SAND MOUNDS FOR EFFECTIVE DOMESTIC EFFLUENT MANAGEMENT

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Abstract

Sand mounds can offer a suitable treatment and land application option for constrained sites, particularly those where separation distance to the water table is limited. Sand mound technologies, commonly called "Wisconsin Mounds", have been extensively developed and utilised in the United States and a number of studies report on their performance. There is growing interest in the application of sand mounds in Australia, but to date little has been published on the performance of such mounds in Australian settings.

As failing septic tanks had been contributory to viral pollution of oysters grown in an estuary, Port Stephens Council required upgrades. One option was to replace the adsorption field by a sand mound and currently 58 mounds are receiving primary treated effluent and nine receiving secondary treated effluent in Port Stephens. This paper reports results where two of the mound systems were monitored in detail for a period of six months from mid-2007 using a variety of soil water samplers and groundwater bores.

Figure 1. Wisconsin mound – Wisconsin.

Introduction

Various water quality investigations in the Tilligerry Creek catchment (30 kilometres north of Newcastle, NSW) have, over the years, characterised the often poor quality of estuary waters with the contamination being attributed to a variety of sources including urban runoff, agricultural wastes and failing on-site wastewater systems. Work characterising the sources of faecal material in estuary waters by Geary and Davies (2003) concluded that "while no single source emerged as the most significant contributor of faecal contamination to either the oyster leases or to Tilligerry Creek, cattle, human and chicken faeces were all found to be contributing to faecal contamination of the drains and estuary".

During 2005 human viruses were found in oyster tissue in part of the estuary and the harvesting of oysters from commercial leases was prohibited by the NSW Food Authority. As a consequence, a number of oyster farms closed. At most unsewered residences near the estuary, wastewater is treated in a standard septic tank and then dispersed subsurface using a small soil absorption system. Given the high water table and sandy soils in the area, there are times when the base of each trench is in contact with the groundwater. The groundwater is intercepted in a number of shallow drains and enters the nearby estuary. For this reason domestic wastewater systems were considered to be the primary source of the human faecal contamination within the estuary.

The local regulatory authority (Port Stephens Council) embarked on an estuary remediation program to improve the quality of runoff waters from the various land use activities within the Tilligerry Creek catchment. In addition to detailed inspections of on–site systems and identification of those that posed a risk to public health or the environment, an investigation was also undertaken to examine the contributions that unsewered development was making to both surface runoff and groundwater in the area (Lucas *et al*., 2007). While this recently completed study used a variety of chemical and microbiological indicators and concluded that human sourced contaminant transport to the estuary from unsewered development was likely to be minor, there were no other identifiable sources of human faecal contamination other than on-site wastewater systems.

As part of the estuary remediation program, a number of sewerage

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Protecting a sensitive oyster lease catchment.

(reticulated and decentralised) options for wastewater on individual properties in the Tilligerry Creek area were considered. One of these on-site options to overcome the land capability constraints of the area was to construct sand (Wisconsin) mound systems. Council commissioned best practice standard designs (Whitehead & Associates, 2005) for two land application options to address the high water tables experienced at the sites: a) secondary treatment with pressure compensating drip irrigation to raised beds and b) primary or secondary treatment followed by Wisconsin mounds.

Upgrades of existing on-site systems were required but in recognition of the cost to individual homeowners for site specific designs, Port Stephens Council has made the standard designs available to homeowners to reduce the overall cost of the necessary system upgrades (Port Stephens Council, 2005).

Mounds as an On-Site Wastewater Management Option

Mound systems were originally developed in North Dakota, USA in the late 1940s and known as NODAK disposal systems (Witz, 1974). Modifications of the NODAK system by researchers at the University of Wisconsin – Madison in the early 1970s led to the mound design most commonly used today and these are most often referred to as Wisconsin mounds (USEPA, 1999). Many thousands of these mound systems are now installed across the USA (Converse and Tyler, 2000) (Figure 1).

Mounds offer the smallest footprint combination of secondary on-site treatment and land application. Consequently they are often suited to small and constrained sites and in particular to sites with the following limitations:

- Slow or fast permeability soils;
- Shallow soils over creviced or porous bedrock; and
- Soils with high water tables (USEPA, 1999).

