Onsite and Decentralised Sewerage and Recycling Conference – Coming Clean: Sustainable Backyards and Beyond. Benalla 12-15 October 2008. Australian Water Association

THE PERCOLATION TEST – A TEST WITH FALSE PRETENSIONS

Robert H.M. van de Graaff and Jude Alexander
van de Graaff & Associates P/L, Mitcham, Victoria, Australia; vdg.robert@vdgraaff-soilshorizons.com.au

ABSTRACT
An inappropriate test lacking predictive value is used in Victoria for sizing EPA-accredited effluent disposal fields. No one has any evidence that the use of the percolation test leads to a sustainable loading rate of a land application area, so why should it not be scrapped?

EPA guidelines continue to refer to the so-called percolation rate of the soil for dimensioning effluent fields, while nationally the Australian Standard (AS/NZS 1547:2000) effluent field sizing is based on a so-called Soil Category, which itself is founded on the texture and structure of the soil. Standards Australia and Standards New Zealand have adopted the constant head well permeameter method as the recommended method for soil permeability measurements for on-site effluent management and discourage the percolation test. In more than 40 years of experience in on-site domestic wastewater management we have not seen a documented relationship between the performance of an effluent disposal field in Victoria or Australia and a measured percolation rate. In all probability there never existed such a relationship that applied to Victorian soil and climatic conditions. Nevertheless, the percolation test procedure as described in EPA Victoria's Publication "Septic Tanks Code of Practice (1990)" was registered with NATA, which subsequently accredited 5 Victorian soil testing laboratories to carry out this particular test under its logo and continues to be used. NATA has advised it is not concerned with the reasons for which any particular test is carried out, nor with the presence or absence of any useful interpretations of the test.

The percolation test as a method to quantify the permeability of a soil is an ad hoc test method devised well before the time that reliable scientific insights had been obtained in the physics of water movement in the soil, particularly unsaturated flow. To the best of our knowledge the methodology is no longer found in any soil testing manuals younger than 25 years and is not taught anywhere by university departments. It lacks a mathematical description. It is a scientific dinosaur!

To evaluate the permeability, or more accurately the hydraulic conductivity, K, of a soil, there are a number of modern *in-situ* and laboratory methods available. With regard to *in-situ* tests, there are methods for measuring K below a ground water table, which always yields a saturated conductivity, Ksat, and above a water table in unsaturated soil, that can yield Ksat and a whole range of Kunsat values depending on how dry or moist the soil is. Whilst a correlation between the long-term rate of effluent absorption by a soil is lacking for the percolation test, there is one in Victoria for the *in-situ* constant head well permeameter test. The well permeameter method has a scientific pedigree going back to the 1950's. The Australian correlation with effluent absorption rates was developed as part of the doctoral research carried out by Joost Brouwer at La Trobe University.

This paper attempts to explain why the percolation test should be removed from the Victorian EPA guidelines and to facilitate its replacement by a modern and practical method for measuring a vital property of soils, worthy of a profession that wants to be respected.

Key words: percolation test, soil hydraulic conductivity, sizing effluent disposal fields

INTRODUCTION

An inappropriate test for sizing EPA-accredited effluent disposal fields, the percolation test, continues to be used in Victoria in spite of its lack of predictive value with respect to the ability of the soil to accept and transmit effluent and takes no account at all of evapo-transpiration losses by vegetation in the land application area. It has received undeserved status by having been registered by EPA Victoria with the National Association of Testing Authorities (NATA). With regard to sizing on-site effluent disposal systems, the Victorian situation can be summarised in Table 1.

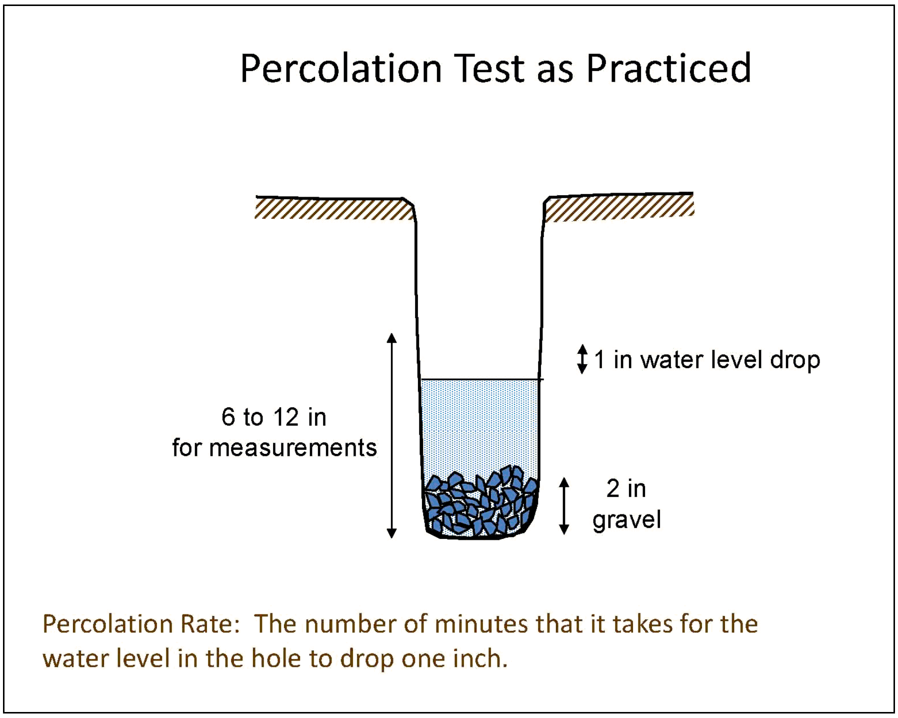
History of Test Methods

Percolation tests carried out by digging or augering a hole of known dimensions and filling it with water to a known height <u>indirectly</u> measure the in-situ flow rate of water through soil by just measuring the rate of fall of the water level in the hole over time (Figure 1). The percolation test was and remains a crude, *ad hoc,* purely empirical test method originally devised by Henry Ryon, a New York State Department of Health (NYSDH) engineer, in 1926. Ryon (1928) related the rate of a water table in a hole dropping over time to the performance of septic tank effluent disposal trench fields. He dug one-square foot holes to the depth of the leach drains, wetted them with water and then refilled them up to a height of six inches above the bottom and measured how long it took for the water level in the hole to fall one inch. The percolation rate thus was stated in minutes per inch (time over length). As it measured merely the rate at which the water in a hole falls, it does not measure the rate or velocity at which water actually moves through the soil, i.e. the true percolation rate, which is governed by the permeability i.e. hydraulic conductivity of the soil and the pressure head acting on the water.

