



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F403

Soil Infiltration Rate – Ring Infiltrometer Method

Standard Operating Procedure

SOP Number	SOP-F403
Revision	0.2
Author(s)	Marc Los Huertos
Date	2026-06-26
Organization	EA Program, Pomona College

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1. Purpose

This procedure describes the field measurement of soil infiltration rate using single-ring and double-ring infiltrimeters. Infiltration rate is the velocity at which water enters the soil surface, typically expressed in cm/h or mm/h. It is a key parameter for evaluating stormwater management, irrigation efficiency, soil compaction, hydrologic modeling, and land use impacts on soil physical properties. The double-ring method follows ASTM D3385 (ASTM International, 2018); the single-ring method follows Bouwer (1986). Infiltration measurements are also essential for calibrating hydrologic models and for evaluating the effects of soil sealing in urban environments (Hillel, 1998; Reynolds et al., 2002).

2. Scope

- **Applies to:** Field measurement of infiltration rate on mineral soils at all EA Program sites, including agricultural plots, photovoltaic panel study sites, restoration areas, and urban soils
- **Does not apply to:** Soils with very low hydraulic conductivity (less than 1×10^{-5} cm/s; see ASTM D5093 for sealed-inner-ring method); rocky or gravelly soils that prevent ring insertion; laboratory column permeability tests
- **Location:** All EA Program field sites

3. Responsibilities

Role	Responsibility
Lab PI	Approve sampling plan, ensure training compliance
Field Lead	Coordinate logistics, select test locations
Trained Personnel	Conduct infiltration tests per this SOP
New Students	Complete training before independent testing

4. Definitions

- **Double-ring infiltrimeter:** A measurement apparatus consisting of two concentric steel rings driven into the soil surface; the inner ring provides the measurement zone; the outer ring creates a buffer that minimizes lateral flow from the inner ring, enforcing predominantly vertical infiltration.
- **Final infiltration rate (steady-state rate):** The constant rate at which water enters the soil after the soil profile is saturated and the infiltration rate has stabilized; approximates the saturated hydraulic conductivity (K_{sat}) of the surface soil.

- **Green-Ampt model:** A physically based infiltration model that describes the rate of water entry into soil as a function of saturated hydraulic conductivity, matric suction at the wetting front, and soil moisture deficit; used to interpret falling-head infiltration data.
- **Infiltration rate:** The volumetric flux of water entering the soil surface per unit area per unit time, expressed in mm h^{-1} or cm h^{-1} ; decreases from an initially high rate in dry soil to a lower, stable final rate as the soil wets.
- **Macropore flow:** Preferential movement of water through large continuous pores (earthworm burrows, root channels, structural cracks); produces non-uniform wetting and anomalously high initial infiltration rates that do not reflect bulk soil hydraulic conductivity.
- **Matric potential:** The energy status of soil water due to capillary and adsorptive forces; expressed in kPa or $\text{cm H}_2\text{O}$; drives water movement from wet to dry zones during infiltration.
- **Saturated hydraulic conductivity (K_{sat}):** The proportionality constant in Darcy's law relating water flux to hydraulic gradient under saturated conditions; the primary soil hydraulic property controlling drainage, runoff, and deep percolation; approximated by the steady-state infiltration rate.
- **Single-ring infiltrrometer:** A simplified apparatus using one ring driven into the soil; easier to deploy than double-ring but subject to lateral flow error; appropriate for screening or comparative measurements when absolute K_{sat} is not required.

5. Safety and Hazards



Hazards

- **Physical:** Driving metal rings into the soil with a sledge or mallet poses a risk of hand, finger, and foot injury. The rings have sharp edges.
- **Ergonomic:** Carrying water containers (20 L jugs) and rings to remote field sites can cause strain.
- **Environmental:** Standard field hazards (heat exposure, uneven terrain, insects).

5.1. Required PPE

- ☐ Closed-toed shoes or field boots (steel-toed preferred when driving rings)
- ☐ Leather work gloves (when handling rings and sledge)
- ☐ Safety glasses (when driving rings)
- ☐ Sun protection (hat, sunscreen)

5.2. Related SOPs

Refer to [SOP-F001 Field Safety](#) for general field safety procedures.

