Important Physical Properties of Peat Materials

D. H. BOELTER
U.S.A.

ABSTRACT

Peat materials from 12 bogs in northern Minnesota, U.S.A., showed significant differences in physical properties. It is pointed out that 1) these properties can be related to the hydrology of organic soils only if the soils represent undisturbed field conditions, and 2) volumetric expressions of water content are necessary to correctly evaluate the amount of water in a peat profile. The differences in physical properties were related to degree of decomposition as measured by bulk density and fibre content. Undecomposed peats with low bulk density and high fibre content contain many large pores which yield as much as 80 per cent of their saturated water content to drainage and permit rapid water movement. With increasing decomposition, fibre content decreases, resulting in increased bulk density and a greater proportion of small pores. The most decomposed peats yield less than 10 per cent of their water to drainage and have very slow water movement rates.

RÉSUMÉ

L'observation des sols tourbeux de 12 fondrières à sphaignes du nord du Minnesota, É.-U., a révélé d'importantes différences de leurs propriétés physiques. L'auteur signale 1) qu'il est possible que ces propriétés découlent du régime hydrologique des sols organiques, lorsque ces sols n'ont pas été bouleversés et 2) qu'il faut exprimer volumétriquement la teneur en eau pour évaluer correctement la quantité d'eau présente dans les couches de tourbe successives. Les différences de propriétés physiques découlent du degré de décomposition, qu'on évalue grâce à la masse volumique du sol et à la proportion de fibres. La tourbe non décomposée, à faible masse volumique et forte proportion de fibres, contient de nombreux pores élargis qui laissent égoutter jusqu'à 80 p. 100 de leur contenu d'eau à saturation et permettent un déplacement très rapide des eaux. La proportion de fibres diminue au fur et à mesure des progrès de la décomposition, accroissant la masse volumique et la proportion des petits pores. La tourbe la plus décomposée laisse égoutter moins de 10 p. 100 de son eau et ralentit fortement les déplacements de l'eau.

Water retention, water yield coefficient, and hydraulic conductivity are important physical properties of peat materials because they determine to a large extent the hydrologic features of organic soils. Although there is extensive literature dealing with various aspects of organic soils, comprehensive studies of the physical properties of peat in their natural state have been reported only recently. Many of the early investigations were concerned with the engineering aspects of organic terrain, the development and management of organic soils for agricultural production, or the commercial use of peat products. Since many of these early data did not evaluate the organic soils as they existed in the field, the results could not be applied to hydrologic studies of natural peatlands.

To evaluate the role of organic soils in peatland hydrology, the North Central Forest Experiment Station is studying the physical properties of a number of different peat materials in northern Minnesota, U.S.A. More than 100 peat samples have been collected from natural organic soils in 12 northern Minnesota bogs. The bogs represent perched bogs (lake-filled deposits), small groundwater bogs (Bay 1966), and large built-up peatlands such as those found in glacial Lake Agassiz (Heinselman 1963). The peat samples, collected from horizons in the upper metre of the organic soil profile, ranged from raw, undecomposed *Sphagnum* moss with a fibre content of 98 per cent and bulk density of 0.009 g/cc to relatively well-decomposed peat with 15 per cent fibre content and bulk density of 0.25 g/cc.

D. H. Boelter, Northern Conifer Laboratory, North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Grand Rapids, Minnesota 55744, U.S.A.

All the sampling and study procedures were designed to measure the physical properties of undisturbed peat. Some properties were measured in place in the field; others were measured in the laboratory, using undisturbed cores and large bulk samples. Samples collected for laboratory procedures were not allowed to dry and were stored at approximately 5°C to discourage any biochemical activity.

Large and significant differences in physical properties were measured for various peat materials and found to be related to the degree of decomposition. This report summarizes these findings and discusses their importance to the hydrology of organic soils.

WATER STORAGE

Organic soils develop under conditions of excess water and are saturated or nearly saturated most of the time. They are known to be porous and to hold a large amount of water when saturated. But the water storage characteristics at conditions other than saturation are equally important because they determine the quantity of water involved with a given water table fluctuation in the peat profile. These values are needed by hydrologists attempting to evaluate water resources of peatland watersheds.

