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Helsinki 1998

ISSN 0039-5471
Suo 49(1): 13–21

Impact of precipitation on the water table level of different ombrotrophic raised bog complexes, central Estonia

Sadannan vaikutus vedenpinnan tasoon kohosuolla

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The impact of precipitation on the water table level of different complexes on an ombrotrophic raised bog during a year (long-term effect) and a rain shower (short-term effect), was investigated on the basis of the data collected in the Männikjärve raised bog, Central Estonia, over the period of 1956–1991. The regression analysis showed that the effect of precipitation on the mean annual level of the water table depended on the bog complex and time-span considered. In the long-term scale, the mean annual water table level depended strongly on the water table level of the previous year. The yearly amount of precipitation affected the water table level of the current year less. These effects were greater in the central pool-ridge complex than in the marginal pine bog forest. On the short-term scale, prerainfall water level affected the water level rise less than the amount of rainfall. The water level rise depended on the prerainfall water level in the central part of the bog ($R^2 = 0.22$), but not in the marginal pine bog forest ($R^2 = 0.04$). The effect of rainfall was of greater importance, explaining as much as 67–75% of the variation in the water level rise.

Key words: precipitation, raised bog, water table level

INTRODUCTION

In an ombrotrophic raised bog, the temporal pattern of water level fluctuation is a dominating factor for the growth of mire vegetation. The annual mean values of the water level may not be as significant to the development and maintenance of raised bogs as seasonal values are (Wheeler & Shaw 1995).

The water table fluctuates because of disproportion in the influx and efflux of water. Over different time spans, the precipitation, the only influx element in the water balance of an ombrotrophic raised bog, affects the water level differently due to the changing role of the efflux elements. Ivanov (1981) concludes that on an annual basis, runoff is the main element of the bog water balance reacting to the variation in influx. The evapotranspiration, which depends mainly on radiation, is quite stable in different years. At the same time, the different plant cover of bog complexes affects the runoff (Romanova 1960, Saveljeva 1991) and evapotranspiration (Romanov 1953, Kalyuzhnyi 1974, Molen & Wijmstra 1992, and others). In short periods, like a single rain shower, the effect of precipitation upon the water table level depends mainly on the capillary and osmotic moisture content of the unsaturated peat layer and on the water level before the rain (Ivanov 1981).

The aim of the present study was to investigate the influence of precipitation on the water table regime of a raised bog in different bog complexes over different time spans as a year and a single rain shower.

MATERIAL AND METHODS

Study area

The Männikjärve ombrotrophic raised bog (176 ha) is a rather isolated part of the Endla mire system (25 110 ha) located in Central Estonia. It is a typical convex bog with dominating hollow-ridge and pool-ridge complexes in the mire expanse and with the pine bog forest on the bog margin (Fig. 1). The margins of the bog are to some extent influenced by drainage. In 1914, ditches were dug in the NE part of the Männikjärve bog. In 1963–1964 the ditches around the bog were deepened and in 1971, the polder building on the SE shore of Lake Männikjärve caused a certain water level rise in the lake level. By today, the ditches have mostly become overgrown with *Sphagnum* and their influence on the bog water regime has diminished.

Measurements

Hydrological and meteorological measurements in the Männikjärve bog have been conducted by the staff of the Tooma Mire Station since 1952. The data have been published in the yearbooks of the Mire Station (Materijaly … 1991).

During the whole year, the daily totals of precipitation are recorded in the meteorological station about 1 km east of the bog. The measurements are performed at a height of 2 m, using the Tretjakov rain-gauge. The beginning and the end of the rain (time) and the amount of precipitation (mm) are recorded automatically by the pluviographs "P-2" in the pool- and hollow-ridge complexes and in the pine bog forest (Fig. 1). The measurement accuracy is ± 0.1 mm (Nastavlenie … 1990).

