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SOIL MOISTURE FORECASTING

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CONTENTS

INTRODUCTION

In many hydrological investigations a large number of guesses have to be made on the effect of climatological conditions and of soil properties in the unsaturated zone on losses of groundwater and on the influence of these factors on groundwater flow. The accuracy by which the groundwater flow can be predicted in groundwater basins from a relatively small number of available data strongly depends on the forecasting of soil moisture extraction patterns under given climatological conditions.

The accuracy by which the soil moisture extraction can be forecasted depends completely on the accuracy by which the soil properties are known. The extraction pattern of soil moisture is not only directly related to the soil physical properties, but is also dependent on the climatological conditions and on the depth of the groundwater table. A good forecasting of soil moisture extraction also results in a fair estimate of the loss of groundwater by capillary rise.

Both the capillary properties and the soil moisture characteristics depend on the granular composition, the density and the poresize distribution of the soil. It is apparent that each soil will have its own properties. It is very often impossible, however, to use for each soil its specific properties in forecasting procedures, as the physical properties of the soil have to be determined in each specific case. For this reason the data of capillary conductivity and soil moisture characteristics available from literature have been collected. These data were averaged for a number of soil groups, resulting in a series of standard soils. When, for instance during hydrological investigations in a groundwater basin, a soil survey has been made with a classification of the soil types present, the physical properties of the corresponding standard soils can be used for forecasting the conditions in the unsaturated zone.

As the soil moisture conditions in the unsaturated zone are also determined by the climatological conditions, the depth of the groundwater table, the practice of farming and by the crop, it is apparent that no data of moisture conditions of each standard soil can be given, which hold under all conditions. A set of standard calculation rules for practical application will be given.

A discussion will be presented of the evaporation from bare soils, which is of particular importance for the hydrological conditions in groundwater basins in semi-arid and arid areas. The evaporation present in the bare areas of groundwater basins is generally not taken into account in hydrological surveys, but it can give under a number of conditions a considerable contribution in the groundwater losses.

Finally, some attention will be given concerning the application of the soil moisture forecasting technique in relation to the forecasting of salt accumulation in the topsoil, when saline groundwater is present.

CAPILLARY CONDUCTIVITY AND SOIL MOISTURE CHARACTERISTICS

The flow of water in unsaturated, as well as saturated soils may be described by Darcy's law which is written as:

$$v = - k \frac{\partial \varphi}{\partial z} \qquad (1)$$

where v is the volumetric flow velocity, φ is the potential, z the direction of flow and k the capillary conductivity. The flow velocity is positive in the positive direction of z.

The hydraulic conductivity k is in saturated media a constant depending on the type of soil. The capillary conductivity in unsaturated soils, however, strongly depends on the soil moisture content, which in turn is related by the soil moisture characteristic to the suction.

WIND (1955) and WESSELING (1957) give as the approximate relation between capillary conductivity and suction (ψ) the empirical equation

$$k = a \psi^{-n} \qquad (2)$$

The exponent n has, according to these authors, a value ranging from 1,5 to 2 in clay soils and higher values in sandy soils. Equation (2), however, has the property that, when ψ equals zero, the saturated conductivity becomes infinite. For this reason GARDNER (1958) proposed a somewhat modified equation expressing the relation between both factors as:

$$k = \frac{a}{\psi^n + b} \qquad (3)$$

According to this equation the saturated conductivity equals a/b at zero suction. The relation proposed by GARDNER requires, in order to be fulfilled, a small suction range near saturation in which the capillary conductivity does not alter considerably. TALSMA (1963) presenting a full discussion of this relation concluded that it holds only for a part of the data given. For other data it was shown that the conductivity decreased rapidly at low suctions and relationships intermediate between those given in the equations (2) and (3) were found.

In connection with the data of capillary conductivity available from literature RIJTEMA (1965) presented a further examination. The data concern in many cases measurements in samples or columns filled with artificially packed soils. Moreover, the measurements cover mostly a limited range from saturation to a suction of 100 to 200 cm. It appeared from the data presented in literature that the relation between capillary conductivity and suction in this range can be expressed for many soils as:

$$k = k_o \, e^{-\alpha\psi} \qquad (4)$$

The conductivity k_o at saturation, obtained by extrapolation of the relationship given in equation (4), is not in all soils equal to the hydraulic conductivity k_s determined under saturated conditions. The extent to which k_s exceeds the value of k_o depends on the existence of an apparent non-capillary pore space, such as rootholes and cracks losing water immediately when a very small suction is present. The systematic deviation present at very low suctions has little influence on the considerations concerning capillary rise, so the extrapolated values can be used in calculations on this subject.

It sometimes appears that the value of capillary conductivity in sandy soils and in artificially packed soil columns remains constant in a small suction range from saturation to a certain value of ψ. Above this suction the conductivity decreases very rapidly with increasing suctions. For soils in which this phenomenon is present equation (4) has to be replaced by the following expressions:

$$k = k_o \qquad \psi \leqslant \psi_a$$
$$k = k_o\, e^{-\alpha(\psi - \psi_a)} \qquad \psi \geqslant \psi_a \qquad (5)$$

where ψ_a is the suction at the air-entry point.

The relations given in the equations (4) and (5) only hold in the low suction range. The maximum suction to which these relations can be applied varies from 300 cm in clay loams to 100 cm in sandy soils. In heavy clay soils this maximum suction is again smaller.

Only a restricted number of data is available from literature concerning the relation between capillary conductivity and suction in the range from field capacity to wilting point. RIJTEMA (1965) discussed the available data and showed, that the relation between capillary conductivity and suction in this range can be represented by equation (2). The value of the exponent n was nearly constant for very different soils, covering the range from medium coarse sand to river basin clay. The smallest value of n was 1.35 for river basin clay, whereas the highest value was found for a fine sandy loam with n = 1.46. This result possibly indicates that the capillary conductivity in this range of high suctions is mainly determined by a film-flow on the surface of the soil particles, whereas the flow through capillaries predominates in the low suction range. For practical application in hydrological forecasting it means that the available data of capillary conductivity in this high suction for each type of soil can be extrapolated using $\psi^{-1.4}$ as variable.

The available data from literature were grouped for various types of soils. The mean relation between capillary conductivity and suction of each group is given in table 1. Equation (4) and (5) have been used in the low suction range and equation (2) in the high suction range with n equalling 1.4. The given value of ψ_{max} in this table represents the suction to which the relations (4) and (5) can be used.

