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Septic Tanks Revisited . . .

Success or Failure of On-site Effluent Disposal

by

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INTRODUCTION

On-site disposal of domestic septic tank effluent by ground absorption is a widespread practice in Australia, both in unsewered suburban fringes of its major cities and in its semi-rural and rural areas. Ignorance of, and disregard for, soil and land features that determine the performance of individual domestic absorption fields have caused unnecessary system failures and hence have given this disposal method an undeserved reputation as a third-rate and "temporary" alternative to full sewerage.

Although septic tanks and on-site effluent disposal have been used for many decades, a new interest is developing in the functioning of on-site disposal systems. This is largely due to environmental concern, but the availability of new research results (mostly American) and a greatly increased insight in soil processes has also promoted this renewed interest. Modern soil science has expanded our knowledge of soil chemistry, soil microbiology and particularly of soil physics, the branch of soil science that studies the movement of fluids such as water or air through the soils, as well as the soil's structure, porosity and mechanical behaviour. The methodology and the research tools which are currently being used to investigate soil absorption of effluent, evapo-transpiration rates and movement of dissolved substances through the soil, etc, have been developed for a good part by soil physicists and irrigation agronomists studying crop water use, water losses, drainage and salinisation.

The interest at Government level is reflected in Victoria by the establishment, upon a suggestion of the Environment Protection Authority and under the auspices of the Ministry of Water Resources and Water Supply, of an Interdepartmental Committee on Household Waste Treatment Options. It consists of representatives of the State Rivers and Water Supply Commission, the Health Commission of Victoria, the Melbourne and Metropolitan Board of Works and the Ministry for Conservation and its associated organisations the Environment Protection Authority and the Soil Conservation Authority, each contributing in the areas where they possess expertise.

This Committee, after having assessed the nature and extent of the problem of unsatisfactory disposal of septic tank effluent, has recently produced a number of recommendations in its first progress report. It has also agreed to publish an up-to-date set of State guidelines regarding criteria for acceptability of, and construction standards for, various on-site disposal methods, including procedures for certain soil tests. This is to combine the publications issued by various Government agencies, and is aimed at achieving a consistent approach at Government level, based as much as possible on the latest research findings.

The object of this article is to consider the results of research carried out on three existing effluent absorption fields.

The project was started in early 1978 and aimed primarily at studying the hydraulic aspects of effluent flow away from the absorption trenches into the surrounding soil. At the same time, the purification capacity of the soil with respect to phosphorus and nitrogen was investigated (Brouwer et al, 1979).

A second project, in close co-operation with the Environment Protection Authority, is concerned with quantitative modelling of non-discharging or sealed evapo-transpiration systems. It is too early to report any findings on the second project.

An article on the use, misuse and limitations of the percolation test is proposed for the future. It may also be appropriate to discuss the significance of Land Capability assessment for various land uses, specifically septic effluent disposal, in a third article.

DESCRIPTION OF EFFLUENT ABSORPTION SYSTEMS

Initially, three existing absorption fields were selected for monitoring, each representing a common and distinct soil type or soil type/slope combination, which occur in the greater metropolitan area of Melbourne. These fields disposed of toilet waste only. At a later date two more monitoring sites were included, but these results are not yet fully analysed. Each absorption trench system had been in use for a period varying from 3 to 8 years, but in the case of system I the trench was relocated during the data collection period because of house extensions.

Absorption system I is located at North Whittlesea, 50km north of Melbourne and has a rainfall of 900-950mm per year. It is covered by lawn and the terrain slope is 6-7%. The soil type at the site is duplex-like, with the following vertical sequence of layers: 0-0.10m grey brown silt loam topsoil; 0.10-0.17m lighter grey silt loam subsurface soil; 0.17-0.27m grey and yellowish silt loam; deeper than 0.27m, changing rather abruptly to a very yellow and progressively mottled silty clay to at least 2m depth (acid, hard, pedal mottled yellow duplex soil: Northcote et al, 1975). The new trench is 18m long, 0.9m wide and 0.4m deep, contains durable self supporting arching fibreglass drain along its full length, 10mm screenings backfill to the top of the drain, and top soil to ground surface. The household using the system consisted of a family with four children aged 6 years to 10 months when monitoring started. The wife and the three younger children were at home most days. The toilet flush volume was 2.6 litres. Daily flow into the trenches averaged 62 litres.

Absorption system II is located in Eltham, an outer suburb of Melbourne, with rainfall of about 750mm. The house was occupied by a family with three children, one of pre-school age. It was situated on a three-quarter acre block wooded with native trees and shrubs, and with a 20% slope. The soil is a yellow duplex soil comparable to the soil at system I, but much shallower. Soil depth is generally a little less than one metre to bedrock. There are three trenches in series, each 9m long and with a distance between them of about 3.5m. The top two contain clay agricultural drain pipes and are between 0.55 and 0.60m wide, while the third trench has arched fibreglass drain and is 0.75m wide. Effluent inflow from two toilets, one of which had a 10 litre flush, averaged 110 litres per day.

Absorption system III was constructed in a red, strongly structured and friable deep silty clay (red and brown rough-ped earths, Northcote et al, 1975) near Kinglake West, rainfall being about 1100mm. The site has a slope of 1-2% and is covered with native grass species. Slotted PVC pipe runs down the 18m long trench, which is 0.4m wide and 0.5m deep. The occupants of the house, a couple with a small child, were all away during the day. Effluent inflow averaged 40 litres per day. A luxuriant growth extended only half-way down the trench, indicating that the effluent did not reach any further. This was subsequently confirmed by monitoring of water levels in stand pipes.

WHAT DOES ONE WISH TO KNOW ABOUT AN ABSORPTION SYSTEM'S PERFORMANCE?

The failure of a septic effluent absorption system is generally defined as its inability to cope with the loading it receives, as evidenced by the effluent overflowing to the surface, causing soggy ground conditions, and unpleasant smells. This happens when the side walls and bottom of the trench, or the soil itself, transmit water too slowly to keep up with inflow from the septic tank. Failure can also be due to the opposite: too rapid infiltration, as may occur in coarse sands or in sands of uniform particle size. This can lead to off-site problems such as pollution of aquifers and nearby open waters as is being experienced in Perth (Whelan et al, 1979). Considering the "too rapid" case as needing no further explanation, it is appropriate to concentrate on the "too slow" case. Thus, the first question is "How fast does the effluent seep out of the absorption trench into the soil?" and secondly "In what direction mainly does the effluent flow?"

The flow of any liquid, eg water, through a porous medium, eg soil, is governed by the Darcy's Law ($v = -ki$), which states the rate of flow (v), is proportional to the gradient of hydraulic head (i). The hydraulic gradient between two points equals the difference in hydraulic head, divided by the distance between the two points. Water moves from a point with high hydraulic head to a point with lower hydraulic head. The proportionality coefficient (k), is often called *permeability*, although *hydraulic conductivity* is the correct term. Materials with different total porosities and pore size distributions usually have different conductivities. A coarse sand may have a hydraulic conductivity of 10m/day, while a compacted clay can have a conductivity which is a million times slower. If the hydraulic gradient is zero there will be no flow regardless of the magnitude of the permeability of the material. To find the rate of flow one must therefore determine both factors.

The hydraulic head of water in soils is the result of capillary forces exerted by the many small pores on water, and the force of gravity. The latter component is often of minor significance in an absorption field. Water in an unsaturated soil exists at a negative pressure, also called suction. The more unsaturated the soil, the higher the suction with which the remaining water is held in the pores. Soil dry enough to cause irreversible wilting of soft-leaved plants has a water suction of about 15 atmospheres; a mighty driving force if there is water nearby! Therefore, water will move spontaneously from the wetter parts of the soil to the drier parts, and movement will stop when equilibrium is achieved between all parts of the soil. The direction of flow is always in the direction of the gradient, hence always perpendicular to any plane of equal water suction (iso-potential planes). In saturated soil the water suction is zero, and if there were standing water on the soil surface, the water in the soil would be under a positive hydraulic pressure. The same processes are at work in a dry or moist sponge of which the fine pores and capillaries can absorb more water, even against the force of gravity, and in a saturated sponge, from which water is dripping.

