CAPSEV

Steady state moisture flow theory
Program description
User manual

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ABSTRACT

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A conversational computer program is presented to calculate the pressure head profiles of an unsaturated multi-layered soil profile under steady-state conditions. The soil moisture flux may be directed upward (capillary rise) or downward (infiltration). The soil physical data (hydraulic conductivity) required for the calculations to be performed are either read in as a table, described by analytical functions or calculated by the program from the grain size distribution. The applied theory is discussed first, followed by the description of the computerprogram and some examples.

Keywords: steady-state water flow, capillary rise, infiltration, grain size distribution, hydraulic conductivity, computer program.

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1 INTRODUCTION

During the past few years many programs have been developed to calculate the height of capillary rise in a heterogeneous soil profile (e.g. Bloemen, 1980b, Aliverti-Piuri and Wesseling, 1979, Bloemen and Van Gils, 1982, Wesseling et al., 1984). The program CAPSEV that will be discussed here is an extension of the program described by Wesseling et al. (1984). Several new options have been added, e.g. the possibility to describe the K(h)-relationship with Van Genuchtens equation. Another new option is the capability of calculating the maximally possible capillary flux in a soil profile. Furthermore the calculation of the moisture content of a specified section of the soil profile and its storage coefficient have been introduced.

Chapter 2 of this report describes the general theory of steady state soil moisture flow. Chapter 3 presents some possibile ways to describe the K(h)-relationship, and chapter 4 presents the equations to calculate the hydraulic conductivity from the grain size distribution and humus content of a soil. In chapter 5 the program CAPSEV is described, together with examples of input and output.

2 STEADY STATE SOIL MOISTURE FLOW

Steady state soil moisture flow in a 1-dimensional, vertical soil profile can be described by Darcy's equation:

$$q = -K(h)\left(\frac{dh}{dz}+1\right) \tag{1}$$

where

q = soil moisture flux density, positive in case of capillary rise, negative in case of infiltration ($cm.d^{-1}$),
K(h) = hydraulic conductivity as a function of h ($cm.d^{-1}$),
h = pressure head (negative in unsaturated zone) (cm),
z = vertical coordinate with origin at the soil surface, directed positive upward (cm).

Rearranging eq. (1) yields:

$$\frac{dz}{dh} = \frac{-1}{1+\frac{q}{K(h)}} \tag{2}$$

When one is interested in a pressure head profile (the relation between z and h) for a certain K(h)-relation and a specified flux q, eq. (2) should be integrated to yield eq. (3):

$$\int_0^{z_r} dz = -\int_0^{h_r} \frac{dh}{1+\frac{q}{K(h)}} \tag{3}$$

where h_r is the pressure head for which one wants to find the position z_r. To see at what depth this pressure head h_r occurs, integration should take place from h = 0 (at the groundwater level) to h_r. When the considered soil profile is heterogeneous (it consists of more than 1 physical layer), integration should take place over each layer separately. Assume $h_1,h_2,...,h_N$ are the pressure heads at the top of layer 1,...,N, where N is the number of layers in the soil profile, so $h_1,h_2,...,h_N$ are the pressure heads at resp. $z_1,z_2,...z_N$ cm above the groundwater level. Integration is then performed using eq. (4):

$$\int_0^{z_N} dz = -\int_0^{h_1} \frac{dh}{1+\frac{q}{K_1(h)}} - \int_{h_1}^{h_2} \frac{dh}{1+\frac{q}{K_2(h)}} - \dots - \int_{h_{N-1}}^{h_N} \frac{dh}{1+\frac{q}{K_N(h)}} \tag{4}$$

The h-values at the boundaries between the layers are initially unknown and have to be determined during the integration procedure. Thus starting from h = 0 and z = 0 at the water table, h is steadily decreased until z reaches z_i, the known position of the i-th boundary. Since the pressure head is continuous across the boundary, the value h_i may be used as the lower limit of the next integration term. In this way the integration will proceed until either the last value of h (h_N) is reached or z reaches the soil surface.

The equations (3) and (4) may be solved analytically for some simple K(h)-relations (e.g. Feddes, 1971, Aliverti-Piuri and

Wesseling, 1979). A more complete overview of analytical solutions is presented by Brandyk (1990, pag.44) . As soon as the description of the K(h)-relationship becomes more complicated, it will be very laborious, if not impossible, to find an analytical solution. Even when an analytical solution exists, often a calculator or computer is required to calculate the values of z.

Nowadays integration as described by the equations (3) and (4) is usually performed numerically. To do so the integration interval is divided into M discrete subintervals of equal size. The eqs. (3) and (4) can be written as eqs. (5) and (6):

$$z = \sum_{i=1}^{M} \frac{\Delta h}{1+\left[\frac{q}{K(h_{av})}\right]} \tag{5}$$

$$z = \sum_{j=1}^{N} \sum_{i=1}^{M_j} \frac{\Delta h}{1+\left[\frac{q}{K_j(h_{av})}\right]} \tag{6}$$

where M_j is the number of sub-intervals in layer j and $K_j(h_{av})$ is the hydraulic conductivity corresponding to pressure head h_{av} in layer j. When h_i and h_{i+1} are the lower and upper boundary value of the i-th interval then:

$$h_{av} = \frac{1}{2}(h_i+h_{i+1}) \tag{7}$$

In case of infiltration the eqs. (3), (4), (5) and (6) may cause problems because the term q/K(h) may be smaller than -1, thus yielding a decreasing z, which is physically impossible. Therefore a different approximation will be used in case of infiltration. Eq. (1) may be rearranged to:

$$dh = -\left(1+\frac{q}{K(h)}\right)dz \tag{8}$$

Discretizing eq. (8) now yields:

$$h_{i+1} = h_i-(z_{i+1}-z_i)\left(1+\frac{q}{K(h_{av})}\right) \tag{9}$$

This means that, starting from the groundwater level, where z = 0 and h = 0, the pressure head at some height z may be found according to eq. (9). As the value of h at height z is required to calculate h_{av}, an iterative procedure has to be applied in order to find the correct pressure head distribution profile in case of infiltration.

The results of these calculations may be presented in a table or as a figure. Fig. 1 shows an example of a graphical representation of the computed results for a profile consisting of several layers: Fig. 1a presents the results for the height of capillary rise, Fig. 1b the pressure head profile in case of infiltration for several fluxes.

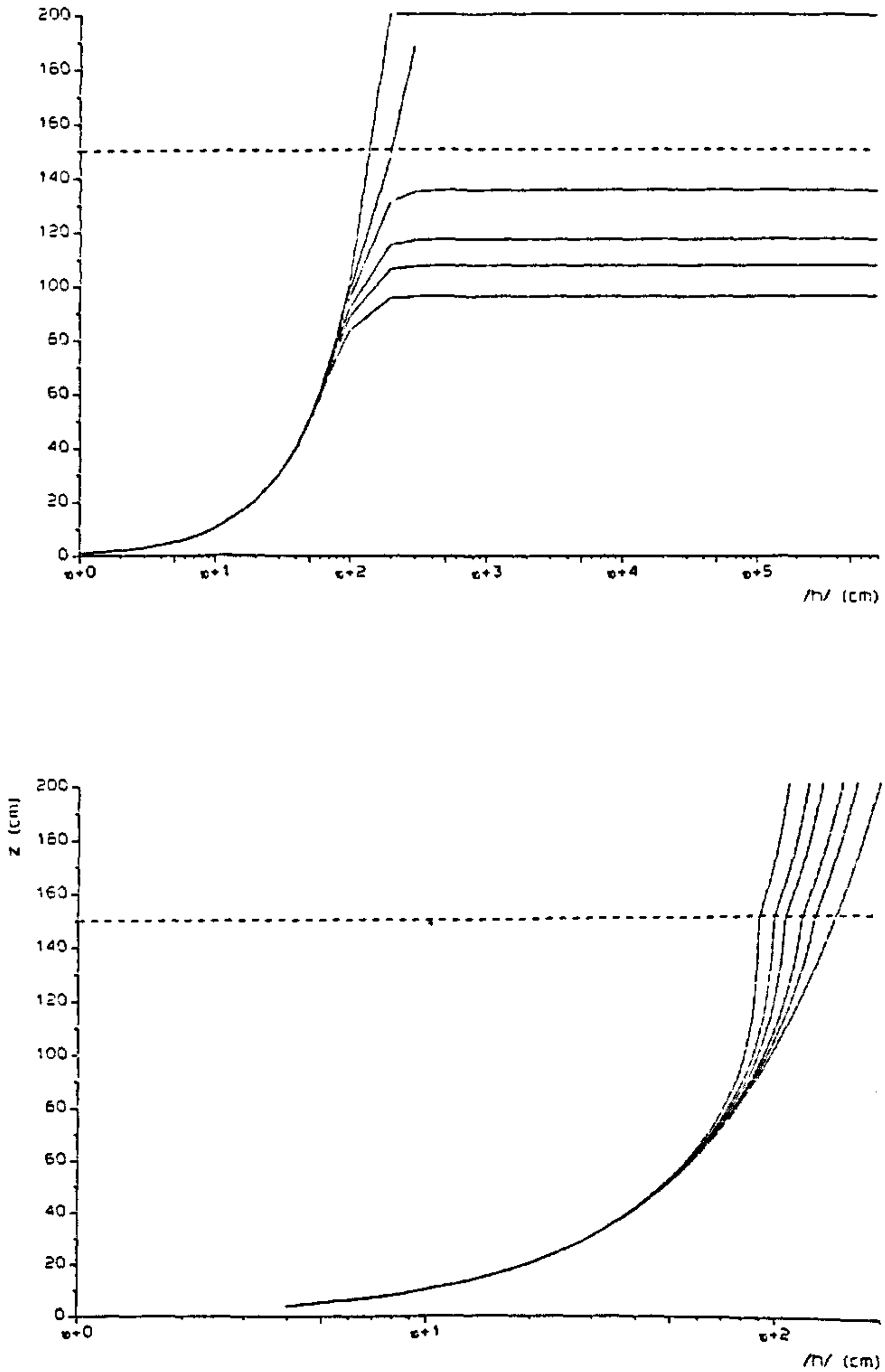


Fig. 1 Pressure head profiles in case of (a) capillary rise and (b) infiltration

Sometimes one is interested in knowing the maximal flux at a certain pressure head and depth. Suppose a crop is transpiring 0.2 $cm.d^{-1}$ as an average. This water is withdrawn from the root zone, say the top 20 cm of the profile. However, it is assumed that this type of crop is suffering from drought when the pressure head in the centre of the root zone is getting below a certain value, say -200 cm. Assuming the groundwater level can be fully controlled, the problem now is to find the groundwater depth that can (as a steady state condition) deliver such a capillary flux that the pressure head value of -200 cm at 10 cm below the soil profile is not exceeded when the root water up-take is 0.2 $cm.d^{-1}$. This value can be found from Fig. 1a. Drawing a figure of the maximum fluxes versus the groundwater level for several pressure heads at a certain depth yields Fig. 2.
In regional groundwater models the so-called storage coefficient is used. This is a constant that represents the average change in the water content of a specified zone of the profile when the groundwater level changes 1 cm. As this value changes with the depth of the groundwater level, it should be calculated for several values of the groundwater level. When the pressure head profile is known for certain flux-values, the storage coefficient μ can be calculated from the following equation:

$$\mu = \frac{\int_{z_b}^{z_t} [\theta_s - \theta(h(z))]\,dz}{z_g} = \frac{\sum_{i=z_b}^{z_t} [\theta_s - \theta(h(z_i))]}{z_g} \qquad (10)$$

where

z_b = depth of bottom of zone under consideration (cm),
z_t = depth of top of zone under consideration (cm),
z_g = depth of groundwater level (cm),
z_i = position of center of discretisation interval i,
θ_s = moisture content at saturation ($cm^3.cm^{-3}$),
$\theta(h(z_i))$ = moisture content corresponding to pressure head h at depth z ($cm^3.cm^{-3}$).