Table 1. Values of K_o, α, ψ_a, ψ_{max} and a for the relations between capillary conductivity and suction

Soil type	K_o $cm \cdot day^{-1}$	α cm^{-1}	ψ_a cm	ψ_{max} cm	a $cm^{2.4} day^{-1}$	
Coarse sand	1120	0.224	10	80	0.080	1
Medium coarse sand	300	0.138	0	90	0.63	2
Medium fine sand	110	0.0822	0	125	3.30	3
fine sand	50	0.0500	0	175	10.9	4
Humous loamy medium coarse sand	1.0	0.0269	0	165	15.0	5
Light loamy medium coarse sand	2.3	0.0562	0	100	5.26	6
Loamy medium coarse sand	0.36	0.0378	0	135	2.10	7
Loamy fine sand	26.5	0.0398	0	200	16.4	8
Sandy loam	16.5	0.0737	0	150	0.24	9
Loess loam	14.5	0.0490	0	130	22.6	10
Fine sandy loam	12.0	0.0248	10	300	26.5	11
Silt loam	6.5	0.0200	0	300	47.3	12
Loam	5.0	0.0231	0	300	14.4	13
Sandy clay loam	23.5	0.0353	0	200	33.6	14
Silty clay loam	1.5	0.0237	0	300	36.0	15
Clay loam	0.98	0.0248	0	300	1.69	16
Light clay	3.5	0.0174	0	300	55.6	17
Silty clay	1.3	0.0480	0	50	28.2	18
Basin clay	0.22	0.0380	0	80	4.86	19
Peat	5.3	0.1045	0	50	6.82	20

Table 2. Soil moisture content in volume percentage in relation to the suction

Soil type	Suction in cm									
	0	2.5	10	31	100	200	500	2500	16 000	10^6
Coarse sand	39.5	36.7	21.5	10.7	3.2	2.4	1.8	1.5	1.2	0.3
Medium coarse sand	36.5	35.7	33.1	27.4	9.5	6.5	5.2	3.1	1.7	0.4
Medium fine sand	35.0	33.4	32.5	30.5	15.5	8.0	6.1	4.3	2.3	0.7
Fine sand	36.4	35.6	35.2	32.8	19.6	15.0	12.9	6.5	4.2	1.2
Humous loamy medium coarse sand	47.0	46.6	46.0	44.0	40.5	36.3	29.3	17.4	10.5	2.8
Light loamy medium coarse sand	39.4	39.0	37.4	35.3	28.0	24.2	20.5	15.1	10.0	3.0
Loamy medium coarse sand	30.1	29.3	28.2	26.5	20.9	18.1	14.1	5.6	2.1	0.5
Loamy fine sand	43.9	43.5	39.9	30.7	17.9	14.6	11.5	8.5	6.0	0.7
Sandy loam	46.5	45.9	44.2	41.9	26.0	19.5	14.2	9.2	6.1	1.5
Loess loam	45.5	44.8	43.6	38.5	34.0	28.3	23.2	17.0	11.0	3.5
Fine sandy loam	50.4	49.9	48.8	48.2	42.3	27.3	22.4	13.2	8.7	1.7
Silt loam	50.9	50.7	49.7	48.4	46.1	33.8	27.9	13.7	9.2	2.0
Loam	50.3	49.8	48.6	48.0	42.0	29.5	24.8	16.7	9.8	2.5
Sandy clay loam	43.2	42.5	40.7	37.6	33.8	31.7	28.8	24.0	18.0	6.0
Silty clay loam	47.5	46.7	43.8	41.0	37.2	34.5	30.5	25.0	18.5	6.0
Clay loam	44.5	43.7	42.9	42.1	41.1	39.3	36.6	34.2	25.5	5.9
Light clay	45.3	45.0	43.5	40.5	36.0	34.0	31.5	27.0	21.5	7.5
Silty clay	50.7	50.0	49.2	48.2	46.3	44.7	42.2	35.2	25.7	6.5
Basin clay	54.0	53.7	53.3	52.7	51.9	49.8	47.0	40.2	32.1	11.9
Peat	86.3	85.5	83.2	81.6	76.3	70.5	64.9	35.6	26.5	9.8

The data given in table 2 are representative for the important groups of soils which are normally present. Within each soil group deviations of the given mean values will be present for each separate soil, but for forecasting purposes the mean values for each soil group will give a reasonable estimate of the capillary properties.

In addition to the capillary properties of the soil groups, information concerning the soil moisture characteristics of the various groups is necessary. Unfortunately the soil moisture characteristic data were not always given in the literature from which the data of capillary conductivity of the various groups were derived. For this reason also other data of soil moisture characteristics were used to obtain a mean characteristic for each group. The representative data of the soil moisture characteristic of each group are given in table 2.

CAPILLARY RISE FROM THE GROUNDWATER TABLE AND SOIL MOISTURE DISTRIBUTION

The amount of capillary rise, the suction distribution, as well as the soil moisture distribution can be calculated from the steady state solution of the capillary flow equation:

$$v = k\left(\frac{d\psi}{dz} - 1\right) \qquad (6)$$

The integration of equation (6) has to be performed in three steps, when calculating the relation between suction and the height z above the groundwater table, depending on the relation between suction and capillary conductivity.

The following expression holds in the suction range in which k remains constant:

$$z = \frac{k_o}{v + k_o} \qquad \psi \leqslant \psi_a \qquad (7)$$

The suction in which the exponential function (5) holds, gives the following equation:

$$z = {}^{1}/_{\alpha} \ln \left\{ \frac{v + k_o}{v + k_o e^{-\alpha(\psi - \psi_a)}} \right\} + \frac{k_o \psi_a}{v + k_o}$$

$$\psi_a \leqslant \psi \leqslant \psi_{max} \qquad (8)$$

The relation between z and ψ in the suction range above ψ_{max} has to be calculated by numerical integration using the expression:

$$\Delta z = \frac{k \Delta \psi}{v + k} = \frac{k(\psi_2 - \psi_1)}{v + k} \qquad (9)$$

where $k = a \bar{\psi}^{-1.4}$, with $\bar{\psi}$ the mean suction equalling $\frac{1}{2}(\psi_2 + \psi_1)$.