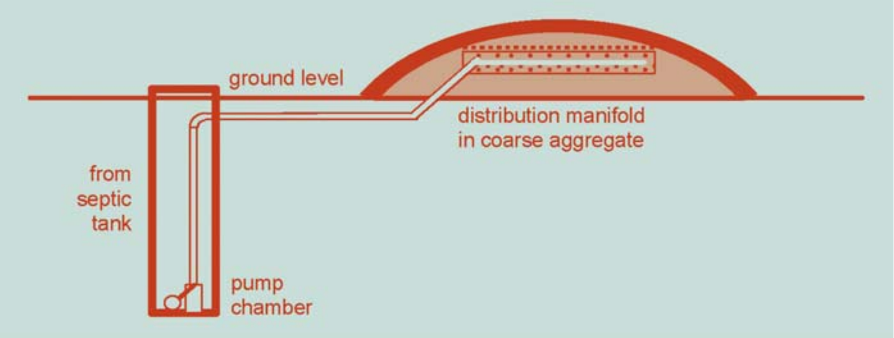

Figure 2. Wisconsin mound (Source: Geary *et al.*, 2005).

In summary, mounds dose primary treated septic tank effluent, by pump or siphon, to a distribution manifold of perforated pipes set in an aggregate distribution bed which sits near the top of an appropriately sized sand-fill media mound (Figure 2). They are considered secondary treatment systems with the characteristics and features as summarised in Table 1. Effluent passes through a mound in much the same way as it would if it passed through an intermittent sand filter, where it undergoes treatment before it enters the native soil beneath.

Mounds have the benefits of increasing separation distance between the point of application and the soil and groundwater, they facilitate nitrogen reduction and they permit increased evaporation and transpiration due to their being raised above ground level. Amended media designs offer opportunities for phosphorus removal where this is a requirement. Mound design and sizing requires professional input and with appropriate design, higher hydraulic loading rates can be applied than to conventional trenches. Mounds can offer an attractive landscape option in situations where soils, high groundwater tables or climate otherwise restrict alternatives.

Table 1. Mound System Description.

Description	Pre-treated effluent is pressure dosed via a manifold in coarse aggregate near the top of a mound of sand through which it permeates. The mound is constructed above grade.
Uses	Mounds are used where soil permeability is low, rock is close to the surface, or if water tables are high. They are suited to most climates.
Performance	Depending upon design, mounds can significantly reduce BOD_5 and TSS. Nitrification can be significant.
Space requirements	Area is determined by analysis of soil tests and is quite variable but can require a large footprint.
Maintenance	The system requires reliable power and pump and control maintenance or replacement; alternately on sloping sites siphons may be used to eliminate the need for power or maintenance. Mound vegetation requires maintenance.

A significant advantage of mound systems over most other types of domestic on-site wastewater management systems is that they offer both treatment and land application on the same footprint. Hence when land availability is limited, mounds may provide both a high (secondary) level of treatment and permit relatively high loading rates for land application. On occasion, on constrained sites, mounds may be the only feasible servicing option. In the case of irrigation systems, wastewater treatment to secondary standard is generally by means of either an aerated wastewater treatment system (AWTS) or a sand filter. In the case of the mound, which acts as a bottomless sand filter, an equivalent secondary treatment standard is achieved by passage of effluent through the media in the mound.

Where appropriate sand media for mound construction are available within close proximity to the site, costs of mound construction are comparable to those of a secondary treatment system plus irrigation. Where transport of media is required, this can add significantly to mound costs, but nevertheless the significantly smaller land area required may prove attractive or indeed may offer the only feasible land application option if the site is small.

Current Practice in Regulation, Design and Construction

Relevant and detailed information is available in the literature, although much of this is published in the United States, and consequently perhaps less readily accessed by practitioners in Australia. Useful guidance on Wisconsin mound siting, design and construction can be obtained from Converse and Tyler (2000). Many aspects of this available literature were reviewed and considered in the light of optimising mound designs in the Australian setting by Bishop & Whitehead (2007).

The sizing and design of mounds is addressed to only a limited degree by

Figure 3. Wisconsin mound at Site F – near Tilligerry Creek.

Figure 4. Wisconsin mound at Site T – near Tilligerry Creek.

current Australian guidelines and Standards. While mound systems have become increasingly popular as an alternative for domestic on-site wastewater management, there is usually only brief reference given and limited guidance provided on design and construction. AS/NZS 1547:2000 (Standards Australia, 2000) provides information on Wisconsin mounds that is mostly consistent with best practice designs available in overseas guidelines. However, it is limited in its scope and coverage of design and construction issues. A review of the 2008 consultation draft of this standard suggests that no major changes are proposed. In Victoria, a Certificate of Approval has been issued by the EPA (EPA VIC, 2006), for a generic Mound System (CA 1.4/06), however, this offers little advice for design, no information on sizing and does not represent a best practice mound design. Despite stating that the system must be designed, installed and operated in accordance with AS/NZS 1547:2000, the design does not look anything like a true Wisconsin mound and appears more like raised absorption trenches or an inverted leach drain. The approval requires secondary level pre-treatment before the mound.

