period after treatment (1969)	100.9	113.7	105.2	114.0	137.6	104.7
Calibration period (1967)	100.8	110.7	103.7	98.9	95.1	103.1
Difference	+0.1	+3.0	+1.5	+15.1	+42.5	+1.6
Testing, t	0.03	1.13	0.53	6.15**	8.56***	0.84

The depth of the snow cover was measured for the second time on February 27, 1970. On each sample plot twenty measurings were taken at regular intervals. The results can be seen from the following figures, which are calculated according to the same method as previously.

Sample plot	2	3	4	5	6	7
Measuring 1970	100.0	112.2	113.4	117.7	134.4	98.1
Calibration period (1967)	100.8	110.7	103.7	98.9	95.1	103.1
Difference	−0.8	+1.5	+9.7	+18.8	+39.3	−5.0
Testing, t	0.15	0.34	2.66*	6.21***	10.42***	1.01

We may conclude from the results that cutting increases the depth of the snow cover, and that the increase is the greater the heavier the cutting. Particularly the results from the year 1970 are clear. An influence of fertilization is also likely; the depth of the snow cover decreases, but only during the second winter after treatment.

Unfortunately, conclusions based on the limited number of snow cover readings available are, at best, risky, especially concerning the melting of the snow cover, a factor which seems to be important in explaining certain phenomena of runoff and ground water level in the spring. The observations made during spring thaw point to the fact that cutting speeds up melting. This has, indeed, been known for some time (cf. e.g. Yli-Vakkuri 1960).

32. Depth of the ground water table

321. Effect of thinning and clear cutting

The data on the depth of the ground water table were handled as follows. The mean depth of the ground water table was calculated for each reading time and sample plot. The regressions for the calibration period (1966—67) and for the period after treatments (1968—69) were calculated so that the figures for sample plot 1 (control) were the independent variables and the figures for the thinned sample plots (3, 4, 5) and the clear-cut sample plot (6), the dependent variables. For a reason which will be discussed later in more detail, the few winter readings were not included in the analysis.

The years after treatment did not differ from each other and it was thus possible to group the readings after treatments together. An exception is sample plot 6, where there seems to be a variation between the two years after clear cutting. Nevertheless sample plot 6 was also handled in the same way as the others (cf. p. 14). Figure 4 shows the results.

The differences between the regression lines representing the calibration period and the period after treatment were studied in two stages. Firstly, the t-test was used to ascertain if there was any significant difference between the regression coefficients. Secondly, when the regression coefficients did not differ from each other, covariance analysis was used to test whether the levels of the regression lines differ from each other. The equations and testings are as follows:

Sample plot		Function and correlation coefficient	Testing $t\ (b_c - b_a)$	Testing $F\ (a_c - a_a)$
3	c:	$y = 0.1 + 1.03\,x,\ r = 0.993$	5.447***	..
	a:	$y = 3.3 + 0.89\,x,\ r = 0.981$		
4	c:	$y = 0.6 + 0.94\,x,\ r = 0.987$	2.736**	..
	a:	$y = 1.6 + 0.85\,x,\ r = 0.970$		
5	c:	$y = 9.4 + 0.78\,x,\ r = 0.971$	1.913	203.42***
	a:	$y = 6.2 + 0.71\,x,\ r = 0.949$		
6	c:	$y = 10.1 + 0.75\,x,\ r = 0.962$	5.821***	..
	a:	$y = 11.7 + 0.47\,x,\ r = 0.815$		

The testing points to the fact that in all cases the *ground water is at a higher level* during the period after treatment than during the calibration period. In other words: thinnings and clear cutting have the effect of raising the ground water table.

Figure 4 shows that the rise in ground water table seems to be the greater the heavier the cutting has been. In the following figures the difference between the regression lines before and after treatment are to be read in centimetres. In other words, the figures show the rise of the ground water table due to cuttings.