Table 1 Victorian accreditation for sizing effluent areas.

Source	EPA Certificate of Approval Or Related Document	Mode of disposal	Sizing method
EPA Victoria, 2003	EPA CA 1.2/03	Absorption trenches and absorption-transpiration trenches	Percolation rate
EPA Victoria, 1993	EPA CA 035/93	Irrigation	Percolation rate
EPA Victoria, 1994	EPA CA 041/94	Niimi trenches	Soil category & permeability
EPA Victoria, 1992	EPA CA 033/92	Constructed wetlands-Reed bed	Soil permeability
EPA Victoria, 2003	EPA Bulletin #746.1	General	Soil percolation rate (Note: its predecessor Bulletin #746 employed the term permeability)

Figure 1 Percolation test as practiced (Amoozegar, 1997)



Kiker (1952), who was a personal acquaintance of Ryon, reports that subsequent to Ryon's work, the NYSDH required percolation testing for each new on-site health system. This new policy spread to several other States in the USA, many of which experimented with the test procedure. During the 1950s, the U.S. Public Health Service (USPHS) carried out extensive percolation testing and related the results with performance of effluent trenches, and then formalised the method as a means of sizing trench systems. The so-called percolation rate was used to predict the trench bottom area per household bedroom. This approach was found wanting due to a clogging layer forming in leach drains, and the discovery that percolation rates with clean water could not represent long term absorption rates (LTAR).

Even as late as 1964 Olson (1964a), in an extension bulletin on how to use soil survey information for solving the problems of an expanding population in unsewered areas, advised: 'Dig or bore six holes (four to twelve inches in diameter depending on the size of stones in soil profiles) at the site and to the depth of the proposed septic tank seepage field (about 3 feet depth for seepage trench; deeper for seepage pit), randomly spaced within the area of the size of the seepage field…'. Allowing the tester free range in selecting the size and shape of the hole implies a view that water infiltrates only vertically through the base of the pit or hole, although the same author (Olson, 1964b) in a more extensive paper clearly had the water entering the soil in all lateral and downward directions as shown in Figure 2.

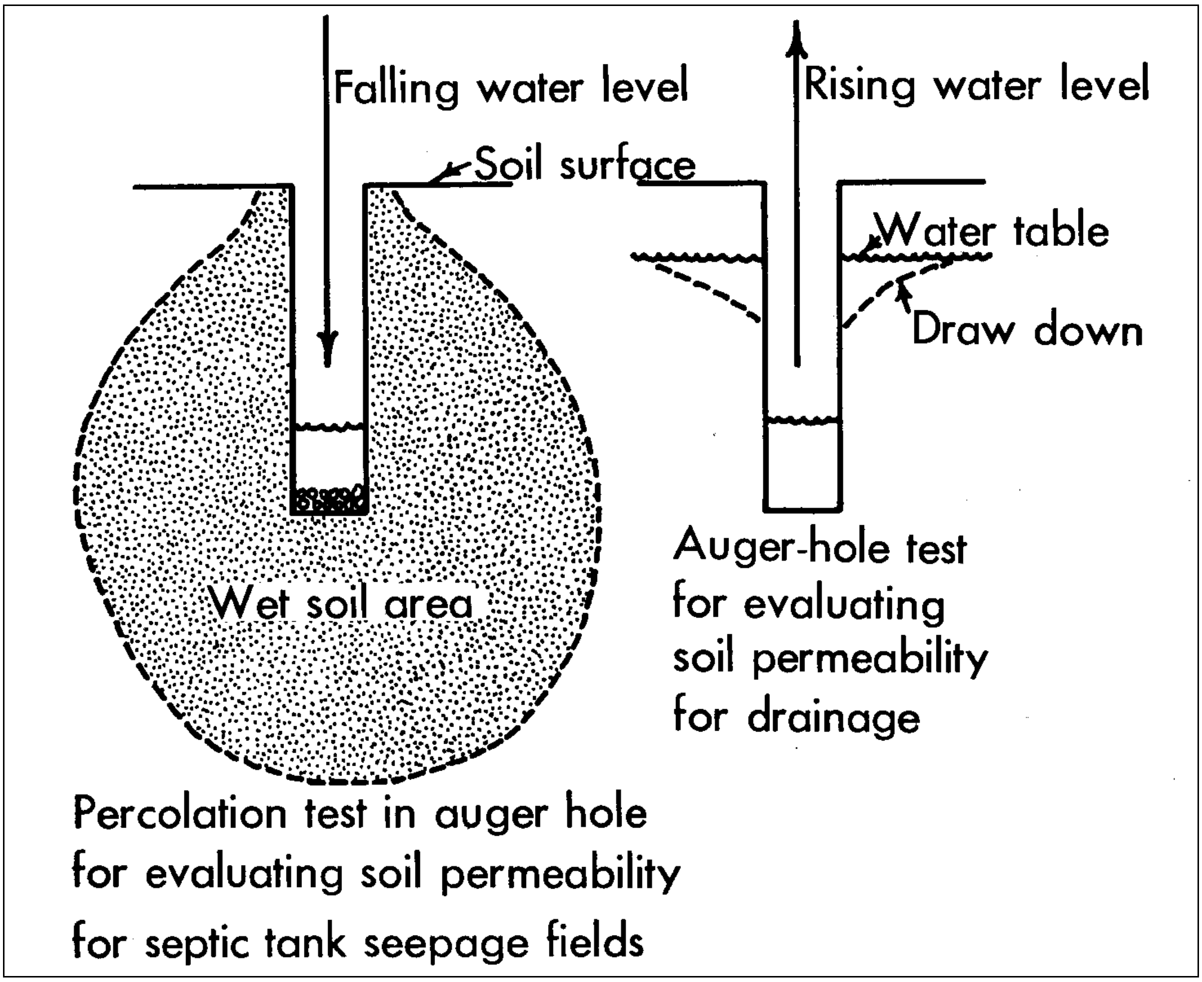


Figure 2 Wetting of soil around test hole (Olson, 1964b).

