2840 OPERATING INSTRUCTIONS

Aardvark Permeameter — January 2016

Model 2840K2 Series

Manual Aardvark Measurements
(0.2 ml accuracy, 50 ft operating depth)

2840K2 Aardvark Kit complete in case

Model 2840K2PC Series .

Automated Aardvark Measurements
(0.2 ml accuracy, 50 ft operating depth)

2840K2PC Aardvark Kit complete in case

Models 2840K1 and 2840K2 for Quick and Easy K_{sat} Measurements

The Aardvark Permeameter is an easy to use instrument to quickly and accurately measure in-situ saturated water flow. Accurate evaluation of soil hydraulic conductivity and matrix flux potential can be made in almost all types of soils.

Model 2840K#PC for Automated K_{sat} Measurements (#: 1 or 2)

If you purchased the PC Kit, this will automate taking K_{sat} readings with the addition of a digital scale 7201W10.

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UNPACKING

The Aardvark Permeameter Kit was thoroughly tested before shipment. When packed, it was in perfect working order. Unpack with care making sure you remove all packing material. Follow the instructions carefully in order to assure long, trouble-free service.

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.

CAUTIONS & WARNINGS

In order to avoid damage to the device and injury, use only those tools included. When completely full, the water container is relatively heavy and additional weight should be taken into account. In order to prevent damage to scale or other parts of the system, make sure that the table is placed on a stable hard surface. Do not use larger volume water containers or replacement containers other than those supplied with your unit.

WARRANTY & LIABILITY

Soilmoisture Equipment Corp. (SEC) warrants all products manufactured by SEC to be free from defects in materials and workmanship under normal use and service for twelve (12) months from the date of invoice provided the section below has been met.

Soilmoisture Equipment Corp. (SEC) is not liable for any damages, actual or inferred, caused by misuse or improper handling of its products. SEC products are designed to be used solely as described in these product operating instructions by a prudent individual under normal operating conditions in applications intended for use by this product.

ACQUAINT YOURSELF WITH THE PARTS

Model 2840K1 & 2840K2 Aardvark Permeameter - For Quick and Easy K_{sat} Measurements

The Aardvark Permeameter Kit (2840K1 for measurements shallower than 3 m (11 ft) and 2840K2 for measurements deeper than 3 m) has everything needed for conducting the measurement and is simple to install and use. Since it has no electronic parts, it can be used everywhere from laboratories to remote areas. At the same time, the kit can be used with a personal computer (not included) and using the SimplyData Software Suite, with no need for manually calculating the parameters.

Fig. 1. Illustration of 2840K1 / 2840K2 components

1. Aardvark Carrying Case
2. Tape Holder
3. Aardvark Permeameter Module
4. Aardvark Reservoir
5. Countdown Timer
6. Flash drive loaded with SimplyData Software Suite
7. Measuring / Suspension line, 15 m (50 ft)
8. Connecting Tube, 15 m (50 ft)
9. Reservoir Outlet Assembly
10. Aardvark Pressure Regulator Unit (not included in 2840K1).
11. Support Package
12. Aardvark Table
13. Tubing Clip
14. Operating Instructions

Aardvark Support Package

1. Hose Clamp
2. SEC 2 Color Pen
3. SEC LED Flash Light
4. Tubing Clip
5. Pin Access Tool
6. Silicon Grease
7. Quick Connection Insert
8. Tubing Barbed Connector
9. Plastic Connection Pin
10. SEC All Weather Notebook
11. SEC Measuring Tape

Model 2840K1PC & 2840K2PC Automated Aardvark Permeameter

These kits consist of an Aardvark Permeameter Kit (2840K1 for measurements shallower than 3 m (11 ft) or 2840K2 for measurements deeper than 3 m) and a Digital Scale (7201W10) which can be connected to a personal computer (not included) and record the measurements automatically and accurately, using the SimplyData Software Suite. There is no need to manually record data or perform the calculations. It is also possible to view the real-time graph of soil-water flux rate during the measurement period. This kit is a perfect option for laboratory experiments where it can easily be connected to a personal computer. It can also be used in the field using a portable laptop computer. This model can even be used to take manual readings (when no PC is available). Using the digital scale significantly adds to the accuracy of readings.

Fig. 2. Photo of 2840K1PC / 2840K2PC

1. Aardvark Permeameter Kit
2. Scale Carrying Case
3. USB Cable
4. SimplyData Digital Scale
5. Scale Power Supply (not shown)
6. Scale Operating Instructions (not shown)

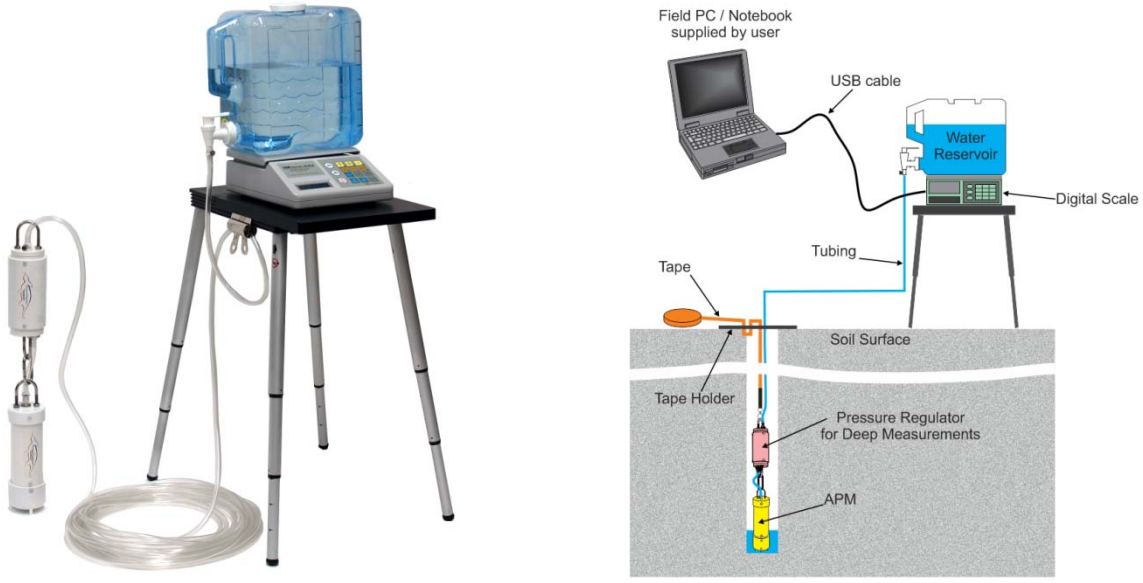

Fig. 3. Right: Model 2840K2PC. Left: Illustration of the model components: a USB cable connects the Digital Scale to a PC (not included). Real time graphs and calculations and data logging are the main features of SimplyData Software Suite installed on your PC. The kit also can be used without a PC (manual data recording and calculation).

AARDVARK GENERAL SPECIFICATIONS

2840-1000 Aardvark Permeameter Unit (comes in 2840K1, 2840K2, 2840K1PC, and 2840K2PC)

Diameter (OD x L): 7.6 x 35.6 cm (3" x 14")
Minimum water supply rate (with 3 ft of water overhead pressure): 1000 ml / min (0.26 gal / min)
Maximum operational depth 15 m (50 ft)

2840-1003-01 Aardvark Reservoir (comes in 2840K1, 2840K2, 2840K1PC, and 2840K2PC)

Volume: 8 liter (2 gal) weight when full about 8 Kg (17.6 lbs.)
Dimensions (L x W x H): 25 × 18 × 23 cm (10" x 7" x 9")

2842 Aardvark Table (comes in 2840K1, 2840K2, 2840K1PC, and 2840K2PC)

Table Top Dimensions (L x W): 38 × 26 cm (15" x 10½")
Height: from 33 to 73 cm (13" to 29")

2843 Aardvark Carrying Case (comes in 2840K1, 2840K2, 2840K1PC, and 2840K2PC)

Dimensions (L x W x H): 71 × 43 × 18 cm (28" × 17" × 7")
Weight When Full: 6.6 Kg (14.6 lbs.)

