SILVA FENNICA 1984, vol. 18 n:o 2: 151–186

SIMULTANEOUS GROUNDWATER TABLE FLUCTUATION IN DIFFERENT PARTS OF VIRGIN PINE MIRES

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SELOSTE

POHJAVESIPINNAN SAMANAIKAINEN KORKEUSVAIHTELU LUONNONTILAISTEN RÄMEIDEN ERI OSISSA

Saapunut toimitukselle 27. 3. 1984

The study discusses the amplitude of the simultaneous groundwater table fluctuation in different parts of pine mires, and factors influencing it. The assumption generally used in hydrological calculations that fluctuation in the groundwater table takes place simultaneously and almost equally inside the whole mire does not hold good in detail. The amplitude of fluctuation was dependent on numerous factors which differ slightly at various sites. If these factors or combinations of them deviated sufficiently, they were responsible for the inequality in the fluctuation between the sites. Despite the possible statistical significance indicating inequality in the fluctuation, the relative differences in altitude between the sites remained small (a few centimetres only).

1. INTRODUCTION

The altitude of the groundwater table generally follows the areal terrain topography the more closely, the smaller the hydraulic conductivity of the soil. If the soil cover is homogeneous, then the altitude position of the groundwater table is, in general, higher in places which represent positive terrain forms (such as hills and ridges) compared to negative forms (such as basins). The same phenomenon has also been noticed when studying virgin peatlands (e.g. Päivänen 1968); in drained mires the relative altitude of the groundwater table is always higher in areas between the open ditches than in areas near to them (see e.g. Huikari 1960, Heikurainen 1971, Ahti 1977, 1978, 1980, Braekke 1983: 188).

Although the altitude position of the groundwater table at places representing higher terrain is naturally higher in absolute terms compared with that in lower land, it lies nearer the soil surface in the latter case, however. The basins, and generally also all the concave terrain forms, represent 'wet' places. The positive terrain forms (hills, ridges) are 'dry' sites with respect to the distance to the groundwater table. Mire surfaces are also composed of basins, hummocks and ridges, although on a microscale.

On the other hand, the general assumption used in computations dealing with mire hydrology is that the fluctuation in the groundwater table is simultaneous and almost egual in different parts even of the same mire (cf. e.g. Ivanov 1957:216; 1981:198–203, Päivänen 1968:20). Virta (1966:36–38, 1967:70, 74) has presented some expressions for this argument as regards precipitation.

The purpose of this study is to test whether the assumption presented above holds good in practice. Testing is carried out by analysing (1) the range of the simultaneous groundwater table fluctuation in different parts of the mire, (2) fitting the fluctuation in the relative groundwater table altitude at one place to that at another place, (3) regularities occurring in the simultaneous groundwater table fluctuation (cf. Ivanov 1981), and (4) the factors affecting the possible variation in the simultaneous groundwater table fluctuation.

The present study was carried out with the co-operation of the local branch of the National Board of Waters (Pohjois-Karjalan vesipiiri), supported by the Finnish Academy. My thanks are especially due to Mrs. M. Ahtiainen, M.Sc. who arranged the observation net necessary for the study. The field material was collected with the assistance of Mr. A. Latja, Mr. J. Riihelä and Mr. M. Korhonen, M.Sc. Valuable comments on the manuscript were given by Dr. J. Päivänen, data processing was performed at the University of Joensuu, most of the figures were drawn by Mrs. Sirkka Nissinen, and the English language was checked by Mr. J. Derome, M.Sc. The author wishes to thank the above persons as well as all the others who have contributed to the completion of the paper.

2. METHODS

The set-up for the experiment was as follows (Fig. 2): Groundwater pipe lines, each comprising 8 pipes, were constructed in two different pine mires. The lines were 33–43 metres long, the pipes being situated at a distance of 3 to 7.5 metres apart. Most of the pipes (each 2.5–3 cm in diameter)were strong plastic tubes with holes drilled in the part of the pipe lying under the mire surface; some perforated iron tubes were also used. The pipes were pushed down into the mineral soil lying under the peat deposit by a pile driver so as to ensure that they could not move during the observation period. The pipes were rinsed by pressure water before starting the measurements. The pipes were checked in order to ensure that they functioned well. The study was carried out over a period of about two months in summer 1982. The distance to the groundwater table (accuracy 0.5 cm), as well as the relative altitude of the mire surface (accuracy 0.1 cm; for details, see Kurimo 1983), was measured approximately every second day. The diurnal throughfall was also measured at five points near the lines. Precipitation was registered automatically by one of the five rain gauges erected in each mire.

Simultaneous groundwater table fluctuations at the points where the different pipes were situated were also analyzed in corrected terms so as to take the effect of the vertical surface altitude fluctuation into account (for detailed description see Kurimo 1983). The relative altitude position of the mire surface was measured simultaneously with that of the groundwater table.

Bulk density (fresh volume basis) of the topmost (0–9 cm), and the underlying (10–29 cm) peat horizons were determined from undisturbed peat samples taken practically simultaneously at points 0.5–1 metres apart from the pipe sites, two series from each mire. The bulk density analyses were performed by the local branch of the National Board of Waters (Water Districts Office of North Karelia) according to the spirit method generally in use (see Andersson 1968; cf. Päivänen 1969).

The data was analysed by means of correlation and regression techniques, comparison of diagrammes, and statistical tests consistent with the data. Data processing was done on the computers available at the University of Joensuu.

3. STUDY AREA

The pipe lines lie on two different virgin pine mires in southern Sotkamo, eastern Finland (63° 52–53' N lat., 28° 38–40' E. long.; elevation 200–210 metres above sea level), situated about 1 km apart from each other. In the Suopuro mire the pipe line lies along the side of a larger peat area, the main part of the mire complex representing a treeless *Sphagnum*-mire. In the Koivupuro area the line is also set out on a pine mire, which in this case is characterized by sedge-type peat. It is joined on one side to a small-sized, treeless mire characterized by *Sphagnum* peat, and on the other side to a spruce swamp. There are no essential differences between the mires as regards the thickness of the peat layer (thickness ranging from about 2.5 to about 3.5 metres). Vegetation along the pipe lines is of the same type on each of the mires. On the Suopuro pipe line, the bottom and field layer vegetation is mainly composed of *Sphagnum* species (*S. angustifolium, S. magellanicum*) with some *Carex pauciflora, Scirpus caespitosus* and *Eriophorum vaginatum*. Other characteristic species are e.g. *Rubus chamaemorus, Vaccicium oxycoccos* and *V. microcarpus, Betula nana, Andromeda polyfolia* and *Melampyrum pratense*, even though they exist more sparsely. On the Koivupuro pipe line the same *Sphagnum* species are also dominant, and the other species except for *Vaccinium microcarpus* are also generally present. The vegetation along the Koivupuro pipe line contains, in addition, sedges such as *Carex lasiocarpa, C. limosa, C. magellanica, C. echinata*, and *Eriophorum angustifolium*. On the other hand, the dwarf shrubs are also larger and more abundant (e.g. *Betula nana, Chamaedaphne calyculata* and, in some places, *Ledum palustre*) compared with the Suopuro pipe line. The main features of the mires, and of the pipe lines are presented in Figs. 1, 2, 18 and 19.

4. RESULTS

The simultaneous vertical fluctuation in the groundwater table and in the mire surface are presented as fluctuation diagrammes for each pipe in Fig. 3 (Koivupuro) and Fig. 4 (Suopuro). The black area in the figures represents the peat horizon between the mire surface (upper limit) and the groundwater table (lower limit). The horizontal line at the top of each of the diagrammes shows the relative mire surface altitude on June 26, the starting day of the observation period.

The absolute altitude values (metres a.s.l.) of the groundwater table, and the mire surface were not determined because of the remote location of the levelling points far away from the objects. The distance to the mire surface was used instead of the real altitude values. (The relative altitude of the mire surface at each site was determined on June 26, = 0).

In order to visualize and compare the simultaneous fluctuation in the groundwater table between different pipe sites in each line, two series of diagrammes were drawn (Figs. 5 and 6). Figures 5A and 6A were created on the basis of non-corrected data, and Figs. 5B and 6B were constructed using data which included the effect of the vertical surface fluctuation (the distance to the groundwater table at the observation time).

The vertical fluctuation in the mire surface follows that of the groundwater table (see Figs. 3 and 4) but takes place on a reduced vertical scale. During a rainless (dry) period the continuous sinking of the groundwater table leads to the drying out of the topmost peat layer – subsequently increasing its shrinkage and, furthermore, causing the mire surface altitude to sink. Sinking of the mire surface may amount to a few centimetres during a single growing season. Periods of rain and melting of snow result in water passing into the peat from both above and below (rising groundwater table). This leads to a swelling of the peat and raising of the mire surface altitude. According to Heikurai-

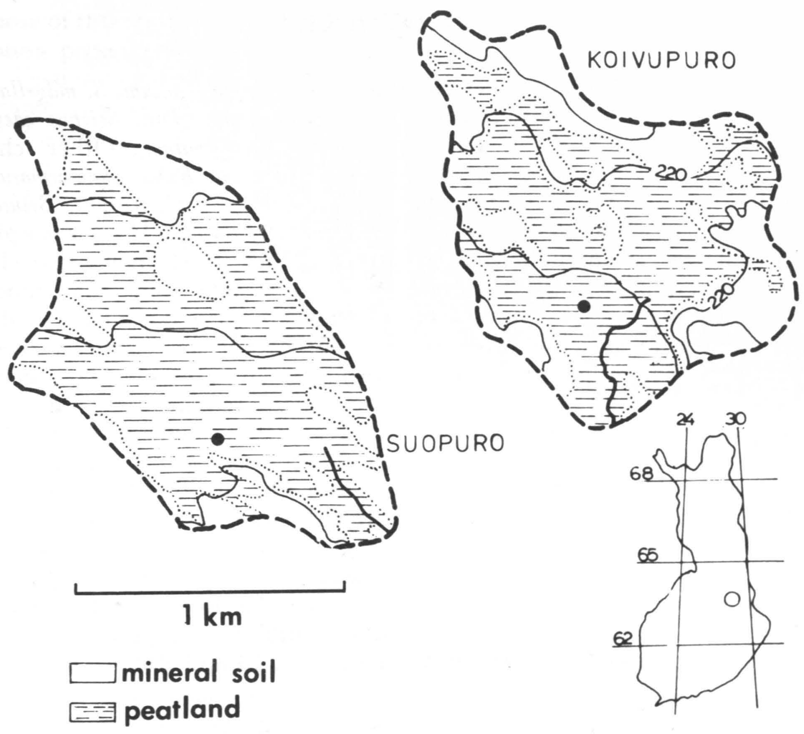


Fig. 1. The study areas. By permission of the National Board of Waters (Vesihallitus).
Kuva 1. Tutkimusalueet. Vesihallituksen luvalla.

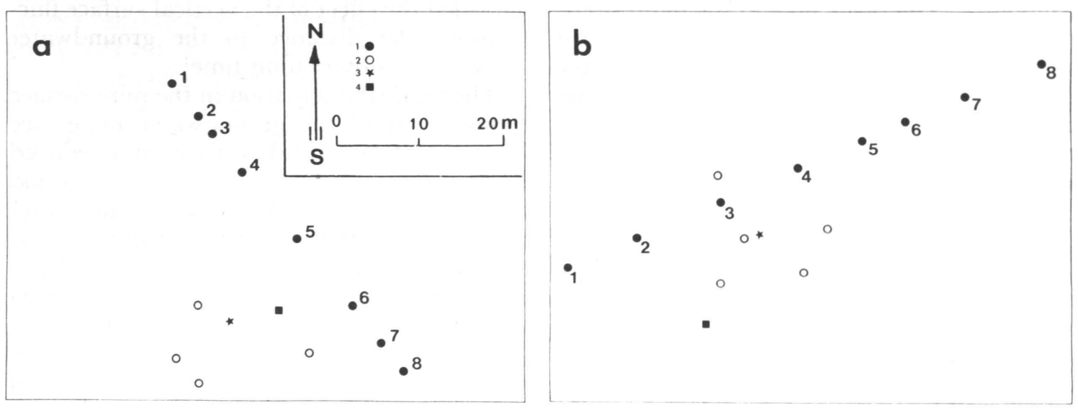


Fig. 2. Lay-out of the observation sites in different mires. (a) Suopuro, (b) Koivupuro. (1) groundwater pipe, (2) rain gauge, (3) automatic precipitation recorder, (4) anemometer + pyranometer.
Kuva 2. Havaintokohteiden sijainti tutkituilla rämeillä. (a) Suopuro, (b) Koivupuro. (1) pohjavesiputki, (2) sadeastia, (3) piirtävä sademittari, (4) tuulimittari + säteilymittari.

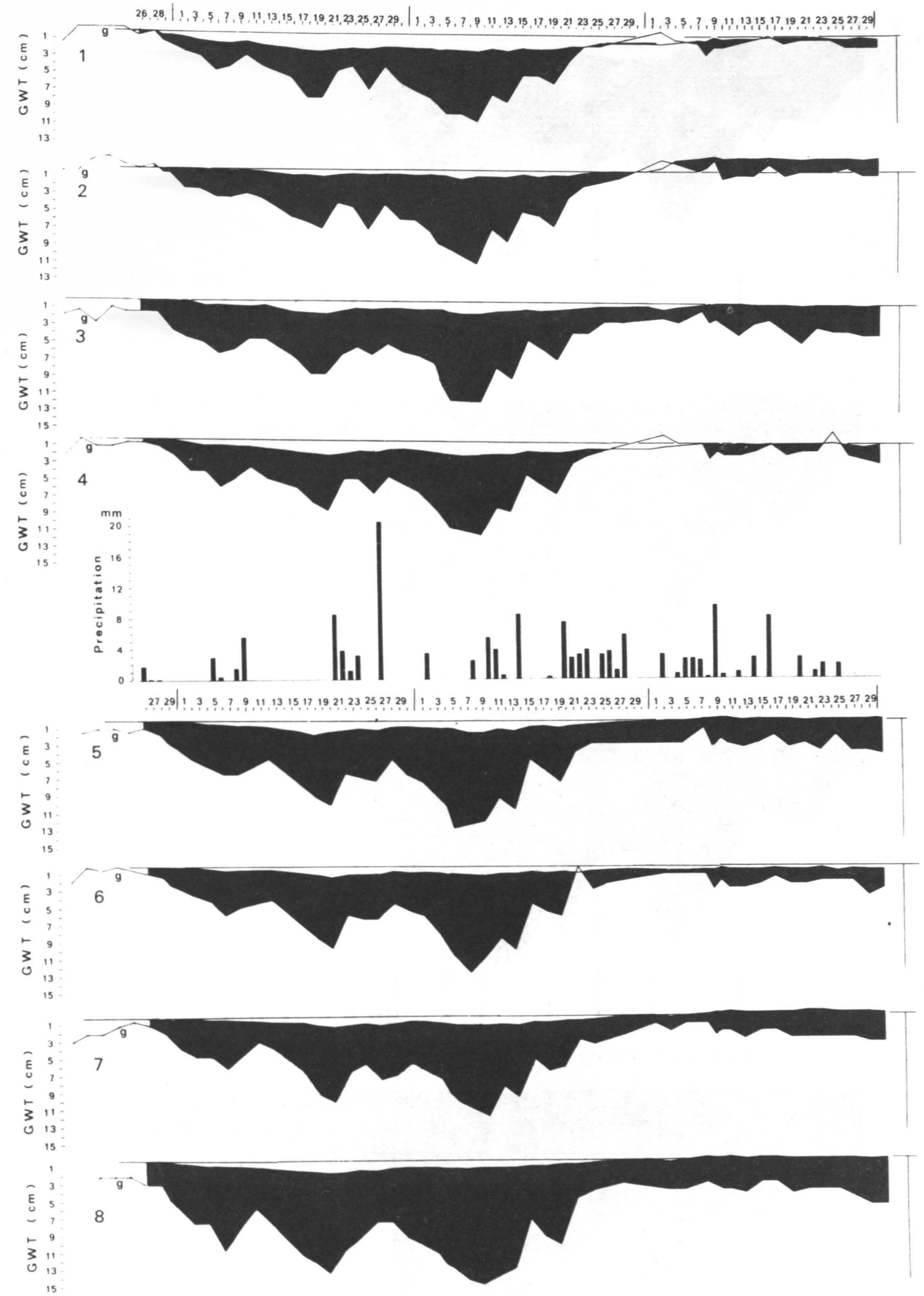


Fig. 3. Simultaneous vertical fluctuation in the groundwater table and that in the mire surface at different pipe sites in the Koivupuro mire. The diurnal precipitation diagramme is included. (g) = relative groundwater table altitude before June 26, 1982. For more detailed explanation, see text.
Kuva 3. Pohjavesipinnan ja suonpinnan samanaikainen korkeusvaihtelu Koivupuron rämeen pohjavesilinjan putkissa. Vuorokausisadantadiagramma kuvion yläosassa. (g) = suhteellinen pohjavesipinta ennen 26. 6. 1982. Tarkemmin tekstissä.

