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WATER BALANCE OF DRAINED PEATLANDS ON THE BASIS OF WATER TABLE SIMULATION DURING THE SNOWLESS PERIOD

ERKKI AHTI

SELOSTE

OJITETTUJEN SOIDEN VESITASEEN ARVIOIMINEN LUMETTOMANA AIKANA POHJAVESIPINNAN SIMULOINTIMALLIN AVULLA

HELSINKI 1987

METSÄNTUTKIMUSLAITOS
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Metsäntutkimuslaitos on maa- ja metsätalousministeriön alainen vuonna 1917 perustettu valtion tutkimuslaitos. Sen päätehtävänä on Suomen metsätaloutta sekä metsävarojen ja metsien tarkoituksenmukaista käyttöä edistävä tutkimus. Metsäntutkimustyötä tehdään lähes 800 hengen voimin yhdeksällä tutkimusosastolla ja kymmenellä tutkimus- ja koeasemalla. Tutkimus- ja koetoimintaa varten laitoksella on hallinnassaan valtionmetsiä yhteensä n. 150 000 hehtaaria, jotka on jaettu 17 tutkimusalueeseen ja joihin sisältyy kaksi kansallis- ja viisi luonnonpuistoa. Kenttäkokeita on käynnissä maan kaikissa osissa.

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The water balance of drained peatlands was estimated for different ditch depths and spacings. The components of the water balance were determined independently as follows:

- runoff: observed,
- precipitation: observed
- evapotranspiration: estimated on the basis of potential evapotranspiration and the water table level
- storage: estimated on the basis of water table level and soil water characteristics; equilibrium of soil water assumed.

The daily level of the water table was calculated by using a simulation model and independent data for reference. After satisfactory verification of model output, conclusions on the general hydrological influences of ditching were drawn.

Tutkimuksessa tarkasteltiin ojitetun suon vesitasetta eri sarkaleveyksin ja ojasyvyyksin ojitetuilla lohkoilla. Vesitaseen osatekijät määritettiin kukin erikseen seuraavasti:

- valunta: havainnointi
- sadanta: havainnointi
- haihdunta: arvioitiin potentiaalisen haihdunnan ja pohjavesipinnan syvyyden avulla
- vesivaraston muutos: arvioitiin pohjavesipinnan syvyysmuutoksen ja turpeen vedenpidätysominaisuuksien avulla; oletuksena maaveden energiatasapaino.

Päivittäinen pohjavesipinnan syvyys laskettiin käyttämällä simulointimallia ja riippumatonta vertailuaineistoa. Mallin verifioinnin onnistuttua tyydyttävästi arvioitiin metsäojituksen yleisiä hydrologisia vaikutuksia.

Keywords: Runoff, evaporation, storage, retention, energy equilibrium
ODC 116.1/.2+2--114.444+232.215

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CONTENTS

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1. INTRODUCTION

11. General

Ditching of peatlands for forestry and agricultural purposes has been a common practice in Finland for most of the 20th century. Likewise, possible hydrological changes due to ditching have been object to scientific interest for a long time. A number of theories on the hydrological role of undrained peatlands have been discussed, and in a number of publications, effects of ditching on hydrology have been reported. The reports, even if based on empirical data in most cases, have been partly contradictory especially as regards the effects of the ditching on runoff.

Not much has been published on the hydrology of natural state peatlands. According to Bay (1969), small bog watersheds were not effective as long term storage areas and regulators of streamflow. The same was reported by Johansson (1974) on the basis of extensive studies in a large highmoor area in Sweden.

According to Romanov (1968), evaporation plays a decisive role in the water balance of highmoor bogs during the snowless period (June-September): from an average precipitation of 280 mm, 240 mm are lost in evaporation and about 65 mm in runoff, which during this period contributes to a decrease in the water store by about 25 mm.

Boelter & Verry (1977) summarize the hydrological behaviour of peatlands as follows: "Peatland does reduce the peak rates of streamflow from snowmelt and heavy summer rains because it is flat and there is some short term detention storage in surface horizons. However, peatland does not sustain streamflow during dry summer months by slowly releasing stored water. On the contrary, it uses water at maximum rates of evapotranspiration and at the expense of streamflow".

As mentioned above, most interest has been paid to the effect of ditching on runoff. In their classical work from 1964 in North-Western Germany, Baden and Engelsmann presented results which agree with the findings of Bay (1967) and Johansson (1974) based on empirical data from undrained highmoor bogs. Comparing an undrained bog area with a drained agricultural area, they concluded that ditching has a levelling effect on the runoff regime of bogs. Similar empirical data has been published by Burke (1963), Heikurainen et al. (1978), and Heikurainen (1980). All these reports agree, however, that ditching increases runoff on an annual basis. As regards the levelling effect, contradictory data has been published by Conway & Millar (1960), Mustonen & Seuna (1971), and Hyvärinen & Vehviläinen (1978).

According to Seuna (1981) the effects of ditching on the hydrology of forested peatlands seem to decline 20 years subsequent to ditching.

12. Experimental procedure

As demonstrated by the contradictions in the empirical data presented so far, the use of sophisticated experimental designs has resulted in different opinions on the hydrological effects of peatland drainage. It is quite obvious, though, that all data presented is valid in certain circumstances. Consequently, the amount of data must, in many cases, have been too scarce for the conclusions presented, or, which is as probable, the data has not been representative as regards site and climate.

Part of the difficulties in interpretation of the data is connected with experimental layout. Scientifically the most precise method, the control basin method, is based on basins large enough to include a natural runoff channel. In large basins, on the other hand, uncontrolled changes during data collection are more probable than in small basins. Second, in spite of the fact that the control basin eliminates the variation caused by long term climatic variation, the possibility always exists that the period of observation does not include vital parts of the climatic continuum. Consequently, very long periods of observation are necessary for each pair of basins if reliable conclusions are aimed at. This is particularly true for basins used for forestry, as the development of the tree stand in many cases starts from the year of ditching and does not stop until perhaps 50 years later.

Because of the difficulties mentioned above and the laborious observations connected, simpler and faster approaches have been tried. The most commonly used method is to compare drained peatlands at different stages of stand development with adjacent undrained areas (e.g. Baden & Engelsmann 1964, Heikurainen 1976, Heikurainen et al. 1978). By choosing areas of the same original site type and the same topography, long term monitoring normally connected with studying long term effects can partly be avoided. The approach, however, has its weaknesses. Comparatively small areas being in question, the natural state control does not involve a natural runoff channel, but has to be supplied with contour ditches. Second, no definite proof of the original similarity of the areas to be compared can be obtained. Third, difficulties arise in the accuracy of runoff recording because of the relatively small area size. On the other hand, the whole basin can be treated with the same ditching treatment.

To be able to determine the basin area, boundary ditches have to be used. This procedure excludes runoff inputs from the hydrological balance. Consequently, the results can be valid for raised bogs only.

The variable spacing method is rather closely related to the one described above. Instead of comparing drained and undrained areas, it is based on comparing small peatland areas drained by using different distances between the ditches. The layout does not include an undrained control. The main assumption is that the magnitude of change caused by ditching is more or less inversely related to spacing. If the assumption holds, the direction of change can be determined and the magnitude of change extrapolated.

The variable spacing method has many of the weaknesses of the previous method. Because of the lacking control, its use is connected with additional uncertainty in interpreting the data. Estimation of tree stand effects usually is more or less bound to the time required by the stand development itself. No uncertainty, however, exists regarding the original site types of the artificial mini-basins to be compared.

13. The model approach

According to Shannon (1975), a model can be defined as a representation of a system in some other form than that of the system itself. Simulation can be defined as the process of designing the model and conducting experiments with it. Simulation modeling simply is an experimental and applied methodology which seeks to describe the behaviour of systems, to construct theories or hypotheses that account for the observed behaviour, and to use these theories to predict the effects that will be produced by changes in the system.

Simulation of the hydrological cycle or parts of it provides a valuable tool for the hydrologist, who usually can not obtain representative data because of limited time and research funds. The power of simulation modeling lies in the fact that it helps to understand the causal relationships between the system variables and eliminates false interpretation of sparse experimental data that itself might not be representative.

The water balance can be expressed with a simple equation:

$$P + q_{in} = E + q_{out} \pm \Delta S/\Delta t \qquad (1)$$

where
P = precipitation
q_{in} = runoff input
E = evapotranspiration
q_{out} = runoff
$\Delta S/\Delta t$ = change in water store

In most cases, runoff prediction is aimed at by simulation modeling. By inserting rainfall and climatological data for evaporation calculation, the model calculates effective rainfall and water storage and results in runoff as an output. If the model operates on a short period basis, for instance on the basis of daily input data, the effective rainfall that actually infiltrates into the soil provides the most difficult problems for the modeler. Here, problems connected with evaporation and interception are vital. As soon as effective rainfall and the change in water store can be successfully simulated, runoff outputs are arrived at through elementary mathematics.

A simple model as equation (1) does not have much information value, because it does not tell anything of the physical processes of the system or the causal relationships between the variables of the system. If it is used for runoff predicition, it requires precipitation, input runoff, evaporation and water storage change as input data, whereafter the runoff component is obtained by simple substraction. The validation of the model by comparing calculated runoff values with measured ones means that all components of the hydrologic equation have been empirically determined. As it was previously mentioned, modeling is used in hydrology to limit the amount of empirical observations to a minimum or to utilize unrepresentative or incomplete data. Hence, the components of the water balance equation are divided into smaller units, part of which operate with theoretical functions rather than empirical data. An example of this is the so-called Monash model originally presented by Porter & McMahon (1971) and later analyzed by Weeks & Hebbert (1980) as follows:

> *"Rainfall is first subject to interception storage with excessive moisture either infiltrating or flowing to the stream channel. The overland flow is subject to diversion to depression storage where the water is then subject to evaporation or infiltration. Infiltrating moisture can either enter the soil moisture storage, subject to evapotranspiration; the ground water storage, subject to drainage as baseflow; or can immediately enter the stream channel as interflow. The soil moisture storage is of finite capacity from which overflow enters the ground water storage which is of infinite capacity. All streamflow is routed to the catchment outlet by a nonlinear routing function".*

The amount of additional information produced by a model is dependent on how much and what kind of input data is used. If only precipitation and climatological input data is used, the whole evaporation-storage-runoff process has to be simulated, and additional information is gained from these processes provided that the model works properly.

If runoff output is not aimed at, but runoff data is used as input, the model becomes simpler: only evaporation and water storage have to be simulated (Fig. 1).

This means that the additional information gained by using the model lies in the area of these two processes.

14. Peatland characteristics

141. Soil water

Peatlands are characterized by a shallow water table. This is particularly true in the humid climate of Finland. Even in drained peatlands, the location of the water table usually varies from 10-20 cm in spring and autumn to 40-60 cm below soil surface in summer and winter (e.g. Heikurainen 1971). According to Päivänen (1973) the capillary rise of water is very effective to about 60 cm above the water table in a typical Finnish peat (ErC, H4, bulk density 0.113 g/cm^3). During most of the time, the capillary fringe reaches soil surface. Consequently, soil moisture tension as well as water content of surface peat are dependent on the location of the water table below soil surface (Heikurainen 1967, Ahti 1978). It has further been pointed out by Ahti (1972) that because of the shallow water table, the term "field capacity" does not mean the same for peat than for mineral soils, where, in most cases, the capillary fringe does not cover the whole unsaturated zone. The capillary connection between the water table and peat surface has been considered so immediate that attempts have been made to use shifts of the water table to predict daily evaporation (Heikurainen 1967, 1971, Laine 1984).

Expressed in volume percentages, Finnish peats contain from 85 to 95 percent of water at saturation.

142. Variable water retention

In Sphagnum peats, depending of the degree of humification, 40—65 % of the total pore space is occupied by so-called macropores (30 μm; Päivänen 1973) which can be drained by gravity.

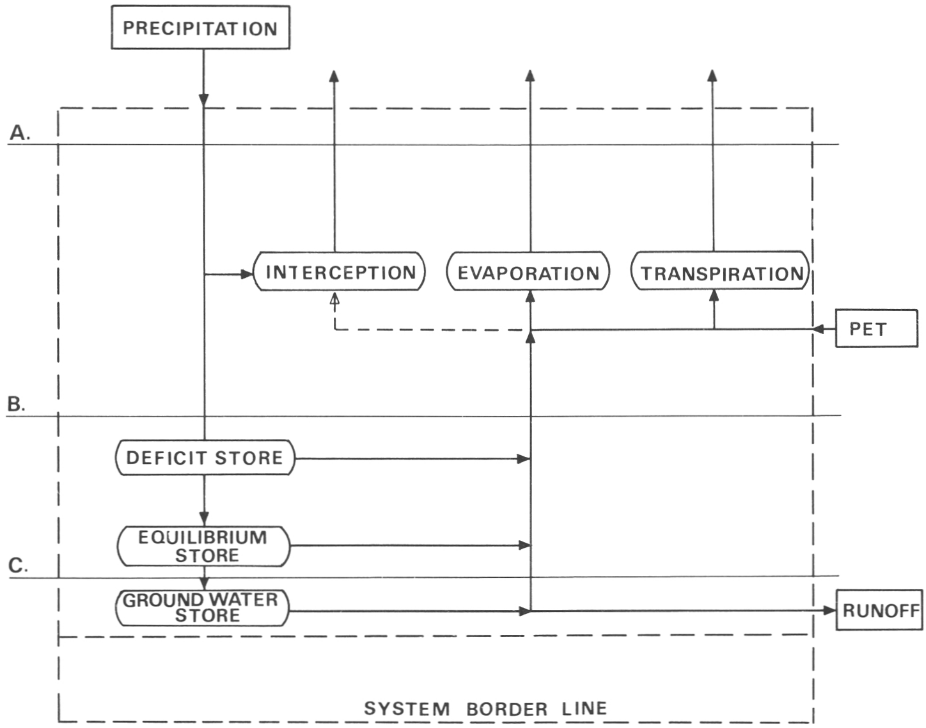


Figure 1. A simplified water storage system of drained peatland forests. Input and output variables outside the border line. A—B: vegetation; B—C: capillary fringe; C: water table.

As the degree of humification increases, the bulk density and the pore size distribution change. In well humified peats water is held by stronger forces than in unhumified peat. The water retention system is made still more complicated by the more pronounced influence of humic matter. Because of the colloidal behaviour of humic acids, especially humified peats show considerable shrinking and swelling as the moisture content varies.

Unhumified Sphagnum peat is commonly described as fibrous (Päivänen 1973, Okruszko 1974). The term fibrous is partly misleading because the solid part of peat actually is formed by cell walls. According to Ekman & Komonen (1972), "unhumified peat contains hollows of diameter 15—20 μm and length 80—120 μm, surrounded by cell walls approximately of thickness 2—3 μm, with entrance openings in the cell walls of diameter 5—8 μm, leading into these hollows".

Unhumified peats do not have a high content of humic acids, but still they shrink and swell considerably with moisture changes. This can be understood by assuming that undecomposed plant remnants, perhaps because of their former water-conducting capillary system, have colloidal properties, and shrink and swell with moisture changes as well as humic matter.

Normally, Finnish peats in situ do not show cracking during dry periods. Because it is unreasonable to assume that shrinking occurs in the vertical direction only, the absence of cracks can be explained by assuming simultaneous subsidence and "fiber" shrinkage. A coarse simplification of this system is illustrated in Figure 2.

If the subsidence of the peat layer is about 10 % as observed by Kurimo (1983), the peat "fibers" or the unhumified cell wall remnants should shrink about 5 % if the system is valid. Consequently, small changes in fiber length cause significant changes in layer thickness, and also, in water retention characteristics.

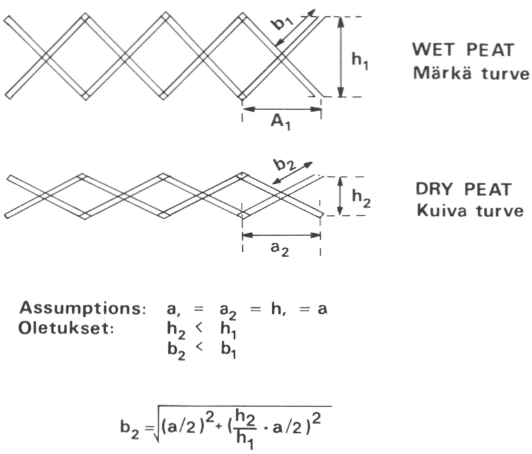


Figure 2. Subsidence of peat and shrinkage of peat fibers during drying. Schematic representation.

143. *Wetting – drying – rewetting*

With known soil moisture characteristic curves it would be easy to calculate soil moisture changes due to changes in water storage, if energy equilibrium of soil moisture would prevail above the water table, and the wetting-drying process would be totally reversible. However, peat soils are characterized by hysteretic effects which probably are partly dependent on the swelling-shrinking process of the colloidal constituents as described above. The shrinking process easily keeps pace with drying, but rainfall being of an instantaneous nature, the swelling and rewetting processes show a time lag that changes with water store (Kurimo 1983). Part of the smallest pores do not refill with water because of several reasons (entrapped air, the inc-bottle effect etc.; Hillel 1971), but the most probable reason for marked hysteresis in peat is that the water retention capacity of peat significantly varies because of the drying-shrinking processes.

The interdependence of water tension and water content is commonly called the soil water characteristic curve. Shrinking and swelling of peat actually means that the form and position of the curve vary with moisture changes.

15. Aims

In this study, the main interest is put on following items:

1) The relationship between evaporation and runoff in drained peatlands during the snowless period as affected by ditching,
2) Water storage characteristics of peatlands as affected by ditching.

The study is divided into two main phases. Because evaporation is not measured but estimated on the basis of climatic and soil water data, a model using estimated evapotranspiration, observed runoff and observed precipitation as basic data is constructed. The model produces daily values for the location of the water table which are compared with field observations made less frequently.

In the second phase, after satisfactory agreement between model output and observations has been attained, the water balance of drained peat is examined by using observed data of runoff and precipitation and estimated data of evapotranspiration and water storage.

2 471840U

2. METHODS

21. General description of site

The field experiment is situated in Karvia, Western Finland (62 10′ N, 22 45′ E, 155 m above see level) in the middle of a large raised bog complex, from which only remnants have remained untouched by agriculture and forestry. The original site type of the experimental area was treeless Sphagnum fuscum bog. Throughout the experimental site, the depth of the peat profile exceeds 2 m.

Ditching was performed partly with a rotary ditcher and partly with a tractor digger in 1963. Seven ditch spacings (5, 10, 20, 30, 40, 60, and 100 m) and three ditch depths (30, 60, and 90 cm) were varied in a more or less systematic manner (Figs. 3 and 4).

In 1974, 11 years after seeding and planting, the average height of the Scots pine stand varied from one meter to 2.5 meters. In large parts, the area could still in 1981 be characterized as open Sphagnum fuscum bog. The pool and ridge formations are still pronounced and the main reason for a rather uneven soil surface with small scale spatial height variation of the magnitude of 0.5 meters.

According to observations in a nearby weather station of the Finnish Meteorological Institute, the annual precipitation averages about 600 mm. The mean annual air temperature is +1 °C, which is about 1—2 degrees lower than normally in Finland at this latitude.

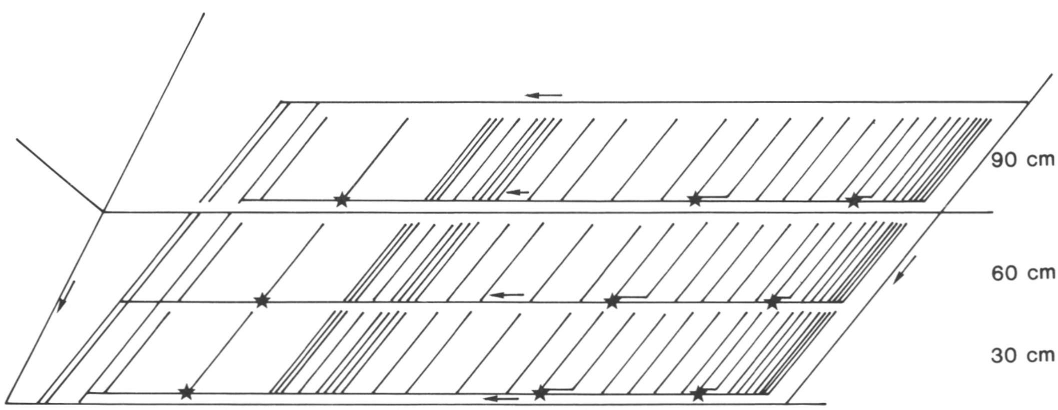


Figure 3. Main runoff observation points. Ditch spacings 5—100 m, ditch depths 30, 60, and 90 cm. x = weir and recorder.

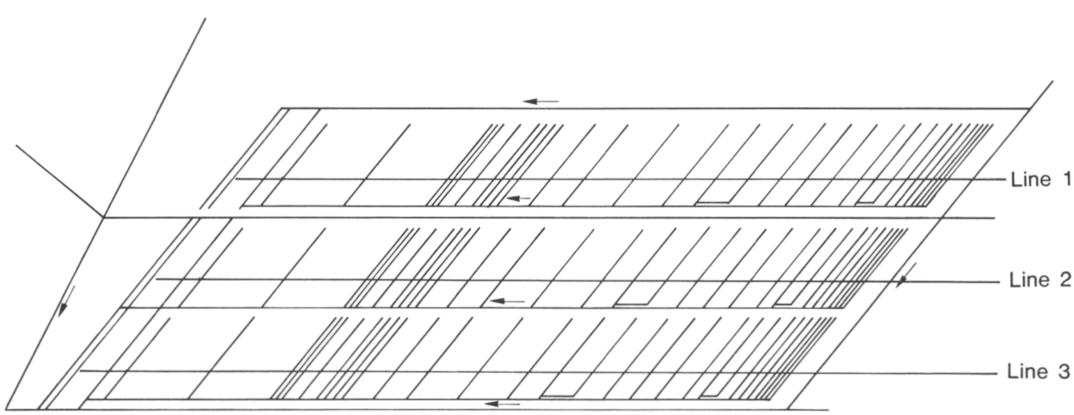


Figure 4. Water table observation lines. Total number of observation points: 640.

22. Experimental layout

The experimental layout is based on the so-called variable spacing principle earlier discussed in the introduction. By varying spacing and ditch depth, and by assuming that more pronounced runoff changes are connected to the more intensive ditching treatments, establishing the general direction of hydrological change caused by ditching is aimed at.

The layout, characterized by small size artificial catchments, provides the possibility to secure minimum site variation between the treatments. Additionally, climatic differences between the catchments can be considered negligible. This is practical from the simulation point of view, as sparse or low quality climatic data does not cause errors between the treatments.

The layout (see Fig. 3 and 4) is systematically varied. The ditch depth treatments are separated from each other by boundary ditches into three adjacent blocks. As the layout does not include boundary ditches between the spacing treatments, accurate determination of the catchment area is difficult. Variation in slope and microtopography might cause irregularities in the water collecting area of the ditches. This is particularly true in the case of the larger spacings, where the boundary ditches of the ditch depth blocks might contribute to drainage more than in the case of the narrower spacings.

23. Field observations

231. General

Two variables were concentrated on: runoff and phreatic level. As regards the climatic variables, observations were done for checking the data obtained from a nearby weather station situated 2 kilometers from the experimental site. Hydraulic conductivity observations were made to get a general idea of the variation of the physical peat properties. The main observation points are given in Figures 3 and 4.

The data collection period is divided into two major stages: the more intensive period in 1967-73 including frequent manual measurements, and the period 1974-83 characterized by weekly manual observations and rough determination of soil physical properties.

Only nine runoff measuring points could be supplied with a recorder. Throughout the study, the main interest is focused on these points.

232. Runoff

Runoff was recorded at nine observation points by using weirs and float recorders (Figure 5).

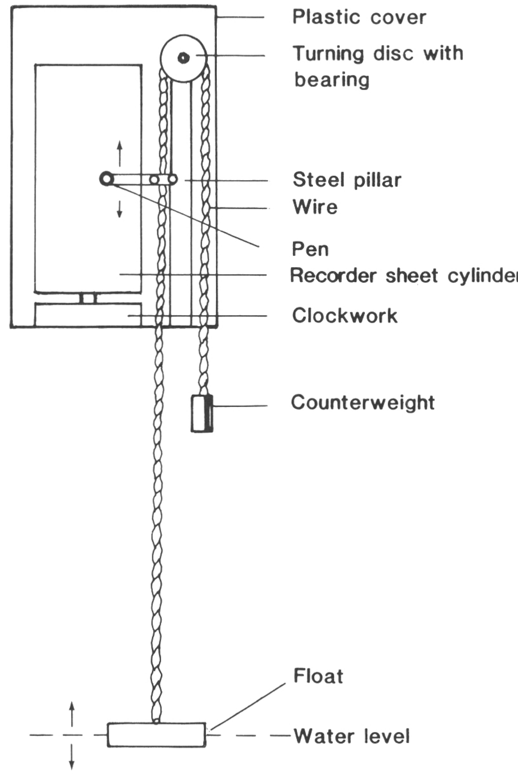


Figure 5. Construction of the float recorder.

The float recorders did not function properly because of a construction very sensitive to friction errors caused by dirt and wearing. Hence, manual control measurements were performed three times weekly. This data is used to fill up gaps created by improper recorder function.

As mentioned above, the determination of catchment area was difficult because of the layout. Calculations based on relative gradients (e.g. Ahti 1983) were not attempted because of the small scale spatial variation in slope and microtopography. Therefore, the catchment border lines for the 40 and 100 meter spacings were roughly determined on the basis on a levelling made in 1983. The catchment area of the 20 meter treatments was considered to be defined well enough by its narrow shape.

Weir discharge was calculated by using following simple formula previously used by Huikari et al. (1966):

$$Q = 0.0146 \cdot h^{2.5} \tag{2}$$

where
Q = discharge, l/s
h = water level at weir notch, cm

233. Climatic variables

Daily precipitation, mean air temperature, air humidity, wind velocity, and cloudiness were obtained from Karvia weather station of the Finnish Meteorological Institute situated about 2 km from the experimental site. For checking purposes, observations on air temperature and precipitation were made at two points in the experimental area in the period 1967—73. Daily temperature at 8.00 am and minimum and maximum temperatures as well as daily precipitation were observed

5—6 times weekly. Precipitation was measured by using simple rain collecting gauges with a collecting area of 100 cm^2. In 1975—1981, only precipitation at one point was recorded by using the Russian-made p-2 pluviograph.

234. Water table level

The level of the water table was approximated by measuring the vertical distance from the soil surface to the free water surface in a bore hole with a diameter of 10 cm at 640 points (for construction see Fig. 6).

In the period 1967—73, the observations were done three times weekly, and in 1974—81 once a week.

235. Soil shrinking and swelling

Because of the elasticity of the organic soil and the definition of water table depth adopted in the study, which allows height variation of the reference level (soil surface), the height variation of the soil surface was observed at nine ground water wells by using wooden poles driven into the underlying mineral soil as reference level. These observations were done in 1982—83.

236. Hydraulic conductivity

For comparison reasons, the hydraulic conductivity of the peat was determined for four depths at nine points. The determination was repeated 4—5 times at each spot. The following method was used: a PVC-tube with an inner diameter of 20 mm was driven vertically into the peat soil so that the lower end of the tube was located at the same level as the upper limit of the peat layer to be studied. The peat which filled the tube was removed with an auger of the same diameter. A 10-cm-long cavity was then bored under the lower end of the tube. With a simple vacuum pump, the water was removed from the cavity, and the rising rate of the water level in the tube was measured.

The rising rate of the water level in the tube was converted into hydraulic conductivity by means of a formula presented by Luthin & Kirkham (1949):

$$k = \frac{\pi \cdot r}{a \cdot (t_2 - t_1)} \cdot \log \frac{h_1}{h_2} \qquad (3)$$

where

k = hydraulic conductivity, cm/sek
r = tube radius, cm
a = geometric function
h_1 = distance form water table to water level in tube at time t_1
h_2 = distance from water table to water level in the tube at time t_2
$t_2 - t_1$ = time interval over which the rise of the water table was measured

24. Laboratory determinations

241. Water retention

In 1982, the peat profile was sampled by taking nine 4.5 × 5.0 cm peat cores to a depth of 60 cm. In the laboratory, 2 cm thick slices were cut at 10 cm intervals from the cores. Water retention capacity was determined with a pressure plate apparatus and oven drying (105 °C) for pressures equivalent to 50 and 100 cm water column height. The chosen pressures were maintained by using the counter pressure of a real water column (see Figure 7).

