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College of Soil Physics

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Saturated flow and saturated hydraulic conductivity.

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College on Soil Physics 2007

Flow of water in saturated soils
Hydraulic conductivity

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FOR EREMOLOGY

Flow of water in saturated soils

- Poisseuillian flow in capillary tube
- Darcian flow –law of Darcy
- Hydraulic conductivity K_s
- Determination of hydraulic conductivity K_s

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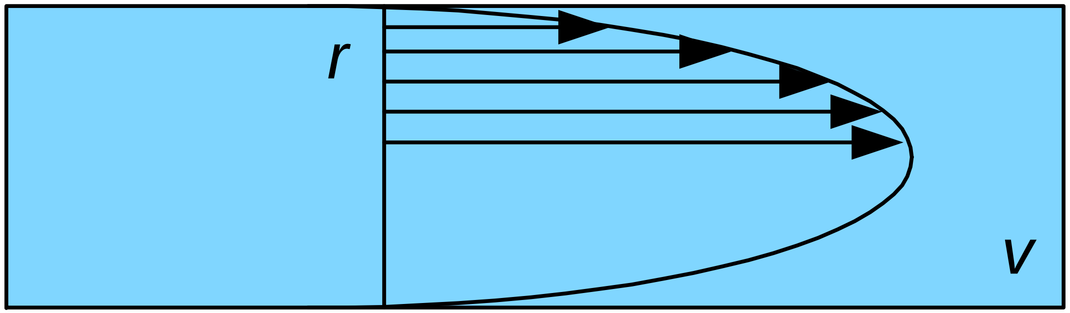
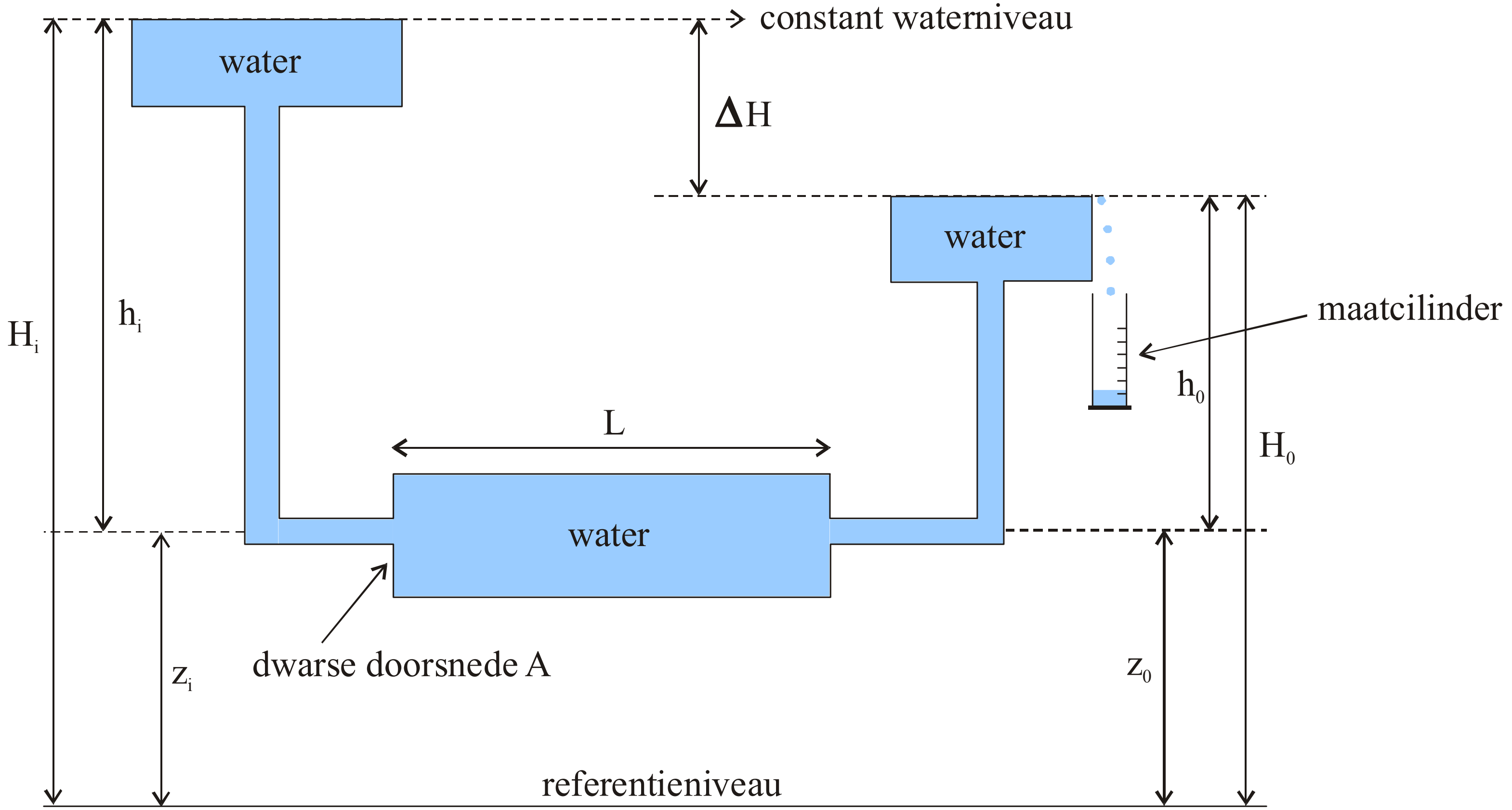
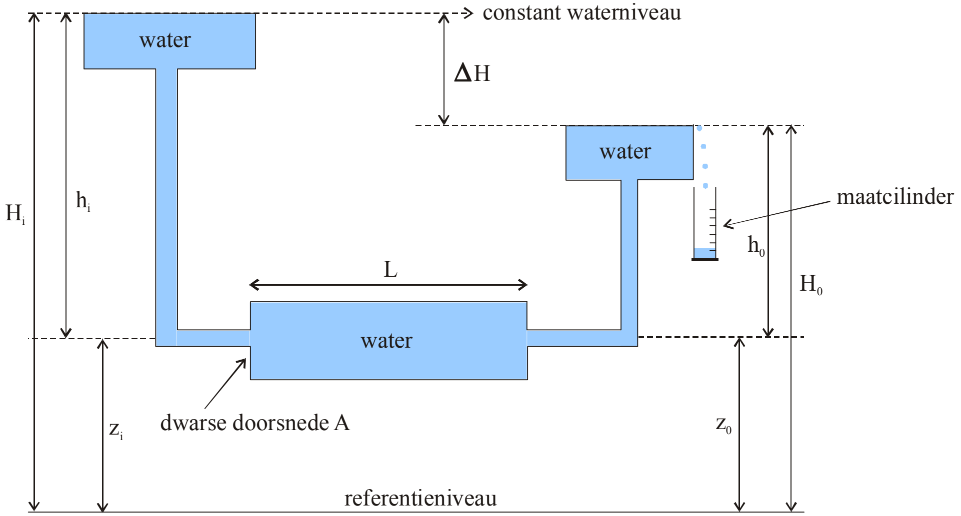
Posseuillian flow in capillary tube



