POTENITAL IMPACTS OF ON-SITE SEWAGE DISPOSAL ON GROUNDWATER

by

Margaret Leonard
Brent Gilpin

June 2006

Client Report
(CSC 0603)

HBRC Publication No. 4838
Report No. SD16-10

POTENITAL IMPACTS OF ON-SITE SEWAGE DISPOSAL ON GROUNDWATER

Alistair Sheat
Science Programme Manager

Margaret Leonard
Project Leader

Murray Close
Peer Reviewer

DISCLAIMER

This report or document ("the Report") is given by the Institute of Environmental Science and Research Limited ("ESR") solely for the benefit of Gisborne District Council and other Third Party Beneficiaries as defined in the Contract between ESR and Envirolink, and is strictly subject to the conditions laid out in that Contract.

Neither ESR nor any of its employees makes any warranty, express or implied, or assumes any legal liability or responsibility for use of the Report or its contents by any other person or organisation.

ACKNOWLEDGMENTS

Our thanks to colleagues: Murray Close, Liping Pang, Brent Gilpin and Jacqui Horswell who have provided information on groundwater contamination and measurement of chemical and microbial markers.

TABLE OF CONTENTS

LIST OF TABLES

SUMMARY

Where on-site sewage and disposal systems are located on shallow groundwater tables there is the potential for contamination. The contaminants potentially affect human health and the environment. The key human health and environmental risks are discussed in this report.

Faecal pollution is a major risk to human health, as very low doses of viruses and some bacteria can cause illness. *E. coli* is used as an indicator of faecal pollution and the New Zealand Drinking Water Standard is zero *E. coli* in 100ml sample. High concentrations of nitrogen can cause methaemoglobinaemia or "blue baby" syndrome, gastric cancer, hypertension, leukaemia and non-Hodgkins lymphoma. The New Zealand Drinking Water standard is 11mg/l nitrate nitrogen. Nutrients such as nitrogen, and phosphorus can also be an environmental risk, where groundwater discharges into freshwater or marine water. In clay soils salt may be dispersive and with adverse effects on soil structure. The recommended key contaminants to measure are *E. coli*, indicative of faecal pollution and nitrogen (ammonia and nitrate). Electrical conductivity can be used to identify discharges of contaminants in general.

A strategy for monitoring groundwater is presented by identifying high risk factors that are high groundwater, permeable soils, high densities of septic tanks. It is proposed that *E. coli*, ammonia, nitrate and electrical conductivity be measured on a regular basis for high risk sites (four times a year). For low level surveillance sites monitoring is recommended to identify when the key contaminants are likely to be at their highest concentration. In areas where the source of contamination is unknown, a screen for Fluorescent Whitening Agents can be undertaken, followed by quantitative chemical analysis and other microbial markers. The effectiveness of these tools for determining groundwater contamination could be undertaken in a larger project.

1. INTRODUCTION

It is generally accepted that two of the key factors to the success of on-site sewage treatment and disposal (OSTD) depend on removal of solids, and on the soil to assimilate effluent. More sophisticated systems may also remove nitrogen. Failure is most readily identified by observable effects such as odour and break though (Martins, 1995; Graham and Futter, 2002; McGlinchey et al., 2002). However, some effects are not observable. Catchment assessments can show significant contamination of groundwater by bacteria (Morrissey, 2004, Bagdol, 2004) or nutrients (Middle, 1996) from on-site systems.

In general, little is known about the scope of OSTD failure in New Zealand. A survey in the Bay of Plenty (Graham and Futter, 2002) found that 64% of 3,251 surveyed septic tanks failed inspection. In Waiheke Island permission was obtained for 33% of properties to be inspected (2000 properties) and of those 17% of on-site systems were either not able to be identified on the section (13%) or in need of repair. However, the problem is likely to be much larger as it is generally assumed that, unless effects are visible, the OSTD system is functioning adequately.

The extent of failure of on-site systems because of groundwater contamination in New Zealand is largely unknown, except for a few studies e.g. Sinton (1982, 1986). While some councils have long term groundwater monitoring programmes, the source of contamination, is often difficult to confirm, as other land uses may also give rise to the presence of indicator bacteria in groundwater. In areas where groundwater is used as drinking water there are potential health risks from microbial and nitrogen contamination. Waterways and marine areas that gain water from the groundwater system may also be sensitive to the contaminants from on-site sewage.