Volumetric Expressions of Water Contents

Water contents of various peat materials at different conditions of wetness have been measured by numerous authors. These data are often calculated on an oven-dry weight basis; i.e., the ratio of weight of water to the oven-dry weight of peat. Though this method has generally been accepted for mineral soils, the expression of water contents of peat on an oven-dry weight basis can lead to erroneous conclusions about the actual amount of water in a peat profile.

This point can best be illustrated with a hypothetical situation where each of several peat materials and a mineral soil contain 40 cc. H_2O in each 100 cc of sample volume. When the water contents were expressed on either an oven-dry or wet weight basis, all the organic materials appeared to contain much more water than the mineral soil (Table I).

TABLE I

Water Contents of Peat Materials Expressed as Per Cent of Oven-dry Weight, Per Cent of Wet Weight, and Per Cent of Volume

Material	Bulk density (g/cc)	Water content as a per cent of		
		Oven-dry weight	Wet weight	Volume
Peat				
Sphagnum moss	0.02	2,000	95	40
Herbaceous	.16	250	71	40
Well decomposed	.24	167	62	40
Mineral soil				
Barnes loam	1.29	31	24	40

The importance of volumetric expression of the water contents of peats was also illustrated by Boelter and Blake (1964) by means of water release curves. Values expressed on an oven-dry weight basis indicated higher water contents for moss peat at all suctions than for herbaceous peat; the latter in turn had higher water contents than did aggregated (decomposed) peat. Volumetric water contents were highest, however, for aggregated (decomposed) peat at all suctions other than saturation, and

were least for moss peat. A medium-textured mineral soil retained volumes of water comparable to herbaceous peat and considerably higher than those of moss peat at most suctions.

Because the oven-dry weight per unit volume (bulk density) of peat in the field is quite low compared to that of mineral soil, and varies considerably for different peat types (Table I), there is no basis for comparing their water contents when calculated as a weight-per-unit-weight. Water contents and water retention characteristics must be corrected for the weight of oven-dry material per unit volume and expressed on a volume basis to accurately describe the properties of natural peat materials in the field.

Water Retention

Water retention characteristics of each of the undisturbed peat materials were determined by means of soil water extraction equipment. For suctions of 0.1 bar or less, a pressure cell was used with a core sample. Water retention at higher suctions was determined by placing pieces of the peat material on pressure membrane and pressure plate extractors.

Saturated water contents varied from nearly 100 per cent for undecomposed *Sphagnum* moss peat in surface or near-surface horizons to about 80 per cent for more decomposed peat in deeper horizons. Thus the total porosity decreases gradually with increased decomposition, but is large for all peat materials. Striking differences were found, however, in the quantity of water retained at conditions less than saturation, indicating that pore-size distribution is more significant than total porosity. The undecomposed peats contain many large pores which are easily drained at low suctions. Water retention curves show that an undecomposed *Sphagnum* moss peat loses a large portion of its saturated water content at suctions of only 5 mbars (5 cm of H_2O) (Figure 1). The finer pores of the more decomposed peats are not drained and, at suctions greater than 5 mbars, water contents are much higher for these peats than for the undecomposed peats.

When water retention of peats in measured at very low suctions, a very precise and consistent water suction must be applied. Simply changing the height of the sample will alter the amount of water suction when measuring maximum water-holding capacity. Because of the large quantity of water released by saturated undecomposed peats at low suctions, a small change in suction will result in a significantly different water content. The data in Figure 1 show that the undecomposed *Sphagnum* retains more water at saturation than the more decomposed peats. The relative water contents, however, are reversed at only 5 mbars suction.

Water Yield Coefficient

Water yield coefficient (also referred to as storage coefficient, coefficient of drainage, and coefficient of groundwater level) is a measure of the quantity of water removed from a peat profile when the water table is lowered. This quantity includes water removed from the saturated zone and water released from horizons in the capillary fringe above the original zone of saturation.

