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## ABOUT THESE INSTRUCTIONS FOR USE



When the symbol on the left is placed before a piece of text, this means that an important instruction follows.



When the symbol shown on the left is placed before a piece of text, this means that an important warning follows pointing out a risk of injury to the user or damage to the device.

### Introduction

For the design of a drainage system the permeability of the soil is necessary. The correct distance between the drains is the first requirement in a successful drainage system. This distance is dependant upon the water permeability of the soil, the depth to be drained, the depth of the first impermeable layer, and the intended use of the soil. The water permeability of a soil may be calculated either in a laboratory (with a laboratory permeameter), or in situ. It is usual to use the Hooghoudt method when determining the permeability in situ. Determining the water permeability using this method involves less time than other methods, requires a minimum of equipment and is simple in operation.

A valuable average indication of the water permeability of a soil is obtained using this method, and the correct distance between the drains may be simply calculated with the use of a formula.

## 1. PRINCIPLE OF THE HOOGHOUTD AUGER HOLE METHOD

The principle of this method is quite simple.

First you need to describe the soil profiles of the location (field) where you want to start doing measurements. Record variations in layer thicknesses and estimate the permeability of the found layers (also see table 1) or if the profile shows a micro-stratification. Search for an impermeable layer (defined as permeability  $< 0.1x$  the permeability of the top soil) if this is within reach of the measurements (generally a depth of 2 m will suffice). Let the profile-boreholes alone for at least an hour (sometimes a day is necessary) to be able to record the actual groundwater level at that location (preferably to be measured with the float). Determine the number of tests you want to perform on the field to fit the variability of soil types and layers you encountered (with a minimum of three spots). The more the profiles varied, the more bore holes you will need to prepare to do the measurements.

If the drilled hole was not made to deep it can be used for the auger hole method tests as well; otherwise you need to drill new boreholes (8 cm in diameter) for the permeability tests to the necessary depth close to the boreholes you made to describe the soil profile.

The water is consequently bailed out and the time necessary for the water level to rise to a certain level is recorded.

With the help of formulas and/or nomograms this rate of water rise together with the profile data can be translated to the average water permeability factor of the soil layer between the original groundwater level until a few decimeters below the bottom of the auger hole. (See Translation of field results).

The following dimensions are of importance when measuring (*See fig.1*):

**z** = float with measuring tape reading in cm at normal ground water level.

**H** = depth of the auger hole in cm below ground water level.

**S** = depth of a (possible) impermeable layer in cm below the bottom of the auger hole.

**Y<sub>0</sub>** = water level depth in the auger hole at commencement of measuring in cm below ground water level.

**Y<sub>n</sub>** = water level depth in the auger hole at end of measuring.

**ΔY** = rise of water level in auger hole between time 0 and time n.

**Y** =  $\frac{1}{2} (Y_n + Y_0)$  = average water level during measuring.

**2r** = auger hole diameter in cm.

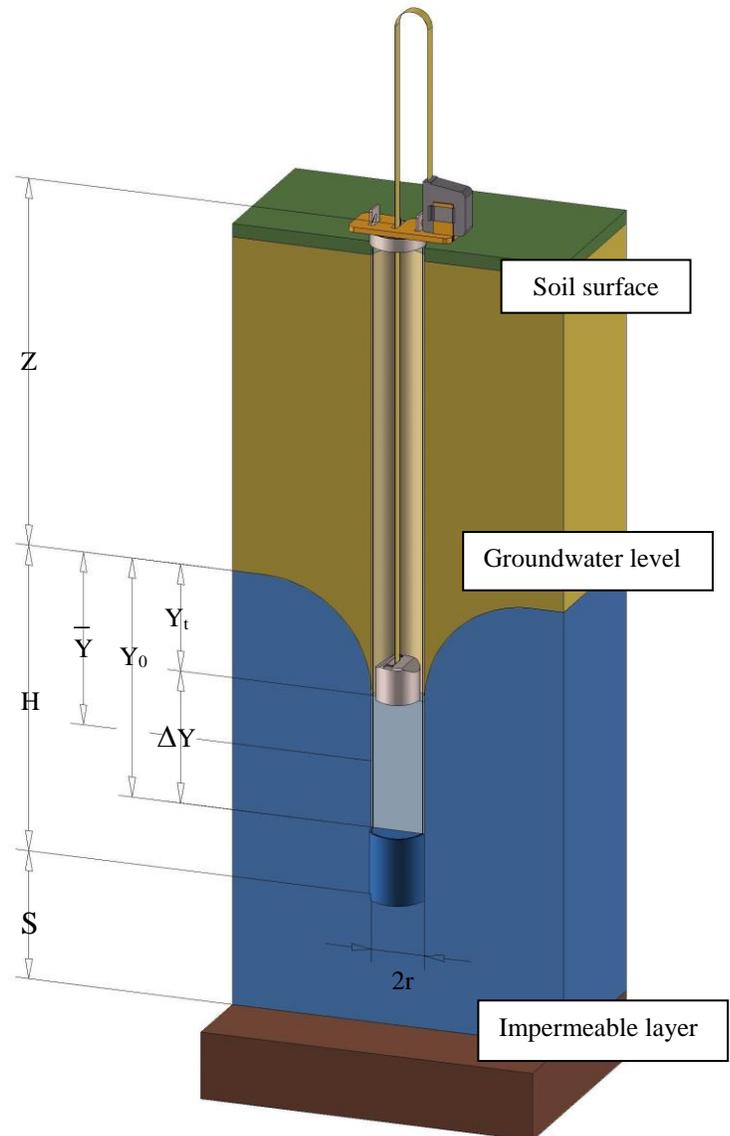
(All readings in cm are expressed as positive (+) values)

The depth of the auger hole depends on the ground water level and the thickness and the permeability of the successive layers in the ground profile. Minor differences in permeability of layers will be more or less “averaged” during the measurement. Major difference in permeability of layers can be determined by doing two (repeated) measurements at two different depths (see paragraph 4.2)

The bottom of an auger hole must remain 0.10 – 0.15 meters above a layer change and be at least 0.20 meters below ground water level.

The maximum depth of the auger hole will generally be not more than 2.00 meters below surface level.

**Fig.1:** The Hooghoudt auger hole method.



- At larger depths generally permeability readings are not taken using the auger hole method but the permeability factors may be judged from the (recognizable) profile properties.
- However if groundwater table is low, deeper measurements can be done using the here described auger hole method. In un-cohesive soils a longer version of the filter (that prevents silting up of the bore hole) can be used.
- In boreholes deeper than 4 m the measuring tape may not work properly anymore and we advise the use of a 10 m range groundwater level datalogger “Diver” to record the rise of the water level.

