Model for the Estimation of Water (and Solute) Transport from the Groundwater to Overlying Soil Horizons

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Water management has particular significance in the Hungarian agricultural development. It can be forecasted with high probability that under the natural conditions of Hungary /moderate climate with changing weather and annual precipitation with extremely high spatial and time variability; negative water balance; hydrogeologically closed basin character with a potential danger of salt accumulation; mosaic-like soil cover; intensive cropping/ the increase or rationalization /improve the quality of the products; decrease the inputs; etc./ of crop production - without any harmful environmental side-effects - will be determined by the water use efficiency. Because increasing demands /increasing water requirements of highly productive crop varieties and fully mechanized agrotechnical operations; increasing water consumption of the other sectors of national economy and social development; environment protection; recreation; etc./ have to be satisfied from limited available resources /atmospheric precipitation, surface and subsurface waters, irrigation water/. These facts emphasize the special importance of soil water management, the control of soil moisture regime /VÁRALLYAY, 1987, 1989/.

The role of groundwater in soil moisture regime

Groundwater has a double-face role in the moisture and substance regimes of Hungarian soils and, consequently, in their fertility, as well /VÁRALLYAY, 1980/. The capillary transport from the groundwater to the overlying soil horizons, to the active root zone may considerably contribute to the water supply of plants - in the case of good-quality groundwater /SZALÓKY, 1972/. On the contrary, this capillary transport may result in harmful salinization-alkalization processes in the case of saline groundwater with unfavourable ion composition. Both phenomena are common in Hungary:

- according to multidisciplinary scientific estimations the total quantity of the plants' water supply from the good-quality groundwater is about three times higher than the total irrigation capacity of the country /VÁRALLYAY, 1980/;
- secondary /human-induced/ salinization-alkalization processes occur on large areas in the Hungarian Plain /according to modest estimations on more than 120 000 hectares in the Tisza-I. /Tiszalök/ Irrigation System/ as a consequence of the rise of saline water table, due to the direct

or indirect impacts of irrigation /seepage from unlined reservoires and canals; unproper irrigation practices as the uneven distribution of irrigation water, lack of adequate natural and artificial drainage; etc./ /SZABOLCS et al., 1969/.
Consequently, the quantitative characterization of soil moisture regime in the unsaturated zone of soil between the soil surface and the groundwater table, and the estimation of the quantity of water and soluble constituents entering the soil profile from the groundwater have particular significance in Hungary. For these purposes a 5-step model was elaborated by VÁRALLYAY in 1974. It was improved and further developed later by VÁRALLYAY and RAJKAI /1983, 1984, 1979/; and it was efficiently used in the planning of the Tisza-II. /Kisköre/ Irrigation System in the Great Hungarian Plain /SZABOLCS et al., 1969; VÁRALLYAY, 1987/ and in the forecast and evaluation of the probable ecological consequences of the Gabcikovo-Nagymaros Hydropower Plant on the Danube between Hungary and Czechoslovakia /Studies on the possible impact..., 1989/.

Main steps of the basic model

1. Unsaturated hydraulic conductivity as a function of sucti

The unsaturated conductivity as a function of suction was determined on a considerable number of soil samples, representing the main soil types of the Hungarian Plain and varying greatly in texture, organic matter content, pH and carbonate status. The measurements were made on undisturbed 50 cm long soil columns by "infiltration method" in the low suction range /<pF 2.7-2.8/ /VÁRALLYAY, 1974a/; and on disturbed soil samples by "evaporation column" method in the high suction range />pF 2.8-3.0/ /VÁRALLYAY, 1976/. The measured k-ψ relationships were described by the classical GARNDER equation:

$$k = \frac{a}{b + \psi^{n}} \qquad /1/$$

where: k = unsaturated hydraulic conductivity, cm/day
a, b = experimentally determined constants, a/b ≈ saturated hydraulic conductivity /ψ = 0/, cm/day
ψ = suction, water column cm;
n = experimentally determined exponent

The measured k = f/ψ/ relations /and the whole model/ are illustrated - as an example - on four soils, represent the various horizons of a calcareous meadow chernozem profile from the Hungarian Danube Valley:

No. 146: A-horizon
No. 198: B-horizon
No. 191: Sandy loess C-horizon
No. 301: Coarse-textured Danube alluvium.

