Model scenarios for a microbial risk assessment tool

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ACRONYMS USED IN THIS REPORT

AET: Actual evapotranspiration

CFU: colony forming units

CSO: Combined Sewer Overflows (CSO)

ECan: Environment Canterbury

ESR: Institute of Environmental Science and Research

FDE: Farming Dairy Effluent

FIB: Faecal indicator bacteria

FSL: Fundamental Soil Layer

GC: Gene copy

GNS: GNS Science

LAS: Land Application System

MRA: Microbial Risk Assessment

MPN: Most probable Number

NZ: New Zealand

OSET: On-Site Effluent Testing

OWMS: On-site Wastewater Management Systems

PET: Potential Evapotranspiration

QMRA: Quantitative microbiological risk assessment

qPCR: quantitative Polymerase Chain Reaction

SSO: Sanitary Sewer Overflows

STEC: Shiga toxin-producing *Escherichia coli*

VCSN: Virtual Climate Station Network

1. INTRODUCTION

Transport of microbial pathogens is a potential risk from various land-use activities, such as application of faecal waste to land, and domestic on-site wastewater treatment system disposal fields. Risk to human health occurs when these wastes, containing pathogens, infiltrate into groundwater resources used for drinking water. In 2010, it was recognised that one particular land use, domestic septic tanks, posed a risk to the quality of groundwater. In response, the *Guidelines for Separation Distances Based on Virus Transport between On-site Domestic Wastewater Systems and Wells* were published (Moore et al., 2010). These guidelines, from here on referred to as the “2010” guidelines throughout this document, considered appropriate setback distances from septic tanks in order to protect drinking water sourced from wells. The guidelines calculated separation distances for domestic on-site wastewater treatment systems based on virus transport and removal in the subsurface environment.

Since the release of the 2010 guidelines, increased awareness of other potential sources of microbial groundwater contamination, not just from on-site wastewater management systems (OWMS), have become an issue worthy of consideration for many regional councils in New Zealand. The recent delineation of source protection zones for drinking water supply wells has prompted consideration of the risk from a range of activities within these zones. Regional councils need to be able to assist consent planners and rural and peri-urban communities in making decisions about the management of a range of activities near drinking water supply wells. A microbial risk assessment tool is one such tool that could be used in this context, focusing on the risk to human health from drinking-water where microbial pathogens are discharged onto or into land near a drinking-water supply well. Some existing land-use activities fall within designated drinking-water protection zones (often defined retrospectively after the activity commenced), which triggers the requirement for a resource consent. Councils need a defensible method to support any recommendations to grant or decline these consents based on quantitative risk modelling.

Environment Canterbury and other regional councils have applied for an Envirolink Tools Grant to engage ESR and GNS to develop a microbial risk assessment tool. This tool proposes to determine the microbial risks associated with multiple land-use practices such as:

- Multiple domestic on-site wastewater management systems (i.e. septic tanks)

- Community size on-site wastewater management systems
- Dairy farming
- Sheep and beef farming
- Wildfowl
- Stormwater systems
- Stockyards
- Animal effluent/manure application to land

The first step in developing a microbial risk assessment tool involved a scoping study that aimed to identify the range of questions that regional councils and unitary authorities would like to see addressed in this tool. This was done via a questionnaire that was developed by ECan, ESR and GNS, and sent out to 17 councils across New Zealand (Tschritter & Moriarty, 2018). The survey results confirmed that there was strong interest by councils in the development of a new microbial risk tool. Councils were very interested in a general guide to set-back distances for drinking water in relation to microbial pollution and in the risks from pathogens associated with farming activities, including the impacts of effluent disposal as well as point sources and diffuse pollution.

The next step focused on the collation and quantification of the source loading inputs for the modelling and ultimately the assessment tool via a literature review. The resulting document, *Quantification of source loading inputs for a microbial risk assessment tool*, was finalised in June 2020 (Humphries et al. 2020). That document focused specifically on collating microbial loading rates for the above-mentioned land-use scenarios from peer-reviewed journal articles, reports, technical notes and book chapters published in the last thirty years (1990-2020).

The next step, and the aim of this document, is to provide details of the assumptions and limitations that will form each model scenario and will include summaries of:

- land-use scenarios
- flow scenarios
- microbial loading and removal rates scenarios.