Annually the water level (cm below the bog surface) is measured every three days in special water level wells (Nastavlenie … 1990) located in the ridges of pool- and hollow-ridge complexes and in the pine bog forest (Fig. 1). The measurement accuracy is ± 5 mm. The beginning and the end of the water level rise (time), the extent of the water level rise (mm) and the prerainfall water level are recorded by the water level recorder "Valdai", (accuracy is ± 1 mm (Nastavlenie … 1990)), installed in the hummock close to the pluviographs.

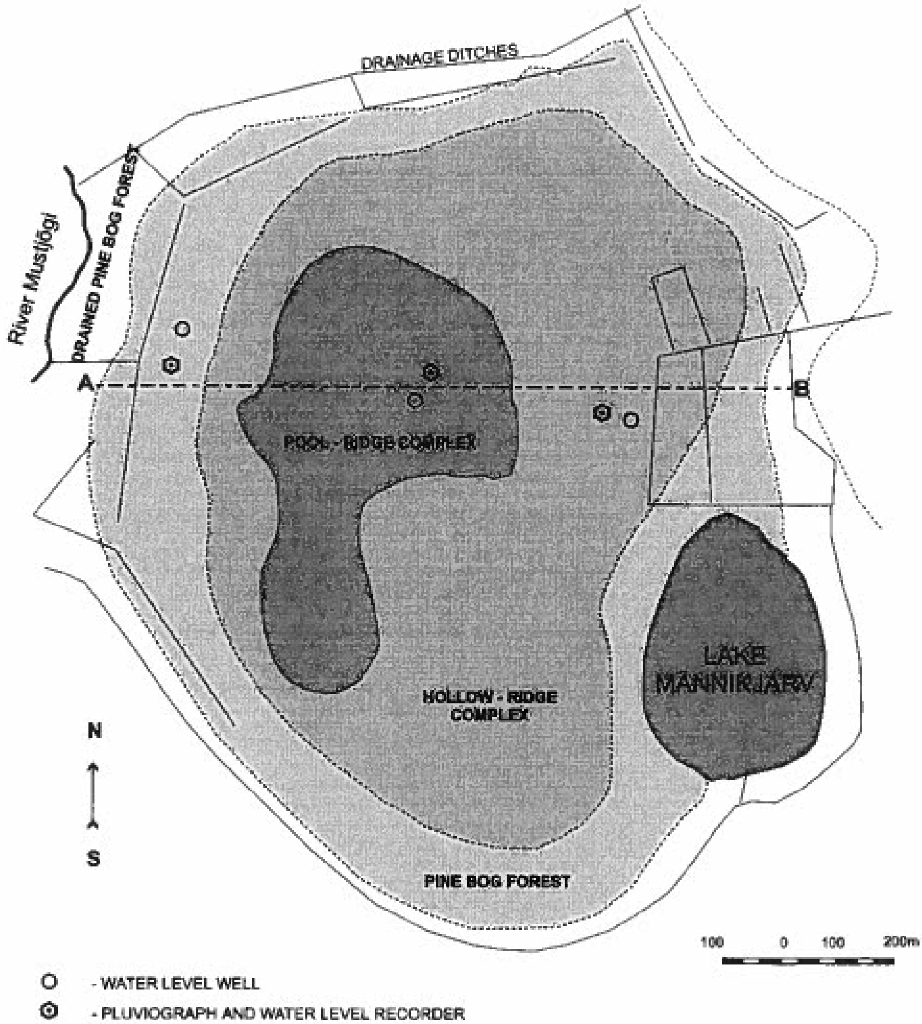
Data analysis

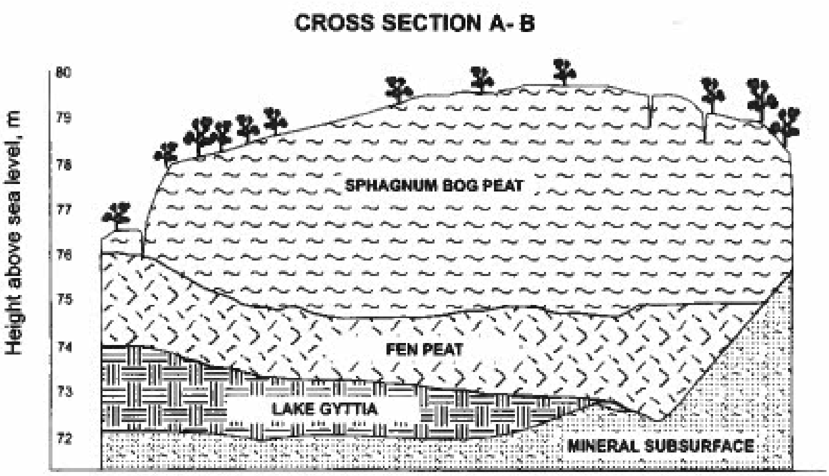
The long-term effect was investigated on the basis of annual precipitation and mean yearly water table level for the period from 1956 to 1991. The investigated 36-year period was considered long enough to reveal the effect of precipitation on the water table level.

Examination of the short-term influence of precipitation on the water level was based on the measurements made during single rain showers. Data on all rain showers, recorded from the occasionally chosen vegetative season of 1983, were