The main characteristics of the soils are given in Table 1.
The measured k = f/ψ/ relations are illustrated these soils in Figure 1 and the experimentally determined a, b and n parameters of equation /1/ are given below:

No	a	b	n	a/b	K /measured/
146.	182	150	1,70	1.2	1.1
198.	5600	5600	2.50	1.0	1.8
191.	$3.17 \cdot 10^5$	$1.0 \cdot 10^4$	2.65	31.7	32.0
301.	$8.0 \cdot 10^7$	$8.0 \cdot 10^5$	4.50	100	98.4

As it can be seen from Figure 1, in the low suction range "k" is higher in coarse - textured or well aggregated soils, because their large pores are nearly saturated and may take part in the conductance of water. The water-filled pore volume, and consequently "k" decreases with increasing suction, particularly in coarse-textured soils, where the volume of fine /capillary/ pores is not significant. In the high suction range k-values are higher in fine textured soils, because a considerable portion of their finer pores are filled with water even under higher suction. Above pF 3.5-4.2 liquid flow is practically negligible, especially in coarse-textured soils.

Table 1
Main characteristics of soils

Characteristics	Soil /Code No/			
	146	198	191	301
pH	8.0	8.2	8.1	8.1
$CaCO_3$-contents, %	1.2	30.5	30.1	25.5
EC mmhos/cm	0.9	2.2	0.9	0.2
CEC me/100 g soil	21.2	16.1	16.3	6.0
ESP	0.5	0.6	0.2	1.7
Organic matter content, %	2.3	1.9	0.4	0.4
Bulk density g/cm^3	1.51	1.33	1.27	1.47
Particle-size distribution:				
Loss in HCl-treatment	3.18	33.17	33.43	23.53
1.00 - 0.25 mm	1.99	-	4.46	14.62
0.25 - 0.05 mm	23.81	11.80	22.86	58.77
0.05 - 0.01 mm	31.32	31.81	24.56	1.14
0.01 - 0.005 mm	5.27	5.04	2.48	0.35
0.005 - 0.001 mm	5.52	6.40	2.36	0.15
< 0.001 mm	28.91	11.78	9.85	1.44
Saturated hydraulic conductivity, cm/day	1.1	1.8	32.0	98.4
Volumetric moisture content at				
pF 0	44.8	54.5	54.9	42.3
0.4	43.0	48.6	48.9	40.9
1.0	41.5	46.0	40.8	38.3
1.5	39.0	44.0	35.0	35.9
2.0	36.5	42.1	28.4	15.1
2.3	34.0	39.9	23.5	8.9
2.7	30.2	33.6	17.3	5.4
3.4	23.2	21.4	10.8	2.9
4.2	17.1	11.1	6.9	2.2
6.2	5.7	1.8	1.4	0.5

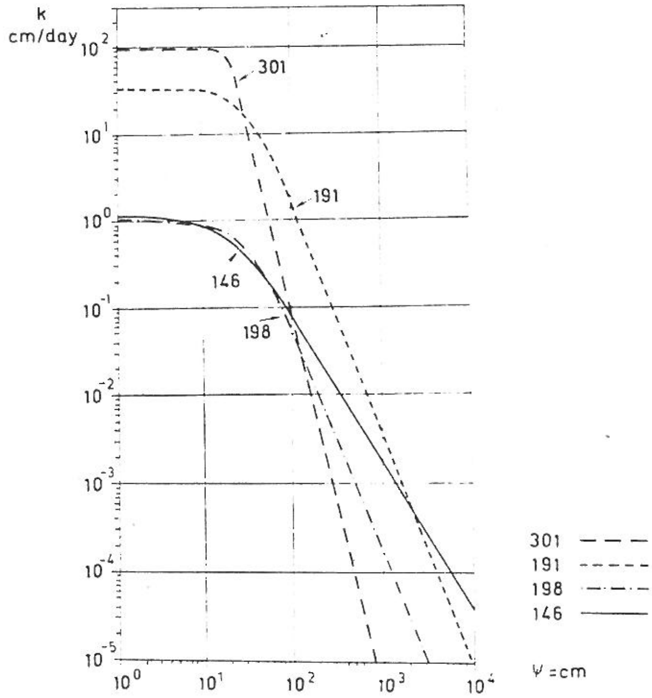

Fig. 1
Relation between capillary conductivity (k = cm/day) and suction (Ψ= cm) for the soils studied

2. *Unsaturated flow in homogeneous soils*

The vertical flow of water through homogeneous soil profiles can be quantitatively characterized by the application of the simplified general unsaturated flow equation. This equation with numerical integration and solving for z gives:

$$z = \int_0^{\psi} \frac{d\psi}{1 + \frac{V}{k}} \qquad /2/$$

where: z = vertical distance above the water table, cm
ψ = suction, water column cm
V = flow velocity /flux/, cm/day
k = unsaturated hydraulic conductivity, cm/day

Based on the experimentally measured k = f/ψ/ relationship /Fig. 1/ with the applicaton of equation /2/ a special type of curve-sets can be constructed, expressing and clearly indicating the direction of vertical capillary flow and the velocity of upward flow, V, as a function of the suction /ψ/ profile and the height above the water table, z. The curve sets are presented for the 4 example soils in Figure 2. It follows from equation /2/

and can be seen from the curve sets /Fig. 2/ that as long as the suction ψ at the soil surface /or at a certain depth in the soil profile/ is greater than the depth to the water table /or the height of this point above the water table: $\psi > z$, water will move upwards. If $\psi = z$ /equilibrium condition/ there is no vertical capillary flow. If $\psi < z$ there is a downward capillary flow /Fig. 2/.

