Hydraulic conductivity – a simple field test for shallow coastal acid sulfate soils

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1. Outline of the method, its limitations and uses.

This is a simple, semi-quantitative field method for assessing the likely range of saturated hydraulic conductivity (K_{sat}) in shallow coastal acid sulfate soils (ASS). It has been developed for extension officers, landholders and field workers who work with ASS. It is based on established field-based methods for assessing K_{sat} in shallow pits (Bouwer and Rice, 1983; Boast and Langebartel, 1984). K_{sat} is a critical variable affecting the hydrology and acid export dynamics of drained ASS. Assessment of K_{sat} in ASS is important in order to design appropriate management strategies for broadacre remediation projects.

K_{sat} can vary greatly, particularly in ASS, which undergo unique, one-way structural changes due to chemical dissolution of clay minerals, precipitation of iron minerals and physical ripening processes. While K_{sat} can often be low (<1 m day^{-1} - Cook and Rassam, 2002), recent work has demonstrated that K_{sat} can be extraordinarily high (>100 m day^{-1}) in the sulfuric horizons in some drained ASS backswamps (Johnston et al., 2003). High values are generally associated with extensive soil macropore networks (Hamming and van den Eelaart , 1993; Johnston et al., 2003).

The spatial heterogeneity of K_{sat} in shallow coastal ASS aquifers means that realistic field scale estimates based on small-scale methods (i.e. slug tests, permeameters, particle size analysis) can be subject to significant errors (Millham and Howes, 1995). This is particularly true when groundwater flow is dominated by macropores whose size and spatial variability are high relative to the size of area sampled (Bouma, 1991). For this reason, tests which average aquifer response over larger areas (i.e. pit bailing or tidal signal damping) are more likely to be representative of actual field K_{sat} values. This method is designed to complement existing methods. It has a number of advantages and limitations which are listed below. These should be understood before conducting the test.

Advantages

- It allows rapid, ***semi-quantitative*** assessment of K_{sat} in shallow ASS environments.
- It is simple to conduct, only very basic equipment is required.
- It avoids complex mathematics.
- Data collected in this method can be used* to derive a quantitative measurement of K_{sat} based on Bouwer and Rice (1983) or Boast and Langebartel (1984). (*Use in this fashion is user-dependent).

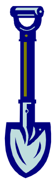
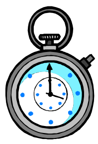
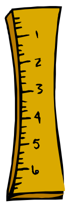
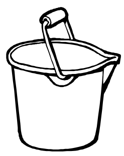
- It can be useful as an extension tool to undertake with landholders.
- It can help assess whether substantial lateral groundwater seepage (to the drain / from the drain) is likely to occur (i.e. during opening of floodgates).
- It can help assess what hydrological pathway (groundwater seepage or surface runoff) may dominate the acid flux at a given site.

Limitations

- It can only be used to assess K_{sat} in shallow soil horizons (i.e. not more than about 0.6 m below the ground surface).
- It can only be used when the water table is ***below*** the ground surface, but no deeper than 0.5 m from the surface.
- In this form it is ***semi-quantitative*** only and provides a K_{sat} estimate within certain ranges (i.e. Low / Medium / High / Extreme).
- It requires the user to stay within defined ranges for pit size, water levels and bailout volumes.
- It is a 'bulk' estimate and does not allow discrimination between horizontal and vertical flow components.

2. Equipment required

- A flat shovel
- Stopwatch
- 50 cm ruler with 1 mm graduations
- 10 L bucket
- Recording data sheet (provided with this method)
- Pen/pencil
- Two people


3. Soil features to look out for

Soil texture, soil structure and visible soil features such as macropores are important to look out for. Macropores can play a very important role in water movement through ASS. Tubular macropores associated with old root channels greater than 20 mm in diameter have been observed in some ASS. The existence of clearly visible soil pores rapidly discharging groundwater after bailing the pit can be an excellent indicator of high K_{sat} soils. When excavating the pit notes should be made on the following features according to MacDonald ***et al***. (1998).

- Soil texture
- Ripeness (Dent, 1986)
- Macropores – size, shape, density, orientation
- Water flow via visible pores
- Peat, organic matter, root material.