Only unconfined aquifers are considered as within scope for this tools project as the inclusion of variable confinement status introduces significant complexity and requires individualised site information. This document will also provide details of the modelling approach employed alongside the key outputs that will be accessible to end users.

A draft version of this report, along with a survey, was distributed to a wide range of stakeholders for feedback in December 2020. The stakeholders included regional and district council staff, city council staff, Ministry for the Environment, and OWMS design engineers and consultants. The purpose of this feedback was to ensure that the scenarios that are simulated for each land use can be considered typical or representative of that land use and that the resulting microbial risk assessment tool will provide useful and fit for purpose guidance. Feedback from the survey was received from 11 participants and additional feedback on the report and study was received via email from an additional 7 participants. A copy of the survey questions together with the survey results and comments are given in Appendix 1. The additional feedback is also included in Appendix 1. The report was modified and revised to incorporate this feedback.

2. LAND-USE SCENARIOS

This Microbial Risk Assessment (MRA) tool proposes to determine the microbial risks associated with multiple land-use practices such as:

- Multiple domestic on-site wastewater management systems (i.e. septic tanks)
- Community size on-site wastewater management systems
- Dairy farming
- Sheep and beef farming
- Wildfowl
- Stormwater systems
- Stockyards
- Animal effluent/manure application to land

Figures 1 illustrates the land-use scenarios included in the MRA tool. Figure 2 shows the opportunity for microbial removal by an OWMS and LAS (land application system) with a potential risk to groundwater down gradient through a drinking water well.

We will be simulating microbial transport under near saturated conditions as this is when the majority of transport occurs and at the most rapid rate (Close et al. 2008; 2010). We will then simulate the frequency for those saturated and near-saturated conditions to occur for each land use, soil and climate location combination. This is discussed in more detail in Sections 3 and 5.

Norovirus was chosen as the most suitable viral pathogen for the MRA tool with regards to the human related land-use scenarios (further discussed in Section 4.1). *Campylobacter* was considered the most appropriate organism to be used for agriculture related land-use scenarios due to its widespread prevalence in animals, and the high rate of infections within the New Zealand population (further discussed in Section 4.2). *E coli* was included for all land-use scenarios as an indicator of faecal contamination and because of its use in regulatory standards.