The soil moisture distribution in the profile can be determined when the calculations of the suction distribution have been performed, using the data of the soil moisture characteristics given in table 2. The relation between flow velocity, suction, soil moisture content and the height z above the groundwater table of the various soil groups are given in annex 1.

Particularly in non-homogeneous soil profiles where the soil changes gradually from a coarse textured soil near the groundwater table to a fine textured soil at the surface height the capillary rise can remain considerable even when the groundwater table is at great depth. In this case the favourable capillary properties of a coarse textured soil are present in the wet range, whereas the better capillary properties of a fine textured soil become predominant in the range of high suctions. When such situations are present a fair estimate of capillary rise and moisture distribution can be made by using proper combinations of the tables given in annex 1.

MOISTURE LOSSES FROM CROPPED SOILS

As moisture losses from cropped soils strongly depend on the climatological conditions (precipitation and evapotranspiration), the crop itself with respect to the reduction in transpiration due to its physiological properties and the suction in the rootzone, it is apparent that no general data of moisture extraction can be given which hold under all conditions. It is obvious that there will be great differences in moisture losses from the soil when farming under humid conditions with a regular distribution of precipitation and small evapotranspiration rates compared with farming under semi-arid and arid conditions. Even under semi-arid and arid conditions large differences exist when applying a system of dry farming compared with farming under irrigation. Nevertheless it remains possible to give the general rules which can be applied for a large variation in boundary conditions.

With respect to soil moisture forecasting, it is necessary to schematize the extraction pattern by the crop. For this reason the effective rootzone of the crop is introduced, which can be defined as that zone of the soil profile in which 80% of the roots is present. When the soil profile is not restricting the rooting depth, the data given in table 3 can be used for the effective rootzone.

Table 3. Type of rootsystem and corresponding effective rootzone

Type of rooting	Effective rootzone in cm - surface	Example of crop
Shallow rootsystem	25	permanent grass
Medium shallow rootsystem	40	potatoes
Medium deep rootsystem	60	cereals
Deep rootsystem	80	alfalfa

It is assumed that in this effective rootzone no vertical suction gradients are present, so water uptake from this zone is only by radial flow to the roots. It also means that a given value of the suction in the effective rootzone holds for this whole zone.

The amount of water coming available from the subsoil and by capillary flow from the groundwater is taken up by the plant at the lower boundary of the effective rootzone.

The contribution of capillary rise from the groundwater has to be calculated from the steady state conditions using the highest values of the mean suction which is present in the effective rootzone. As the capillary flow rate from the groundwater increases very rapidly with low suctions at the lower boundary of the effective rootzone a fair estimate of the total capillary rise from the groundwater can be obtained by taking 75 per cent of this figure and by multiplying it with the number of days of the growing season.

The moisture losses from the subsoil between the lower boundary of the effective rootzone and the groundwater table have to be determined from the steady state conditions using the highest values of the mean suction which is present in the effective rootzone. The corresponding moisture profiles can be derived with the aid of the moisture content data given in annex 1. As the main part of the water extracted from the subsoil comes from the layers close to the lower boundary of the effective rootzone of the crop, the error made in the calculation of the moisture extraction will be generally small when using steady state conditions for this calculation.

The moisture losses from the effective rootzone have to be calculated with the aid of the soil moisture characteristic data given in table 2. The difference between the moisture content at field capacity and the moisture content at the highest value of the mean suction in this zone, multiplied with the effective rooting depth gives the amount of water lost from this layer.

Adding together the calculated losses from the effective rootzone, the subsoil and the contribution of capillary rise from the groundwater table gives the total possible loss of moisture.

It will be clear that under humid climatological conditions the maximum value of the difference between potential evapotranspiration and precipitation during growth determines the contribution of each of the three water sources in the total water loss. It has been shown (RIJTEMA, 1969) that under humid climatological conditions the potential evapotranspiration must be less than about 60% of the sum of maximum water extraction and precipitation during growth, in order to ensure a potential evapotranspiration rate throughout the whole growing season.

When irrigation is applied the mean suction in the effective rootzone just before each irrigation gift has to be used in the calculation of the moisture extraction from the soil. It must be realised that the extraction from the rootzone and the subsoil is replenished completely or partly with each irrigation gift, so the extraction from both layers has to be taken into account only once. The contribution by capillary rise from the groundwater is in this system a continuous source throughout the whole growing season.

Under conditions of dry farming the moisture extraction from the soil can be calculated assuming at the end of the growing season a mean suction of 16 000 cm in the effective rootzone of the crop.

In the preceding discussion a system was given with the groundwater table at such a constant depth that a contribution from the groundwater table by capillary rise was present. The effect of a falling water table during growth, as well as the moisture extraction from the soil with the groundwater table at great depth will be considered now.

For forecasting purposes the system of a falling watertable has to be schematized. The suction profile in the soil at the end of the wet season at minimum groundwater table depth will be considered as the equilibrium suctions for steady state conditions of zero flux. In that case the suction at each level equals the height above the groundwater table. Considering the apparent equilibrium conditions of field capacity, corresponding to a suction of 200 cm, for the layers which are more than 2 m above the groundwater table, it is possible to determine the moisture distribution for zero flux from the minimum groundwater table depth. A similar moisture distribution profile for steady state conditions of zero flux can be calculated for the maximum groundwater table depth at the end of the dry season. The normal procedure of the calculation of moisture extraction from the effective rootzone, the subsoil and the contribution of capillary rise from the groundwater at the maximum groundwater table depth can be performed. However, an additional amount of water is present in this case, due to the moisture differences of both equilibrium curves. It depends on the hydrological conditions in the area under consideration, whether this additional amount of water is completely available for evapotranspiration or not. Particularly in areas with a sloping watertable part of this amount of water is lost by deep drainage. The evapotranspiration rate directly after the wet season, determines at the other side the quantity of this water that will be used by the crop. As the watertable falls gradually with time, the main part of the additional water between the two extreme groundwater table depths will be available for evapotranspiration. This additional amount of water is often a relatively small quantity and for forecasting purposes a fixed quantity of 50% of this amount can be used as additional water for moisture extraction by evapotranspiration.

