FACTORS AFFECTING THE PERFORMANCE OF SEPTIC TANK SYSTEMS TREATING DOMESTIC WASTEWATER IN DEVELOPING COUNTRIES

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ABSTRACT

Septic tank systems are in widespread use for treating domestic wastewaters. They are particularly attractive to developing countries because they are simple in concept and, if correctly designed, installed and maintained, require little attention from householders. However, present design guidelines disregard the influence of climatic conditions and surface vegetation on septic tank system performance. A combined field monitoring and numerical modelling study was undertaken to evaluate how these factors affect the hydrological performance of septic tank absorption trenches. The study revealed that a substantial proportion of water inflows to trenches is lost via evaporation and transpiration.

Keywords *- absorption trench; evaporation; numerical model; on-site soil absorption systems (OSAS); transpiration.*

1. INTRODUCTION

Septic tanks, the commonest type of on-site absorption systems (OSAS), are widely used to dispose of domestic wastewaters in rural and peri-urban areas that lack centralised wastewater collection systems. This is the case in both less developed and industrialised countries. In Australia, for example, around 800 000 households rely on septic tanks for wastewater disposal (Beal *et al.*, 2005). Provided they are well designed, well managed, and properly installed on an appropriate site, septic tank systems can be an effective, safe and relatively cheap means of disposing of household wastewaters.

For developing countries in particular, the design simplicity of septic tank systems is an important advantage. As shown in Figure 1, septic tank systems have only two main components, a settling or septic tank, and an absorption (dispersion) trench. Wastewaters flow by gravity to the septic tank where most solids settle out. The clarified wastewater overflows into a distribution box from where it passes to the absorption trench and thence into the surrounding soil. Some contaminant removal occurs in the trench itself but much takes place as the wastewaters disperse outwards and downwards through the soil.

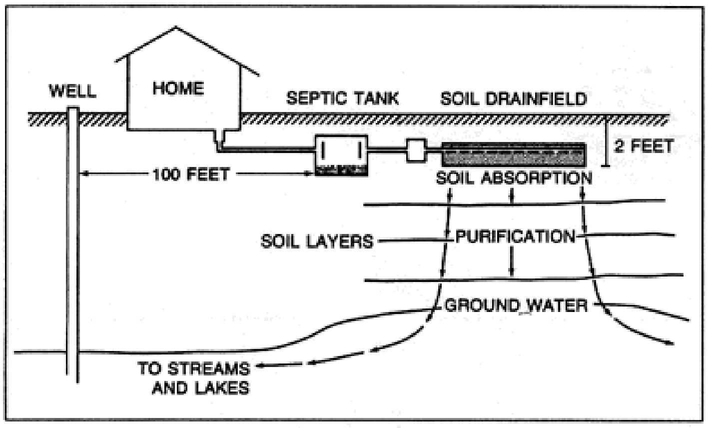


Figure 1. *A typical septic tank system*

In the tank the settled solids undergo anaerobic decomposition, with up to 80% of the solids breaking down over time. A slow build up of solids occurs, however, making it necessary for the tank contents to be pumped out every 3 to 5 years (Bitton, 2005). For the rest of the time the system operates passively, and once installed requires little attention and no external energy inputs. This feature, together with the very low operating costs, further enhances the potential suitability of septic tanks for use in developing countries.

Despite their merits, septic tanks also have a number of shortcomings. If they are poorly designed, overloaded, or installed in inappropriate locations, pollution of surface and ground waters can result, with potential risks to health. Concerns about septic tank failures are widespread in both developed and developing countries and a growing reluctance to install new septic tank systems is becoming evident. This situation has developed in spite of the fact that in most countries quite extensive guidelines on the design, installation and operation of septic tank systems are available. The main problem seems to be that these guidelines are based largely on experience and empirical rules of thumb and are not necessarily underpinned by good science. Where authorities are aware of the shortcomings of existing guidelines, large safety factors tend to be incorporated into local regulations in order to obviate failures, and so septic tank systems can end up being heavily overdesigned. Whilst such overdesign may not be that important in more affluent areas, poorer communities are much less able to afford the extra costs associated with overdesigned systems.