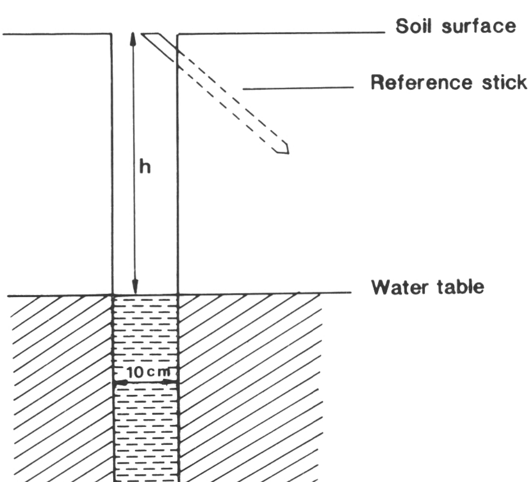


Figure 6. The construction of an observation well: h = the level of the water table.

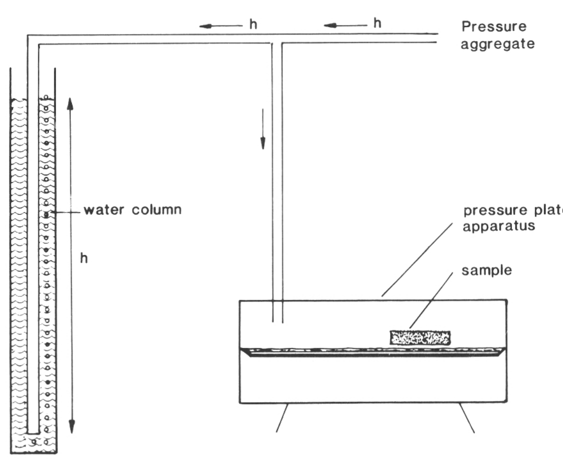


Figure 7. The principle of using a water column as counter pressure when using the pressure plate apparatus.

3. DATA

31. Precipitation regime during the study period

The daily precipitation data obtained from Karvia weather station was compared with the data collected within the experiment. The largest differences being of the magnitude of 1 to 5 millimeters, depending on daily precipitation, and because no systematic differences could be observed, the daily observations from the weather station were accepted for the study.

According to long term (1931—60) averages from the nearby Kihniö weather station, situated about 20 km east from the experiment, the annual precipitation for the area normally is 545 mm. Out of this amount, about 260 mm falls in June-September, monthly precipitation averaging 55 mm in June and September and 75 mm in July and August.

In Figures 8—9, monthly precipitation for the two periods of major interest are given. In 1967—72, all summers except 1967 were drier than normal. Especially in June and July, the monthly precipitation was lower than normal. In 1977—81, only 1980 can be characterized as drier than normal. The years 1977, 1979, and 1981 were clearly wetter than normal mainly due to excessive rainfall in June (1981) and July (1977, 1979). In Figure 10a—b, the average number of rainy days per month in each precipitation class is given for the two periods.

It is characteristic to the Finnish precipitation regime that the daily precipitation rather seldom exceeds 10 mm. In the data, a 10—15 mm daily rainfall occurred once a month on the average. In the period 1977—81, the number of rainy days per month was 6—7 days higher than in the period 1967—72.

On the average, the monthly precipitation was more evenly distributed within the classes of daily precipitation during both of the periods (Figures 11a—b).

The major differences are to be found in June and July, as monthly precipitation in August and September was rather similar during the two periods.

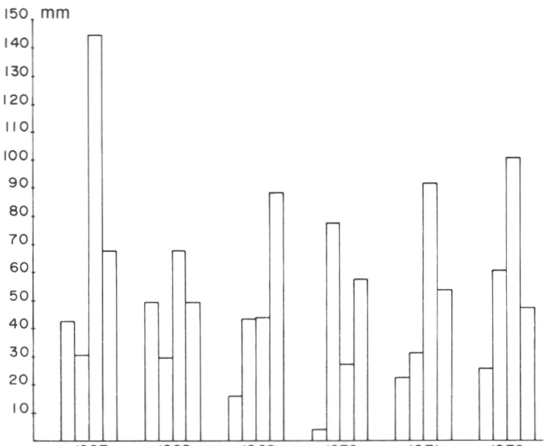


Figure 8. Average monthly precipitation during June—September in 1967—72.

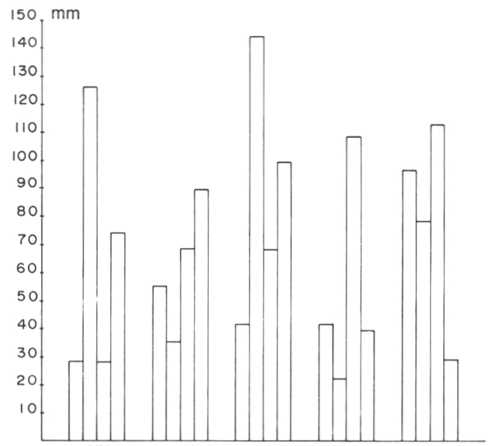


Figure 9. Average monthly precipitation during June—September in 1977—81.

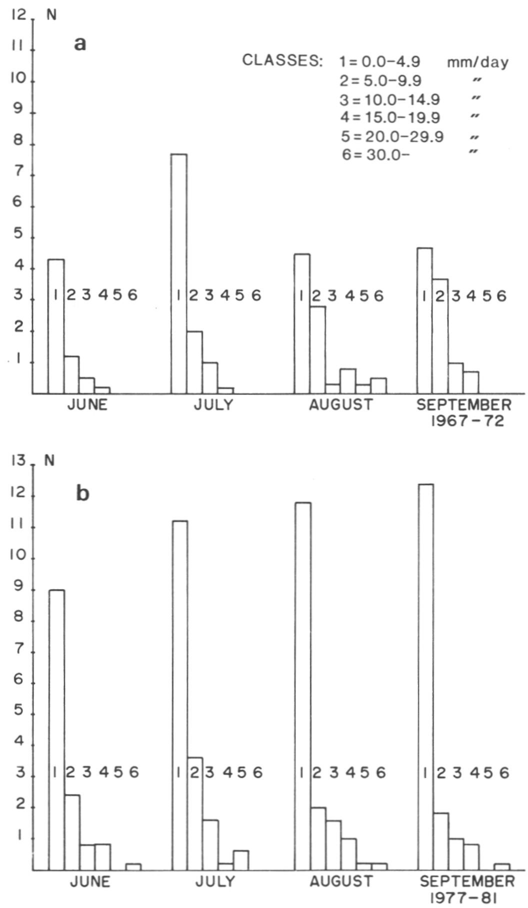


Figure 10a—b. The average number of rainy days per month as classified on the basis of daily precipitation in 1967—77 (a) and 1977—81 (b).

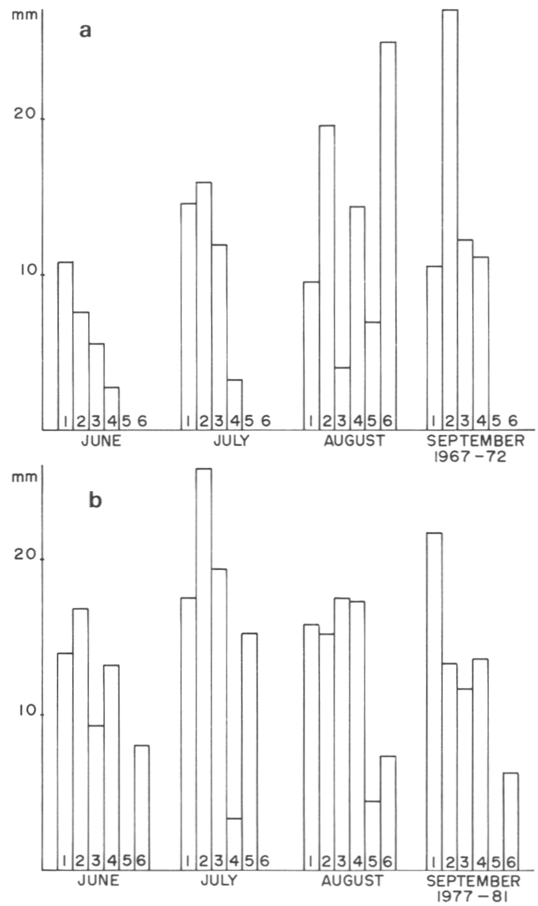


Figure 11a—b. Average monthly precipitation as distributed into classes of daily precipitation in 1967—72 (a) and 1977—81 (b). For classification see Figure 10a.

32. Potential evapotranspiration

321. Definition

Moisture transfer from a vegetated surface is often referred to as evapotranspiration, and when the moisture supply in the soil is unlimited then potential evapotranspiration (PET) is used.

There are two principal lines of approach for estimating evaporation through physical relationships: the aerodynamic (or mass transfer) method and the energy budget method. The aerodynamic method considers factors controlling the removal of vapour from the evaporating surface and concentrates on the vertical gradient of humidity and the turbulence of the air flow. In the energy budget method, the three processes consuming net radiation energy are considered: transfer of sensible heat to the atmosphere, transfer of latent heat to the atmosphere, and transfer of sensible heat into the ground.

A number of methods have been developed to combine the aerodynamic and energy budget approaches. The most videly used combination method was derived by Penman (1963), who expressed PET as a function of available radiant energy (Rn) and a term (E_a) combining saturation deficit and wind speed.

$$R_n = (1 - r) \cdot s - L_n \qquad (4)$$

where
s = solar radiation
r = albedo
L_n = net long wave radiation from the surface

$$E_a = 0.35 \cdot (1.0 - 0.01 \cdot u) \cdot (e_s - e) \quad (5)$$

where
u = wind speed at two meters (miles/day)
e_s = saturation vapour pressure (mmHg) at mean air temperature
e = actual vapour pressure at mean air temperature and humidity

$$PET = (\gamma \cdot R_n/L_n + E_a)/(\gamma + 1) \quad (6)$$

where γ = Bowens ratio

The Penman approach was accepted in this study. However, instead of an albedo of 25 %, 16 % typical to highmoor bogs was used (Virta 1966, Romanov 1968).

322. PET during the study period

Monthly values of potential evapotranspiration calculated by using weather station data and the Penman formulae (4—6) are given in Table 1.

The typical pattern for the northern hemisphere is clearly visible. During June and July, PET normally exceeds 100 mm, as the decrease in solar energy is displayed during August and September with monthly PET averages of about 60 and 20 mm, respectively.

Table 1. Monthly values of potential evapotranspiration in 1967—72 and 1977—81.

Year	June	July	August	September	Total
1967	111.1	113.6	44.1	20.2	289.0
1968	120.4	104.9	60.0	17.9	303.2
1969	117.8	106.2	86.9	21.9	332.8
1970	152.5	90.2	71.2	21.2	335.1
1971	123.3	123.3	65.1	20.1	331.8
1972	105.9	104.9	51.8	19.8	282.4
1977	106.4	78.0	52.8	30.1	267.3
1978	105.0	81.8	61.2	19.2	267.2
1979	113.0	64.0	48.9	25.3	251.2
1980	112.9	96.5	46.0	20.6	276.0
1981	72.7	87.8	40.6	15.2	216.3

33. The level of the water table during the study period

The level of the water table as function of time is displayed in Figure 12.

Each point in the figure represents the arithmetic mean of 10—26 individual observations (observation points). It is clearly visible that from 1974 onwards, only weekly observations have been made. Also, it can be seen from the figure that the water table has been considerably closer to soil surface in 1977—81 than in 1967—72.

Ditching intensity has clearly influenced the level of the water table (Table 2), and the effect is logical within all three ditch depths: the distance from the soil surface to the water table decreases with increasing spacing. Within the series of the 20-m spacings, the 60-cm ditch depth treatment shows the deepest water tables instead of the 90-cm ditch depth treatment. This can be explained with irregularities in slope, this treatment having the biggest height difference between peat surface and the V-notch of the weir.

On the basis of these time series, it is difficult to see trends that could be ascribed to ditch deterioration or changes due to stand development. This might be because these two processes logically have opposite effects.

34. Runoff

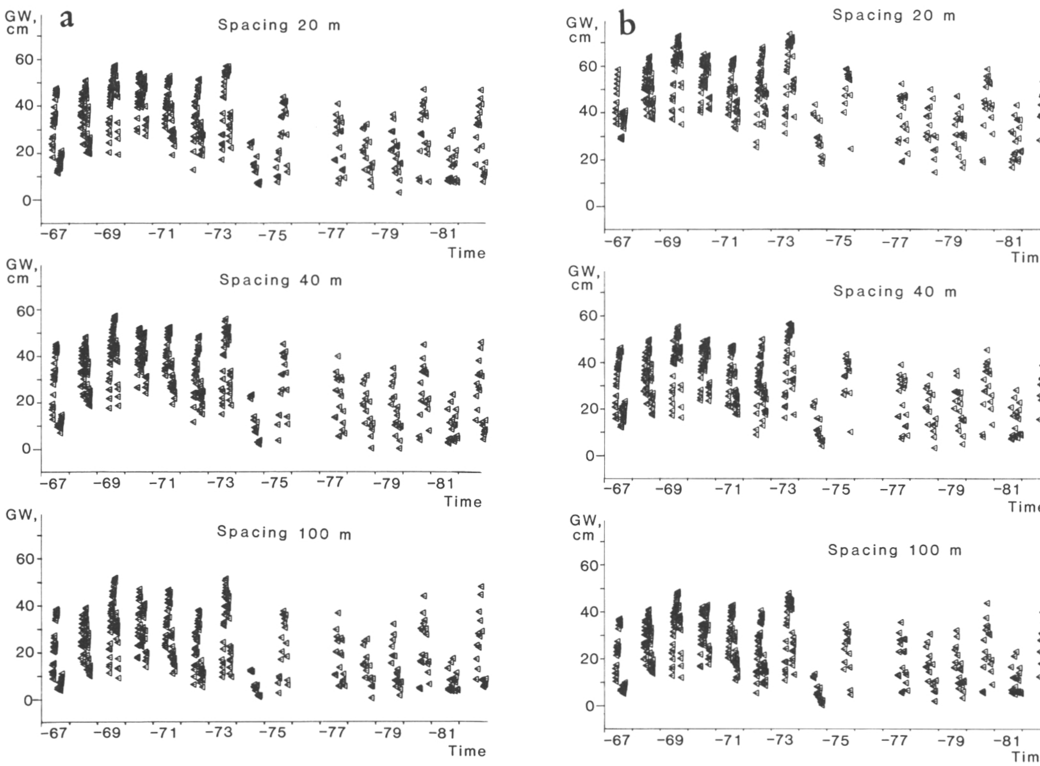
It can be seen from Figures 13—15 that during the years 1967—72, only the year 1967 shows marked runoff during June—September. In the years 1968—71, runoff was practically zero irrespective of spacing-ditch depth combination.

In 1967, a lot of runoff was recorded in August—September. During this time, the heaviest daily rainfall of the study period (75 mm/day) was observed.

Table 2. Mean vertical distance from water table to soil surface in the periods 1967—72 and 1977—81.

Period	Ditching treatment (spacing/ditch depth)								
	20/30	40/30	100/30	20/60	40/60	100/60	20/90	40/90	100/90
1967-72	38.0	27.6	27.7	53.0	35.6	27.6	46.3	36.6	31.4
1977-81	22.3	18.5	12.8	36.0	22.2	13.8	34.8	23.3	21.8*

*) No observations in 1977



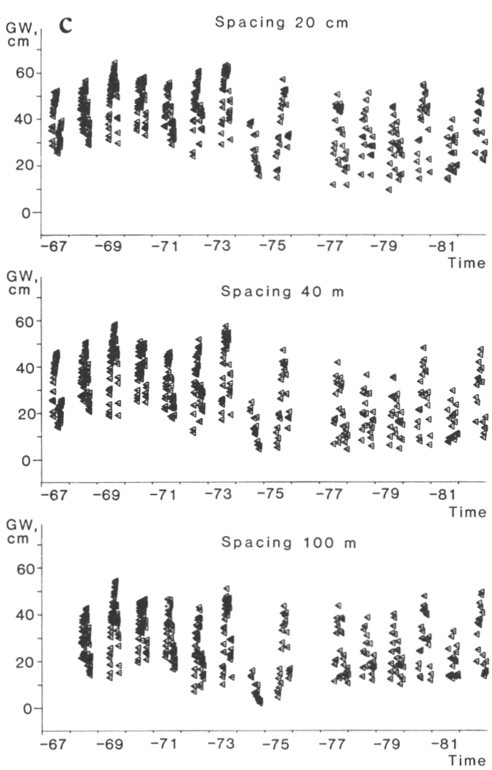


Figure 12a—c. Annual variation range of the water table on the basis of daily averages in 1967—75 and 1977—82. Ditch depths: a 30 cm, b 60 cm, c 90 cm.

In the period 1977—81, all years except 1980 showed marked runoff. Obviously, this was because of high precipitation sums and low values of PET, as indicated by sections 31. and 32.

From Figures 13—15, the effects of the different treatments can be summarized as follows:

1) Shallow ditches (30 cm) seem to be accompanied with a labile runoff behaviour: sharp runoff peaks are separated by periods of zero runoff. This is easily discernible during the wet period of 1977—81 (Fig. 14).
2) The 100-m spacings show much lower runoff peaks than do the 20-m and 40-m spacings. There is not much difference between the 20-m and 40-m spacings. However, narrow spacings appear to have a levelling effect on the runoff peaks when combined with deep ditches. This is particularly striking in the case of the 20/60-combination (spacing 20 m, ditch depth 60 cm), which, as indicated by the levelling data, has the deepest runoff threshold and can be regarded as the most efficiently drained treatment included in Figures 13—15.

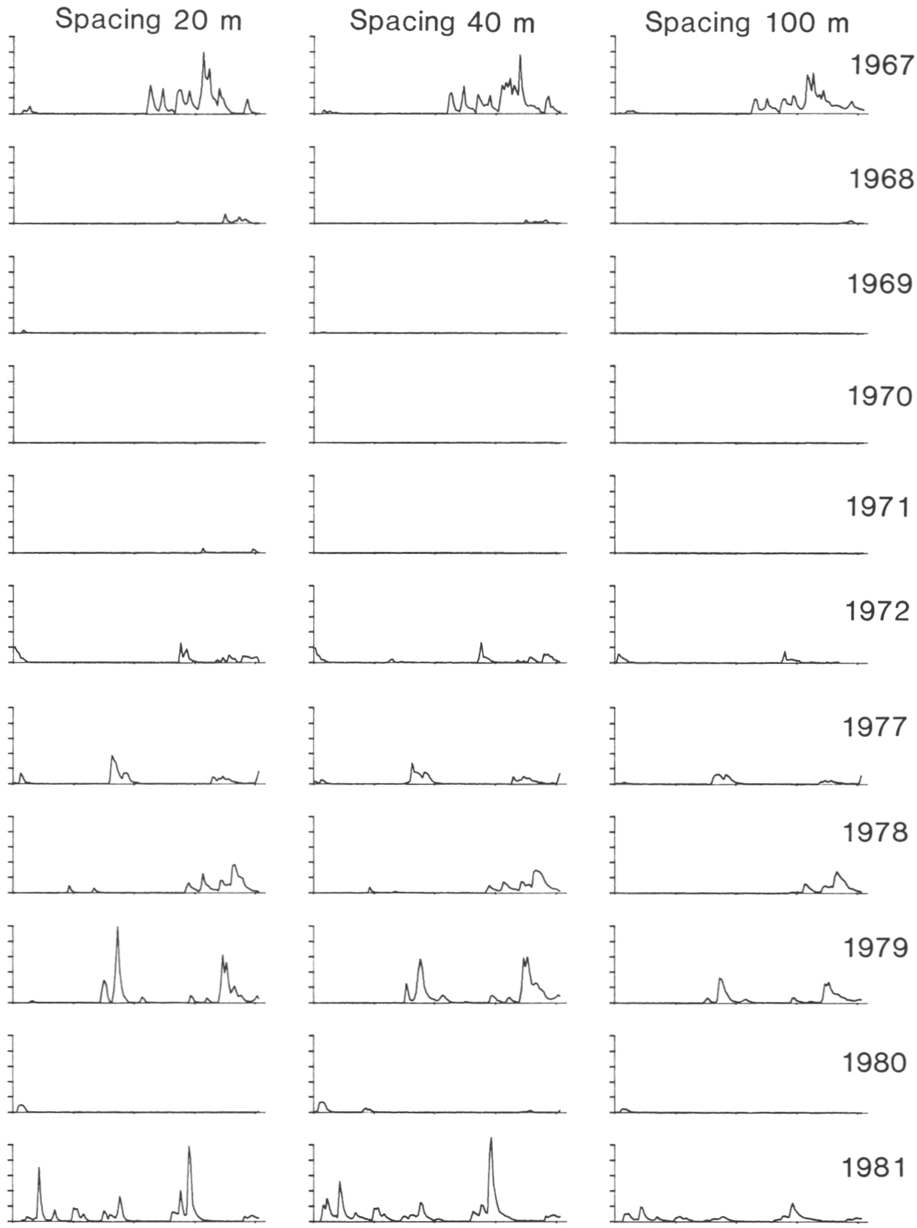


Figure 13. Runoff as function of time in 1967—81. Vertical scale: 0—10 mm/day. Horizontal scale: June 1st—September 30th. Ditch depth: 30 cm.

As regards runoff peaks, there are two years of particular interest: 1967 and 1981. In 1967, a long period of zero runoff was followed by a long period of regular runoff in late summer, which is most normal in Finland. The year 1981 differs from 1967 in that the early summer, especially June, was much wetter than normal, showing runoff during most of the four months of observation.

35. Soil water retention

As regards the reactions of the water table to inputs and outputs of water to and from the system, the most important factor is water retention. Volumetric water content at two moisture tensions for 27 sampling points and 6 sampling depths is presented in Table 3.

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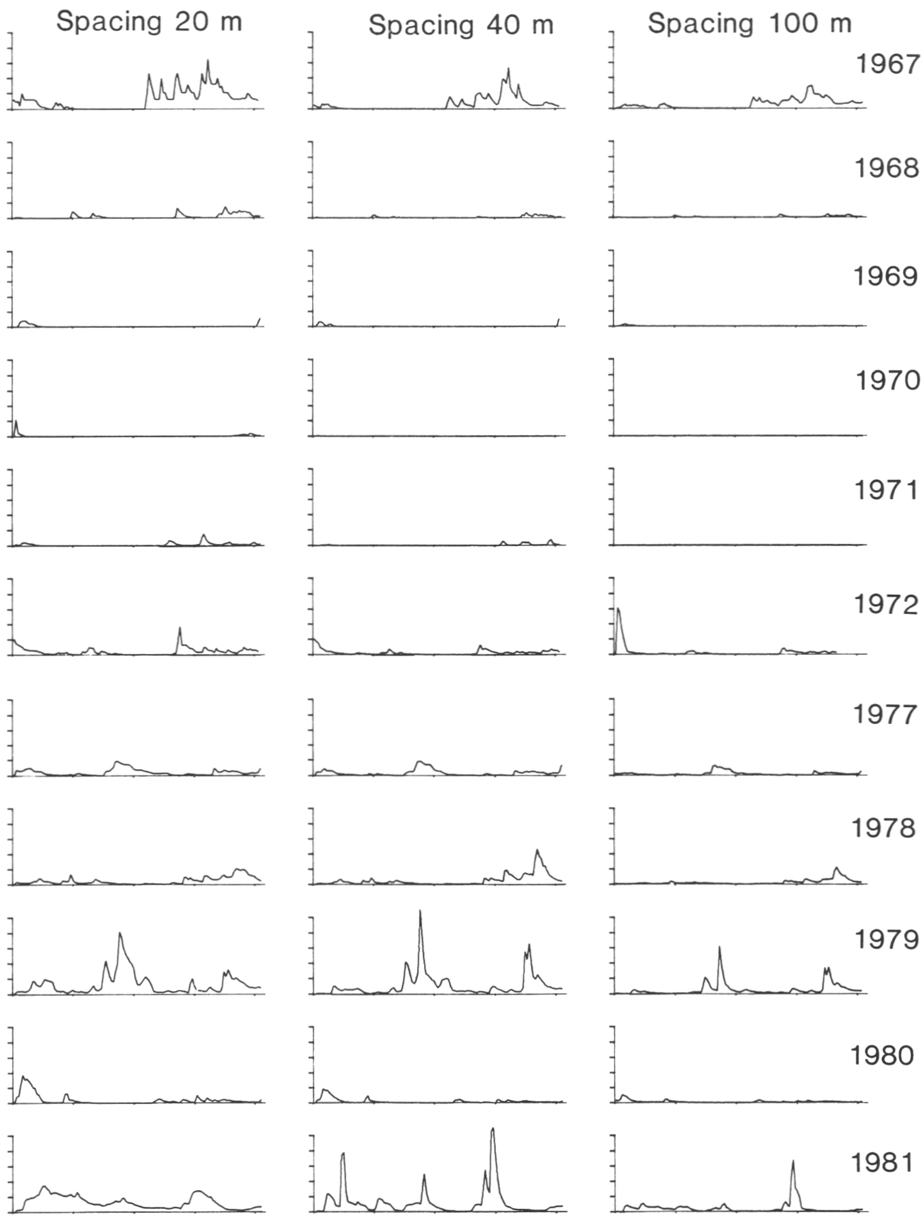


Figure 14. Runoff as function of time in 1967—81. Vertical scale: 0—10 mm/day. Horizontal scale: June 1st—September 30th. Ditch depth: 60 cm.

The retention values agree reasonably well with the values presented by Päivänen (1973) for Sphagnum peats with a low degree of humification. The retention capacity increases towards the deeper peat layers. Shallow ditches seem to be accompanied by a lower water retention capacity than the deep ones. It is not possible to say, whether there is a causal relationship as well.

36. Hydraulic conductivity

The average hydraulic conductivity for four depths in the Alkkia experiment is given in Figure 16. Again, Päivänen's (1973) data are used as a comparison.