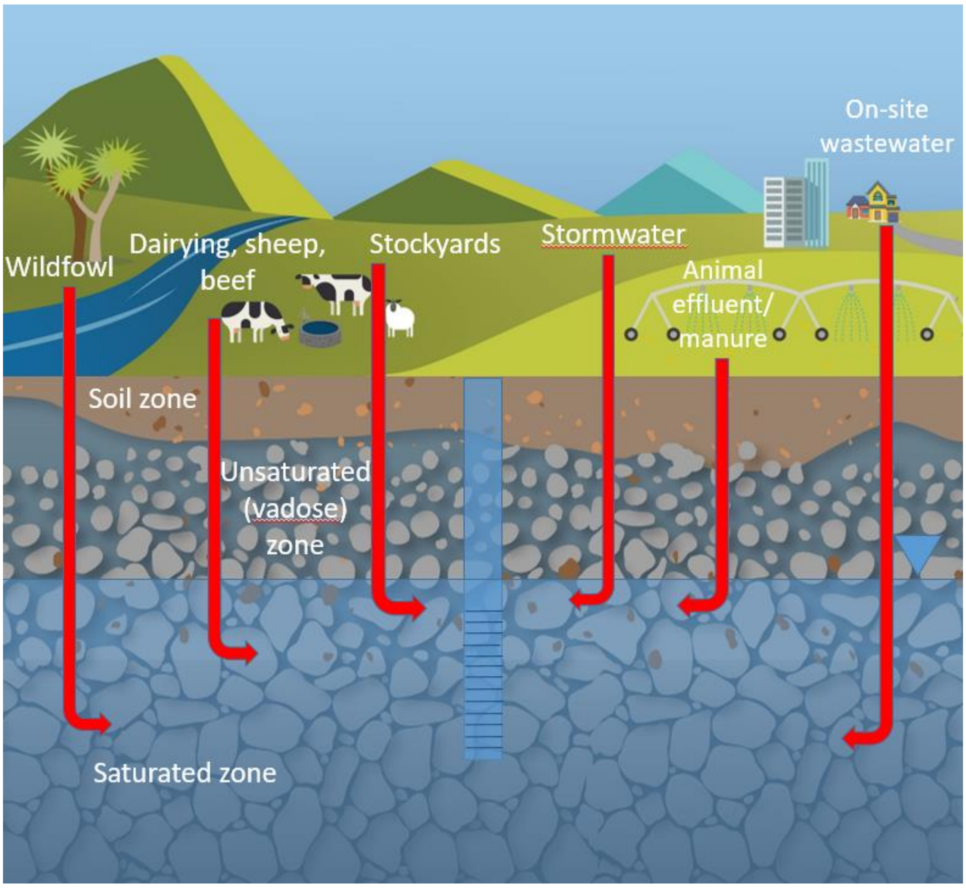

Figure 1: Schematic for land-use scenarios

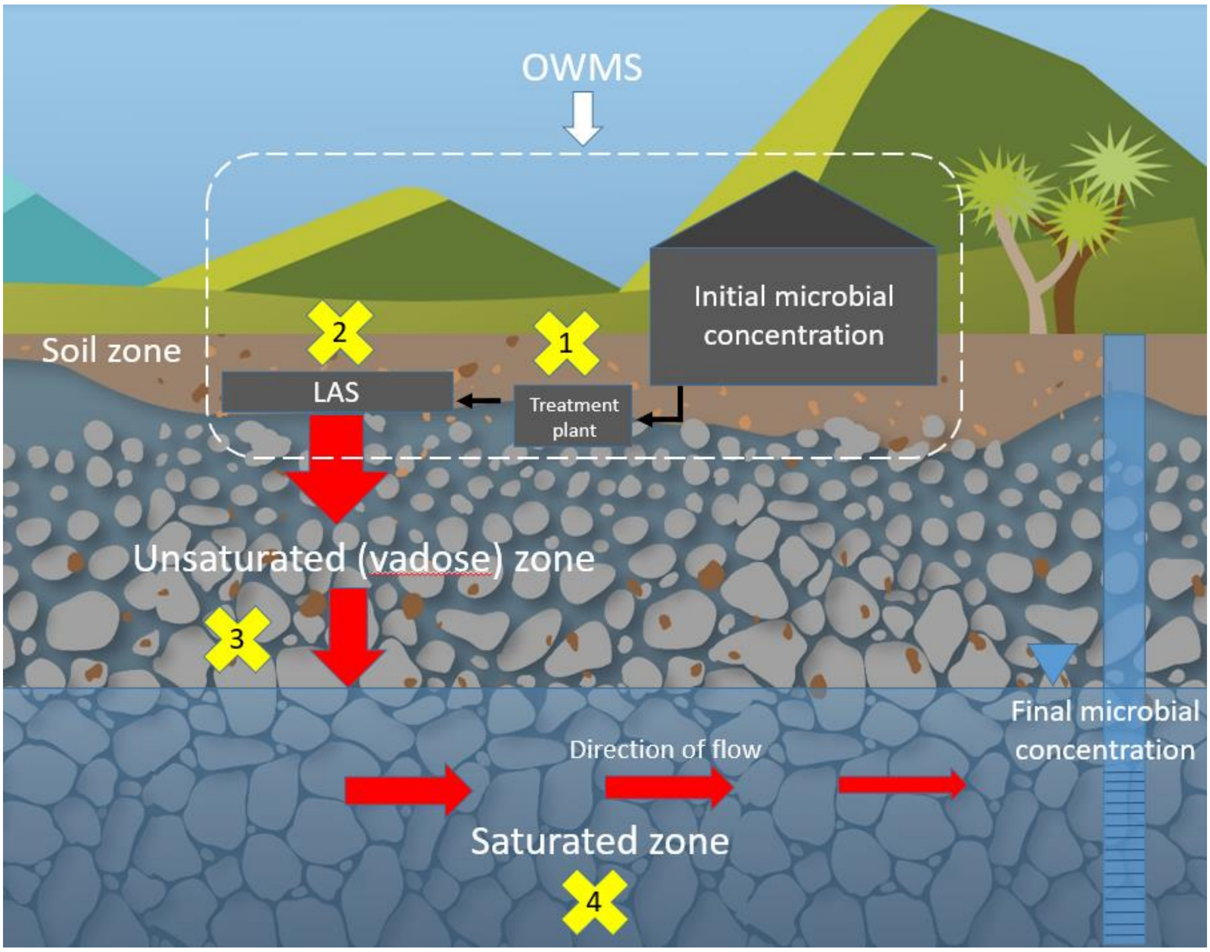

Figure 2: Components of microbial removal between the On-site Wastewater Management System (OWMS) and groundwater abstraction point. 1) microbial reduction within the treatment plant, 2) microbial reduction within the Land Application System (LAS), 3) microbial reduction within the unsaturated (vadose) zone, 4) microbial reduction within the saturated zone. Note: The abstraction well is directly down gradient of the LAS. The red arrows give the direction of flow and perceived reduction in microbial concentration from the OWMS to the abstraction well.

A summary of the assumptions and limitations of each land-use scenario with the MRA tool is given below.

2.1 MULTIPLE DOMESTIC ON-SITE WASTEWATER MANAGEMENT SYSTEMS

The term septic tank has been used historically in New Zealand to describe a system which processes human excreta and domestic wastewater and discharges it to the receiving environment. This term however does little to describe the variety of systems which are now commonly used in New Zealand. These systems may include primary treatment systems (solids settling tank) to secondary and advanced treatment systems which may involve biological processes to assist microbes to digest and break down the wastewater, sand filters or ultraviolet light units (MfE, 2008). The wastewater is then discharged to the receiving environment using a Land Application System (LAS) such as a soakage trench or subsurface drip irrigation. A common term which has now been adopted by the industry in New Zealand to cover multiple types of systems is an On-site Wastewater Management System (OWMS).

As in 2010, there remains a dearth of information concerning quantitative measured enteric virus concentrations within domestic OWMSs (Blaschke et al., 2016, Humphries et al. 2020). The enteric virus concentration data that is available for domestic OWMSs is highly variable compared to the data that is available for homogenised effluent from centralised treatment systems. This is because the concentrations within individual domestic OWMSs depend on whether there are infected people in the individual dwelling. When occupants of a household are unwell, the peak concentrations of those enteric viruses being shed into the OWMS will be much higher than a centralised wastewater facility, which offers dilution with non-contaminated wastewater (Blaschke et al., 2016). The literature review also found that available microbial loading concentrations were typically sourced from a single domestic OWMS and not community sized OWMSs.