Note that the schematic on the right, as shown in Figure 2, applies to measuring the permeability of the soil <u>below</u> the water table, by pumping out the water from the hole and measuring the rate of rise of the water in the hole. Obviously, that test is not applicable to effluent disposal by means of septic tank absorption trenches as trenches are not intended to be installed below a water table. Hence all *in situ* test methods fall into one of two groups of fundamentally different methodologies (i) <u>above</u> the water table tests, and (ii) <u>below</u> the water table tests. In past years some Victorian EPA officers (and likewise a number of consultants) have laboured under a misapprehension and consultants have been criticised for not carrying out percolation testing until the soils were saturated in winter or spring – that is, below a water table. The misunderstanding that the percolation test can provide useful data when the soils are already saturated is quite widespread.

Kiker (1952), who was Chairman of the Committee on Rural Sanitation, understood clearly the empirical and *ad hoc* nature of the percolation test and in his Report to the Eightieth Annual Meeting of the Engineering

Section of the American Public Health Association he invited comments and suggestions from those who had at least 10 years experience and carried out a thousand percolation tests, excluding those who "are mere armchair strategists", to develop reasonable and realistic standards. He asked for professional insights!

History of Test Methods – the Beginning of Enlightenment

With our present scientific insights in soil physics we can appreciate that water added to a hole will infiltrate into the soil through the entire wetted bottom and sidewall surface of the pit, not just through the bottom, and that the ratio of the infiltrating area and the volume of water in the pit depends on the shape and size of it. While Ryon used standard dimensions for his pits, subsequent prescribed soil testing requirements varied them. This caused a number of soil scientists and engineers to compare test results from holes of different sizes. For example, two square holes, one (A) with sides of 200 mm and the other (B) with sides 400 mm, filled to the same level with water, say 200 mm, contain respectively 8 and 32 litres of water and have infiltrating surface areas of 0.2 and 0.48 m^2, so that the ratio of water volume to infiltrating area is 40 for (A) and 66.7 for (B). In Hole A the 8 L of water has 0.2 m^2 of infiltrating surface available, a ratio of 8/0.2 = 40 L/m^2, whereas Hole B has a ratio of 32/0.48 = 66.7L/m^2. Hole B has proportionally much more water infiltrating per m^2 than A and so, the soil and all other driving factors being the same, the percolation rate in B will be 40/66.7 = 0.6 times, much slower than the percolation rate in Hole A. Ryon may well have assumed the water only infiltrates vertically through the bottom, in which case the size and shape of the hole do not matter, but he did standardise the size and shape of the pits.

From the sixties onwards the science of soil physics and soil hydrology was developing rapidly, particularly in the United States, as the mathematical treatment and computational skills improved greatly, and new test methods for measuring soil permeability were put forward. In the 1970s, along with a renewed scientific interest in the performance of septic tank effluent disposal systems, further research was carried out to evaluate the percolation test as a means of determining the soil's potential for effluent disposal (Bouma, 1971), to correlate it to other methods of determining soil permeability (Winneberger, 1974) and to prescribe the manner in which it should be carried out Machmeier (1977). For the first time the test methods in use for effluent disposal were analysed in terms of physics of water movement under both saturated and unsaturated conditions and the processes given mathematical descriptions. Evapo-transpiration also became a process of interest that needed to be quantified.

In 1973, Healy and Laak pointed out the weaknesses of the percolation test methods and argued that comparisons between different soils could only be made if the test procedures were exactly the same. This was followed by an article by Barbarick, Warrick and Post (1976) who demonstrated that the percolation rates in three different soils were inversely related to the diameter of the test holes. For example, in all three soils, the percolation rate in a 10-cm diameter hole was 1.8 to 2.4 times greater than in a 30-cm diameter hole. Amoozegar (1997) portrayed these effects in two eloquent diagrams (Figures 3 and 4). Figure 3 shows that for any given soil permeability, Ksat, the percolation rate is different depending on how high the level of water in the test hole is.

None of these problems can occur with the saturated hydraulic conductivity, Ksat, of the soil, as that is a unique soil property, not depending on the shape and size of the test holes. Obviously, the percolation rate is related to hydraulic conductivity, but it is also related to the geometry of the test holes, the initial depth of water in the hole, and the time interval selected between readings. Moreover, during a percolation test the head of water in the hole falls continually as does the area through which infiltration takes place, rendering a mathematical description of the physical process an unsolvable nightmare.

Note how the observed percolation rate for any given soil permeability, Ksat, and constant depth of water in the test hole varies with the diameter of the hole.

The percolation test however died slowly. In the mid-seventies Kessler and Oosterbaan (1974) still provided the percolation test as a possible method for determining Ksat using the Poirée and Ollier test method and its associated mathematical description. In 1962, French irrigationists Poirée and Ollier made a simplifying assumption to describe the water flow around the test hole under a falling head test, such as the percolation test. They assumed the velocity of the infiltrating water was the same for lateral infiltration from the test hole wall as for vertical infiltration through the bottom, and that the hydraulic gradient was unity in all directions. In reality this cannot be the case, but making this simplifying assumption enabled them to write an equation for the infiltration based on Darcy's Law.

