USER GUIDE

ETC PASK (CONSTANT HEAD WELL) PERMEAMETER FOR IN-SITU MEASUREMENT OF SOIL FIELD SATURATED HYDRAULIC CONDUCTIVITY

Manufactured by:

DYNAMIC MONITORS.COM

1-16 Myrtle St., Stratford, PE
Canada   C1B 2W2
Toll Free 1-888-747-SOIL (7645)

Table of Contents

Index of Tables

Index of Figures

Appendices

Appendix A
Field Permeability Test Example
Example Field Permeability Test Data Sheet

Appendix B
Procedure to Verify Integrity of Permeameter Seals
Warranty Information

Disclaimer:

This guide was prepared by Engineering Technologies Canada Ltd. (ETC) using information compiled from a number of published sources and from our professional experience.

While ETC has taken care to include recommendations and technical guidance which are based on currently accepted practice, any use which a third party makes of this guide, or any reliance on or decisions to be based on it, are the responsibility of such third parties.

ETC will accept no damages, if any, suffered by any third party as a result of decisions made or actions based on the information contained herein.

1 INTRODUCTION

Saturated hydraulic conductivity, **Ks**, is a measure of the "ease" with which water flows through a permeable material such as soil. The higher the Ks value, the greater the water flow rate for a given hydraulic gradient. In-situ methods that infiltrate the water into unsaturated soil do not measure Ks, but rather a reduced "field-saturated" hydraulic conductivity, **Kfs**, because of air entrapment during the infiltration process (Reynolds, 1993).

As noted in Reynolds (1993), Kfs can be less than or equal to half of Ks due to partial blocking of soil pores by air bubbles. For the design of on-site sewage disposal fields and stormwater infiltration systems, Kfs is preferred over Ks because drainage through the soil will occur under conditions less than complete soil saturation.

2 CONSTANT HEAD WELL PERMEAMETER METHOD

2.1 Research and Development

In-situ measurement of Kfs can be achieved using the "constant head well permeameter" (CHWP) method (Reynolds, 1993; Elrick and Reynolds, 1986). The CHWP method is based on the observation that when a constant height or "head" of water is ponded in a borehole or "well" augured into unsaturated soil (see Figure 2.1), a "bulb" of *field-saturated* soil is gradually established around the base of the well (see Fig. 3 in Elrick et al., 1989 and associated discussion).

“Field saturated” means that the bulb in not truly saturated, but contains a certain amount of air that is entrapped or encapsulated by the infiltrating water (Constantz et al., 1988). As this field saturated bulb becomes established, the flow of water out of the well and into the soil approaches a ***quasi steady flow rate***. Once this quasi steady flow rate is attained, the Kfs of the soil surrounding the well can be determined using the flow rate, the radius of the well, and the head of ponded water in the well.

The CHWP method represents an improvement over previous borehole techniques (such as the Glover analysis) by addressing **all three components of borehole flow**, namely:

1) flow due to the hydrostatic pressure of the ponded water,
2) gravity-driven infiltration out through the base of the test hole, and
3) infiltration due to the capillary suction or “capillarity” of the surrounding unsaturated soil.

The *field saturated hydraulic conductivity*, Kfs, determined using the CHWP technique, is a much more scientifically and technically sound indicator of soil permeability than the outdated percolation test (PT). Kfs testing controls for variables that can substantially affect the PT such as: pit/borehole dimensions, depth of water ponding, soil capillary properties, and background soil moisture content at the time of the test.

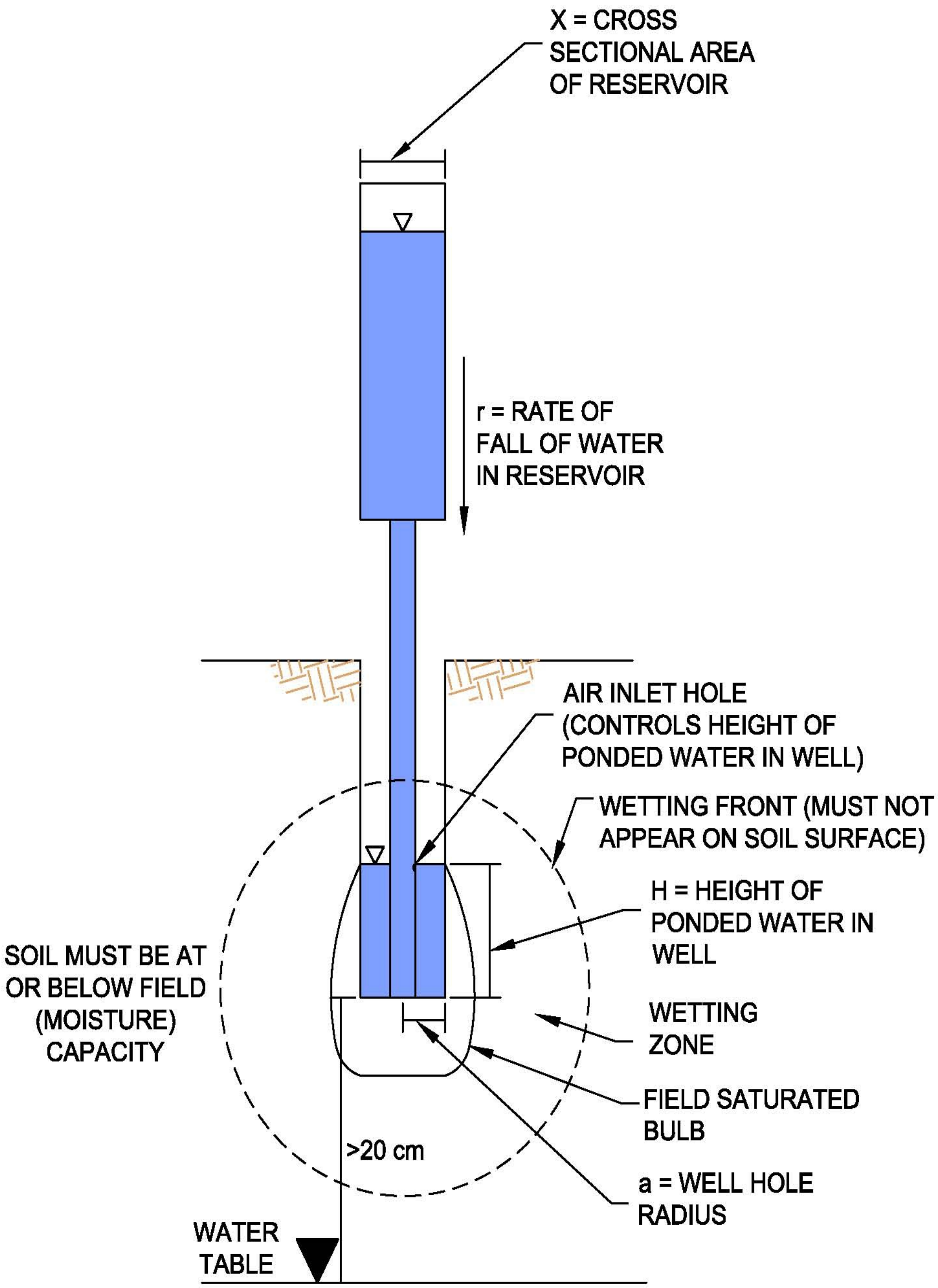


Figure 2.1: Constant Head Well Permeameter

2.2 Calculating Kfs

The CHWP calculations presented here are based on the work of W.D. Reynolds (Agriculture and Agri-Food Canada) and D.E. Elrick (University of Guelph, Ontario, Canada). As with any measurement method, the assumptions and procedures involved with the CHWP technique should be understood before it is used as a field assessment procedure. Various well permeameter analyses have been developed, including single-head, two-head and multiple head procedures. In-depth reviews and descriptions of the CHWP method can be found in Elrick and Reynolds (1986, 1992a,b); Reynolds (1993); Bagarello et al., (1999); and elsewhere. This guide outlines the "**extended single-head"** analysis described by Reynolds (2008).

