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CALCULATION OF HYDRAULIC CONDUCTIVITIES AND CAPILLARY RISE IN PEAT SOILS FROM BULK DENSITY AND SOLID MATTER VOLUME

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CONTENTS

SUMMARY

The values of the three constants in a convenient formula for the calculation of capillary conductivities of peats can be evaluated from bulk density and solid matter volume. The capillary properties of homogeneous fen peats and high bog peats with increasing bulk density are comprised in some diagrams. For a survey of the capillary properties of soil profiles with peat layers these profiles should at first be properly classified and described for the purpose of the necessary calculations.

1. INTRODUCTION

Recently it was demonstrated how unsaturated hydraulic conductivities of soils can be calculated from granular composition and organic matter content (BLOEMEN, 1980a). This type of calculations has to be restricted to mineral soils because the capillary properties of organic soils will not be determined by the granular composition of the minor mineral part. Still it would be of use if hydraulic conductivities of organic soils could also be calculated from easily determined soil properties. From information in literature and measurements in samples of peat soils a simple method for the calculation of capillary properties of peat soils proceeded. As in the case of mineral soils, it is based on the Brooks and Corey formula (BROOKS and COREY, 1964) which is

$$k(h) = k_s\left(\frac{h_a}{h}\right)^{n_d} \qquad (\mathrm{cm.d^{-1}}) \qquad (1)$$

where k_s is saturated hydraulic conductivity, h_a is air entry suction, which is the suction at which during desorption of saturated samples the largest pores lose their capillary water and n_d is the ratio $d[\log_{10}k(h)]/d(\log_{10}d)$ during desorption, as related to pore size distribution.

Eq. (1) can be adjusted to account for the effect of pore water hysteresis. The modified formula is

$$k(h) = k_e\left(\frac{h_w}{h}\right)^{n_s} \qquad (\mathrm{cm.d^{-1}}) \qquad (2)$$

where k_e is the maximal conductivity after wetting, estimated at 0.5 k_s, and h_w is the suction at which maximum saturation after rewetting is attained. It is generally called water entry suction and can be measured or calculated from h_a. n_s is the ratio $d[\log_{10}k(h)]/d(\log_{10}h)$ of the average scanning curve between sorption and desorption and can be calculated from n_d (BLOEMEN, 1980a).

In this paper it is shown how the dependency of the values of the constants in eq. (2) on bulk density and solid matter volume of peat soils is a basis for the calculation of hydraulic conductivities. As easy applicability of the presented method was meant to be an important feature, only two types of peat are distinguished i.e. fen peats (f.i. wood peat, moss peat, sedge peat and phragmites peat), and high bog peats of which sphagnum peat is the major part. A more precise determination of peat types is too much an experts job. This study applies to soils with more than 30% of organic matter.

2. MATERIAL AND METHODS

For the presented study respectively 155 and 72 vertical cores with a volume of 100 cm^3 were sampled in fen peat and high bog areas in the Netherlands. A large part of the fen peat cores were sampled under the groundwater level. In 29 cases vertical cores, sampled in high bog peat, were duplicated by horizontal cores. Technical difficulties prohibited horizontal sampling in fen peats.

In the cores air entry suctions were measured with the apparatus described by STAKMAN (1969). The cores were vacuum saturated first. The apparatus was slightly improved to prevent mechanical influences to damage the samples. Therefore the ferrule on the brass disc between core and suction cup, which penetrates into the sample was removed. Also the threaded brass coupling sleeves with rubber O-rings, connecting core and suction cup, are replaced by a clamping system with packings.

After the measurement of air entry values, saturated conductivities in the cores were measured with the apparatus described by WIT (1967) and converted to a water temperature of $10^{o}C$.

The regression lines in this paper give the least sum of squares calculated parallel to the y-axis. Sometimes, f.i. in the case of Fig. 1b, when there is a difference with a comparable relationship the question is raised if some other method would not have been preferably. However, the determination error of k_s is considered to be so much larger than the error of bulk density or solid matter volume that the chosen regression lines seem to give the best fit.

3. DECOMPOSITION OF PEATS AND THEIR SATURATED HYDRAULIC CONDUCTIVITY

Since 1940 it has been advanced in literature that a relation exists between the rate of decomposition of peat soils and their saturated hydraulic conductivity k_s. At first evidence was mainly drawn from experience. EGGELSMANN (1960) is the first to give results of a small number of measurements. Some years later BADEN und EGGELSMANN (1963) published results of measurements in a large number of peat soils as obtained with the auger hole method. There is a pronounced decrease of k_s with increasing decomposition. k_s is considerably lower in sphagnum peat than in fen peat, in which moss peat, sedge peat and phragmites peat exceed one another slightly in this order as far as k_s is concerned. VOS (1975), who also used the auger hole method, gives the same order but is not explicit about real values of k_s and ignores the significance of decomposition in this matter. KORPYAAKKO and RADFORTH (1972) show a rapid decrease of k_s-values (measured in the laboratory in cores) of high bog peat with increasing decomposition. PÄIVÄNEN (1973) gives regression equations for the relationship between rate of decomposition and k_s-values of sphagnum peats and sedge peats. BOELTER (1975) also shows decreasing values of k_s for peats with increasing decomposition.

The influence of the rate of decomposition on k_s-values is not further pursued in this study. Though decomposition can be assessed instantly in the field, this determination is subject to personal appeciation and therefore has a bad reproducibility. Laboratory methods to determine the rate of decomposition are complicated and time consuming and not considered to be recommendable for routine application. Besides there are other and more attractive possibilities.

4. CALCULATION OF SATURATED HYDRAULIC CONDUCTIVITIES OF PEAT SOILS FROM BULK DENSITY

Bulk density is equal to the mass of dry material per unit wet bulk volume. It can be determined quickly and objectively as ovendry weight at 105°C of a core of undisturbed and saturated peat. It is therefore to be preferred as a parameter for the calculation of hydraulic condictivities of peat soils. According to several authors it is a measure of decomposition and could therefore be used to evaluate the information referred to in the previous section. More practical, however, is the direct calculation of k_s-values from bulk density on the basis of established relationships between these two properties. Information in literature about this mainly originates from the need for drainage of fen or high bog areas. Therefor, in these studies field measurements with the piezometer or auger hole methods are mostly used (BOELTER, 1969, PÄIVÄNEN, 1973). These are not representative of vertical water movement which is typical of unsaturated flow between freatic level and root zone. In this study emphasis should be laid on vertical saturated hydraulic conductivities.

In Fig. 1 k_s-values in vertical cores of fen peats and high bog peats are plotted against their bulk denstities. Though there is a considerable scatter in both cases there are also distinct relationships.

From Fig. 1a and b it follows that according to this study vertical saturated hydraulic conductivity (k_s) can be calculated from bulk density (ρ_b) with

$$k_s = 0.00266\ \rho_b^{-3.625} \qquad r = -0.64 \qquad (3)$$

for fen peats, and with

$$k_s = 0.0036\ \rho_b^{-2.83} \qquad r = -0.523 \qquad (4)$$

for high bog peats.

A curve given by KORPYAAKKO and RADFORTH (1972) also based on laboratory measurements in vertical cores from high bogs, is significantly different from the one determined in this study.

