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Operating instructions

09.09 Tension Infiltrometer

Quick start instructions for the use of the 20 cm Tension Infiltrometer

Note:

1) The nylon membrane on the disc is easily damaged. Always place the disc with membrane on a soft and clean surface such as a wetted bath towel. Never place the disc with membrane on a rocky, hard surface.

2) It is best to delay calibration un-till one is fully familiar with the instrument. Calibration can be done at a later time, if deemed necessary.

3) Before making actual field measurements, try to make measurements on a site close to work or home.

4) It takes some practice to make good infiltration measurements.

Soil preparation:

Push the blue soil ring that came with the instrument, into the soil to establish a round circle. Place fine sand inside the circle and flatten it into a 2 to 3 mm thick layer.
Make sure there is no, or minimal sand outside the blue ring. When done, carefully remove the ring.

Use of the Infiltrometer:

1. Fill a dishpan or oil pan with tap water.

2. Place the disc with membrane and attached tube and valve in the dishpan and let it soak. Open the valve and try to get all air out of the disc above the membrane, and out of the tube. Then close the valve again.

3. Place a small stopper in the lower outlet of the water tower.

4. Fill the water tower with water, and carefully replace its top.

5. Fill the bubble tower with water till about 7 cm from the top.

6. Slide the bubble tower tube down, so its lower end is at 9 cm (4 + 5) below the water level in the bubble tower. That means the first infiltrometer experiment is done with a -5 cm pressure at the soil surface. The calibration factor is assumed to be 4.0 cm.

7. Close the tubing clamp on the tube between the water tower and the bubble tower.

8. It is convenient to now place the infiltrometer on a 10 cm high support.

9. Remove the stopper from the water tower outlet near the bottom, and then connect the large tube from the disc to this out-let, while keeping the disc submerged.

10. Open the valve in the large tube, and move the infiltrometer such that all air in the tube (and in the top of the disc) bubbles to the top of the water reservoir.

11. Carefully lift the disc out of the dishpan and place it on the circle of sand. Simultaneously move the water tower next to the disc.

12. Open the clamp on the tube between the water reservoir and the bubble tower.

13. Open the tubing clamp on the top of the bubble tower.

14. If all works well, water should infiltrate into the soil, and one should see air bubbles rising in the water tower, and in the bubble tower.

15. In most soils it should take less than 30 or 40 minutes before the infiltration rate reaches steady state.

16. Measure and record the water level in the water tower with time, at 30 seconds to 1 minute time intervals. When a data logger is used to record the water level, an initial time interval of 10 seconds may be preferable.

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I. Introduction

The SMS tension infiltrometer is designed to measure the unsaturated flow of water into soil rapidly, accurately, and easily.

Applications of the infiltrometer include measurement of macropore and preferential flow, estimation of soil structure, and characterization of the soil hydraulic conductivity/water potential relationship.

II. Design features

The 20 cm diameter infiltrometer has been designed to operate in two modes. In mode one the infiltration disc is separated from the water tower. In mode two the infiltration disc is attached to the bottom of the water tower, using the supplied connector. Operating the infiltrometer in mode one is especially advantageous when taking measurements under windy conditions. If the infiltration disc is attached to the water tower, even a small movement of the water tower by wind, or by accidentally touching it, will affect the contact between the disc and the soil surface and thereby the rate of infiltration of water into the soil. By separating the control tower from the disc, chances of affecting the contact between the disc and the underlying soil are greatly reduced. A second advantage of operating the infiltrometer in this mode is that the weight of the infiltrometer disc is constant during the measurements. In mode two the weight of the infiltrometer, and thus the pressure on the soil surface, changes during measurements as the water tower empties.
Operating the infiltrometer in mode two is advantageous where space is limited, such as in a soil pit or in a small excavation.

In both modes 1 and 2 the water level in the water reservoir can be determined by reading the level on the attached centimeter scale, or by measuring the pressure in the upper end of the water reservoir. The pressure in the air pocket at the top of the water reservoir (always negative) is linearly related to the height of water in the reservoir. A centimeter change in water height means a centimeter change in pressure in the air pocket. Thus, infiltration rates can be monitored by recording pressure changes measured with a pressure transducer with digital read-out (Tensimeter), or with pressure transducers and a datalogger over time.

Using two pressure transducers, one on top of the water reservoir, and a second one mounted on the infiltrometer disc, gives the most complete information. Using two pressure transducers virtually eliminates bubbling 'noise' which increases measurement precision (Ankeny, et.al. 1988).

Figure 1 shows the SMS infiltrometer. The major components are 1) the bubble tower (the shorter 1" ID tube) which controls tension at the soil surface, 2) the water reservoir (the longer 2" OD tube) which empties as water flows into the soil, 3) the disc to establish hydraulic continuity with the soil, and 4) the 1/2" ID tube between the disc and the water tower. Note the one way valve, in the middle of the 1/2" ID tube.