It was concerns about the appropriateness of regulations and guidelines applicable to septic tank installations that led to the study described in this paper. The aim of the study was to develop a better understanding of how septic tank systems work and how designs can be improved to reduce the likelihood of failures. Whilst the project focused on conditions on the outer fringes of Melbourne in Australia, its findings should be applicable in many parts of the world where septic tanks are used.

2. WHY DO SEPTIC TANKS FAIL?

One of the initial tasks in the study was to look at what causes septic tank systems to fail. Interviews with homeowners and local authorities indicated that both technical and non-technical problems contribute to poor septic tank performance.

2.1 Non-technical problems

On the non-technical side, it became clear that there was a good deal of complacency and ignorance about septic tanks. Prescribed installation procedures were often poorly observed and inspections of new installations by local authorities were sometimes quite perfunctory. In addition, householders often knew very little about septic tank processes and their management. This brought home the importance of providing sufficient funds for communication, education and training, of both local authority personnel and also householders, when on-site wastewater treatment systems like septic tanks are being installed. Whilst these findings relate specifically to Melbourne, we believe them to be of equal or even greater relevance to Third World communities.

2.2 Technical problems

The major technical problems encountered with septic tank systems relate to their design. Development of designs that are appropriate to a specific location requires a depth of understanding of the fundamentals underlying septic tank operation and the performance of dispersion trenches that we presently do not have. Guidelines in the form of codes and/or recommended loading rates exist for most countries but these tend to be rather general, with only limited cognisance taken of local conditions. Evidently, better ways are needed of predicting how septic tanks will perform in specific locations, and what the risks of system failure are.

According to the Australian/New Zealand Standard AS/NZS 1547:2000, failure (of a septic tank system) can be defined as an unsatisfactory performance of the system or an undesirable and unfavourable impact on the environment (Standards Australia and Standards New Zealand, 2000). (This is not particularly helpful since deciding whether or not failure has occurred tends to be based more on people’s perceptions than on quantitative criteria.) Two types of failures need to be considered. The most readily detected is *hydraulic failure*, which occurs when water flows into the septic tank dispersion trench faster than it can be absorbed by the surrounding soil, and the excess water rises to the soil surface. This water will often contain sufficient viable pathogens to create a significant health risk. The second type is *treatment failure*; this occurs when waters passing through the soil merge with ground waters or nearby surface waters before adequate removal of contaminants and pathogens has occurred.

Depending on the local situation, both types of failure can be of concern. In areas such as Melbourne, where only limited use is made of groundwater, avoiding hydraulic failures is probably the major concern of local authorities. Elsewhere in the world, especially in areas where water for domestic use comes mainly from sub-surface sources such as wells, treatment failures would be expected to be of much more importance; if wastewater disposal systems and water sources are too close together, contamination of water sources with pollutants and pathogens is likely, with potentially serious consequences for the health of local communities.

3. FIELD STUDY

Field investigations were undertaken at eight different septic tank sites around Melbourne over a one year period from November 2006 to November 2007. Soils on these sites were all of the silt or silt loam type. When choosing the study sites care was taken to ensure that: systems were properly installed and well maintained; hydraulic loading rates could be estimated with reasonable accuracy; and sites were flat and readily accessible. The fieldwork included: the collection of soil samples for classification and laboratory testing; in-situ testing to determine soil physical and hydraulic properties; a twelve month monitoring program to establish how moisture levels in the vicinity of the absorption trenches altered over a full annual cycle; and regular monitoring of ponding levels inside the trenches.