The performance of OWMSs is variable based on the level of maintenance undertaken, with some studies finding that around 30% of systems reported some failure (Canterbury Public Health, 2014). We have allowed for a lower level of treatment in a proportion of OWMS.

Assumptions

- For a typical 3 bedroom (5 persons) home it is assumed that the daily volume of wastewater entering an OWMS is approximately 750 – 1000 L/day.
- Wastewater entering an OWMS consists of toilet, shower/bath, kitchen and laundry wastewater.
- That 70% of the domestic OWMS are correctly operated and maintained by the homeowner to ensure optimal performance (see below) and 30% of domestic OWMS are not correctly operated and operate at 0.5 log removal lower than the expected performance given below.

- We will simulate three types of OWMS that currently exist in New Zealand and offer the following levels of microbial treatment (as summarised in Moore et al. 2010):
    - Primary treatment OWMS: solids settling tank followed by an effluent disposal field such as a soakage trench or subsurface low pressure effluent distribution drip irrigation. Treatment = 0.6 log removal

- Secondary OWMS: additional treatment such as aerobic biological processing and settling or filtering of effluent received from a primary treatment unit. Additional Treatment of 1.0 log removal
- Advanced secondary treatment: an advanced treatment system may pass the effluent through a sand filter, a packed bed filter or a textile bed reactor, where effluent trickles through the bed material containing micro-organisms that treat any remaining fine solids before being pumped to the disposal field. Additional treatment of 1.0 log removal.

- Users will be able to specify the number and locations of OWMSs in a cluster that will be assessed.

Limitations

- Since 2008 44 OWMS designs have been tested by the On-Site Effluent Testing (OSET) testing facility in Rotorua. The MRA Tool does not factor in the level of treatment provided by any one particular OWMS design.
- This work does not incorporate any details on various OWMS designs and how systems are installed or operated and maintained.
- The MRA tool does not consider other forms of on-site wastewater management systems such as composting toilets and vermiculture systems.