microscopic flow



Posseuillian flow in capillary tube



$$Q = -\frac{\pi r^4}{8\eta} \nabla P$$

$$\nabla P = \frac{\rho_w g \Delta H}{L} \qquad \Delta H = H_i - H_o$$

$$q = \frac{Q}{A} = \frac{Q}{\pi r^2} = -\frac{r^2}{8\eta} \nabla P$$

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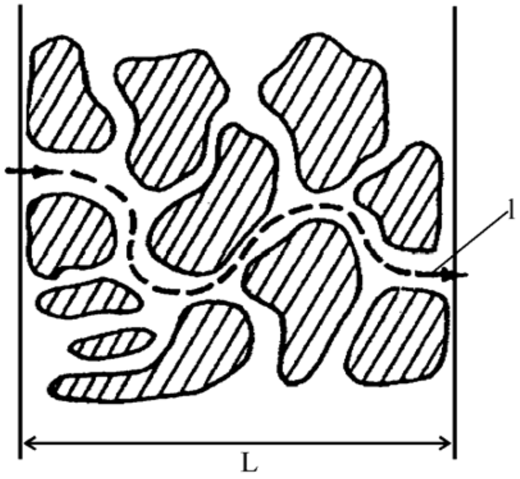
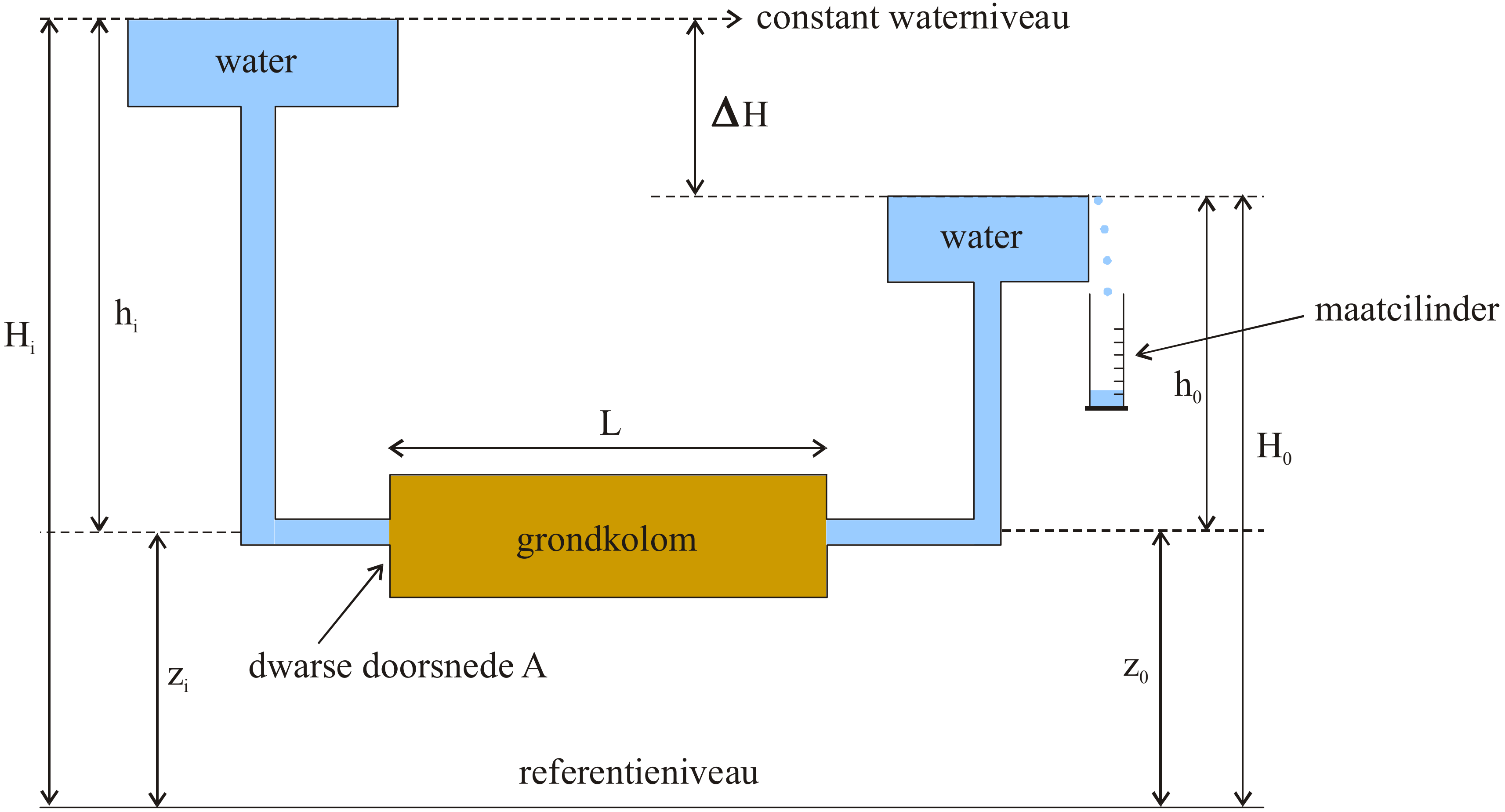
Darcian flow – law of Darcy



