APPENDIX C

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SOILS IN-SITU

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In-Situ Measurement of Field-Saturated Soil Hydraulic Conductivity

Saturated hydraulic conductivity, Ks, is a measure of the “ease” with which water flows through a saturated, 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 water into unsaturated soil do not measure Ks, but rather a reduced “field-saturated” hydraulic conductivity, $K_{fs,}$ because of air entrapment during the infiltration process (Reynolds, 1993). In the design of on-site sewage disposal fields, K_{fs} is preferred over Ks because drainage through the soil should be designed to occur at less than complete soil saturation.

In-situ measurement of K_{fs} 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 (Fig. 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). As this field-saturated bulb becomes established, the flow of water out of the well and into the soil approaches a constant rate. Once this steady flow rate is attained, the K_{fs} of the soil surrounding the well can be determined using the constant water flow rate, the radius of the well, and the head of ponded water in the well.

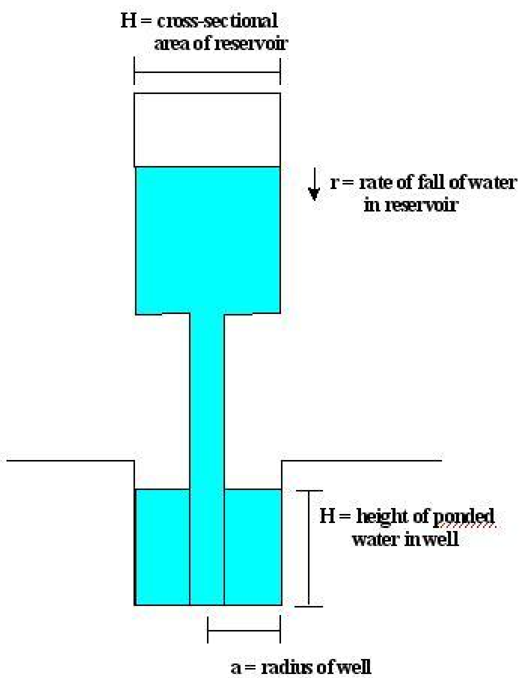

Figure 1. Constant Head Well Permeameter

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). 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. In-depth reviews and descriptions of the CHWP method can be found in Elrick and Reynolds (1986, 1992a,b); Reynolds et al. (1992); Reynolds (1993); Bagarello et al., (1999); and elsewhere.

A convenient and simple apparatus for ponding a constant head of water in a well and simultaneously measuring the flow into the soil is the well permeameter device shown in Fig. 1. An appropriately
placed air-inlet hole in the permeameter outflow tube (Fig. 1) establishes and maintains the desired water ponding head (H) in the well. Measuring the rate of fall of the water level in the permeameter reservoir (r) and reservoir cross-sectional area (X) allows determination of water flow rate (Q) into the soil (i.e. Q = rX). The K_{fs} is then calculated using the equation (Reynolds, 1993):

$$K_{fs} = CQ / [2\pi H^2 + C\pi a^2 + (2\pi H/\alpha^*)] \qquad [1]$$

where C is a shape factor selected from Fig. 2 (or Fig. 56.3 in Reynolds, 1993), a is the well radius, and α^* is a soil texture-structure parameter selected from the appropriate category in Table 1 (or Table 56.1 in Reynolds, 1993). An example calculation is given on page C-7. As noted in Reynolds (1993) and elsewhere, K_{fs} can be less than or equal to half of Ks due to partial blocking of soil pores by air bubbles entrapped by the infiltrating water. It should also be noted that, strictly speaking, the C-value curves in Fig. 2 and the α^* values in Table 1 apply for soils that are at field capacity or dryer, and when the wetting front from the test hole does not appear on the soil surface (Elrick and Reynolds, 1986).

The recommended procedure for determining in-situ field-saturated hydraulic conductivity by a consultant or site inspector is: i) dig one or more test pits in the immediate area of the proposed disposal field to estimate soil texture and structure so that the appropriate α^* value can be selected from Table 1; ii) make a number of permeameter measurements throughout the proposed disposal field so that a good estimate of the magnitude and variability of K_{fs} within the area can be established; iii) use equation [1] above (or one of its variants such as given in the example calculations) to determine K_{fs} at each measurement station; iv) examine both the mean K_{fs} and its variation throughout the proposed drain field to determine both the suitability of the site (Table 2.1of the Guidelines), and the value of K_{fs} to be used in the system design.