The ***ETC Pask Permeameter*** is a convenient and easy-to-use apparatus for ponding a constant head of water in a well and simultaneously measuring the flow rate into the soil. The *Standard* and *Slow Soil* models are shown in Figure 3.1. An appropriately placed air-inlet hole in the permeameter outflow tube establishes and maintains the desired water ponding head (H) in the well.

Measuring the rate of fall (R) of the water level in the permeameter reservoir and reservoir cross-sectional area (X) allows determination of *quasi steady state water flow rate* (**Q**) into the soil (i.e Q = XR). Kfs is then calculated using Equation 1 (Reynolds, 1993).

$$\mathbf{Kfs = CQ / [2\pi H^2 + C\pi a^2 + (2\pi H/\alpha^*)]} \qquad \textbf{(Eq. 1)}$$

The shape factor, **C**, is selected from Figure 2.2, **a** is the well hole radius, and **α*** is a parameter which is visually estimated from the soil texture-structure (capillarity) categories in Table 2.1.

Table 2.1: Soil texture – structure categories for visual estimation of α*

TEXTURE – STRUCTURE CATEGORY	Soil Capillarity	α^* (cm^{-1})
Coarse and gravelly sands; may also include some highly structured soils with large cracks and /or macropores.	Weak	0.36
Most structured and medium textured materials; including structured clayey and loamy soils, as well as unstructured medium single-grain sands. This category is generally the first choice for most soils.	Moderate	0.12
Porous materials that are both fine textured and massive; including unstructured clayey and silty soils, as well as very fine to fine structureless sandy materials.	Strong	0.04
Compacted, structureless, clayey materials such as landfill caps and liners, lacustrine or marine sediments.	Very Strong	0.01

Source: Adapted from Reynolds, W.D., (2008) and Reynolds et al (2015).

It should also be noted that the C-value curves in Figure 2.2 and the α* values in Table 2.1 apply for soils that are at ***field capacity*** or dryer, and when the wetting front from the well hole does not appear on the soil surface (Elrick and Reynolds, 1986).

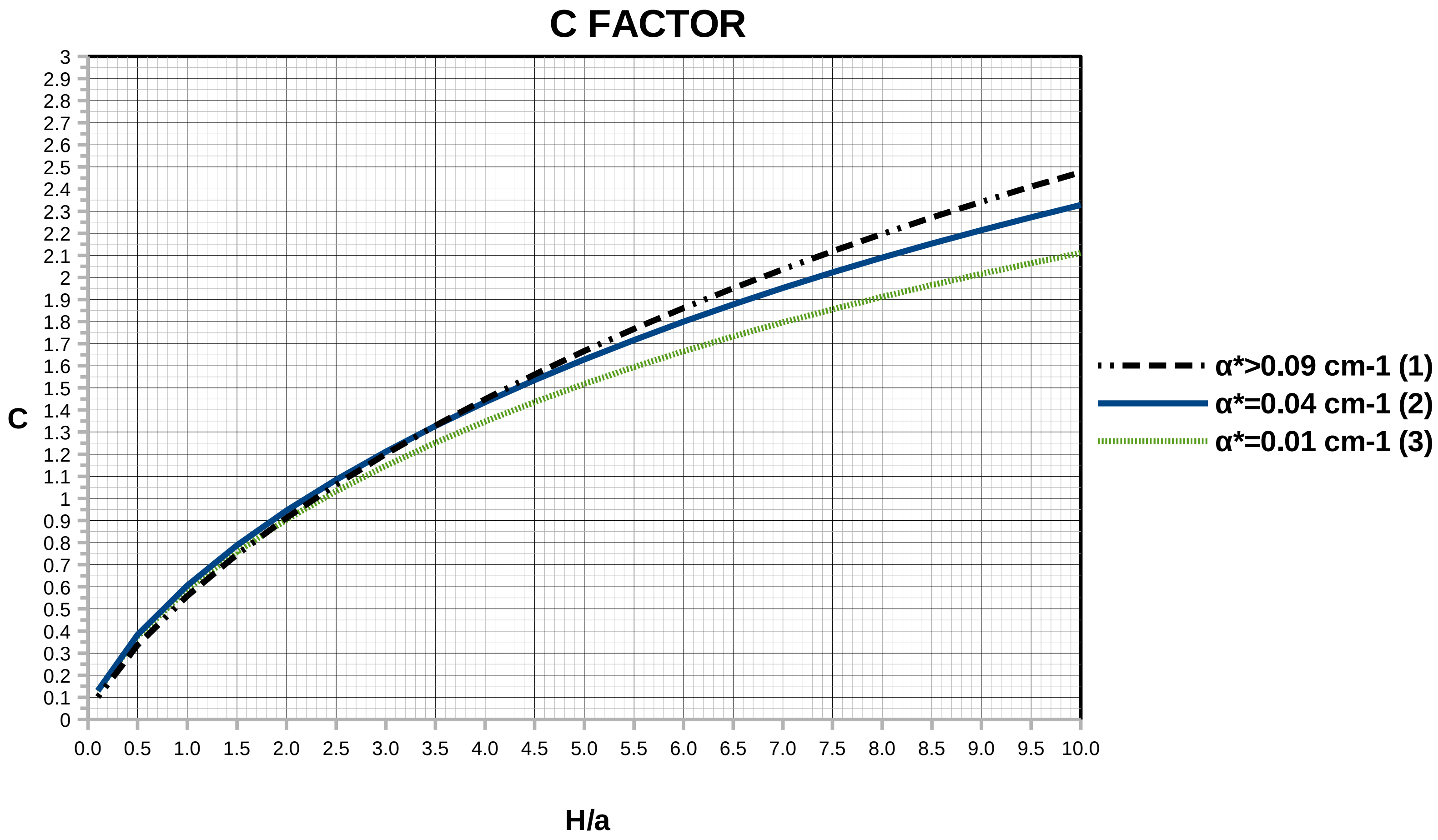


Figure 2.2: C factor chart, adapted from Reynolds (2008)

Quick field reference tables have been prepared by Dynamic Monitors for each soil texture-structure (capillary) category. The use of these tables are discussed in Section 2.2.2.