It has been recognised that lack of trained professionals and/or unproven design modifications (Converse & Tyler, 2000) and lack of rigour in design, selection of appropriate materials and attention to detail in construction (Bishop & Whitehead, 2007), are major impediments to successful mound operation. By incorporating much more detail on design and construction, based on the sound research available elsewhere, AS/NZS1547:2000 and the State Government codes and guidelines could help advance Australian mound practice significantly.

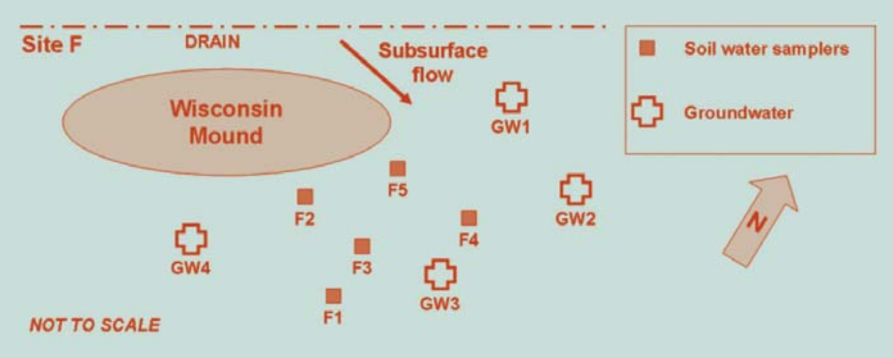

Figure 5. Schematic of Monitoring Network – Site F.

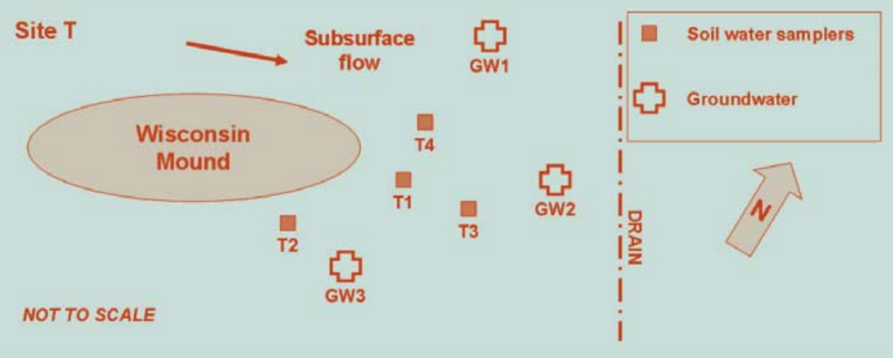

Figure 6. Schematic of Monitoring Network – Site T.

Study Methodology

As previously mentioned, two of the sand mound systems installed in 2006 (according to standard designs for mound systems (Whitehead & Associates, 2005)) were monitored in detail to determine the effectiveness of the systems in treating and reducing contaminants from each household and as the effluent entered the groundwater. The unsewered properties were located in the Michael Drive subdivision at Salt Ash adjacent to the Tilligerry Estuary. The mound at Site F had a surface area of 146 m^2 (Figure 3) and that at Site T had a surface area of 170 m^2 (Figure 4). The properties studied were typical of the 40 other lots in the subdivision (one hectare allotments) where existing subsurface systems were performing poorly due to the presence of sandy soils and high groundwater tables.