Water yield coefficients have been determined in bogs by measuring the change in water level with precipitation (Heikurainen, 1963; Vorob'ev 1963) and by computing the regression coefficient between water level change and precipitation (Bay, 1967). They have also been computed by Vorob'ev (1963) from measurements of the pore volume distribution of peat samples. He related water retained by various pore sizes to capillary forces in effect at specific water table elevations and tabulated water yield coefficients by integrating water content changes for all horizons with given increments of water table change.
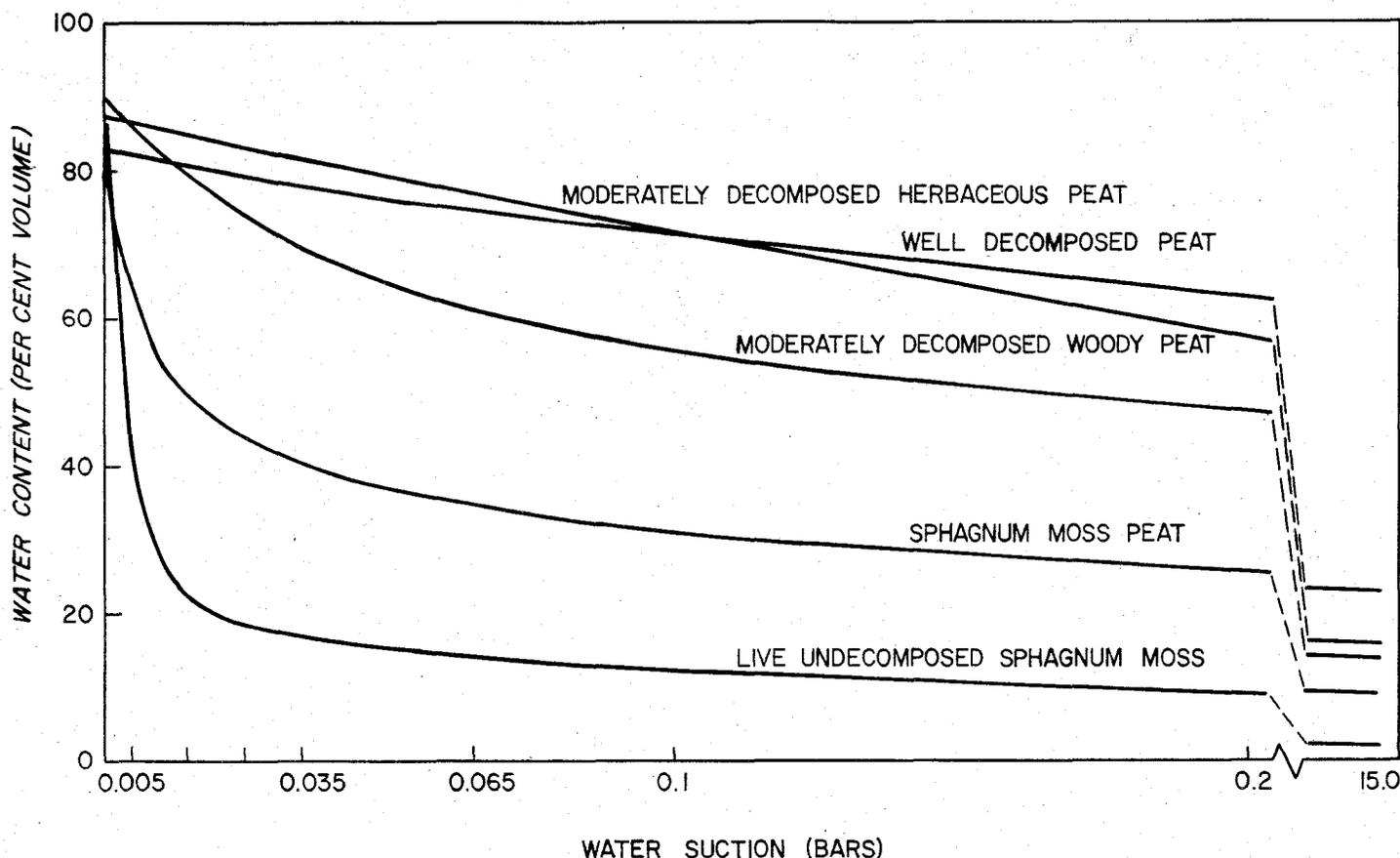
Figure 1. Water retention curves for several northern Minnesota peat materials.