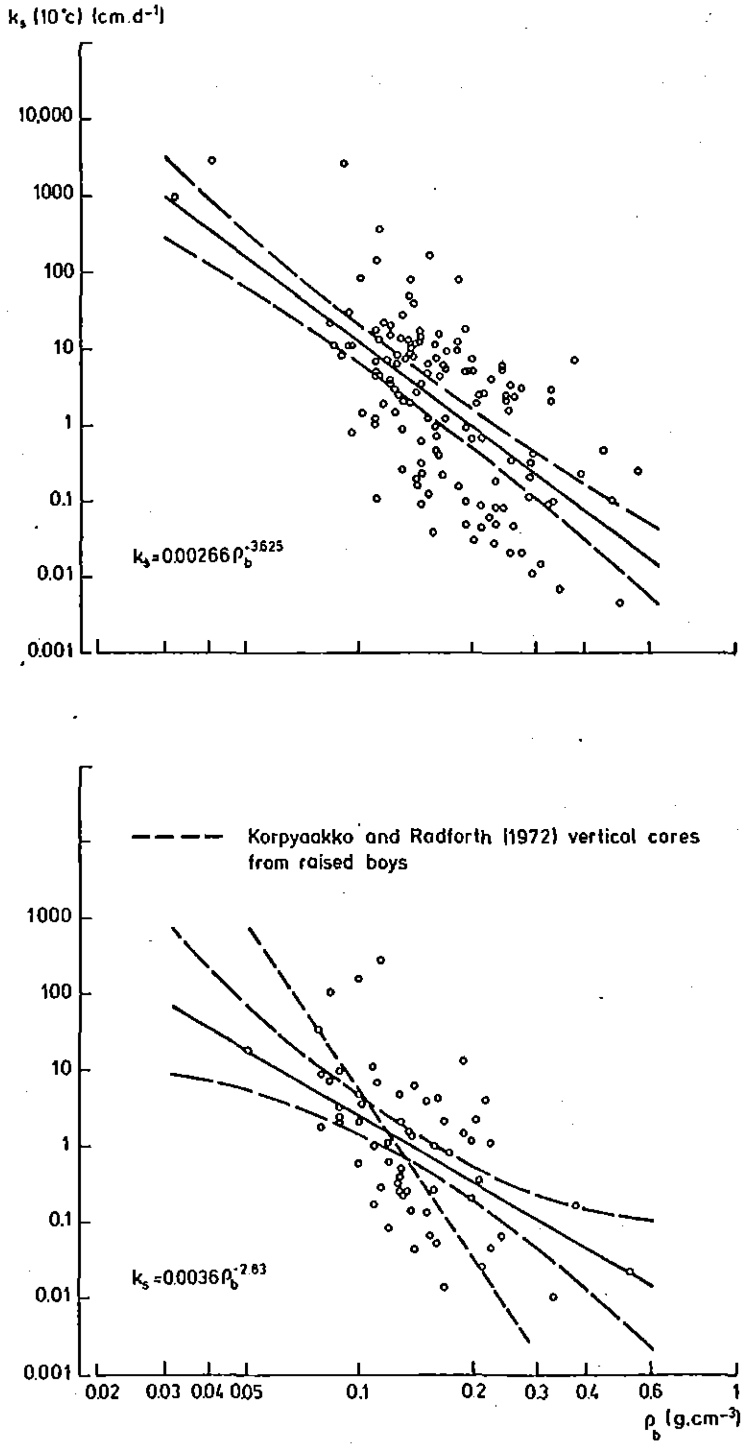

Fig. 1. Relationships between bulk densities (ρ_b) and saturated conductivities (k_s) in fen peats (A) and high bog peats (B), as obtained from measurements in vertical cores

5. CALCULATION OF VERTICAL SATURATED HYDRAULIC CONDUCTIVITIES OF PEAT SOILS FROM VOLUME PERCENTAGES OF SOLID MATTER

The volume percentage of peat soils occupied by solid matter is a popular parameter for the calculation of k_s with German investigators. BADEN und EGGELSMANN (1963) and GEBHARDT und WOJAHN (1966) found decreasing values of k_s with increasing solid matter volume percentages, both for fen peats and high bog peats.

Solid matter volumes (percentual or fractional) can be calculated from bulk density ρ_b and specific weight, which is rather inconvenient because the determination of the specific weight of a peat soil is time-consuming and requires laboratory facilities. SEGEBERG (1964) therefore proposed the use of mean values of the specific weights S of the mineral part of the soil (S_m = 2.65) and of the organic part (S_o = 1.60). He obtains an expression which can be written as

$$V_s = 100 \frac{(S_m - M)\ \rho_b}{S_m - S_o} \qquad (\%) \qquad (5)$$

where V_s is the solid matter volume and M is the mineral fraction of the dry soil.

The solid matter volumes of the samples collected for this study were calculated with Eq. (5) because the values of V_s of 23 samples calculated from bulk density and determined specific weights showed a very high correlation with V_s as calculated with Eq. (5), (r^2 = 0.99).

In Fig. 2a and b saturated hydraulic conductivities are plotted against solid matter volumes of respectively fen peats and high bog peats with 30% or more of organic matter.

From Fig. 2a and b it follows that k_s in Eq. (1) can be calculated from the solid matter volume percentage (V_s) with

