Determination of Vertical Water Exchange in Forest Mires Underlain by Mineral Strata

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In the article it is shown, that when ground water is fluctuated in the forest mires of intermediate and upper types, changes occur not only in thickness of peat of fully saturated with water, but also in the coefficient of filtration and piezometrical pressure of gravitational water, which is in the deposit. Given these conditions and by using elementary theory of filtration of water flowing in heterogeneous grounds, we proposed original formulae for determination of water exchange in forest mires with underlying mineral strata. It was determined, that the more intensive the forest mires of intermediate and upper types, are drained , the weaker the vertical (ΔQ) water exchange occurs in them. Also it was ascertained, that in Kuras hydrological station (Kaunas reg.) in forest mires of intermediate and upper types value ΔQ on average makes up 16-23 mm over vegetation period (May 13-15 - October 26-31 days) or 4.2-6.0% from the amount of precipitation.

Key words: coefficients of filtration, intensity of drainage, forest mires, ground water level, vertical water exchange

Introduction

Estimation of the rate of water exchange in the peat deposit of peatlands underlain by mineral strata and a water-bearing stratum is an important task for hydrological calculations for providing foundation for the schemes of drainage and regulation of water regime of wetlands and for determination of the role of peatlands in feeding water-bearing layers with underground water.

Besides, the speed of water exchange in mire's water affects the genesis, development and decomposition of organic matter of the peat stratum and in general, the circulation of greenhouse gas (Charman, Aravena, Warner, 1994; Siegel, Reeve, Glaser, Romanovicz, 1995; Sirin, Shumov, Vlasova, 1997).

Exact direct estimation of this component of wetland water balance is labour consuming and demands organization of hydrogeological observations on the searching territory and detailed investigation of water permeability of the layer, separating the peat deposit from the underlying water-bearing stratum (Volfcun, 1972; Vorobjov, 1981; Zalitis, 1983). In connection with this in the calculations of water-balance magnitude of the water turnover of the peat deposit with the underlying strata are evaluated approximately, as the rest member of the equation of wetland water balance (Šhebeko, 1970). However, as indicated by P. K. Vorobjov (1981) such a way of calculations gives sufficiently approximate evaluation of the underground feeding, because the rest member of the equation of balance may have no connection with the latter, which over the short periods of time can be commensurable with the value calculated.

In connection with this, for determining of value Q more accurately, some researchers (Ferronsky, Polyakov, 1982; Plummer et al., 1993; Sirin et al., 1997) suggested to measure not the very vertical flow of water in the mire, but age of water, according to natural ^3H in different depths of peat. Although natural ^3H is a perfect indicator of water age, determination of exact primary concentration of ^3H in the rain water, for example, which was fallen 50-150 years ago, is problematic (it is known, Sirin; 1999, that natural content of ^3H in the atmospheric precipitations fluctuated in time in the wide diapason, i.e. from 5 up to 15 TE and, particularly, nuclear experiments also influence its concentration).

Since, we cannot exactly determine the concentration of natural ^3H in the water of precipitation, which fell x-years ago, the method described cannot completely substitute more exact direct methods (they need closer definition too) of determining vertical water exchange in the peat stratum.

Independent determination of the component of water balance of the territory - water filtration in the peat deposit with the underlying mineral stratum - entails difficulties, because when the level of ground water fluctuates in connection with nonmonolitism of the peat, water permeability of the peat deposit, being lower the ground water is strongly changed too. For such case in the meanwhile there is no united scheme of calculating vertical water filtration.

Materials and methods

For deducing of the formulae of calculating for the vertical filtration in nonmonolitic strata we should apply theory of filtration of water in anysotrophic strata (Aravin, Numerov, 1953).