The moisture content is considered to be constant with depth (field capacity $\psi = 200$ cm) at the end of the wet season when the groundwater table is at great depth. The main difficulty is present in the determination of the moisture extraction from the subsoil. The extraction pattern depends completely on the evapotranspiration surplus during growth. An surplus of 500 mm in 100 days will give a totally different extraction pattern than the same surplus in 200 days. The assumption for instance of a moisture extraction of 100 mm from the effective rootzone gives a necessary extraction of 400 mm from the subsoil. For the period of 100 days it corresponds to a mean extraction rate of 4 mm. day^{-1} and for the 200 days period a rate of 2 mm. day^{-1}. In both cases the suction profiles will have a tendency to approach the suction distribution for a steady state flux of 4 and 2 mm. day^{-1} respectively. From the differences between the corresponding moisture distribution and the equilibrium moisture contents, the total necessary extraction from the subsoil can be calculated to reach the steady state distribution. By varying the amount of moisture extraction from the effective rootzone a combination of mean extraction rate from the subsoil in mm-day^{-1} and total moisture extraction can be found in which flux times period length equals total moisture extraction from the subsoil.

For forecasting purposes it will be sufficient in many cases to determine the maximum amount of available water during the growth of the cropl In that case a final suction of 16 atm. in the effective rootzone can be assumed. With a known length of the growing season the proper combination of daily extraction rate and total moisture extraction from the subsoil can be found from the steady state curves for moisture flux,

EVAPORATION FROM BARE SOILS

In the steady state case the flux v through the soil profile equals the evaporation rate E from the soil surface. Considering the influence of meteorological conditions on the evaporation rate and therefore on the flux through the soil, it will be clear that the evaporation rate E_s from nearly saturated soil is an adequate specification of the meteorological conditions. With respect to the real evaporation rate three possible cases can be considered.

Firstly, when the watertable is reasonably close to the surface. In that case the general condition can be present that evaporation from the soil is not limited by the water transmitting properties of the soil, or $E_s < v_{max}$, where v_{max} is the maximum flux rate by capillary rise. In this case the flux through the soil is controlled completely by meteorological conditions.

Secondly, when E_s equals v_{max}, the flux through the soil profile is just sufficient to maintain the evaporation rate E_s. The only difference with the first case is a different suction or moisture distribution in the profile above the watertable.

Thirdly, when E_s exceeds v_{max}, the water transmitting properties of the soil become the limiting factor in evaporation, so the real evaporation rate equals v_{max}. The moisture or suction distribution remains virtually the same as in the second case, apart from a dry zone at the soil surface through which the moisture is transmitted partly in the vapour phase.

So far the movement in the liquid phase only has been considered, but the contribution of flow in the vapour phase is of interest when the flux through the soil is smaller than the evaporative demand. The movement of water in the liquid phase can be considered possible to moisture contents corresponding to 16 atm. suction. At values of the relative humidity between 1.00 and 0.988, corresponding to suctions from 0 to 16 atm., vapour pressure gradients are so small that flow in the vapour phase can be neglected. When the suction increases beyond 16 atm. flow in the vapour phase soon becomes predominant and occurs through a small layer at the surface. The length of this zone is increasing when the difference between E_s and v_{max} increases.

The reduction of evaporation by a surface mulch is well-known. Defining for forecasting purposes a mulch as a medium which conducts moisture in the vapour phase only, one has from simple diffusion theory the relation:

$$E = D_m (p_1 - p_2) / L$$

where D_m is the vapour diffusion coefficient for the mulch, p_1 the vapour concentration at the lower boundary of the mulch, p_2 the vapour concentration at the soil surface and L the length of the mulch.

Expressing the vapour concentrations in vapour pressures (mm Hg) and introducing the ratio D_m/D_a, where D_a is the vapour diffusion coefficient in air, results in the following expression for the mulch length:

$$L = \alpha \frac{D_m}{D_a} \frac{(e_1 - e_2)}{v_{max}}$$

where L is mulch length in cm, α the diffusion coefficient in air in $cm^2 . day^{-1} mm\,Hg^{-1}$, e_1 and e_2 the vapour pressures at the lower boundary of the mulch and at the soil surface in mm Hg, v_{max} the maximum flux by capillary rise in $cm . day^{-1}$ and D_m/D_a a dimensionless ratio of the diffusion coefficients of the mulch and the air.
The values of α depend on the mean temperature in the mulch, while the ratio D_m/D_a depends on the air filled pore space x_a. Values of α in relation to temperature and values of D_m/D_a in relation to the air filled pore space are given in table 4.

Table 4. Values of α in relation to the temperature (T) of the mulch and values of D_m/D_a in relation to the air filled pore (x_a) in the mulch

Temperature °C	10	15	20	25	30	35
α $cm^2 day^{-1} mm\,Hg^{-1}$	2.57	2.67	2.77	2.86	2.96	3.05
x_a	0.20	0.25	0.30	0.35	0.40	0.45
D_m/D_a	0.08	0.125	0.170	0.215	0.260	0.305

Assuming a suction of 1000 atm., corresponding with a relative humidity of 50%, and a mean temperature of 35° centigrade at the soil surface, and a suction of 16 atm., corresponding with a relative humidity of 98,8%, combined with a mean temperature of 25° centigrade, results in mulch length of 15 cm when the value of v_{max} equals 0.1 $cm. day^{-1}$, with the air filled pore space equalling 0.35.

It will be clear from this example that under arid and semi-arid conditions the evaporation losses from bare soils still can be considerable when a surface mulch is present.

The magnitude of the evaporation losses through the mulch strongly depends on the mean temperatures at the soil surface and at the lower boundary of the mulch.