used in this work. On the basis of these data, the duration of the rainfall (min), the beginning and the end of the water level rise after the beginning and the end of the rain (min) were calculated. To determine the mean values of the water level rise resulting from 1 mm precipitation in different bog complexes, the mean water level rise was divided by the mean amount of precipitation. The corresponding mean values were calculated to find out the mean beginning and the end of the water level

Fig. 1 (Opposite). Distribution of the main complexes and location of the hydrological monitoring sites, and a schematic cross-section (W–E) of the Männikjärve bog (after Materialy … 1986).

Kuva 1 (Oikealla). Männikjärvensuon rakenne sekä hydrologisten mittauspisteiden sijainti.


DRAINAGE DITCHES
River Mustjõgi
DRAINED PINE BOG FOREST
A
B
POOL - RIDGE COMPLEX
HOLLOW - RIDGE COMPLEX
LAKE MÄNNIKJÄRV
PINE BOG FOREST
N
S
100 0 100 200m
- WATER LEVEL WELL
- PLUVIOGRAPH AND WATER LEVEL RECORDER


CROSS SECTION A- B
Height above sea level, m
80
79
78
77
76
75
74
73
72
SPHAGNUM BOG PEAT
FEN PEAT
LAKE GYTTIA
MINERAL SUBSURFACE

