KEEPING WATERS APART – NEW SEPARATION DISTANCE GUIDELINES FOR ONSITE WASTEWATER SYSTEMS AND WELLS

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ABSTRACT

The discharge of domestic wastewater to ground and the proximate abstraction of groundwater for domestic purposes can contaminate drinking water. Adequate separation distances between these two activities can reduce the likelihood of well-water contamination. However, none of the existing separation distances used by regional councils are designed to protect against the most infectious pathogens, viruses. The environmental robustness of these organisms means that they may still be viable, and therefore infectious, after travelling substantial distances through the ground. Moreover, present separation distances do not take account of how differing subsurface materials affect contaminant transport. To address these shortcomings, a two-year, Envirolink-funded project developed scientifically defensible separation distance guidelines, based on virus transport through various combinations of hydrogeological settings and using Monte Carlo techniques to take account of uncertainties in the input data. The Guidelines document, with a full technical discussion, is now complete and available on the Envirolink website (http://www.envirolink.govt.nz/Envirolink-reports/). This paper briefly describes the guidelines, outlining the approach taken to the modelling and its limitations, and explains the use of the Guidelines.

KEYWORDS

Separation distance, setback distance, onsite wastewater disposal, septic tank, drinking water, viruses, well, bore.

1   INTRODUCTION

1.1   BACKGROUND

Aquifers are sources of drinking water for many households and communities in New Zealand. All regions of New Zealand have groundwater resources that are used as sources of domestic water for some dwellings. About 50,000 wells are registered on regional council databases as used for domestic water supplies, and it is likely that this is only about half of the total number of wells used for domestic supplies, as many are not registered[1].

About 270,000 on-site domestic wastewater systems are in use in New Zealand (MfE, 2008). Most households that have a private water supply well also have an on-site wastewater system. The well and the on-site wastewater system for a dwelling are often located in close proximity to the dwelling, and to each other. Neighbouring wells and on-site domestic wastewater systems may be close by, particularly in small rural settlements and areas of rural-residential housing and lifestyle blocks. Domestic wells generally access shallow groundwater, or where deeper groundwater is the source of supply, this is usually from an unconfined aquifer. In both situations the water quality is vulnerable to contaminants discharged from on-site domestic wastewater systems.

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[1] Personal communications and data from groundwater staff of 11 regional councils and three unitary authorities.

The drinking water taken from private domestic wells in New Zealand is, in almost all instances, not treated before use. Many small community water supplies do not have water treatment. A survey of small water supplies serving less than 500 people (in residences, small institutions and commercial users such as schools, marae, hospitals, hotels and restaurants) was undertaken for the Ministry of Health in 2002. It showed that half of these supplies are sourced from groundwater and that only one-third of these systems had any form of treatment for microbiological contaminants (NZWERF, 2002).

A wide range of disease-causing microorganisms (pathogens) can be present in sewage. Three broad classes of pathogens are recognised as being a threat to human health: bacteria (e.g. *Campylobacter*), protozoa (e.g. *Cryptosporidium*) and viruses (e.g. hepatitis A virus). The presence or absence of these organisms in sewage depends on the number of infected people in the contributing population. In large populations common pathogens will almost always be present. In dwellings with on-site wastewater treatment and disposal systems, there may be extended periods during which pathogens are absent in the sewage because none of the occupants are infected. However, a household with infected occupants will produce sewage effluent that contains pathogens.

The pathogens in faecal matter present a range of health risks, but viruses present the greatest health concern because they:

- are present in groundwater contaminated by sewage

- are environmentally robust so are expected to survive longer in the soil and water environment than bacteria. Longer survival may mean viruses remain infective after being carried longer distances than other pathogens in groundwater

- are highly infectious, more so than bacteria or protozoa. Ingestion of a very small number of viruses can cause infection, although the infective dose depends on the virus species

- can be resistant to disinfection processes, and have been detected in drinking water that met acceptable specifications for treatment and levels of conventional indicator organisms.

Some of the viruses in sewage discharged into the ground are adsorbed to soil and subsurface media, but the remainder are carried through into the groundwater in which they are carried away from the discharge area. The extent of adsorption and the distance they can be carried depend on the nature of the soil and aquifer materials – the hydrogeological settings. These vary throughout the country.

In 2007, the regional councils' Groundwater Forum identified the need for a tool for determining satisfactory separation distances between on-site wastewater discharges and neighbouring wells. To this end, a project to produce separation distance guidelines, based on viral transport through a range of hydrogeological settings with Monte Carlo modelling techniques to allow uncertainties to be taken into account, was funded by Envirolink.

The output from this project was a document: *Guidelines for separation distances based on virus transport between on-site domestic wastewater systems and wells* (the Guidelines), available on the Envirolink website http://www.envirolink.govt.nz/Envirolink-reports/. The guidelines are based on existing information obtained from either the scientific literature or field measurements made by regional councils. This paper briefly describes the guidelines outlining the approach taken to the modelling and its limitations, and explains the use of the Guidelines.


2 DEVELOPMENT OF THE GUIDELINES

2.1 APPROACH

To determine the overall attenuation in the virus concentration between the wastewater entering the wastewater treatment tank and the well, four locations where virus concentrations may be reduced were identified, as shown in Figure 1.