2.2 COMMUNITY SIZE ON-SITE WASTEWATER MANAGEMENT SYSTEMS

The first land-use scenario (2.1) considers the impact of clusters of OWMS such as non-reticulated towns and subdivisions while for this scenario (2.2) considers the impact of a community sized OWMS located, for example, at marae, schools, camping grounds, hotels, motels and restaurants. There are more data available for large, centralised wastewater systems with regard to enteric virus concentrations than an individual OWMS (reviewed in Humphries et al. 2020). The same can be said for community size on-site wastewater management systems. The review of the literature revealed no additional microbial loading data other than what is available for a single domestic OWMS.

Assumptions

- For the community sized OWMS land-use scenario it assumes an occupancy of between 40 – 250 people using a single OWMS.

- A community scale OWMS could include up to 250 households but for the MRA tool we have simulated scenarios for 40 people and 250 people. Estimates for community OWMS serving different populations can be approximated using interpolation.

Limitations

- The risks of a town or city wastewater treatment plant and the associated disposal of wastewater to land is out of scope for the MRA tool.

2.3 DAIRY FARMING

Dairy farming accounts for just over 14% of New Zealand's agricultural and horticulture land use with nearly 5 million cows nationally (DairyNZ, 2019). This land-use scenario includes the faecal inputs of dairy cows directly onto open pasture as they are rotated around the farm. Results for dairy farming microbial loading rates are generally presented as outputs per animal per day.

We have simulated microbial transport from typical grazing patterns, as detailed below, for high and medium intensity dairy farming. We have simulated transport under near saturated conditions and then estimated how frequently those conditions will occur for high and medium intensity dairying in different regions of New Zealand, as described more fully in Section 3.1. The effluent application to land is covered in Section 2.8. In depth simulation of a working dairy farm is out of scope for this MRA tool.

Assumptions

- The dairy land-use scenario assumes two scenarios based around land-use intensity and herd size:
    - High intensity, large (700 – 800 cows) with 3.5 cows per hectare on a 25-day rotation (7 hectares per day of feed) with irrigation (Ministry for Primary Industries, 2012a).
    - Medium intensity, small (200 – 250 cows) with 2.5 cows per hectare on a 25-day rotation (7 hectares per day of feed) with no irrigation (L Fietje, pers. Comm, 2020).

Limitations

- The MRA does not model the microbial loading implications of off-paddock facilities such as dairy cow housing/barns, stand-off pads or permanent feed pads.
- The MRA tool does not account for practices such as wintering off and feeding of supplements.

2.4 SHEEP AND BEEF FARMING

This land-use scenario includes the faecal inputs from sheep and beef directly onto open pasture. Sheep and beef grazing rotations are typically much longer than dairy cows.

Assumptions

- For the purposes of the MRA tool it has been assumed that the most relevant sheep and beef farming land type for groundwater contamination risks is flat land farming. It has therefore been assumed that:
  - Flat dry sheep and beef farming typically has between 10 – 12 stock units per hectare and a typical farm size of 400 hectares (L Fietje, pers. Comm, 2020).
  - Flat irrigated sheep and beef farming typically has between 20 – 22 stock units per hectare and a typical farm size of 400 hectares (Ministry for Primary Industries, 2012b).
- It is assumed that sheep and beef farming grazing patterns consist of set stocking during lambing and calving (varies nationally from Aug – Oct), approximately 30 day rotations from Nov – May and winter crop grazing during June – July (L Fietje, pers. Comm, 2020).

Limitations

- The impact of high country and hill country sheep and beef farming has not been included in the MRA tool due to the limited groundwater resources used for community drinking water supplies commonly found in these areas. If hill country sheep & beef is likely to impact a particular drinking water supply then a scaled estimate could be made using a stocking rate of around 4 stock unit per ha for hill country and around 1 stock units per ha for high country sheep and beef farm compared to the stocking rate for flat country of around 10 stock units per ha (Ministry for Primary Industries, 2012b)

2.5 WILDFOWL

Microbial contamination from wildfowl faeces is a nationwide issue particularly around wetlands and lakes. Wildfowl may also camp around effluent and irrigation ponds. This can pose a risk to the quality of water found in both effluent and irrigation ponds which may be hydraulically connected to groundwater if not properly contained, and microbes can also be transported directly from the camping areas into groundwater. For example, flock size can be up to 500 birds for geese with a camping area of 1 – 2 hectares (L Fietje, 2020, pers. comm.) Most impacts from wildfowl are expected to be direct impacts to surface waters. However, for the MRA tool we are focussing on microbial transport and impacts to groundwater.