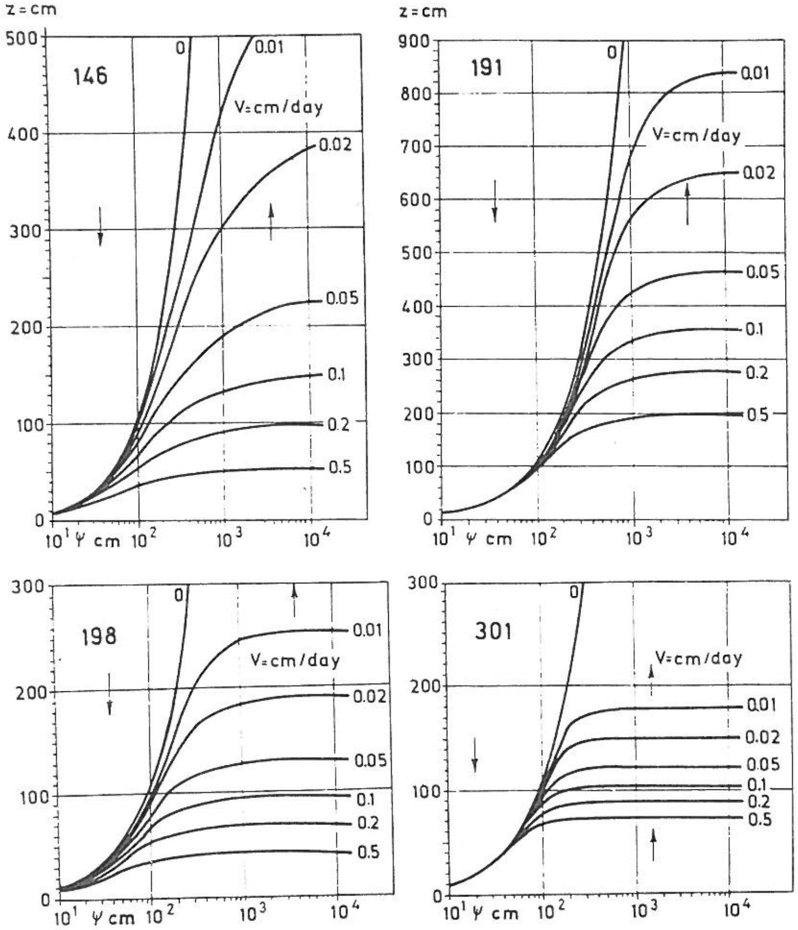

Fig. 2

The direction of vertical capillary flow and the velocity of upward capillary flow (V = cm/day) as a function of the height above the water table (z = cm) and suction (ψ= cm) in the studied soils

The velocity of upward capillary flow depends on the capillary conductivity /k/ at the given suction and on the suction gradient $\frac{\Delta \psi}{\Delta z}$, as follows from equation /2/. Because capillary conductivity is a function of suction which depends on the vertical distance above the water table, the velocity of upward capillary flow depends to a great extent on the height above the water table /or with other words on the depth of water table/, especially in coarse-textured soils, where "k" decreases sharply with increasing suction /Fig. 1/.

In coarse-textured soils V sharply decreases with increasing z and is practically independent of ψ: capillary flow transports a considerable amount of water /and water soluble salts/ from a shallow groundwater to the overlying horizons, while this quantity is negligible in the case of a deep water table. In finer-textured soils V only moderately decreases with increasing z and depends, to a great extent, on the suction profile /Fig. 2/: capillary flow transports relatively large quantities of water /and soluble salts/ even from a deep groundwater to the overlying horizons, especially in the case of a high suction gradient.

Assuming, for instance, that the soil surface is dried out up to the wilting point /$\psi = 10^{4.2}$ cm/ the maximum rate of upward capillary flow will be 0.5; 0.2; 0.1; 0.05; 0.02 and 0.01 cm/day in the studied soils if the depths to the water table are as follows:

No. 146.	54	97	150	225	385	578 cm
No. 198.	43	70	97	130	192	254 cm
No. 191.	194	271	354	460	648	840 cm
No. 301.	71	89	103	122	151	179 cm

If the soil surface is moist /ψ= 200 cm/ these values are as follows:

No. 146.	42	69	94	121	150	170 cm
No. 198.	41	64	85	108	140	160 cm
No. 191.	144	167	181	190	195	198 cm
No. 301.	70	87	101	117	140	158 cm.

