2800K1

OPERATING INSTRUCTIONS

Model 2800K1 Guelph Permeameter March 2010

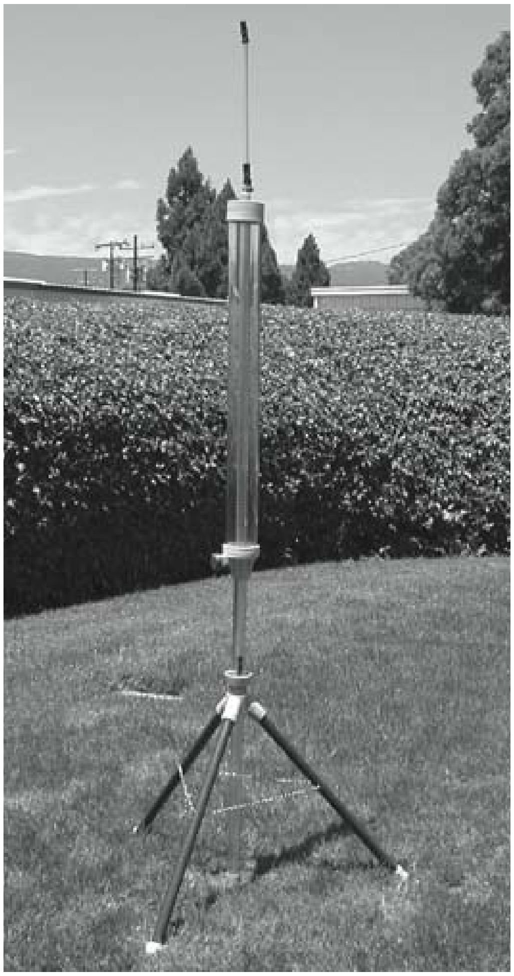

Fig. 1a - Guelph Permeameter / Assembled

The Guelph Permeameter is an easy to use instrument for quickly and accurately measuring in-situ hydraulic conductivity. Accurate evaluation of soil hydraulic conductivity, soil sorptivity, and matrix flux potential can be made in all types of soils.The equipment can be transported, assembled, and operated easily by one person. Measurements can be made in 1/2 to 2 hours, depending on soil type, and require only about 2.5 liters of water.

Measurements can be made in the range of 15 to 75 cm below the soil surface. The Guelph Permeameter is a complete kit consisting of the permeameter, field tripod, well auger, well preparation and cleanup tools, collapsible water container, and vacuum test hand pump, all packaged in a durable carrying case. Accessory attachments are available for extending the measurement capability of the permeameter. Depth attachments increase the depth of operation by 80 cm. The maximum practical operating depth is 315 cm. Ring attachments allow ring infiltrometer measurements from 10-cm and 20-cm diameter rings. A tension adapter allows measurements to be made under tensional and very low head conditions.

Fig. 1b - Guelph Permeameter Carrying case

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YOUR 2800K1 GUELPH PERMEAMETER

The 2800K1 Guelph Permeameter (GP) is a constant-head device, which operates on the Mariotte siphon principle and provides a quick and simple method for simultaneously determining field saturated hydraulic conductivity, matric flux potential, the α^* parameter and soil sorptivity in the field.

Using the Guelph Permeameter, measurements in high and moderately permeable soils can usually be made and results calculated in less than an hour by following the step-by-step procedure and calculations, which are detailed in this instruction booklet.

The Guelph Permeameter is sold as a kit and can be broken down into several segments for convenient storage in its easily transportable carrying case. Component parts of the Guelph Permeameter assembly are made of high impact polycarbonate, PVC, or thermoplastic rubber .

Unpacking

The 2800K1 Guelph Permeameter shipped to you has been thoroughly tested before shipment. When packed, it was in perfect order. Unpack with care being sure to remove all packing material. Follow the instructions carefully in order to assure long, trouble-free service.

Note

Any damage found upon receipt should be reported immediately to the transport carrier for claim. It is important to save the shipping container and all evidence to support your claim. Be sure to read all operating instructions thoroughly before operating the unit.

Not Liable For Improper Use: Read this Entire set of Instructions

Soilmoisture Equipment Corp. is not responsible for any damage, actual or inferred, for misuse or improper handling of this equipment. The Guelph Permeameter Kit is to be used solely as directed by a prudent individual under normal conditions in the applications intended for this equipment.

It is highly recommended that users read this instruction manual thoroughly and familiarize themselves with the General Procedure and Generalized Calculations as well as the assembly of the Permeameter before beginning formal field investigations. Although very little water is required for each measurement, it is necessary to make provisions for obtaining or bringing water on site.

ACQUAINT YOURSELF WITH THE PARTS

Fig. 2

1. Utility Cavity w/strap
2. Water Container and Tube w/strap
3. Sizing Auger
4. Soil Auger
5. Tripod Base
   Tripod Bushing
6. Well Prep Brush
7. Reservoir Assembly
8. <u>On Top</u>
   Support Tube & Lower Air Tube
   <u>On Bottom</u>
   Well Head Scale & Upper Air Tube
9. Vacuum Test Hand Pump
10. Auger Handle Assembly
11. Tripod Legs

The Guelph Permeameter is broken down into four basic sections for easy storage and transportability. These four sections are:

- Tripod Assembly
- Support Tube and Lower Air Tube Fittings
- Reservoir Assembly
- Well Head Scale and Upper Air Tube Fittings

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Tripod Assembly

In addition, auxiliary tools are included to provide a complete, self-contained kit that can be easily transported as luggage for making field measurements in most soils. Measurements in slowly permeable soils such as unstructured clays and compacted clay liners can be obtained using early-time measurements with the Guelph Pressure Infiltrometer.

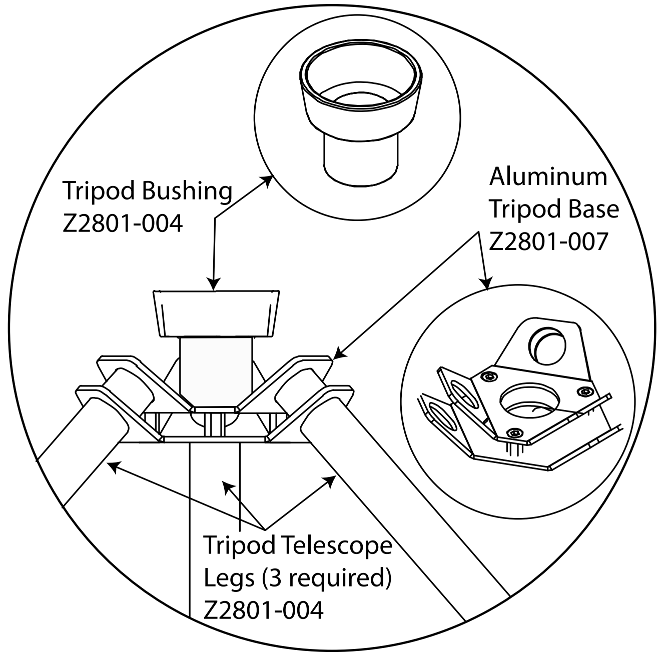

Fig. 3

The Tripod Assembly consists of a Tripod Base with moveable Tripod Bushing and 3 detachable telescope Tripod Legs complete with end tips. The Tripod Base has 3 leg sockets into which the Tripod Legs are inserted (Fig. 3). The telescope legs allow a vertical hold on an inclined landscape. To adjust the length of the leg(s) simply twist leg counter clockwise, to secure that height tighten the leg by turning it clock-wise. A Heavy Duty Guelph Stand (model 2806) is also available to firmly secure and stabilize the GP.

Support Tube And Lower Air Tube Fittings

These are the fittings that conduct water from the Reservoir Assembly into the well hole and provide the means for establishing and maintaining a constant head in the well hole.

The Support Tube supports the Reservoir Assembly over the well hole and conducts water from the Reservoir to the Water Outlet Tip.

The Water Outlet Tip serves as a base for the Permeameter and disperses the energy of the outflowing water through the ribbed vents at the bottom of the tip to minimize erosion of soil in the well hole. The Air Tip Seating Washer rests on the inside step of the Water Outlet Tip and is the seat for the Air Inlet Tip. When the Air Inlet Tip is fully seated against the Air Tip Seating Washer, air cannot move up the Support Tube and there is no flow of water out of the reservoir.

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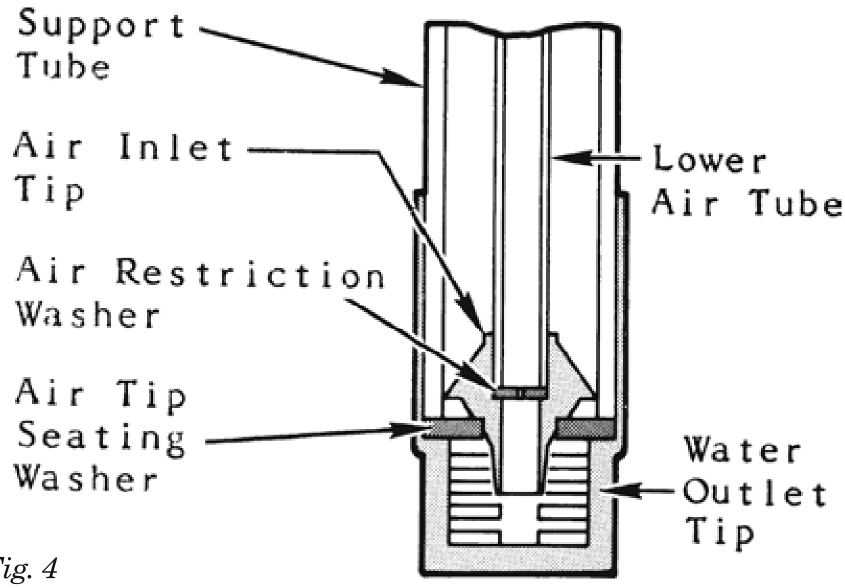

Fig. 4

The Air Inlet Tip is connected to the bottom of the Lower Air Tube and is used to regulate the well head height. The Air Restriction Washer is located inside the Air Inlet Tip and regulates airflow to provide a constant, non-fluctuating head in the well (Fig. 4). The Guelph Permeameter employs the Mariotte Principle to maintain a constant well head and this is described in further detail in the "Water Transmission Theory and Parameters" section on page 40.

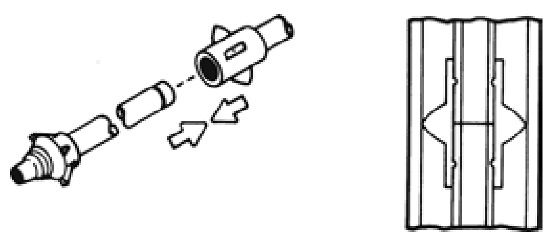

Fig. 5

The Air Tube Coupling joins the Lower Air Tube to the Middle Air Tube and is designed with stabilizing fins to center and prevent bowing of the air tube inside the Support Tube (Fig. 5).

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RESERVOIR ASSEMBLY

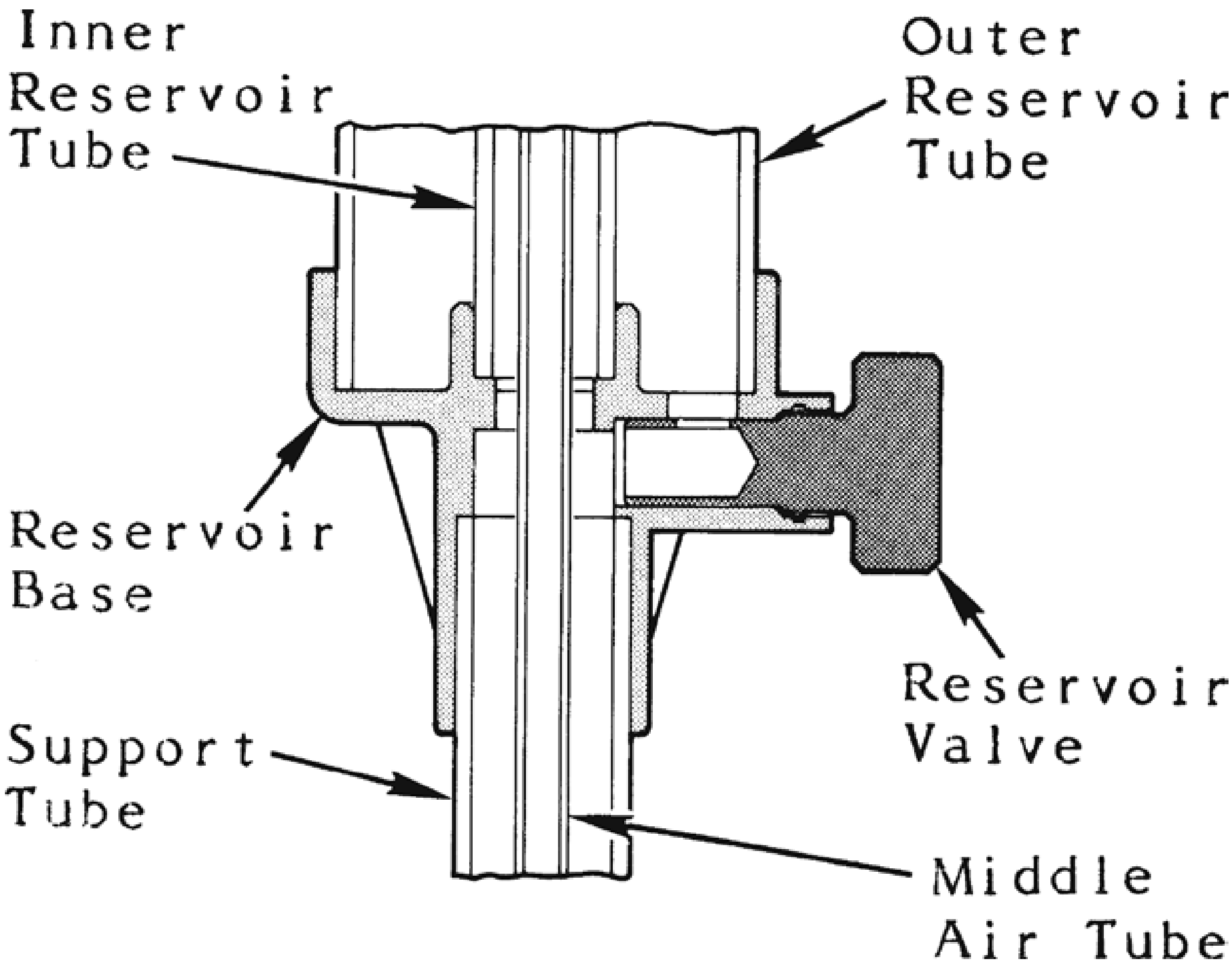

Fig. 6

The Reservoir Assembly provides a means of storing water and measuring the outflow rate while the Guelph Permeameter is in use. For studies in low permeability soils, for example some clays, use of the inner reservoir *only* is required to provide adequate resolution of outflow rate when making a reading. When working in moderate to high permeability soils, for example sands and structured loams, the reservoir combination is used. A scale, delineated in centimeters, is stamped on the Inner Reservoir Tube for measuring the rate of fall of water out of the reservoir in both situations. Fittings are located at the top and bottom of the reservoirs to allow filling and selection of the proper reservoir.