## 2. DESCRIPTION OF THE HOOGHOUTT AUGER HOLE METHOD KIT

### 2.1 Standard kit for determining water permeability in situ (to a depth of 2 meters) using the auger hole method.

	<b>Item nr</b>	<b>Description</b>	<b>number</b>
	0901SA	Hydraulic conductivity test kit, model Hooghoudt, standard set for measurements to a depth of 2meters	1
(1)	011017B	Handle, normal, 60cm, with all synthetic, detachable grip (incl. coupling sleeve), bay.	1
(2)	01020208B	Edelman auger, bottom part, comb. type, bay, diam. 8cm	1
(3)	01040007B	Riverside auger, bottom part, bay., diameter 7cm	1
(4)	011007B	Extension rod, 100 cm (incl.coupling sleeve) bay.	1
(5)	01120701B	Bailer, diam. 63mm, stainless steel, with bailer shoe (stainless steel valve), operational length 75cm, bayonet	1
(6)	01120702	Bailer shoe with steel valve, diam.63mm	1
(7)	090103	Measuring tape, 5 metres, steel enameled	2
(8)	090104	Measuring tape holder for hydraulic conductivity measurement	1
(9)	090105	Float	2
(10)	090109	Stopwatch, digital, measuring range 10 hours, incl. 1.5 Volt Penlite (AA) battery	1
(11)	090106	Filter galvanized steel, diam. 76mm, length 100cm, with pvc filter container	1
(12)	090108B	Spatula for filter, bay.	1
(13)	011009B	Coupling sleeve	1
(14)	090110	Carrying bag for field equipment, ø 15×120cm	1
(15)	09011001	Bag for float	1

Standard kit for determining water permeability in situ (to a depth of 2 meters) using the auger hole method.



## 2.2 Description of the standard kit

A hole can be bored using the bi-partite Edelman auger with extension rod.

It may be necessary to insert a filter in the hole depending upon the type of soil. In a sandy soil or clay with sandy layers, it is advisable to use the filter to prevent the bored hole from collapsing.

Difficult and hard strata, or fine gravel layers, can be penetrated using the Riverside auger (*fig 1; 3*). The diameter of the Riverside auger ( $\text{\O} 70\text{mm}$ ) is narrower than that of the metal filter ( $\text{\O} 75\text{mm}$ ) and boring to deeper depths through difficult layers is therefore in most cases possible without removing the said filter.

Fluid sand is removed easily using the stainless steel bailer (*fig 1; 5*), enabling the filter to be lowered to the required depth. For this purpose you may apply the extendable filters (optional).

Fouling of the steel valve can hinder bailing in a gravel soil by preventing the valve from closing. Bailers with synthetic valve (that do not have this problem) in both 63 or 50 mm diameter are optional.

An extra measuring tape and float are included in the kit so that original water levels can be measured in newly drilled boreholes while another person is doing permeability measurements in earlier prepared boreholes. The standard kit fits easily into a handy carrying bag and PVC container. The complete outfit takes up very little space and is easily transported.

Galvanized steel filter in PVC filter container and carrying bag for the complete kit



### 3. WORKING METHOD

Requirements: Complete Edelman auger and extensions, riverside auger, stainless steel bailer, stopwatch, measuring tape 5m, float, filter, measuring tape holder

To determine the K-value of a layer, start doing 5 measurements per bore hole. If these show stable after e.g. 3 measurements (stable means within e.g. 10%-15% variation) you may reduce the measurements to 3 for this location. It is more important to measure in a sufficient number of boreholes than do numerous measurements in only a few !

Measuring steps:

1 boring the hole; measuring the depth of the bore hole; waiting for stabilisation of the groundwater level; measuring the level of the groundwater

2 removing water from the borehole with a bailer

3 measuring the rate the water rises

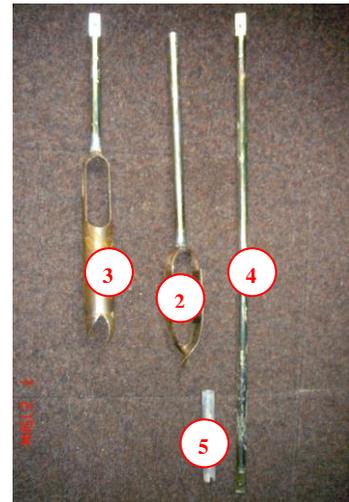
#### 3.1 Boring the hole

The following equipment may be used for boring holes:

- *in cohesive to slightly cohesive soils: a hand-operated 8 cm auger*
- *in uncohesive soils: If augering does not work anymore because the soil acts as a fluid (auger comes out empty) then you may use the bailer to lower the filter. Be sure that the filter lowers with the same speed as the valve (bottom part) of the bailer otherwise you are loosening up the soil in which you are going to measure ! In case this layer is deeper you will need extendable filters. The walls of the hole must not be disturbed when sliding in the filter (this may cause faulty readings).*

The main parts to use are the upper part with screwable handle and the Edelman auger (or Riverside auger)

- ① Upper part with mounted handle
- ② Edelman auger (bottom part)
- ③ Riverside auger (bottom part)
- ④ Extension rod
- ⑤ Extension rod connections



Connect the parts. (If the length is insufficient, also connect the extension rod).

Start to auger a hole at the selected site, using the Edelman or Riverside auger.



You may tap the auger body on the ground to remove the soil. Sticky soil should be removed by hand.



Make a soil profile of the bore hole.



The minimum drop in water level you should be able to create is 20 cm. This means that the auger hole should have a minimum depth of 25cm under the groundwater level (preferably 35cm). A deeper hole will facilitate the bailing out of water and increase the volume of soil in which you are measuring so of which you are determining the permeability.



➔ **In a sandy soil a filter is inserted into the hole to prevent the walls of the bore hole from collapsing.**

**If this filter is not long enough, extendable filter sections can be supplied as an option.**

**Leave the hole until the ground water rises to its original level. This may take a few minutes (course sand) to a day or more (clay).**

## Determining H and Z values.

After having finished the borehole two important parameters have to be determined: Depth of the borehole compared to field surface and original (undisturbed) water level.

These parameters are determined in the following way:

D = depth of the borehole is measured with a tape (without float) or by means of an auger that has been lowered in the borehole.

Z = Depth of the water table compared to reference level is measured with measuring tape + float

➔ Note: Measuring Z with tape + float will cause an error of 5 cm (the height of the float). This compensates the same measuring errors that you will make when doing the water rise measurements later on with the same float!