3. Application for stratified /layered/ soil profiles

For layered soils the maximum upward capillary flow velocities /as a function of suction/ at a given height above the water table can be determined only by an integrated analysis of the $k = f/\psi/$ relationships /Fig. 1/, or by using the characteristic set of curves /Fig. 2/ for the consecutive layers. The data show, that:

- The upward capillary flow velocity depends largely on the capillary conductivity, thickness and sequence of the horizons in the soil profile.
- If the texture becomes heavier with depth /sand on clay/ the upward capillary flux decreases, because both the clay in the low suction range /near the water table/ and sand in the high suction range /far from the water table/ have relatively low capillary conductivity. This is an unfavourable situation from the viewpoint of additional moisture supply of plants from good-quality groundwater: "Sand on clay - money is thrown away!".
- If the texture becomes coarser with depth /clay on sand: characteristic alluvial stratification/ the upward capillary flux increases, because both the clay in the high suction range and sand in the low suction range have relatively high capillary conductivity. This is a favourable profile-sequence for additional water supply of plants from good-quality groundwater: "Clay on sand: - money in hand!"

Data support the statements of several authors, that the capillary flow transports considerable amounts of water /and soluble salts - if the groundwater or deeper soil horizons contain high amounts of soluble salts/

even from relatively deep groundwater to the overlying horizons, first of all in moderately heavy textured soils and in soil profiles where texture becomes coarser with depth /alluvial stratification/. These conditions are favourable for the water supply of plants from the groundwater /in the case of fresh groundwater and naturally good or properly controlled drainage/, but they are also favourable for salt accumulation in soils from the groundwater /in the case of saline, stagnant groundwater and improper drainage/.

4. *Application for layered soil profiles with fluctuating water table*

In the case of a rising or fluctuating water table the stratification of a natural soil profile changes as a result of the change in the unsaturated cross-section of the soil between the soil surface and the water table. In Figure 3 two schematic soil profile models are illustrated, their stratification and the rising water table are indicated. Between the soil surface and the rising water table an infinite number of variously stratified soil profiles can theoretically be distinguished. Using the previously mentioned calculation procedure computations were made for two profile models to determine the height above the water table where 0.5, 0.1 and 0.02 cm/day upward capillary flow velocities may exist /assuming again that on the soil surface $\psi = 10^{4.2}$ cm/. With these calculations an adequate number of $z_{0.5}$, $z_{0.1}$ and $z_{0.02}$ values can be produced and from the $z_{0.5}$, $z_{0.1}$ and $z_{0.02}$ points $z_{0.5}$ $z_{0.1}$ and $z_{0.02}$ curves can be constructed as it is illustrated in Figure 3. The vertical distance between the water table and the intersection of the above mentioned z-curves and the soil surface represents the depth to the water table at which the given upward capillary flow may exist.

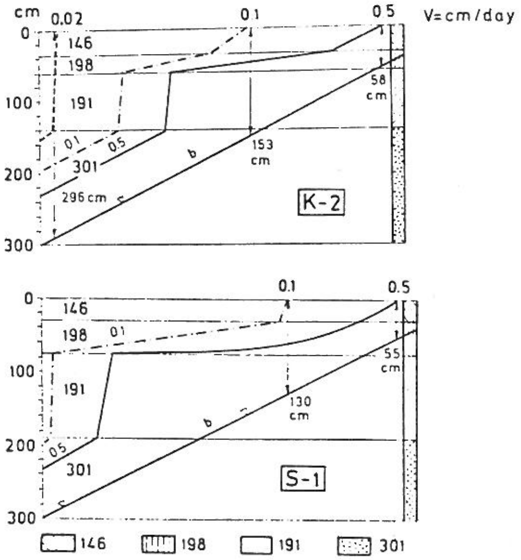

Fig. 3

Relation between the depth to the water table (z = cm) and the maximum upward capillary flow velocity (V = cm/day) in layered soil profile models with rising water table ($\psi = 10^{4.2}$ cm)

5. *Application for solute transport*

As a first approximation, disregarding the chemical and physico-chemical aspects /differences between the flow of water and solutions; interactions between the solid and liquid phases of the soils, etc./, salt transport in the soil profile and salt accumulation in the soil from the groundwater can be described and/or forecasted on the basis of water flow /discussed above/ and the measured, calculated or predicted concentration and chemical composition of the filtrating solution

$$V_{salt} = V_{water} \cdot C_{solution} \cdot 10^{-3} \qquad /3/$$

where V_{salt} = net influx of salts from the groundwater to the overlying soil horizons, t/ha/year;