Nine 50mm diameter soil sampling holes were drilled at the upstream end of each trench (Figure 2). Two or three similar holes were also drilled close to each trench but in an area not expected to be affected by the dispersing wastewater; these holes were used as controls. Three PVC standpipes were installed along the centre line of each trench, as shown in Figure 2, to enable ponding levels inside each trench to be monitored. Samples of surface vegetation were collected and the major plant species present identified. Leaf Area Index (LAI) and root depth characteristics for each site were established. Full details of the field and laboratory programs, and all test results can be found in Jayarathne (2008).

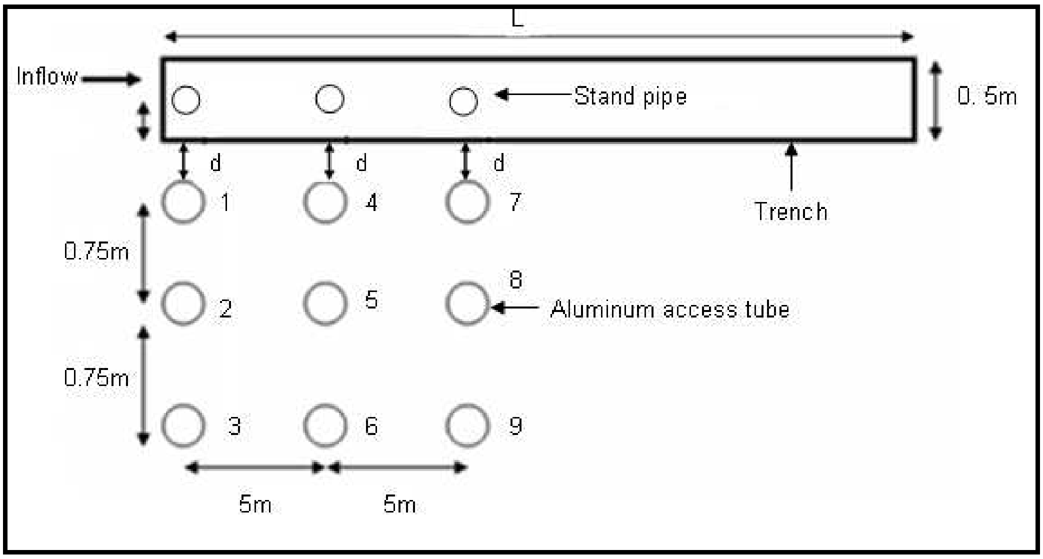


Figure 2: *Plan view showing soil moisture and ponding level monitoring points relative to each study trench (not to scale).*

4. THE HYDROLOGICAL MODEL

To complement the fieldwork component of the study, a dynamic hydrological model was developed to describe the behaviour of wastewaters dispersing into soils around septic tank trenches. Such a model would have the capacity to predict when hydraulic failure was to be expected and would also provide information helpful in assessing the risk of treatment failure occurring.

The model was constructed using the VADOSE/W module of the "GeoStudio 2004" software package developed by GEO-SLOPE International Ltd, Canada. This module uses a finite element approach to determine moisture flow patterns in soil as a function of both spatial position and time. It is able to take into account variations in soil type, soil horizons, surface vegetation parameters and climatic conditions. It was chosen specifically because of its ability to allow for variations in the latter two parameters as these have hitherto been largely neglected in septic tank studies. Figure 3 shows the various hydrological processes and features incorporated into the model. Details of how the model was developed as well as technical details about the model domain, finite element grid sizes, boundary conditions, and correlations used can be found in Jayarathne *et al*. (2007) and Jayarathne (2008).

