Appendix I: Measurement of hydraulic conductivity – Using in situ and ex situ (laboratory) sampling methods

CRC for Water Sensitive Cities

Australian Government
Department of Industry and Science

Business Cooperative Research Centres Programme

CRC for Water Sensitive Cities

Condition assessment and performance evaluation of biofiltration systems

Practice note 1: measurement of hydraulic conductivity

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This Practice Note for *In Situ* Measurement of Hydraulic Conductivity is the first in a series of Practice Notes being developed to assist practitioners with the assessment of construction and operation of biofiltration systems.

1. Scope of document

This Practice Note for In Situ Measurement of Hydraulic Conductivity is designed to complement the Guidelines for Filter Media in Biofiltration Systems (Appendix A) (visit http://www.monash.edu.au/fawb/publications/index.html for a copy of these guidelines). However, the recommendations contained within this document are more widely applicable to assessing the hydraulic conductivity of filter media in existing biofiltration systems.

For new systems, this Practice Note does not remove the need to conduct laboratory testing of filter media prior to installation.

2. Determination of hydraulic conductivity - In Situ

The recommended method for determining in situ hydraulic conductivity uses a single ring infiltrometer under constant head. The single ring infiltrometer consists of a small plastic or metal ring that is driven 50 mm into the filter media. It is a constant head test that is conducted for two different pressure heads (50 mm and 150 mm). The head is kept constant during all the experiments by pouring water into the ring. The frequency of readings of the volume poured depends on the filter media, but typically varies from 30 seconds to 5 minutes. The experiment is stopped when the infiltration rate is considered steady (i.e., when the volume poured per time interval remains constant for at least 30 minutes). This method has been used extensively (eg. Reynolds and Elrick, 1990; Youngs *et al.*, 1993).

Note: This method measures the hydraulic conductivity at the surface of the filter media. In most cases, it is this top layer which controls the hydraulic conductivity of the system as a whole (i.e., the underlying drainage layer has a flow capacity several orders of magnitude higher than the filter media), as it is this layer where fine sediment will generally be deposited to form a "clogging layer". However this shallow test would not be appropriate for systems where the controlling layer is not the surface layer (eg. where migration of fine material down through the filter media has caused clogging within the media). In this case, a 'deep ring' method is required; for further information on this method, see Le Coustumer et al. (2008).

2.1 Selection of monitoring points

For biofiltration systems with a surface area less than 50 m2, in situ hydraulic conductivity testing should be conducted at three points that are spatially distributed (Figure 1). For systems with a surface area greater than 50 m2,an extra monitoring point should be added for every additional 100 m2. It is essential that the monitoring point is flat and level. Vegetation should not be included in monitoring points.

Figure 1. Spatially distributed monitoring points.

2.2 Apparatus

The following is required:

- 100 mm diameter PVC rings with a height of at least 220 mm – the bottom edge of the ring should be bevelled and the inside of the ring should be marked to indicate 50 mm and 150 mm above the filter media surface (Figure 2)
- 40 L water
- 100 mL, 250 mL and 1000 mL measuring cylinders
- Stopwatch
- Thermometer
- Measuring tape
- Spirit level
- Hammer
- Block of wood, approximately 200 x 200 mm

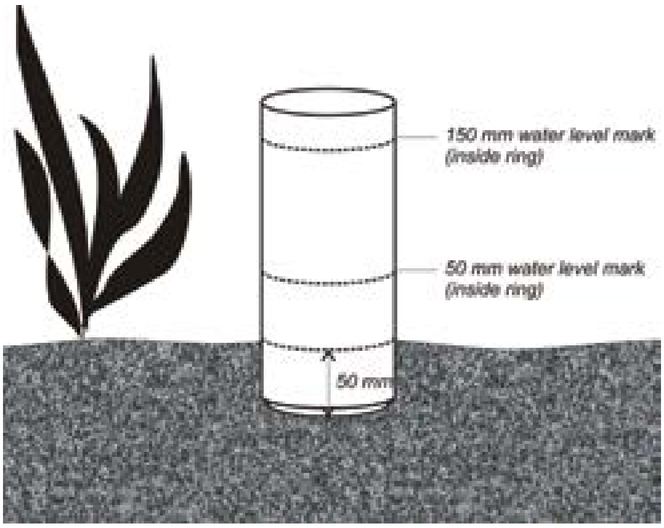

Figure 2. Diagram of single ring infiltrometer.

2.3 Procedure

a. Carefully scrape away any surface covering (eg. mulch, gravel, leaves) without disturbing the soil filter media surface (Figure 3b).

b. Place the ring on the surface of the soil (Figure 3c), and then place the block of wood on top of the ring. Gently tap with the hammer to drive the ring 50 mm into the filter media (Figure 3d). Use the spirit level to check that the ring is level.