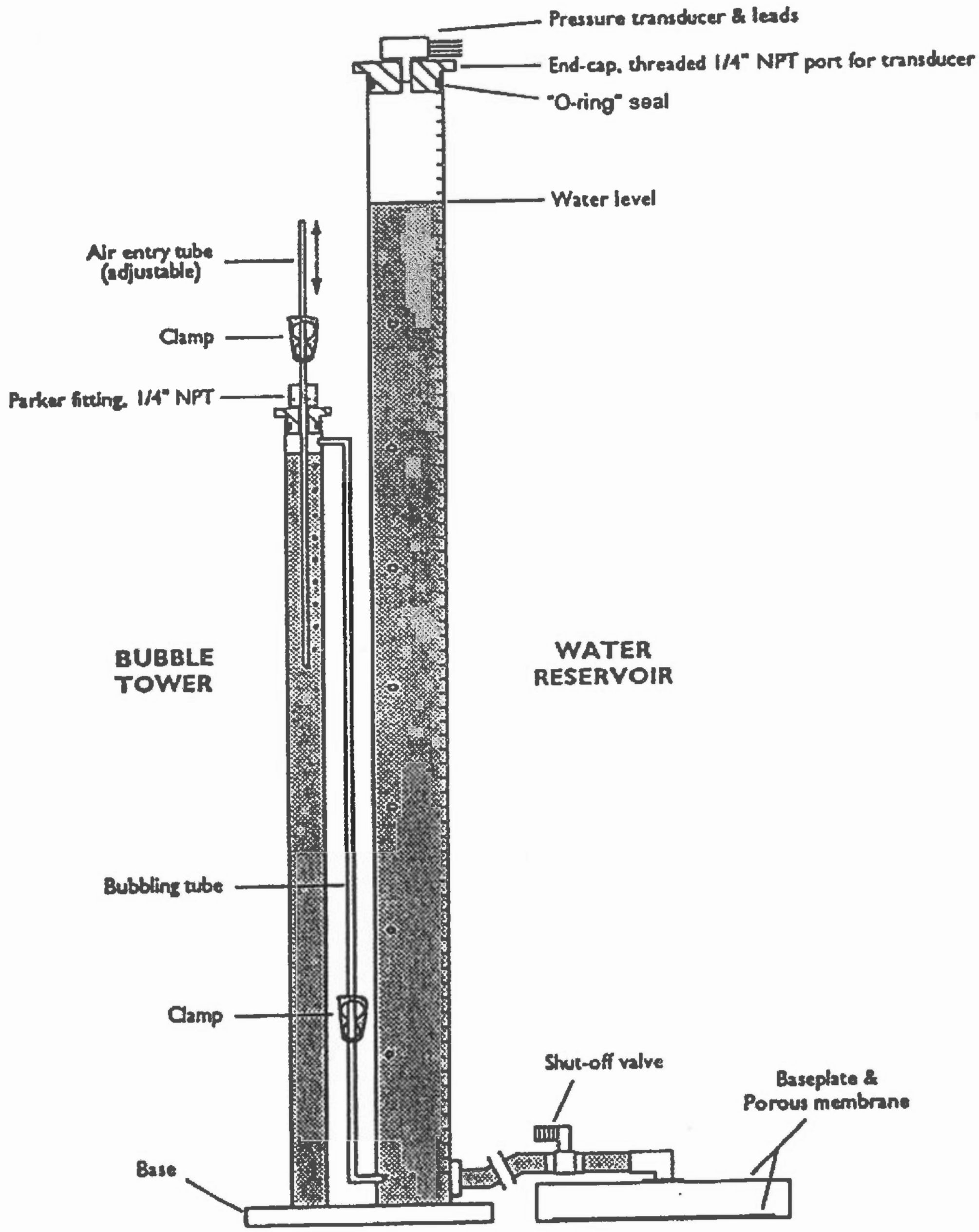

Figure 1 View of the tension infiltrometer

III. Initial setup and use

1. Initial tests

The tension infiltrometer has been tested before shipment; however, after extensive use in the field, there may on occasion be a need to check for air leaks. This is best accomplished as follows. Separate the disc from the water tower, by removing the 1/2-inch tygon tubing from the disc elbow. Close all valves. Inflate the infiltrometer to a pressure of 100 mbar (100 cm water pressure) using a small hand pump. Use care not to over-inflate the infiltrometer; this may damage the instrument. Use a Tensimeter, sensitive manometer, or a water column to check the pressure. Now hold the lower part of the infiltrometer under water in a large bucket, and check for air bubbles. Following this, hold the top part of the infiltrometer under water. Again no continuous stream of air bubbles should come from the infiltrometer. In case there is a leak, repair the leak using either (depending on where the leak is) nylon tape, or vacuum grease.

2. Filling the infiltrometer in the field

To fill the infiltrometer disc, it is most convenient to submerge the disc, without the 1/2-inch tubing attached, in a dishpan with water. This will completely wet the pores of the nylon mesh attached to the disc, and allows one to eliminate all air from the disc.

Close the one-way valve of the 1/2-inch tubing connected to bottom of the water tower, and remove the top from the water supply tube. Fill the water supply tube until about 5 cm from the top. When full, replace the top.

Hold the water tower over the dishpan holding the disc, and slip the open end of the 1/2" flexible tube over the elbow of the disc. Open the one-way valve, and move the water tower back and forth so that all air in the 1/2" tubing moves to the top of the water reservoir. Place the disc and water tower on a flat, clean surface, and then fill the bubble tower until 7 cm from the top. When full replace the top with pressure adjusting tube.

To fill between measurements close the valve in the tubing between the tower and the disc, remove the top, and refill the water reservoir tube until about 5 cm from the top. Replace the top and re-open the 1/2-inch valve.