2.2.1 Calculating Kfs from first principles

Kfs is calculated from Equation 1 as follows:

$$\mathbf{Kfs = CQ / [2\pi H^2 + C\pi a^2 + (2\pi H/\alpha^*)]} \qquad \text{(Eq. 1)}$$

where

a = well hole radius, cm
H = height of air inlet hole from bottom of the test hole, cm
(typically 15 cm for ETC Pask Permeameters)
C = from C Factor graph (Figure 2.2) (unitless)
α^* = visually estimated soil structure/texture parameter (see Table 2.1), cm^{-1}
X = cross-sectional area of permeameter reservoir, cm^2
R = quasi steady state (constant) rate of fall of water in permeameter reservoir (cm/min)

Calculate the rate of discharge into the well hole using $Q = X\,R$ (cm^3/min); where

X = 53.46cm^2 for ETC **Standard** Pask Permeameter
X = 13.79cm^2 for **Slow Soils** Permeameter made from PC tubing (after Nov. 2021)
X = 12.81cm^2 for **Slow Soils** Permeameter made from PVC tubing (prior to Nov. 2021)

Refer to section 5.1 for a worked example showing how to calculate Kfs from first principles.

2.2.2 Determine Kfs using ETC Quick Field Reference Tables

Convenient *Quick Field Reference Tables* have been prepared by Dynamic Monitors for the specific permeameter characteristics and typical well hole diameter produced by the auger supplied with our kits. From testing conducted in sandy loam soil, the nominal 7.0cm (2-3/4") AMS Riverside auger was found to produce a typical well hole approximately 8.3cm in diameter.

The *Quick Field Reference Tables* give Kfs for various rates of fall (R) and α^* values. Alternative tables are provided for the Slow Soils Permeameter.

CAUTION: Ensure you are using the correct table which applies to the ETC Pask Permeameter being used, the permeameter material of construction (PVC or PC), the applicable H value and well hole diameter. The *Quick Field Reference Tables* supplied by Dynamic Monitors should not be used with constant head permeameters constructed by others, or when the well hole diameter is significantly different than indicated above. Calculate Kfs from first principles using Equation 1 instead.

Custom *Quick Field Reference Tables* may be ordered from Dynamic Monitors for alternative H values and auger (well hole) diameters.

Refer to section 5.2 for a worked example showing how to determine Kfs using the *Quick Field Reference Tables*.

2.3 Temperature Correction

The temperature of the water moving through the soil can have a significant effect on the measured Kfs because of the different viscosities of water at different temperatures. Warm water will flow through soil easier than cold water. Therefore, it might be advisable to adjust the Kfs value measured at the soil test temperature to obtain Kfs that is more representative of expected design or operating conditions e.g. the temperature of the soil during septic disposal field or subsurface stormwater infiltration system operation. This adjusted value (Ka) can be calculated by multiplying Kfs by a *temperature correction factor*.

The temperature correction factor is equal to the viscosity of water at the soil test conditions temperature divided by the viscosity of water for the expected soil temperature during system operation.

Calculate the adjusted **Ka** value using Equation 2.

$$\mathbf{Ka = Kfs \times \mu_k/\mu_a} \qquad \text{(Eq. 2)}$$

where

Ka = adjusted permeability for design temperature conditions
Kfs = calculated permeability from the field test
μ_k = viscosity of water at the test conditions
μ_a = viscosity of water at the adjusted operating (design) temperature.

For on-site sewage systems in northern climates, an assumed design temperature of 4°C may be appropriate for sewage systems used year round. Table 2.2 provides the temperature correction factor for different water/soil test temperatures, assuming a system design (operating) temperature of 4°C. Alternative correction factors can be calculated for regions with different design or operating temperature requirements.

If we were to assume that water and soil temperature of a septic disposal field were approximately 4°C in winter and the water/soil temperature was 20°C during the in situ permeability test, the adjusted Kfs value, (Ka) would be approximately equal to Kfs x 0.644. This difference may be within the design or other inherent factors of safety. However, the designer needs to be aware of this temperature effect and be sure that the system has adequate capacity under all operating conditions.

Refer to section 5.3 for a worked example showing how to apply a temperature correction to the Kfs value.

Table 2.2: Viscosity of water for temperature corrections.
Adapted from (Streeter and Wylie, 1975)

Water/soil Test Temperature °Celcius	Viscosity μ kg/m x s μ X 10^3	μ_k/μ_a For $\mu_a = 4^0$ C
4	1.560	1.000
5	1.519	0.974
6	1.469	0.942
7	1.419	0.910
8	1.369	0.878
9	1.319	0.846
10	1.308	0.838
11	1.268	0.813
12	1.228	0.787
13	1.188	0.762
14	1.148	0.736
15	1.140	0.731
16	1.110	0.712
17	1.080	0.692
18	1.040	0.667
19	1.010	0.647
20	1.005	0.644
21	0.975	0.625
22	0.945	0.606
23	0.915	0.587
24	0.885	0.567

2.4 Potential Errors and How to Mitigate Them

One of the most common sources of error, is **not letting the test run long enough for the rate-of-fall to reach quasi steady-state conditions**. As discussed in Section 4.4, typically quasi steady state flow can be assumed to have been achieved after getting three to five consecutive rate-of-fall readings which are the same. Not waiting until steady state flow has been reached will typically result in **overestimation** of Kfs values.

Smearing and compaction from augering may also cause erroneous results. To avoid this, hold the auger handles with a light grip, and employ the “two-finger, two-turn rule” discussed in Section 4.3. The wire brush provided with the kit should also be used to brush the sides of the well hole and remove or scarify any smeared layer. Generally speaking, errors caused by smearing and compaction will result in **under-estimation** of Kfs values.

As discussed in Section 4.2, wet (near-saturated) soils of all types, will have a **moisture content which is above field capacity.** Conducting tests in very wet, fine-textured, structureless soils may cause the *single-head* CHWP analysis to overestimate Kfs (Reynolds, 2008, 2015). Soil should therefore not be tested in these conditions. Practitioners should therefore be capable of recognizing that soil conditions are at, or drier than field capacity as a prerequisite to visually estimating α^* to determine Kfs.

There is the potential for error due to **inappropriate selection of α^***. Reynolds (2008) explained that possible errors due to improper selection of α^* were not excessive and could be mitigated by using a ponded well height (H) that is as large as possible. However, caution should be used not to make H too large, as this increases the likelihood of encountering **heterogeneity** such as layering, horizonation, cracks, worm holes, root channels, etc. If there were large variations in the soil profile such as a restrictive layer just below the hole or lenses of different soil textures throughout the tested range, the test may not provide representative results. To balance these two considerations, ETC has chosen a default well height of 15 cm for our permeameter kits. This height appears to be suitable for most slow to moderately permeable soils. Alternative well heights which are better suited to very fast soils can also be provided upon request.

The well hole should be **cylindrical and have as flat a bottom as possible**. Small variations in hole diameter should not significantly affect the results (Twigg and Lilly, 1991, Reynolds, personal communication, 2015). Some manufacturers of other permeameters provide a *sizing auger* with their kit to facilitate creating a well hole with as flat a bottom as possible. However, Lilly (1991) recommends against using a sizing auger as it can increase soil smearing. In our opinion, the Riverside auger supplied with our kit typically produces a sufficiently flat bottomed well hole for most common applications (septic site assessments, stormwater system design).