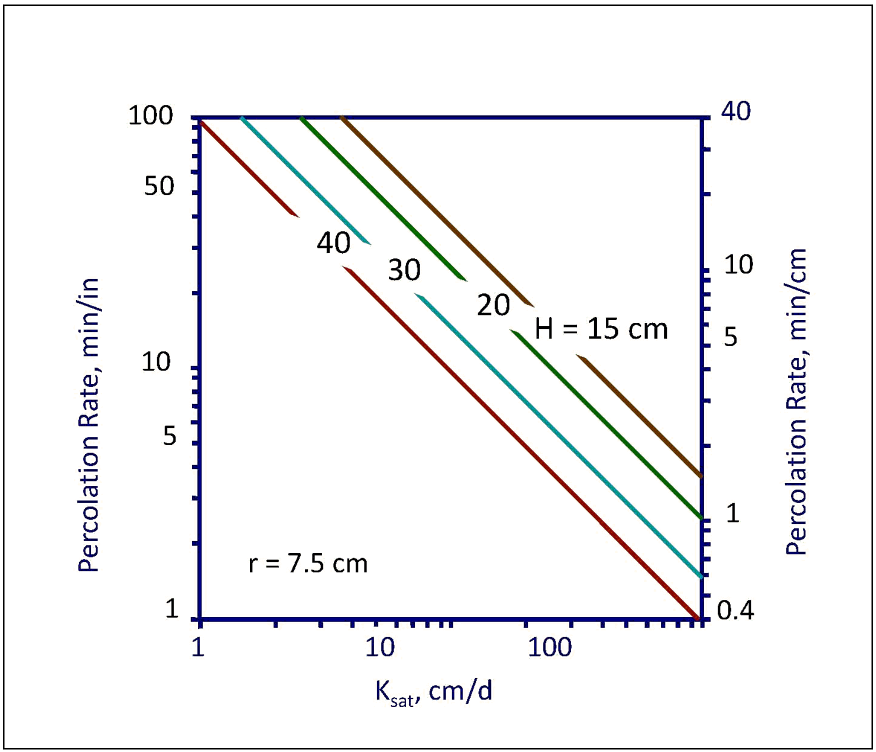


Figure 3 Changes in percolation rate K_{sat} with water depth H in hole (Amoozegar, 1997)

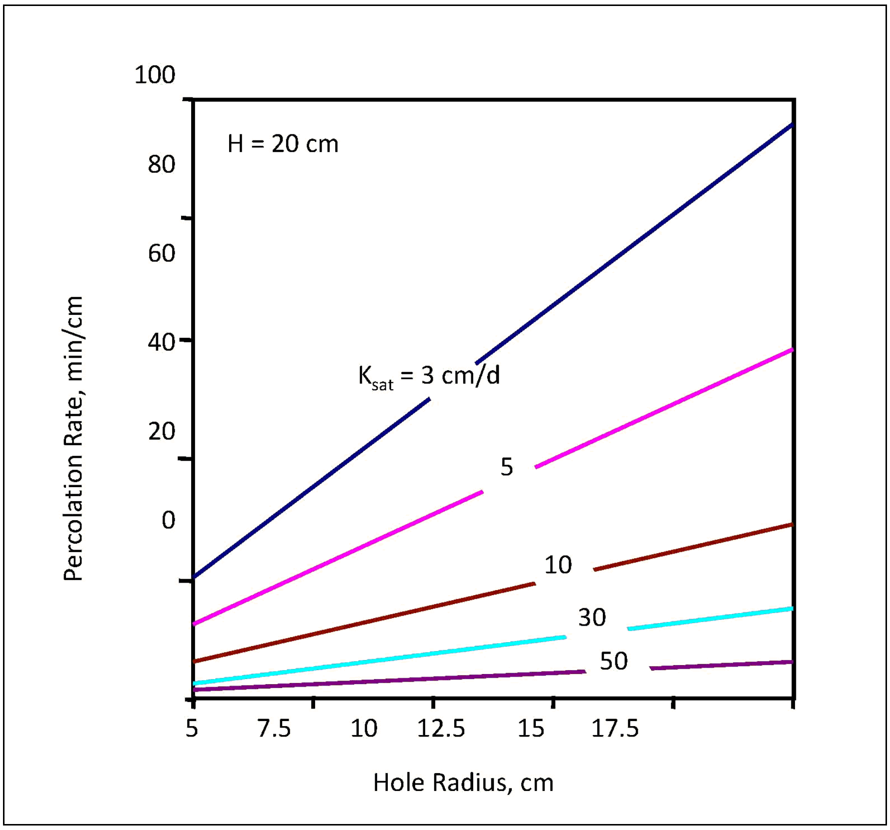
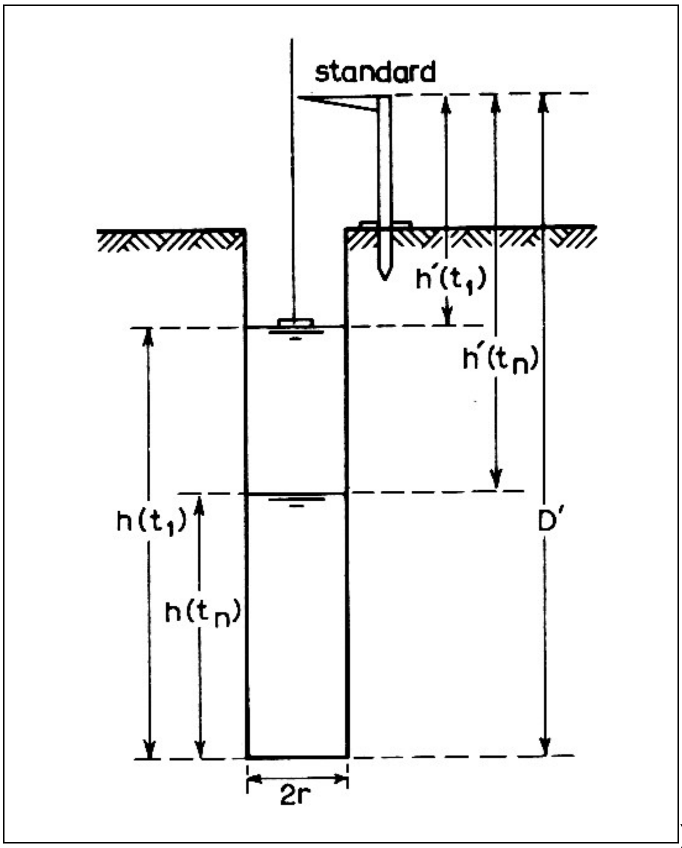