Though the daily evaporation rate from bare soil is not exceptionally high, when the groundwater table is at greater depth, it may have a large influence on the hydrological situation, particularly under semi-arid and arid conditions. This has been shown, for example, in a hydrological study of the Varamin groundwater basin in Iran in which a loss of $40. 10^6$ m^3 water per year could not be explained. The lower most part of the basin consists of medium fine and fine textured soils which can be classified as sandy clay loam to silty clay loam. These types of soils have generally excellent capillary properties. The groundwater table in this lower part varies from less than 1 m to 5 m and more. Under the prevailing climatological conditions these factors are favourable for large losses by capillary rise. However, the question concerning the order of magnitude of this capillary rise from the groundwater remained difficult to answer, as the basic data of soil profile, capillary conductivity and depth of the groundwater table were not or only poorly known. Only from 18 observation wells the depth of the groundwater table was known for the lower area of 31, 582 ha. In order to obtain an estimate of the maximum amount of water which can be lost by capillary rise and evaporation, the whole area was considered as an homogeneous sandy clay loam. With the data given in table 1 for the capillary properties of a sandy clay loam the evaporation losses by capillary rise were calculated. The maximum evaporation from this area was found to be, under the given as sumption of soil type, of the order of $65. 10^6$ m^3 per year. This was considerably more than the quantity which had to be explained, but it shows that the loss of $40. 10^6$ m^3 per year from this area was very well possible. The mean evaporation rate of this lower part was 0, 35 $mm. day^{-1}$, but it resulted in a total loss which was 30% of the total inflow to the groundwater of the whole basin of 131, 000 ha.

SOIL PHYSICAL PROPERTIES AND GROUNDWATER QUALITY

The soils of semi-arid and arid areas often contain solvable salts, which are redistributed by a developing water table and appear at the surface where the water table approaches a dangerous level. It has long been recognized already that an important factor affecting salinization is the depth at which saline groundwater is present and nearly all control measures are aimed at lowering the water table, often to a considerable depth.

The concept 'critical depth', originally put forward by POLYNOV (see TALSMA, 1963) is defined as that maximum height above the water table, to which the salts contained in the groundwater can rise under natural conditions both by capillary rise and diffusion. This critical depth is dependent on a variety of factors as the salt concentration of the groundwater, the soil physical properties, diffusion phenomena, climatic factors (evaporation and precipitation), leaching action of precipitation and irrigation water and vegetation. The latter may influence the critical level in two ways, firstly in relation to moisture withdrawal from the profile by evapotranspiration and secondly because of differences in salt tolerance of various species.

TALSMA (1963), presenting a critical review of the various requirements for salinity control given in literature, concludes that the critical depth of the groundwater table coincides approximately with a maximum capillary rise of 0.1 $cm. day^{-1}$ from the groundwater table. It is immediately apparent, however, that differences in groundwater salinity have a pronounced effect on actual salinization. The higher the concentration of solvable salts in the groundwater, the greater is the danger of salinization. Generally speaking, doubling the concentration under a given set of conditions will double the danger.

The annual amount, as well as the distribution of precipitation and evapotranspiration are the main climatic factors causing movement of salt in the soil profile. In periods where precipitation exceeds actual evapotranspiration there is a downward movement of water and solvable salts. When actual evapotranspiration exceeds rainfall there is an upward movement. For irrigated fields within an area, the amount of irrigation water applied has to be added to the amount of precipitation. It must be realized, that even when the groundwater table is below the critical depth, harmful amounts of salts may accumulate, provided sufficient time is allowed for this process.

In cropped soils of medium fine and fine texture the salinization rate increases rapidly during the initial stage of moisture extraction, at a rather low suction at the lower boundary of the rootzone, but it approaches a limiting value when the moisture content in the rootzone is kept quite high.

Reduction in evaporation from bare soils might be present due to the formation of a salt crust at the soil surface. Salt encrustation will be less pronounced in soils with a clay texture at the surface showing numerous cracks thus facilitating the establishment of a natural mulch.

When the salt content of the groundwater is known a forecasting of salt accumulation can be given using the procedures discussed in the preceding sections.

SUMMARY

The capillary properties and the soil moisture characteristics of a series of standard soils are given. These data can be applied in forecasting soil moisture conditions and capillary rise from the groundwater table.

A scheme is given of the forecasting technique which can be applied under a large variation of the boundary conditions.

Special attention is given to the evaporation from bare soils, which affects the groundwater losses in basins under semi-arid and arid climatological conditions.

Finally, a short discussion is given of the possibilities to predict with the soil moisture forecasting technique the accumulation of salt in the topsoil, when saline groundwater is present.

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Annex 1. The height (Z) of capillary rise in relation to flow velocity, suction and soil moisture content of the standard soil types.

1. Coarse sand

ψ cm	θ vol. %	Z cm / V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	14.5		19.98	19.98	19.99	19.99	19.99	19.99	20.0	20.0
50	6.6		43.30	44.06	44.96	46.10	46.80	47.63	48.43	49.4
100	3.2		44.4	45.4	46.7	48.5	49.8	51.6	53.9	58.8
250	2.7		44.5	45.5	46.7	48.6	49.9	51.7	54.0	59.2
500	1.8		44.5	45.5	46.8	48.6	49.9	51.8	54.1	59.5
1 000	1.6		44.5	45.5	46.8	48.6	49.9	51.8	54.2	59.7
2 500	1.5		44.5	45.5	46.8	48.6	49.9	51.8	54.2	59.8
5 000	1.4		44.5	45.5	46.8	48.6	50.0	51.8	54.3	59.9
10 000	1.3		44.5	45.5	46.8	48.6	50.0	51.9	54.3	60.0
16 000	1.2		44.5	45.5	46.8	48.6	50.0	51.9	54.3	60.0

2. Medium coarse sand

ψ cm	θ vol. %	Z cm / V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	30.0		19.8	19.8	19.9	19.9	19.9	19.9	20.0	20.0
50	16.0		42.9	43.9	45.0	46.3	47.1	47.9	48.7	49.5
100	9.5		46.4	48.0	50.1	53.0	55.1	58.0	61.7	69.7
250	6.2		46.5	48.2	50.3	53.3	55.5	58.7	62.8	73.0
500	5.2		46.6	48.2	50.4	53.3	55.8	59.1	63.5	74.9
1 000	3.8		46.6	48.3	50.5	53.7	56.0	59.4	64.0	76.3
2 500	3.1		46.7	48.4	50.6	53.8	56.1	59.6	64.4	77.5
5 000	2.5		46.7	48.4	50.6	53.9	56.2	59.7	64.6	78.2
10 000	2.0		46.7	48.4	50.7	53.9	56.3	59.9	64.8	78.8
16 000	1.7		46.7	48.5	50.7	54.0	56.4	59.9	64.9	79.1