Studies of microbes in wildfowl faeces in NZ have been carried out by Moriarty et al (2011). Where there was little information on concentrations of microbes in NZ faecal samples for particular wildfowl species, international studies were used alongside NZ prevalence data to generate loading rates. Prevalence data helps to inform priority research on pathogen concentrations in NZ wildfowl with high prevalence.

Assumptions

- Due to the difficulties in determining wild bird flock numbers the MRA tool assumes a flock size of between 100 – 500 birds (L Fietje, 2020, pers. comm.)
- The transport to groundwater is assumed to occur from the camping areas near wetlands, ponds or lakes.
- Microbial loading rates were sourced for four wildfowl species: geese, ducks, swans and gulls.

Limitations

- Any microbial transport from wildfowl to surface waters has been excluded from these scenarios as transport to groundwater is the focus.

2.6 STORMWATER SYSTEMS

Pathogens can be found in stormwater runoff and subsequently transported to environmental water bodies through sewer overflows, and urban and agricultural runoff. Faecal contamination in stormwater is largely dependent on the land use in the catchment and mostly includes sewage, septage and animal faeces. Storm events have the potential to re-suspend sediment-bound faecal indicator bacteria (FIB) and pathogens back into the water column, resulting in elevated levels of contamination. Depending on the catchment, runoff can be expected to occur year-round with stormwater runoff occurring primarily in winter and spring, and dry-weather runoff from irrigation of residential landscapes and car washing occurring when precipitation is low (Huang et al., 2018).

Routine monitoring of stormwater quality focuses on quantification of *E. coli* and enterococcus. Rainfall-induced microbial contamination of surface waters due to stormwater runoff, combined sewer overflows (CSO) and sanitary sewer overflows (SSO) has been well documented. High concentrations (>4 $\log_{10}$ cfu/100 ml) of FIB are generally found in stormwater runoff and receiving waters, and a number of studies report the presence of enteric pathogens or faeces-associated genetic markers in stormwater (for example, Jiang et al., 2015, Steele et al. 2018). Nonetheless, data on pathogen abundance in stormwater runoff and outfalls remain scarce, and the overall quality of stormwater in terms of microbial contaminants, particularly pathogens, is poorly understood (Ahmed et al. 2019). Rural or high-density residential areas are reported to contribute 30-50 times greater *E. coli* levels in stormwater compared with sparsely populated residential areas (as reviewed by Humphries et al. 2020).

Assumptions

- The MRA tool has assumed that stormwater includes combined sources of sewage, septage, runoff and animal faeces.
- We have assumed that major urban centres will have stormwater treatment systems and that the greater risks will be associated with smaller centres that have stormwater disposal into a simple soak pit
- Flow from stormwater is assumed to be discharged to groundwater via a soak pit (essentially a point source).
- The first flush of stormwater recharge is assumed to contain most of the microbial load and a saturated discharge for 6 hours has been used to simulate this concentrated discharge of stormwater to groundwater

Limitations

- The MRA tool does not differentiate between various types of stormwater but treats all stormwater as combined from various sources.

2.7 STOCKYARDS

Stockyards are premises wherein livestock are held or contained for a range of purposes, including sale, receipt, transport, exhibition, husbandry, weaning, and slaughter (Fotheringham, 1995, Department of Water, 2015). They may be temporary or permanent in nature and used continuously or occasionally. They may differ significantly in size and scale, from small on-site or community pens, to slaughterhouses with capacity for more than 250-1000 head at a time (e.g. Kiermeier et al., 2006). The largest stockyard in the Southern Hemisphere is the Fielding Sale Yards in Manawatū, at 70,000 square meters (7 ha). Thousands of head of cattle and sheep are sold each week, with the animals retained in permanent pens. Volume and management of effluent will differ between yards of different scale. Small or temporary systems may simply manually remove solid manure, while larger systems will likely dispose of wastes through a treatment system. For example, at the Fielding Sale Yards, all effluent deposited through the day is hosed down through a series of drains that connects to a sump, which in turn is connected to the Manawatū District Council waste stream and on to the treatment plant.