In Fig. 6, above, the reservoir combination is being used to make a reading. The Guelph Permeameter, on the left, shows the closed or sealed state with the Air Inlet Tip sealed against the Air Tip Seating Washer. As illustrated on the right, upon uplift of the Air Tube with accompanying Air Inlet Tip and Well Height Indicator, water flows from the reservoir down the inside of the Support Tube through the Water Outlet Tip and into the well. The water height in the well is established by the height of the Air Inlet Tip. This water height in the well can be set and read using the Well Height Indicator in conjunction with the Well Head Scale.

RESERVOIR BASE

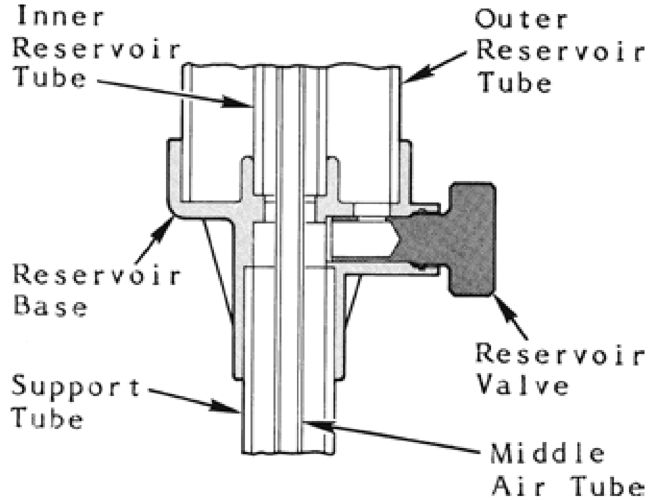

Fig. 7

The Reservoir Base supports the Reservoir Valve and connects and seals the Inner and Outer Reservoir Tubes to the Support Tube (Fig. 7). In use, water flow is controlled by the notched Reservoir Valve. When the notch is pointing straight up, or in the 12 O'clock position, both reservoirs supply water to the well hole. When the notch is point-ing straight down, or in the 6 O'clock position, only the Inner Reser-voir supplies water to the well hole (Fig. 8).

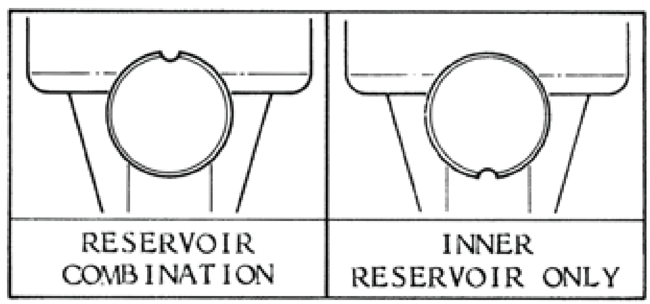

Fig. 8

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RESERVOIR CAP

The Reservoir Cap includes a #0 Stopper and Vacuum Tube connections. The Reservoir Cap provides an airtight cover for the top of the reservoir, a seal for the Air Tube, and supports the Well Head Scale on the central "boss" (Fig. 9).

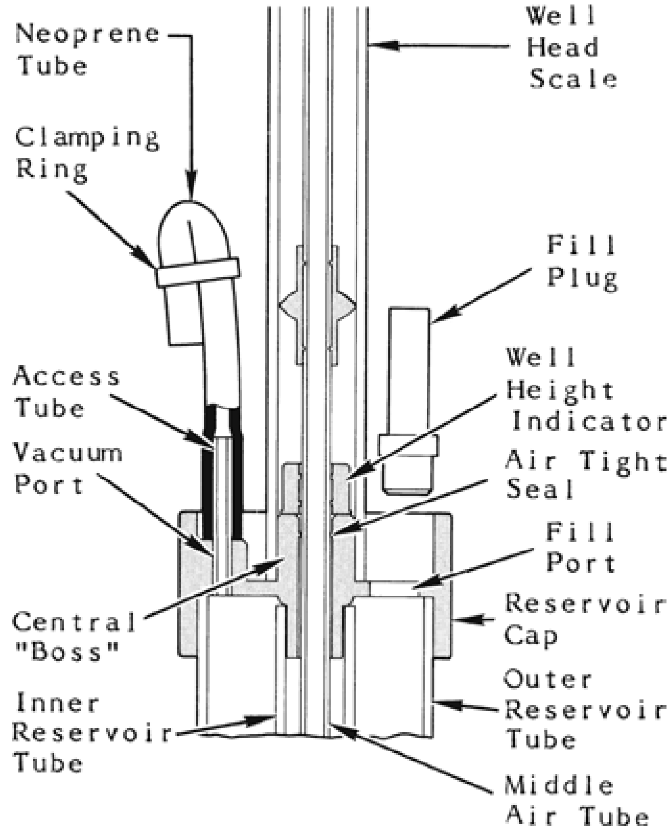

Fig. 9

Should it become necessary to replace the O-Ring Seal, a wooden tooth-pick or similar implement should be used to remove the old O-Ring and replace the new (Fig. 10). Sharp, pointed metal implements are not recommended for use when removing the O-Ring, because the O-Ring, or more importantly the O-Ring seat, may be damaged.

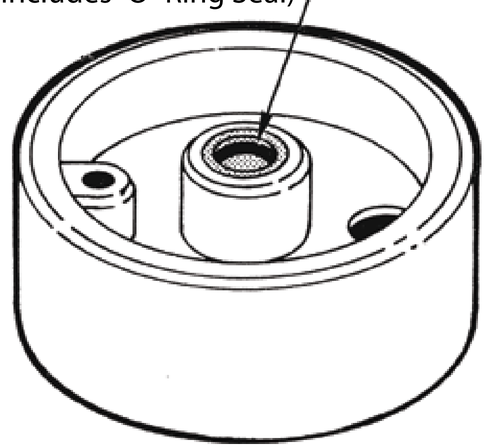

Fig. 10

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The 2800K1 Guelph Permeameter comes equipped with an airtight seal as part of the Reservoir Cap. As shown in the sketch below, the Reservoir Cap includes a removable O-Ring Seal, (Fig. 11).

Fig. 11

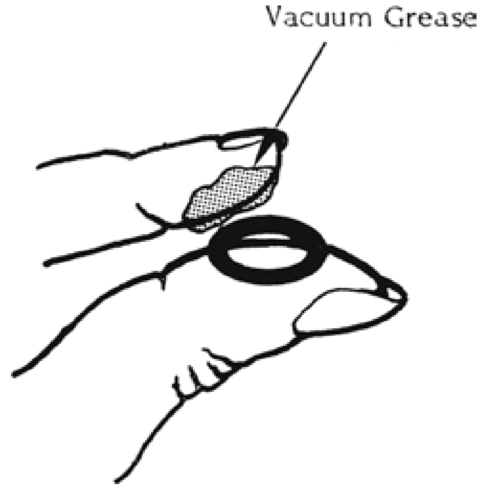

Fig. 12

A thin film of vacuum grease should be applied to the O-Ring to insure an airtight seal (Fig. 12).

The Middle Air Tube is located inside the Inner Reservoir Tube and slides through an airtight seal in the Reservoir Cap. The Well Height Indicator slides over the Middle Air Tube above the Reservoir Cap and indicates on the Well Head Scale the head of water being maintained in the well hole (Fig. 9).

Two ports are located in the Reservoir Cap. The reservoirs are filled through the Fill Port and sealed with a #0 Stopper (part number 2080X0). The Vacuum Port consists of an Access Tube, Neoprene Tube, and Clamping Ring. The Vacuum Port facilitates pulling a vacuum if necessary in low permeability soils when the Reservoirs are not initially completely filled, (Fig. 41 page 34, Making a Reading With Limited Water Supply). After a vacuum is created, the Neoprene Tube is bent over and closed off with the Clamping Ring.

WELL HEAD SCALE AND UPPER AIR TUBE FITTING

The Upper Air Tube is connected to the Middle Air Tube with an Air Tube Coupling. The Upper Air Tube serves as an extension to facilitate setting the well head after the Well Head Scale is put in place.

The Well Head Scale is numbered in centimeters and graduated in millimeters. The Well Head Scale fits snugly over the central "Boss" on the Reservoir Cap (Fig. 9).

Once the Air Inlet Tip at the bottom of the Permeameter is seated and sealed, the Well Height Indicator is pushed down the Air Tube until it rests against the "Boss" on the Reservoir Cap, as shown in Fig. 13.

Next the Well Head Scale is mounted. The Air Tube is then pulled up, raising the Well Height Indicator to the height desired. The height is read on the Well Head Scale. A check on the well height can easily be made using a ruler or a wettable paper strip.

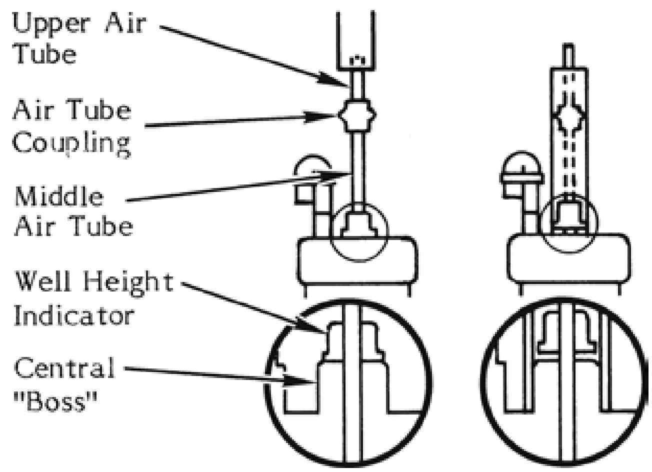

Fig. 13

AUXILIARY TOOLS

The Guelph Permeameter Kit includes a Soil Auger for excavating a well, a Sizing Auger, a Well Prep Brush, a Vacuum Hand Pump for pulling a vacuum in the reservoir, and a collapsible Water Container for carrying water to the field (Fig. 2).

The Well Prep Brush is included to assist in removing any smear layer that exists in the augered well hole that may create a barrier to the natural flow of water out of the well into surrounding soil. Note that in some cases the brush may not be effective in removing the smear layer. In difficult situations an ice pick (or similar tool) or a spiked roller may be more effective in removing the smear layer (Reynolds et al., 2002).

The Soil Auger, Sizing Auger, and Well Prep Brush are all equipped with quick connect fittings for use on the same auger shaft.

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SPECIFICATIONS OF UNIT

Auger Cutting Diameter
- 6.0 cm (2-3/8")

Well Height Range - 2.5 cm to 25 cm

Hydraulic Conductivity Range
- 10^{-4} to 10^{-7} m/sec
- (10^{-2} to 10^{-5} cm/sec)

Collapsible Water container Capacity - 11.36 liters (3.0 gallons)

Maximum Permeameter Capacity - 3.18 liters (.84 gallons)

Overall Carrying Case Size
- 132.08 cm (50") long x 44.45 cm (17.5") wide x 15.24 cm (6") deep

Overall Carrying Case Weight
- 11 kg (25 lbs)

Depth Range, "Standard Unit" - 15 - 75 cm (Note: with Extension Tubes, measuring depths can be increased).

Cell Constant Values with Standard Deviation

- X = 35.22 ($\pm$0.18 (1%)
- Y = 2.16 ($\pm$0.04 (2%)

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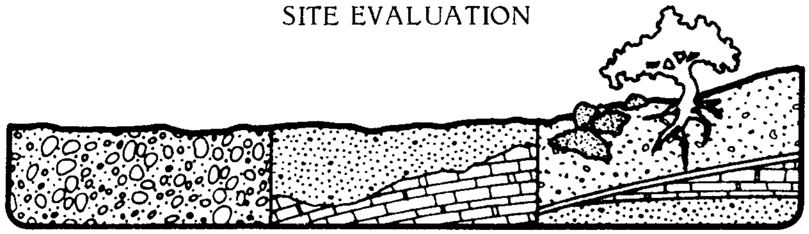
FLOWCHART OF PROCEDURE FOR STANDARDIZED METHOD OF MEASUREMENT USING THE GUELPH PERMEAMETER

SITE EVALUATION



SOIL TYPE? SUBSURFACE? ANOMALIES?

↓

WELL HOLE PREPARATION

↓

ASSEMBLE PERMEAMETER

↓

FILL RESERVOIRS

↓

PLACE PERMEAMETER

↓

SELECT RESERVOIR

RESERVOIR COMBINATION (FAST BUBBLING)	INNER RESERVOIR (SLOW BUBBLING)
SET H_1 = 5 cm — DETERMINE $\overline{R}_1$	SET H_1 = 5 cm — DETERMINE $\overline{R}_1$
↓	↓
SET H_2 = 10 cm — DETERMINE $\overline{R}_2$	SET H_2 = 10 cm — DETERMINE $\overline{R}_2$
↓	↓
CALCULATE $K_{fs} = (.0041)(X)(\overline{R}_2) - (.0054)(X)(\overline{R}_1)$ $\phi_m = (.0572)(X)(\overline{R}_1) - (.0237)(X)(\overline{R}_2)$	CALCULATE $K_{fs} = (.0041)(Y)(\overline{R}_2) - (.0054)(Y)(\overline{R}_1)$ $\phi_m = (.0572)(Y)(\overline{R}_1) - (.0237)(Y)(\overline{R}_2)$

In the preceding flowchart, the following terms are used, and defined as follows:

H_1 = The first head of water established in the well hole, measured in cm.

$\overline{R}_1$ = The steady state rate of fall of water in the reservoir when the first head H_1 of water is established. Rate of fall expressed in cm/sec.

H_2 = The second head of water established in the well hole, measured in cm.

$\overline{R}_2$ = The steady state rate of fall of water in the reservoir when the second head H_2 of water is established. Rate of fall expressed in cm/sec.

X = Reservoir constant, used when reservoir combination is selected, and corresponds to the cross sectional area of the combined reservoirs expressed in cm^2.

Y = Reservoir constant used when the inner reservoir only is selected, expressed in cm^2.

K_{fs} = Field-saturated hydraulic conductivity expressed in cm/sec.

ϕ_m = Matric flux potential, expressed in cm^2/sec.

