APPROACHES FOR ASSESSING BACTERIAL REMOVAL IN SOILS

by

Margaret Leonard
Liping Pang

July 2006

Client Report
FW0642

APPROACHES FOR ASSESSING BACTERIAL REMOVAL IN SOILS

Alistair Sheat
Science Programme Manager

Margaret Leonard
Project Leader

Murray Close
Peer Reviewer

ACKNOWLEDGMENTS

We are grateful to Mark Flintoft and Rod Dan for their practical advice, Murray Close for peer review and Hilary Michie for editing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

The ability of soils to remove microbial pathogens from wastewater is a critical component of the on-site wastewater treatment process. Insufficient treatment leads to potential contamination of groundwater, or nearby surface water bodies such as the coastal area or rivers. If these water bodies are used for drinking water, recreation or aquaculture, microbial contamination may adversely affect public health.

Marlborough District Council (MDC) wishes to identify the most appropriate way of assessing the ability of soils to remove bacteria in its region. The approaches considered were application of literature values to Marlborough soils, modelling bacterial removal and field work. The literature shows that soils without preferential pathways and for systems with imported soils (e.g. sand filters), a 3-log/m bacterial removal may occur in clay and sand soils with 600-900mm depth of soil. In alluvial gravels 1.3-log removal may occur, but it may be as little as 0.17-log/m removal in gravels with preferential pathways. Modelling values from literature of field studies in loam soils gave a wide range of bacterial removal values for silty clay loams (0.5–3.5 log/m), sand loams (0.09–0.8 log/m) and silt loam (1.9–4.7 log/m). The ranges of values illustrate the difficulty in broadly applying literature values to general soil classifications.

It is recommended that data be supplemented by modelling literature values of horizontal and vertical movement of pathogens to identify sensitive receiving environments. It may be that the removal in the aquifer may be sufficient to protect sensitive end uses. Field trials are recommended to confirm typical bacterial removal values for Marlborough soils where the groundwater is sensitive to contamination. Using existing wells that are located in shallow groundwater near drainage trenches is the simplest approach. Alternatively, piezometers can be installed beneath existing drainage trenches, providing suitable sites can be found. Lysimeters could also used to determine bacterial removal rates for fine soils. However, stony soils with more than 10% of soil >2 mm diameter particles can be difficult to set up as lysimeters. Lysimeters are the most expensive approach owing to the work involved in obtaining the cores and they need to be equilibrated with wastewater over many weeks, before experiments can begin. A summary of the different approaches and rough order of costs is presented.

It is also recommended that indicator viruses be included, as these pose a potentially greater risk because they survive longer, travel further and are infectious at lower doses than bacteria.

1. INTRODUCTION

It is generally accepted that two key factors in the success of on-site sewage treatment and disposal systems (OSTD) depend the removal of solids, and on the soil to assimilate effluent. Soils have an important role in removing pathogenic protozoa, bacteria and viruses by filtration, adsorption, desiccation and predation by other soil micro-organisms. Ultraviolet (UV) rays from sunlight when wastewater is applied to the surface also remove microorganisms. Failure of OSTDs is most readily identified by effects such as odour and break though (Martens, 1995; Graham and Futter, 2002; McGlinchey et al., 2002).

However, some effects indicating the failure of OSTDs cannot be so easily detected. Catchment assessments can show significant contamination of groundwater by bacteria (Morrissey, 2004, Bagdol, 2004) or nutrients (Middle, 1996) from on-site systems. This may be caused either by direct discharge to groundwater (e.g. soak holes) or by insufficient soil depth to remove pathogenic micro-organisms. The potential adverse impacts of microorganisms and nutrients on groundwater may be to make the water unsuitable as a source of drinking water, and if the OSTD drains into rivers or the coastal environment, it may also make the water unsuitable for recreational use or aquaculture.

To protect groundwater from the adverse effects of OSTDs, both vertical and horizontal setback distances can be set by a regional council. Setback distances recognise the importance of the depth of the soil through which bacterial removal can occur, the movement through the aquifer and the time taken for the contaminated water to be transported to the drinking water well, or swimming beach.

This report focuses on identifying the most effective approach to determining potential vertical setback distances by reviewing methods for establishing the removal of bacteria in soils. Pathogenic viruses have not been considered in determining which approach would be most effective, but Marlborough District Council (MDC) may wish to include these in future, because they potentially pose a greater risk to human health, as they travel further in groundwater and can cause infection at very low doses (e.g. < 1 rotavirus).