7201W10 10Kg Digital USB Scale (comes in 2840K1PC and 2840K2PC)

Maximum load: 10 Kg
Resolution: 0.2 g
Dimensions (L x W x H): 26.4 × 20.1 × 7.9 cm (10.4" × 7.9" × 3.1")
Platform Size: 5.7" x 7.5"
Weight 1.05 Kg (2.3 lbs.)
Power Consumption: 0.035 W

8010SDS02 SimplyData Software Suite (comes in 2840K1, 2840K2, 2840K1PC, and 2840K2PC)

System requirements:
Windows 2000 or newer,
Minimum display resolution of 1024x768 and
.NET Framework (included in Windows Vista and newer)

2840-2000 Aardvark Regulator Unit (comes in 2840K2 and 2840K2PC)

Maximum operating range: 34 KPa (5 PSI)
Minimum operating range: 690 KPa (100 PSI)
Diameter (OD x L): 7.6 x 31 cm (3" x 12")
Operational depth with Aardvark unit: from 3 m (10 ft) to 15 m (50 ft)

THEORY OF OPERATION and DEFINITIONS

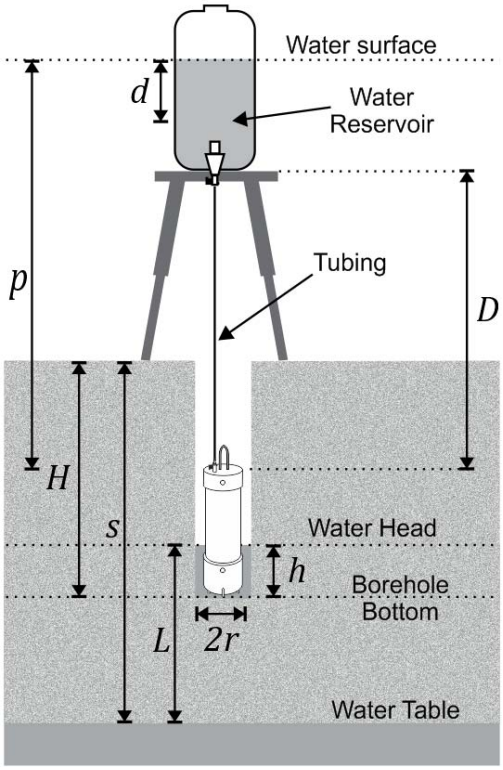

Fig. 4. Schematic of a Standard Setup of an Aardvark Permeameter. Where d is drop in reservoir water level, D is vertical distance between Reservoir and APM, H = borehole depth, r = borehole radius, h = constant water head height in borehole, p = vertical distance between water surface in reservoir and constant water head, s = water table depth and L = the vertical distance between constant water head and water table / impervious layer.

Saturated hydraulic conductivity (K_{sat}) is an indicator of water flow rate in soil and is a key parameter for studying water flow and chemical transport through a soil profile. These measurements can be vital to scientific and engineering studies. For example, it can be used in leach line placement in rural sewer systems and determine limits of rain/runoff conditions, and the ability of holding ponds to retain water.

The Aardvark is a constant-head permeameter. This means that the depth of water in the borehole (h) does not change during the measurement period (Fig. 6). As a result, the measurement conditions remain constant during the measurement period. The rate of water supplied corresponds to soil infiltration rate from the bottom and side surfaces of the testing borehole.

The Aardvark Permeameter estimates soil hydraulic conductivity using the amount of supplied water (determined using d) measured at equal time intervals (Fig. 6). This is equivalent to the amount of water that was infiltrated by soil. Soil-water infiltration rate is the amount of percolated water over time which is equivalent to the reservoir flow rate (see equation below).

$$reservoir\ flow\ rate = \frac{reservoir\ water\ change}{time}$$

The measurement ends when the reservoir flow rate (soil-water infiltration rate) does not change over several consecutive readings. Soil hydraulic conductivity (K_{sat}) then can be calculated using this steady flow rate (Q). For more details see section "*Calculations and Applications*".

REQUIREMENTS PRIOR TO USE

Before making a measurement with the Aardvark Permeameter (APM) in the field, it is recommended 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 and intended for testing of the soils under study.

The suggested borehole diameter is about 10 cm (4"). Your APM will establish a stable water head height in the borehole. This standard combination is practical for almost all soils. For soils with very fine textures such as heavy clays a wider borehole can be used (not suggested) as well as higher head heights. Conversely, open textured soils such as coarser sands may do better with smaller borehole diameters.

The Aardvark Permeameter is designed to be installed in a borehole in soil profile from 20 cm (7.9") to 15 m (50 ft) depth. Therefore before installing the Aardvark Permeameter a borehole will need to be prepared. The equipment needed to dig a borehole depends on the width and depth desired. Our Model 0237D10L10 contains all the required tools and instructions to auger and clean a borehole with a 10 cm (4") width (recommended width for the Aardvark) down to a 3 m (10 ft) depth.

This set includes:

1. Loam Soils Auger
2. Auger Extension (30")
3. Well Prep Brush
4. Carrying bag
5. Sizing Auger
6. Auger Handle

Fig. 5. Model 0237D10L10 components.

If you are using the Model 2840K1, 2840K2, 2840K1PC, or 2840K2PC and want to record the readings manually, we have a provided a data sheet in Appendix A for your convenience. We suggest a rugged pen or pencil for taking readings and notes. As part of your Aardvark Kit we have supplied a Countdown Timer to take readings on a scheduled basis. It is also advisable to have access to additional water in order to refill the reservoir in porous soils and for multiple tests. Please note that water used in permeameter tests should be clear and free of debris as it could have an effect on internal regulator functionality and on weight of water use calculations; therefore clean pure water is advised for all testing.

On windy days it may be difficult to read the water level in Reservoir. Wind also may have a negative effect on Digital Scale accuracy. In the case of severe wind the system can be set up inside a tent.

Operating Model 2840K1 and Model 2840K2

Aardvark Pressure Regulator Unit (RU)

In these instructions, we refer to “Shallow Measurements” for measurements with a *D* (Fig. 6) less than 3.44 m (11.3 ft) using only the Aardvark Permeameter Module (no RU in line). We also refer to “Deep Measurements” - measurements with a D more than 3.44 m (11.3 ft) using the RU and APM in line.

For Deep Measurements use the RU in line with the Aardvark Permeameter Module (Shallow Measurements do not require the use of an RU; the APM can be connected directly to the Reservoir). Install the RU above the APM (with minimum vertical distance). If you need to perform a Deep Measurement, follow these steps:

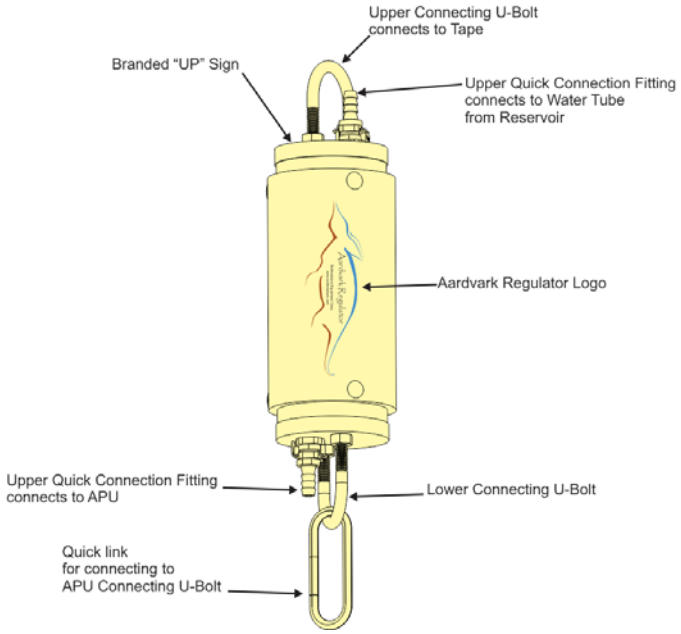

Fig. 6. Aardvark Regulator Unit

Determine input and output of the RU. The RU is completely symmetrical, so it is very important to install the RU right side up. (The Aardvark in the Logo should be “crawling out of the hole”). The RU input tube is towards the Aardvark head in logo (up). The input tube connects the RU to the Reservoir. The RU output tube is towards Aardvark’s tail in the logo (down). The RU output (Fig. 8) connects the RU to the APM. If, for any reason, the Aardvark Regulator logo cannot be clearly seen on the RU, there is a Branded “UP” sign on the top of the RU that can be used for proper orientation.

Connect the Quick Link to the RU’s Lower U-Bolt. The Quick Link provides an easy and secure connection between the two units.

Connect the RU output to the APM Quick Connection using the RU-APM connection tube.