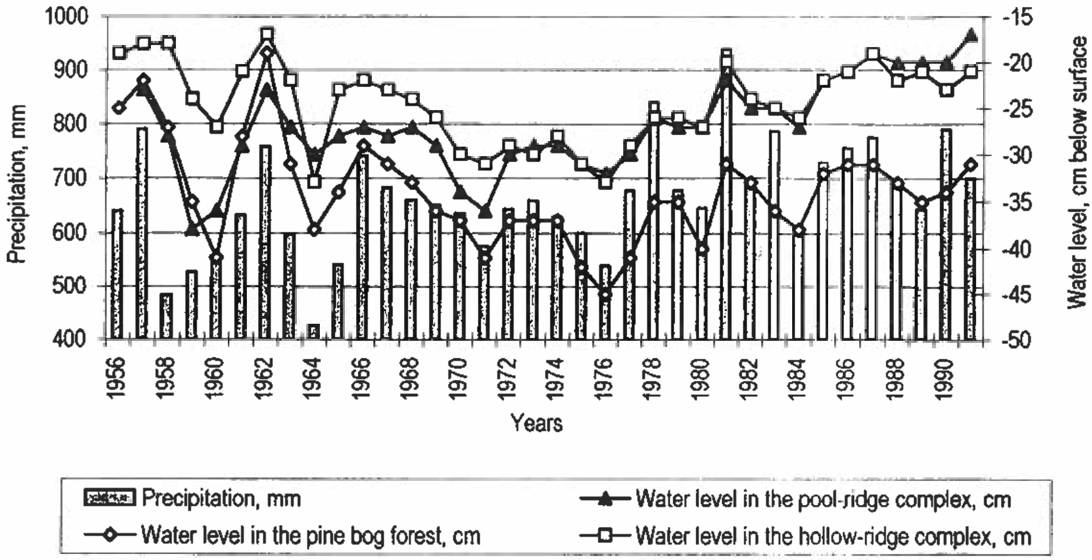


Fig. 2. The mean annual water level (cm) in the different bog complexes and the yearly amount of precipitation (mm).

Kuva 2. Vedenpinnan tason vuotuiset keskiarvot suon eri osissa (cm) sekä vuotuinen kokonaissademäärä (mm) tutkimusjaksolla.

rise after the beginning and the end of the rain in different complexes. The data were standardised and transformed for statistical analysis.

RESULTS

The average annual precipitation was 660 mm in 1956–1991 (max. 939, min. 426 mm). In the Männikjärve bog, the average water table level in the ridges of the hollow-ridge complex was 25 cm (max. 17, min. 33 cm) below the bog surface, in the pool-ridge complex 27 cm (max. 17, min. 38 cm) and in the pine bog forest on the mire margin 34 cm (max. 19, min. 45 cm) below the bog surface.

The fluctuation of the mean annual water table level followed quite well the run of the yearly amount of precipitation, but was also influenced by the water table level of the previous year (Fig. 2). The regression analysis showed that the effect of the water level of the previous year was even greater than that of the amount of precipitation of the current year (Equations 1–6). Depending on the bog complex, the water level of the previous year explained 30–55% of the variation of the water table level while the yearly amount of precipitation accounted for 15–40%.

$$WTL_{\text{pool-ridge complex}} = -58 + 0.78 * WTL_{\text{previous year}} \quad (R^2 = 0.55) \tag{1}$$

$$WTL_{\text{hollow-ridge complex}} = -10 + 0.59 * WTL_{\text{previous year}} \quad (R^2 = 0.35) \tag{2}$$

$$WTL_{\text{pine bog forest}} = -16 + 0.53 * WTL_{\text{previous year}} \quad (R^2 = 0.30) \tag{3}$$

$$WTL_{\text{pool-ridge complex}} = -47 + 0.30 * PREC \quad (R^2 = 0.41) \tag{4}$$

$$WTL_{\text{hollow-ridge complex}} = -37 + 0.19 * PREC \quad (R^2 = 0.20) \tag{5}$$

$$WTL_{\text{pine bog forest}} = -48 + 0.21 * PREC \quad (R^2 = 0.15) \tag{6}$$

WTL = water table level, PREC = precipitation of the current year

The water table level could be best predicted using both the amount of precipitation and the average water table level of the previous year (Equations 7–9). In different bog complexes these parameters could explain up to 74% of the original variability.

$$WTL_{\text{pool-ridge complex}} = -24 + 0.22 * PREC + 0.65 * WTL_{\text{previous year}} \quad (R^2 = 0.75) \tag{7}$$

$$WTL_{\text{hollow-ridge complex}} = -23 + 0.18 * PREC + 0.57 * WTL_{\text{previous year}} \quad (R^2 = 0.55) \tag{8}$$

$$WTL_{\text{pine bog forest}} = -31 + 0.26 * PREC + 0.60 * WTL_{\text{previous year}} \quad (R^2 = 0.55) \tag{9}$$

All these relationships were strongest in the pool-ridge complex and weakest in the pine bog forest on the mire fringe.

Human activities could also influence the bog water level. Certain fluctuation may have been caused by the ditching in 1963–1964 and polder building in 1971, but this is not considered in the present work.