macroscopic flow

Darcian flow – law of Darcy



$$Q = \frac{V}{t} \sim A \frac{\Delta H}{L}$$

$$\Delta H = H_i - H_o$$

Darcian flow – law of Darcy

$$q = \frac{Q}{A} = \frac{V}{t\,A} \sim \frac{\Delta H}{L}$$

flux density or *flux*

→ $$q = K_s \frac{\Delta H}{L}$$

law of Darcy

valid for steady state flow
q = constant in time and space

$$q_x = \enclose{circle}{-K_s} \frac{\mathrm{d}H}{\mathrm{d}x}$$

water flows in direction opposite to
increasing hydraulic potential

Darcian flow – law of Darcy

(one-dimensional) vertical flow

$$q_z = -K_s \frac{\mathrm{d}H}{\mathrm{d}z}$$

three-dimensional flow

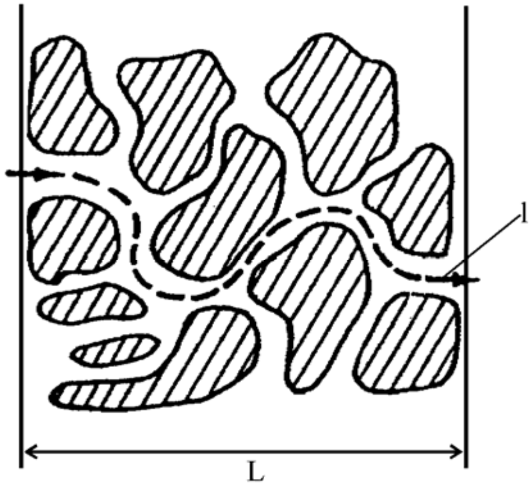
$$q = -K_s \left(\frac{\partial H}{\partial x} + \frac{\partial H}{\partial y} + \frac{\partial H}{\partial z} \right)$$

$$q = -K_s \nabla H$$

Darcian flow – law of Darcy

units: generally L T^{-1}

but flux ≠ velocity



turtuosity $$\tau = \frac{l}{L} > 1$$

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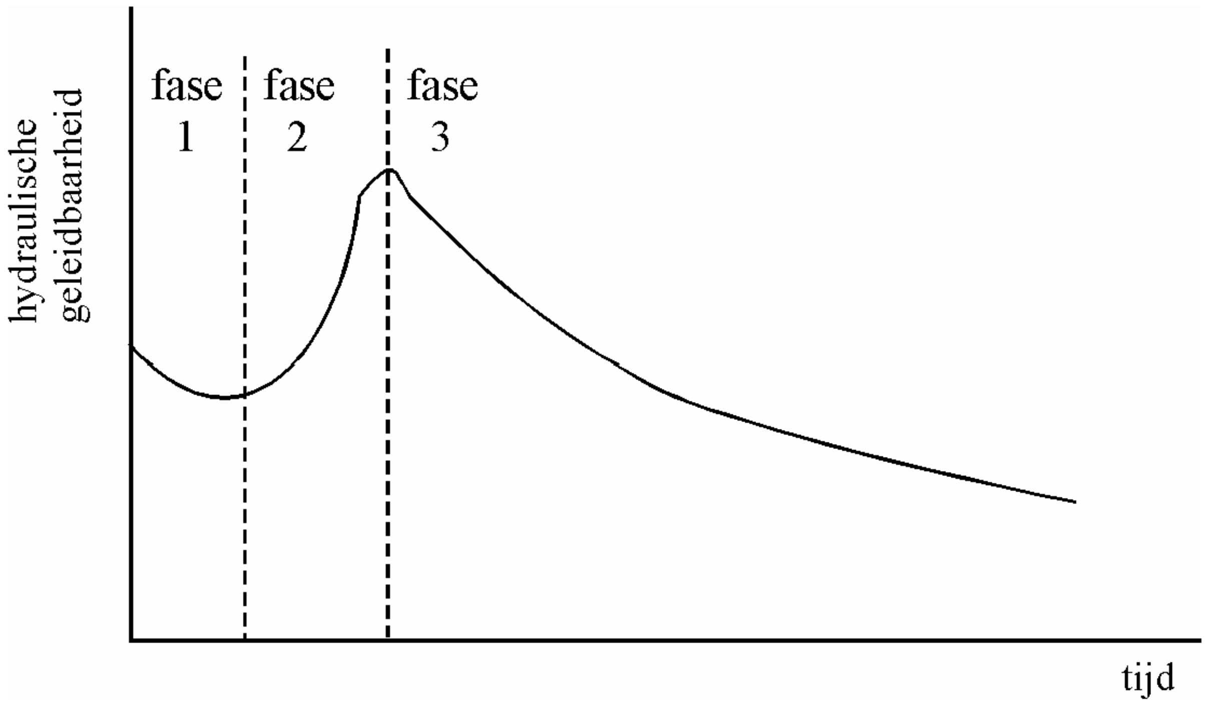
Hydraulic conductivity K_s

depends on

1. <u>*structure*</u>



Hydraulic conductivity K_s

depends on

fluid characteristics

$$K_s = \frac{k \;\; \rho_w \;\; g}{\eta}$$

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Determination of hydraulic conductivity K_s

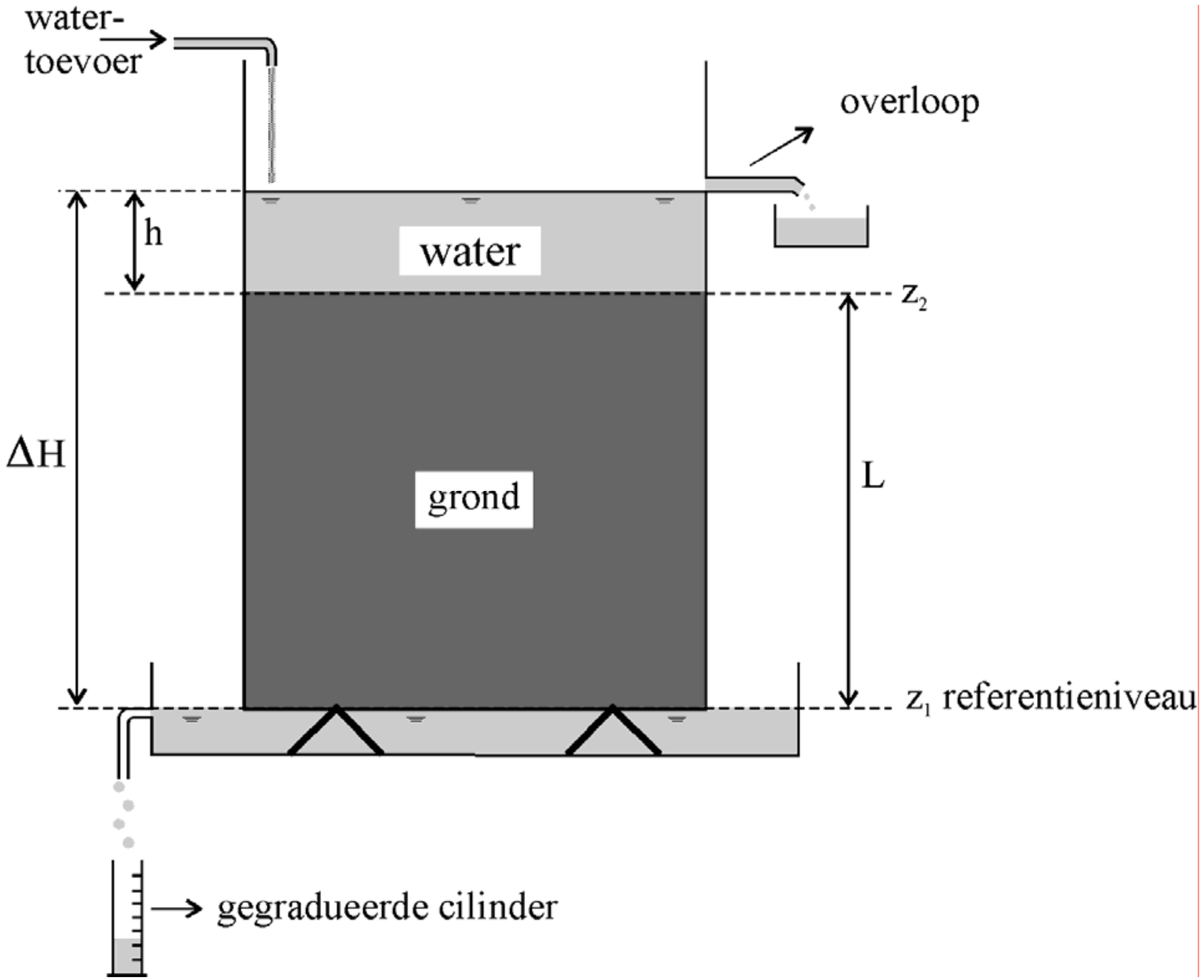
- Laboratorium
  - constant water head
  - variable water head
- Field
  - in saturated zone: auger hole method
    piezometer method
  - in unsaturated zone: double ring infiltrometer
    Guelph-permeameter
    disk infiltrometer
    tension infiltrometer