   Note: It is essential that this the ring is driven in slowly and carefully to minimise disturbance of the filter media profile.

c. Record the initial water temperature.

d. Fill the 1000 mL measuring cylinder.

e. Using a different pouring apparatus, slowly fill the ring to a ponding depth of 50 mm, taking care to minimise disturbance of the soil surface (Figure 3f). Start the stopwatch when the water level reaches 50 mm.

f. Using the 1000 mL measuring cylinder, maintain the water level at 50 mm (Figure 3g). After 30 seconds, record the volume poured.

g. Maintain the water level at 50 mm, recording the time interval and volume required to do so.

   Note: The time interval between recordings will be determined by the infiltration capacity of the filter media. For fast draining media, the time interval should not be greater than one minute however, for slow draining media, the time between recordings may be up to five minutes.

   Note: The smallest measuring cylinder that can pour the volume required to maintain a constant water level for the measured time interval should be used for greater accuracy. For example, if the volume poured over one minute is 750 mL, then the 1000 mL measuring cylinder should be used. Similarly, if the volume poured is 50 mL, then the 100 mL measuring cylinder should be used.

h. Continue to repeat Step f until the infiltration rate is steady i.e., the volume poured per time interval remains constant for at least 30 minutes.

i. Fill the ring to a ponding depth of 150 mm (Figure 3h). Restart the stopwatch. Repeat steps e – g for this ponding depth.

   Note: Since the filter media is already saturated, the time required to reach steady infiltration should be less than for the first ponding depth.

j. Record the final water temperature.

k. Enter the temperature, time, and volume data into a calculation spreadsheet (see “Practice Note 1_Single Ring Infiltration Test_Example Calculations.xls”, available at www.monash.edu.au/fawb/publications/index.html, as an example).

2.4 Calculations

In order to calculate K_{fs} a ‘Gardner’s’ behaviour for the soil should be assumed (Gardner, 1958 in Youngs *et al.*, 1993)

$$K(h) = K_{fs} e^{\alpha h}$$: Eqn. 1

where *K* is the hydraulic conductivity, α is a soil pore structure parameter (large for sands and small for clay), and h is the negative pressure head. K_{fs} is then found using the following analytical expression (for a steady flow) (Reynolds and Elrick, 1990):

$$K_{fs} = \frac{G}{a}\left(\frac{Q_2 - Q_1}{H_2 - H_1}\right)$$ Eqn. 2

where *a* is the ring radius, H_1 and H_2 are the first (50 mm) and second (150 mm) pressure heads, respectively, Q_1 and Q_2 are the steady flows for the first and second pressure heads, respectively, and G is a shape factor estimated as:

$$G = 0.316\frac{d}{a} + 0.184$$ Eqn. 3

where *d* is the depth of insertion of the ring and *a* is the ring radius.

G is nearly independent of soil hydraulic conductivity (i.e., K_{fs} and α) and ponding, if the ponding is greater than 50 mm.