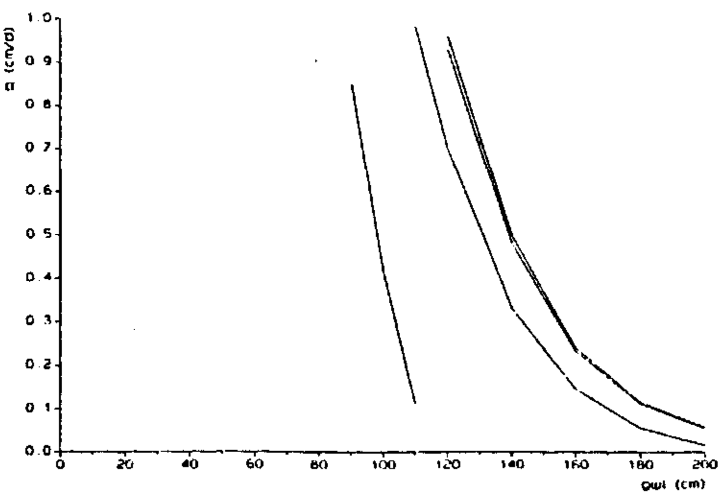


Fig. 2 The maximum possible fluxes in relation to the depth of the groundwater level for specified pressure heads.

3 THE DESCRIPTION OF THE K(h)-RELATION

The relationship between the hydraulic conductivity K and the pressure head h of a soil layer is difficult to describe analytically. Many authors have attempted to find an equation that could describe all of the measured values and that required as few parameters as possible. Many different techniques have been applied: exponential functions, power functions, polynomials, splines, etc. It is beyond the scope of this manual to describe all of these methods. Only the 6 possibilities that are included in the computer program CAPSEV, will be described.

Brooks and Corey (1964) approximated the K(h)-relationship by the following equations (see Fig. 3):

$$K = K_e \quad for \quad h \geq h_w \tag{11}$$

$$K = K_e \left(\frac{h_w}{h}\right)^{n_s} \quad for \quad h < h_w \tag{12}$$

where

K_e = effective conductivity attained after rewetting ($cm.d^{-1}$)

h_w = pressure head at which K_e is attained after rewetting (cm)

r = conversion factor

n_s = slope of the average scanning curve between wetting and desorption.

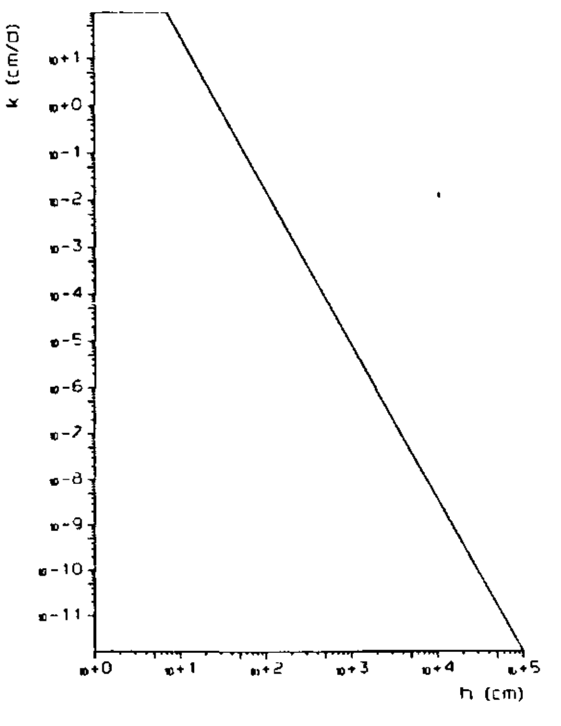


Fig. 3 An example of the K(h)-relationship as approximated by Brooks and Corey (1964).

Bloemen (1980a) adapted the Brooks and Corey equations and introduced the following equations:

$$K = 0.5 \cdot K_s \quad for \quad h \geq h_a \tag{13}$$

$$K = 0.5 \cdot K_s \cdot \left(\frac{\frac{h_a}{r}}{h}\right)^{n_s} \quad for \quad h < h_a \tag{14}$$

All of these values can be computed from the grain size distribution. These calculations can be performed by the program CAPSEV as well, as will be explained in chapter 5 of this manual.

Rijtema (1965) approximated the K(h)-relationship by the following equations (see Fig. 4):

$$K = K_s \quad for \quad h \geq h_a \tag{15}$$

$$K = K_s \cdot e^{-b(h_a - h)} \quad for \quad h_{lim} \leq h < h_a \tag{16}$$

$$K = a \cdot (-h)^{-n} \quad for \quad h < h_{lim} \tag{17}$$

where
K_s = saturated conductivity ($cm.d^{-1}$),
h_a = pressure head at air entry point (cm),
h_{lim} = some arbitrary pressure head value limiting the validity of the conductivity function (cm),
a,b,n = constants.

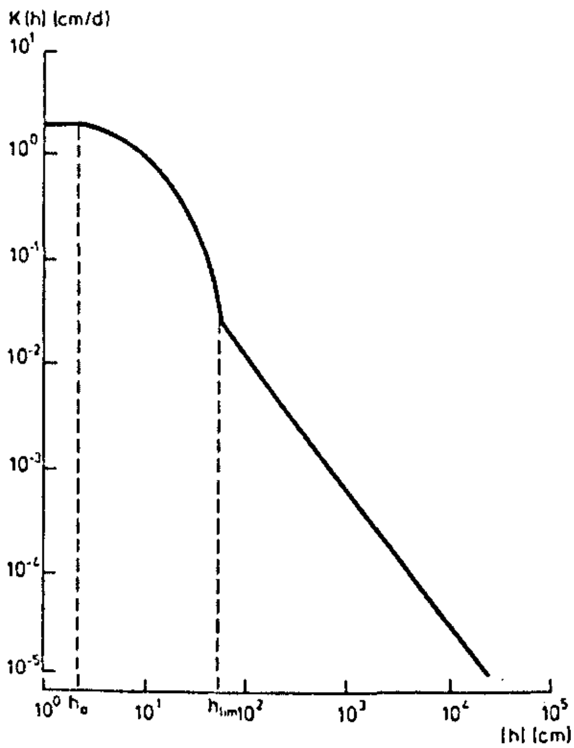


Fig. 4 The K(h)-relationship described by three straight line pieces on a log-log scale.

Wesseling (1981) approached the K(h)-relationship by three straight line pieces on a log-log scale (see Fig. 5). Each line piece is described by the following equation:

$$K = a(-h)^b \tag{18}$$

where a and b are constants.

Van Genuchten (1980) showed that both the K(h)-relationship and the soil moisture retention curve may be described with the same set of parameters (see Fig. 6):

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{(1+|\alpha h|^n)^m} \tag{19}$$

$$K = K_s \cdot \frac{[(1+|\alpha h|^n)^m - |\alpha h|^{n-1}]^2}{(1+|\alpha h|^n)^{m(l+2)}} \tag{20}$$

$$m = 1 - \frac{1}{n} \tag{21}$$

where

K_s = saturated hydraulic conductivity ($cm.d^{-1}$),
θ = moisture content ($cm^3.cm^{-3}$),
θ_r = residual moisture content ($cm^3.cm^{-3}$),
θ_s = moisture content at saturation ($cm^3.cm^{-3}$),
α,n,m,l = parameters

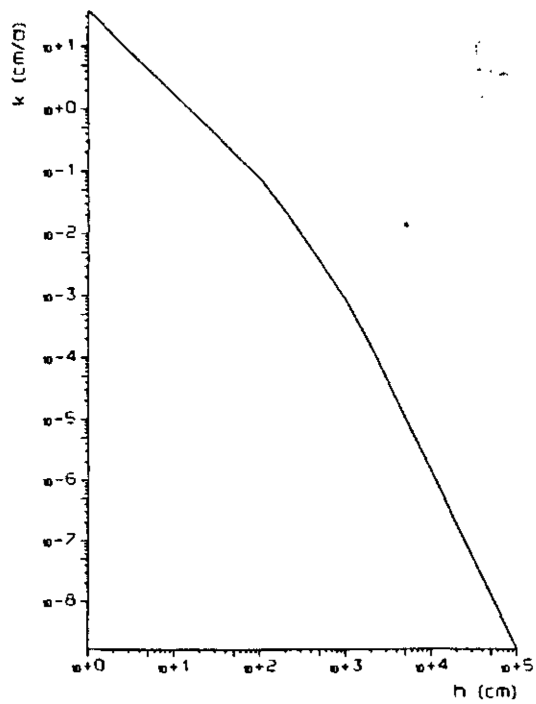


Fig. 5 The K(h)-relationship described by three straight line pieces on a log-scale.

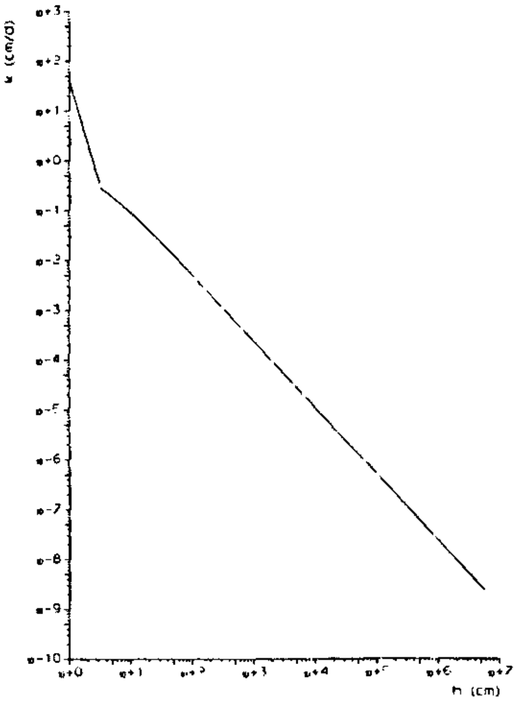


Fig. 6 A K(h)-relationship described by the function of Van Genuchten (1980).

Another method to describe the K(h)- and h(Θ)-relationships is just to present a table of values. From this table the required values may be obtained by linear or logarithmic interpolation.

4 CALCULATION OF THE K(h)-RELATIONSHIP FROM THE GRAIN SIZE DISTRIBUTION

In many cases the hydraulic conductivity function of a soil is not known. However, a texture analysis of the soil often has been made for other purposes. From the data obtained by the texture analysis it is possible to find an approximation of the K(h)-relationship for the soil under consideration. This is realized by calculating the parameters of a generalized K(h)-description from the soil texture data. The equations describing the relationship will be discussed first. Then the quations required for calculating the parameters will be presented.

