MANUAL

J. BLÖCHER AND M. KURÁŽ

MANUAL: RING INFILTRATION AND GUELPH PERMEAMETER

CONTENTS

LIST OF FIGURES

* *Department of Water Resources and Environmental Modeling, Faculty of Environmental Sciences, Czech University of Life Sciences*

INTRODUCTION

Infiltration can be used to determine the field saturated hydraulic conductivity K_{fs}. The difference to the saturated conductivity K_s measured in the laboratory is that the complete saturation of the pores space is above the groundwater table is close to never given. An important role for the value of the saturated hydraulic conductivity is the presence of secondary pores, e.g. fractures and cracks in soils with high clay content, weathered root channels, earth worm path.

Infiltration is the process of water entering the soil when water is added to the system. The infiltration behavior of a soil is influenced by the added water, the initial dryness of the soil and hydraulic conductivity of the soil. Additionally, the state of the soil as well as the presence of stagnation layers impact infiltration.

Infiltration capacity is the infiltration rate of the soil, which occurs when a bigger area of land is covered by water. This value of special interest as it allows determination of the corresponding value of surface runoff.

RING INFILTRATION

Ring infiltration is a well-established method to measure the maximal infiltration capacity of soil. The initial infiltration rate is high in a typical ring infiltration. The infiltration rate gradually drops to a constant rate given a homogeneous soil. The initial infiltration rate differs depending on soil and initial dryness and can be twice (sand) to a hundredfold (clay) of the final infiltration rate.

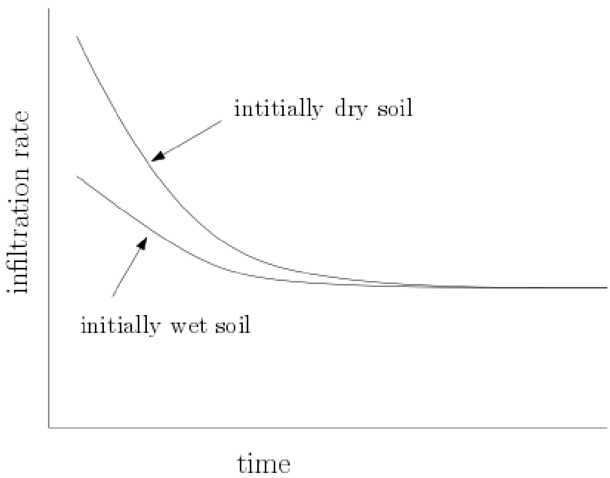

Figure 1: Schematic representation of infiltration in dry and in a wet soil.

The asymptotically established infiltration rate that is closely related to the hydraulic conductivity at field saturation. Infiltration experiments are therefore useful to estimate the saturated hydraulic conductivity K_s. For an idealized infiltrometer with an infinite radius (purely 1D vertical water movement) and negligible water well head, we can assume that at full saturation in the wet soil the gradient of the hydraulic (or matrix) head can be assumed to be:

$$\frac{dh}{dz} = 0 \tag{1}$$

Replacing this in the Darcy-Buckingham law, we obtain:

$$q = -K(\frac{dh}{dz} - 1) = -K(0 - 1) = K \tag{2}$$

The main issue with the interpretation of the results of the ring infiltration measurements is the lateral flow component of the water flow, which makes the analysis of the flow problem complicated. The lateral flow causes the stationary infiltration flow to always be higher than the infiltration capacity and the hydraulic conductivity of a soil. Stagnating layers throughout the soil affected by the infiltration also cause an overestimation of the infiltration capacity.

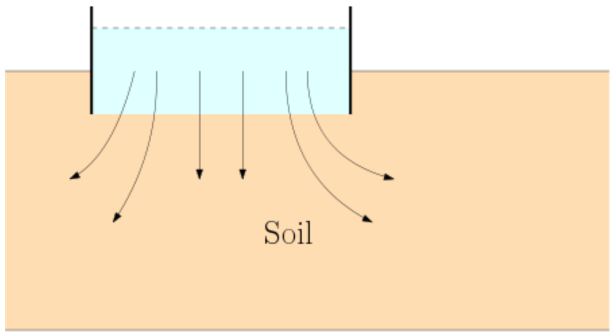

Figure 2: Schematic of ring infiltration with lateral flow.

To avoid lateral flow double ring infiltrometer can be used. However, especially in organic soils or forest soils, they can cause unnecessary preferential flow paths. Generally, it is preferable to use rings with a large radius to have a better ratio between ring and experimental area. Using a large enough ring leads to improvement in the representativeness and can compensate for small heterogeneities.