V_{water} = net influx of water from the groundwater to the overlying horizons, t/ha/year;

$C_{solution}$ = average concentration of the filtrating solution, g/l

This rough estimation is valid only for ideal cases. In natural soil-water-salt systems the differences between the water and solution flow, due to the reversible and irreversible, direct and indirect influences of the concentration and ion composition of the filtrating solution on the

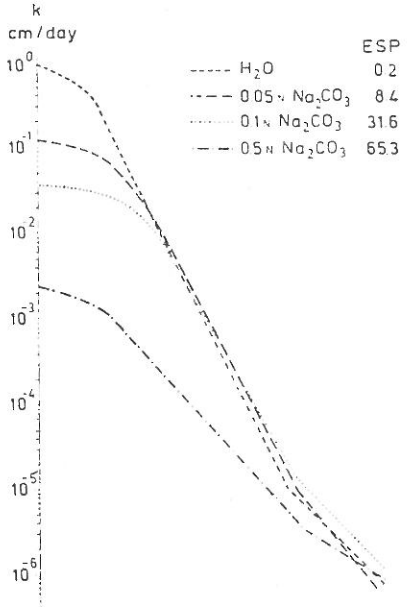

Fig. 4

Relation between capillary conductivity (k = cm/day) and suction (ψ= cm) in a loam /No. 146/ under the influence of Na_2CO_3 solutions of various concentration

interactions between the solid and liquid phases of the soils have to be taken into consideration. Only few data are available in the literature on the influence of salinity and/or alkalinity on the unsaturated flow. For the illustration of the particular importance of the chemical properties of soils and the chemical composition /concentration, ion composition/ of the liquid phase on flow rate /especially in saline and/or alkali environment/ data of a model experiment are summarized in Fig. 4 /KOVDA and SZABOLCS, 1979; VÁRALLYAY and MIRONENKO, 1979/. Unsaturated flow was strongly influenced by the chemical composition of soil solution and by the physico-chemical interactions between the solid and liquid phases.
Hydraulic conductivity sharply decreased under the influence of increasing ESP, especially in saturated conditions /pF $\approx$ 0/ and in the low suction range. The rate of k-decrease with increasing suction was moderated with increasing ESP /"n" decreased/. This is an indirect proof of non-Darcian flow behaviour in heavy textured soils with high ESP. Unsaturated conductivity, calculated for the water-filled cross section of the soil matrix, increased with an increasing gradient of the acting forces /~grad ψ/ because an increasing part of the relatively strongly-bound pore water /which is immobile and has a special "semi-solid" character below a certain hydraulic gradient/ was mobilized and took part in the flow process. As a consequence of this, the influence of high alkalinity /ESP/ gradually decreased with increasing suction: it was only moderate in the medium suction range /pF 2.7-4.0/, and in the high suction range /at pF 4.5-5.0/ the k-values proved to be similar in all the variants /~ $1\text{-}3\times10^{-6}$ cm/day/. But here, of course, the liquid flow has negligible significance. Under such conditions the infiltration and downward flow /wet conditions, low gradient/ are more limited than the upward capillary flow /dry conditions, high gradient/ promoting progressive salinization and alkalization in the presence of a shallow, saline, Na_2CO_3-containing, consequently highly alkaline groundwater. These unfavourable changes cannot be balanced by the traditional leaching and drainage techniques, but need complex ameliorative measures.

Further developments

Because the direct determination /measurement/ of the k-ψ relationships is a rather complicate, work- and time-consuming procedure /not applicable for large-scale routine analyses/ and there are a lot of potential errors in it /e.g. changes in soil structure and consequently pore-size distribution and "pore-architecture" during the measurement, etc./, it seems to be rational to find some calculation procedure for its estimation. Therefore:

/i/ a regression model was introduced and efficiently used for the estimation of water retention characteristics /pF-curves/ on the basis of particle-size distribution, bulk density and organic matter of the soil /RAJKAI et al. 1981/; and

/ii/ the MUALEM concept was applied to generate k-ψ function on the basis of measured or calculated pF-curves and measured saturated hydraulic conductivity values /RAJKAI, 1984/.

For both purposes a computer model has been built by RAJKAI /1981, 1984/. The critical evaluation of these models were summarized by RAJKAI in 1983.

Bulk density, which is a highly variable, rapidly and easily changeable soil parameter in arable lands, has strong influence on both the water retention curves and the k-ψ functions. These influences are illustrated on two soil samples: B-horizons of a meadow chernozem soils, differing in bulk density. The main characteristics of the soils /at the same time the necessary model inputs/ are given in Table 2.