To identify the impact of on-site systems on groundwater and any long term trends, a focused study is required. The study should be able to identify trends, and provide tools to investigate elevated concentrations of indicator micro-organisms and confirm the likely source of contamination.

This report discusses health and environmental risks from on-site sewage disposal systems and a plan for preparing a short and long term groundwater monitoring programme for Gisborne District Council.

2. HEALTH RISKS

The presence of water borne pathogens is of particular concern where water may be used by people for drinking water, recreational use or collection of food. Animal health may also be of concern if stock water becomes contaminated. Human waste may contain a wide range of microbial pathogens; bacteria, viruses and protozoa[1]. There is a wide range of on-site sewage treatment and disposal systems available that have varying abilities to remove microbial pathogens. For most systems the disposal system is an integral part of the pathogen removal process. If there is insufficient treatment in the disposal system, underlying groundwater may become contaminated with microbial pathogens.

2.1. Microbial Pathogens

Microbial pathogens are excreted by people who have symptoms of disease and also by those who have no symptoms (carriers). The concentrations of common pathogens in municipal sewage have been measured in New Zealand and internationally, but these are likely to be irrelevant to on-site systems. With on-site systems, if a member of the household is ill, the concentrations of pathogens in the treatment system can be extremely high. While discharges into an on-site system are mostly water from the bathroom, kitchen and laundry waste, about 200g of faeces are produced by a person each day. A person infected by Campylobacter may excrete between 1,000,000 and 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 particles/g of faeces (Wadell, 1984, Albert, 1986) and may continue to excrete organisms for long periods. Assuming about 250l/person/day and three members in the household, the concentration of *Campylobacter* in the sewage could be 27,000-2,700,000/100ml, which is lower than in municipal systems e.g. concentrations measured at Christchurch City council range from 9,300-110,000 /100ml in July-August 2003.

The dose which causes infection may be high e.g. 1,000,000 *for typhoid* or very low as seen for viruses or Shigella (Table 1).

[1] Helminths are not typically a problem in New Zealand.

Table 1 Some waterborne microbial pathogens and disease present in faecal matter

Organism	Infectious dose	Disease & Symptom
Bacteria		
Vibrio cholerae	1,000,000	Cholera - severe diarrhea, dehydration
Salmonella sp.	<1000 for typhoid	Salmonellosis includes typhoid fever (gastroenteritis)
Shigella	10	Shigellosis (or dysentery) bloody diarrhea
Campylobacter sp.	<500	Watery diarrhoea, vomiting, nausea, abdominal cramps, chills fever
Protozoa		
Giardia		Giardiasis (gastroenteritis)
Cryptosporidium	<30 (*C. parvuum*)	Cryptosporidiosis -diarrhoea
Viruses		
Enterovirus includes Poliovirus[2], Coxsachie Echovirus		Meningitis, respiratory disease, fever, diarrhoea
Reovirus includes rotavirus	<1 (rotavirus)	Common cold, respiratory tract infections, diarrhoea, hepatitis, gastroenteritis (rotavirus)
Adenovirus		Fever, respiratory infection, enteritis, conjunctivitis.
Hepatitis		Infectious hepatitis
Astrovirus		Diarrhea and symptoms like calicivirus
Calicivirus		Norwalk like viruses gastroenteritis

Adapted from Schroeder and Wuertz (2003) Stott (2003), Hass et al. (1999) http:// www.ce.berkley.edu, http:/www-micro.msb.le.ac.uk

[2] No live poliovirus vaccines are given in New Zealand so they should no longer be present in sewage

If sewage is inadequately treated before it comes in contact with people there is a potential health risk. Often illness is unreported to a doctor and goes unnoticed. Therefore it is difficult to put a figure on the rate of illness related to contamination of an individual's bore water or food by sewage. However it does happen and when the disease is more typically contracted overseas, contamination of drinking water or food with sewage are more readily identified. An outbreak of Shigellosis in Canterbury in November and December 2004 is an example. There were 13 notified cases of Shigellosis, compared to one in the same period the year before. Contamination of an institution's drinking water source by a break in the irrigation line for an on-site wastewater disposal system was identified as a source of infection. An outbreak of hepatitis at Lake Wallace, NSW, highlighted the potential effect of contamination of water by on-site sewage systems. The source of the outbreak was shellfish contaminated with hepatitis. The subsequent investigation identified unsatisfactory on-site wastewater systems, which was addressed by more stringent approvals of on-site systems.