The instrument to measure the magnitude of soil water suction is called a *tensiometer.* Those used in this research were small porous ceramic cups linked to a vessel with mercury by a narrow plastic tube. The cup and tube were filled with water, and the cup was buried at a selected position in the soil where the water suction was to be measured. Water can pass both ways through the porous ceramic cup. As the soil surrounding the cup dries out, water moves out of the cup into the soil, and the mercury is drawn upwards in the above-ground portion of the plastic tube (Fig 1). If the soil wets up,

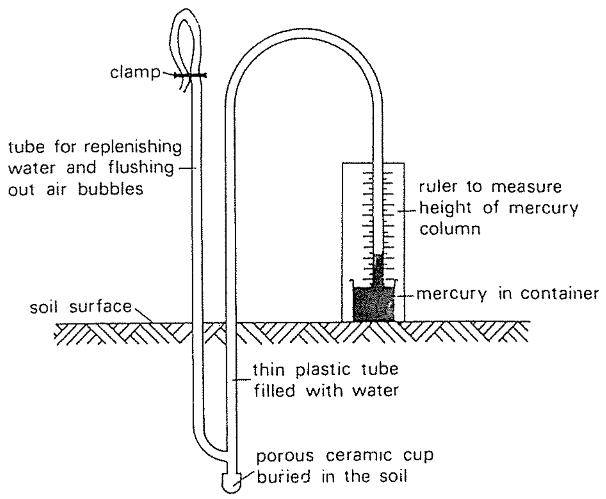

Fig 1. Tensiometer for measuring soil water suction.

water moves into the cup and the mercury falls. At equilibrium the water stops moving and the level of mercury is constant. Thus, at any time, the magnitude of soil water suction near the buried cup equals the height of the mercury column in the tube.

Knowing the soil water suction in a number of locations in a vertical plane at right angles to the absorption trench enables a plot of the direction of flow. This will show whether the effluent moves mainly through the side-walls, or through the bottom surface, or both; a topic on which there exist different strong opinions. Thus the answer to the second question is obtained first. At the same time, it indicates how close to saturation the soil in the vicinity of the trench is at any time, and thus how close the disposal field is to possible failure. The pattern of tensiometers (26 in number) positioned in a perpendicular plane is shown in Fig 2 for the North Whittlesea site.

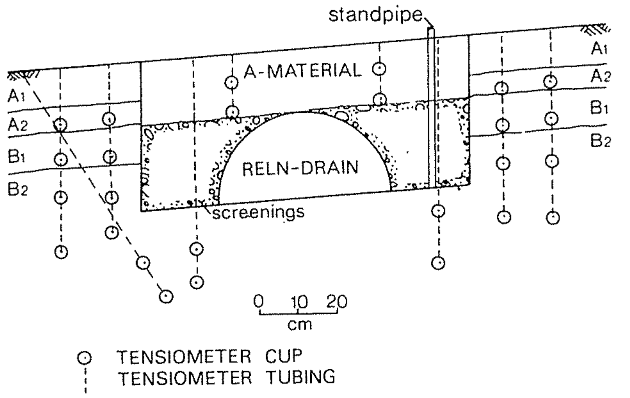

Fig 2. Pattern of tensiometer positions around an absorption trench at North Whittlesea.

Smaller sets of tensiometers were installed at the other disposal systems investigated. In Eltham (Fig 6)

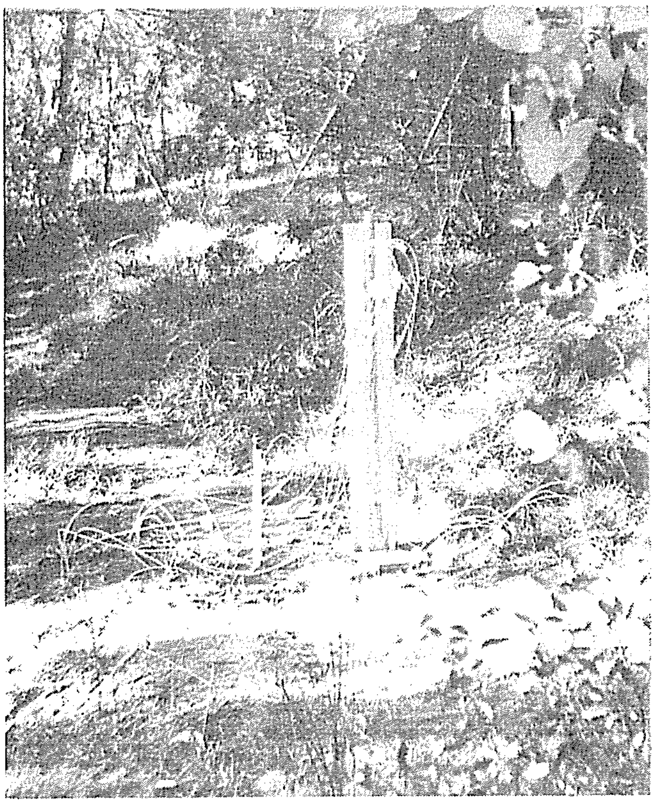

Fig 6. Absorption trench monitoring assembly at Eltham.

there was one set on each of the three trenches, and in Kinglake where there was only one trench, one set was positioned near the beginning and one set at the end of the trench.

Next, it was more convenient to determine the flow rate by an independent measurement of the input of waste water into the trenches, rather than by measuring permeabilities. This was done by installing a small electronic counting device on the toilet flush (septic systems treating only toilet waste!). Each was read daily. Because infiltration from rainfall over the disposal area obviously has an effect on the soil's ability to absorb effluent, the daily rainfall was also recorded on each site. Finally, as it is only the trench surfaces below the level of ponded effluent which are transmitting effluent, it was necessary to monitor the depth of ponding in the trench. The average total daily flow was then divided by the total transmitting surface area, resulting in an average daily flow rate per unit area.

The third question that could be asked concerns the distance that chemical pollutants and pathogens can travel through the soil; in other words, to what degree does the soil purify the effluent? Soil water samplers were used that can extract water from unsaturated soil through the application of a vacuum. The project only measures various forms of phosphorus and nitrogen in the soil water at 2m, 5m and 10m downslope from the trench. These were compared to levels of the same compounds in the effluent in the trench, which served as a control. Only a few of these chemical analyses were made. Nitrogen and phosphorus are essential plant nutrients, and small amounts of them can be expected to occur in every soil.

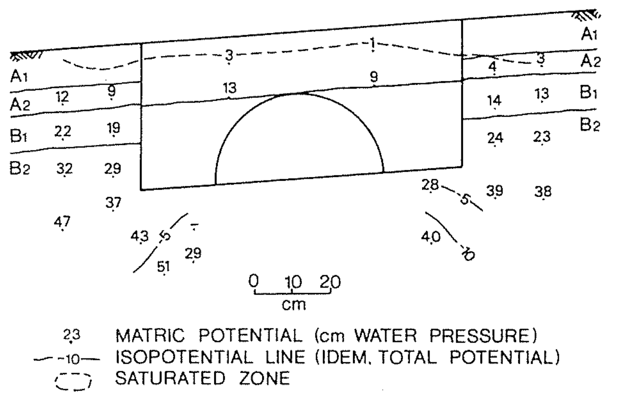

Fig 3. Isopotential lines at North Whittlesea on 19 November 1978, during a wet period.