Sample plot	Treatment and thinning intensity	Depth of ground water table on control plot, cm: 25	35	45	55
		Rise of ground water table, cm			
3	Thinning, 20 per cent	0.2	1.8	3.1	4.1
4	Thinning, 40 per cent	1.1	2.1	3.0	4.1
5	Thinning, 60 per cent	5.0	5.5	6.3	6.9
6	Clear cutting	5.3	6.0	12.0	13.7

We see that the rise of the ground water table is *the greater the heavier the cutting*. The difference between sample plots 3 and 4 seems to be an exception. The reason for this might be that the thinning did not actually reduce the crown closure on sample plot 4 as much as it was expected on the basis of the removed volume. This said, the results on the effect of thinning and clear cutting on the ground water level are quite logical.

The great dispersion on sample plot 6 perhaps merits closer examination. We can see that most of the points for 1968 are closer to the regression line of the calibration time than the points for 1969 (cf. Fig. 4). The most likely explanation for this is that because the interception due to fresh logging waste just after cutting diminished the amount of water reaching the ground (cf. p. 11), the ground water table in the first summer after cutting did not rise so much as in the second sum-

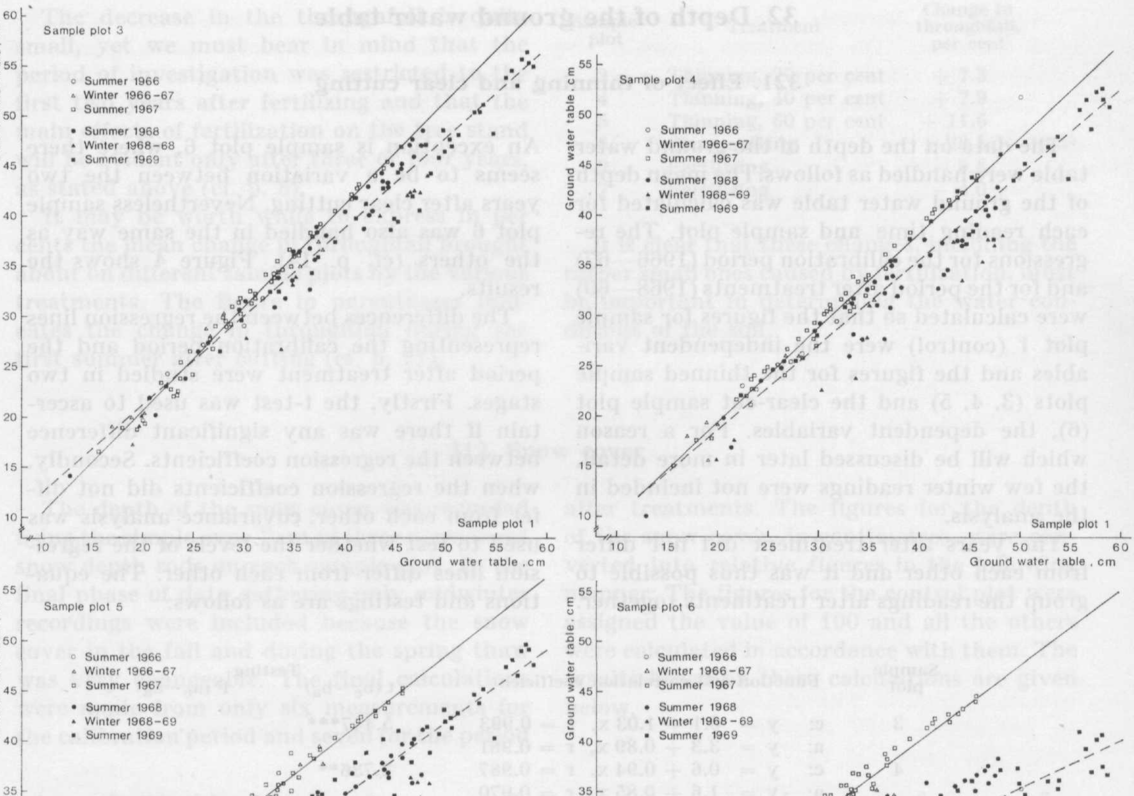

Figure 4. Effect of thinning and clear cutting on the depth of the ground water table. (Unbroken line = before treatment, broken line = after treatment.)

mer when the needles of the logging waste had already fallen.