3. Medium fine sand

		V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
ψ cm	θ vol. %	Z cm								
20	31.6		19.8	19.8	19.9	19.9	19.9	19.9	20.0	20.0
50	26.0		47.1	47.6	48.2	48.7	49.0	49.4	49.6	49.9
100	15.5		65.0	67.5	70.7	75.1	78.1	82.0	86.5	93.7
250	7.7		66.1	68.9	72.6	77.9	81.7	87.3	94.9	114.4
500	6.1		66.5	69.4	73.2	78.9	83.0	89.3	98.1	123.9
1 000	5.0		66.8	69.8	73.7	79.6	84.0	90.5	100.6	131.3
2 500	4.3		67.1	70.1	74.2	80.2	84.8	91.8	102.7	137.7
5 000	3.2		67.2	70.3	74.4	80.6	85.3	92.5	104.0	141.4
10 000	2.5		67.3	70.4	74.6	80.9	85.7	93.1	105.0	144.4
16 000	2.3		67.4	70.5	74.7	81.1	86.0	93.5	105.5	145.9

4. Fine sand

		V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
ψ cm	θ vol. %	Z cm								
20	33.5		19.7	19.7	19.8	19.9	19.9	19.9	20.0	20.0
50	29.2		47.9	48.3	48.7	49.1	49.3	49.6	49.7	49.9
100	19.6		82.0	84.5	87.4	90.8	92.7	94.8	96.7	98.9
250	14.7		92.8	97.3	103.3	111.7	117.9	126.7	138.3	165.8
500	11.9		94.1	99.0	105.4	115.0	122.1	133.1	148.7	194.6
1 000	9.2		95.1	100.2	107.1	117.4	125.4	138.0	156.8	218.1
2 500	6.5		95.9	101.3	108.5	119.5	128.2	142.2	163.8	238.9
5 000	5.3		96.4	101.9	109.3	120.7	129.9	144.6	167.9	251.0
10 000	4.7		96.8	102.4	109.9	121.7	131.2	146.2	171.2	260.9
16 000	4.2		97.0	102.6	110.3	122.3	131.9	147.6	172.9	266.1

5. Humous loamy medium coarse sand

ψ cm	Θ vol. %	Z cm / V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	44.8		12.1	13.1	14.3	15.8	16.7	17.7	18.5	19.5
50	42.4		25.2	27.9	31.3	35.6	38.3	41.5	44.5	48.0
100	40.5		36.1	40.7	46.9	55.7	61.8	69.9	78.6	91.1
250	33.6		41.3	47.1	55.2	67.6	77.1	91.1	109.7	152.4
500	29.3		43.1	49.3	58.2	72.0	82.9	99.7	123.8	190.3
1 000	23.3		44.4	51.0	60.4	75.4	87.4	106.5	135.0	212.1
2 500	17.4		45.6	52.5	62.4	78.3	91.3	112.2	144.5	250.5
5 000	14.0		46.2	53.3	63.5	80.0	93.5	115.6	150.1	267.2
10 000	11.7		46.8	54.0	64.4	81.4	95.2	118.3	154.7	280.8
16 000	10.5		47.1	54.4	64.9	82.1	96.3	119.8	157.1	288.0

6. Light loamy medium coarse sand

ψ cm	Θ vol. %	Z cm / V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	36.3		14.4	15.2	16.2	17.3	17.9	18.5	19.1	19.7
50	32.6		26.3	28.7	31.7	35.6	38.1	41.1	44.1	47.8
100	28.0		30.4	33.6	37.9	44.2	48.7	55.1	63.0	78.4
250	23.2		31.5	35.0	39.8	47.0	52.4	60.6	71.9	101.9
500	20.5		32.1	35.8	40.9	48.6	54.5	63.7	77.1	116.8
1 000	18.0		32.6	36.4	41.7	49.8	56.1	66.1	81.0	128.4
2 500	15.1		33.0	36.9	42.3	50.8	57.5	68.1	84.4	138.5
5 000	13.0		33.2	37.2	42.7	51.4	58.3	69.3	86.4	144.4
10 000	11.1		33.4	37.5	43.0	51.9	58.9	70.3	88.0	149.2
16 000	10.0		33.5	37.5	43.2	52.1	59.2	70.7	88.8	151.7

7. Loamy medium coarse sand

		V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
Ψ cm	Θ vol. %	Z cm								
20	27.2		3.7	4.3	5.0	6.0	6.6	7.5	8.3	9.4
50	24.7		11.6	13.6	16.5	20.9	24.2	28.9	34.4	43.1
100	20.9		13.9	16.4	20.1	26.2	31.0	38.3	48.1	68.8
250	17.1		14.5	17.2	21.1	27.6	32.9	41.1	52.7	81.5
500	14.1		14.7	17.5	21.5	28.2	33.7	42.4	54.8	87.6
1 000	10.0		14.9	17.7	21.8	28.7	34.3	43.3	56.4	92.3
2 500	5.6		15.1	17.9	22.1	29.1	34.9	44.1	57.7	96.4
5 000	4.3		15.2	18.0	22.3	29.4	35.2	44.6	58.5	98.7
10 000	3.0		15.3	18.1	22.4	29.5	35.5	45.0	59.1	100.6
16 000	2.1		15.3	18.2	22.5	29.6	35.6	45.2	59.5	101.6

8. Loamy fine sand

		V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
Ψ cm	Θ vol. %	Z cm								
20	35.5		19.4	19.6	19.7	19.8	19.8	19.9	19.9	20.0
50	24.9		47.2	47.8	48.3	48.8	49.1	49.4	49.6	49.9
100	17.9		83.2	85.7	88.6	91.8	93.6	95.6	97.2	99.0
250	14.0		101.2	106.8	114.1	124.4	131.8	142.3	155.8	185.1
500	11.5		103.2	109.2	117.3	129.3	138.2	151.8	171.1	225.9
1 000	9.9		104.6	111.1	119.8	133.0	143.1	159.2	183.2	260.5
2 500	8.5		105.9	112.6	121.9	136.1	147.3	165.5	193.7	291.4
5 000	7.2		106.6	113.6	123.1	138.0	150.0	169.1	199.8	309.7
10 000	6.5		107.2	114.4	124.1	139.4	151.8	172.1	204.8	324.6
16 000	6.0		107.6	114.7	124.7	140.2	152.8	173.7	207.4	332.5