1. The wastewater treatment tank

2. The wastewater disposal field and the soil beneath the disposal field

3. The unsaturated (vadose) zone above the water table

4. The groundwater as it flows through the aquifer (saturated zone).

Figure 1   Overview of components required to determine the separation distances and primary data requirements
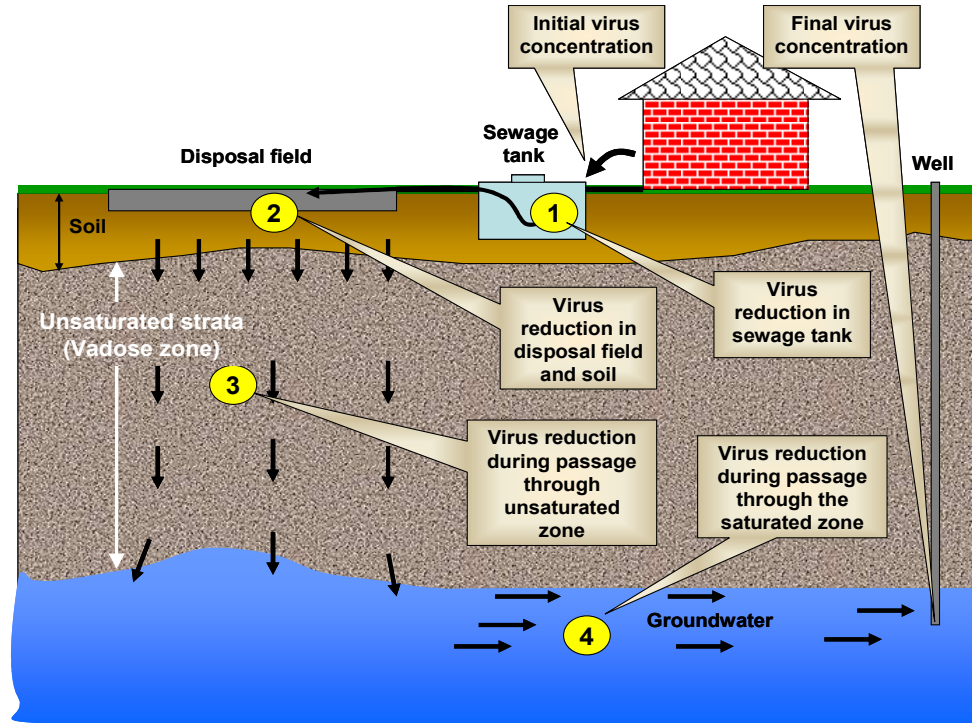
It is convenient to express the reduction in virus concentration in each component as a $\log_{10}$ value, e.g. a 99% reduction expressed as a $\log_{10}$ value is 2. This allows the virus reductions required to be determined through addition and subtraction. The overall reduction in the virus concentration required to provide safe water at the well can be calculated by subtracting the $\log_{10}$ value of the acceptable virus concentration in the well water from the virus concentration in the sewage expressed as a $\log_{10}$ value. Subtraction of the $\log_{10}$ reductions in components 1 and 2 (the wastewater treatment tank and the disposal field and soil) from the required overall reduction yields the reduction that must be achieved during transport through the vadose and saturated zones combined. For each combination of hydrogeological setting in the vadose and saturated zone, the modelling calculated the $\log_{10}$ reduction at increments of vadose zone thickness and horizontal separation. Thus, for given types of onsite treatment, disposal system and soil, the separation distance required for a particular vadose zone thickness can be determined.

A measure of the uncertainty in the modelling output was obtained through the use of Monte Carlo (probabilistic) techniques. In situations where values input into a model are uncertain, i.e. there is a range or distribution of values, Monte Carlo techniques allow the variable to be input as a probability distribution, rather than a unique value. Probabilistic calculations produce an output that is also a probability distribution, which allows a result be stated that meets a required level of confidence. Ninety-five percent confidence levels were used for this work, i.e. for the separation distances given in the Guidelines there is a 1 in 20 chance that the distance is too short, and the virus concentration in the water may exceed the acceptable concentration.

2.2   THE REQUIRED VIRUS REDUCTION

2.2.1   INTRODUCTION

To calculate the virus reduction required overall , two pieces of information are required:

1. the number of viruses initially in the wastewater and

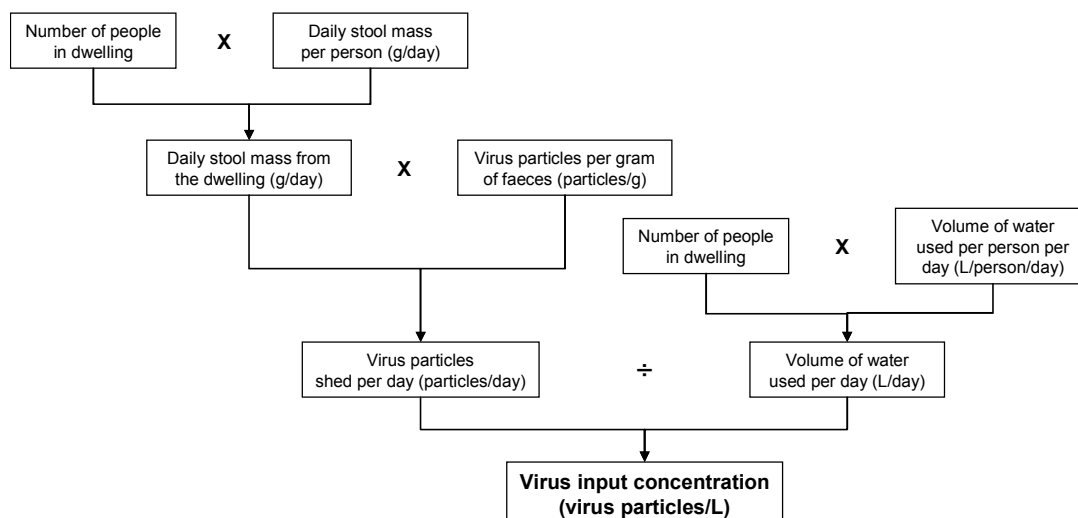2. the tolerable virus concentration in the well water.

Both figures depend on the virus. Five pathogenic viruses or virus groups that are linked to waterborne disease were initially considered for the calculations, however, the calculations were based on rotavirus and hepatitis A virus only to simplify the decisions required in using the guidelines.

The overall $\log_{10}$ reduction required is obtained by subtracting tolerable virus concentrations from initial numbers (as $\log_{10}$ values).

2.2.2   VIRUS CONCENTRATIONS IN WASTEWATER

Sampling directly from on-site domestic wastewater systems to determine the virus concentrations in wastewater is impracticable because of the need to sample when at least one resident is infected and the difficulty in knowing these events occur. Consequently, the estimation of virus concentrations in domestic wastewater entering the system from a single dwelling was made on the basis of what is known about typical virus concentrations in human faeces. The dataset needed for the calculation and how these data were combined is shown in Figure 2. The calculations assume all in the household shed viruses, although they may not be ill.