Table 2
Main characteristics of soils used in the bulk density experiment

Soil code	Particle fractions /mm/ 0.25–0.05	 0.05–0.02	 0.02–0.01	 0.01–0.005	 0.005–0.002	 < 0.002	Org. matter %	K cm/day	Bulk density g/cm^3
639	47.2	18.5	7.6	3.6	3.3	19.3	2.4	1	1.72
640	43.3	19.3	8.4	1.6	4.8	22.6	2.3	5	1.43

In order to introduce the effect of the soil bulk density on the unsaturated hydraulic conductivity, pF-curves were calculated by the /i/ model on the basis of the particle-size distribution of the soil No. 640. The effect of the applied bulk density values /1.25, 1.45, 1.65 g/cm3/ on the pF-curve is presented in Fig. 5. It can be seen from the Figure that equilibrium moisture contents of soils were affected by bulk density only in the low suction range /pF 0-2/, and the change linearly depends on bulk density, as it is shown in Fig. 6. The influence of bulk density at saturated conditions proved to be more significant: results 12 vol.% difference between 1.25 and 1.65 g/cm^3 bulk densities; while it causes only about 3% change at pF 2.

To control the calculated bulk density effect on the pF-curve /Fig. 5 and 6/ we present measured pF-curves for two soils with similar texture /soil No. 639 and 640/ but with different bulk densities in Fig. 7.

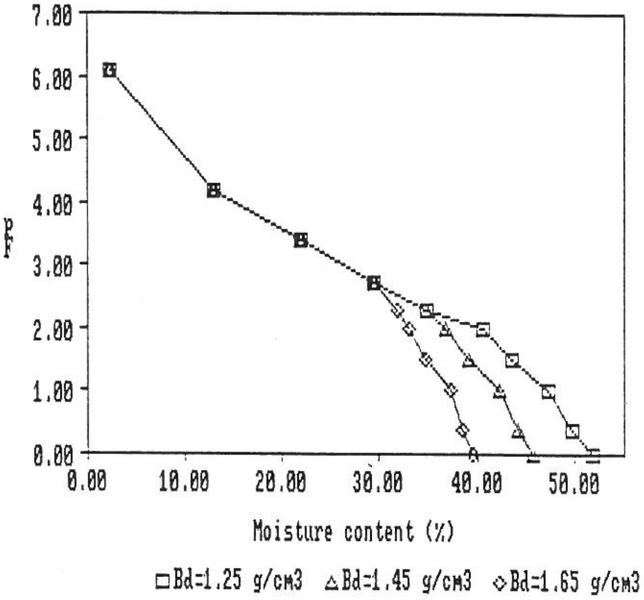

Fig. 5
The influence of bulk density of soils on calculated water retention /pF/ curves

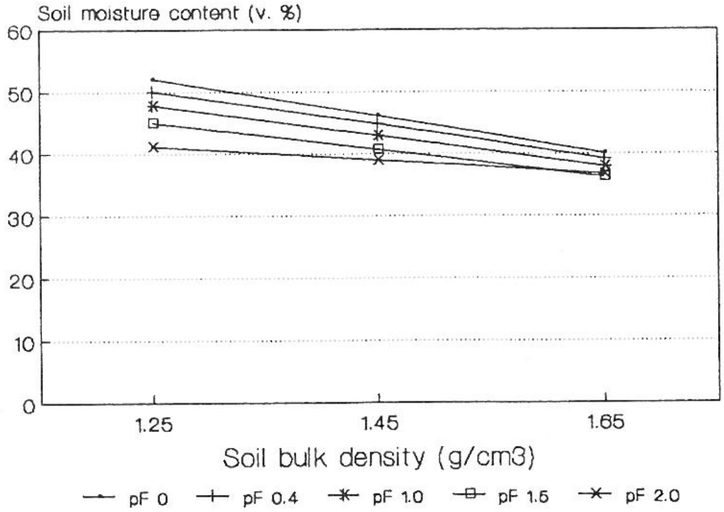

Fig. 6
The effect of bulk density in the low suction range

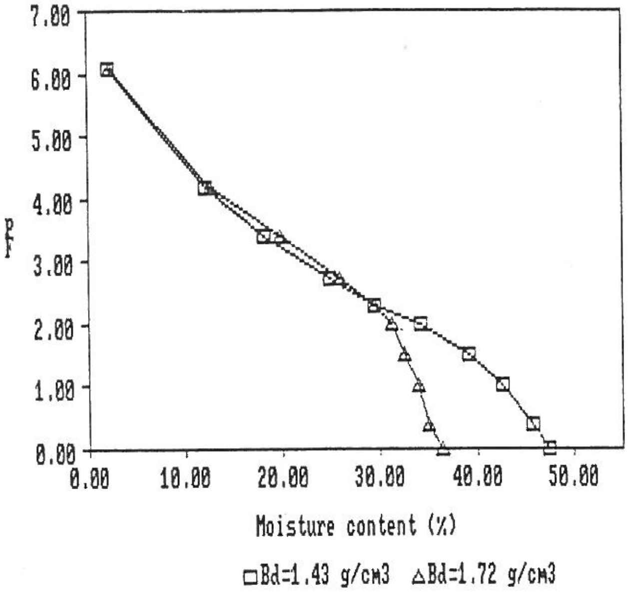

Fig. 7
Measured pF-curves for two soils with similar texture but different bulk densities