The **temperature of the water in the permeameter** should be as close to the ambient air temperature as possible when conducting the test. If not, as the water temperature increases or decreases, the rate of water drop in the permeameter may vary and the rate of fall will not reach become constant.

Several permeameter tests should be conducted at a site to be sure that the test results are representative of the true soil conditions. The examination of test pits in the area of the permeameter tests, plus the experience and judgment of the practitioner will help ensure that any results which are not consistent with the soil texture and structure are considered to be suspect or are rejected.

3 ETC PASK CONSTANT HEAD PERMEAMETER

3.1 Background

Several different constant head well permeameters are commercially available. Each have specific advantages, disadvantages and limitations which can affect their usefulness and suitability for a particular application. **Only the ETC "PASK" permeameter is described in this guide**.

ETC's PASK Permeameter is named after Mr. David Pask (1931-2016), a Public Health Engineer with the Nova Scotia Department of Health (1981-1992). Mr. Pask was in search of a convenient and reliable method of measuring soil permeability when he became aware of the pioneering research being carried out in the 1980s by Elrick and Reynolds at the University of Guelph (Ontario, Canada). Mr. Pask learned of a simplified CHWP being used by Elrick and Reynolds in their research and development of the single ponded height method. He adapted the concept of Elrick and Reynold's simplified constant head permeameter and advocated for its use in Nova Scotia for on-site sewage disposal assessment and design.

ETC/Dynamic Monitors made further improvements to the design, such as the provision of a plastic end cap with water flow holes (instead of a solid rubber stopper) which allowed for better flow through the base of the well hole. Custom *Quick Field Reference Tables* were developed to simplify calculations in the field. The ETC Pask Permeameter is being used in several jurisdictions in Canada, the USA, Europe, Asia and South America.

3.2 General Application

ETC Pask permeameters are easy to use and provide reliable results when used under appropriate conditions. The current components of the Comprehensive ETC Pask Permeameter Kit are shown in Figure 3.1.

3.3 Anisotropic Conditions (Horizontal versus Vertical Kfs)

In *anisotropic* soil where the horizontal Kfs differs from the vertical Kfs, constant head well permeameters normally give an averaged Kfs value that is weighted toward the soil's horizontal Kfs. The degree of weighting will depend primarily on the H/a ratio, i.e. the larger the ponding depth (H) relative to borehole radius (a), the greater the weighting toward the soil's horizontal Kfs. This is primarily due to the submerged surface area of the well hole wall being much greater than the submerged surface area of the well hole base.

For example, in the case of the ETC Pask Permeameter and an 8.3cm diameter well hole, if the ponding depth is, H = 15 cm, and the well hole radius is, a = 4.15 cm, then the infiltration surface area of the borehole wall is, Aw = 2πaH = 391.1 cm^2, while the infiltration surface area of the well hole base is, Ab = πa2 = 54.1 cm^2. Thus the infiltration surface area of the well hole wall is a factor = 391.1/54.1 = 7.2 times greater than the well hole base.

Reynolds and Elrick (1985) describe how Kfs from a CHWP test method averages Ks from vertical and horizontal intact soil core samples. Some example calculations and practical advice related to in situ permeability testing in anisotropic soils can also be found in the manuscript by Reynolds and Elrick (1986).

Figure 3.1: Components of the Comprehensive ETC Pask Permeameter Kit (from left to right): 2-piece Riverside (bucket) auger, wire brush, Standard Pask Permeameter, Slow Soils Pask Permeameter, Quick Field Reference Tables.

3.4 ETC Standard Pask Permeameter

The standard ETC Pask Permeameter is suitable for testing a wide range of soils from loams and sands to clays - USDA/CSSC: sand to clay; USCS: Sand, silty sand, silt and clay. The standard permeameter can also be used to determine Kfs of built-up beds of prepared fill materials and constructed soil liners.

For the ETC Standard Pask Permeameter, the applicable Kfs range is 10^{-8} m/sec to 10^{-4} m/sec.

3.5 ETC Slow Soils Pask Permeameter

The Slow Soils Pask Permeameter (included in the ETC Comprehensive Pask Permeameter Kit and also sold separately), is a variation of the ETC Standard Pask Permeameter. It is better suited for testing soils which have very low Kfs values such as: clay, silt, silt loam, clay loam, loam, sandy silt, etc. It is ideal for practitioners who need to test slowly permeable natural soil horizons, or compacted clay liners for lagoons, stormwater ponds and landfills.

The Slow Soils Permeameter has a smaller reservoir diameter than the Standard Pask Permeameter. For every unit volume of water which flows out of the well hole into the soil, there will be a larger drop on the Slow Soils Permeameter reservoir than the Standard Pask Permeameter reservoir. This makes the Slow Soils Permeameter more accurate at the lower (slower) end of the Kfs range because it is easier to discern small water level drops (small rates of fall) on the scale of the Slow Soils Permeameter. When testing very slowly permeable soils, the results obtained with the Slow Soils permeameter will be slightly more accurate and it won't take as long to confirm that steady state conditions have been reached.

The applicable Kfs range for the ETC Slow Soils Pask Permeameter is 10^{-9} m/sec to 10^{-6} m/sec.

3.6 Applicable Testing Depth

ETC Pask Permeameters must sit on the bottom of the well hole as shown in Figure 4.1. Therefore, without removing any upper soil layers, the practical maximum test depth using the Standard Pask Permeameter is about 60cm (24 inches) below ground surface and approximately 80cm (31 inches) below ground surface with the Slow Soil Pask Permeameter.

It is not possible to add extensions to increase the depth range of ETC Pask Permeameters. However, it is possible to conduct tests at greater depths such as 90cm to 180cm below ground surface by simply widening the top of the well hole or removing some of the soil at the ground surface. A hand shovel or a machine can be used, as appropriate, to excavate to within approximately 40cm of the desired testing depth. The auger should be used to bore the remaining distance to reach the bottom of the well hole.

To ensure safety of personnel, test access holes should not be deeper than 1.2m (4 ft) unless they are shored or sloped in accordance with local occupational health and safety requirements.

4 CONDUCTING TESTS WITH THE ETC PASK PERMEAMETER

Following are the steps and considerations to conduct a test with an ETC Pask Permeameter.

4.1 Well Hole Location and Weather Conditions

Care should be taken to locate test hole(s) at sites that will most closely represent the Kfs values of the area under investigation. Attention should be paid to any soil conditions that may cause erroneous Kfs values such as the presence of excessive worms or rodent activity, roots, clay or gravel lenses or soil cracks.

Strong winds can result in inaccurate readings from movement of the permeameter and/or movement of the water within the permeameter. If the permeameter can not be sufficiently stabilized, the test should be carried out another day.