Not all people that are infected become ill and those who become ill may have a range of symptoms. Typically, those who are often most sensitive are the very young, very old, or those whose immunity is compromised by another condition. However for some illness such as Hepatitis A virus it appears that children have no or mild symptoms and may not be recognized as being ill. These people may continue to attend work, school or pre-school spreading the infection. A recent example is the outbreak of Hepatitis A in Christchurch. In January 2006, 16 cases were associated with a child care centre and seven of these cases had household contact with another case http://www.surv.esr.cri.nz/surveillance/monthly_surveillance.php. In some instances multiple people were infected within a household, extended family or friends. Seven of these cases had household, extended family or social contact with another case, or cases, indicating considerable person-to-person spread. At least 15 cases appeared to have occurred from secondary spread in these circumstances. While not waterborne in this case, the outbreak demonstrates the rapidity and extent to which disease can spread. In addition, once the disease is in the community the opportunities for infection increase. Most risk assessments only take into account the effects of infection by direct consumption of contaminated water or shellfish and typically for those who are in good health. The actual effect on the health of a community may be greater.

Linking cause and effect is however, difficult, except in the unusual cases cited above, as many people put up with gastroenteritis rather than visit the doctor. Low notification rates along with secondary infections hinder the ability to undertake epidemiological studies of the actual health risks from on-site systems contaminating groundwater. Yates (1985) cites several cases in the US where there has been clear evidence of on-site sewage contamination of drinking water. For small communities in New Zealand it is important to identify risk factors and to monitor them in order to manage the risks better.

2.2. Chemicals

In addition to pathogenic micro-organisms, on-site wastewater systems may also be a source of chemical contamination. Household sewage does not usually contain concentrations of chemicals likely to contaminate drinking water, except for nitrate. Nitrate is produced by degradation of the organic nitrogen in sewage.

Many human diseases have been linked at various times to the presence of high nitrate in drinking water. They include methaemoglobinaemia or “blue baby” syndrome, gastric cancer, hypertension, leukaemia and non-Hodgkins lymphoma. Use of toddler milk formulas may increases the length of time to which a small child may be exposed to high nitrate concentrations.

In certain areas of New Zealand, changes to land uses have increased nitrate concentrations above half the Maximum Acceptable Value (MAV) (New Zealand Drinking Water Standards). This is the concentration that triggers more extensive monitoring in a community supply, but will be unnoticed for individual supplies. Some groundwaters have values that greatly exceed the MAV. As removal of nitrate from water is difficult contamination needs to be managed before high concentrations are identified.

3. ENVIRONMENTAL RISKS

When discharged into a sensitive receiving environment, on-site sewage has the potential to adversely affect the environment owing to its chemical constituents. Potential impacts on human health have been discussed above, but there is also the potential to adversely affect soil and aquatic systems. The chemical constituents are discussed in detail in the New Zealand Land Disposal Systems Guidelines and are only briefly discussed here. The most important contaminants are nitrogen, phosphorus and salt.

3.1. Water Quality

On-site systems have also been identified as being significant sources of contaminants (Middle, 1996). In areas where contaminated groundwater upwells into surface waterways, or coastal waters, there is also the potential for the contamination to affect surface water ecosystems.

Contamination by nutrients can lead to undesirable biological growth in surface and coastal waters. Typical municipal sewage contains nitrogen concentrations around 35mg/l, in the form of organic nitrogen and ammonia. It is converted through the sewage treatment and disposal process to nitrate, which moves rapidly through the environment. It is an essential nutrient and high concentrations can lead to biological growth and eutrophication. Fortunately biological growth in most New Zealand streams is typically limited by low concentration of phosphate, another essential nutrient for growth. While municipal sewage typically contains about 7 mg/l of phosphorus (NZ LTC, 2000), household products such as laundry powders detergents can concentrations up to 50mg/l (Patterson, 2004).

3.2. Soil

Soil type is a critical parameter in determining the size of a drainage field. A common failure of on-site systems is that the hydraulic load does not match the drainage properties of the soil. Overloading results in effluent rising to the surface and ponding, or run-off if the site has a slope. Most councils adopt guidelines to assist in design, as it can be very dependant on soil types and rainfall in a particular area.