MDC wishes to identify how to assess the appropriate depth of soil to remove bacteria for the main classes of soils in its region. This report examines different approaches, as follows:

- interpretation of research data and modeling of literature values,
- field studies, and a
- combination of the above.

The alternative approach of identifying sensitive receiving environments by modelling bacterial removal through horizontal movement in an aquifer is also presented.

Recommendations are presented using field data from existing systems as the best approach, with alternatives if such systems are not available.

2. TREATMENT PROCESS

2.1. Microbiological Removal

Microbial pathogens are excreted by people who have symptoms of disease, those who have no disease symptoms (carriers) and people who are in the post-infectious stage of these diseases. The concentrations of common pathogens in municipal sewage are not as high as they can be in OSTDs. Where a member of a household with an OSTD is ill, the concentrations of pathogens in the treatment system can be extremely high. A person infected by *Campylobacter* may excrete between 1,000,000–100,000,000 *Campylobacter* per gram faeces/day (Taylor *et al*. 1993), while a person infected with adenovirus may excrete up to 100,000,000,000 viral particles per gram of faeces per day (Wadell, 1984, Albert, 1986), and may continue to excrete pathogenic microbes for long periods. Assuming about 250 litres waste per person per day and three members in the household, the concentration of *Campylobacter* in the sewage could be 27,000–2,700,000/100ml, higher than in a municipal system.

Traditionally, indicator micro-organisms are used to identify risk of faecal contamination. For example *Escherichia coli (E. coli)* is found in faeces of warm blooded animals and birds. The presence of *E. coli* indicates the potential for faecal contamination and a risk to public health. As faecal coliforms and *E. coli* are always excreted in high numbers in human sewage (typical concentrations in raw sewage being 1,000,000–100,000,000 /100ml) and the tests are comparatively cheap ($30-$40/test), it is a useful indicator. It has commonly been used in research and therefore it's behaviour is often reported in the literature. As there are millions of bacteria in the effluent discharge, it is common to refer to the removal as "log removal". Reductions in concentrations from 1,000,000 to 100,000 are 1-log removal; reductions from 1,000,000 to 10,000 is 2 log removal etc.

It must be noted that *E. coli* or other indicator bacteria are *not* useful indicators for the survival of viruses or protozoa. Typically, a phage (a virus which infects bacteria) is used as a surrogate for human viruses.

Unless there is chlorination or UV treatment, the OSTD is an integral part of the microbial pathogen removal process. The mechanisms that remove pathogens before they reach groundwater are:

- physical processes e.g. filtration (which may be in a sand filter within the treatment system or through soil underlying drainage trench or irrigated soil), desiccation (surface application), UV (surface application or mechanical);
- biological processes e.g. food source for other micro-organisms, which are most active in the aerobic zone in the upper 200mm of soil;
- die-off – micro-organisms will die-off over time, in both soils and in the aquifer.

The level of microbial removal achieved as the wastewater travels through the soil depends on the pathogen type, the characteristics of the unsaturated zone (e.g. thickness, pore size, permeability, temperature, pH and moisture) and the loading rate.

Protozoa are likely to be removed by filtration even in coarse soils, owing to their comparatively large size e.g. *Giardia* 10–20 µm, compared to bacteria, e.g. *E. coli* 2–6 µm, or *Enterococcus faecalis* 0.5–1 µm, and viruses, e.g. enterovirus 0.025–0.030 µm, and calicivirus (e.g. Norwalk-like viruses) 0.027–0.040 µm. Bacteria and viruses are likely to move through larger pore sizes in soils. All microbial pathogens may move rapidly through soils using preferential pathways such as the cracks in clays and volcanic rock, or large porous gravels.

Once bacteria and viruses have moved through the unsaturated zone in the soil to groundwater removal by adsorption, filtration and die-off continues. There are models which predict the removal of bacteria as the wastewater plume mixes in the groundwater. Modelling this horizontal movement can be an alternative approach to setting separation distances for OSTD in sensitive receiving environments.

If soils are overloaded, soils become saturated, this increases pathogen movement through the soils. Intermittent saturation may also occur as OSTD flows tend to be episodic rather than continuous.