The winter readings are widely dispersed, especially following treatments (see Fig. 4). This is difficult to explain. One reason may be different runoff during the winter. In the winter of 1969 the runoff drain on sample plot 1 worked until March 5, whereas all the other runoff drains had frozen by January 23. Thus it is understandable that during the winter of 1969 the depth of the ground water table was greater in sample plot 1 than in the other sample plots.

322. Effect of fertilization

The method of analysing the data is the same here as in the preceding section. Because the effect of fertilization becomes visible only gradually — as was expected — the years after treatment were calculated separately. Figure 5 gives the general results. A closer survey of the functions is provided below. The method of testing is the same as in the foregoing section.

Sample plot	Time period	Function and correlation coefficient	Testing t ($b_c - b_a$)	F ($a_c - a_a$)
2	Calibration	$y = -5.4 + 1.07\,x$, $r = 0.976$		
	1968	$y = 1.8 + 0{,}96\,x$, $r = 0.983$	(2.696**)	70.00***
	1969	$y = -0.9 + 1.07\,x$, $r = 0.996$	0.008	110.62***
7	Calibration	$y = 8.4 + 0.69\,x$, $r = 0.970$		
	1968	$y = 8.7 + 0.71\,x$, $r = 0.986$	0.710	17.77***
	1969	$y = 9.9 + 0.82\,x$, $r = 0.991$	4.745***	

The functions and testings indicate that already in the first summer after fertilizing, which was done in early spring, the ground water table sinks a little. The differences in coefficient b are not significant. In this case of sample plot 2, the deviation of the regression line between the calibration period and the year 1968 is converse and difficult to interpret (see also Fig. 5). The differences in the constant a, however, are in both cases highly significant. In the second year the deviation is clear and much greater. The increase in the depth of the ground water table in the second year after fertilizing can be seen in the following figures.

Sample plot	Depht of the ground water table on the control plot, cm 25	35	45	55
	Increase in the depth of the ground water table, cm			
2	4.8	4.7	4.6	4.6
7	4.7	6.0	7.3	8.5

In this connection it is difficult to satisfactorily explain why the change in direction of the regression lines differs a bit on these

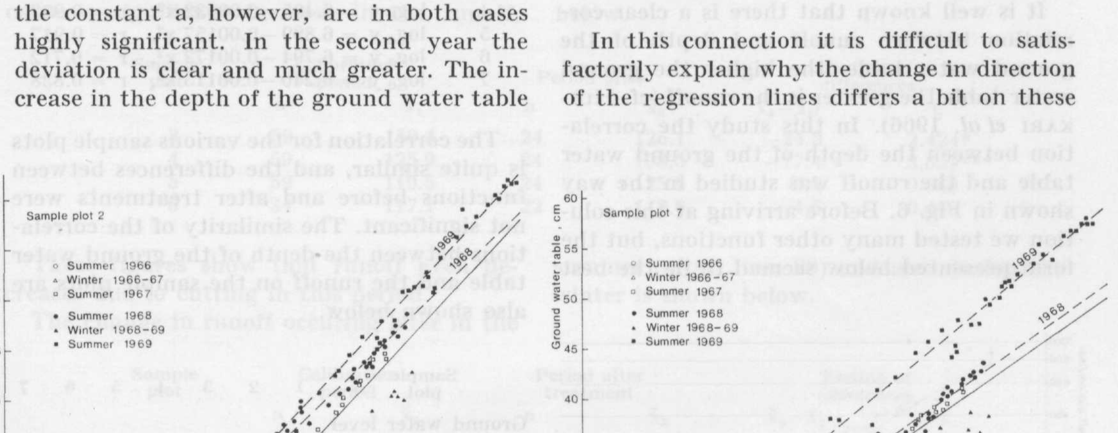

Figure 5. Effect of fertilization on the depth of the ground water table. (Unbroken line = before treatment, broken line = after treatment.)

two sample plots, but the nature of the change is the same for both sample plots; to wit, a fairly great increase in the depth of the ground water table due to fertilizing in the second year after treatment.