9. Sandy loam

ψ cm	θ vol. %	Z cm V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	42.6		18.7	19.0	19.2	19.5	19.6	19.7	19.8	19.9
50	36.0		39.7	41.2	42.9	44.8	45.9	47.1	48.2	49.4
100	26.0		47.6	50.4	54.2	59.4	63.0	68.0	74.1	85.5
250	18.0		47.9	50.8	54.7	60.1	64.0	69.5	76.4	91.7
500	14.2		47.9	50.9	54.7	60.2	64.1	69.6	76.7	92.6
1 000	11.8		47.9	50.9	54.8	60.2	64.2	69.8	77.0	93.2
2 500	9.2		48.0	50.9	54.8	60.3	64.3	69.9	77.1	93.8
5 000	7.9		48.0	50.9	54.8	60.3	64.3	70.0	77.3	94.1
10 000	6.8		48.0	51.0	54.8	60.4	64.3	70.0	77.3	94.3
16 000	6.1		48.0	51.0	54.8	60.4	64.4	70.0	77.4	94.5

10. Loess loam

ψ cm	θ vol. %	Z cm V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	41.0		18.9	19.1	19.3	19.5	19.7	19.8	19.9	20.0
50	37.3		43.8	44.9	46.0	47.3	47.9	48.6	49.1	49.7
100	34.0		65.4	69.0	73.3	78.9	82.4	86.8	91.1	96.6
250	26.9		71.5	76.4	83.0	92.7	100.1	111.2	126.6	165.5
500	23.5		74.2	79.8	87.4	99.3	108.8	124.0	147.3	218.3
1 000	20.3		76.2	83.3	90.8	104.4	115.6	134.1	163.8	264.7
2 000	17.0		78.0	84.5	93.7	108.8	121.3	142.7	178.2	307.0
5 000	14.3		79.0	85.8	95.4	111.3	124.7	147.8	186.7	332.1
10 000	12.2		79.8	86.8	96.8	113.4	127.5	151.9	193.5	352.5
16 000	11.0		80.3	87.3	97.5	114.4	128.9	154.1	197.1	363.4

11. Fine sandy loam

		V(cm . day^{-1}) 0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
ψ cm	θ vol. %	Z cm							
20	48.6	19.1	19.3	19.5	19.7	19.7	19.8	19.9	20.0
50	46.8	47.0	47.5	48.1	48.7	49.0	49.4	49.6	49.9
100	42.0	88.0	90.1	92.3	94.7	95.9	97.2	98.3	99.4
250	25.5	137.0	145.1	155.5	169.8	179.5	192.3	206.9	230.0
500	22.2	140.9	150.0	162.0	179.4	192.0	210.6	235.5	297.1
1 000	17.5	143.3	153.1	166.0	185.3	199.4	222.4	254.7	350.6
2 500	13.2	145.4	155.6	169.4	190.4	206.7	232.5	271.6	399.9
5 000	11.2	146.6	157.1	171.4	193.4	210.7	238.4	281.5	429.3
10 000	9.6	147.5	158.3	173.0	195.8	213.9	243.2	289.5	453.2
16 000	8.7	148.0	158.9	173.9	197.1	215.6	245.8	293.7	465.9

12. Silt loam

		V(cm . day^{-1}) 0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
ψ cm	θ vol. %	Z cm							
20	48.7	18.3	18.6	18.9	19.3	19.4	19.6	19.8	19.9
50	47.4	44.2	45.3	46.3	47.5	48.1	48.7	49.2	49.7
100	46.1	81.2	84.2	87.6	91.3	93.3	95.4	97.2	99.0
250	32.5	127.7	137.2	149.2	165.7	176.8	191.3	207.3	231.3
500	27.9	134.4	145.4	160.0	181.4	197.2	220.5	252.1	326.9
1 000	20.5	138.6	150.7	167.0	191.9	211.1	241.0	285.4	414.7
2 500	13.7	142.3	155.3	173.0	201.0	223.2	259.1	315.2	500.3
5 000	12.5	144.4	157.9	176.6	206.3	230.2	269.6	322.8	552.2
10 000	10.3	146.1	160.1	179.4	210.6	236.0	278.2	347.0	594.7
16 000	9.2	147.0	161.2	180.9	212.8	239.0	282.8	354.6	617.4

13. Loam

ψ cm	θ vol. %	Z cm / V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	48.3		17.7	18.2	18.6	19.0	19.3	19.5	19.7	19.9
50	46.7		42.2	43.5	45.0	46.5	47.3	48.2	48.9	49.6
100	42.0		74.0	77.7	82.1	87.0	89.8	92.9	95.6	98.5
250	28.1		102.6	111.0	122.1	137.8	148.8	164.0	182.0	214.3
500	24.8		104.6	113.7	125.7	143.1	155.7	174.2	198.4	256.5
1 000	21.3		105.9	115.3	127.8	146.3	160.1	180.6	209.1	287.2
2 000	16.7		107.0	116.7	129.7	149.1	163.8	186.2	218.3	314.4
5 000	14.2		107.7	117.5	130.7	150.7	165.9	189.4	223.7	330.5
10 000	11.6		108.2	118.2	131.6	152.0	167.7	192.0	228.0	343.5
16 000	9.8		108.5	118.5	132.1	152.7	168.6	193.4	230.3	350.5

14. Sandy clay loam

ψ cm	θ vol. %	Z cm / V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	38.7		19.4	19.5	19.6	19.7	19.8	19.9	19.9	20.0
50	35.9		47.3	47.8	48.3	48.9	49.1	49.4	49.7	49.9
100	33.8		85.1	87.5	90.1	93.0	94.6	96.3	97.7	99.2
250	30.9		110.0	116.3	124.4	136.0	144.3	156.0	170.9	201.7
500	28.8		113.9	121.2	130.9	145.7	157.0	174.6	200.3	272.7
1 000	26.3		117.0	125.0	136.0	153.2	167.0	189.4	224.5	338.6
2 500	24.0		119.6	128.2	140.3	159.6	175.6	202.3	245.8	400.5
5 000	21.5		121.1	130.1	142.8	163.4	180.6	209.8	258.3	437.6
10 000	19.4		122.3	131.6	144.8	166.5	184.6	215.9	268.4	467.9
16 000	18.0		123.0	132.4	145.9	168.1	186.8	219.1	273.8	484.0