In short periods, during a rainfall, the effect of precipitation on the water level differed in different bog complexes. Comparison of the calculated mean values of the water level rise per 1 mm precipitation revealed only small differences around some millimetres. Although the mean water level rise was bigger in the hollow-ridge complex than in the pine bog forest and in the pool-ridge complex, the variation of water level rise of different complexes was remarkable (Table 1).

The water level started to rise simultaneously in all bog complexes considered — about 25 min after the beginning of the rain. The histograms in Fig. 3 show that the water level began to rise 10 min after the start of the rainfall in 33% of cases. The start of the water level rise did not correlate with the prerainfall water level ($p > 0.05$).

Differences between bog complexes were best observed in the duration of water level rise after the end of the rainfall. The histograms in Fig. 4 show that the water level rise ended most rapidly in the pool-ridge complex — 10 min after the end of the rainfall in 60% of cases. In the hollow-ridge complex this time was recorded in only 25% of the cases. The water level rise lasted longer in the marginal pine bog forest, where during one hour the water level rise stopped in 22% of the cases only.

The regression analysis showed that in pool-ridge and hollow-ridge complexes the water level rise may somewhat depend on the prerainfall water level (Equations 10–11), but no dependence was observed in the pine bog forest (Equation 12). The results of calculations indicated that there the rainfall was the most important factor, explaining as much as 76% of the variation in the water level rise (Equation 15). In the hollow-ridge complex the impact of rainfall was somewhat smaller, explaining 72% and in the pool-ridge complex only 67% of variability (Equations 13–14).

$$WLR_{\text{pool-ridge complex}} = -8.05 + 0.62 * \text{Prev WT} \quad (R^2 = 0.22) \tag{10}$$

$$WLR_{\text{hollow-ridge complex}} = -3.70 + 0.46 * \text{Prev WT} \quad (R^2 = 0.23) \tag{11}$$

$$WLR_{\text{pine bog forest}} = -0.76 + 1.27 * \text{Prev WT} \quad (R^2 = 0.04) \tag{12}$$

Table 1. Impact of a rain shower on the water level in different bog complexes (mean ± standard deviation, n = number of observations).

Taulukko 1. Yksittäisen sadetapahtuman vaikutus vedenpinnan tasoon suon eri osissa (keskiarvo ± keskihajonta, n = havaintojen määrä).

	Pool-ridge complex (n = 53)	Hollow-ridge complex (n = 100)	Pine bog forest (n = 42)
Water level rise due to 1 mm precipitation, mm *1 mm sadannan aiheuttama vedenpinnan tason nousu, mm*	3 ± 2	6 ± 4	4 ± 2
Beginning of water level rise after the start of the rain, min *Vedenpinnan tason nousun alkaminen sateen alun jälkeen, min*	24 ± 25	26 ± 24	27 ± 31
End of water level rise after the end of the rain, min *Vedenpinnan tason nousun päättyminen sateen päättymisen jälkeen, min*	27 ± 44	84 ± 166	109 ± 64
Mean water level before rain shower, mm *Keskimääräinen vedenpinnan taso ennen sadetta, mm*	– 336 ± 58	– 273 ± 112	– 467 ± 84