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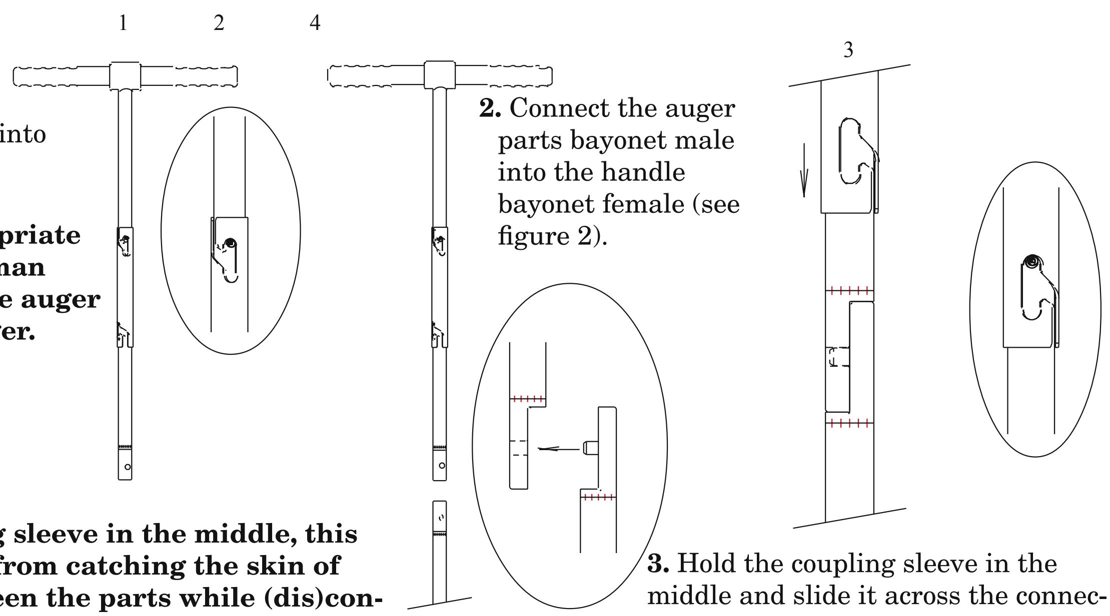
PROCEDURES FOR FIELD USE

Site and Soil Evaluation

Before making a measurement with the Guelph Permeameter in the field, it is necessary to perform a site and soil evaluation, prepare a well hole, assemble the Permeameter, fill the Reservoirs, and place the Permeameter in the well hole. Upon arrival at the site, the user must evaluate the site with regard to topography, general soil appearance, intended application, and select the number and location of areas that are representative of the soils under study. At each site use Table 1 to determine the appropriate value for $\alpha*$. If the computer program is used, then the value for C (one-head analysis) or the values for C_1 and C_2 (two-head analysis) will automatically be determined.

Well Preparation

The implements needed for excavating and preparing a well borhole are included in the Guelph Permeameter Kit. They consist of a two-piece handle, which is assembled as shown in Fig. 14, and three inter-changeable auxiliary tools, which are connected to the handle by means of the quick connect fitting.



1. Screw the handle into the upper part.

Select the appropriate auger. The Edelman combination type auger or the sizing auger.

2. Connect the auger parts bayonet male into the handle bayonet female (see figure 2).

Hold the coupling sleeve in the middle, this will prevent you from catching the skin of your hands between the parts while (dis)connecting them.

3. Hold the coupling sleeve in the middle and slide it across the connection and click it onto the sleeve stop. The sleeve is locked when it cannot be rotated.

Fig. 14

The Soil Auger, shown in Fig. 15, is used to remove bulk amounts of soil. Auger the well hole by rotating the handle in a clockwise direction while applying steady, somewhat firm, downward pressure on the handle, as shown. When the auger body is full, lift the auger out of the hole and push the collected sample out of the auger body. When augering, be careful to keep the shaft of the auger handle vertical to avoid excessive enlargement of the well hole.

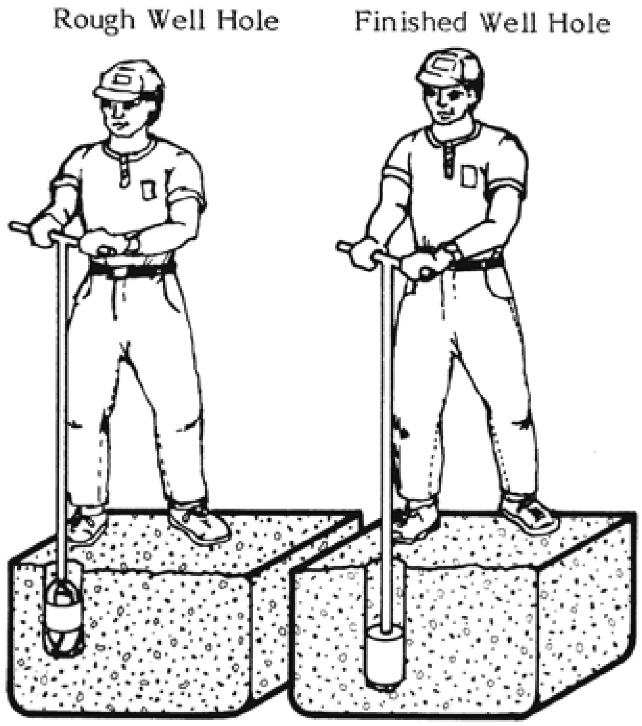


Fig. 15

The Sizing Auger, shown in Fig. 15, is used as a finishing tool to produce a proper sized well hole uniform geometry, meeting the size and shape requirements of the model, and to clean debris off the bottom of the well hole. The Sizing Auger is designed to produce a hole that is uniformly 5 cm in diameter with a flat bottom. It is also important to keep the blade sharpened to a knife-blade edge in order to minimize smearing.

Generally, the preferred procedure is to use the Soil Auger to excavate the well hole down to a depth of 15 cm less than that desired for the final well hole. The last 15 cm can then be excavated using the Sizing Auger to produce a debris-free well hole of uniform geometry.

In rocky or gravely soils, it may be necessary to use the Soil Auger to excavate all the way to the bottom of the well hole. The Sizing Auger is then used afterwards to clean loose debris off the bottom of the well hole.

In medium-textured soils of good tilth that are rock free, the well hole is started with the Soil Auger to a shallow depth and then the Sizing Auger alone can be used to excavate the well hole. Apply light down ward pressure and take only small bites with the auger (two finger, two turn rule) when augering within the measurement zone. Variations of the procedures for excavating the well hole that are recommended above can be used as soil conditions dictate.

The soil and site evaluation is an ongoing process. Soil textural and structural stratification should be identified while augering the hole. A record of this information is an important part of measuring and reporting the hydraulic properties of soil materials.

Fig. 16

In moist soils, and particularly in medium to fine-textured soils, the process of augering a hole may create a smear layer which can block the natural flow of water out of the well into the surrounding soil. In order to obtain reliable and representative results using the Guelph Permeameter, this smear layer must be removed. The Well Prep Brush is provided for this purpose. The Well Prep Brush is designed to use in the standard 5 cm diameter well hole, and has an outside diameter that is somewhat greater than the diameter of the well. In fine textured soils the brush may not be effective and alternative techniques such as an ice pick or spiked roller should be used (Reynolds et al., 2002).

Attach the Well Prep Brush (Fig. 16) to the auger shaft using the quick-connect fitting. Push the Well Prep Brush into the well hole and all the way to the bottom. Next, quickly and evenly pull the Well Prep Brush straight up and out of the well hole (Fig. 17). When the direction of the brush is reversed, the bristles will dig into the sides of the well hole, roughen the surface and scour the smear layer. This operation should not be done more than once or twice, since each operation removes a layer of soil. Repeated operations will enlarge the hole diameter beyond the desirable limits needed to obtain accurate results.

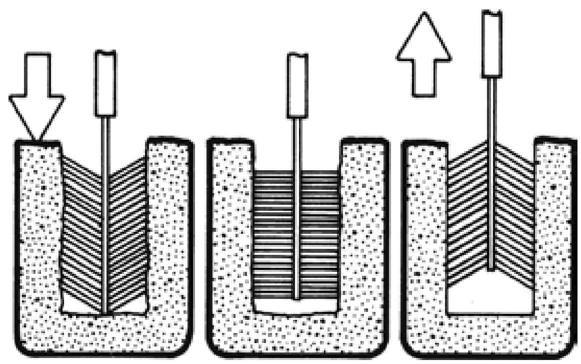


Fig. 17

Typically, the difficulty of removing the smear layer increases with increasing wetness of the soil and in finer textured soils. It is recommended that fine textured soils not be augered when they are in a very wet state.

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PERMEAMETER ASSEMBLY

NOTE: The Tripod Base and the Tripod Legs of the Guelph Permeameter have been updated. The images in this assembly instruction is of the old model tripod base, legs and support chain. The basic assemblage is the same.

The Guelph Permeameter Kit is shipped with its component parts disassembled to provide convenient storage in its hardshell carrying case and for portability to field sites. The Permeameter is easily assembled; See steps below:

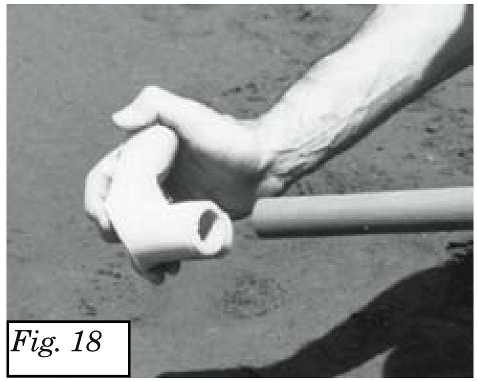

Fig. 18

STEP 1

First, assemble the Tripod by connecting the Tripod Legs to the Tripod Base (Fig. 18).

When working on slopes, flexibility at the Tripod Base allows the angle of the Tripod Legs to be adjusted as needed. In these situations, adjust the Tripod leg length to accommodate leg angle adjustment by turning the leg counter clockwise to adjust and clockwise to tighten.

Fig. 20

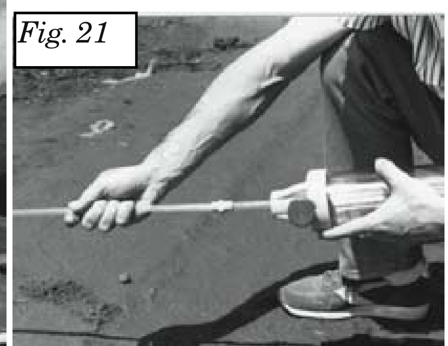

Fig. 21

STEP 2

Next, remove the Reservoir Assembly and the Lower Air Tube from the case. The Lower Air Tube is stored inside the Support Tube (Fig. 20). Connect the Lower Air Tube to the Middle Air Tube at the base of the Reservoir using the Air Tube Coupling, as shown in Fig. 21. Firmly push the Lower Air Tube into the coupling until the ridge on the inside of the coupling snaps into the groove on the end of the Lower Air Tube.

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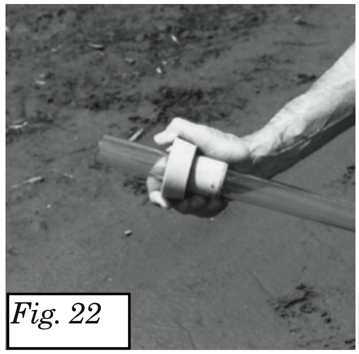

Fig. 22

Fig. 23

STEP 3

Remove the Tripod Bushing and Support Tube from the case. Slide the Tripod Bushing, with the wide end oriented up, onto the outside of the Support Tube (Fig. 22). Then, with the Tripod Bushing in place, slide the Support Tube over the Air Tube and connect it firmly into the recess on the bottom of the Reservoir Base, as shown in Fig. 23. This is an airtight, friction fitting and it is important that the Support Tube be seated completely into the Reservoir Base.

Fig. 24

Fig. 25

STEP 4

The Support Tube can then be lowered into the Tripod, as shown in Fig. 24. To support and stabilize the Permeameter, push the Tripod Bushing downward fully into the Tripod Base, as shown in Fig. 25. Additional support may be required in under windy conditions, on sloping soils and perhaps under other conditions. A steel rod driven into the soil near to the hole and clamped to the reservoir, may be sufficient to support the Permeameter. If the bottom tip of the GP appears to sink into the base of the well, independently supporting the body of the GP is important.

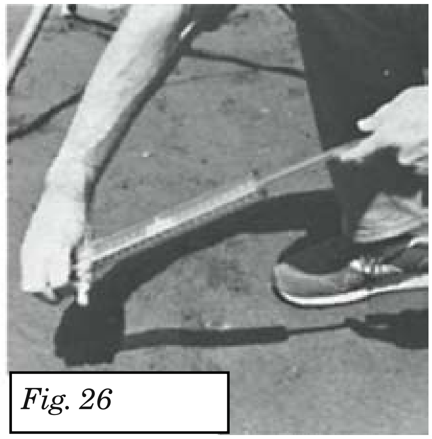

Fig. 26

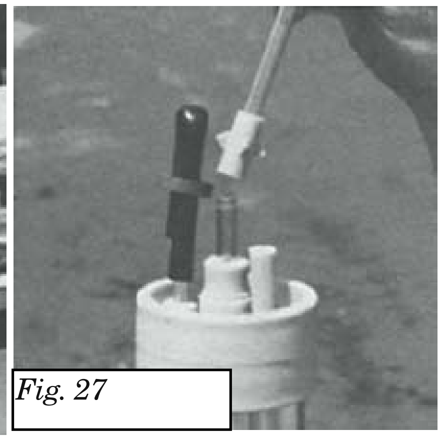

Fig. 27

STEP 5

Remove the Upper Air Tube from its storage inside the Well Head Scale in the carrying case, as shown (Fig. 26).

Before connecting the Upper Air Tube to the Middle Air Tube, make sure that the Well Height Indicator is in place. The Upper Air Tube is connected to the top of the Middle Air Tube with an Air Tube Coupling. Again, when connecting the Air Tube sections, be sure that the ridges on the inside of the coupling fully snap into the grooves on the ends of the Air Tube sections (Fig. 27).

Fig. 28

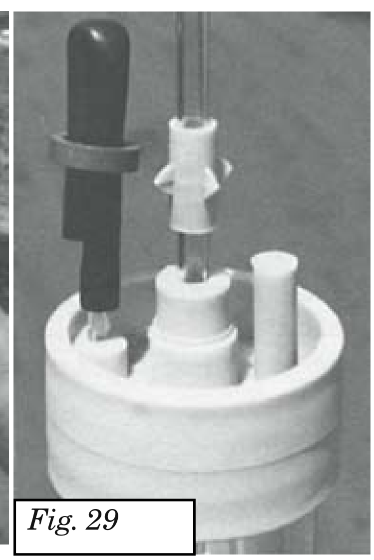

Fig. 29

STEP 6

Fully seat the Air Inlet Tip into the Air Tip Seating Washer by pushing down on the Upper Air Tube (Fig. 28). Once the Air Inlet Tip is seated, lower and seat the Well Height Indicator flush against the Reservoir Cap, as shown in Fig. 29.