  Rainfall simulation

- Pedotransfer functions

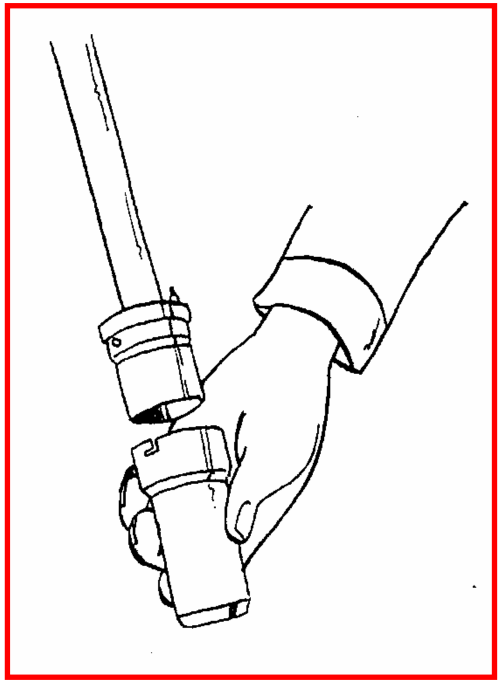
Determination of hydraulic conductivity K_s

- Lab – constant water head



Sampling: Kopecky ring

Sampling in field



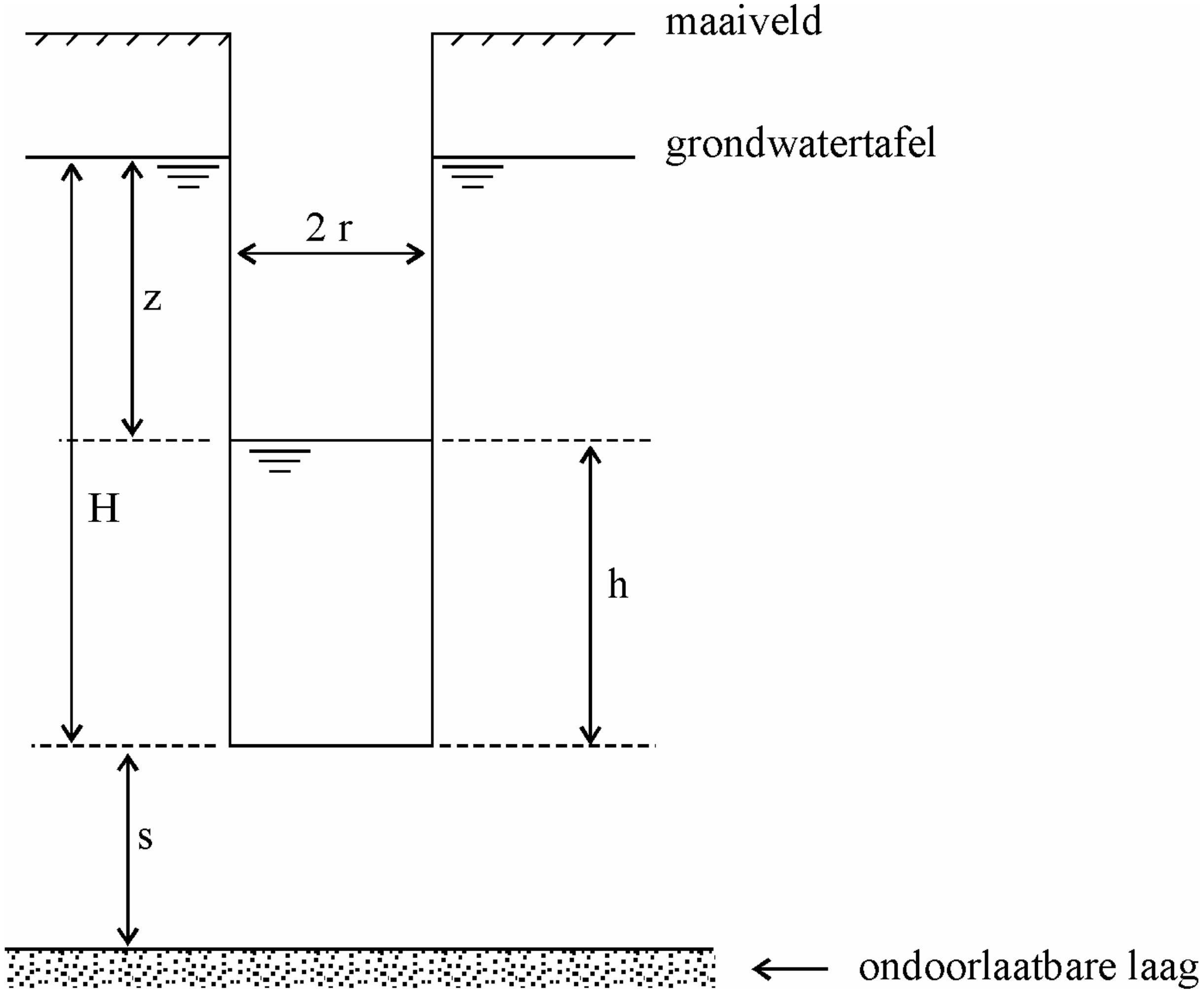
sample

