# CAN WE PREDICT FAILURE OF SEPTIC TANK - ABSORPTION TRENCHES? A REVIEW OF THEIR HYDROLOGY AND BIOGEOCHEMISTRY

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## Abstract

Septic tank soil absorption systems (ST/SAS) are the most common form of on-site disposal technology in Australia (approximately 225,000 in Queensland alone) and are likely to retain a major fraction of the on-site market in the future because of their apparent simplicity and relatively low costs. High failure of ST/SAS has been attributed to trench length under-design, solids carry over, poor construction and poor householder maintenance.

In Australia, the on-site wastewater industry seems to have an empirical approach to the design of absorption systems, not withstanding the best available advice contained within AS/NZS 1547:2000. In this paper, we describe the hydrology and biogeochemistry of septic trenches from first principles. The hydraulic behaviour of ST/SAS and role of the biological layer (biomat) is discussed. We also show, using simple numerical modelling, how the interaction of biomat resistance with soil hydraulic properties determines long-term acceptance rate (LTAR). Our findings are similar to Bouma (1975), in that a two to three order of magnitude variation in saturated soil hydraulic conductivity collapses to a one order of magnitude variation in LTAR.

## Keywords

biomat, hydraulic resistance, LTAR, septic absorption trench, septic trench failure

## 1 Introduction

On-site wastewater treatment and disposal systems (OWTS) are used in non-sewered areas to treat and dispose of household wastewater. Approximately 18-20% of the Australian population rely on OWTS in peri-urban and rural communities (O'Keefe 2001). The most common OWTS in Australia is the septic tank – soil absorption system (ST/SAS), with approximately 90% of the 250,000 unsewered properties in Queensland using this technology (Diatloff unpub.).

A ST/SAS operates by initial treatment of effluent in a septic tank followed by subsoil infiltration and absorption of effluent from gravel filled trenches. The mechanisms governing purification and hydraulic performance of a ST/SAS are complex and have been shown to be highly influenced by the biological mat or 'clogging' layer which develops on the soil surface within the trench (Bouma 1975). Both hydraulic and purification failure may occur, resulting in effluent pollutants (eg. nutrients and pathogens) being exported from the application area and entering surface and / or groundwaters. This paper focuses on the causes of hydraulic failure in ST/SAS systems.

Ground and surface water contamination, and potential health hazards have been linked to ST/SAS (eg. Cogger 1988; Geary and Whitehead 2001; Hoxley and Dudding 1994). Circumstantial evidence rather than a thorough scientific evaluation has, in many cases, led to such conclusions, particularly in Australian investigations. Rapid improvements in technology and design of ST/SAS in the United States has occurred as a result of rigorous scientific investigation demonstrating the impacts of poorly performing systems. The ST/SAS is likely to retain a major fraction of the on-site market in the future because of its apparent simplicity and relatively low cost. Adopting both theoretical as well as empirical approaches to designing ST/SAS in Australia, as has been done in other countries, will improve the overall design and long term performance of ST/SAS in Australian soils.

## 2 Hydraulic behaviour of ST/SAS

A number of factors influence the hydraulic sustainability of soil absorption systems. These include wastewater quality and quantity (eg. sodium concentration, biochemical oxygen demand (BOD), suspended solids, and hydraulic loading rates into the trench), *in situ* soil properties (texture, hydraulic conductivity, permeability, biogeochemical properties), site conditions (rainfall, slope, seasonal and permanent water table depths) and the geometry and sizing of the trench (or mound). If the effluent loading rate onto the infiltration surface is greater than the infiltration rate through the biomat then effluent will pond within the trench system. The biomat generally has a low hydraulic conductivity. Bouma (1975) calculated values of approximately 0.6mm/day for clay soils and 2mm/day for sandy soils. The main mechanisms occurring within an operating trench system that lead to failure are shown in Figure 1.

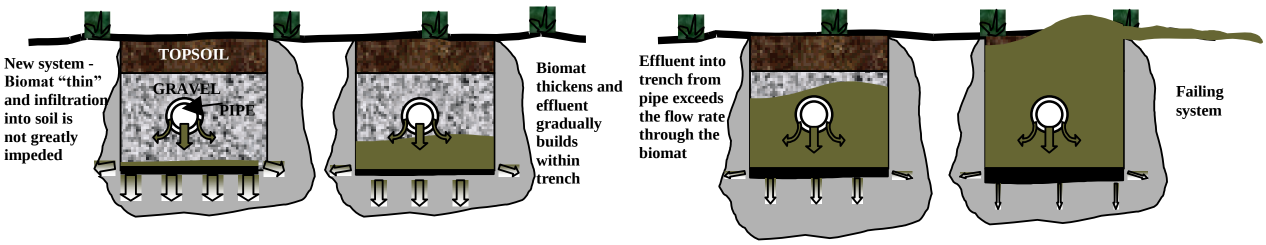



**Figure 1. Over time the development of a biomat impedes flow of effluent into the soil. Hydraulic failure occurs if the long term effluent loading rate exceeds the infiltration rate of the biomat.**