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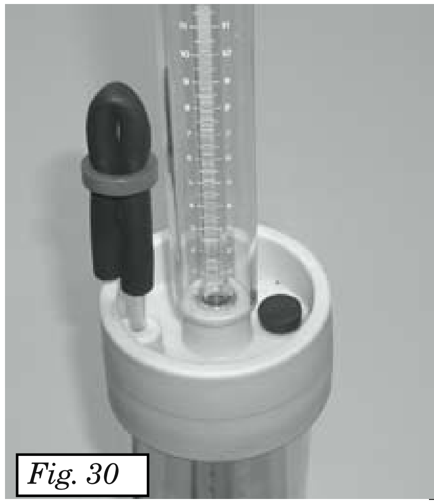

Fig. 30

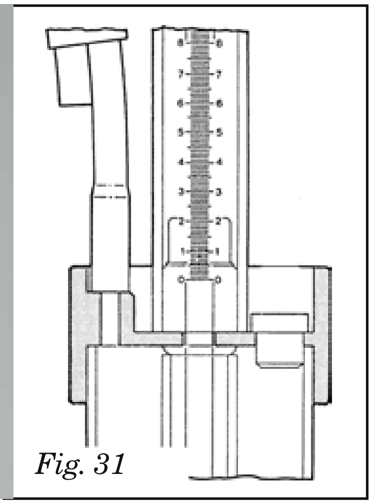

Fig. 31

STEP 7

Lower the Well Head Scale over the Upper Air Inlet Tube and fully seat it against the bottom of the recess in the Reservoir Cap (Fig. 30). The counter bore in the Well Head Scale fits snugly onto the central “boss” of the Reservoir Cap. The “MM” mark at the top of the scale should be oriented up. The Well Head Scale is properly mounted when the “O” reading of the Well Head Scale is 5 mm below the top of the Reservoir Cap, and the bottom of the Well Height Indicator lines up with the 5 mm mark on the Well Head Scale, see Fig. 31.

WATER FILLING

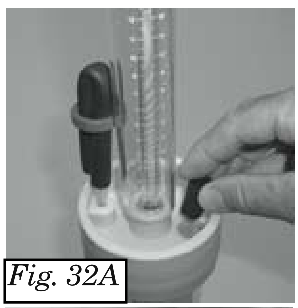

Fig. 32A

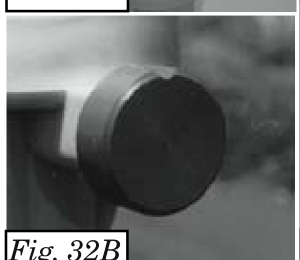

Fig. 32B

Fig. 32C

After the Permeameter is assembled and mounted in the Tripod, it can be easily filled with water. Remove the #0 Stopper in the Reservoir Cap, see Fig. 32A, and adjust the Reservoir Valve so that the notch is in the up, or 12 o’clock position (Fig. 32B). The Inner and Outer Reservoirs are now connected and ready for filling. Pour water into the recess on the Reservoir Top Cap. For convenience, the Tube Assembly can be connected to the plastic water container, and foot pressure can be used to pump water to the Permeameter, as shown in Fig. 32C. Alternatively, small amounts of water may be added consecutively in order to fill the reservoir. The recess prevents water from splashing and spilling over. It is important to fill the reservoir until no air bubbles readily emerge from the fill hole. When only limited quantities of water are available and the reservoir cannot be filled completely, follow the procedure on page 34, "Making a Reading With Limited Water Supply". After filling, replace and fully seat the #0 Stopper in the fill hole and make sure that the Neoprene Tube from the Vacuum Port is folded over and closed with the Clamping Ring. As a precaution, water can be added to the recess area to ensure that there are no leaks.

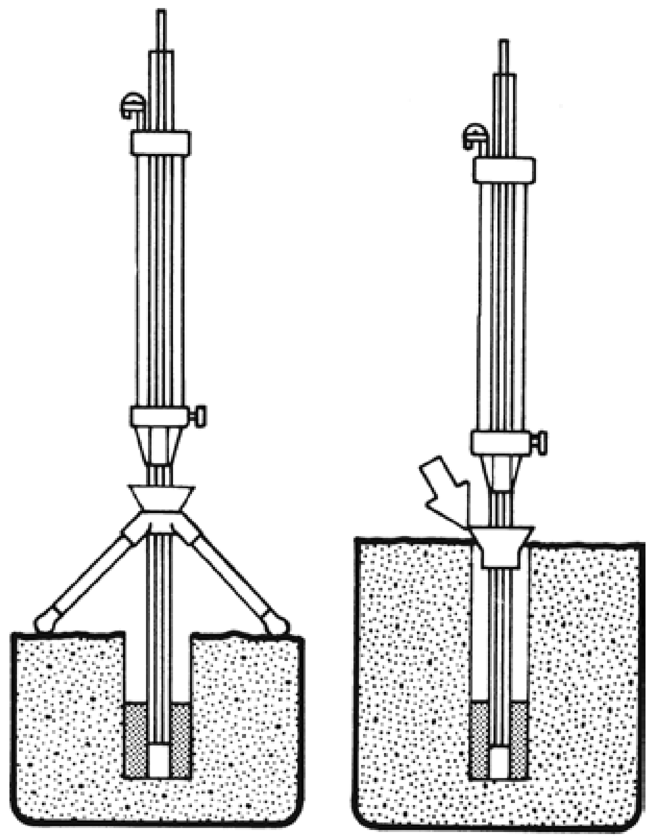

Fig. 33A *Fig. 33B*

Simply center the Tripod over the well hole and slowly lower the Permeameter so that the Support Tube enters the well hole, being careful not to knock debris off the sides of the well into the hole bottom (Fig. 33A). Flexibility in the Tripod Base allows the angle of the Tripod Legs to be adjusted to accommodate variation in slope of the land. The Tripod is used to support the Permeameter in wells down to approximately 38 cm (15 inches) in depth. The tripod chain can be loosened as necessary to allow the Tripod Legs to flex.

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MAKING A READING

For use in wells deeper than 38 cm (15 inches), the Tripod Bushing alone provides the functions of centering and stabilizing the Permeameter. Lift the Tripod Bushing from its position in the Permeameter base. The entire Permeameter can then be lifted clear of the Tripod. Lower the Permeameter slowly into the well hole until the Water Outlet Tip rests on the well bottom. Again, care should be taken to avoid knocking debris from the sides of the well into the bottom. Once the Permeameter is in place, center and stabilize it by lowering the Tripod Bushing into the top of the well hole. Secure the Tripod Bushing with a firm push into the soil, as shown in Fig. 33B.

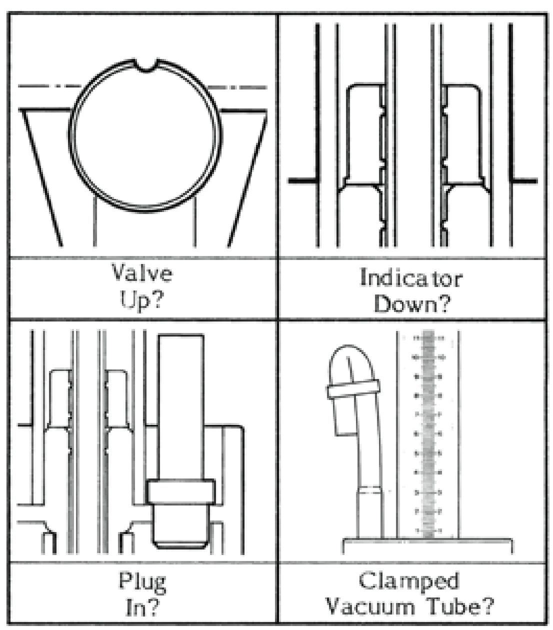
In unstable soils, pea gravel or coarse sand can be used to backfill around the Permeameter tip to the top of the measurement zone. At times it may be necessary to tape the Water Outlet Tube to the Sup-port Tube to prevent the Tip being pulled off by the backfill material when the Permeameter is removed from the well. *Be careful; do not cause debris to fall into the well.*

For deep well holes where the weight of the water column/reservoir assembly may cause the Water Outlet Tip to "sink" into the saturated soil, it is recommended that our accessory "Heavy Duty Guelph Stand" (2806) be used to support the water column securely at the height of the bottom of the well hole. See Accessories List, page 51. Make certain that adequate water is available to perform the number

of measurements required for your particular field investigation. After the Permeameter has been assembled, filled, and placed in the prepared well hole, the following procedure should be followed for making measurements.

STEP 1 - One-Head or Two-Head Procedure

Fig. 34



Verify both Reservoirs are connected. The Reservoirs are connected when the notch on the Reservoir Valve is pointing up. It is also important to verify that the Well Height Indicator and the Well Head Scale are seated down flush against the top of the Reservoir Cap. This is described under “Permeameter Assembly”, Page 17. In addition, the #0 Stopper must be fully seated against the Reservoir Cap and the Vacuum Tube closed off with the Clamping Ring, see Fig. 34.

Then decide on whether the one or two-head procedure is to be used.

The one-head procedure is simpler, but may be less accurate than the two-head procedure. One advantage of the one head procedure, how-ever, is that it will always give a positive result. The single-head procedure is for applications where the saturated hydraulic conductivity, K_{fs} need only be known within a factor of 2 or less. For many applied engineering applications, this level of accuracy is probably sufficient. The two-head procedure is more research-oriented and is preferred when a higher level of accuracy is required. The two-head approach also provides data for two one-head analyses and the results can be averaged.

STEP 2 - Establish a Well Head Height (H_1)

Note that this is the only head required if the one-head procedure is used. See the Flow Chart on page 13 to select the proper value.

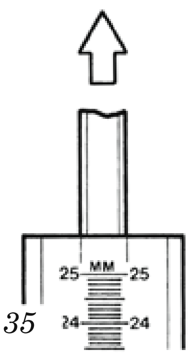


Fig. 35

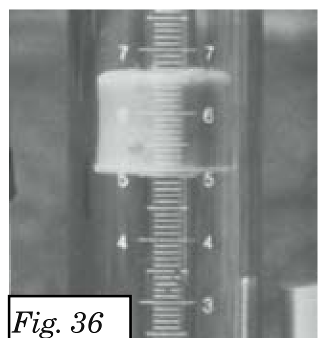


Fig. 36

Slowly raise the Air Inlet Tip (Fig. 35), by grasping the Upper Air Tube to establish the first well head height.

NOTE: Raising the Air Tube too quickly can cause turbulence and erosion in the well and a potential surging effect that could cause the well to temporarily overfill.

Raise the Air Tube until the well height H_1 is established, as indicated by reading the lower edge of the Well Height Indicator against the Well Head Scale (Fig. 36).

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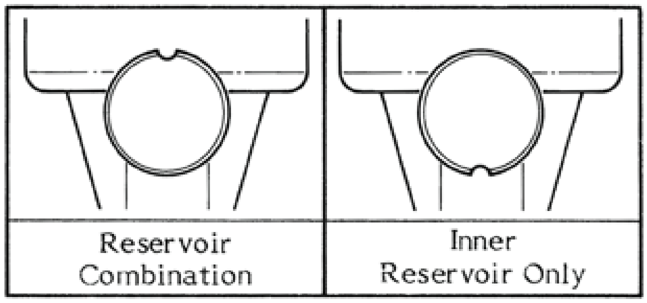


Fig. 37

STEP 3 - Select Reservoir

Based on the site evaluation you may have selected either the combination or inner reservoir. If difficult to evaluate, then choose the combination reservoir (valve up). Observe the rate of fall of the water level in the reservoir. If it is too slow to easily distinguish the drop in level between consecutive readings, usually a 2-minute interval, then turn the Reservoir Valve so that the notch is pointing down in the 6 o'clock position. Water will then be supplied only from the small diameter Inner Reservoir which will result in a much greater drop in water level between readings, see Fig. 37.

NOTE: Once the appropriate reservoir is selected, DO NOT CHANGE THE RESERVOIR VALVE.

STEP 4 - Measure Permeameter Outflow, First Well Height Outflow of water from the Permeameter into the soil is indicated by the rate of fall of water in the reservoir.

Note and record the water level in the selected reservoir as read against the scale stamped on the Inner Reservoir Tube.

Readings should be made at regular time intervals. As a suggested procedure, try 1 or 2-minute intervals between readings. The difference of readings at consecutive intervals, divided by the time interval, equals the rate of fall of water, R, in the reservoir.

When investigating slowly permeable soils, situations my arise where the rate of fall of water is so slow that a 2-minute time interval may not be long enough to detect a measurable change in the water level in the reservoir. In these cases, a longer time interval is more appropriate. Increase the time interval as needed for measurement of the rate of fall of water in the reservoir, perhaps 15-minute intervals, or longer.

On the other hand, in situations where the rate of fall of water is very fast, such as in sandy soils, a time interval as short as 15 seconds may be more appropriate. Make sure the calculation for R is based on the actual time interval selected.

For example, at time = 0 minutes, assume the level of water in the reservoir is at 5.9 cm as read on the Reservoir Scale. After the elapse of the first time interval, time = 2 minutes, the level of water is at 6.5 cm. The rate of fall, R, of water in the reservoir, is calculated as the change in the level of the water, in centimeters, divided by the time interval for the change, expressed in seconds.

The calculation is shown below for Example 1, first applied head (page 29).

R = (6.5 cm - 5.9 cm)/(2 min) (60 sec/min)
R = (.6 cm)/(2 min) = .3 cm/min
R = .3 cm/60 sec = .005 cm/sec

Continue monitoring the rate of fall of water in the reservoir until the rate of fall does not significantly change in three consecutive time intervals. This rate is called R, and is defined as the "steady-state rate of fall" of water in the reservoir at H_1. H_1 is the first well height established. See Flowchart on page 13.

In heavy clay soils, where the hydraulic conductivity is very low, the Permeameter can be left in place for a long period of time while other tasks are being performed. Under these circumstances, periodic readings can be made at convenient intervals until the rate of fall reaches a steady-state value. A stable value is achieved when essentially the same rate of fall is obtained in consecutive time intervals. The rate of fall for each time interval is determined by dividing the change in water height in the reservoir in centimeters by the time interval in seconds. The "steady-state rate of fall" in this situation is simply the stable value obtained. In very slowly permeable soils, the measurement of these very slow flow rates may not be accurate and different procedures may have to be used (see Elrick and Reynolds, 2003).