2.2. Soils and Geology

Disposal of wastewater from OSTDs can be undertaken in a number of ways. Typically, a conventional drainage trench, subsurface irrigation, evapotranspiration seepage bed or a mound is used. Some of these systems use imported material, rather than the natural soils. Drainage trenches, for example, may be filled with pea gravel in poorly drained soils and sand in rapidly drained soils. Mounds, which are used in poorly drained areas, are also likely to be built from sand. Imported soils are more likely to have a more uniform structure and therefore reduce preferential flow paths. However, over time this uniformity can diminish resulting in preferential flow. Micro-organisms will also die-off over time, in soils and in the aquifer. Depending on the receiving environment, this may be the most important removal mechanism for bacteria.

MDC has provided a list of the major soil types in the region from DSIR Soil Bureau Bulletin DSIR Soil Bureau Bulletin 27 (1968) (Appendix 1). The basic classifications for the soils are:

- Silty clay
- Sand loams
- Silt loam
- Stony sandy loam
- Stony loam
- Gravely silt loam

Guidelines for design of on-site disposal focus on the hydraulic properties of soils using the soil classification and drainage properties. This is to match hydraulic loading from the system, with the capacity of the soil to drain. It also prevents soils from becoming saturated, thereby minimising the risk of rapid transport of micro-organisms. Soils that drain more rapidly than expected because of fissures, periodic drying and cracking or high porosity are not normally considered a problem. However, rapid drainage means that micro-organism removal is not occurring, so a soil classification does not necessarily provide sufficient information on potential pathogen removal.

To identify the capacity of the soil to remove micro-organisms, an understanding of the nature of the soil and mechanisms of microbial movement through the soil is important. McLeod *et al.* (2005) have classified New Zealand vadose zones and soil types as having high or low risk of microbial movement. This extremely broad classification arises from the paucity of data about the ability of micro-organisms to move through them. High risk soils include alluvial gravels, fractured rocks, while compact sedimentary rocks tend to be categorised as low risk. As well as the potential for adsorption, the structure of the soil is taken into account. For example, while clays with their high surface area may have high adsorptive capacity, in areas where they are prone to drying and cracking, they will be high risk.

The unsaturated zone above groundwater is called the vadose zone. It provides vertical separation from the OSTD and the groundwater. During discharge from a typical drainage field this zone may become saturated. Flows from on-site systems are typically episodic, with high flows during the morning and evening, and with washing, especially if multiple loads are discharged in one day. Depending on the nature of the flow, disposal field and depth to groundwater, this zone may become saturated for long periods of time. Micro-organisms will move through saturated soil much faster than through unsaturated soils. Over a long time and frequent effluent loading, the adsorption sites on aquifer media will become occupied and fewer will be available, increasing the distance that micro-organisms must travel before being removed (Pang *et al*. 2005).

3. APPROACHES

The ability of soils to purify wastewater by subsurface infiltration and percolation has been from OSTD has been studied in soil columns under laboratory conditions and in the field. Data from both types of studies are discussed below. Even if removal rates by soils are low, removal continues in groundwater, so a second approach is to combine vertical and horizontal removal. Field trials are also discussed to determine the most effective approach to confirming literature data.

3.1. Approach A: Literature values and modelling existing data

The ability of soil to remove bacteria can be determined from literature, but the applicability of the data relies heavily on the way it was derived e.g. whether the soil was undisturbed cores or packed aggregates, length of soil column, dosing regime. Bouma (1975) identified the requirement to use large undisturbed soil columns, but many of the values in the literature are from packed columns (Jenssen, 1988, van Cruyk *et. al*, 2001), so care is needed in application of the data to the environment.

The removal values identified below, do not apply in saturated conditions. Horizontal movement of faecal coliforms has been reported in downstream groundwater (Gunn, 1997), (Scandura and Sobsey, 1997). It must be noted that bacterial removal does *not* imply good removal of viruses (Scandura and Sobsey, 1997, Nicosia *et al*. 2001).

3.1.1. Sand and Clay

From laboratory column and field studies Bouma (1975) predicted that 1 m of soil would remove bacteria and viruses, if there was unsaturated flow. Even dispersion of the wastewater was critical and he recommended different dosing regimes based on different soil types with sand soils requiring four doses a day, with a maximum loading rate of 50 mm/day and clay soils requiring 10 mm/day.