RESULTS

North Whittlesea

The North Whittlesea disposal field was on the verge of failure during prolonged wet periods in winter, in that the water-table at times rose to within a few centimetres of the surface, shown in Fig 3. During a prolonged dry period the effluent in the trench was ponded to a depth of 0.15-0.20m (Fig 5), and appeared to flow mainly through the side-walls at an average rate of about 10mm/day. The intermediate case is shown in Fig 4. These figures also show the magnitude of soil water suction and isopotential lines. The effluent level in the trench rose markedly if more than 10mm of rain fell in the local area. It appeared that in dry periods all the effluent was transpired by the grass growing over the disposal field as the soil immediately surrounding the trench became quite dry. In wet periods when rainfall exceeds evapotranspiration, the effluent joints the general subsurface and downhill seepage of excess precipitation.

Nitrogen levels in all samples of soil water collected at 2m, 5m and 10m downslope from the trench, less than 1.5gm/litre, were well within standards set for domestic

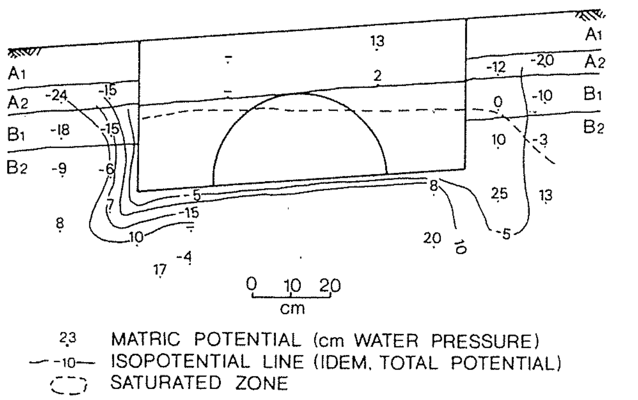

Fig 4. Isopotential lines at North Whittlesea on 24 November 1978, during a period of intermediate soil wetness.

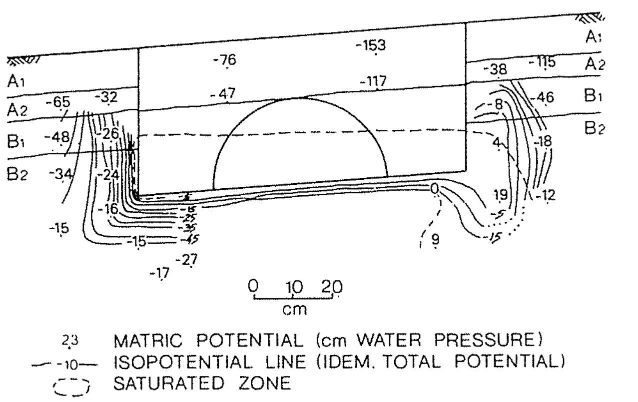

Fig 5. Isopotential lines at North Whittlesea on 29 November 1978, during a dry period.

water supply (Hart, 1974). With respect to total phosphorus levels this was also the case with 11 out of 14 measurements, while the three other measurements gave levels only slightly higher than the maximum permissible level (0.2mg/litre). These nutrient levels point to excellent purification of the effluent. However, some aquatic eco-systems could conceivably deteriorate if large volumes of this seepage water would reach them.

Eltham

In the Eltham absorption system the depth of effluent in the first trench was generally about 0.10m, in the second trench 0.07m, while effluent never appeared to reach the third trench. Tree roots were observed extending into the screenings in the trenches. Infiltration was apparently through the wetted sidewall at an average rate of 35mm/day. On the basis of measured nitrogen and phosphorus levels in the soil water at either 2m or 6m distance downslope of the second trench, it was not apparent that there was a septic system in the immediate area. All evidence points to the effluent as being fully contained on the site.

Kinglake West

In Kinglake West the seepage flow from the trench appeared to be straight down. All effluent disappeared somewhere between the two stand pipes at the beginning of, and at a point 5.5m down the trench. As a result, the exact wetted area could not be ascertained, so that no flow rate could be calculated. However, the flow rate would probably be in excess of Eltham's 35mm/day. Here nitrogen purification was not good, probably because the effluent was able to seep down rapidly, carrying the nitrogen beyond the depth of plant roots and hence beyond the depth of plant uptake. At 0.90m below the surface a nitrogen concentration of 54mg/litre was found. Phosphate retention by the soil on the other hand was very good, as could have been predicted from the properties of the soil. In agriculture it is a well-known fact that the red soils, such as Kinglake West, with their fine granular structure, and hence large exposed grain surface area, which is coated with iron oxides, have a great capacity to chemically bind phosphates.

DISCUSSION OF FINDINGS AND THEIR RELATION TO PRESENT DAY VICTORIAN SEPTIC TANK PRACTICE

It has been pointed out already that in North Whittlesea and Eltham the side walls of the trench appear to be the main effluent transmitting surfaces, while at Kinglake West the bottom surface was responsible for nearly all the flow. The obvious explanation was that where the soils were deep and very permeable in a vertical direction (Kinglake West) the flow would be mainly through the bottom of the trench; where the subsoil, or shallow bedrock, is slowly permeable the effluent will tend to flow sideways through the more permeable surficial soil layers.

In general, the limited data on phosphorus and also nitrogen show a seepage quality some one-tenth the concentration of the outflow of a well maintained sand filter. Most soil scientists would probably not be greatly surprised by the purifying capacity of a natural soil in conjunction with the vegetation and soil inhabiting microbes as compared with a sandfilter.

It is interesting to note that transpiration by the vegetation on absorption fields appears to play a significant role in effluent disposal. The soils at North Whittlesea and Eltham are comparable, but the former disposal field is under a lawn while the latter is covered by a native bush. The effluent transmission rate at Eltham was 3.5 times faster than at North Whitlesea, and even during the wettest weather it did not come close to failure. It is highly probable that the much higher transpiration rate of the native bush is mainly responsible for the difference in performance; however, lower rainfall and lack of seepage from upslope probably also made some difference.

In most septic tank manuals it is common practice to treat absorptions fields separately from transpiration beds. Given the reality of the nature of soil types common in Australia and the climatic regime of many parts of this country, the concept of either absorption or transpiration in isolation is questionable. In most systems both processes take place concurrently. The beneficial effect of evergreen vegetation, particularly shrubs and trees, on disposal rates is strongly indicated by this research. Transpiration by plants provides an extra driving force to move the effluent, helping to overcome the effect of the clogging layer in the trenches.

Judging from all this, only on deep permeable soils would it be permissible to halve the length required for conventional trenches by using arched fibreglass drains which employ trenches approximately twice as wide as conventional ones.

On other soils, it appears that this type of drain has no advantage over conventional agricultural pipe or slotted plastic pipe, except for the extra effluent storage capacity under the arched fibreglass.

One of the currently prescribed percolation tests (Environment Protection Authority Victoria, 1975) was carried out at North Whittlesea and Kinglake West, but it did not discriminate well between successful disposal and failure. At North Whittlesea all of 12 tests indicated that the soil was unsuitable for absorption of effluent, whereas it is a fact that the disposal system worked satisfactorily for most of the year. Four of these tests gave a zero percolation rate, and the others ranged from 2 to 14mm per hour, with the average for all tests being 3mm per hour. At Kinglake West 15 tests were carried out on a soil known to be highly suitable for absorption. The percolation rates ranged from 20mm per hour to 54mm per hour, with an average of 35mm per hour. In view of the fact that soil hydraulic conductivities can vary over several orders of magnitude, this average is only a little over the presently prescribed minimum permissible percolation rate of 25mm per hour.