After completing the outflow measurements, DO NOT disturb the Permeameter in any manner, and proceed immediately to Step 5.

STEP 5 - Establish the second Well Head Height H_2 if the Two-Head Procedure is being used

Slowly raise the Air Inlet Tip by grasping the Upper Air Tube to establish the second well head height H_2. See the Flowchart (page 13) for the choice of H_2. Note that continuous measurements are required and do not refill the reservoir at this time. It may be possible when using the small reservoir to partially refill the small reservoir with water from the large reservoir during the switch-over from H_1 to H_2. Partially turn the reservoir valve to slowly refill the small reservoir at the same time as the air tube is being raised from H_1 to H_2. This reduces the chance of running out of water in the small reservoir during the H_2 measurements and also prevents over-filling the well at H_2.

Raise the Air Tube until the well height H_2 is established, as indicated by reading the lower edge of the Well Height Indicator against the Well Head Scale, see Fig. 38.

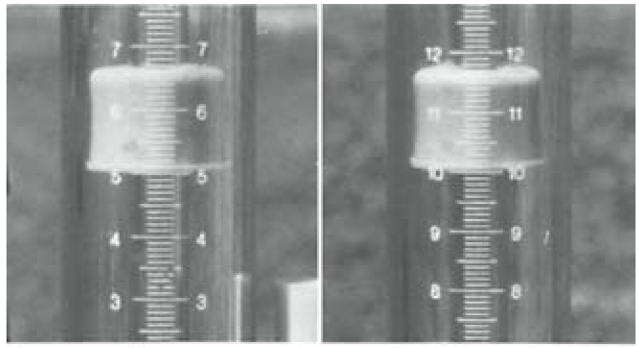


Fig. 38

5 cm to 10 cm

STEP 6 - Measure Permeameter Outflow, Second Well Height if the Two-Head Method is being used.

As in STEP 4, monitor the rate of fall of water, R, in the reservoir until a stable value of R is measured. This rate is called R_2 and is defined as the "steady-state rate of fall" of water in the reservoir at H_2.

The field-saturated hydraulic conductivity K_{fs}, the matric flux potential F_m, and the alpha parameter α^*, can now be readily calculated using the computer program provided to carry out the calculation. Follow the step-by-step procedures to input your data. If the computer program is not available, see the THEORY section on Page 40 for the appropriate equations.

NEGATIVE (UNREALISTIC) RESULTS -TWO-HEAD METHOD

If invalid (negative) values of α^* are obtained (either K_{fs} or Φ_m will also be negative in value) or when α^* values are obtained that lie outside the realistic range of $0.01 \leq \alpha^* \leq 0.5$ cm^{-1} , then the One-Head Analysis should be applied to each of the two heads and the resulting values for K_{fs} and Φ_m averaged.

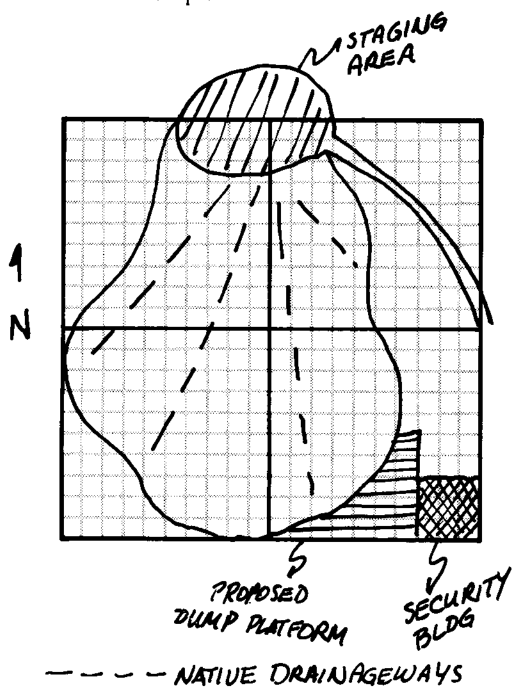
GP FIELD DATA SHEET **SECTION 1: SITE INFORMATION**

Date 4/1/05 Investigator G. Howell

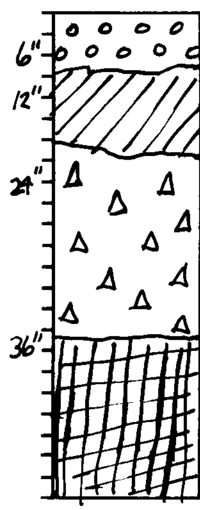
Site Location SITE #24A, BAKER LANDFILL, 2 mi. east of BAKER

Dominant Soil Type(s) BAKER LOAM

Site Map: NW¼, Sec.14, T21E, R42W



Soil Profile Description (horizon depth, texture, structure, color, etc.):

Depth	Description
	DARK BROWN LOAM, GRANULAR, WAVY BOU MANY ROOTS & RODENT ACTIVITY LIGHT BROWN CLAY LOAM, ANGULAR BLO SOME RODENT ACTIVITY LIGHT GRAY LOAM, SUBANGULAR BLOCKY, VERY FEW ROOTS, NO RODENT ACTIVITY LIGHT GRAY CLAY, MASSIVE, NO ROOTS OR RODENT ACTIVITY

Presence of special soil conditions (mottling, water table depth, hardpan, induration, compacted layers, etc.):

PRESENCE OF MOTTLING AT 14-36" INDICATES SEASONALLY FLUCTUATING WATER TABLE; PRESENCE OF CLAY PAN AT 36"+

Comments and Notes (topography, slope, vegetation, etc.):

(1) WELL DEPTH = 2 ft.

(2) GENTLY ROLLING SLOPE (0-8%); NO VEGETATION (RECENT WILDFIRE)

(3) NOTE PRESENCE OF CLAY PAN AT 3 FT.; EXISTS OVER ENTIRE PROPERTY

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GP FIELD DATA SHEET

SECTION 2: STANDARDIZED PROCEDURE FOR PERMEAMETER READINGS AND CALCULATIONS

Date 4/1/05 Investigator G. HOWELL

Reservoir Constants: (See label on Permeamter)

Combined Reservoirs	X 35.39	cm²
Inner Reservoir	Y 2.14	cm²

☑ CHECK RESERVOIR USED

Depth of Well Hole 2 ft.

Note: In standardized procedure the radius of the well hole is always 3.0 cm

1st Set of Readings with height of water in well (H_1) set at 5 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_1, (CM/MIN)
1	0	—	5.2	—	—
2	2	2	5.9	.7	.35
3	4	2	6.5	.6	.3
4	6	2	7.1	.6	.3
5	8	2	7.7	.6	.3
6	10	2	8.3	.6	.3
7	12	2	9.0	.7	.35
8	14	2	9.6	.6	.3
9	16	2	10.1	.5	.25
10	18	2	10.7	.6	.3
11	20	2	11.3	.6	.3
12	22	2	11.9	.6	.3
13	24	2	12.5	.6	.3

$\bar{R}_1$

2nd Set of Readings with height of water in well (H_2) set at 10 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_2, (CM/MIN)
1	0	–	14.8	–	–
2	1	1	15.3	.5	.5
3	2	1	15.9	.6	.5
4	3	1	16.4	.5	.6
5	4	1	16.9	.5	.5
6	5	1	17.4	.5	.5
7	6	1	17.9	.5	.5
8	7	1	18.4	.5	.5
9	8	1	18.9	.5	.5

CALCULATIONS

$\bar{R}$, the steady state rate of flow, is achieved when R is the same in three consecutive time intervals.

For the 1st Set of Readings $\bar{R}_1$ = (.3)/60 = .005 cm/sec

For the 2nd Set of Readings $\bar{R}_2$ = (.5)/60 = .0083 cm/sec

Input the required data into the computer program to calculate K_{fs} and Φ_m. If the two height procedure is used, α will also be calculated, unless a negative value is produced.

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MAKING A READING IN DEEP WELLS

Adding Extensions

Extension tubes and couplings are available for the Support Tube, Air Tube, and Auger for use in making measurements at extended depths. The Guelph Permeameter can theoretically be used to considerable depths below the surface soil, to approximately 6 meters (20 ft.), when extension tubes are utilized. The procedure is essentially the same as that for use without extension tubes. Some notes are important regarding preparations for making a measurement in deep well holes.

For very deep well holes, it is preferable to place Extension Tubes and Air Tubes down the well hole before connecting them to the Reservoir assembly. To avoid loss of equipment in deep well holes, it may be desirable to use hose clamps on each end of the support tube coupling; the weight of the extended support tube column may separate the coupling from the support tube. It is advisable to use the 2806 Heavy-Duty Tripod to support the extended column. CAUTION: In loose single grain textures, it may be extremely difficult to make measurements at extended depths due to the ease of dis-lodging soil material from the upper horizons and partially filling the well hole. In such cases, a 3" auger hole is prepared to a depth of 15 cm. A 3" PVC casing is inserted to the bottom of bore hole, then the 2-inch Well Prep Auger may be used to prep a clean well hole without additional debris in the well. The remaining steps are the same. Remember to prepare the well so that K_{fs} at 5cm and 10cm depths may be measured.

The procedure for adding Air Tubes and Support Tube Extensions is illustrated in Fig. 39.

Connect the first Air Tube Extension, using an Air Tube Coupling, to the Lower Air Tube. Slide the coupled Air Tube into the Support Tube and make sure the Air Inlet Tip is seated in the Air Tip Seat. Slide the Support Tube Extension with connected Support Tube Coupling over the Air Tube and couple the Support Tubes. Add additional tubing in the same fashion until sufficient for the desired depth, adding Air Tube Extensions first and then Support Tube Extensions.

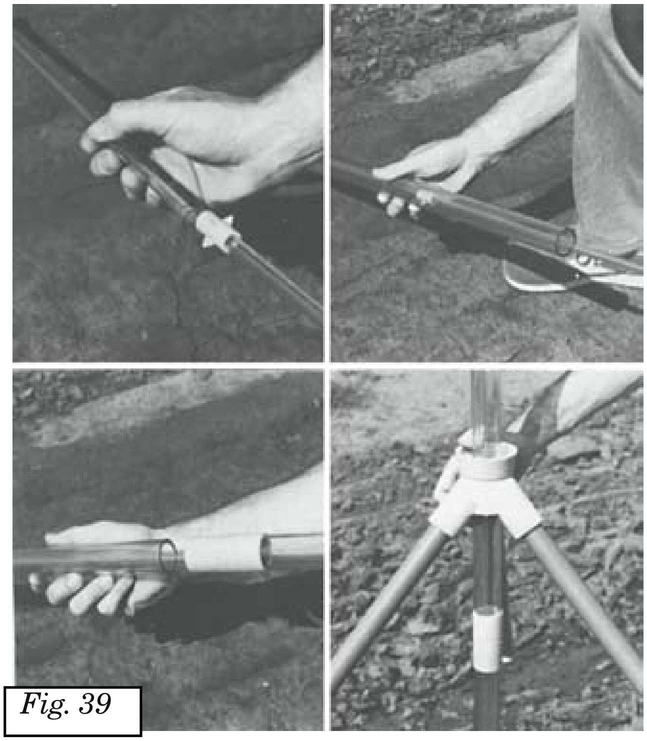

Fig. 39

Slide the Tripod, with Tripod Bushing in place, over the last Support Tube Extension that is added. If the Reservoir Base will be closer than 38 cm (15 inches) to the soil surface, omit the Tripod and use the Tripod Bushing alone to center and stabilize the Permeameter in the well hole. Use of the Tripod Bushing alone is described more completely under “Placement of Permeameter”, page 21.

Fill the reservoir as described under “Water Filling” on Page 20. Make sure that the reservoir is filled close to the top with only a small air space remaining. On deep measurements, an initial vacuum should be created in the reservoir before setting the well height. See the next section, “Making a Reading With Limited Water Supplies” for details.

After the Permeameter is placed in the well hole and the reservoir is filled, follow the procedure for “Making a Reading”, as described on page 22.

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MAKING A READING WITH LIMITED WATER SUPPLIES

When sufficient water is not available to completely fill the Permeameter, readings can still be made, but there are additional procedures that must be followed in order to do so.

To prevent overfilling of water into the well when establishing the well head and to insure proper operation, an initial vacuum may be created in the air space above the water in the reservoir. After making sure that the Air Inlet Tip is fully seated, remove the Clamping Ring and attach the Vacuum Hand Pump to the Vacuum Tube located in the Reservoir Cap. Pull a vacuum of 20 centibars, bend the Vacuum Tube over with the Hand Pump still attached, and close it off with the Clamping Ring (Fig. 40). Disconnect the Vacuum Hand Pump and continue with the procedure as described in STEP 2, Establish the first well height H_1.

Fig. 40

When using the Permeameter in deep applications, an additional initial vacuum of about 10 centibars must be applied for each additional 80 cm long 2800K2 Extension Kit that is used.

USE AND APPLICATION

The Guelph Permeameter can be used anywhere a hole can be augered in soil. This instruction booklet presents a generalized method for determining field-saturated hydraulic conductivity, matric flux potential, and the α^* parameter.

Because of the practical improvements incorporated in the operation of the Guelph Permeameter and the advanced analysis the theory provides, it is ideally suited for applications involving the design and monitoring of:

- Irrigation Systems
- Drainage Systems
- Canals
- Reservoirs
- Sanitary Landfills
- Land Treatment Facilities
- Tailings Areas
- Hazardous Waste Storage Sites
- Septic Tank systems
- Soil and Hydrologic Studies and Surveys

THE PERCOLATION TEST

The Percolation Test is commonly used to determine both site suitability and filter field design for on-site wastewater treatment facilities such as septic tank systems. Unfortunately, the “Perc” Test uses a falling head procedure, is empirical in nature and not standardized in many jurisdictions. The GP uses the more accurate constant-head technique to determine K_{fs}. An approximate relationship between the GP steady-state rate of fall R (cm/min) and the “Perc” Test T (min/cm) is available and can be obtained from Soilmoisture Equipment Corporation. An approximate relationship between K_{fs} and T is also avail-able.. These relationships are approximate because in many jurisdictions the “Perc” Test in not standardized.

DEPTH PROFILING

It is almost always the case that the water transmission properties of

soil vary with depth. The Guelph Permeameter can be used to investigate changes in the hydraulic properties of soils with depth. When using the Permeameter for this purpose, it is recommended that the investigator auger a hole at shallow depth first. After making a measurement at the shallow depth, the well hole can be extended by further augering to successive depths and making the respective measurements (Fig. 41).