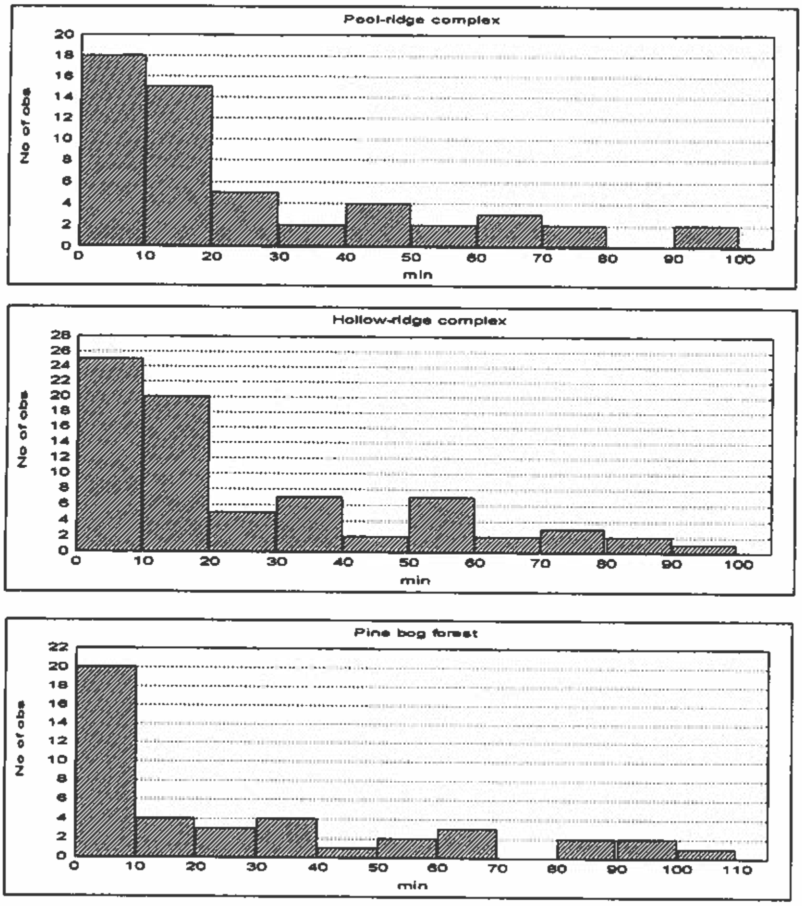


Fig. 3. Histograms of the start of the water level rise after the start of the rainfall in the different bog complexes.

Kuva 3. Histogrammit vedenpinnan tason nousun alkamisajankohdasta (minuutteina sadetapahtuman alusta) suon eri osissa.

$$WLR_{\text{pool-ridge complex}} = -0.01 + 1.62 * PREC \ (R^2 = 0.68) \quad (13)$$

$$WLR_{\text{hollow-ridge complex}} = -0.05 + 1.99 * PREC \ (R^2 = 0.73) \quad (14)$$

$$WLR_{\text{pine bog forest}} = -0.16 + 1.96 * PREC \ (R^2 = 0.76) \quad (15)$$

WLR = water level rise, Prev WT = prerainfall water level, PREC = precipitation during the rainfall event.

Precipitation and prerainfall water level together explained 82–85% of the total variability (Equations 16–18).

$$WLR_{\text{pool-ridge complex}} = -8.933 + 1.53 * PREC + 0.499 * Prev\ WT \ (R^2 = 0.82) \quad (16)$$

$$WLR_{\text{hollow-ridge complex}} = -4.919 + 1.84 * PREC + 0.317 * Prev\ WT \ (R^2 = 0.83) \quad (17)$$

$$WLR_{\text{pine bog forest}} = -8.604 + 2.02 * PREC + 0.384 * Prev\ WT \ (R^2 = 0.85) \quad (18)$$

DISCUSSION

The relationships between a bog water level and precipitation are rather diverse being, besides the spatial differences, highly dependent on the time span considered.

The yearly amount of precipitation is assumed to affect the mean annual water table level. Accordingly to Valk (1988), the mean water table level of the current year is also connected with the mean water table level of the previous year. The data from the Männikjärve bog indicate that the mean annual water table level is even more dependent on that of the previous year than on the amount of precipitation of the current year (Equations 1–6).