Bloemen (1980a) first modified the Brooks and Corey expression to account for hysteresis. He obtained the following hydraulic conductivity function (see Fig. 7, line s):

$$K = K_e \quad for \quad h \geq h_w \tag{22}$$

$$K = K_e\left(\frac{h_w}{h}\right)^{n_s} \quad for \quad h < h_w \tag{23}$$

where
K = hydraulic conductivity ($cm.d^{-1}$),
K_e = effective conductivity ($cm.d^{-1}$) obtained after rewetting, assuming $K_e = 0.5\ K_s$, where K_s is the saturated conductivity,
h = pressure head (cm),
h_w = pressure head (cm) at which K_e is obtained after rewetting,
n_s = slope of the average scanning curve between wetting and drying.

Bloemen (1980a) rewrote these equations in terms of the desorption curve (Fig. 7, line d):

$$K = 0.5 K_s \quad for \quad h \geq h_a \tag{24}$$

$$K = 0.5 K_s\left(\frac{\frac{h_a}{r}}{h}\right)^{n_s} \quad for \quad h < h_a \tag{25}$$

where
K_s = saturated conductivity ($cm.d^{-1}$),
h_a = pressure head (cm) at air entry point,
r = factor to convert h_a into h_w, depending on the type of soil, i.e. $r = h_a/h_w$,
n_s = slope of the scanning curve.

The slope of the scanning curve n_s can be calculated according to the following equation:

$$n_s = \frac{\log_{10}\left[2\left(\frac{h_a}{h_0}\right)^{n_d}\right]}{\log_{10}\left(\frac{\frac{h_a}{r}}{h_0}\right)} \tag{26}$$

where
h_0 = pressure head (cm) at which K becomes negligibly small,
n_d = slope of the desorption curve.

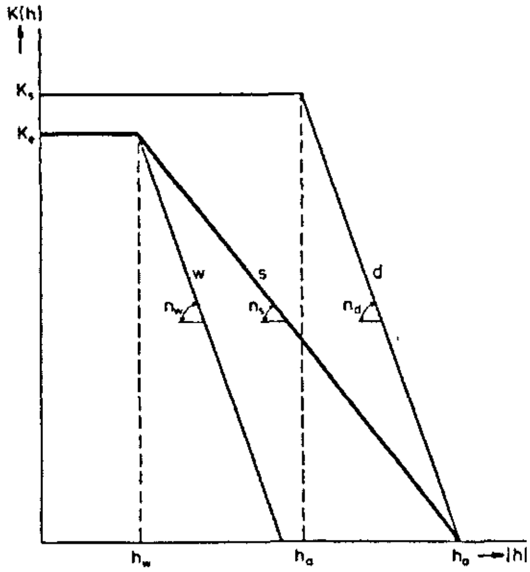


Fig. 7 Approximation of the K(h)-relationship according to Bloemen (1980a).

The parameters K_s, h_a, r, h_0 and n_d may all be calculated from the grain size distribution, humus content and bulk density values. These values are all obtained when a standard textural analysis of a soil profile is made. The equations to be applied will be described here only briefly. For further explanation the reader is referred to Bloemen (1980b) and to Bloemen and Van Gils (1982).

Three different categories of soils are distinguished in the calculation of the parameters. For each category different equations are presented and knowledge of different data is requested:
- Mineral soils: grain size distribution and organic matter content are required,
- Fen peat: only bulk density is required,
- High bog peat: only bulk density is required.

The grain size distribution index, f, is defined as:

$$f = \frac{\sum_{i=2}^{n} f_i}{\sum_{i=2}^{n} (p_i - p_{i-1})} \tag{27}$$

where

$$f_i = (p_i - p_{i-1}) \frac{\log\left(\frac{p_i}{p_{i-1}}\right)}{\log\left(\frac{S_i}{S_{i-1}}\right)} \tag{28}$$

in which
p_i = cumulative weight percentage,
S_i = size interval limit (μ).

An example of the textural data of a soil profile is presented in Table 1.

Table 1 Example of the grain size distribution and humus content of a marine clay soil consisting of five different soil layers (after Wesseling et al., 1984).

	Sandy clay	Heavy clay	Peat	Clayey sand	Sand
Thickness (cm)	15.0	35.0	25.0	75.0	150.0
Humus (%)	5.4	3.7	-	0.8	0.6
Density ($g.cm^{-3}$)	-	-	0.24	-	-
S-values (μ):					
2	19.2	50.0	-	6.6	3.3
16	11.3	23.9	-	2.7	2.6
50	43.8	21.5	-	13.9	11.9
75	12.6	2.3	-	38.1	19.8
105	9.4	1.3	-	34.9	27.7
150	2.6	0.5	-	3.7	27.4
210	1.2	0.5	-	0.1	6.7

The saturated conductivity K_s ($cm.d^{-1}$) can be found from the following equations:
- for mineral soils:

$$K_s = 0.02\, M_d^{1.93}\, f^{-0.74} \tag{29}$$

- for fen peat:

$$K_s = 0.00266\, g_b^{-3.625} \tag{30}$$

- for high bog peat:

$$K_s = 0.0036\, g_b^{-2.83} \tag{31}$$

where
M_d = median grain size (μ) (Note: $M_d \neq M_{50}$),
g_b = dry bulk density ($g.cm^{-3}$).

The air entry value h_a (cm) is calculated according to:
- for mineral soils:

$$h_a = -2914\, M_d^{-0.96}\, f^{0.79} \tag{32}$$

- for fen peat:

$$h_a = -416\ g_b^{1.12} \tag{33}$$

- for high bog peat:

$$h_a = -794\ g_b^{1.17} \tag{34}$$

The value of the reduction factor r is depending only on the type of soil:
r = 4.5 for sandy soils with $M_d > 50$,
r = 2.9 for clayey soils with $M_d \leq 50$,
r = 3.1 for fen peat,
r = 1.9 for high bog peat with $g_b < 0.1$ $g.cm^{-3}$,
r = 3.4 for high bog peat with $g_b \geq 0.1$ $g.cm^{-3}$.

The slope n_d of the desorption curve can be calculated according to the following equations:
- for mineral soils:

$$n_d = 1.41 + 4.536\ (e^{0.3f}-1) - 0.75\ f^{1.6} \log H \tag{35}$$

- for fen peat:

$$n_d = 2.54 - 2.42 g_b \tag{36}$$

- for high bog peat:

$$n_d = 2.57 - 2.27 g_b \tag{37}$$

where H is the humus content of the soil (%).

The value of h_0 can be found from the grain size distribution factor f and the median grain size M_d. To find a general relation between h_0, f and M_d, a large amount of soil profiles from the archives of the Soil Survey Institute in Wageningen was investigated. Based on an iterative method, starting from initially assumed values of h_0, relationships between h_0, f and M_d were found (Bloemen and Van Gils, 1982). The results of these calculations are presented in Fig. 8.

If horizontal cracking occurs in a soil layer, the following corrections should be made for the values of h_a/r and n_s (Bloemen, 1980b, Bloemen and Van Gils, 1982:

$$\frac{h_a}{r} = 100 \cdot \left(0.01 \frac{h_a}{r}\right)^{\frac{n_s}{n_s+1.7}} \quad for \quad \frac{h_a}{r} > -100 \tag{38}$$

$$n_s = n_s + 1.7 \tag{39}$$

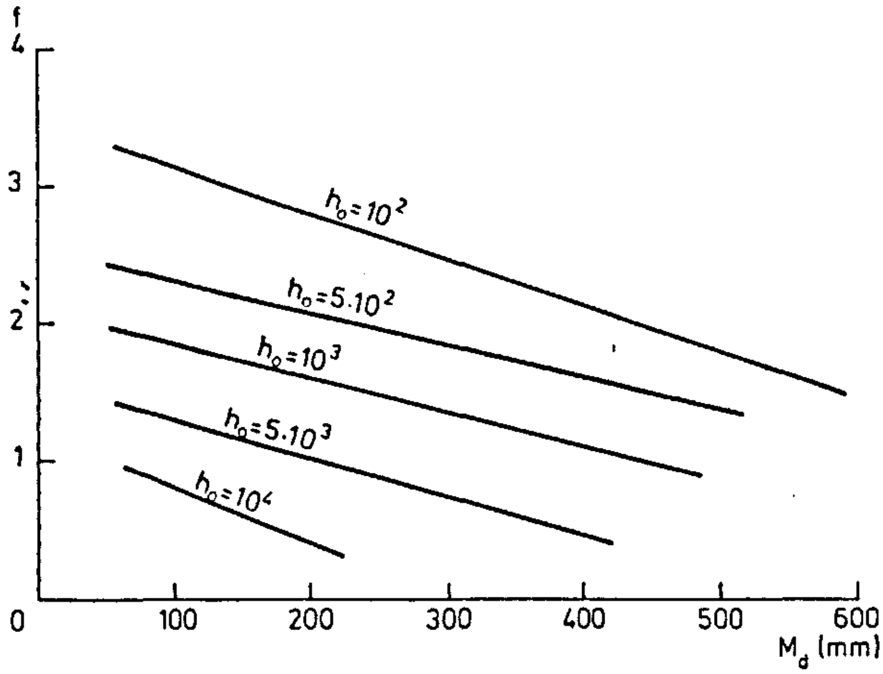


Fig. 8 *Values of H_o for existing combinations of M_d and f. It is assumed that the M_d-values are valid for the entire area between two lines.*

5 THE PROGRAM CAPSEV

The program CAPSEV has been written in FORTRAN-77 and it may be divided into two parts: the first part calculates the soil hydraulic conductivity function from the grain size distribution and organic matter content; the second part calculates the pressure head distribution for capillary rise and for infiltration in a layered soil profile. It is also possible to calculate maximally possible capillary fluxes for a number of groundwater levels or the storage coefficients at different depths in the soil profile under consideration. For practical reasons the maximum number of soil layers that can be considered is 10, the maximum number of fluxes (positive and negative together) is set equal to 15 and the maximum number of groundwater levels equals 15 as well. In practice these values are sufficiently large for most cases.

In principle CAPSEV is a conversational program, i.e. the program will ask the user to type answers to questions on a keyboard. In some cases however the possibility is offered to read data from a previously prepared data file. This alternative has been included because it takes quite some time to type the same set of data when several cases have to be computed with only minor differences, e.g. calculations have to be performed for the same set of soil physical data but with varying values of groundwater levels or fluxes. In these cases a file should contain the required data and the user of the program only has to type the name of the file.

The output of CAPSEV is directed to a file CAPSEV.OUT. This file may be typed on the screen, retrieved into a text-editor or sent to a line-printer. For the users of a PC-version of CAPSEV, a warning may be issued here: the output file is created on a basis of 132 characters per line, so typing on a normal PC-screen may cause difficulties in reading. Making a hardcopy of the file is then advised.

Table 2 shows the names of the subprograms of CAPSEV, arranged according to their primary task.

Table 2 The parts of the program CAPSEV. I: main program; II: HELP utility; III: input of soil characteristics; IV: grain size distribution; V: pressure head distribution; VI: moisture content; VII: output.