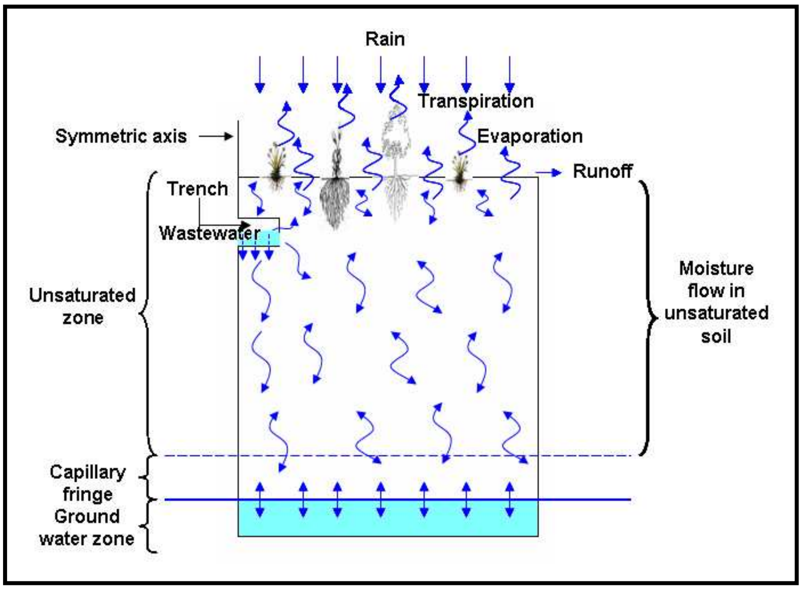


Figure 3.
The hydrological processes affecting moisture flows in soils around septic tank absorption trenches.

Preliminary evaluation of the model's capabilities was carried out using the published results from an earlier study at Mount Macedon, northwest of Melbourne (Brouwer and Bugeja, 1983). Inputs to the model included published soil property data from the above study together with data on local climate conditions during the study period. A vegetation-related boundary condition was applied to the top surface of the model domain. Soil moisture content profiles predicted by the model compared encouragingly well with those measured by Brouwer and Bugeja.

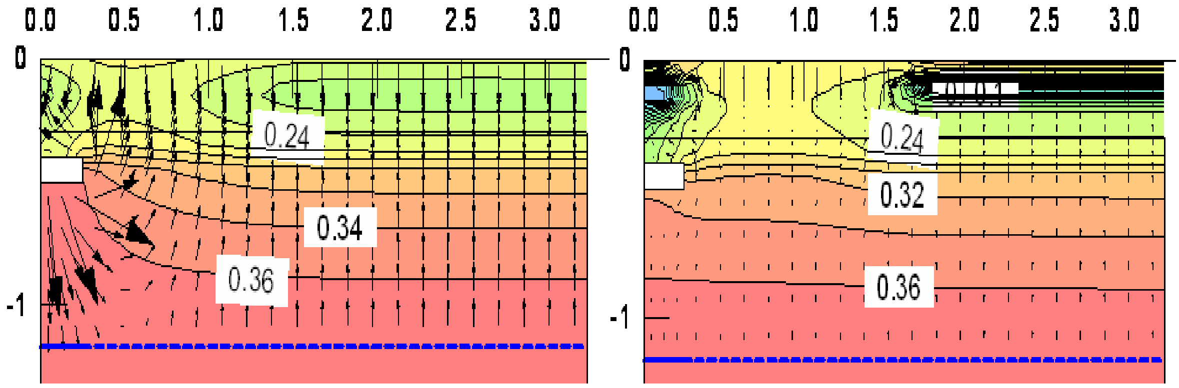
More extensive calibration of the model was then undertaken using soil property and hydrological data obtained from the eight septic tank installations in the greater Melbourne area referred to earlier. Hydrological information was collected monthly at each of these sites over a full year. A wide range of on-site and laboratory tests were undertaken on soil samples from each site to characterise soil properties.

Water balances calculated for each of the sites using the model showed that 38-65% of the total water entering the trenches (this includes rainfall as well as wastewater inflows) was lost by transpiration. This shows just how significant the uptake of water by surface vegetation from the absorption trench and surrounding areas can be. An additional 10-13% of the incoming water was lost by evaporation. This means that, according to the model, more than half the water received by the trench system is lost through evapotranspiration. The model was then used to compute water balances around trenches under climatic conditions typical of those at a number of locations across Australia. Again evapotranspiration was predicted to be a major, and often the predominant, water loss pathway.