If the findings arising from this work were to be translated into design recommendations, based on an all-waste septic tank, a town water supply and 1000 litres of waste water per day, and standard trenches (0.45m wide and deep) ponded with effluent to a depth of 0.2m, the North Whittlesea system would require 250m of trench, the Eltham system about 75m of trench, while in Kinglake West perhaps 50m would be adequate. It is quite encouraging that this corresponds well to sizing recommendations for five categories of soil in the exhaustive 1978 United States Environmental Protection Agency study (Kreissl, 1978). At $8-$12 per metre trench these differences are important with up to a five-fold increase in costs. In the US a slower loading rate than 10mm/day (like North Whittlesea) is considered impractical for trench disposal because of the length of trench required: more than 250m. No doubt Australians would find a trench length requirement of more than 250m equally unacceptable.

In the light of the present work it would seem that the most common causes of absorption field failure are:

1. Underdesign, synonymous with overloading, causing the effluent to fill the whole trench for long periods and finally to emerge at the surface;

2. careless installation, causing poor infiltration through smeared, compacted trench walls or localised concentration of effluent due to uneven grades;

3. lack of maintenance of septic tanks causing sludge to enter the trenches and reduce the permeability of the trench wall and bottom surfaces.

Whilst none of the current SCA-sponsored research projects is attempting to monitor the possible spread of pathogens, it is useful to note that some American research work indicated ten to one hundredfold reductions in bacteria counts for every 50mm travel through the soil (Brown et al, 1979) *so long as the soil is not in a saturated condition.* (Our italics!) Hence, the importance of proper sizing of disposal fields. Another study reported that only 30cm away from the trench, bacterial levels were back to normal for the soil (Ziebell et al, 1975). Similar trends apply to viruses.

It is clear that more comprehensive assessments and characterisations of soils and sites than is common practice are needed to decide on the right type of disposal system, and on the proper design, to achieve the aim of environmental protection.

Given continued progress in understanding our soils and our environment, the septic tank, combined with the appropriate on-site disposal system, on suitable soils, could well gain the respectability which it deserves.

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The Hydrology of on-site Septic Tank Effluent Disposal on a Yellow Duplex Soil

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SUMMARY A trench system for on-site disposal of septic tank effluent, situated on a yellow duplex soil was monitored for several months. Observations were made on various factors affecting the pattern of flow of the effluent through the soil, and on the change in quality of the effluent while it passed through the soil. The effluent disperses mainly through interflow during wet periods and through evapotranspiration during dry periods. Purification by the soil with respect to nitrogen and phosphorus is considerable and apparently adequate. Comparison is made with two other systems also monitored, one on a similar soil and one on a krasnozem.

1 INTRODUCTION

A recent survey carried out by the authors among the health inspectors of the municipalities in the outer suburbs of Melbourne showed that of the roughly 140,000 unsewered occupied lots by far the greatest number have a septic tank as a part of their wastewater treatment system.

The smaller lots, up to about 0.2 ha, usually have a septic tank for toilet waste only, followed by effluent absorption trenches or sandfilters. The absorption trenches and the soil surrounding them treat and dispose of the septic tank effluent. Sandfilters produce a higher quality effluent which goes into the municipal drains and from there into the streams. The sullage water, i.e. the wastewater from kitchen, bath, laundry, etc. on small lots usually passes through a grease trap before going into the municipal drains.

On the larger lots, about 0.4 ha or more, 2 systems are used; all the wastewater tends to be treated in an all-waste septic tank and then discharged into absorption trenches; or the sullage water is kept separate, passes only through a grease trap, but is required to be contained within the boundaries of the property.

The problems associated with these practices have been shown to be considerable, and are mostly related to nitrogen, phosphorus, and/or micro-organisms still being present when the effluent joins ground or surface water; nitrogen and phosphorus can cause algal bloom and associated problems while microorganisms may be pathogenic (Bouma et al, 1972). Sandfilter effluent is also far from being completely purified when it enters drains or streams. According to work carried out by the Department of Health of Victoria (1976) effluent from small sandfilters still contains a mean of 16 $mg\ell^{-1}$ suspended solids, 14 $mg\ell^{-1}$ BOD_5 (Biological Oxygen Demand in 5 days), 130 $mg\ell^{-1}$ nitrogen mostly in ammonia form, and 15 $mg\ell^{-1}$ total phosphorus measured as PO_4. Sullage water presents a greater problem, from figures given by Laak in Winneberger (1974) it can be calculated that sullage water in the USA has an average content of about 290 $mg\ell^{-1}$ BOD_5, 165 $mg\ell^{-1}$ nitrogen and 25 $mg\ell^{-1}$ phosphorus. Septic tank effluent although reasonably clean by some standards when led into absorption trenches can cause problems with absorption and further purification when the capacity of the soil *in situ* is incorrectly estimated before or inadvertently altered during construction of the trenches.

This paper is concerned with the estimation of the absorption and purification capacities of the soil. The Soil Conservation Authority of Victoria is attempting to adapt the US Department of Agriculture land capability rating system for septic tank effluent absorption systems to Victorian conditions. It is hoped that this will provide a guide for determining the size of the systems under different circumstances and a sound basis for planning decisions in this respect to prevent pollution from on-site wastewater disposal systems to be constructed in the future. Existing problems may be alleviated when the results of this project are known and by the extension of sewerage lines as mentioned by the Melbourne and Metropolitan Board of Works (1979) which is intended to reduce those 140,000 unsewered occupied lots by 90,000 in the mid 1980's.

To properly assess the capability of certain land types for on-site wastewater treatment and disposal several effluent absorption systems were monitored while in operation. The monitoring covered the quality and quantity of flow into the systems from the household including the effect of precipitation and the flow out of the system into the environment. This paper presents results from one site monitored in detail and compares them with results from other sites.

2 NOTATION

h = pressure or matric potential of soil water, expressed on a volume basis in

$$J.m^{-3} = N.m^{-2}$$

z = gravitational potential of soilwater relative to an arbitrary horizontal plane, also in

$$J.m^{-3} = N.m^{-2}$$

H = hydraulic potential of soil water, here equalling h + z, in $N.m^{-2}$

v = flux, the volume of water crossing a unit area per unit time, in

$$m^{-3}.m^{-2}.s^{-1} = m.s^{-1}$$

$\frac{dH}{dx}$ = hydraulic gradient

3 MATERIALS AND METHODS

3.1 Site Description

The septic tank-absorption trench system on which these observations were made was located at North Whittlesea, 50km north of Melbourne. Rainfall is estimated to average 900-950mm per year.

The household in question consists of a family with 4 children aged 6 yrs to 10 months. The wife and 3 children are at home most days, indicating that the septic tank system probably received a larger than average hydraulic load. A counter was installed on the toilet flush of volume 2.6ℓ and read daily to estimate the effluent flow into the trench. Sullage water was not taken through the septic tank.

The trench was sited under the front lawn at the start of observations. At a later date due to house extensions the trench was relocated. Observations on the new trench started immediately after installation November 1, 1978. The new trench was 18m long, 90cm wide, 40cm deep and was laid along the contour on the 6-7% slope. Reln drain was put in along its full length. Reln drain consists of corrugated fibreglass lengths forming a halfdome 50cm wide and at most 25cm high. The trench was filled with 10mm screenings (porosity when packed 50%) level with the top of the Reln drain and then with the previously excavated A horizon material up to surface level. Grass re-established itself on top of the trench in a matter of weeks.