Figure 2   Algorithm showing the data requirements and their relationship in the calculation of the virus concentration entering a wastewater treatment tank from an infected household

2.2.3   TOLERABLE VIRUS CONCENTRATION IN THE WELL WATER

Figure 3 shows an overview of the approach to determining the tolerable virus concentration in the drinking water. The *Drinking-water Standards for New Zealand* set no tolerable daily probability of infection. A value set by the USEPA, which has also been used in other countries, was used for the modelling.

The USEPA (USEPA, 1989) has set requirements for the removal of *Giardia* by water treatment plants to meet a tolerable probability of microbiologically-caused infection of 1 in 10^4 per year, (i.e. no more than one person in a population of 10,000 becoming ill from waterborne pathogens per year). The USEPA stated:

"*EPA believes that public water supplies should provide much greater protection than simply that necessary to avoid this level of risk from waterborne disease. EPA believes that providing treatment to ensure less than one case of microbiologically caused illness per year per 10,000 people is a reasonable goal.*"

Note that this statement refers to *illness*, but it is the probability of *infection* that the USEPA finally used to determine the water treatment requirements. The distinction is important because not everyone infected

becomes ill. As a result, a target based on infection probability is more protective than one based on the probability of illness.

Figure 3   Algorithm for calculating the tolerable virus concentration in water in a well
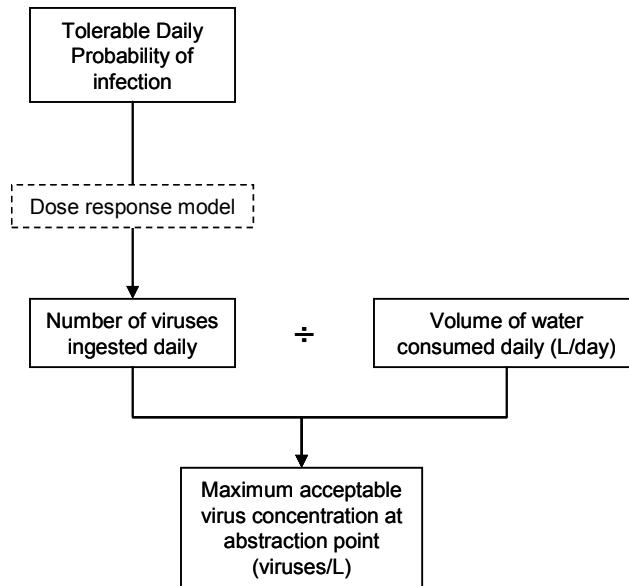
Dose-response models are the mathematical expressions that relate the number of infective organisms ingested by an individual to the likelihood of that individual becoming infected. The dose required to infect an individual depends on the species of pathogen. Moreover, individuals possess differing levels of resistance to infection. Thus a specific dose that will cause infection cannot be given, and infection of an individual has to be expressed as a probability.

The dose-response model used in this modelling was the simplified beta-Poisson model[2], which can be expressed as:

$$P_d = 1 - \left[1 + \frac{N}{N_{50}} \left(2^{\frac{1}{\alpha}} - 1 \right) \right]^{-\alpha}$$

where N_{50} is the median infective dose, and α is a shape parameter for the beta distribution.

Data from two New Zealand surveys (Russell et al., 1999, Parnel et al., 2003) were used for the water consumption values. The surveys show a median daily consumption of 600 mL of unboiled water for people older than 15 years, with a 95th percentile of 2,100 mL.

2.3   VIRUS REMOVAL IN THE WASTEWATER TREATMENT TANK

The guidelines do not provide virus reduction figures for all types of treatment system, only two generic categories, primary and secondary treatment systems. A few studies have reported results for virus removal in conventional septic tanks (primary treatment). A range of virus reduction values is reported, but a reduction of approximately 75% (0.6 $\log_{10}$) was found in several studies (e.g. Higgins et al., 2000; CRC, 2004) and is the

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[2] A rigorous derivation of this model gives: $P_d = 1 - {}_1F_1(\alpha, \alpha + \beta, -N)$, where ${}_1F_1$ is the Kummer confluent hypergeometric function. The approximation becomes poorer at large N (Haas et al., 1999).

value used in the Guidelines. Only one study (CRC, 2004) reports virus removal in aerated systems, and gives a reduction figure of 90% (1 $\log_{10}$).

Monte Carlo modelling was not used in calculating virus removal in wastewater treatment tanks. A single value only is used for whichever treatment system is the closest approximation to the tank at the site.

To take account of disinfection, where it is used, a value of 1 $\log_{10}$ is given for the virus reduction resulting from disinfection by ultraviolet light (UV) or chlorine. A CRC factsheet (CRC, 2004) reported a virus reduction of 1–1.7 $\log_{10}$ by disinfection systems. The conservative end of this range was selected because of the relative ease with which the performance of such systems can decline with inadequate maintenance.

2.4   VIRUS REMOVAL IN THE DISPOSAL FIELD AND SOIL

2.4.1   REMOVAL IN THE DISPOSAL FIELD

The guidelines give values for calculating the reduction in virus concentration in three types of disposal field, conventional trench, shallow dripper and mound. Some virus removal is achieved in the disposal field by the distribution aggregate medium used, e.g. pea gravel in the case of the conventional trench and sand in the case of the mound. The reduction in virus concentration in the disposal field (a $\log_{10}$ value) is calculated by multiplying the depth of aggregate the wastewater passes through (in metres) by the virus removal rate per metre ($\log_{10}$/m).

This calculation excludes the virus removal that occurs in soil surrounding, or below, the sparge lines[3] of the disposal field. Removal in the soil is covered next.

2.4.2   REMOVAL IN SOIL

The extent to which soil horizons can reduce the microbial loading of wastewater percolating through them depends on such factors as their composition, structure and thickness. Estimates of virus removal in New Zealand soils were made on the basis of two studies of bacteriophage (viruses that infect bacteria) (Pang et al., 2008; Mcleod et al., 2008). By combining information from the two datasets, estimates were made of spatial removal rates ($\log_{10}$/m) for a range of generic New Zealand soil types (based on the New Zealand Soil Classification).

The removal of viruses in a particular soil, expressed as a $\log_{10}$ value, is calculated by multiplying the removal rate ($\log_{10}$/m) by the soil thickness (m).