In this case the effective coefficient of filtration K_e for the bisequal stratum is equal (Aravin, Numerov, 1953):

$$K_e = \frac{2}{\frac{1}{K} + \frac{1}{K'}},$$

where K and K' are the coefficients of filtration of the upper and lower layers, respectively. In a generalized form for any thickness of the deposit this formula has the form:

$$K_e = \left(H_n - H_{n-1}\right) / \int_{H_{n-1}}^{H_n} \frac{1}{K_h} dh \qquad (2)$$

where H_n, H_{n-1} - lower and upper co-ordinates of the depth of calculated ground layer, respectively. Then the layer of water Q, flowing through the thickness of stratum H_n-H_{n-1}, according to the Darsi law, will be equal (Volfcun, 1972):

$$Q = K_e \frac{S}{H_n - H_{n-1}} W \qquad (3)$$

where S -pressure of water (difference between water levels in piezometric boreholes, installed in different depths or difference between the pressure in piezometer and ground water level (Figure 1); W - area of the wetland territory, in which are observed the uniform hydraulic gradients are observed.

Putting magnitude K_e from formula 2 into formula 3 and simplifying it, we obtain:

$$Q = W \cdot S / \int_{H_{n-1}}^{H_n} \frac{1}{K} dh \qquad (4)$$

Based on formula (4) work formulae were formed in Table 1. There are the most known equations of the relationships between the depth of the layer (by calculating from the soil surface) and the coefficient of filtration (see Table 1).

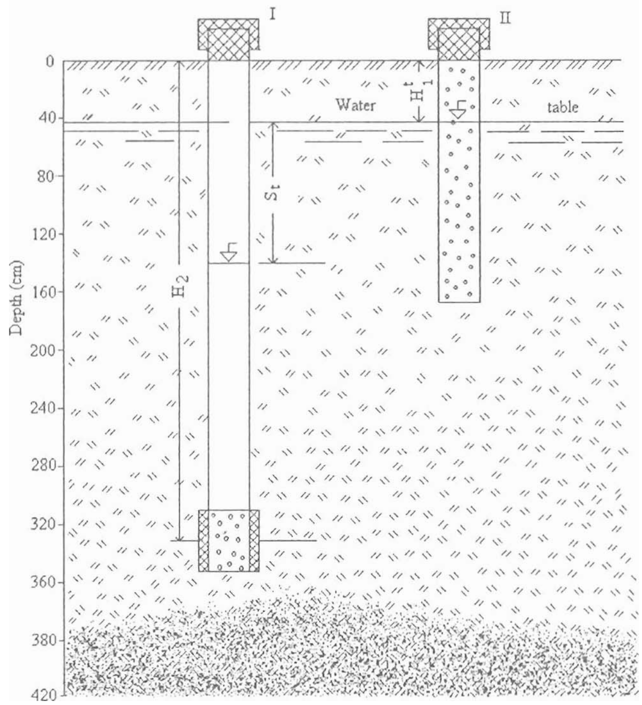

Figure 1. Scheme of installation of piezometers for determination of water filtration speed through peat deposit on the high bog in the experimental hydrological station "Kuras".

Table 1. Formulas for the determination of vertical water filtration (Q) in the nonmonolithic grounds

Equation of the connection of the coefficients of filtration K_h with the depth (H)	Formula for the determination of Q
1	2
$K_h = aH$	$Q = \frac{aWS}{\ln aH_2 - \ln aH_1}$
$K_h = a + bH$	$Q = \frac{bWS}{\ln(bH_2 + a) - \ln(bH_1 + a)}$
$K_h = \frac{\ }{H^m}$	$Q = \frac{WS \cdot a(m+1)}{H_2^{m+1} - H_1^{m+1}}$
$K_h = \frac{a}{(H+1)^m}$	$Q = \frac{WS \cdot a(m+1)}{(H_2+1)^{m+1} - (H_1+1)^{m+1}}$
$K_h = aH^2 + bH + c$ $(b^2 - 4ac > 0)$	$Q = \frac{WS\sqrt{b^2 - 4ac}}{\ln\left(\frac{2aH_2 + b - \sqrt{b^2 - 4ac}}{2aH_2 + b + \sqrt{b^2 - 4ac}}\right) - \ln\left(\frac{2aH_1 + b - \sqrt{b^2 - 4ac}}{2aH_1 + b + \sqrt{b^2 - 4ac}}\right)}$
$K_h = aH^2 + bH + c$ $(4ac - b^2 > 0)$	$Q = \frac{WS\sqrt{4ac - b^2}}{2\left(arctg\frac{2aH_2 + b}{\sqrt{4ac - b^2}} - arctg\frac{2aH_1 + b}{\sqrt{4ac - b^2}}\right)}$

In nature the investigation of the dynamics of peat deposit water exchange with the underlying water-bearing horizons was carried out on the experimental basins - watersheds in Kuras hydrological station. Short characteristic of experimental watersheds is presented in Table 2. In the experimental watersheds we established 56 boreholes of usual type and 24 boreholes of a piezometric type. The coefficients of water return and filtration were determined in the laboratory conditions by using the apparatus (Ruseckas, 1982, 1991) created by us. Adjustment of water return coefficients was made in the field conditions according to a rise in ground water level, when rainfall was heavy in late autumn.

