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USDA LTAR Common Experiment measurement: Saturated hydraulic conductivity

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Abstract

The saturated hydraulic conductivity (K_{sat}) represents the speed at which a fluid can move through a porous medium, and it is a fundamental parameter that governs water flow through soil or rock. Darcy's law governs one-dimensional flow through a porous medium:

$Q = K_{sat}\,(dh/dx)$ (Equation 1)

where Q is the flux of water [m/s], K_{sat} is the saturated hydraulic conductivity [m/s], and dh/dx is the gradient in the hydraulic head [m/m]. More complicated forms of Darcy's equation apply to representing three-dimensional flow in a saturated medium. Additionally, flow in an unsaturated medium, as is often the case in soil, is represented through equations such as Richards' equation, based on Darcy's law. Usually, the saturated hydraulic conductivity is the most important parameter governing water flow in the saturated zone.

The basic idea when measuring saturated hydraulic conductivity is to saturate the medium (i.e., the soil) and measure how quickly water moves through it. This procedure can be quite simple. For example, the lab setup that formed the basis of Darcy's experiments in the 1850s was homogenous sand placed in a tube with a known gradient in the hydraulic head so that K_{sat} could be calculated from Eqn. 1. The setup becomes more complicated in the field, where the soil is heterogeneous; we are typically interested in a bulk estimate of K_{sat} in a soil that is nonuniform and may contain soil cracks or holes from roots or worms. It is also difficult to completely saturate a soil column in the field and control the applied hydraulic gradient. The techniques presented here help account for these challenges.

Materials

Equipment

- Infiltrometer (can be as simple as a bucket with a hole cut in the bottom)
- Water
- Stopwatch
- Measuring tape

Data collection

2h

1 There is no standard approach to determining the saturated hydraulic conductivity, but the most common method is using single-ring or double-ring infiltrometers (Bouwer, 1986).

- Double-ring infiltrometers were developed with the idea that the outer ring would prevent water infiltrating from the inner ring from spreading radially. In practice, this idea does not work (Bouwer, 1986); therefore, single-ring infiltrometers are recommended.

Infiltrometers measure the K_{sat} at the soil surface.

1.1 Frequency of measurement

- Measurements are generally only required once per plot or treatment, although additional measurements after several years of treatments might have usefulness. Repeat measurements spatially to represent heterogeneity in the field.
- If the plot/experimental unit has disturbances such as tillage, wait for at least one large precipitation event after disturbance to perform the measurement.
- No standard number of measurements exists, but due to high soil heterogeneity, “as many measurements as possible” is a good rule of thumb. Mason et al. (1957) determined that making five measurements provides a 30% chance of successfully classifying a soil into an NRCS soil class. So, we want many more samples.
- Number of spatially distributed samples should vary based on size of plot/heterogeneity of soils. Minimum of 5 measurements/plot. Individual sample locations do not need to be geolocated, but record the measured values and the location of the plot.

1.2 There are several approaches to performing infiltrometer measurements, the simplest being a falling head technique:

1. Push the ring infiltrometer ~5 cm into the soil. Some soil disruption is inevitable, but try to minimize disruption. If the soil is hard, the ring may need driving into the soil. Place a metal plate above the ring and hit it with a sledgehammer to drive the infiltrometer into the soil.
2. Pour a predefined amount of water into the infiltrometer, minimizing disruption of the soil surface. The initial ponding depth should be 5 to 10 cm.
3. Time how long the water takes to infiltrate.
4. In post-processing, perform the mathematical corrections outlined in Nimmo et al. 2009 for radial spreading, sorption, and positive surface pressure.

1.3 A constant head infiltrometer also works well. Measurements take longer to perform, but less post-processing is required.

1. Push the infiltrometer ~5 cm into the soil, minimizing soil disruption.
2. Fill the infiltrometer with water to a predefined head level; 5 to 10 cm is appropriate.

3. Continue to supply water to the infiltrometer until the infiltration rate stabilizes. The initial infiltration rate will be higher than the saturated hydraulic conductivity as sorption pulls water into the soil.
4. Time how long a known volume of water takes to infiltrate, and calculate the infiltration rate.