2.5   VIRUS REMOVAL IN THE VADOSE ZONE

To provide flexibility so that the guidelines can be applied in different hydrogeological settings, the vadose zone modelling was carried out for 10 settings, listed below.

- Alluvial gravel
- Alluvial sand
- Coastal sand
- Pumice sand
- Sandstone and non-karstic limestone
- Karstic and fractured rock (e.g. basalt and schist).
- Silt
- Clay
- Ash
- Peat

Contaminant transport was modelled using a one-dimensional transport model (Bidwell, 2000). Two models were run in parallel for these calculations: the first described matrix flow (even movement through the bulk of

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[3] Wastewater distribution lines with fine holes along their length through which the wastewater is fed into the soil.

the subsurface material), and the second, the flow through macropores (more rapid movement through cracks and other larger spaces in the matrix).

An unsaturated vadose zone might provide substantial virus removal. However, the vadose zone under a disposal field is unlikely to be unsaturated, and this will influence the extent to which it removes viruses. The level of the groundwater may be many metres below the disposal field, but continual effluent discharge will result in saturated flow conditions dominating the flow of water and microbes. It generally takes 24 hours of drainage for a "soil" to return to nominal field capacity[4], so that effluent from a normally functioning wastewater treatment tank will be moving in hydraulic conditions above field capacity for most of the time (pers. comm. M Close, ESR).

The models were run in conjunction with @RISK[®5] (software providing Monte Carlo calculation capability) to allow input parameters to take a range of values. The output from the Monte Carlo simulation was a distribution of possible $\log_{10}$ reductions in virus concentration predicted to be achieved at the specified vadose zone thickness.

2.6   VIRUS REMOVAL IN THE SATURATED ZONE

As with the vadose zone modelling, the saturated zone modelling was carried out for a suite of hydrogeological settings to make the guidelines more broadly applicable. The settings modelled were the same as for the vadose zone except that silt, clay, ash and peat were omitted.

Figure 4 shows the steps in modelling the saturated zone. In brief, groundwater flow and virus transport were modelled using MODFLOW[6] and MT3D[7] software packages, respectively. These modelling packages require the hydraulic properties (hydraulic conductivity and porosity) of the aquifer materials and removal rates, amongst other values as inputs. The heterogeneous nature of most aquifer systems means that their hydraulic properties vary randomly throughout the aquifer, and cannot be analytically calculated. Instead, stochastic (probabilistic) approaches have to be used for modelling.

Wherever possible, field data were used to determine the hydraulic property fields to use for modelling each type of aquifer. The field data consisted of regional scale (tens of kilometres) measurements of hydraulic properties, obtained from regional council pump-test data, and, for alluvial gravels, small scale (tens of metres) measurements, obtained from ESR tracer tests. Variograms summarise the spatial variability of these field data. A variogram is a mathematical description of how the differences in the value of a property at two locations, change with the separation between the locations.

Using the mean values of hydraulic conductivity and porosity from field data (supplemented with literature information, as necessary), and variogram descriptions adjusted to represent the predictive model scale, the PEST[8] utility FIELDGEN was used to generate multiple realisations[9] of fields for both parameters for each aquifer type. All of these realisations are considered to be equally likely representations of the aquifer characteristics, given the available data.

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[4] Field capacity is the water content held in soil.
[5] Palisade Corporation,798 Cascadilla St., Ithaca, NY USA 14850.
[6] McDonald, M.G. and Harbaugh, A.W. (1988). A modular three-dimensional finite-difference ground-water flow model. USGS Techniques of Water Resources Investigations, Book 6, Chapter A1. Washington DC.
[7] Chunmiao Zheng and P. Patrick Wang (2006). A modular three-dimensional multispecies transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems. (Release DoD_3.50.A) by Department of Geological Sciences Department of Mathematics University of Alabama, Tuscaloosa, Alabama 35487-0338.
[8] Doherty J, 2007, PEST: Model independent Parameter Estimation. Version 11. Downloadable from www.sspa.com
[9] A realisation is one of a number of equally possible descriptions of the hydraulic properties of the aquifer. Each realisation contains a randomly generated hydraulic property value at each point within the aquifer.

Figure 4   *Overview of the saturated zone modelling*

1 Numeric models need hydraulic properties as input.

Gravel only because of data unavailability for other media

Obtain small scale data

Obtain regional scale data

Burnham tracer test data

Regional council pump test data

Calibration of tracer data

2 Hydraulic property uncertainty relates to the groundwater flow paths within an aquifer. Flow paths through heterogeneous aquifers are random and spatially variable, consequently so are the hydraulic properties.

Field data showing the variability of the hydraulic properties are available, but not at the scale of interest. **Variograms** can be constructed to describe this variability. Variograms describe the likely variation in the value of an aquifer property measured at two locations as a function of distance of separation between the locations.

Determine variability of hydraulic properties at predictive scale using variograms

Using **FIELDGEN**

3 **Realisations** are equally likely descriptions of the hydraulic properties. Each is a "picture" of how the hydraulic properties of the aquifer will change through the volume of interest in the aquifer.

Generate 500 realisations

Using **MODFLOW** and **MT3D**

4 Using the hydraulic properties, and how they change at each location in the aquifer, as described by each realisation, the numerical models simulate how the groundwater will flow through the aquifer and from this how the initial virus concentration will change as the viruses are carried through the aquifer.