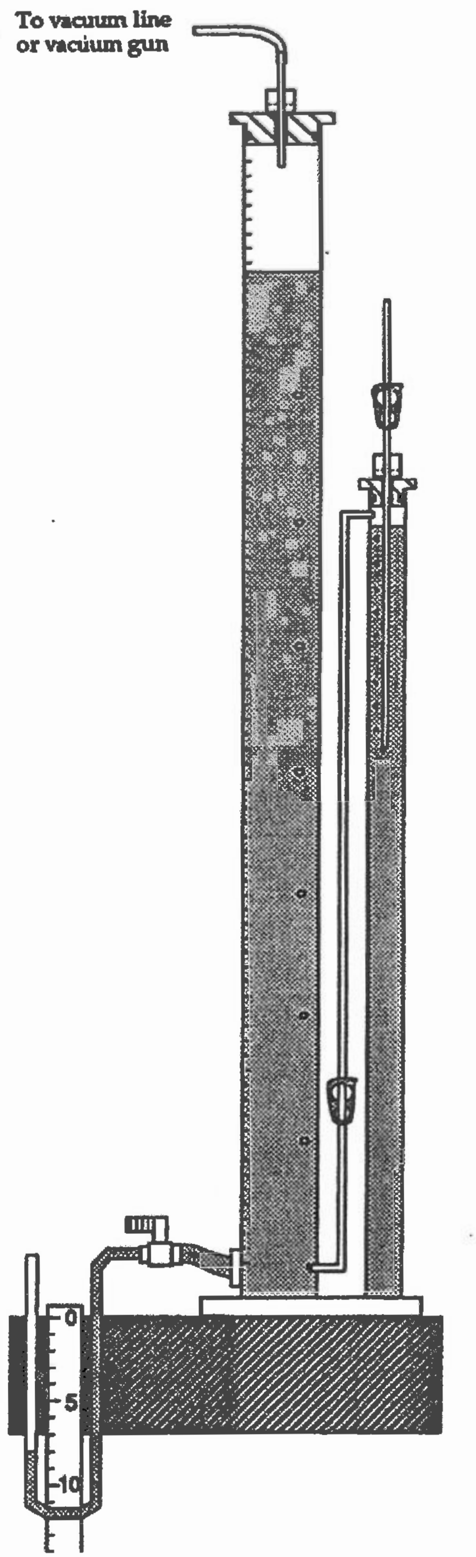

Figure 2 Calibration of surface tensions

3. Calibration

It is recommended to check the calibration of the infiltrometer, before taking the unit to the field. Tension at the soil surface is controlled by the relative position of the air entry tube in the bubble tower. By turning the setscrew on top of the bubble tower counter clock wise, the air entry tube is loosened, and can be moved up and down. The air entry tube slides up or down easiest when wet. Once the tube is set, turn the setscrew clockwise till it is finger tight. This will ensure that the closure is airtight.

Under normal operating conditions the air entry tube has to be set such that its lower end is 4.0 + x cm below the water level in the bubble tower. For example, if the first measurements are to be taken at a surface tension of -15 cm H2O, then the lower end of the tube should be set at 19.0 cm below the water level. If the next readings are to be taken at -10 cm, then the tube outlet should be set at 14.0 cm below the water level. However, it is good practice to verify this in the laboratory, before taking the unit to the field.

To calibrate the air entry tube settings in the laboratory, disconnect the 1/2" tube between the disc and the water tower at the disc. Connect a 75 cm length of 1/4" or similar tygon tubing to the open end of the tube. Use a regular tubing connector for this purpose. The 1/4" tygon is used as a water manometer as shown in Figure 2. The water manometer is connected to the 1/2" tube with valve and looped over the bench top adjacent to a meter stick (Figure 2). After filling the water tower, open the 1/2" valve for a short time to force all air out of the manometer and out of the 1/2" tube to avoid calibration errors. Water will spill out of the open end of the manometer tube. Now apply a small vacuum to the top of the water reservoir tube, such that air bubbles are seen rising in the tube. This can be done with a small hand pump available from SMS, or better with a regulated vacuum source. Then open the tubing clamp on the tubing between the water tower and the bubble tower, as well as the tubing clamp on the short end of tubing on top of the air entry tube. Slide the air entry tube up or down until the desired tension on the manometer is reached. Tension is read directly off the meter stick taped to the bench top edge. The bench top is the zero reference, which represents the soil surface. The vertical distance between the bench top and the water level in the left arm of the manometer represents the tension (in cm water) that will be applied to the soil surface. Figure 2 shows the infiltrometer at 8.0 cm water tension. To accomplish this, the air entry tube had to be set at about 12 cm below the water level in the bubble tower.

Following are step by step instructions on how to set the tensions.

1. Place the infiltrometer water tower on a table or bench top.

2. Close the one way valve and remove the cap on the water tower.

3. Fill the water tower until 5 cm below the top. Replace the cap.

4. Fill the bubble tower until 7 m below the top, and place the cap with the air entry tube on top of the bubble tower.
5. Attach 1/4 inch tygon tubing to a hand held vacuum pump. and

6. Remove the end cap from the water tower. Unscrew the pipe plug from the end cap, and replace this plug with a 1/4" NPT tubing adaptor. If no suitable pipe plug can be found, use a one-hole stopper to close the upper end of the water tower. Push a short end of plastic tube through the hole, and attach the tygon tubing from the hand pump to this tube.

7. Attach tygon tubing to the valve and bend it under the bench in front to a meter stick to make a manometer (see Figure 2).

8. Quickly open and close the 1/2" one way valve after removing the end cap from the water tower. This causes water to force all air out of the 1/2" tube and out of the manometer tubing. Attach the manometer tubing to the meter stick. Verify there is no air in the tubing near the valve or in the valve. Replace the end cap on the water tower.

9. Open the clamp on the tubing between the water tower and the bubble tower. Also open the clamp on the air entry tube. Apply vacuum with the hand pump until a steady stream of bubbles appears in the water column. It is best to use quick, relatively short pump strokes.