Figure 4 Changes in percolation rate K_{sat} with varying hole radius (Amoozegar, 1997)



)

Figure 5 Geometry of falling head test (Kessler and Oosterbaan, 1974)

At any time $t_{i,}$ when the depth of water in the hole is h(ti), the area through which water infiltrates in a cylindrical test hole with hydraulic conductivity K and with radius r is:

$$A(ti) = 2\pi.r.h(ti) + \pi\, r^2$$

Assume the hydraulic gradient is approximately unity (1), then according to Darcy's law we may write for the volume Q(ti) of infiltrating water:

$$Q(ti) = KA(ti) = 2K\pi\, r\, [h(ti) + r/2]$$

If during the time interval dt the water levels falls over a distance dh, the quantity water that has infiltrated is:

$$Q(ti) = - \pi\, r^2 \left(\frac{dh}{dt}\right)$$

By substitution one has:

$$2K\pi\, r\, [h(ti) + r/2] = - \pi\, r^2 \left(\frac{dh}{dt}\right)$$

Integrating between the limits of t_1 when the depth of water in the hole is h_1 and t_n when the depth of water is h_n, one obtains:

$$\frac{2K}{r}(t_n - t_1) = \ln\, [h(t_1) + r/2) - \ln\, (h(t_n) + r/2]$$

Re-arranging the terms and changing to 10-based logarithms one has:

$$K = 1.15\, r\, [\, \log\, (h(t_1) + r/2) \; - \; \log(h(t_n) + r/2)]\, /\, (t_n - t_1)$$

The Planning and Research Branch of the Victorian EPA (1975) published a document on soil percolation tests with regard to effluent absorption based on a study of American literature. The author, though not trained in soil science, was a physicist and hence well aware of the absolute need to keep hole diameter, depth, soaking time and water levels during soaking uniform. However, the document persisted with the percolation test rather than opting for measuring soil hydraulic conductivity as the ultimate relevant soil property freed of the foregoing factors. It established the test as done in cylindrical holes made with a 10-inch auger and a prior soaking depth of 300 mm of water, followed at least 4 hours later, but preferably 24 hours, by lowering the water level to 150 mm, at which time the percolation rate was to be measured in terms of how long it took for the water level to fall 25 mm. The very large test holes prescribed by this publication often forced a tester to bring a Furphy water cart along to supply the hundreds of litres of water that were needed. The results were then converted to a trench bottom loading rate as in Table2 below.

Table 2 Loading rates based on empirical evidence from the USA.

Time for 25 mm drop (minutes)	1	2	5	10	20	40	60	>60
Loading rate (L/m^2.day or mm/day)	150	125	100	75	50	30	25	N.S.

Poirée and Ollier's equation, notwithstanding the incorrect assumption of unit hydraulic gradient, was implicitly endorsed by EPA Victoria in the effluent loading diagram in the 1990 EPA Code of Practice – Septic Tanks (Figure 6) to enable percolation rates from a test as prescribed in EPA 1990 to be converted to Ksat values and vice versa. This made it possible to arrive at loading rates either from the conventional percolation test or from a modern soil permeability test. The 1990 Code presented a prescribed methodology for the percolation test but also was accepting, and explicitly enabling, of proper science-based soil permeability tests to be carried out in lieu of the percolation test. Developing this two-way system of using the old percolation test method and the modern determination of hydraulic conductivity was done in the belief that it would enable the practitioners and the regulator to educate themselves without loss of previous experience.

Entry is possible via the percolation Y-axis and via the Ksat-X-axis. The P/K line connects percolation rate to Ksat only for testholes of 110 mm diameter and initial height of water of 150 mm.

The absorption trench sizing method in the 1990 Code was wholly based on a rough but conservative relationship between measured long-term effluent absorption rates and properly measured Ksat values, using the Talsma and Hallam (1980) constant head well permeameter method for 13 sites around Melbourne (Brouwer, 1982). In truth, therefore, the Ksat-long term absorption rate (LTAR) relationship is the only established and documented basis for sizing effluent application areas. The relationship as it appeared in a paper by van de Graaff (1998) is shown below (Figure 7) and is thus far the only 'local' correlation between Ksat and LTAR in Australia.

The subsequent 1996 EPA Code of Practice, published under the new "Best Practice Management Series", threw all this away in favour of a method already discredited 20+ years earlier. In addition, it changed the geometry of the percolation test, from the 1990 initial water depth of 150 mm to the 1996 initial water depth of 250 mm, but kept the 1990 sizing diagram, which it converted from a graph to a Table.

Note that except for one data point, all others are above the design curve so as to incorporate a large safety margin in design.

None of the EPA-convened committee members, mainly selected EHO's, involved with this "Best Practice" label had any understanding of how the change of water depth would also change the associated Ksat, and hence the effluent loading rates. Alerted to this mistake, the committee chair ignored the advice. Years later, the term 'Soil permeability' as a factor in land capability assessment, which was still present in Bulletin 746(EPA Victoria, 2001), was deleted in favour of 'percolation rate' in its successor Bulletin 746.1 (EPA Victoria, 2003).

Thus, in the 1996 Code of Practice, Tables 6.1 and 6.2 are incorrect, and especially at the low soil permeability end of the spectrum the recommended loading rates grossly optimistic with increased risk of trench failure and risk to human health! For example, Table 6.3 considers soils with percolation rates <15 mm/hour or the incorrectly assigned permeability Ksat <0.06 m/day as "not suitable" for absorption trenches. However, after the change of the percolation procedure a percolation rate of 15 mm/hour is now equivalent to permeability 0.03 m/day and such formerly unsuitable soils have suddenly become just acceptable. The current EPA CA 1.2/03 and EPA CA 035/93 are based on these 1996 Tables and hence are also in error.