Results and discussion

As an example, a part of the results of calculations of vertical water exchange Q according to formula 5, which depends upon the depth of ground water, is presented in Figure 2. As seen from this graph, in an empiric way we succeeded in obtaining values Q only for narrow diapason (41-65 cm) of fluctuation of ground water level (H_1^l). This is explained by the fact, that when ground water level is higher, the runoff is formed in ditches (then fall of ground

Table 2. Short characteristics of experimental watersheds

No of watershed	Area, ha	Initial forest type	Stand age, years	Drain age, year	Distance between draining objects,m	Ditch depth, m	Peat type	Peat depth, m	(underlying peat mineral ground)
1	15,0	Pinetum sphagnosum	45-65	1963	200	0,9-1,1	Oligotrophic	2,2-4,6	fine sand
2	10,1	Pinetum carico-sphagnosum, pinetum ledosum	20-45	1963	150-200 (175)	1,0-1,3	mesotrophic, oligotrophic	0,6-1,9	
3	3,8	Pinetum carico-sphagnosum	15-40	1963	50	1,0-1,2	mesotrophic	1,2-1,5	
4	4,7	Pinetum carico-sphagnosum	15-40	1963	50-75 (63)	1,1-1,3	mesotrophic	0.8-1.8	
5	6,9	Pinetum carico-sphagnosum, pinetum ledosum	20-45	1963	75-100	1,0-1,3	mesotrophic, oligotrophic	1,2-2,1	
6	14,5	Pinetum carico-sphagnosum	40-60	1975	150-200	0,9-1,2	mesotrophic	0,4-0,9	

For the determination of water exchange (Q) in peat with the underlying mineral strata, we select such time intervals in late autumn and winter periods when evapotranspiration, runoff in the ditches and migration of moisture in peat under the influence of temperature gradients are absent, and precipitation does not penetrate into the peat layer.

Then for calculation of water exchange (Q) in the peat layer with the underlying water-bearing horizons we used the following formula of water-balance:

$$Q_t = (H_t - H_{t-1}) \cdot F_h \qquad (5)$$

where H_t; H_{t-1} are lower and upper coordinates of the depth of ground layer calculated, respectively.

F_h - coefficient of water return of peat layer H_t - H_{t-1} .

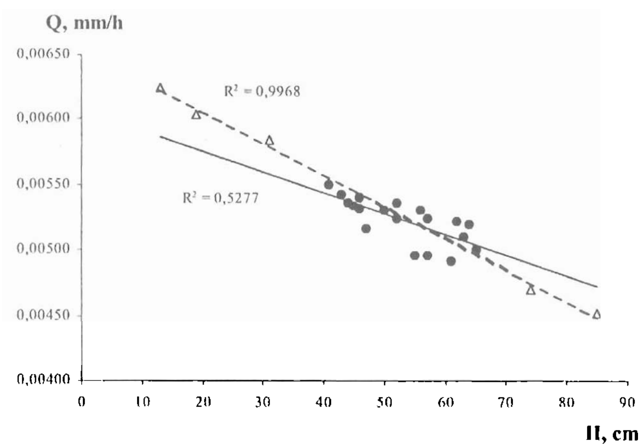

Figure 2. Dependence of intensity (Q) of mire's water infiltration through the bottom of mires bed into mineral strata on height (H) of soil-ground water level (• - experimental data; Δ - data, obtained using formula 8).

water level largerly depends not on value Q, but on the intensity of runoff in the ditches) and when ground water level is low, it is complicated to determine the coefficients of water return in the field conditions (low levels of ground water in mires are usually observed only in summer, when field method of determining water return of peat, in connection with active evaporation of moisture, is not exact).