4. Locating your pit

Choose sites that are representative of the area you wish to assess. K_{sat} can be highly variable over short distances and often varies vertically down the soil profile according to the characteristics of the soil horizons (Fig. 1). For example, K_{sat} is often low in the unoxidised, gel-like sulfidic horizons. K_{sat} can also be different in the horizontal and vertical planes within an individual soil horizon. In ASS backswamps K_{sat} may be related to the geomorphic history and origins of the underlying sediments, and thus may show some trends related to site topography. The number of tests you conduct and where you locate them should be related to your data needs. If you want some idea of the variability of K_{sat} it will be important to construct a number of pits across the site.

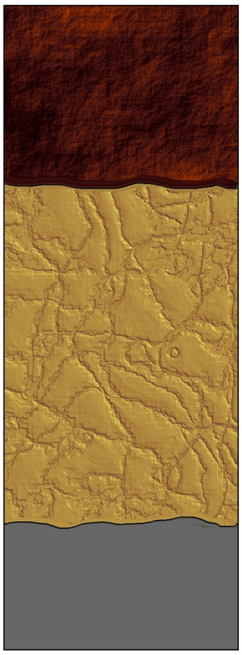


Fig. 1. Schematic diagram of how hydraulic conductivity may vary with depth. The sulfuric horizon is most significant from an acid export point of view as it may contain a large store of acid groundwater, and being closer to the ground surface, is more likely to be intercepted by a drain.

5. Pit construction – dimensions, size limits, water table boundaries

While the data analysis component of this test avoids complex mathematics, it has been field calibrated only within a certain range of pit dimensions and water table heights. ***This point is important. Pit excavation should follow these instructions closely (see Fig. 2). Failure to do so will compromise the accuracy of the test.***

- The pit should be as square as possible with vertical sides and a 'flat' (as possible) bottom (see Fig. 2 for pit geometry and abbreviations). Avoid excessive smearing of pit faces.
- Minimum area of 30 cm x 30 cm (W x B).
- Maximum area of 50 x 50 cm (W x B).
- Maximum depth of pit from ground surface (D) = 60 cm.
- A minimum of 10 cm water depth is required in the bottom of the pit (L) at equilibration with the surrounding water table.

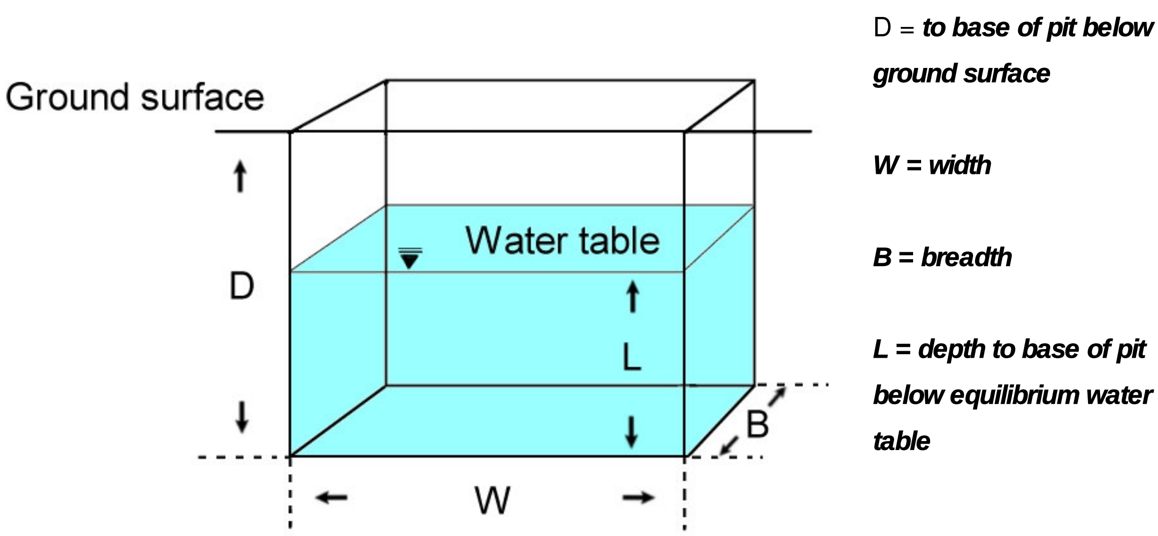


Fig. 2. Example of pit geometry and abbreviations.