$$k_s = 16{,}982\ SV^{-4.1} \qquad r = 0.64 \qquad (6)$$

for fen peats, and with

$$k_s = 631\ SV^{-3.04} \qquad r = 0.513 \qquad (7)$$

for high bog peats

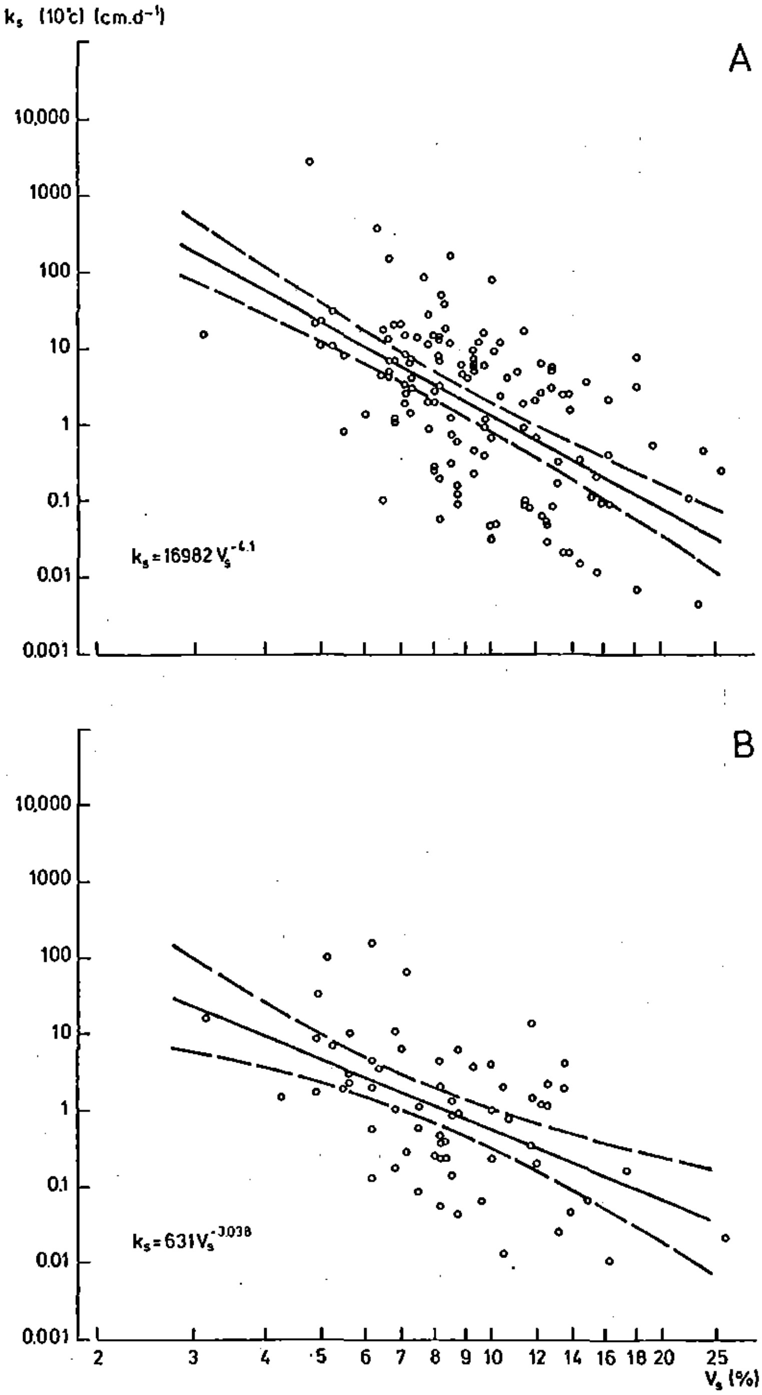

Fig. 2. Relationships between solid matter volumes V_s and saturated conductivities (k_s) in fen peats (A) and high bog peats (B) as obtained from measurements in vertical cores

6. CALCULATION OF WATER ENTRY SUCTION FROM BULK DENSITY OR SOLID MATTER VOLUME IN FEN PEATS AND HIGH BOG PEATS

There is a lack of information in literature about air or water entry suction in peat soils. KUNTZE (1966) performed routine measurements of both properties. According to his data there is a wide range of air and water entry suction in peat soils, but he only distinguished between fen peat and high bog peat, the latter divided in better decomposed and less decomposed. In Tabel 1 mean values for the three groups are given.

Table 1. Mean values of air and water entry suction in peat soils (according to KUNTZE, 1966)

	Fen peat	High bog peat	
		less decomposed	better decomposed
Air entry suction h_a	60 cm	116 cm	150 cm
Water entry suction h_w	19 cm	59 cm	43 cm
Ratio h_w/h_a	0.32	0.51	0.29

Kuntze's data are not specified enough to give information on the influence of V_s or ρ_b on air or water entry suction of peat soils

BURGHARDT (1976) gives data on air and water entry suctions and solid matter volume for the different layers of peat soil profiles. These data do not allow for the establishment of any significant relationship. Yet such relationships will exist for, as follows from Fig. 3, the values of k_s and h_a measured in the core samples collected for this study, are closely related; $r^2 = 0.727$ for the entire material of fen peats and high bog peats. KUNTZE (1966) also points out that such a relationship exists.

In Fig. 4 is shown how in vertical cores from fen peats air entry suction (h_a) is related to bulk density (ρ_b) and solid matter volume (V_s). Fig. 5 shows the same for high bog peats. The regression equa-

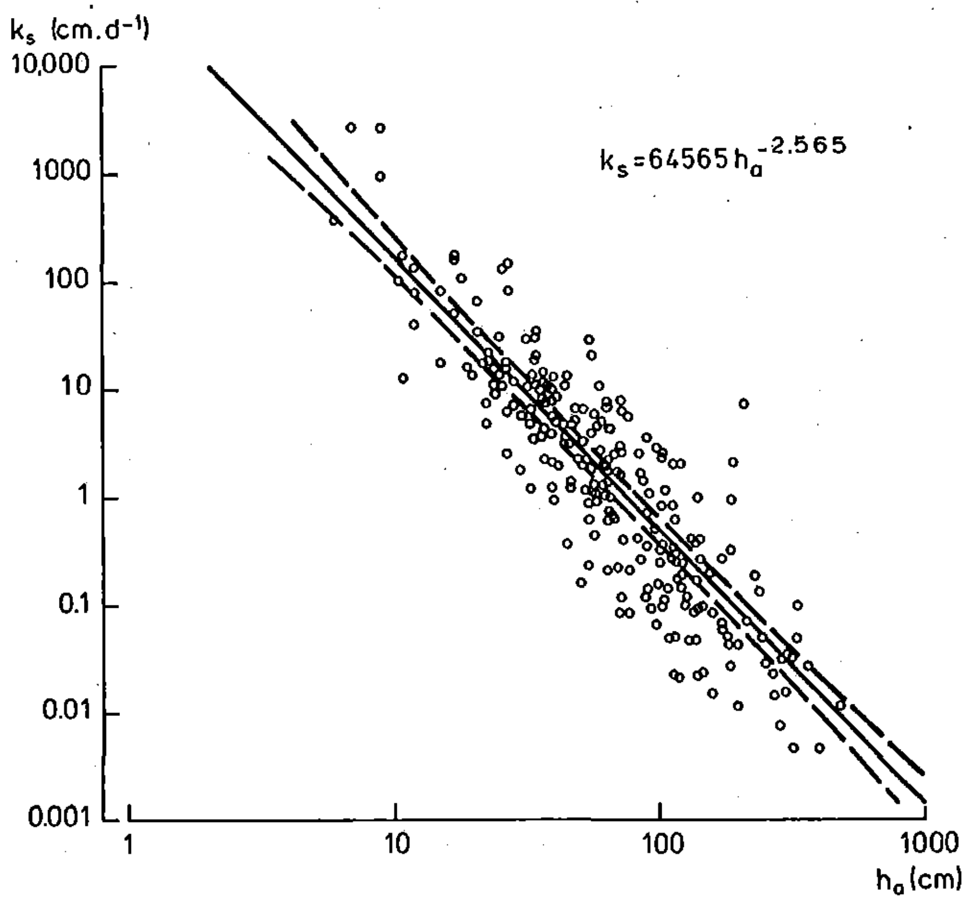

Fig. 3. Relationship between air entry suctions (h_a) and saturated conductivities (k_s) as measured in vertically sampled cores in fen peats and high bog peats