Naturally, these effects also appear in the parameters of the function fitted on the calculated pF-values and consequently in the parameters of the capillary conductivity functions calculated from the pF-curve parameters using MUALEM theory /Table 3 /. The influence of the bulk density of soil

Table 3
Effect of soil bulk density on the parameters of hydrophysical functions of soil No. 640.

Bulk density g/cm^3	pF-curve parameters Θ_o	ψ_o	b	Unsaturated hydraulic conductivity parameters α	m
1.25	54.8	922.2	0.4111	0.0131	0.2760
1.45	46.8	1785.5	0.4363	0.0090	0.2380
1.65	39.3	4217.0	0.5107	0.0043	0.2040

function of the pF-curve: $\Theta = \dfrac{\Theta_o}{1+/\frac{\psi}{\psi_c}/^b}$ /RAJKAI, 1984; VÁRALLYAY, 1988/

function of the unsaturated hydraulic conductivity /k-ψ/ is the MUALEM-model /RAJKAI, 1984/

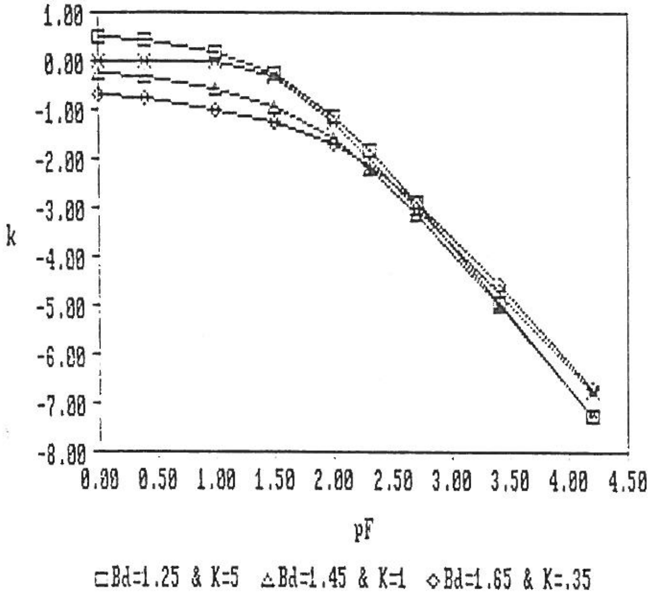

Fig. 8
The influence of the bulk density of soil on unsaturated hydraulic conductivity

on the unsaturated hydraulic conductivity /k-ψ function/ is demonstrated by Figure 8. It can be seen from the Figure that the influence of bulk density on the hydraulic conductivity is significant at and near to saturated conditions, in the low suction range /<pF 2/. Since the capillary conductivity function is largely dependent on the saturated hydraulic conductivity value we use two different cases calculating the height of the capillary transport. In the first case we assume that the saturated conductivity is constant /1 cm/day/ within the entire bulk density domain. In the second case saturated conductivity is decreasing with the increase of bulk density, roughly exponentially. The results are summarized in Fig. 9. In the case of constant saturated hydraulic conductivity the height of 0.2 cm/day capillary flux was increased by increasing bulk densities. This tendency can be explained as the consequence of soil compaction, which increases the quantity of capillary pores and allows the same capillary flux from a longer distance from the groundwater level /from a deeper water table/.

In the simulated case of decreasing saturated hydraulic conductivity, the tendency is just the opposite. It means that the highest rise is in the less compacted soil /which has the highest saturated conductivity/, and the rise is decreased with increasing bulk density /compaction/. The consequence of the simultaneous influences of these two phenomena is, that the bulk density doesn't change the capillary rise considerably.
Here, we wish to emphasize the simplifications of the applied model, which might cause significant deviation from those cases, when the soil is layered and heterogeneous in the properties considered, and the capillary transport is not steady-state.