- B and W should be as equal as possible (ie a square pit).
- The ratio L/W ***must*** be between 0.2 and 0.75. This is important as the data processing is calibrated to these ranges. See Table 1 for example pit dimensions which generate an acceptable L/W ratio.
- The pit water level at equilibration with surrounding water table must be at least 5 cm below ground surface.
- Bail out between 50% to 90% of water volume in the pit.

Table 1: Example of pit dimensions (L, W) which generate acceptable ratios of L/W (0.2 to 0.75).

	L (cm)					
W (cm)	**10**	**15**	**20**	**25**	**30**	**35**
30	***0.33***	***0.50***	***0.67***	-	-	-
40	***0.25***	***0.38***	***0.50***	***0.63***	-	-
50	***0.20***	***0.30***	***0.40***	***0.50***	***0.60***	***0.70***

6. Recording field information

- When recording L (where L = average depth to base of pit below equilibrium water table, see Fig. 2) make at least 10 random measurements across the pit. More can be made if required. The mean of these measurements will be used in the data analysis component of this test. This will help reduce errors from having a slightly uneven pit base.
- Record pit dimensions on the record sheet provided with this method as per the example of pit geometry provided in Fig. 2. The mean of several measurements of B and W may be required if the pit is slightly uneven. Use your discretion.

7. Conducting the test

- Dig the pit so that the dimensions accord to the instructions outlined in section 5 ‘Pit construction’. Observe and record soil features as outlined in section 3.
- Wait until the pit water level has reached equilibration with the surrounding water table.
- Record the pit dimensions and water table depth parameters on a record sheet (provided with this method).
- Insert the 50 cm ruler ***vertically*** several centimetres into sediment in the base of the pit in one corner where you can easily read it. Make sure the ruler is stable. **Note** – make sure you record the **raw** equilibrium water level depth on the ruler. (ie L might be ~20 cm but you insert the ruler several cm into the sediment so the **raw** water level reading on ruler before bailing is 24 cm). This is vital for later calculations.
- Rapidly bail out the water in pit using 10 L bucket. Be slow and steady during the last bail to minimise ‘sloshing’ and water level oscillation in the pit.
- Have one person start the stopwatch immediately after the last bail and begin counting the seconds out loud. Have the other person watching the water level on the ruler and recording the level ***from zero seconds onwards***.
- Record the water level approximately every 5 seconds (on record sheet) for a minimum of 3 minutes or until at least ~80% of the pit bail out volume is replaced, up to a maximum of 30 minutes if required.
- If the pit infill rate is slow, then record the water level at time intervals which are long enough to allow accurate measurement (ie rise in water level of at least 1 mm per time increment). Adjust the time intervals on your record sheet accordingly.
- Wait until equilibrium level is obtained and repeat the test at least once in the same pit.

8. Data entry and plotting

The data you record should be entered onto the Excel spreadsheet provided with this method. Instructions for data entry are provided within the spreadsheet (**Ksat pit test data analysis.xls**). Read the instructions thoroughly ***before*** entering data. The spreadsheet also calculates the ratio L/W and the percentage of the pit water volume you bailed out so that you can check to see if it is within the permissible ranges listed in section 5 ‘Pit construction’.

The spreadsheet will perform very simple calculations and plotting automatically. ***No responsibility is taken if you alter the calculations in any way!*** After you enter your data the resultant plot will show the normalised pit refill rate vs time and should look something like Fig. 3. The plot line will fall into one of four pre-set categories listed below which ***approximate*** the following K_{sat} ranges*.

- Low = less than 1.5 m day^{-1}
- Medium = 1.5 to 15 m day^{-1}
- High = 15 to 100 m day^{-1}
- Extreme = greater than 100 m day^{-1}

****Note: This is an approximation only. Quantitative assessment of K_{sat} from the data collected in this method will require the user to apply the calculation method(s) outlined in Bouwer and Rice (1983) or Boast and Langebartel (1984).***