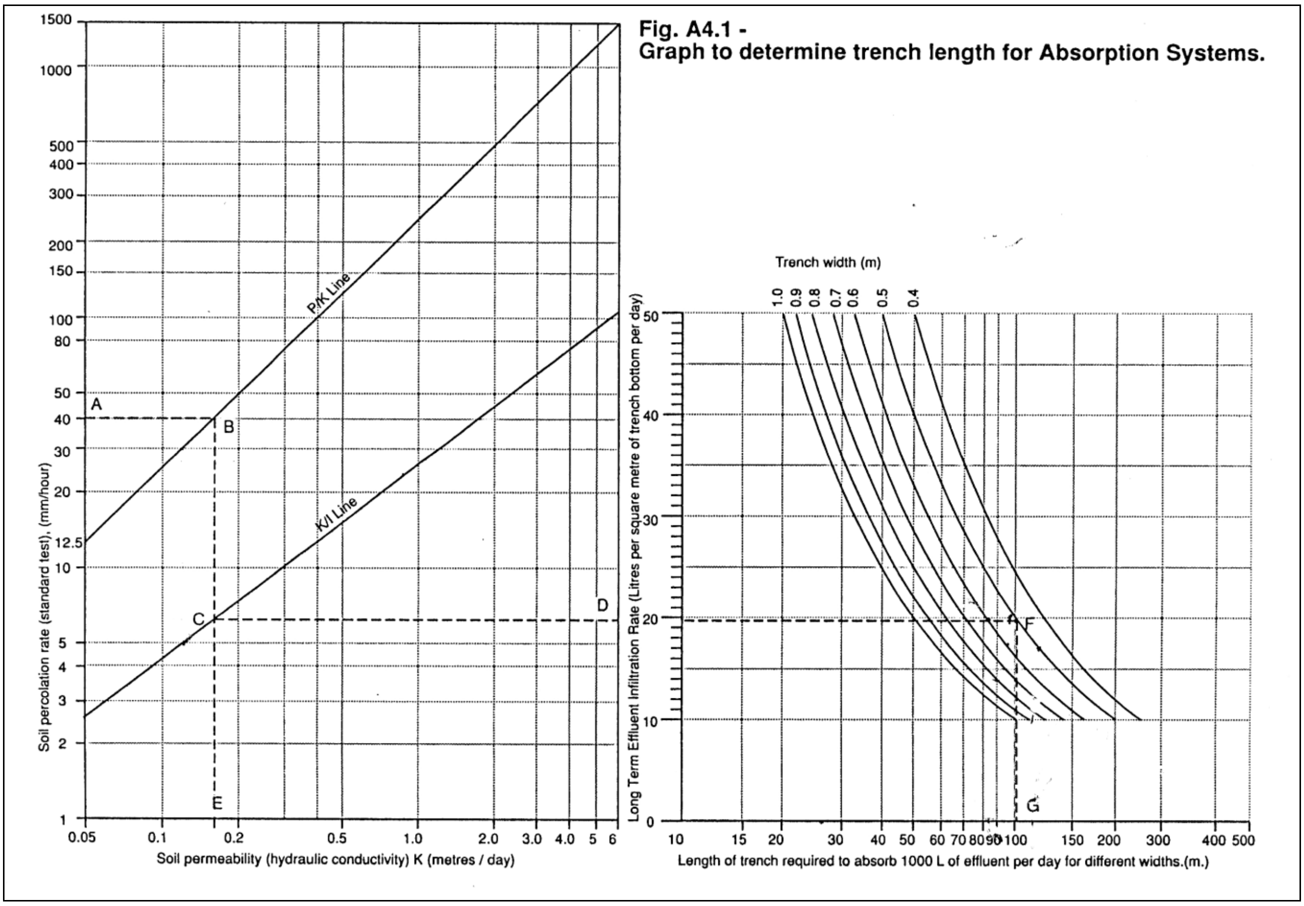


Figure 6 Copied from EPA Victoria (1990)

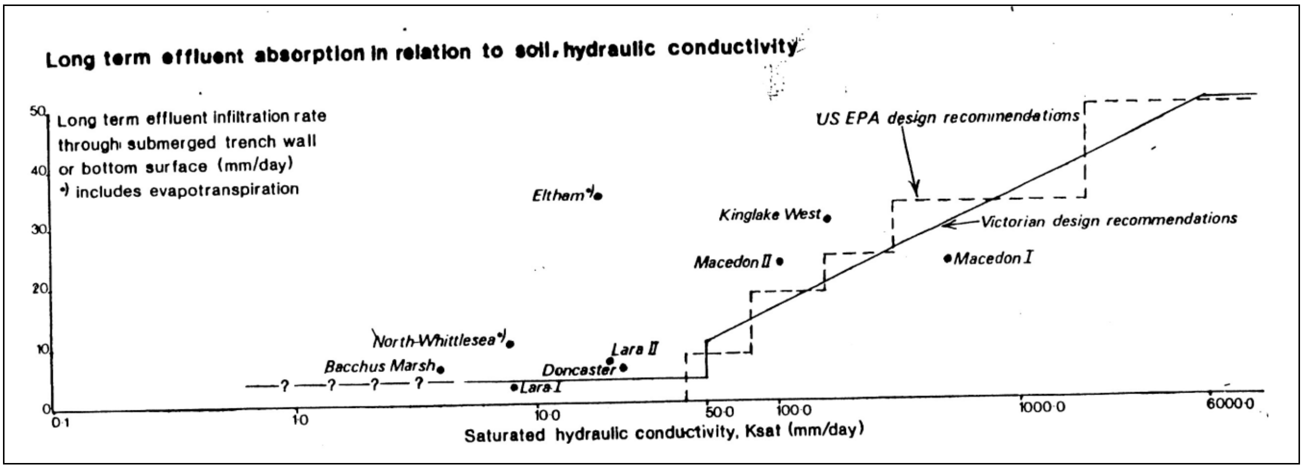


Figure 7. Empirical relation between long term absorption rate and soil hydraulic conductivity (Van de Graaff, 1998)

The constant head well permeameter test

As saturated hydraulic conductivity is usually denoted as K_{sat}, likewise unsaturated conductivity is denoted as K_θ, where θ represents the soil water content at the time of measurement. K_θ can easily be several orders of magnitude smaller than K_{sat}, depending on the degree of dryness of the soil. K_{sat} is easily measured in the field by the Talsma and Hallam (1980) constant head method. Measuring K_θ is much more complicated and time consuming, not least because it can have an infinite number of values depending on the infinite levels of moisture content at the time of measurement. K_θ therefore is usually represented as a curve in a graph against moisture content, θ, or against soil moisture suction (tension), φ.