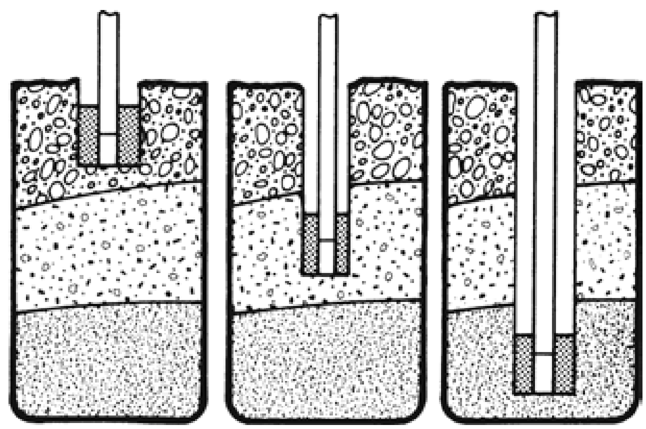

Fig. 41

HETEROGENEOUS SOILS

Soils typically have three-dimensional heterogeneity. The Guelph Permeameter method yields essentially a “point” measurement. The size of land under investigation, degree of soil heterogeneity, soil type, and kind of application will dictate the number of measurements needed to adequately characterize a given area and depth of soil.

A soil profile description and soil survey report will greatly enhance the value and understanding of data obtained with the Guelph Permeameter.

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Because of the ease and simplicity of the Guelph Permeameter and its depth profiling capability, it is a very useful method for understanding the three dimensional distributions of the water transmission properties of soils.

As noted previously, readings in highly heterogeneous soils can lead to negative values. Negative results may be obtained under these circumstances because the GP theory assumes that the soil properties surrounding the base of the permeameter (the measurement zone) are homogeneous. Use of the One-Height Procedure can then be used to obtain valid data.

HELPFUL HINTS IN NORMAL USE

The reservoir combination is used in soil of moderate to high permeability. Soils that fit into this category typically have some degree of structure, medium to coarse texture, and little to no cementation or compaction. The Inner Reservoir only is used for work in soils of low permeability. Soils that fit into this category are typically fine textured, structureless, or are significantly cemented or compacted.

It is helpful to make readings of R, the rate of fall of water in the reservoir, at specific intervals, as described in the standardized procedure. By using a specified time interval, it is very easy to determine when R, the steady-state rate of fall of water in the reservoir, is obtained.

For shallow use (wells less than 30 inches deep), it is recommended that the reservoir be filled before the Permeameter is placed in the well hole. This enables the operator to verify proper functioning of Permeameter fittings and insure that the Air Inlet Tip is fully seated in the Air Tip Seat. The possibility of an unexpected water spill into the hole is also reduced when the reservoir is filled away from the hole. When an operator is making measurements in deep wells, it may be necessary to fill the reservoirs after the Permeameter has been placed in the well hole. Care should be taken to insure that all Air Tube and Support Tube Couplings are tightly fitted to their respective extensions and that the Air Inlet Tip is fully seated in the Air Tip Seat. (See “Making a Reading in Deep Wells”, Page 32).

Familiarize yourself with the setup, operation, procedure theory, and calculations before going to the field with the Guelph Permeameter. Doing so will facilitate accurate measurements and interpretation of results.

The moveable, molded plastic parts of the Permeameter may exhibit a slight seizing or sticking effect. It is this characteristic of the plastics that assists in obtaining the airtight/watertight seals needed on the Guelph Permeameter. Fittings, such as the Reservoir Valve, may stick a very little bit when first moved. However, they will then move freely.

The Soil Auger included with the Guelph Permeameter is designed for general use. Accessory auger bits are available for use in specialized situations. The 01.04.00.05.B Auger is a bucket auger to increase the ease of operation in sticky, wet soils. It is useful in wet silts and heavy clay soils. The AA.00.01.33.9 Coarse Sand Auger bits have been specifically shaped for cutting into dry, sandy soils without allowing the contents to escape and refill the augered hole. Ordering information is located in the back of this booklet, under "Accessory Items".

GENERAL CARE AND MAINTENANCE

A general cleanup is recommended as soon as practical after each field use to maintain the transparency of plastic tubes and to prevent clog-ging, scratching and fouling of Permeameter fittings by soil grit. Wipe the Permeameter with a cloth or rinse it with clean water to remove soil and grit. Make sure to pay particular attention to small openings where grit can accumulate or soil can dry and cake, such as in the Water Outlet Tip, Air Inlet Tip, Tripod Bushing, and behind the Reservoir Valve. Use a clean, soft cloth to wipe down and dry off the outer surfaces of the Permeameter.

Take apart the Permeameter for a thorough cleaning when necessary using soap and water. DO NOT USE SOLVENTS!

CAUTION: If the Permeameter is taken apart, be sure the tubes are pushed all the way to the bottom of the end caps when reassembled.

The Air Tube Coupling has an inner pair of ridges that must seat in the routed tip of the polycarbonate Air Tube. Both Air Tubes on either side of the coupling must seat similarly. The Air Tip and the Water Outlet Tip have a square shouldered seat where the Air Take Coupling must seat.

After cleaning with soap, rinse thoroughly with clean water and dry.

The various flexible plastic fittings used in the Permeameter are all friction fits to the various tubes. No cement or other sealant is used. The fittings can be disconnected by carefully "working" them off with your hands. As the Permeameter ages, however, the reservoir end caps may start to leak. This can usually be fixed by tightening with a gear/ hose clamp and/ or by placing silicone sealant on the seam.

The Reservoir Valve fits into the Reservoir Base by means of a ridge-and-groove friction fitting. To remove for cleaning, place your fingers behind the valve, brace against the Reservoir Base, and pull sharply straight out as shown in Fig. 42. The Reservoir Valve can be lubricated with vacuum grease or Vaseline if it is sticking or seizing excessively.

After cleaning the Middle Air Tube, use a toothpick or small wooden implement to remove the O-Ring Seal from the Reservoir Cap for cleaning and to reapply vacuum grease for an airtight seal. Inspect the O-Ring (M802X012) and replace as necessary. The Middle Air Tube should slide easily through the Reservoir Cap and Reservoir Base.

Special Note: At the positions where vacuum grease or Vaseline have been used, it is particularly important to clean these areas thoroughly with soap and water. Dirt or grit will accumulate at these points and must be removed and re-greased prior to re-assembly.

Fig. 42

Clean the carrying case lining regularly to prevent accumulation of soil and grit that can cause scratching of the transparent plastic tubes.

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TROUBLESHOOTING

PROBLEM	POSSIBLE REASONS
1)Well hole overfills upon initial filling	1)Too much air above the water in the reservoirs at beginning of measurement, #0 Stopper is not fully seated, Vacuum Line is not shut off with Clamping Ring.
2) Water leaks at Water Outlet Tip when Permeameter is off.	2) Air Inlet Tip is not properly seated against Air Tip Seat.
3) Well head level falls below that set by Well Head Indicator.	3) Air Tube clogged; inspect Air Restriction Washer.
4) Well Head level rises above that set by Well Head Indicator.	4) Too much air above the water in the reservoirs at beginning of measurement, #0 Stopper not fully seated, Vacuum Line is not fully shut off with Clamping Ring.
5) Stable well head level does not correspond with that set by Well Head Indicator.	5) Water Outlet Tip is not seated on the Bottom of the well hole, Well Height Indicator was not fully seated Against Reservoir Cap before raising Air Inlet Tip, Well Head Scale was not zero height set at reference to the level of the Reservoir Cap Central “Boss”. Well Height Indicator was not fully seated against the top of the Reservoir Cap Central “Boss” when marking .0 cm. Reference with Air Inlet Tip fully seated against the Air Tip Seating Washer.

The transmission of water through unsaturated soil can be described by Darcy's law:

$$q = -K(\theta)\frac{\partial H}{\partial z} = -K(\psi)\frac{\partial H}{\partial z} \qquad (1)$$

where

$$H=\Psi+z \qquad (2)$$

and q $[L^3L^{-2}T^{-1}]$ is the volume flux density of water (volume of water passing per unit time through a unit cross-sectional area of porous medium perpendicular to the direction of flow), $\delta H/\delta z$ $[LT^{-1}]$ is the hydraulic head gradient, $K(\theta)$ $[LT^{-1}]$ is the hydraulic conductivity (K) ver-sus volumetric water content (θ) relationship, $K(\Psi)$ $[LT^{-1}]$ is the hydraulic conductivity versus pore water pressure head relationship, H[L] is hydraulic head, Ψ [L] is pore water pressure head, and z [L] is elevation or gravitational head (positive upward).

When the porous medium is saturated,

$$K(\theta) = K(\Psi) = \text{constant} = K_s \qquad (3)$$

where K_s $[LT^{-1}]$ is known as the saturated hydraulic conductivity. The K_s parameter is highly sensitive to porous medium texture and structure, and as a consequence, its value ranges from as high as 10^{-2} - 10^{-4} m s^{-1} in coarse-textured and/or highly structured or cracked soils, to as low as 10^{-8} - 10^{-10} m s^{-1} in compacted, structureless clay soils and landfill liners. When hydraulic conductivity is measured via ponded infiltration into initially unsaturated soil, it is often referred to as the "field-saturated" hydraulic conductivity, K_{fs}, as some amount of air is usually entrapped in the soil by the infiltrating water. This can result in $K_{fs} \leq K_s$, but it is often argued that K_{fs} is more appropriate than K_s because most natural and man-made infiltration processes result in entrapment of air in the soil.

Ponded infiltration ($\Psi \geq 0$) into initially unsaturated soil is affected not only by K_{fs}, but also by one of several parameters that derive from the $K(\Psi)$ relationship. To illustrate this, we can conveniently use the empirical $K(\Psi)$ function of Gardner (1958):

$$K(\Psi) = K_{fs} \exp[\alpha(\Psi-\Psi_e)] \ ; \ 0 < \alpha < + \ ; \ \Psi < \Psi_e \leq 0 \qquad (4a)$$

$$K(\Psi) = K_{fs} \ ; \ \Psi \geq \Psi_e \qquad (4b)$$

where α $[L^{-1}]$ is a slope parameter that depends primarily on soil texture and structure, and Ψ_e [L] is the air-entry or water-entry pressure head, depending on whether the soil is draining or wetting, respectively. Integrating (4a) between $\Psi = \Psi_i$ and $\Psi = \Psi_e$ produces,

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$$\phi_m = \int_{\psi_i}^{\psi_e} K(\psi)d\psi = \frac{K_s - K_i}{\alpha} \approx \frac{K_s}{\alpha^*} \quad (5)$$

where Φ_m [L^2T^{-1}] is the matric flux potential, Ψ_i L] is the initial or back-ground pore water pressure head in the unsaturated porous medium, and K_i [LT^{-1}] is the initial or background hydraulic conductivity corresponding to Ψ_i. The Φ_m parameter is an indicator of the capillary pull or "capillarity" exerted by the unsaturated porous medium on the water during an infiltration or drainage process. Under saturated conditions, $\phi_m = 0$ because $K_i = K_s$ in (5).

In most natural unsaturated soils we can assume that:

$$\alpha \approx \alpha^* \equiv \frac{K_{fs}}{\phi_m} = -\frac{1}{\psi_f} = \left|\frac{1}{\psi_f}\right| \quad (6)$$

where the macroscopic capillary length parameter, α^* [L^{-1}], represents the ratio of gravity to capillarity forces during infiltration or drainage and Ψ_f [L] (negative in value) represents the effective wetting front pressure head of the Green-Ampt infiltration model (Green and Ampt, 1911). Large α^* values indicate dominance of gravity over capillarity, which occurs primarily in coarse textured and/or highly structured porous media. Small α^* on the other hand, indicate dominance of capillarity over gravity, which occurs primarily in fine textured and/or unstructured porous media. Although, K_{fs} and $\phi_m$can individually range over many orders of magnitude in a porous medium, α^* generally varies from about 0.01 cm^{-1} to 0.5 cm^{-1}. The reduced variability of α^*, along with its connection to porous medium texture and structure, make it a useful parameter in simplified single-head analyses for estimation of K_{fs} and $\phi_m$in unsaturated porous media (dis-cussed further below, and in Reynolds et al., 2002).

Sorptivity (S) is a measure of the ability of an unsaturated porous medium to absorb or store water as a result of capillarity. The S and ϕ_m parameters for one-dimensional flow under a constant head H are related by (White and Sully, 1987):

$$S_H = \left\{\frac{(\Delta\theta)\phi_m}{b} + 2(\Delta\theta)K_{fs}H\right\}^{1/2} \quad (7)$$

where $\Delta\theta = (\theta_{fs} - \theta_i)$, θ_{fs} ($L^3 L^{-3}$) is the field-saturated volumetric soil water content, θ_i ($L^3 L^{-3}$) is the initial volumetric soil water content, b is a dimensionless empirical constant, and H is the applied constant head of water. Setting b = 0.55 for infiltration gives an error of less than 10% in S_H. The first term in (7) gives the sorptivity, S_0, for H = 0 and the second term gives the increase in sorptivity due to the positive (ponded) head, H. Note that either ϕ_m or S or α^* are needed along with K_{fs} to predict and characterize ponded infiltration into unsaturated porous media. Note also that under saturated conditions, $S_H = 0$ because $\Delta\theta = 0$ in (7) (i.e. $\theta_i = \theta_{fs}$). See Elrick and Reynolds (1992a) for the equation to obtain S using the Guelph Permeameter.

MODE OF OPERATION

The Guelph Permeameter is an in-hole constant-head Permeameter, employing the Mariotte Principle. The method involves measuring the steady-state rate of water recharge into unsaturated soil from a cylindrical well hole, in which a constant depth (head) of water is maintained.

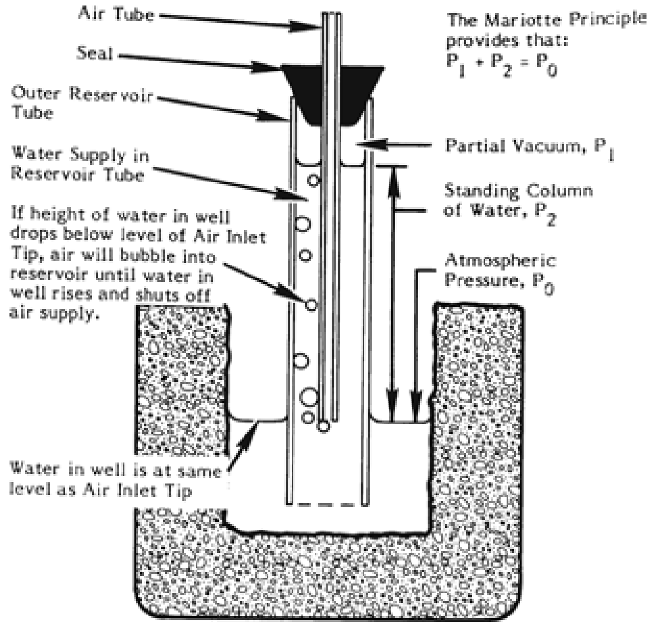

Fig. 43

A constant head level in the well hole is established and maintained at the level of the bottom of the air tube by regulating the position of the bottom of the Air Tube, which is located in the center of the Permeameter. As the water level in the reservoir falls, a vacuum is created in the air space above the water. The vacuum can only be relieved when air of ambient atmosphere pressure, which enters at the top of the Air Tube, bubbles out of the Air Inlet Tip and rises to the top of the reservoir. Whenever the water level in the well begins to drop below the Air Inlet Tip, air bubbles emerge from the tip and rise into the reservoir air space. The vacuum is then partially relieved and water from the reservoir replenishes water in the well. The size of opening and geometry of the Air Inlet Tip is designed to control the size of air bubbles in order to prevent the well water level from fluctuating.