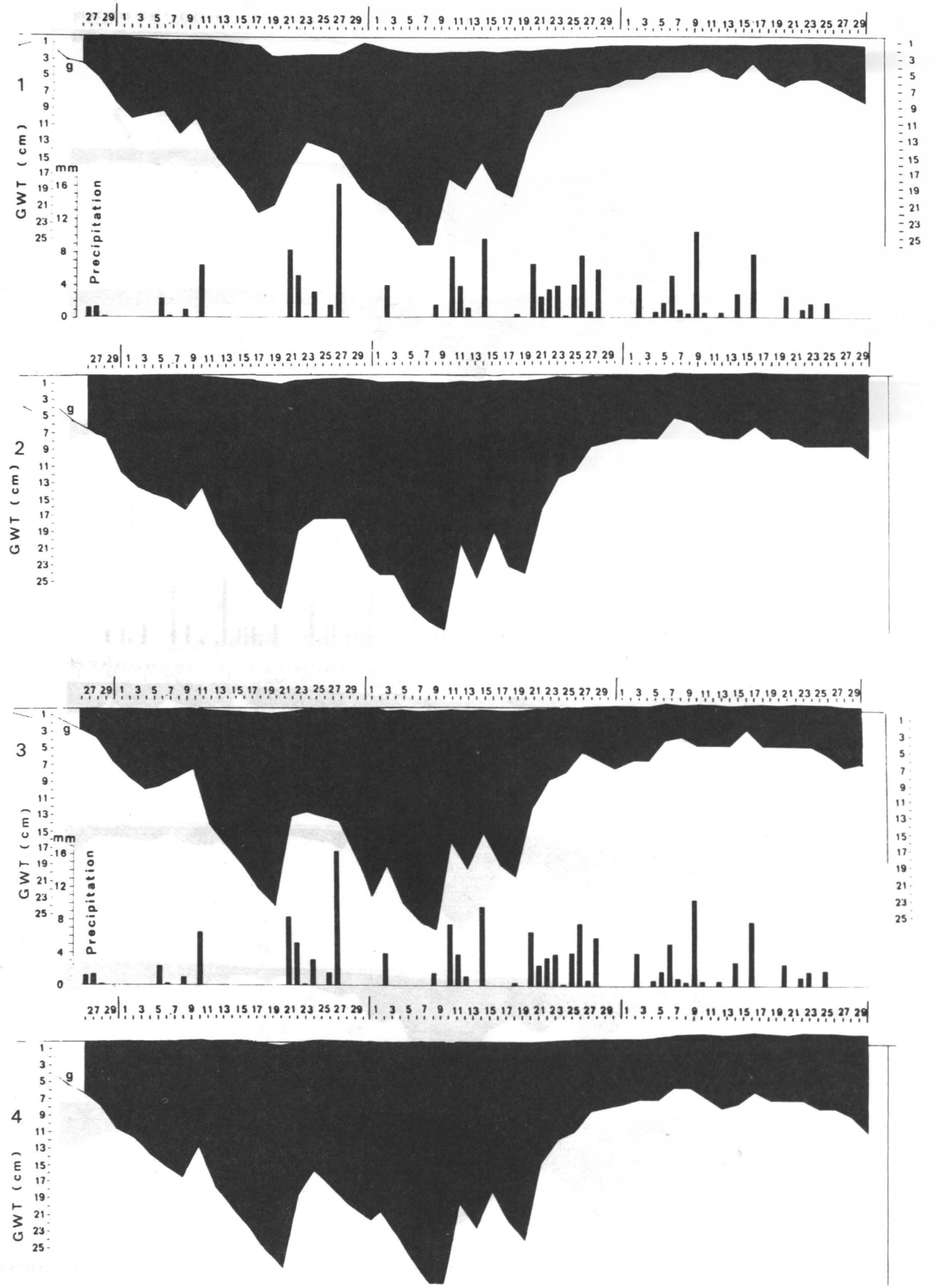


Fig. 4. Simultaneous vertical fluctuation in the groundwater table and that in the mire surface at different pipe sites in the Suopuro mire. For explanations, see Fig. 3 and text.
Kuva 4. Pohjavesipinnan ja suonpinnan samanaikainen korkeusvaihtelu Suopuron rämeen pohjavesilinjan putkissa. Muut selitykset Kuvassa 3 ja tekstissä.

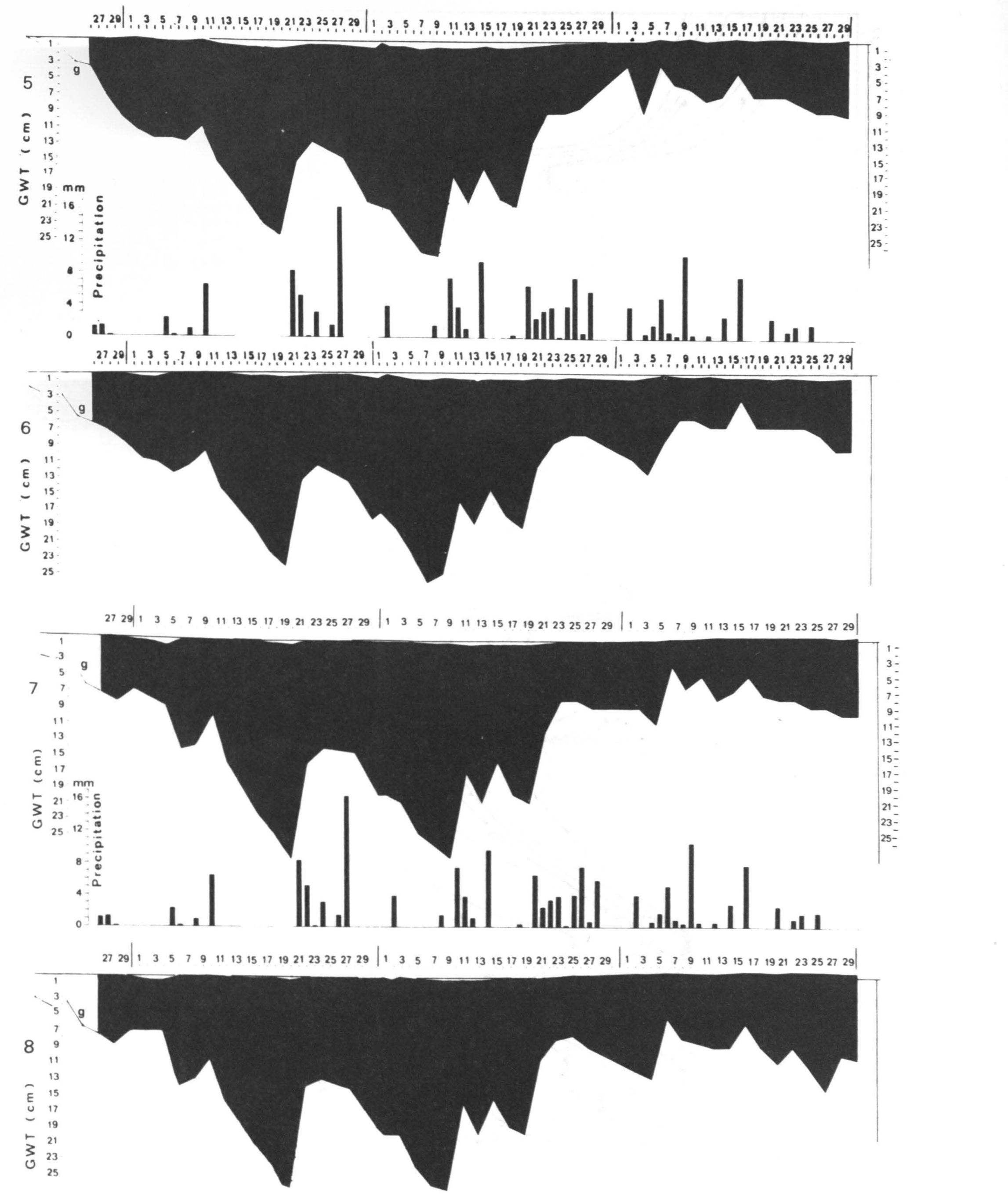


Fig. 4. continued
Kuva 4. jatkoa

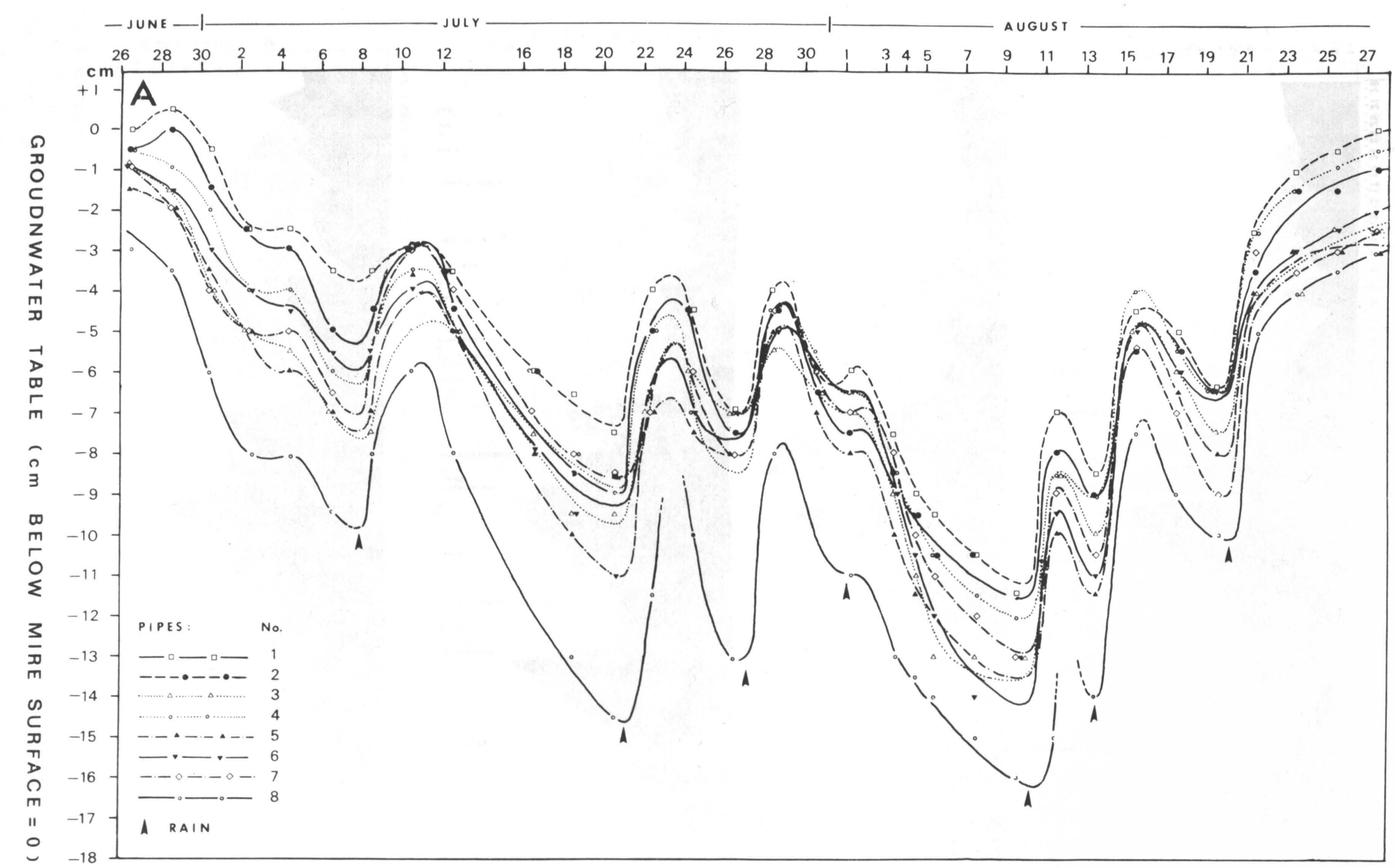
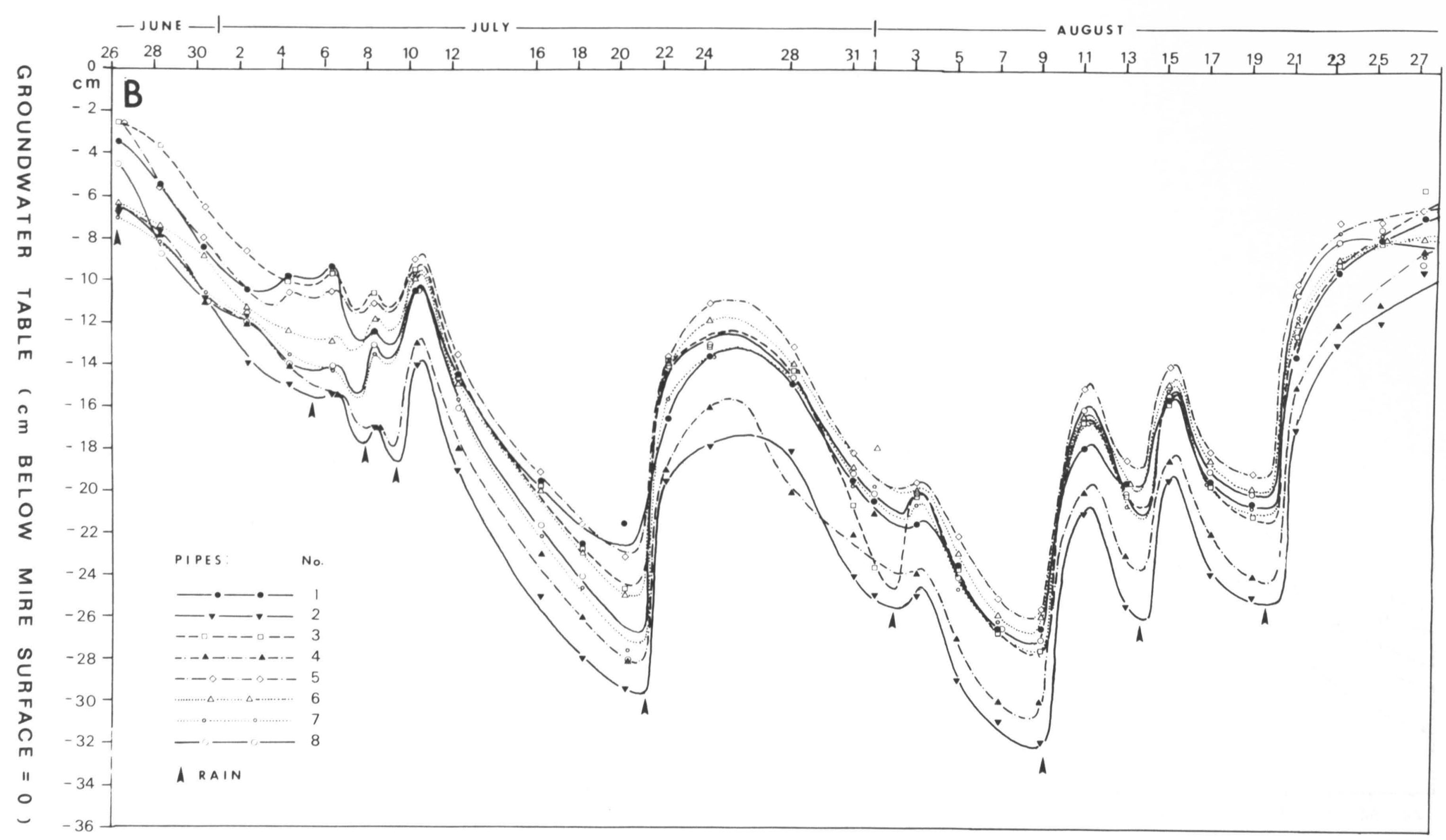


Fig. 5. Simultaneous groundwater table fluctuation; Koivupuro mire. Simultaneous surface subsidence (A) not included, (B) included. The start of periods of rain are shown by arrows.

Kuva 5. Pohjavesipinnan samanaikainen korkeusvaihtelu Koivupuron rämeellä (A) huomioimatta suonpinnan samanaikaista alenemista, (B) aleneminen huomioituna. Sedejaksojen alku on merkitty nuolin.