Determination of hydraulic conductivity K_s

- Lab – constant water head

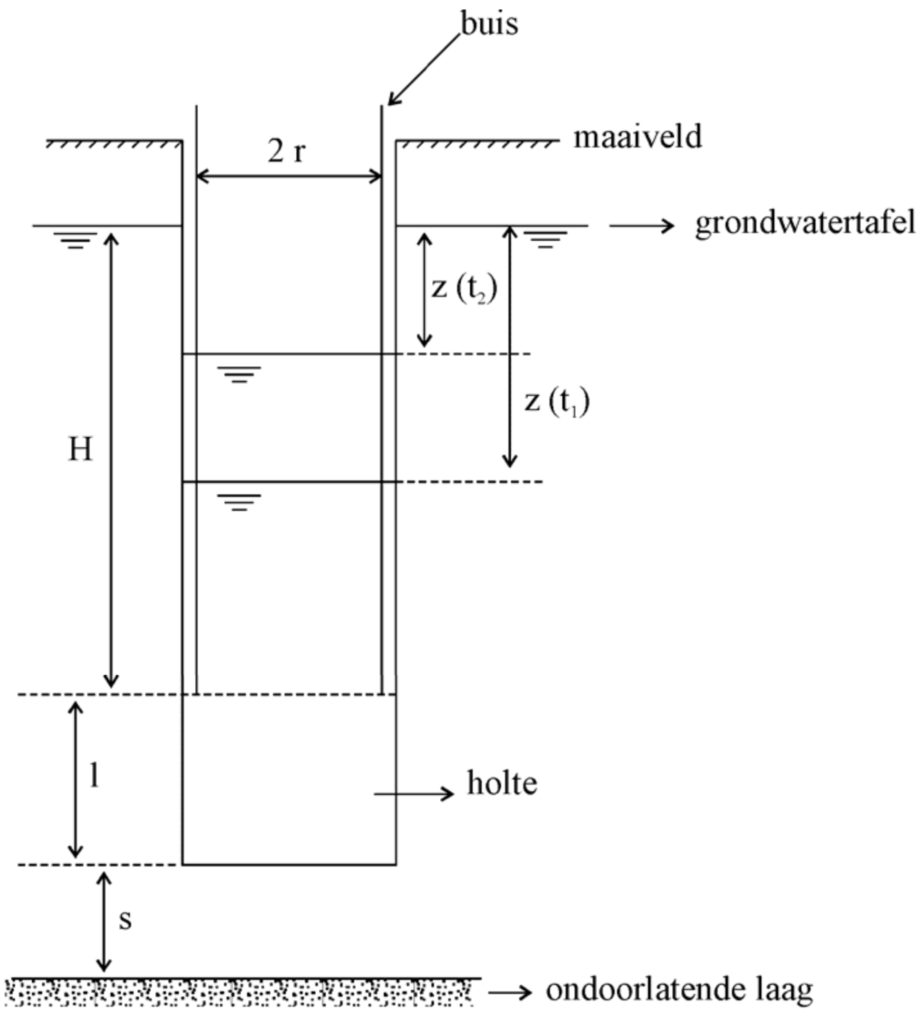
Determination of hydraulic conductivity K_s

- Field – Saturated zone – auger hole method



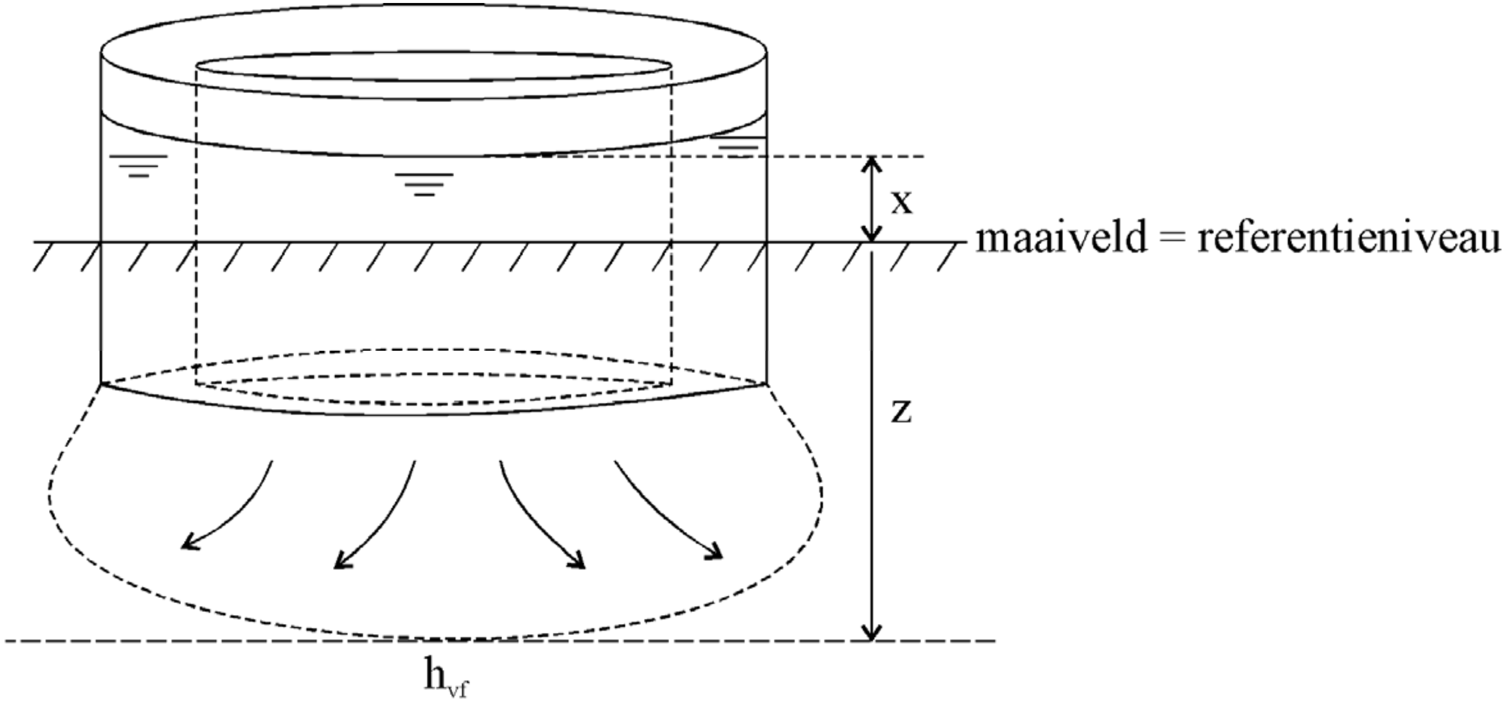
Determination of hydraulic conductivity K_s