When a constant well height of water is established in a cored hole in the soil, a “bulb” of saturated soil with specific dimensions is rather quickly established (Fig. 44). This “bulb” is very stable and its shape depends on the type of soil, the radius of the well and head of water in the well. The shape of the “bulb” is included in the value of the C factor (Reynolds et al., Groundwater Monitoring Review 6:1:84-95, 1986) used in the calculations.

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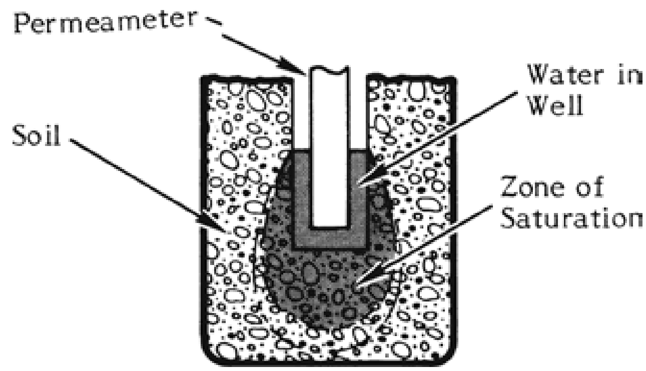

Fig. 44

Once the unique “bulb” shape is established, the outflow of water from the well reaches a steady-state flow rate, which can be measured. The rate of this constant outflow of water, together with the diameter of the well, and height of water in the well can be used to accurately determine the field saturated conductivity, matric flux potential, α^* parameter and sorptivity of the soil.

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GOVERNING ANALYTIC EQUATIONS

The analysis of steady-state discharge from a cylindrical well in unsaturated soil, as measured by the Guelph Permeameter technique, accounts for all the forces that contribute to three dimensional flow of water into soils: the hydraulic push of water into soil, the gravitational pull of liquid out through the bottom of the well, and the capillary "pull" of water out of the well into the surrounding soil.

GENERALIZED CALCULATIONS - C-FACTOR

The C Factor is a numerically derived shape factor, which is dependent on the well radius a and head H of water in the well. Fig. 46 below shows the "C" curves for three classes of soil. Empirical equations adapted from (Zang et al., 1998) were used to calculate the "C" values.

The upper curve, C_1, is used for conditions where the estimated α^* value is ≥ 0.12 cm^{-1}, the middle curve, C_2, for $\alpha^* = 0.04$ cm^{-1}, and the lower curve, C_3, for $\alpha^* =$ 0.01 cm^{-1}.

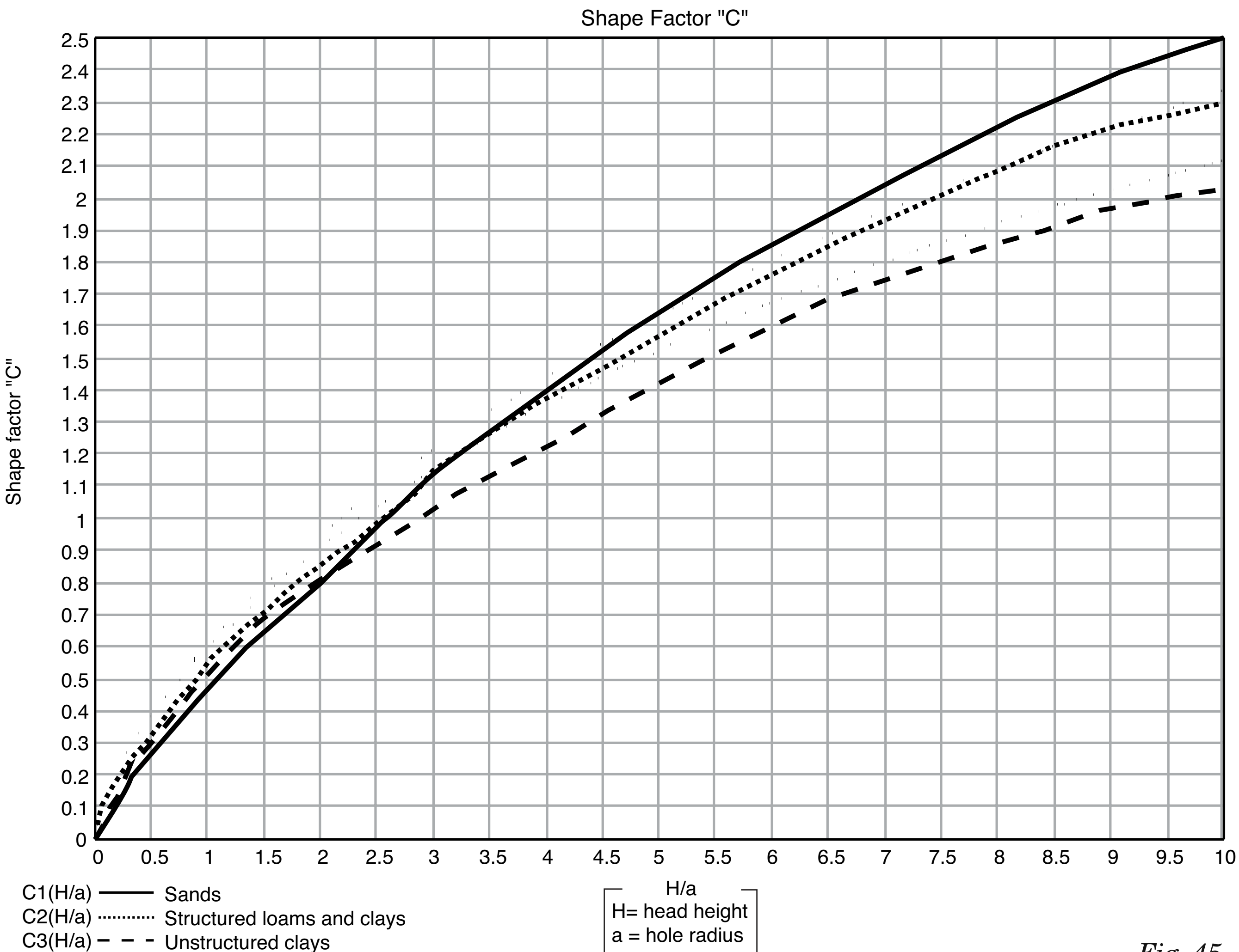

Fig. 45

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"C" values can be read from Fig. 45 or calculated directly from the equations given below:

$$C1 = \left(\frac{H/a}{2.074 + 0.093(H/a)}\right)^{0.754} \qquad C2 = \left(\frac{H/a}{1.992 + 0.091(H/a)}\right)^{0.683}$$

$$C3 = \left(\frac{H/a}{2.081 + 0.121(H/a)}\right)^{0.672}$$

ONE-HEAD ANALYSIS

$$K_{fs} = \frac{C_1 Q_1}{2\pi H_1^2 + \pi a^2 C_1 + 2\pi \dfrac{H_1}{\alpha^*}}$$

$$\phi_m = \frac{C_1 Q_1}{\left(2\pi H_1^2 + \pi a^2 C_1\right)\alpha^* + 2\pi H_1}$$

where α^* is obtained from the site analysis and Table 1.

Note that $Q_1 = XR_1$ or YR_1, depending on whether the combination reservoir was used (X) or the inner reservoir was used (Y).

TWO-HEAD ANALYSIS

$$K_{fs} = G_2 Q_2 - G_1 Q_1$$

where

$$G_1 = \frac{H_2 C_1}{\pi\left(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1)\right)}$$

$$G_2 = \frac{H_1 C_2}{\pi\left(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1)\right)}$$

Note that $Q_1 = XR_1$ or YR_1 and $Q_2 = XR_2$ or YR_2.

$$\phi_m = G_3 Q_1 - G_4 Q_2$$

where

$$G_3 = \frac{\left(2H_2^2 + a^2C_2\right)C_1}{2\pi\left(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1)\right)}$$

$$G_3 = \frac{\left(2H_1^2 + a^2C_1\right)C_2}{2\pi\left(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1)\right)}$$

$$\alpha = K_{fs}/\phi_m.$$

GLOSSARY

a	Well radius, in cm.
C	Shape factor dependent primarily on the $H_{/a}$ ratio
C_1, C_2	C factors corresponding to $H_{/a}$ and $H_{2/a}$, respectively
GP	Guelph Permeameter
H_1, H_2	Well height for first and second measurements respec tively, in cm.
K	Hydraulic conductivity, in cm/sec.
K_{fs}	Field-saturated hydraulic conductivity (entrapped air present), in cm/sec.
$K(\varphi)$	Hydraulic conductivity/pressure-head relationship for unsaturated flow.
R	Rate of fall of water in the Reservoir Tube of the Permeameter, in cm/min.
$\bar{R}$	Steady-state rate of fall.
$\bar{R}_1$, $\bar{R}_2$	Steady State rate of fall corresponding to H_1 and H_2, respectively, and converted to cm/sec.
S	Sorptivity, in cm/sec$^{1/2}$
α	Alpha Parameter, slope of the line relating the natural log of K, hydraulic conductivity, to Q, the soil water pressure head, in cm^{-1}.
θ_i	Initial volumetric water content in the soil, in cm^3/cm^3.
θ_{fs}	Field-saturated volumetric water content of the soil (entrapped air present), in cm^3/cm^3.
$\Delta\theta = (\theta_{fs} - \theta_i)$,	Difference between field saturated and AMBIENT (INITIAL) VOLUMETRIC WATER CONTENT OF SOIL, in cm^3/cm^3.
ϕ_m	Matric flux potential in cm^2/sec.
ψ	Soil water pressure head, measured in cm of water.

Table 1. Soil texture-structure categories for site-estimation of α^* (adapted from Elrick et al., 1989)

Soil Texture - Structure Category	α^* (cm^{-1})
Compacted, structureless, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.	1.01
Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12
Coarse and gravelly sands; may also include some highly structured soils with large and/or numerous cracks, macropores, etc.	0.36

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GP FIELD DATA SHEET **SECTION 1: SITE INFORMATION**

Date ____________ Investigator ____

Site Location ____

Dominant Soil Type(s) ____

Site Map:

Soil Profile Description (horizon depth, texture, structure, color, etc.):

Depth Description

Presence of special soil conditions (mottling, water table depth, hardpan, induration, compacted layers, etc.):

Comments and Notes (topography, slope, vegetation, etc.):

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GP FIELD DATA SHEET

SECTION 2: STANDARDIZED PROCEDURE FOR PERMEAMETER READINGS AND CALCULATIONS

Date__________Investigator____________________

Reservoir Constants: (See label on Permeamter)

Combined Reservoirs X	cm²	☐	CHECK RESERVOIR USED
Inner Reservoir Y	cm²	☐	

Depth of Well Hole__________

Note: In standardized procedure the radius of the well hole is always 3.0 cm

1st Set of Readings with height of water in well (H_1) set at 5 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_1, (CM/MIN)

2nd Set of Readings with height of water in well (H_2) set at 10 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_2, (CM/MIN)

CALCULATIONS

$\bar{R}$, the steady state rate of flow, is achieved when R is the same in three consecutive time intervals.

For the 1st Set of Readings $\bar{R}_1 = (\underset{R_1}{\_\_\_\_\_\_\_})/60 = \_\_\_\_\_\_\_$ cm/sec

For the 2nd Set of Readings $\bar{R}_2 = (\underset{R_2}{\_\_\_\_\_\_\_})/60 = \_\_\_\_\_\_\_$ cm/sec

K_{fs} = [(.0041)(_______)(_______)] - [(.0054)(_______)(_______)] = _______ cm/s

FIELD SATURATED HYDRAULIC CONDUCTIVITY; RESERVOIR CONSTANT; $\bar{R}_2$ - STEADY STATE RATE OF FLOW; RESERVOIR CONSTANT; $\bar{R}_1$ - STEADY STATE RATE OF FLOW

ϕ_m = [(.0572)(_______)(_______)] - [(.0237)(_______)(_______)] = _______ cm²/

MATRIC FLUX POTENTIAL; RESERVOIR CONSTANT; $\bar{R}_1$ STEADY STATE RATE OF FLOW; RESERVOIR CONSTANT; $\bar{R}_2$ STEADY STATE RATE OF FLOW

$\alpha = (\underset{K_{fs}}{\_\_\_\_\_\_\_}) / (\underset{\phi_m}{\_\_\_\_\_\_\_}) = \_\_\_\_\_\_\_\ cm^{-1}$