It is apparent that the conductivity of the deeper peat layers in Alkkia exceed the mean values of Päivänen for Sphagnum peats. The

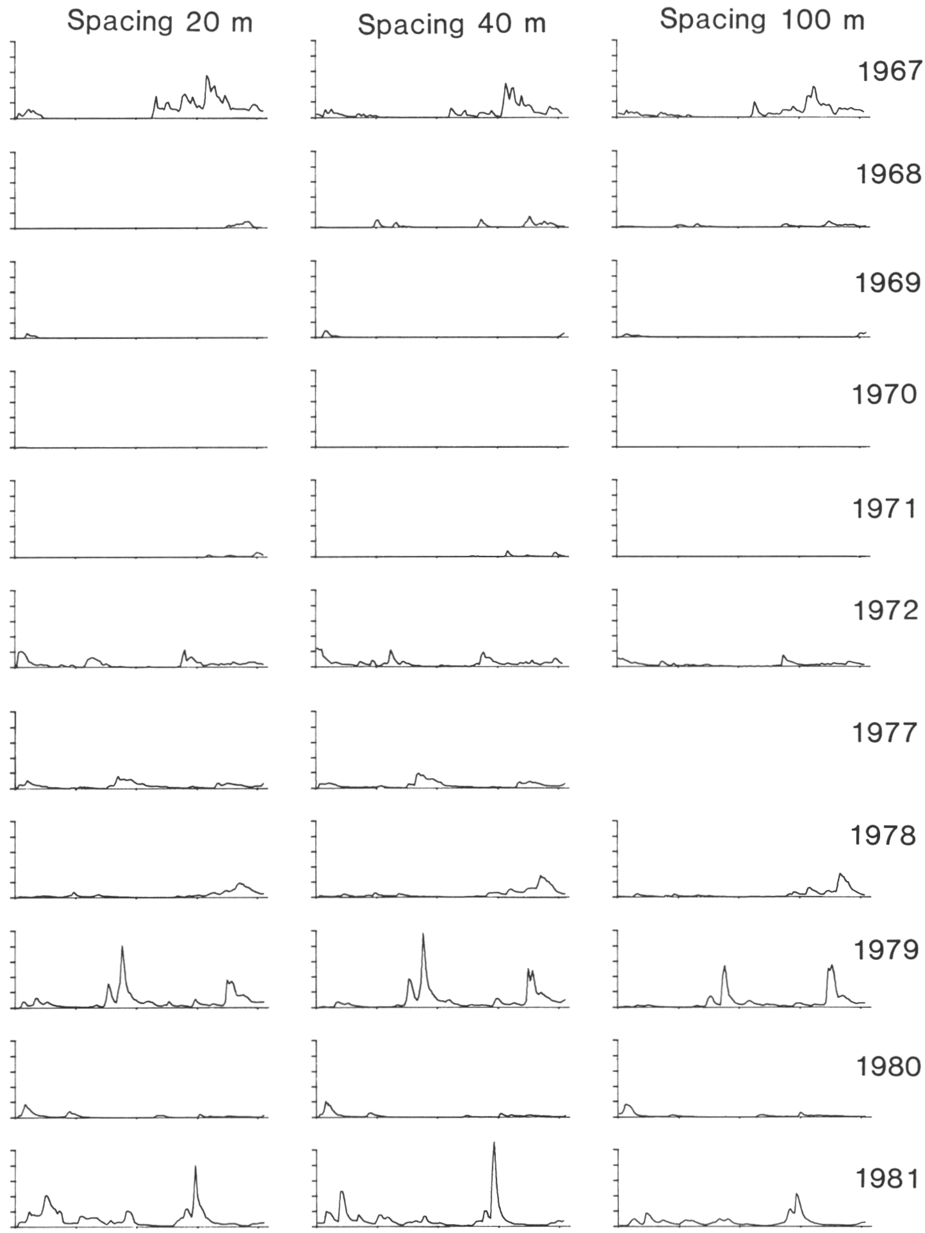


Figure 15. Runoff as function of time in 1967—81. Vertical scale: 0—10 mm/day. Horizontal scale: June 1st—September 30th. Ditch depth: 90 cm.

hydraulic conductivity data is not used in model construction.

37. Soil swelling and shrinking

As indicated by appendixes 5—7, the shrinking of the peat layer seems to be influenced by hysteretic phenomena: in the rewetting phase, the water table rises faster than could be expected. This might be an artifact caused by overestimation of the rise of the water table, as suggested later in section 425.

Table 3. Volumetric water content of Alkkia Sphagnum peat at suctions corresponding to 50 cm and 100 cm of water column height. Each value is an average of three samples.

Sampling depth, cm	Suction cmH_2O	Ditching treatment (spacing/ditch depth)								
		20/30	40/30	100/30	20/60	40/60	100/60	20/90	40/90	100/90
7.5	50	32	37	45	43	41	44	45	42	45
	100	22	27	33	29	27	31	35	33	36
17.5	50	36	33	37	43	37	43	37	44	41
	100	25	25	27	30	25	31	29	35	33
27.5	50	38	35	32	46	46	34	42	46	32
	100	27	26	23	38	39	28	34	37	24
37.5	50	50	30	39	50	45	43	41	46	44
	100	40	22	29	41	39	36	34	38	37
47.5	50	54	24	39	61	52	52	54	47	42
	100	45	16	30	51	35	45	47	39	35
57.5	50	48	26	38	58	50	59	52	45	52
	100	41	18	29	51	41	52	43	36	44
7.5-57.5	50	43	31	38	50	45	46	45	45	43
	100	33	22	28	40	34	37	37	36	35

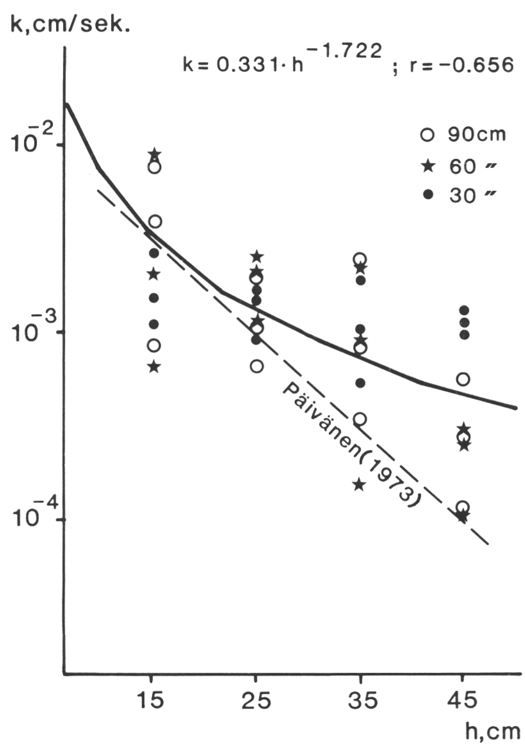


Figure 16. Vertical distribution of hydraulic conductivity as compared with Päivänen's (1973) data for Sphagnum peats.

4. WATER TABLE SIMULATION

41. Construction of the model: main principles

The water table level, the measurement of which does not involve special difficulties, was selected as the independent variable of the model. The principal aim of the model was to predict the course of the water table level on the basis of runoff data, precipitation data and potential evaporation estimated by using the Penman approach. Starting from the beginning of June, the water table level was to be estimated for each day until the end of September. As the initial location of the water table, the first observed value was annually chosen.

42. Description of the model

421. Evaporation

Evaporation, or actually evapotranspiration, is estimated by the model from three sets of data:

1) Potential evapotranspiration, as estimated from weather data by using the Penman principle
2) The level of the water table, as calculated with the model
3) Precipitation regime of the previous days.

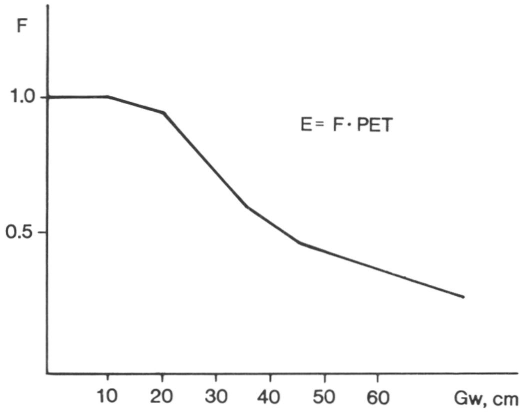


Figure 17. The interdependence between water table level and potential evapotranspiration as assumed in the model.

Between the depth of the water table and evapotranspiration, the simple relationship illustrated in Figure 17 was adopted.

The values of F are based on data presented by Romanov (1968) for highmoor bogs, and supported by the data of Laine (1984). When using the so-called simplified thermal balance method of equation (7),

$$E = \alpha \cdot R_b + c \qquad (7)$$

where
E $=$ evaporation form soil surface
R_b $=$ total radiation
c $=$ constant
α $=$ a coefficient dependent on the level of the water table

Romanov (1968) used different values of α for different times of the vegetation period to compensate for changes in the activity of the vegetation. In the model presented here, using potential evapotranspiration instead of total radiation as a basis, constant coefficients are assumed.

422. Interception losses

Interception is commonly determined as the amount of rainfall that is held by the surfaces of the vegetation. In peatlands which even after ditching are frequently characterized by a cover of living Sphagnum mosses, it is difficult to separate between vegetation and soil and, consequently, between interception and infiltration. Here, that rainfall which is temporarily held by the surface moss layer is considered to be included in interception, i.e. interception is defined as the difference between total rainfall and infiltration rather than the difference between bulk rainfall and throughfall. In the model, interception is related to potential evapotranspiration by a coefficient (y) that depends on day length according to the equations of Figure 18. During days of high potential evapotranspiration and rainfall, high interception losses will result. To-

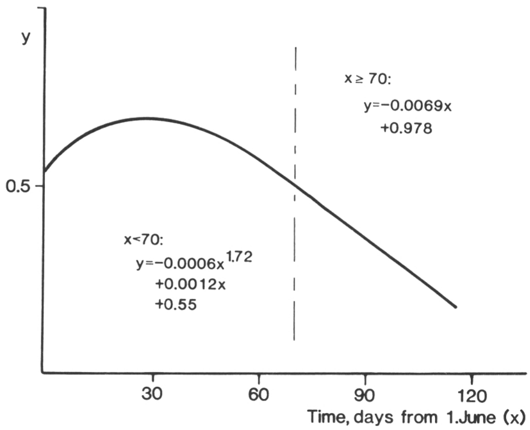


Figure 18. The interdependence of interception coefficient (y) and time (x). Assumption: the time required for intercepted water to evaporate is a function of PET.

wards the autumn, interception is assumed to decrease even faster than potential evapotranspiration as the general wetness of the vegetation (dew formation etc.) increases. Simultaneously, the balance between infiltration and interception will shift toward infiltration. The tree stand being very sparse, no attempts are made to use existing data from Scots pine stands.

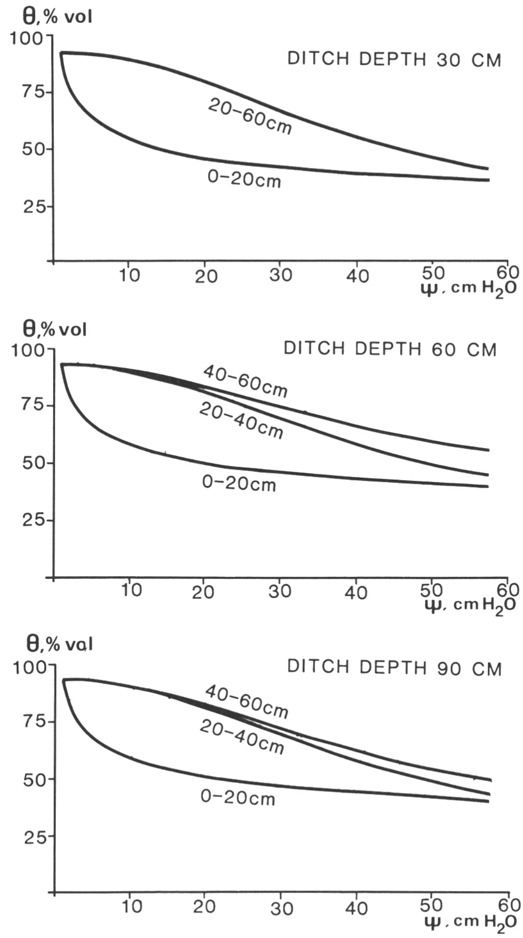


Figure 19. Average soil water characteristic curves for the three ditch depth treatments.

423. Soil water retention and distribution

4231. General procedure of the model

The model, after calculating the daily change in the water store and, correspondingly, after determining the potential direction of water table shift, starts estimating the new level of the water table. This is done by applying the principle of iteration: the water table is changed by minute steps (0.01 mm) in the direction of the potential water table shift, and between the steps, the new water store is calculated using the soil water characteristic curves and assuming equilibrium. The iteration continues until a change in the calculated water store is reached, which is equal to the actual change estimated on the basis of P, Q and PET data.

4232. Soil water characteristic curves

The soil water characteristic curves used by the model were constructed on the basis of the retention determinations given in Table 3 and Päivänen's (1973) data. For each 10-cm layer down to 60 cm, a separate curve was used for all ditching treatments. For deeper peat layers (60—80 cm), the curves of the 50—60 cm layer were used.

For surface peat (0—20 cm), the general curve form corresponding to equation (8) and implying low water retention capacity at low suctions was chosen. This type of peat is represented in Päivänen's data by Sphagnum peat samples 173—176 (Päivänen 1973, p. 42—43).

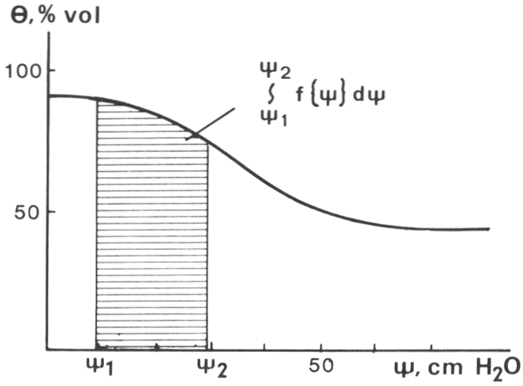


Figure 20. Determination of the water store in the peat layer between ψ_1 and ψ_2 cm from the water table. The soil water characteristic curve is expressed as $\Theta = f(\psi)$.

$$\Theta_\psi = \Theta_0 \cdot (\psi - 1)^\beta \tag{8}$$

where
Θ_ψ = volumetric water content corresponding to ψ cmH_2O suction
Θ_0 = water content at saturation, here chosen as 93 $\%_{vol}$
ψ = suction, cmH_2O
β = parameter; < 0

For deeper peat layers, the curve form of equation (9), implying higher water retention at low suctions and corresponding to a number of samples in Päivänen's data, was chosen.

$$\Theta_\psi = (\Theta_0 - \zeta) \cdot e^{-(\beta \cdot \psi)^\lambda} + \zeta \tag{9}$$

where
Θ_ψ, Θ_0, ψ = the same as in equation (8)
β = 0.025
λ = 2.0
ζ = parameter, the value of which equals Θ_{50} (Table 3).

The average soil water characteristic curves arrived at by applying the above principles are given in Figure 19 for three ditch depth treatments.

The store estimation performed by the model is largely based on the assumption that soil water is close to the state of energy equilibrium. As an example, water tension is assumed to be 0.01 bars 10 cm above the water table, i.e. a tension equivalent to 10 cmH_2O occurs 10 cm above the water table. At energy equilibrium, the whole tension profile is determined by the level of the water table, and accordingly, the water store can conveniently be calculated from the soil water characteristic curves by using area integration (Figure 20) separately for each 10-cm layer.

4233. Correction for deficits from equilibrium

Close to the water table, the assumption of energy equilibrium is justified. At greater distances above the water table, considerable deviations from equilibrium might occur (e.g. Päivänen 1973, Ahti 1978). The deviations from equilibrium tension are not, however, necessary connected with large deviations from equilibrium water content, as can be seen from the water characteristic curves of Fig. 19.

According to Päivänen (1973, p. 56), the water tension in surface peat remains close to equilibrium, until the vertical distance between the point of observation and the water table increases to 50—55 cm. According to Ahti (1978, p. 27), the critical limit is approximately 45 cm. For the model, 45 cm was chosen. In cases with the water table below this limit and the daily precipitation below 1 mm, part of the soil water consumed in evaporation was thought to increase the deviation from energy equilibrium instead of lowering the water table. For days of substantial rainfall, infiltration was allowed to compensate for the deficit, before a rise in the water table level could occur. The daily increase in the deficit was estimated from water-table dependent soil water evaporation by equation (10):

$$E_{def} = \frac{h - 45.0}{45.0} \cdot \frac{E_{soil}}{3.0} \tag{10}$$

where
h = estimated distance from water table to soil surface (condition: $h > 45$ cm)
E_{def} = daily increase in the deficit (mm)
E_{soil} = uncorrected water-table dependent evaporation (mm)

With a PET-value of 6 mm, E_{soil} would be about 2 mm, if the water table is at 60 cm below soil surface (see Fig. 17). This would result in a E_{def}-value of 0.22 mm.

The parameters of equation (10) were chosen to result in rather small deficit corrections because of the form of the soil water characteristic curves of surface peat (Fig.

19). It should be noted that the daily water balance remains unaffected by the correction procedure:

E_{def} is included in the daily evaporation. In long term, the daily corrections have a retarding effect on water table shifts and, consequently, a slight effect on water table-dependent evaporation will result. In spite of the correction, most of the soil water lost in evaporation will influence the water table level.

4234. Water yield

The water yield coefficient is mostly defined as the ratio between the change in the water store and the corresponding shift of the water table:

$$C_{yield} = \frac{\Delta S}{\Delta GW} \quad (11)$$

where
ΔS = the change in water store, mm
ΔGW = the water table shift, mm

Traditionally, Finnish peatland hydrology (Heikurainen 1963, Päivänen 1964, Laine 1981, 1984) uses the inverse value of the water yield coefficient, or the so-called ground water coefficient:

$$C = \frac{\Delta GW}{\Delta S} \quad (12)$$

Normally, both C_{yield} and C are determined to correspond to energy equilibrium of soil water, i.e. energy equilibrium is assumed in the peat layer that is situated above the water table. In response to a water table shift, soil moisture is simultaneously redistributed in this layer, untill a new equilibrium is attained. Consequently, the ground water coefficient is a function of changes in soil water content both in the layer where the shift takes place, and in the layer above it.

In a homogeneous peat profile with constant retention properties, the change in water store corresponding to a constant shift of the water table increases with depth, because the soil layer object to change grows thicker. Consequently, the C-value would decrease with depth.

In Finnish Sphagnum peats, the retention capacity tends to increase with soil depth. If this is accepted, and the same form of the soil water characteristic curve is applied throughout the profile (Fig. 21a), the corresponding C-value distribution would still show a regular decline with depth (Fig. 21b).

Assuming very low retention capacity of surface peat, and considerably higher retention capacity and a different curve form for the deeper peat layers (Fig. 21c), the C-value distribution displayed in Fig. 21d is obtained. This distribution corresponds very well with several samples in the data of Laine (1981) in the 5—40 cm layer.

The diagrams displayed in Figure 21e and 21f are valid in a situation, in which a thicker surface layer of unhumified peat with low water retention is assumed. This pair of diagrams is in accordance with the retention capacities accepted for the present model.

424. Testing the main assumptions of the model

An attempt was made to test the general validity of the major assumption included in the model, i.e. the relationship between the water table and evaporation as illustrated in Figure 17. As assumed by the model, evapotranspiration is partly a function of potential evapotranspiration:

$$E = F \cdot PET \quad (13)$$

and

$$F = f(GW) \quad (14)$$

where GW = the vertical distance between soil surface and water table

By using the ground water coefficient as defined by Heikurainen (1963), the change in the water store (S) can be denoted as

$$\Delta S = \frac{\Delta GW/\Delta t}{C} \quad (15)$$

and

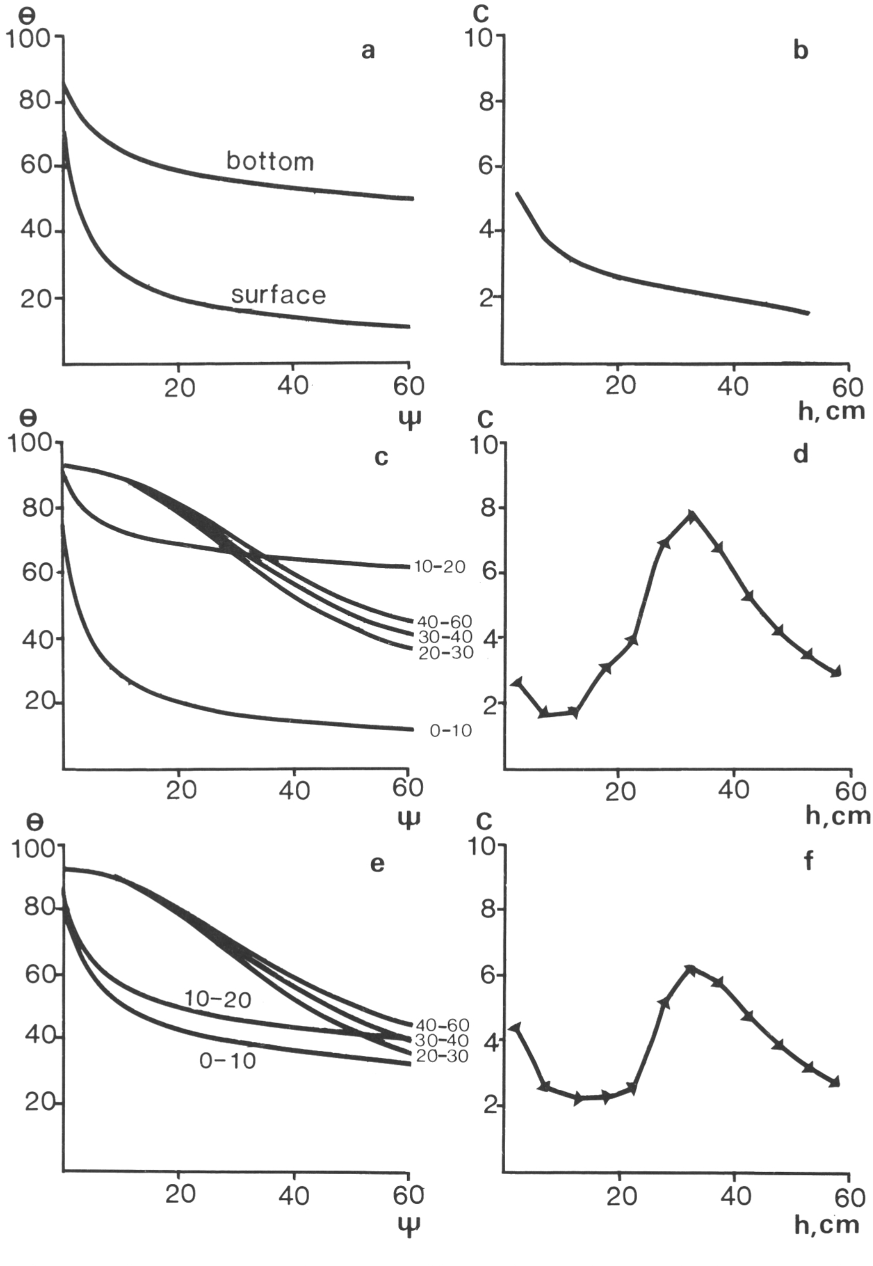


Figure 21. Examples on the effect of the soil water characteristics on the C-value distribution. To the left soil water characteristic curves, to the right C-value distributions. Continuous change from surface to bottom of the profile is assumed for a—b; c—d and e—f: layered profiles.

$$C = f(h) \tag{16}$$

where
$\Delta GW/\Delta t$ = the magnitude of water table shift, mm
C = the ground water coefficient
h = the vertical distance (mm) between soil surface and the layer in which the shift takes place.

Assuming linear relationships in (14) and (16) for simplicity, and no water flow into the basin from the surroundings, the general water balance equation (1) can be rewritten as follows:

$$P = q + (a \cdot GW + b) \cdot PET + \frac{\Delta GW/\Delta t}{(c \cdot h + d)} \quad (17)$$

where ΔGW is negative when the water table is lowered.

Using observed precipitation and runoff, estimated PET, and observed values of GW and nonlinear regression analysis basing on iteration, the values of parameters a, b, c and d were determined for the nine ditching treatments and for the two periods (1967—72 and 1977—81).

It can be concluded from Table 4 that the values of coefficients a and b, defining a linear relationship between water table -dependent evaporation and PET, correspond relatively well to the assumption included in Fig. 17. When plotted against average distance of water table from soil surface (Fig. 22), the values of F (= a · GW + b) in the model appear to be slightly overestimated for the higher water tables. The difference can, however, be attributed to overreactions of the water table, and additionally, to the fact that total evapotranspiration is not a simple function of the water table location.

As regards the parameters c and d, which define the ground water coefficient (C), the values of Table 4 are more difficult to interprete. For high water tables, the regression coefficient tends to be positive, and for deep water tables, negative. If the average values of C are plotted against average water table levels (Fig. 23), a clear relationship cannot be detected: high values of C appear to occur for all ditching treatments during both periods. Additionally, the C-value distributions of the two periods do not coincide. Again, the true relationship might be obscured by overreactions of the water table. As a whole, however, the regression analysis performed does not give rise to neglect the water retention characteristic curves chosen for the model.

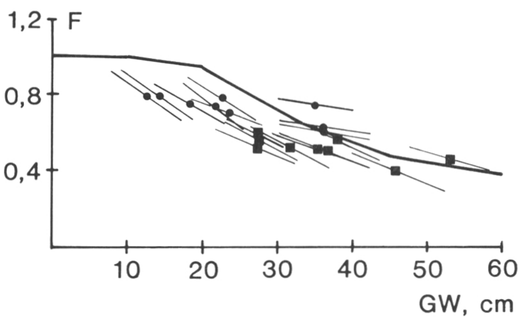


Figure 22. The relationship between the coefficient F and water table level on the basis of Table 4. Squares 1967—72, dots 1977—81. The regression coefficient is indicated by a short line.

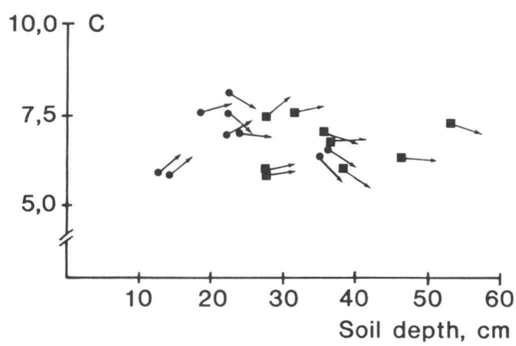


Figure 23. The C-value distribution of the profiles on the basis of Table 4. Squares 1967—72, dots 1977—81. The value of the regression coefficient is indicated by an arrow. The average C-values were plotted against the average water table of each submaterial.

Table 4. The values of parametres of equation (20) (n = number of observations, R^2 = coefficient of determination).

Treatment	1967—72						1977—81					
	a	b	c	d	n	R^2, %	a	b	c	d	n	R^2, %
20/30	−.018	1.26	−.124	10.7	279	75	−.025	1.34	−.122	10.8	76	60
40/30	−.021	1.13	+.037	4.8	277	70	−.022	1.16	+.053	6.6	76	61
100/30	−.021	1.16	+.177	2.6	278	72	−.028	1.15	+.191	3.4	76	55
20/60	−.011	1.05	−.055	10.2	280	66	−.006	0.82	−.112	10.6	77	71
40/60	−.016	1.08	−.038	8.3	279	68	−.011	0.86	−.167	11.2	77	71
100/60	−.019	1.06	+.037	4.8	277	71	−.028	1.17	+.141	3.9	76	68
20/90	−.016	1.12	−.018	7.2	279	63	−.005	0.94	−.193	13.1	77	68
40/90	−.016	1.07	+.003	6.7	280	64	−.016	1.07	−.070	8.7	76	70
100/90	−.021	1.08	+.056	5.8	280	56	−.030	1.41	+.113	4.5	60	59

R^2 was approximated as follows: $R^2 = \frac{SST - SSE}{SST} \cdot 100$

$SST = s_d^2 \cdot (n-1)$

s_d = standard deviation of the dependent variable

n = number of observations

SSE = residual square sum

425. Water table and upper limit of saturated zone

At early stages of the model construction it was realized that such changes in water table depth occur that cannot be connected with merely changes in soil water store. This was particularly clear in the data of 1968 which was a dry year: long dry spells were disconnected by a few rainfalls of about 20 mm. Unsuccessful attempts were made to account for the large water table shifts by applying models considering hysteresis and rewetting lags. It was concluded that phenomena related to "the lisse-effect" by de Zanger (1981) were involved. According to this theory, the phreatic level can rise rapidly due to an increased pressure of the soil air above the capillary fringe. According to de Zanger the increased pressure is caused by infiltration of rain water. It is one of the basic assumptions of the present model that there is a continuous capillary fringe between water table and peat surface. Obviously, the "overreaction" of the water table cannot be explained with the equations of de Zanger.

As rainwater enters the peatland system (vegetation + soil), the elasticity of the soil leads to compression which is a function of the additional weight. The weight of intercepted water will soon be eliminated through evaporation. If the water table is deep, and the equilibration process after infiltration is slow, a long term compression effect is to be expected by the weight of infiltrated water. The well-humified peat layer immediately above the water table being close to saturation, the compression of the pore space leads to an immediate rise of the phreatic level. The weight factor has been discussed in detail by Ivanov (1981).