10. Slide the air entry tube up or down, until the correct reading on the manometer is obtained. For example, if a 5 cm tension is desired at the membrane, the manometer should read 5 cm (distance from the top of the bench to the top of water in the tube of the manometer with the water reservoir bubbling). If, necessary adjust the air entry tube up or down. Keep pumping in short strokes to keep the air bubbles moving.

11. Now (while the air is moving), determine the vertical distance in cm, between the water level in the bubble tower, and the lower end of the air entry tube. For a 5 cm tension this distance should be approximately 9 cm.

12. Repeat step 11 for tensions of 10 and 15 cm. Verify that the correction factor is about 4 cm for all tensions. If this is not the case apply different correction factors for each tension setting to be used in the field.

13. It is recommended to perform the calibration in the laboratory.

14. In the laboratory a precisely regulated source of vacuum is much more convenient than the use of a hand pump.

While tensions can in principle be calibrated to an accuracy of millimeters, the precision of tension control is limited by tension fluctuations due to bubbling (+/- approximately 1 cm). Therefore, at very low tensions, soil surface tension may fluctuate to zero potential. This fluctuation should be given careful consideration before measuring or interpreting infiltration rates less than two or three centimeters tension. The 400 mesh nylon membrane will bubble if tensions are set for greater than 35 cm. Tension settings of 3-, 6-, and 15 cm have proven convenient across a variety of soils and soil conditions.

IV. Field use of the tension infiltrometer

1. Estimating measurement times

For the analysis presented in section V it is necessary to reach steady state infiltration. The time needed to obtain a steady-state rate in unconfined infiltration measurements depends upon initial soil water content and upon hydraulic properties of a given soil. In general, drier soil and lower hydraulic conductivity result in a longer infiltration period needed to reach steady-state infiltration. The change in rate over time should be monitored to confirm that steady-state rates are reached. Data is collected for 1000 seconds under most conditions except for dry, high bulk density areas. Not reaching steady-state results in an overestimate of hydraulic conductivity. In very porous and sandy soils, steady-state rates are reached much earlier and measurement times can be shorter.

2. Data Collection

The water level in the water reservoir can be read directly on the cm scale attached to the water reservoir. A simple timer or stopwatch is useful to obtain readings at regular time intervals.

The water level can also be obtained by placing the transducer head of a Tensimeter over a Tensimeter adaptor tube screwed into the end-cap closing the water tower. This adaptor tube is available from SMS. The Tensimeter is calibrated in mbar, and 1 mbar = 1.02 cm water pressure. Thus a 10-mbar decrease in tension on the Tensimeter is the result of a 10.2 cm drop in water level.

The water level may also be recorded with one or two pressure transducers and a Campbell Scientific datalogger, or equivalent data logger. One-PSI differential pressure transducers (26PC), available from Soil Measurement Systems, are recommended.

3. Preparing the soil surface

Infiltration can be measured with or without removal of any soil crust. Typically, about 2-3 cm of soil surface is removed in a 40 cm diameter. A pointing trowel works well to prepare the surface. If the soil is too wet to avoid smearing, the measurement should wait. Gently press the metal ring into the prepared surface. When the soil is cracked, or otherwise has many visible "macro pores", place 3 layers of cheesecloth on the soil surface in the ring to reduce soil slaking into the macro pores. Place the contact material (e.g., fine white, slightly moistened, silica sand) in the ring and level with a straightedge. There should be no sand outside the ring. Center the infiltrometer disc over the ring and gently press the device down onto the sand.

Inspect the sand/device interface to assure good contact. Poor contact results in poor data.

Note that the effective diameter for calculating the conductivity is the diameter of the sand circle.

It is very important that the bottom of the bubble tower and the nylon membrane be at the same elevation during measurement. If this is not the case the tension at the membrane will be different than set with the air entry tube.

4. Starting the measurements

1. Remove the sand outside the ring. The effective diameter for calculating the conductivity is the diameter of the sand circle.

2. Remove the metal ring and place the disc on the sand.

3. Inspect the sand/disc interface to assure good contact. Poor contact results in poor data.

4. Make sure the bottom of the bubble tower and the disc membrane are at the same elevation during measurement (use of a carpenters level is recommended). If this is not the case, the tension at the membrane will be different than set with the air entry tube.

5. Start infiltration as quickly as possible after putting the disc on the sand surface. If this is not possible, and in order to prevent air bubbles from entering the disc through the membrane, use a water atomizer (used to spray house plants) to moisten the surface of the sand before placing the disc on the sand.

6. It is recommended to make measurements from high to low tensions (e.g. 15, 6, 3,). If the soil is wet initially, for example after an experiment at h=-3 cm, then it will take some time before air bubbles commence at a higher tension, e.g. at h=-15.

V. Infiltration data analysis

1. Theory: from 3-D rates to hydraulic conductivity

The following method based on Wooding's work (1968) can be used to calculate the hydraulic conductivity versus water content relationship from unconfined infiltration. Wooding proposed the following algebraic approximation of steady-state unconfined infiltration rates into soil from a circular source of radius r (cm)

$$Q = \pi r^2 K \left[1 + \frac{4}{\pi r \alpha} \right] \qquad \textbf{(1)}$$

Where Q is the volume of water entering the soil per unit time (cm^3 hr^{-1}), K (cm hr^{-1}) is the hydraulic conductivity, is a parameter, and h (cm) is the matric potential or tension at the source. The value of h will normally be negative corresponding to a tension at the water source; however, it can also be zero. It is assumed that the unsaturated hydraulic conductivity of soil varies with matric potential h (cm) as proposed by Gardner (1958).

$$K(h) = K_{sat} \exp(\alpha h) \quad (2)$$

Where K_{sat} is the saturated hydraulic conductivity (cm hr^{-1}). Although (1) can be used for unsaturated and ponded infiltration, (2) applies only for $h \leq 0$.