The fairly marked sinking of the ground water table in the second summer after fertilizing is hard to explain merely by a decrease in throughfall, which was quite limited. There are good grounds for assuming that the transpiration of trees and perhaps of ground vegetation, too, increased due to fertilization. Unfortunately, we were not in a position to measure transpiration in this study.

The winter readings after fertilizing are again difficult to explain. The reasons set forth at the end of the foregoing section should again be in evidence. That the winter points for the fertilization experiment correspond closely to those for cutting (see Fig. 4) is obviously due to the different runoff on the control plot in the winter of 1969 compared with the runoff on the other sample plots.

33. Runoff

331. Correlation between runoff and depth of the ground water table

First of all it is necessary to point out that the measurements of runoff do not cover the whole runoff because part of the surface water moved directly into the open ditches surrounding the sample plots. Thus, the figures for runoff given here describe only the runoff relations between the sample plots.

It is well known that there is a clear correlation between runoff and depth of the ground water table: the higher the ground water table the greater is the runoff (cf. HUIKARI *et al.* 1966). In this study the correlation between the depth of the ground water table and the runoff was studied in the way shown in Fig. 6. Before arriving at this solution we tested many other functions, but the form presented below seemed to be the best one. The functions for the various sample plots are:

Sample plot	Function and correlation coefficient
1	$\log_e y = 6.669 - 0.00156\,x^2, \quad r = 0.910$
2	$\log_e y = 6.364 - 0.00145\,x^2, \quad r = 0.913$
3	$\log_e y = 6.802 - 0.00136\,x^2, \quad r = 0.949$
4	$\log_e y = 6.405 - 0.00132\,x^2, \quad r = 0.923$
5	$\log_e y = 6.899 - 0.00157\,x^2, \quad r = 0.917$
6	$\log_e y = 6.794 - 0.00172\,x^2, \quad r = 0.712$
7	$\log_e y = 6.240 - 0.00113\,x^2, \quad r = 0.838$

The correlation for the various sample plots is quite similar, and the differences between functions before and after treatments were not significant. The similarity of the correlations between the depth of the ground water table and the runoff on the sample plots are also shown below.

Sample plot	1	2	3	4	5	6	7
Ground water level (cm) when runoff is 20 cu.cm/min	49	48	53	51	50	47	52

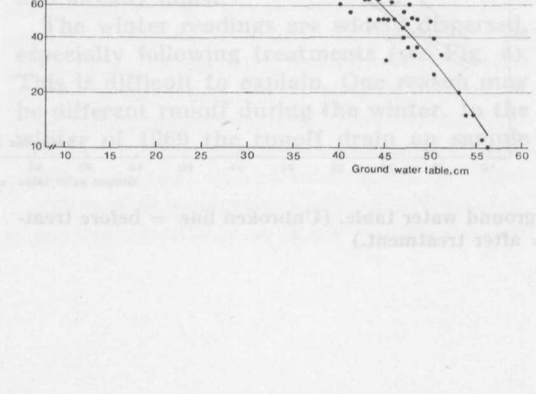

Figure 6. Correlation between the depth of the ground water table and runoff.

332. Effect of thinning and clear cutting

The following method of analysis was used here: The runoff values for the control plot were assigned a value of 100, and comparable relative figures were calculated for the runoff values of the other sample plots. From these relative figures the arithmetic means were computed for the calibration period and for the period after it. Further analysis of the data revealed that in the spring and early summer after treatments, the behavior of the runoff was markedly different from that of the other part of the summer. Therefore, arithmetic means were computed separately for the period before and after June 20.

Below are given the arithmetic means of the whole material for the calibration period and for the period after treatments.