1.4 Nimmo et al. (2009) present a simple approach to measuring K_{sat} with a falling head infiltrometer. Often, time is the primary constraint to making many K_{sat} measurements; it can take 1 to 2 hours to measure a single sample with a constant head ring infiltrometer because the infiltration rate slowly stabilizes. Their approach allows you to take measurements rapidly and mathematically correct them for errors.

Note

This is the recommended method at sites without previous experience measuring Ksat.

Quality assurance

2 Recommendations on quality assurance follow the general recommendations for water quantity variables. Please refer to the "Placement and site maintenance" section in the *USDA LTAR Common Experiment measurement: Best practices for collection, handling, and analyses of water quantity measurements* protocol (Baffaut et al., 2024). In addition, specific recommendations for measuring saturated hydraulic conductivity are as follows:

2.1 The primary quality assurance comes from careful measurement in the field. When using infiltrometers, three major sources of uncertainty need accounting for: (1) sorption acts to pull water into the soil, (2) water will spread radially beneath the infiltrometer, as well as vertically, and (3) ponding of water on the soil surface leads to water entering the soil at a positive pressure.

- The design of a double-ring infiltrometer addresses the effects of lateral spreading of infiltrated water, but the efficacy of this approach is doubted (Bouwer, 1986). Single-ring infiltrometers are simpler and thus recommended.
- To minimize errors from the lateral spreading of water, a large ring is recommended (1 m diameter or larger), which can be impractical to build. Place this ring on a flat surface. Avoid placing the infiltrometer on rows or furrows in a field.
- When inserting the infiltrometer into the soil, minimize soil disturbance. Use large infiltrometers with thin walls. Walls with a beveled edge are preferable.
- When adding water to the infiltrometer, avoid the direct impact of water on the soil surface, which can suspend clays and silts in the water column. Realize this avoidance by supplying water to the infiltrometer through a small, flexible tube placed on an inverted lid to break up the water flowing into the infiltrometer.

Quality control

3 Quality control recommendations follow the general recommendations for water quantity variables. Please refer to the "Quality control" section in the *USDA LTAR Common Experiment measurement: Best practices for collection, handling, and analyses of water quantity measurements* protocol (Baffaut et al., 2024).

3.1 We recommend several measurements in space, which allow comparing saturated hydraulic conductivity values with nearby values.

3.2 Care is required when making this comparison because saturated hydraulic conductivity can vary by several orders of magnitude in different soil types.

Data file formats and metadata

4 Keep data in a spreadsheet. Record the individual Ksat measurements as well as the plot/experimental unit mean value. The location of the plot/experimental unit, which treatment they represent, and the date when the samples were obtained is the required metadata.

Recommendations for data collection

5 Table 1. Summary of recommendations for measuring saturated hydraulic conductivity.

A	B	C	D
Attribute	**Preferred**	**Minimum**	**Comments**
Spatial scale	Plot and Field	Plot and Field	
Frequency	Once	Once	Soil Ksat should change slowly in response to treatments; resample every 5-10 years
Covariate metrics	None	None	

Protocol references

Baffaut, C., Schomberg, H., Cosh, M. H., O'Reilly, A. M., Saha, A., Saliendra, N. Z., Schreiner-McGraw, A., & Snyder, K. A. (2024). USDA LTAR Common Experiment measurement: Best practices for collection, handling, and analyses of water quantity measurements. protocols.io

Bouwer, H. (1986). Intake rate: Cylinder infiltrometer. p. 825–844. In A. Klute (ed.) Methods of soil analysis. Part 1. SSSA, Madison, WI.

Mason, D.D., J.F. Lutz, & R.G. Petersen. (1957). Hydraulic conductivity as related to certain soil properties in a number of great soil groups: Sampling errors involved. Soil Sci. Soc. Am. J. 21:554–560.

Mohanty, B.P., Kanwar, R.S., & Everts, C.J. (1994). Comparison of saturated hydraulic conductivity measurement methods for a glacial till soil. Soil Science Society of America Journal, Vol 58 (3).

Nimmo, J.R., Schimdt, K.M., Perkins, K.S., & Stock, J.D. (2009). Rapid measurement of field saturated hydraulic conductivity for aerial characterization. Vadose Zone Journal, 8, 142-149.