Investigations show that the hydraulic conductivity of the biomat reduces over time, an effect due initially to a physical clogging of the pores in the infiltrative surface of the *in situ* soil (Siegrist and Boyle 1987). Two or three main phases of biomat development have been identified, starting with a sharp reduction in the infiltration rate, followed by a period of gradually decreasing infiltration rates (eg. Allison 1947). The third phase, an equilibrium state of low infiltration, has also been observed by some researchers (eg. Siegrist and Boyle 1987).

The reduction in the biomat hydraulic conductivity can occur to such an extent that the effluent can build up (pond) above the biomat while the underlying soil can remain unsaturated (Kristiansen 1981a). It is the unsaturated flow characteristics ($K(\Psi)$) of the soil and the resistance properties of the biomat that govern the effluent flow rates though the biomat and sub-biomat zone (Huntzinger Beach and McCray 2003). A crust-capped soil, as is the case in a mature ST/SAS, has been shown to behave as a "self-adjusting" system, where a steady state infiltration rate and soil moisture profile develops over time (Hillel 1980). This steady state is reached when sub-biomat soil moisture potentials ($\Psi$) create a gradient across the biomat, and the unsaturated hydraulic conductivity below the biomat, allows a state of equal flux through both zones (Hillel 1980).

In simple mathematical terms:

$$Q_b = Q_u = K_b(dH/dZ)_c = K_u(dH/dZ)_u \qquad \text{........................[1]}$$

where $Q_b$ represents the steady state flux through the biomat and $Q_u$ represents the steady state flow through the unsaturated zone below the biomat. The biomat hydraulic conductivity and biomat hydraulic gradient is represented by $K_b$ and $(dH/dZ)_c$, respectively. The unsaturated hydraulic conductivity and hydraulic gradient of the unsaturated sub-biomat zone are represented by $K_u$, and $(dH/dZ)_u$, respectively. The resultant *Q* represents the long term steady state flux at which, theoretically, a ST/SAS can continue to accept effluent without hydraulic failure occurring. This flux value is also known as the long term acceptance rate (LTAR), with units of mm/day or L/m$^2$/day.

The interaction between unsaturated soil hydraulic conductivity and biomat resistance is not the only factor causing low flow rates in absorption systems. Dispersion or swelling in sodic soils, resulting from low electrical conductivity: high sodium absorption ratio effluent applications, can be a substantially decrease soil permeability (Patterson 2001). In this case the interaction described in Equation 1 would be diminished and less easily predicted.

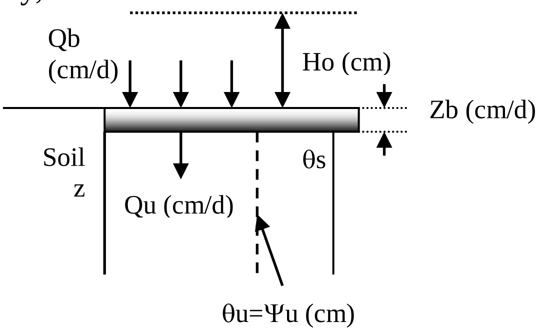
## 3 Predicting long term flux through the biomat zone

The hydraulic effects of a biomat on *long term* effluent flow rates (Q) can be predicted if the resistance of the biomat ($R_b$) and the K(Ψ) relationship of the underlying soil are known. Bouma (1975) showed that the hydraulic conductivity of the biomat ($K_b$) is a function of both $R_b$ and the moisture potential (soil suction) of the soil immediately underlying the biomat. Biomat resistance is the product of the inverse of $K_b$ and the effective thickness of the biomat (Zb). Taking $Kb(dH/dZ)_c$ from Equation 1 and assuming a steady infiltrating soil profile where the hydraulic gradient approximates unity, we can write:

$$Qu = K(\Psi) = Kb(dH/dZ)_c$$
$$= Kb((H_o + \Psi + Zb) / Zb)$$

This is easily rearranged to yield:

$$\frac{K(\Psi)}{H_o + \Psi + Zb} = \frac{Kb}{Zb} \equiv \frac{1}{Rb\ (\text{days})} \qquad \text{……… [2]}$$




where K(Ψ) is the unsaturated hydraulic conductivity of the sub-biomat zone as a function of soil moisture potential, and Ho is the positive hydraulic head on top of the biomat.