Connect the RU input to the Reservoir using the Connection Tube.

Components of the Aardvark Permeameter Module (APM)

The Aardvark Permeameter Module is shipped completely assembled and ready to use (Fig. 9 left). The Aardvark Permeameter Module has three major parts: The Head Cap, The Body Tube and The Dispersive End Cap (Fig. 9, right).

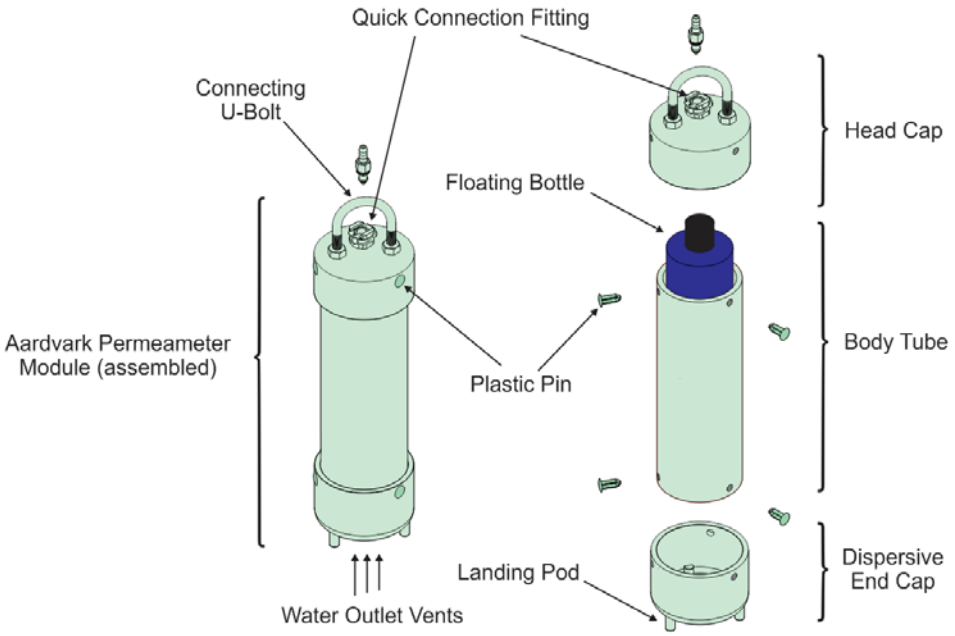

Fig. 7. Left: assembled Aardvark Permeameter Unit. Right: Major Components of APM.

On the top of the Head assembly there is a stainless metal U-Bolt (UB) for connecting to the Suspension Line (Measuring Tape) or Quick Link of the Pressure Regulator (Fig. 8). It is used for hanging and lowering the APM in a Borehole. The Quick Connection (QC) provides an easy and secure connection between the Head Assembly and Connecting Tubing (Fig. 9 right).

The Body Tube creates a head height about 7.5 cm deep (see section "*Installing APM in a Borehole*" for more details).

The Dispersive End Cap lands on the bottom of Borehole and serves as a base for the Permeameter and disperses the energy of out-flowing water from the vents and minimizes the risk of erosion of Borehole surfaces.

Assembling your Reservoir Unit:

Connect the Quick Connection provided in the Kit to the end of Tubing (Fig. 10a). The other end of Tubing connects to the APM or RU (if using an RU).

Connect the Valve to Reservoir and make sure the Valve is closed (Fig. 10b).

Connect the Quick Connection (Tubing) to Reservoir Valve (Fig. 10c).

Fill the Reservoir with clean water.

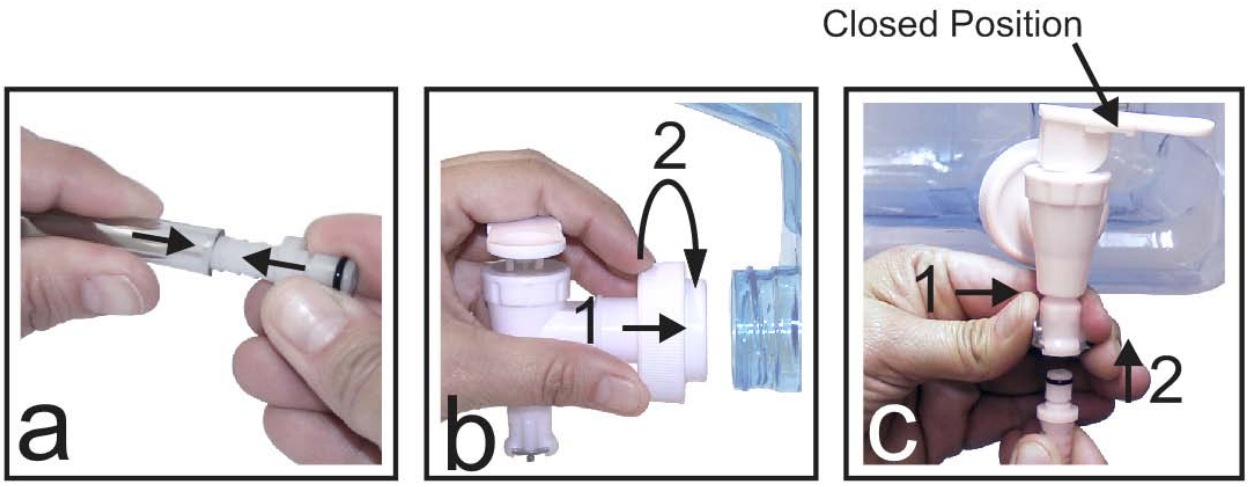

Fig. 8. Reservoir Assembly.

Assembling Aardvark Table

Slide open the Aardvark Table Cover (Fig. 11a).

Open each telescopic leg to the proper length and twist it until it is locked at the desire length (Fig. 11b). Use only 2/3 of the table height (56 cm) to add to its strength and stability. This height provides the proper amount of overhead pressure for shallow measurements.

Place the O-ring in the proper position. The small O-ring on the top of the leg may be a little off-set (Fig. 11c) and the leg may not be positioned correctly in the hole. Make sure the O-ring is in its proper place (Fig. 11d).

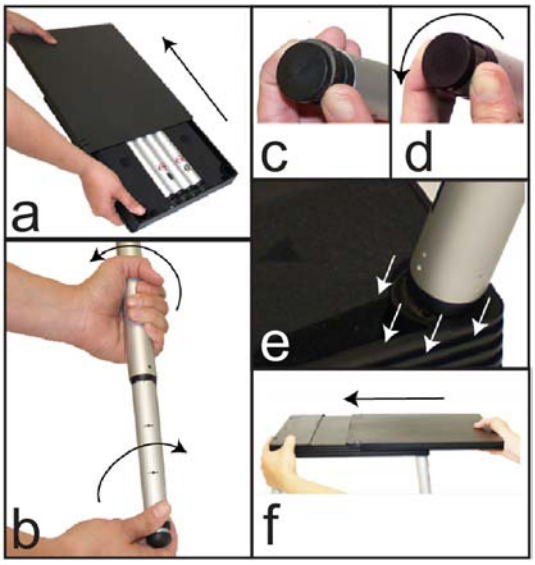

Fig. 9. Assembling Aardvark Table.

Put the top of each leg in its base under the table top (Fig. 11e) and turn it until it locks. Please note that the legs are <u>not</u> completely perpendicular with the table top.

Slide the cover over the table top (Fig. 11e). It is important to place the Table on a sturdy surface so the legs do not penetrate into the soil and the Table is steady and level.

Table Placement

Place the Table next to the borehole. Try to position the Reservoir directly over the Borehole opening. This will eliminate excess water in the Connecting Tubing and allow for the most direct path between the Reservoir and the APM in the hole. Clear excess leaves, dried grass, and soil from the edge of the borehole and around the Table to prevent these materials from falling down the borehole during the test. Do not step on or across the well hole during the testing process.

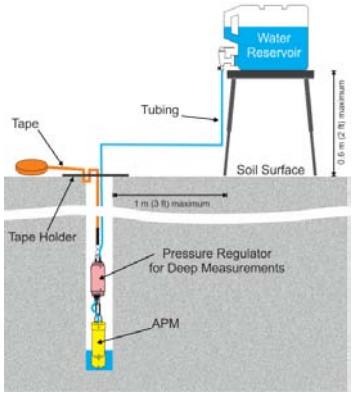

Fig. 10. Schematic positioning of Aardvark Permeameter components.