No specific information was found on the microbial loading from stockyards during the literature review. A loading rate however could be estimated using the loading rates from the various farmed animals detailed in this report, factoring in the capacity of a stockyard, its function (short- or longer-term housing) and what, if any, waste treatment or management exists on site. The faecal load (and hence microbes) is likely to be much lower from animals at stockyards compared to on the farm as the animals have been held away from feed on farms before transport and effluent during transport is collected and treated. An estimate of 10% of the normal faecal load was used for animals at stockyards (L Fietje, 2020, pers. comm.).

Assumptions

- The MRA tool assumes that a small stockyard would be typically utilised for 2 – 3 days per month with an area of between 10,000 – 20,000 m^2 (1 – 2 hectares). An example would be the Temuka saleyards (2 ha) where 300,000 sheep and up to 70,000 cattle are sold annually.
- The MRA tool assumes that there is no specific waste management process and looks at microbial transport from the number of animals over a 1 ha area. We have simulated transport under near saturated conditions and then estimated how frequently those conditions will occur for different regions of New Zealand, as described more fully in Section 3.1.
- The faecal load was estimated as 10% of the normal faecal load because the animals have been held in pens on farms before transport and effluent during transport is collected and treated.

Limitations

- Due to larger stockyards most likely having their own wastewater treatment facilities or solutions (i.e. Fielding Stockyards) the MRA tool focuses on smaller stockyards with no on-site wastewater treatment facilities.

2.8 ANIMAL EFFLUENT/MANURE APPLICATION TO LAND

In New Zealand sheep, beef and pig farming commonly only contribute animal manure to land in association with their normal grazing rotations. With regard to dairying, large volumes of Farming Dairy Effluent (FDE) are concentrated at the dairy shed and winter herd housing facility. The effluent is subsequently collected and stored within a holding structure (i.e. effluent storage pond or bladder system). These holding facilities may offer no or several forms of effluent treatment before its application to land via an irrigation system (i.e. travelling irrigator). The irrigation of dairy shed effluent onto land is therefore a common and integral part of New Zealand's farming practice.

Specific notes on animal effluent/manure application to land include:

- Travelling irrigators typically have high instantaneous rates of application, >100 mm/hr. Assuming the average depth of FDE is divided by the time for a complete pass, average application rate is approximately 20-30 mm/h.
- Low rate applicators apply at rates of <10 mm/h and therefore reduce the chance of exceeding the soils infiltration capacity, preventing ponding and surface runoff.

Assumptions

- It is assumed that a FDE storage pond and its application to land is tailored to farm-specific requirements that considers catchment rainfall, shed water use, number of cows, irrigation hardware, management and soil information.
- It is assumed that the land application of FDE is avoided when soils are saturated and applied at an average rate less than the infiltration rate to prevent ponding in soils with impeded drainage or low infiltration rate.
- It is assumed that FDE is avoided on land with a slope greater than 7 degrees.

Limitations

- The MRA tool does not consider the case where storage ponds are not correctly designed, installed or maintained, which might result in overtopping of effluent ponds and/or land application to already saturated soils. These situations need to be separately assessed.

3. FLOW SCENARIOS

Fluxes and flows of water transporting pathogens through the soil, unsaturated and saturated zones are affected by hydrologic, hydrogeologic and anthropogenic factors. Infiltration rates and transport velocity are influenced primarily by the hydraulic gradient and the permeability of the media. Factors controlling the hydraulic gradient are, for example, topography, recharge rates, and the response of the aquifer to pumping, whereas permeability is a result of the connected pore spaces of the media in the soil, unsaturated and saturated zone.

The rate and amount of transport of microbes increases exponentially as a soil nears saturation and most microbial transport occurs at saturated or near-saturated conditions (Close et al. 2008; 2010). Therefore, we will be simulating microbial transport under these conditions. We will then simulate the frequency for those saturated and near-saturated conditions to occur for each land use, soil, and climate location combination using the Irricalc daily soil water balance, as described in Section 3.1. The climate regions were taken from the NZ Meteorological Service delineation (New Zealand Meteorological Service, 1983) and modified by excluding the mountainous, high rainfall areas as not directly relevant to groundwater systems. Other regions were combined resulting in a total of 10 modified climate regions for simulation.