With the tension infiltrometer one measures the volume of water (Q) entering the soil per unit time through the porous membrane at a minimum of two tensions, e.g. h_1 and h_2.

For unsaturated soil, and upon replacing K in (1) with Ksat exp (αh), and after substitution of h_1 and h_2, respectively for h in the combined equation one obtains:

$$Q(h_1) = \pi r^2 K_{sat} \exp(\alpha h_1)\left[1 + \frac{4}{\pi r \alpha}\right] \quad (3)$$

$$Q(h_2) = \pi r^2 K_{sat} \exp(\alpha h_2)\left[1 + \frac{4}{\pi r \alpha}\right] \quad (4)$$

Dividing (4) by (3) and solving for α yields:

$$\alpha = \frac{\ln\left[Q(h_2) / Q(h_1)\right]}{h_2 - h_1} \quad (5)$$

Because $Q(h_1)$ and $Q(h_2)$ are measured, and h_1 and h_2 are known, α can be computed directly from (5).

With α known, one can now calculate K_{sat} from (3) or (4).
Once K_{sat} and α are known, their values can be substituted in (2), yielding the relationship between hydraulic conductivity and tension for the soil. This relationship can be used to calculate the unsaturated conductivity at the desired tensions. Note however, that the K_{sat} value obtained with the above method may be different from the value obtained for K_{sat} if measured directly. One reason is that the relationship of K(h) versus h is often not linear near h=0.

<u>Example:</u>

The inside diameter of the water supply tube of the tension infiltrometer is 4.45 cm, and it's radius is 4.45/2=2.225 cm.

Assume that the radius of the sand layer between the membrane and the soil is 10 cm. Assume further that upon reaching steady state, the water level in the supply tube fell on average at a rate of 60 cm/hour for h_1 = -5 cm, and at a rate of 10 cm/hour when the tension was set at -15 cm.

Calculations:

Based on the above date, the infiltration rates were:

$$Q_1 = (3.14)\ (2.225)^2\ (60) = 933\ cm^3/hour \quad at\ h_1 = -5$$

$$Q_2 = (3.14)\ (2.225)^2\ (10) = 155\ cm^3/hour \quad at\ h_2 = -15$$

Calculate α from (5):

$$\alpha = \frac{\ln(155/933)}{-15-(-5)} = \frac{-1.795}{-10} = 0.1795 cm^{-1}$$

From (3) one obtains:

$$933 = (3.14)(10.0)^2 K_{sat} \exp[0.1795(-5)]\left[1 + \frac{4}{(3.14)(10.0)(0.1795)}\right]$$

$K_{sat} = 4.3$ cm/hour

With α and K_{sat} known, (2) becomes:

$$K(h)=4.3 \exp(0.1795\ h) \tag{6}$$

From (6) one can calculate the unsaturated hydraulic conductivity, as follows:

h = -10 cm,	K(-10)	= 0.71 cm/hour
h = -20 cm,	K(-20)	= 0.12 cm/hour
h = -40 cm,	K(-40)	= 0.0033 cm/hour

2. Matric flux potential

Partitioning of unconfined flow in the above method yields both hydraulic conductivity and matric flux potential Φ=K/α. Note the supply potential does not have to be zero.

3. Sorptivity

Estimation of sorptivity, S (Ψ_1, Ψ_2) is discussed in detail by White and Perroux (1989). Because sorptivity is often sought as a means of obtaining hydraulic conductivity, this manual focuses on the more direct method above. Note that sorptivity can be calculated directly from the short time behavior following White and Sully, 1987.

4. Capillary lengths

Calculation of capillary lengths is also discussed by White and Perroux (1989). Philip (1985) proposed the use of the macroscopic sorptive length. A length scale simply related to the sorptive length is the macroscopic capillary length, λc (White and Sully, 1987), where:

$$\lambda_c = \left[K(\psi_0) - K(\psi_n)\right]^{-1} \int_{\psi_n}^{0} K(\psi)d\psi \qquad (7)$$

Wooding's results (1986) were based on (2) for which λc is simple α^{-1}. White and Sully (1987) and others have used the more basic definition (7) as a basic soil property, but note that λc is a function of the integration limits as well as $K(\Psi)$ for the general case.

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VI. Troubleshooting

1. Main body of device

This device is constructed of polycarbonate (Lexan) and plexiglass. Therefore, the device should withstand normal field abuse. If any piece of plastic does crack or leak, a syrupy solution of plexiglass dissolved in dichloromethylene should seal the pieces together. A glue gun will usually seal a leak, also.

The tubing on the air entry ports may lose its resiliency over time due to the pinch clamps. Periodic replacement increases ease of use.

2. Porous base plate

During long term storage, the infiltrometer should by emptied to prevent decay of the membrane on the base. A dirty base also promotes short-term decay.

If the nylon membrane is damaged, the base will leak. If the base leaks, first try to knock any entrapped air out of the membrane by bumping the base into the bottom of a shallow pan of water. If this fails, the membrane will need replacing. Unscrew the stainless steel tubing clamp. Now remove the damaged screen and replace it with new membrane material (available from Soil Measurement Systems). Lay the membrane over the base plate, and force the O-ring over the membrane and the base plate, such that the membrane material is tight. Replace and tighten the tubing clamp. Wetting the membrane by soaking it in water will facilitate its installation. Only after testing the new membrane for leaks, should the extra membrane material be cut off. Use a razor blade to trim the membrane on the edges.