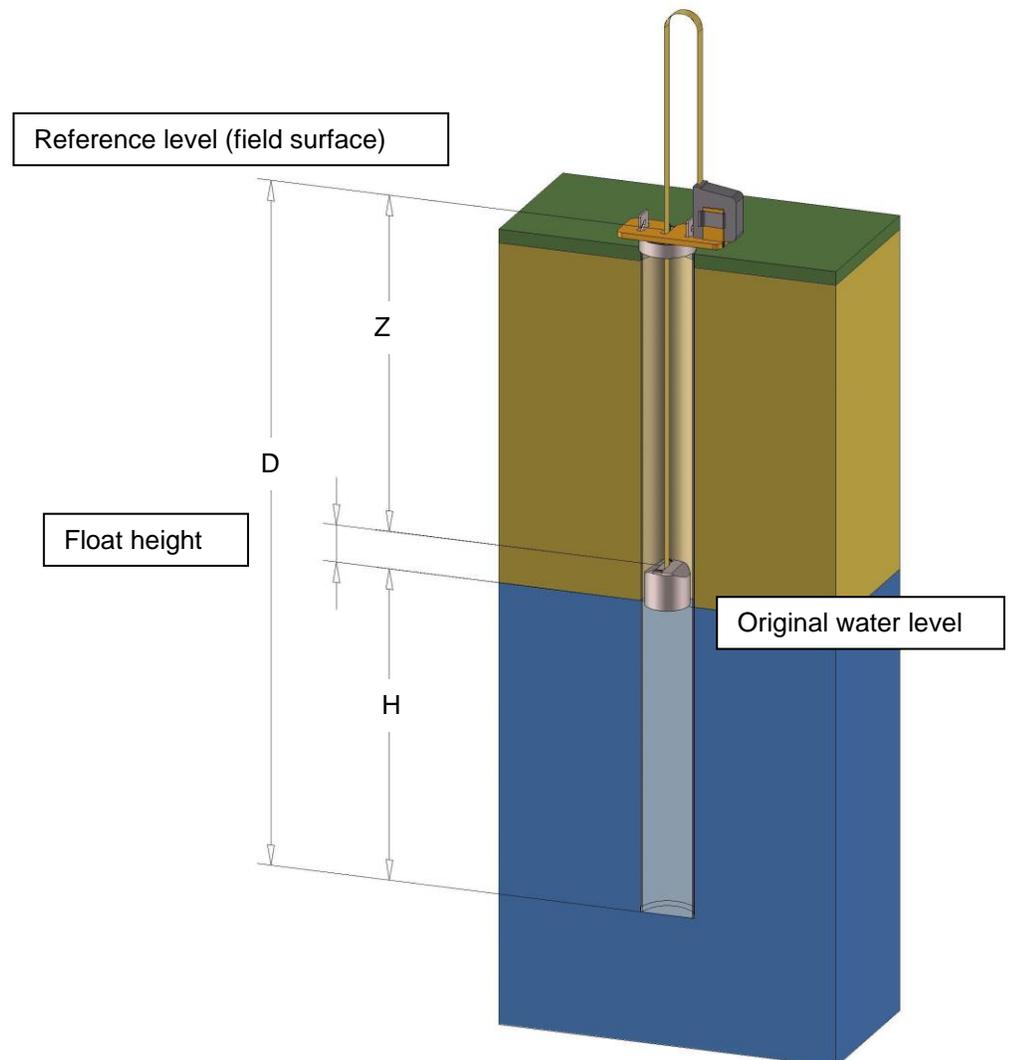
(If you do measurements with another water level measuring device, subtract 5 cm from the obtained value Z).

Then **H** must be calculated which is  $D(\text{epth}) - Z(\text{waterlevel with float}) - 5 \text{ cm} (\text{height of float})$

Example:  $D = 185 \text{ cm}$

Z measured with float:  $65 \text{ cm}$

$H = 185 - 65 - 5 \text{ cm} = 115 \text{ cm}$



### Removal of the filter screen

After using the support filter the filter must be removed after having finished the measurements. For this, the spatula (numbered 12 on the picture in paragraph 2.1) is connected to an extension rod (or handle). Then lower this tool, and twist it into the hooks mounted on the top of the filter. Then pull up the filter.

After all measurements are finished leave the filter to dry completely before closing the PVC container.



An approximation of the permeability factor may be made by classifying the soil removed from the hole based on the average grain size (See table 1).

M 50 ( $\mu\text{m}$ ) M= median- average grain size	K (m/day) K=permeability in m/day
< 105	< 0,50
105-150	0,50-0,80
150-210	0,80-1,50
210-300	1,50-3,50
300-420	3,50-8,00
>420	>10,00

Table 1: indication of the water permeability of sand with less than 4% lutum

In a clay soil the permeability is primarily influenced by pore size, porosity, the silt/sand fraction, structure, layering and may vary between 0.01 and 0.50 meters per 24 hours.

The permeability in a peaty soil is affected by the composition, density and structure of the peat and the presence of very thin clay layers.

The M50 figure can be estimated with the use of a sand ruler.

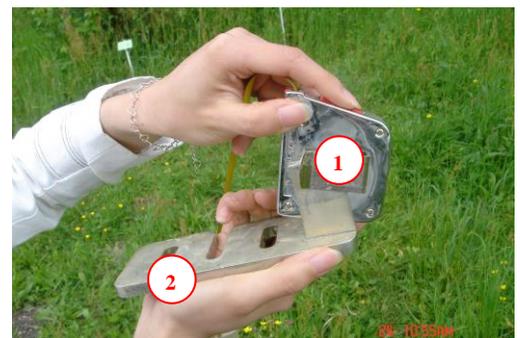
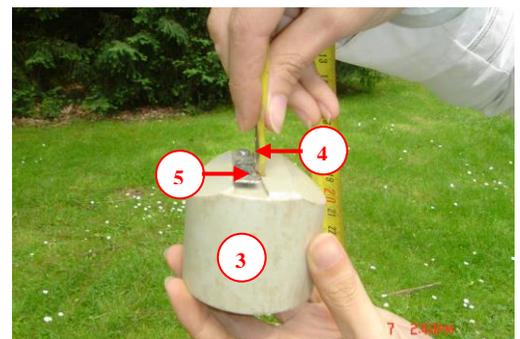


Sand ruler

### 3.2 Bailing out the hole

The measuring tape housing is fixed with the clamp on the tape holder and the tape is fixed to the float before the bailing operation starts.

- ① Measuring tape
- ② Measuring tape holder
- ③ float
- ④ tape end slipped under clamp of float
- ⑤ clamp



When a stable water level has established lower the float and record the reading (see fig.1) (Value z).

➔ **Z is the distance from the float to the top of the tape holder.**



Remove float and measuring tape and bail out the water using the stainless steel bailer connected to the upper part and/or extension rod.



### 3.3 Measuring the rate the water rises



Immediately after bailing, lower the float in the borehole and re-install tape holder. (Lower picture shows most normal position of tape holder; on top of soil).



The reading on the measuring tape ( $Y_0$ ) is immediately recorded and a stopwatch activated ( $t_0$ ).



The rate the water rises can now be recorded in two ways:

- by timing a pre-determined rise rate ( $\Delta Y$ ), so the time (in seconds) necessary for each rise of 2cm.
- by measuring the rise rate in a pre-determined period of time ( $\Delta t$ ), so the number of cm of rise per, for instance, 10 seconds

**Method a.** has the following advantages:

- It is possible to concentrate more on the measuring tape and consequently the consistency of the rise rate.
- It is easier and more accurate to take readings with a stopwatch than to try to take readings from a moving measuring tape.

**Method b.** has preference, however, when a timepiece with only second intervals is available.

The time interval choice (normally 5-30 seconds) is dependant upon the permeability of the soil. A rise of 1 cm per time interval is the ideal unit when choosing the correct measuring method.