The temperature of the water moving through the soil can have a significant effect on the measured K_{fs} because of the different viscosities of water at different temperatures. Warm water will flow through soil easier than cold water. Therefore, depending on test and design operating temperatures, it may be necessary to adjust the measured K_{fs} to get permeability that is more representative of operating conditions. This adjusted value (Ka) can be calculated by multiplying K_{fs} by the viscosity of water at the temperature of water at which K_{fs} was measured divided by the viscosity of water at the system operating temperature.

$$Ka = K_{fs} \times V_K / Va$$

where: Ka = adjusted permeability for design temperature conditions
K_{fs} = the calculated permeability from the field test
V_K = the viscosity of water at the test conditions
Va = the viscosity of water at the adjusted design temperature

The temperature of the water in the permeameter should be close to air temperature 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 will not become constant. If we were to assume that water and soil temperature down slope of the disposal field were approximately 4^o C in winter and the water temperature was 20^o C during the test, the value of Ka would be approximately 0.6 x $K_{fs.}$ Under normal design conditions this difference may be within the design or other inherent factors of safety however the designer must be aware of this temperature effect and be sure that the system has adequate capacity under all operating conditions.

Another important consideration in conducting permeability tests is the depth of the soil and the presence of any layering. As mentioned on page C-1, the test assumes water moves away from the hole in a bulb shape. 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 hole, the test may not give a representative soil permeability. The examination of test pits in the area of the permeameter tests, plus the experience and judgement of the person conducting the test are critical to assure that test results are representation of the expected soil permeability.

There are many different constant head well permeameters. A list of some of the more common ones is included in Reynolds (1993, p. 600). Although all these designs are capable of measuring K_{fs}, they each have specific advantages and limitations which can affect their usefulness and suitability for a particular application. Only the "PASK" permeameter is described below. This permeameter has proven to be easy to use and appropriate for use intended in these guidelines. For details on the construction specifications of the Pask in-situ permeameter see Fig# 3.

Table 1. Suggested α* values

α^* (cm^{-1})	**Soil Structure and Texture**
0.36	Coarse sands and highly structured soils
0.12	Most structured soils and medium sands
0.04	Unstructured fine textured soils and fine sands
0.001	Compacted clays (e.g. clay liners)

Figure 2. Determination of C values
(After Elrick and Reynolds, 1985)