If tensions beyond 30 cm tension are to be imposed on the soil surface, the bubbling point of the nylon membrane may be exceeded. Membranes down to submicron pore diameter are available. Nylon filters are recommended because they are thin, tough, and hydrophilic. A caveat: high tensions usually mean low flow rates. As flow rates decrease, other factors become more of a problem. Expansion of water due to heating by the sun in the water reservoir may make it difficult to maintain tension. Electronic noise and calibration errors also become more of a problem.

3. Test Infiltrometer For Leaks

1. Remove disc from the infiltrometer.
2. Close side hole with a stopper.
3. Close all the white clamps on the infiltrometer bubble tower.
4. Close the water reservoir with a septum stopper.
5. Inflate the unit to about 60 cm water pressure (60 mbar).
6. Hold the complete unit under water and check for leaks.

4. Check disc for leaks

Before replacing the mesh screen material, the disc and the material should be free from soil particles. They might cause leaking.

1. Connect 1/4" tygon tubing (2 feet long) with connector to the disc.
2. Immerse the disc and tubing in water. The tubing should be completely full of water. Make sure there is no air under the membrane or in the tubing.
3. Close open end of tubing with a tubing clamp or with a small stopper.
4. Remove disc with attached tubing from water.
5. Turn the disc, so the screen is facing up.
6. Position tubing so end of tubing is at the same level as the top of the screen. Open the tubing, and slowly lower the end of the tubing . Watch for air bubbles to appear below the screen. Air bubbles should start appearing when the open end of the tubing is 25-30 cm below the level of the screen . This is the bubbling pressure of the nylon fabric.
7. If air bubbles appear when the tubing outlet is less than 25 cm below the screen level, then there is a leak in the screen. Replace the screen, making sure no loose particles are lodged between the screen and the screen support, or between the o-ring and the screen.

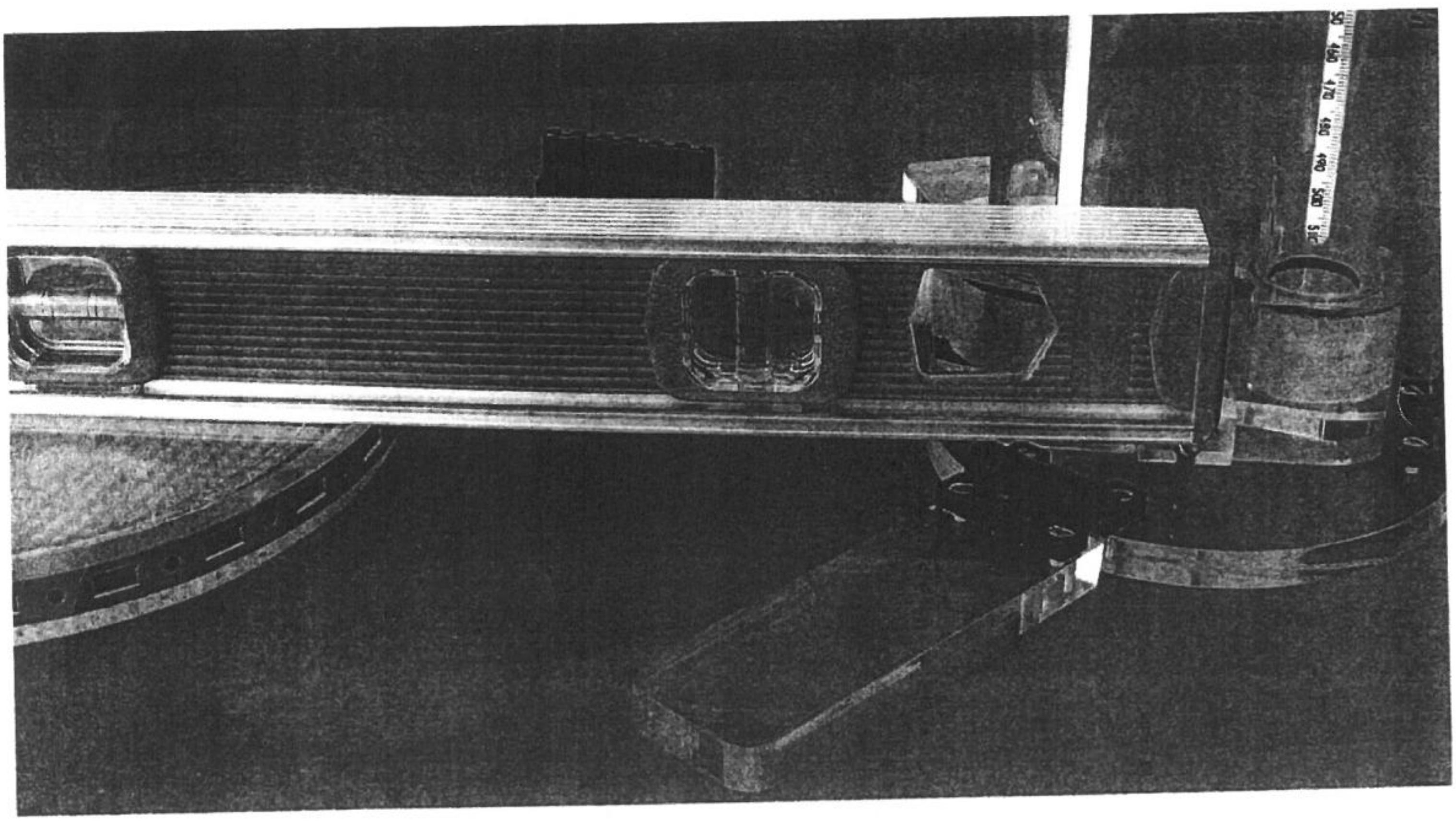
Appendix I

Elevation of the water tower and disc

In the sample calculations shown in the manual it was assumed that the bottoms of the disc and the water tower are at the same elevation.