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Kuva 5. jatkoa

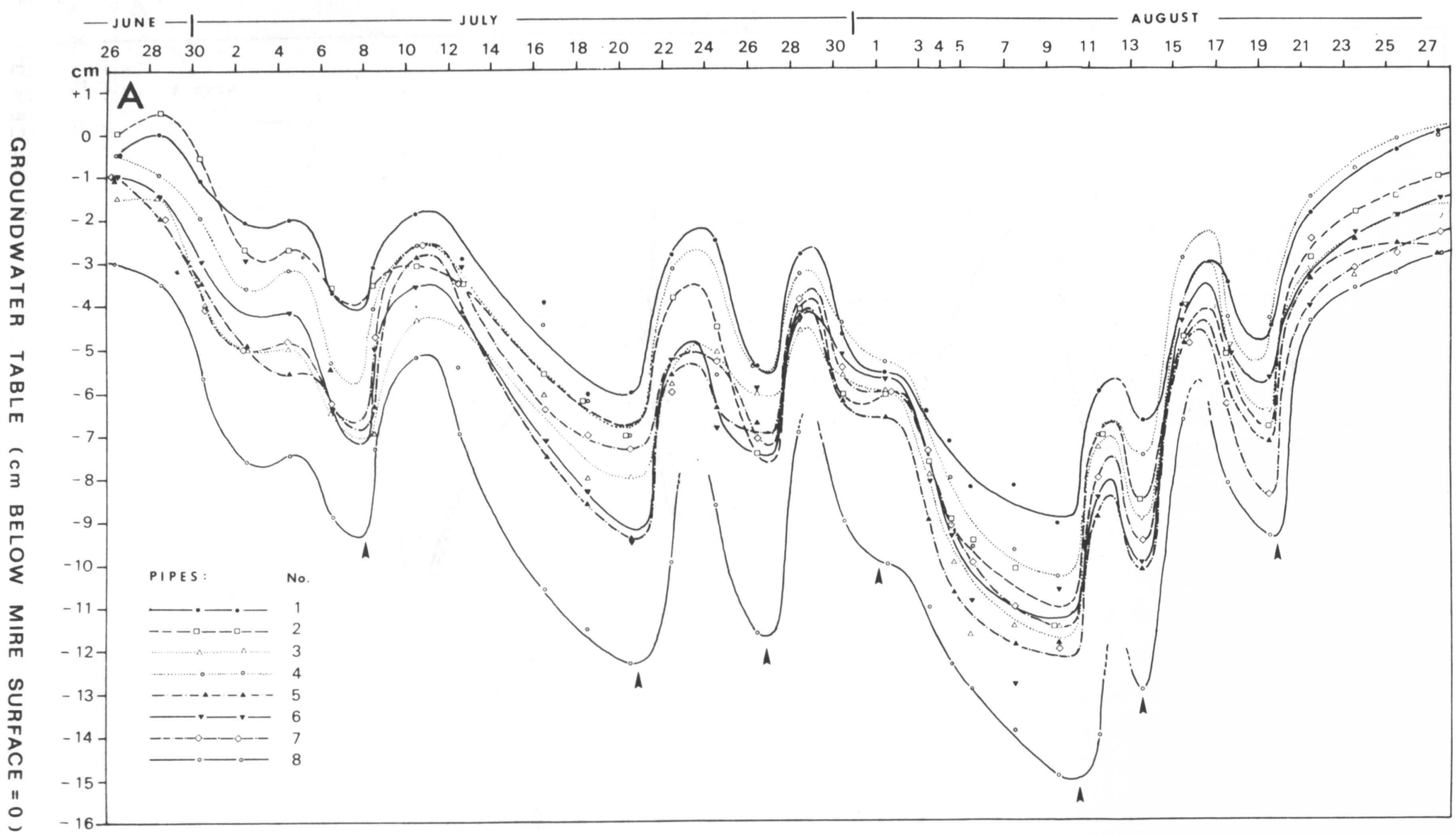


Fig. 6. Simultaneous groundwater table fluctuation; Suopuro mire. Simultaneous surface subsidence (A) not included, (B) included. The start of periods of rain are shown by arrows.

Kuva 6. Pohjavesipinnan samanaikainen korkeusvaihtelu Suopuron rämeellä (A) huomioimatta suonpinnan samanaikaista alenemista, (B) aleneminen huomioituna. Sadejaksojen alku on merkitty nuolin.

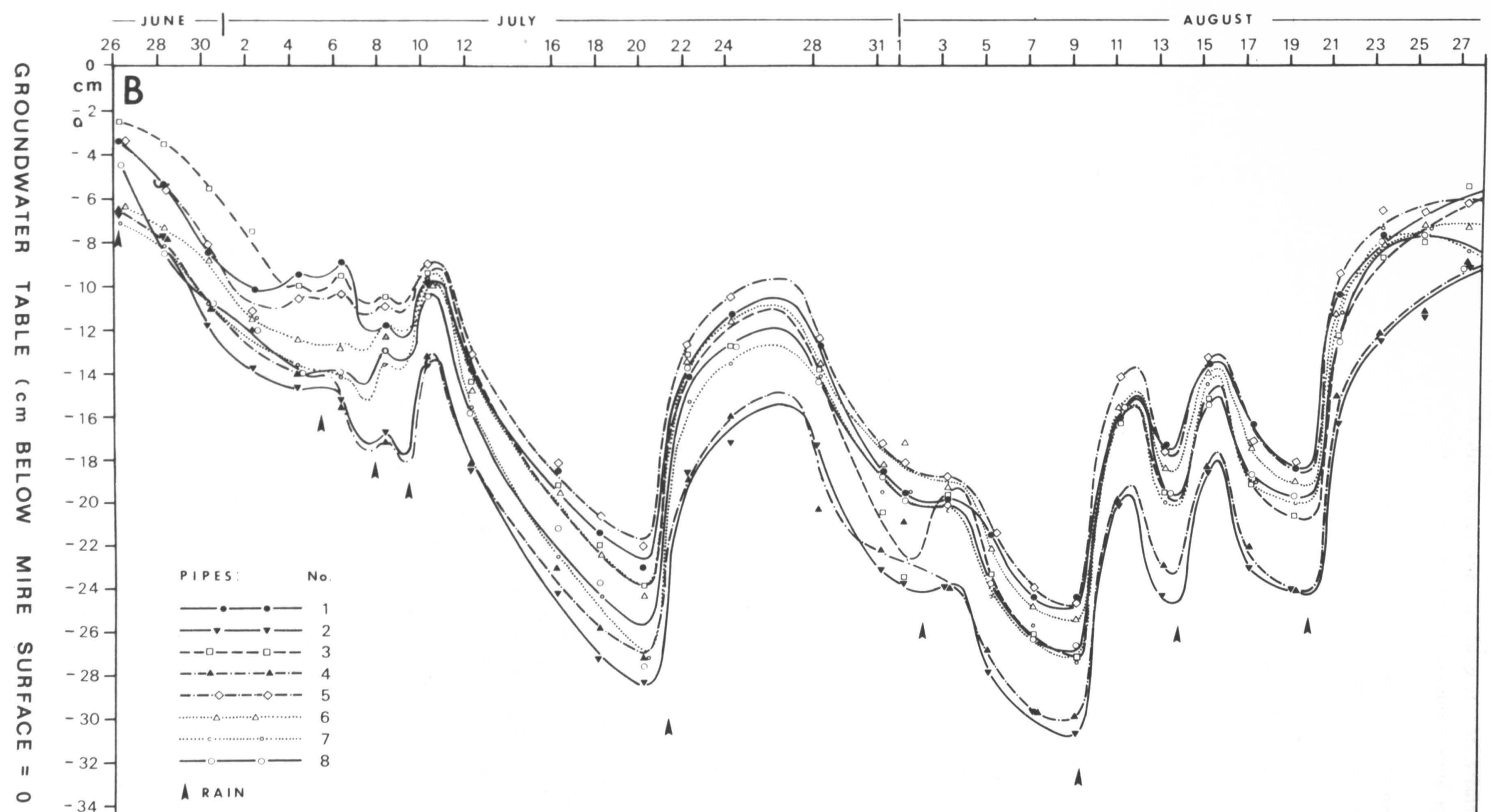


Fig. 6. continued

Kuva 6. jatkoa

Table 1. Bulk density, density gradient, mire surface subsidence and average volumetric water content at pipe sites along the pipe lines. Values in columns A and B represent mean of two samples taken c. 0.5 metres away from the pipe sites.

Taulukko 1. Turpeen tiheys, tiheysero, suonpinnan painuminen sekä vesipitoisuus putkien kohdalla turpeen pintakerroksessa. Sarakkeiden A ja B arvot edustavat kahden, ko. putkesta noin puolen metrin päästä otetun näytteen keskiarvoa.

pipe site	bulk density (fresh volume basis; g/cm³) A: 0–9 cm	B: 10–29 cm	A+B/2: 0–29 cm	bulk density gradient g/cm³ B–A	surface subsidence cm	volumetric water content (fresh vol. basis) per cent
Koivupuro mire						
1	0.064	0.111	0.088	0.047	2.00	78.0
2	0.024	0.058	0.041	0.035	1.00	48.0
3	0.030	0.094	0.062	0.064	1.50	57.0
4	0.036	0.091	0.064	0.055	1.75	58.0
5	..	0.104	..	..	1.75	..
6	0.024	0.068	0.046	0.044	1.25	55.0
7	0.064	0.107	0.086	0.043	1.25	78.0
8	0.032	0.066	0.049	0.034	1.50	57.0
Suopuro mire						
1	0.046	0.089	0.068	0.043	2.25	59.0
2	0.060	0.067	0.064	0.007	1.00	71.5
3	0.053	0.048	0.051	−0.005	0.75	67.0
4	0.036	0.044	0.040	0.008	0.50	54.0
5	0.043	0.046	0.045	0.003	1.00	64.0
6	0.042	0.052	0.047	0.010	1.00	63.5
7	0.047	0.051	0.049	0.004	0.75	72.5
8	0.052	0.068	0.060	0.016	0.50	71.0

nen et al. (1964), a short shower of rain which does not cause any rise in the groundwater table is responsible for a rise in the mire surface altitude of short duration only.

The simultaneous fluctuation in the groundwater table is considerable smaller in the Koivupuro area than in the Suopuro mire, but follows the same regularities in both mires.

The high gradient (great difference) in the range of the bulk density between the topmost (0–9 cm; bulk density 0.037; mean of 13 determinations), and the next (10–29 cm) peat horizon (bulk density 0.087; mean of 16 determinations), is evidently reflected in the variation of the hydraulic conductivity, and is the main reason for the small groundwater table fluctuation in the Koivupuro area. In the Suopuro mire the gradient of the bulk density with increasing depth is much flatter (bulk density for the surface peat layer 0.045; mean of 24 determinations, for the deeper peat horizon 0.058, respectively).

The fluctuation in the mire surface altitude is, on the other hand, smaller in the Suopuro area than in the Koivupuro mire (Table 1).

According to Päivänen (1982:252), the range of both the bulk density and the shrinkage of different peat types is highest in *Sphagnum*-type peats. However, this peat type is less dense on average, and shrinks more than *Carex*-type and woody-type peats. Owing to the fact that the top peat layer (0–29 cm) is in most cases less dense in Suopuro than in Koivupuro, the mire surface in Suopuro would be expected to sink more than that in the Koivupuro area. On the other hand, however, Päivänen (1982:254–256, Figs. 2–6) has pointed out that the volumetric shrinkage (to be compared with the mire surface subsidence) increases with increasing bulk density and asymptotically approaches a certain level. Furthermore, the deeper the peat layer and/or the higher its water content, the more intense its shrinkage will be.

For the reasons mentioned above, it seems

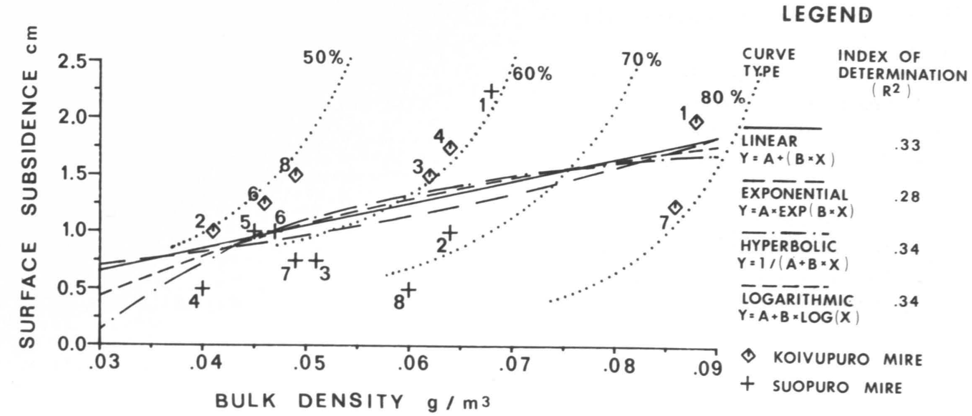


Fig. 7. Dependence of the mire surface subsidence on the bulk density of the top peat layer. Volumetric water content (per cent of fresh volume) of the peat layer is indicated as tentative (dotted) contours. Numbers refer to pipe sites.

Kuva 7. Suonpinnan painumisen riippuvuus turpeen pintakerroksen tiheydestä (tuoretilavuudesta). Turvekerroksen vesipitoisuus (% tuoretilavuudesta) on kuvattu pisteviivana korkeuskäyrin. Numerot viittaavat pohjavesiputkiin.

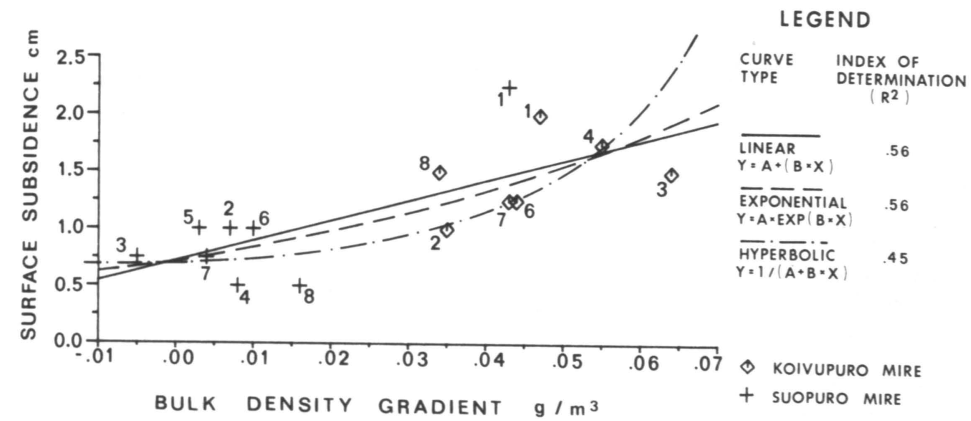


Fig. 8. Dependence of the mire surface subsidence on the bulk density gradient between the topmost, and the underlying peat layer. Numbers refer to pipe sites.

Kuva 8. Suonpinnan painumisen riippuvuus turpeen pintakerroksen ja sitä syvemmän turvekerroksen tiheyserosta. Numerot viittaavat pohjavesiputkiin.

logical that the graphs shown in Fig. 7 depicting the dependence of the mire surface subsidence on bulk density have the same trend as the graphs indicating the relationship between shrinkage and bulk density, and between volume loss and water loss, reached by Päivänen (1982: Figs. 2–6, 11), even though his results were obtained in laboratory experiments. The bulk density gradient between the topmost and the underlying peat layer seem to explain the mire surface subsidence (Fig. 8) even better than bulk density alone.

The results obtained in this study concerning the simultaneous groundwater table and mire surface fluctuation are in agreement with those published earlier for the same mires, but which were not based on the same data (cf. Kurimo 1983).

Figures 5 and 6 indicate that the groundwater table begins to sink slowly shortly after the dry period has started. The sinking accelerates already during the initial part of the dry period; later on it begins to slow down progressively. The same process takes place at the beginning of a period of rain but it now proceeds in the opposite direction: the rising trend in the groundwater table is first slow, then fast, and slows down again towards the end of the period. This kind of hydrologic dynamics is generally called hysteresis; (see Kurimo 1983; cf. Aref'eva 1963, Kuntze 1965).

The vertical mire surface fluctuation is approximately proportional to the simultaneous fluctuation in the groundwater table. It takes place on a reduced vertical scale, and is characterized by a certain lag (for details, see Kurimo 1983).

5. PAIRED REGRESSION METHOD

The simultaneous groundwater table fluctuation (actually determined as the distance to the groundwater table) within each pipe line was compared in the following way. The fluctuation at the pipe sites was first subjected to paired regression analysis (Figs. 9–10) so that the groundwater table values of the two pipes to be compared, both representing the same point of time, were used. According to the mutual relations obtained, it seems obvious that the regressions between pairs of pipe sites are not exactly linear in all cases, but are slightly nonlinear. The deviation from linearity is in most cases quite small, however, and in some cases almost non-existant. After the regression equation for the groundwater table fluctuation between pairs of pipe sites had been determined, the fitting test was carried out in order to test whether the difference between the linear regression coefficient value and the theoretical value 1 (b=1 indicates the case where the fluctuation at sites to be compared is precisely the same) is statistically significant. The equation $t=|1-b|:s$ was used for calculating the value of the t-test (b=regression coefficient, s=its standard deviation).

The results of the test are shown in Figs. 11–12. Cases where the coefficient representing the linear regression between pairs of pipe sites differs to a statistically significant degree from the theoretical value 1, are indicated as lines between the points (pipes). The lines are the thicker, the smaller the risk level.

The difference is statistically significant in very many cases. This means that the simultaneous fluctuation in the groundwater table between the sites compared is different. From this it follows that the groundwater table fluctuation is not exactly the same at all pipe sites (or all places representing the mire surface) even though it takes place synchronously. The assumption that the groundwater table fluctuation in different parts of the mire is the same, thus does not hold good *in toto*.

In the Koivupuro area especially, the simultaneous groundwater table fluctuation is unevenly distributed (see Fig. 11). The number of points having a different range of fluctuation is much smaller in the Suopuro mire than in the Koivupuro area.

Figures 9–11 also demonstrate that the strongest fluctuation differences generally occur between 'dry' and 'wet' places; the difference between two 'dry' or two 'wet' sites is less frequently statistically significant.