6. Equipment and Materials

6.1. Method A: Double-Ring Infiltrometer (ASTM D3385)

Item	Notes
Inner ring	Minimum 30 cm (12 in) diameter, 20 cm tall; 14-gauge or heavier steel
Outer ring	Minimum 60 cm (24 in) diameter, 20 cm tall; same gauge as inner ring
Sledge hammer (3–5 kg)	For driving rings
Driving cap or wooden plank	Placed on top of the ring to distribute hammer blows evenly and prevent ring deformation
Carpenter's level	For checking ring verticality
Ruler or graduated staff (mm)	For measuring water level in the inner ring
Stopwatch or timer	For recording time intervals
Water supply	40–80 L per test; carry in jerrycans or connect to a portable tank
Bucket or pitcher	For filling rings without disturbing the soil surface
Plastic sheeting or burlap	Placed inside the ring during initial filling to prevent soil disturbance
Mariotte bottle (optional)	For maintaining constant head automatically
Field data sheet	Printed from Appendix A
Clipboard and pencil	Mechanical pencil preferred
GPS unit or smartphone	For recording test locations
Tape measure	For measuring ring insertion depth

6.2. Method B: Single-Ring Infiltrometer

Item	Notes
Single ring	30 cm diameter minimum (larger is better; 90 cm preferred for accuracy); 20 cm tall
All other equipment	Same as Method A, minus the outer ring

7. Procedure

7.1. Site Selection and Preparation

1. Select test locations based on the project sampling plan. Avoid locations with visible animal burrows, large root channels, cracks, or other macropore features unless the objective is specifically to characterize preferential flow.
2. Record GPS coordinates and site description
3. Clear surface litter and loose organic debris from a 1 x 1 m area without disturbing the mineral soil surface
4. Note antecedent conditions in the field notebook: recent rainfall, soil moisture (qualitative: dry, moist, wet), and surface condition (bare, vegetated, crusted)

 Tip

Collect a companion bulk density core ([SOP-F402](#)) and a texture-by-feel assessment ([SOP-F401](#)) at each infiltration test location. These measurements help interpret the infiltration results.

7.2. Ring Installation – Double-Ring Method

1. Center the inner ring at the test location
2. Place the driving cap or wooden plank on top of the ring
3. Drive the inner ring vertically into the soil to a depth of approximately 5–10 cm (2–4 in) using even blows from the sledge. Avoid tilting the ring; check periodically with the level.
4. Measure and record the insertion depth on at least two sides
5. Center the outer ring around the inner ring. Drive it to approximately 10–15 cm (4–6 in), deeper than the inner ring, to prevent test water from escaping beneath the outer ring.
6. Check that the inner ring is still centered and level

 Important

Do not drive the rings deeper than necessary. Over-driving compresses the soil along the ring walls and creates an artificial seal that reduces measured infiltration rates. If the soil cracks or separates from the ring wall, abandon the test location and start at a new spot.

7.3. Ring Installation – Single-Ring Method

1. Place the single ring at the test location
2. Drive to approximately 5 cm depth using the same technique as above
3. For best accuracy, use the largest diameter ring available (90 cm or larger reduces lateral flow error) (Bouwer, 1986). Single-ring measurements tend to overestimate true vertical infiltration because lateral divergence below the ring cannot be eliminated; the magnitude of overestimation decreases as ring diameter increases (Gregory et al., 2006).

7.4. Initial Filling

1. Place a sheet of plastic or burlap on the soil surface inside the inner ring (and inside the annular space for the double-ring method) to cushion the water and prevent soil disturbance during filling
2. Gently pour water into the outer ring (annular space) first, then into the inner ring, to approximately 10–15 cm depth
3. Carefully remove the plastic or burlap
4. For the double-ring method, maintain the water level in the outer ring at approximately the same height as the inner ring throughout the test. This eliminates the lateral pressure gradient and forces flow beneath the inner ring to be vertical.

7.5. Measuring Infiltration Rate

Falling-head method (most common for EA Program):

1. Record the initial water level in the inner ring and the start time
2. Allow the water to infiltrate. Record the water level at regular time intervals. Suggested intervals:

Elapsed Time	Recording Interval
0–30 minutes	Every 5 minutes
30–60 minutes	Every 10 minutes
60–120 minutes	Every 15 minutes
120+ minutes	Every 30 minutes

3. When the water level drops to approximately 3 cm above the soil surface, refill to the original level and record the new starting level and time. Record each refill event.
4. Maintain the water level in the outer ring by refilling as needed.
5. Continue the test until the infiltration rate reaches a steady state (three or more consecutive readings with less than 10% change). This is the steady-state or “final” infiltration rate.
6. For most soils, steady state is reached within 1–3 hours. Clayey soils may require 4–6 hours or longer.