Clay soils not only have poor drainage but are also sensitive to salt (sodium) that can disrupt the structure of clay soils. While some sodium can be removed in biological processes in wastewater treatment, Patterson (2004) identifies it as a common additive to dishwashing detergents and washing powders. Caution is required to ensure that soils are not adversely affected by on-site disposal of sewage.

Some clay soils can be prone to cracking which can result in rapid transport of water and contaminants through the soil with minimal treatment.

3.3. Water Table

Where there are high discharges of water to groundwater and low movement of groundwater, the water table can rise. This reduces the distance to groundwater and consequently the ability of the soils to remove contaminants, particularly microbial pathogens. Higher groundwater levels may increase discharge to local streams.

4. RISKS FROM ON-SITE SEWAGE SYSTEMS

The main health risks from on-site systems are contamination of drinking water and food by microbial pathogens and nitrate values above the Drinking Water Standard. The behaviour of these contaminants in the receiving environment is discussed below.

4.1. Nitrate Removal and Transport

Most nitrogen in raw of sewage is in the form of organic nitrogen or ammonia. In aerobic environments such as surface water, or shallow groundwater, ammonia is rapidly oxidized to nitrate. Nitrogen is unlikely to be removed within a standard on-site system. Some systems are available, but their effectiveness is unknown. Currently five systems are being evaluated by Environment Waikato (Fletcher *et al.* 2006).

Once in groundwater nitrogen tends to behave conservatively (i.e. not removed). At Yaldhurst on the fringes of Christchurch, groundwater used by residents for drinking water was found to be slightly contaminated with nitrate, which increased in concentration as distance (and households) increased. On-site septic tanks that discharged to groundwater at 10-14m, via 4m deep soak holes (Sinton, 1982) were presumed to be one of the major contaminant sources. A two dimensional model of contamination of the groundwater by Pang et al. (2006) confirmed cumulative contamination by nitrate. McCray (2005) has also identified that dilution has only a limited ability to control nitrate concentrations.

4.2. Microbial Removal and Transport

For most on-site systems the disposal system is an integral part of the microbial pathogen removal process. The mechanisms that remove pathogens are

- physical 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 e.g. food source for other micro-organisms, which are most active in the aerobic zone in the upper 200mm of soil
- chemical e.g. chlorination

As well as these processes micro-organisms will also die-off over time. This is an important removal mechanism for bacteria that don’t form spores. Spore forming bacteria are able to survive in a non-vegetative state for a longer period.

The transport of microbial pathogens through unsaturated soil to groundwater is highly dependent on the receiving environment. Older literature reviews suggest that bacteria can be removed within 600-900mm (Gunn, 1997), but more recent data on movement of bacteria and viruses show that greater soil depth may be required, particularly for viruses which are smaller than bacteria. Nicosia *et al*. (2001), found viral contamination at 600mm in a field study on septic tank drainage fields. At Yaldhurst, Christchurch, 23 of 25 wells, which were used by residents for drinking water, were found to be contaminated with indicator bacteria during monthly sampling over an eight month period (Sinton, 1982). The impact on drinking water quality was minimized by the distance between houses that varied from about 130m to 360m (Pang *et al*. 2006). At Burnham, Sinton (1986) showed faecal indicator contamination in an unconfined sand and gravel aquifer, with the water level at 9-10m. The shallow bores were 10m deep and up to 9m distant from the 5.5m deep boulder pit receiving septic tank wastewater. The radial pattern of contamination suggested groundwater mounding beneath the boulder pit. Some sealing of the soakage pit occurred, but 80% of tank effluent rapidly percolated through the side walls into the groundwater through a preferential pathway. To achieve the New Zealand Drinking Water Standard of no *E. coli* in 100ml, a down gradient separation distance of 180m was calculated. While a boulder pit in alluvial gravels might not be expected to provide much removal of microbial contamination, application of oxidation pond effluent, by border dyke, to the silt loam soils at Templeton Canterbury, (15-25cm thick), also shows microbial contamination of the groundwater at 12-13m (Sinton *et al*., 1997). Coliphages showed greater attenuation than faecal coliforms in the 13m above the groundwater, but travelled faster in the aquifer. Contamination of groundwater up to 445m was observed.