There was no reticulated water supply, and rainwater at each residence is used for potable purposes, although the majority of properties extract shallow groundwater for outside and garden use. Water use was monitored at each property (Sites F and T) using Smartmeters and the direction of groundwater flow determined using a

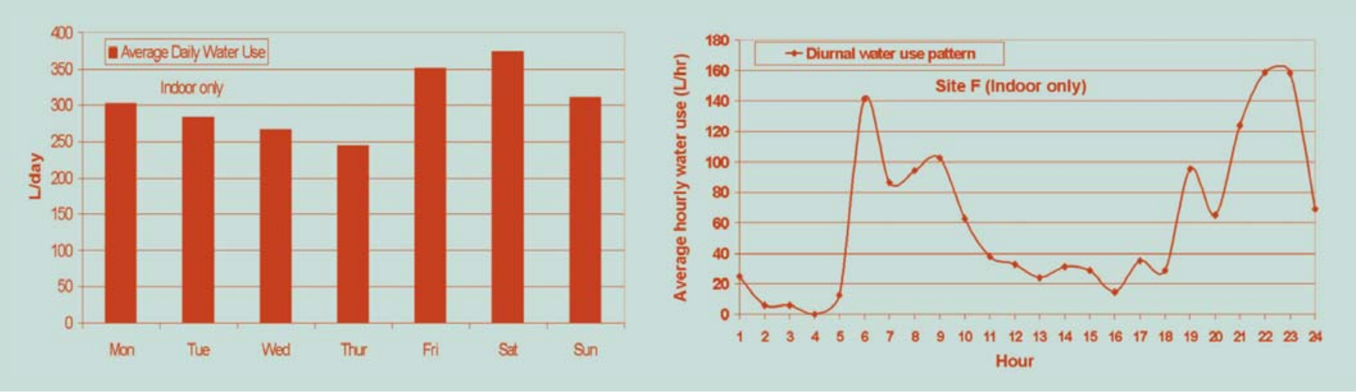

Figure 7. Daily Average Water Use and Average Diurnal Water Use Pattern - Site F.

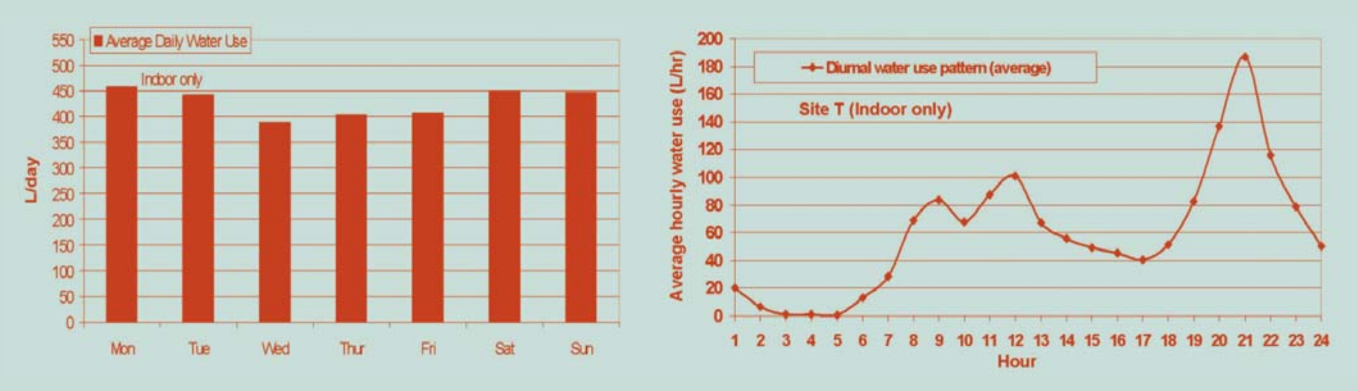

Figure 8. Daily Average Water Use and Average Diurnal Water Use Pattern - Site T.

network of shallow bores. The direction of flow was consistent with the regional groundwater flow towards the estuary. Groundwater level variation was recorded in-situ using data loggers installed in piezometers and groundwater samples were collected (Geary *et al*., 2008). Suction lysimeters were also installed (Figures 5 and 6) and a suite of wastewater contaminants in the septic tank, vadose zone and groundwater (including nitrate and orthophosphate) was measured between mid 2007 and January 2008. A groundwater tracer (LiBr) was also added to each of the mound systems at Sites F and T on 26/09/07 to confirm hydraulic connections between the wastewater treatment systems and the groundwater samplers.

Hydraulic Loads and Effluent Quality

Site F. The average daily indoor water use for the family of four was 295 L/day. The weekday figure was as low as 250 L/day with the highest use of up to 370 L/day occurring on a weekend as shown in Figure 7. The average diurnal water use pattern is typical of a working family with two high school age children. Distinct morning and evening peaks can be observed. Nine septic tank samples were collected and analysed at each of the sites to gauge the typical quality of effluent delivered to each of the mound systems. Characterising the quality of the effluent is important as a background to understanding the treatment afforded by the sand mounds, however, it is well known that effluent quality varies between individual households and can even vary over a 24 hour period in a household. At this household, grey water from the laundry was directed to the garden, so the effluent quality from the septic tank which is shown in Table 2, reflects the remaining combined wastewater streams. The analysis results indicated that the concentrations of nitrogen (as ammonium) and phosphorus were relatively high, electrical conductivity was also high, BOD_5 was moderate and faecal coliform numbers, as expected, were high and highly variable.