Sample plot	Calibration period		Period after treatment		Testing of differences	
	n	$\bar{x}_1$	n	$\bar{x}_2$	$\bar{x}_2-\bar{x}_1$	t
3	59	150.4	58	153.0	2.6	0.304
4	59	125.9	58	150.4	24.5	3.079**
5	59	119.5	58	190.5	71.0	5.724***
6	34[1]	117.1	56	228.3	111.2	5.966***

[1] The number of recordings on sample plot 6 is smaller than on the other sample plots due to high water level in the ditch where the end of the runoff pipe in question was located.

We see that thinning increases runoff and that this increase is directly proportional to the intensity of the thinning. The testing shows that thinning of 20 per cent does not cause a significant increase in the runoff, whereas 40 per cent thinning increases it significantly and 60 per cent thinning and clear cutting, highly significantly.

The change in runoff in the spring is shown below.

Sample plot	Calibration period		Period after		Testing of differences	
	n	$\bar{x}_1$	n	$\bar{x}_2$	$\bar{x}_2-\bar{x}_1)$	t
3	59	150.4	24	126.1	−24.3	2.424*
4	59	125.9	24	108.5	−17.4	3.629***
5	59	119.5	24	125.5	6.0	0.889
6	34	117.1	22	112.6	−4.5	0.489

These figures show that runoff even decreases due to cutting in this period.

The change in runoff occuring later in the summer (after June 20) and also during the winter is shown below.

Sample plot	Calibration period		Period after treatment		Testing of differences	
	n	$\bar{x}_1$	n	$\bar{x}_2$	$\bar{x}_2-\bar{x}_1$	t
3	59	150.4	34	174.6	24.2	2.446*
4	59	125.9	34	181.0	55.1	5.832***
5	59	119.5	34	236.4	116.9	7.315***
6	34	117.1	34	303.1	185.0	8.711***

The changes in runoff, except in spring, are very marked, and runoff increases with heavier cutting. It is worth mentioning that thinning of 20 per cent also caused nearly significant increase in the runoff.

It is difficult to explain the unique behavior of runoff in the spring, but this could be simply due to the fact that snow and ground frost melt at different times in different sample plots. During the calibration time the snow on all the sample plots melted at the same time, but after treatment, it melted in the thinned area nearly a week, and in the clear-cut area, over a week earlier than in the control area. Also the different freezing and melting of runoff pipes (cf. p. 14) may introduce a factor of error in the measurements of runoff in the spring.

333. Effect of fertilization

The effect of fertilization on runoff was studied in the way described in the foregoing section, but the years after treatment were dealt with separately. The results are given below.

Sample plot	Calibration period		Period after fertilizing			Testing of differences	
	n	$\bar{x}_1$	Year	n	$\bar{x}_2$	$\bar{x}_2-\bar{x}_1$	t
2	59	104.0	1968	34	87.0	−17.0	3.436**
			1969	24	75.6	−28.4	4.763***
7	59	130.0	1968	34	107.8	−22.2	2.032
			1969	24	104.8	−25.2	2.099*

As early as in the first summer after fertilizing the runoff decreased, though this was not significant on sample plot 7. In the second summer the decrease in the runoff was greater; on sample plot 2 it was highly significant and on sample plot 7, nearly significant.

Differences between the spring and the later summer were not clear. In the spring (before June 20) the decrease in runoff was also very marked, which is to be seen from the following figures showing the arithmetic means for the spring in both years after fertilizing.

Sample plot	Calibration period		Period after fertilizing		Testing of differences	
	n	$\bar{x}_1$	n	$\bar{x}_2$	$\bar{x}_2-\bar{x}_1$	t
2	59	104.0	24	91.4	−12.6	2.307*
7	59	130.0	24	95.1	−34.9	3.945***

The similarity of the changes in runoff during the spring and summer was also expected because there was no change in snow depth and snow melting caused by fertilization.