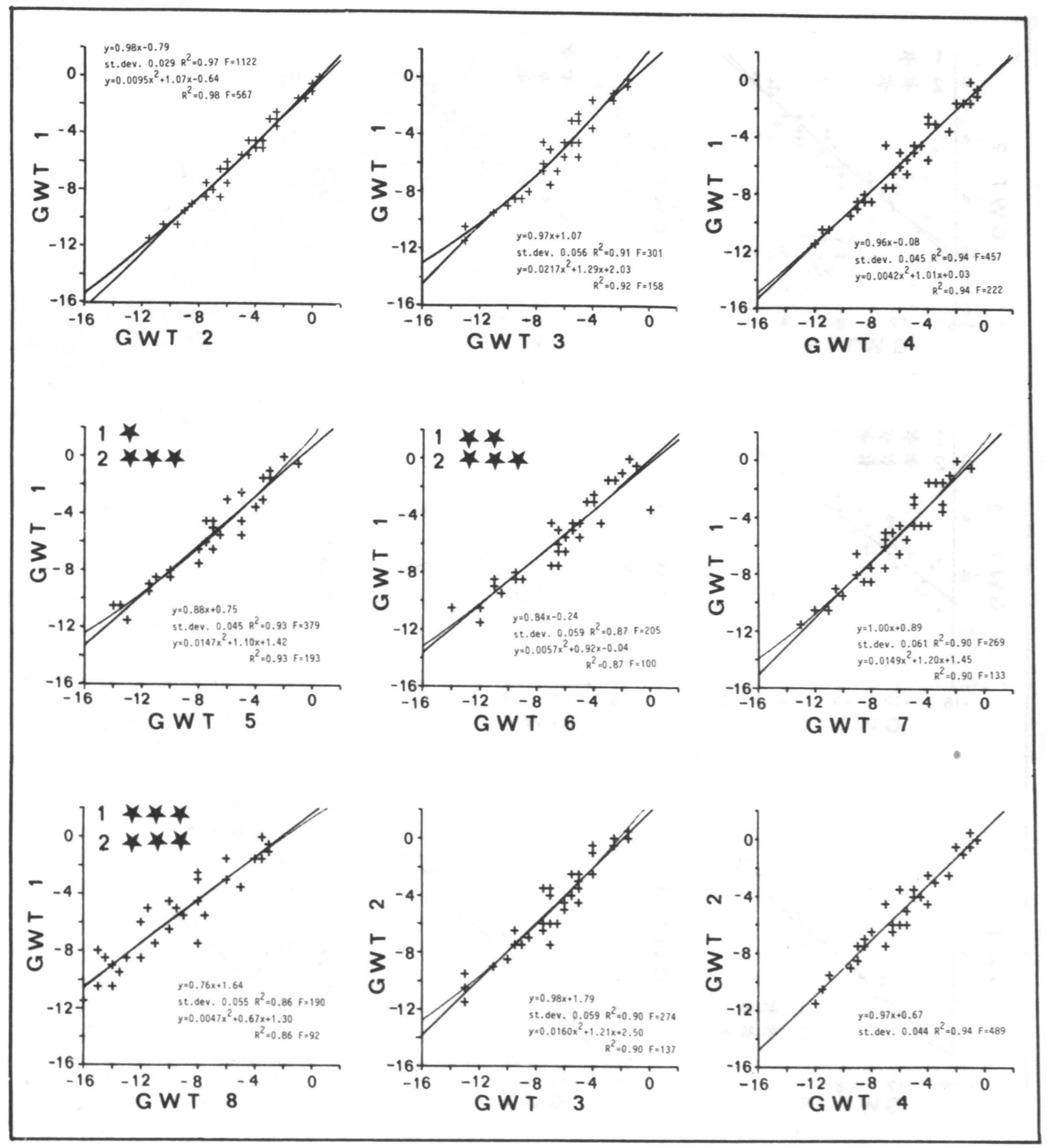


Fig. 9. Relationship of the simultaneous groundwater table fluctuation between pairs of pipe sites (x, y); Koivupuro mire. Both linear and squared regressions are drawn. The risk level is presented in cases where (1) the linear regression coefficient differs to a statistically significant degree from the theoretical value 1, (2) where the linear regression coefficient is, to a statistically significant degree, greater or smaller than 1. Risk levels for statistical significance: (o) 10 %, (*) 5 %, (**) 1 %, (***) 0.1 %. Simultaneous surface subsidence not included.

Kuva 9. Pohjavesipinnan (x, y; cm suonpinnasta) samanaikaisen korkeusvaihtelun vuorosuhde putkiparien välillä; Koivupuron räme. Sekä lineaarinen että kvadraattinen kuvaaja on esitetty. Riskitaso on esitetty tapauksissa, kun (1) suoraviivaisen regression kulmakerroin eroaa tilastollisesti merkitsevästi arvosta 1, (2) kun ko. regression kulmakerroin on tilastollisesti merkitsevästi suurempi tai pienempi kuin 1. Tilastollisen merkitsevyyden riskitasot: (o) 10 %, (*) 5 %, (**) 1 %, (***) 0.1 %. Samanaikaista suonpinnan alenemista ei ole huomioitu.

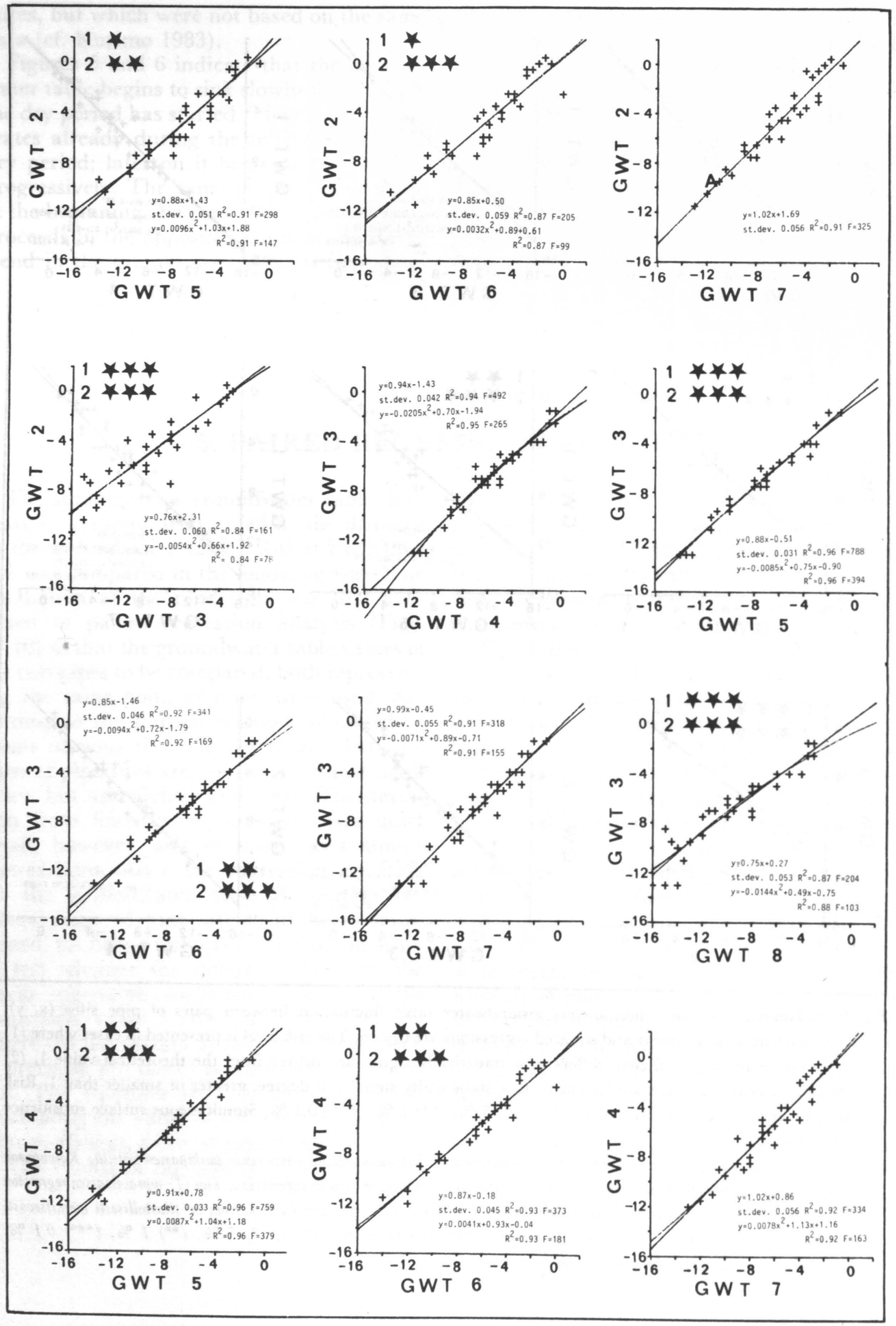
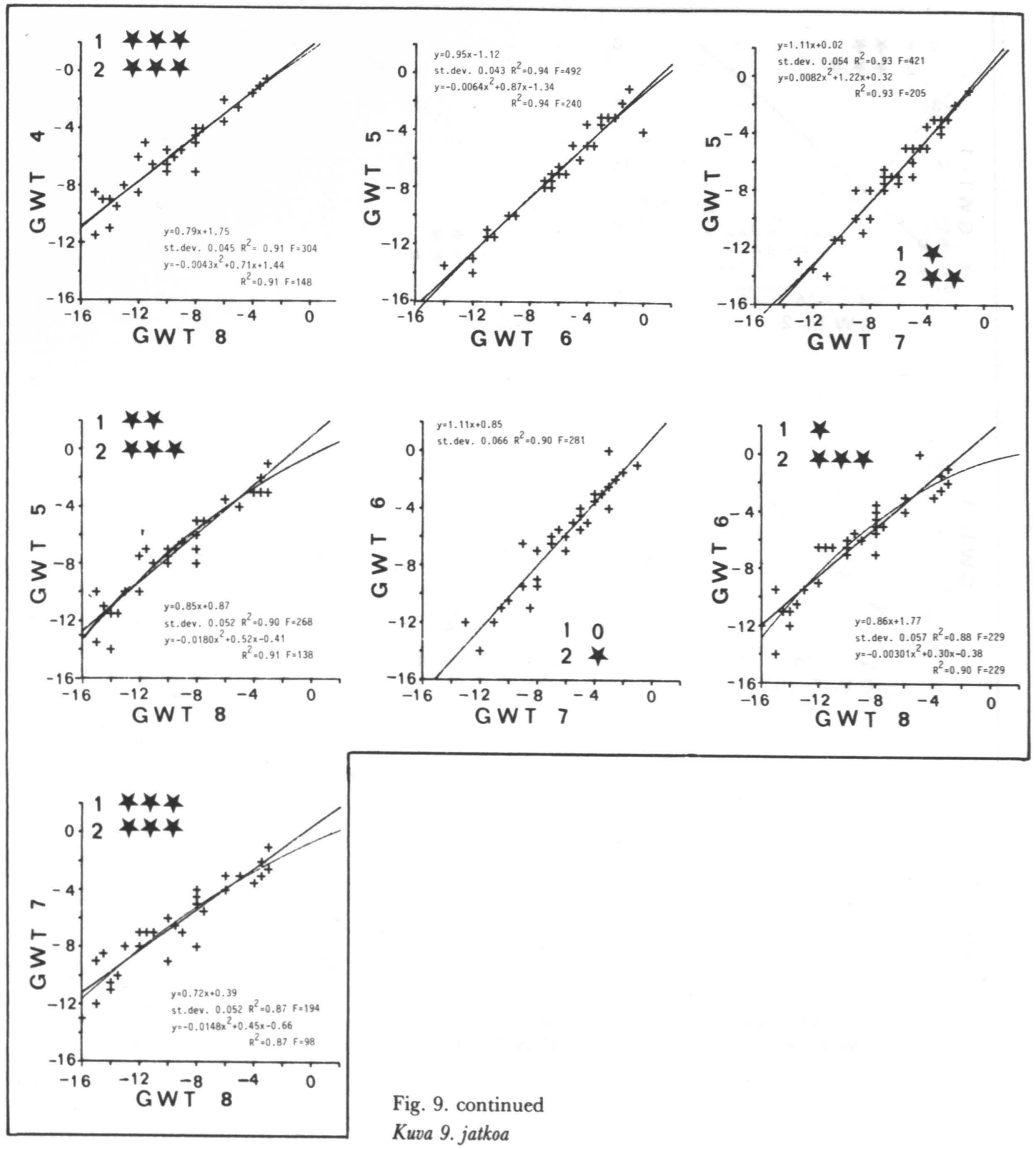


Fig. 9. continued
Kuva 9. jatkoa



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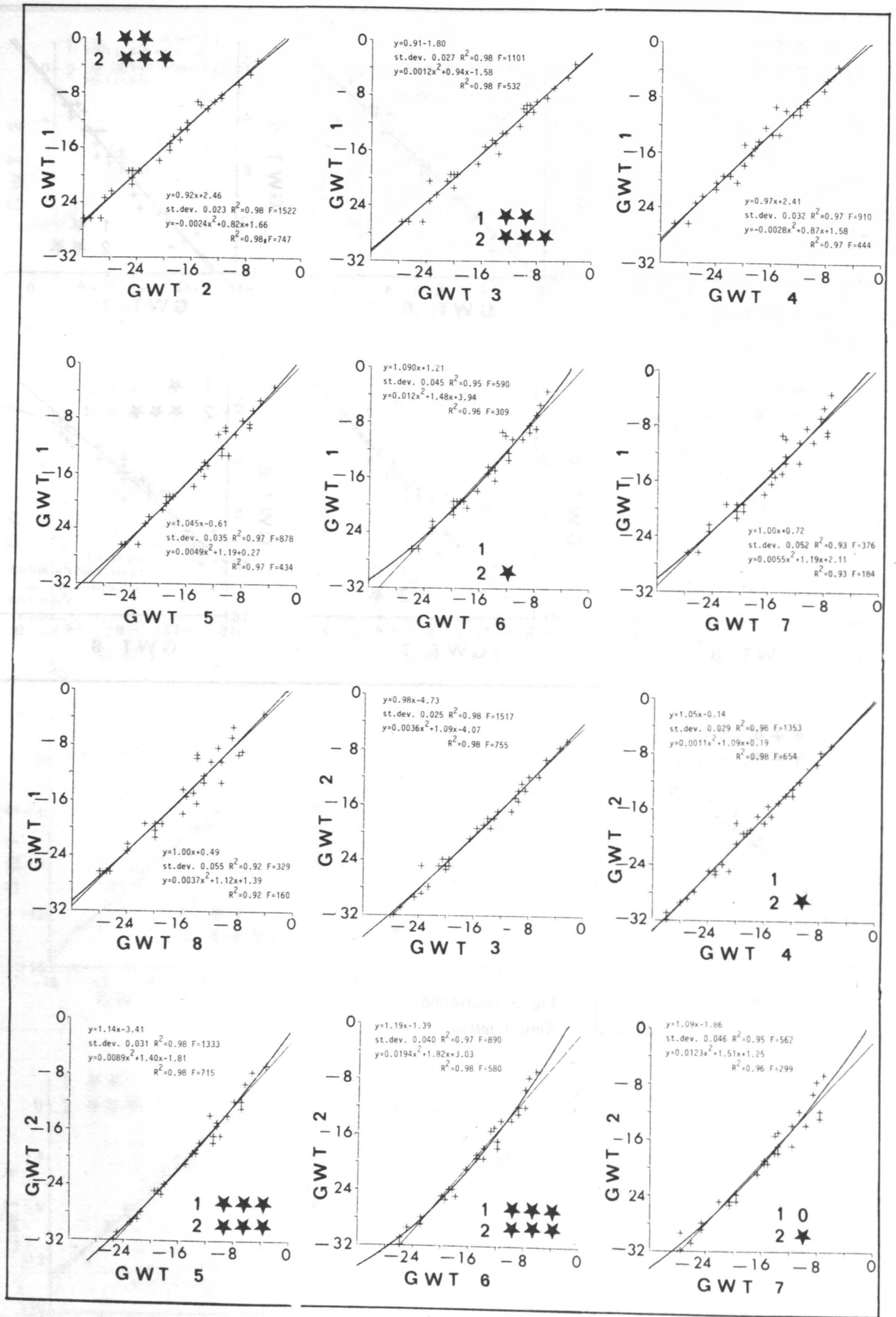
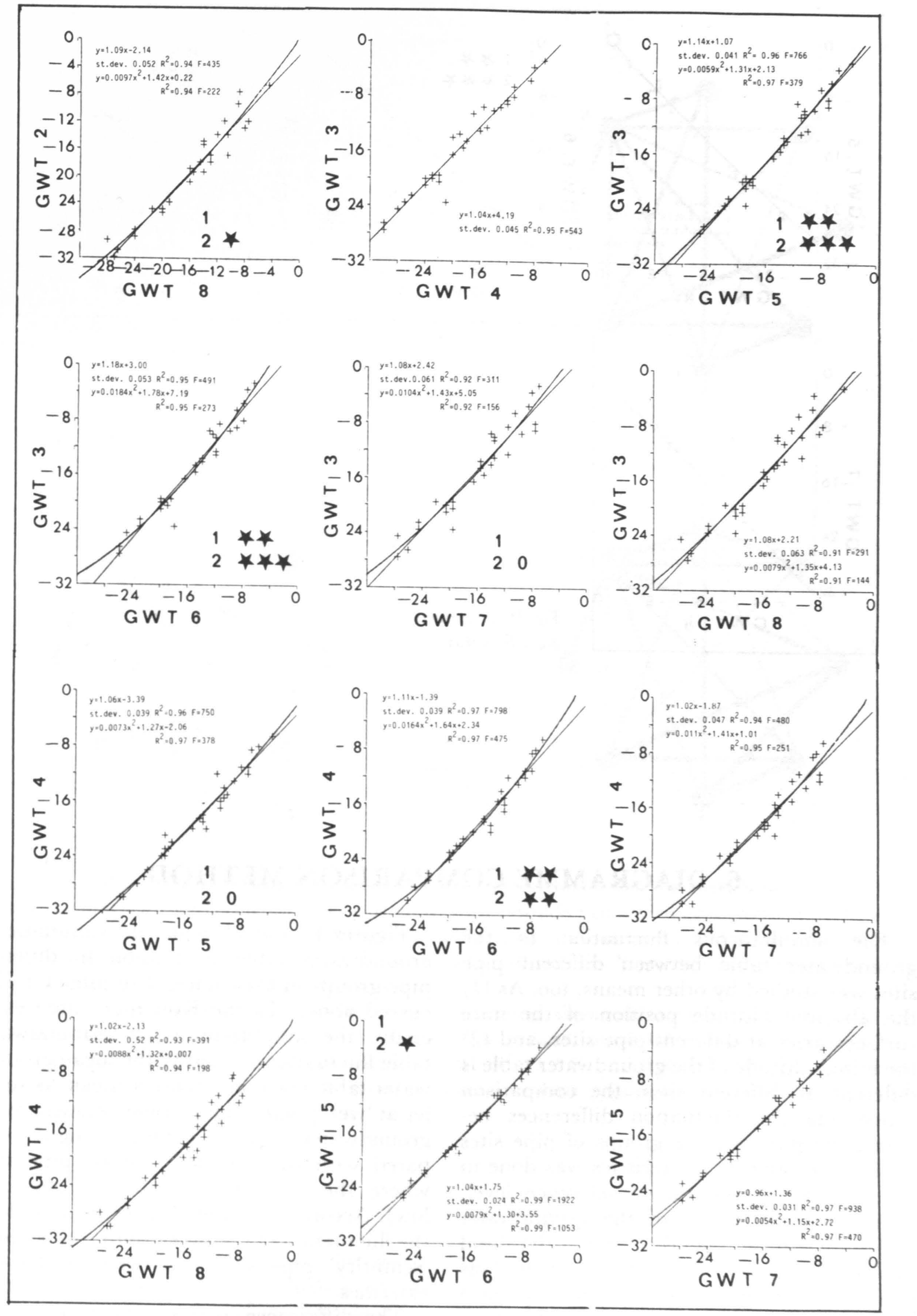


Fig. 10. Relationship of the simultaneous fluctuation in the groundwater table altitude between pairs of pipe sites in the Suopuro mire. Simultaneous surface subsidence not included. For explanations, see Fig. 9.
Kuva 10. Pohjavesipinnan samanaikaisen korkeusvaihtelun vuorosuhde putkiparien välillä Suopuron rämeellä. Samanaikaista suonpinnan alenemista ei ole huomioitu. Selitykset Kuvassa 9.