The infiltration curve against time can be described with the 2-parametric equation according to Phillips [2]:

$$\begin{aligned} I(t) &= S \cdot t^{1/2} + A \cdot t + C \\ i(t) &= 0.5 \cdot S \cdot t^{-1/2} + A. \end{aligned} \tag{3}$$

The constant C describes the initial state of $C = 0$. S is the sorptivity [cm d$^{-\frac{1}{2}}$]. The infiltration rate i for t $\rightarrow \infty$ is A. The constant A [cm d^{-1}] is therefore with a small overhead $A = K_s$. Both Parameters A and S can be determined by fitting the infiltration data to Eq. 3.

To compensate for lateral flow and the overcompensation [3] identified scaling factors, so that:

$$i(t) = fK_s \tag{4}$$

where f is the appropriate scaling factor. f can be computed using

$$f = \frac{H + \phi_m / K_s}{z + r/2} + 1 \tag{5}$$

where H is the height of the water column above the soil, ϕ_m is the matric flux potential defining the influence of the water absorption through the unsaturated soil, z is the installation depth and r is the radius of the infiltration ring. Some values of f can be found in Tab.

Table 1: Values for the scaling factor f Eq. 5 [3]. The values are for z=5cm,H=5cm and an initial pressure head of pF= 3.

Soil	r=10cm
Fine sand	2.6
Loam	1.9-2.1
Clay	3.2

Experiment procedure

1. Install the ring with the sharp side downward. For this, use the provided metal cross and hammer. Make sure that the ring enters the ground evenly.
2. Set-up the wooden holder on top of the ring and install the spike-meter. Make sure the wooden holder is level using a water level ruler.
3. Measure the diameter of the ring. Take two or more measurements if the ring is very elliptical.
4. Set-up your water supply
5. Get your stop-watch ready
6. Make sure you are familiar with the spike-meter as in Fig. 3
7. Fill the ring with water above the spike-meter
8. Taking measurements:
   a) Pick one of the spikes as your reference and get a water-filled cup of known volume ready.
   b) When the water reaches the tip of your reference spike, the measurement starts. This is time 0.
   c) As soon as the water reaches the tip of your reference spike, add the volume of water and and start the time.
   d) Note down the time it takes to reach the reference spike again and add water again. Repeat this until the end of the experiment. If the volume is too large or too small, change it and make sure you know how much water was ended between time intervals.
   e) Use normed containers of known volume to refill water to upper reference spikes.
   f) The experiment ends when the infiltration is stationary.
9. Take out the ring from the soil using provided tools.

Figure 3: Reference spike meter used to read water levels during ring infiltration.

Evaluation

We measure cumulative infiltration I [cm] as the Volume entering the specific area as a function of time.

$$\Delta V = \pi r^2 \delta h \tag{6}$$

where r is the radius of the Mariotte's bottle and δh is the water height difference in regard to the initial value.

$$I(t) = \frac{\Delta V}{A} \tag{7}$$

The infiltration rate can be calculated as:

$$i = \frac{dI}{dt} \approx \frac{\Delta I}{\Delta t} \tag{8}$$

To evaluate we can plot the infiltration rate against time and fit the Phillip's equation to estimate Sorptivity S and the final infiltration rate i_f. The saturated conductivity can be estimated using the correction factor f.

GUELPH PERMEAMETER

The Guelph Permeameter (Fig. 4 and 5) can be used to estimate the near-surface hydraulic conductivity. The Guelph Permeameter creates a constant head and requires only approx. 2 Liter per experiment. It's working principle is based on the Mariotte's bottle. Known problems occur with soils that show silting, where the K_s will be underestimated, whereas with layered soils K_s will be overestimated.

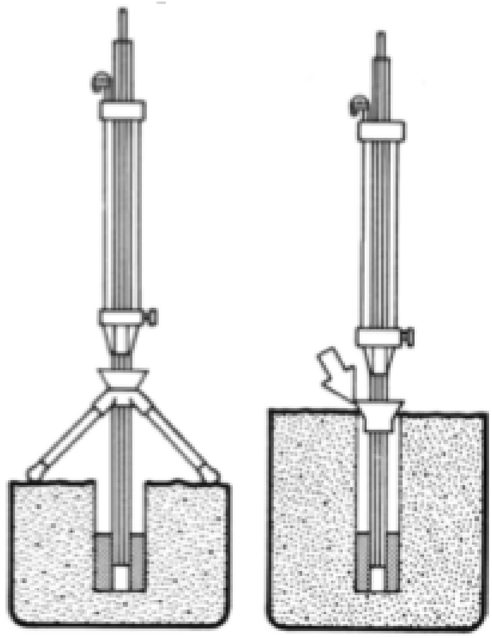

Figure 4: Set-up of in-hole Guelph permeameter [1].