The compression theory would suggest that the "overreaction" of the water table actually occurs and is not an artifact connected to the method of observation. The theory seems to be contradicted by tensiometric observations by Ahti (1978), who did not observe corresponding overreactions of the water table in spite of considerable changes in soil water tension caused by infiltrated water. In this case, however, the deepest tensiometers were installed at a depth of 30 cm. A more important difference between the tensiometer study and the study at hand probably is that the peat layer was shallower (1 m) in the tensiometer study. If the water table is close to the bottom of the peat layer, the compression of the wet layers can be assumed to be less marked.

In a study by Laine & Mannerkoski (1975) it is clearly demonstrated that other than compression effects are involved: tensiometers that were installed below the water table did not react to rainfalls as sharply as did the water level in an observation well. In this case the water level in the well seems to have been higher than the phreatic level after rainfalls, i.e. an error connected to the method of observing the phreatic level seems obvious. Problems in observing the rise of the water table in bore holes were reported by Heikurainen (1971). After five rain events in 1969, an average rise of 16 cm and 8 cm was observed in wells of 20 and 50 cm in diameter, respectively. Heikurainen concludes as follows:

> *"In measurements of the rising ground water table after rain, the rain peak appearing in narrow holes magnifies the change that actually takes place in water relations. A ground water hole with a sufficiently large diameter, on the other hand, slows down the rate of rising because of the large body of water it contains".*

At energy equilibrium, the gravitational force influencing soil moisture is equilibrated by capillary forces. In therms of energy, gravitational energy is equal to the matric potential which can be expressed as the vertical pressure distance between the point of observation and water table. As rain water enters the profile, an excess pressure head is created (c.f. Hanrahan & Rogers 1980), which, assuming no excess head at the boundary wall of the bore hole, should result in lateral flow of water towards the well in the capillary fringe, here defined as the layer of capillary connection above the water table. The hydraulic conductivity of the peat profile decreasing with depth, a zone of saturation (pearched water table) accompanied by a seepage face towards the well might temporarily be created (Hillel 1971). According to Donnan (1947), lateral flow occurs in the unsaturated parts of the capillary fringe as well.

In October 1986, a small scale field experiment connected with the lateral flow theory was conducted in an old drained pine bog in

Central Finland. During a period of water table stability, two litres of water were added into each of two observation wells, as two adjacent wells served as control. The effect of the water addition on the water level in the wells was observed during 8 hours (Fig. 24).

The recession of the water level matched reasonably well with simulated recession (for simulation procedure see Appendix 12). It is obvious that equilibration of potential lateral flow of water into an observation well is a slow process indeed, even if the water table is rather close to the soil surface, and even if the flow towards the well would be of instantaneous rather than of continuous nature.

Overreactions of the water table as observed in this study and discussed by Heikurainen (1971) are to be expected, if the lateral flow towards the well is not equilibrated by simultaneous lateral flow from the well into the profile. In peat profiles, where conductivity decreases considerably with depth, this theory seems well justified. The connection between hole diameter and rise of the water table observed by Heikurainen (1971) can be explained by the fact that with increasing diameter, the lateral flow surface increases in the quadratic dimension and volume of the hole in the cubic dimension.

A third alternative is provided by the theory that the boundary between the unsaturated and saturated zones may not be at the water table, but at some elevation above it (Childs 1947, Hillel 1971). This zone of saturation, defined by the two authors as the capillary fringe (in contrast to the definition adopted in the Nordic countries and in this paper; see Johansson 1984), is characterized by a subatmospheric pressure distribution and cannot be perceived by tensiometric observations. It is not unreasonable to think that during infiltration and water redistribution, the pressure distribution of this "capillary fringe" is altered, and as a consequence, lateral flow of water from the "fringe" into the observation well starts before infiltrating water reaches the water table. The slight change in pressure that is required to trigger such a flow reaction could be created through capillary transmission of the excess head in the upper peat layers or through the compression effect described earlier.

The three alternative explanations for the overreaction, resulting in the same apparent

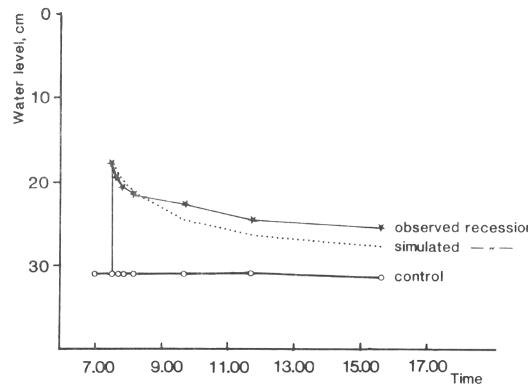


Figure 24. Recession of the water level in an observation well after water addition.

level of the water table, are schematically illustrated in Fig. 25.

Irrespective of which theory is the correct one, or whether all three are simultaneously valid, the overreaction seems to be governed by two major factors:

1) The amount of infiltrated water
2) The vertical distance between soil surface and water table prior to the start of infiltration.

By using the data of 1968 and the method of trial and error, the following relationship between the excess rise of the water level and the two major factors was arrived at:

$$h_g = \Delta S \cdot \sqrt{h_{n-1}} \qquad (18)$$

where
ΔS = change in soil water store, cm/day
h_{n-1} = distance from water table to soil surface during the previous day

As important as to estimate the immediate magnitude of the overreaction is to estimate its duration. In doing this, the following criteria were adopted: 1) The effects of subsequent cases of infiltration are additive, and 2) each case of infiltration has its independent duration and recession time. The recession was taken into consideration by defining a recession coefficient (c):

$$h_{g_n} = h_{g_{n-1}} - h_{g_{n-1}} \cdot c \qquad (19)$$

where
h_{g_n} = the fraction of the pressure effect left n days after day of rainfall event
$h_{g_{n-1}}$ = the fraction left during day n − 1
c = recession coefficient

Using the data of 1968, a value of 0.1 for c was arrived at.

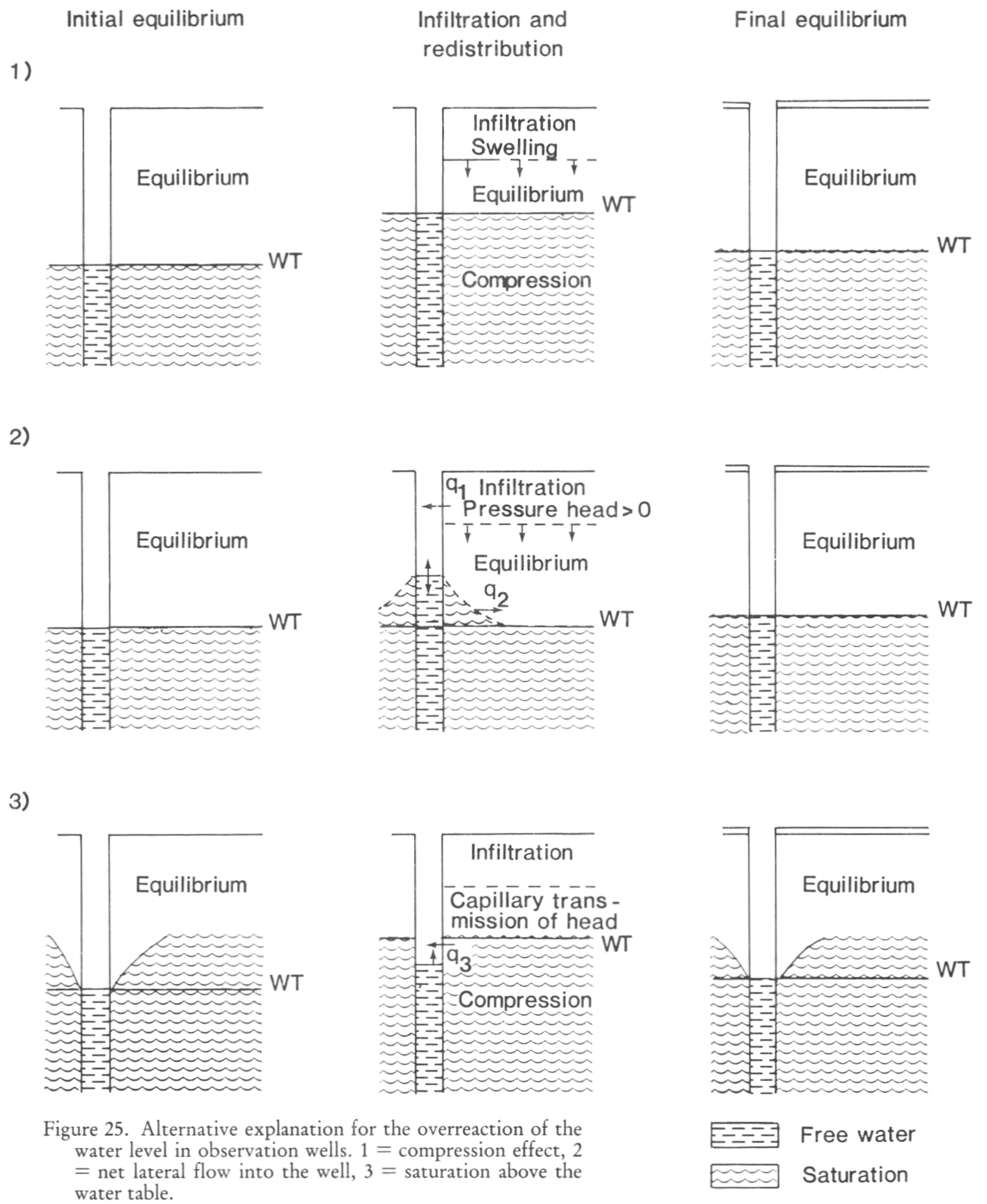


Figure 25. Alternative explanation for the overreaction of the water level in observation wells. 1 = compression effect, 2 = net lateral flow into the well, 3 = saturation above the water table.

426. Flow chart

The essential features of the calculation procedure are demonstrated in the flow chart of the model program (Fig. 26).

There are a few aspects to be noted. First, the model assumes energy equilibrium as it estimates the new water table level. Corrections for deviations in the dry direction (subprogram DEF) and the wet direction (PRESS) are made partly on physical and partly on mathematical grounds. Second, daily values for the output variables are created from daily values of the input variables and on the basis of previous values of estimated water table level; i.e. the field observations of the water table level are utilized only for defining the initial condition at the beginning of the iteration sequence (beginning of June) and as test values for model output.

Shrinking and swelling of peat is modelled as a fully reversible process that is linearly dependent on the estimated level of the water table.

The water table -dependent evaporation is estimated on the basis of the estimated water table level, i.e. the value of water table level after the program control returns from the subprograms STORIT => IT2 => RET to the main program. It is discussed later whether it would be justified to use values corrected by DEF, SHRINK and especially by PRESS.

43. Input data and initial conditions

The model uses daily values of precipitation (observed), runoff (observed), and potential evapotranspiration calculated by using Penman's approach. For each ditching treatment and for each year of observation, an initial water level value for the iteration process has to be defined. The natural value to select is the first field observation of the year corrected by possible effects of dry spells (deviation from energy equilibrium in the dry direction), and effects of infiltration pressures (deviation from energy equilibrium in the wet direction). Because the model neglects water deficits if the water table is close to the soil surface, which is the case in early June, only the effect of infiltration pressures has to be considered when correcting the initial water table level. This is done by using precipitation data of the week prior to the first water table observation: the immediate pressure is estimated by formula (20), which gives a correction value that corresponds to observed overreactions of the water table:

$$h_{g_n} = 3.3 \cdot P_n \cdot c^n \qquad (20)$$

where

h_{g_n} = the correction value for a rain event that occurred n days before the day of inition, cm

P_n = daily precipitation n days before the day of inition, cm

c = the recession coefficient of the pressure correction

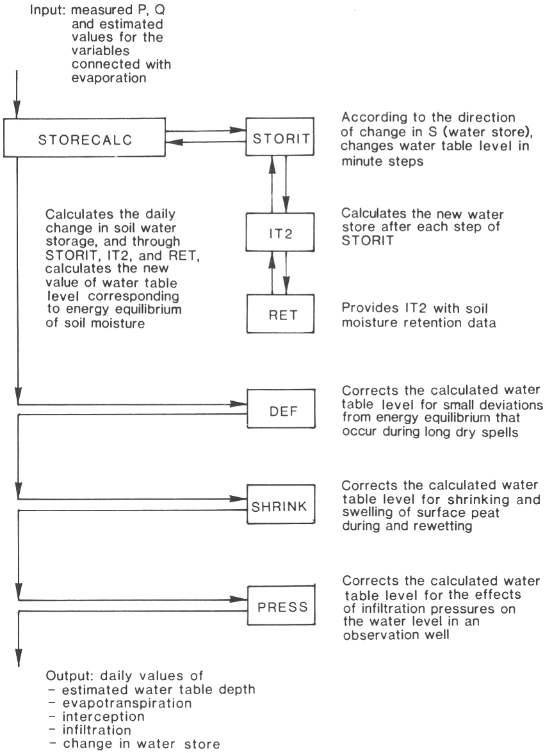


Figure 26. The flow chart of the model program STORECALC.

When defining the initial value of water table level by formula (20), the value of c was assumed 0.5. As can be seen later, the correction procedure has practical value only in 1972 and in 1980. In the other years, no substantial precipitation occurred during the week prior to the first water table observation.

The procedure of defining the initial value being uncertain because of deficient data, the recession coefficient was chosen much larger than in the actual modelling (c = 0.5 at the beginning instead of 0.1 in later phases of simulation). This was done in order to emphasize the pressure effects caused by rainfall events that occurred immediately before or during the day of the first water table observation.

44. Model verification

441. Test data

It is a general requirement that when testing a model, the test data should be independent from the data that has been used in constructing the model. This requirement is readily satisfied here as the water table observations are used in merely defining the initial value for the water table simulation process.

Another requirement is that the test data should be representative, i.e. it should cover the essential range of variation of the test variable. Here 11 years of observation adequately covers the climatic variation.

The third essential requirement for test data is that its reliability should be unquestionable. As regards the accuracy of observation, the data on the water table level of this study meets the requirement. It is more difficult to demonstrate that the number of observation points per ditching treatment is big enough to consider the spatial variation within the treatments.

442. General agreement

Figures 27—35 are considered by the author to contain all the information necessary for judging, how the model output fits the test data.

Each of the figures represents one ditching treatment, and each of the diagrams in one figure represents four months of calculated and observed values of water table level. The triangular dots are the test data, i.e. arithmetic means of 10—26 observation wells. The lower line represents the equilibrium water table calculated by the model, as corrected for deviations from equilibrium during dry spells as well as for effects of peat shrinking and swelling. The upper line represents the model output as further corrected for infiltration pressure effects as earlier described.

In judging the general agreement of the model by the diagrams, the most important criteria were as follows:

a) If output data and test data agree both at the beginning and at the end of the four month period, the model output is close enough to reality. Systematic deviations are probably due to inaccurate determination of the water retention characteristics.
b) If the difference between observed and calculated values systematically increases towards the end of the four month period, the model output is considered poor.

In general, the model output fits very well to the test data. This is particularly true in the dry period of 1968—72. In most cases, the values corrected for infiltration pressure effects show better agreement with the test data than the uncorrected ones.

There is a tendency for the general agreement of the model to be worse during the wet period of 1977—81. Especially year 1980 appears difficult for the model: treatments 20/60 and 20/90 (the most efficient drainage treatments) show much deeper water tables than is model output. It is obvious that either evaporation has been underestimated or runoff has been erraneously measured. The latter is improbable because 1980 was a rather dry year. An underestimated interception and evapotranspiration is more probable, because the development of the tree stand, which has been especially fast in these very treatments, is not taken into consideration by the model.

443. Effect of wet and dry years

The excellent fit during the dry summers of 1968—72 proves that evapotranspiration (including interception) has been satisfactorily estimated for that period. The same, of course, stands for the runoff observations, the relative importance of which, however, is not great because of the dry years.

In the wet period of 1977—81, except for 1980, the model more conspiciously produces too deep water tables than in the dry period of 1968—72. Because it is improbable that runoff has been overestimated, a feasible explanation is that the infiltration pressure correction procedure underestimates the reaction of the water level in the wells, when the water table is close to soil surface. The water table observations having been made weekly during this period, the time series of the water table level are not dense enough to allow modification of the correction procedure.

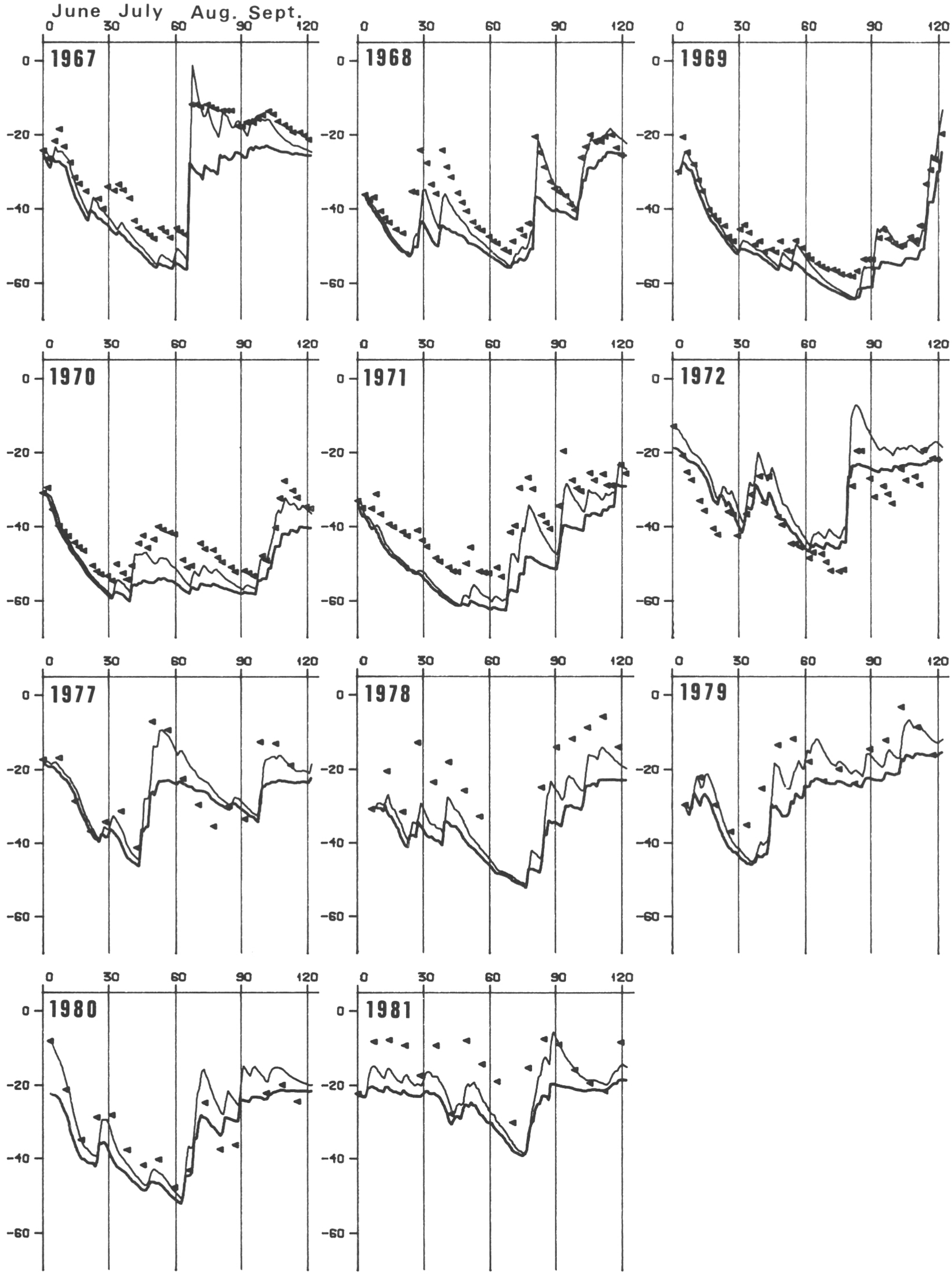


Figure 27. The agreement of measured (dots) and calculated water table level at the 20/30 treatment. Lower line: equilibrium water table, upper line: water table corrected for infiltration pressure effects. Horizontal axis of the diagrams: time, days from June 1st.

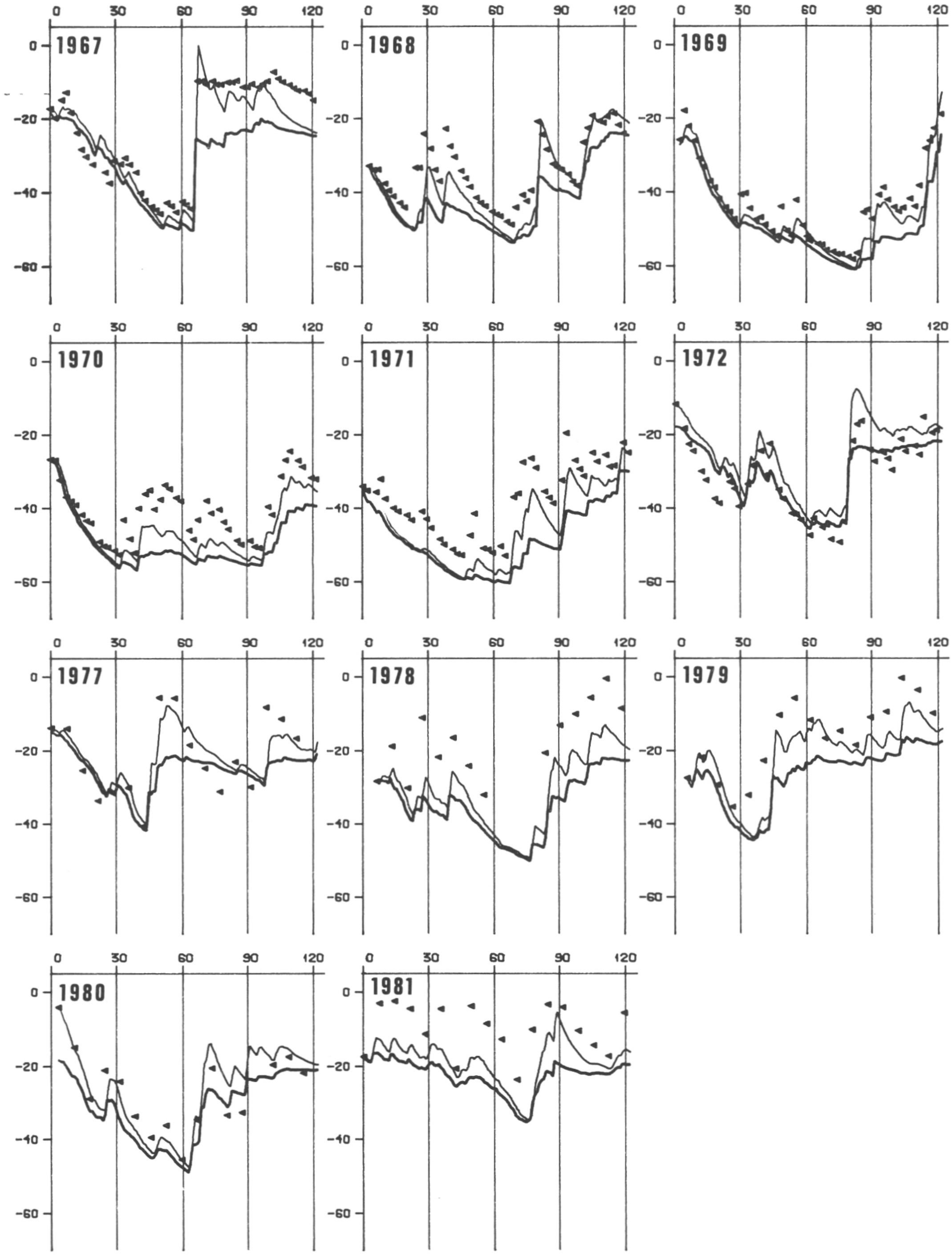


Figure 28. The agreement of measured (dots) and calculated water table level at the 40/30 treatment. For symbols see Fig. 27.

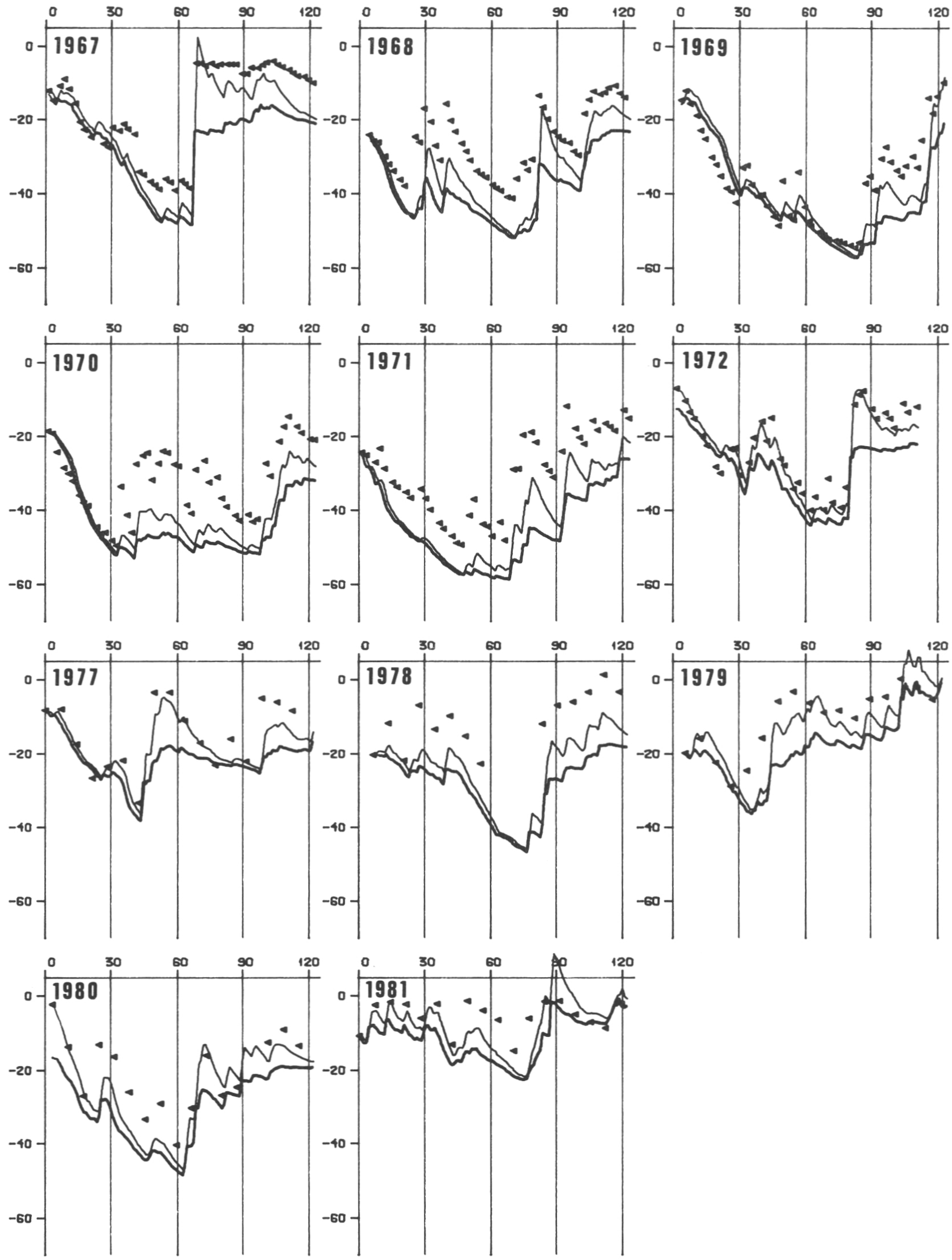


Figure 29. The agreement of measured (dots) and calculated water table level at the 100/30 treatment. For symbols see Figure 27.