These examples show that in coarse gravels, and shallow soils removal in the unsaturated vadose zone below the soil, but above groundwater is low. Although data specific to transport of micro-organisms in unsaturated New Zealand soils is scarce, a preliminary relative risk model of microbial transport has been undertaken (McLeod *et al*, 2005). Because of lack of specific data, soil types have been categorised as high or low risk. High risk soils include alluvium, fractured rocks, while compact sedimentary rocks tend to be categorised as low risk. Pang's modeling of indicator bacteria and phage (a virus that infects bacteria) through soil shows that about 2m is required for one log removal (i.e. reduction from 1,000,000 to 100,000) for sandy soils. Further work is currently being undertaken by Pang and colleagues to provide estimates of vertical setback distances as part of a Foundation for Science Research and Technology Project.

Once in groundwater microbial contamination can occur over an extensive length depending on the nature of the aquifer. Pang *et al*. (2005) have modelled the transport of viruses and bacteria injected directly into different types of aquifers (i.e. worst case scenario without any removal by overlying soil). The concentrations of *E. coli* in raw sewage is about 1,000,000cfu[3]/100ml, so to achieve the drinking water standard of zero *E. coli* a seven log removal is required (<1cfu/100ml). A similar level of removal is required for viruses to ensure 0/100L. Enterovirus are typically <10,000pfu/L at Christchurch City Council wastewater treatment plant, but concentrations of 100,000pfu[4]/l have been reported in Costa Rica (Dahling, et al., 1989). Setback distances have been estimated by Pang *et al*. (2005)from modelling the transport of bacteria and viruses in groundwater, i.e. assuming the worst case that no removal occurs in the unsaturated zone. This is likely to be an overestimation, as Sinton (1982) shows at Templeton that indicator bacteria contamination is mitigated within 130m, yet at Templeton contamination was recorded at 300m (bore 11). . To achieve a seven log reduction in viruses and bacteria Pang et al (2005) a setback distance of 37-44m is required for river and coastal sand aquifers, 33-61m in clean sandy fine gravel aquifers and 125-280m in coarse gravel aquifers. However, as contamination increases, as it might with discharges over many years, the model shows that the distance required to ensure 7-log removal increases to 33-129m for contaminated sandy fine gravel aquifers and 1.7-3.9km in contaminated gravel aquifers.

[3] cfu colony forming unit
[4] pfu plaque forming unit

Restrictions on vertical and horizontal separation distances are most commonly used to minimize effects. The most important management tool is to restrict the density of septic tanks (Yates, 1985). USEPA has designated areas with more than 1 system per 16 acres as regions of potential contamination of groundwater (US EPA, 2002).

5. GISBORNE GROUNDWATER MONITORING

This report proposes that a short term investigation be undertaken to confirm if Wainui has contamination from on-site systems, identify other sites for monitoring and a determine long term monitoring plan to identify trends from changes in land use, or increases in housing density.

5.1. Identify High Risk Sites for Monitoring

The nature of the receiving environment has a significant effect on the potential risks associated with on-site discharges. Critical parameters in determining the risk of contamination of waters from on-site sewage disposal systems are

- Type of on-site system
  - Level of treatment in the wastewater treatment plant
  - Material used in drainage trench
- Soil
  - Types
  - Permeability
  - Depth
- Groundwater
  - aquifer characteristics e.g. confined, unconfined, high velocity
  - height of groundwater table
  - use of groundwater
  - water quality
- Separation distances
  - To receptor e.g. a bore for taking household drinking water, shellfish beds
  - between on-site systems

A table could be used summarizing the features and qualitative level of risk for microbial contamination as shown below in Table 2.

Table 2 Summary of risk factors for microbial contamination of groundwater

Factor	High		Low
Land use	High density of on-site systems, intensive farming	→	Horticulture, forest, bush
Soil type	Gravel, basalt	→	Sandy/loam
Depth of soil	Shallow soils	→	Deep soils of silt loam or clay
Groundwater	Drinking water, aquaculture	→	Not used
Groundwater depth	Shallow	→	Deep

Factor	High		Low
Groundwater protection	Highly permeable overlying soils	→	Confining layer
Aquifer characteristics	Preferential flow paths, high yielding	→	Low yielding

A brief overview of the aquifer in Gisborne Plains shows a sand/gravel aquifer with shallow groundwater e.g. PA87 is 1.8m. Previous studies have shown contamination of groundwater in the Wainui area by faecal coliforms/*E. coli*. As there is a high density of on-site systems in this area and water is used for drinking water, it is recommended that groundwater monitoring be undertaken. Unfortunately the "control" site is also contaminated.