Bouma (1975) calculated biomat resistances ranging from 5-7 days for sands, 150 days for silt loams and 45-65 days for clays and silty clays. The variation in values was attributed to differences in porosity, structural instability and biological activity between soils. The wetted perimeter or lower boundary of the saturated biomat is likely to be less abrupt in sandier soils compared with the finer soils. This may have affected the tensiometer readings and hence the calculated Rb values, particularly if the position of the tensiometers in the soil profile was the same for each soil type.

Measured moisture retention characteristics, (ie. soil moisture tension as a function of soil water content,$\Psi(\theta)$), of some Australian soils (eg. Cresswell 2002; Forrest *et al.* 1985; Talsma 1985) were used to predict steady state fluxes for various biomat resistances and soil textures. The predicted effect of increasing biomat resistance on flow rates for various soils is shown in Figure 2.

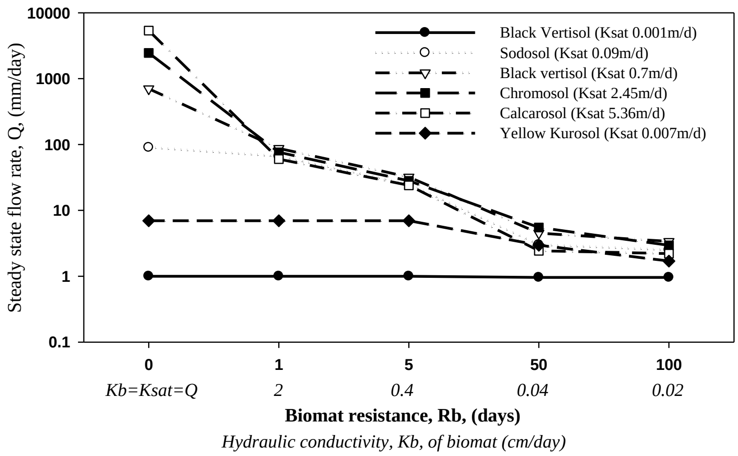



**Figure 2 Predicted effect of increasing biomat resistance on steady state flow rates for a range of Australian soils (Note: X axis is not to scale)**

The steady state flux through the biomat was calculated using Equation 2. Campbell's (1974) model, using the known saturated hydraulic conductivity values as the matching K factor, was used to calculate the unsaturated hydraulic conductivity of the sub biomat zone. The Campbell model is represented as $K = Ks(\Psi e/\Psi)^{2+3/b}$, where b is the slope of the $\Psi(\theta)$ relationship. The value Q*c* = Q*u* (Equation 1) was solved as a simultaneous equation for a range of biomat resistances. This was performed by "Flux for Septic Trenches" (FLUX), a spreadsheet model developed using Excel. Results were checked by running the same input parameters in SWIM v1.0 (Ross 1990). Biomat resistances used in the model encompassed a range of values reported in the literature (eg. Magdoff and Bouma 1974).

As the hydraulic resistivity of the biomat increases, the infiltration rate through the biomat decreases and soil moisture tensions immediately below the biomat increase (ie. the soil becomes drier). Our findings (Figure 2) are similar to other studies (eg. Huntzinger Beach and McCray 2003) in that a 2–3 order of magnitude variation in saturated hydraulic conductivity between the soils will collapse to a one order of magnitude variation in long term flow rates. A number of curves were generated for four different Australian soil types illustrating the predicted effect on flow by biomats of various resistances (Figure 3). Hydraulic conductivity curves for the soils were derived using the Campbell (1974) model in FLUX. The Rb curves were generated from Equation 2, assuming an Ho of 5 cm, Zb of 2 cm and Rb values in the range reported in the literature. Biomats of the same resistance and ponded depth will induce different moisture tensions in the underlying soil. For example, a biomat with an Rb of 100 days will induce potentials of -22 cm (sand) and -2 cm (Black Vertisol) immediately below the biomat, with corresponding flow rates of 2.9 and 0.92 mm/day respectively (Figure 3). The difference in these hydraulic characteristics are largely due to varying porosity of the soils. Typical loading rates to trenches are 5 to 20 $L/m^2$/day (ie. 5 to 20 mm/day). Biomats of low resistance (eg. Rb = 1 day) can have a marked effect on flow rates in sandy soils, but not in clay soils (Figure 3).