Connecting Tubing and Suspension Line

You may need to cut the Tubing according to the distance between the Reservoir and the APM (Fig. 12). Should you need to cut the Tubing, always cut a few feet longer than what you need. If you cut the Tubing too short, you can always reconnect the two pieces using a Tubing Coupler provided in the support kit.

Fig. 11. Connecting two pieces of tubing using a Tubing Coupler.

Connect the QC fitting to the end of Tubing. Make sure that the fitting is fully inserted to prevent leaking (Fig. 14a). Do not use lubrication. This will increase the risk of leakage or the tubing may disconnect under pressure in Deep Measurements.

Connect the fitting to its base. Depending on the depth of your measurement, the Tubing from the Reservoir can either be connected directly to the APM (for Shallow Measurements) or to the RU (for Deep Measurements). Push in the small lever on the side of the base and connect the fitting (Fig. 14b). It is important to make sure that Tubing does not leak water.

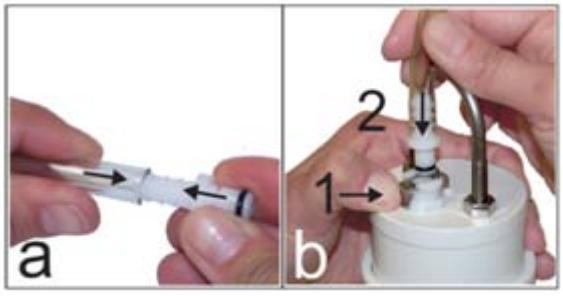

Fig. 12. Connecting the Quick Connection to the RU.

Connect the Tape Hook (Fig. 17). For Deep Measurements you will need to add the Pressure Regulator Unit in the line above the APM Unit (Fig. 16 right). Note that when the APM hangs from the Tape (with no Regulator Unit in the line), the numbers on the Tape show the distance to the very bottom of the APM. When the Regulator Unit is added in the line, it adds 30.5 cm (one foot) to the total length (Fig. 16 right). Please also note that one side of the Tape is in meters/centimeters and the other side in feet and tenths of a foot (not inches).

Fig. 13. Connecting Tape Hook to RU.

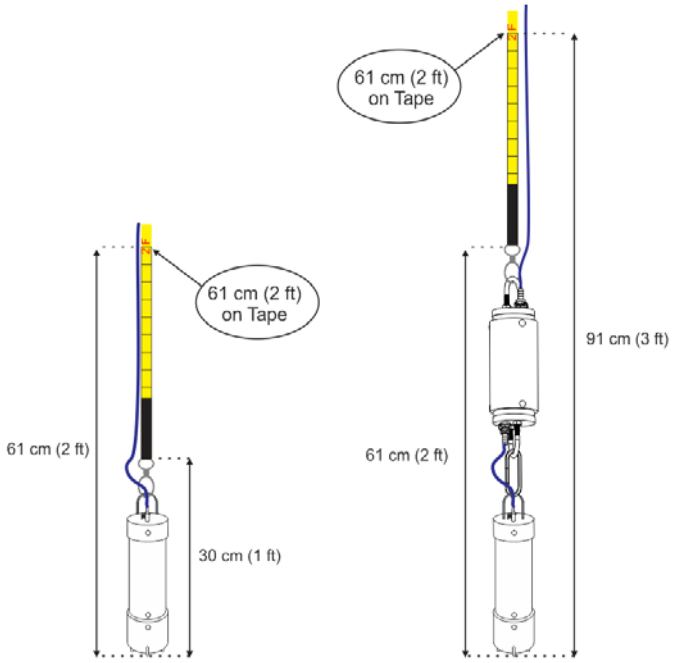

Fig. 14. Illustration of numbers on Tape. Left: APM without Regulator in the line (Shallow Measurements), right: APM with Regulator in the line (Deep Measurements).

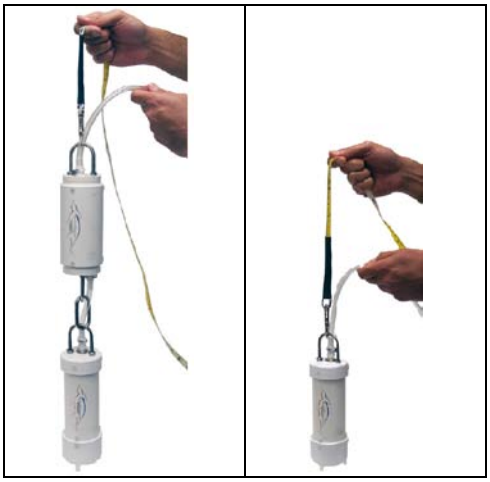

Fig. 15. Left: RU and APM are used for Deep Measurements. Right: for shallow measurements (less than 3 m or 11 ft depth) only APM is used.

Installing the APM in the Borehole

Standard Method:

After preparing the well and assembling the Table and Reservoir, connect the APM and Reservoir with their Tubing, and then lower the APM in the Borehole. The standard procedure is to make sure that APM is touching the bottom of the Borehole.

Fig. 16. Lowering RU and APM in borehole. Note do not hang from Tubing.

Carefully approach the Borehole Opening. Keep your feet away from the opening of the borehole as much as possible in order to prevent collapsing the upper parts of Borehole.

Using the Tape, carefully lower the APM into the Borehole until it reaches the bottom. It should touch the Borehole bottom and hang from the Tape at the same time (Tape is not slack). Note that if the APM is not in a vertical position, it may not work properly.

Fig. 17. Tape secured using Tape Holder.

Secure the Tape using the Tape Holder when you feel the unit has touched the bottom of the borehole (Fig. 19).

Secure the Tubing. Never let the Tubing hang directly from the Reservoir Valve. It may tip the Reservoir over in Deep Measurements. The Tubing is relatively heavy when filled with water. This is especially important when you are using the Digital Scale. Use the Tubing Clip provided in the Kit to secure the Tubing. See Fig. 5 for the proper way to secure the Tube with the Tubing Clip.

Secure the Borehole opening to prevent collapsing the upper parts of the well.

Record the depth of Borehole using Tape. When the APM is hanging in the Borehole, the numbers on Tape represent the distance from bottom of the APM (bottom of borehole). If the RU is in line, add another 30.5 cm (1 ft) to the Tape reading (Fig. 16).

Record the height of Reservoir (Table top) from soil surface. Use the Soilmoisture measuring tape provided in the Support Package.

Determine parameter D (Fig. 6**).** It is the vertical distance between the APM Floating Valve and Reservoir.

D (cm) = Depth of Borehole (cm) <plus> Height of Reservoir from Soil Surface (cm) <minus> 18.5 (cm)
D (inch) = Depth of Borehole (inch) <plus> Height of Reservoir from Soil Surface (inch) <minus> 7.25 (inch)

Determine the water head height. The normal head height for all applications is about 7.5 cm. However, with slight pressure changes in the APM due to the parameter D (Fig. 6), as well as small variations in the borehole, the specific head height can vary slightly from one test to another. While in many applications it is safe to assume that the head height is equal to 7.5 cm, for best accuracy it may be best to measure the actual water level height in the borehole during a test.

The water change in the reservoir during the test has a negligible effect on water head height (about 0.002 cm per cm change in reservoir water level). Therefore there is no need for adjustment.

Raised Method Installation

In this method, the bottom of the APM does not land on the Borehole floor and it hangs from the Tape (never hang the APM from Tubing). In the Raised Method, the height of water head is determined by the length of the hanging part of Tape. This method may have some limited applications. For example, in soils with very low hydraulic conductivity raising the water head height will increase the borehole active surface area (the area that is in contact with water) and decrease the time needed for performing the measurement. It also increases the accuracy of measurements.

Although the Raised Method gives the user more flexibility in establishing different head heights, it is a little more complicated than the Standard Method.

Using the Raised Method in soils with high hydraulic conductivity can be problematic. The APM has been designed to create a small head height (about 7.5 cm).