Characteristics given above should be used to identify high risk areas. Gisborne's well database should be to identify existing wells with the following characteristics

- high groundwater levels
- shallow bore depth
- used for drinking water
- in close proximity to on-site systems
- information on depth of screens (if possible).

Field inspections of potentially suitable wells are needed to confirm good well-head protection, that the depth to the water table can measured and identify the surrounding land use. Ideally, at least three wells should be selected to allow the direction of groundwater flow to be determined. The wells need to be surveyed in (or high quality GPS). If wells are situated close to each other, groundwater mounding may affect localised groundwater flow (Sinton, 1986). One well would be a control. If the only suitable control well appeared to be contaminated, the source of contamination could be identified using faecal source markers. However, to undertake faecal source marker tests on a regular basis would be very expensive.

5.2. Traditional Microbial Indicators

Microbial pathogens in sewage can vary depending on illness. 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. Its presence in groundwater indicates that potential for faecal contamination and therefore a risk to public health. *E. coli* is more specific than total coliforms that include organisms commonly found in soil, or faecal coliforms that may include *Klebsiella, Enterobacter and Citrobacter* that able to grow under the conditions defined for the culture of faecal coliforms. However, it is also present in birds, cows, and domestic animals. Activities other than discharge may be the source of contamination.

5.3. Chemical and Microbial Markers for Faecal Source Discrimination

As identified in the Wainui study (Gisborne District Council undated) , *E. coli* can be present when there are other land uses such as farming. In the presence of high *E. coli* concentrations and when there is more than one potential source other indicators need to be used to confirm the source of contamination. Contamination of groundwater by animals may be as significant as from human sewage as common microbial pathogens, which are carried by animals but cause disease in humans, are *Campylobacter*, *Salmonella*. However, identifying the source allows a council to implement the most appropriate controls.

Combinations of chemical and microbiological markers allow the source of faecal material to be identified. If investigated to an appropriate degree, inference can be drawn about the proportions of various sources and the 'freshness' of the faecal input. The range of tools to distinguish between include

- Fluorescent whiteners determined initially by screening and then quantified
- Cholesterol and related sterols which occur in animals and humans in different ratios
- Microbiological markers

A brief description of some techniques is given below.

5.3.1. Fluorescent whitening agent (FWA)

Fluorescent whitening agents (FWA) are common constituents of washing powders that adsorb to fabric and brighten clothing. They are synthetic compounds not found in nature. There are a range of FWAs, but only one (4,4'-bis[(4-anilino-6-morpholino-1,3,5-triazin-2-yl)-amino]stilbene-2,2'-disulfonate) is used in New Zealand. Most household plumbing mixes effluent from toilets (blackwater) with "grey water" from washing machines. As a consequence, in both septic tanks and community wastewater systems, FWAs are usually associated with human faecal contamination. However, there are some circumstances where FWA's may only indicate greywater discharges. Because of this, sole use of FWAs without other complimentary techniques may not be appropriate in some circumstances. ***The presence of FWAs indicates human effluent.***

Preliminary identification of FWA can also be undertaken using its signature fluorescent spectrum, by scanning through a defined wavelength range. This is a rapid and inexpensive method, which is able to provide preliminary and discriminatory information on the presence of FWAs in an aquatic environment. Once identified a quantitative analysis can be undertaken. Analysis is can be expressed in parts per billion (ppb) equivalent to μg/litre. FWAs have been widely used to evaluate a range of water bodies. The current HPLC based methodology has a detection limit of 0.01 ppb. Practical experience with this tool, supported by faecal sterol analysis, molecular analysis and physical investigation, has generated the following general "rules of thumb" for interpreting analysis.

- Detected levels of less than 0.1 ppb it may be difficult to easily identify a source. Additional indicators are required to make a determination.
- Levels of 0.1 to 0.2 indicate strongly indicate a human source, but additional indicator are advisable.

- Levels above 0.2 very strongly indicate high levels of human sewage inputs that are invariably supported by other indicators and site investigation.