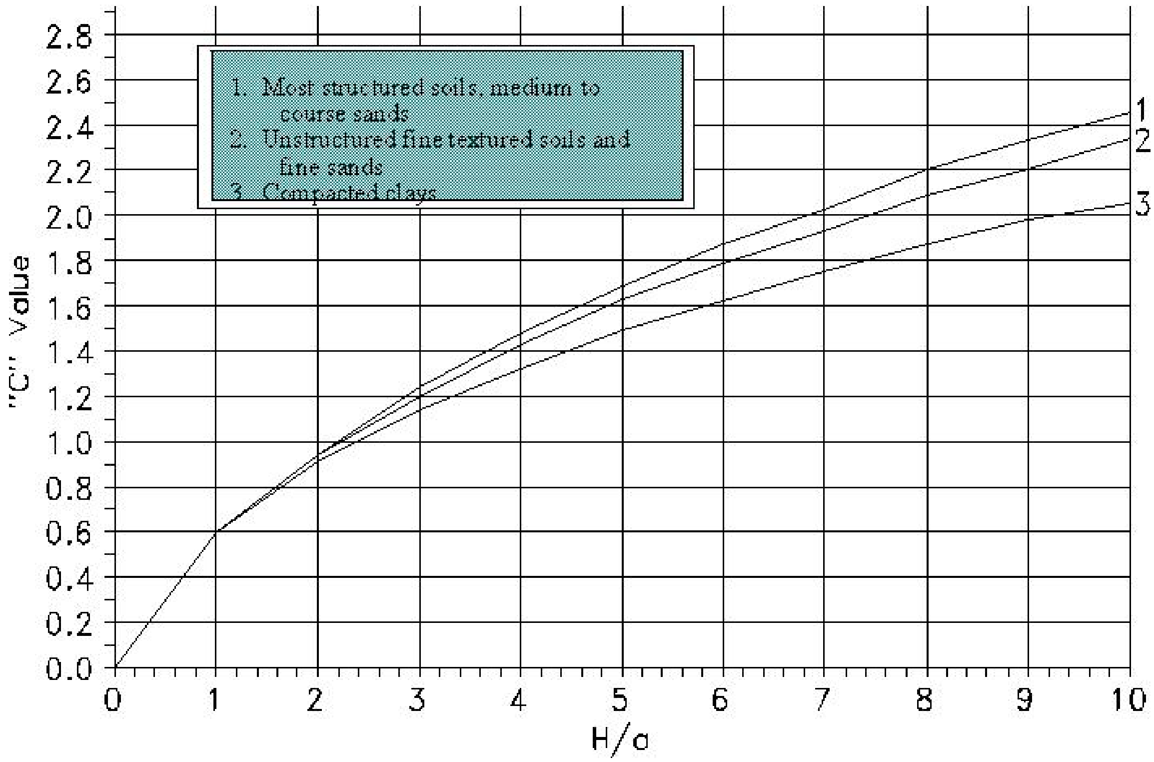

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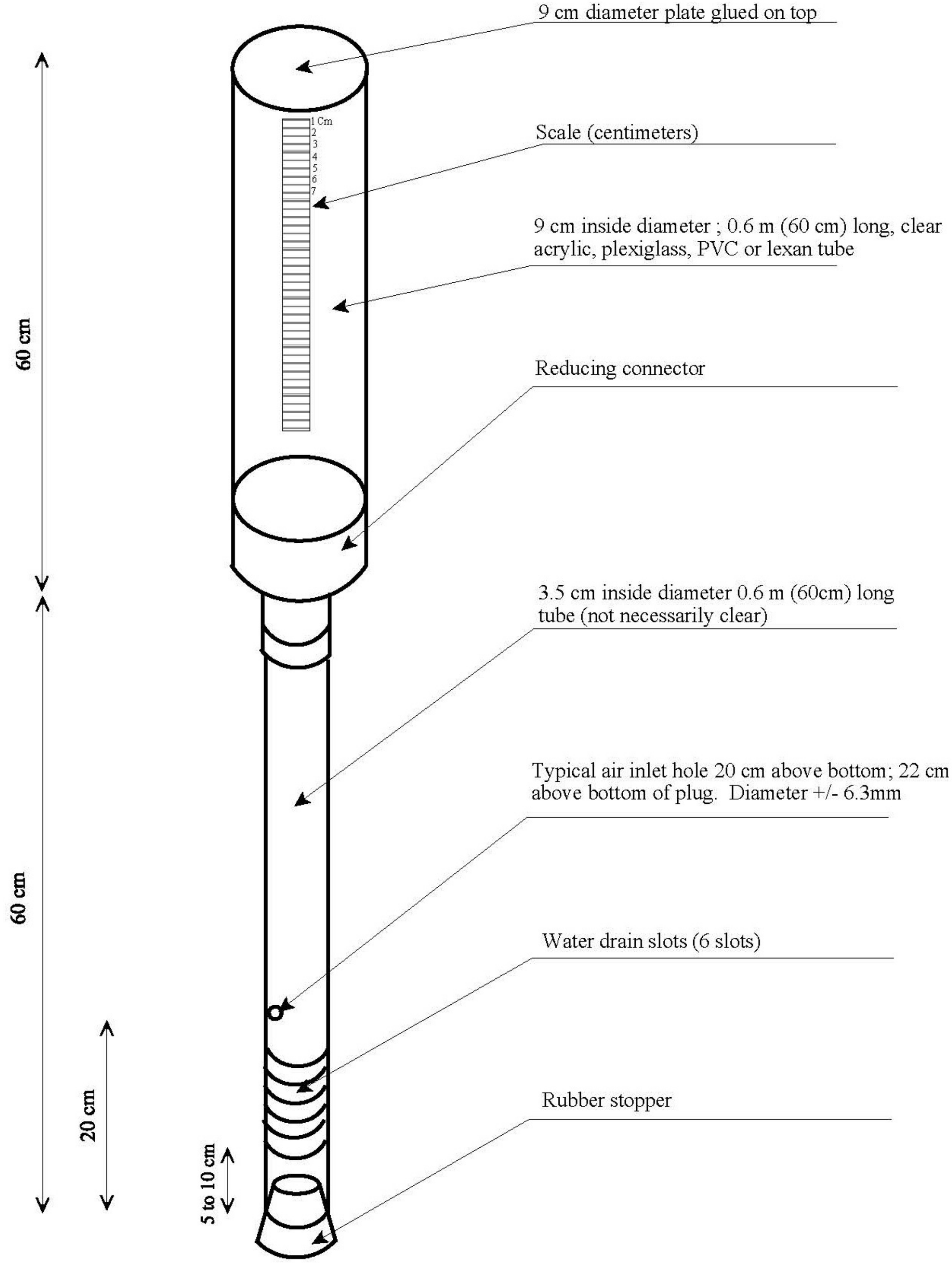
FIGURE 2C