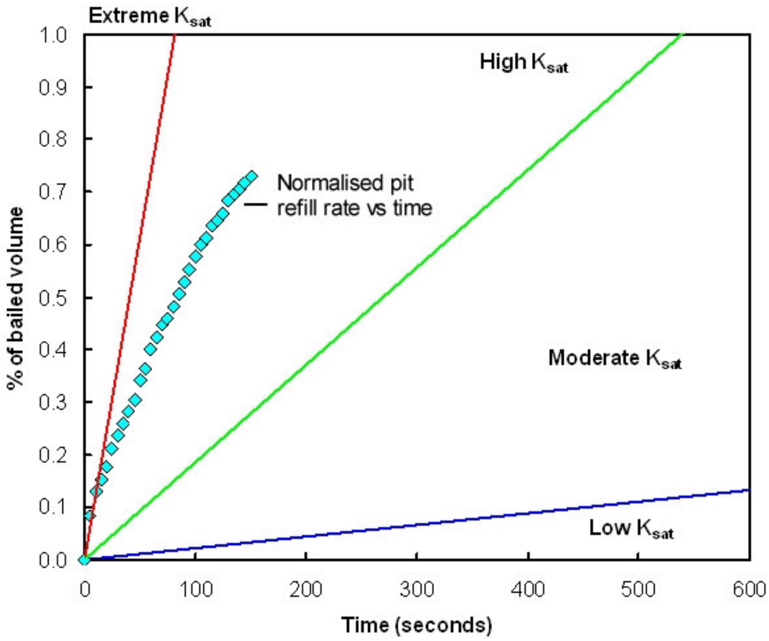


Fig. 3. An example of pit refill data after plotting in spreadsheet.

9. Interpreting data and assessing K_{sat}

The example pit refill data shown in Fig. 3 shows a K_{sat} in the high range (ie between approximately 15 to 100 m day^{-1}).

If a site's K_{sat} falls in the high or extreme range, then depending on other factors (i.e. elevation of acid horizons relative to local low tide levels, whether the drain intercepts those high K_{sat} soil horizons, any 'pugging' and blockage of macropores at the drain bank face), there is a very real probability that groundwater seepage may be a major hydrological pathway of acid export. In this case, a containment strategy will likely be an important management option. Acid groundwater may be contained by infilling or shallowing drains, or by using a retention structure to keep drain water levels high and stable and prevent the development of effluent groundwater gradients through tidal drawdown (Fig. 4).

High or extreme range K_{sat} also means that if floodgates are opened and saline water introduced into a drain there is a possibility that this saline water could move laterally away from the drain over substantial distances. However, this will also be dependent on the driving head and will only occur ***if the gradients are influent*** (i.e. the drain water level is higher than the groundwater level).

If a site's K_{sat} falls in the low range then the risk of lateral salt water seepage if floodgates are opened is likely to be minimal.

If a site's K_{sat} falls in the medium range then further quantitative assessment of K_{sat} may be warranted in order to assess the risk of lateral salt water seepage due to floodgate opening. Monitoring the response of the water table adjacent to the drain during a freshwater floodgate opening event may also be useful.