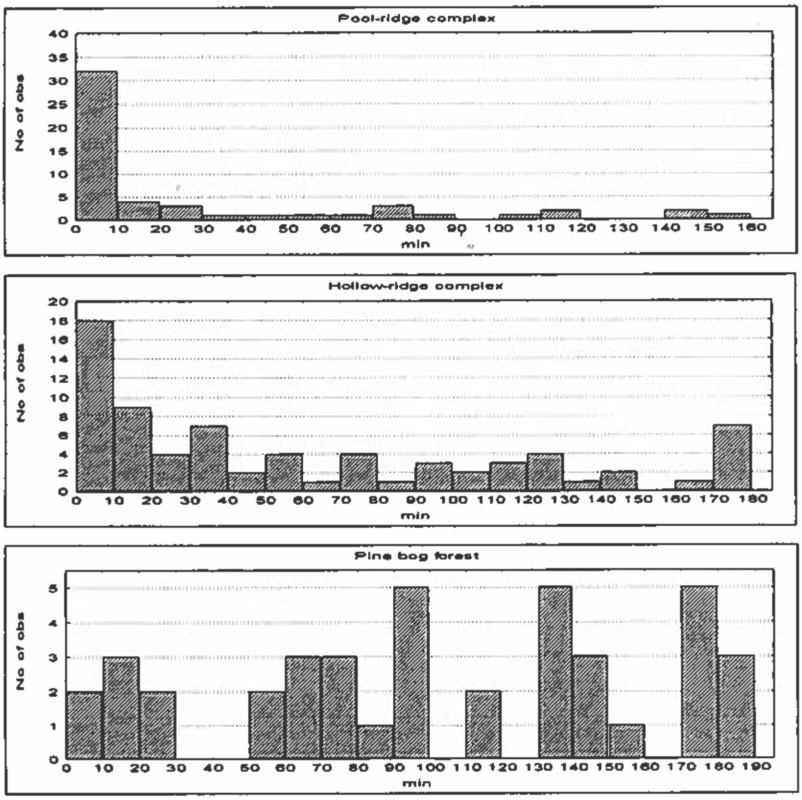


Fig. 4. Histograms of the end of the water level rise after the end of the rainfall in the different bog complexes.

Kuva 4. Histogrammit vedenpinnan tason nousun päättymisajankohdasta (minuutteina sadetapahtuman päättymisestä) suon eri osissa.

At the same time, the effect of the water table level of the previous year on the mean annual water table level may vary in the bog complexes considered. The pool-ridge and hollow-ridge complexes are located in the central part of the bog and have a very gently sloping bog surface, but the pine bog forest is growing on the bog margin with a rather steep slope (Fig. 1). The runoff from a bog depends markedly on the slope of the bog surface and on the hydraulic conductivity of underlying peat (Ivanov 1953, 1981, Ingram 1992, and others). Vomperski et al. (1988) and van der Molen et al. (1992) have concluded that the hummock-hollow complexes occur in the parts of a bog with reduced water flow. The calculations show that the flow rate might be lowest in the hummock-hollow complex (ca. 0.04 mm*hr^{-1}) and highest on the transition from the mire expanse to the disturbed margin (ca. 31.0 mm*hr^{-1}) (van der Molen et al. 1992). Therefore, we may suppose that, due to the slower water movement in the central pool- and hollow-ridge complexes, the water table level of the previous year affects the water table level of the current year more in the central part of the bog than on the slope. For the same reason, the impact of precipitation on the mean annual water table level is greater in the central part than on the bog slope. The weaker effect of precipitation and water table level of the previous year on the pine bog forest compared with the pool-ridge complex could also be explained by the influence of the surrounding area of the bog on the water regime of the marginal pine bog forest. Supposedly, the ditches around the Männikjärve bog may somewhat influence the water table level in the pine bog, but they do not affect the water table level in the pool-ridge complex. Also, the damming and the dredging of the Mustjõgi River (see Fig. 1), whose catchment area includes also the Männikjärve bog, may have certain impact on the water table level of the marginal pine bog forest.