➔ Of course it is essential that the level reading is done at the noted time (or the time reading is done at the noted level reading; the latter being more difficult since the tape moves constantly). You may use one of the tables 2a or 2b below to record the field data.

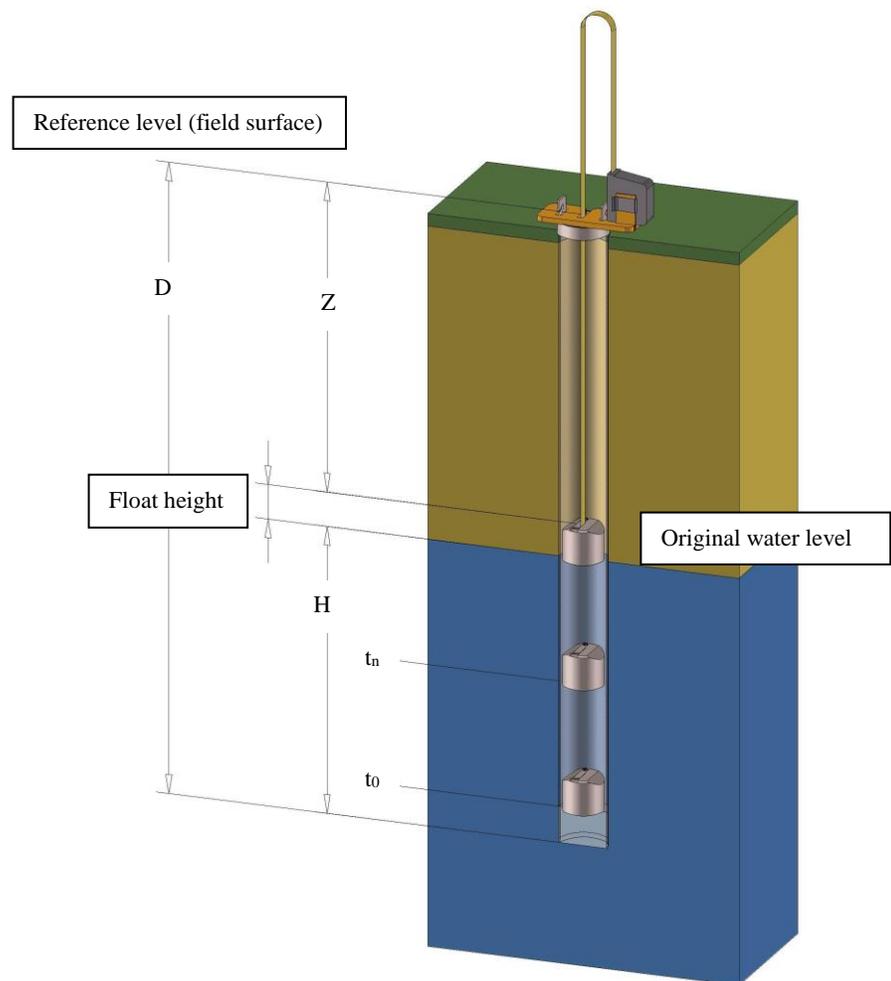
Example for one measurement:

Note: Shown in **black** parameters that will be used in nomograms or equations.

Example:  $D = 185$  cm

**Z** measured with float: **65 cm**

**H** =  $185 - 65 - (\text{height of float} = 5 \text{ cm}) = \mathbf{115 \text{ cm}}$  (see: Determining H and Z values earlier in this document).



Suppose tape reading at starting time ( $t_0$ ) = 175 cm

Suppose tape reading at end time ( $t_n$ ) = 150 cm

Then value  $Y_0$  will become  $175 - Z = 110$  cm

And value  $Y_n$  will become  $150 - Z = 85$  cm

$\Delta Y$  can then be calculated being  $Y_0 - Y_n = 25$  cm

$Y$  (being the average of  $Y_0$  and  $Y_n$ ) can also be calculated being  $(110 + 85)/2 = 97,5$  cm

Imagine it took 480 seconds for the water to rise from  $Y_0$  to  $Y_n$  then  $\Delta t = 480$  s

**Rising speed  $V_s = \Delta Y / \Delta t$**

**$V_s = 25 / 480 = 0,052$  cm/sec**

All necessary values are now available to input in one of the nomograms or the empirical equations.

Suppose an impermeable layer was not found ( $S > 0,5 H$ ) then that nomogram will show a C value of 2.8

To calculate the resulting K value the following is valid:  $V_s = K/C$  or  $K = V_s * C$

whereby

K = permeability (in meters per day)

C = found in nomogram or calculated

When we put  $C = 2.8$  and  $V_s = 0.052$  cm/sec in  $K = V_s \times C$  we will get:

$K = 0.052 \times 2.8 = 0.145$  meters / day for this measurement.

Further information on how to use the nomograms or equations can be found further down.

For one borehole S, H and Z are "fixed" and measured only once, prior to all measurements, except in cases where water table might vary quickly for instance near the sea.

However the time elapsed for each measurement will change, as well as  $\Delta Y$ , the resulting Y and the rise speed  $V_s$

So it is more logical to average  $\Delta Y$ , Y and  $V_s$  after having done all planned measurements in a borehole.

Then you input these in the nomogram (or equation) read C and calculate K, which will automatically be expressed in m/day.

Measuring method (a)	The time necessary for each rise of 2 cm.						Y (cm)	$\Delta Y$ (cm)	Z (cm)	H (cm)	S (cm)	Above ground level (cm)
	1	2	3	4	5	6						
I												
II												
III												
IV												
V												

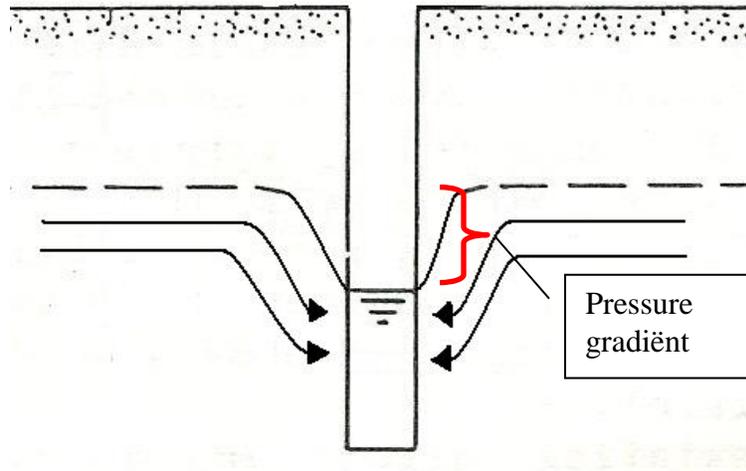
Table 2a to record field data using method a

Measuring method (b)	The number of cm risen per ... seconds (cm).						Y (cm)	$\Delta Y$ (cm)	Z (cm)	H (cm)	S (cm)	Above ground level (cm)
	1	2	3	4	5	6						
I												
II												
III												
IV												
V												

Table 2b to record field data using method b

I-V = number of test in one borehole

When the difference between the original water level and the actual water level in the emptied bore hole gets less the rise rate diminishes (see fig.2) due to the pressure gradiënt getting less. Rising of the water will become slower and slower.