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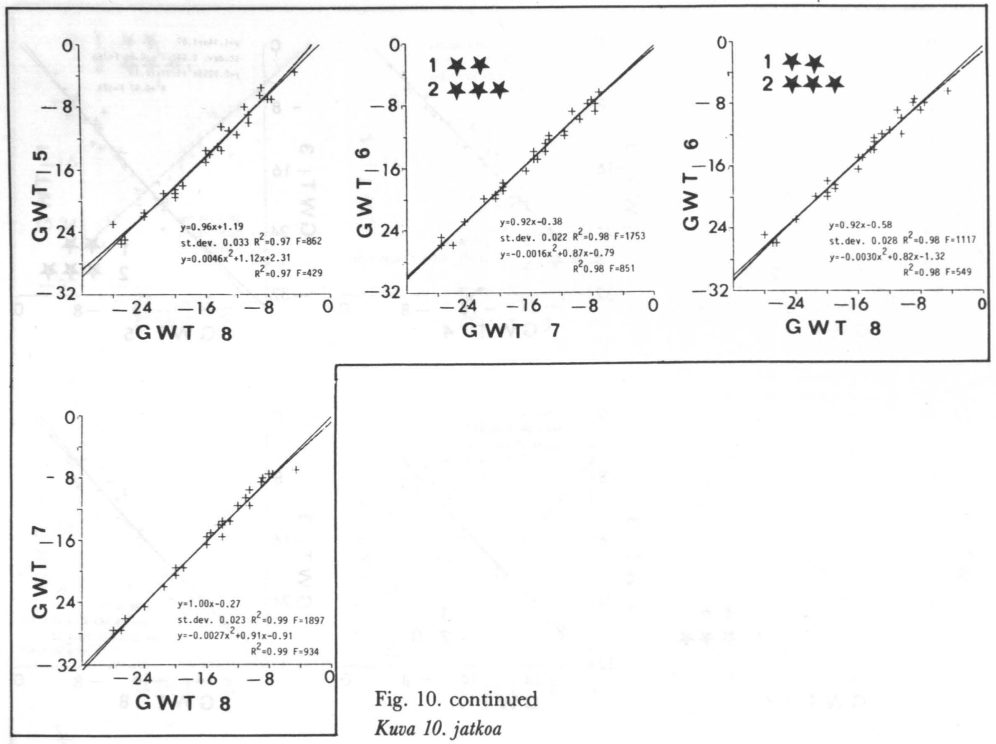

Fig. 10. continued
Kuva 10. jatkoa

6. DIAGRAMME COMPARISON METHOD

The simultaneous fluctuation in the groundwater table between different pipe sites was studied by other means, too. As (1) the absolute altitude position of the mire surface varies at different pipe sites, and (2) the initial altitude of the groundwater table is different at different sites, the comparison concerning the fluctuation differences between the pipe sites or groups of pipe sites having the same characteristics was done in relation to a standardized reference level. Thus the comparison of the groundwater table fluctuation between 'wet', 'dry' and 'semi-dry' pipe sites (groups of pipes) was performed using the periodical (summer) mean of the groundwater table (cm below surface level) at each pipe site for the reference level.

Figures 13 and 14 depict the simultaneous groundwater table fluctuation in different pipe groups in each mire, determined as discussed above. In the Koivupuro area especially, the amplitude in the groundwater table fluctuation related to the mean groundwater table position (summer mean) is smaller at 'wet' points, (i.e. at pipe sites where the groundwater table is generally high) compared with that at 'dry' points (pipe sites where the groundwater table is generally low). According to Fig. 13, the amplitude of the fluctuation of the pipe group composed of 'semi-dry' pipe sites lies between the two extremes.

The differences in the groundwater table fluctuation between 'wet', 'dry' and 'semi-dry' places are small and partly even unclear

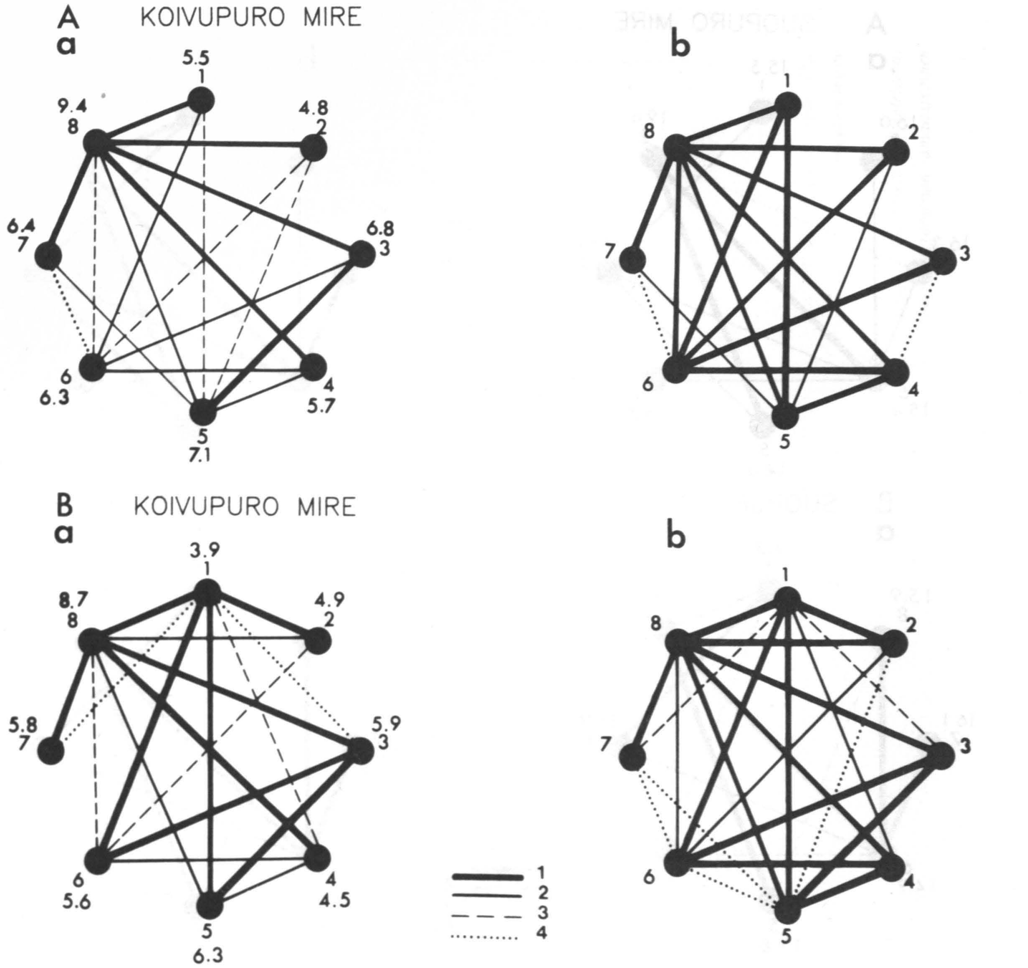

Fig. 11. Statistically significant differences (a) in the simultaneous groundwater table fluctuation between pairs of pipe sites, (b) cases where the fluctuation at one pipe site is, to a statistically significant degree, greater or smaller than that at another site. Koivupuro mire. Risk level symbols for statistical significance: (1) 0.1 %, (2) 1 %, (3) 5 %, (4) 10 %. Simultaneous surface subsidence (A) not included, (B) included. Numerals next to the numbers of the pipe sites indicate the summer mean of the groundwater table.

Kuva 11. Tilastollisesti merkitsevät erot (a) pohjavesipinnan samanaikaisessa korkeusvaihtelussa linjan putkiparien välillä, (b) tapaukset, jolloin pohjavesipinnan vaihtelu tietyssä putkessa on tilastollisesti merkitsevästi suurempi kuin vertailuputkessa. Koivupuron räme. Tilastollisen merkitsevyyden riskitasot: (1) 0.1 %, (2) 1 %, (3) 5 %, (4) 10 %. (A) huomioimatta samanaikaista suon pinnan alenemista, (B) aleneminen huomioituna. Luvut pohjavesiputkien numeron vieressä esittävät pohjavesipinnan etäisyyttä suonpinnasta kesäjakson keskiarvona.

in the Suopuro mire.

Figures 13 and 14 have been drawn up using data in which the influence of the simultaneous, vertical surface subsidence is taken into account. The same result is arrived at using uncorrected data, however.

Figure 15 indicates the relationship between the current distance to the groundwater table (y-axis), and the summer mean groundwater table (x-axis) at certain dates (A-D) which were chosen to represent high and low groundwater table positions (periods

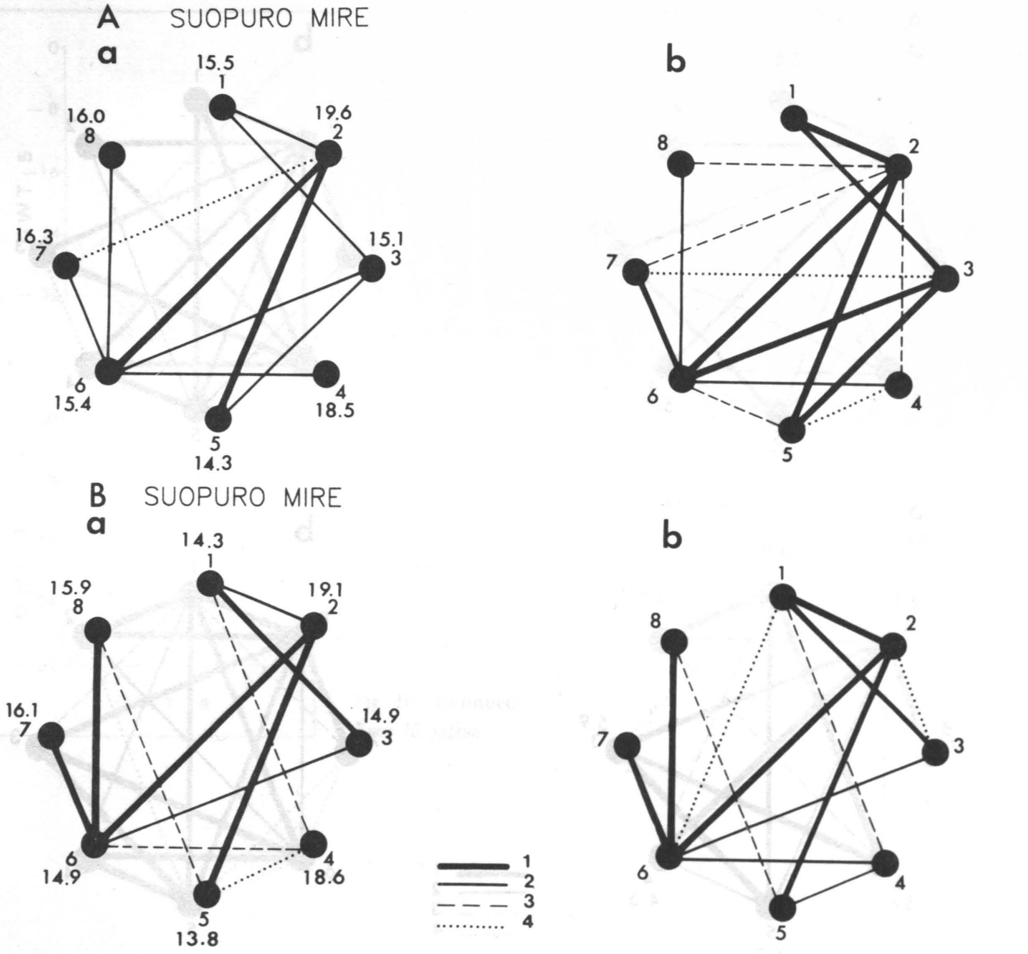

Fig. 12. Statistically significant differences (a) in the simultaneous groundwater table fluctuation between pairs of pipe sites, (b) cases where the fluctuation at one pipe site is, to a statistically significant degree, greater or smaller than that at another site. Suopuro mire. (A) simultaneous surface subsidence not included, (B) included. For explanations, see Fig. 11.

Kuva 12. Tilastollisesti merkitsevät erot (a) pohjavesipinnan samanaikaisessa korkeusvaihtelussa linjan putkiparien välillä, (b) tapaukset, jolloin pohjavesipinnan korkeusvaihtelu tietyssä putkessa on tilastollisesti merkitsevästi suurempi kuin vertailuputkessa. Suopuron räme. (A) huomioimatta samanaikaisista suon pinnan alenemista, (B) aleneminen huomioituna. Selitykset kuvassa 11.

of rain, dry periods). Figure 15 depicts the magnitude of the differences in the distance to the groundwater table between 'dry', 'semi-dry' and 'wet' points during high and low groundwater table positions. The absolute value of the regression coefficients exceeds 1 on the days with a low-positional groundwater table, but is less than 1 during periods when the groundwater table is high. This means that the differences in the distance to the groundwater table between 'dry' and 'wet' sites are reduced when the groundwater level is high, i.e. the gradient is diminished.

The pipes presented in Fig. 15 are arranged in such a way that the first (furthest to the left; pipe No. 1) represents the 'wettest' place on the basis of the minimum of the summer mean in the groundwater table, and the last (furthest to the right; pipe No. 8) represents the 'driest' place. The numbers on

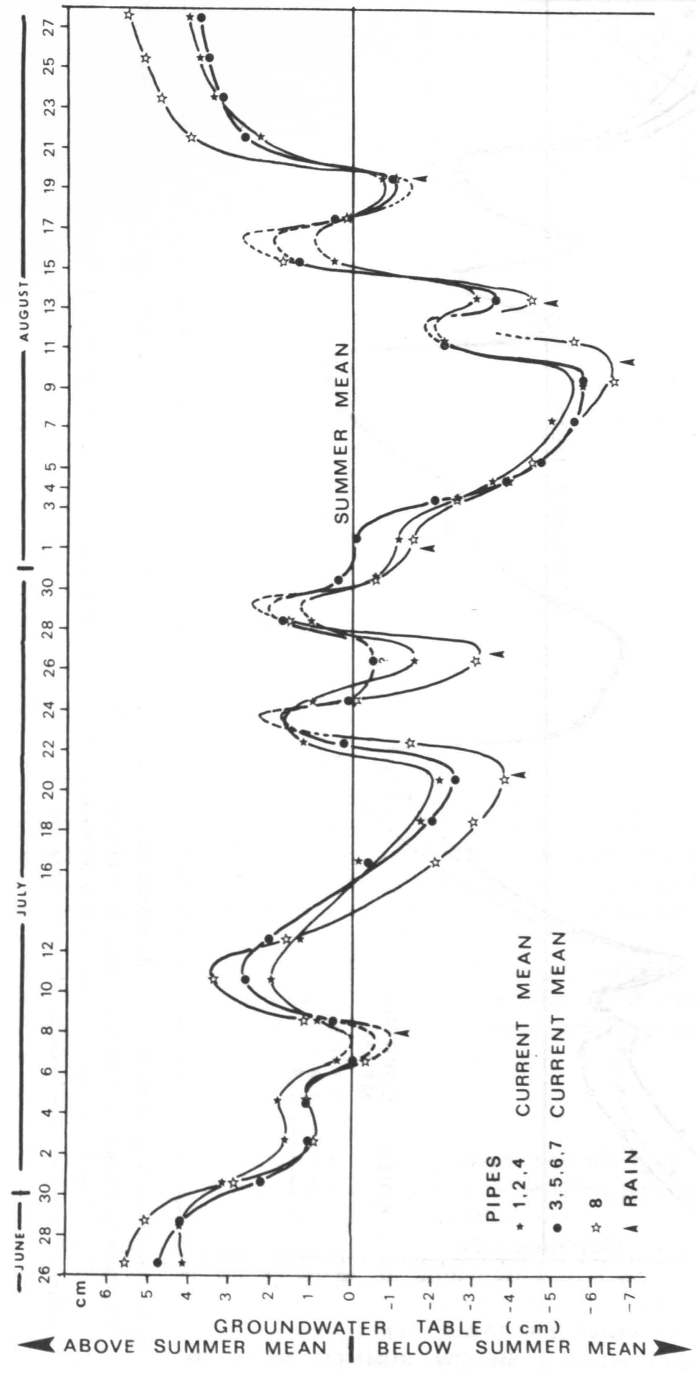

Fig. 13. Simultaneous groundwater table fluctuation in relation to the standardized summer mean groundwater table of the sites. Koivupuro mire. The start of periods of rain is indicated by arrows. Pipe sites having almost the same mean values are grouped together. Simultaneous surface subsidence included.