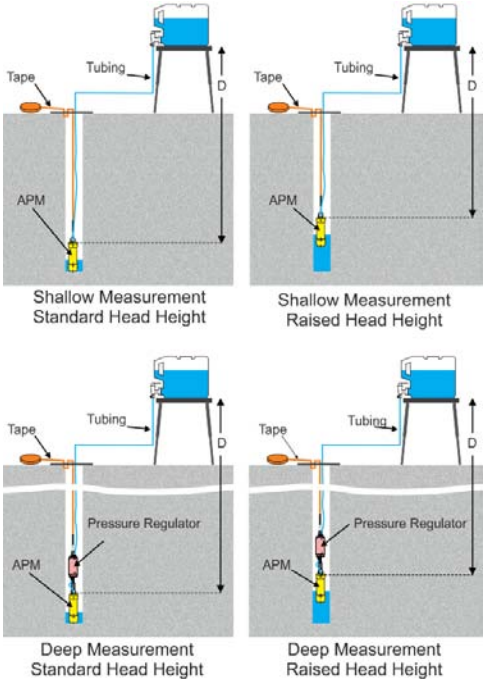

Fig. 18. Creating Standard (right figures) and Raised (left figures) head heights. Note that D is less than 3.44 m (11.3 ft) in Shallow Measurements while it is greater than 3.44 m (11.3 ft) in Deep Measurements.

Assuming the Borehole has the standard diameter of 10 cm (4"), the APM water supply would be sufficient to reach the water head in a short period of time. Using the Raised Method, the excess volume of the Borehole must be filled with Reservoir water and it takes more water and time to establish the water head height (in comparison with the Standard Method).

The Standard Method is more reliable since the water head depth is more accurate. In the Raised Method, there would be more Borehole erosion since water falls from the outlet vent in the borehole and, depending on the soil type and the distance of APM from the bottom of the hole, may cause significant erosion.

Carefully approach the Borehole Opening. In order to prevent collapsing the upper parts of the Borehole; try to keep clear from the Borehole opening as much as possible.

Using the Tape, carefully lower the APM into the Borehole until it reaches the bottom.

Secure the Tape using the Tape Holder (Fig. 19).

Secure the Tubing. Never let the Tubing directly hang from the Reservoir Valve. It may tip over the Reservoir in deep measurements. The Tubing is relatively heavy when filled with water. It is especially important when you are using Digital Scale. Use the Tubing Clip provided in the Kit. See Fig. 5 for the proper way to secure the Tube with the Tubing Clip.

Record the height of the Reservoir from the soil surface. Use the Soilmoisture Measuring Tape provided in the Support Package.

Record the depth of Borehole using the Tape. Remember that the numbers on the Tape represent the distance from the bottom of the APM (bottom of borehole). If the RU is in line, add another 30.5 cm (one ft) to the Tape reading (Fig. 16).

Raise the APM to the desired height considering that the water height would be equal to the raising height plus an additional height of about 7.5 cm. Record the amount of the APM Raise for future reference.

Determine the depth of the APM. Remember that the number on the tape represents the distance to the bottom of the APM (if an RU is in the line, add another 30.5 cm (1 ft) to the number). Also note the distance between the bottom of the APM and its float valve is 18.5 cm (7.25"). Therefore the depth of the APM (actually the depth of its water valve) is equal to the number read on the tape at the borehole opening minus 18.5 cm (7.25"). If an RU is also in line, add another 30.5 cm (1 ft) to the number.

Calculate the parameter D (Fig. 6). It is the vertical distance between the APM unit and the Reservoir.

D (cm) = Depth of APM (cm) <plus> Height of Reservoir from Soil Surface (cm)
D (inch) = Depth of APM (inch) <plus> Height of Reservoir from Soil Surface (inch)

Determine the water head height. The normal head height for all applications is about 7.5 cm. However, with slight pressure changes in the APM due to the parameter D (Fig. 6), as well as small variations in the borehole, the specific head height can vary slightly from one test to another. While in many applications it is safe to assume that the head height is equal to 7.5 cm, for best accuracy it may be best to measure the actual water level height in the borehole during a test.

The water change in the reservoir during the test has a negligible effect on water head height (about 0.002 cm per cm change in reservoir water level). Therefore there is no need for adjustment.

Documentation Prior to Performing a Measurement

Appendix A is a sample datasheet that can be used for recording the measurements. For each sampling site, write the name and address (or lat/long) of the location, date, soil type and structure, borehole diameter, water head height, borehole depth, and water table depth. One can also record water temperature and sampling horizon description (optional). It is important to note that there are several standards and methods for calculating K_{sat}.

Making a Reading

Fill out the upper section of the data sheet provided in Appendix A (A sample data sheet is provided in Table 1).

Record the initial water level/volume in the Reservoir under column "Water Level in Reservoir" and the time under column "Time" in the first row of the table.

Open the Reservoir Valve. Depending on the Borehole's dimensions and soil permeability, it may take from less than one minute to several minutes before establishing a constant water head. Boreholes wider than 10 cm (4") would need considerably more time to establish a constant water head. Also water heads higher than the standard height need more time. In Shallow Measurements, since the overhead pressure from the Reservoir is low, it will take more time to achieve a constant water head.

Record the level of Reservoir water and time after appropriate interval. Use the Countdown Timer provided in the Support Kit. The time interval between recordings depends on the diameter of the Borehole, soil type and texture.

In soils with coarse textures the infiltration rate is higher and therefore smaller intervals are more suitable (between 1 to 5 min). Depending on method of calculation and considering that each increment on the Reservoir body is translated to 100 ml of water, for measuring a K_{sat} as low as 10^{-7} to 10^{-8}, a 60-minute sampling interval would be needed (assuming that the Borehole dimensions are standard). Also a deeper borehole or a larger Borehole diameter increases the total infiltration rate (*Q*) of the well and a smaller time interval can be used.

Note: If you are using a 2840K#PC, the accuracy of your readings would be 500 times more (0.2 ml vs. 100 ml accuracy). Therefore for a K_{sat} as low as 10^{-7} to 10^{-8}, a 1- to 5-minute sampling interval would be enough.

It is not critical to record reading "sat exactly equal time" intervals but it is important to accurately record the time for each reading. It is possible to start recording several minutes after opening the Valve and when it seems that a constant water head has been well established and the soil around the Borehole is saturated. For each reading (data point) write the current time under column "Time" and write the level of water in the Reservoir under column "Reservoir Water Level".

Add more water if Reservoir is low. Record the reservoir water level as well as time right before and after refilling. It is recommended not to let the Reservoir run out of water.

Determine the Steady Water Consumption Rate. The measurement ends when the "Water Consumption Rate" does not change over several consecutive readings. For each reading, Water Consumption Rate is calculated using the following formula:

$$R_i = \frac{d_{(i-1)} - d_i}{t}$$

Where R_i is Water consumption Rate of the current reading (ml/min), $D_{(i-1)}$ is Reservoir Water Level of the previous reading (ml), d_i is Reservoir Water Level of the current reading (ml), and t is the time interval between the previous reading and the current reading (min).

If you are using the SimplyDATA Software Suite application, there is no need to manually perform this calculation. If you are recording data manually, use Appendix A. You would need to calculate R_i for each reading until it reaches a steady state (the amount of R_i does not change significantly over several readings).

In the Steady Water Consumption Rate stage (Fig. 21), the steady "Water Consumption Rate" is equivalent to the soil Steady Flow Rate (Q) or Soil-Water Steady Infiltration Rate which is the key parameter to calculate saturated hydraulic conductivity.

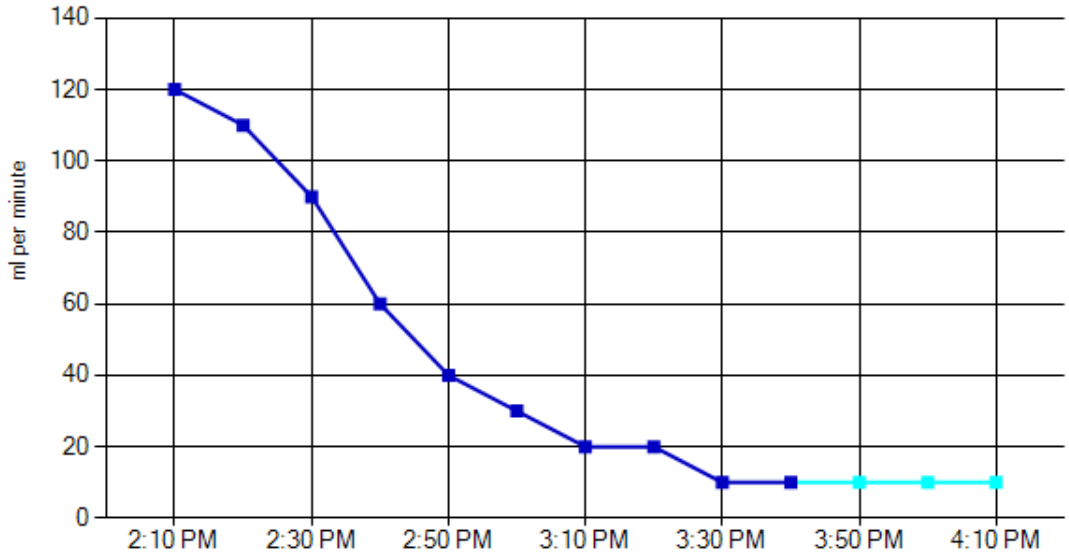

Fig. 19. Water Consumption Rate against time. The cyan points represent steady flow rate (Q).