The soil *in situ* when wet had a grey brown A_1 horizon 0-10cm and slightly lighter A_2 horizon 10-17cm changing with a clear boundary into the B_1 horizon which graded into a very yellow B_2 horizon which extended from 27cm down, a typical duplex soil. The excavation for the new septic tank showed that there was mottled clay below about 1m extending to at least 2m, at which depth there was no sign of the groundwater table. Soil was taken at 8 and 30cm and analysed for texture, pH, nitrogen, available phosphorus, organic carbon, total cation exchange capacity and the base saturation. These results are presented in Table 1. Baldwin (1950) indicates the soil is a Hallam loam and Northcote et al. (1975) an acid, hard, pedal mottled yellow duplex soil, a very common soil in the Eastern suburbs of Melbourne. For both classifications it is a rather silty example.

3.2 Monitoring of the flow pattern

Flow of liquid through the soil, irrespective of the state of saturation, has been found to be governed by Darcy's law,

$$v = -k \frac{dH}{dx}$$

which expresses that the volume flux is proportional to the gradient of hydraulic potential in the direction of the flux. k is by definition equal to the flux when dH/dx = 1.

Horizon	A_1	B_1	Above Trench
Depth (cm)	5-10	25-30	
Texture (CSIRO)	Silty Loam	Silty Loam	Silty Loam
% G(>2mm)	0	0	0
C.S.%	<1$^+$	1	<1$^+$
F.S	37	34	34
Si.	41	44	42
C.	11	14	15
Σ	89	93	91
pH (1:5)	4.7	4.8	4.4
ORG. C%	2.88	1.12	1.59
N%	0.18	0.060	0.099
P(AV.) ppm	22	17	23
C.E.C.	21.3	13.6	16.7
BASE SAT.%	5	2	3

$^+$ H_2O_2 pretreated to destroy organic matter

Table 1: Soil Analyses North Whittlesea. For methods of soil analysis see Nicholson (1978)

To monitor the flow pattern of effluent from the trenches into the soil 26 tensiometers were placed in a plane perpendicular to the trench in positions as shown in Fig.1, 3m from one end of the trench. Given the length of the trench and the assumed homogeneity of the surroundings, flow was assumed to be two dimensional. The tensiometers were small ceramic cups 28mm long and 6.5mm O.D., glued onto 10cm of hard perspex tubing out of which two plastic tubes led to the surface; one into a container of mercury to measure the soil water matric potential around the ceramic cup, and the other a filler tube to be used when flushing the system of air bubbles. This was done as necessary. A 2.5cm O.D. pipe, perforated at the bottom end was installed to monitor the level of ponding of effluent in the trench. Rainfall was measured to give some indication of the amount affecting the flow pattern around the trench, both through vertical infiltration and through seepage. Observations were made daily during November and 3 or 4 times per week during December.

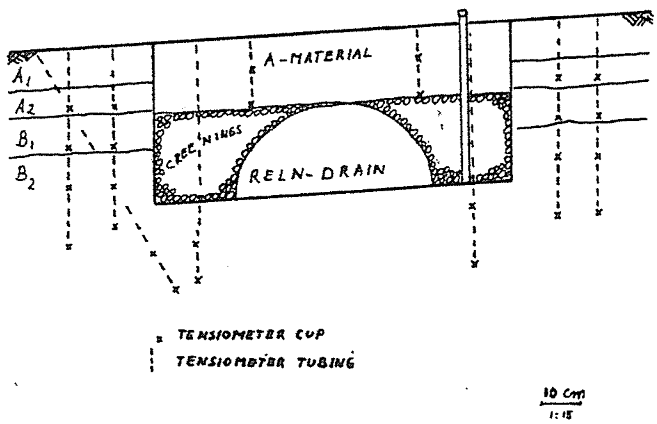

Fig.1 : Tensiometer positions at North Whittlesea

For each day the observations were assembled into a diagram showing the isopotential lines around the trench. Potential was expressed in cm of water pressure, the accuracy being ± 3cm. Gravitational potential was taken to be zero at the level of ponding in the trench. The flow lines perpendicular to the isopotential lines, can be estimated from the relative hydraulic conductivities of the various soil horizons at different degrees of saturation. From the flow lines it can be determined in which cases flow from the trench is mainly through the sidewalls and in which cases it is mainly through the bottom. Sizing guidelines can be set up accordingly. The United States Publ. Health Service (1967) advocates sizing on bottom area, The Environment Protection Authority of Victoria (1975) sizing on side wall area.

3.3 Monitoring of the water quality

To monitor the quality of the effluent after it had passed through varying lengths of soil, soil water samplers as described by Wagner (1962), capable of extracting water from the unsaturated zone were installed. These samples are not always regarded as representative of the area being studied but the sample analysis does give an indication of the trends. Two samplers were installed, one in the B_2 horizon at 33-40cm, one in the A_2 horizon at 15-20cm at 2,5, and 10m down slope of the trench, and also 6m to the side of and up slope from the trench. This latter one served as a control. Samples were collected after the vacuum had been applied for 24 hours and were also taken from the trench itself, through the pipes put in to monitor the level of ponding. Samples were quick frozen with dry ice, and analysed for total kjeldahl nitrogen (TKN), nitrate and nitrite (copper-cadmium reduction, diazotisation, colorimetric), total phosphorus (digestion, colorimetric) and orthophosphate (colorimetric) (Environment Protection Authority of Victoria, 1976). Samples were taken on a number of days after two periods of medium to high rainfall (20mm in 48 hours and 83mm in 24 hours respectively). Analyses could not be done in 24 hours so ammonia concentration was not determined, and while the importance of microbiological pollution is recognised actual tests were beyond the scope of this project. Some analyses, but none of those for TKN may have been affected by thawing and refreezing the sample. The two sets of data show the same trends and the latter set is discussed in detail.

4 RESULTS AND DISCUSSION

4.1 Flow Pattern Around the Trench

4.1.1 North Whittlesea

Daily rainfall data from the period of observations are presented in Fig.2, together with the level of ponding in the trench. The flush counter showed that for the first five weeks, until a blockage of the septic tank in the beginning of December, the flow of effluent into the trench averaged 44ℓ day^{-1} computed from a weekly total. To prevent further blockage the toilet was flushed an extra number of times a day and flow increased to 62ℓ day^{-1}. Small daily fluctuations in effluent inflow did not seem to have any effect on the level of ponding in the trench, but the general increase from 44 to 62ℓ day^{-1} did. During a prolonged dry period in late November ponding was relatively constant at about 13cm on the high side of the trench, 18cm on the low side, while it hovered around 18 and 23cm respectively during a similar period in early January. As ponding and inflow were relatively constant it can be assumed that in each case a state of equilibrium had been reached. Considering the ratio of daily inflow volume, during these two periods was 44:62ℓ or 0.71, and the ratio of wetted sidewall areas was (13+18) : (18+23) cm or 0.75 would indicate that flow was by and large through the sidewalls, at a rate of about 10mm day^{-1}. The formation of the clogging layer of settled solids and bacterial slime on the bottom and sidewalls of the trench makes this conclusion somewhat less straightforward. This layer inhibits infiltration into the soil and usually takes about 6 months to fully develop and reach a state of equilibrium (McGauhey and Krone, 1967). In soils with a low hydraulic conductivity however the clogging layer does not really affect the infiltration rate, and this may be the case here.

The level of ponding in the trench reacts to a local rainfall of 10mm or more. Under these conditions effluent couldn't flow from the trench as easily and infiltrating rainwater and seepage were added to the effluent. This is clearly illustrated in the isopotential pattern of Fig.3 (wet conditions) when compared with Figs. 4 and 5 (intermediate and dry conditions respectively).