tions are

$$h_a = 416\ \rho_b^{1.12} \qquad r = 0.618 \tag{8}$$

and

$$h_a = 3.58\ V_s^{1.224} \qquad r = 0.607 \tag{9}$$

for fen peats, and

$$h_a = 794\ \rho_b^{1.17} \qquad r = 0.634 \tag{10}$$

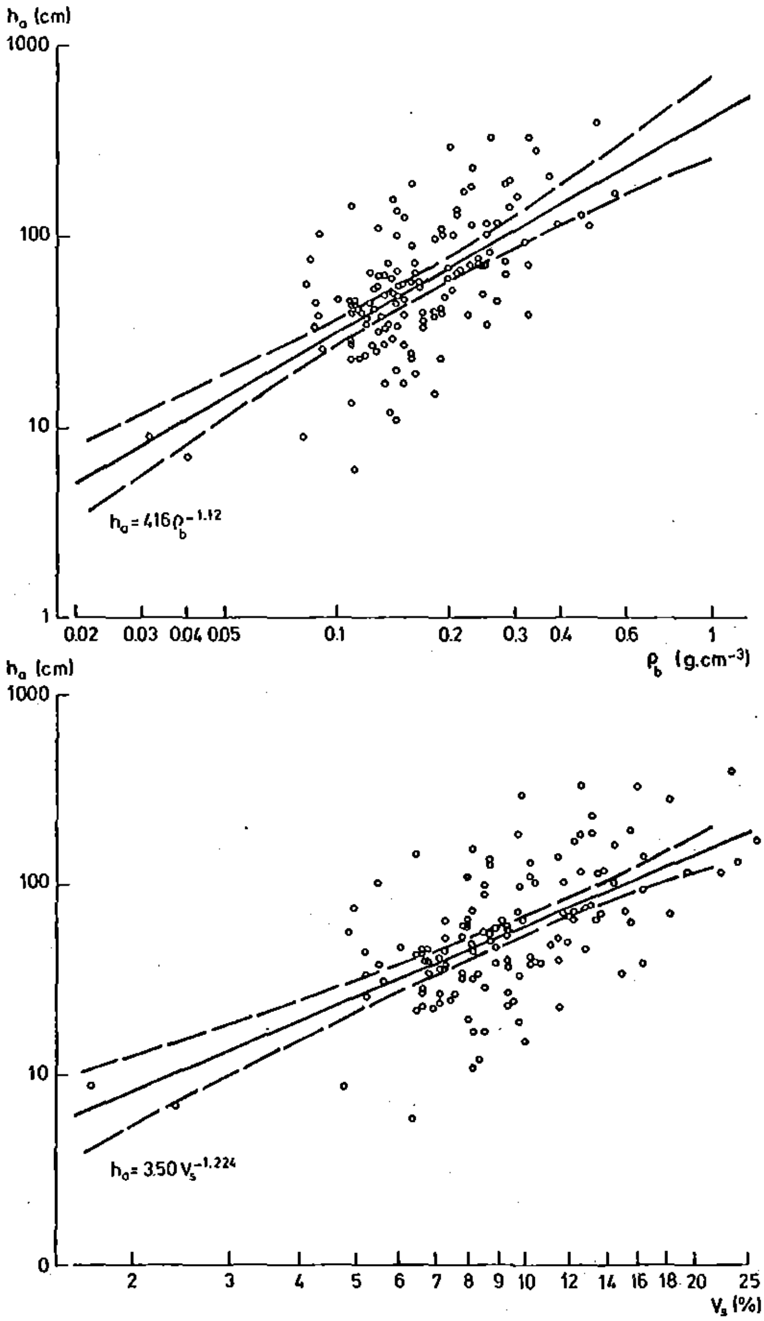

Fig. 4. Relationships between air entry suctions (h_a) and bulk densities (ρ_b) or solid matter volumes (V_s) in vertical cores sampled in fen peats

and

$$h_a = 5.75\ V_s^{1.233} \qquad r = 0.635 \tag{11}$$

for high bog peats.

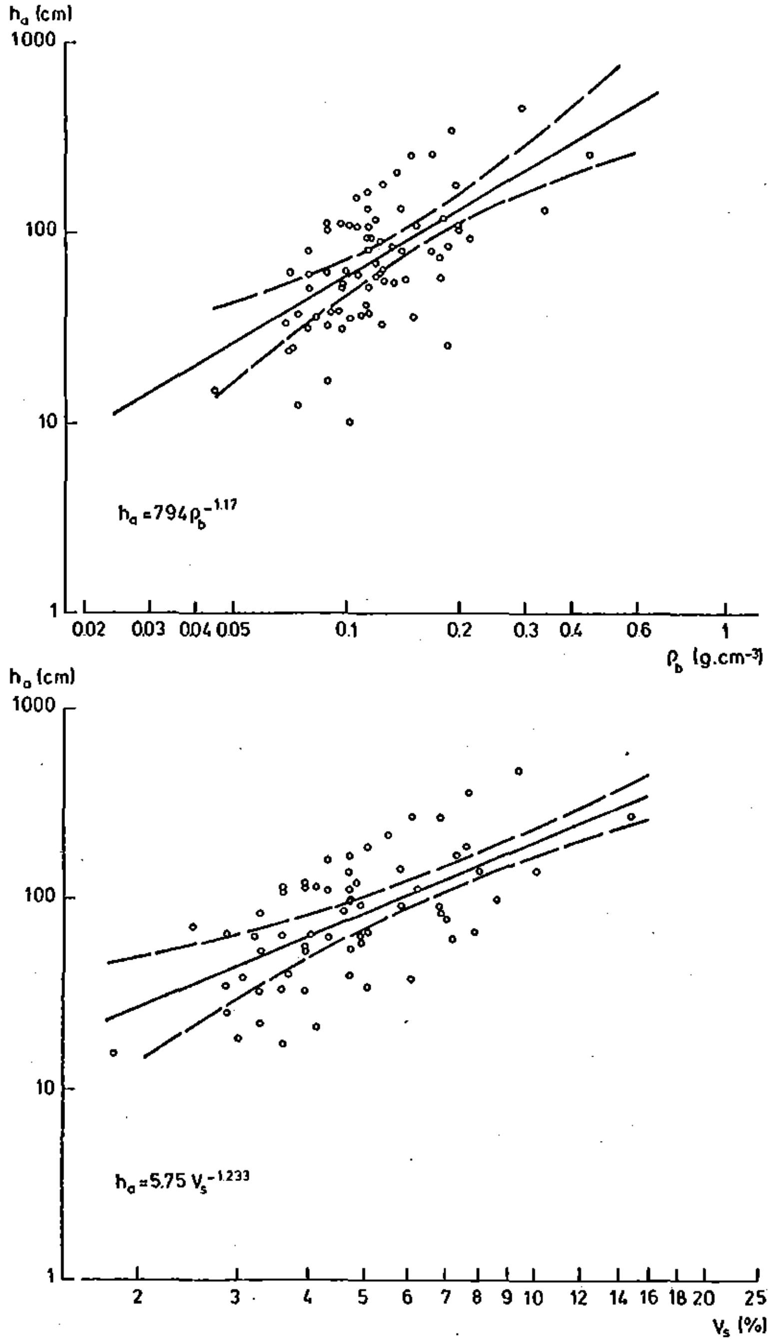

Fig. 5. Relationships between air entry suctions (h_a) and bulk densities (ρ_b) or solid matter volumes (V_s) in vertical cores sampled in high bog peats

Water entry suctions, which are featured in Eq. (2) were not measured because the used apparatus was not suited to the purpose. Water entry suctions can be calculated from air entry suctions with the ratios, given by KUNTZE (1966) and in Table 1. According to relationships provided by PÄIVÄNEN (1973, Fig. 9) the better decomposed high bog peat, as meant by Kuntze, refers to bulk densities of > 0.1 g.cm^{-3} (which is > 6 volume percentages of solids); less decomposed refers to < 0.1 g.cm^{-3} (< 6 volume percentages of solids).

As far as the ratio h_w/h_a in Table 1 concerns Kuntze does not distinguish between less and better decomposed fen peats.

7. HORIZONTAL SATURATED HYDRAULIC CONDUCTIVITIES AND AIR ENTRY VALUES IN HIGH BOG PEATS

In Fig. 6 of horizontally sampled cores from high bog peats k_s and h_a values were plotted against ρ_b. Horizontal saturated conductivity in high bog peats appears to be higher than vertical saturated conductivity by a factor 4 when bulk densities are small, increasing to a factor 10 when bulk densities are large. As should be expected according to fig. 3, air entry suctions in horizontal cores are lower than in vertical cores, more so when bulk densities are higher.