ALPHA PARAMETER

$\Delta\theta$ = (______________) - (____________) = _______ cm³ / cm³

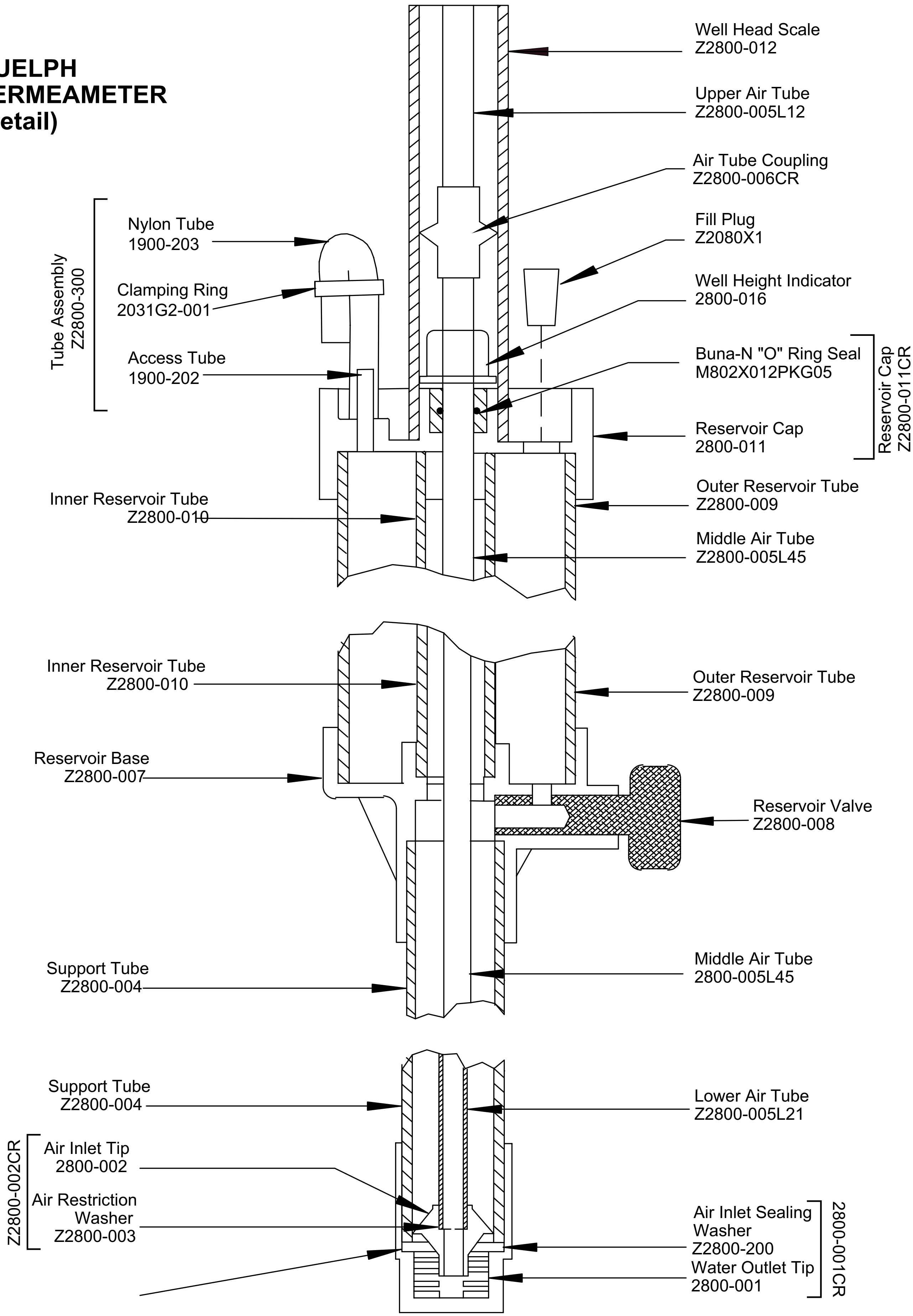
DELTA THETA; θ_{fs}, FIELD SATURATED WATER CONTENT OF SOIL, IN CM/CM; θ_i, AMBIENT WATER CONTENT OF SOIL, IN CM/CM

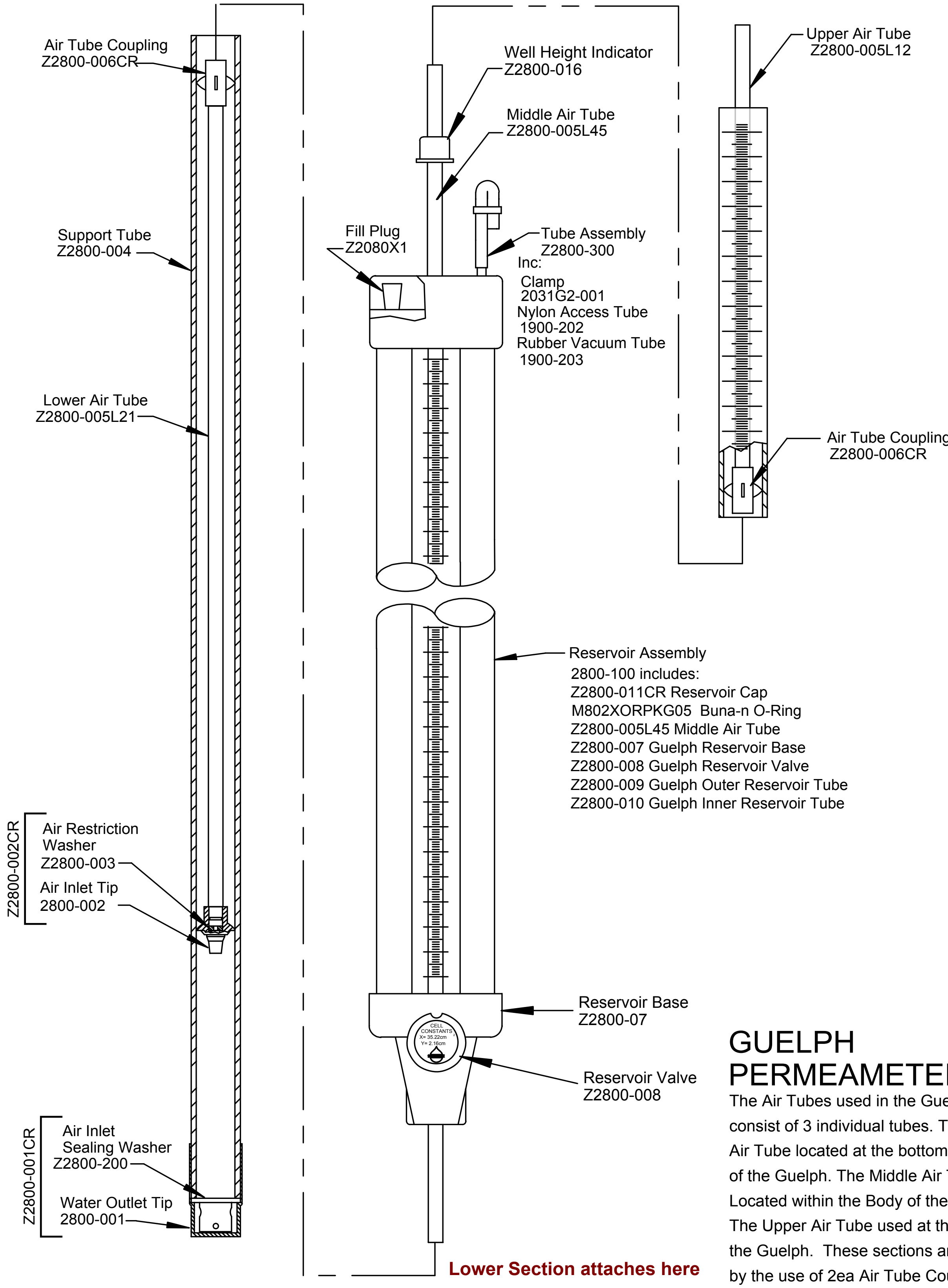
ESTIMATED	☐	CHECK ONE
MEASURED	☐	

$S = \sqrt{2(\underset{\Delta\theta}{\_\_\_\_\_\_\_})(\underset{\phi_m}{\_\_\_\_\_\_\_})} = \_\_\_\_\_\_\_\ cm\ sec^{-1/2}$

SORPTIVITY

GUELPH PERMEAMETER (Detail)





GUELPH PERMEAMETER

The Air Tubes used in the Guelph consist of 3 individual tubes. The Lower Air Tube located at the bottom section of the Guelph. The Middle Air Tube Located within the Body of the Guelph. The Upper Air Tube used at the top of the Guelph. These sections are linked by the use of 2ea Air Tube Couplings.

SOILMOISTURE EQUIPMENT CORP.
P.O. Box 30025, Santa Barbara, CA 93105 U.S.A.
Telephone 805-964-3525 - Fax No. 805-683-2189
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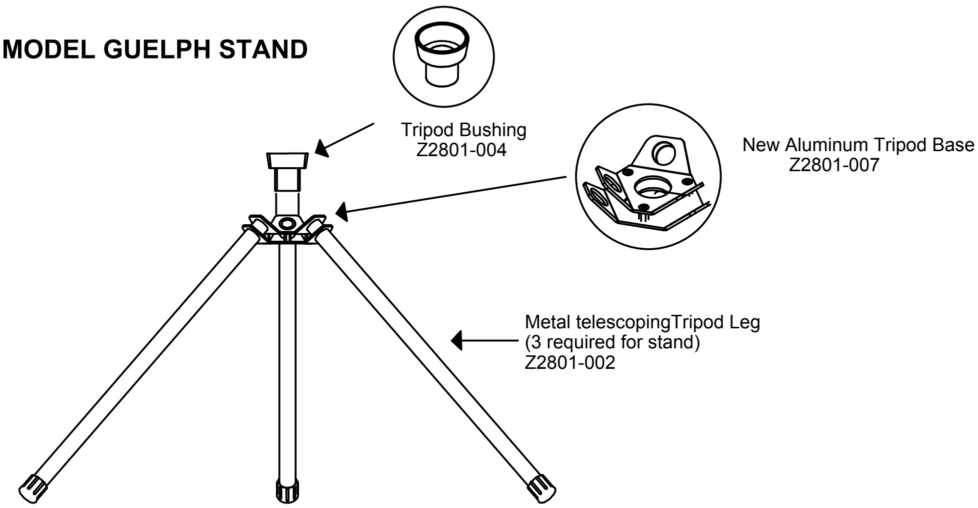
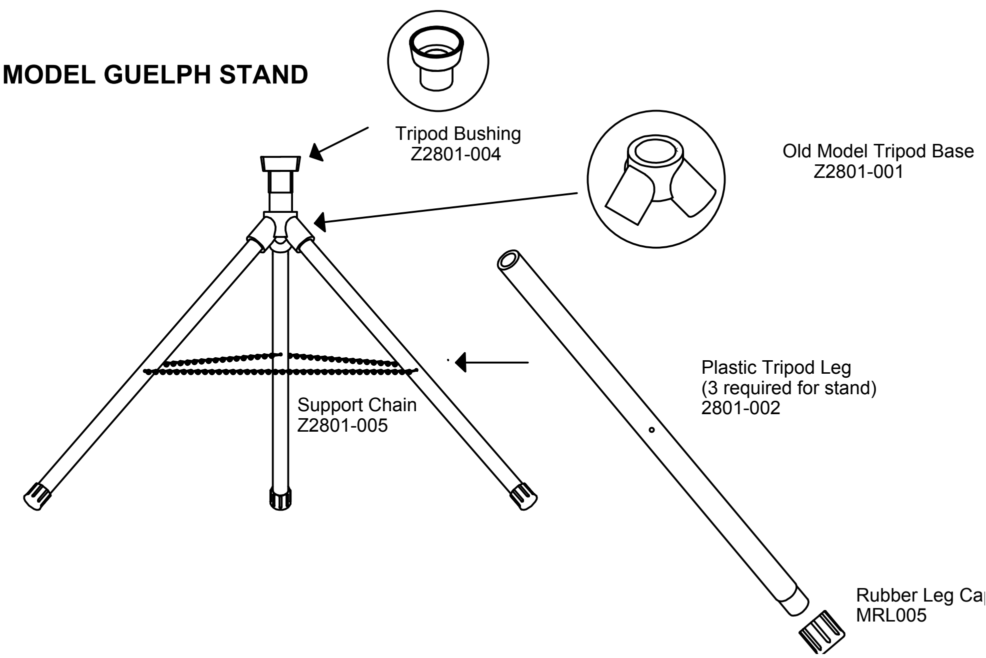
NEW MODEL GUELPH STAND



OLD MODEL GUELPH STAND



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PARTS LIST

Z2800-001CR	Water Outlet Tip
Z2800-002CR	Air Inlet Tip
Z2800-003	Air Restriction Washer
Z2800-004	Support Tube
Z2800-005L12	Upper Air Tube
Z2800-005L21	Lower Air Tube
Z2800-006	Air Tube coupling
Z2800-007	Reservoir Base
Z2800-008	Reservoir Valve
Z2800-009	Outer Reservoir Tube
Z2800-010	Inner Reservoir Tube
Z2800-011CR	Reservoir Cap
Z2800-012	Well Head Scale
Z2800-013	Extension Coupling
Z2800-016	Well Height Indicator
Z2800-200	Air Tip Seating Washer
Z2801-007	New Model Tripod Base
Z2801-002	Tripod Leg
MRL005	Leg Tip
Z2801-004	Tripod Bushing
Z2801-005	Tripod Support Chain
Z2801-006	Tripod Support Sleeve (old style)
2804-003	Sizing Auger
2803	Carrying Case
2804-002	Well Prep Brush
2804-006	Guelph Combination Auger diam. 6 cm
0234SHDLB	Handle
Z2800-300	Tube Assembly
1900-202	Access Tube
1900-203	Vacuum Tube
2005G2	Vacuum Hand Pump
2031G2-001	Clamping Ring, 1 doz
2038V3	Water Container (3 gal.)
2038V3-001	Water Container Tube

ACCESSORIES

2800K2 Extension Kit, 80 cm long

Consists of:

2800-004	Support Tube
2800-005L31	Air Tube Extension
2800-006	Air Tube Coupling
2800-013	Support Tube Coupling

0234RVB06	Riverside Auger diam. 6 cm
0243SHDLBXL100	Extension, 1 meter (includes coupling)
0234SLB	Coupling Sleeve
2806F1	Heavy Duty Guelph Stand, Improved
2800K4	Guelph Permeameter only (No case)
2800K5	2800K2 + 0234SHDLBXL100

RENTAL INFORMATION

See www.soilmoisture.com

ATTACHMENTS

2805D10	Pressure Infiltrometer Adapter Kit (require 2800K1 for operation)
2805D20	Pressure Infiltrometer Adapter Kit (require 2800K1 for operation)
2825	Pressure/Tension Infiltrometer Adapter Kit (requires 2800K1 for operation)
2805D10K1	Pressure Infiltrometer Complete Adapter Kit (does not replace 2800K1)
2805D20K1	Pressure Infiltrometer Complete Adapter Kit (does not replace 2800K1)
2825K1	Pressure/Tension Infiltrometer Complete Kit (does not replace 2800K1)

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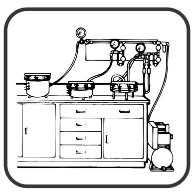
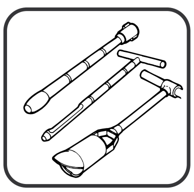
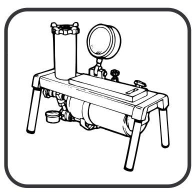
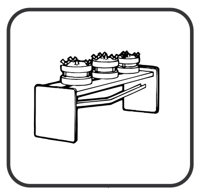

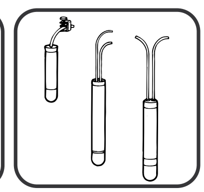
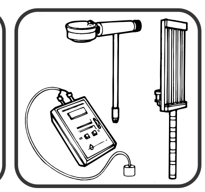

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