Fig.3 shows the situation immediately after 83mm of rainfall in 24 hours when all but the very top of the profile was saturated. The B_2 horizon impeded inflow and the top of the B_2 and the lower part of horizons above became saturated forming a perched water table (Northcote et al., 1975). A perched water table would normally be parallel to the impeding horizon, and in this situation, the presence of the effluent filled trench, it is more or less horizontal. The slight rise in the water table at the left of Fig.2 is probably caused by runoff from mounds of soil left from the trench excavation, which were not removed till later. The bottom of the trench apparently impedes infiltration for the isopotential lines indicate that flow takes place from the side of trench to underneath it. This is further illustrated in Figs.4 and 5.

In Fig. 4, the drying situation, effluent flows relatively freely through the sidewall on the low side of the trench, and then away on top of the B_2 horizon. The B_1 horizon is still fairly saturated and has a relatively high hydraulic conductivity. On the high side the trench itself blocks the flow of effluent downslope over the B_2 horizon and the effluent is forced to flow down into the B_2 horizon, forming a bulb of saturation, partly intruding underneath the trench.

This bulb is more obvious in Fig.5, the dry situation. The saturated zone caused by the rain has disappeared. There is little saturation on the low side and underneath the trench, but the bulb on the high side is still considerable. Apparently flow is mainly through the sidewalls, dispersing freely on the low side, and accumulating to a certain extent on the high side. Flow through the bottom in theory should only go down, similar to the flow through the sidewall on the high side. Thus a saturated zone should occur below the trench but was not found. The conclusion reached is that flow through the bottom is much less than through the side walls.

In summary, design of a trench system in a situation such as this should be based on a rate of flow of about 10mm day^{-1} through the wetted sidewall area. Saturation is found to occur near the surface after heavy rainstorms. During these wet periods most of

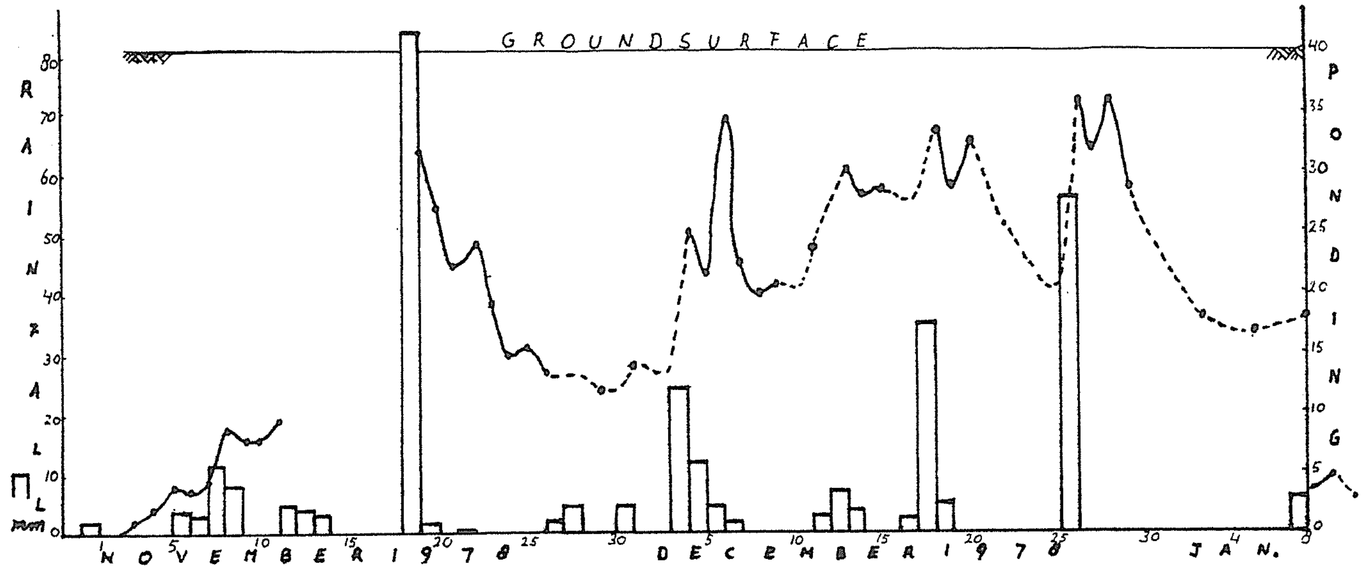

Fig.2 : 24 hour rainfall and level of ponding in the trench at North Whittlesea.

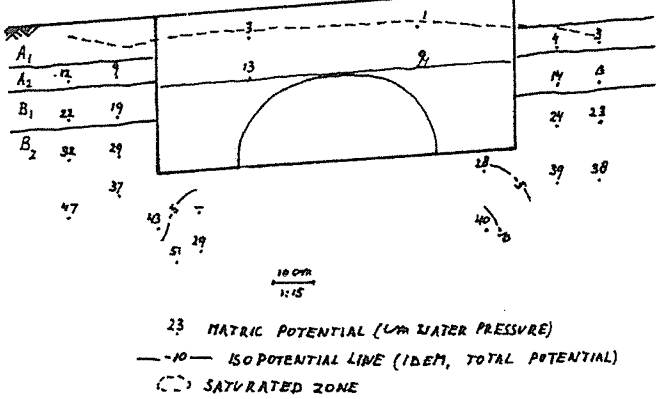

Fig.3 : Isopotential lines North Whittlesea
19 November 1978 (wet)

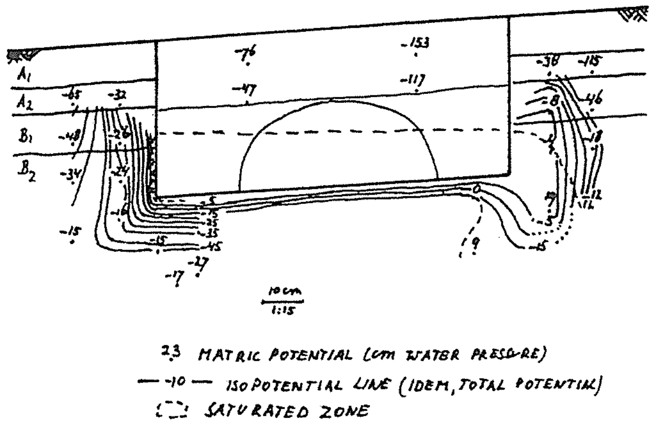

Fig.5 : Isopotential lines North Whittlesea
29 November 1978 (dry)

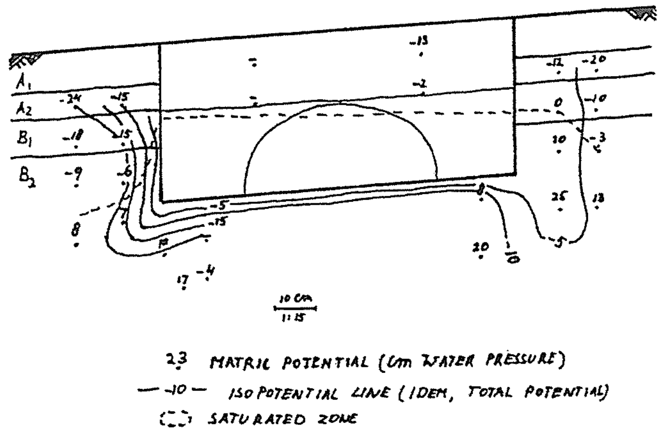

Fig.4 : Isopotential lines North Whittlesea
24 November 1978 (intermediate)

the effluent seems to join the interflow of which it forms a small part. During dry periods all the effluent is apparently transpired *in situ*. More data have to be analysed to confirm the above.