Differences between horizontal and vertical saturated conductivities are reported in literature. BOELTER (1965) refers to some authors and gives data to the same effect as in Fig. 6, but claims these differences to have no significancy.

As mentioned in Section 2 fen peats were not horizontally sampled. Yet fen peats may just like high bog peats have a horizontal laminar structure. Practical interest of horizontal permeabilities of fen peats - at least for calculation of unsaturated conductivities - is less obvious compared to high bog peats for reclamation of soils will sooner be considered in high bog areas.

The regression equations for the relationships in Fig. 6 are respectively:

$$k_s = 0.447\ \rho_b^{-2.6} \qquad (12)$$

and

$$h_a = 398\ \rho_b^{1.23} \qquad (13)$$

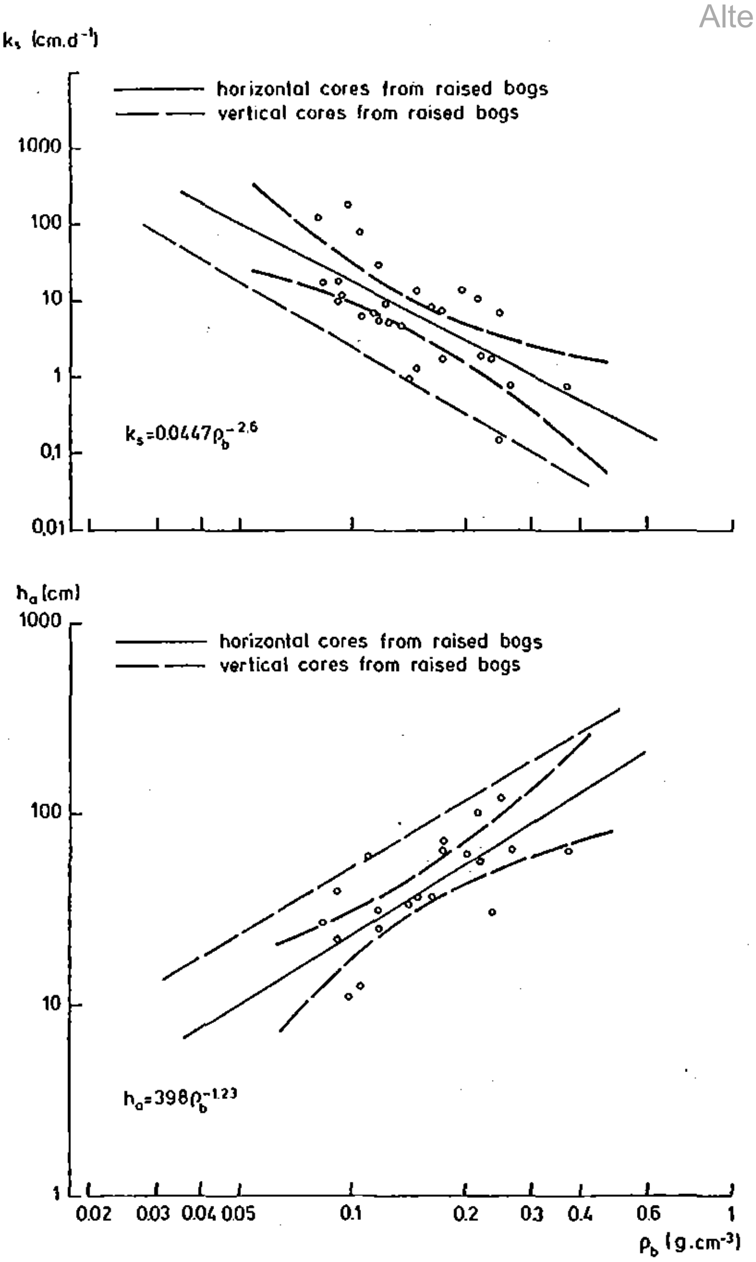

Fig. 6. Relationships between saturated conductivity (k_s) and bulk density (ρ_b) and between air entry suction (h_a) and ρ_b in horizontally sampled cores in high bog peats

8. SLOPE FACTORS n_d OF CONDUCTIVITY FUNCTIONS PROVIDED IN LITERATURE

The ratio n_d = d[log k(h)]/d(log h) can be calculated from hydraulic conductivity measurements. It is the slope factor of the linear regression of log k(h) on log h. Because as a rule hydraulic conductivities are measured during the drying procedure of saturated samples, this value is n_d in eq. (1).

As early as 1938 WILSON and RICHARDS (1938) gave sufficient data of k(h) and h to calculate values of n_d. They are not very specific about the properties of the relative peat soils and a relationship between the values of n_d and ρ_b or V_s is not clear.

WIND (1966) calculates k(h) relations for a young and an old moss peat and gets a lower value of n_d for the peat with the higher bulk density or solid matter volume.

BARTELS und KUNTZE (1973, Table 2) give vertical hydraulic conductivities at suctions of 63, 100, 316 and 1000 cm for two high bog peats and two fen peats with different degrees of humification. Both in high bog peat and in fen peat the value of n_d is lower when the solid matter volumes, as derived from the specified degrees of humification by means of relationships given by PÄIVÄNEN (1973, Fig.), are higher.

BURGHARDT (1976) gives vertical hydraulic conductivities at suctions of 60, 100 and 300 cm for different layers of fen peats. Solid matter volumes can be read from the cross-sections of his profiles. There is again some evidence of decreasing values of n_d with increasing solid matter volume.

RENGER a.o. (1976) give solid matter volumes and k-values at suctions of 63, 100, 316 and 1000 cm for 6 high bog peats and 5 fen peats which were sampled vertically. Calculated n_d values suggest a relationship between the two properties, both for high bog and fen peats.

ILLNER und RAASCH (1977) give measured k-values at suctions of 63, 100, 316 and 794 for phragmites peat. There is a slight indication of the coincidence of lower n_d values with higher solid matter volumes.

The data in Table 2 are plotted in Fig. 7.

For high bog peats a relationship between n_d and solid matter volumes proceeds. In spite of one deviating date point the correlation coefficient is fairly high ($r = -0.827$). For fen peats there is not much conformity between the data of the four authors. Botanical differences between fen peats are not likely to be of influence in this matter, as may appear from the scatter of the data points for

Table 2. Specification of the data from literature used for comparison of solid matter volumes (V_s) and slope factors n_d of conductivity functions for peat soils with more than 30% of organic matter. H is rate of decomposition