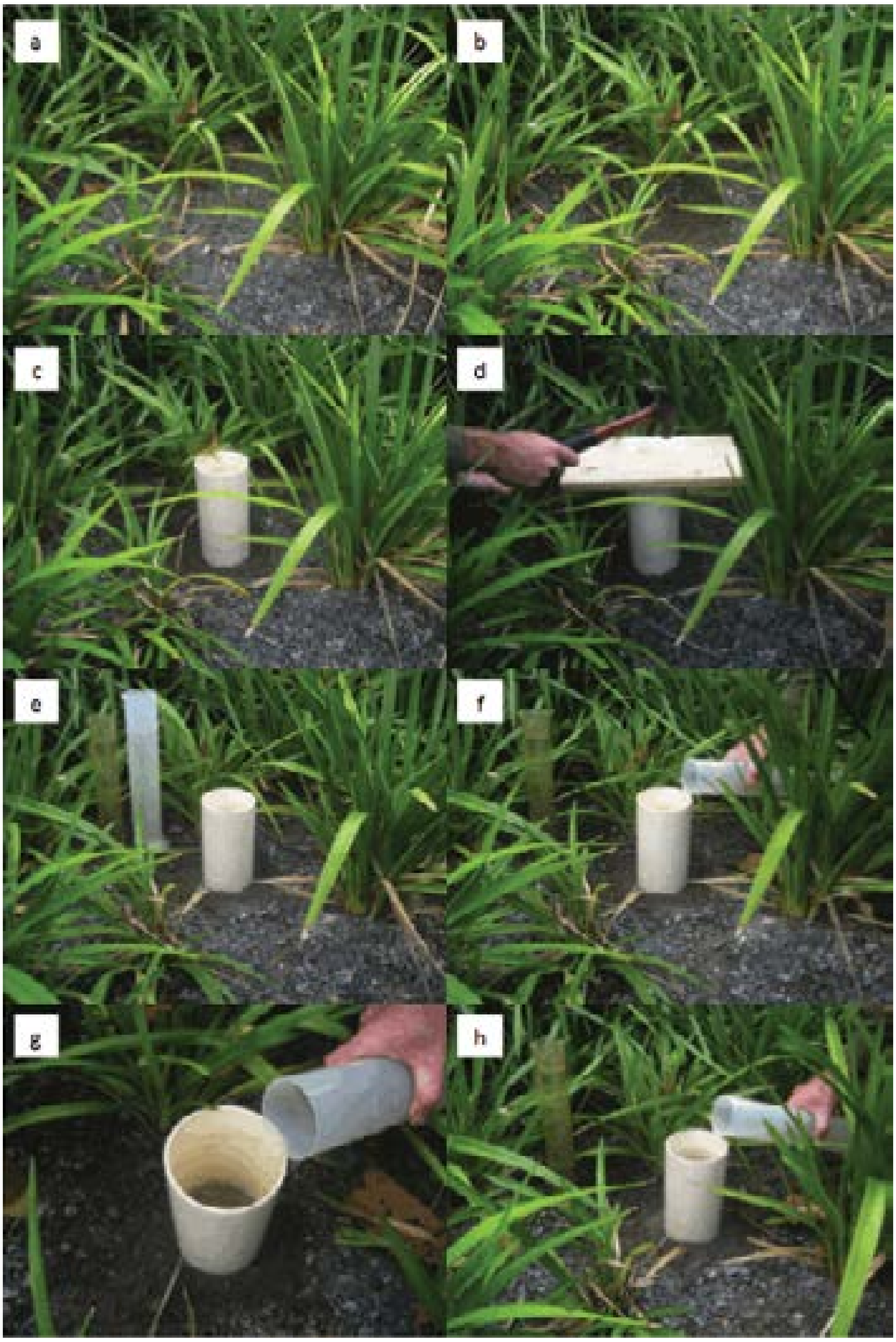

Figure 3. Measuring hydraulic conductivity.

The possible limitations of the test are (Reynolds et al., 2000): (1) the relatively small sample size due to the size of the ring, (2) soil disturbance during installation of the ring (compaction of the soil), and (3) possible edge flow during the experiments.

2.5 Interpretation of results

This test method has been shown to be relatively comparable to laboratory test methods (Le Coustumer et al., 2008), taking into account the inherent variability in hydraulic conductivity testing and the heterogeneity of natural soil-based filter media. While correlation between the two test methods is low, results are not statistically different. In light of this, laboratory and field results are deemed comparable if they are within 50% of each other. In the same way, replicate field results are considered comparable if they differ by less than 50%. Where this is not the case, this is likely to be due to a localised inconsistency in the filter media, therefore additional measurements should be conducted at different monitoring points until comparable results are achieved. If this is not achieved, then an area-weighted average value may need to be calculated.

2.6 Monitoring frequency

Field testing of hydraulic conductivity should be carried out at least twice: (1) One month following commencement of operation, and (2) In the second year of operation to assess the impact of vegetation on hydraulic conductivity. Following this, hydraulic conductivity testing should be conducted every two years or when there has been a significant change in catchment characteristics (eg. construction without appropriate sediment control).

3. Determination of hydraulic conductivity – Ex Situ (Laboratory testing)

In situ testing is valuable as it allows testing of the media under (as close as possible to) undisturbed conditions, in terms of compaction, soil structure and the critical surface clogging layer. However, it is not always feasible to undertake in situ testing of the hydraulic conductivity, either due to resource constraints, such as time and costs, a lack of available water supply near the site or the potential for high spatial variability in hydraulic conductivity. If this is the case then useful information can still be determined by collecting samples from the field for laboratory analysis.

Samples can be collected from cores or as bagged samples, and these may then be composited with multiple samples across the site to gain some overall understanding of soil properties across the filter surface. Samples can be collected across a range of depths and care should be taken to observe the thickness of any clogging layer when determining the thickness of the surface sample. In larger systems, samples may be collected from distinct zones, such as near the inlet versus areas closer to the outlet.