15. Silty clay loam

ψ cm	θ vol. %	Z cm / V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	42.1		14.0	14.9	15.9	17.1	17.7	18.4	19.0	19.7
50	39.4		31.0	33.5	36.5	40.0	42.1	44.4	46.4	48.8
100	37.2		48.1	53.1	59.4	67.9	73.3	80.0	86.6	94.9
200	33.5		58.2	65.3	75.0	89.5	100.1	115.3	134.7	175.0
500	30.5		61.4	69.4	80.5	97.4	110.6	130.8	159.4	235.7
1000	27.9		64.7	73.5	85.9	105.6	121.3	146.7	185.2	305.6
2500	25.0		67.5	76.9	90.5	112.5	130.5	160.4	208.0	371.7
5000	22.2		69.1	79.0	93.2	116.5	135.9	168.5	221.4	411.5
10000	19.5		70.4	80.6	95.3	119.8	140.2	175.0	232.2	443.9
16000	18.5		71.1	81.5	96.5	121.5	142.6	178.5	238.0	461.1

16. Clay loam

ψ cm	θ vol. %	Z cm / V(cm. day^{-1})	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	42.4		12.1	13.1	14.3	15.8	16.7	17.7	18.5	19.5
50	41.5		25.6	28.3	31.7	36.0	38.6	41.7	44.7	48.1
100	40.6		37.6	42.4	48.8	57.7	63.8	71.8	80.3	92.0
250	38.5		43.6	49.7	58.2	71.2	80.9	95.2	113.7	153.9
500	36.5		43.9	50.1	58.7	71.8	81.8	96.4	115.8	160.2
1000	34.4		44.0	50.3	58.9	72.2	82.3	97.2	117.1	164.0
2500	32.0		44.1	50.4	59.1	72.5	82.7	97.9	118.2	167.2
5000	28.6		44.2	50.5	59.3	72.7	83.0	98.2	118.8	169.1
10000	26.5		44.3	50.6	59.4	72.9	83.2	98.5	119.4	170.7
16000	24.2		44.3	50.6	59.4	73.0	83.3	98.7	119.6	171.5

17. Light clay

ψ cm	Θ vol. %	V(cm. day^{-1}) Z cm	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	41.8		17.1	17.6	18.1	18.7	19.0	19.3	19.6	19.9
50	39.0		40.8	42.4	44.0	45.8	46.8	47.8	48.6	49.5
100	36.5		73.4	77.4	81.9	87.0	89.9	93.0	95.6	98.5
250	33.6		114.5	124.7	137.9	156.0	168.3	184.5	202.4	229.3
500	31.5		122.0	134.0	150.1	173.8	191.4	217.3	252.0	332.9
1 000	29.4		127.1	140.3	158.3	186.1	207.7	241.3	290.7	432.8
2 500	26.7		131.3	145.6	165.4	196.7	221.8	262.4	325.5	532.3
5 000	24.5		133.8	148.7	169.6	203.0	230.1	274.9	346.1	593.1
10 000	22.4		135.8	151.2	173.0	208.0	236.8	284.9	362.9	642.9
16 000	21.0		136.9	152.6	174.7	210.7	240.4	290.3	371.8	669.6

18. Silty clay

ψ cm	Θ vol. %	V(cm. day^{-1}) Z cm	0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	48.5		12.3	13.3	14.5	15.9	16.8	17.2	18.6	19.5
50	47.4		22.3	24.8	28.0	32.3	35.2	38.8	42.4	47.1
100	46.3		28.0	31.7	36.7	44.4	50.0	58.1	67.9	84.8
250	44.0		33.8	38.9	46.2	58.1	67.7	83.0	105.0	158.0
500	42.2		37.1	43.1	51.7	66.3	78.5	98.8	130.2	220.6
1 000	39.1		39.7	46.2	56.0	72.6	86.9	111.3	150.7	277.1
2 500	35.2		41.9	49.0	59.6	78.0	94.1	122.1	168.6	329.4
5 000	31.7		43.1	50.5	61.7	81.2	98.4	128.4	179.1	360.7
10 000	28.0		44.2	51.8	63.4	83.8	101.8	133.5	187.6	386.1
16 000	25.7		44.7	52.5	64.3	85.1	103.6	136.3	192.1	399.7

19. Basin clay

ψ cm	Θ vol. %	V(cm. day^{-1}) → z cm: 0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	52.9	4.7	5.5	6.7	8.6	10.0	12.0	14.3	17.6
50	52.6	7.9	9.5	11.7	15.5	18.5	23.1	29.0	39.8
100	51.9	9.4	11.3	14.1	19.0	23.0	29.5	38.7	60.1
250	49.3	10.4	12.6	15.8	21.6	26.5	34.6	47.0	82.2
500	47.0	11.0	13.3	16.8	23.0	28.4	37.5	51.7	95.9
1 000	44.3	11.4	13.8	17.6	24.1	29.9	39.7	55.4	106.8
2 500	40.2	11.8	14.3	18.2	25.1	31.1	41.5	58.5	116.1
5 000	37.5	12.0	14.6	18.5	25.6	31.8	42.6	60.3	121.5
10 000	34.4	12.2	14.8	18.8	26.0	32.4	43.5	61.8	125.9
16 000	32.1	12.3	14.9	19.0	26.3	32.7	44.0	62.6	128.3

20. Peat

ψ cm	Θ vol. %	V(cm. day^{-1}) → z cm: 0.5	0.4	0.3	0.2	0.15	0.1	0.06	0.02
20	82.4	15.4	16.1	16.9	17.8	18.3	18.8	19.3	19.7
50	79.6	22.9	24.8	27.1	30.4	32.7	35.8	39.3	45.0
100	76.3	24.4	26.6	29.6	34.0	37.4	42.5	49.5	66.5
250	70.5	25.9	28.5	32.0	37.6	42.2	49.5	60.8	95.6
500	64.9	26.7	29.5	33.4	39.7	44.9	53.5	67.4	114.4
1 000	50.5	27.3	30.3	34.4	41.2	46.9	56.6	72.5	129.5
2 500	35.6	27.9	30.9	35.3	42.5	48.7	59.2	76.9	142.5
5 000	32.3	28.2	31.3	35.8	43.3	49.7	60.8	79.5	150.1
10 000	28.9	28.4	31.6	36.2	43.9	50.5	62.0	81.5	156.3
16 000	26.5	28.5	31.8	36.3	44.3	51.0	62.7	82.6	159.6