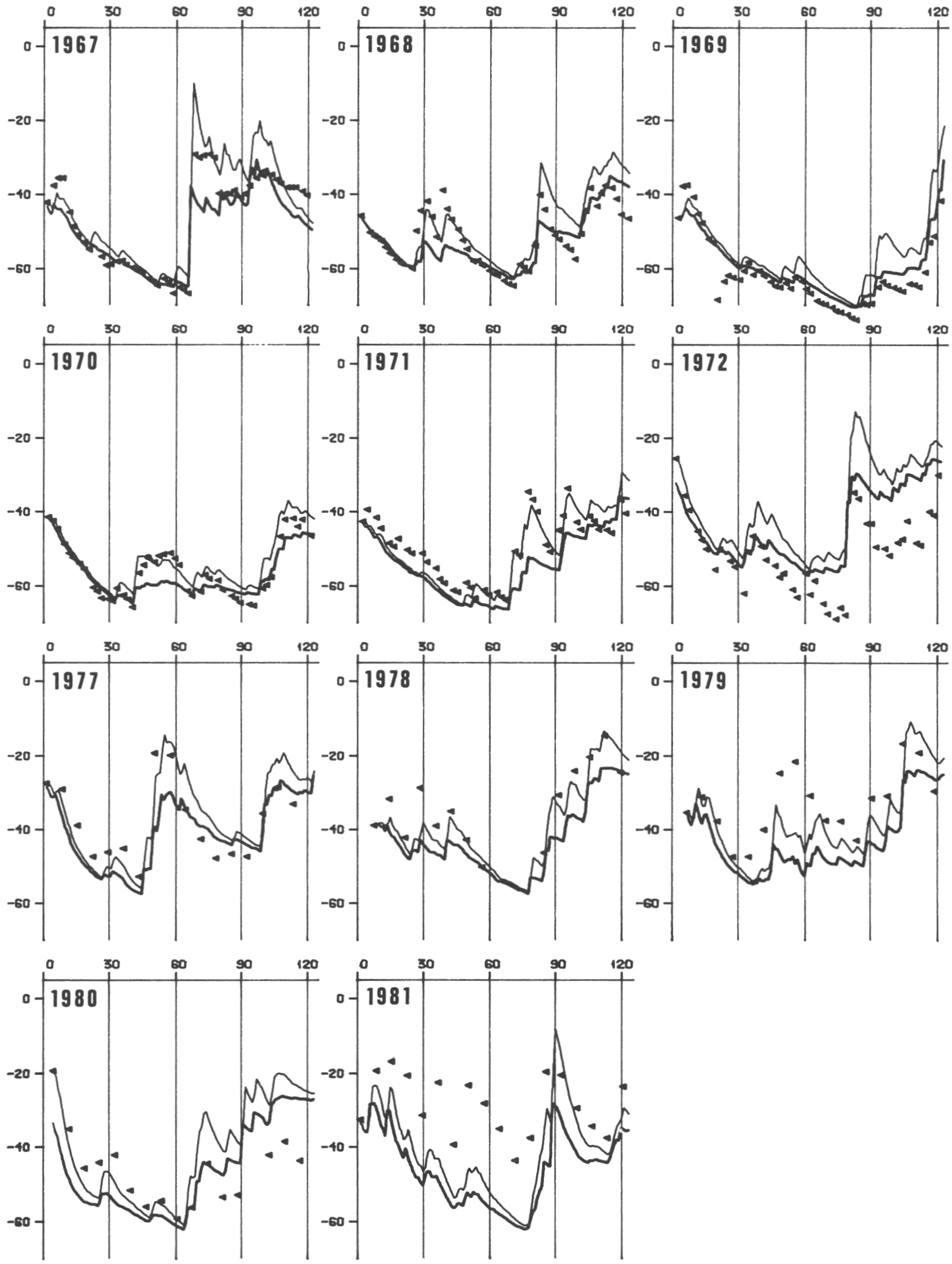


Figure 30. The agreement of measured (dots) and calculated water table level at the 20/60 treatment. For symbols see Figure 27.

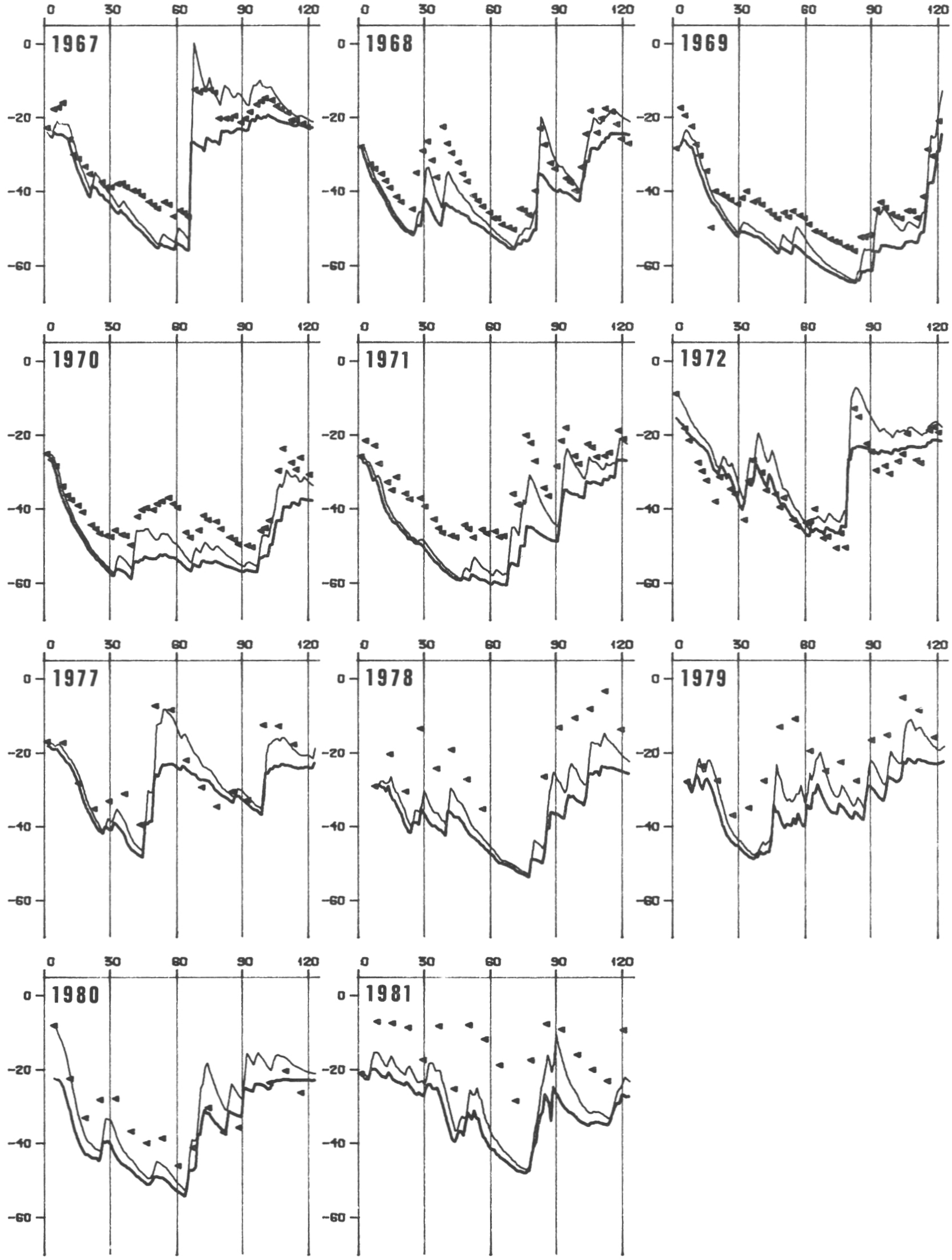


Figure 31. The agreement of measured (dots) and calculated water table level at the 40/60 treatment. For symbols see Figure 27.

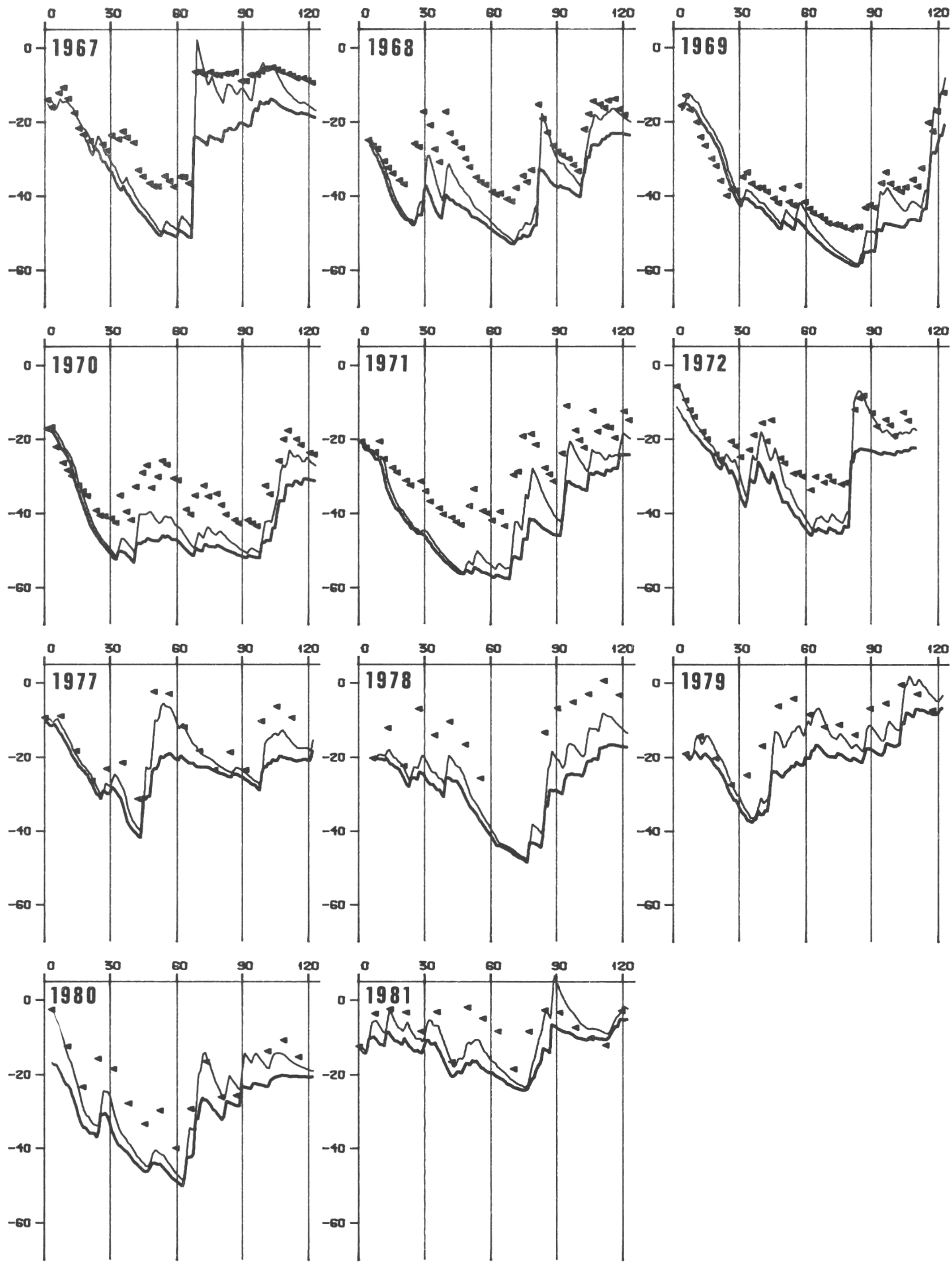


Figure 32. The agreement of measured (dots) and calculated water table level at the 100/60 treatment. For symbols see Figure 27.

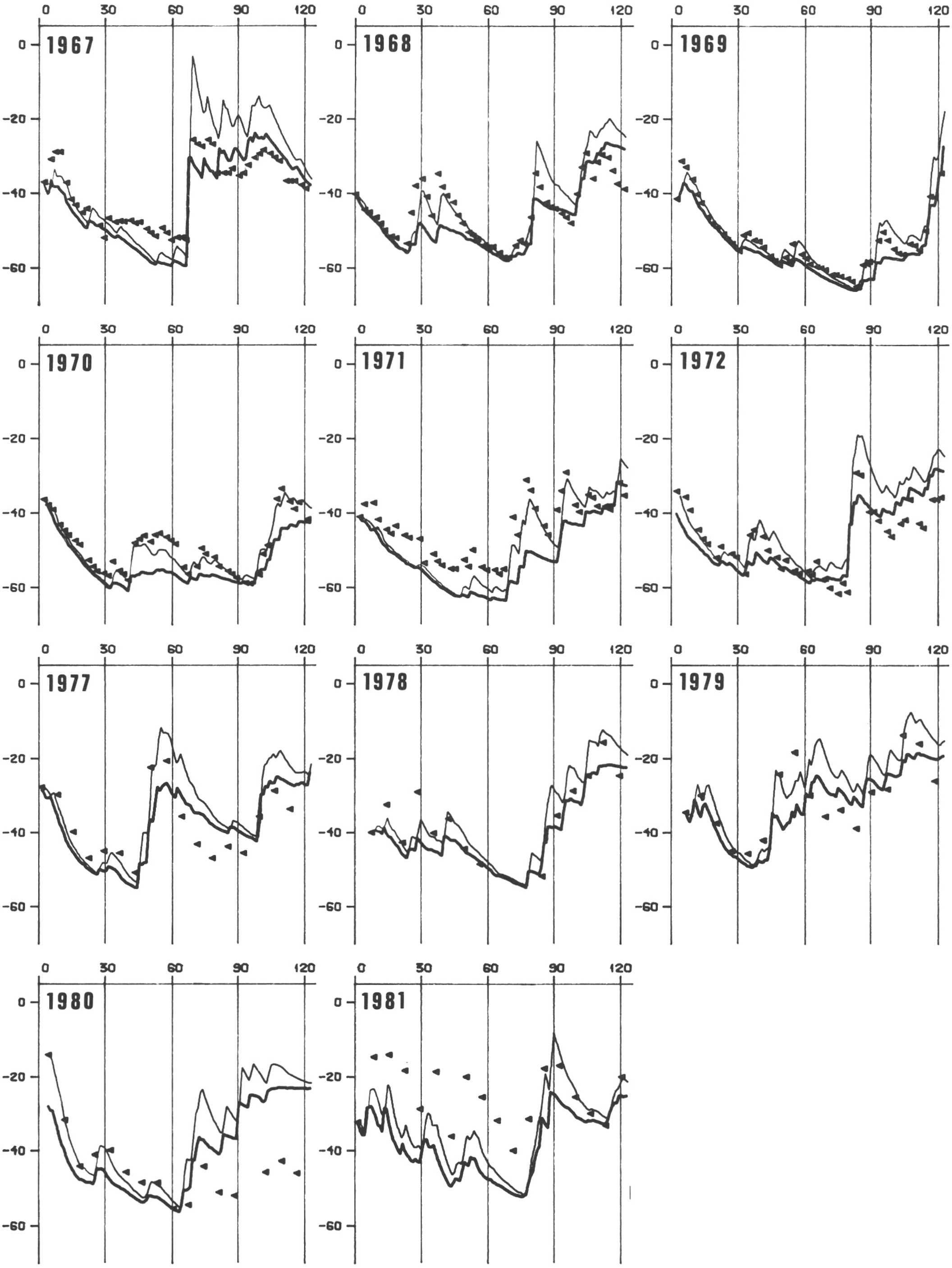


Figure 33. The agreement of measured (dots) and calculated water table level at the 20/90 treatment. For symbols see Figure 27.

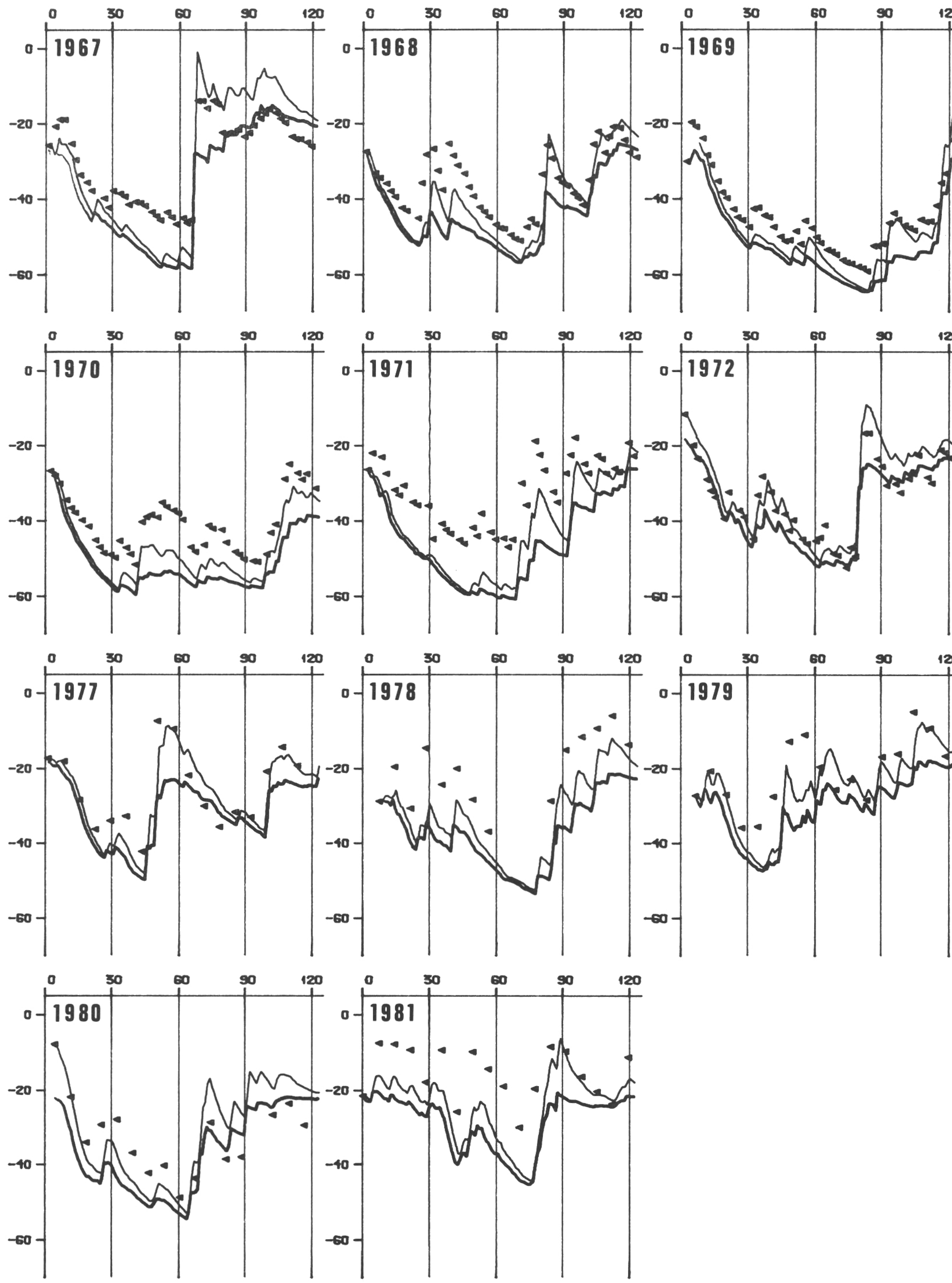


Figure 34. The agreement of measured (dots) and calculated water table level at the 40/90 treatment. For symbols see Figure 27.

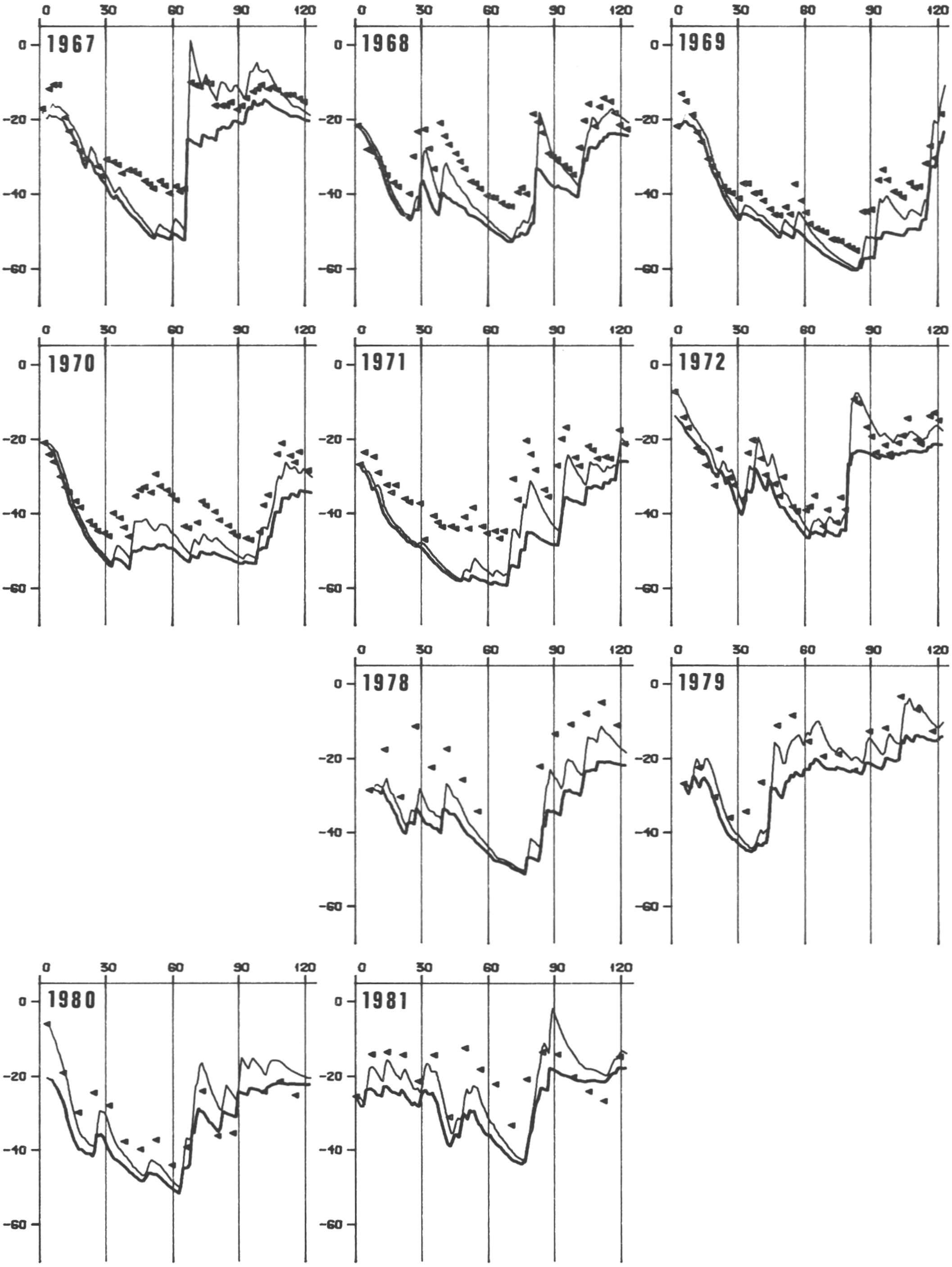


Figure 35. The agreement of measured (dots) and calculated water table level at the 100/90 treatment. For symbols see Figure 27.

5. EFFECTS OF DITCHING ON THE HYDROLOGICAL VARIABLES

51. Runoff

After having served as input data in a satisfactory water balance model, the runoff data presented in Table 5 can be examined on a more solid basis.

In most cases, the irregular differences between the ditching treatments can now be considered to be real instead of inaccurate or erroneous.

Throughout the long period of observation, the 20-m and 40-m treatments do not differ much from each other, and simultaneously, they both differ clearly from the 100-m treatments. The effect of spacing tends to be less pronounced than indicated by earlier papers (Huikari et al. 1967, Ahti 1974, 1977, 1980), and the spacing effect varies considerably with time (e.g. Ahti 1977).

As regards the effect of ditch depth, no consistent logic between treatment and summertime runoff can be detected. During the wet years of 1977—1981 in particular, not the 90-cm ditches but the 60-cm ditches show the highest runoff. Evidently this is partly due to the fact that in the case of the 20/60 -treatment, the effective ditch depth is greater than in the case of the 20/90 -treatment. It is clear, however, that the runoff response to ditching is dependent on the characteristics of the ditch network in a more complicated way than has been previously assumed. (e.g. Ahti 1977).

In most publications referred to in connection with runoff increases, the increase in runoff caused by ditching has been argumented by a corresponding decrease in evapotranspiration. Logically, therefore, the difference should be created during the short period of high potential evapotranspiration during May—July. To test this theory, the monthly runoff totals were examined (Tables 6—9). The theory is supported by the fact that during August—September, no substantial differences in runoff between the ditch depth treatments can be detected (Tables 8—9). Instead, considerable differences were measured in June—July (Tables 6—7). It is obvious, therefore, that the irregularities in the interrelation of ditch depth treatment and runoff behaviour are in most cases included in the differences between the annual June—July periods. Additionally, the hydrological conditions during

Table 5. Values of observed runoff (mm) for the period June—September in 1967—72 and 1977—1981.

Year	Ditch depth, cm: 30			60			90			
	Spacing, m: 20	40	100	20	40	100	20	40	100	Mean
1967	86	87	78	143	69	66	110	66	72	86
1968	6	2	1	22	7	5	6	17	12	9
1969	1	0	0	6	4	1	2	4	4	2
1970	0	0	0	3	0	0	0	0	0	0
1971	2	0	0	13	5	0	4	4	0	3
1972	22	18	8	45	26	25	44	52	30	30
1967—72	20	18	15	39	19	16	28	24	20	22
1977	32	27	17	53	40	24	40	44	40[1)]	35
1978	42	39	27	57	63	29	37	50	40	43
1979	68	77	38	159	134	62	101	107	76	91
1980	2	6	1	37	19	10	15	15	15	13
1981	79	106	42	160	149	125	126	112	70	108
1977-81	45	51	25	93	68	50	64	66	48	58
1967-81	31	33	19	64	47	32	44	43	33	38

[1)] No model output because of lacking runoff observations; estimated on the basis of the other treatments for calculating the arithmetic mean

Table 6. Monthly runoff totals (mm) in June.

Year	Ditching treatment								
	20/30	40/30	100/30	20/60	40/60	100/60	20/90	40/90	100/90
1967	3	1	1	17	3	7	7	10	10
1968	0	0	0	2	1	1	0	2	2
1969	1	0	0	5	3	1	2	3	2
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	2	0	0	0	0	0
1972	4	3	2	10	7	14	10	15	10
1977	3	2	1	11	8	3	8	8	—
1978	1	1	0	10	7	3	5	5	4
1979	1	0	0	23	10	3	10	6	3
1980	2	5	1	23	11	5	9	9	8
1981	19	31	13	63	42	15	46	37	18

Table 7. Monthly runoff totals (mm) in July.

Year	Ditching treatment								
	20/30	40/30	100/30	20/60	40/60	100/60	20/90	40/90	100/90
1967	0	0	0	0	0	0	0	0	1
1968	0	0	0	3	0	1	0	2	2
1969	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0
1972	0	1	0	7	4	3	10	11	3
1977	19	15	11	22	19	12	16	19	—
1978	1	0	0	6	5	3	3	5	2
1979	31	26	14	76	60	25	42	49	25
1980	0	0	0	0	0	0	0	0	0
1981	19	21	8	41	36	11	29	21	17

Table 8. Monthly runoff totals (mm) in August.

Year	Ditching treatment								
	20/30	40/30	100/30	20/60	40/60	100/60	20/90	40/90	100/90
1967	37	30	27	58	25	23	42	11	18
1968	0	0	0	4	1	1	0	3	2
1969	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	3	0	0	0	0	0
1972	7	6	5	13	6	4	11	12	7
1977	0	0	0	8	3	2	6	4	—
1978	4	3	1	8	7	4	3	6	4
1979	3	7	4	23	20	8	14	14	11
1980	0	0	0	7	4	2	3	2	3
1981	35	42	13	32	58	25	37	24	27

Table 9. Monthly runoff totals (mm) in September.