Simulate groundwater flow and virus transport for each realisation

Determine maximum virus concentration from each realisation for a given separation distance

log10 removal at 50m travel distance

Generate, at each separation distance, a distribution of virus log reduction values

2.7   LIMITATIONS OF THE GUIDELINES

a) The guidelines are only valid for single dwellings. The volumes of wastewater discharged, and numbers of viruses in the wastewater when a household is infected, are based on New Zealand statistics for dwelling occupancy. The guidelines cannot be reliably used when much larger numbers of people are contributing to the discharge, such as a rural school or marae. Wastewater from a larger number of people will contain larger numbers of viruses (in the event of infection) and larger separation distances will be required to provide an adequate reduction in virus numbers.

b) The guidelines protect groundwater wells against a *single* on-site wastewater disposal system. Cumulative effects of more than one disposal system are not taken into account.

c) The guidelines are generic. The *ranges* of data used as inputs for the modelling were to encompass typical values for modelling, not unusual, or specific, situations. The guidelines are designed to provide adequate protection in at least 95% of cases. This means that there will be many situations in which the calculated separation distances over-protect groundwater. This is unavoidable.

d) The guidelines are not appropriate for wells drawing from confined aquifers. The modelling assumes that wastewater percolates through the vadose zone directly into the groundwater. A confining layer

prevents this. Use of the guidelines where the aquifer is confined will result in separation distances that over-protect the groundwater quality at the abstracting well.

e) The guidelines cannot take account of the malfunction of components of the system. For example, the model assumes even discharge of the wastewater over the area of the disposal field. If a shallow dripper system, for example, becomes clogged somewhere within the dripper line and the discharge occurs over a small area, the modelling cannot take account of how this might affect the quality of water at the well.

f) The level of protection provided by the guidelines is based on the range of *typical* periods over which viruses are shed by an infected individual. The guidelines do not take account of infrequent situations where prolonged shedding may occur.

g) Estimates of virus removal are provided for only two generic categories of on-site wastewater treatment systems. This is primarily because of a scarcity of data on the removal of viruses in proprietary wastewater treatment systems.

h) Deterministic approaches (in which the input values are fixed) were adopted for the simulation of virus reduction in the on-site domestic wastewater system (i.e., the treatment tank) and in the disposal field and soil. In contrast, probabilistic approaches utilising Monte Carlo sampling methods were considered important for the vadose and saturated zone modelling.

i) Verification of the guidelines has not been possible. Ideally, the accuracy of the predictions of a model should be verified by empirical testing via aquifer sampling. Verification testing is impracticable in this case. It would require discharging pathogenic viruses into the ground at concentrations that a household of infected occupants would produce. Moreover, a number of sites with suitable orientation and separation of disposal field and well would have to be found, and well water sampled and monitored for days or months.

j) Model outputs are not presented for separation distances less than 40 m. The accuracy of the modelling results at shorter distances is questionable because of the grid size used in the model. A finer grid size would have resulted in model runs times that were unworkable. As the minimum existing separation distances set by councils are of the order of 30–40 m, this limitation was considered acceptable. The exception to this 40 m limit is a 20 m minimum separation distance suggested for pumice sand. The calculated virus reductions are so high in this case, that despite the large calculation uncertainties, 20 m is still considered a conservative estimate of a satisfactory separation distance.

k) The accuracies of the calculated virus removals and separation distances that can be achieved through the use of the guidelines are influenced by the accuracy of the data on which the calculations are based.

l) The guidelines are restricted to use in situations in which there is no significant drawdown at the well. This restriction is usually met by domestic wells although in some circumstances a domestic well may also be used for other purposes requiring high-capacity pumping. In this situation, pumping could significantly affect groundwater velocity, and the impact of this would need to be assessed on a case-by-case basis.

3   USE OF THE GUIDELINES

3.1   WHO MIGHT USE THE GUIDELINES AND WHY?

Table 1 summarises the organisations that may find the Guidelines helpful and identifies some of the applications in which the document may be used.

Table 1   Organisations that may find the Guidelines useful

Organisation	Guidelines application
Regional councils and unitary authorities	• Developing policies and rules for regional plans • Resource consent processing • Implementing the National Environmental Standard for Sources of Human Drinking Water 2007
District councils	• Developing district plans • Implementing the Local Government Act 2002 • Implementing the Building Act 1994
Drinking water supply authorities	• Implementing the Health [Drinking water] Amendment Act 2007
Public health agencies	• Implementing their powers and responsibilities under the Health [Drinking water] Amendment Act 2007
On-site wastewater system manufacturers and providers	• Improving the efficacy of their systems
Developers	• Planning
Land use planning and wastewater consultants	• Location of wells and on-site wastewater systems
Well drillers and on-site wastewater system installers	• Location of wells and on-site wastewater systems

3.2   HOW TO USE THE GUIDELINES

3.2.1   INTRODUCTION

The Guideline document provides a process and the necessary data by which satisfactory separation distances can be determined for a specific set of circumstances. As depicted in Figure 5 the process provided in the Guidelines requires three types of information: data taken directly from the literature (provided in the Guidelines document), data derived from models (which required literature data and New Zealand field data as input), and information specific to each location (which the user has to provide). Worksheets, described later, guide the user through the process.

Part of the process contained in the Guidelines helps the user by combining data from the literature with location specific data. This allows the relatively simple calculation for virus removal in the wastewater treatment tank, the disposal field and the soil. The bulk of the modelling effort in the project involved the use of sophisticated techniques to undertake probabilistic calculations. This modelling was associated with the vadose zone and, more particularly, the saturated zone.

The numerical results from this modelling are contained in two sets of tables generated from the vadose and saturated zone modelling, each set containing 50 tables. The first set of tables contains Log Reduction tables

(see Table 2). These tables give the log reduction in virus concentration for a given vadose zone thickness and horizontal separation distance for each combination of vadose and saturated zone hydrogeological settings.

Figure 5   Diagram showing the data inputs required for determination of separation distances

Literature data   NZ Field data

Literature data   Data generated from models   Location specific data

Process

Guidelines Content

Separation distance   Worksheets

Table 2   Example of a Log Reduction table

Log Reduction Table 33   Vadose zone: Clay - Saturated zone: Coastal Sand

Vadose Zone Thickness (m)	Separation Distance (m)											
	40	50	60	70	80	90	100	120	140	160	180	200
1	5.1	6.0	6.5	7.6	8.3	9.1	9.8	12.4	13.9	16.6	18.2	20.6
2	6.4	7.3	7.8	8.9	9.6	10.5	11.2	13.8	15.4	18.1	19.6	22.1
3	7.6	8.5	9.1	10.2	10.9	12.0	12.6	15.2	16.8	19.4	21.1	23.5
4	8.6	9.7	10.4	11.4	12.2	13.2	13.8	16.5	18.2	20.8	22.4	24.9
5	9.8	10.8	11.4	12.6	13.4	14.4	15.1	17.7	19.5	22.1	23.8	26.2
6	10.9	11.9	12.5	13.7	14.6	15.6	16.4	19.0	20.7	23.4	25.3	27.6
7	11.8	12.9	13.6	14.8	15.7	16.8	17.3	20.1	22.1	24.7	26.3	28.9
8	12.9	13.9	14.7	16.0	16.8	18.0	18.6	21.4	23.3	25.8	27.8	30.0
9	13.9	15.0	15.6	16.9	17.9	19.1	19.7	22.5	24.6	26.9	28.7	31.5
10	14.9	16.1	16.8	18.1	19.0	20.1	20.8	23.6	25.4	28.3	30.1	32.7
15	20.0	21.1	22.0	23.2	24.2	25.5	26.3	29.1	31.4	34.1	36.2	38.7
20	29.8	30.9	31.7	33.0	34.1	35.7	36.4	39.4	42.0	44.7	46.8	49.9