**Fig.2:** The pressure gradiënt

***The following guideline therefor is used:***  
*The level of water entering the bored hole must, when measuring is stopped, not be more than 25% of the water bailed out ( $\Delta Y \cong \frac{1}{4} Y_0$ ). This will assure a sufficient linearity.*

Example: If 40 cm water column is bailed out of the hole then the guideline indicates the first 10cm ( $\Delta y = \frac{1}{4} \times 40\text{cm}$ ) to be used during the test.

It is quite common that the first reading shows a relatively high  $\Delta Y$  value, caused by water trickling down the walls of the hole immediately after bailing operations. ***In this case the first test is ignored.***

➔ **It is important to ensure that the measuring tape and float remain undisturbed during measuring operations and precautions must be taken to prevent the wind blowing the equipment against the hole wall or the measuring tape holder. Sometimes some tapping may unblock a float that sticks to the wall of the borehole.**

An alternative to the Hooghoudt method is the so-called **“inversed” method**. In this case water is pumped from a container, by means of a hand pump, into the auger hole. The water permeability can now be calculated by recording the lowering of the water level in the auger hole during a fixed period of time (see fig. 3). Also see the paragraph The “inversed” auger hole method.

This method is normally used when investigating permeability of soils which are not (yet) within the boundary of ground water level.

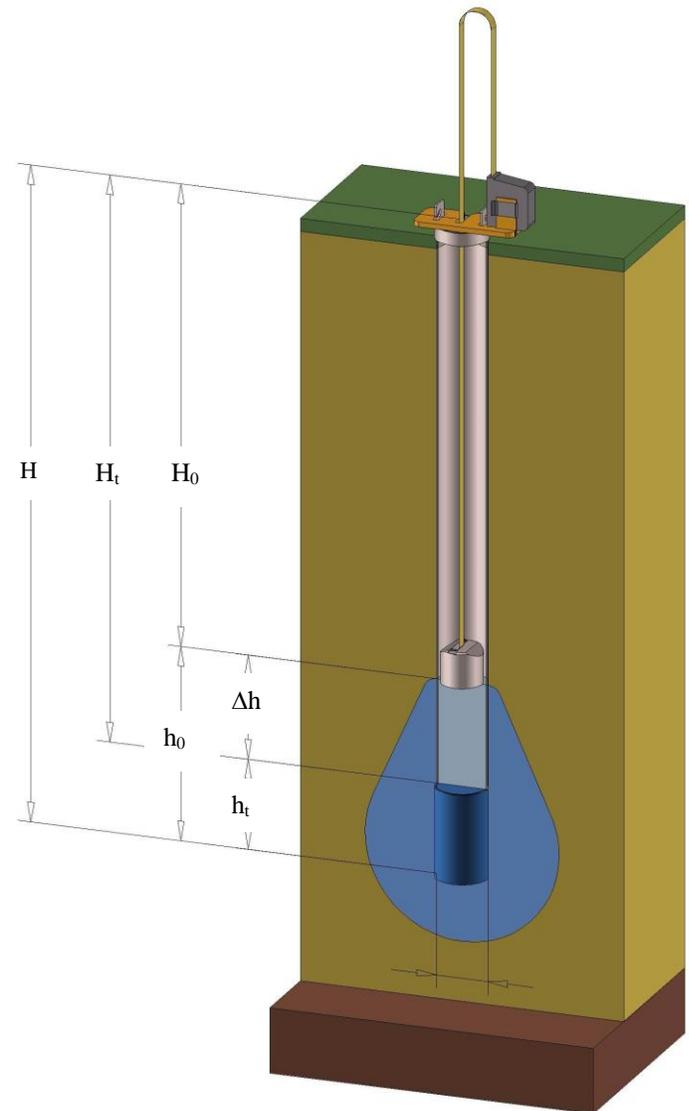


Fig. 3 The “inversed” auger hole method

#### 4. CALCULATION OF K-VALUE (m/d)

Results obtained from K measuring mostly show sizable discrepancies, even when the auger holes are not too far apart.

There are two reasons for this:

- measuring errors
- natural variation in the permeability of the soil

The variation of the soil itself is the main cause of widely varying measuring results. This variation may be divided into two parts:

- **Larger (natural) variations**, which are recognizable in the soil profile; and smaller variations.
- **The smaller variations** differ widely according to the type of soil and are difficult to distinguish from measuring errors.

A more concentrated measuring area cannot guarantee to eliminate these variations. Measuring in two fold also has no effect. A better picture can be obtained by using the known soil properties; permeability factors can be deduced from (known) profile properties.

The K value can be estimated in this manner.

These estimations are supported by the measurements with the auger hole method.

##### 4.1 The Hooghoudt auger hole method by using Nomograms

Nomograms can be used when calculating K-factors.

The following dimensions are used when using nomograms (according to Ernst):

**H = depth of the auger hole in cm below ground water level**

**S = depth of an (possible) impermeable layer in cm below the bottom of the auger hole**

**$\Delta Y$  = rise of water level in auger hole during measuring operations**

**Y =  $1/2 (Y_n + Y_0)$  = average water level during measuring operations**

**t = time curve during complete measuring operations**

(All values are expressed as positive (+) values in cm)

In words: The dimensions influencing the permeability are: The effective (= wetted) surface of the borehole (= diameter + depth of the hole compared to the original water level).

Further: Position of an impermeable layer; rise of water level in time (= rise speed) and average position of the water level during the rising !

The average position of the water level during the rising determines potential gradient (force) with which the water is pushed into the borehole.

For the rise rate the following is valid:  $V_s = \Delta Y / \Delta t$

whereby:  $V_s$  = rise rate (cm per second)

For the resulting K value the following is valid:  $V_s = K/C$  or  $K = V_s * C$

whereby

K = permeability (in meters per day)

C = found in nomogram or calculated

Note that all input parameters are in cm and seconds but that the resulting K value is in meters per day.



**The C-factor can be determined in two ways. It can be calculated with empirical equations that you will find further down. The equations are useful if you want to calculate permeability with a (hand-held) computer. Here we will first show you how to determine C by means of two nomograms. The nomograms are more accurate (error approximately 5% max) than the equations (error max 20%).**

**C depends on:**

- The distance between an impermeable layer and the bottom of the auger holes (S)
- Diameter of the auger hole (2r)
- Depth of the hole below water level (H)
- The average water level during measuring operations (Y)

Ernst nomograms are used in two cases with an auger hole diameter 8cm to determine the permeability factors:

**a. bottom of the auger hole above impermeable layer;  $S > 0.5 H$  (see fig.4)**

**b. bottom of the auger hole on impermeable layer;  $S = 0$  (see fig.5)**

If  $S =$  between  $\frac{1}{2}H$  and  $\infty$  use nomogram mentioned under a.