Vertical water exchange at any levels of ground water has been determined by the following method. At the beginning, according to modified formula 3

$$K_e = \frac{Q(H_2 - H_1^l)}{S \times W} \qquad (6)$$

we determined effective coefficient of filtration (K_e) of the peat layer which is in depth $H_2 - H_1^l$ (Figure 1) (where H_2 - depth of installation of piezometer; H_1^l = 41 - 65 cm, i.e. the depth of ground water level, when we have values Q, derived in an empirical way).

For the determination of value S, we used the data of approximately 230-300 measurements for each watershed area, which we had gleaned over 12 years. It turned out, that of six (watershed areas 1-5) cases in five of them there is reliable straightlinear inverse correlation (r = 0.594-0.684, p <0,004) between the ground water level and pressures. As an example of dependence of piezometric pressure on the level of ground water on the first watershed area is presented in Figure 3. Equation of regression, characterizing the dependence of pressure S on the depth of the level

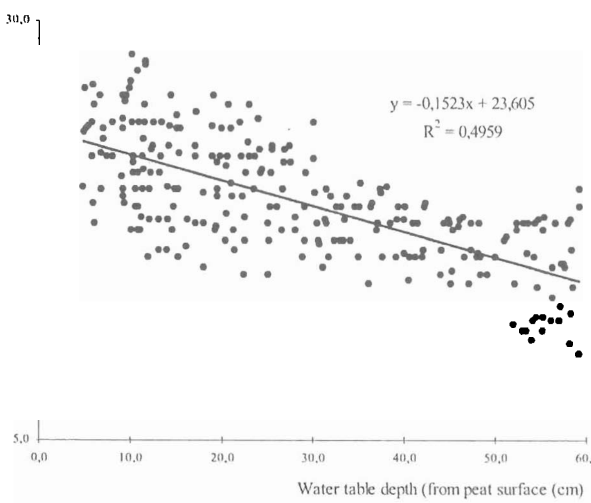

Figure 3. Dependence of piezometrical pressure (St) (difference between water level in usual and piezometrical boreholes) on height (H_1^l) of ground water level in extensively (L = 200 m) drained high mire (I - watershed).

of ground water (H_1^l) on the VI watershed area is approximated as parabola of the following nature: S = -0,122(H_1^l)^2 + 5,5303 H_1^l - 17,565; η - 0,796; limitations: 3 cm < h < 90 cm. In this case value S increases, when the depth of ground water level rises up to 24 cm, and then decreases. This phenomenon is attributed to a decrease in piezometric inclination (increase of pressing) of interlayer water in the area of mire, when the water level is high and in rainy periods, because the interlayer water in mire and adjacent mineral stratum is continuous (in a hydraulic way connected). In our case feeding of them in the area of mineral stratum is episodical, coinciding with high ground water level in the mire.

Thus, when we knew all components, in formula 6, we calculated effective coefficient of filtraton K_e for separate watershed areas for layers ($H_2 - H_1^l$) of peat, which were below ground water (Figure 1). It was found, that magnitude K_e on the territory of Kuras hydrological station fluctuated from 0.61 × 10^{-4} cm × s^{-1} to 4.4 - 10^{-6} cm × s^{-1}.

When we have in a such way established coefficients of filtration (K_e) of peat at least for narrow diapason of fluctuation of ground water level (in our case H_1^l = 0,4-0,6 m) and by comparing them with approximate value K_e calculated according theoretical formulas and simplified in an empirical way, we have specified function $K_h = f(H_2 - H_1^l)$ of distribution of peat filtration coefficients K_h for the whole diapason (H_1^l = 0,05-0,9 m) of fluctuation of ground water level. For example, function K_h = f($H_2 - H_1^l$) corrected in such a way for the first watershed is the following:

$$K_h = \frac{2085}{(H+1)^{3,8}} \qquad (7)$$

where H - the depth of calculated peat layer from the mire's surface.

In accordance with function $K_h = f(H)$ we chose the formula of calculating value Q from Table 1. It looks so:

$$Q = \frac{W \cdot S \cdot a(m+1)}{(H_2+1)^{m+1} - (H_1+1)^{m+1}} \qquad (8)$$

By connecting formulas 7 and 8 we obtained:

$$Q = \frac{2085\, W \cdot S_t (3,8+1)}{(H_2+1)^{(3,8+1)} - (H_1+1)^{(3,8+1)}} \qquad (9)$$

where *W* - area of the wetland territory in which the uniform hydraulic gradients are observed.