Constant-head method (Mariotte bottle):

1. Set up the Mariotte bottle to maintain a constant water depth (typically 5–10 cm) in the inner ring
2. Record the volume of water consumed from the bottle at regular time intervals
3. Calculate the infiltration rate from the volume consumed, the ring area, and the time interval
4. Continue until steady state is reached

7.6. Ending the Test

1. Record the final water level, time, and cumulative number of refills
2. Remove the rings by rocking gently and pulling upward
3. Backfill the holes and restore the site
4. Record any observations about the wetting front depth, root channels, or other features visible after ring removal

8. Quality Control and Acceptance Criteria

8.1. Calculations

Infiltration rate for each time interval (falling-head method):

$$f = \frac{\Delta h}{\Delta t}$$

where f = infiltration rate (cm/h), Δh = drop in water level (cm) during the interval, and Δt = duration of the interval (h). If the ring was refilled during the interval, add the refill depth to Δh .

Cumulative infiltration:

$$F = \sum_{i=1}^n f_i \times \Delta t_i$$

where F = cumulative infiltration (cm) and n = number of intervals.

Steady-state infiltration rate (f_c) is the final, approximately constant rate, typically reported as the mean of the last three or more consistent readings.

8.2. Expected Ranges

Steady-state infiltration rates vary widely with soil texture and structure:

Soil Type / Condition	Expected f_c (cm/h)
Coarse sand, well-structured	5 – 25+
Sandy loam	2.5 – 7.5
Loam, well-structured	1.0 – 5.0
Silt loam	0.5 – 2.5
Clay loam	0.1 – 1.0
Compacted or crusted soil	less than 0.5

Values outside the range of 0.01–50 cm/h should be investigated for measurement error or unusual soil conditions.

Rates measured at EA Program sites in the Pomona/Claremont area should be interpreted in the context of the local aridic moisture regime, where antecedent moisture is often very low and hydrophobicity may develop under prolonged dry conditions (Hillel, 1998). Urban and peri-urban soils may show infiltration rates well below their textural expectation due to compaction from foot traffic and construction (lai2010?).

8.3. QC Requirements

- Conduct a minimum of three replicate tests per plot or treatment to capture spatial variability
- Record antecedent soil moisture and recent precipitation for each test; these strongly affect initial rates
- Verify that the outer ring water level is maintained throughout the test (double-ring method)
- Inspect ring installation for gaps between the ring wall and the soil; if gaps are visible, the test is invalid

- Ring insertion depth and ponded water depth both influence measured infiltration rate; standardize these dimensions across replicates and sites to ensure comparability (Gregory et al., 2006).
- Plot the infiltration rate versus time curve for each test. A monotonically decreasing curve approaching a constant value is expected. Erratic increases may indicate macropore activation or ring leakage.

9. Waste Disposal

Waste Type	Disposal Method
Test water	Allowed to infiltrate on site; no disposal needed
Used plastic sheeting	Standard trash
Used gloves	Standard trash

10. References

- ASTM International. (2018). *Standard test method for infiltration rate of soils in field using double-ring infiltrometer* (Nos. D3385-18). ASTM International. <https://doi.org/10.1520/D3385-18>
- Bouwer, H. (1986). Intake rate: Cylinder infiltrometer. In A. Klute (Ed.), *Methods of soil analysis, part 1: Physical and mineralogical methods* (2nd ed., pp. 825–844). American Society of Agronomy; Soil Science Society of America. <https://doi.org/10.2136/sssabookser5.1.2ed.c32>
- Gregory, J. H., Dukes, M. D., Jones, P. H., & Miller, G. L. (2006). Effect of ring diameter, insertion depth, and ponded-water depth on soil infiltration measurements using ring infiltrometers. *Soil Science*, 171(6), 487–499. <https://doi.org/10.1097/01.ss.0000228040.96182.84>
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- Reynolds, W. D., Elrick, D. E., Youngs, E. G., Amoozegar, A., Booltink, H. W. G., & Bouma, J. (2002). Saturated and field-saturated water flow parameters. In J. H. Dane & G. C. Topp (Eds.), *Methods of soil analysis, part 4: Physical methods* (pp. 797–878). Soil Science Society of America. <https://doi.org/10.2136/sssabookser5.4.c30>

11. Training Record

Before conducting infiltration tests independently, personnel must:

1. Read this SOP in full
2. Complete [SOP-F001 Field Safety](#) training
3. Observe a trained operator perform a complete double-ring infiltration test from ring installation through steady state
4. Demonstrate proper ring driving technique without ring deformation or soil cracking
5. Conduct at least one complete test under supervision and produce an infiltration curve that reaches steady state
6. Be signed off by the field lead or PI

12. Appendix A: Infiltration Test Field Data Sheet

Print this sheet and use it in the field.