SUBPROGRAMS						
I	II	III	IV	V	VI	VII
CAPSEV	HELP	GRNINP	GRAIN	CAPTOT	MOISCN	TABINF
		LININP	CALCUL	MAXFLX	MOIST	TABLE
		BRCINP	COMPHO	INTEGR	SATCON	
		TABINP		CAPQUE	THETA	
		RYTINP		FLXQUE		
		GENINP		CAPRIS		
				CAPINF		
				CONDUC		

5.1 A short description of the program

CAPSEV has been written in a modular way. It consists of one main program and 24 subprograms, each with their own specific task. A short description of all the program parts will be presented here.

CAPSEV

The main program welcomes the user and reads the commands (variable COMMAND), after which it calls the appropriate subroutines.

HELP

Consists of only 1 write statement, resulting in a list of possible commands on the users screen.

GRNINP

Performs the data input required to calculate the parameters of the hydraulic conductivity function from grain size distribution. There are 2 possible ways of input:

a) from a terminal. In this way the program will ask the user to type in the data it requires.
b) from a disk file with data prepared according to the questions that would be asked if method a) was chosen.

Which way of input will be chosen depends on the answers to questions asked.

For the grain size classes:

- the values of the grain sizes between which the distribution must be known, may be typed in or
- the following standard set may be chosen: 2, 16, 50, 75, 105, 150, 210, 300, and 2000 μ.

Maximally 15 grain size classes may be entered.

GRAIN

Calls the subroutines performing calculations on the soil texture data.

CALCUL

Computes the parameters of the conductivity function according to eqs. (22) to (39).

COMPHO

Assigns values to the reduction factor (r) and to the value of the pressure head (h_0) where K becomes negligible small.

CAPTOT

Controls the calculations of pressure head distribution. It reads the required depths of groundwater level from either terminal or file, and checks whether the flux densities are positive or negative. A choice has to be made between two alternative ways to prepare the output:

a) For each groundwater level tables and printplots are prepared; height of capillary rise versus height above the groundwater level in case of capillary rise, and pressure heads versus height above the groundwater level in case of infiltration.
b) A table is prepared of maximum capillary flux densities versus depth of the groundwater level for a specified pressure head, a printplot of the results is presented.

MAXFLX

Performs calculations to find the maximally possible flux and creates an output table and a printplot.

INTEGR

Function INTEGR performs the numerical integration and checks if a certain flux reaches a given level (e.g. the surface).

CAPQUE

Inquires which conductivity description function should be used. The answer is read into the variable METHOD, which may have one of the following values:

1: Modified Brooks and Corey (eqs. (11) and (12))
2: Bloemen (eqs. (13) and (14))
3: Rijtema (eqs. (15), (16) and (17))
4: Wesseling (eq. (18))
5: Van Genuchten (eq. (20))
6: Table

FLXQUE

Reads the flux densities for which the calculations should be performed. It is possible to use one or both of the "standard" sets of flux densities. However, it is also possible to use values read from terminal or data file. A negative flux represents infiltration, a positive flux represents capillary rise. The fluxes should be given in either ascending or descending order.

BRCINP

Takes care of the input from terminal or file necessary for the modified Brooks and Corey method.

RYTINP

Reads data required for the K(h)-relationship according to Rijtema (1965) from terminal or file.

LININP

Reads data required for the K(h)-relationship according to Wesseling (1981). The K- and h-value of the end points of each line piece are either read from the terminal or from a data file.

TABINP

Reads the data when the K(h)-relationship is given as a table. Input is only possible from a file.

CAPRIS

Calculates the height of capillary rise z according to eq.(6). The results are stored in the array z for a range of pressure heads between -1 and -1,000,000 cm. These pressure heads are divided into intervals with a different size as presented in Table 3. Calculations continue until either the lowest value of h is reached or z reaches the soil surface.

CAPINF

Calculates the pressure head distribution in the profile in case of infiltration according to eq. (9). In some cases the pressure head may become positive. Then all the pressure heads for the corresponding flux density are set equal to 0. A warning is sent to the users terminal that the specified flux density is physically impossible for the soil under consideration.

Table 3 Integration intervals related to the value of the pressure head (h) (the independent variable).

Pressure	head	Interval
-10^1	to -10^0	-10^0
-10^2	to -10^1	-10^1
-10^3	to -10^2	-10^2
-10^4	to -10^3	-10^3
-10^5	to -10^4	-10^4
-10^6	to -10^5	-10^5

CONDUC
Function CONDUC calculates the unsaturated hydraulic conductivity.

TABLE
Creates a table and printplot of the height of capillary rise z as a function of pressure head h for positive flux densities (upward flow from the groundwater table).

TABINF
Creates a table and a printplot of pressure head h as a function of position z for negative flux densities (downward flow towards the groundwater table).

MOISCN
Calculates the soil moisture profile and the storage coefficients of a specified zone for either specified or maximum values of fluxes.

MOIST
Calculates the total moisture content of a zone in the soil profile from the pressure head profile.

SATCON
Calculates the water content of a specified zone in the soil profile in case of saturation.

THETA
Calculates moisture content from a specified pressure head.

5.2 Running the program

After starting the program from disk, it welcomes the user and writes the possible commands on the screen. Four possible choices are offered to the user:

C : calculate pressure head profiles or maximally possible fluxes,
E : return to operating system,
G : calculate hydraulic conductivity function from grain size distribution and organic matter content,
H : show possible commands.

If the E-option is chosen, all opened output files will be closed and control will be returned to the operating system. The H(elp)-command presents the list of commands shown above. This is meant to be used when calculations have been finished. Then the program will ask for a new command. Typing H gets the list of commands mentioned above. The G-option will be described in section 5.2.1, the C-option in section 5.2.2.

5.2.1 Calculating the hydraulic conductivity function from the grain size distribution and organic matter content

When the letter G has been typed after the COMMAND-question of CAPSEV, calculations will be performed according to the equations presented in chapter 4. The data required for these calculations are presented in chapter 4 as well. It is advised to type the required data interactively once, just to obtain an insight in the way CAPSEV reads its data. Afterward the data may be prepared in a data file. Running the G-option of CAPSEV then only requires typing Y after the question whether the data are prepared in a data file and typing the name of the appropriate file. An example of a data file for a 5-layer profile is presented in Example 1. On the right-hand side of the input data some comment has been added to explain the meaning of the values on the line. This is possible due to the fact that CAPSEV reads only one variable (or string of limited length) per line.

After reading the name of the soil profile, the user is asked whether the standard set of grain sizes is to be used. This standard set consists of the following 9 values: 2, 16, 50, 75, 105, 150, 210, 300 and 2000 μ. If different grain sizes are required, the values have to be specified. A maximum of 15 values for the grain sizes may be entered. If less sizes are entered, the sizes should be followed by a letter (e.g. X). After the grain sizes the number of soil layers in the profile should be entered. Next the program requires input data for each layer. These data consist of:
- a description of the layer (max. 15 characters),
- the thickness of the layer,
- the humus content (in % for mineral soils, the letter P should be typed for peat soils),
- the percentage of grains in each first grain class,
- the letter Y if cracking occurs, otherwise the letter N.

When all the required input data are read, the calculations according to the equations (22) - (39) will start and the results of the calculations will be written to the output file. Then control is returned to the main program, so the COMMAND-prompt is written to the screen. Now the data calculated for the grain size distribution and humus content may be used to calculate capillary rise or infiltration profiles.

Example 1 *An input file prepared to calculate the K(h)-relationship from the grain size distribution and organic matter content for a soil profile consisting of 5 layers (after Wesseling et al., 1984).*

```
Marine clay
N                      Non-standard grain sizes
  2.                   First boundary of grain size classes (μ)
 16.                   Second boundary, etc.
 50.
 75.
105.
150.
210.
X                      End of boundaries. Note: max. 15 classes
  5                    Number of layers in profile
Sandy clay             Description of top layer
 15.                   Thickness of top layer (cm)
  5.4                  Humus content of top layer (%), for peat: type P
 19.2                  Percentage of first grain size class
 11.3                  Percentage of second class, etc.
 43.8
 12.6
  9.4
  2.6
  1.2
N                      No horizontal cracking in this layer
Heavy clay             Second layer
 35.                   Thickness of second layer (cm)
  3.7
 50.0
 23.9
 21.5
  2.1
  1.5
  0.5
  0.5
Y                      Horizontal cracking does occur in this layer
Peat                   Third layer
 25.                   Thickness of third layer (cm)
P                      P for peat
  1                    1 for fen peat (2 for high bog peat)
  0.24                 Bulk density of peat (g/cm**3)
N                      No horizontal cracking in this layer
Clayey sand            Fourth layer
 75.                   Thickness of fourth layer (cm)
  0.8
  6.6
  2.7
 13.9
 38.1
 34.9
  3.7
  0.1
N                      No horizontal cracking in this layer
Sand                   Fifth layer
150.                   Thickness of fifth layer (cm)
  0.6
  3.3
  2.6
 11.9
 19.8
 27.7
 27.4
  6.7
N                      No horizontal cracking in this layer
```

5.2.2 Calculation of pressure head profiles and maximally possible fluxes

Typing the letter C on the keyboard as a response to the COMMAND-prompt means that pressure head profiles or maximally possible fluxes have to be calculated. Before the actual calculations start, a number of questions has to be answered. The possible answers to some of these questions will be discussed in the following sections.

5.2.2.1 The K(h)-relationship

Before calculations of capillary rise or infiltration can take place, the K(h)-relationship should be known. As was seen in chapter 3, CAPSEV offers several ways to describe this relationship. These options are presented on the screen. The required method should be selected by typing the corresponding number on the keyboard. Each option requires its own input data. These data may be typed directly on the keyboard or read from file (except option 6, the table, which must be prepared in a file). When input of pressure head is required, this may be either positive or negative, as CAPSEV will change it to a negative value itself. The possible options are those for the modified Brooks and Corey equations (eqs. (11) and (12), the Bloemen equations (eqs. (13) and (14)), the Rijtema equations (eqs. (15), (16) and (17)), the linear relation (eq. (18)), the Van Genuchten equation (eq. (20)) and the data entered for a table. In this section the required input for each option is described.

1. Modified Brooks and Corey (eqs.(11) and (12))
   Required data:
   - description of the soil profile (max. 80 characters),
   - number of soil layers (only when data are typed conversationally),
   - for each layer:
   - description of layer (max. 15 characters),
   - thickness of layer (cm),
   - effective conductivity ($cm.d^{-1}$),
   - effective air entry value (cm),
   - slope of K(h)-curve,
   - horizontal cracking (Y or N).

An example of an input file is presented in Example 2.

Example 2 An input file in case the K(h)-relationship is described according to Brooks and Corey.

```
Imaginary profile
Cover sand                Description of first layer
100.                      Thickness of first layer (cm)
93.5                      Effective conductivity (cm/d)
-7.                       Effective air entry value (cm)
3.31                      Slope
N                         No horizontal cracking in this layer
River clay                Description of second layer
150.                      Thickness, etc.
9.0
-17.
1.26
Y                         Horizontal cracking does occur in this layer
```

2. Bloemen (eqs.(13) and (14))
   To use this option, the required parameters should have been calculated first by CAPSEV.