Water yield coefficients presented here were calculated from laboratory-measured water retention values. They are equal to the difference in water contents at saturation and 0.1 bar suction and represent the change in water content with water

TABLE II

Water Yield Coefficients, Hydraulic Conductivities, and Bulk Densities of Several Northern Minnesota Peat Materials

Peat type	Sampling depth (cm)	Hydraulic conductivity (10^{-5} cm/sec.)	Water yield coefficient (cc/cc)	Bulk density (g/cc)
Sphagnum moss peat				
Live, undecomposed mosses	0 – 10	*	0.85	0.010
Undecomposed mosses	15 – 25	3,810.00	.60	.040
Undecomposed mosses	45 – 55	104.00	.53	.052
Moderately decomposed with wood inclusions	35 – 45	13.90	.23	.153
Woody peat				
Moderately decomposed	35 – 45	496.00	.32	.137
Moderately well decomposed	60 – 70	55.80	.19	.172
Herbaceous peat				
Slightly decomposed	25 – 35	1,280.00	.57	.069
Moderately decomposed	70 – 80	.70	.12	.156
Decomposed peat				
Well decomposed	50 – 60	.45	.08	.261

*Water movement was too rapid to measure with the techniques used in this study.

level fluctuation in a profile consisting entirely of each specific material. The values for various peats (Table II) vary from 0.85 to 0.08 and were related to the pore size distribution. They are similar to coefficients of groundwater table measured for bogs in Finland; those coefficients ranged from approximately 0.10 to 0.67 (Heikurainen, 1963). Any change in water table elevation in horizons of less decomposed peat (which is usually found in surface horizons) represents considerably more water than a corresponding change in deeper, more dense peats.

HYDRAULIC CONDUCTIVITY

Hydraulic conductivity is a measure of the rate of water movement through soil. This has important hydrologic implications since it will influence the runoff characteristics of organic soils.

Saturated hydraulic conductivity of various northern Minnesota peats was measured by the piezometer method in the field (Boersma, 1965). This technique measures the horizontal conductivity below the water table. Although several investigators have reported that horizontal hydraulic conductivity was greater than vertical (Malmström, 1925; Colley, 1950), equal values were found for northern Minnesota peats (Boelter, 1965).

The hydraulic conductivity values covered a wide range (Table II). Water movement was very rapid in surface or near-surface horizons of Sphagnum moss peats, often too rapid to measure with piezometers. When it could be measured it was found to be quite variable. Deeper, more dense peat materials permitted very slow water movement and showed lower hydraulic conductivities than clays and glacial tills. Here again, differences in pore-size distribution of the various peat materials resulted in striking differences in the physical characteristic.

PHYSICAL PROPERTIES AND DEGREE OF DECOMPOSITION

Physical properties of any soil are dependent to a large degree on porosity and pore-size distribution. These in turn are related to particle-size distribution. In peat materials, both the particle size and structure and the resulting porosity are controlled primarily by the degree of decomposition. With increasing decomposition, the size of organic particles decreases, resulting in smaller pores and more dry material per unit volume.

Numerous studies have considered the decomposition of peats, but few have reported quantitative comparisons with physical properties. Kuntze (1965) discussed the dependence of water retention on degree of decomposition as measured by "substance volume", ash content, and humus content. Baden and Eggelsmann (1963) showed the relationship of hydraulic conductivity to substance volume and the von Post measure of decomposition.

Degree of decomposition appears to be a key property of organic soils, but it is not clearly defined and is difficult to quantify. It is a relative quantity which is usually approximated by using a measure of one of the chemical or physical characteristics which change with advance of decomposition.