Kuva 13. Pohjavesipinnan samanaikainen korkeusvaihtelu Koivupuron rämeellä pohjavesilinjan putkien vakioituun kesän pohjavesipinnan keskiarvoon suhteutettuna. Sadejaksojen alku on merkitty nuolin. Putket, joissa pohjavesi on lähes samalla etäisyydellä suon pinnasta on yhdistetty samaksi ryhmäksi. Suonpinnan samanaikainen aleneminen on huomioitu.

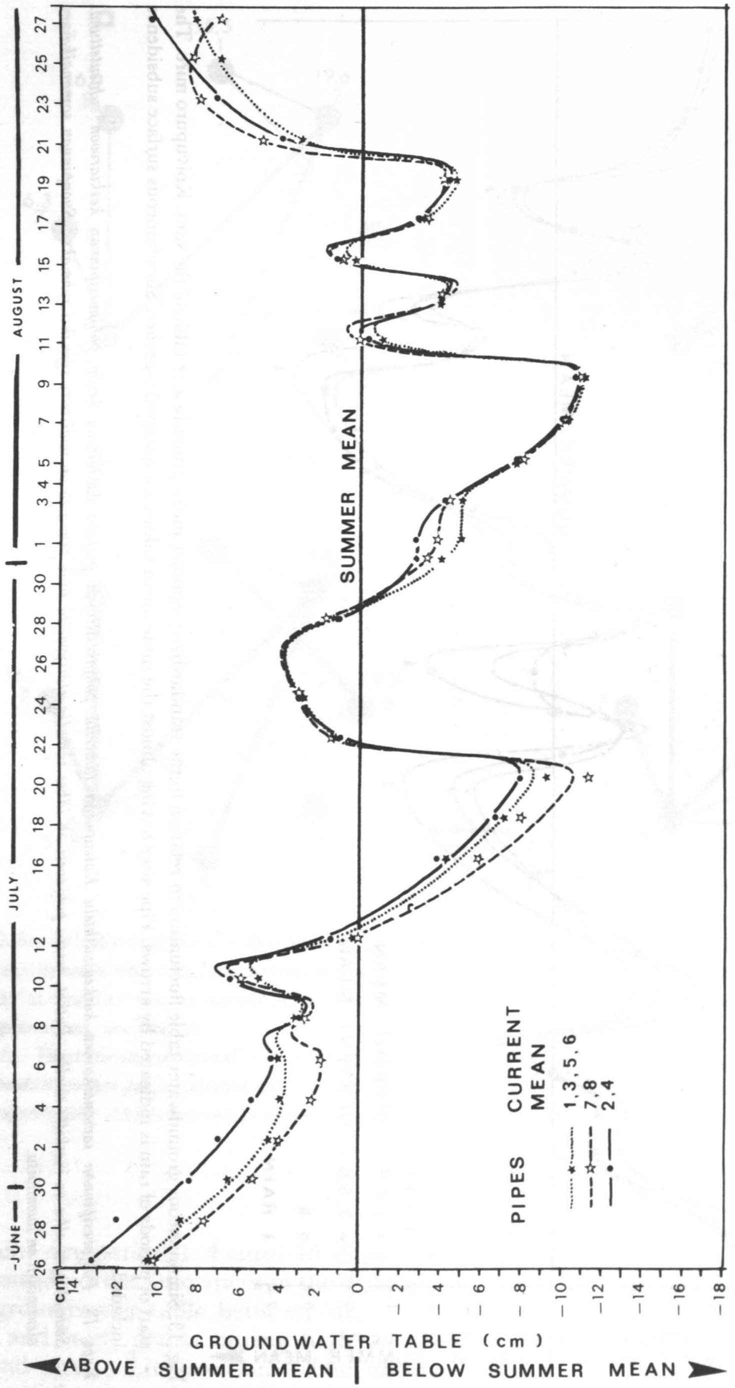

Fig. 14. Simultaneous groundwater table fluctuation in relation to the standardized summer mean groundwater table of the sites. Suopuro mire. Simultaneous surface subsidence included. For explanations, see Fig. 13.

Kuva 14. Pohjavesipinnan samanaikainen korkeusvaihtelu Suopuron rämeellä linjan putkien vakioituun kesän pohjavesipinnan keskiarvoon suhteutettuna. Suonpinnan samanaikainen aleneminen on huomioitu. Muut selitykset kuvassa 13.

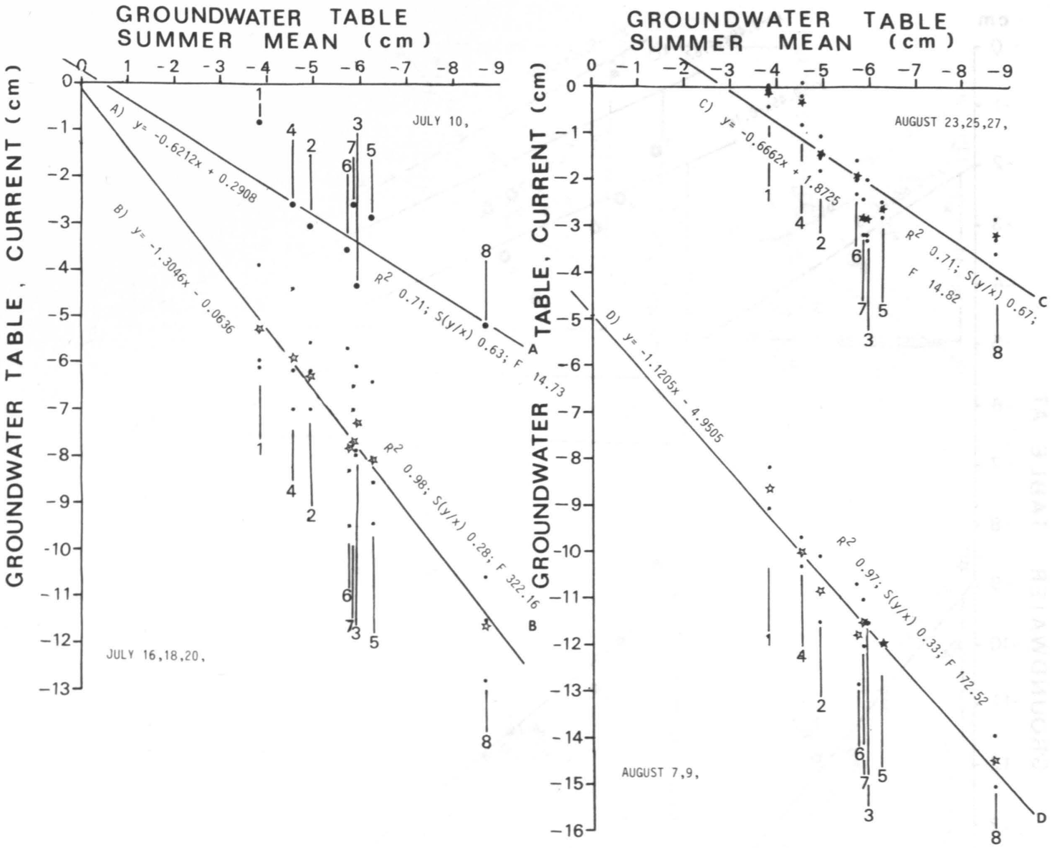

Fig. 15. Linear relationship in the relative groundwater table altitude between summer mean (x-axis), and the current (y-axis) value at periods of time when the groundwater table was high (A,C) and low (B,D). Koivupuro mire. Asterisks represent the mean values of a period representig several days' observations (B,C,D; small points). S. (y/x) = standard deviation for the regression coefficient. Simultaneous surface subsidence included. For further explanations, see text.

Kuva 15. Kesäjakson keskimääräisen pohjavesipinnan (x-akseli) ja havaintohetken pohjavesipinnan (y-akseli) vuorosuhde Koivupuron rämeellä ajankohtina, jolloin pohjavesi oli epätavallisen korkealla (A,C) tai matalalla (B,D). Tähtimerkit kuvaavat usean päivän pituisten jaksojen keskiarvoja (B,C.D; pisteet edustavat päivittäisiä havaintoja). S(y/x) = regressiokertoimen standardipoikkeama. Suonpinnan samanaikainen aleneminen on huomioitu. Lähemmin tekstissä.

the x-axis are summer mean-values for the groundwater table (cm below the mire surface level), and the numbers on the y-axis represent the current groundwater table (cm), i.e. that observed at the moment in question (A, B, C, D).

The fan-like arrangement of the group of lines presented in Fig. 15 indicates that the simultaneous fluctuation in the groundwater table is smaller at those pipe sites where the groundwater table generally is higher compared with those sites where it is lower. Attention has earlier been drawn to this phenomenon when discussing fluctuation relations between pairs of pipe sites (cf. Figs. 9–10).

The amplitude of the groundwater table fluctuation at a 'dry' place (e.g. pipe No. 8) between the days July 10, (high groundwater table position) and July 16, 18, 20, (mean value of these dates; low groundwater table position) was about 7 cm, but at a 'wet' point (e.g. pipe No. 4) it was only about 4 cm between the same dates. The difference in the amplitude between 'dry' and 'wet' points was in this case about 3 cm.

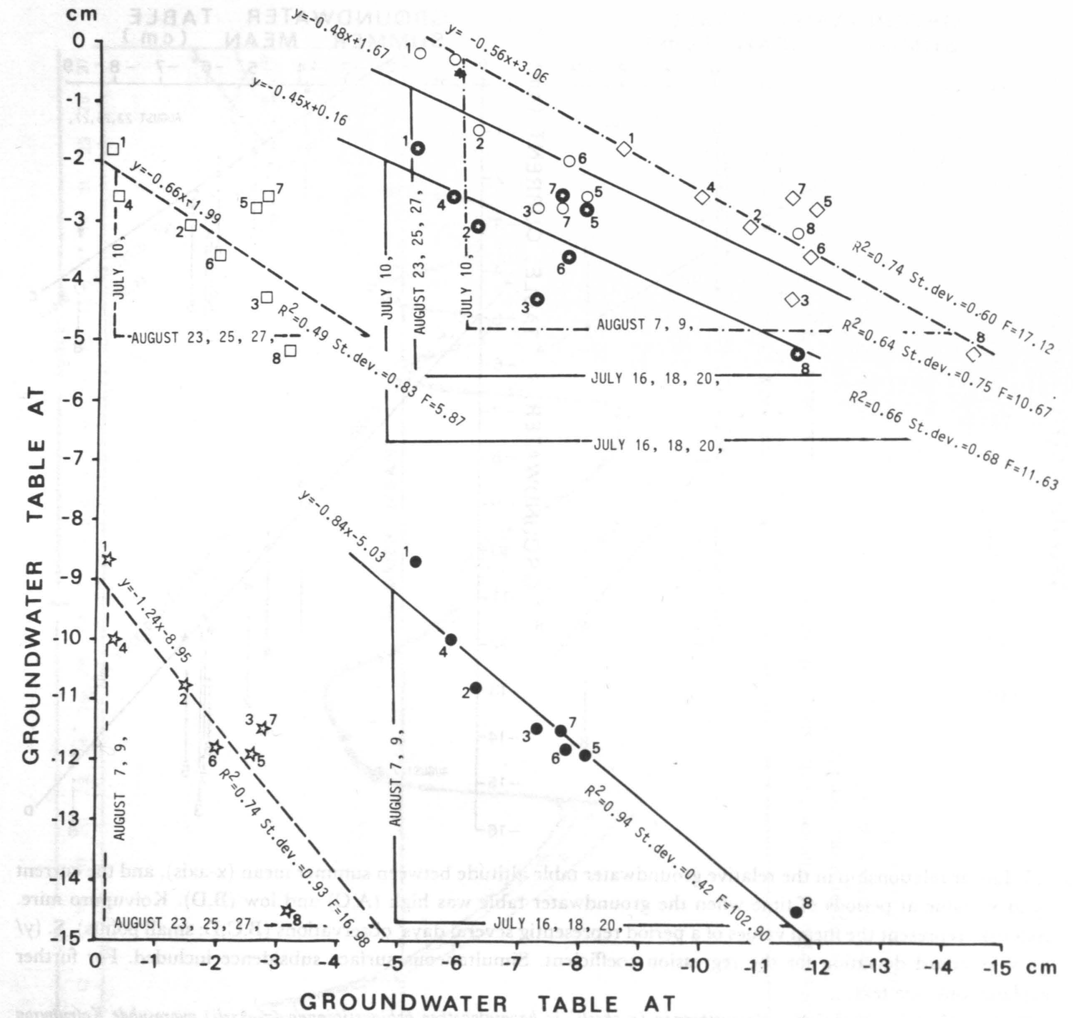

Fig. 16. Linear relationship depicting a sequence of pipe sites, arranged according to their summer mean distance to the groundwater table during periods where the groundwater table was exceptionally high or low. Koivupuro mire. Inside the sequence the 'wettest' site is furthest to the left (pipe No. 1) and the 'driest' site furthest to the right (pipe No. 8). Simultaneous surface subsidence included. Compare with Fig. 15. For more detailed explanation, see text.

Kuva 16. Pohjavesipinnan suoraviivainen vuorosuhde kesäjakson pohjavesipinnan keskiarvon mukaisesti 'kosteimmasta' 'kuivimpaan' järjestetyssä putkisarjassa aikoina, jolloin pohjavesi oli epätavallisen korkealla tai matalalla. Koivupuron räme. 'Kostein' paikka (No. 1) on äärimmäisenä vasemmalla, 'kuivin' (No. 8) oikealla. Suonpinnan samanaikainen aleneminen on huomioitu. Vertaa kuvaan 15. Lähemmin tekstissä.

The lines in Fig. 15 also depict the linear dependence of the current relative groundwater table altitude on its long-durational mean. The values of the correlation coefficient are high when they represent the relationship in cases there is a low-positional groundwater table (Fig. 15B, D), but are considerably smaller when they represent periods reflecting a high groundwater table position (Fig. 15A, C). It is not absolutely certain, however, that the relationship described above really is of a linear nature.

According to Fig. 16, the relationship for the current relative groundwater table between the same pipe sites is different during periods representing low and high groundwater table positions (cf. Fig. 15). The gradient of the groundwater table thus varies according to the general altitude position of the groundwater table.

It is not certain whether the relationships shown in Fig. 16 are of a linear nature. Slightly higher values for the coefficient of determination are reached when using nonlinear regression equations (Fig. 17). It is obvious, however, that the nature of the relationship in question is slightly nonlinear (cf. Figs. 9–10). Figures 15–17 are constructed on the basis of data which includes the effect of the synchronous surface subsidence.