3. Rijtema (eqs.(15),(16) and (17))
   Required data:
   - description of the soil profile (max. 80 characters),
   - number of soil layers (only when data are typed conversationally),
   - for each layer:
   - description of layer (max. 15 characters),
   - thickness of layer (cm),
   - saturated conductivity ($cm.d^{-1}$),
   - air entry value (cm),
   - limiting pressure head (cm),

- value of parameter a,
- value of parameter n.

An example of an input file containing the K(h)-relationship described according to Rijtema (1965) is presented in Example 3.

Example 3 An input file prepared for a 1-layer profile with the K(h)-relationship of that layer described according to Rijtema (1965).

Sandy loam profile	
Sandy loam	Description of layer
200.	Thickness of layer (cm)
3.52	Parameter K_s (cm/d)
-42.4	Parameter H_a (cm)
0.271	Parameter b
-63.0	Parameter H_{lim} (cm)
1.39	Parameter a
1.12	Parameter n

4. Wesseling (eq.(18))
   Required data:
   - description of the soil profile (max. 80 characters),
   - number of soil layers (only when data are typed conversationally),
   - for each layer:
   - description of layer (max. 15 characters),
   - thickness of layer (cm),
   - saturated conductivity ($cm.d^{-1}$),
   - The h- and K-value at the intersection of the first and second line piece (smallest absolute value of h),
   - The h- and K-value at the intersection of the second and third line piece (intermediate absolute value of h),
   - The h- and K-value at the end of the third line piece (highest absolute value of h).

The description of a four-layer soil profile by three line pieces describing the K(h)-relationship can be found as Example 4.

Example 4 The description of a four-layer soil profile when the K(h)-function has been approximated by three straight line pieces on a log-log scale.

Peaty mucky soil	
Muck	Description of first layer
20.	Thickness of first layer (cm)
91.5	K_s (cm/d) of first layer
.530E+02 .3092E+00	K (cm/d) and h (cm) at first node
.910E+03 .1266E-02	Values of K and h at second node
.800E+07 .9748E-14	Values of K and h at third node
Peat	Description of second layer
20.	Thickness ....
37.5	
.120E+03 .5932E-01	
.126E+04 .5140E-03	
.800E+07 .5045E-14	
Peat-sand	Description of third layer
10.	Thickness....
264.	
.110E+03 .6811E+00	
.100E+04 .1076E-02	
.220E+07 .7433E-12	
Sand	Description of fourth layer
151.	Thickness.....
491.	
.730E+02 .1758E+01	
.560E+03 .3888E-03	
.175E+06 .1921E-09	

5. Van Genuchten (eq.(20))

In this case 2 possible ways of entering data are presented as well: the program can ask for the values of the parameters or read them from a data file. When the data have to be obtained from a data file, the input file has a structure that differs from the ones discussed previously. In this case each soil layer has its own file with the 6 required parameters. The names of the files containing these parameters are read from a separate input file, where the thickness of each layer is specified as well.

Now the following input is required:
- description of the soil profile (max. 80 characters),
- for each layer:
- thickness of layer (cm),
- filename containing the parameters of eq. (20) (max. 20 characters).

Example 5 shows the input file of a 2-layer profile.

Example 5 The input file when the analytical relationship of Van Genuchten is to be applied.

```
A two-layer profile
50.0                            thickness of first layer
genuchte.b04                    file containing parameters
150.0                           thickness of second layer
genuchte.o01                    file containing parameters
```

The files containing the parameters of Van Genuchten's equation should contain the following information:
- description of soil layer (max. 15 characters),
- the parameters Θ_r, Θ_s, K_s, α, 1 and n.

Example 6 present the contents of the file genuchte.b04 from example 5.

Example 6 The parameters of soil b04 described by the parameters Θ_r, Θ_s, K_s, α, 1 and n according to Van Genuchten (1980).

```
soil   b04
0.0      0.4200      54.8      0.0163      0.1770      1.559
```

6. Table
   If the K(h)-relationship is presented in the form of a table, it is not possible to type the data interactively. This is because of the possibility of making mistakes when typing a large table of data. The data should always be prepared in a data file. The name of this file should be entered when CAPSEV asks for it. The input file has to be constructed in the following way (see Example 7):
   - description of the soil profile (max. 80 characters),
   - for each layer:
   - thickness of layer (cm),
   - name of file containing the table (max. 20 char).

Example 7 *Example of a 2-layer profile where the soil physical data are described by tables.*

```
Just an imaginary profile.
50.                            Thickness of layer 1
starb04.inp                    File containing data for layer 1
250.                           Thickness of layer 2
staro01.inp                    File containing data for layer 2
```

The files containing the tables should be built in the following way (see Example 8):
- description of layer (max. 15 characters),
- corresponding Θ-, h- and k-values.
  The data should be put in ascending order of Θ. This line should be repeated until saturation is reached.

Example 8 *The contents of datafile starb04.inp from example 7.*

B4 Θ (cm3/cm3)	h (cm)	K (cm/d)
0.000	0.1000E+08	0.6350E-07
0.010	0.1460E+07	0.3940E-06
0.020	0.2470E+06	0.2100E-05
0.030	0.5450E+05	0.8660E-05
0.040	0.1750E+05	0.2490E-04
0.050	0.8077E+04	0.5200E-04
0.060	0.4159E+04	0.1050E-03
0.070	0.2500E+04	0.1800E-03
0.080	0.1668E+04	0.2830E-03
0.090	0.1187E+04	0.4600E-03
0.100	0.9000E+03	0.7860E-03
0.110	0.7030E+03	0.1450E-02
0.120	0.5690E+03	0.2660E-02
0.130	0.4870E+03	0.4370E-02
0.140	0.4270E+03	0.6820E-02
0.150	0.3770E+03	0.1100E-01
0.160	0.3340E+03	0.1600E-01
0.170	0.2980E+03	0.2400E-01
0.180	0.2680E+03	0.3400E-01
0.190	0.2430E+03	0.4700E-01
0.200	0.2210E+03	0.6200E-01
0.210	0.2020E+03	0.8100E-01
0.220	0.1850E+03	0.1040E+00
0.230	0.1690E+03	0.1310E+00
0.240	0.1550E+03	0.1650E+00
0.250	0.1420E+03	0.2070E+00
0.260	0.1300E+03	0.2610E+00
0.270	0.1180E+03	0.3320E+00
0.280	0.1080E+03	0.4280E+00
0.290	0.9800E+02	0.5610E+00
0.300	0.8800E+02	0.7590E+00
0.310	0.7900E+02	0.1057E+01
0.320	0.7000E+02	0.1493E+01
0.330	0.6200E+02	0.2100E+01
0.340	0.5500E+02	0.2878E+01
0.350	0.4800E+02	0.3773E+01
0.360	0.4000E+02	0.4948E+01
0.370	0.3100E+02	0.6490E+01
0.380	0.2200E+02	0.9200E+01
0.390	0.1400E+02	0.1402E+02
0.400	0.9000E+01	0.2287E+02
0.410	0.3000E+01	0.4300E+02
0.417	0.0000E+00	0.5480E+02

In all of the cases discussed above the maximum number of layers in the soil profile is 10. All of the input data are written to the output file in tabular form.

The Soil Survey Institute of Wageningen analyzed a number of different (dutch) soil types and presented the results both as tables (Wösten et al., 1987) and as the parameters of the analytical equations according to Van Genuchten (Wösten, 1987). An overview of these parameters is presented in Appendix 1. The correlation between the U.S. nomenclature and the dutch nomenclature is given in Appendix 2. These so-called Staring-series are (both as tables and as the parameters of Van Genuchtens equation) available on request.

Note: In the present version of the program all layers of a soil profile should be described with the same method. So it is not possible to describe the top layer by Van Genuchten and the bottom layer by a table, for example.

5.2.2.2 Groundwater levels

Both in case of calculation of pressure head profiles and in case of calculation of maximally possible fluxes, it is necessary to specify the depth of the groundwater level. As one is usually interested to see what is the difference between the results for several depths of the groundwater level, CAPSEV offers the possibility to perform the same calculations for several (maximally 15) groundwater levels without the need of re-entering the other data. Therefore the different groundwater levels should be entered before calculations can take place. These values may either be entered from the keyboard or read from a data file. The layout of this file is very simple: just insert one value of groundwater level at each line. See Example 9.

Example 9.
The data file containing the groundwater levels (cm below the surface).

```
 20.0
 40.0
 60.0
 80.0
100.0
120.0
140.0
160.0
180.0
200.0
```

5.2.2.3 Fluxes

In case of calculations of pressure head profiles, it is necessary to specify the fluxes for which calculations are to be performed. Usually one is interested in the results with a standard set of fluxes, either for infiltration or for capillary rise. To prevent the need of repeatedly reading the same set of data, two sets of standard fluxes are included in the program. These sets consist of the following flux-values:
- infiltration: -0.5, -0.3, -0.2, -0.1, -0.05, and 0.0 $cm.d^{-1}$,
- capillary rise: 0.0, 0.05, 0.1, 0.2, 0.3, and 0.5 $cm.d^{-1}$.

Either one or both of the standard sets may be selected. A fourth possibility is to enter the required flux-values (maximally 15) either by keyboard or data file. The layout of the file with flux-values is exactly the same as the one for the file with groundwater levels (see Example 9).

5.2.2.4 Pressure heads

In case one is interested in the maximally possible fluxes, it is necessary to specify the pressure head for which calculations should take place by typing them on the keyboard. It is possible to enter several (maximally 10) values of pressure heads for which calculations will be performed. Another item the program requires for its calculations is the depth at which the specified pressure head occurs.

5.2.2.5 Moisture content

CAPSEV offers the possibility to calculate the moisture content of a part of the soil profile. The boundaries of this section should be typed on the keyboard. The storage coefficient will be calculated from these data according to eq. (10). To do so, the soil moisture retention curve of each layer is required. Therefore these calculations can only take place when the K(h)-relationship was described either by a table of data or by the equation of Van Genuchten.

5.3 The output

During calculations the program will show what it is doing. After finishing calculations, the user will be asked whether a plot file is required. This plot file (named PLOT.OUT) can be read by a plotprogram to generate a graphical representation of the calculated results. The output file CAPSEV.OUT contains the read input, tables with results and a printplot of the values in these tables. These files will be discussed in the following sections. Some examples will be presented.

5.3.1 The file CAPSEV.OUT

The first part of the file CAPSEV.OUT contains the data read from the input files. In case of calculation of hydraulic conductivity from grain size distribution and humus content the parameters of the equation of Bloemen (eqs. (22) - (39)) are calculated and written to the output file. Example 10 presents the contents of the output file when the input data are read from the file presented in Example 1.

If pressure head profiles were calculated for negative fluxes, a table with pressure heads in case of infiltration is written to the file. The first column contains the height above the groundwater level, while the other columns contain numbers representing the pressure head at the specified depth calculated for the flux that has been written on top of the column. The next page then contains the same data, but presented as a printplot. These pages are repeated for each groundwater level for which computations are performed. An example is presented for one groundwater level in Example 11.