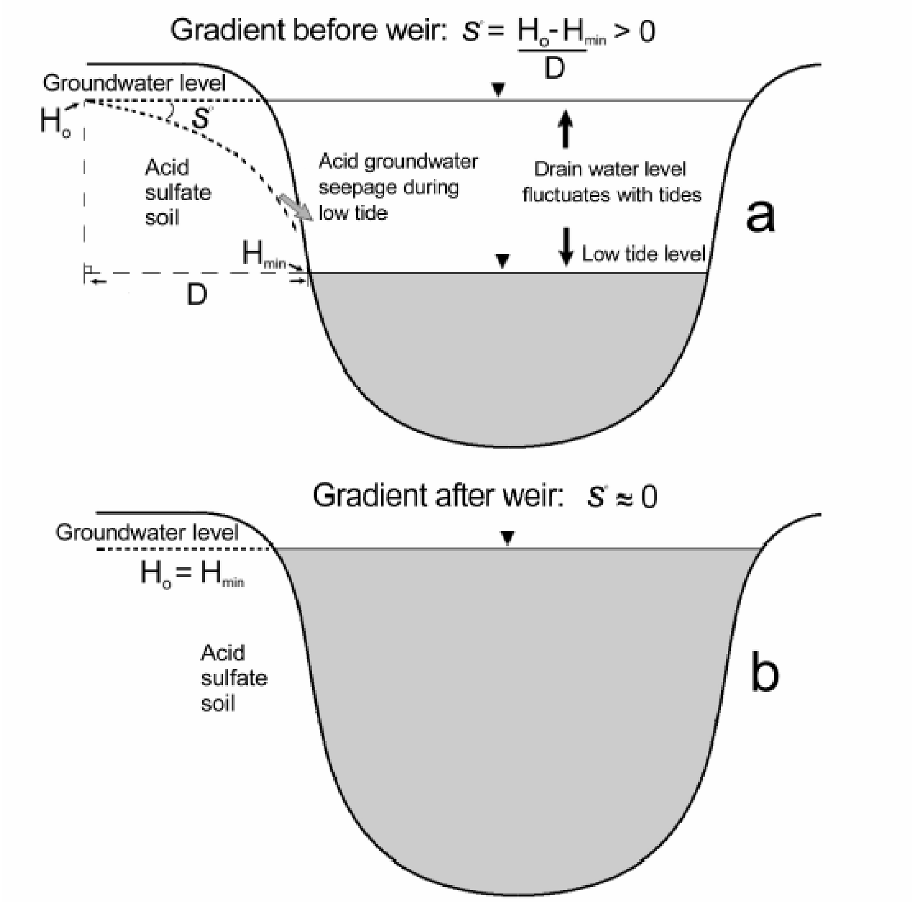


Fig. 4. A schematic representation of (a) the development of effluent groundwater gradients during low tides, leading to acid groundwater seepage and (b) the use of a retention structure (weir) to prevent tidal draw down in drain water levels and thereby reduce gradients and subsequent groundwater seepage.

10. Availability of this method

This method, including these instructions, recording sheets and an Excel spreadsheet for data entry, is available on CD from NSW Agriculture at Wollongbar Agricultural Institute. Alternatively, copies of the above can be downloaded for free at www.agric.nsw.gov.au/reader/floodgate-guidelines.

11. References and suggested further reading

Beven K and Germann P (1982) Macropores and water flow in soils. ***Water Resources Research*** **18**, 1311-1325.

Boast CW and Langebartel RG (1984) Shape factors for seepage into pits. ***Soil Science Society of America*** **48**, 10-15.

Bouma J (1991) Influence of soil macroporosity on environmental quality. In 'Advances in agronomy - Volume 46'. (Ed. DL Sparks) pp.1-37. (Academic Press)

Bouwer H and Rice RC (1976) A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. ***Water Resources Research*** **12**, 423-428.

Bouwer H and Rice RC (1983) The pit bailing method for hydraulic conductivity measurement of isotropic or anisotropic soil. ***American Society of Agricultural Engineering*** **26**, 1435-1439.

Bouwer H (1989) The Bouwer and Rice slug test – and update. ***Groundwater*** **27**, 304-309.

Butler JJ (1996) Slug tests in site characterisation: some practical considerations. ***Environmental Geosciences*** **3**, 154-163.

Cook FJ, Rassam DW, Blunden BG, Gardner EA and Carlin GD (1999) Irrigation and drainage: effects on acid export from acid sulfate soils. In ***'Proceedings of Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils, Lismore'*** (Ed. Slavich P) pp. 78-87. (Acid Sulfate Soils Management Advisory Committee: Wollongbar)

Cook FJ and Rassam DW (2002) An analytical model for predicting water table dynamics during drainage and evaporation. ***Journal of Hydrology*** **263**, 105-113.

Dent D (1986) 'Acid Sulphate Soils: a Baseline for Research and Development.' ILRI Publication No. 39. (International Institute for Land Reclamation and Improvement: Wageningen)

Hamming AFJ and van den Eelaart ALJ (1993) Soil permeability, interflow and actual acidity in acid sulphate soils, South Kalimantan, Indonesia. In '***Selected Papers of the Ho Chi Minh City Symposium on Acid Sulphate Soils.'*** pp.155-159 (Eds Dent DL and van Mensvoort MEF) (ILRI: Wageningen)

Lomen DO, Warrick AW and Zhang R (1987) Determination of hydraulic conductivity from auger holes and pits – an approximation. ***Journal of Hydrology*** **90**, 219-229.

Johnston SG, Slavich PG and Hirst P (2003) Hydraulic conductivity in the sulfuric horizons at Partridge Creek acid sulfate soil hotspot. Report to Hastings Council no. DAN13/1, 9 pp. (NSW Agriculture, Wollongbar, Australia)

MacDonald RC, Isbell RF, Speight JG, Walker J and Hopkins MS (1998) Australian Soil and Land Survey – Field Handbook, 2nd edition. (CSIRO, Canberra)

Millham NP and Howes BL (1995) A comparison of methods to determine K in a shallow coastal aquifer. ***Groundwater*** **33**, 49-57.