4.1.2 Two other systems

Observations were also done of a system in a shallower yellow duplex soil, less than a meter to bedrock, which according to Baldwin (1950) is the shaley phase of a Hallam loam. The site was wooded, with a slope of 20%. Rainfall averaged about 750mm year^{-1}. There were three 9m lengths of trench, one below the other with about 3.5m between them, connected in series so that when ponding rose to about 10 or 11cm in one trench the effluent would start flowing to the next lower one. The top two trenches had clay agricultural drain pipes, and were consequently only 55-60cm wide while the third trench had Reln drain. During the period of the experiment effluent never reached the third trench. The level of ponding in the first trench was mostly about 10cm, in the second trench about 7cm. Effluent inflow was from the toilet only and averaged 110ℓ day^{-1}. Infiltration rates of about 35mm day^{-1} through the wetted sidewall area were calculated in this case. This high rate compared to the infiltration rate in North Whittlesea must be due to the trees and bushes which greatly enhance evapotranspiration; while the steep slope reduces rainfall infiltration.

A third system was on a red, structured and friable silty clay loam commonly referred to as a krasnozem soil. The site had a slope of 1-2% and was covered with native grass species. Rainfall was about 1100mm year^{-1}. The trench was 18m long and slotted PVC pipe used, it was 40cm wide and 50cm deep. Septic tank effluent came only from the toilet. Ponding was mostly around 2cm, reaching 5 after 25mm of rain in 24 hours. Judging by the growth of the untended grass, effluent never reached further than about halfway down the length of the trench, which was confirmed through an observation pipe installed there. Flow from the trench appeared to be straight down. As the exact wetted area is not known the infiltration rate can not be calculated, but the system was obviously grossly oversized for its average effluent inflow of 40ℓ day^{-1}.

4.2 Soil Water Quality Around The Trench

4.2.1 North Whittlesea

The results of soil water sample analyses are presented in Table 2. The volume of sample obtained on a number of occassions was small therefore the total number of determinations is limited.

The concentrations for all parameters were reduced drastically by travel of the effluent through the soil. In fact, the concentrations found downslope of the trench were mostly smaller than the ones found at the control point (6m to the side and upslope from the trench). The nitrogen concentrations in the A_2 horizon at 5m from the trench form an exception. For some unknown reason they were roughly the same as the control values. It is suggested that these decreases may be due to increased microbial activity due to the presence of effluent, which more than compensates for the increased concentrations caused by the effluent.

Total nitrogen levels were, at all points, higher in the A_2 horizon than in the B_2 horizon by a factor of 1.5 to 3.5. The concentrations tended to increase somewhat with distance from the trench, but at the various points showed only a possible slight decrease with time. Trench levels varied between 28 and 66ppm, control and downslope levels both varied between 0.3 and 1.4ppm.

Nitrite values outside the trench were negligible, with only two values (at 5m in the A_2) of more than 0.005ppm : 0.017 and 0.008ppm. Nitrate values varied between 0.002 and 0.07ppm. The percentage of total nitrogen in nitrate or nitrite form was about 0.4 in the trench. Outside the trench it was still about 4% on the day after the rain, but when anaerobic conditions started to have their effect it dropped to an average of 0.7%.

According to Hart (1974) nitrate levels of 10ppm are permissible in water for domestic supply. Total nitrogen levels determined in the soil never reached 1.5ppm, so there should be no problem here, even if the effluent did reach the groundwater. Ammonia levels should preferably not exceed 0.1ppm, at most 0.5ppm when the water is heavily treated before use. If all the nitrogen not oxidised is in ammonia form or is converted to that, levels could easily reach 1ppm at 10m from the trench under some circumstances. Much, therefore, depends on the aerobicity of the soilwater, particularly during very wet periods. An added problem during such periods can be that the effluent rises to the surface and flows overland before it undergoes purification and is only diluted by soilwater and rainwater. From Fig.2 it can be seen that this is a real possibility and when overland flow occurs samples will have to be taken to assess this danger.

The situation for phosphorus was similar, trench levels of total phosphorus were 6.5-6.9ppm measured as P, soilwater levels were never more than 0.26ppm downslope 0.62 control. Orthophosphate concentrations were no more than 2.3ppm in the trench while it was 0.03ppm downslope and 0.04ppm. at the control. In Hart (1974) a maximum of 0.2ppm as P is recommended for raw water intended for domestic supply. In the downslope samples this level was found in only 3 out of 14 samples and those three cases are quite likely to be due to the local soil and vegetation rather than the presence of an effluent absorption trench. As with nitrogen there is a possibility that during wet conditions phosphates enter the surface run off, the damage of which has to be assessed.

4.2.2 Two other systems

Total nitrogen levels in the trench on the shaley Hallam loam varied between 363 and 623ppm in the first trench, and a greatly reduced 105 and 144ppm in the second trench. After 70mm of rain in 24 hours total nitrogen levels varied between 0.7 and 2.3ppm 2m downslope of the second trench, and between 0.5 and 1.0ppm 6m downslope of the third trench. This is the trench in which effluent was never found. The latter sampling points later proved to be on the former site of a vegetable plot but can still serve as a kind of reference. After 7 and 15mm of rain on two consecutive days levels were much higher generally and varied between 3.1 and 10.9ppm (with one exception of 0.27ppm) at 2m and 0.9 and 10.2ppm at the control. Nitrogen levels of the soilwater apparently were not influenced by the presence of effluent absorption trenches.

The situation for phosphorus was similar; total phosphorus levels varied between 31.5 and 33.8ppm in the first trench, 18.1 and 21.1ppm in the second trench, 0.05 and 0.51ppm at 2m, 0.30 and 0.69ppm at the control. Everything points to the effluent being contained on site.

On the friable red earth the situation was very different. Levels of between 430 and 573ppm total nitrogen in the trench decreased to still high values of 44.3 to 56.1ppm 10cm below and just to the side of the trench while values of 40.7 to 54.2ppm occurred 40cm below the trench after 85mm of rain in 24 hours. At 2m downslope of the trench the level did not rise above 0.52ppm and at 5m not above 0.24ppm. After 6.5 and 25mm of rain on two consecutive days levels were between 56.8 and 88.8 ppm 10cm below the trench, 47.4 and 69.0ppm 40cm below, 0.4 and 1.6ppm 2m away and 0.3 and 1.8ppm 5m away. Clearly effluent flow is downwards and the rain dilutes the soilwater rather than aggravates the effect of the effluent. Nitrogen purification was not very good and the hazard of groundwater pollution with nitrogen is probably quite real.

Retention of phosphorus by the friable red earth was better. Levels between 31.8 and 33.3ppm total phosphorus in the trench dropped to between 0.01 and 0.73ppm 10cm below the trench and between 0.03 and 0.16 40cm below, after the heavy rainfall. At 2m levels varied between 0.000 and 0.03ppm, at 5m between 0.000 and 0.35ppm. After the lighter rainfall levels varied between 0.000 and 0.58ppm 10cm below the trench, were undetectable at 40cm below, and varied between 0.05 and 0.82ppm at 2m, and between 0.000 and 0.47ppm at 5m. Phosphate pollution of the groundwater seems most unlikely.