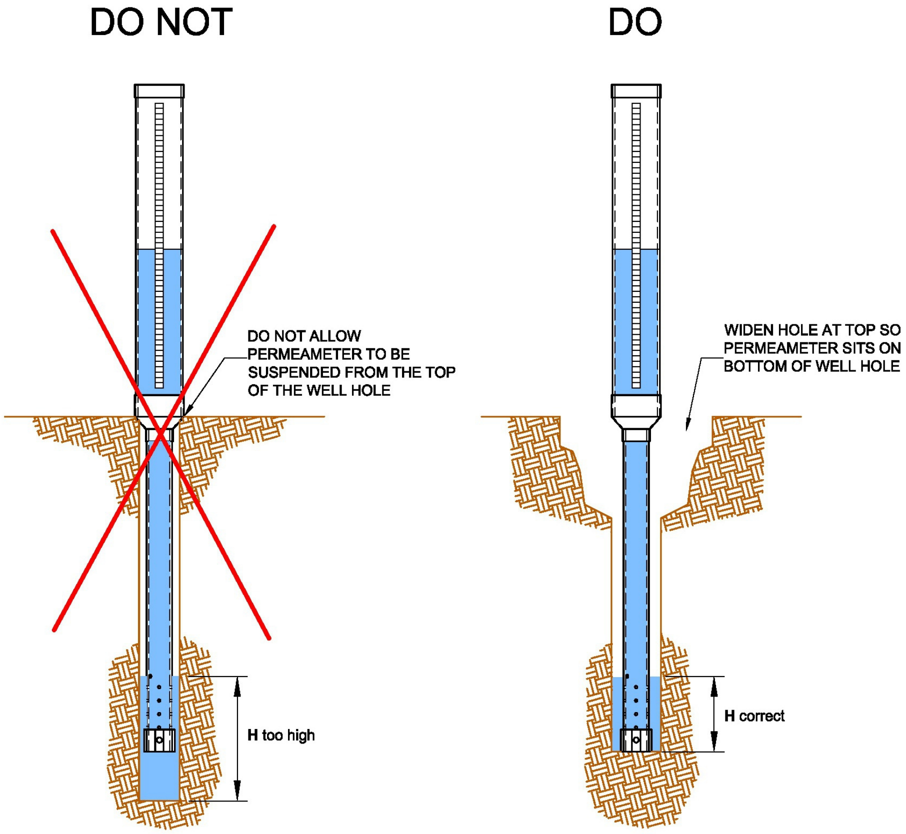


Figure 4.1: Proper installation of the Pask Permeameter.

4.2 Soil Moisture Conditions

As mentioned in Section 2.4, as long as the soil moisture condition is less than ***field capacity***, α* can be selected from one of four general capillarity categories (from Table 2.1) which are primarily related to the soil structure and texture. One working definition of "field capacity" (Reynolds et al, 2015) is "the water content that exists in the soil once drainage stops after a soaking (saturating) rain". Cessation of soil drainage corresponds roughly with the time at which subsurface tile drains stop flowing after a rain event. As a rough guide, soils at field capacity water content or drier do not compress under foot and they tend to crumble (rather than remold or smear) when worked in the hand.

The field capacity soil water content usually corresponds to the *pore water pressure head* (or *matric potential*) of $\psi = -1$ m; and it is the pore water pressure head that actually imparts soil capillarity, not the soil water content. A *field tensiometer* (e.g. Quickdraw tensiometer, Soilmoisture Equipment Corp., CA) should be used for measurement of soil matric potential if practitioners are not confident in their ability to assess the field capacity condition based on visual and textural indicators alone.

4.3 Well Hole Preparation

1. Using the Riverside/Bucket auger provided with the kit, bore a well hole to the desired test depth. Note: If you are planning to use the *ETC Quick Field Reference Tables* supplied with your kit, ensure that the well hole diameter produced by your auger is similar to what is indicated in the tables. The top layer of soil may be removed with a shovel or machine before using the auger to complete the hole. Ensure the permeameter will rest on the bottom of the well hole, and not be suspended from the ground surface (i.e. Figure 4.1). Take care to not remove too much soil however, as it is important that the *wetting front* does not appear at the ground surface during the test.

2. The auger may smear the sides of the hole, particularly if the soil is fine textured and moist to wet. Smearing will usually result in an erroneous (lower) field saturated hydraulic conductivity (Kfs). *Sizing augers* (distributed with some permeameter kits made by others) should not be used, as it can make the smearing worse (Twigg and Lilly, 1991).

3. The "two finger method / two turn rule" is recommended to minimize the potential for smearing and compaction. It is described by Reynolds (2008) as follows:

   "once the top of the measurement zone has been reached, use only two fingers on each hand to apply downward pressure on the auger (ie. the weight of the auger applies most of the pressure), and make only two complete turns of the auger before emptying it out."

4. The bottom of the well should be at least 20 cm above the water table or capillary fringe (see Figure 2.1) to prevent the water table from entering the well (Reynolds, 2008). If groundwater appears to be entering the well hole from the walls of the well, then the constant head method of testing may not be appropriate for this situation (Amoozegar A, Warrick AW. 1986).

5. Inspect well for smearing within the measurement zone using a flashlight. If smearing is present (soil generally appears smooth and polished), use the wire brush provided to scarify or remove it. Do not "over-scarify" the hole. If removal of the smeared surfaces results in an appreciable increase in the size of the well hole, the new diameter should be measured and used in the calculations (Reynolds, 2008).

4.4 Water Dispersal from the Permeameter

1. Fill the permeameter with water and apply the orange plastic cap so that the spring clip button locks it in place.

2. Place the support screen, if one is being used, on the bottom of the well hole.

3. Quickly invert the permeameter into the hole, <u>ensuring that it rests on the bottom of the hole</u>. Carefully lean the permeameter against the side of the well hole so that it is stable and will not shift during the test. It should be relatively straight, but it is not necessary for the permeameter to be perfectly vertical during the test. It is more important for the

instrument to be stable, so it will not shift once you start taking readings.

4. Water will initially flow out of the permeameter reservoir, filling the well, until the head of water in the well reaches the level of the air inlet hole. With some soil conditions, this initial rapid flow can cause "slaking" of the side walls of the well hole into the water. This may be prevented by using a *well screen* or by backfilling around the lower tube of the permeameter with clean pea gravel (Lilly 1994, p75).

5. As water flows out of the well hole into the soil, the water level in the well will eventually drop below the level of the air inlet hole, causing one or more air bubbles to periodically occur and move up through the reservoir. Begin recording the water level on the scale on the reservoir (to the nearest millimeter) and the time of the reading (to the nearest second).

6. With highly permeable soils, the bubbling may be continuous and readings should be taken at close intervals (seconds or minutes apart) before the permeameter runs out of water. However, with slowly permeable soils, it may be several minutes to an hour or more between bubbles, and a longer interval between readings will be feasible.

7. Sometimes, too much water may initially flow out of the permeameter if it is inverted too slowly into the well hole. This can cause overfilling of the well to a depth above the level of the air inlet hole. If the soil is slowly permeable, it may take a long time before the water drops to the level of the air inlet hole and bubbling starts to occur. In such cases, the ***water extraction syringe and tubing*** (included with the Slow Soils Permeameter) may be used to remove excess water, just until one or more bubbles occur.