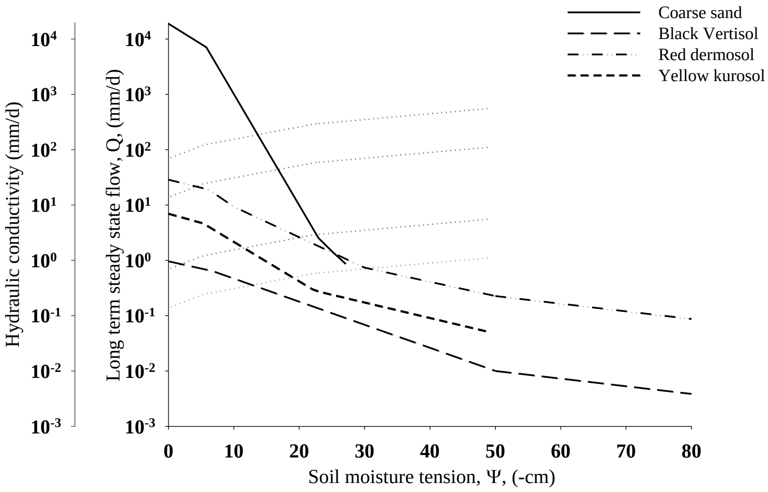



**Figure 3 The dotted curves represent the change in biomat saturated conductivity as the soil moisture tension below the biomat increases (thus gradient increases across biomat). The K(Ψ) curves for four Australian soils show the decrease in unsaturated hydraulic conductivity as soil moisture tensions increase. An equilibrium steady state flow occurs at the point at which the curves intersect (Figure adapted from Bouma 1975). Note: at Ψ=0, θ=Ksat for Rb=0.**

This can be directly attributed to the moisture retention characteristics of sandy soils as they undergo substantial pore water draining at high matric potentials (ie. low soil tensions) and consequently the conductance of water through the soil will be reduced as the larger pores drain (as flow is proportional to the fourth power of the pore radius). Conversely, in soils of inherently low saturated hydraulic conductivities (eg. <10 mm/d), biomats of low resistance will not markedly effect the underlying soil hydraulic properties. For example, flow rates in a Black Vertisol of low hydraulic conductivity (1 mm/d) will only begin to be impeded by a biomat of Rb 100 days or greater. This result confirms those from similar investigations (eg. Huntzinger Beach and McCray 2003).

Although not modelled here, by increasing the ponded depth on top of a biomat (Ho), an increase in the flow rate (Q) will occur with a subsequent increase in soil moisture content (Kropf *et al.* 1977). Although not all researchers have found this to occur, Bouma (1975) observed a minimal increase of flow with increasing Ho and this only occurred if the resistance of the biomat remained the same.

# 4 Comparison of long term acceptance rates

Using the hydraulic resistance of the biomat for a range of major soil textures, Bouma (1975) estimated a long term effluent loading rate for each soil type. Four different hydraulic loading rates were recommended from Bouma's work (1975) ranging from 50 mm/d for sands to 10 mm/d for clays. It is believed that this work contributed to the development of USEPA wastewater management publications (eg. USEPA 2002). In Australia, Brouwer and Bujega (1983) developed an empirical curve which showed the relationship between soil saturated hydraulic conductivity and long term effluent infiltration rate (ie. LTAR) for some Victorian soils. This LTAR curve was adopted in AS 1547:1994.

The long term loading rates recommended in AS 1547:1994 and AS/NZS 1547:2000 and also data calculated from Bouma (1975) are shown in Figure 4. The design loading rates (DLR) in AS/NZS 1547:2000 are based on the LTAR recommended in the 1994 publication but the relationship between the two is unclear. Some predicted long term flow rates for two biomat resistances, Rb = 5 and 50, calculated for a range of soils using the FLUX model are also shown in Figure 4.

Some general observations can be drawn from Figure 4. A low biomat resistance (5 days) has a greater effect on flow rates in soils with initially high Ks than soils with lower Ks values. The LTAR values generated from FLUX show that flow reduction in sandy soils (ie. high Ks values) starts to occur under a biomat of low resistance (ie Rb = 5) compared with clay soils where flow reduction becomes more marked at higher biomat resistances. As noted earlier this is a function of the unsaturated hydraulic conductivity characteristics of the soil.