Gunn (1997) reviewed seven studies that focused on bacteria removal in soils below soakage trenches. For a range of soil types including clays and sand a depth of 600 mm–900 mm appeared to remove bacteria (Gunn, 1997), but final concentrations were not reported.

Data from sand filters (Jenssen, 1990), gave the following removal (assuming that the concentration of faecal coliforms in sewage is 1,000,000 cfu[1]/100ml):

- Coarse sand approximately 3-log removal/m
- Fine sands (mean grain size d_{50} 0.01–0.8mm) approximately 4-log removal/m.

Van Cruyk *et al*. (2001) also showed that lysimeters packed with moist sand achieved 4-log removal of faecal coliforms (< 100 cfu/100ml) in both 600 and 900 mm of sand after 48 weeks of operation (i.e. 5-log removal/m). However, these data must be interpreted

[1] cfu= colony forming units

cautiously as sand filters and lysimeters will be carefully packed to avoid preferential flows and may not reflect the structure of natural sands.

3.1.2. Loams

A model for loam soils has been developed by Pang, using field data collected from literature (e.g. Rahe et al. 1978; McCoy and Hagedorn 1980; Jansons et al. 1989; Ho et al. 1992). Pang (unpublished data) has derived spatial removal rates of faecal coliforms for three major loam soil types identified in Marlborough:

- Silty clay loam: 0.493–3.5 log/m
- Sand loams: 0.0932–0.844 (mean 0.463) log/m
- Silt loam: 1.93–4.7 log/m

These results are derived from sewage "contaminated" sites, so they are realistic. There are only two values for silty clay loam and silt loam, hence no mean is given for these soil types. The sand loams have high permeability, which is reflected in the low removal rate. Note the difference in removal between sand and sand loams. This may be a reflection of methodology used in removal experiments.

Using these removal rates, one can readily calculate the depth of soil required for various degree of bacteria reduction as seen in Table 1.**Error! Reference source not found.**

Table 1 Log Removal Rate for Bacteria in Different Soil Types Modelled from Literature Values

Soil Type	Reduction/m	
	4-log	**7-log**
Silty clay loam:	1.1-8.1	2-14.2
Sand loams	4.7-43 (mean 8.6)	8.3-75.1 (mean 15.1)
Silt loam	0.9-2.1	1.5-3.6

3.1.3. Gravels

Preliminary data are not available to model the two stony soils or the gravel soil, in the same way as given above for loams, but studies on bacterial removal by gravel soils and contamination of the underlying alluvial gravel aquifer in Canterbury is available from studies by Sinton and colleagues.

At Burnham in Canterbury, Sinton (1986) showed faecal indicator contamination shallow bores (10m) located in an unconfined sand and gravel aquifer. The depth of soil (gravel containing sand and clay) beneath the disposal "trench" (boulder pits) and groundwater was 4 m. A lysimeter was inserted 1.5m beneath the soakage pit. Some sealing of the soakage pit had occurred, but 80% of tank effluent rapidly percolated through the side walls into the groundwater through a preferential pathway. This study indicated that increased removal of bacteria over time through clogging may not occur in gravels. The removal of faecal coliforms, as calculated from the median of the discharge from the soakge pit and the lysimeter was 1.3 log removal/m.

However, one of the shallow bores had higher median concentrations than the lysimeter, indicating that preferential flow paths could result in lower removals of bacteria (0.6 log removal/m). Even lower removals of faecal coliforms by alluvial gravels is observed by Sinton *et al*., (1997). In these experiments, oxidation pond effluent was applied to shallow silt loam soils (15–25 cm thick), underlain by alluvial gravels at Templeton Canterbury, with groundwater at 12 m below the surface. Bores were located downstream of the border dyke and groundwater sampled 1 m below the water table. Groundwater was contaminated with faecal coliforms and F-RNA phage. Removal of faecal coliforms calculated from reductions measured after travel of 12 m in the gravel unsaturated zone and mixing with underlying groundwater were 0.17-log/m. It was noted that while viral indicators were reduced more in the soil, they travelled further than faecal coliforms, causing contamination of groundwater at a distance of 445 m.

In summary the following removals may be used for gravel soils:

- Gravel with some clay and sands 1.3 log removal/m
- Gravel with preferential pathways 0.17-log - 0.6-log/m

The differences in removal demonstrate the importance of field testing to take into account the macrostructure of the soil and its effect on the ability of the soils to remove bacteria. In sensitive receiving areas, field data or detailed modeling of horizontal and vertical removal is necessary to support the minimum microbial removal values. As a precautionary approach no removal could be assumed in these types of soils and setback distances be modeled based on transport in groundwater.