- Field – Saturated zone – piezometer method



Determination of hydraulic conductivity K_s

- Field – Unsaturated zone – Double ring infiltrometer



Determination of hydraulic conductivity K_s

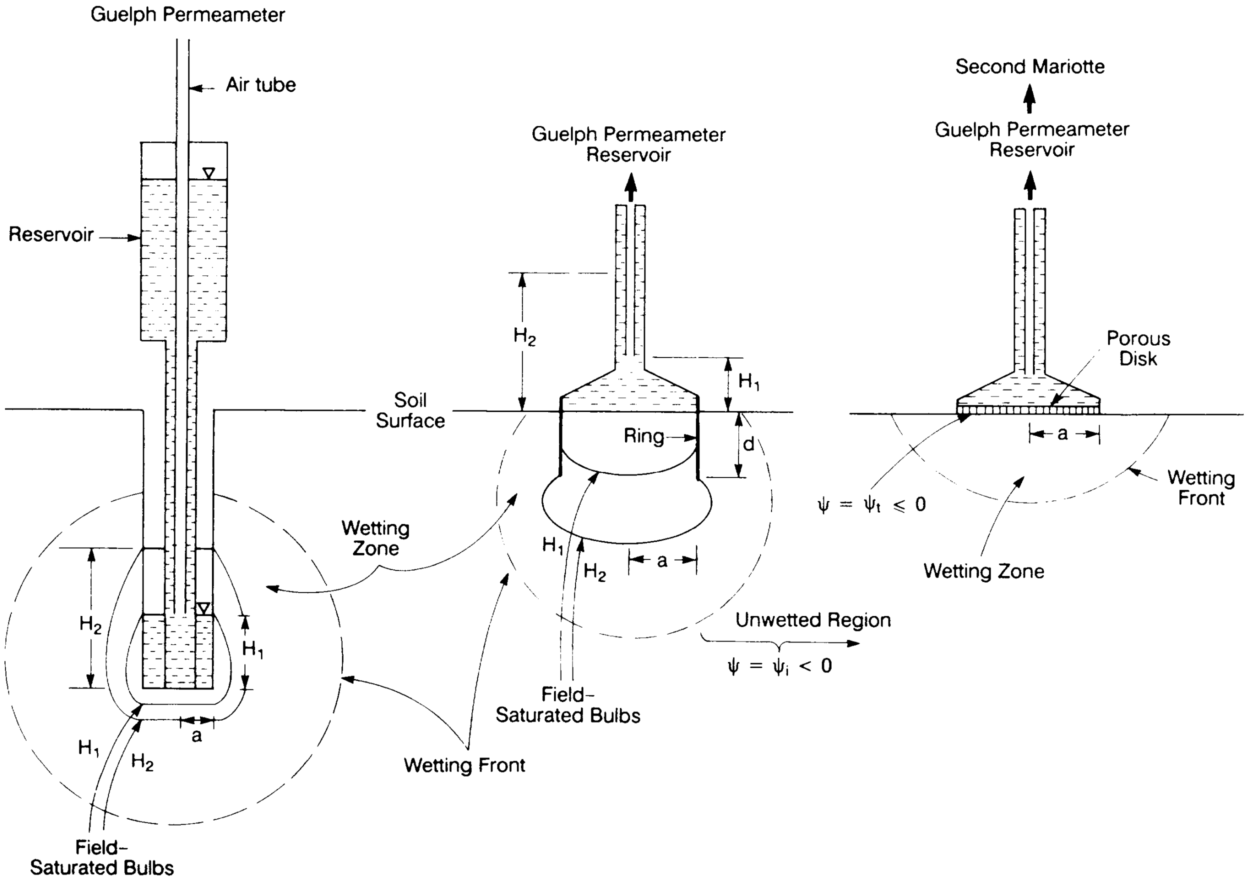
- Field – Unsaturated zone – Double ring infiltrometer

Determination of hydraulic conductivity K_s

- Field – Unsaturated zone – Inverse auger hole method

Determination of hydraulic conductivity K_s

- Field – Unsaturated zone – Guelph permeameter
  Disk infiltrometer
  Tension infiltrometer



Determination of hydraulic conductivity K_s

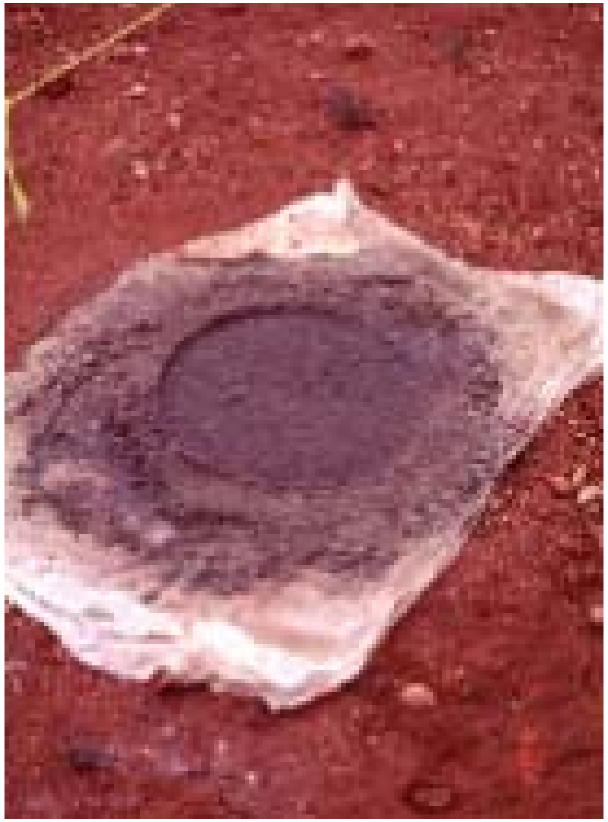
- Field – Unsaturated zone – Guelph or well permeameter