Specification	H (-)	V_s (%)	n_d (-)
from: WILSON and RICHARDS (1938)			
1 woody peat with reed and sedge peat (virgin)	-	-	2.92
2 same as 1, cultivated 20 years	-	-	2.27
3 woody peat, screened	-	-	2.38
4 well decomposed woody peat, cultivated 2 years	-	-	2.91
from: WIND (1966)			
1 young moss peat	-	9.2	2.70
2 old moss peat	-	11.6	2.10
from: BARTELS und KUNTZE (1973)			
1 high bog peat (Sphagnumtorf)	2- 3	7.0	3.09
2 fen peat (Schilftorf)	3- 4	9.6	1.75
3 high bog peat (Sphagnumtorf)	8- 9	15.0	1.17
4 fen peat (Schilftorf)	8- 9	18.3	1.36
from: BURGHARDT (1976)			
1 fen peat (Bruchwaldtorf)	7- 8	9.4	1.81
2 fen peat (Bruchwaldtorf)	5- 6	7.0	1.94
3 idem (Seggentorf)	2- 3	6.0	1.04
4 idem (Seggentorf)	2- 3	7.0	1.29
5 idem (Uebergangsmoortorf)	3	7.5	1.36
6 idem (idem)	2- 3	15.0	1.29
from: RENGER, BARTELS, STREBEL und GIESEL (1976)			
1 high bog peat (Sphagnumtorf)	2- 3	3.2	3.44
2 idem	2- 3	5.3	3.17
3 idem	2- 3	10.6	2.48
4 idem	4- 5	7.1	2.87
5 idem	4- 5	14.2	1.36
6 idem	8- 9	6.0	1.79
7 fen peat (Schilftorf)	3- 4	8.8	1.43
8 idem (Schilf-Seggentorf)	7- 8	7.9	1.50
9 idem (idem)	7- 8	8.6	1.28
10 idem (Bruchwaldtorf)	7- 8	12.8	0.68
11 idem (Schilf-Seggentorf)	9-10	16.0	1.16
from: ILLNER und RAASCH (1977)			
1 fen peat (Schilftorf)	-	7.9	2.53
2 idem	-	7.2	2.93
3 idem	-	9.7	2.63
4 idem	-	8.4	2.67

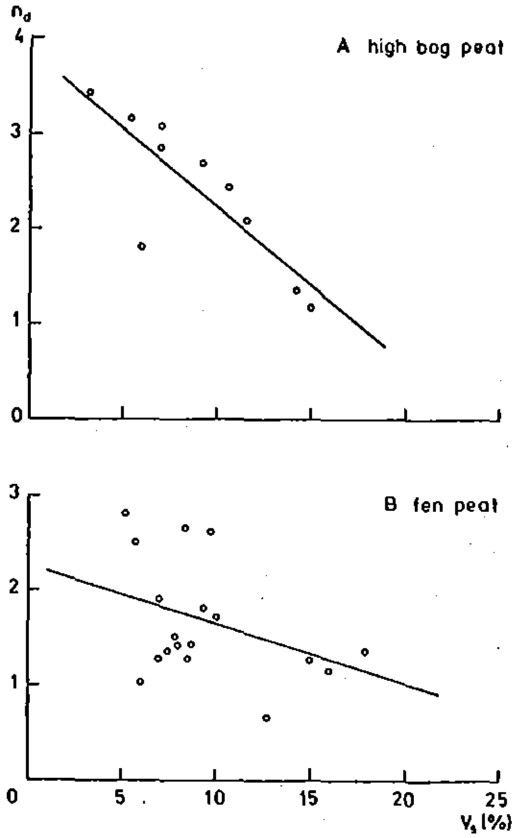

Fig. 7. n_d-values from Table 2 plotted against respective solid matter volumes

phragmites peat alone. A regression line can be calculated for the entire material of fen peats, but it has a rather low correlation coefficient ($r = -0.336$).

There are definitely some reasons to have doubts about the applicability of the relationships in Fig. 7. For fen peats there is the low significancy of the correlation. For high bog peats there is the appearance of reliability, but a strong suspicion of the opposite is caused by the improbability of the big differences between n_d-values and of the very low n_d-values which would result from the relationship. It is in contradiction with a statement by BURGHARDT (1976) to the effect that there are only small differences in pore size distribution in high bog peats. Besides in Fig. 7a there is hardly any duplication of observations.

9. SLOPE FACTORS n_d OF CONDUCTIVITY FUNCTIONS OBTAINED FROM MOISTURE RETENTION CURVES

It is for the reasons given in Section 8 that n_d-values are derived from mean moisture retention curves of peat soils with very different bulk densities by means of the method described by BROOKS and COREY (1964, app. II). These mean moisture retention curves were calculated from data on water contents and matric suction in PÄIVÄNEN (1973, Tables 14, 15, 16) and some were provided by the Soil Survey Institute at Wageningen (the Netherlands). Every curve is the mean of a number of comparable curves. As a consequence they show smooth courses which is in favour of an accurate determination of n_d. Between the separate curves differences in n_d-values occurred, which were clearly related to the bulk densities of the separate mean curves.

In Table 3 bulk densities and solid matter volumes, relative to the mean curves, are entered, as well as n_d-values, obtained from these curves. The solid matter volumes in Table 3 are calculated with Eq. (3) from bulk densities and ash contents, also provided by PÄIVÄNEN (1973, Tables 8, 9, 10) and the Soil Survey Institute. These solid matter volumes are correlated with bulk densities according the equation:

$$SV = 0.219 + 58.83\ \rho_b \qquad r = 0.9986 \qquad (14)$$

The n_d-values in Table 3 are related to bulk densities and solid matter volumes according to the equations:

$$n_d = 2.54 - 2.42\ \rho_b \qquad r = -0.953 \qquad (15)$$

$$n_d = 2.55 - 0.04\ V_s \qquad r = -0.957 \qquad (16)$$

for fen peats, and for high bog peats:

$$n_d = 2.57 - 2.27\ \rho_b \qquad r = -0.81 \qquad (17)$$

$$n_d = 2.58 - 0.038\ V_s \qquad r = -0.82 \qquad (18)$$

Table 3. Mean values of bulk density ρ_b, solid matter volume (V_s) and the values of n_d in eq. (1), as determined according to Brooks and Corey (1964, app. II) from moisture retention curves

Specification	Bulk density ($g.cm^{-3}$)	V_s (%)	n_d (-)
from: Päivänen (1973, tables 14,15,16)			
Sphagnum peat	0.047	2.9	2.50
	0.081	5.0	2.30
	0.110	6.8	2.37
	0.146	8.9	2.15
Sedge peat	0.054	3.3	2.42
	0.085	5.2	2.34
	0.112	6.9	2.27
	0.135	8.3	2.15
	0.161	9.9	2.01
	0.190	11.7	2.09
Woody peat	0.103	6.3	2.28
	0.155	9.3	2.24
	0.207	12.3	2.02
from: Soil Survey Institute, Wageningen			
young Sphagnum peat	0.150	9.0	2.29
old Sphagnum peat	0.140	8.5	2.27
woody fen peat	0.175	10.3	2.09
sedge peat (with Phragmites)	0.190	11.1	2.12

For actual calculation of hydraulic conductivities calculated n_d-values have to be converted to appear as n_s in Eq. (2). For that purpose the expression:

$$n_s = \log\left\{2\left(\frac{h_a}{h_o}\right)^{n_d}\right\}/\log \frac{h_w}{h_o} \qquad (19)$$

was introduced in a previous paper (BLOEMEN, 1980a, Eq. 22). Here h_o is a suction were hydraulic conductivity becomes negligibly small. For the calculations in Section 10 it is chosen to be 10^5 cm.

10. CONDUCTIVITY FUNCTIONS FOR PEAT SOILS

The calculation of hydraulic conductivities with eq. (2) can be performed for every specific peat soil if it is characterized by bulk density and solid matter volume. Because of the low significancy of the relative regressions it is to be recommended to calculate the parameters k_e and h_w in Eq. (2) from both properties and take the mean value for each parameter. The n_s-value will be the same whether it is calculated from bulk density or from solid matter volume because of the high correlation coefficients of the Equations (14) up to and including (18).