The above results were obtained for systems that were not excessively loaded and for which a significant layer of surface vegetation was present. In heavily loaded systems with few plants growing above the absorption trench losses by transpiration would be much lower, though this would in part be offset by higher evaporative losses. However, what makes the above findings so important is their demonstration that a substantial fraction of the flows entering an absorption trench can be lost to the atmosphere via evaporation and transpiration, something that is not properly accounted for in current design guidelines. The findings also imply that maintaining a clear well-vegetated surface above absorption trenches when trenches are heavily loaded reduces significantly the risk of hydraulic and treatment failure.

The model was then used to predict moisture dispersion patterns around septic tank trenches under a variety of soil, climate, vegetation, loading rate and other conditions. Of particular interest was the impact that groundwater table depths might have on soil moisture content and moisture dispersion patterns. Model runs were undertaken to establish how predicted moisture distribution patterns around a specific trench would be affected by changing the depth of the groundwater table from 4 m to 1.2 m (the minimum distance to the water table permitted in the Standard AS/NZS 1547:2000).

Figures 4 and 5 show model predictions for a silt loam soil with a saturated hydraulic conductivity (K_{sat}) of 0.003 m/day and a volumetric water content (VMC) at saturation of 0.36, conditions similar to those at one of the study sites. Climatic conditions typical of those used in Melbourne were applied and a typical surface vegetation cover was assumed. The left hand diagram in each Figure shows predicted patterns for the case when the trench was subjected to a hydraulic loading of 5 mm/day, the maximum permitted in the Australian/ New Zealand Standard AS/NZS 1547:2000 for the given soil type.



(a) (b)

Figure 4. *Predicted soil moisture content distributions around an absorption trench for a groundwater table depth of 1.2 m and wastewater loading rates of: (a) 5mm/day; (b) 0 mm/day*