Table 3   Example of a Separation Distances table

Separation Distances Table 33b   Vadose zone: Clay - Saturated zone: Coastal Sand

Vadose Zone Thickness (m)	Log reduction													
	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5
1	109	113	117	121	127	134	140	144	148	152	155	159	165	171
2	97	102	106	110	114	117	122	129	135	141	144	148	152	156
3	81	86	91	99	103	107	111	115	119	124	130	136	141	145
4	66	71	78	83	88	95	101	105	109	112	116	120	126	132
5	53	61	65	69	75	81	86	92	98	103	107	111	115	119
6	41	46	51	59	64	68	73	79	84	89	95	101	105	109
7			41	46	51	59	64	68	72	78	83	88	94	101
8					41	46	51	57	62	66	70	76	82	86
9							41	46	50	58	63	67	71	76
10									41	45	49	56	62	66
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The second set of tables contains Separation Distances tables (Table 3). These tables give the separation distances required to achieve a given log reduction at a specified vadose zone thickness for each combination of hydrogeological settings.

The blank areas in the table denote a calculated separation distance of less than 40 m. Uncertainties in the modelling meant that reliable results could not be provided at distances less than 40 m. With the exception of pumice sand aquifers, all other hydrogeological settings have a minimum separation distance of 40 m. An exception is made for pumice sand in the Guidelines because in this setting the rate of virus removal is so high that a minimum separation distance of 20 m was considered adequate.

3.2.2   SELECTING THE VIRUS

The first step in establishing a satisfactory separation distance is deciding whether rotaviruses or hepatitis A virus will be used as the basis for calculating the overall $\log_{10}$ reduction that has to be achieved.

Rotaviruses and hepatitis A viruses were selected as the viruses for which calculations would be provided because they represent two extremes. Rotaviruses are highly infectious, and shed at high concentrations in the faeces of an infected individual. These characteristics mean that, all other things being equal, the separation distances required to reduce rotavirus to a satisfactory level will be greater than for any other virus considered. The calculation of separation distances based on rotavirus, therefore, will ensure satisfactory protection against *all* the viruses considered.

Hepatitis A virus, on the other hand, was selected because of the more severe illness it can cause, that includes damage to the liver, the prolonged period for the liver to heal and its estimated 1% mortality rate. The calculation of separation distances based on hepatitis A virus, therefore, will ensure satisfactory protection against the most severe illness, but may not provide the same level of protection against the viruses that produce less severe illnesses. Satisfactory separation distances for hepatitis A virus are shorter than those calculated for rotavirus, all else being equal.

Thus, the Guidelines provides the user with the information needed to decide about the trade-off between the separation distance and the potential consequences of infection. <u>This decision should be made in consultation with the appropriate district health board</u>.

The guidelines do not direct the user in selecting the virus on which to base their calculations, a council must decide for itself whether the increased likelihood of infection by some virus types is an appropriate trade-off for shorter separation distances. However, the following may assist a council in reaching this decision:

Rotavirus *should* be selected as the basis for the calculation, if a council:

a) wishes to provide a high level of protection for its residents against infection by *all* of the key water-borne viruses, OR

b) is uncertain about which virus to chose – this follows the precautionary principle of taking the most protective action when there is uncertainty.

Hepatitis A virus *could* be used for the basis of the calculation, if a council believes:

- that the protection provided by using rotavirus is excessive, OR, the separation distances calculated using rotavirus are impracticable, AND

- that while infection by hepatitis A virus should be avoided, the health consequences of infection by the other key water-borne viruses can be tolerated.

3.2.3   WORKSHEETS AND WORKED EXAMPLES

The Guidelines contains two *pro forma* worksheets. Each sheet guides the user in determining which data are needed for the calculation, how to perform the calculation, and which table of modelling results is required for the calculation. The two worksheets use the same data, but are designed to address two different questions.

One sheet answers the question: 'Is separation distance X satisfactory?' The second answers the question: 'What separation distance is required to ensure the water quality from the bore will be satisfactory?'

Accompanying each worksheet is a worked example. The following shows the worked example for Worksheet No.2.

Worked Example for Worksheet 2

Worksheet No. 2 is used to determine what the separation distance between a wastewater disposal field and a bore should be.

The situation:

A regional council has decided to base its separation distance requirements on the calculations for rotavirus contained in the Guidelines. It has chosen rotavirus as the basis for the calculations because it knows that by ensuring protection from rotavirus, protection will also be achieved for the other viruses considered most likely to be a concern in water, including hepatitis A virus. This decision means that the separation distance between a disposal field and well must be able to achieve a $\log_{10}$ reduction in virus concentration of at least a 16.2

A consent applicant is wishing to sink a new well close to his neighbour's boundary. His neighbour's wastewater disposal field is not far from the boundary. The neighbour's wastewater undergoes treatment by an aerated wastewater treatment system before UV treatment and discharge into the ground.

The question:

What separation distance between his neighbour's disposal field and his proposed well does the consent applicant need to adequately protect against contamination of his drinking water, should an outbreak caused by a waterborne virus occur in his neighbour's household?