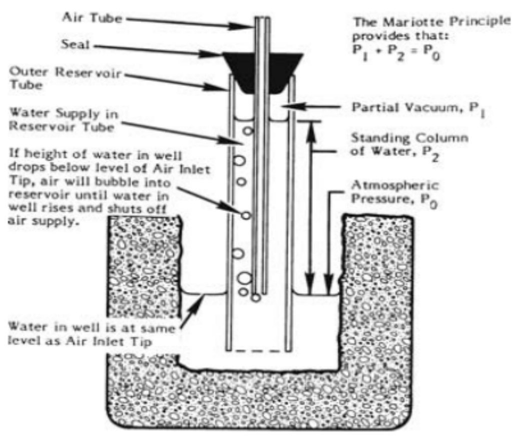

Figure 15. In-hole constant-head permeameter setup

Figure 5: Working principle of in-hole Guelph permeameter [1].

Experiment procedure

1. Make a bore hole using an auger drill. Note down diameter of the hole.
2. Install of the Guelph permeameter. Note down the installation depth.
3. Fill the Guelph permeameter with water using a siphoning technique.
4. Set the constant head with the air entry valve.
5. Write down reference water levels at which time will be measured.
6. Use a stop watch to measure the time at which the reference water levels are reached.

Evaluation

We can use the procedure by [4] stating

$$Q = [\frac{2\pi H^2}{C} + \pi r^2]K_s + \frac{2\pi H}{C}\phi_m = A \cdot K_s + B \cdot \phi_m \tag{9}$$

If we neglect the matrix-flux potential, the relationship becomes linear. Considering correcting factors we can assume that the velocity v of the water drop can be linearly related to K_s, so that

$$v = f_{cor} K_s \tag{10}$$

where f_{cor} is a correction factor that we assume to be 10 for our set-up. This factor already contains all of the volume information. v is therefore equal to Δh.

ERROR PROPAGATION

When doing an experiment, it is of vital importance to understand the effect of measurement errors and how they impact the uncertainty of our calculated or estimated property.

Multiplication and Division

Our final calculations only contain multiplications and divisions. Using Taylor's expansion a simple way to determine errors can be established.

We assume that the experiments requires knowledge of 3 parameters a,b and c to calculate x, e.g.

$$x = a \cdot \frac{b}{c} \tag{11}$$

We know that the absolute error to be representable by the standard deviation. The error is ϵ_a for a, ϵ_b for b and ϵ_c for c. We assume that a,b and c are independent and do not correlate. The relative error can then be calculated as:

$$\delta_x = \frac{\epsilon_x}{x} = \sqrt{(\frac{\epsilon_a}{a})^2 + (\frac{\epsilon_b}{b})^2 + (\frac{\epsilon_c}{c})^2} \tag{12}$$

This equation gives us the relative error $\delta_x = \frac{\epsilon_x}{x}$. The absolute error is $\epsilon_x = \delta_x \cdot x$.

Addition and Subtraction

We assume that the experiments requires knowledge of 3 parameters a,b and c to calculate x, e.g.

$$x = a + b - c \tag{13}$$

Again, the error is ϵ_a for a, ϵ_b for b and ϵ_c for c. We assume that a,b and c are independent and do not correlate. The absolute error can then be calculated as:

$$\epsilon_x = \sqrt{\epsilon_a^2 + \epsilon_b^2 + \epsilon_c^2} \tag{14}$$

The relative error is $\delta_x = \frac{\epsilon_x}{x}$.

Expressing Results

Let's assume we calculated $x = 1.2683783$ and ϵ_x 0.1. This reduces our significant figures to 2. Therefore, x should not be given in more detail, but also the error value should be expressed $x = 1.3 \pm 0.1$.

Warnings

We assumed our parameters to be uncorrelated and independent. Error propagation should not be used when we measure uncertainty directly, e.g. through repetition of the same experiment.

REFERENCES

[1] Eijelkamp. Operating instructions. 09.07 guelph permeameter. http://pkd.eijkelkamp.com/portals/2/eijkelkamp/files/manuals/m1-0907e%20guelph%20permea.pdf. 2011.

[2] JR Philip. The theory of infiltration: 1. the infiltration equation and its solution. *Soil science*, 83(5):345–358, 1957.

[3] L Wu and L Pan. A generalized solution to infiltration from single-ring infiltrometers by scaling. *Soil Science Society of America Journal*, 61(5):1318–1322, 1997.

[4] DE Elrick and WD Reynolds. Methods for analyzing constant-head well permeameter data. *Soil Science Society of America Journal*, 56(1):320–323, 1992.