Since we are calculating for one m² of a typical mire territory, magnitude *W* in our case is equal 1 (i.e. *W* = *1*), S_t - pressure of water. We take this magnitude at different levels of the ground water table (H_l) from the graphs of dependence of piezometric pressure on the height of ground water level. An example of such a graph is presented in Figure 3. H_2 - depth of piezometer installing. The scheme of measuring the depth of piezometer installation is shown in Figure 1.

Good coincidence (differences do not exceed 10-15%) of values *Q* (Fig. 3) calculated according to formula 8 and predicted according to empirical data demonstrates, that our deduced formulas are correct (Table 1).

The data on runoff of mire water through mire bed to the mineral stratum, which have been calculated in the way described above, are presented in Table 3.

Table 3. Flowing of mires water through the bottom of mires bed to mineral ground over period May 13-15 till October 26-31, 1978-1989, mm.

Year	Distance between draining objects, m					
	200	150-200	50	50-75	75-100	150-200
	No of watershed					
	1	2	3	4	5	6
1978	20,3	19,4	14,1	13,8	16,3	18,9
1979	22,1	19,9	15,6	16,1	17,9	17,6
1980	28,5	25,9	20,1	21,1	23,9	18,8
1981	26,4	24,2	17,6	19,7	22,8	18,4
1982	16,7	14,6	10,1	11,1	11,8	17,4
1983	14,8	12,2	8,6	9,0	11,5	18,2
1984	25,3	23,3	19,1	17,8	21,4	17,6
1985	22,5	20,2	15,6	16,0	17,7	20,1
1986	26,3	24,3	20,1	20,7	23,2	19,1
1987	29,6	27,7	21,1	21,8	24,0	17,7
1988	22,5	20,8	16,1	15,9	17,9	19,4
1989	20,3	18,6	13,4	14,0	16,4	19,2
Average	22,5	20,92	15,96	16,4	18,73	18,53

As shown in Table 3, the more intensive the drainage, the weaker the water exchange is expressed in mires water with the underlying water-bearing horizon. For instance, in May-October when *L* = 200 m, average value *Q* is equal 22.5 mm and when *L* = 50 m, it diminishes up to 15.9 mm. For prediction of the changes in water exchange Δ*Q* in mires underlain by mineral strata, which are supposed to occur under the influence of drainage or renaturalization of drained mires, we should make a graph of the dependence of magnitude *Q* upon level (h) of ground water and according to this graph make a prediction of magnitude *Q(Q = f(h))*. A supposed decrease in the ground water level or a rise in it must be allowed for. These data are of paramount importance when draining or during renaturalization of the areas that supplementary feed the water-bearing layer with ground water in which water collecting boreholes for potable water are installed.

Conclusions

1. When the level of ground water in the mires is fluctuated, especially in the high bog, the changes occur in water permeability of peat deposit which is lower the ground water. For the calculation of vertical water exchange in such cases we propose theoretical formulae (Table 1).

2. The more intensive the drainage of mires, the weaker the water exchange (*Q*) is in mires with the underlying water-bearing horizon. For instance, in the vegetation period (May 13-15 till October 26-31) when *L* = 200 *m*, average value *Q* over 12 years is equal 22.5 *mm*, and when *L* = 50 *m* - magnitude *Q* decreases on 29% and makes up 15.9 *mm*.

3. In the conditions of the lowland of Middle Lithuania the flowing of mires water through the bottom of mires bed into the underlaying mineral strata on average makes up 16-23 *mm/year* over the vegetation period (May 13-15 till October 26-31) or 4.2-6.0% from the precipitation sum.

Reference

Charman D. J., Aravena R., Warner B. G. 1994. // Ecology. 1994. V. 82. P. 55.

Ferronsky V. I., Polyakov V. A. 1982. Environmental Isotopes in the Hydrosphere. N.Y.: John Wiley, 182. 458 p.