FWA was detected in 11% of 86 groundwater samples taken at Yaldhurst, during May and June 1986, indicating that it is a suitable indicator of on-site sewage disposal faecal contamination in a boulder pit discharge and that it can be measured in groundwater. However, it must be noted that non-detection does not indicate the absence of OSTD contamination (Close *et al.*, 1989). Statistically, there was a slight correlation ($P<0.05$) between faecal coliforms and FWA. This was attributed to there being more than one source of faecal contamination in the area and the temporal variability of septic tank discharge.

5.3.2. Faecal Sterols

Faecal sterols are a group of C27-, C28- and C29-cholestane-based sterols found mainly in animal faeces. The sterol profile of faeces depends on the interaction of three factors. Firstly, the animal's diet determines the relative quantities of sterol precursors (cholesterol, 24-ethylcholesterol, 24-methylcholesterol, and/or stigmasterol) entering the digestive system. Secondly, animals differ in their endogenous biosynthesis of sterols (for example, human beings on a low cholesterol diet synthesise cholesterol). Thirdly, and perhaps most importantly, is that the anaerobic bacteria in the animal gut biohydrogenate sterols to stanols of various isomeric configurations. Analysis of the sterol composition of animal faeces can generate a sterol fingerprint, which can be quite distinctive from one species to another.

Faecal sterols analysis was performed, by filtering 2–4 litres of river water onto glass fibre filters. Filters were stored frozen until they were analysed using the extraction procedure described by Gregor et al. (2002). Each sterol and stanol result is expressed as parts per trillion (ppt). The key sterol values reported were the level of coprostanol, and two key ratios.

- **Coprostanol** is the principal human biomarker. High relative amounts indicate fresh human faecal material.
- **Coprostanol:24-ethylcoprostanol:** These stanols are present in both human and herbivore faeces, but in significantly different amounts. Human faecal pollution typically has a ratio greater than one.
- **Coprostanol:cholestanol:** The ratio of coprostanol:cholestanol can indicate whether the coprostanol present is of faecal origin. A ratio greater than 0.5, suggests faecal contamination (preferential reduction from sterol by gut microbiota), whereas a ratio less than 0.3 may suggest environmental reduction by, for example, anaerobic bacteria in sediments.

5.3.3. Molecular Indicators

There are a range of microorganisms present in faeces, which are specific to animal hosts. Difficulties in culturing and identifying these organisms have however limited their useful application to faecal source identification. An alternative approach is to extract total DNA from a water sample and examine the sample using PCR for DNA from these source specific organisms. Two such source specific organisms are *Bifidobacterium adolescentis*, and an unculturable *Bacteroidetes*, both of which have only been detected in human faecal samples. ***The presence of these markers therefore indicates human effluent.***

Less well characterized are the herbivore *Bacteroidetes* marker, and a marker specific for Ruminococcus group of bacteria. Neither of these have been detected in human effluent, but are common in faeces of dairy cows, sheep and other farmed animals.
The presence of these markers therefore indicates non-human source.

5.4. Groundwater Monitoring

Routinely *E. coli*, nitrate and ammonia should be measured every quarter for sites where the risk factors are high (high level surveillance wells). After five years the data could be reviewed to determine when peak contamination occurs. While contamination from human sewage will occur when groundwater levels are highest, it is likely that contamination from farming may occur contaminants are flushed from the soil into the groundwater, e.g. spring rains or irrigation. This would need to be confirmed by initial quarterly sampling. A few additional sites in shallow groundwater that is sensitive to contamination by land use should also be selected as it is impossible to predict long term development (low level surveillance wells).

If during routine monitoring of groundwater high *E. coli* concentrations are measured, an extra litre of sample be taken and sent to ESR for screening for FWA. If the groundwater is used for drinking water, and confirmation of the faecal sources is required, then a quantitative analysis of FWA and the other chemical and microbial markers could be undertaken.

The Wainui site has already been identified as being potentially contaminated and further investigation to confirm the source could be undertaken with additional funding from Envirolink. This would also provide an opportunity to determine the suitability of the chemical and microbial markers for source discrimination.