In case of pressure head profiles calculated for positive flux-values, a table of heights of capillary rise is written to the file. The first column shows the pressure head under consideration, the other columns show the position where this pressure head occurs for the flux-value written on top of the column. The next page of the output file contains a graphical representation of the data in these columns, presented as a printplot. These pages are repeated for each considered groundwater level. Example 12 presents the results of the calculations for one groundwater level.

In case of calculations of maximally possible fluxes, the first table presents the maximally possible fluxes for a specified pressure head (first column), and groundwater level (written on top of each column). As CAPSEV only performs calculations for fluxes between 0.0 and 1.0 $cm.d^{-1}$, it is possible that the maximum flux can not be found in this range. In this case the value -1 will be written into the table. These fluxes are represented graphically in the printplot on the following page. Finally the moisture content of the specified section of the soil profile and the calculated storage coefficients are presented in a table. See also Example 13.

Example 10 Results of calculation of soil physical parameters from grain size distribution and soil moisture content. Calculations are performed with the input file presented in Example 1.

Marine clay

descript	*	thick (cm)	hum %	med.	*	s-values in microns 2.	16.	50.	75.	105.	150.	210.
Sancy clay	*	32.1	5.4	31.1	*	19.2	11.3	43.8	12.6	9.4	2.6	1.2
Heavy clay	*	35.0	3.7	2.0	*	50.0	23.9	21.5	2.1	1.5	.5	.5
Peat	*	25.0		fen peat, bulk density= .24 g. cm**-3								
Clayey sand	*	75.0	.8	67.6	*	6.6	2.7	13.9	38.1	34.9	3.7	.1
Sand	*	150.0	.6	88.4	*	3.3	2.6	11.9	19.8	27.7	27.4	6.7

layer	thick	f	n	ns	ha	h0	ksat	r	ke	ha/r	cracks
Sancy clay	32.	.55	2.01	1.74	-67.22	-1000000.	23.64	2.90	11.82	-23.18	n
Heavy clay	35.	.19	1.64	1.36	-403.52	-1000000.	.26	2.90	.13	-139.15	y
Peat	25.	-	1.96	1.47	-84.13	-10000	.47	3.10	.23	-27.14	n
Clayey sand	75.	1.61	4.36	3.09	-74.21	-5000	47.90	4.50	23.95	-16.49	n
Sand	150.	1.27	3.76	2.83	-47.76	-10000	95.48	4.50	47.74	-10.61	n

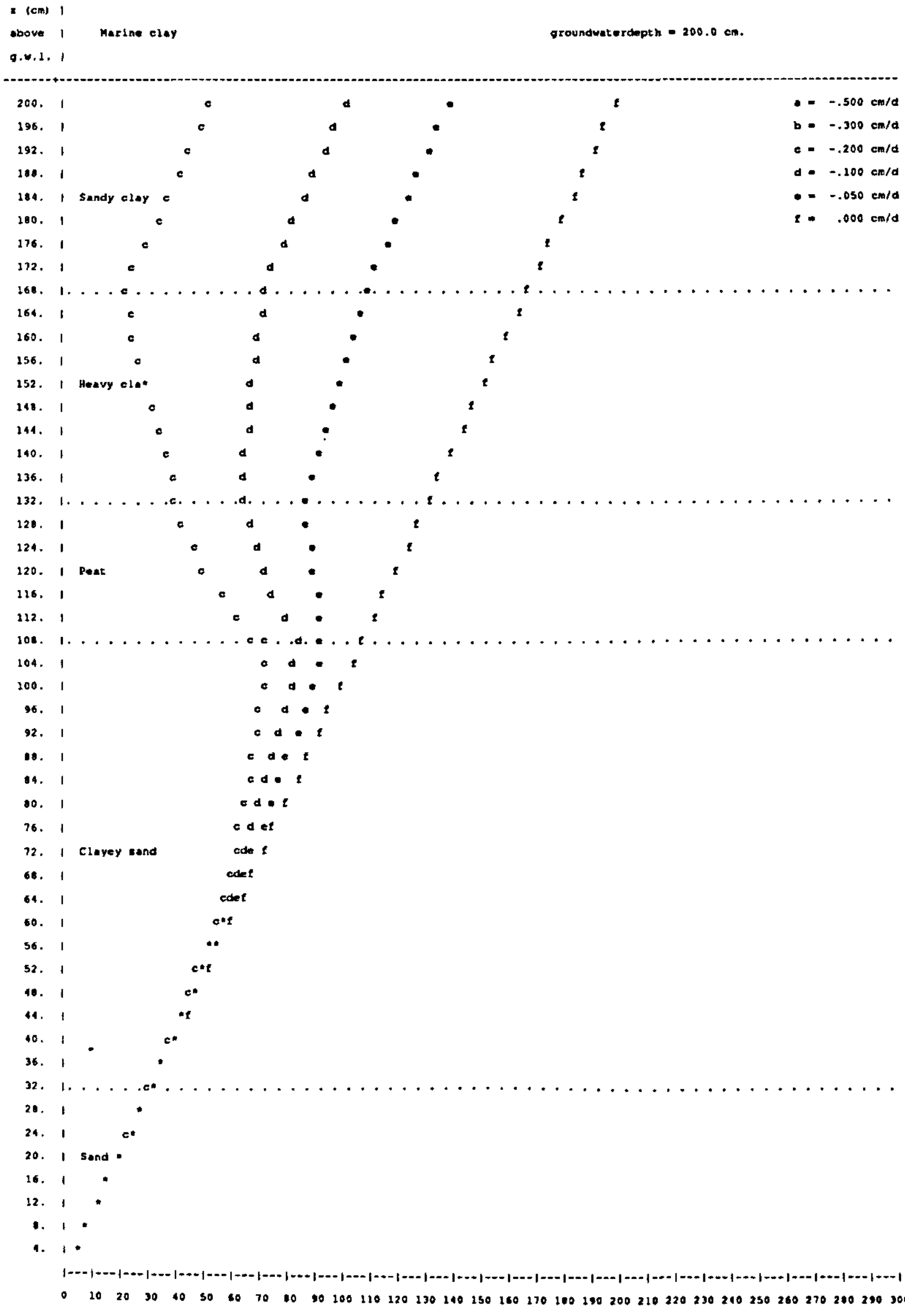
Example 11 The results of the calculations of capillary rise. The K(h)-relationship is the one from example 10. The standard set of fluxes was chosen and the depth of the groundwater level is 200 cm.

pressure heads in case of infiltration.

Marine clay groundwaterlevel = 200.0 cm.

z	*	*f l u x d e n s i t i e s* (cm/day)					
cm.	*	-.500	-.300	-.200	-.100	-.050	.000
4.	*	.0	.0	-4.0	-4.0	-4.0	-4.0
8.	*	.0	.0	-8.0	-8.0	-8.0	-8.0
12.	*	.0	.0	-11.9	-12.0	-12.0	-12.0
16.	*	.0	.0	-15.9	-16.0	-16.0	-16.0
20.	*	.0	.0	-19.8	-19.9	-20.0	-20.0
24.	*	.0	.0	-23.7	-23.9	-23.9	-24.0
28.	*	.0	.0	-27.5	-27.8	-27.9	-28.0
32.	*	.0	.0	-31.2	-31.6	-31.8	-32.0
36.	*	.0	.0	-34.9	-35.4	-35.7	-36.0
40.	*	.0	.0	-38.5	-39.2	-39.6	-40.0
44.	*	.0	.0	-42.0	-42.9	-43.5	-44.0
48.	*	.0	.0	-45.3	-46.6	-47.3	-48.0
52.	*	.0	.0	-48.5	-50.1	-51.0	-52.0
56.	*	.0	.0	-51.4	-53.5	-54.7	-56.0
60.	*	.0	.0	-54.2	-56.8	-58.3	-60.0
64.	*	.0	.0	-56.8	-60.0	-61.9	-64.0
68.	*	.0	.0	-59.2	-63.0	-65.3	-68.0
72.	*	.0	.0	-61.3	-65.9	-68.7	-72.0
76.	*	.0	.0	-63.3	-68.6	-72.0	-76.0
80.	*	.0	.0	-65.1	-71.2	-75.1	-80.0
84.	*	.0	.0	-66.6	-73.5	-78.2	-84.0
88.	*	.0	.0	-68.0	-75.8	-81.1	-88.0
92.	*	.0	.0	-69.3	-77.8	-83.9	-92.0
96.	*	.0	.0	-70.4	-79.7	-86.5	-96.0
100.	*	.0	.0	-71.3	-81.4	-89.0	-100.0
104.	*	.0	.0	-72.2	-83.0	-91.4	-104.0
108.	*	.0	.0	-72.4	-84.2	-93.5	-108.0
112.	*	.0	.0	-63.3	-79.6	-92.3	-112.0
116.	*	.0	.0	-56.4	-75.6	-91.3	-116.0
120.	*	.0	.0	-51.1	-72.2	-90.2	-120.0
124.	*	.0	.0	-47.0	-69.2	-89.3	-124.0
128.	*	.0	.0	-43.7	-66.7	-88.5	-128.0
132.	*	.0	.0	-41.2	-64.5	-87.7	-132.0
136.	*	.0	.0	-39.0	-64.8	-89.5	-136.0
140.	*	.0	.0	-36.9	-65.7	-92.0	-140.0
144.	*	.0	.0	-34.7	-66.6	-94.4	-144.0
148.	*	.0	.0	-32.6	-67.6	-96.9	-148.0
152.	*	.0	.0	-30.4	-68.5	-99.3	-152.0
156.	*	.0	.0	-28.3	-69.4	-101.8	-156.0
160.	*	.0	.0	-26.1	-70.4	-104.3	-160.0
164.	*	.0	.0	-24.0	-71.3	-106.7	-164.0
168.	*	.0	.0	-22.1	-72.4	-109.3	-168.0
172.	*	.0	.0	-26.1	-76.1	-113.0	-172.0
176.	*	.0	.0	-30.0	-79.8	-116.7	-176.0
180.	*	.0	.0	-33.9	-83.5	-120.4	-180.0
184.	*	.0	.0	-37.7	-87.2	-124.1	-184.0
188.	*	.0	.0	-41.5	-90.8	-127.8	-188.0
192.	*	.0	.0	-45.3	-94.5	-131.5	-192.0
196.	*	.0	.0	-49.1	-98.1	-135.1	-196.0
200.	*	.0	.0	-52.8	-101.6	-138.8	-200.0