Information Needed:	For this example
What type of wastewater treatment system is used??	Proprietary aerated wastewater treatment system
Does the wastewater receive additional disinfection before discharge?	UV
What type of disposal system is used?	Shallow dripper
How deep is the sparge (the wastewater distribution pipe) under the ground?	0.1 m
What is the thickness of soil on the site?	1.2 m
What is the soil classified as under the NZSC system?	Organic soil
What is the depth to groundwater?	10 m
What is predominant material in the vadose zone?	Alluvial sand
What is the aquifer material?	Alluvial sand

Worksheet No.2 To calculate the separation distance needed to achieve a specified $\log_{10}$ reduction in virus concentration

Worksheet No.2 is used to determine what separation distance between a wastewater disposal field and a well is needed to provide adequate protection for the well-water quality.

Step 1 Identify the target log reduction required.

From Table I choose the virus to be used in the calculation and enter the $\log_{10}$ reduction required in **Box A**

RC is basing its calculations on rotavirus

Table I	$\log_{10}$ reduction required
Rotavirus	16.2
Hepatitis A virus	11.1

A	**16.2**

Step 2 Determine the log reduction achievable by the wastewater treatment system

From Table II choose the type of treatment system and enter its $\log_{10}$ reduction achievable in **Box B**

Treatment is by aerated wastewater treatment system

Table II	$\log_{10}$ reduction achievable
Primary treatment system (septic tank)	0.6
Secondary treatment system (AWTS[1])	1.0

B	**1.0**

Step 3 Determine any additional log reduction if disinfection is used

If chlorination or UV disinfection is used, enter "**1.0**" in **Box C,** otherwise enter "**0**".

Additional disinfection is by UV

C	**1.0**

Step 4 Calculate the log reduction achievable in the disposal field and soil
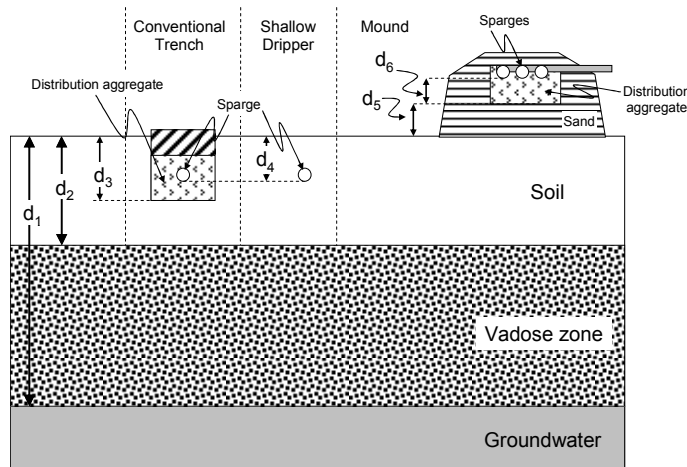

Fig. I

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[1] Proprietary aerated wastewater treatment system

1   Choose the type of disposal field

2   From Fig. I write down the dimensions in Table III in metres.

Table III (no data needed in shaded cells).

Dimension (metres)	Conventional Trench	Shallow Dripper	Mound
d_1		**10**	
d_2		**1.2**	
d_3			
d_4		**0.1**	
d_5			
d_6			

Depth to groundwater

Thickness of soil

Depth of dripper line

3   In Table IV write down the soil type and its $\log_{10}$ reduction (see **Table 8.6** or **Table 8.7** in Section 8.6.2 of the Guidelines).

Table IV

Soil type	Reduction $\log_{10}$/m
Organic soil	**1.0**

This is value **a** in Table V

NZSC Feature	Virus removal $\log_{10}$ m^{-1}
Organic soils	1.0
•	•
Brown soils	2.0
•	•
Allophanic soils	2.5

4   Carry out the calculations in Table V for the disposal system in use. There will be only one result in **Box D**. [Grey shaded cells do not need to be filled.]

Table V (no data needed in shaded cells).

Reduction in distribution aggregate						
	Conventional Trench		Shallow Dripper		Mound	
Distribution aggregate	Calculation	Result	Calculation	Result	Calculation	Result
Pea gravel	**0.36 x (d₃-d₄)**				**0.36 x d₆**	
Sand	**0.49 x (d₃-d₄)**				**0.49 x d₆**	
Reduction in sand						
					0.49 x d₅	
Reduction in soil						
	a x (d₂-d₃)		**a x (d₂-d₄)**	**1.1**	**a x d₂**	
Sum the above Result column <u>for the disposal system in use</u> to give the **total $\log_{10}$ reduction** in **Box D**						
D			OR	**1.1**	OR	

"d₂" and "d₄" are obtained from Table .III, "a" is from Table IV. The result is 1.1.

Step 5   Calculate the overall log reduction required

1   Transfer data from **Boxes A, B, C** and **D** to Table VI

2   Subtract **Boxes B, C** and **D** from **Box A** and write this result in **Box E.**

Table VI

A	**16.2**
B	**1.0**
C	**1.0**
D	**1.1**
E	**13.1**

> Data are copied from boxes earlier in the form.

> This value (16.2 -1 -1 -1.1) will be used to look up the separation distance in the table in Step 6

This is the total log₁₀ reduction required.

Step 6   Determine the separation distance needed to achieve the required log reduction (E)
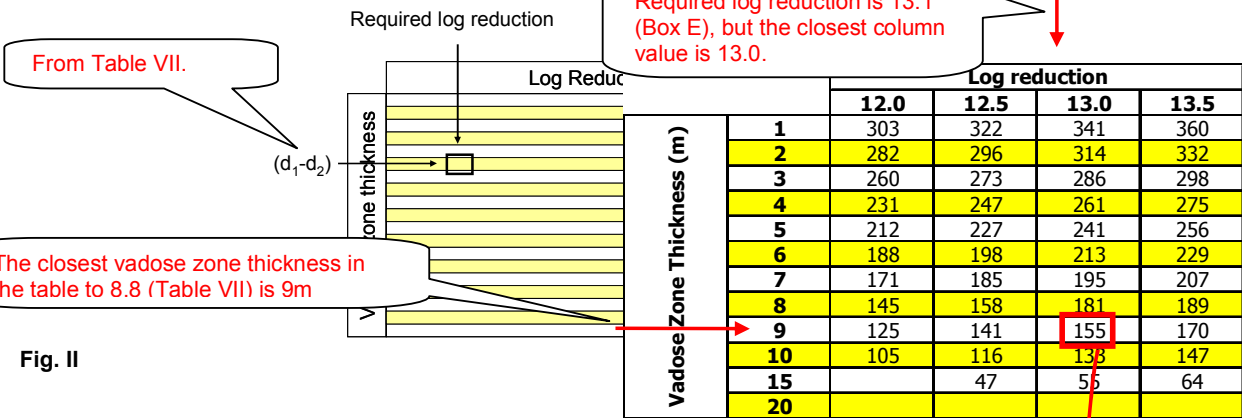
1   Write the vadose zone and saturated zone (aquifer) materials at the site in Table VII. Possible materials are given in Section 8.6.4 of the Guidelines.