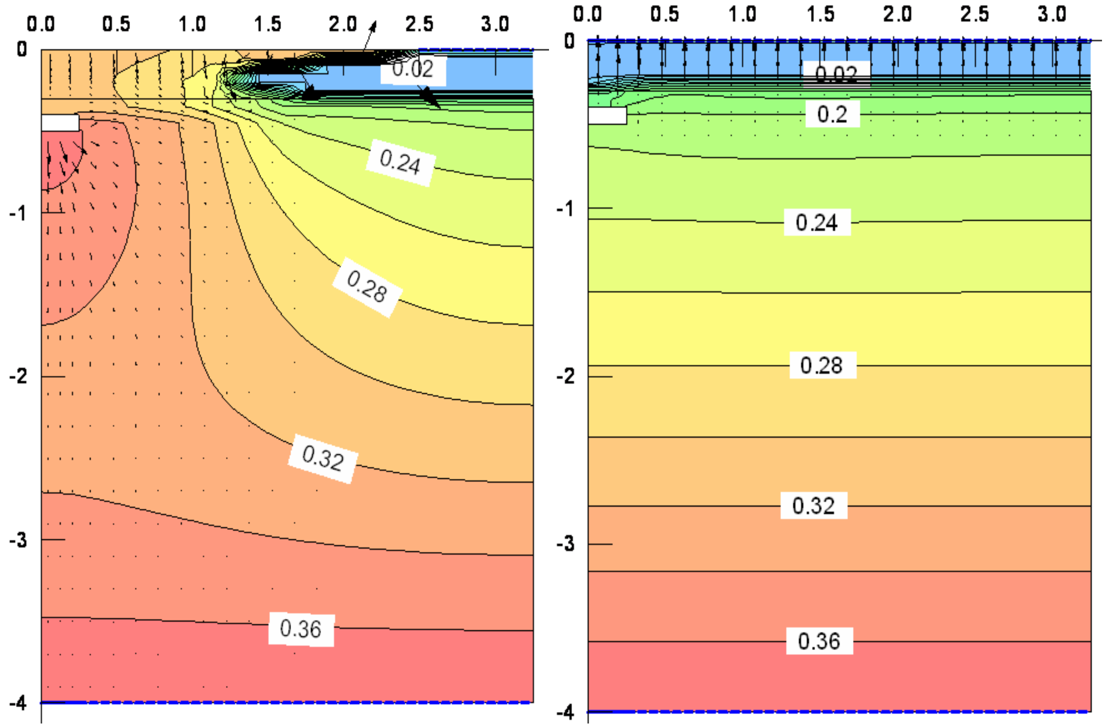


Figure 5. *Predicted soil moisture content distributions around an absorption trench for a groundwater table depth of 4 m and wastewater loading rates of: (a) 5mm/day; (b) 0 mm/day*

The right hand diagram in each Figure shows predicted patterns for the case where no wastewater is supplied to the trench and the only water inflows are those due to rainfall. In all cases the top boundary of the diagram lies along the soil surface and the boundary at the left lies along a vertical centreline through the trench; the white rectangle adjacent to the left hand axis shows the position of the right half of the trench, which has its base 0.5 m below the ground surface. The right hand boundary of each diagram lies along a vertical line 3.5 metres from the trench centreline. The blue horizontal line shows the position of the groundwater table. Soil moisture content distributions are shown by a combination of labelled contour lines and shading – zones of saturated soil are present whenever the VMC > 0.36. In all cases the patterns shown are those predicted for the wettest day of the year (when the probability of failures is highest).

5. DISCUSSION

Figure 4 shows predicted moisture distribution patterns for the case where the groundwater table is 1.2m below the ground surface (effectively a worst case scenario). Comparison of Figures 4(a) and 4(b) shows how the introduction of wastewater into the trench causes moisture distribution patterns to change from those determined by climate and surface vegetation conditions alone. It is apparent that even with the water table as close as 1.2m to the ground surface, soil moisture contents above the level of the trench base stay well below saturation levels; hence hydraulic failure would not be expected. However, Figure 4(a) also shows that a saturated soil zone extends upwards from the groundwater table right to the base of the trench. This suggests that much of the wastewater dispersing from the trench will not pass through an unsaturated zone. Since passage of wastewater through unsaturated soil zones is known to help greatly in the inactivation of pathogens, the absence of such an unsaturated soil zone between the trench and the groundwater surface indicates an increased risk of treatment failure.

How moisture distribution patterns are affected when the distance to the groundwater table is increased to 4 m is shown in Figure 5. From Figure 5(a) it is evident that in this case there is no longer an uninterrupted zone of saturated soil connecting the trench to the groundwater below. Instead there is a 2.5m wide unsaturated zone, which ensures that all wastewaters will spend a substantial period in an unsaturated zone before entering the groundwater. This should markedly reduce the chances of treatment failures occurring.

6. CONCLUSIONS

The model developed during our study provides useful insights into what happens around and beneath septic tank absorption trenches. It showed that evapotranspiration can be the major water loss pathway from soils around absorption trenches. This highlights the value of keeping the ground above absorption trenches clear and of maintaining a good surface vegetation cover over the trench area. Use of the model also demonstrated that while groundwater depth limits in current guidelines and Standards may be adequate to prevent hydraulic failures they may not be appropriate where treatment failures can have serious consequences. Revision of guidelines to address the above findings is highly desirable, especially where there is heavy reliance on groundwater for potable use, as is the case in many developing countries.

Whilst the findings of our study relate primarily to conditions around Melbourne, we believe they have considerable relevance throughout the world wherever installation of septic tank systems is under consideration.

7. ACKNOWLEDGEMENTS

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