8. Monitor the reservoir water level **until the rate of fall becomes relatively constant and it reaches equilibrium** (i.e. a constant, *quasi "steady state"* flow rate). While not necessary, some practitioners find it convenient to take readings at a consistent timing interval, so that consecutive rate of fall readings which are the same will be evident without having to do any math in the field. Quasi steady state flow can be considered to have been achieved after getting three to five consecutive rate-of-fall readings which are the same. Most medium permeability soils will reach quasi steady state flow conditions within 30 minutes to an hour. However, this can take as little as a few minutes in highly permeable materials to several hours in very slowly permeable soils.

9. Record the value for the steady state rate of fall (**R**) on the field permeability test sheet. An example test sheet is provided in Appendix A.

4.5 Care and Cleaning of End Cap and Spring Clip

Flush the lower part of the tube, end cap and spring clip with clean water upon completion of each test. This will maintain smooth operation, and prevent the cap or clip from sticking due to soil particles becoming lodged between the parts. We recommend flushing the cap and tube in the stream of water as it flows from the permeameter when emptying it.

4.6 Determining Kfs

1. Use the table of soil structure and texture categories (Table 2.1) to estimate an appropriate α^* value for the soil zone tested.

2. Determine the *field saturated hydraulic conductivity* (Kfs) from the *ETC Quick Field Reference Tables* (Section 2.2.2), or from first principles by using the formula and method outlined in Section 2.2.1.

3. Apply a temperature correction to Kfs if deemed appropriate (see Section 2.3).

4.7 Verifying Integrity of Permeameter Seals

All ETC Pask Permeameters are tested at our facility, to verify they are water tight, before being shipped. Dropping or rough handling of the permeameter could result in a crack in the reservoir tubing of seals causing leakage and erroneous test results. Therefore, it is important that your Permeameter be checked immediately upon receiving it, and thereafter on a periodic basis to ensure it is water tight. The procedure recommended by Dynamic Monitors can be found in Appendix B.

4.8 Testing Imported Fill Material

The ETC Pask Permeameter can also be used to determine Kfs of constructed beds of septic sand and other imported sand or porous media fill materials. Compliance or quality assurance testing may be carried out on a properly prepared *test pad* of fill constructed at the project site, or at the pit or stockpile location for the fill material. A suggested procedure for constructing a test pad is described in the ***CAN CSA B65-12 Installation code for decentralized wastewater systems*** (Canadian Standards Association, 2012) and is summarized as follows:

- Build a representative “test pad” of fill having a minimum area of 3m x 3m (10ft x 10ft).

- Test pad should have a minimum thickness of 900mm (3ft), constructed using maximum 150mm (6inch) thick layers, lightly compacted to a density approximating that of the completed bed of imported fill.

- The bottom of the well should be deep enough so that the wetting front does not appear on the surface of the fill during the test, but also shallow enough so the *field saturated bulb* does not reach the underlying native soil below the fill. (ETC Note: We recommend making sure there is at least 30cm (12”) of fill below the bottom of the well hole.)

5 Worked Examples for Calculation of Kfs

5.1 Calculate Kfs From First Principles

The soil type as determined from examination of a test pit near to the permeability test location is a *sandy loam* with a *weak blocky structure*. Based on this assessment, from Table 2.1, we select:

$\alpha^* = 0.12\ \text{cm}^{-1}$

From the field permeameter test, the quasi steady state rate of fall (R) was determined to be:

$R = 0.20\ \text{cm/min}$

Using the auger supplied with the ETC Pask Permeameter Kit, the well hole diameter was approximately 8.3 cm, therefore, the well hole radius, a = 4.15 cm.

For the ETC Standard Pask Permeameter:

X = Reservoir cross sectional area = 53.46 cm^2 (inside diameter is 8.25 cm)

Calculating:

$Q = XR = 53.46 \times 0.20 = 10.69\ \text{cm}^3/\text{min}$

H = Height of constant head in well=15 cm (from bottom of cap to air inlet hole)

Calculating:

$H/a = 15/4.15 = 3.61$

Therefore, from Figure 2.2 we can determine that:

$C = 1.36$ (for $\alpha^* = 0.12\ \text{cm}^{-1}$, use line 1 in Figure 2.2)

Calculate Kfs using Equation 1:

$$Kfs = CQ / [2\pi H^2 + C\pi a^2 + (2\pi H/\alpha^*)]$$

Where formula constants are grouped and named as “A” and “B”:

$A = 2\pi H^2/C + \pi a^2$ $\quad B = 2\pi H/C$

Therefore, to calculate the field saturated hydraulic conductivity:

$$Kfs = Q/(A + B/\alpha^*)$$

Calculating:

$A = (2\pi 15^2)/1.36 + \pi 4.15^2 = 1093.60cm^2$

$B = (2\pi 15)/1.36 = 69.30cm^2$

Finally calculating:

$Kfs = Q/(A + (B/\alpha^*)$
$Kfs = 10.69/(1093.60+69.30/0.12)$ cm/min
$Kfs = 6.3 \times 10^{-3}$ cm/min
$Kfs = 1.1x10^{-6}$ m/sec

5.2 Determine Kfs from ETC Quick Field Reference Tables

Using the table for $\alpha^* = 0.12\ cm^{-1}$, pick the Kfs value which corresponds to a rate of fall, R = 0.20cm/min. The Kfs value in the column next to 0.20 is 1.1E-06 m/sec = **1.1×10^{-6} m/sec**.

Kfs can be expressed in other units as desired based on local regulations or design preference.

e.g. $Kfs = 1.1x10^{-6}$ m/sec x 86,400,000 = 95 mm/day
Kfs = 95 Lpd/m^2
Kfs = 3.7 inches/day

5.3 Temperature Correction

Assume that the soil and water temperature at time of testing in the example above was 10° C. If the septic system is to operate during the winter and the design winter soil/effluent temperature is anticipated to be 4° C, then the temperature corrected permeability would be calculated using Equation 2 as follows:

$$Ka = Kfs \times \mu_k/\mu_a$$

where

Ka = corrected permeability adjusted for design temperature conditions
Kfs = the calculated permeability from the field test
μ_k = the viscosity of water at the test conditions (Table 2.2)
μ_a = the viscosity of water at the adjusted design temperature (Table 2.2)

Therefore:
μ_k = 1.308 at 10°C
μ_a = 1.56 at 4°C
μ_k/μ_a = 0.838 (from Table 2.2)

$Ka = 1.1 \times 10^{-6}$ m/sec x 0.838 = **8.9×10^{-7} m/sec**

Therefore, it would be more conservative to use the temperature corrected value of Kfs = 8.9×10^{-7} m/sec for septic system design purposes.

6 RELATIONSHIP OF Kfs TO PERCOLATION TIME

The percolation test (PT) rate of fall or “Perc Time” is still used in many jurisdictions to determine suitability for onsite sewage disposal or for sizing of soil absorption systems (drainfields). It has been recognized for some time, however, that PT is less than ideal because it is not just a function of soil permeability, but also a function of test conditions.

The field saturated hydraulic conductivity, Kfs, determined using the CHWP technique, is a much more scientifically and technically sound indicator of soil permeability than the PT. Kfs testing controls for variables that can substantially affect the PT such as pit/borehole dimensions, depth of water ponding, soil capillary properties, and background soil moisture content at the time of the test.