Figure 8 shows how the hydraulic conductivity declines with decreasing pressure potential (increasing capillary suction) as the soil becomes drier, quite dramatically in sand.

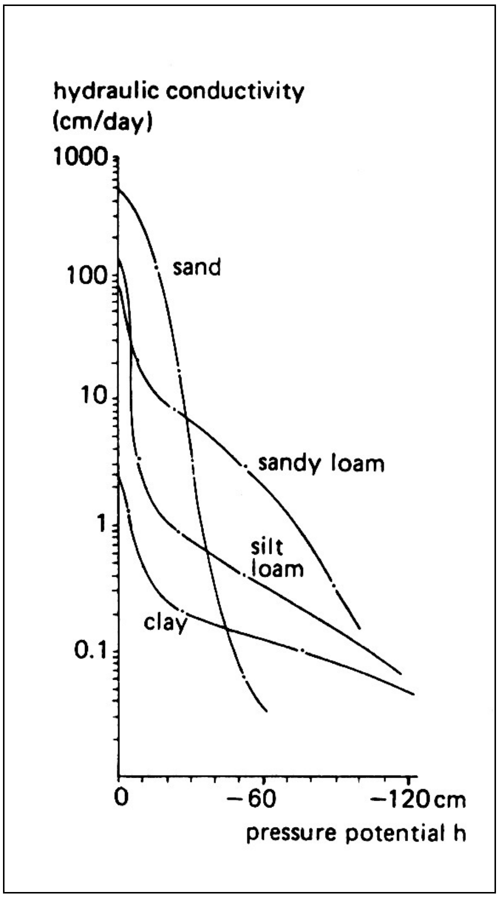


Figure 8 Relationship between hydraulic conductivity and soil moisture suction (Bouma, 1972)

The curve for sand relates hydraulic conductivity to negative pressure potential (capillary suction). It shows that at a capillary suction of almost nil (-0.1 cm), in saturated soil, the conductivity, K_{sat}, is about 800 cm/day, but at a suction of 60 cm it, K_θ, has declined to about 0.02 cm/day. At that suction, all pores with diameters smaller than 0.005 mm are still filled with water, while all larger pores are filled with air and do not participate in water transport. At this suction, by the way, plants have no trouble whatsoever in getting water from the soil. **Note** how soil hydraulic conductivity declines from a saturated state (pressure potential φ = - 0.1 cm) to increasingly unsaturated states (pressure potential up to - 100 cm). Between saturation and Field Capacity[1] the permeability of many soils declines to 1/100th to 1/1000th of their permeability at saturation.

Pore diameter and soil water suction are roughly related as follows:

$$\text{Pore diameter (cm)} = \frac{0.3}{h}$$

where h is expressed as the length in cm of a suspended column of water.

Talsma and Hallam (1980), both from CSIRO, adopted the constant head well permeameter test method that was originally devised by Jones (1951) and Zangar (1953), both of the U.S. Bureau of Reclamation (USBR), for routine *in situ* measurement of Ksat. The USBR method was designed for measurements by equipment requiring a truck-mounted mobile rig, but Talsma and Hallam used the same principles for a miniaturised

[1] The point where a saturated soil ceases to drain spontaneously under the gravitational force.

easily portable version. In contrast to the aforementioned percolation tests, the well permeameter method has a thorough theoretical and mathematical pedigree.

The Talsma and Hallam method consists of an auger hole which is filled instantly from a reservoir resting on a tripod over the hole. As the head of water remains constant during the test, the wetted sides of the hole retain the same dimensions and the infiltrating surface area remains constant as well. The unifying principle that applies to all test methods for hydraulic conductivity, whether in the lab or in the field is Darcy's Law (1856), which states that the velocity of seepage flow, V, is proportional to the hydraulic gradient, i, which is the loss of head divided by the length of the flow path, and the permeability, better called hydraulic conductivity, K:

$$V = K \times i$$

It follows that when i = 0, regardless how big K may be, V = 0. Thus, to measure K by monitoring and measuring V, one must choose conditions when i is not zero.

The driving force that causes the water to enter the soil is the capillary suction from the surrounding soil that is not saturated. Capillary forces are far stronger than the force of gravity as is demonstrated by the fact that water is drawn up in the soil well above a water table. Above the water table the soil is not saturated and the higher above the water table, the drier the soil will be. Capillary forces are zero when all the capillaries are filled with water, meaning the soil is saturated.

The notion that percolation tests ought to be done when the soil is at its wettest, which still persists in some quarters, is inspired by ignorance. Lay people can be forgiven for confusing the seasonal soil wetness regime with soil hydraulic conductivity. This confusion has given rise to unnecessary conflict between the Regulator and land capability assessors and was brought to the attention at the highest level in the EPA but to no avail.

A corollary erroneous notion, evidently still held by the Regulator (EPA Bulletin 746.1, p.8 Land Capability Assessment Table), is that seasonal perched water tables in the soil are identical to permanent groundwater tables in their impact on soil capability for on-site effluent management. A seasonally perched water table by definition has unsaturated soil below and continues to drain, albeit more slowly than may be desirable. Nearly the whole of Victoria has a perched water table at some times during the year but nowhere near as much land is unsuitable for on-site effluent management!

CONCLUSIONS AND RECOMMENDATIONS

Between 1975 and 2008 the Branch in the Victorian EPA that deals with on-site effluent management policy has consistently lacked in depth expertise in relevant aspects of soil science, such as soil physics and hydrology. It has therefore been unable to benefit from the research work done locally (Brouwer, 1982) and elsewhere in the world, e.g. the vast research data base provided by the USEPA (1978) and allowed guidelines and regulations to suffer unnecessarily.