Determination of hydraulic conductivity K_s

- Field – Unsaturated zone – Pressure infiltrometer

Determination of hydraulic conductivity K_s

- Field – Unsaturated zone – Tension or disk infiltrometer



Determination of hydraulic conductivity K_s

- Field – Unsaturated zone – Hood infiltrometer

Comparison of Methods for measuring K_s

K_s = 10-5 m.s-1

	Sand		**Loam**		**Clay Loam**	
	CT	**NT**	**CT**	**NT**	**CT**	**NT**
Tension Infilt.	**3.1** (60%)	**2.6** (47%)	**1.6** (164%)	**4.2** (68%)	**1.0** (45%)	**2.3** (63%)
Presion Infilt.	**9.5** (51%)	**5.4** (58%)	**1.5** (102%)	**6.9** (80%)	**0.1** (362%)	**1.9** (5058%)
Ring sample	**8.0** (49%)	**8.1** (74%)	**1.2** (219%)	**3.4** (·345%)	**0.03** (10^5%)	**13.6** (207%)

CT: Conventional Tillage

NT: No Tillage

( ): Variation Coefficient

Rainfall simulation for determination of infiltration and sediment transport

Theoretical models: STM

– Green-Ampt concept

  - based on Darcy equation:

$$i = -K_s \frac{\Delta(\Psi_m + \Psi_g)}{x_{wf}(t)}$$

with: i = infiltration rate (kg.m.s^{-1})

K_s = sat. hydraulic conductivity (kg.m.s^{-1})

Ψ_m = matrix potential (J.kg^{-1})

Ψ_g = gravitational potential (J.kg^{-1})

x_{wf} (t) = depth of wetting front at time t (m)

Theoretical models: STM

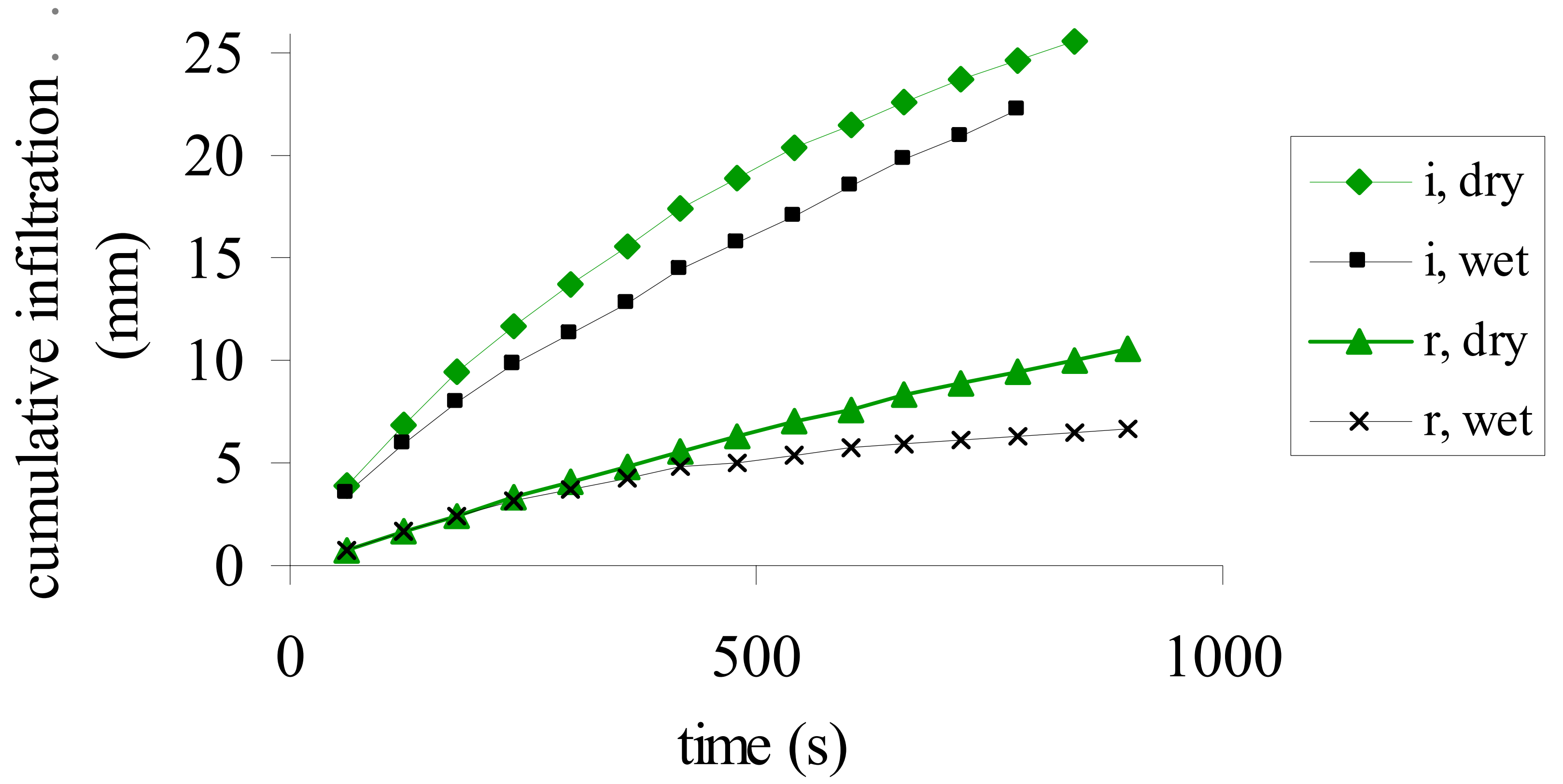
- Stationary component:

$$i_1 = -K_s \frac{\Delta\Psi_g}{x_{wf1}} = -K_s g = \rho_w \Delta\theta \frac{dx_{wf1}}{dt}$$

integrating results in:

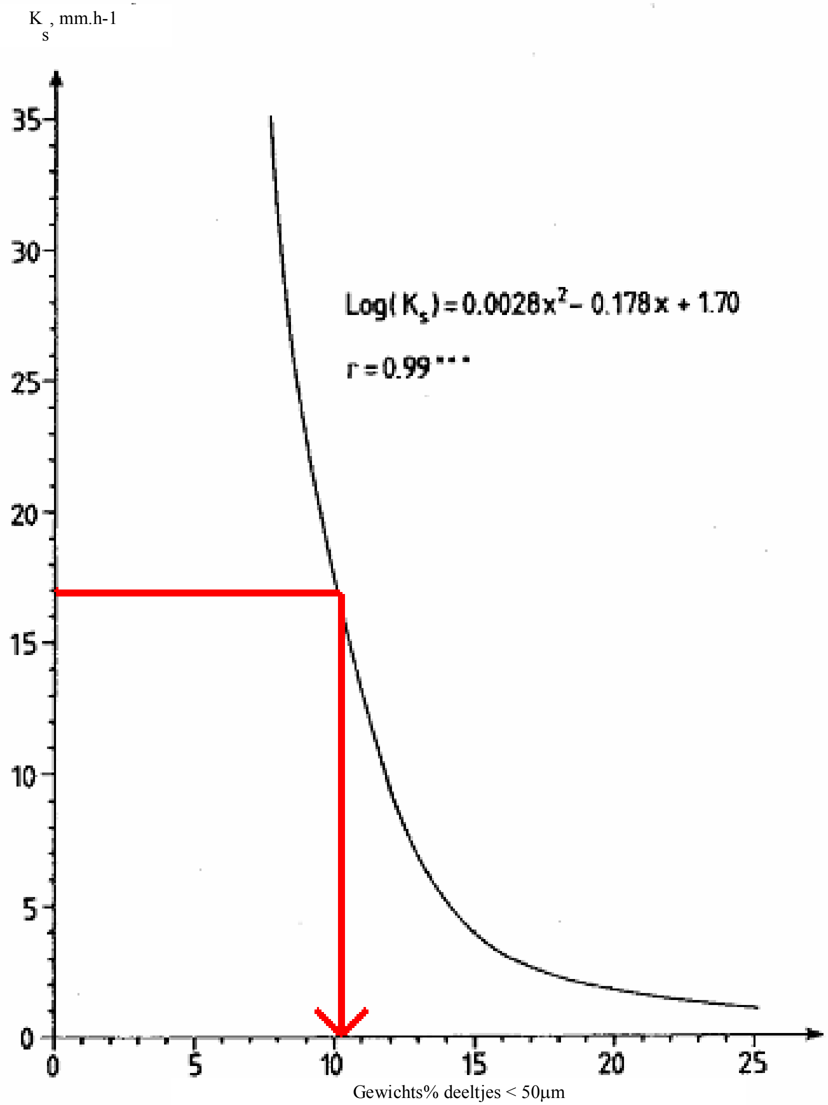
$$x_{wf1} = -\frac{K_s g t}{\rho_w \Delta\theta}$$

Soil infiltration characteristic for an initially dry and an initially wet soil, using the Kamphorst infiltrometer (i) and the rainfall simulator (r)



Ks for different textures

Texture	Ks (cm/hr)
sand	62.5
Loamy sand	56.3
Sandy loam	12.5
Silt	2.5
Sandy clay	0.8
Loamy clay	0.4
Clay	0.5



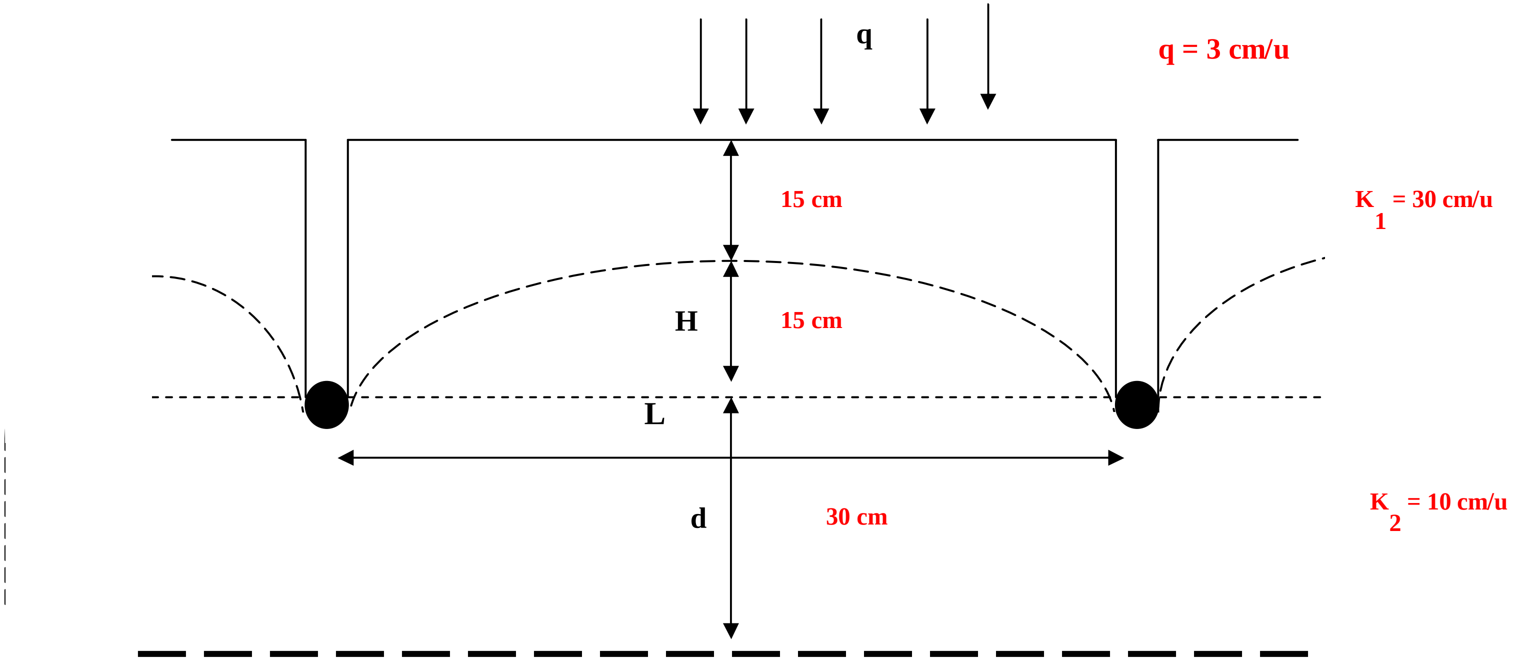
$\mathrm{Log}(K_s) = 0.0028x^2 - 0.178x + 1.70$

$r = 0.99^{***}$

Ks for different sandfractions

	Ks (cm/hr)
Very fine (50-100 µm)	**10**
Fine (100 – 250 µm)	**30**
Medium (250 – 500 µm)	**80**
Course (500 – 1000 µm)	**100**
Very course(1000 – 2000 µm)	**130**

Distance (L) between drains



$$L^2 = \frac{4K_1H^2}{q} + \frac{8K_2dH}{q}$$

L = 1,45 m

≅ 1,50 m