The fairly great decrease in runoff due to fertilization is surprising and difficult to explain only in terms of decreasing throughfall. In this context there is also evidence in support of the assumption of possible increase in transpiration due to fertilization (cf. p. 16).

4. DISCUSSION

Before summarizing the results and discussing them it may be necessary to explain some notions that figure in this section. When speaking about the changes in hydrology caused by treatments we chose to use the terms *favorable* and *detrimental changes*. These notions are to be understood from the silvicultural point of view regarding peatland areas drained for forestry. In these areas excess water of the substrate is the usual state; thus, a change in terms of decreasing soil water is favorable and the opposite change, detrimental.

Another group of notions used here is *biological* and *technical drainage*, the first of which means the decrease in soil water due to evapotranspiration, and includes interception, and the second, that caused by runoff through draining.

In order to survey the hydrological effects of cuttings three thinnings were made. The lightest removed 20 per cent of the stand volume, the next in intensity, 40 per cent, and the heaviest, 60 per cent. In addition one sample plot was clear-cut. The thinnings of 20 and 40 per cent were directed at the dominated tree layer, and therefore the decrease in crown closure was only 10 and 14 per cent. The 60 per cent thinning was directed at the dominant tree layer, too, and the decrease in crown closure was about 37 per cent.

During the first two years after cutting the interception was diminished so that the throughfall was increased by 7 per cent for the 20 per cent thinning, by 8 per cent for the 40 per cent thinning and by 12 per cent for the 60 per cent thinning. Clear cutting increased the throughfall by 29 per cent. Due to the freshness of the logging waste throughfall was about 9 per cent smaller in the first summer.

The thinnings increased the depth of the snow cover clearly, and the more the heavier the thinning. Clear cutting caused the greatest increase in the depth of the snow cover. Melting of the snow cover seemed to be earlier in the thinned and cut areas than in the untouched areas.

Even the lightest thinning raised the ground water table, but the difference between 20 and 40 per cent thinning was not marked. The heaviest thinning caused a very marked rise in the ground water table, but the rise caused by clear cutting was still greater. In general the rise of the ground water table was relatively small compared with the studies carried out earlier (cf. Heikurainen 1967). This is due to the better drainage provided by the runoff drains on the sample plots of this study. It is worth mentioning that a rise of the ground water table seems to be the case in winter and spring, too, although measurings for these periods were insufficient.

Cuttings increase runoff, and this effect is the greater the heavier the cutting. In the spring there was a short period when such an effect could not be observed. Otherwise the increase in runoff was very marked; 24 per cent even with the lightest thinning and altogether 186 per cent with clear cutting.

It is to be seen that all the hydrological changes referred to above are detrimental to the site. The throughfall has increased, the snow cover become deeper, and the ground water table risen. The increase in runoff may be considered a favorable effect, but it is naturally caused by a rise of the ground water table and so it is more the consequence of the detrimental effects of cutting. We can consider that biological drainage is weakened by cuttings.

However, the detrimental effects of 20 and even 40 per cent thinnings are not very strong. There seems to be a jump between the thinnings of 40 and 60 per cent, after which the detrimental effects are very marked. Actually, thinning in which 60 per cent of the stand volume is removed ceases to be a silvicultural thinning and usually disturbs the stand.

In order to survey the hydrological effects of fertilization, two sample plots were fertilized after the calibration period. Fertilizing was done in accordance with present-day recommendations and will lead to a very great increase in the increment in the third growing season after treatment, but in this study it was possible to survey only the first two growing seasons.

Fertilization had a clearly favorable effect on the hydrology of the peatland studied. The length of needles showed an increase by the first summer after treatment and the needle mass noticeably increased, too. The interception increased and therefore the throughfall decreased about 5 per cent. The depth of snow did not decrease in the first winter after treatment, but in the second winter there was a probable decrease.

The favorable effect of fertilization on hydrology was clearly to be seen in the increase of the depth of the ground water table. In the first summer after fertilization it was rather small, but during the second summer, the sinking of the ground water table was marked, 5—8 cm in all.