In order to make sure that the bottoms of the disc and the water tower are at the same elevation in the field, a simple carpenters level can be used as shown in the picture below.
Support one end of the level on the disc, and the other end on the small adjustable support block attached to the water tower. Increase or decrease the elevation of the water tower by removing or adding soil till the air bubble in the horizontal level glass is between its two lines.

Note that the support block attached to the water tower can be adjusted up or down a small distance. The reason for this is that commercially available acrylic does not always have the same thickness. To correctly set the small adjustable support block, place the water tower and the disc on a clean level surface. Then using a carpenters level, adjust the support block on the water tower up or down until the carpenters level is perfectly level. Tighten the setscrew, and from this time on no further adjustments need to be made to the small support block.



Additional Infiltrometer Instructions

The top of the infiltrometer has two outlets that can each be closed with a clamp. One of the outlets is always closed, but is opened only when one needs to refill the water tower. When this clamp is open, it is easier to remove the cap (one does not create a surge in negative pressure when removing the cap).

The second outlet at the top of the water tower can be used to attach a pressure transducer. If the transducer is attached here, one measures the rate of falling water in the water tower, and thus the infiltration rate.

A second outlet at the bottom of the water tower can be used for a differential pressure transducer. The best method to record the falling water level in the water tower (and thus the infiltration rate) is with a 1 psi (67 mbar) differential pressure transducer installed at the bottom of the water tower (see Casey and Derby, 2002).
Connect one port of the pressure transducer to the bottom outlet, and the other port of the pressure transducer with tubing to one of the 2 outlets at the top of the water tower. This way the negative pressure in the top of the water tower is measured not with respect to the atmospheric pressure, but with respect to the nearly constant pressure near the bottom of the water tower. This causes less fluctuation in the pressure data that is recorded.

Making sure the bottoms of the disc and the water tower are at the same elevation:

The small acrylic rectangular block attached to the bottom if the infiltrometer can be used to make sure the bottoms of the tower and the disc are at the same elevation. Place a carpenters level with one end on the disc and with its other end on the acrylic block. The acrylic block can be moved up and down a bit by loosening the set-screw. This is done before taking the unit to the field, as follows.
Place the tower and disc on a flat surface. Then place the carpenters level with one end on he disc and with the other end on the acrylic block. Then move the acrylic block up or down untill the level is perfectly level. Then fasten the set-screw. This needs to be done only once.

Removing the caps on the water, and bubble towers:

The small piece of matting around the top of the water tower can be used to get a better grip on the caps. This makes it easier to remove the caps from the water tower and from the bubble tower.

Replacing the membrane:

If the nylon membrane is damaged, the infiltrometer disc will leak. If the disc leaks, first try to knock any entrapped air out of the membrane by bumping the disc into the bottom of a shallow pan of water. If this fails, the membrane will need replacing.

It is very important that the base plate or disc and the new screen material are clean, and free from dirt particles. Check the base plate before putting on a new screen.

Use a 13" (33 cm) square sheet of nylon screen material.
Place the replacement screen in water, and let it soak a few seconds.

Unscrew the stainless steel clamp on the disc. Remove the large o-ring and the damaged screen. Lay the new, wetted membrane over the inverted disc. Force the o-ring over the membrane and over the bottom of the base plate. Pull on the outer edges of the membrane material, such that the membrane material fits tightly over the base plate. Replace and tighten the large clamp. Wetting the membrane by soaking it in water facilitates correct installation of the membrane. After testing the new membrane for leaks cut off the extra membrane material with a razor blade.

CALIBRATION AND USE OF 1 PSI PRESSURE TRANSDUCERS FOR TENSION INFILTROMETERS.

Use of the 26 PC transducer:

The 26PC series pressure transducers used for infiltrometers have a narrow range (+/- 0-1 PSI, or +/- 67 mbar) for greatest sensitivity. However the transducer can be used beyond this range, because the output from the transducer is nearly linear up to 250 mbar. The narrow range of the 1 PSI transducer is optimal for tension infiltrometers.

The 1 PSI transducer from SMS is a differential transducer, which can be used to measure the pressure relative to atmospheric pressure (this is the most common use). However, it can also be used in differential mode. In this mode both ports are connected to water, or one to water and the other one to air at a different pressure than atmospheric pressure. The millivolt output from the transducer now represents the difference in pressure between two water lines, or between a water line and a pressure line, connected to the two ports of the transducer. The transducer was designed to have water contacting either or both sides of the transducer.

Use 4-conductor 22-gage wire to connect the pressure transducer to the datalogger. Pin 1 (Vs(+)) of the transducer connects to the red wire. Pin 1 is notched and/or marked red. Pin 2 is to the left of Pin 1, and should connect to the white wire. Pin 3 (Ground (-)) should connect to the black wire. Pin 4 connects to the green wire.

If a Campbell Scientific CR10 data logger is used, the transducer wires are connected as follows: red wire to CR10 EX1; green wire to CR10 1H; black wire to CR 10 G, and white wire to CR10 1L. If a second transducer is used it should be connected as follows: red wire to CR10 EX1; green wire to CR10 2H; black wire to CR10 G, and white wire to CR10 2L.