3.1.4. Summary

From the literature the following faecal coliform removals have been identified for different soil types :

- Coarse sand, with no preferential flow paths approximately 3 log/m
- Fine sand and clays with no preferential flow paths, approximately 4 log/m
- Silty clay loam: 0.493–3.5 log/m
- Sand loams 0.0932–0.844 (mean 0.463) log/m
- Silt loam 1.93– 4.7 log/m
- Gravel with no preferential flow paths: 1.3-log/m
- Gravel or sandy gravel soils, with preferential flow paths: 0.167 log/m

3.1.5. Relevance to MDC

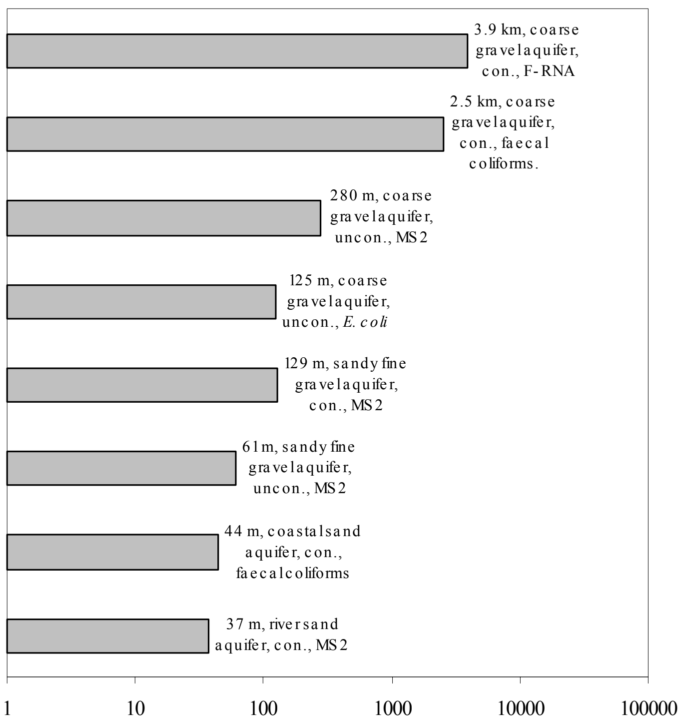
Interpretation of literature values using the modelled data, identifies a wide range of values for different soil types. This range may be a reflection of the methodology used to derive the data, or the natural variation in soil especially with regard to its structure. A model of bacterial removal in soil should be used in conjunction with a horizontal bacteria transport model to overcome the difficulties in applying these widely ranged literature values. A horizontal model may show that bacteria are rapidly filtered out in the aquifer.

3.2. Approach B: Horizontal and Vertical Model

While some values have been identified from the literature above, it is likely that if a conservative approach was used and the minimum soil removal value used, in many areas there would be insufficient depth of soil to remove pathogens. If groundwater is high and the soil is saturated, then the literature values do not apply. Identifying the distance that bacteria travel in the aquifer (horizontal modelling) may be an effective planning tool.

Pang *et al* (2006) constructed a two-dimensional model from data collected at Yaldhurst where OSTDs discharged to boulder pits. This study shows that bacterial contamination is likely to be low at a horizontal separation distance of 130 m because of filtration and die-off. This is consistent with the calculated value for an uncontaminated coarse gravel aquifer (Pang *et al.* 2005) and shown in Figure 1. Pang *et al* (2005) modelled the worst-case scenario where removal of bacteria and viruses in soil is negligible. The following horizontal separation distances are calculated for a 7-log removal of viruses and bacteria, which would protect drinking water.

Figure 1 Schematic illustration of setback distances for 7-log reduction in concentrations of MS2 or F-RNA phages and faecal bacteria for different aquifer categories (Pang *et al.* 2005)



3.2.1. Relevance to MDC

MDC could use the literature values and this horizontal model (which assumes no removal in soil) to identify which receiving environments are sensitive to bacterial contamination, and the soil types for which field soil removal data is necessary. This would focus the investigation towards these sensitive areas. To refine this model, information on aquifers and soils would be required e.g. pump tests, porosity and groundwater velocity.