This approach will not be nearly as accurate as the in situ test for hydraulic conductivity, but it is a useful approach for diagnosing problems such as clogging. For example, the upper 0-50 mm or 0-100 mm may be sampled and the hydraulic conductivity compared to samples from lower in the profile. The laboratory testing is also more straightforward and cost effective. However, as discussed, it is best applied for investigating problems and not to determine an accurate hydraulic conductivity.

References

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Reynolds, W. D. and D. E. Elrick (1990). Ponded infiltration from a single ring: Analysis of steady flow. *Soil Science Society of America journal* 54: 1233-1241.

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Single Ring Infiltration Test

Site: ______________________________

Date: ______________________________

Constant water level = 50 mm		
Time (min)	Volume (mL)	Q (mL/s)

Constant water level = 50 mm		
Time (min)	Volume (mL)	Q (mL/s)

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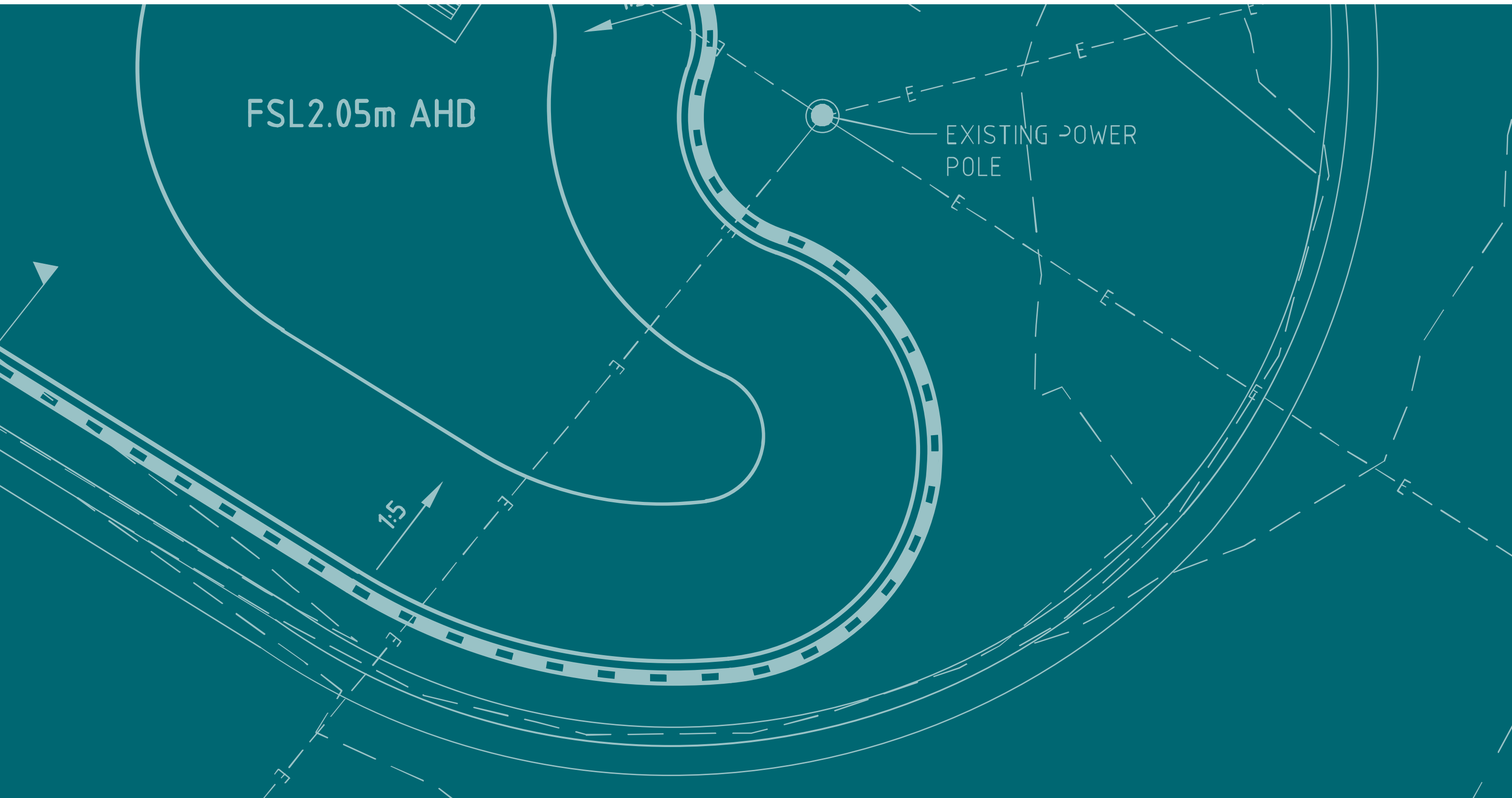
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