Methods for Measuring Hydraulic Conductivity
OUTLINE

- Hydraulic Conductivity
  - Definition
  - Importance
- Methods
  - Saturated Hydraulic Conductivity
  - Unsaturated Hydraulic Conductivity
- Applications
What is Hydraulic Conductivity:

- Ability of a porous medium to transmit water under saturated or nearly saturated conditions

Dependent on:

- Size distribution, roughness, tortuosity, shape and degree of interconnection of water-conducting pores
Hydraulic Conductivity Curve

- Well Structured Clayey Soil
- Structureless Sandy Soil
- Poorly Structured Clayey Soil

Unsaturated Flow $K(h)$

Field-Saturated Flow $K_{fs}$

$h_o$
Why do we care?

- Hydrology Modeling
- Agricultural decisions
- Landfill Cover efficacy
- Geotechnical design
METHODS
Methods – Saturated Hydraulic Conductivity ($K_s$ or $K_{fs}$)

- **Laboratory ($K_s$)**
  - Flow Cells
  - KSAT

- **Field ($K_{fs}$)**
  - Ring Infiltrometers
  - Borehole Permeameters
  - Pressure Infiltrometers
Flow Cells

- Constant & Falling head technique
- Measurement of Soil Cores in Lab
- Undisturbed or Disturbed samples
Flow Cells – How they work

- Water Passes through Saturated Soil Core
- Steady State flow rate is measured
- Calculations correct for pressure head
## Flow Cells – Pros & Cons

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>• Simple calculations</td>
<td>• Expansive soils are confined</td>
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<tr>
<td>• No corrections for 3-dimensional flow</td>
<td>• Values may differ from field methods</td>
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<tr>
<td>• Separate different horizons</td>
<td>• Requires additional equipment to automate</td>
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<tr>
<td>• Multiple samples can be stored</td>
<td>• Dedicated lab space</td>
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<tr>
<td>• Fairly easy setup</td>
<td>• Small surface area</td>
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UMS-KSat

- Same concept as flow cells
- Automation built into device
- Falling & Constant Head technique
KSat – How it works

Darcy equation

\[ K_s = \frac{(L \cdot V)}{(H \cdot A \cdot t)} \]

- \( L \): length of the sample
- \( V \): percolated volume of water
- \( H \): height of the water column
- \( A \): area of the probe
- \( t \): time

- water
- water column height
- soil sample
- water discharge
- pressure sensor
- USB connection to computer
Ring Infiltrometers

- Thin-walled open ended cylinders
- Various Cylinder Arrangements
- Constant- and falling-head techniques
Single-Ring Infiltrometer

- Single measuring cylinder
- Diameters range from 10 to 50 cm
- Corrections are made for 3-dimensional flow
Double-Ring Infiltrometer

- Single measuring cylinder placed inside larger buffer cylinder
- Intention of buffer cylinder is to prevent flow-divergence from measuring cylinder
Ring Infiltrometer – Pros & Cons

Advantages

- Larger rings encompass more spatial variability
- Results represent field conditions

Disadvantages

- Time consuming
- Requires estimation of soil properties ($\alpha$) to correct for 3-dimensional flow
- Buffer cylinder often is not effective
Pressure Infiltrometer

- Similar to single-ring infiltrometer
- Analysis on Single or multiple heads
- Can also determine macroscopic capillary length parameter ($\alpha$)
Pressure Infiltrometer – Pros & Cons

Advantages
- Measurement of ($\alpha$) improves analysis of $K_f$.
- Can also be used to determine sorptivity and matric flux potential.

Disadvantages
- More complex measurement apparatus.
- Multiple-head technique requires more time.
Borehole Permeameters

- Constant head method
- Several permeameter designs
- Single and Multiple Head analysis
- Can also determine $\alpha$
• Well is augured to desired depth
• Permeameter is mounted over the well
• Marriotte bubbler maintains constant head
Borehole – Pros & Cons

Advantages
- Measurement of $\alpha$ improves analysis of $K_f$s
- Analysis of different soil layers
- Can also be used to determine sorptivity and matric flux potential

Disadvantages
- Small surface area
- Long measurement times
- Potential smearing and siltation
- No visibility in measurement site
Methods – Unsaturated Hydraulic Conductivity ($K(y)$)

- **Laboratory**
  - Tempe Cells
  - Evaporation Method

- **Field**
  - Tension Infiltrometers
Flow Cells

- Can also be used for measuring $K(\psi)$
- Simultaneous water transmission & retention properties
- Requires tensiometers
Flow Cells – How they work

- Steady flow rate into column
- Flow rate maintained until both tensiometers read same suction
- Flow rate is then increased
Flow Cells – Pros & Cons

Advantages

• Simultaneous water transmission & retention properties

• Estimation of saturated and unsaturated flow parameters on same soil column

Disadvantages

• Requires a method of maintaining a constant flow

• Complex operation
Evaporation Method

- First Introduced by Wind (1968)
- Saturated Soil Core allowed to evaporate
- Constant evaporation rate
- Simultaneous measurements of matric head
HyProp

- Simplified Wind/Schindler Evaporation Method
- Two Tensiometers at different Heights
- Calculated Using Inversion of Darcy-Equation

\[ K^i(\bar{h}^i) = -\frac{q^i}{\Delta h^i / \Delta z + 1} \]
HyProp – Pros & Cons

Advantages
• Simultaneous water transmission & retention properties
• Automated measurement
• Good measurement resolution

Disadvantages
• Unreliable $K(\psi)$ data near saturation
• Learning curve
• Only Desorption Characteristics
Tension Infiltrometers

- Infiltration under imposed suctions
- Three dimensional infiltration analysis
- Also used for determining repellency
Porous plate is placed on the soil

Suction is controlled by bubble tower

Analysis using transient and steady-state methods
Advantages

• Controlled suction
• Larger disks account for more spatial variability
• Estimation of sorptivity and repellency

Disadvantages

• Steady-state methods are time consuming
• Requires estimation of soil properties to correct for 3-dimensional flow
DualHead Infiltrometer

- Automated Ring Infiltrometer
- Similar to Pressure Infiltrometer
- Multiple Ponded head analysis
How It Works

- Constant Water Level
- Different pressure heads controlled by air pressure
How It Works

- Constant Water Level
- Different pressure heads controlled by air pressure
How It Works

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How It Works

- Constant Water Level
- Different pressure heads controlled by air pressure
- Improved estimates of $K_f$s
- $\alpha$ directly measured
APPLICATIONS
Comparing the effects of Landscape & Land-use on hydraulic properties of the same soil type

- Tall grass native prairie
- Improved pasture—grazed
- Conventional tillage (corn/corn/wheat)
Where to measure?
Land-use effects

- Triplicate measurements made using Double-Ring Infiltrometers
• How do hydraulic properties of soil-less substrates effect plant available water

• Many soil-less substrates are gap-graded
• Can Hydraulic Conductivity affect plant available water?

Plant Available Water

![Graph showing the relationship between hydraulic conductivity and plant available water.](image)
QUESTIONS?