In Table 4 parameters and hydraulic conductivities in fen peats and high bog peats at increasing bulk densities are given. In Fig. 8 the conductivity functions of the extremes of fen peats and high bog peats in Table 4 are visualized. In peats with lower bulk densities hydraulic conductivities decrease more rapidly with increasing suction than in peats with higher bulk densities. That is why with increasing suction differences in conductivity between peats with different bulk densities are dwindling away. When in fen peats suction is over 1000 cm conductivities are already higher in peat with a higher bulk density. In high bog peats this occurs at suctions of about 600 cm. Such effects have been pointed out in literature (f.i. BARTELS und KUNTZE, 1973, Figs. 2 and 4).

11. STEADY STATE CAPILLARY RISE IN PEAT SOILS

When the constants in Eq. (2) are known steady state capillary rise in peat soils can also be calculated. The calculation is based on Darcy's law for unsaturated flow, written as:

Table 4. Solid matter volumes (SV), parameter values in eq. (1) and eq. (2) and hydraulic conductivities of fen peats and high bog peats with increasing bulk densities

	ρ_b	V_s	k_s	h_a	n_d	k_e	h_w	n_s	k(h)		
	$(g.cm^{-3})$	(%)	$(cm.d^{-1})$	(cm)	(-)	$(cm.d^{-1})$	(cm)	(-)	$(cm.d^{-1})$		
		eq.(5)	eq.(3),(6)	eq.(8),(9)	eq.(15)or(16)	$0.5k_s$	Table 1	eq.(19)	eq.(2)		
									h=100 cm	h=500 cm	h=1000 cm
fen peats	0.050	3.16	145.1	14	2.42	72.6	4.5	2.08	0.115	0.0040	0.00095
	0.150	9.04	2.31	52	2.17	1.16	16.5	1.80	0.045	0.0025	0.00072
	0.250	14.93	0.33	93	1.93	0.165	30	1.58	0.025	0.0019	0.00065
	0.350	20.80	0.094	138	1.69	0.047	44	1.35	0.016	0.0018	0.00069
	0.450	26.69	0.036	185	1.45	0.018	59	1.13	0.010	0.0016	0.00074
		eq.(5)	eq.(4),(7)	eq.(10),(11)	eq.(17)or(18)			eq.(19)	eq.(2)		
high bog peats	0.050	3.16	18.2	24	2.46	9.1	12	2.19	0.088	0.0026	0.00057
	0.150	9.04	0.778	86	2.23	0.389	34	1.88	0.051	0.0025	0.00068
	0.250	14.93	0.169	159	2.00	0.085	47	1.59	0.026	0.0020	0.00066
	0.350	20.80	0.066	237	1.77	0.033	69	1.37	0.020	0.0022	0.00085
	0.450	26.69	0.031	321	1.55	0.016	93	1.18	0.015	0.0022	0.00097

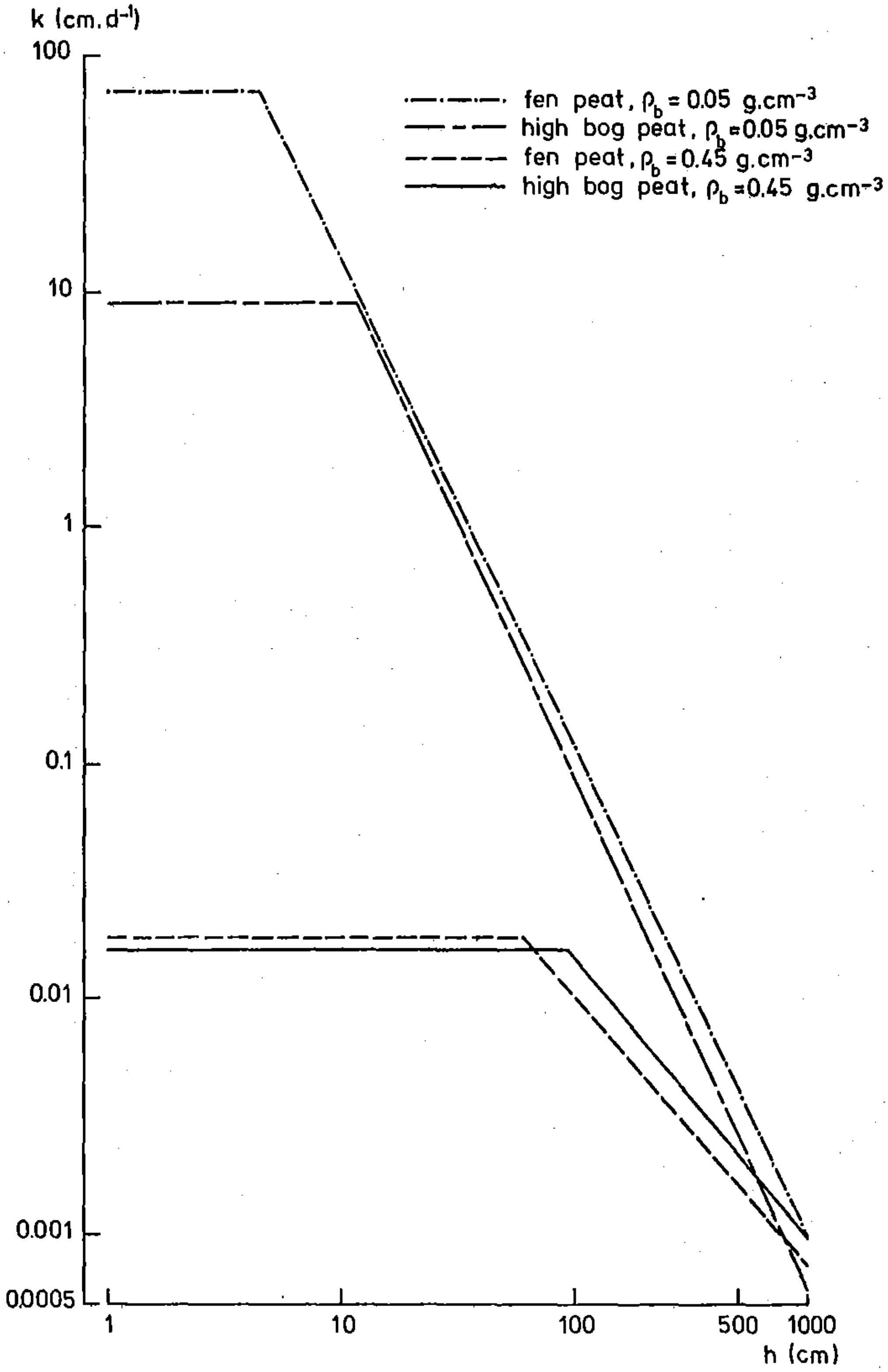

Fig. 8. Hydraulic conductivity k as a function of suction h for the extremes of fen peats and high bog peats in Table 4

$$V = k\left[\frac{dh}{dz} - 1\right] \tag{20}$$

where V is volumetric flux ($cm^3.cm^{-2}.d^{-1}$), k is hydraulic conductivity ($cm.d^{-1}$), h is suction (cm) and z is gravitational head (cm, zero at phreatic level and positive in upward direction). Substitution of Eq. (2) in Eq. (20) and subsequent integration gives steady state flux equations. In the suction range were $k = k_e$, the equation is:

$$z = \frac{k_e\ h}{V + k_e} \qquad \text{(cm)} \qquad \text{when } h < h_w \tag{21}$$

When $h > h_w$ numerical integration must be performed, according to:

$$z_2 = z_1 + \frac{k(\bar{h}).(h_2 - h_1)}{V + k(\bar{h})} \qquad \text{(cm)} \qquad \text{when } h > h_w \tag{22}$$

For the calculation of the height of capillary rise z as a function of flux v, suction h and the depth of the phreatic surface in single and multi-layered soil profiles, based on the Eqs. (2), (21) and (22), a computer program has been developed which is elaborately discussed by BLOEMEN (1980b). The following calculations were performed with this program.