As the mean annual water table level and the effect of yearly precipitation differ in the bog complexes considered, we may suppose that the impact of precipitation on the water level depends on the bog complex also in the short-term scale — during a rainfall. The water table is higher in hollow- and pool-ridge complexes than in the marginal pine bog forest. This allows us to assume that the water level may start to rise sooner in the complexes located in the central part of the bog, where the distance from the bog surface to the water level is shorter in comparsion with the marginal pine bog forest. Also, the amount of water needed to moisten the upper peat layer may be smaller in the central part. However, the data from the Männikjärve bog indicate that the water level starts to rise at about the same time in all bog complexes considered: on average, 20 min after the beginning of the rain (Fig. 3). This could be due to a higher vertical hydraulic conductivity of the acrotelm in the marginal pine bog forest (Ivanov 1953, Ingram 1983). At the same time, the greater duration of the water level rise after the end of the rain in the pine bog forest (Fig. 4) could be explained by the marginal position of the forest. As the water flow from the central parts of the bog to its margins takes a certain time, the effect of rainfall lasts longer in the marginal areas.

As shown above, the water table level depends mainly on the water table level of the previous year in an annual scale. Thus, we could suppose that the rise of the water level during a rainfall is also related to the prerainfall water level. The data from the Männikjärve bog show that such dependence is very low (Equations 10–12). Depending mainly on the amount of precipitation (Equations 13–15), the moisture content of the peat layer above the water level could notably affect the water level rise (Ivanov 1981). If the pores in the acrotelm are airfilled, most of the rainwater fills the empty pores and the water level may not rise at all. If at the same water level the moisture content in the acrotelm is high, i.e. the pores are at least partly filled with water, the same amount of rainfall may raise the water level remarkably.

ACKNOWLEDGEMENTS

I thank Dr. Mati Ilomets for discussions and comments on the manuscript, Mr. Andres Kimmel for valuable advice and Mr. Edgar Karofeld for helpful reviews of this manuscript. This study was partly supported by the Estonian Science Foundation (Grant No.1592) and EC project PL 930051.

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TIIVISTELMÄ:

Sadannan vaikutus vedenpinnan tasoon kohosuolla

Sadannan vaikutusta kohosuon eri osien vedenpinnan tasoon tutkittiin vuosi- ja sadetapahtumatasolla. Tutkimuksessa käytettiin Keski-Virossa sijaitsevalta Männikjärvensuolta vuosina 1956–1991 kerättyä aineistoa.

Tarkastelujakson vuotuinen kokonaissademäärä oli keskimäärin 660 mm (vaihteluväli 426–939 mm). Vedenpinnan taso oli suon keskiosan kermi-kuljuvyöhykkeellä keskimäärin 25 cm syvyydessä (17–33 cm; mitattu kermistä), kermi-allikkovyöhykkeellä 27 cm (17–38 cm; mitattu kermistä) ja suon reunaluisun rämeellä 34 cm (19–45 cm) syvyydessä.

Vedenpinnan tason vuotuinen keskiarvo noudatteli melko tarkoin vuotuisen kokonaissademäärän vaihtelua, mutta regressioanalyysin perusteella edellisen vuoden vedenpinnan tasolla oli siihen vielä jonkin verran voimakkaampi vaikutus. Käyttämällä selittävinä muuttujina sekä saman vuoden sademäärää että edellisen vuoden vedenpinnan tasoa voitiin selittää parhaimmillaan 74% vedenpinnan tason keskiarvon vuotuisesta vaihtelusta. Parhaiten vedenpinnan tason vaihtelua voitiin selittää kohosuon keskiosan kermi-allikkovyöhykkeellä ja heikoimmin suon reunaluisun rämeellä.

Tarkasteltaessa yksittäisiä sadetapauksia sademäärä vaikutti vedenpinnan tason nousuun enemmän kuin sadetta edeltävä vedenpinnan taso. Sademäärä selitti vedenpinnan tason nousun vaihtelusta 67–75%. Sadetta edeltävällä vedenpinnan tasolla oli merkitystä vain reunaluisun rämeellä.

(Toimituksen käännös)

Received 20.9.1996, accepted 2.3.1998