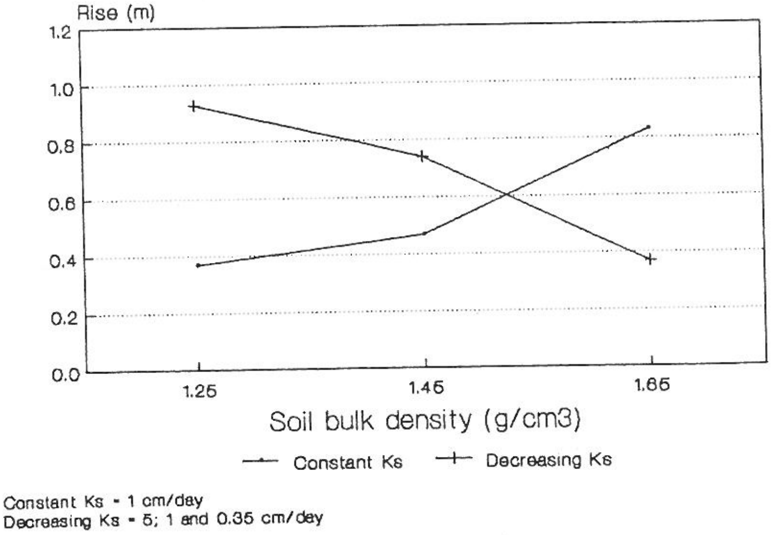

Fig. 9
The influence of bulk density on the height of 0.2 cm/day capillary flux above the water table

Practical applications

With the application of the presented 5-step model, on the basis of directly measured or computed data on the time and territorial distribution of suction /or moisture/ profiles of soils, on the depth of the groundwater table and on the necessary hydrophysical characteristics of soils, the direction and the velocity of vertical capillary flow within the unsaturated zone of the soil /between the soil surface and the groundwater table/ can be determined, quantitatively characterized and interpreted for soil profiles, mapping units or territories. By using forecasted values instead of measured ones /from the meteorological and hydrogeological prognosis, irrigation plans/ a more or less accurate prognosis can be given for the water /and solute/ movement in layered soil profiles with fluctuating water table, and the quantity of water and soluble constituents entering the soil profile from the groundwater can be forecasted as well.

The model can be used efficiently for the calculation of the

- "optimum depth" /or optimum regime/ of the groundwater table, which ensures a maximum contribution to the water supply of plants from a good-quality groundwater /RIJTEMA, 1965; SZALÓKY, 1972; VÁRALLYAY, 1980/;
- "critical depth" /or critical regime/ of the groundwater table, which prevents the harmful soil salinization-alkalization processes from poor-quality /high salinity, unfavourable ion composition: high SAR/ groundwater /TALSMA, 1963/.

The "critical depth" concept was an important part of the comprehensive soil survey-analysis-mapping-monitoring system which was elaborated by SZABOLCS, DARAB and VÁRALLYAY /1969/ for the prognosis and prevention of salinization-alkalization processes in the Hungarian Plain. The system was widely and effectively used in the planning and implementation of the Tisza-II. /Kisköre/ Irrigation System.

The "optimum depth" concept was applied in the forecast of the possible ecological impacts of the planned Gabcikovo-Nagymaros Hydropower Station on the Danube between Hungary and Czechoslovakia. In the framework of the joint Hungarian-Slovakian scientific cooperation programme 1:50 000 scale maps were prepared on the characteristics of hydrophysical properties and moisture regime of soils and on the present and forecasted groundwater conditions. With the application of our 5-step model the consequences of the forecasted changes in the groundwater regime /water table and its fluctuation; quality and pollution aspects/ were interpreted for a soil moisture and substance regime prognosis.

In the area three main cases were distinguished, quantified and spatially delineated /mapped/:

/a/ Both the present and forecasted groundwater level is in the gravel strata. In this case the capillary transport from the groundwater to the overlying horizons are negligible /~ 0/ and there will be no changes in the soil moisture regime as a consequence of the construction.

/b/ Both the present and forecasted groundwater level is in the finer-textured strata. In that case the sink of the water table will reduce, the rise of the water table will increase the flux of capillary transport from the groundwater to the overlying horizons. The changes were quantitatively forecasted with the application of our models. In the area of sinking water table a 10-50 mm/year moisture loss was predicted. Because of the favourable natural drainage conditions and the good quality of the groundwaters /~ filtrated Danube water/ the potential possibilities of secondary salinization-alkalization processes are negligible and that of waterlogging and overmoistening are also limited.

/c/ At present the groundwater level is fluctuating in finer-textured alluvial deposits and will sink /at least periodically/ into the gravel strata. In that case the present, considerable capillary water transport will stop /or will be limited for certain periods/. In such territories 50-150 mm/year /!/ moisture supply losses were predicted. At places where the $CaCO_3$-containing groundwater is fluctuating between the gravel strata and the overlying finer deposits carbonate accumulation, in more serious cases the formation of hard petrocalcic horizons were forecasted /Studies on the possible impact ...., 1989/.

We are convinced that the computerized model - with further improvements - will be an efficient scientific tool for soil water management.

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