Runoff decreased owing to a decrease in throughfall and an increase in the depth of the ground water table. In the first summer it was small, but in the second summer the decrease in runoff was 25—28 per cent of the runoff before treatment.

We can consider that fertilization improves the biological drainage. In general the favorable hydrological effects resulting from fertilization seemed to be surprisingly rapid and large. Although transpiration was not studied, it is difficult to explain the fairly great effect of fertilization on the hydrology without assuming that transpiration increased due to fertilization. In this study it was possible to follow these effects only two years after treatment, and it is to be expected that the favorable effects will increase with time.

The results discussed above may have some practical importance for silviculture. Because all cuttings have an adverse effect on the hydrology of drained peatlands, it is necessary to grow denser forest stands on these sites than is usual. Especially in old drainage areas where ditches are no longer fully effective the biological drainage caused by tree stands is very important and any treatment that diminishes it is detrimental. In order to regenerate tree stands it is, of course, necessary to carry out intense cuttings like clear cutting, seedtree cutting, etc., and in this connection repeated drainage will be required.

It seems that fertilization has a favorable effect on the hydrology that is both quick acting and fairly strong. Because of this, fertilizing stands growing on drained peatlands is to be recommended. Increasing biological drainage by fertilization makes it possible to do away with technical drainage to some extent, for instance, with the need of maintenance of old ditches.

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SELOSTE:

HARVENNUKSEN, AVOHAKKUUN JA LANNOITUKSEN VAIKUTUS OJITETUN SUON VESIOLOIHIN

Tutkimus on suoritettu Keski-Suomessa Korkeakosken hoitoalueessa vuosina 1966–1970. Koejärjestely sekä eräät mittauslaitteistojen yksityiskohdat on esitetty kuvassa 1 (s. 6). Tutkimusmenetelmän pääpiirteistä mainittakoon seuraavaa. Vuosina 1966 ja 1967 mitattiin sadantaa, pidäntää, pohjavesipinnan syvyyttä, lumen paksuutta ja valuntaa seitsemällä koealalla. Talvella 1968 yksi koeala harvennettiin siten, että poistettiin 20 % kuutiomäärästä (koeala 3), toisella koealalla (4) harvennettiin 40 % ja kolmannella koealalla (5) 60 % kuutiomäärästä. Yksi koeala (6) hakattiin paljaaksi. Aikaisin keväällä 1968 lannoitettiin kaksi koealaa (2 ja 7). Yksi koeala (1) jätettiin vertailukoealaksi. Toimenpiteitten jälkeen vuosina 1968 ja 1969 jatkettiin samoja mittauksia. Lisäksi on mitattu lumen paksuutta talvella 1970. Tutkimalla mitattujen suureiden korrelaatioita vertailukoealan ja eri tavalla käsiteltyjen koealojen välillä ennen ja jälkeen toimenpiteitten on selvitetty, mikä vaikutus erilaisilla toimenpiteillä vesioloihin on ollut.

Hakkuut pienensivät pidäntää siten, että maahan tuleva sadanta lisääntyi 20 %:n harvennuksessa 7 %, 40 %:n harvennuksessa 8 % ja 60 %:n harvennuksessa 12 %. Avohakkuu lisäsi maahan tulevaa sadantaa 29 %. Ensimmäisenä kesänä hakkuiden jälkeen tuoreet hakkuutähteet pidättivät osan sateesta. Avohakkuualueella tämä pidäntä oli n. 9 % sadannasta.

Hakkuut aiheuttivat myös lumipeitteen paksuuden lisääntymistä, joka oli sitä suurempi, mitä voimakkaampi oli hakkuu. Lumipeitteen sulaminen nopeutui hakkuun vaikutuksesta.

Jo 20 % harvennus aiheutti selvän pohjavesipinnan nousun ja yleensä nousu oli sitä suurempi, mitä voimakkaampi oli hakkuu. Ero 20 % ja 40 % harvennuksen välillä oli kuitenkin vähäinen. Itse asiassa 20 % ja 40 % harvennukset eivät luonteeltaan poikenneet toisistaan kovin paljon, esim. latvuspeiton muutos oli joltisenkin samanlainen.