> Values for "d_1" and "d_2" come from Table III. The difference (10 - 1.2)

Table VII

	Material	Vadose Zone thickness (d_1-d_2)
Vadose zone	**Coarse sand**	**8.8**
Saturated zone	**Coarse sand**	

2   Calculate the vadose zone thickness (use the values d_1 and d_2 from Table III), and write it in Table VII.

> Required log reduction is 13.1 (Box E), but the closest column value is 13.0.

> From Table VII.

> The closest vadose zone thickness in the table to 8.8 (Table VII) is 9m

Required log reduction

Log Reduc

(d_1-d_2)

Fig. II

Vadose Zone Thickness (m)	Log reduction			
	12.0	**12.5**	**13.0**	**13.5**
1	303	322	341	360
2	282	296	314	332
3	260	273	286	298
4	231	247	261	275
5	212	227	241	256
6	188	198	213	229
7	171	185	195	207
8	145	158	181	189
9	125	141	155	170
10	105	116	138	147
15		47	55	64
20				

3   Use the catalogue in **Table 8.9** and the vadose and saturated zone materials written in Table VI to find the table needed in Section 8.6.4.

4   Read the log₁₀ reduction from the table as shown in Fig.II.

The calculated vadose zone depth and required log₁₀ reduction may not exactly match the values given in the vertical and horizontal scales of the table. Read from the row and column with the closest value.

5   Write the separation distance in the box below

Separation Distance required (m)	155

> To protect users of the well water against viral infection, the new well must be at least 155 m away from the disposal field**.**

4   CONCLUSIONS

Domestic onsite disposal systems can contaminate groundwater wells in the vicinity unless their relative positions are properly chosen. Ensuring an adequate separation between the two activities is one means by which the likelihood of cross-contamination can be minimised.

The guidelines described in this paper provide a scientifically defensible basis for establishing separation distances by:

- basing the calculation of separation distance on viral transport, which provides protection against other classes of pathogen because viruses are highly infectious and their survival characteristics favour their transport over long distances

- calculating separation distances for different hydrogeological settings, to allow for variations in settings throughout the country

- taking account of the uncertainties in model inputs through the use of Monte Carlo techniques that yield a range of possible output values, rather than a unique value, thereby allowing calculated results to be provided at a specified level of confidence.

The guidelines are based on virus removal rates gathered by an extensive search of the scientific literature and from field data obtained from regional councils in New Zealand. The document provides a process for the calculation which is encapsulated in worksheets. These guide the user through the separation distance calculation, showing how to incorporate: the literature data, data generated from the modelling and location-specific data required from the user.

The best available scientific data and modelling techniques were used in preparing the Guidelines. However, measurement of virus removal rates and hydrogeological variables in some settings were not available, and our best estimates of these values, made on the basis of the data that are available, were used in these situations. The Guidelines is a step forward in establishing separation distances, and provides a more rigorous basis for setting separation distances. However, the document is not the final answer, and refinement of the values it contains will be needed when sufficient new information becomes available.

Future extensions of the modelling done in this project that have already been identified as being of interest to regional councils are: modelling of the effects of increased abstract rates to assist with the protection of community supply wells; and use of a finer modelling grid to allow the modelling of separation distances less than 40 m.

REFERENCES

Bidwell V. (2000) 'A formula for predicting advection-dispersion in the vadose zone at uneven drainage intervals' *Water Resour. Res*., 36, 3077-3080.

CRC (2004) *Pathogen movement and survival in catchments, groundwaters and raw water storages,* Cooperative Research Centre for Water Quality and Treatment Fact sheets. Available at: http://www.waterquality.crc.org.au/dwfacts/techfact_pathogen_movement.PDF

Haas C. N., Rose J. B., Gerba C. P. (1999) *Quantitative Microbial Risk Assessment*, John Wiley, New York.

Higgins J., Heufelder G., Foss S. (2000) 'Removal efficiency of standard septic tank and leach trench septic systems for MS2 coliphage' *Small Flows Quarterly*, 1, 26-27, 57.

McLeod M., Aislabie J., Ryburn J., McGill A. (2008) 'Regionalizing potential for microbial bypass flow through New Zealand soils' *J. Environ. Qual.*, 37, 1959-1967.

MfE (2008), *Proposed National Environmental Standard for On-site Wastewater Systems Discussion Document* Ministry for the Environment, July 2008.

NZWERF (2002), *New Zealand Small Water Systems Surveys*, New Zealand Water Environment Research Foundation, August 2002.

Pang L., McLeod M., Aislabie J., Simunek J., Close M., Hector R. (2008) 'Modelling transport of microbes in ten undisturbed soils under effluent irrigation' *Vadose Zone J.,* 7, 97-111.

Parnell W., Scragg R., Schaaf D., Fitzgerald E. (2003) *NZ Food NZ Children: Key Results of the 2002 National Children's Nutrition Survey,* Ministry of Health.

Russell D., Parnell W., Wilson N., Faed J., Ferguson E., Herbison P., Horwath C., Nye T., Reid P., Walker R., Wilson B., Tukuitonga C. (1999) *NZ Food: NZ people - Key results of the 1997 National Nutrition Survey,* Ministry of Health.

USEPA (1989) 'National Primary Drinking Water Regulations; Filtration, Disinfection; Turbidity, *Giardia lamblia*, Viruses, *Legionella*, and Heterotrophic bacteria, Final Rule' *Fed. Reg.*:54:27486, June 29, 1989.