4.3 General Conclusions and Recommendations

Evidence indicates that it is worth while adapting septic tank effluent absorption trenches to the general circumstances *in situ*, in order to limit pollution of the environment. On two different yellow duplex soils chances of pollution appeared very small, and the effluent contributed little or

Date of Sampling	Depth of Sampling (cm)	POSITION OF SAMPLER RELATIVE TO TRENCH														
		CONTROL			TRENCH			2m DOWNSLOPE			5m DOWNSLOPE			10m DOWNSLOPE		
		TKN	NO_2	NO_3	TKN	NO_2	NO_3	TKN	NO_2	NO_3	TKN	NO_2	NO_3	TKN	NO_2	NO_3
20 Nov'78	15-20	1.4	0	0.07	30.6	0.011	0.12	0.7	0	.03	1.1	0.002		1.0	0	0.02
	35-40		0.003	0.04				0.5	0	.02	0.6	0	0.02	0.7	0	0.05
21 Nov'78	15-20	1.1	0	0	28.2	0.36	0.30	0.6	0	0.001	1.4	0.008	0.02	0.6	0	0.01
	35-40	0.5						0.4	0	0.003	0.5			0.4	0	0.01
22 Nov'78	15-20	1.1	0.001		36.8	0.14	0.21	0.6	0	0.001	1.4	0.017	0.01	0.9	0	0.002
	35-40	0.4	0.002					0.4	0	.01	0.3			0.5		
24 Nov'78	15-20	1.1	0.005	0.01	66.0	0	0.07	0.7	0.002	0.003				0.8	0	0.01
	35-40	0.3						0.5	0		0.3			0.4		

Date of Sampling	Depth of Sampling (cm)	POSITION OF SAMPLER RELATIVE TO TRENCH									
		CONTROL		TRENCH		2m DOWNSLOPE		5m DOWNSLOPE		10m DOWNSLOPE	
		TOTAL P	ORTHO P	TOTAL P	ORTHO P	TOTAL P	ORTHO P	TOTAL P	ORTHO P	TOTAL P	ORTHO P
20 Nov'78	15-20			6.9	2.3		0.02				0.01
	35-40	0.03	.04				0.02		0.02		0.01
21 Nov'78	15-20	0.16	.03	6.5	1.0	0.04	0.02	0.07	0.01	0.18	0.01
	35-40	0.62	.02			0.14			0.01		
22 Nov'78	15-20	0.34	.02			0.26	0.01	0.25	0.00	0.03	0.03
	35-40								0.01	0.11	0.05
24 Nov'78	15-20						0.01			0.26	0.01
	35-40					0.03	0.01		0.01	0.20	0.03

Blank space indicates sample not analysed

Table 2 : Chemical Analysis of Soilwater at North Whittlesea

nothing to the groundwater, interflow, or surface flow. On a friable red earth effluent proved to percolate mostly down through the soil, while purification of the effluent in regard to nitrogen was insufficient. Chances of groundwater pollution in such a situation appeared real. To minimise future problems more research will have to be undertaken to evaluate these findings and assess the situation in other frequently occurring circumstances.

5 ACKNOWLEDGEMENTS

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SEPTIC TANK EFFLUENT ABSORPTION SYSTEMS
NEAR MELBOURNE, VICTORIA:
LAND CAPABILITY AND DESIGN

by

Joost Brouwer B.Agr.Sc. (Wageningen)

A Thesis
submitted for the degree of
Doctor of Philosophy
in the
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La Trobe University

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On-Site Treatment and Disposal of Household Wastewater with particular reference to Sealed Evapotranspiration Systems.

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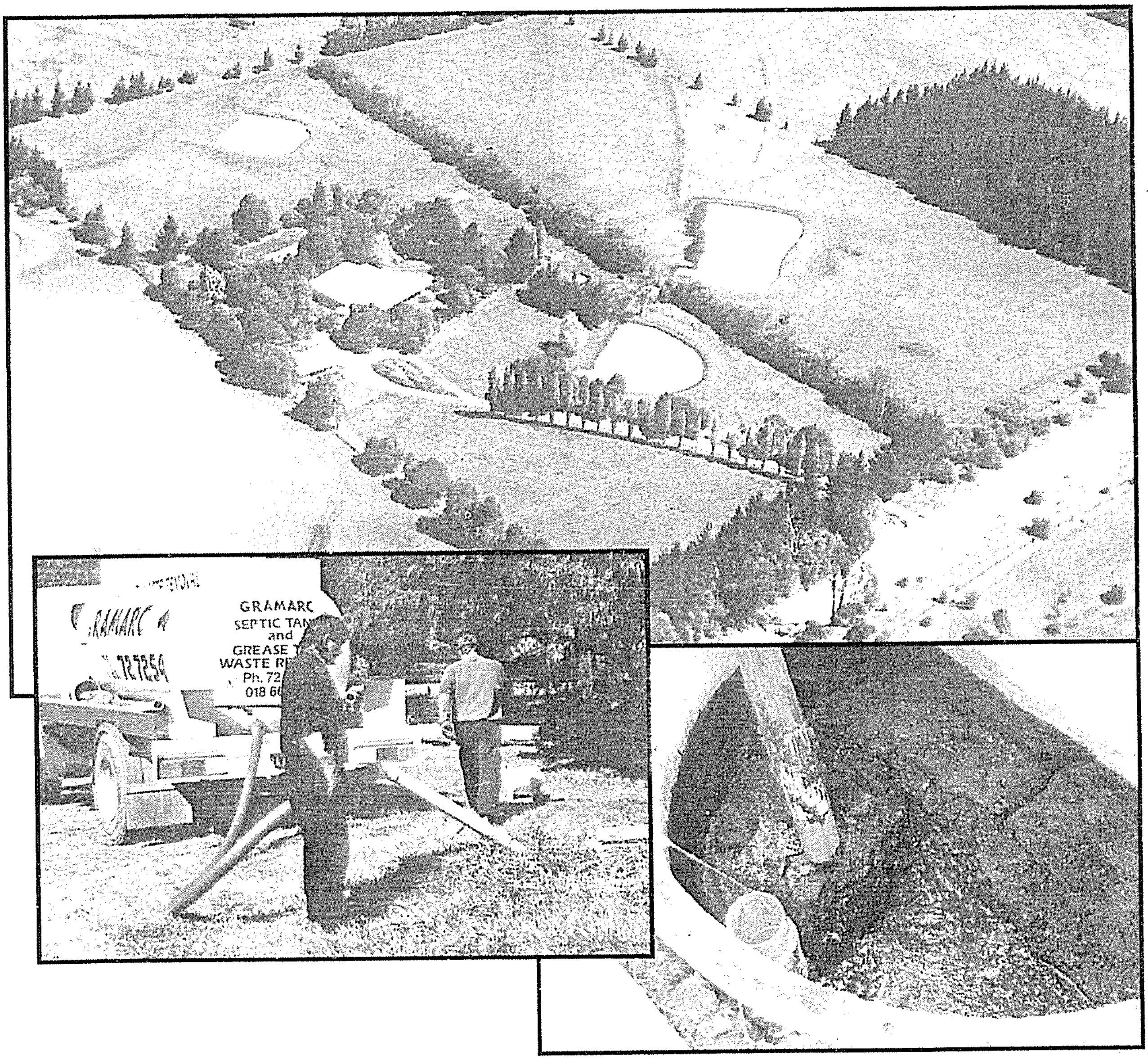

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THE WIZARD OF ID

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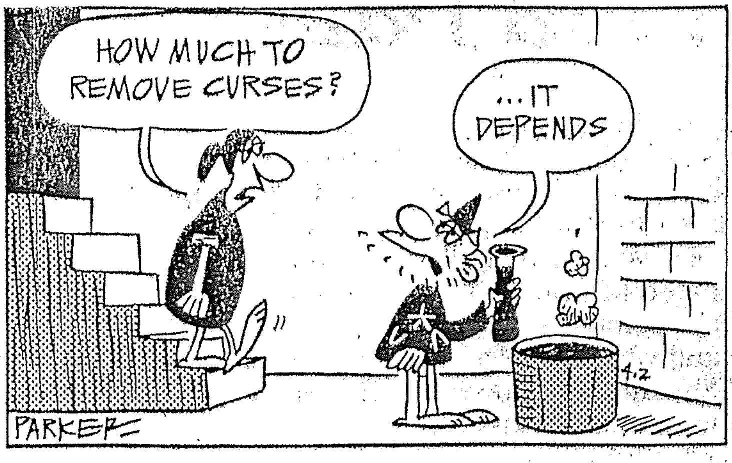

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