Operating Model 2840K1PC and Model 2840K2PC

(Automated Readings Using a PC)

Performing measurements are much more accurate and easy using the PC Kits. These kits contain a 2840K1 kit (for Shallow Measurements) or a 2840K2 kit (for Deep Measurements) as well as a Digital Scale (Model 7201W10). See kit components in Fig. 2 and Fig. 3.

The Digital Scale is connected to a personal computer or laptop (not included) using a USB port and records the measurements automatically. The accuracy of measurements for water flow rate is 0.2 gram (one gram is equivalent to one ml (cc or cm^3) of volume for pure water). Once the steady flow rate is established in the Borehole, the software calculates K_{sat} automatically and there is no need to continue the measurements (although it is possible). This kit is ideal for automated and accurate measurements in the laboratory and outdoors (when a personal computer is available).

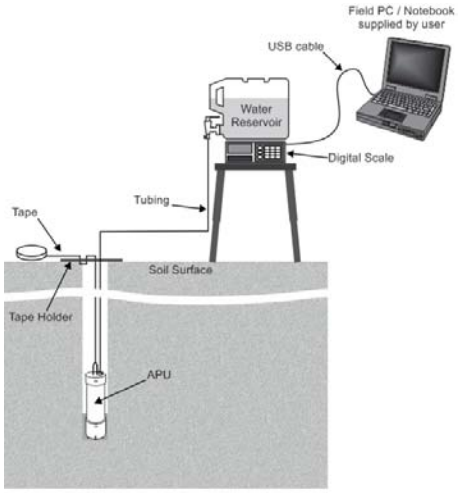

Fig. 20. Schematic of Model 2840K1PC setup and arrangement.

In case a PC is not available, the 2840K1PC and 2840K2PC can still be used as a more accurate version of the Basic Aardvark. The SimplyDATA Scale operates on batteries. Therefore it can be used wherever needed.

The Installation procedure is similar to Model 2840K1. Refer to the section “Operating Model 2840K1 and Model 2840K2” for instructions about assembling and placement of the Aardvark Table; components; assembling and installing the Aardvark Permeameter Module (APM) in a Borehole and assembling the Aardvark Reservoir Unit (RU).

After preparing a Borehole and Installing the APM, follow these steps:

Place Scale and Reservoir on the Table and make sure that they are centered with the Table legs (Fig. 23). Note that the Reservoir is relatively heavy and if it is not centered with Table legs, it may tip over.

Connect the Scale to your PC using the USB cable provided in the kit. Please refer to the USB Digital Scale (Model 7201) operating Instructions for more details and illustrations.

Install the SimplyDATA Software Suite on your computer (if not already installed). Please refer to the SimplyDATA Software Suite (Model 8010SDS02) Operating Instructions for more details.

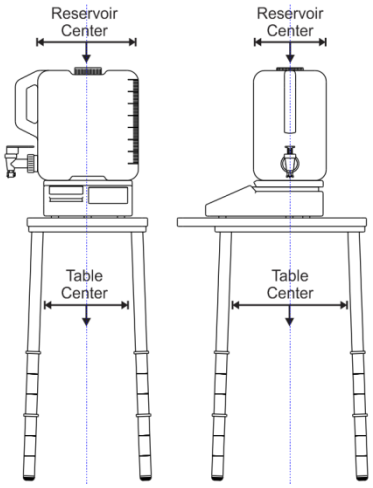

Fig. 21. How to center Scale and Reservoir with Table.

Turn on the Scale.

Tare the Scale if needed. It is not really important for the software to tare the scale. However it ensures more readable data (especially if making readings manually).

Connect the Valve Quick Connection provided in the kit to the end of the Tubing (Fig. 14 a). The other end of the Tubing should be already connected to the RU or APM.

Connect the Valve to the Reservoir and make sure the spigot is closed (Fig. 10).

Fill Reservoir with clean water up to 7 liters (2 gallons) and replace the Cap. Dry the Reservoir exterior if needed. Note that the Scale is an electronic device and for better performance it needs to be kept dry and clean.

Carefully place the Reservoir on the Scale and make sure that both the Reservoir and Scale are level and centered with the four legs of the Table.

Connect the Tubing to the Reservoir Valve and secure the Tubing to the Table using the Tubing Clip provided (see Fig. 3 left, for a suggested Clip position). NOTE: the Tubing should not hang from the Reservoir otherwise moving the tubing would affect the Scale readings. Also try not to shake the Reservoir. It can affect the Scale readings. Wind can have a dramatic effect on Scale performance. Protect the Table setup from wind if necessary. In the case of severe wind, it is recommended to set the table up in a tent.

Remove the Reservoir Cap.

Making a Reading

If you are recording readings manually, please refer to the section “Making a Reading” in the 2840K1 instructions. Please note that the precision of the Scale is relatively high (0.2 ml). In comparison with the increments on the Reservoir, it is 500 times more accurate; therefore you can reduce the reading interval time dramatically. Using a Borehole with standard dimensions (10 cm diameter and about 10 cm water head) and with a one minute reading interval you are able to measure K_{sat} values as small as 10^{-7} to 10^{-8} m/s. In the case that the Scale is connected to a PC, you would be able to make readings automatically. Please refer to the SimplyDATA Software Suite (Model 8010SDS02) Operating Instructions for more details.

USEFUL HINTS DURING NORMAL USE

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

If you collapse the Borehole, the RU and APM could fall in. The Suspension Line (Tape) is robust and durable; however you should protect it with a rope or cable line. This would be a great help when you are trying to remove the APM from a collapsed borehole.

Wash the APM after each measurement. It will protect it against leaking and guarantee a long and reliable performance.

Always keep an eye on connections. Leaks in connections can dramatically reduce the measurement accuracy. Aardvark connections are robust and reliable; however, putting stress on connections (e.g. hanging the APM from tubing or using lubrication to connect two pieces of tubing) can make them susceptible to leaks especially in deep measurements when the overhead pressure is high.

Never let the Tubing hang directly from the Reservoir Valve. When the Tubing is filled with water, its weight can tip over the Reservoir and if it doesn't, it definitely would have a negative impact on Scale readings. Secure the Tubing in the way that its weight is not on the Reservoir Valve. Also use Tubing Clip to secure Tubing on Table.

TROUBLESHOOTING

Problem	Possible Reason
The Scale "Self-test" procedure takes a long time	The scale is shaking due to wind or other reasons. Protect Scale and the Table setup from wind. The ultimate solution to the wind problem is to set up the Table in a secured tent.
The numbers on Scale jump up and down	This usually happens due to wind. Try to protect the Table setup from wind.
From the beginning of the measurement, Water Consumption Rate does not reduce over time.	It may have two specific reasons. First: soil is too fast (excessive hydraulic conductivity, for example coarse sand or gravel). In this case Aardvark water supply rate is less than soil infiltration rate and a constant heat cannot be established. Second: the Floating Valve is not working properly. Remove the APM Cap and check it.
Reservoir body collapses gradually over time	The Reservoir Cap is on. Take the Reservoir Cap off to let water flow freely to the Borehole.

GENERAL CARE AND MAINTENANCE

Disassembling the Aardvark Permeameter Module

You may want to take the APM apart to clean it. Remove the Connecting Pins from the APM and separate it from the Body Tube. The Pins are designed so you can push them in or take them out easily without any tools. However there is a Pin Access Tool in the Support Kit should you need it. To avoid injury, please take special care while working with the Pin Access Tool. Avoid removing a Pin using a screwdriver or other sharp tools.

Cleaning APM

1. Use the Pin Access Tool to remove Pins from the upper part of Body Tube. Detach Head Assembly from Body Tube. There is no need to detach the End Cap from the Body Tube.