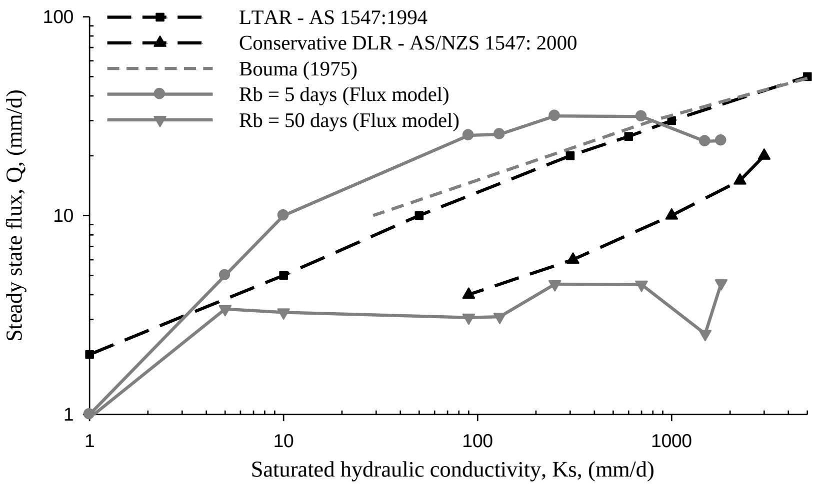



**Figure 4. Comparison of calculated long term flow rates in the literature with modelled flow rates using FLUX**

Assuming a biomat resistance of Rb = 50 represents a mature trench with a steady state infiltrating profile, Figure 4 suggests that the DLR recommended in AS/NZS 1547: 2000 for permeable soils may overestimate the capacity of these soils to accept effluent over the long term. However, comparisons between LTAR curves should be made with caution as the assumption used to generate data for the FLUX curves and Bouma's (1975) curve are such that they represent the hydraulic conditions for a specific combination of Rb, Zb and Ho values. In addition, the model has not accounted for two dimension flow and transpiration sinks. More advanced modelling is planned as part of this research project, where lateral (sidewall) effluent flow through a trench will also be simulated for various soil textures.

## 5 Overview of the role of biomat in ST/SAS treatment process

The formation of a biomat is critical for the treatment process in a soil absorption system. The hydraulic and purification processes that occur when effluent passes through the biomat and underlying unsaturated zone are closely linked together. The development of a biomat reduces and regulates the flow of effluent into the unsaturated soil thus allowing prolonged and extensive contact with the soil matrix. The extended contact time of effluent within the soil, known as hydraulic retention time (HRT) allows for effluent constituents to undergo various processes that ultimately act to reduce, remove or de-activate them. This is similar to the way that an intermittently-dosed sand filter operates (Crites and Tchobanoglous 1998). The biomat zone has shown to facilitate pathogen removal directly by increasing the infiltrating surface area available for pathogen removal processes to occur, and indirectly by increasing the HRT and aerobic conditions of the sub-biomat soil (Van Cuyk and Siegrist 2001).

The biomat acts as a good filter in straining and trapping biodegradable organics (eg. BOD), and suspended solids. The major removal mechanisms for N and P within the biomat have not been rigorously investigated to date. There is evidence to suggest that ST/SAS can be an effective in reducing nutrient concentrations within ≤10 m from the trench (Cromer 2001; Gerritse *et al.* 1995).

## 6 Summary and conclusions

The physical, chemical and biological processes that occur in the biomat layer and underlying unsaturated zone are complex and highly interactive. It is clear that a "Catch-22" situation exists for the performance of ST/SAS. Hydraulic failure usually means that slow infiltration through a well aerated subsoil is likely to be occurring (in the absence of a shallow water table) – an ideal condition for good effluent treatment. On the other hand, if there is no evidence of hydraulic failing (that is no surface ponding or boggy soils), the system is typically considered to be operating well, but this may be accompanied by effluent travel through the subsoil at a rate that precludes adequate treatment of effluent. This situation can make it a difficult task for regulators and engineers to establish appropriate performance criteria and design guidelines. The use of LTARs based on the resistance properties of biomats at steady state infiltration, may help to achieve the balance between hydraulic and purification performance.

This paper has revisited the work done by Bouma and others in that we have attempted to describe, from first principles, the interaction of unsaturated soil hydraulic properties with biomat resistance to determine LTAR. We have adapted these equations into a model, FLUX, to predict this interaction, and hence LTAR, for a range of Australian soils. Preliminary modelling indicates that the relationship between design loading rates and soil saturated conductivity described in AS/NZS 1547:2000 seems to overestimate the long term flow rates for permeable soils. Independent measurements of biomat resistance in Australian soils is required to build on these findings. It is also intended to extend the model to predict flow in two dimension systems and for transient flow conditions. Recent efforts have been made to predict biomat development (Siegrist and Boyle 1987) based on BOD and SS loadings. Further research in this area will be attempted for Australian soils.

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