For a Campbell Scientific CR-800 data logger the pressure transducer wires are connected as follows: red wire to VX1, green wire to diff1 H (SE1), black wire to ground (next to SE2), and white wire to diff1 L (SE2). If a second pressure transducer is used it should be connected as follows: red wire to VX2, green wire to diff2 H (SE3), black wire to ground (next to SE3), and white wire to diff2 L (SE4).

In the differential mode the pressure difference between two points of the water tower, one near the bottom and one near the top, are recorded (for details see: article by Francis X. M. Casey* and Nathan E. Derby, Dep. of Soil Science, North Dakota State Univ., Fargo, ND 58105 *Soil Science Society of America Journal* 66:64-67 (2002)). The falling water level in the water tower is now measured at the bottom of the water tower, and referenced not with respect to atmospheric pressure, but instead referenced to the air pressure in the top of the water tower.

According to Casey and Derby measurement precision is much improved with this method using a differential pressure transducer.

Installation of the transducer:

If the infiltrometer is purchased with a pressure transducer provided by SMS, the transducer is already in place, and the user only has to connect the four color coded wires that come from the pressure transducer to the datalogger, as described above.

If the pressure transducer is purchased separately, the user has to install it. The steps needed for the installation are listed below:

1. Cut the tygon tubing, connecting the top of the water tower to the bottom of the water tower, about two inches from its lower end.
2. If there is white clamp on this tubing, remove it, and save it for future use.
3. Now connect one end of the tubing to one port of the pressure transducer, and the other end to the other port of the transducer.
4. Place the 4-wire plug on the 4 pins of the pressure transducer. Make sure that the red wire connects to the pin with a red dot, or small notch on the pin.
5. Connect the 4 leads of the 6 feet wire to the datalogger as explained in the manual.
6. The pressure transducer is now ready for use.

Calibration:

The transducers need to be calibrated. The calibration depends on the excitation voltage applied to the transducer. Generally a 5 to 12 volt constant voltage needs to be used to excite the pressure transducer. Many data loggers, such as the Campbell data loggers, provide a constant voltage. The Campbell CR-10 and CR-800 dataloggers provide 2.5-volt excitation. Although this is a lower excitation voltage than is generally provided, this still works very well.

The output from the transducers is in millivolts (mV). Typically with 10 Volts excitation, the output ranges from 0 mV at 0 mbar pressure to 24 mV at 100 mbar pressure.

If one does not have a constant power supply one can still **test** the transducer using a standard 9 Volt battery as the power supply. For example by connecting a 9 Volt battery to Pins 1 and 3 of the transducer, and the applied vacuum to the transducer outlet is 250 mbar, one measures approximately 57 mV across Pins 2 and 4 for the 1 PSI transducer. The transducer output for the 1 PSI transducer may no longer be linear at or above 250 mbar. The output values vary slightly with each transducer, but vary much more with different excitation voltages. Note, that if one has a digital multimeter with mV scale, this is an easy way to check a transducer.

Calibration of the single transducer using the water tower:
(see also the paper by Casey and Derby, cited above)

It is assumed here that the differential transducer is already installed near the bottom of the water tower.
Connect the plug of the four conductor wire to the pressure transducer in such a way that the transducer Pin marked red connects to the red wire. Connect the other end of the four-conductor wire to the data logger. Take a reading of the millivolt output of the data logger. This is the zero reading.
Close the black valve in the large tube, and then close the white clamp on the tubing between the water tower and the bubble tower.
Fill the water tower with water till near the top but below the air inlet from the bubble tower. Now replace the cap on the water tower with the white tubing clamp on the cap open. After replacing the water tower cap on the top of the water tower, close its white tubing clamp.
Slowly open the black valve, and let some water run out. If no more water runs out, determine the difference in water levels between the water in the water tower and the water level at the end of the tubing from the black valve.
The weight of the water in the water tower will cause a negative pressure in the air space above the water in the water tower. This negative pressure is equal to the vertical distance from the top of the water in the water tower, and the outlet of the tube attached to the valve (provided the latter is filled with water).
Record the vertical distance in cm, as well as the transducer reading. This is the highest point of the calibration curve of the transducer. Because the output from the transducer is linear, a high point and a zero point (when the transducer is exposed to atmospheric pressure, i.e. when the cap is removed from the water tower) are all that are needed for a good calibration. However, if additional calibration points are needed, just open the white clamp on top of the water tower and let some water run out. Then close the white clamp and determine the vertical distance between the water levels as above, as well as the output from the transducer etc.

Once the pressure transducer is calibrated, one can use the datalogger to record the falling head in the water tower versus time, and from this the infiltration rate as a function of time, knowing the inside diameter of the water tower tube.

Calibration of the single transducer with a manometer:

Attach the open end of the to be calibrated transducer to a 20 cm section of flexible tubing. Attach a tee to the other end of the tubing. Attach a source of vacuum to the tee. Attach a manometer (water or mercury type), or calibrated pressure transducer to the remaining open end of the tee.

Take a reading of the transducer using a digital voltmeter, or a datalogger. This is the output at zero pressure. Apply a small amount of vacuum (20 cm or 20 mbar) to the tee. Record the reading from the pressure transducer. Increase the vacuum in steps of about 20 cm or 20 mbar and at each step record the output from the transducer. The maximum vacuum needed is 100 cm H_2O or mbar.
Regress the transducer output versus the manometer reading. This is your calibration curve.