Plummer L. N., Michel R. L., Thurman E. M., Glynn P. G. 1993. Regional Groundwater Quality. N.Y.: Van Nostrand Reinhold, 1993. P. 255.

Siegel D. I., Reeve A. S., Glaser P. H., Romanowicz E. A. 1995. // Nature. V. 374. P. 531.

Аравин В. И. и Нумеров С. Н. 1953. Теория движения жидкостей и газов в недеформируемой пористой среде. [Theory of motion of the liquids and gases in the nondeformating porous medium]. Москва, изд. тех. теорет. лит., - 615 с. (in Russian).

Иванов К. Е. 1957. Основы гидрологии болот лесной зоны. [Bases of the hydrology of the mires of forested zone]. Ленинград, Гидрометеоиздат, - 500 с. (in Russian).

Вольфцун И. В. 1972. Расчеты элементов баланса грунтовых вод. [Calculations of elements of the ground water balance]. Ленинград, Гидрометеоиздат, Gidrometeoizdat, 271 с. (in Russian).

Воробьев П. К. 1981. Исследование водообмена торфяной залежи с нижележащим водоносным горизонтом. // Вопросы гидрологии болот. [Investigation of water exchange of peat deposit with the lower lying water bearing horizon. Questions of mires hydrology]. Ленинград, Гидрометеоиздат, с. 25-45. (in Russian)

Залитис П. П. 1983. Основы рационального лесоосушения в Латвийской ССР. [Bases of rational forest drainage in Latvia SSR]. Riga, "ЗИНАТНЕ", - 228 с. (in Russian).

Русецкас Ю. Ю. 1982. А.с. № 958916 СССР. Устройство для определения водно-физических характеристик почвогрунтов (76) Б.И. [Authors certificate No 958916 USSR. Equipment for determination of water-physical characteristics of soil-ground]. B.I. No 34., с. 201 (in Russian).

Русецкас Ю. Ю. 1991. Теоретические основы совершенствования гидролесомелиорации. [Theoretical bases of improvement of forest hydro amelioration]. Дисс. на соиск. у.с. д-ра с.х.н. Каунас-Гирионис, 480 с. (in Russian).

Сирин А. А. 1999. Водообмен и структурно-функциональные особенности лесных болот (на примере европейской тайги). Water exchange and structural-functional peculiarities of the forest mires (on the example of European taiga). Автореферат дисс. докт. биол. наук. Москва, с. 44.

Сирин А. А., Шумов Д. Б., Власова Л. С. 1997. Изучение водообмена в болотных водах с помощью результатов анализа ^{3}H. [The investigation of water exchange in the mire's water using results of the ^{3}H analysis]. Водные ресурсы, том 24, № 6, с. 67-687.

Щебеко В. Ф. 1970. Гидрологический режим осушаемых территорий. [Hydrological regime of drained territories]. Минск "Урожай" - 298 с. (in Russian).

ОПРЕДЕЛЕНИЕ ВЕРТИКАЛЬНОГО ВОДООБМЕНА ЛЕСНЫХ БОЛОТ С НИЖЕЛЕЖАЩИМИ МИНЕРАЛЬНЫМИ ГРУНТАМИ

Ю. Русецкас

Резюме

В статье показано, что при колебании уровней грунтовых вод в верховых и переходных лесных болотах меняются не только мощность слоя торфа, насыщенного до полной влагоемкости, но и его коэффициент фильтрации, а также и пьезометрический уровень гравитационной воды. В этих условиях, используя элементарную теорию фильтрационного движения воды в анизотрофных грунтах, предложены оригинальные формулы для определения водообмена торфяной залежи с нижележащими минеральными грунтами. Установлено, что чем лесные болота верхового и переходного типа осушены интенсивнее, тем слабее проявляется вертикальный водообмен (ΔQ) болотных вод с нижележащими минеральными грунтами. Выявлено, что величина ΔQ в гидрологическом стационаре "Курас" (Каунасский р-он) на лесных болотах верхового и переходного типа в среднем за вегетационный период (V.13-15 - X.26-31) составляет 16-23 мм или 4,2-6,0% от величины выпадающих осадков.

Ключевые слова: вертикальный водообмен, интенсивность осушения, коэффициенты фильтрации, лесные болота, уровень грунтовых вод