Even though the accuracy of the groudwater table measurements is maximally 0.5 cm, and thus the maximum error of the two subsequent records may be as high as 1 cm, the numerous pairs of values, each pair representing the same point of time make the regressions shown in Figs. 9 and 10 reliable assumed that the variation of the measure-

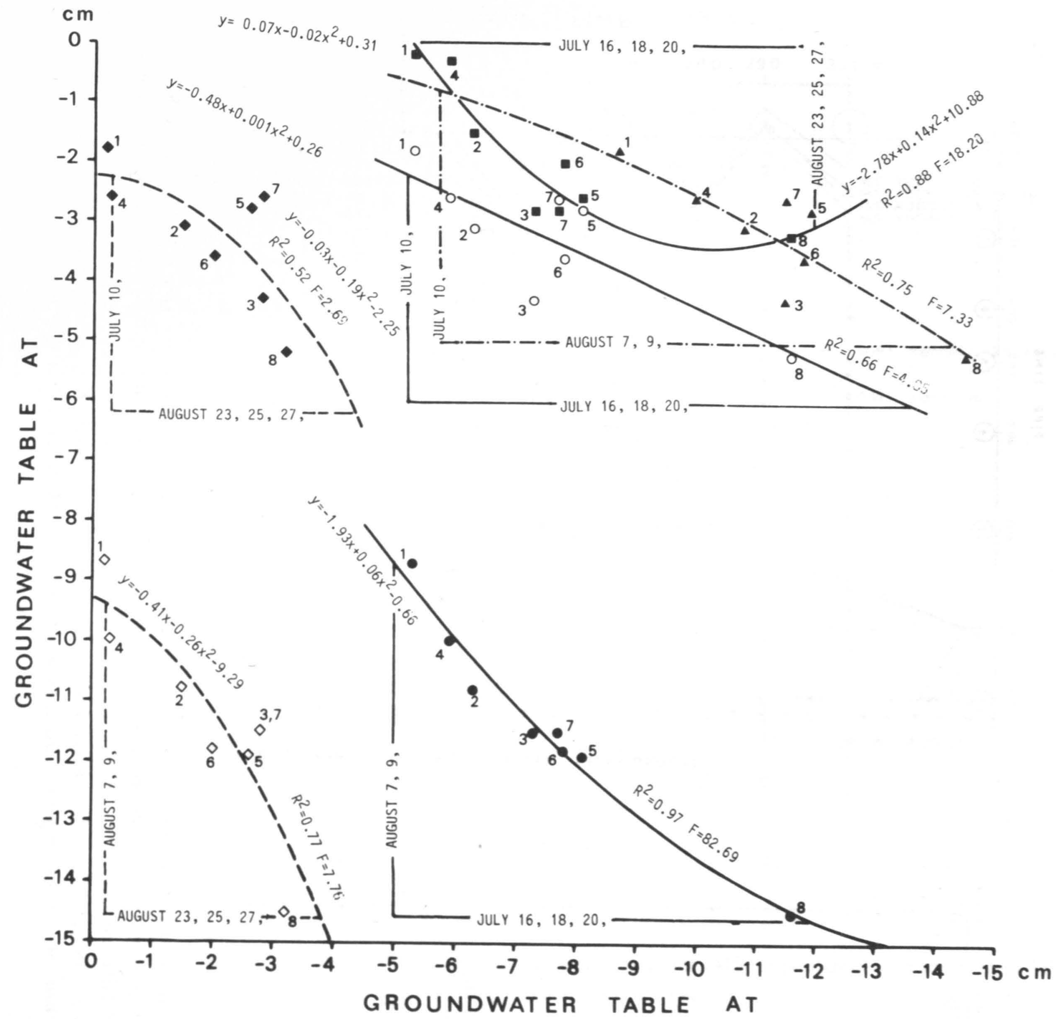

Fig. 17. Curvilinear relationship for the same sequence of pipes depicted in Fig. 16, drawn up on the basis of the same data. Compare with Fig. 16.

Kuva 17. Kuvassa 16 esitetyn putkisarjan käyräviivainen vuorosuhde, laadittu samasta aineistosta. Vertaa kuvaan 16.

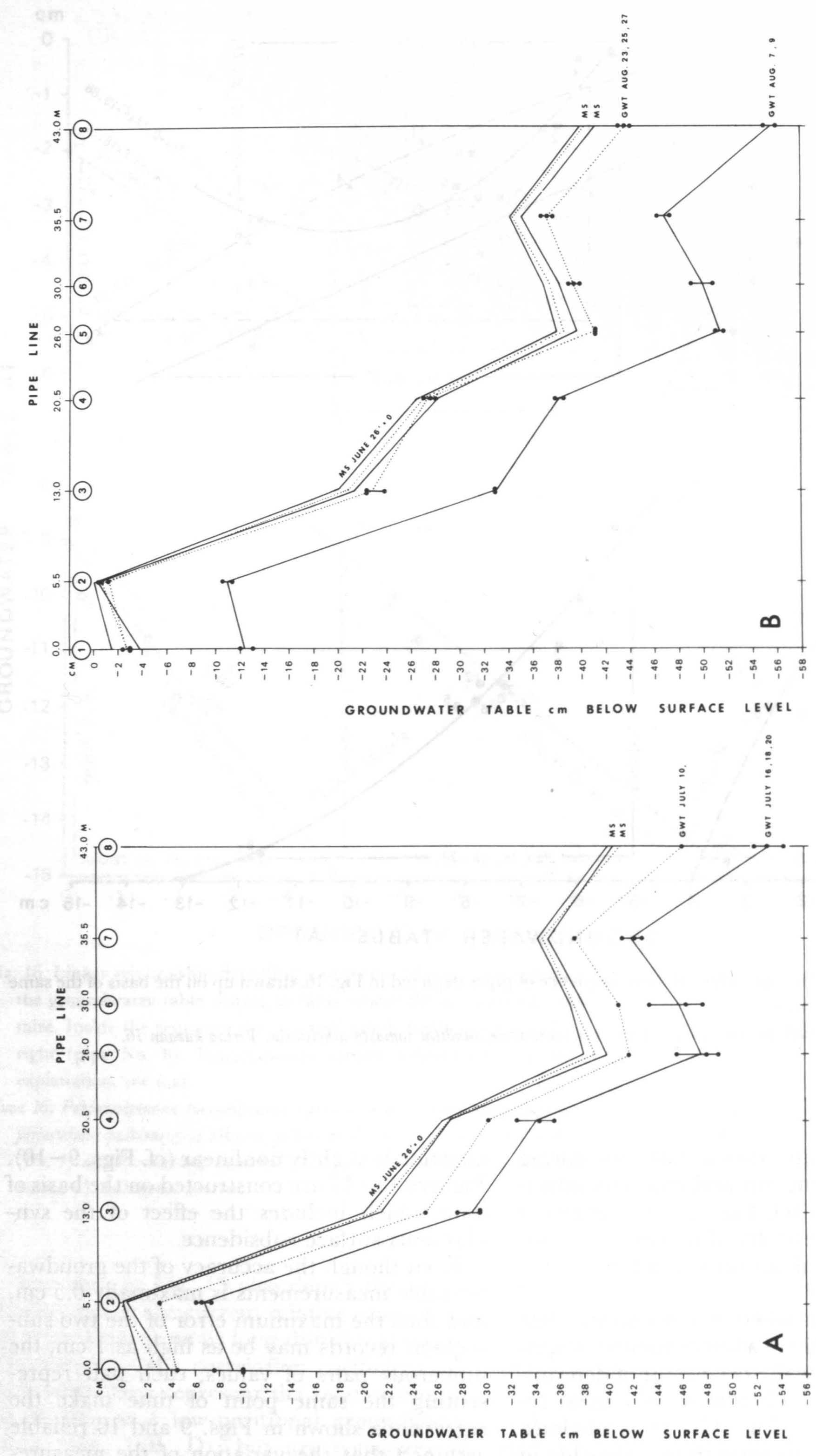

Fig. 18. Profile of the relative groundwater table (GWT) and that of the mire surface (MS) at periods of time where the GWT was exceptionally high or low; Koivupuro mire. All the profiles, except that representing date for July 10, are composed according to the mean values representing the 2 or 3-record (points) group of the reference period. Compare with Figs. 15−17. For details, see text.

Kuva 18. Pohjavesipinnan (GWT) ja suonpinnan (MS) profiili ajankohtina, jolloin pohjavesipinta oli epätavallisen korkealla tai matalalla. Koivupuron räme. Profiilit, lukuunottamatta 10.7. edustavaa, on laadittu 2 tai 3 havaintoa (= pisteet) käsittävien jaksojen keskiarvojen perusteella. Vertaa kuviin 15−17. Yksityiskohtaisemmin tekstissä.

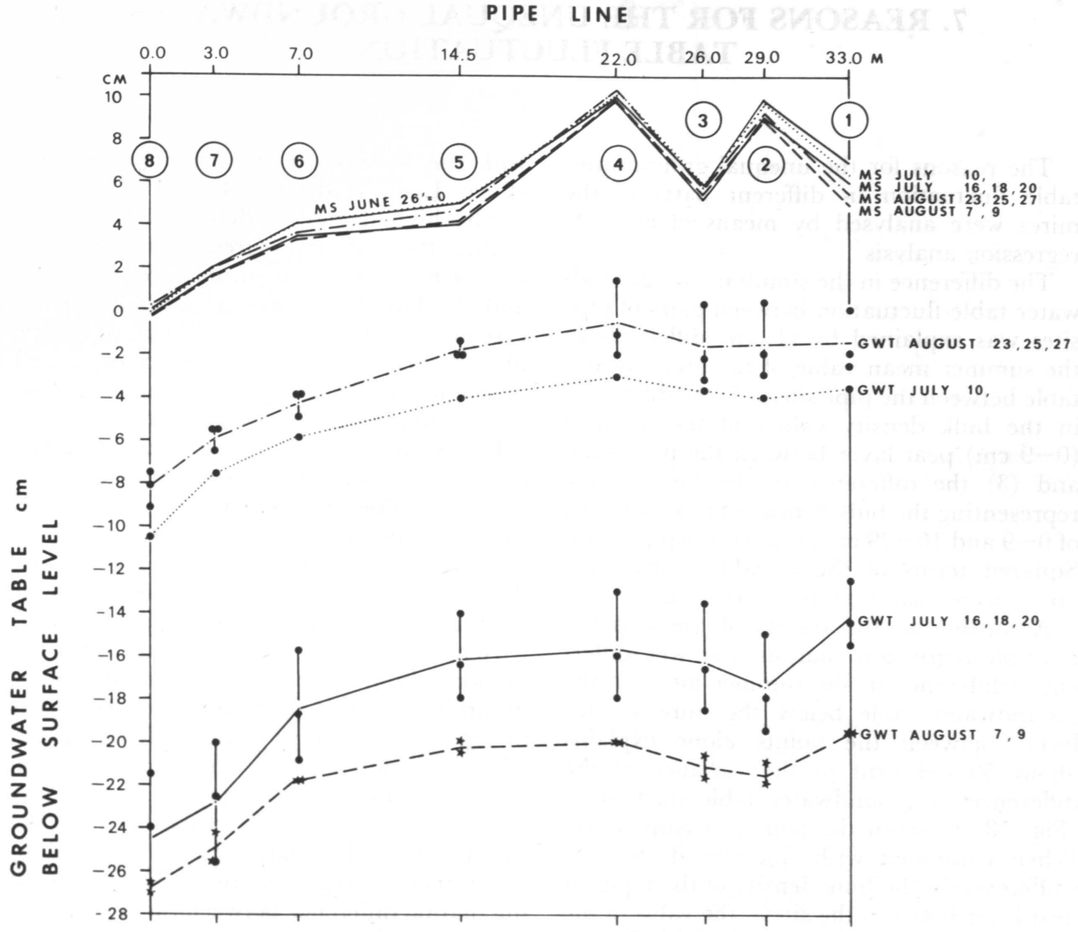

Fig. 19. Profile of the groundwater table (GWT) and that of the mire surface (MS) at periods of time where the GWT was exceptionally high or low. Suopuro mire. For explanations, see Fig. 18.

Kuva 19. Pohjavesipinnan (GWT) ja suonpinnan (MS) profiili jaksoina, jolloin pohjavesipinta oli epätavallisen korkealla tai matalalla. Suopuron räme. Selitykset kuvassa 18.

ment error follows the normal distribution curve, i.e. the regression graph representing all of the subsequent records does not include the measurement error. Furthermore, most of the graphs presented in Figs. 15−19 are based on the mean of several subsequent records, and the accuracy is estimated to be sufficient for the conclusions made.

Figures 18 and 19 shows the influence of the groundwater table fluctuation on the groundwater table gradient along the pipe lines on certain days (cf. Fig. 15). According to Figs. 18 and 19, the scale in which fluctuation takes place is slightly different at each site (cf. Fig. 15). In some cases the fluctuation even apparently takes place irregularly. As a whole, however, the form of the profile illustrating the groundwater table gradient remains almost constant despite the fact that the altitude level of the groundwater table varies.

7. REASONS FOR THE UNEQUAL GROUNDWATER TABLE FLUCTUATION

The reasons for the unequal groundwater table fluctuation in different parts of the mires were analysed by means of multiple regression analysis.

The difference in the simultaneous groundwater table fluctuation between pairs of pipe sites was explained by (1) the difference in the summer mean value of the groundwater table between the pipe sites, (2) the difference in the bulk density values of the topmost (0–9 cm) peat layer between the pipe sites, and (3) the difference in the mean value representing the bulk density of peat horizons of 0–9 and 10–29 cm between the pipe sites. Squared terms of the variables mentioned above were also used in the analysis.

According to the results of the stepwise multiple regression analysis, the 'wet'-difference (difference in the summer mean of the groundwater table below the mire surface level) between the points alone explains about 50 per cent of the variance of the difference in groundwater table fluctuation (Fig. 18) between the points in Koivupuro. When combined with the second variable (difference in the bulk density of the topmost peat layer between the sites), the value of the coefficient of determination is 0.57. In the case of the Koivupuro mire, including the third variable does not increase the value of the coefficient of determination of the regression model, nor does that of the squared terms.

In the case of the Suopuro mire, the coefficient of determination for the first-step regression model including only the first variable is poor (0.26). However, when the second variable is included it increases strongly (0.59; see Fig. 19). Together with all three variables the coefficient of determination for the model is 0.67 (in the Suopuro basin the groundwater table sinks strongly during dry periods). In this case, too, the squared terms do not increase the explanation degree of the model.

Using the deeper peat layer as an explaining variable together with the others may be fortuitous, however, because, in some cases, it correlates to a statistically significant degree with the second variable (multicollinearity; cf. e.g. Laine 1981: 46–54).

The high degree of determination representing the first-step regression model in the case of Koivupuro (rough microtopography), and the low degree of determination in the case of Suopuro (relatively flat microtopography), indicate the strong influence of a rough microtopography on the unequal simultaneous fluctuation in the groundwater table.

Cases where the linear regression coefficient representing regression between pairs of pipe sites does not differ to a statistically significant degree from the theoretical value 1 are presented as black squares in Figs. 20 and 21. Such cases are much more common in the Suopuro area than in the Koivupuro mire.

According to Fig. 20 (Koivupuro), the deviation from the equal, simultaneous, groundwater table fluctuation between pairs of pipe sites is always statistically significant when the difference in the summer mean values representing the pipe sites is more than 0.5 cm. If the difference between the mean values is less than 0.5 cm the probability of there being a statistically significant fluctuation difference between the sites is only 42 per cent.

The 'wet'-difference between the sites in the Suopuro mire (Fig. 21) must be much greater (about 1.3 cm) than that in the Koivupuro area since it is able to cause a statistically significant difference in the groundwater table fluctuation between the sites. On the other hand, the difference in the bulk density values (i.e. differences in the physical properties of the peat) between the sites is of great importance and in this case causes areal inequality in the groundwater table fluctuation. Analyses made on peat samples taken from sites representing the pipes along the lines clearly support this conclusion.

The multiple regression analyses discussed above were performed using data in which the effect of mire surface subsidence was not included. The same analyses were performed also using corrected data in which the vertical movements of the mire surface were taken

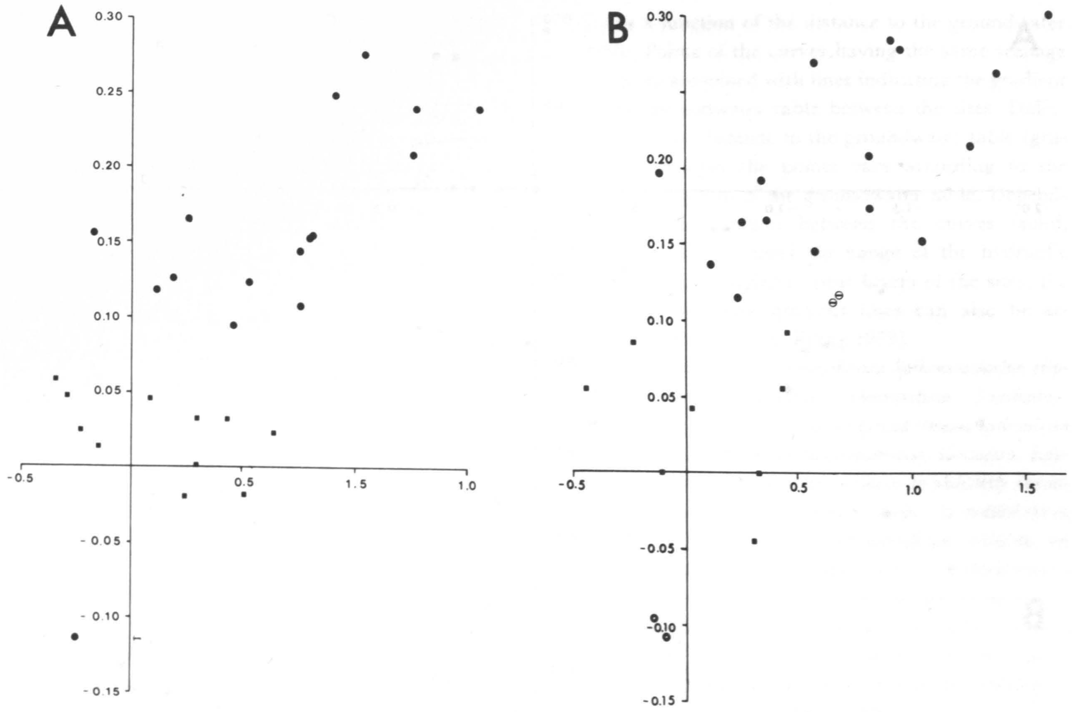

Fig. 20. Dependence of the deviation from the equal, simultaneous groundwater table fluctuation on the 'wet'-difference between the sites. Koivupuro mire. Points indicate a statistically significant difference in the fluctuation, squares represent cases without any statistical significance. (x-axis): difference in summer mean distance to the groundwater table between the sites (cm), (y-axix): deviation from the regression coefficient value 1. Simultaneous surface subsidence (A) not included, (B) included. For more detailed explanation, see text.