Pask In - Situ Permeameter



PASK IN-SITU PERMEAMETER OPERATING INSTRUCTIONS

1. Loosen the ABS adjustable connector. Extend the small diameter tube fully. Re-tighten the connector.

2. Using an auger which will give a hole radius of 40-50 mm, auger hole(s) in the area of the proposed disposal field. If the soil is uniform make the hole depth 450-500 mm. If you wish to test a soil located deeper than 500 mm, the top layer of soil should be removed before you auger the hole. Care should be taken to locate the hole(s) in locations that will most closely represent the K_{fs} values of the area in question. Attention should be paid to any soil condition that may cause an unrepresentative value of K_{fs} such as the presence of excessive worm or rodent activity, roots, clay or gravel lenses or soil cracks.

3. The auger may smear the sides of the hole particularly if the soil is fine grained and damp. The smear layer can be removed from the sides of the hole with a brush or spiked roller. (A windshield snow brush with bristles cut to ¼ length will do.)

4. Stand the device upside down, fill with water to the air inlet hole and insert the rubber stopper.

5. Invert the permeameter and quickly insert it into the hole, resting the rubber stopper on the bottom of the hole.

6. Water will initially flow very rapidly out of the permeameter reservoir until the head of water in the well reaches the level of the air inlet hole. Allow the flow out of the permeameter to "equilibrate" (approach a constant flow rate), which usually requires 5-30 minutes depending on soil type and soil structure. Monitor the rate of fall of the reservoir water level at a set timing interval until the rate becomes constant for at least three consecutive readings.

7. Convert the measured constant rate of fall of the reservoir water level to units of cm/min or cm/sec, and calculate K_{fs} as indicated in the example calculation.

8. Adjust K_{fs} for water/soil temperature if necessary depending on the temperatures at the time of testing and the design operating temperature conditions.

CALCULATION SUMMARY FOR DETERMINING K_{fs}

Following is a summary of the calculation of K_{fs}
To calculate K_{fs} you will need:

a - test hole radius (cm)
H - height of air inlet hole from bottom of test hole (cm)
C - from C vs. H/a graph
α^* - from table of soil types (cm^{-1})

X - cross-sectional area of permeameter reservoir (cm^2)
r - constant rate of fall of water in permeameter reservoir (cm/min)

Calculate the rate of discharge of water using Q=X r (cm^3/min)

Equation (1) is:

K_{fs} **= CQ/[2 Π H² + Π a² C + (2 Π H/α*)]** (Where Π = 3.14)

rewriting gives:

$$K_{fs} = \frac{Q}{\left\{ \frac{2 \Pi H^2}{C} + \Pi a^2 + \frac{2 \Pi H}{C \alpha^*} \right\}}$$

Where formula constants are grouped and named as *A* and *B*:

$$A = \frac{2\Pi H^2}{C} + \Pi a^2 \qquad B = \frac{2\Pi H}{C}$$

To calculate the saturated field hydraulic conductivity:

$$K_{fs} = \left(\frac{Q}{A + \frac{B}{\alpha^*}} \right)$$

EXAMPLE PROBLEM FOR CALCULATION OF K_{fs}

Soil type (as determined from examination of a test pit) is a fine textured silty material without structure, significant clay or coarse sand content. Based on this assessment, from Table 1 use:

$\alpha^* = 0.04\ cm^{-1}$

For the permeameter used:

$X = 63.6\ cm^2$ (inside diameter is 90mm)
$H = 22$ cm (bottom of plug to air hole)
$a = 4$ cm

The air and water temperature at time of testing were 20^0 C

Form the field permeameter test the constant rate of water drop was determined to be:

$r = 3.1$ cm/min

$H/a = 22/4 = 5.5$ Therefore from Figure 2:

C= 1.7 (for fine textured sandy material- line #2)

$Q = X\ r = 63.6 \times 3.1 = 197.2\ cm^3/min$

$A = [(2\pi H^2)/C] + \pi a^2$
$A = [(2\pi 22^2)/1.7] + \pi 4^2 = 1838.1$

$B = (2\pi H)/C$
$B = (2\pi 22)/1.7 = 81.2$

$K_{fs} = Q/[(A+(B/\alpha^*)]$
$K_{fs} = 197.2/(1838.1+(81.2/0.04)$
$K_{fs} = 5.1 \times 10^{-2}$ cm/min $= 8.5 \times 10^{-6}$ m/sec

From Table 2.1 of the Guidelines this permeability is in the range given for silty sand but close to the sandy silt - silty sand cutoff of 8×10^{-6} m/sec. From out test pit examination, we had described the soil as a fine textured silty material without structure, significant clay or coarse sand content. Based on that assessment we had chosen α^* as 0.04 from Table 1 and used line #2 in Figure #2. Our K_{fs} results are for a soil of similar texture as that assumed from the test pit. Therefore the use of α^* as 0.04 and line #2 in Figure #2 was appropriate.

If the measured $K_{f\,s}$ was for a soil that was different from the texture described from the test pit examination something would have been wrong. If this were to happen more test pits should be examined and more permeability tests conducted until the observed texture (and corresponding values of α^* and line in Figure #2) and the texture corresponding to the measured $K_{f\,s}$ were similar.

If the system is to operate during the winter and the design winter soil/effluent temperature is chosen to be 4^0 C than the adjusted permeability would be:

$Ka = K_{fs} \times V_K / Va$

where: Ka = adjusted permeability for design temperature conditions
K_{fs} = the calculated permeability from the field test
V_K = the viscosity of water at the test conditions
Va = the viscosity of water at the adjusted design temperature

Ka $= 8.5 \times 10^{-6}$ m/sec x 2/3.5
$= 5.7 \times 10^{-6}$ m/sec (which is in the range for sandy silt from Table 2.1)

ADDITIONAL COMMENTS

Many of the soils in which we will wish to use the permeameter in addition to test pit observations to assist in estimating soil class or permeabilities will be unstructured fine textured silts and sands. If this is the case, α^* will be 0.04. If we use a permeameter with dimensions as described in this Appendix, X will = 63.6 (the inside diameter of the reservoir is 90 mm), H will= 22, a will = 4, H/a will = 5.5, and from Fig.2 C will = 1.7. A will then = 1838.1 and B will = 81.2. Q will = 63.6 (cm^2) x r (cm/min)

<u>Under these given conditions and for this permeameter only</u>**,** the formula for calculating K_{fs} is then reduced to:

$K_{fs} = (X \times r)/(A+(B/\alpha^*))$
$= 63.6\ r / (1838.1+ (81.2/.04))$
$=0.016 \times r$ cm/min
$=2.7 \times 10^{-6} \times r$ m/sec (Where r is the measured drop in cm/min.)

<u>If the soil is not an unstructured fine textured silt or fine sand and/or if the dimensions of the permeameter and/or the hole diameter are not the values stated above, equation [1] on page C-2 of this Appendix must be used to calculate K_{fs}</u>

Remember that this measurement gives an **<u>estimate</u>** of the soil permeability and other tools such as the examination for soil texture, density, uniformity, color, structure etc. from a test pit as well as the overall lot assessment **must** be considered before deciding on the suitability of the site for on-site disposal and the type and size of disposal field. More than one permeameter test **must** be conducted at a site to be sure that the test results are representative of the true soil conditions. When using Kfs in design at least 3 tests should be carried out. Where there is not an extreme variation in K_{fs} in the area of the proposed disposal field it may be appropriate to use the average value of K_{fs}. However if there is an extreme variation in measured K_{fs} the reason should be verified before a value of K_{fs} is selected.