Site: _____ **Plot ID:** _____ **Date:** _____

Observer: _____ **GPS:** _____

Method: Double-ring / Single-ring (circle one)

Inner ring diameter: _____ cm **Outer ring diameter:** _____ cm (if double-ring)

Ring insertion depth: Inner _____ cm, Outer _____ cm

Antecedent conditions: Last rain _____ days ago, _____ mm; Soil moisture: dry / moist / wet

Surface condition: bare / vegetated / crusted / mulched

Initial water depth in inner ring: _____ cm

Read- ing #	Clock Time	Elapsed (min)	Water Level (cm)	Refill? (Y/N)	Level After Refill (cm)	Interval Δh (cm)	Interval Rate (cm/h)	Notes
0		0		–	–	–	–	Start
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Steady-state rate (f_c): _____ cm/h (mean of last _____ readings)

Total test duration: _____ minutes

Additional notes: _____

13. Appendix B: Example Calculation and Plotting

```

library(tidyverse)

# Example data from a falling-head double-ring test
# Ring inner diameter = 30 cm
ring_diam_cm <- 30
ring_area_cm2 <- pi * (ring_diam_cm / 2)^2

infiltration <- tibble(
  elapsed_min = c(0, 5, 10, 15, 20, 30, 45, 60, 90, 120, 150, 180),
  water_level_cm = c(15.0, 13.8, 12.9, 12.1, 11.4, 10.2, 8.8, 7.6,
                     5.8, 4.2, 2.8, 1.5)
)

# Calculate interval infiltration rates
infiltration <- infiltration %>%
  mutate(
    delta_h_cm = -diff(c(NA, water_level_cm)),
    delta_t_h = c(NA, diff(elapsed_min)) / 60,
    rate_cm_h = delta_h_cm / delta_t_h,
    cumulative_cm = cumsum(replace_na(delta_h_cm, 0))
  )

# Steady-state rate (last 3 intervals)
f_c <- mean(tail(infiltration$rate_cm_h[!is.na(infiltration$rate_cm_h)], 3))
cat(sprintf("Steady-state infiltration rate: %.2f cm/h\n", f_c))

# Plot infiltration rate vs time
ggplot(infiltration %>% filter(!is.na(rate_cm_h)),
  aes(x = elapsed_min, y = rate_cm_h)) +
  geom_point(size = 3) +
  geom_line() +
  geom_hline(yintercept = f_c, linetype = "dashed", color = "blue") +
  annotate("text", x = max(infiltration$elapsed_min) * 0.7,
    y = f_c + 0.3,
    label = sprintf("f[c] == %.2f~cm/h", f_c),
    parse = TRUE, color = "blue") +
  labs(
    x = "Elapsed time (min)",
    y = "Infiltration rate (cm/h)",
    title = "Double-Ring Infiltration Test"
  ) +
  theme_minimal()

```

14. Appendix C: Troubleshooting

Symptom	Probable Cause	Corrective Action
Water leaks around the outside of the ring	Insufficient insertion depth; gap between ring wall and soil	Drive ring deeper; pack bentonite or moist soil around the outside base
Infiltration rate increases mid-test	Macropore activation; preferential flow path opened	Note in field notebook; this may be a real feature of the soil. If clearly an artifact (ring shifted), restart.
Very slow infiltration (less than 0.1 cm/h)	Dense clay; surface crust; compacted layer	Continue test for at least 4–6 hours to confirm steady state; consider ASTM D5093 sealed-ring method
Rate never stabilizes	Heterogeneous soil; macropores draining and refilling	Extend test duration; collect additional replicates; report the range rather than a single value
Ring deformed during installation	Rocks or roots; excessive force	Replace with a new ring at a nearby location
Soil disturbed inside the ring	Overly aggressive filling; ring bounced during driving	Restart at a new location; always use plastic sheeting during initial fill
Single-ring rate much higher than expected	Lateral flow beneath the ring	Use a larger-diameter ring (90 cm+) or switch to the double-ring method