3.3. Approach C: Field Tests

As data from the literature are so variable, it would be useful to undertake some field tests to confirm bacterial removal rates. Approaches to field tests include:

- Option A: monitoring existing wells located near OSTDs
- Option B: piezometers located beneath drainage trenches
- Option C: conducting lysimeter trials.

3.3.1. Option A: Monitoring Existing Wells

Interrogation of MDC's well database could identify shallow wells, located in a range of soil types and adjacent to drainage fields. Surrounding wells could be used to confirm the direction of groundwater flow and upstream water quality. The wells could be sampled weekly for two months when groundwater is at its highest and the samples analysed for *E. coli,* which is more commonly used than faecal coliforms. We recommend that F-RNA phage is also determined as a model virus.

The advantage of this approach is that it uses existing wells, the soil will be pre-treated with sewage effluent and it represents a real situation. The disadvantage is finding suitable sites.

3.3.2. Option B: Piezometers Beneath Drainage Trenches

If there are sites where the groundwater is less than 2 m below the surface, the movement of bacterial pathogens through the soil can be determined by monitoring the groundwater quality upstream and downstream of an existing drainage trench. A piezometer can be inserted into the top 100 cm of the groundwater, sampled during the main flow periods during the day. The groundwater and effluent in the tank should analysed for *E. coli*. We would recommend that F-RNA phage also be determined as a model virus. In addition, the direction of groundwater flow would need to be confirmed.

A key advantage of this approach is that it is simpler to set up and manage than lysimeters, the soil will already be pre-treated with sewage effluent and it represents a real situation. Piezometers can be inserted in stony soils that may not be suitable for lysimeter trials. The disadvantages are the difficulty in finding appropriate sites in the range of soils with shallow groundwater.

3.3.3. Option C: Lysimeters

Lysimeters can be taken from appropriate soils, transported back to an experimental site with access to primary screened domestic sewage, and regularly dosed with sewage to mimic an OSTD. Topsoil would be removed to mimic the ground conditions of drainage trenches and suction applied to the base of the lysimeter to mimic the capillary action that drains leachate *in situ*. Lysimeters are initially dosed with tap water to verify that there are no "native" populations of *E. coli*, then they are dosed with sewage. Van Cruyk *et. al* (2001) identified that flow characteristics changed on sand lysimeters over an eight-week period, so an equilibrium period would be required. The sewage and leachate would be collected and analysed for bacterial indicators e.g. for *E. coli*. Phage analysis should also be included.

Typically five cores are required for each soil type. The cores need to be a minimum of 20 cm in diameter and 0.5 m deep and sealed around the edges to ensure the wastewater flows through the pores and not down the sides. This method would be satisfactory for the smaller sized soils, but in stony and gravely soils (more than 10% of soil > 2mm diameter particles) it is difficult to set up the cores.

The advantages of this method is that soils are tested *in situ* and a number of soils can be tested at one time. However, this method is more labour intensive. As soils have not received sewage, dosing over an equilibration period (e.g. 8 weeks) would be necessary. Stony soils may not be suitable for this approach.

3.3.4. Summary

Literature values may need to be supported by field measurements in sensitive receiving environments where water is used for domestic or recreational use, or aquaculture. Monitoring existing systems is the preferred approach to gathering field data, using either existing shallow wells near OSTDs (Option A), or installing piezometers beneath drainage fields (Option B) to monitor the concentrations of micro-organisms in groundwater. Alternatively, the model of the horizontal distance (Approach B) could be used to identify sensitive receiving environments and the soils overlying the sensitive aquifers identified for lysimeter trials (Option C).

3.4. Costs

A summary of the costs for the different approaches is given in Table 2. The advantages and disadvantages for each are also summarized. These costs are estimates only, the exact costs will need to be determined once the location of sites is identified and the number of soils that require field data is known. The costings are therefore given for a single soil type and would need to be confirmed once the scope of the project was known. It is recommended that MDC uses the opportunity to measure F-RNA phage as well, as viruses survive longer, travel further in groundwater and are therefore more likely to be a potential health risk. Only *E. coli* tests are included in Table 2.

Field work is divided into existing sites and lysimeters. The following assumptions are made for existing sites:

- MDC will identify sites from databases and local knowledge;
- two sites of each soil type will be tested;
- sites are located in close proximity.