2. Soak the components in soapy water for 5 minutes and then rinse with clean water.

3. In order to clean the internal parts of the Head Assembly and Floating Valve, pour soapy water into the Reservoir. Then connect the Reservoir to the Head assembly using the Tubing and open the Valve and let the soapy water run through Head Assembly. Repeat this procedure with clean water allowing it to flow through the Head Assembly for one or two minutes. This will assure a long and reliable performance of the unit.

4. Put Floating Bottle inside Body Tube and make sure that it can move up and down freely.

5. Connect Head Cap to Body using Pins.

USE AND APPLICATION OF PRODUCT OPTIONS

Borehole Preparation Kit

The Aardvark permeameter is designed to be installed in a borehole in a soil profile from 20 cm (7.9") to 15 m (50 ft) depth. Therefore before installing Aardvark Permeameter, you need to dig and prepare a borehole. The equipment needed to dig a borehole depends on the width and depth of the desired hole. Our Model 0237D10L10 contains all the required tools and instructions for augering and cleaning a borehole with 10 cm (4") width (Aardvark recommended width) and up to 3 m (10 ft) depth.

Fig. 22. Model 0237D10L10 Borehole Preparation kit.

Aardvark Pressure Regulator Unit (RU)

The APM has been designed to perform under a maximum of 5 psi (about 344 kPa or 3.44 m of water column). Therefore for Deeper Measurements (D ≥ 3.44 m), you need to use an Aardvark Pressure Regulator in-line. The RU reduces the overhead pressure to 344 kPa (5 psi). Simply add the RU in line with the APM so that water goes through the RU before the APM. Note that the vertical distance of the RU and APM must be minimal. An RU Connection Tubing and a Quick Link comes with the RU to connect the RU and APM (Fig. 27).

In Shallow Measurements you do not need the Regulator Unit (RU).

The Aardvark Permeameter can be used anywhere a hole can be augered in soil. Because of the practical improvements incorporated in the operation of the Aardvark 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

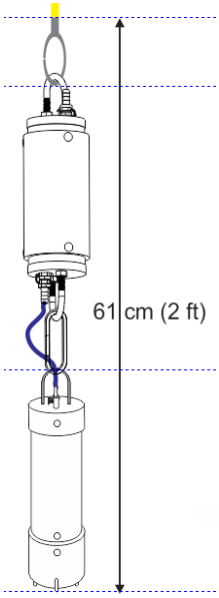

Fig. 23. Regulator Unit in line with APM.

CALCULATIONS AND APPLICATIONS

Using the SimplyDATA Software Suite for manually recorded data

The Aardvark Permeameter kit contains a flash drive with the SimplyDATA Software Suite. The software performs all the necessary calculations required for calculating soil hydraulic conductivity. To use the software you will need a personal computer. Simply enter the raw measurements data and it calculates K_{sat} as well as some other useful parameters and graphs. Please refer to the "SimplyDATA Software Suite Operating Instructions" for more details. If you are using the Model 2840K#PC connected to a computer, the software performs all the measurements and calculations automatically. Please refer to the SimplyDATA Software Suite Operating Instructions for more details.

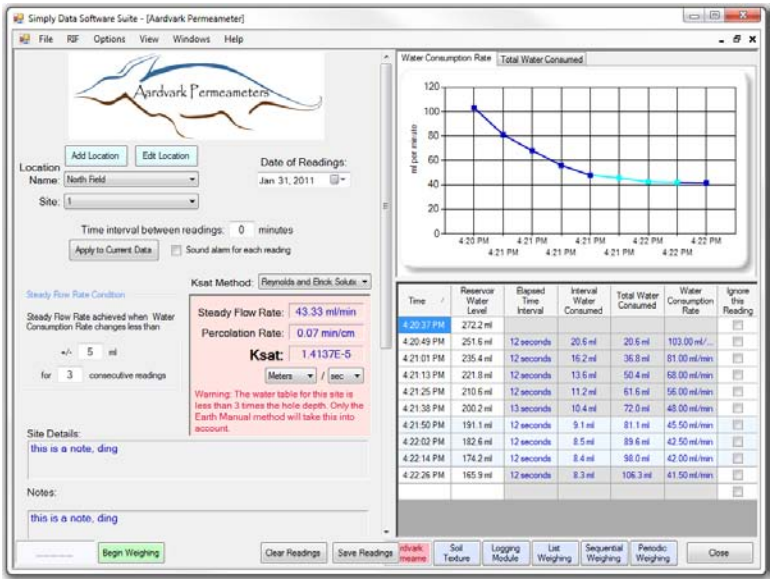

Fig. 24. Permeameter application of the SimplyDATA Software Suite.

Manually Performing the Calculations

These instructions use the method introduced by US Department of Interior (Earth Manual Part2, Third Edition, and P. 1234-5. Denver, Colorado 1990). The SimplyDATA Software Suite is able to calculate K_{sat} using three different methods.

Determining the Steady Flow Rate (Q)

A sample data sheet is presented in Table 1. For determining Steady Flow Rate, fallow the below instructions.

Calculate "Elapsed Time Interval" for each reading in minutes. It is the difference of "Time" of the reading with "Time" of the previous reading (see the bold calculations in each cell of table). Therefore for the first row of the table (the first reading), "Elapsed Time Interval" is not calculated.

Calculate "Interval Water Consumed" for each reading in milliliter (ml). It is the amount of water that goes to Borehole during the two consecutive intervals. On the other words, it is the difference between "Reservoir Water Level" of a reading and "Reservoir Water Level" of the previous reading (see the bold calculations in each cell). Therefore for the first line of the table (the first reading), "Reservoir Water Level" is not calculated. Not the volume of one gram of water is one ml (cc or cm^3). Therefore generally speaking, for pure water, the three units are equivalent and one can use any of them for the other one.

Calculate "Total Water Consumption" as the total sum of "Water Consumption Rate" (see the bold calculations). Calculating of this column is optional.

Calculate "Water Consumption Rate" for each reading in ml/s. For each line of Table 1, "Water Consumption Rate" can be calculated by dividing "Interval Water Consumed" by "Elapsed Time Interval" (see the bold calculations). Therefore for the first line of the table (the first reading), "Water Consumption Rate" is not calculated.

Determine the Steady Flow Rate (Q). It is established when "Water Consumption Rate" (flow rate) does not change significantly over several consecutive readings. Obviously "Water Consumption Rate" would not be exactly equal between consecutive readings even when a steady flow has been established. Using the Water Consumption Rate graph against time is a useful tool for determining Q. In this graph, the horizontal phase of curve (parallel with time axis) represents the amount of Q. In Table 1, since "Water Consumption Rate" does not change from Reading 10 to Reading 14, we assume that the Steady Flow Rate (Q) is 10 ml/min. Fig. 29 is the graphical presentation of the same data. For converting Q unit from ml/min to gallon/s, it has to be multiplied by 0.000264.

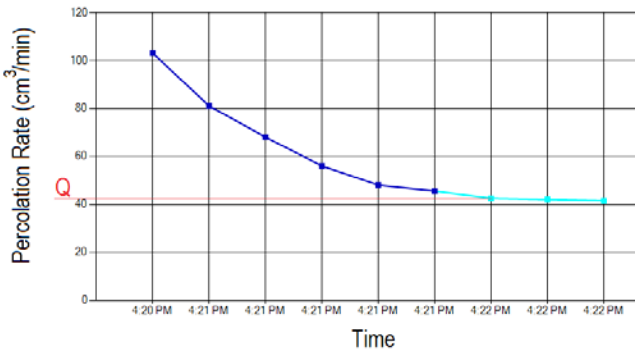

Fig. 25. Soil-water infiltration rate over time and Steady Flow Rate (Q).

Table 1. A sample data sheet. The bold writings are for illustrating the calculations. Columns “Time” and “Water Level in Reservoir” are the readings from Aardvark Permeameter. Other columns have to be calculated.