Various correlations between Perc Time (PT) and field-saturated hydraulic conductivity (Kfs) have been proposed. Reynolds et al (2015) analysed PT versus Kfs correlations from Virginia, Georgia, Connecticut, and Ontario. None of the correlations were found to be generally applicable, accurate or scientifically defensible, in part because they did not completely describe the factors affecting PT and Kfs.

An accurate and physically based analytical expression relating PT to Kfs for cylindrical test holes was proposed (Reynolds, 2015 and Reynolds et al, 2015) from which usable PT versus Kfs relationships are now possible. A procedure has been described which shows how to determine PT from Kfs using the single-ponded height CHWP method. The reader should consult Reynolds et al (2015) for a detailed discussion of the factors and applicability of the newly developed PT to Kfs relationship. A summary of a simplified procedure to determine PT from Kfs which is applicable to the ETC Pask Permeameter Kit is outlined below.

Step 1: Determine Kfs and α* using the single-head method outlined in this user guide.

Step 2: Determine the appropriate PT to Kfs *conversion factor*, ***m***, from Table 6.1 (next page).

Step 3: Determine the “equivalent” PT that corresponds to the H, d (a), α* and Kfs values, using the relationship, **PT = m/Kfs**, where Kfs is in meters/sec.

The calculated PT value is referred to as “equivalent” because borehole water level is held constant (at H) by the CHWP, thereby preventing direct measurement of PT = $\Delta t/\Delta H$.

It should be noted that the equivalent PT is based on the borehole geometry and constant water level used to carry out the Kfs testing, i.e. in the case of the ETC Pask Permeameter Kits, a = 4.15cm and H = 15cm. As a result, the PT values determined from CHWP measurements may not relate well to decades old PT values found in onsite sewage regulations and codes if they were developed based on percolation tests which used different **H** and **a** values.

To address this discrepancy, the PT values obtained using CHWP tests could be “scaled” up or down to the same borehole geometry and water level used to derive the original PT criteria found in the respective regulation/code. Alternatively, the original reference PT criteria could be scaled up or down to match the same borehole geometry and water level used for the CHWP tests. i.e. $\mathbf{PT_{scaled} = m_{scaled}/Kfs}$. Consult our web site for further guidance on scaling PT values.

Table 6.1: Conversion factor, *m*, relating Perc Time (PT) to Kfs for constant head, H=15.0cm and well hole diameter, d=8.3cm. PT=m/Kfs, where Kfs is in meters/sec.

Constant Head, H = **15.0** cm
Ave. Well Hole Diameter, d = **8.3** cm

Capillarity Category	Representative α* (cm-1)	m (for PT in min/cm)	m (for PT in min/inch)
Negligible	1.0	7.74E-06	1.97E-05
Weak	0.36	7.00E-06	1.78E-05
Moderate	0.12	5.39E-06	1.37E-05
Strong	0.04	3.18E-06	8.07E-06
Very Strong	0.01	1.05E-06	2.68E-06

CAUTION: It must be emphasized that Table 6.1 only applies to the well characteristics indicated. Refer to our web site (DynamicMonitors.com) for conversion tables applicable for other auger/well hole sizes and constant heads, or contact us to order custom tables.

REFERENCES

Amoozegar A. and Warrick A.W. 1986. Hydraulic conductivity of saturated soils: field methods. Methods of Soil analysis, Part 1 – Physical and mineralogical methods. 2nd edition. Agronomy Monograph No. 9, (American Society of Agronomy/Soil Science Socitety of America: Madison).

Bagarello, V., M. Iovino, and W.D. Reynolds. 1999. Measuring hydraulic conductivity in a cracking clay soil using the Guelph permeameter. Transactions of the American Society of Agricultural Engineers. 42(4):957-964.

Canadian Standards Association, 2012. CSA B65-12 Installation Code for Decentralized Wastewater Systems. Canadian Standards Association, Toronto, ON, Canada.

Constantz, J., W.N. Herkelrath, and F.Murphy. 1988. Air encapsulation during infiltration, Soil Sci. Soc. Am. J., 52, 10–16.

Elrick, D.E., and W.D. Reynolds. 1986. An analysis of the percolation test based on three dimensional saturated-unsaturated flow from a cylindrical test hole. Soil Science. 42:308-321.

Elrick, D.E., W.D. Reynolds, and K.A. Tan. 1989. Hydraulic conductivity measurement in the unsaturated zone using improved well analyses. Ground Water Monitoring Review. 9:184-193.

Elrick, D.E., and W.D. Reynolds. 1992a. Infiltration from constant-head well permeameters and infiltrometers. Pages 1-24. In G.C. Topp, W.D. Reynolds, and R.E. Green (eds.) Advances in Measurement of Soil Physical Properties: Bringing Theory into Practice. Soil Science Society of America Special Publication No. 30, Soil Science Society of America, Madison, USA.

Elrick, D.E., and W.D. Reynolds. 1992. Infiltration from constant-head well permeameters and infiltrometers. Soil Science Society of America Special Publication No. 30:17, 20.

Elrick, D.E., and W.D. Reynolds. 1992b. Methods for analysing constant-head well permeameter data. Soil Science Society of America Journal. 56:320-323.

Lilly, A. 1994. The determination of field-saturated hydraulic conductivity in some Scottish soils using the Guelph Permeameter. Soil Use and Management 10, 72-78.

Lilly, A. 2000. The relationship between field-saturated hydraulic conductivity and soil structure: development of class pedotransfer functions. Soil Use and Management 16, 56-60.

Reynolds, W.D. and D.E. Elrick. 1985. In situ measurement of field-saturated hydraulic conductivity, sorptivity and the α-parameter using the Guelph permeameter. Soil Science. v.140, no.4, pp. 292-302.

Reynolds,W.D. and Elrick, D.E. 1986. A method for simultaneous in situ measurement in the vadose zone of field saturated hydrulic conductivity, sorptivity and the conductivity-pressure head relationship. Ground Water Monitoring Review. Winter 1986: pp.84-95.

REFERENCES, continued

Reynolds,W.D., S.R. Vieira, and G.C. Topp. 1992. An assessment of the single-head analysis for the constant headwell permeameter. Canadian Journal of Soil Science. 72:489-501

Reynolds,W.D. 1993. Saturated hydraulic conductivity: field measurement. In Carter, M.R. (ed.) Soil Sampling and Methods of Analysis. Canadian Society Soil Science. Lewis Publishers, Boca Raton, FL, USA. pp.599-613

Reynolds,W.D. 2008, Saturated Hydraulic Properties: Well Permeameter. In Carter, M.R. and Gregorich, E.G. (Eds.), Soil Sampling and Methods of Analysis (2nd ed.). Canadian Society of Soil Science. CRC Press, Boca Raton, FL., USA, pp. 1025-1042.

Reynolds, W.D., 2016. A unified perc test – well permeameter methodology for absorption field investigations. Geoderma 264 (2016) 160–170.