Kuva 20. Eri paikkojen pohjavesipinnan samanaikaisesta, yhtäläisestä korkeusvaihtelusta poikkeaman riippuvuus samojen paikkojen välisistä 'kosteus'eroista. Koivupuron räme. (piste): tilastollisesti merkitsevä ero pohjavesipinnan korkeusvaihtelussa paikkojen välillä, (neliö): ei tilastollisesti merkitsevää eroa paikkojen välillä. (x-akseli): pohjavesipinnan kesäkeskiarvon erotus paikkojen välillä, (y-akseli): poikkeama yhtäläistä vaihtelua osoittavan regressiokertoimen arvosta 1. (A) huomioimatta suonpinnan samanaikaista alenemista, (B) aleneminen huomioituna. Tarkemmin tekstissä.

into account. Results from these latter analyses did not differ to a statistically significant degree from the former results. The coefficient of determination for the latter analyses were 0.46 and 0.60 (Koivupuro; in the former analysis 0.50 and 0.57 respectively) and 0.28, 0.54 and 0.64 (Suopuro; in the former analysis 0.26, 0.59 and 0.67, respectively).

Naturally, the differences in the relative groundwater table altitude between 'dry' and 'wet' sites are the smaller, the higher the current position of the groundwater table. The maximum difference is reached already after the groundwater table remains at the average (normal) level; further sinking of the groundwater table does not further alter the situation.

This means that further sinking in the groundwater table is small at both 'dry' and 'wet' places in absolute terms, and the difference in the groundwater table altitude between the sites cannot be changed any further. Usually the bulk density, hydraulic conductivity, and the horizontal seepage of the peat horizon corresponding to the low groundwater table position are almost equal at both sites, and the difference in the groundwater table between the sites remains constant (see sheme, Fig. 22; cf. Ingram 1983:104, Table 3.6).

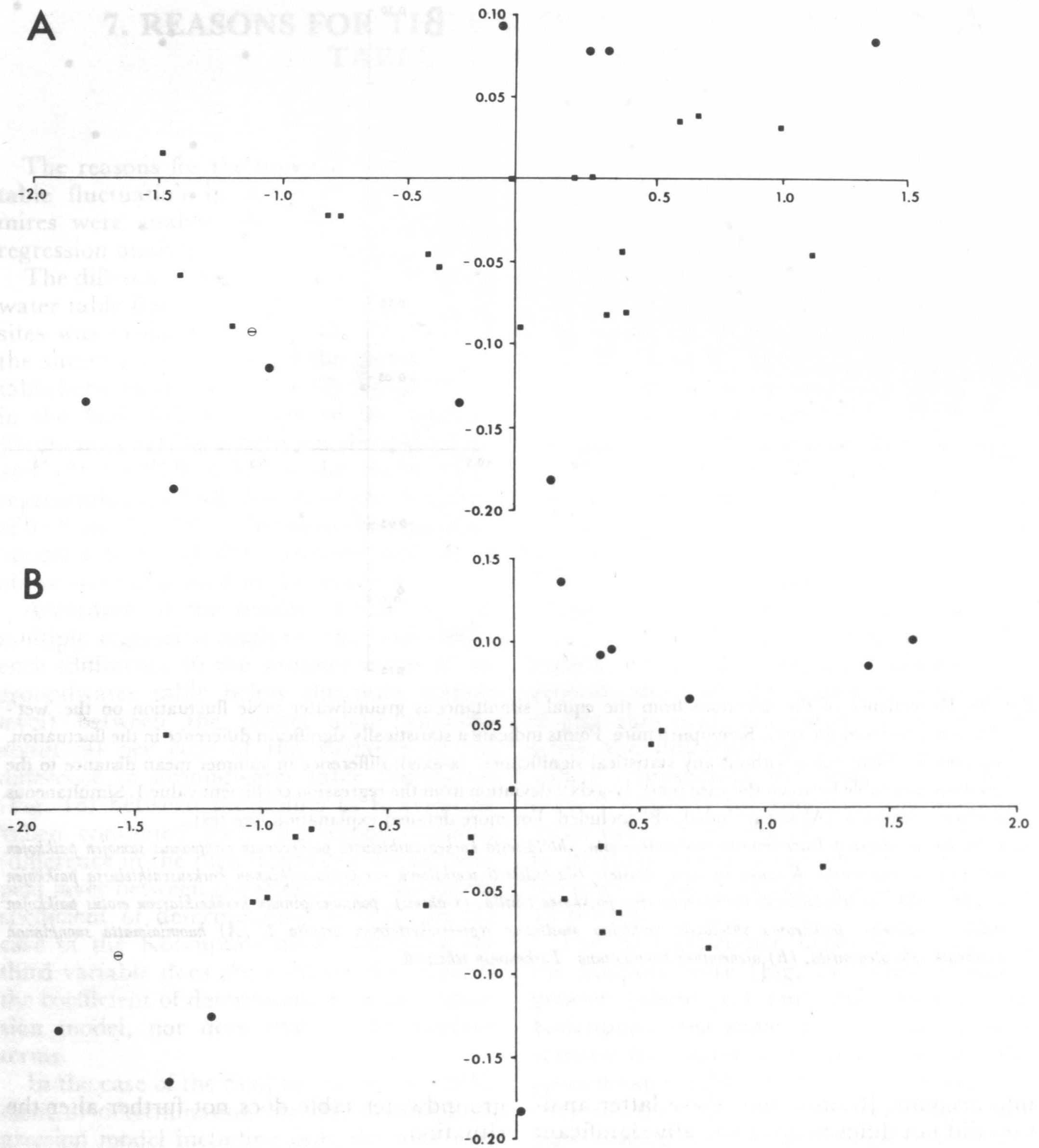

Fig. 21. Dependence of the deviation from the equal, simultaneous groundwater table fluctuation on the 'wet'-difference between the sites. Suopuro mire. (A) Simultaneous surface subsidence not included, (B) included. For explanations, see Fig. 20.

Kuva 21. Eri paikkojen pohjavesipinnan samanaikaisesta, yhtäläisestä korkeusvaihteluista poikkeaman riippuvuus samojen paikkojen välisistä 'kosteus'eroista. Suopuron räme. (A) huomioimatta suonpinnan samanaikaista alenemista, (B) aleneminen huomioituna. Muut selitykset kuvassa 20.

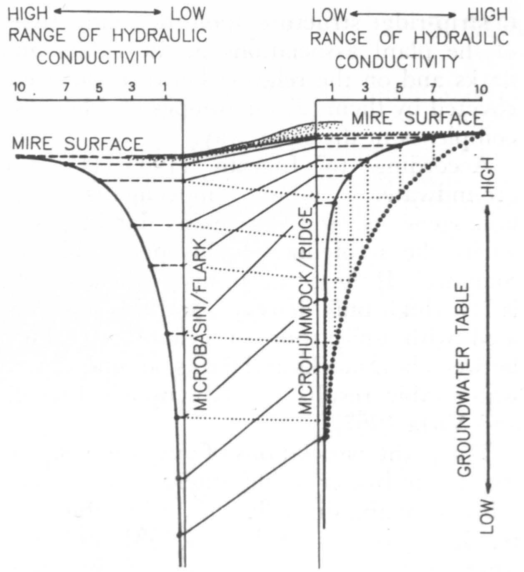

Fig. 22. Scheme depicting the dependence of the simultaneous groundwater table fluctuation on the intensity of subsurface runoff (seepage). Hypothetical gradient curves represent ranges of hydraulic conductivity as a function of the distance to the groundwater table. Points of the curves having the same seepage intensity are joined with lines indicating the gradient of the groundwater table between the sites. Differences in the distance to the groundwater table (gradient) between the points vary according to the altitude position of the groundwater table. Depending on the relation between the curves (solid, pointed) which reflect the range of the hydraulic conducticity in different peat layers of the sites, the groundwater table gradient lines can also be arranged differently (cf. Bragg 1978).

Kuva 22. Pohjavesipinnan samanaikaisen korkeusvaihtelun riippuvuus pintakerrosvalunnan intensiteetistä (suodanta); kaavio. Hypoteettisistä gradienttikäyristä ilmenee hydraulisen johtavuuden heikentyminen pohjavesipinnan alentuessa. Käyrien ne pisteet, joissa on sama suodanta on yhdistetty kuvaamaan pohjavesipinnan kaltevuutta rimpi- ja mätäskohtien välillä. Turpeen ollessa ominaisuuksiltaan erilaista eri paikoissa suota sekä lisäksi eri syvyyshorisonteissa pohjavesipinnan vaihtelussa eri paikkojen välillä syntyy eroja. Riippuen gradienttikäyrien muodosta ja keskinäisestä suhteesta (yhtenäinen viiva, pisteviiva) suon eri kohteiden turvekerroksissa pohjavesipinnan kaltevuus ko. kohteiden välillä saattaa myös vaihdella (vrt. Bragg 1978).

8. CONCLUSIONS

The small fluctuation differences in the groundwater table between 'dry' and 'wet' sites in the Koivupuro basin (2–3 cm) during periods when the groundwater table is high (after periods of rain, snowmelt) can be explained as follows.

The higher the groundwater table rises, the more effectively the water runs away because of the increased subsurface runoff (seepage). This, in turn, is caused by the fact that the pore volume, and hence the hydraulic conductivity, too, decreases with increasing depth (see e.g. Ivanov 1957, 1981: 198–200, Huikari 1960, Bay 1969, Korpijaakko and Radforth 1972, Päivänen 1973: 17–28; 1976, 1982, Ahti 1977). The same input volume of water is thus responsible for a smaller rise in the groundwater table altitude in the surface peat layer compared with that in the deep-lying peat horizon because the surplus water cannot escape from the denser deep layer as quickly as from the porous surface horizon (cf. Sjörs 1948: 42, Päivänen 1968: 20). The process is so also connected with the different ground water coefficient, or the water yield coefficient, studied e.g. by Heikurainen (1963, 1967, 1971), Päivänen (1964, 1968) and Boelter (1974; cf. also Laine 1981) which indicates the pore-volume distribution in the peat profile.

When the groundwater table lies exceptionally low, the further sinking of the groundwater table is almost the same both at 'dry' and 'wet' places. The explanation for this is that the lower the groundwater table sinks, the smaller is the subsurface runoff caused by the factors discussed above. Sinking of the groundwater table generally slows down the more progressively, the lower it sinks during a prolonged dry period due to the reduced seepage and the reduced evapotranspiration of the peat horizon corresponding to the current low groundwater table.

Heavy rain after a dry period is responsible for a strong rise in the groundwater table altitude only to a certain depth from the mire surface. After this horizon has been reached, the rise in the groundwater table generally slows down rapidly when the increased subsurface runoff begins to reduce the rise in the groundwater table. The reduction grows progressively the stronger, the higher the groundwater table rises (for changes in the horizontal seepage or subsurface runoff caused by changes in the hydraulic conductivity, see e.g. Virta 1967, Päivänen 1969, 1973, 1976, 1982, Ahti 1977, Ivanov 1981: 198–203, for the influence of the ground water coefficient, see e.g. Heikurainen 1963, Päivänen 1964, Laine 1981).

Correspondingly, the recession of the groundwater table is rapid only down to a certain depth, and after this horizon has been reached the sinking speed is reduced progressively (cf. e.g. Heikurainen 1971). It is also the reduction in evapotranspiration itself, caused by the increasing distance to the groundwater table, which strongly reduces the fall of the groundwater table, i.e. the capillary rise of the water is reduced when the groundwater table sinks.

According to Virta (1966) and Päivänen (1968;20, Fig. 2), the gradient of the groundwater table is concentrated on sites representing microhummocks or peat ridges when the groundwater table is exceptionally high in such a way that the microbasins or flarks become filled with water. Sjörs (1948:91) claims that the same situation also prevails during periods of low groundwater table position due to the different hydraulic conductivity of the peat of the various microforms. Ivanov (1981:201) has stated that "it is impossible to guarantee the constancy of the average groundwater table when seepage changes along the flowline and is not proportional to changes of slope unless there is a corresponding change in the hydraulic conductivity, i.e. unless the plant cover changes". Ivanov (1981:201) also presents equations depicting the dependence of the acrotelm's (=the active surface peat layer of the mire soil) conductivity in (1) microtopes of strip-ridge structure upon the conductivity of the plant associations in the ridges and flarks and on the relation between the areas covered by them (2) microtopes of ridge-pool complexes in the same way.

According to Ingram (1983:111), the groundwater table movements are homogeneous, and it remains flat in places where the acrotelm is highly permeable (cf. Suopuro). If the permeability of the acrotelm is low (high bulk density), and fluxes associated with infiltration or evaporation differ between hummocks and flarks, an undulating water table results (cf. Koivupuro, Fig. 22 and Virta 1967).

The plant associations of virgin mires, and the groundwater table interact with each other to maintain a flexible, reversible self-regulating system (cf. Ivanov 1981: 198–203) where both the configuration of the plant associations (indicated by microtopography) and the groundwater table show a tendency to maintain the state of equilibrium. The same interacting system also includes the remains of the former plant associations (now changed into peat) having different vegetation-derived properties, still reflecting the distribution of the former plant associations. Ivanov (1981:198) represents "the conversation of the similarity between the relief and the lower tier of the plant cover and that of the water table one of the clearest examples of the self-regulatory properties of mire systems, which is at the same time one of their fundamental characteristics. The similarity is maintained in the process of accumulation and modification of the relief of mire massifs." The mechanism of the self-regulatory process prevailing in virgin mires is examined in more detail by Ivanov (1981:198–204).

Equilibrium can never be reached exactly, however, for a number of factors always alter the situation, such as precipitation, evapotranspiration, runoff etc.

Although the simultaneous fluctuation in the groundwater table is not precisely the same at all points in a mire, the deviation from equal fluctuation is not great, and always remains inside limits of a few centimetres. Similar results are presented from other mires, too (e.g. by Sjörs 1948, Ivanov 1957, 1981, Päivänen 1968).

9. SUMMARY

In the present paper, the simultaneous fluctuation in the groundwater table at different sites of pine mires is examined and compared. The material for the study was collected during the growing season 1982 from two virgin pine mires situated in eastern Finland. The basic data is composed of observations, mainly registered every second day, three series for each mire.

The methods used in the study were correlation and regression techniques associated with statistical tests, and comparison of diagrammes. The main results were as follows:

The assumption generally used in hydrological computations, that the simultaneous fluctuation in the groundwater table in different parts of mires is equal, does not hold good in detail. Numerous cases were detected where the fluctuation at one place did not correspond to that at another site.

There was great variation between the mires studied. This, however, refers to the simultaneous fluctuation difference between various sites in the same mire.

The difference in the mean groundwater table between different sites in the mire always remains quite small (a few centimetres) despite its possible statistical significance.

During periods when the groundwater table is high, differences in the relative groundwater table altitude are smaller than those registered during periods when the groundwater table is low; i.e. the gradient of the groundwater table is dependent on its relative altitude position.

The simultaneous fluctuation in the groundwater table is generally stronger on dry sites (sites where the groundwater table is generally low) compared with that on wet sites (sites where the groundwater table is generally near to the mire surface). This indicates the influence of the microtopography.

The simultaneous fluctuation in the groundwater table is dependent on both the relative altitude difference, and the difference in the hydraulic conductivity of the peat (expressed by means of bulk density) between the sites.

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SELOSTE

POHJAVESIPINNAN SAMANAIKAINEN KORKEUSVAIHTELU LUONNONTILAISTEN RÄMEIDEN ERI OSISSA

Tutkimuksessa vertaillaan soiden eri osissa tapahtuvien pohjavesipinnan samanaikaisten vaihtelujen suuruutta toisiinsa kahdella luonnontilaisella rämeellä. Tutkimuksen päätulokset ovat seuraavat:

Pohjavesipinnan samanaikaiset korkeusvaihtelut luonnontilaisten rämeiden eri kohteissa ovat aina melko vähäisiä (muutamia senttimetrejä), joskin vaihtelussa samankin suon eri kohteiden välillä saattaa esiintyä tilastollisesti merkitseviä eroja.

Eri kohteiden pohjavesipinnan vaihtelun yhtäläisyysasteessa esiintyy suurta vaihtelua eri soilla.

Ajankohtina, jolloin pohjavesi on lähellä suon pintaa erot pohjavesipinnan vaihtelussa rämeiden eri kohteiden välillä ovat pienempiä kuin ajankohtina, jolloin pohjavesi on syvällä, ts. pohjavesipinnan kaltevuus on riippuvainen siitä, kuinka syvällä pohjavesipinta kulloinkin yleisesti on.

Pohjavesipinnan samanaikainen vaihtelu on yleensä voimakkaampaa kuivilla paikoilla (kohteissa, missä pohjavesipinta yleensä on syvällä) kuin kosteilla paikoilla (paikoilla, missä pohjavesi yleensä on lähellä suon pintaa).

Pohjavesipinnan samanaikainen vaihtelu riippuu sekä keskinäisistä korkeuseroista että pintaturpeen tiheysarvojen eroista eri kohteiden välillä.