Hakkuiden aiheuttama pohjavesipinnan nousu osoittautui tässä tutkimuksessa pienemmäksi kuin eräissä aikaisemmissa tutkimuksissa (Heikurainen 1966 ja 1967). Syy tähän on siinä, että tämän tutkimuksen koekenttien kuivatus oli valuntaputkien (vrt. kuva 1) ansiosta erittäin tehokas aikaisempien tutkimusten koekenttiin verrattuna.

Valunta lisääntyi hakkuiden vaikutuksesta ja lisäys oli sitä suurempi, mitä voimakkaammasta hakkuusta oli kyse. Lievimmän harvennuksen vaikutuksesta lisäys oli 24 % ja avohakkuun vaikutuksesta peräti 186 %.

Kaikki edellä kuvatut hydrologiset muutokset ovat puun kasvua ajatellen haitallisia, valunnan lisäystä tietysti lukuunottamatta. Valunnan lisäystä on pidettävä epäedullisten muutosten seurauksena.

Lannoituksen hydrologisia vaikutuksia tarkasteltaessa on muistettava, että tutkimus koski kahta ensimmäistä lannoituksenjälkeistä kasvukautta. Lannoituksen vaikutus puustoon on tässä vaiheessa vielä suhteellisen vähäinen; ilmeisesti vain neulasten pituus on lisääntynyt.

Tulokset osoittivat, että pidäntä lisääntyi siten, että maahan tuleva sadanta pieneni n. 5 %. Lumen syvyys todennäköisesti pieneni toisena lannoituksenjälkeisenä talvena.

Pohjavesipinta aleni jo ensimmäisenä lannoitusta seuranneena kesänä. Muutos oli kuitenkin pieni. Toisena kesänä pohjavesipinnan aleneminen oli jo voimakkaampi eli 5–8 cm.

Valunta pieneni lannoituksen vaikutuksesta. Ensimmäisenä kesänä pieneneminen oli vähäistä, mutta toisena kesänä jo selvää ja määrältäänkin verrattain suurta.

Lannoituksen nopeita ja etenkin toisena kesänä jo suhteellisen suuria hydrologisia vaikutuksia selitettäessä päädyttiin olettamaan, että lannoitus ilmeisesti lisää myös puuston ja aluskasvillisuuden haihduntaa.

Ottaen huomioon, että tutkimus koski vasta kahta ensimmäistä lannoituksenjälkeistä kasvukautta, on ilmeistä, että myöhemmin lannoituksen hydrologiset vaikutukset vielä voimistuvat.

Tutkimus antaa aihetta pohtia myös mahdollisia metsänhoidollisia ja ojitusalueiden hoitoa koskevia sovellutuksia. Kun hakkuiden hydrologiset vaikutukset ovat puuston kasvua ajatellen epäedullisia, lienee syytä välttää voimakkaita kasvatushakkuita.

Etenkin vanhoilla ojitusalueilla, joilla ojat eivät enää ole täydessä kuivatustehossaan, puuston biologinen kuivatusvaikutus on erittäin tärkeää, ja kaikki toimenpiteet, jotka sitä pienentävät, ovat vahingollisia. Uudistamisen yhteydessä joudutaan luonnollisesti suorittamaan voimakkaita hakkuita ja tällöin näyttäisi ojituksen uusiminen olevan välttämätöntä.

Lannoituksen edulliset hydrologiset vaikutukset näyttävät olevan nopeita ja suuruusluokaltaankin varteen otettavia. Näin ollen lannoitusta on myös tässä mielessä pidettävä suositeltavana toimenpiteenä ojitusalueiden hoidossa. Voidaan jopa ajatella, että vanhoilla ojitusalueilla lannoitus – tiettyyn rajaan asti – korvaa vanhojen ojien perkaustarpeen.

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