Reynolds,W.D. and Galloway, K.A. and Radcliffe, D.E. 2015. The relationship between perc time and field-saturated hydraulic conductivity for cylindrical test holes. Proceedings of the Annual Conference of the National Onsite Wastewater Recycling Association, West Virginia Beach, West Virginia. November 2015.

Reynolds,W.D. 2015, Personal e-mail communication to K.Galloway

Streeter, V. and E.B. Wylie. 1975, Fluid Mechanics, 6th edition, (New York, US: McGraw-Hill Inc, 1972)

Twigg, R.J. and Lilly, A. 1991. Some problems and solutions concerning the use of the Guelph permeameter (GP) model 2800k1. *(Restricted circulation).*

APPENDIX A

Field Permeability Test Example

Example Field Permeability Test Data Sheet

FIELD PERMEABILITY TEST EXAMPLE

You have excavated a test pit and logged the data as shown in the following table.

Depth below the root mat (cm)	Soil Description
0 - 30	Loamy Sand, loose, dry
30 - 90	Loam, compact, moderate blocky structure
90 - 120	Loam, very dense, weak blocky structure
120 - 180	Clay loam, massive

You decide to do a field permeability test at a depth of 60cm with your Standard Pask Permeameter in the middle of the compact loam layer.

The most appropriate α* value for *Loam, compact, and moderate blocky structure* would be $\boldsymbol{\alpha^* = 0.12}$ **cm**$^{-1}$.

The data recorded during the test are shown in the table below.

FIELD PERMEABILITY TEST #: 1

D – reservoir diameter (cm)	8.25	**Soil Texture**	Loam
d – well hole diameter (cm)	8.3	**Soil Structure**	Moderate Blocky
H – height of water in well (cm)	15	**α* (cm-1)**	0.12
Depth below ground surface	60 cm	**C – Factor**	1.36

TIME (min)	(1) CHANGE IN TIME (min)	RESERVOIR WATER LEVEL (WL) (cm)	(2) CHANGE IN WL (cm)	(2) ÷ (1) RATE OF FALL (R) (cm/min)
0	-	**80.9**	-	-
6	6	**60.5**	20.4	3.4
12	6	**42.5**	18.0	3.0
15	3	**34.7**	7.8	2.6
19	4	**26.7**	8.0	2.0
22	3	**21**	5.7	1.9
30	8	**5**	16.0	2.0

The last three readings have stabilized (approached steady state). A rate of fall value of **R = 1.9 cm/min** is selected and the quick reference table for $\boldsymbol{\alpha^* = 0.12}$ **cm**$^{-1}$should be used. The field saturated hydraulic conductivity Kfs = 1.0E-05 m/sec = 1.0 x 10^{-5} m/sec.

Engineering Technologies Canada Ltd.

OWNER'S NAME: ______________________

SITE LOCATION: ______________________

PID #: ______________________

TEST PIT #: ______________

TECHNICIAN: ______________________

DATE: ______________

WEATHER/TEMPERATURE: ______________________

FIELD PERMEABILITY TEST #:

D – reservoir diameter (cm)		Soil Texture	
d – well hole diameter (cm)		Soil Structure	
H – height of water in well (cm)		α* (cm-1)	
Depth below ground surface (cm)		C – Factor	

TIME (min)	(1) CHANGE IN TIME (min)	RESERVOIR WATER LEVEL (WL) (cm)	(2) CHANGE IN WL (cm)	(2) ÷ (1) RATE OF FALL (R) (cm/min)

Quasi Steady-State Rate of Fall (R) = ______________ cm/min

APPENDIX B

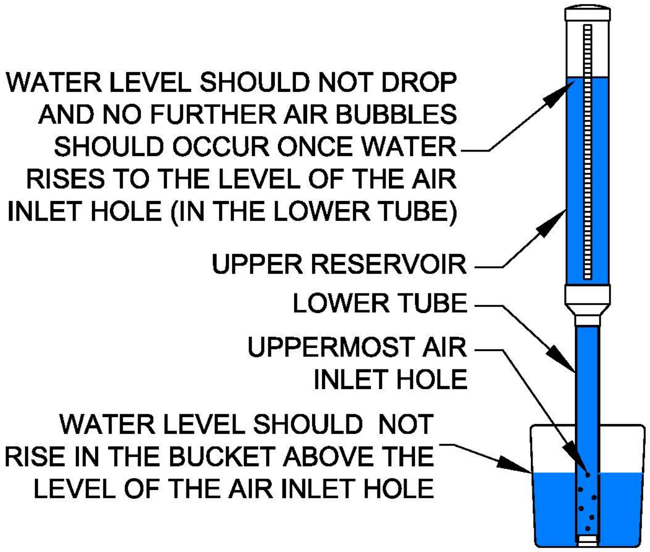
Procedure to Verify Integrity of Permeameter Seals

Warranty Information

ETC PASK PERMEAMETER – PROCEDURE TO VERIFY INTEGRITY OF PERMEAMETER SEALS

All ETC Pask Permeameters are tested at our facility to verify that they are water tight, before shipping to the customer. Dropping or rough handling of the permeameter could result in a crack or seal leakage. This could cause erroneous test results. Therefore, it is important that your Permeameter be checked immediately upon receipt, and thereafter on a periodic basis to ensure it is water tight. The procedure recommended by ETC / Dynamic Monitors is provided below.

1) Pre-fill a minimum 150mm (6”) deep bucket with water to a depth of at least 150mm (6”). Place the small bucket inside a larger deeper bucket in case water overflows or permeameter leaks.
2) Fill the permeameter with water. Attach cap to end of lower tube.
3) Invert the permeameter right side up into the small bucket (ie. same orientation as when conducting a test in the field).
4) <u>Stabilize the permeameter so it will not fall over.</u>
5) Water should rise to the level of the uppermost (air inlet) hole in the permeameter and stop.
6) Note the starting water level on the clear scale. Check the permeameter again after a minimum of 15 minutes. Note if the water level on the scale has dropped (it should not).
7) If the water level has dropped, or if there is any on-going air bubbling, it means that the permeameter is leaking. This will result in erroneous Kfs values.
8) If the permeameter is leaking, stop using it immediately. Contact Dynamic Monitors to see if it would be covered under warranty, or if it can be repaired.



DYNAM!C
MONITORS.COM

1-16 Myrtle St., Stratford, PE
Canada, C1B 2W2
Toll Free 1-888-747-7645 (SOIL)

PRODUCT REGISTRATION & WARRANTY

Register your product with us so that we may keep you informed with any updates pertaining to scientific developments, formulas or the quick field calculation tables used with our permeameters, or of any significant developments related to determining permeability and hydraulic conductivity using constant or falling head permeameters.

Dynamic Monitors will extend warranty coverage to two (2) years when you register your product within thirty (30) days of purchase. If you do not register your product, the one (1) year Base Limited Warranty will apply.

REGISTER YOUR PERMEAMETER ON-LINE TODAY

To review detailed warranty terms and to be eligible for the 2 Year, extended Registered Limited Warranty, visit our web site (**DynamicMonitors.com**) under the "**RESOURCES**" tab or by visiting this link:

https://dynamicmonitors.com/permeameter-warranty-product-registration/