pressurehead profiles in case of infiltration



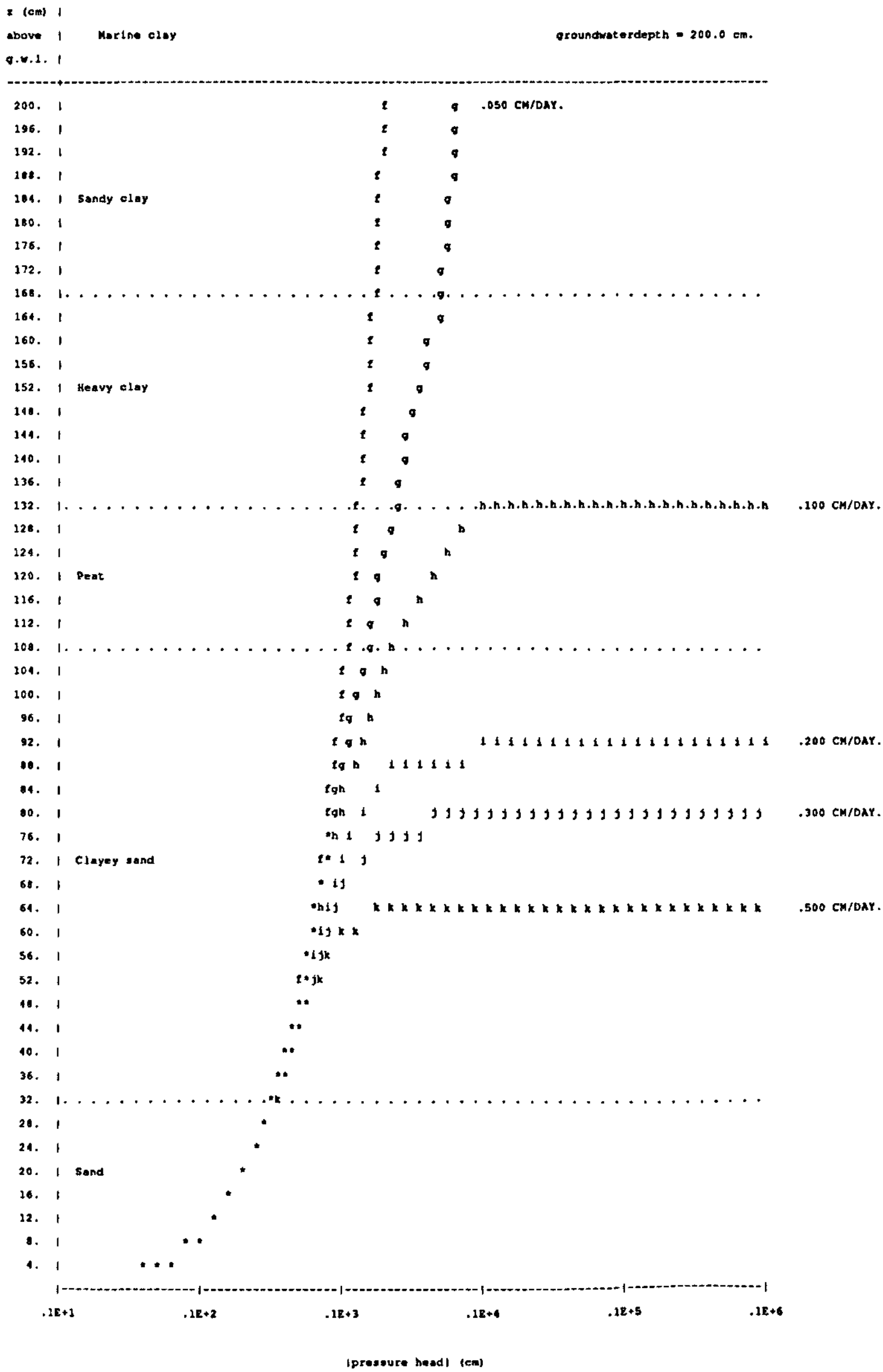
Example 12 A pressure head profile in case of infiltration. The K(h)-relationship is the one from example 10. The fluxes are the ones from the standard set. The groundwater level is 200 cm below the surface.

height of capillary rise.

Marine clay groundwaterlevel = 200.0 cm.

pr.head cm.	*	f l u x d e n s i t i e s (cm/day) .000	.050	.100	.200	.300	.500
-1.	*	1.0	1.0	1.0	1.0	1.0	1.0
-2.	*	2.0	2.0	2.0	2.0	2.0	2.0
-3.	*	3.0	3.0	3.0	3.0	3.0	3.0
-4.	*	4.0	4.0	4.0	4.0	4.0	4.0
-5.	*	5.0	5.0	5.0	5.0	5.0	4.9
-6.	*	6.0	6.0	6.0	6.0	6.0	5.9
-7.	*	7.0	7.0	7.0	7.0	7.0	6.9
-8.	*	8.0	8.0	8.0	8.0	8.0	7.9
-9.	*	9.0	9.0	9.0	9.0	8.9	8.9
-10.	*	10.0	10.0	10.0	10.0	9.9	9.9
-20.	*	20.0	20.0	19.9	19.8	19.8	19.6
-30.	*	30.0	29.8	29.7	29.4	29.1	28.5
-40.	*	40.0	39.6	39.2	38.5	37.8	36.4
-50.	*	50.0	49.2	48.4	46.9	45.6	43.3
-60.	*	60.0	58.3	56.9	54.3	52.1	48.6
-70.	*	70.0	67.1	64.6	60.6	57.5	52.7
-80.	*	80.0	75.2	71.5	65.9	61.7	55.8
-90.	*	90.0	82.7	77.5	70.2	65.1	58.1
-100.	*	100.0	89.5	82.7	73.7	67.7	59.9
-200.	*	200.0	124.0	105.8	87.2	77.3	65.9
-300.	*	300.0	145.0	113.7	90.0	79.2	67.1
-400.	*	.0	158.7	119.0	91.0	79.8	67.5
-500.	*	.0	165.6	122.7	91.4	80.1	67.6
-600.	*	.0	188.8	125.5	91.7	80.3	67.7
-700.	*	.0	230.5	127.7	91.8	80.4	67.8
-800.	*	.0	.0	129.5	91.9	80.4	67.8
-900.	*	.0	.0	130.9	92.0	80.5	67.8
-1000.	*	.0	.0	132.2	92.0	80.5	67.9
-2000.	*	.0	.0	133.9	92.1	80.6	67.9
-3000.	*	.0	.0	134.1	92.2	80.6	67.9
-4000.	*	.0	.0	134.1	92.2	80.6	67.9
-5000.	*	.0	.0	134.2	92.2	80.6	67.9
-6000.	*	.0	.0	134.2	92.2	80.6	67.9
-7000.	*	.0	.0	134.2	92.2	80.6	67.9
-8000.	*	.0	.0	134.2	92.2	80.6	67.9
-9000.	*	.0	.0	134.2	92.2	80.6	67.9
-10000.	*	.0	.0	134.2	92.2	80.6	67.9
-20000.	*	.0	.0	134.2	92.2	80.6	67.9
-30000.	*	.0	.0	134.2	92.2	80.6	67.9
-40000.	*	.0	.0	134.2	92.2	80.6	67.9
-50000.	*	.0	.0	134.2	92.2	80.6	67.9
-60000.	*	.0	.0	134.2	92.2	80.6	67.9
-70000.	*	.0	.0	134.2	92.2	80.6	67.9
-80000.	*	.0	.0	134.2	92.2	80.6	67.9
-90000.	*	.0	.0	134.2	92.2	80.6	67.9
-100000.	*	.0	.0	134.2	92.2	80.6	67.9
-200000.	*	.0	.0	134.2	92.2	80.6	67.9
-300000.	*	.0	.0	134.2	92.2	80.6	67.9
-400000.	*	.0	.0	134.2	92.2	80.6	67.9
-500000.	*	.0	.0	134.2	92.2	80.6	67.9
-600000.	*	.0	.0	134.2	92.2	80.6	67.9
-700000.	*	.0	.0	134.2	92.2	80.6	67.9
-800000.	*	.0	.0	134.2	92.2	80.6	67.9

height of capillary rise



Example 13 The results of computations of maximally possible fluxes, moisture content and storage coefficients.

Test file with Van Genuchten

Layer	Description	Thickness	theta-r	theta-s	ks	alfa	l	n
1	b04	50.0	.00	.42	54.8000	.016	.177	1.559
2	o01	150.0	.00	.35	99.7000	.022	.796	2.186

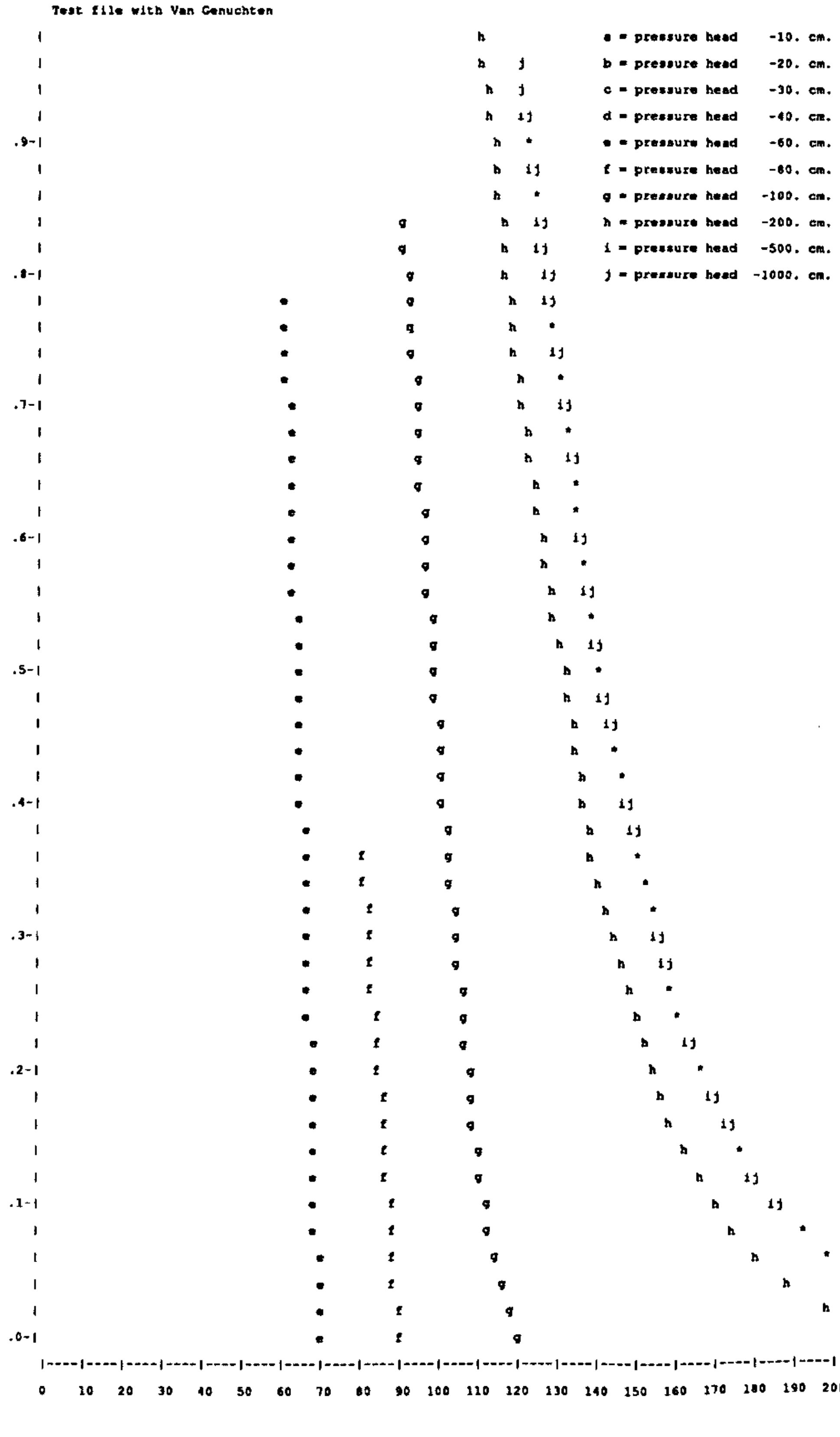
maximally possible fluxes (cm/day)