In Fig. 9 the height of capillary rise of a capillary flux of 2 $mm.d^{-1}$ in relation to suction in the peat types in Table 4 is shown. In Fig. 10 the maximal heights of capillary rise of various fluxes in these peat types, with an upper limit of 16,000 cm for suction, are given.

It appears that capillary properties of fen peats with low bulk densities are somewhat better than those of comparable high bog peats. When bulk densities are increasing the differences between fen peats and high bog peats are becoming negligibly small. As a matter of fact capillary properties of all peat soils of high bulk density are rather bad.

For the calculations, providing Figs. 9 and 10, it is assumed that above the phreatic level the peat soil is homogeneous up to the

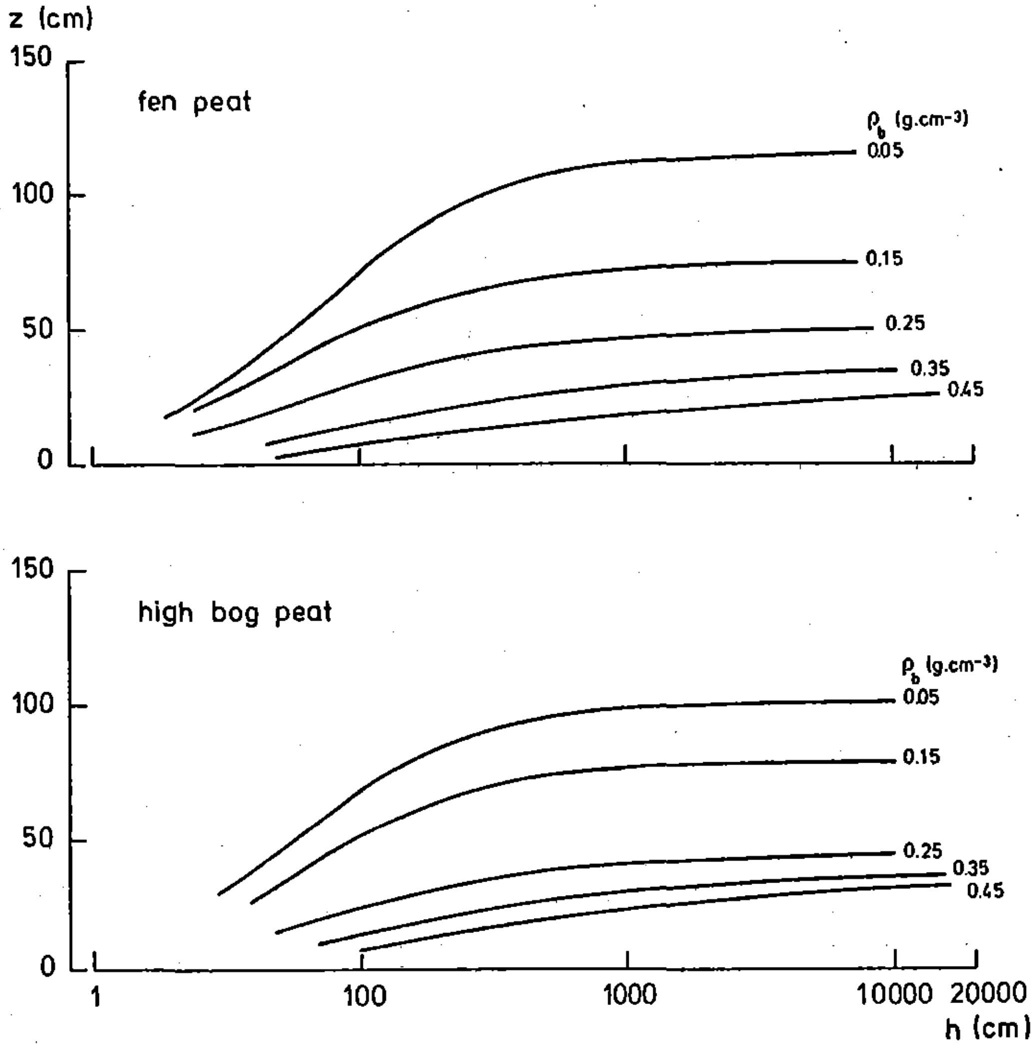

Fig. 9. The height of capillary rise z of a capillary flux v of 2 mm.d^{-1} in relation to suction h in fen peats or high bog peats of increasing bulk densities

height z. This may incidentally by the case, but more often a peat soil will have a profile, showing layers of peat of different nature and varying bulk densities covered by layers of sand or clay and with mineral subsoils. Capillary rise in any peat profile can be calculated when the peat layers are characterized by bulk density and solid matter volume and the mineral top layer and subsoil by texture and organic matter content (BLOEMEN, 1980a). Soil profiles with peat layers show a large variability and before a survey of their capillary properties can be given they should be properly classified and described for the purpose of the necessary calculations. To give

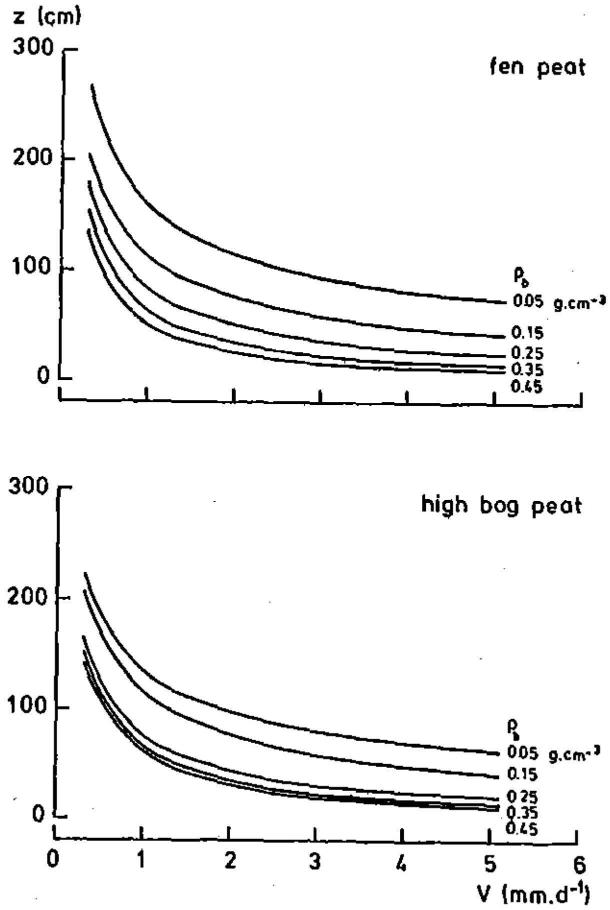

Fig. 10. The maximal heights of capillary rise z of various fluxes v in fen peats and high bog peats, with an upper limit of 16,000 cm for suction h

heights of capillary rise for some casual examples is not in agreement with the general purpose of this paper.

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