6. CONCLUSIONS AND RECOMMENDATIONS

Domestic sewage contains contaminants that can adversely affect public health and the environment. The concentrations of pathogens in on-site sewage can be greater than in municipal systems. While gastroenteric illness is not likely to be reported, as few people visit the doctor, there is a potential health risk if partially treated effluent is discharged to groundwater and subsequently used for drinking water. The potential effect is exacerbated by secondary infections that can spread disease rapidly in a community. While separation distances can provide some protection from microbial contamination, it appears that nitrate levels are less likely to be mitigated by separation distance. The two key parameters to measure are therefore those that indicate faecal pollution (e.g. *E. coli*) and nitrate. Adverse effects on the environment include eutrophication, dispersion of clay soils and elevated groundwater levels, which may lead to groundwater mounding.

We would recommend identifying high risk sites and selecting appropriate wells for long term monitoring (high level surveillance wells). The potential for long term development should also be considered in identifying key areas. A few additional sites in shallow groundwater that is sensitive to contamination by land use should also be selected, as it is impossible to predict long term development (low level surveillance wells).

In high risk areas groundwater should be tested quarterly for *E. coli*, ammonia, nitrate, electrical conductivity and the water levels in the wells recorded. Sampling should be timed to reflect periods when the highest level of contamination is likely. Once a database is established the frequency of sampling could be reduced.

The Wainui site has already been identified as being potentially contaminated and further investigation to confirm the source could be undertaken. This would also provide an opportunity to determine the suitability of the chemical and microbial markers for source discrimination.

REFERENCES

Albert M.J. 1986. Enteric adenoviruses: Brief Review. Archives of Virology. 88:1-17.
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
Close, M. E., Hodgson, L.R. Tod, G. 1989. Field evaluation of fluorescent whitening agents and sodium tripolyphosphate as indicators of septic tank contamination in domestic wells, New Zealand Journal of Marine and Freshwater Research 23:563-568.
Fletcher, B. P. Futter, A. Lowe. (2006) Testing the performance of advanced on-site effluent treatment systems (OSET trial). In *New Zealand Land Treatment Collective: Proceedings for the 2006 Annual Conference*, Nelson 14-17 March 2006
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. 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 New Zealand guidelines for the utilisation of sewage effluent on land. 2000 New Zealand Land Treatment Collective and Forest Research Institute
Gisborne District council Undated. Wainui Ground and Surface Water. A summary of microbiological and chemical data collected from (1980-2005).
http:// www.ce.berkley.edu,
http:/www-micro.msb.le.ac.uk
http://www.surv.esr.cri.nz/surveillance/monthly_surveillance.php
Marterns D. (1995). Impacts of On-site Domestic Wastewater Disposal in Sydney in *NZWWA Conference Proceedings*.
McCray, J.E., Kirkland, S.L. Siegrist, R.L. and Thyne, G.D. 2005. Model parameters for simulating fate and transport of on-site wastewater nutrients. Ground Water 43: 628-639.
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 waterbodies. 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.
NZ LTC 2000. New Zealand Guidelines for Utilisation of Sewage Effluent on Land. New Zealand Land Treatment Collective and Forest Research.
New Zealand Ministry of Health. 2000. Drinking-Water Standards for New Zealand.
Patterson, R. A. 2004 A resident's role in minimising nitrogen, phosphorus and salt in domestic wastewater. Tenth National Symposium on Individual and small community

sewage systems proceedings. Kyle R. Mankin (ed). Scaramento, California March 21-24 ASAE 740-749
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, p165-194.
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
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.
Schroeder, E.D. and Wuertz, S. 2003 Bacteria. *In* The Handbook of Water and Wastewater microbiology. Ed D. Mara and N. Horan Academic Press. 2003.
Stott, R. 2003 Fate and behaviour of parasites in wastewater treatment systems. *In* The Handbook of Water and Wastewater Microbiology. D. Mara and N. Horan (Eds) Academic Press. 2003.
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
US EPA Onsite wastewater treatment systems manual. 2002 EPA/625/R-00/008.
Wadell G. 1984. Molecular epidemiology of human adenoviruses. Curr. Topics Microbiol. Immunol. 110:191-220.
Yates, M. V. 1985 Septic tank density and ground-water contamination. Ground Water 23: 586-591

APPENDIX 1 REPORT DISTRIBUTION

Copies have been made and distributed to:

Judith Robertson Gisborne District Council (2 copies)
Margaret Leonard ESR, CSC

Further copies of this report may be obtained from:

Information Research Services
Kenepuru Science Centre
P O Box 50 348
Porirua