Year	Ditching treatment								
	20/30	40/30	100/30	20/60	40/60	100/60	20/90	40/90	100/90
1967	45	56	49	69	41	35	61	45	44
1968	6	2	1	13	5	3	7	10	6
1969	0	0	0	2	1	0	0	1	2
1970	0	0	0	2	0	0	0	0	0
1971	2	0	0	8	5	0	4	3	0
1972	10	9	1	15	9	4	13	14	10
1977	10	10	6	12	11	6	11	12	—
1978	35	34	26	34	45	20	26	36	30
1979	33	44	21	36	44	25	35	38	37
1980	0	11	7	25	13	4	13	11	9
1981	6	11	7	25	13	4	13	11	9

May might play an important role in the runoff behaviour of drained peatlands in June.

The analysis of Tables 6—9 allows the conclusion, that the effect of ditch depth is connected with the period of high evaporation, as the effect of ditch spacing appears to be dependent on the occurrence of intensive rainfalls and their timing with respect to preceding hydrologic conditions (cf. the differences between 1967 and 1981). If intensive rainfalls occur in the period of high potential evapotranspiration, the runoff behaviour is extremely difficult to predict.

To test whether changes in the runoff treshold had occurred in time, the relationship between runoff and water table level was estimated for the periods 1967—72 and 1977—81 by using regression analysis; days with zero runoff were neglected. The regression curves, corresponding to equation $q = a \cdot h^b + c$ are given in Figure 36.

With few exceptions, runoff tends to cease at higher water table levels during the later period of 1977—81. Whether this is due to ditch deterioration or more frequent overreactions of the water table during that period, is difficult to judge. The general difference in curve form would suggest the latter alternative.

52. Evapotranspiration

Because evapotranspiration was assumed to be dependent on the location of the water table when constructing the model, it is self-evident that ditching efficiency shows a clear influence on evapotranspiration in model output (Table 10).

Differences of 50—70 mm are not rare. Large differences are not unexpected in dry years, as capillary rise from the water table dominates the evaporation process. It is unexpected, though, that even in wet years, evapotranspiration is conspiciously dependent on the ditching treatment.

In estimating evapotranspiration, two evident sources of error exist, the occurrence of which is difficult to test. The first one is connected with rainy summers. The water table -dependent evaporation was estimated on the basis of the equilibrium water table, and the effect of infiltration periods was not considered. This could apparently lead to underestimation of evaporation in the case of a deep water table, i.e. the efficient ditching treatments. This possibility of error is partly eliminated by the fact that during rainy days, the model estimates evapotranspiration predominantly on the basis of potential evapotranspiration: if the amount of precipitation exceeds PET, no water table — dependent evaporation is included in total evapotranspiration at all. If potential evapo-

Table 10. Values of estimated evaporation (mm, interception included) for the period June-September in 1967—72 and 1977—81.

Year	Ditch depth, cm / Spacing, m: 30			60			90			Mean
	20	40	100	20	40	100	20	40	100	
1967	182	212	225	135	185	214	160	176	202	188
1968	155	161	176	144	167	172	154	166	187	165
1969	163	172	207	143	166	201	152	162	185	172
1970	167	175	201	153	175	203	161	171	191	177
1971	173	174	188	157	180	201	162	178	180	177
1972	200	216	225	158	214	217	149	190	214	198
1967—72	173	185	204	148	181	201	156	174	193	179
1977	223	239	249	177	218	243	184	213	220[1]	218
1978	162	166	191	146	159	186	149	160	163	165
1979	185	189	210	146	171	208	170	180	189	183
1980	185	202	205	145	177	199	161	177	186	182
1981	190	197	209	137	171	208	148	177	178	179
1977—81	189	199	213	150	179	209	162	181	187	185
1967—81	181	191	208	149	180	205	159	177	190	182

1) No model output because of lacking runoff observations; estimated on the basis of the other treatments for calculating the arithmetic mean.

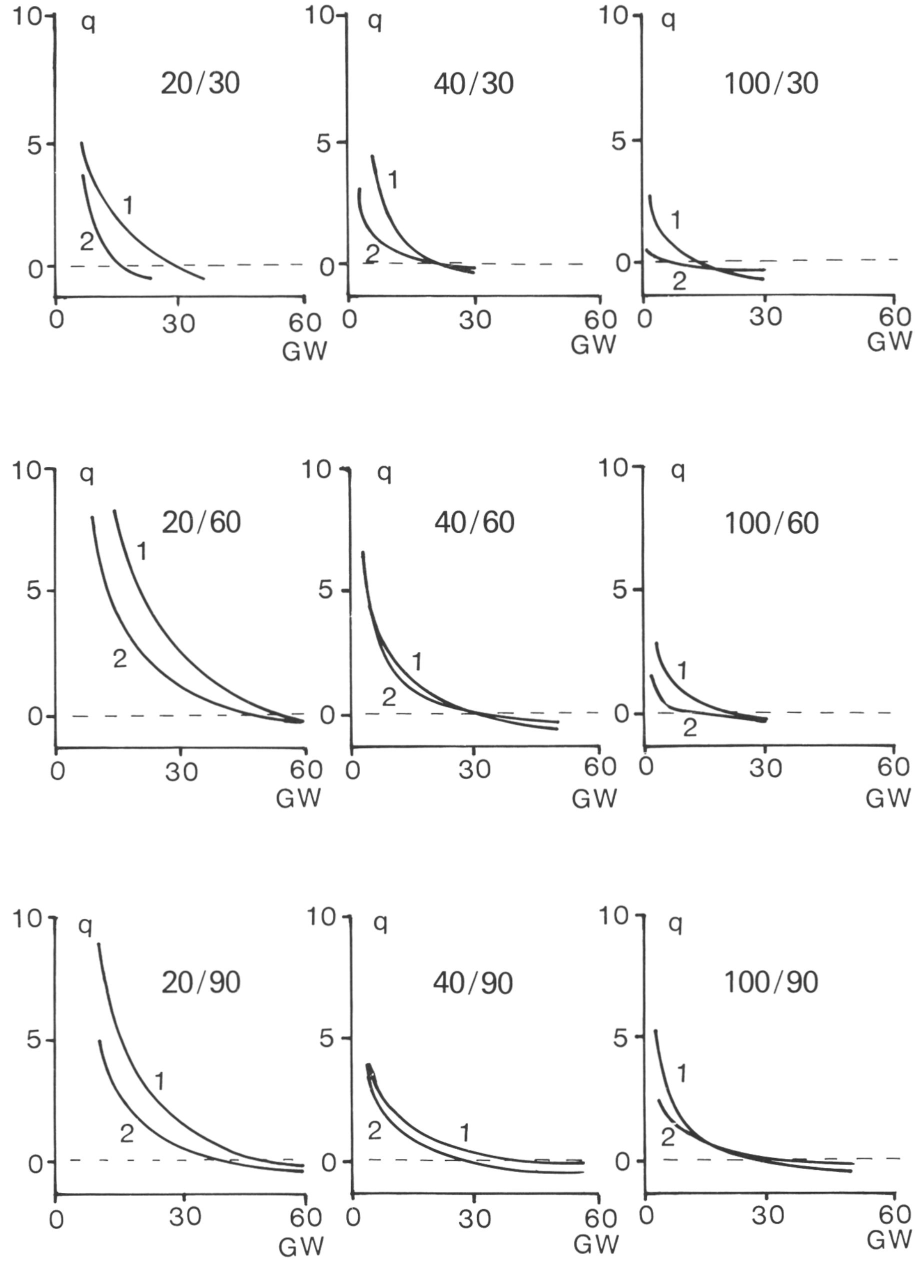


Figure 36. The relationship between runoff (q, mm/day) and water table level (GW, cm) in the periods of 1967—72 (1) and 1977—81 (2).

transpiration exceeds the amount of precipitation, evaporation of intercepted water is greater in the intensive ditching treatments, and correspondingly, the amount of water table -dependent evaporation greater in the case of the less effective ditching treatments.

Another fact that could lead to underestimation of total evapotranspiration of the efficient ditching treatments in dry years is that the development of the tree stand is not considered in this treatise, and nor are the differences in tree stand development between the ditching treatments. Accordingly, increasing interception and transpiration

Table 11. Values of estimated water storage (mm) for the period June-September in 1967—72 and 1977—81.

Year	Ditch depth, cm 30			60			90			
	Spacing, m 20	40	100	20	40	100	20	40	100	Mean
1967	+ 18	−14	− 17	− 2	+31	+ 6	+16	+44	+11	+10
1968	+ 35	+33	+ 19	+30	+22	+19	+36	+13	− 3	+23
1969	+ 28	+19	− 15	+45	+25	+10	+41	+27	+ 4	+20
1970	− 1	− 9	− 35	+10	− 9	−37	+ 5	− 4	−24	−12
1971	+ 25	+26	+ 11	+30	+14	− 1	+33	+17	+19	+19
1972	+ 3	− 1	− 18	+28	− 8	−26	+38	−10	−13	− 1
1967—72	+ 18	+ 9	− 9	+24	+13	− 5	+28	+15	− 1	+10
1977	+ 2	− 8	− 9	+27	− 1	− 9	+34	0	−10[1)]	+ 3
1978	+ 46	+44	+ 32	+46	+27	+34	+63	+39	+45	+42
1979	+101	+88	+106	+49	+49	+84	+83	+68	+89	+80
1980	+ 26	+ 5	+ 6	+31	+17	+ 4	+36	+20	+11	+17
1981	+ 48	+14	+ 66	+19	− 3	+54	+43	+29	+69	+38
1977—81	+ 45	+29	+ 40	+34	+18	+33	+52	+31	+41	+36
1967—81	+ 30	+18	+ 13	+28	+15	+13	+39	+22	+18	+22

1) No model output because of lacking runoff observations; estimated on the basis of the other treatments for calculating the artihmetic mean.

Table 12. Monthly values of water storage (mm) in 1979.

Month	Ditching treatment 20/30	40/30	100/30	20/60	40/60	100/60	20/90	40/90	100/90
June	−20	−21	−35	−30	−28	−39	−21	−25	−24
July	+59	+63	+72	+20	+33	+61	+50	+43	+65
August	+19	+15	+16	+16	+11	+13	+13	+12	+11
September	+43	+31	+54	+44	+33	+49	+41	+38	+38

could lead to underestimation of total evapotranspiration in the later years of the observation period. This phenomenon appears to be discernible during 1980, the only dry year of the wet period of 1977—81: the water table levels calculated by the model are considerably higher for the most efficient ditching treatments (20/60 and 20/90) than the observed water tables (Fig. 30 and 33).

Another striking feature is that the amount of precipitation does not influence total evapotranspiration very much. Evidently, the amount of energy available for evapotranspiration is not necessarily the dominating factor. In dry years, a lot of energy is available for the process, and in wet years, usually characterized by less radiation energy, a lot of moisture is available. As a result, the amount of water lost in evapotranspiration remains fairly constant. The same has been reported by Virta (1966).

53. Water storage

The relationship between water storage and ditching treatment (Table 11) appears to be as complicated as the one between runoff and ditching treatment.

In general, the water balance of drained peatlands tends to be positive during the period of June—September: a drained peatland area contains more water at the end of September than at the beginning of June. In most years, the amount of water that has been stored is directly proportional to ditching efficiency.

Year 1979 shows a particularly great increase in the water store. This is the very year during which heavy rainfall at the end of July caused severe summer flooding of the rivers of the western coast of Finland. At that time, the floods were generally attributed to the extensive drainage of peatlands in that area. According to the monthly values of water storage in 1979 (Table 12), that attribution evidently was justified: more water has been stored in the less effectively drained parcels. Simultaneously, more water has also evaporated from these treatments.

On the average during the whole period of observation, more water has been stored in the efficiently drained parcels. This is particularly true in dry years. It might appear contradictory that both storage and runoff increase with increasing efficiency of ditching. It must be taken into consideration, however, that evapotranspiration also contributes to the amount of water lost, and this loss is considerably smaller in the efficiently drained parcels.

6. DISCUSSION

61. Water table and water store

611. Problems connected with the method of observation

In most studies so far, the depth of the water table has been observed in observations wells. Not much attention has been paid to possible discrepancies between the method of observation and the variable that is object to interest. A few exceptions exist. Heikurainen (1971) pointed out that "measuring the depth of the water table after rain in ground water holes always involves inaccuracy, whatever the diameter of the holes used". The basis of his conclusion has been discussed earlier in this paper.

It is evident that no problems are connected with observing the water level in a bore hole when energy equilibrium of soil water prevails or when the water table is receding after a phase of equilibrium. Recession of a water table is a slow process which hardly leads to significant differences between the phreatic level and the water level of an observation well. Further, during the recession phase no disturbing lateral flow of water can be assumed above the water table.

In section 425., three explanations for the overreactions of the water table were offered. First, this phenomenon was attributed to compression of the peat layers close above or below the water table, which are close to saturation or saturated, respectively. Second, it was suggested that the overreaction is caused by net lateral flow from the profile into the observation well caused by the excess head that is created through infiltrating water. Third, it was considered possible that the soil is saturated at some distance above the 0-pressure level, which would result in water flow into the well after even small changes in the vertical pressure distribution of soil water.

It was found out in a small field test in 1986 that lateral flow is a very slow process when occurring in the vicinity of the water table, and from the well into the surrounding profile. No reason exists to believe that lateral flow from the hypothetical saturated region above the water table into the well would be much faster. Because the overreaction is fast, the above deduction appears to exclude the third theory; i.e. the overreaction is probably not due to lateral flow from an oversaturated region above the water table.

As the compression theory is contradicted by tensiometric observations, the second alternative, i.e. lateral flow in the wetted surface peat layer, appears to be the most probable one.

612. Comparison of the empirical and physical approach

As described by Laine (1984),

> *"In Finland the ratio of fall in the ground water table to the amount of water lost has been termed the ground water coefficient (Heikurainen 1963, 1967, 1971, Päivänen 1964, Heikurainen and Laine 1974). The coefficients in these studies have been determined empirically using large undisturbed peat samples and removing (or adding) a known quantity of water and measuring the corresponding fall (or rise) in the water table. The coefficients have then been attained by the formula*
>
> $$C = G/W$$
>
> *where C = ground water coefficient, G = fall or rise of the water table, and W = the amount of water causing the change in the water table (e.g. Heikurainen 1963)."*

In this study, the above procedure is referred to as the empirical approach in determining the relationship between water table and water store. The physical approach applied here involves the combined use of the energy distribution of soil water and the soil water characteristics of the different peat layers.

Ground water coefficient distributions derived by applying the empirical approach (Heikurainen 1963, Päivänen 1964, and Laine 1984) and the physical approach

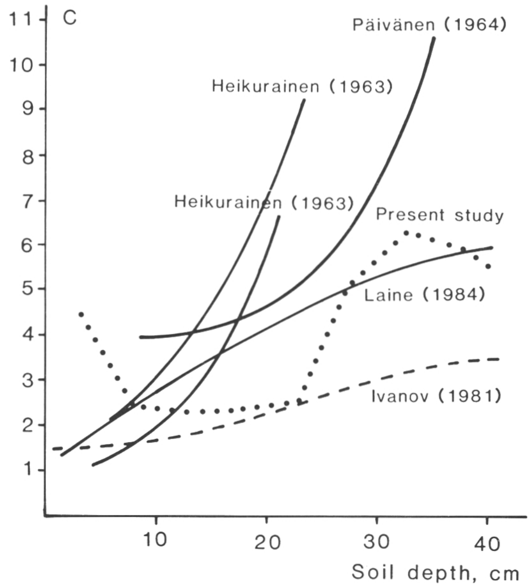


Figure 37. C-value distribution of Sphagnum peats as reported by different authors. Päivänen (1964), Laine (1984): average distribution of several profiles. Present study: based on the average profile and 5 cm shifts of the water level.

(Ivanov 1981, the present study) are compared in Figure 37.

The range of variation is large, and there is a striking variability in curve form. By using field lysimeters, Heikurainen (1963) and Päivänen (1964) arrived at values which increase exponentially with depth. Laine (1984), basing his values predominantly on laboratory lysimeters, presented distributions that are characterized by a tendency to stabilize towards greater depths. Except Päivänen (1964) and the present study, the C-value tends to approach value 1.0 in the surface peat layer.

As demonstrated in section 4234., the particular form of the C-value distribution used in this study corresponds to a set of soil water characteristic curves that easily can be constructed on the basis of Päivänen's (1973) data. Not knowing the water retention characteristics connected with the rest of the C-value distributions, it is difficult to judge, whether the differences displayed in Fig. 37 are caused by differences in peat profile, or whether other factors are involved.

The water yield coefficients published by Boelter (1964) are not comparable with the Finnish ones, because they are based on drainage to a suction of 0.1 bars and not on the equilibrium condition. Vorobyev (1963), using a laboratory method comparable with the empirical and physical approaches described above, arrived at highly different distributions of water yield coefficient for different peats. Both the curve form of Laine (1984) and the one produced by the physical approach occur in his results.

62. The assumption of energy equilibrium

During most of the period of June—September, an energy equilibrium of soil water exists in theory only. Either the water level in the observation wells is considerably higher than the theoretical equilibrium water table, thus indicating infiltration and water redistribution, or the surface peat layer is not at energy equilibrium due to capillary rise of water from the water table. Because both phenomena can be present simultaneously, the real situation was found much too complicated to simulate. First, accurate data on the current soil moisture distribution in the peat profile would have been required, and having the data, extremely laborious computations would have been involved. Hence, the simplification of the system allowed by the assumption of energy equilibrium was regarded to be necessary for the whole simulation procedure.

The question arises, whether it would have been more justified to use the water table level corrected for infiltration pressures as the basis of estimating evaporation from the water table. In this way, the wet conditions of the surface peat layer during infiltration would have been considered. Again, however, the simulation process would have become much more complicated. Because it was concluded by the author that the infiltration pressure effect is connected with the method of observation rather than the actual level of the water table, the functions used in relating evaporation and water table level could not have been used on any physical basis.

In spite of fact that energy equilibrium is a theoretical state of soil water, the moisture conditions of the profile do not deviate much from it as regards the volumetric water content, and anyhow, deviations in both directions (wet and dry) occur regularly. Accordingly, great errors should not be created by the assumption in the long term, even if errors in the daily estimates of evapotranspiration after rainfall might be considerable.

63. The validity of summertime runoff observations in small-scale field experiments

The starting point for simulating the water table instead of runoff, the more commonly used variable in this kind of models, was that the runoff data obtained from the spacing-experiment was felt to be less reliable as reference data. There are several factors that tend to decrease the accuracy in observing runoff in small basin areas:

1) Small areas are characterized by small runoff rates, and consequently, even small errors in observing the water level at the weir lead to errors of significance when converted into runoff.
2) The determination of water dividers at basin area border must be accurate to produce accurate runoff values. In the experiment at hand, determining the basin area in the case of the parcels with 100 m ditch spacing proved problematic, and an overestimation of the basin area is possible. As a consequence, this would lead to underestimation of runoff.
3) In small artificial basins which are separated from each other by ditches, and which are characterized by an even topography, the basin area might be dependent on the level of the water table (e.g. Ahti 1983).
4) The runoff peaks of small basins are shortlived, and even short periods of improper recorder function might lead to considerable underestimation of runoff. This is particularly true after dry periods with no runoff, which were frequent in the present data.
5) During periods of minimum runoff, the possibility exists that significant amounts of water evaporates from the collecting ditch or from the seepage face of the ditches. Again, this would lead to underestimation of runoff, as was also pointed out by Laine (1981).
6) Runoff that occurs in the deeper peat layers below the ditch bottoms is usually neglected because of low hydraulic conductivity. In the case of the shallow ditches of this experiment, this form of runoff probably has not been negligible, and the runoff has been underestimated.

Most of the factors mentioned above tend to lead to underestimation of runoff, and the last one (6) might even have influenced the effect of ditch depth on runoff. Correspondingly, an overestimation of water storage might have occurred.

There are some further aspects connected with the short observation period during summer, which might have an influence on the interpretation of differences in runoff between the treatments. Obviously, the ditching treatment has an influence on runoff timing, and accordingly, differences in runoff behaviour in June might be explained by observations made in early spring. The soil of drained peatlands being frequently frozen until the end of May, the observations made in early spring were excluded from the material. The same applies for late autumn.

It remains to conclude that even if the runoff data of this study was validated by applying a physical model, its validity should still be accepted with certain reservation. The relative differences in runoff between the ditching treatments can be considered more reliable, but even here, deep runoff might have disturbed the ditch depth effect.

64. Conclusions concerning the general effects of ditching

As the water table is lowered by ditching, and a new hydrological equilibrium is created, three principal changes in the original water balance are generally accepted, as confirmed by two extensive bibliographies on the hydrological influences of forestry (Kurimo & Hovi 1984, Sallantaus 1986). First, runoff in general increases, second, evaporation decreases, and third, water storage capacity increases. These phenomena occur simultaneously, and two of them, the decrease in evaporation and the increase in water storage capacity are causally related with the lowering of the water table by a physical relationship. Runoff as a hydrological variable tends to be connected with high ground water levels rather than low ones, but in the humid climate of Finland, the level of the water table seldom reaches the level of ditch bottom, and runoff continues during deep water tables as well.

In cases of substantial summer rainfall, runoff peaks are increased by ditching. Even if the maximum flows are not treated in detail in this study, it is evident on the basis of the monthly runoff totals that ditch spacing rather than ditch depth is the decisive factor (e.g. Ahti 1980, c.f. Huikari et al. 1966). This is presumably because fast flow occurs in the surface peat layers. Thus it appears that the level of the water table as influenced by ditching efficiency and tree stand does not play a decisive role in the case of runoff peaks in connection with substantial summer rainfalls (e.g. Ahti 1980, Sallantaus 1986).

The above deduction would allow the conclusion that a slow deterioration of the ditch network, or reversed, ditch cleaning, would not have significant influences on maximum summer runoff. Instead, complementary ditching through digging new ditches between the old ones would narrow the spacing and increase maximum flows.

During periods of more limited precipitation, ditch depth rather than spacing appears to be the important factor. In dry periods disconnected by normal rainfall events of 10—20 mm, runoff seems not to be prevented by the larger storage capacity created through ditching (e.g. Mustonen & Seuna 1971).

In the most extensive study on the hydrological changes caused by ditching in Finland (Mustonen & Seuna 1971, Seuna 1981), after draining 40 % of a small basin area, annual runoff was increased by 65 mm per year for the whole basin, or 163 mm as converted to correspond the drained area. According to the authors, it was difficult to judge, which of the values is closer to the actual change.

Assuming a slow long term decrease in the water store, it was further deduced that the change in annual evapotranspiration, correspondingly, had decreased by 65—163 mm.

According to the present study, the differences in runoff and evapotranspiration between the most and the least effective treatment (period June—September) were as follows:

	1967—72 (dry)	1977—81 (wet)
Runoff	24 mm	68 mm
Evapotranspiration	56 mm	65 mm

The greatest difference in runoff was observed in 1967, and the greatest difference in evapotranspiration estimate (118 mm) was obtained in 1981.

Regarding the shorter time interval, and accepting that changes in evapotranspiration logically must be created in the snowless period, the figures agree reasonably well with the ones of Mustonen & Seuna (1971). The small runoff value for 1967—72 is partly misleading, because most of the runoff in that data occurred during one summer (1967), and during the other years (1968—72), very little runoff was recorded for all ditching treatments.

Storage of water in drained peatlands is always of a temporary nature. The occurrence of periods of water storage and water loss is largely dependent on the weather, as is demonstrated by the present material. In dry years, the rate of evaporation is faster than the rate of runoff, and hence, more water is temporarily stored in the runoff-dominated drained areas during the summer. In wet years, runoff is faster than evaporation, and more water will be stored in undrained peatlands.

It has been shown by Heikurainen et al. (1978) & Seuna (1981) that with time, the hydrological changes caused by ditching will gradually be eliminated by ditch deterioration and stand development. In this material, i.e. during the first 20 years after ditching, no definite changes in that direction can be observed. As regards maximum summer runoff connected with heavy rainfall, the decline of the ditching effect was not supported by the data.

65. General applicability of the model

In this context, the simulation model was used for validating runoff observations, which were considered unreliable because of the reasons listed in section 63. By using climatical and water table input data, and by modifying the model respectively, it should be possible to estimate runoff from drained peatlands. It follows from model construction that old drainage areas with a mature tree stand are not suitable objects for application. Also, estimating runoff from undrained areas could be attempted. These possibilities, however, should first be submitted to a field test.

REFERENCES

Ahti, E. 1972. Kenttäkapasiteetti ojitettujen turvemaiden vesisuhteiden ilmentäjänä. Summary: Field capacity as an indicator of water relations in drained peatlands. Suo 23:105-109.

— 1974. Measuring seasonal moisture variation of drained peatlands by using tensiometers. Proc. Int. Symp. Forest Drainage, September 2-6, 1974. Jyväskylä-Oulu, Finland, 81—86.

— 1977. Runoff from open peatlands as influenced by ditching. I. Theoretical analysis. Seloste: Metsäojituksen vaikutus avosuon valuntaan. I. Teoreettinen analyysi. Communicationes Instituti Forestalis Fenniae 92(3). 16 p.

— 1978. Maaveden energiasuhteista ojitetulla suolla. Summary: Energy relationships of soil water on drained peat. Communicationes Instituti Forestalis Fenniae 94(3). 56 p.

— 1980. Ditch spacing experiments in estimating the effects of peatland drainage on summer runoff. The influence of man on the hydrological regime with special reference to representative and experimental basins. Proc. Helsinki Symp., June 1980, IAHS—AISH Publ. 130:49-53.

— 1983. Fertilizer-induced leaching of phosphorus and potassium from peatlands drained for forestry. Seloste: Lannoituksen vaikutus fosforin ja kaliumin huuhtoutumiseen ojitetuilta soilta. Communicationes Instituti Forestalis Fenniae 111. 20 p.

Baden, W. & Engelsmann, R. 1964. Der Wasserkreislauf eines Nordwestdeutchen Hochmoores. Eine hydrologische Studie ber den Einfluss von Entwässerung des Königsmoores b. Tostedt/Han. Summary: The hydrologic budget of a raised bog area of North Western Germany. Schr.reihe des Kuratoriums fr Kulturbauwesen 12. 156 p.

Bay, R.R. 1969. Runoff from small peatland watersheds. Journal of Hydrology 53:90—102.

Boelter, D.H. 1964. Water storage characteristics of several peats in situ. Soil Science Society of America, Proceedings 28:433—435.

Boelter, D.H. & Verry, E.S. 1977. Peatland and water in the northern Lake States. USDA For. Serv. Gen. Techn. Rep. NC-31, St Paul. 22 p.

Burke, W. 1968. Drainage of blanket peat at Glenamoy. In: Robertson, R. A. (ed.): 2nd Int. Peat Congr., Leningrad 1963, Trans. 2:809—817. Edinburgh.

Childs, E.C. 1947. The water table equipotentials and streamlines in drained land. Soil Science 63:361—376.

Conway, V.M. & Millar, A. 1960. The hydrology of some small peat covered catchments in the northern Pennines. J. Inst. Water. Engin. and Scint. 14:415—424.

de Zanger, F.A.P. 1981. Exceptional groundwater level fluctuations at the Dutch island of Shiermonnikoog. Nordic Hydrology 12:111—118.

Ekman, E. & Komonen, P. 1972. Factors affecting to porosity of peat coke. Proc. 4th Int. Peat Congr., Otaniemi, Finland, June 25-30, 1972, IV:203—212.

Hanrahan, E.T. & Rogers, N.G. 1980. Two-dimensional flow to a partially-penetrating drainage trench. Proc. 6th Int. Peat Congr., Duluth, Minnesota U.S.A., August 17—23, 1980, 570—572.

Heikurainen, L. 1963. On using ground water table fluctuations for measuring evapotranspiration. Seloste: Pohjavesipinnan vaihteluista haihdunnan mittaamisessa. Acta Forestalia Fennica 76(5). 16 p.

— 1967. Hakkuun vaikutus ojitettujen soiden vesitalouteen. Summary: On the influence of cutting on the water economy of drained peatlands. Acta Forestalia Fennica 82(2). 45 p.