Aardvark Permeameter Field Data Sheet **READING AND CALCULATION**

DATE: **INVESTIGATOR:**

Q: Steady Flow Rate (ml/min): 10

2r: Borehole Diameter (cm): 10.16
H: Borehole Depth (cm): 340
D: Vertical distance between Reservoir and APM (cm): 400
Soil Texture/Structure Category: structured agri. soil

h: Water Height in Borehole (cm): 10.1
S: Depth of Water Table (cm): 350
Water Temperature:20

Reading Number	Time	Water Level in Reservoir (ml)	Elapsed Time Interval (min)	Interval Water Consumption (ml)	Total Water Consumption (ml)	Water Consumption Rate (ml/min)
1	2:00 pm	7000				
2	2:10 pm	5800	**2:10 - 2:00=** 10	**7000 - 5800=** 1200	1200	**1200 / 10=** 120
3	2:20 pm	4700	**2:20 - 2:10=** 10	**5800 - 4700=** 1100	**1200 + 1100=** 2300	**110 / 10=** 110
4	2:30 pm	3800	**2:30 - 2:20=** 10	**4700 - 3800=** 900	**2300 + 900=** 3200	**900 / 10=** 90
5	2:40 pm	3200	**2:40 - 2:30=** 10	**3800 - 3200=** 600	**3200 + 600=** 3800	**600 / 10=** 60
6	2:50 pm	2800	**2:50 - 2:40=** 10	**3200 - 2800=** 400	**3800 + 400=** 4200	**400 / 10=** 40
7	3:00 pm	2500	**3:00 - 2:50=** 10	**2800 - 2500=** 300	**4200 + 300=** 4500	**300 / 10=** 30
8	3:10 pm	2300	**3:10 - 3:00=** 10	**2500 - 2300=** 200	**4500 + 200=** 4700	**200 / 10=** 20
9	3:20 pm	2100	**3:20 - 3:10=** 10	**2300 - 2100=** 200	**4700 + 200=** 4900	**200 / 10=** 20
10	3:30 pm	2000	**3:30 - 3:20=** 10	**2100 - 2000=** 100	**4900 + 100=** 5000	**100 / 10=** 10
11	3:40 pm	1900	**3:40 - 3:30=** 10	**2000 - 1900=** 100	**5000 + 100=** 5100	**100 / 10=** 10
12	3:50 pm	1800	**3:50 - 3:40=** 10	**1900 - 1800=** 100	**5100 + 100=** 5200	**100 / 10=** 10
13	4:00 pm	1700	**4:00 - 3:50=** 10	**1800 - 1700=** 100	**5200 + 100=** 5300	**100 / 10=** 10
14	4:10 pm	1600	**4:10 - 4:00=** 10	**1700 - 1600=** 100	**5300 + 100=** 5400	**100 / 10=** 10

Calculating saturated hydraulic conductivity (K_{sat})

Saturated Hydraulic conductivity can be calculated using several methods. The following calculations are based on USBR 7300-89 procedure (Earth Manual Part2, Third Edition, and P. 1234-5. Denver, Colorado 1990). SimplyData Software Suite is able to perform some other methods (please refer to SimplyData Software Suite Operating Instruction).

Depending on the value of L/h ratio (L is the vertical distance between constant water head (h) and water table / impervious layer; see Fig. 6), K_{sat} can be calculated from different formulas:

Condition I: when L/h is greater than three ($L/h > 3$)

$$K_{sat} = \frac{Q}{2\pi h^2}\left\{\ln\left[h/r + \sqrt{(h/r)^2 + 1}\right] - \frac{\sqrt{1 + (h/r)^2}}{h/r} + \frac{1}{h/r}\right\} \quad \text{Unit: cm/min} \quad \text{Equation [1]}$$

Condition II: when L/h is between one and three ($1 \le L/h \le 3$)

$$K_{sat} = \frac{Q}{2\pi h^2}\left[\frac{\ln(h/r)}{\frac{1}{6} + \frac{1}{3}\left(\frac{L}{h}\right)}\right] \quad \text{Unit: cm/min} \quad \text{Equation [2]}$$

Condition III: when L/h is greater than three ($L/h < 1$)

$$K_{sat} = \frac{Q}{2\pi h^2}\left[\frac{\ln(h/r)}{\frac{L}{h} + \frac{1}{2}\left(\frac{L}{h}\right)^2}\right] \quad \text{Unit: cm/min} \quad \text{Equation [3]}$$

Where K_{sat} is saturated hydraulic conductivity (cm/s), Q is steady flow rate (ml/s), h is height of constant water head in Borehole (cm), r is radius of Borehole (cm) and L is the vertical distance between water surface in Borehole and the water table (cm), ln is the symbol for natural logarithm and π is 3.14. Note: for converting K_{sat} unit from cm/s to inch/s, it has to be multiplied by 0.39.

Parameter L can be easily calculated:

$$L = s - H + h = 350 - 340 + 10.1 = 20.1 \quad \text{Unit: cm} \quad \text{Equation [4]}$$

Where H is borehole depth, h is constant water head height in borehole, s is water table depth and L is the vertical distance between constant water head and water table/impervious layer.

Since the L/h ratio in Table 1 is between 1 and 3, Equation [2] has to be used for calculating K_{sat}:

$$K_{sat} = \frac{10}{2\pi 10.1^2}\left[\frac{\ln(10.1/5.08)}{\frac{1}{6} + \frac{1}{3}\left(\frac{20.1}{10.1}\right)}\right] = 0.0010 \quad \text{Unit: cm/min} \quad \text{Equation [5]}$$

REPLACEMENT PARTS LIST

REPLACEMENT PARTS

ITEM	PART #	DESCRIPTION
Aardvark Carrying Case	XCASE-PLBD25X14X7	
Tape Holder	2840K1-0000-03	
Aardvark Permeameter Module	2840-1000	
Aardvark Reservoir	2840-1003-01	
Countdown Timer	XLB-TIMER60MMECH	
Measuring Tape/ Suspension Line	2844L50	50 feet
Connecting Tube	XTPTY-0.250X0.375	50 feet
Aardvark Pressure Regulator Unit	2840-2000	For measurements deeper than 3 m (10 ft)
Aardvark Table	XUTABW14XH11	
Aardvark Operating Instructions	0898-2840	
Aardvark Support Package	2840K1SUPKG	
SEC All Weather Notebook	0899-006	
Plastic Connection Pin	XFPNY.250AC9	
Tubing Coupler (Barbed Connector)	XPB44T-4BTX4BTPP	¼'' to ¼''
Quick Connection Insert	XPBQC-4BTPMCAT	¼'' hose to PMC
Pin Access Tool	XTLH-4''TACKPULLER	
Hose Clamp	XHWCHC-5/16-13/32	5/16'' to 13/16'' to 13/32'' Zinc Plated Steel
LED Flash Light	XHWMIS-LEDFLASH	
Tubing Clip	XHWCL-#4CLIP	
SILICON Grease	MFJ012PK	¼ Ounce
SEC Writing Pen	0899-009	
SEC Tape Measure		6 ft.
Flash Drive Loaded with SimplyData Software Suite	8010SDS02	
Digital Scale Package	7201W10PKG	Complete package in the case
Digital Scale	7201W10-001	The unit itself (10 Kg, 0.2g accuracy)
Scale Carrying Case	7202	
USB Cable	XCMPC-UFUML05	For Digital Scale
Scale Power Supply	7201PWR	

ACESSORIES AND USEFUL ITEMS FOR THIS UNIT

ITEM	PART #	DESCRIPTION
Borehole Preparation Kit	0237D10L10	
Loam Soils Auger	0234LOMBD10	10 cm Loam Soil Auger, Dutch Type, bayonet connection
Auger Extension Rod	0234SHDLBXLE30	30 cm Auger Extension Rod, bayonet connection
Well Prep Brush	0234WPBBD10	10 cm Well Prep Brush, bayonet connection
Carrying bag	XBAG-0237	Auger Kit Carrying Bag
Sizing Auger	0234HBPBD10	Sizing Auger, 10cm hole, bottom prep, bayonet connection
Auger Handle	0234SHDLB	Auger Handle with detachable grip, 60 cm, bayonet connection

Appendix A

Aardvark Permeameter Sample Datasheet

Aardvark Permeameter Field Data Sheet **READING AND CALCULATION**

DATE: **INVESTIGATOR:**

Q: Steady Flow Rate (ml/min):

2r: Borehole Diameter (cm):
H: Borehole Depth (cm):
D: Vertical distance between Reservoir and APM (cm):
Soil Texture/Structure Category:

h: Water Height in Borehole (cm):
S: Depth of Water Table (cm):
Water Temperature:

Reading Number	Time	Water Level in Reservoir (ml)	Elapsed Time Interval (min)	Interval Water Consumption (ml)	Total Water Consumption (ml)	Water Consumption Rate (ml/min)

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