Kaila (1956) studied several characteristics and concluded that volume weight (bulk density) could be used as a basis for estimating the degree of decomposition of peats. More recently, Farnham and Finney (1965) used the content of fibres greater than 0.1 mm in the total mass of organic material. Both bulk density and fibre content were measured for the peat materials discussed in this report and were related to the physical properties described above.

Bulk Density

Bulk density is equal to the mass of dry material per unit bulk volume. It can be used not only as a measure of decomposition, but also for converting water and nutrient contents measured on a weight-per-unit-weight basis to the more useful volume-per-unit-volume or weight-per-unit-volume.

When peat materials are dried, their volume is reduced considerably. Therefore, bulk density must be calculated on the basis of the wet bulk volume if it is to represent field conditions. If bulk densities are measured using a reduced volume, they will be too high, and volumetric water contents calculated with these values will also be too high. Some reports show bulk densities and water contents (oven-dry weight basis) that result in volumetric water contents well over 100 per cent.

The bulk densities reported in Table II were measured using oven-dry weight of a core of peat of known volume obtained in the field at field water content. The range of values is typical for peat materials found in northern Minnesota.

Curvilinear regression analyses were used to relate water retention values at each of several suctions to bulk density (Figure 2).[1] Coefficients of multiple determination (R^2) ranged from 0.69 to 0.89. Similar relations were found when water yield coefficient was compared to bulk density ($R^2 = 0.89$). A linear regression analysis showed a good correlation ($r^2 = 0.54$) of the logarithm of hydraulic conductivity to bulk density.

Fibre Content

The content of particles or fibres larger than a designated size will decrease with increasing decomposition. Farnham and Finney (1965) have arbitrarily selected fibre greater than 0.1 mm

[1]Regression equations and coefficients of determination for the relations of various physical properties to bulk density and fibre content are contained in a paper to be submitted to the Proceedings of Soil Science Society of America for publication.
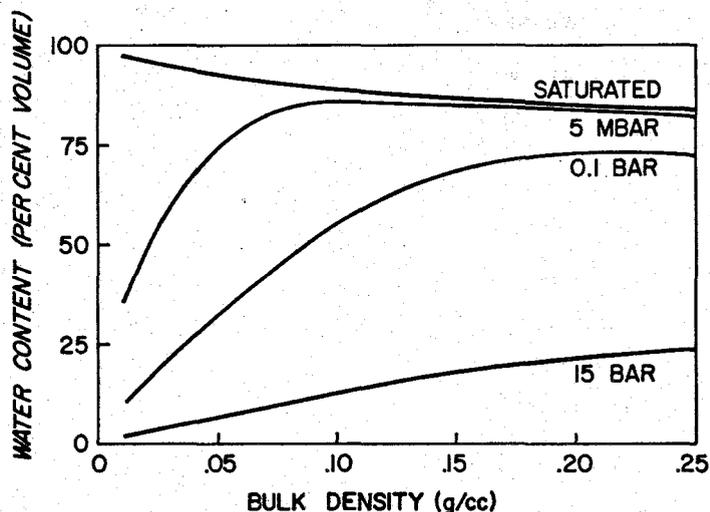

Figure 2. Relationship of water content of peats at saturation, 5 mbar, 0.1 bar, and 15 bar suction to bulk density.

TABLE III
Peat Classification by Proportion of Fibre Size Larger Than 0.1 mm

Portion of the total mass consisting of fibres larger than 0.1 mm	Designation of material
Less than one-third	Sapric (the most decomposed peat)
One-third to two-thirds	Hemic (intermediate stage of decomposition)
More than two-thirds	Fibric (the least decomposed peat)

as a criterion for classification of peats. Their designations are as shown in Table III.