— 1971. Pohjavesipinta ja sen mittaaminen ojitetuilla soilla. Summary: Ground water table in drained peat soils and its measurement. Acta Forestalia Fennica 113. 23 p.

— 1976. Comparison between runoff conditions on a virgin peatland and a forest drainage area. Proc. 5th Int. Peat Congr., Sept. 1976, Poznan, Poland, 1:76—86.

— 1980. Effect of forest drainage on high discharge. The influence of man on the hydrological regime with special reference to representative and experimental basins. Proc. Helsinki Symp., June 1980. IAHS—AISH Publ. 130:80—96.

— , & Laine, J. 1974. Estimating evapotranspiration in in peatlands on the basis of diurnal water table fluctuation. Proc. Int. Symp. Forest Drainage, September 2—6, 1974, Jyväskylä-Oulu, Finland, 87—96.

— , Kenttämies, K. & Laine, J. 1978. The environmental effects of forest drainage. Lyhennelmä: Metsäojituksen ympäristövaikutukset. Suo 29:49—58.

Huikari, O., Paarlahti, K., Paavilainen, E. & Ravela, H. 1966. Sarkaleveyden ja ojasyvyyden vaikutuksesta suon vesitalouteen ja valuntaan. Summary: On the effect of strip-width and ditch depth on water economy and runoff on peat soil. Communicationes Instituti Forestalis Fenniae 61(8). 39 p.

Hyvärinen, V. & Vehviläinen, B. 1978. The influence of forest draining on discharge in Finland. Nordic IHP Meeting Hanasaari, Finland, July-Aug. 1978. Papers of Session 3. 10 p.

Ivanov, K.E. 1981. Water movement in mirelands. Transl. from Russian by A. Thomson and B.A. Ingram. Academic Press, London-New York-Toronto Sydney-San Fransisco. 276 p.

Johansson, I. 1974. Hydrologiska undersökningar inom myrkomplekset Komosse. IHD. Swed. Natural Sci. Res. Council Rep. 4. 161 p. Stockholm.

Johansson, I. 1984. (Ed.) Nordic glossary of hydrology. Almqvist and Wiksell Int., Stockholm, Sweden. 224 p.

Kurimo, H. 1983. Surface fluctution in three virgin pine mires in Eastern Finland. Seloste: Suon pinnan korkeusvaihtelu kolmella Itä-Suomen luonnontilaisella rämeellä. Silva Fennica 17:45—64

— , & Hovi, A. 1984. Metsätaloudellisten toimenpiteiden hydrologiset ja hydrometeorologiset vaikutukset. Kirjallisuustutkimus. Summary: Hydrological and hydrometeorological effects of silvicultural treatments. National Board of Waters, Finland, Report 251. 139 p.

Laine, J. 1981. Haihdunnan määrittäminen suon pohjavedenpinnan vuorokautisen vaihtelun avulla. Unpublished manuscript, Dept. of Peatland Forestry, Univ. of Helsinki. 124 p.

— 1984. Estimation of evapotranspiration from peat-

lands by means of daily water table hydrographs. Tiivistelmä: Suon haihdunnan määrittäminen vedenpinnan vuorokautisen alenemisen avulla. Publ. Dept. Peatland Forestry, Univ. Helsinki, 5. 100 p
— , & Mannerkoski, H. 1975. Tensiometrin käyttö turvemaiden kosteusolojen kuvauksessa. Summary: On the use of tensiometers in describing moisture conditions of peat soils. Suo 26:17-24.
Luthin, J.N. & Kirkham, D. 1949. A piezometric method for measuring permeability of soil in situ below the water table. Soil Science 68:349—358.
Mustonen, S. & Seuna, P. 1971. Metsäojituksen vaikutuksesta suon hydrologiaan. Summary: Influence of forest draining on the hydrology of peatlands. Publications of the Water Research Institute, Finland, 2. 63 p.
Okruszko, H. 1977. Ecological condition of a grassland ecosystem on the Wizna fen connected with the genesis and nature of the peat deposit. Polish Ecological Studies 3:7—16.
Penman, H.L. 1948. Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London A 193:120—146.
Porter, J.W. & McMahon, T.A. 1971. A model for the simulation of streamflow from climatic records. Journal of Hydrology 13:297—324.
Päivänen, J. 1964. Menetelmä pohjavesikertoimen ja pintakasvillisuuden haihdunnan määrittämiseksi. Summary: A method to determine the ground water coefficient and the ground vegetation transpiration. Suo 15:88—91
— , 1973. Hydraulic conductivity and water retention in peat soils. Seloste: Turpeen vedenläpäisevyys ja vedenpidätyskyky. Acta Forestalia Fennica 129. 70 p.
— 1976. Effect to different types of contour ditches on the hydrology of an open bog. Proc. 5th Int. Peat Congr., Sept. 1976, Poznan, Poland, 1:93—106.
Romanov, V.V. 1968. Hydrophysics of bogs (Gidrofizika bolot). Jerusalem. (Translated, 1st published in 1961, Leningrad). 299 p.
Sallantaus, T. 1986. Soiden metsä- ja turvetalouden vesistövaikutukset — kirjallisuuskatsaus. Abstract: Impacts of peatland forestry and peat mining on watercourses — a review. Maa- ja Metsätalousministeriö, Luonnovarajulkaisuja 11. 203 p.
Seuna, P. 1981. Long-term influence of forestry drainage on the hydrology of an open bog in Finland. Publications of the Water Research Institute, Finland, 43:3—14.
Shannon, R.E. 1975. System simulation. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 387 p.
Weeks, W.D. & Hebbert, T.H.B. 1980. A comparison of rainfall-runoff models. Nordic Hydrology 11:7—24.
Virta, J. 1966. Measurement of Evapotranspiration and computation of water budget in treeless Peatlands in the natural state. Commentationes Physico-Mathematicae, Societas Scientiarum Fennica 32(11). 70 p.
Vorobyev, P.K. 1963. Investigations of water yield of low-lying swamps in Western Sibiria. Soviet Hydrology, selected papers 1963, 226—252.

Total of 48 references

SELOSTE

Ojitettujen soiden vesitaseen arvioiminen lumettomana aikana pohjavesipinnan simulointimallin avulla

Tavoite

Tutkimuksen tavoitteena oli selvittää metsäojituksen vaikutuksia valunnan ja haihdunnan suhteeseen ja toisaalta veden varastoitumiseen. Tutkimuksen keskeisenä osana on fysikaalinen malli, jolla vesitaseen osatekijöiden estimaatit varmennetaan. Toisessa vaiheessa tarkastellaan ojitustehon (sarkaleveys/ojasyvyys) ja vesitaseen välisiä yhteyksiä.

Menetelmä

Mitattuja muuttujia ovat sadanta, valunta ja pohjavesipinnan syvyys. Haihdunta arvioidaan keskeisiltä osiltaan potentiaalisen haihdunnan ja päivittäisen pohjavesipinnan syvyyden avulla. Vesivaraston muutos arvioidaan pohjavesipinnan syvyyden ja turpeen vedenpidätyskyvyn avulla. Tässä laskelmassa on oletuksena, että maavesi on energiatasapainossa.

Simulointimallilla, jossa muuttujina ovat vesitaseen osatekijät, lasketaan päivittäinen pohjavesipinnan syvyys. Alkuarvona käytetään vuotuisten aikasarjojen ensimmäistä pohjavesipintahavaintoa. Muilta osin pohjavesihavaintoja käytetään vain mallin verifiointiin.

Ojituksen vaikutuksia koskevat päätelmät pohjautuvat oletukseen, että ojitustehon kasvaessa ojituksen yleiset vaikutukset näkyvät yhä selvempinä.

Tulokset

Lasketun ja havaitun pohjavesipinnan vastaavuus oli suhteellisen hyvä vuosina 1967—72, jotka olivat vähäsateisia vuotta 1967 lukuunottamatta. Tästä pääteltiin, että haihdunnan ja vesivaraston muutoksen suuruusluokka oli arvioitu oikein. Vuosien 1977—81 suhteellisen märän jakson aikana vastaavuus oli heikompi, mutta kuitenkin useimmissa tapauksissa tyydyttävä.

Lumettoman ajan valunta oli selvästi ojitustehon tunnuksista riippuvainen. Sarkaleveyden pieneneminen lisäsi kokonaisvaluntaa ja valuntahuippuja, kun taas ojien syveneminen suurensi alivalumia.

Haihdunta käyttäytyi ojitustehon suhteen päinvastoin kuin valunta eli pieneni selvästi ojitustehon kasvaessa. Eri ojituskäsittelyiden erot olivat suurimmillaan usein 50—70 mm.

Kun tarkastellaan koko tutkimusjaksoa, koealueen vesivarasto kasvoi kesä-syyskuun aikana keskimäärin 10—40 mm ojitustehosta riippuen. Vuosivaihtelu oli kuitenkin voimakasta. Vettä varastoitui yleensä enemmän tehokkaasti ojitetuille lohkoille, mutta tässäkin suhteessa esiintyi vaihtelua.

Pohjavesikaivoista mitattu pohjavesipinnan syvyys osoittautui sateiden yhteydessä epätarkaksi vesivaraston tunnukseksi. Tutkimuksessa päädyttiin siihen, että infiltraatiotilanteessa tapahtuu veden virtausta pohjavesikaivoon turpeen pintakerroksessa, ts. pohjavesipinnan yläpuolella.

Päätelmät

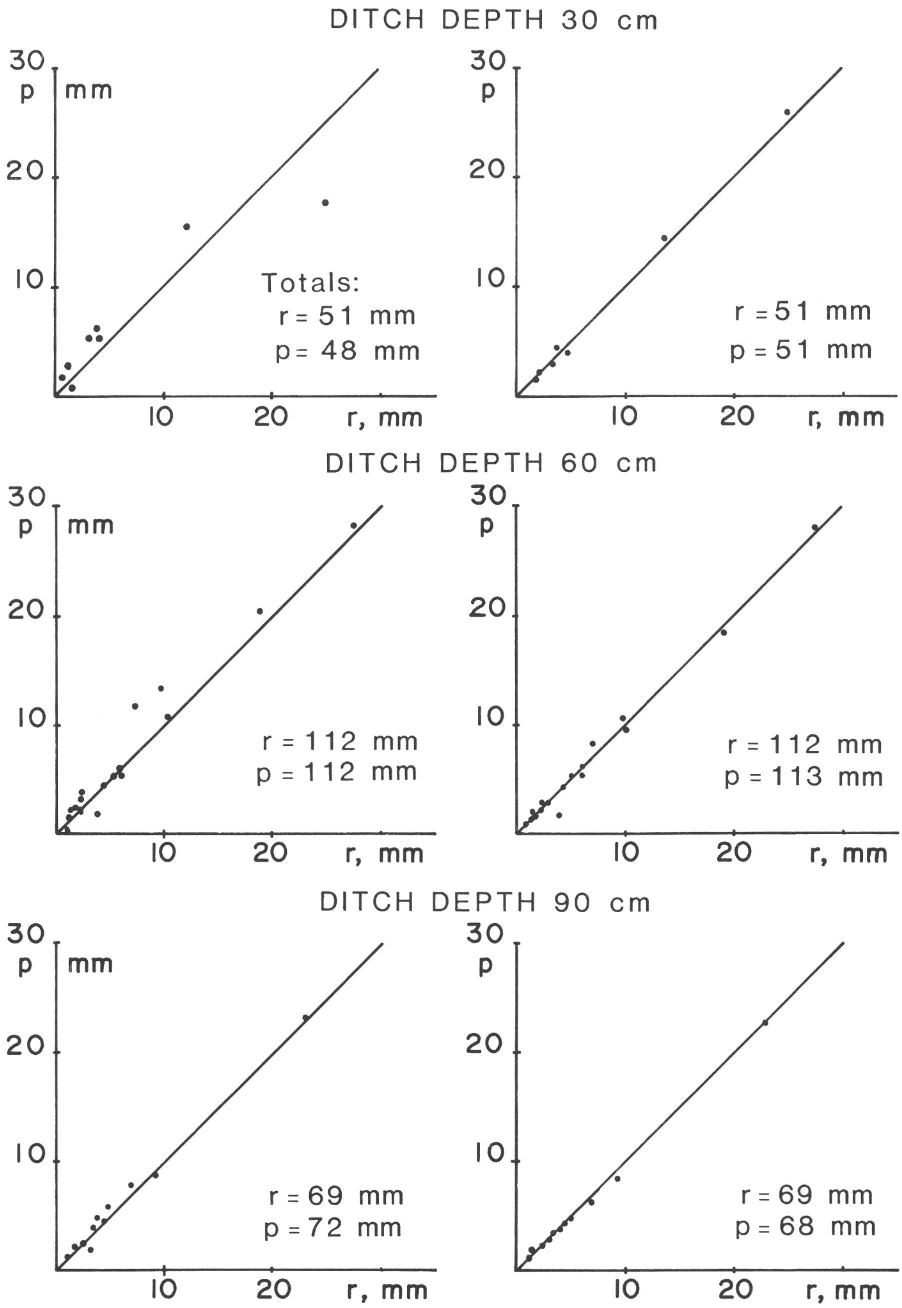
Kun ojituksella alennetaan pohjavesipintaa ja syntyy uusi hydrologinen tasapainotilanne, tapahtuu kolme yleisesti hyväksyttyä muutosta, jotka havaittiin tässäkin tutkimuksessa:

1) Valunta lisääntyy
2) Haihdunta pienenee
3) Turveprofiilin varastotila kasvaa.

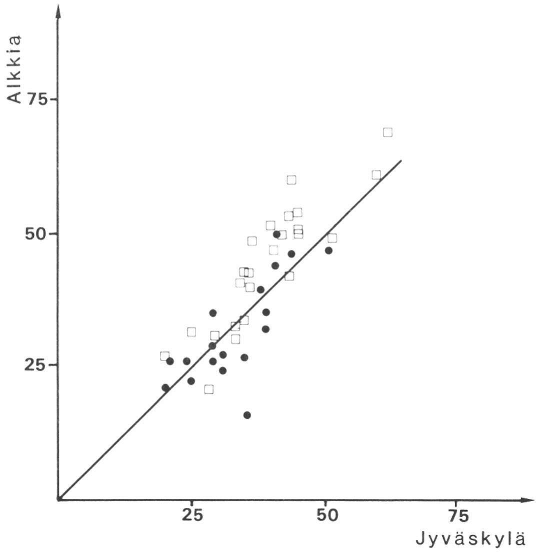
Metsäojitus suurentaa merkitsevien kesäsateiden aiheuttamia valuntahuippuja. Erityisesti sarkaleveys näyttää olevan tähän muutokseen kytkeytyvä ojitustehon tunnus. On ilmeistä, että ojituksen aiheuttama suon varastotilan kasvu ja puuston kehittyminen eivät oleellisesti vaikuta voimakkaiden kesäsateiden aiheuttamiin valuntahuippuihin. Sama koskee ojasyvyyttä. Nämä päätelmät viittaavat siihen, että ojien mataloitumisella ja ojanperkauksella ei ole suurta vaikutusta kesän ylivalumiin. Sen sijaan täydennysojituksella, jolla vaikutetaan sarkaleveyteen, voisi tässä mielessä olla vaikutusta.

Vähäsateisten jaksojen aikana ojasyvyydellä on selvä vaikutus valuntaan. Metsäojitus näyttää lisäävän alivalumia silloin, kun ojasto on riittävän syvä. Jos ojasyvyys on pieni, metsäojituksen vaikutus alivalumiin saattaa olla jopa päinvastainen.

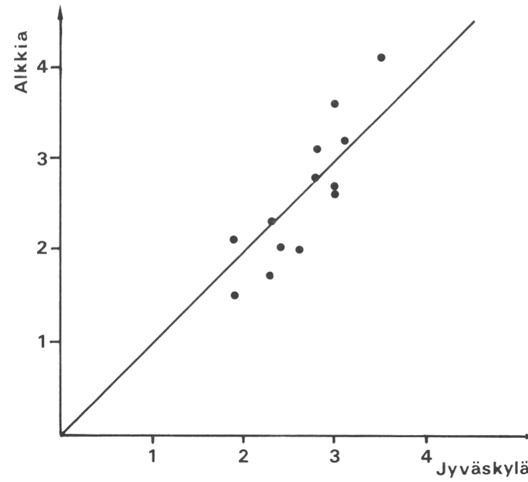
AHTI, E. 1987. Water balance of drained peatlands on the basis of water table simulation during the snowless period. Seloste: Ojitettujen soiden vesitaseen arvioiminen lumettomana aikana pohjavesipinnan simulointimallin avulla. Communicationes Instituti Forestalis Fenniae 141. 64 p.



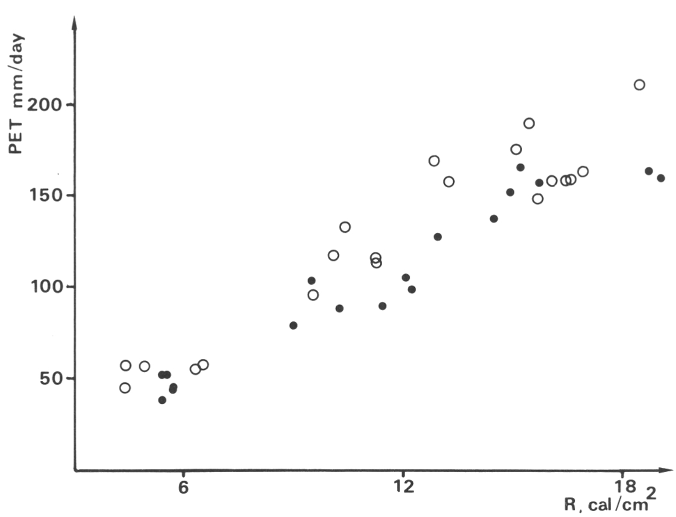
Appendix 1. Comparison of recorder data (r) and point observations (p) as a basis for weekly runoff estimates. Alkkia May 5 th—October 19th 1980. Ditch spacing 20 m. Diagrams to the left: 3 point observations/week, diagrams to the righ 7 point observations per week.



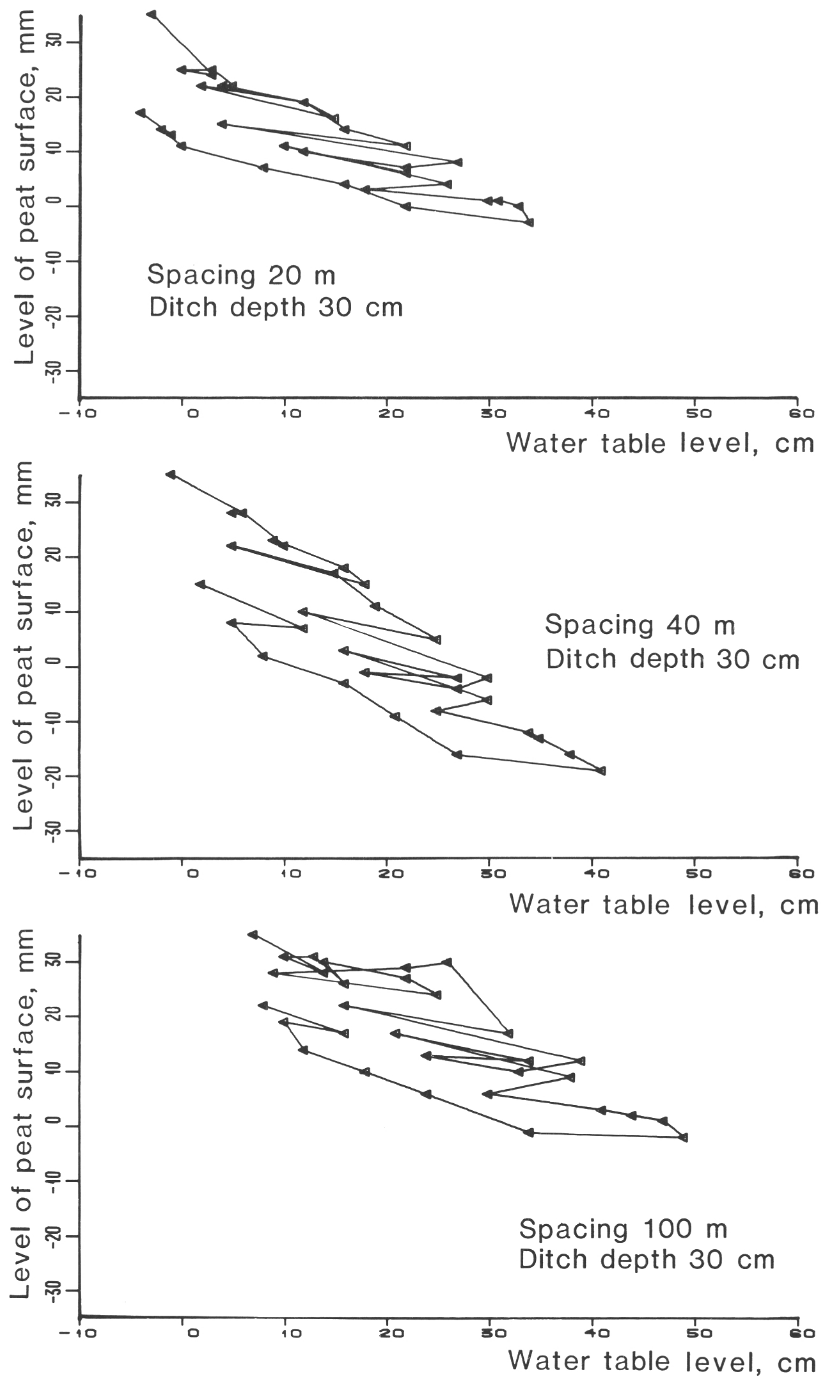
Appendix 2. Percentage of clear scy as estimated in Alkkia and by the Jyväskylä weather station of the Finnish Meteorological Institute. Monthly averages.



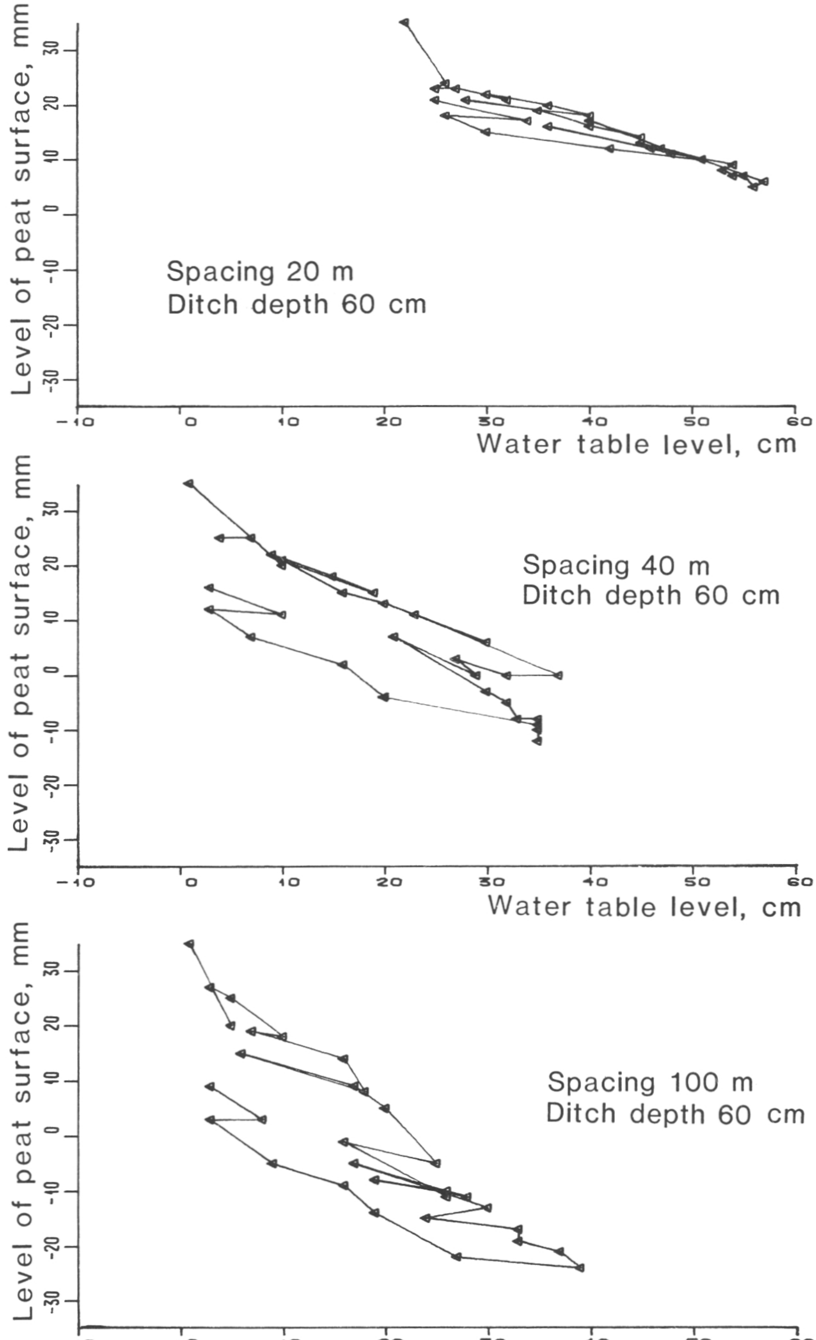
Appendix 4. Average wind velocity as estimated in Alkkia 1979—81 and measured in Jyväskylä. Monthly values.



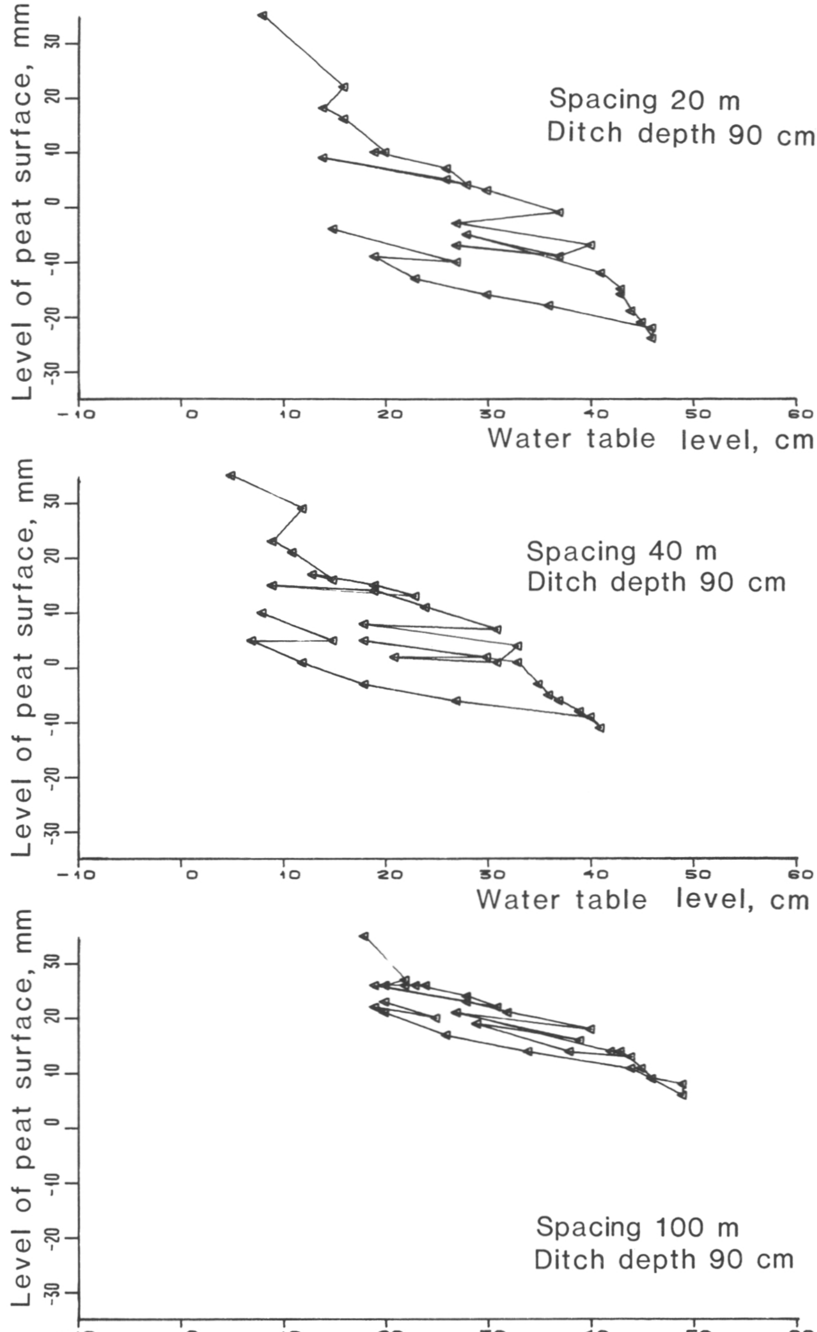
Appendix 3. Monthly potential evapotranspiration (PET) as estimated in Alkkia and correlated with values of total radiation (R) measured in Jyväskylä.