For lysimeters it is assumed

- a dosing period of eight weeks is required;
- lysimeter is located close to sewage source and able to be dosed regularly;
- five cores are used.

Table 2 Summary of Different Approaches to Determining Bacterial Removal by Soils

Approach	FTE	Materials /Analyses	Sampling	Rough order of cost excl GST	Advantages	Disadvantages
Modelling horizontal & vertical transport based on existing data	0.12			$20,000	Interpret existing information. Uses worst case to determine which aquifers or coastal waters are most sensitive, rather than addressing all scenarios	Wide range of values and may not be relevant to soil types in Marlborough; data collected under variable experimental conditions Assumes worst case and therefore overestimates separation distances
Field Work Option A Monitoring bores	0.05	$3,000	64 samples upgradient & downgradient, 16 times at two sites	$12,000	No set up costs as uses existing sites. Using real systems equilibrated with wastewater. Relevant to soils in Marlborough	Locating wells in close proximity to drainage trenches in the soil type with shallow groundwater. Real systems may have more variable depths to groundwater, so more sites might be required.
Field Work Option B Piezometers	0.1	$6,000	64 samples upgradient & downgradient, 16 times at 2 sites	$20,000	Confirming literature values. Relevant to soils in Marlborough. Using real systems equilibrated with wastewater	Locating drainage trenches in the soil type with shallow groundwater. Real systems may have more variable depths to groundwater, so more sites might be required.
Field Work Option C Lysimeters	0.22	$10,000	100 samples 5 cores for 16 days & control before & after washing cores	$42,000	Confirming literature values. Relevant to soils in Marlborough. Controlled experimental conditions	Time involved in taking cores and irrigating them with sewage effluent

4. RECOMMENDATIONS

The potential effect of microbial pathogens in discharges from OSTD is controlled by their removal as they travel through soils and the distance they travel in groundwater. Information in the literature on the removal of bacteria in soil has been identified, but for the loam soil types in Marlborough it gives very wide ranges. Literature values for gravel or stony soils indicate very low removals are likely.

We recommend that field trials be undertaken to confirm bacterial removal rates for Marlborough soils after a preliminary model of horizontal movement has indicated that there would be insufficient removal between the OSTD and a sensitive receiving environment. We recommend the following approaches, listed by preference:

- Model horizontal distance assuming no treatment in soils required to determine worst case separation distances;
- Monitor existing wells, if suitable ones can be identified;
- Piezometers in shallow groundwaters, if suitable sites can be identified;
- Lysimeter trials.

It is also recommended that F-RNA phage, which are viruses that infect *E. coli,* be measured as a model for human viruses, as it is viral contamination rather than bacterial contamination of waters which is likely to give rise to the greatest human health risk.

REFERENCES

Bagdol, J.L., Soegrost. R.L., and Lowe, K.S., 2004. Mass Balance Modeling and Water Quality Monitoring for Impact Assessment of Development with Onsite Wastewater Systems Compared to that with Centralized Treatment Plants, in *Proceedings of On-site Wastewater Treatment* X 21-24 March 2004.

Bouma, J., 1975. Unsaturated flow during soil treatment of septic tank effluent. Journal of the Environmental Engineering Division. 967-983.

DSIR., 1968. Soil Bureau Bulletin 27. General survey of the soils of South Island, New Zealand.

Graham, F. and Futter, P., 2002. Managing Septic Tanks in the Bay of Plenty, New Zealand – Environment P O P's Septic Tank Maintenance Programme, in *NZWWA Conference Proceedings*. Christchurch 2002.

Gunn, I., 1997. On-site wastewater systems and bacterial reduction in sub-soil disposal areas a Review. On-site NewZ Special Report – 97/2 A CaRE for the Environment project.

Ho, G.E., Gibbs, R.A., Mathew, K., Parker, W.F., 1992. Groundwater Recharge of Sewage Effluent through amended sand. Water Res. 26 (3), 285-293.

Jansons, J., Edmonds, L.W., Speight, B., Bucens, M.R., 1989. Movement of viruses after artificial recharge. Water Res. 23, 293–299.

McCoy, E.L. and Hagedorn, C., 1980. Transport of Resistant-labled *Escherichia coli* Through a Transition Between Two Soils in a Topographic Sequence. J. Environ. Qual. 9 (4), 686–691.