Site T. The average daily indoor water use for the family of five was higher than at Site F and was between 400 and 450

Table 2. Septic Tank Effluent Quality - Site F and T.

Site	n = 9	pH	EC	NO_3^-	NH_4^+	Total P	PO_4^{3-}	FC	BOD_5
	units		uS/cm	mg/L	mg/L	mg/L	mg/L	cfu/100 mL	mg/L
Septic Tank F	Average	7.2	1944	0.2	232	20	17	1.18 x 10^6	215
	Maximum	7.6	2430	0.3	300	24	20	6.00 x 10^6	303
	Minimum	5.7	1230	0.1	170	16	14	2.50 x 10^4	102
	SD	0.7	377	0.2	45	3	2	2.13 x 10^6	75
Septic Tank T	Average	7.7	1234	0.4	133	13	10	3.44 x 10^4	187
	Maximum	7.8	1420	0.4	165	18	11	6.70 x 10^4	324
	Minimum	7.4	1140	0.4	100	10	9	5.46 x 10^3	85
	SD	0.1	90	0	22	3	1	2.15 x 10^4	99

Table 3. Water Quality Analysis of Groundwater Samples - Site F.

Site	n = 9	Depth to GW	pH	EC	NO_3^-	NH_4^+	Total P	PO_4^{3-}	FC n = 7
	units	cm		uS/cm	mg/L	mg/L	mg/L	mg/L	cfu/100 mL
GW1	Average	28	5.7	225	0.73	0.33	0.43	0.27	1
	Maximum	66	6.5	422	1.1	0.68	0.80	0.56	5
	Minimum	10	5.3	107	0.40	0.11	0.18	0.07	0
	SD	17	0.4	97	0.24	0.21	0.19	0.18	2
GW2	Average	31	5.4	445	0.99	0.43	0.25	0.21	149
	Maximum	69	6.6	599	2.5	0.90	0.68	0.58	1000
	Minimum	11	4.6	216	0.10	0.07	0.14	0.09	1
	SD	18	0.6	119	0.68	0.33	0.15	0.23	376
GW3	Average	41	5.2	500	0.79	0.89	0.19	0.12	34
	Maximum	79	5.8	828	1.30	1.92	0.32	0.14	120
	Minimum	21	4.9	266	0.40	0.13	0.07	0.10	2
	SD	18	0.3	180	0.30	0.71	0.07	0.03	47
GW4	Average	53	5.2	212	1.0	0.99	1.97	0.25	228
	Maximum	90	6.5	386	1.70	1.90	8.40	0.40	1000
	Minimum	33	4.8	59	0.40	0.29	0.13	0.10	3
	SD	18	0.6	103	0.50	0.61	3.21	0.13	391

L/day, as shown in Figure 8. All wastewater was delivered from the household to the septic tank (i.e., no separate grey water use). The average diurnal pattern of water use also had morning and evening peaks, however, the morning peak was smaller and broader than at Site F. The effluent quality in the septic tank at this site, while also of variable quality (shown in Table 2), indicated that the concentrations of most of the parameters measured were lower than at Site F. In short, the effluent quality/quantity at Site F was characterised as high concentration/low volume compared to relatively lower concentration/higher volume at Site T.

Groundwater Monitoring Results

Groundwater samples were collected from the piezometers which had been installed along the general direction of groundwater flow. The summarised results at both Sites F and T which are shown in Tables 3 and 4 should be examined in relation to the schematic diagrams of each of the monitoring networks (Figures 5 and 6). Also shown in these tables are the recorded depths to groundwater at each of the monitoring locations. The results from the monitoring of soil water in the vadose zone using the suction lysimeters are not reported here.