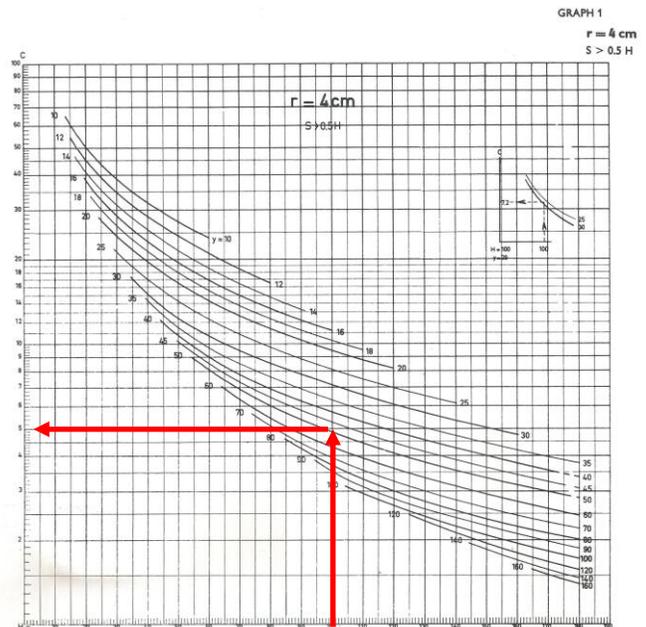
If S is larger than 0 but smaller than  $\frac{1}{2}H$ , no special equation or graph is available.

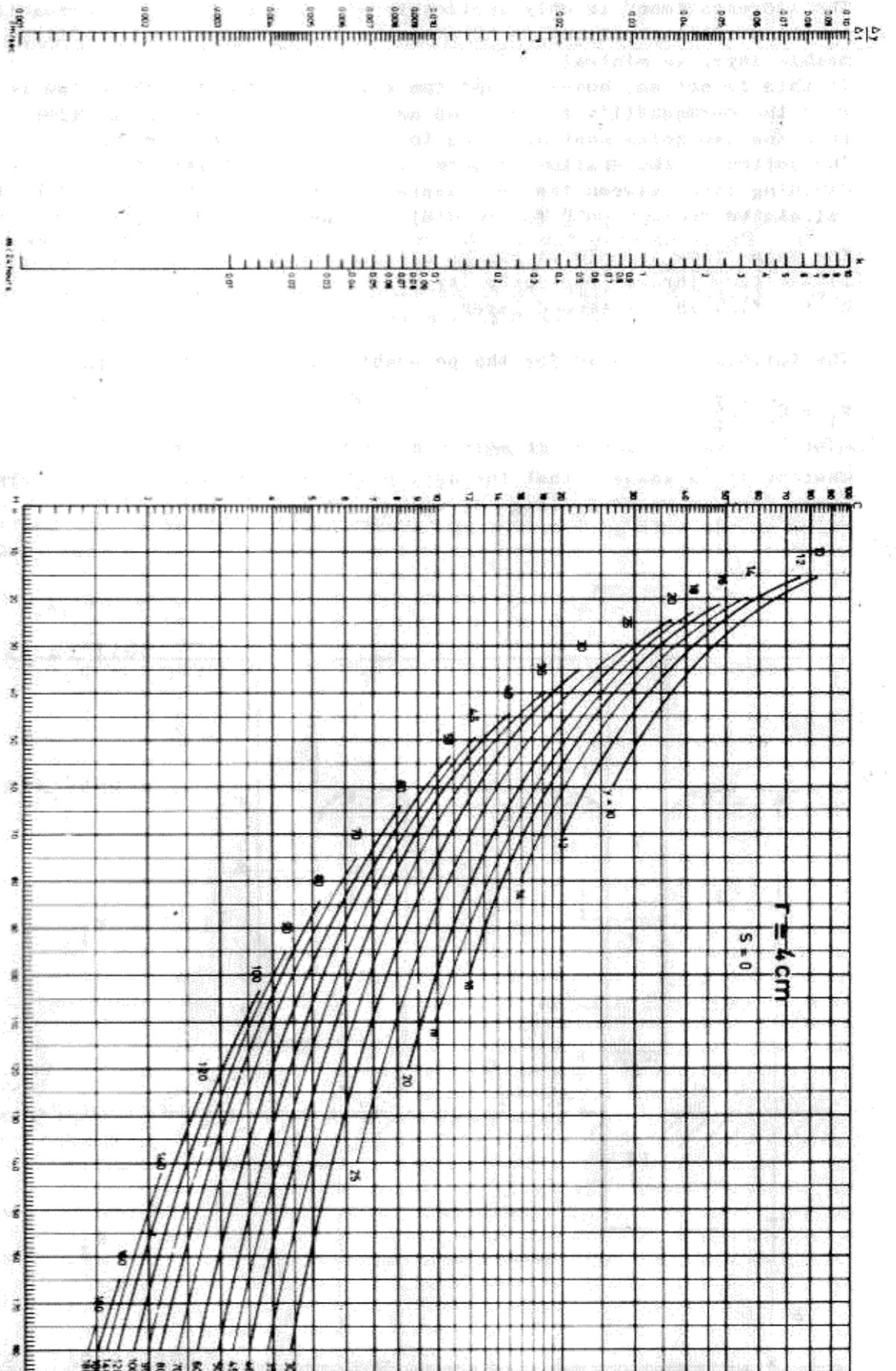
Hence an estimate has to be made between the K-value for  $S > \frac{1}{2}H$  and  $S = 0$ .

The nomograms are used in the following way:

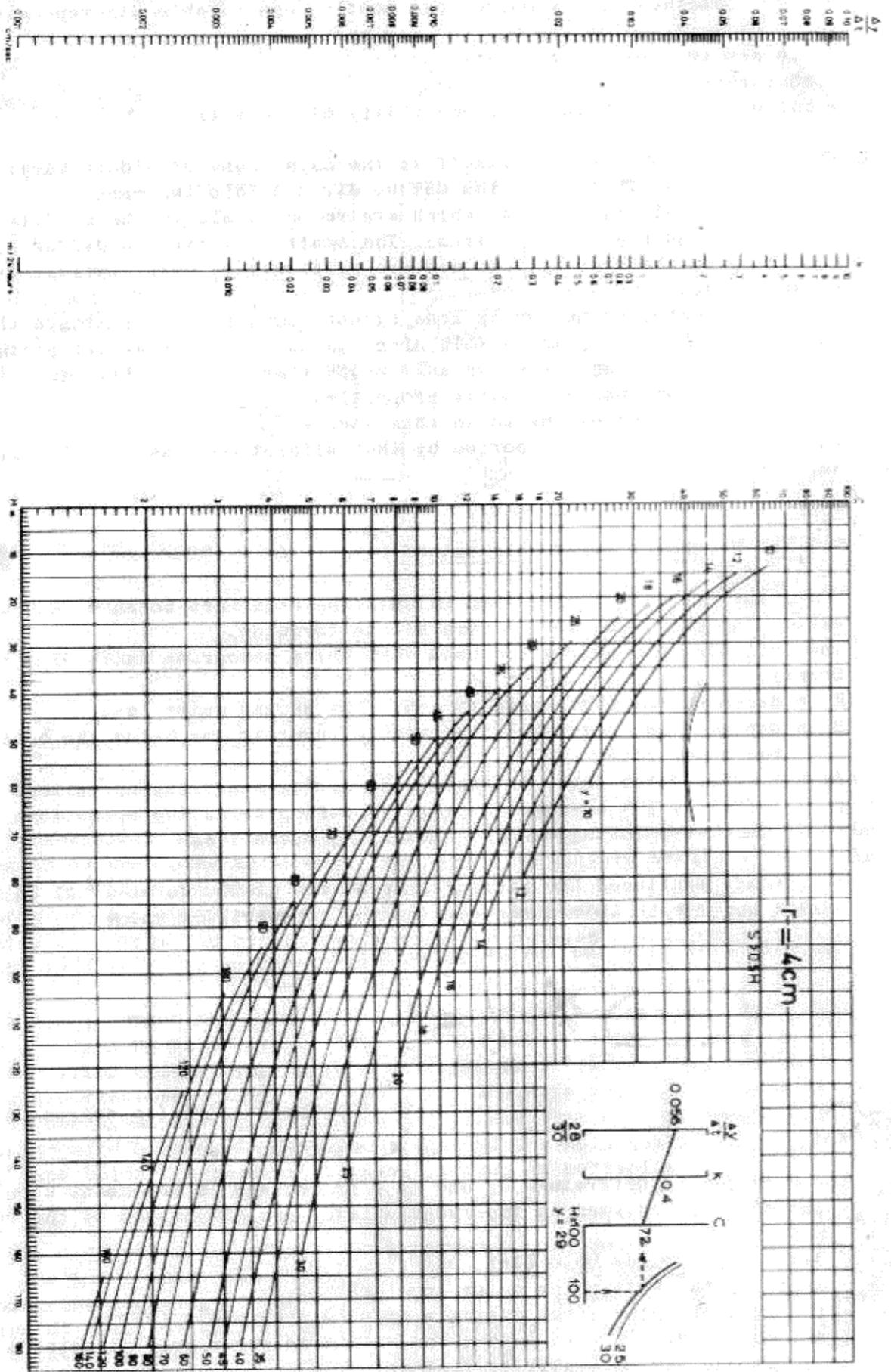
C is read from the diagrams as a function of Y and H. H is found at the abscissa in cm. Then go to the curved line which comes closest in value to the found Y value. Then go to the left and read C as the ordinate. After this the value of K itself can be derived using the graph consisting of vertical lines at the left of the nomogram. Connect the found C on the ordinate with  $\Delta Y/\Delta t$  as shown on the far left vertical line. The crossing point with the vertical line in the middle shows the K in meters per day.

**The example shows the determination of C based on a measurement where  $H=100$  cm and  $\bar{Y}= 50$  cm. The resulting C is then  $C=4,8$**





**Fig. 4:** Nomogram for  $S = 0$   
 Bulletin No1 THE AUGER HOLE METHOD, W.J.F.van Beers



**Fig 5:** Nomogram for  $S > 0,5H$   
 Bulletin No 1 THE AUGER HOLE METHOD; W.J.F. van Beers

## 4.2 Measuring in soils with two permeable layers.

The before mentioned method is only applicable if the variations in permeability in the soil profile between the freatic level and the first impermeable layer are minimal.

If this is not so, however and the soil consists of perhaps two layers with the permeability represented as  $K_1$  (upper layer) and  $K_2$  (lower layer), then the two holes must be bored to different depths (*see fig.6*).

The bottom of the shallowest hole (I) must be at least 15cm above the dividing line between the two layers. In this hole the value of  $K_1$  is calculated from graph 3 ( $S > 0.5H$ ) and the values  $H_1$  and  $y_1$ .

The water flow in hole I is only determined by hydraulic properties of the upper layer.

The water flow in hole II, however, can be divided into:

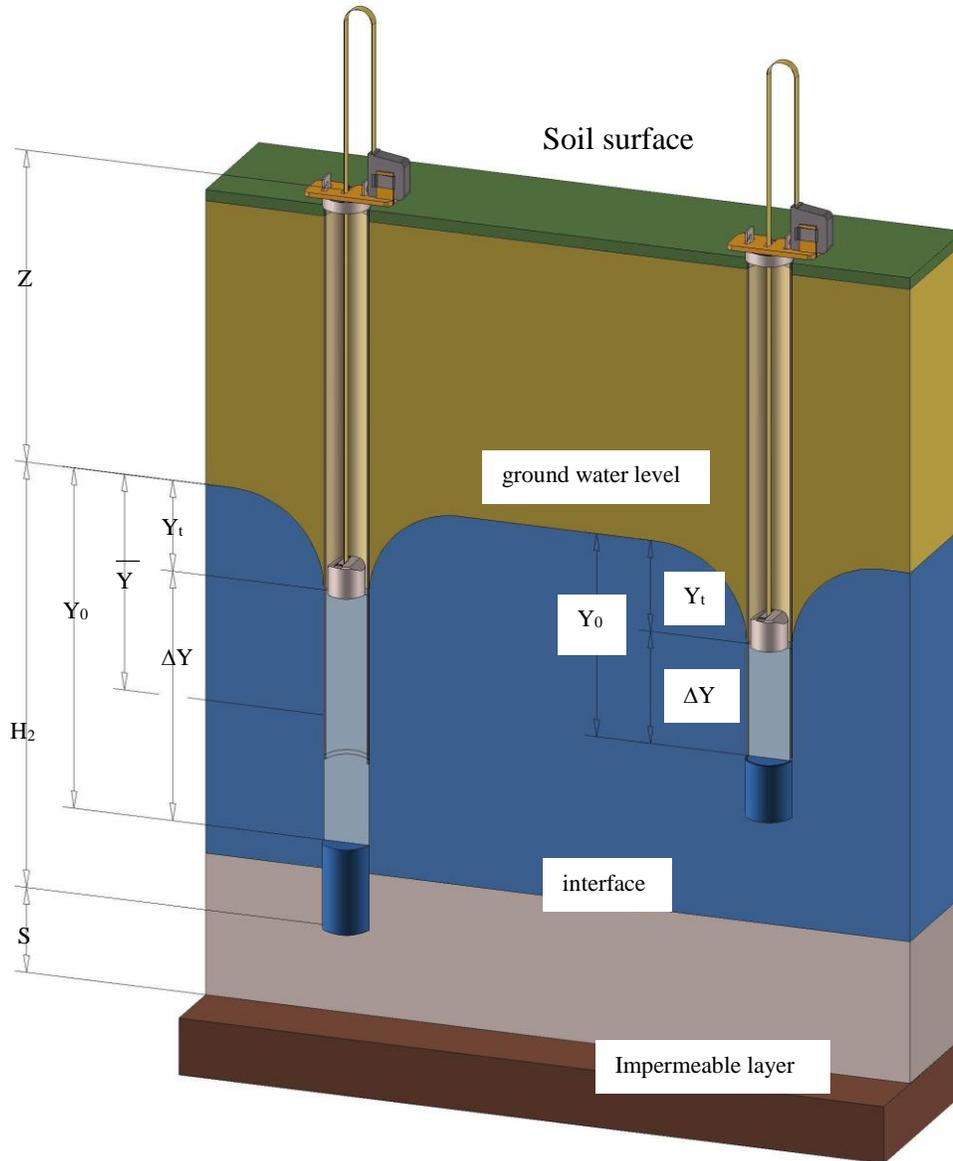
**a. the flow through the upper layer**

**b. the flow in the second layer**

The following is valid for the permeability factor in the upper layer:

$$K_1 = C \frac{\Delta y}{\Delta t}$$

Whereby it is assumed that the bottom of the hole touches the impermeable layer for the value  $C_0$  (*fig.4, with  $S = 0$  and  $H_2$  and  $y_2$* ).



**Fig.6:** Auger hole method for two layers with differing permeability

The following is valid for the K factors in the second layer:

$$K_2 = \frac{C_0 \frac{\Delta y'}{\Delta t'} - K_1}{\frac{C_0}{C_2} - 1}$$

In other words the water flow with the C value for the deepest hole is calculated as if the permeability values are consistent everywhere ( $H = H_2$ ) (with  $S = 0$  or  $S > 0.5$ ; depending on the depth of the impermeable layer). But the flow above the dividing line, which is estimated too high, must be reduced by the same  $C_0$  value that was used for  $K_1$ . In this way two K values for two subsequent layers can be determined !

### 4.3 Calculation of K-factor

Situations may occur where you may or can not use one of the nomograms. For instance if another borehole diameters then 8 cm is used. Also if you want to calculate the K value with a hand held computer the below mentioned equations can be used.

a) for  $S \cong 0.5H$

$$K = \frac{4000}{\left(\frac{H}{r} + 20\right) \left(2 - \frac{y}{H}\right)} \frac{r}{y} \frac{\Delta y}{\Delta t} \quad \text{or in another form:} \quad K = \frac{4000 r^2}{(H + 20 r) \left(2 - \frac{y}{H}\right) y} \frac{\Delta y}{\Delta t}$$

The equations are empirical approximations. If the following conditions are applicable the highest inaccuracy is 20%:

$$\begin{aligned} 3\text{cm} < r < 7\text{cm} \\ 20\text{cm} < H < 200\text{cm} \\ y &> 0.2 H \\ S &> H \\ \Delta Y &\leq 1/4 y_0 \end{aligned}$$

b) for  $S = 0$

$$K' = \frac{3600 r^2}{(H + 10 r) \left(2 - \frac{y}{H}\right) y} \frac{\Delta y}{\Delta t}$$

### 4.4 The “inversed” auger hole method

Here, water is added into a borehole instead of removed (see figure 3). Use this method with some precaution. Smearing of the borehole wall of a clayey soil can have a drastic (reducing) effect on permeability. The dropping water level will not only diminish the pressure gradient but also diminish the surface of the area where the infiltration can take place. This creates an extremely complex situation in soils that show a micro-stratification. However good comparative results were obtained in soils showing no microstratification (Literature J.W. van Hoorn) between measurements with a ring infiltro meter (placed in dug soil pits) and the auger hole method applicable in the wet season when water table was high.

Other “inversed” methods are now available that apply a constant level head of water in the borehole. This eliminates important error sources.

Important parameters of influence (for all “inversed” methods) are that the natural ground water level (or an impermeable layer) should not be too close to the bottom of the borehole (e.g. > 20 cm) and that the measurement itself should be repeated several times (1-3 times for loam and clay; 3-6 times for sand) before getting results within 10-15% of the final value.

If the “inversed” auger hole method is used, the K factor can be calculated in the following way:

The surface area from which water enters the soil during time period t is equivalent to:

$$A_t = 2 \pi r h_t + \pi r^2$$

Assuming that the hydraulic gradient equals approx. 1, then, according to Darcy's law, the following applies:

$$Q_t = K \cdot A_t = 2 \cdot K \cdot \pi r \left( h_t + \frac{r}{2} \right) = -\pi r^2 \frac{dh}{dt}$$

Integration between the limits  $t=0, h_0$  and  $t, h_t$  leads, after reduction to:

$$K = 1.15r \frac{\log\left(h_0 + \frac{r}{2}\right) - \log\left(h_t + \frac{r}{2}\right)}{t} \quad \mathbf{K \text{ will be expressed in m/day.}}$$

## 5. TROUBLESHOOTING

Block the measuring tape with the red button to allow a tensionless free upward movement of the float..



When using the bailer to remove water, the bailer should not touch the bottom of the hole. Bailing out too much sand is not correct and will enlarge the diameter and depth of the borehole.



Do not overfill the auger. In clayey soils this will cause severe smearing of the borehole wall and reduce permeability greatly.



Prevent small tools and contents of your pockets (mobile phone !) to drop in the borehole. Lay small tools preferably on a small table far enough from the borehole. Hang the stopwatch around your neck instead of putting it on the ground !

Should anything drop in however think of any of the following “fishing” techniques:

- Use the riverside auger to fish out objects up to 5 cm in diameter (together with some soil probably).
- Lower a bailer in the borehole. A dropped in extension rod or smaller tool can be grabbed because the valve will close when pulling up the bailer.

## 5.1 Variations

**a.** The maximum error in the graphs is estimated at 5 percent.

**b.** The error caused by a wrong measurement of H and y is inversely proportional to the magnitude of H and Y. For instance: a 1 cm error in the measurement of H causes a 2 percent error in the K-value if H = 50 and a 1 percent error if H = 100. The same is true for Y. This shows that there is no need to measure H and Y with an accuracy of millimeters.

**c.** If a wrong figure is used for the radius r the order of magnitude of the error is usually about 20 percent for half a centimeter difference in radius, or 20 percent for the difference of 1 cm between the diameter of the hole used for computing the K-factor and the actual diameter.

**d.** A difference of 10 percent is quite normal when the K-factor is measured several times in the same hole. The **variation in K-value** within short distances or between soil profiles classified as one soil type is often a factor 2-6. On the other hand, **between** distinctive soil layers the K-value may vary with a factor thousand or more! Some soils have a very low hydraulic conductivity ( $K = 0.01$  m/day), whereas others have a very high one ( $K = 10$  m/day). Hence the order of magnitude in K-value is more important than individual measurements with the highest accuracy. After all, we are usually not interested in knowing the hydraulic conductivity of the soil in a plot 1sq.m. in area, but rather in the hydraulic conductivity of a larger area. Consequently accuracy should be obtained by averaging several measurements done in many holes.

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