Martens D., 1995. Impacts of On-site Domestic Wastewater Disposal in Sydney in *NZWWA Conference Proceedings*. 5-8 September Auckland 1995

McGlinchey, L.D., Cartwright, D., and Peters G., 2002. Waiheke Wastewater Property Inspection Programme, in *NZWWA Conference Proceedings*. Christchurch 2002.

McLeod, M., Close, M. and Collins, R., 2005. Relative risk indices for microbial transport from land to water bodies. Landcare Research report, Prepared for Ministry of Agriculture and Fisheries.

Middle, G., 1996. Environmental Requirements for the Disposal of Effluent from Wastewater Disposal Systems. Desalination, 106, 323-329.

Morrissey, D. Clark, M.K., Couglas, B., Macrellis, A. Petersen, V. and Dean, C., 2004. Risk Assessment of decentralized Wastewater Treatment Systems in High Priority Areas in the City of Malibu, California- Conceptual Hydogeological Model, in *Proceedings of On-site Wastewater Treatment* X 21-24 March 2004.

Nicosia, L. A. Rose, B. J. Stark, L. and Stewart, M.T., 2001. Groundwater quality a field study of virus removal in septic tank drainfields. J. Environ. Qual. 30, 1933-1939.

Pang. L. Close, M. Goltz, M. Noonan, M. Sinton, L., 2005. Filtration and transport of *Bacillus subtilis* spores and the F-RNA phage MS2 in a coarse alluvial gravel aquifer: Implications in the estimation of setback distances Journal of Contaminant Hydrology 77, 165-194.

Pang, L. Nokes, C. Simunek, J., Hector, R. Kikkert, H., 2006. Modeling the impact of clustered septic tanks systems on groundwater quality. Vadose Zone Journal 5, 599-609.

Rahe, T.M., Hagedorn, C., McCoy, E.L., Kling, G.F., 1978. Transport of Antibiotic-resistant Escherichia Coli through Western Oregon Hillslope Soils Under Conditions of Saturated Flow. J. Environ. Qual. 7 (4), 487–494.

Scandura, J.E. and Sobsey, M.D., 1997 Viral and bacterial contamination of groundwater from on-site sewage treatment systems. Wat. Sci. Tech. 35 (11), 141-146.

Sinton, L., 1982. A groundwater quality survey of an unsewered, semi rural area. New Zealand of Marine and Freshwater Research 16, 317-326
Sinton, L.W., 1986. Microbial contamination of alluvial gravel aquifers by septic tank effluent. Water, Air and Soil Pollution 28: 407-425.
Sinton, L.W. Finlay, R.K., Pang, L. and Scott, D.M., 1997. Transport of bacteria and bacteriophages in irrigated effluent into and through an alluvial gravel aquifer. Water, Air and Soil Pollution. 98:17-42.
Taylor, D.N., Perlman, D.M., Echeverria, P.D., Lexomboon, U., Blaser, M.J., 1993. *Campylobacter* immunity and quantitative excretion rates in Thai children. The Journal of Infectious Diseases. 168, 754-758
Wadell G., 1984. Molecular epidemiology of human adenoviruses. Curr. Topics Microbiol. Immunol. 110, 191-220.
Van Cruyk, S., Siegrist, A., Masson, S., Fischer, E. and Figueroa, L., 2001. Hydraulic purification behaviours and their interactions during wastewater treatment in soil infiltration systems. Wat. Res. 35 (4), 953-964.

APPENDIX 1 - KEY SOIL TYPES IN MARLBOROUGH DISTRICT

Area	Name	Category	Description
Marlborough Sounds	Kenepuru	Lowland yellow brown earth	Silty clay
	Ketu	Lowland yellow brown earth	Silt loam
	Manaroa	Lowland yellow brown earth	Silt loam
	Arapawa	Lowland yellow brown earth	Silt loam

Wairau Plains	Renwick	Yellow grey earth	Stony silt loam
	Waimakariri	Recent soil	Sandy loams to silt loams
	Taitapu	Gley recent soil	Silt loam
	Taumutu	Yellow brown sand	Stony sandy loam to stony loams

Southern Valleys	Templeton	Recent soil	Silt loams and sandy loams
	Wither	Yellow grey earth	Silt loam

Awatere Valley	Dashwood	Yellow grey earth	Silt loam and gravely silt loam
	Seddon	Yellow grey earth	Silt loam to sandy loam

INFORMATION SUPPLIED BY MDC