If the septic tank effluent quality is considered typical of the concentrations pumped to the mound system, then it is possible to examine the data in Tables 3 and 4 to determine the effectiveness of the system in removing or reducing contaminant concentrations. Of interest also were the contaminant concentrations as they entered and travelled in the groundwater along the general direction of flow. In overall terms there were significant reductions in the concentrations of all measured parameters from the septic tank to the groundwater concentrations measured down-gradient from each mound system. pH was typically two units lower on average in the groundwater than the septic tank effluent. As the mound treatment is an aerobic process and as nitrification is an acid-forming process, this would normally be expected in these sandy, coastal locations. Electrical conductivity was substantially lower in the groundwater, possibly due to dilution and dispersion processes. Of major interest and significance, however, were the reductions in nitrogen (both nitrate and ammonium), phosphorus (both total and ortho) and faecal coliforms in the groundwater relative to the input concentrations from the septic tank.

In an aerobic environment such as the unsaturated soil in a sand mound, ammonium is readily nitrified to nitrate, yet the maximum nitrate concentration recorded at any groundwater sampler was only 2.5 mg/L (GW2 at Site F). The maximum ammonium concentration of 1.92 mg/L was at GW3 at Site F. Overall there was substantial nitrogen loss as the

Table 4. Water Quality Analysis of Groundwater Samples - Site T. Note: GW1 contained negligible water on all occasions.

Site	n = 9	Depth to GW	pH	EC	NO_3^-	NH_4^+	Total P	PO_4^{3-}	FC N = 7
	units	cm		uS/cm	mg/L	mg/L	mg/L	mg/L	cfu/100 mL
GW2	Average	54	5.0	135	0.90	0.21	0.34	0.24	38
	Maximum	86	5.4	199	1.40	0.41	0.52	0.38	250
	Minimum	35	4.9	82	0.60	0.11	0.26	0.10	1
	SD	16	0.1	44	0.20	0.1	0.11	0.20	94
GW3	Average	52	4.7	236	0.70	0.27	0.23	0.12	280
	Maximum	84	5.1	396	0.90	0.41	0.48	0.22	1960
	Minimum	32	4.5	94	0.50	0.14	0.06	0.03	2
	SD	16	0.2	94	0.10	0.08	0.14	0.08	741

effluent from the septic tank passed through the mound and vadose zone into the groundwater. Processes such as dilution, plant uptake and soil adsorption (for ammonium), and even denitrification under certain anoxic conditions can be potential loss mechanisms for nitrogen. While they were not individually assessed, the mound system results in a better outcome for groundwater quality with respect to nitrogen compared to a nearby soil absorption system area where high nitrate concentrations can be found only metres away from subsurface trenches (Geary, 2005). In terms of the high phosphorus concentrations which were applied to each mound, the majority of groundwater samples collected had very low concentrations (relative to the septic tank), even though the native soils on site are known to have low phosphorus adsorption. While one sample collected on 23/08/07 at GW4 had a high concentration of Total Phosphorus of 8.40 mg/L, the majority of samples collected were sufficiently low to suggest that phosphorus was being removed within the mound. Again, processes such as dilution and plant uptake may also be responsible for these reductions but they were not individually assessed. The outcome whereby approximately 99% of the phosphorus applied to the mound from the septic tank was lost and not recovered in the groundwater suggested that the treatment system resulted in a better outcome for groundwater quality. Phosphorus has previously been shown to be transported in groundwater in this sandy environment over considerable distances from subsurface trenches (Geary, 2005), so the loss of phosphorus is an important outcome. Of most interest, however, are the substantial reductions in the faecal bacteria concentrations in all the groundwater samples collected (Tables 3 and 4). The 2-3 order-of-magnitude decrease in concentrations would appear to reflect a variety of bacterial removal processes including die-off which occur during the passage of effluent through the mound.

Conclusion

On the basis of the groundwater results presented in this paper, it is clear that the two sand mounds are performing effectively as treatment systems. The treatment afforded by each of the mounds resulted in significantly reduced contaminant concentrations entering the shallow groundwater which, throughout the study period, was always less than one metre from the surface. The overall efficacy of the treatment system can be directly linked to the increased vertical separation distance to the groundwater which is provided by the mound and the unsaturated conditions which exist as a result of the periodic dose loading of effluent from the septic tank. Compared to higher results obtained from groundwater monitoring adjacent to sub-surface absorption trenches in the area, it would appear that the sand mounds monitored are performing very effectively in reducing contaminants entering the shallow groundwater in the area. There has been substantial interest in the overall performance of these systems within various sections of the community given that they are substantially more expensive than the soil absorption systems they are replacing. Based on these data they do appear to have a better environmental outcome and do offer a suitable treatment and land application option for these constrained sites.

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