The Department of Primary Industries would have been much more likely to have possessed the expertise to develop on-site policy with better success; however it has no mandate to address issues concerning public and environmental health. It may be possible for the EPA to work with or fund personnel from DPI to assist with the development of scientifically valid soils-based policy in the future.

The retention of the percolation test as a means of sizing effluent disposal systems in the absence of its own locally established relationship with long term effluent absorption is a symptom of this lack of expertise as well as a deficiency of logic. The retention of the percolation test in official guidelines strongly discourages consulting professionals from adopting modern proper soil testing methods.

The percolation test and all references to it should be removed from all of the EPA's literature and guidelines in favour of proper *in-situ* methods of measuring soil hydraulic conductivity. NATA should be requested to remove the EPA percolation test method from its books.

It is gratifying that Standards Australia and Standards New Zealand have adopted the constant head well permeameter method as the recommended method for soil permeability measurements for on-site effluent management and discourage the percolation test, on the grounds that it may have a detrimental impact on the environment.

REFERENCES

Amoozegar, A 1997. *Comparison of saturated hydraulic conductivity and percolation rate: Implications for designing septic tank systems.* In: Site Characterization and Design of On-Site Septic Systems. ASTM STP 1324 M.S. Bedinger, A.I. Johnson, and J.S. Fleming, Eds. Am. Soc. Testing and Materials.

AS/NZS 1547:2000..*On-site domestic wastewater management*. Standards Australia

Barbarick, K.A., Warrick, A.W., and Post, D.F. 1976. Percolation tests for septic tank suitability in Southern Arizona soils. *J. Soil Water Conservation*, Vol. 31,110-112.

Bouma, J 1971. Evaluation of the field percolation test and an alternative procedure to test soil potential for disposal of septic tank effluent. *Soil Sci. Soc. Amer. Proc*. 35:871-875.

Bouma, J 1975. Unsaturated flow phenomena during subsurface disposal of septic tank effluent. *J. Am. Env. Eng. Div. Am. Soc. Civ. Eng.*, Vol.1o1. No.EE6: 967-983

Bouma, J 1977. *Soil Survey and the Study of Water in Unsaturated Soil - Simplified Theory and some Case Studies*. Soil Survey Paper No. 13, Soil Survey Institute, Wageningen, The Netherlands.

Brouwer, J 1982 *Septic Tank Effluent Absorption Systems near Melbourne, Victoria – Land Capability and Design*. Doctoral Thesis La Trobe University

Brouwer, J and Bugeja, R.M., 1983, *Land Capability for Septic Tank Absorption Fields.* Australian Water Resources Council Tech Paper 80, Aust. Govt. Publishing Service, Canberra

EPA, 1990. *Septic Tanks Code of Practice*, Household Waste Treatment Committee, Environment Protection Authority, Dept. Water Resources Victoria & Health Dept. Victoria

EPA, 1996. *Code of Practice - Septic Tanks. On-Site Domestic Wastewater Management.* Publ. 451.

EPA, 2003. *Land capability for onsite domestic wastewater management*. Publ. 746.1

Healy, K.A. and Laak, R. 1973 Factors affecting the percolation test. J. Water Pollution Control Federation, Vol.45, 1508-1516

Jones, C.W. 1951. Comparison of seepage based on well permeameter and ponding tests. Earth Materials Lab. Rep. No. EM-264. Bur. Reclamation, Denver, Colorado.

Kiker, John E 1952. *Progress in the design of rural sewage disposal systems*. 80th Annual Meeting, Am. Public Health Assoc., Eng. *Section*, Cleveland, Ohio.

Kessler, J., and Oosterbaan, R.J., 1974. *Determining hydraulic conductivity of soils.* In: Drainage Principles and Applications, Part III: Surveys and Investigations. Publ. No.16, Intern. Inst. for Land Reclamation & Improvement (ILRI), Wageningen, The Netherlands.

Machmeier, R.E. 1977. *How to run a percolation test*. Extension Folder 261, University of St Paul, Minnesota.

Olson, G.W. 1964a. *Using soils surveys for problems of the expanding population in New York State.* New York State College of Agriculture, Cornell Extension Bulletin 1123.

Olson, G.W 1964b. *Application of soil survey to problems of health, sanitation, and engineering.* Agric. Experiment Station Memoir 387, Cornell University.

Poirée, M and Ollier, Ch 1962. *Irrigation* (Edition Peyrolles).

Ryon, Henry. 1928. Notes on the design of sewage disposal works with special reference to small installations. Albany, N.Y., 1928. 30 pp. Private Publication.

USEPA, 1978 *Management of Small Waste Flows.* 810 pp. Municipal Environmental Research Laboratory, Office of Research and Development, USEPA, Cincinnati, Ohio, 45268

Talsma, T., and Hallam, P.M. 1980. Hydraulic conductivity measurement of forest catchments. *Aust. J. Soil Research,* vol.18, p.139-148.

Van de Graaff, R.H.M., 1998. How to assess land for its ability to absorb septic tank effluent & render it harmless to human health and the environment. 67th Annual State Conference, Aust. Inst. Env. Health, Vic. Division.

Winneberger, J.T. 1974. Correlation of three techniques for determining soil permeability. *Environ. Health,* 37:108-118.

Zangar, C.N. 1953 *Theory and Problems of water Percolation*. Engineering Monograph No.8, Bureau Reclamation, U.S. Dept of the Interior, Denver, Colorado.

ACKNOWLEDGEMENTS

Figures 1, 3 and 4 were reprinted, with permission, from ASTM STP 1324- Site Characterization and Design of On-Site Septic Systems, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428, as well as with permission from Professor Aziz Amoozegar, Ph.D., Professor of Environmental Soil Physics, Soil Science Department, North Carolina State University, Raleigh, NC 27695-7619; permission to reproduce Figure 2 was obtained from Cornell University Cooperative Extension, Ithaca, N.Y. 14850; Figure 5 is reproduced with permission from IWRM, Alterra-ILRI Wageningen University and Research Centre, The Netherlands; Figure 8 was reproduced with permission from Emeritus Professor Dr J. Bouma, Spoorbaanweg 35, 3911CA, Rhenen, The Netherlands.