Test file with Van Genuchten — level of calculations= 5. cm. below surface

pr.head (cm.)	*	groundwater level (cm. below surface) 20.	30.	40.	50.	60.	70.	80.	90.	100.	110.	120.	140.	160.	180.	200.
-10.	*	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
-20.	*	-1.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
-30.	*	-1.000	-1.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
-40.	*	-1.000	-1.000	-1.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
-60.	*	-1.000	-1.000	-1.000	-1.000	.788	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
-80.	*	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.368	.000	.000	.000	.000	.000	.000	.000	.000
-100.	*	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.851	.418	.114	.000	.000	.000	.000	.000
-200.	*	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.984	.704	.335	.146	.057	.016
-500.	*	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.931	.484	.234	.113	.057
-1000.	*	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	.962	.503	.242	.117	.059

note :the figure -1.000 indicates the occurrence of a flux > 1.0 cm/day !!

printplot of capillary rise (cm/day) versus groundwaterdepth



moisture content [cm], and storage coefficient at max. fluxes

Test file with Van Genuchten — Calculated over the zone : 0. to 40. cm.

pr.head [cm]	groundwater level [cm below surface] 0.	20.	30.	40.	50.	60.	70.	80.	90.	100.	110.	120.	140.	160.	180.	200.
-10.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.2	12.6	12.1	11.6	11.1	10.3	9.6	9.0	8.5
		.01	.02	.03	.03	.04	.04	.04	.05	.05	.05	.05	.05	.05	.04	.04
-20.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.2	12.6	12.1	11.6	11.1	10.3	9.6	9.0	8.5
		.01	.02	.03	.03	.04	.04	.04	.05	.05	.05	.05	.05	.05	.04	.04
-30.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.2	12.6	12.1	11.6	11.1	10.3	9.6	9.0	8.5
		.01	.02	.03	.03	.04	.04	.04	.05	.05	.05	.05	.05	.05	.04	.04
-40.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.2	12.6	12.1	11.6	11.1	10.3	9.6	9.0	8.5
		.01	.02	.03	.03	.04	.04	.04	.05	.05	.05	.05	.05	.05	.04	.04
-60.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.2	12.6	12.1	11.6	11.1	10.3	9.6	9.0	8.5
		.01	.02	.03	.03	.04	.04	.04	.05	.05	.05	.05	.05	.05	.04	.04
-80.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.0	12.6	12.1	11.6	11.1	10.3	9.6	9.0	8.5
		.01	.02	.03	.03	.04	.04	.05	.05	.05	.05	.05	.05	.05	.04	.04
-100.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.2	12.6	11.7	11.5	11.1	10.3	9.6	9.0	8.5
		.01	.02	.03	.03	.04	.04	.04	.05	.05	.05	.05	.05	.05	.04	.04
-200.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.2	12.6	12.1	11.6	11.1	8.8	8.6	8.5	8.4
		.01	.02	.03	.03	.04	.04	.04	.05	.05	.05	.05	.06	.05	.05	.04
-500.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.2	12.6	12.1	11.6	11.1	7.1	6.4	5.8	5.6
		.01	.02	.03	.03	.04	.04	.04	.05	.05	.05	.05	.07	.06	.06	.06
-1000.	16.8	16.6	16.3	15.8	15.2	14.5	13.8	13.2	12.6	12.1	11.6	11.1	10.3	5.3	3.8	2.8
		.01	.02	.03	.03	.04	.04	.04	.05	.05	.05	.05	.05	.07	.07	.07

Note : For max. fluxes > 0.5 cm/day, moisture content/storage coefficient is calculated for flux = 0 cm/day.

5.3.2 The plot file

Before calculations start, CAPSEV asks the user whether a plot file is required. If so, a file PLOT.DAT will be opened. When the program is finished, this file will contain the following information, depending on the kind of calculations performed:
- In case of infiltration:
  - name of soil profile (80 characters),
  - the number 1, indicating infiltration,
  - the number of layers in the soil profile,
  - for each layer:
  - description of layer (15 characters),
  - thickness of layer (cm),
  - number of fluxes for which calculations are performed,
  - flux-values,
  - groundwater level,
  - number of positions above the groundwater level,
  - for each position:
  - position above groundwater level and absolute value of pressure head for each considered flux-value.

- In case of capillary rise:
  - name of soil profile (80 characters),
  - the number 2, indicating capillary rise,
  - the number of layers in the soil profile,
  - for each layer:
  - description of layer (15 characters),
  - thickness of layer (cm),
  - number of fluxes for which calculations are performed,
  - flux-values,
  - groundwater level,
  - number of pressure heads above the groundwater level,
  - for each pressure head:
  - pressure head value and position above groundwater level where this pressure head occurs for each flux-value.

- In case of maximally possible fluxes:
  - name of soil profile (80 characters),
  - the number 3, indicating maximally possible fluxes,
  - the number of layers in the soil profile,
  - for each layer:
  - description of layer (15 characters),
  - thickness of layer (cm),
  - depth for which calculations are performed,
  - number of groundwater levels,
  - values of groundwater levels,
  - number of pressure heads,
  - values of pressure heads,
  - for each groundwater level:
  - number of groundwater level and the maximally possible flux for each pressure head.

For every performed calculation such a block of data is written to the plotfile, so it is recommended to use a plot program that reads data until the end-of-file character is encountered. At the moment two plot-programs are available on request: one for a VAX computer and one for a PC or PC-compatible. The VAX program runs under VMS and is based upon the plot-package SIMPLOT. The PC-program is written in TurboPascal and runs on most PC's, independent of the video-board. The executable version runs stand-alone, so TurboPascal is not required.

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APPENDIX 1 *Moisture content at saturation (Θ_s) and saturated hydraulic conductivity (K_s) for the soils of the Staring series together with the parameters α, n and l for each soil (after Wösten (1987).*

Type	Name	Θ_s ($cm^3.cm^{-3}$)	K_s ($cm.d^{-1}$)	α (cm^{-1})	n (-)	l (-)
Top soils						
b01	fine sand	0.37	33.34	0.0208	1.646	0.571
b02	fine loamy sand	0.43	32.21	0.0224	1.436	-0.304
b03	fine loamy sand	0.45	17.81	0.0152	1.412	-0.213
b04	fine sandy loam	0.42	54.80	0.0163	1.559	0.177
b07	sandy loam	0.40	25.10	0.0158	1.287	0.248
b08	sandy loam/silty loam	0.40	22.90	0.0313	1.200	-3.578
b10	silty clay loam	0.44	31.10	0.0519	1.126	-6.552
b11	silty clay loam/ silty clay	0.51	63.60	0.1562	1.099	-8.067
b12	clay	0.57	98.20	0.1689	1.068	-10.286
b16	sandy peat/peat	0.73	13.44	0.0134	1.320	0.534
b18	clayey peat	0.71	34.80	0.0284	1.141	1.086
Bottom soils						
o01	fine sand	0.35	99.70	0.0220	2.186	0.796
o02	loamy sand	0.38	63.90	0.0182	1.870	0.911
o03	loamy sand	0.34	44.60	0.0265	1.543	-0.333
o04	sandy loam	0.36	53.10	0.0216	1.540	-0.520
o05	coarse sand	0.33	223.00	0.0524	1.912	0.873
o06	loam	0.41	5.48	0.0291	1.152	-6.864
o08	sandy loam	0.42	26.40	0.0248	1.321	-0.622
o09	sandy loam/silty loam	0.41	24.00	0.0280	1.283	-1.559
o10	loam	0.44	25.60	0.0231	1.212	-2.220
o11	silty clay loam	0.42	61.00	0.0420	1.125	-3.706
o12	silty clay loam/ silty clay	0.49	10.80	0.0384	1.113	-6.743
o13	clay	0.58	38.00	0.1122	1.063	-12.538
o15	silty loam	0.43	57.42	0.0207	1.224	-2.077
o16	oligotrophic peat	0.87	14.66	0.0179	1.275	0.539
o17	mesotrophic peat/ eutrophic peat	0.89	30.45	0.0145	1.252	1.019

APPENDIX 2 *The correlation between the U.S. nomenclature for soil types and the nomenclature from the Staring Series (after Kabat et al., 1989).*

Staring code	Description	U.S. code
Top soils		
b01	fine sand	fS
b02	fine loamy sand	(f)LS-
b03	fine loamy sand	(f)LS+
b04	fine sandy loam	(f)SL
b07	sandy loam	SL
b08	sandy loam/silty loam	SL+/SiL
b10	silty clay loam	(Si)CL
b11	silty clay loam/silty clay	(Si)CL/(Si)C-
b12	clay	C+
Bottom soils		
o01	fine sand	fS
o02	loamy sand	LS-
o03	loamy sand	LS+
o04	sandy loam	SL-
o05	coarse sand	cS
o08	sandy loam	SL
o09	sandy loam/silty loam	SL+/SiL
o10	loam	L
o11	silty clay loam	(Si)CL
o12	silty clay loam/silty clay	(Si)CL/SiC-
o13	clay	C+
o15	silty loam	SiL

APPENDIX 3 List of symbols

a	constant
b	constant
f	grain size distribution index
g_b	dry bulk density (g.cm^{-3})
h	pressure head (negative in unsaturated zone) (cm)
H	humuscontent of soil (%)
h_a	pressure head at air entry point (cm)
h_{av}	average of the pressure heads at the top and the bottom of a compartment
h_{lim}	some arbitrary pressure head value limiting the validity of the conductivity function (cm)
h_w	pressure head (cm) at which K_e is obtained after rewetting
h_0	pressure head (cm) at which K becomes negligibly small
K	hydraulic conductivity (cm.d^{-1})
$K(h)$	hydraulic conductivity as a function of h (cm.d^{-1})
K_e	effective conductivity (cm.d^{-1}) obtained after rewetting, assuming $K_e = 0.5\ K_s$
$K_j(h)$	K-value corresponding to pressure head h in layer j
K_s	saturated hydraulic conductivity (cm.d^{-1})
l	constant
m	constant
M_d	median grain size (μ)
M_j	number of sub-intervals in layer j
n	constant
N	number of layers in soil profile
n_d	slope of the desorption curve
n_s	slope of the average scanning curve between wetting and drying
p_i	cumulative weight percentage
q	soil moisture flux density, positive in case of capillary rise and negative in case of infiltration (cm.d^{-1})
r	factor to convert h_a into h_w, depending on the type of soil, i.e. $r = h_a/h_w$
S_i	size interval limit (μ)
z	vertical coordinate with origin at the soil surface, directed positive upward (cm)
z_b	depth of bottom of zone under consideration (cm)
z_g	depth of groundwater level (cm)
z_t	depth of top of zone under consideration (cm)
α	constant
Θ	moisture content (cm^3.cm^{-3})
$\Theta(h(z))$	moisture content corresponding to pressure head h at depth z (cm^3.cm^{-3})
Θ_r	residual moisture content (cm^3.cm^{-3})
Θ_s	moisture content at saturation (cm^3.cm^{-3})