Appendix 5. The height variation of soil surface connected with the drying-rewetting cycle. 1983.



Appendix 6. The height variation of soil surface connected with the drying-rewetting cycle. 1983.



Appendix 7. The height variation of soil surface connected with the drying-rewetting cycle. 1983.

Appendix 8. Model output for June (mm).

Spacing 20 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	42.70	2.61	66.87	9.90	−36.68
68	49.40	0.00	46.49	10.41	−7.49
69	16.00	0.50	60.62	2.43	−47.55
70	4.00	0.00	70.18	2.94	−69.12
71	22.70	0.00	56.44	11.21	−44.95
72	25.70	3.90	81.62	4.10	−63.92
77	28.80	2.74	82.40	6.61	−62.96
78	55.40	1.30	43.80	10.08	0.22
79	41.80	0.58	56.24	4.66	−19.67
80	41.90	1.54	68.44	8.98	−37.05
81	96.80	19.24	62.58	3.39	11.59

Spacing 20 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	42.70	16.56	43.34	13.73	−30.94
68	49.40	1.84	46.26	11.06	−9.76
69	18.40	4.71	46.64	4.32	−37.27
70	4.00	0.49	60.54	3.49	−60.52
71	22.70	2.21	45.84	12.15	−37.50
72	22.40	10.34	48.36	7.69	−43.99
77	28.80	11.08	52.98	10.47	−45.73
78	55.40	10.00	34.13	13.70	−2.42
79	41.80	22.89	42.99	6.24	−30.32
80	41.90	22.83	43.87	11.89	−36.69
81	96.80	62.89	41.09	13.11	−20.30

Spacing 20 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	42.70	7.01	48.45	12.59	−25.35
68	49.40	0.00	49.84	10.73	−11.17
69	18.40	2.02	51.33	3.81	−38.76
70	4.00	0.08	65.21	3.26	−64.55
71	22.70	0.00	47.65	11.87	−36.82
72	22.40	10.18	43.74	8.42	−39.93
77	28.80	7.55	54.07	10.41	−43.23
78	55.40	4.69	34.38	13.70	2.63
79	41.80	9.72	47.11	5.87	−20.89
80	41.90	9.11	52.13	10.78	−30.12
81	96.80	46.06	42.55	12.64	−4.45

Spacing 40 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	42.70	1.39	91.66	4.81	−55.17
68	49.40	0.00	49.29	10.16	−10.05
69	16.00	0.27	66.13	1.96	−52.36
70	4.00	0.00	76.02	2.65	−74.67
71	22.70	0.00	56.16	11.27	−44.72
72	25.70	2.61	86.50	3.38	−66.79
77	28.80	1.53	92.22	4.39	−69.35
78	55.40	1.07	46.82	8.84	−1.32
79	41.80	0.00	59.30	4.21	−21.71
80	41.90	4.76	81.56	6.65	−51.07
81	96.80	31.30	66.26	1.25	−2.01

Spacing 40 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	42.70	3.31	68.02	8.96	−37.59
68	49.40	0.82	57.55	10.11	−19.08
69	18.40	2.68	62.90	2.31	−49.49
70	4.00	0.11	76.63	2.51	−75.25
71	22.70	0.40	61.72	8.95	−48.37
72	22.40	6.68	85.82	3.35	−73.45
77	28.80	7.53	80.20	6.87	−65.80
78	55.40	7.06	43.93	9.82	−5.40
79	41.80	10.38	54.67	4.56	−27.81
80	41.90	10.61	64.01	9.54	−42.26
81	96.80	42.03	61.05	3.62	−9.91

Spacing 40 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	42.70	9.73	58.96	10.69	−36.68
68	49.40	2.29	58.80	10.36	−22.04
69	18.40	3.22	60.35	2.56	−47.74
70	4.00	0.00	73.45	2.63	−72.08
71	22.70	0.00	60.32	9.24	−46.86
72	22.40	14.74	73.20	4.92	−70.47
77	28.80	7.57	77.21	7.18	−63.16
78	55.40	5.29	44.50	9.59	−3.98
79	41.80	5.88	56.32	4.40	−24.80
80	41.90	8.61	63.96	9.56	−40.24
81	96.80	36.94	61.01	3.82	−4.97

Spacing 100 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	42.70	1.62	99.17	2.75	−60.84
68	49.40	0.00	59.44	8.98	−19.02
69	16.00	0.00	94.04	0.99	−79.04
70	4.00	0.00	97.57	2.05	−95.61
71	22.70	0.00	68.03	9.07	−54.40
72	25.70	2.37	94.06	2.18	−72.91
77	28.80	0.75	98.32	2.57	−72.84
78	55.40	0.00	62.62	2.78	−10.01
79	41.80	0.00	75.77	2.19	−36.16
80	41.90	1.20	83.35	6.42	−49.07
81	96.80	13.45	68.04	0.06	15.25

Spacing 100 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	42.70	7.10	93.18	4.72	−62.30
68	49.40	0.59	57.07	9.28	−17.54
69	16.00	0.94	90.34	1.02	−76.31
70	4.00	0.00	99.31	1.92	−97.23
71	22.70	0.00	78.98	7.20	−63.47
72	25.70	13.66	90.79	2.81	−81.56
77	28.80	3.23	95.21	3.55	−73.18
78	55.40	2.67	61.75	3.13	−12.15
79	41.80	3.43	75.38	2.29	−39.30
80	41.90	4.79	79.94	7.35	−50.18
81	96.80	14.93	67.94	0.16	13.77

Spacing 100 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	42.70	9.72	83.14	6.08	−56.24
68	49.40	1.69	72.79	9.02	−34.10
69	18.40	2.25	78.13	1.41	−63.39
70	4.00	0.00	89.11	2.22	−87.33
71	22.70	0.00	60.53	9.25	−47.08
72	22.40	9.85	86.33	3.37	−77.16
78	55.40	3.66	45.51	9.23	−3.00
79	41.80	2.65	58.75	4.17	−23.77
80	41.90	7.50	70.08	8.77	−44.45
81	96.80	17.61	57.47	6.34	15.38

Appendix 9. Model output for July (mm).

Spacing 20 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	30.50	0.00	47.16	7.85	−24.51
68	29.50	0.00	45.82	7.33	−23.65
69	43.80	0.00	41.94	14.02	−12.16
70	77.50	0.00	34.40	18.80	24.30
71	31.20	0.00	45.36	12.59	−26.75
72	60.60	0.00	60.26	10.04	−9.69
77	126.10	18.68	47.38	13.80	46.24
78	35.30	1.06	43.80	9.25	−18.81
79	144.30	31.46	38.67	15.47	58.70
80	22.20	0.00	44.60	7.14	−29.53
81	78.30	18.81	72.87	5.71	−19.09

Spacing 20 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	30.50	0.00	40.31	8.08	−17.89
68	29.50	2.88	40.42	7.74	−21.55
69	43.80	0.00	37.29	14.54	−8.03
70	77.50	0.00	31.94	19.38	26.18
71	31.20	0.00	42.48	12.58	−23.86
72	60.60	6.66	43.27	12.94	−2.27
77	126.10	21.84	36.13	17.79	50.34
78	35.30	5.79	36.00	10.87	−17.36
79	144.30	76.36	26.78	21.54	19.62
80	22.20	0.34	36.19	7.72	−22.06
81	78.30	40.87	35.91	16.25	−14.73

Spacing 20 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	30.50	0.00	44.17	7.93	−21.59
68	29.50	0.00	43.38	7.51	−21.39
69	43.80	0.00	39.92	14.27	−10.39
70	77.50	0.00	33.77	18.95	24.79
71	31.20	0.00	44.36	12.57	−25.73
72	60.60	9.54	41.20	13.24	−3.38
77	126.10	15.93	38.12	17.13	54.92
78	35.30	3.41	37.34	10.61	−16.06
79	144.30	42.29	33.18	18.56	50.27
80	22.20	0.37	39.73	7.43	−25.33
81	78.30	29.47	42.06	14.49	−7.71

Spacing 40 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	30.50	0.00	55.65	7.30	−32.45
68	29.50	0.00	47.59	7.18	−25.27
69	43.80	0.00	43.72	13.72	−13.64
70	77.50	0.00	36.02	18.38	23.11
71	31.20	0.00	46.73	12.53	−28.07
72	60.60	1.21	63.09	9.34	−13.04
77	126.10	15.11	54.20	11.14	45.65
78	35.30	0.42	46.06	8.78	−19.96
79	144.30	25.93	41.47	13.70	63.21
80	22.20	0.00	49.48	6.80	−34.08
81	78.30	21.19	78.56	3.47	−24.92

Spacing 40 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	30.50	0.00	47.92	7.81	−25.23
68	29.50	0.47	46.45	7.25	−24.66
69	43.80	0.00	42.01	14.01	−12.21
70	77.50	0.00	35.31	18.56	23.63
71	31.20	0.00	47.37	12.53	−28.70
72	60.60	3.61	60.92	9.71	−13.64
77	126.10	18.68	45.57	14.26	47.59
78	35.30	4.59	41.68	9.64	−20.61
79	144.30	59.82	32.33	18.85	33.30
80	22.20	0.22	42.17	7.27	−27.45
81	78.30	35.99	59.38	9.61	−26.68

Spacing 40 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	30.50	0.11	45.43	7.93	−22.97
68	29.50	2.43	45.38	7.36	−25.68
69	43.80	0.00	41.55	14.06	−11.82
70	77.50	0.00	34.84	18.67	24.00
71	31.20	0.00	47.08	12.50	−28.38
72	60.60	11.00	49.30	11.92	−11.62
77	126.10	19.44	44.02	14.82	47.81
78	35.30	4.50	42.08	9.54	−20.83
79	144.30	48.81	35.46	17.24	42.79
80	22.20	0.23	42.04	7.27	−27.35
81	78.30	21.42	60.97	9.13	−13.23

Spacing 100 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	30.50	0.00	61.22	6.88	−37.60
68	29.50	0.00	52.27	6.77	−29.55
69	43.80	0.00	50.04	12.25	−18.49
70	77.50	0.00	38.54	17.65	21.31
71	31.20	0.00	48.55	12.43	−29.78
72	60.60	0.00	69.25	7.99	−16.64
77	126.10	10.50	61.44	7.84	46.32
78	35.30	0.00	60.62	5.28	−30.60
79	144.30	14.00	50.26	8.72	71.32
80	22.20	0.00	50.64	6.70	−35.14
81	78.30	8.15	87.29	0.25	−17.39

Spacing 100 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	30.50	0.00	54.48	7.36	−31.35
68	29.50	0.50	50.78	6.89	−28.67
69	43.80	0.00	48.15	12.69	−17.04
70	77.50	0.00	38.51	17.65	21.34
71	31.20	0.00	49.73	12.39	−30.92
72	60.60	2.73	63.96	9.08	−15.17
77	126.10	12.03	56.35	9.93	47.78
78	35.30	2.59	57.00	6.20	−30.49
79	144.30	25.36	47.91	10.17	60.87
80	22.20	0.09	47.61	6.97	−32.46
81	78.30	10.80	86.75	0.46	−19.71

Spacing 100 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	30.50	0.69	52.02	7.53	−29.73
68	29.50	2.08	51.14	6.89	−30.60
69	43.80	0.00	45.24	13.42	−14.86
70	77.50	0.00	37.48	17.95	22.07
71	31.20	0.00	48.15	12.45	−29.40
72	60.60	3.03	61.01	9.78	−13.22
78	35.30	2.25	44.32	9.12	−20.39
79	144.30	24.61	41.07	13.96	64.65
80	22.20	0.26	44.59	7.13	−29.78
81	78.30	17.23	62.08	8.89	−9.89

Appendix 10. Model output for August (mm).

Spacing 20 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	144.30	37.54	27.39	4.64	74.73
68	68.00	0.37	26.47	6.93	34.22
69	43.90	0.00	30.81	2.34	10.75
70	27.10	0.00	27.19	3.13	−3.22
71	91.70	0.00	25.48	8.73	57.50
72	100.80	7.44	28.73	7.32	57.31
77	28.10	0.09	42.39	3.65	−18.04
78	68.80	4.34	27.28	9.88	27.29
79	68.40	3.41	42.87	2.67	19.45
80	108.70	0.00	29.10	7.79	71.82
81	113.00	34.90	27.12	4.03	46.95

Spacing 20 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	144.30	57.78	19.19	6.88	60.45
68	68.00	3.84	22.59	6.86	34.71
69	43.90	0.00	27.62	2.30	13.98
70	27.10	0.00	25.42	3.08	−1.40
71	91.70	2.91	23.99	8.59	56.20
72	100.80	13.18	23.68	8.17	55.77
77	28.10	8.11	29.04	7.39	−16.44
78	68.80	7.79	24.63	9.79	26.59
79	68.40	23.33	21.42	7.67	15.98
80	108.70	6.59	20.06	9.22	72.84
81	113.00	31.76	16.04	6.02	59.17

Spacing 20 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	144.30	41.91	24.59	5.81	71.99
68	68.00	0.00	24.74	6.93	36.33
69	43.90	0.00	29.69	2.30	11.91
70	27.10	0.00	26.74	3.08	−2.72
71	91.70	0.00	24.88	8.59	58.23
72	100.80	11.44	21.68	8.40	59.28
77	28.10	5.95	32.75	6.36	−16.97
78	68.80	2.81	25.67	9.79	30.53
79	68.40	13.70	36.80	4.76	13.14
80	108.70	2.68	23.74	8.96	73.32
81	113.00	37.00	18.85	5.89	51.26

Spacing 40 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	144.30	30.30	30.02	3.67	80.31
68	68.00	0.00	27.34	6.93	33.73
69	43.90	0.00	32.52	2.34	9.03
70	27.10	0.00	28.36	3.13	−4.40
71	91.70	0.00	25.87	8.73	57.11
72	100.80	5.97	29.30	7.29	58.25
77	28.10	0.12	45.79	2.70	−20.51
78	68.80	3.46	28.04	9.84	27.47
79	68.40	6.77	43.48	2.43	15.72
80	108.70	0.06	31.21	7.03	70.40
81	113.00	42.96	29.97	3.34	36.74

Spacing 40 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	144.30	25.04	29.33	3.74	86.18
68	68.00	0.70	27.72	7.22	32.36
69	43.90	0.00	30.86	2.34	10.70
70	27.10	0.00	27.86	3.13	−3.89
71	91.70	0.11	26.63	8.73	56.24
72	100.80	6.09	28.71	7.28	58.72
77	28.10	3.26	40.72	4.07	−19.95
78	68.80	6.79	26.48	9.79	25.74
79	68.40	20.16	31.35	6.22	10.68
80	108.70	3.57	26.80	8.36	69.98
81	113.00	57.84	20.59	5.59	28.98

Spacing 40 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	144.30	10.78	29.16	3.71	100.65
68	68.00	2.73	25.86	6.86	32.55
69	43.90	0.00	30.65	2.30	10.95
70	27.10	0.00	27.50	3.08	−3.48
71	91.70	0.22	26.44	8.59	56.45
72	100.80	11.92	26.52	7.61	54.75
77	28.10	4.41	39.36	4.39	−20.07
78	68.80	5.62	26.59	9.79	26.80
79	68.40	13.59	38.04	4.42	12.36
80	108.70	2.18	27.34	8.21	70.97
81	113.00	42.72	22.96	4.88	42.44

Spacing 100 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	144.30	27.17	32.14	2.72	82.27
68	68.00	0.00	28.89	6.86	32.25
69	43.90	0.00	34.93	2.30	6.67
70	27.10	0.00	30.17	3.08	−6.15
71	91.70	0.00	27.00	8.59	56.11
72	100.80	4.68	30.34	7.06	58.71
77	28.10	0.13	49.18	1.56	−22.77
78	68.80	0.65	31.40	9.28	27.47
79	68.40	3.80	48.52	0.21	15.87
80	108.70	0.00	31.80	6.79	70.11
81	113.00	13.10	38.73	0.58	60.59

Spacing 100 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	144.30	23.07	31.26	3.02	86.95
68	68.00	1.13	28.29	6.86	31.73
69	43.90	0.00	34.13	2.30	7.48
70	27.10	0.00	30.14	3.08	−6.12
71	91.70	0.00	28.24	8.59	54.87
72	100.80	4.49	29.36	7.13	59.82
77	28.10	2.16	47.30	2.29	−23.65
78	68.80	3.66	29.86	9.54	25.75
79	68.40	7.76	47.84	0.56	12.24
80	108.70	2.24	30.60	7.23	68.62
81	113.00	25.44	37.36	0.97	49.22

Spacing 100 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	144.30	17.99	30.81	3.20	92.31
68	68.00	2.09	28.18	6.86	30.88
69	43.90	0.00	33.14	2.30	8.47
70	27.10	0.00	29.42	3.08	−5.40
71	91.70	0.00	26.83	8.59	56.28
72	100.80	6.95	28.88	7.29	57.68
78	68.80	4.22	27.48	9.88	27.21
79	68.40	11.14	44.26	2.13	10.87
80	108.70	3.43	28.40	8.03	68.84
81	113.00	26.82	23.89	4.66	57.63

Appendix 11. Model output for September (mm).

Spacing 20 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	67.90	45.43	17.26	0.87	4.34
68	49.50	5.71	11.24	0.62	31.93
69	88.30	0.00	9.39	1.80	77.11
70	57.70	0.00	9.20	1.06	47.45
71	53.90	1.70	11.12	1.74	39.35
72	47.40	10.25	17.05	0.76	19.34
77	74.30	10.41	23.86	3.33	36.70
78	89.70	34.91	15.11	2.81	36.87
79	99.80	32.77	24.27	0.37	42.39
80	39.80	0.17	18.36	0.82	20.45
81	29.00	5.75	14.36	0.23	8.66

Spacing 20 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	67.90	68.66	11.24	1.74	−13.74
68	49.50	13.38	8.47	0.60	27.05
69	88.30	1.54	8.27	1.75	76.75
70	57.70	2.10	8.35	1.03	46.22
71	53.90	8.01	9.30	1.69	34.89
72	47.40	14.85	12.90	1.37	18.28
77	74.30	12.07	19.03	4.44	38.75
78	89.70	33.67	13.48	3.11	39.44
79	99.80	36.20	17.30	2.49	43.81
80	39.80	6.93	14.68	1.77	16.42
81	29.00	24.82	8.07	0.88	−4.78

Spacing 20 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	67.90	60.68	15.43	1.24	−9.44
68	49.50	6.82	10.27	0.62	31.79
69	88.30	0.00	8.78	1.75	77.77
70	57.70	0.00	8.85	1.03	47.82
71	53.90	4.23	10.25	1.69	37.72
72	47.40	12.80	11.42	1.34	21.84
77	74.30	10.54	20.61	4.11	39.04
78	90.00	26.36	14.75	2.84	46.05
79	99.80	34.98	22.93	0.95	40.94
80	39.80	3.08	17.17	1.26	18.29
81	29.00	13.09	11.04	0.83	4.04

Spacing 40 m, ditch depth 30 cm

Year	P	q	E	Int	Store
67	67.90	55.62	18.30	0.52	−6.55
68	49.50	2.31	11.60	0.60	34.99
69	88.30	0.00	9.71	1.80	76.79
70	57.70	0.00	9.58	1.06	47.07
71	53.90	0.00	10.85	1.74	41.32
72	47.40	8.68	17.22	0.71	20.79
77	74.30	10.21	25.51	2.73	35.84
78	89.70	34.21	15.62	2.48	37.39
79	99.80	44.39	24.22	0.40	30.79
80	39.80	1.16	18.62	0.70	19.32
81	29.00	10.77	14.03	0.30	3.90

Spacing 40 m, ditch depth 60 cm

Year	P	q	E	Int	Store
67	67.90	41.10	19.04	0.43	7.33
68	49.50	5.23	10.31	0.60	33.36
69	88.30	0.98	9.45	1.80	76.07
70	57.70	0.00	9.68	1.06	46.96
71	53.90	4.97	12.59	1.74	34.61
72	47.40	9.39	17.19	0.73	20.09
77	74.30	10.50	23.11	3.40	37.29
78	89.70	44.97	14.34	3.04	27.36
79	99.80	43.61	21.12	1.82	33.26
80	39.80	4.11	17.82	1.04	16.83
81	29.00	12.94	10.16	0.88	5.01

Spacing 40 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	67.90	45.06	19.88	0.13	2.83
68	49.50	9.60	10.79	0.60	28.50
69	88.30	1.12	9.34	1.75	76.09
70	57.70	0.00	9.47	1.03	47.20
71	53.90	3.37	12.58	1.69	36.26
72	47.40	13.84	15.54	1.21	16.81
77	74.30	12.33	22.57	3.54	35.86
78	89.70	34.58	15.28	2.60	37.24
79	99.80	38.36	23.27	0.74	37.43
80	39.80	4.38	18.10	0.93	16.39
81	29.00	10.89	13.36	0.49	4.26

Spacing 100 m, ditch depth 30 cm

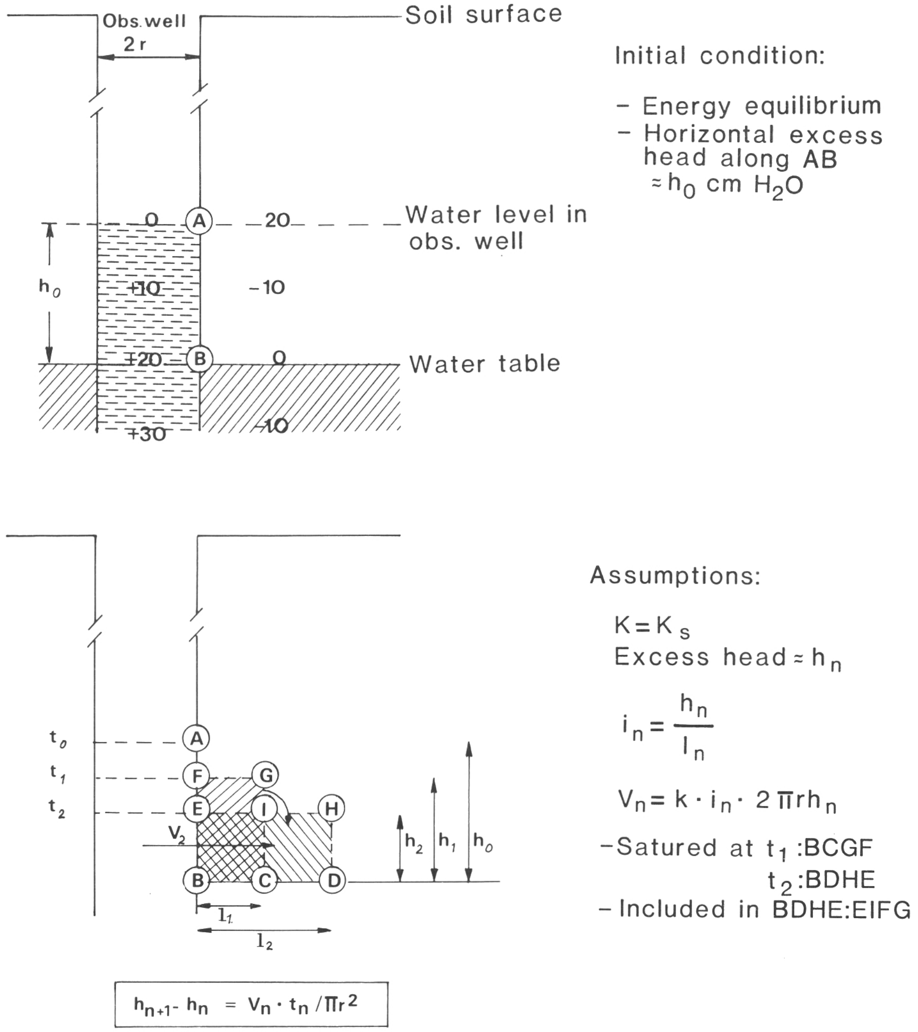
Year	P	q	E	Int	Store
67	67.90	49.23	19.75	0.14	−1.23
68	49.50	1.43	12.33	0.51	35.23
69	88.30	0.00	11.06	1.74	75.50
70	57.70	0.00	11.04	1.03	45.63
71	53.90	0.00	12.51	1.69	39.70
72	28.30	0.83	13.85	0.51	13.11
77	74.30	5.58	27.94	1.26	39.52
78	89.70	25.87	17.55	1.12	45.16
79	99.80	20.57	25.26	0.01	53.96
80	39.80	0.00	19.24	0.44	20.12
81	29.00	6.95	15.20	0.00	6.85

Spacing 100 m, ditch depth 60 cm

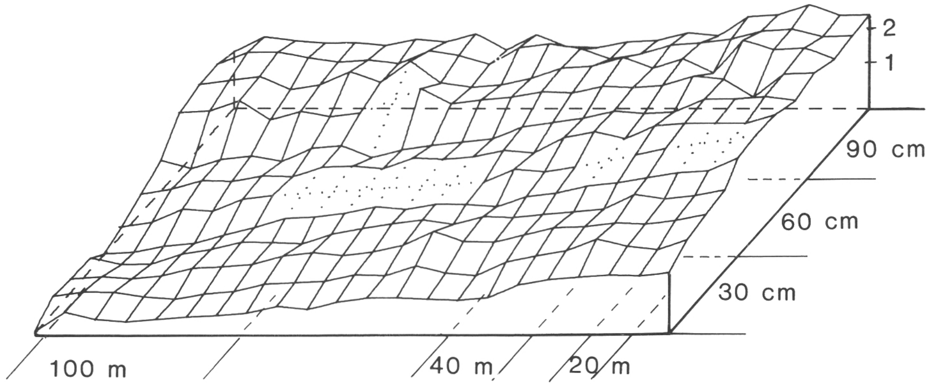
Year	P	q	E	Int	Store
67	67.90	35.47	19.96	0.13	12.34
68	49.50	3.23	12.11	0.53	33.63
69	88.30	0.00	10.85	1.74	75.71
70	57.70	0.00	11.22	1.03	45.45
71	53.90	0.00	14.08	1.68	38.14
72	28.30	4.00	12.93	0.54	10.83
77	74.30	6.14	26.58	2.06	39.52
78	89.70	20.01	17.32	1.29	51.08
79	99.80	25.34	25.14	0.07	49.25
80	39.80	3.14	18.82	0.62	17.21
81	29.00	4.17	15.20	0.00	9.63

Spacing 100 m, ditch depth 90 cm

Year	P	q	E	Int	Store
67	67.90	43.54	19.91	0.13	4.32
68	49.50	6.05	11.86	0.57	31.02
69	88.30	2.21	10.24	1.75	74.10
70	57.70	0.00	10.46	1.03	46.21
71	53.90	0.00	12.51	1.69	39.69
72	47.40	9.80	17.16	0.74	19.70
78	89.70	30.16	15.66	2.40	41.47
79	99.80	37.46	24.62	0.23	37.49
80	39.80	3.54	18.14	0.92	17.21
81	29.00	8.76	14.55	0.19	5.50



Appendix 12. Simulation of lateral flow of water from an observation well into the profile after water addition.



Appendix 13. A schematic levelling map on the experimental area. Levelling in 1983. Height scale on the vertical axis in meters.

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