Fibre contents were measured by a wet sieving process. A weighed sample (100 - 200 g) of undisturbed and undried peat was soaked 15 to 20 hours in a 5 per cent solution of dispersing agent (sodium hexametaphosphate and sodium carbonate mixture). The sample was then washed through sieves to collect all particles larger than 0.1 mm. A gentle stream of water was used and care was taken to prevent rubbing or abrasion which could reduce the fibre size. The fibre collected from the sieves was oven-dried, weighed, and compared to the oven-dry weight
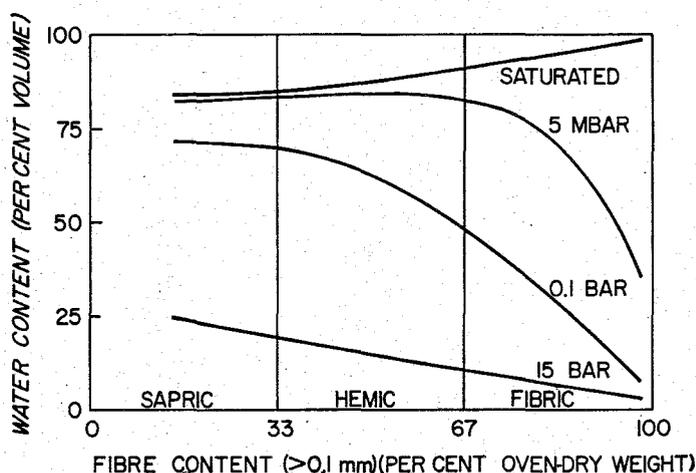

Figure 3. Relationship of water content of peats at saturation, 5 mbar, 0.1 bar, and 15 bar suction to fibre content (> 0.1 mm).

TABLE IV

Range of Important Physical Properties of Fibric, Hemic, and Sapric
Peat Materials From Northern Minnesota Bogs

| Organic material	Bulk density (g/cc)	Total porosity (per cent)	Water yield coefficient (per cent)	0.1 bar H_2O content (per cent)	Hydraulic conductivity (10^{-5} cm/sec.)
Fibric	<0.075	>90	>42	<48	>180
Hemic	.075–.195	85–90	15–42	48–70	2.1–180
Sapric	>.195	<85	<15	>70	<2.1

of the original sample. The oven-dry weight of the sample was based on the water content of a duplicate sample of the material.

Curvilinear regressions were used to show the relation with water storage values (Figure 3); coefficients of multiple determination (R^2) ranged from 0.68 to 0.84. The relation to water yield coefficient was also curvilinear with $R^2 = 0.84$. The relationship of the logarithm of hydraulic conductivity to fibre content was linear with $r^2 = 0.54$.

The range of physical properties was determined for fibric, hemic, and sapric peat materials, using regression equations (Table IV). Values given show a big range for each property, with significant differences between the three peat types. These differences are related to the decomposition of the peat material. Knowing the degree of decomposition as measured by bulk density or fibre content will provide soil scientists and land managers with significant information about the physical and hydrologic characteristics of the organic soil.

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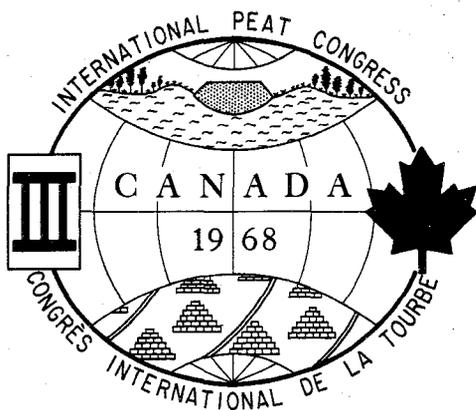
Proceedings of the

Third International Peat Congress

Quebec, Canada
18-23 August, 1968

Sponsored by

Department of
ENERGY, MINES AND RESOURCES, Ottawa, Canada
and
NATIONAL RESEARCH COUNCIL OF CANADA

Comptes rendus du

Troisième Congrès international d'étude de la tourbe

Québec, Canada
du 18 au 23 août 1968

sous les auspices du

Ministère de
l'ÉNERGIE, DES MINES ET DES RESSOURCES, Ottawa, Canada
et
CONSEIL NATIONAL DE RECHERCHES DU CANADA