Physical and chemical attributes of the material also affect the removal rates of microbial (and other) contaminants (Pang, 2009). For example, there is an inverse correlation between infiltration rates, and transport velocity, and microbial removal rates (Pang, 2009).

Microbial removal and transport through different aquifer types for various land-use activities is simulated. **Only unconfined aquifers will be considered as within scope for this tools project** as the inclusion of variable confinement status introduces significant complexity and requires individualised site information. **Only fixed head and no flow boundary conditions will be simulated within this project.**

For the Microbial Risk Assessment Tool, the most important flow parameters are:

- Rainfall recharge
- Pumping rate
- Soil type and properties
- Aquifer type and properties
- Soil, vadose zone and saturated thicknesses.

The following sections provide an overview of these parameters and the values, and/or value ranges, that will be used as input parameters for the Microbial Risk Assessment Tool.

3.1 RECHARGE

NZ-wide annual, monthly and daily rainfall recharge for the Microbial Risk Assessment Tool will be derived from the IrriCalc soil water balance model (Bright, 2009; Wheeler & Bright, 2015). IrriCalc is a single-layer soil water balance model that calculates daily soil water content based on daily measurements or estimates of irrigation, rainfall, drainage, and actual evapotranspiration (AET). The key assumptions used in the IrriCalc modelling include:

a) The soil is free draining.

b) Crop canopy development is sufficiently consistent across years to enable use of a crop factor time series to transform evapotranspiration of a reference crop into evapotranspiration from the crop or pasture of interest. In east-coast New Zealand environments, crop factors developed for irrigated conditions should not be used for un-irrigated conditions, and vice versa.

c) All rainfall and irrigation intercepted and retained on leaf and stem surfaces is effective for meeting the evapotranspiration load.

Irricalc has been tested against Overseer (Wheeler & Bright, 2015) and both models gave similar estimates of recharge (drainage) in the absence of irrigation. Irricalc will be used to provide frequencies of soil saturation across New Zealand for different land uses, soils and climate zones.

3.2 PUMPING RATE

The rate of pumping affects the hydraulic gradient in the vicinity of the pumped well. The higher the pumping rate is, the larger will be the cone of depression or zone of influence around the well or wells. Whereas the 2010 guidelines only addressed single domestic groundwater supplies (pumping rate approx. 20 m^3/day), the Microbial Risk Assessment Tool will also include small community supplies and larger municipal supplies (Table 1).

Table 1. Pumping rate ranges and screen depths per aquifer type. Numbers in the parentheses are the assumed screen depths in metres below the water table (mbwt).

Aquifer type	Pumping rate (m^3/d) and screen depths (mbwt)		
	Single dwelling	Small community supply	Larger community supply
Alluvial gravel (AlGr)	10 (0)	200 (30)	500 (50)
Alluvial sand (AlSa)	10 (0)	200 (30)	-
Pumice sand (PuSa)	10 (0)	200 (30)	-
Coastal sand (CoSa)	10 (0)	200 (30)	-
Sandstone and non-karstic limestone (SaSt)	10 (0)	200 (30)	-
Karst and fractured rock (KaFr)	-	200 (30)	500 (50)

Assumptions

- Only single bores, pumping from unconfined aquifer are considered.
- Pumping rates are assumed constant so that steady-state flow conditions have been achieved in the aquifer.

Limitations

- Interference from other existing pumping wells within the same or other aquifers are not considered.

3.3 SOIL TYPE AND PROPERTIES

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 depth. For the MRA tool we have taken the upper 1 m as the soil zone and from 1 m to the groundwater table as the unsaturated zone, as the microbial transport and removal processes are different in these zones and need to be treated separately. Only removal of microbes in the soil will be considered in this part of the modelling. The vast majority of microbial transport through the soil occurs at saturated or near-saturated conditions (Close et al. 2008; 2010) so the transport of microbes has been simulated for near-saturated conditions and the frequency of those conditions for each land use is used to estimate the total microbial transport. The 2010 guidelines assumed that saturated or near-saturated conditions existed under OWMS, so the approach and microbial removal rates used for the guidelines are assumed to be similar to those used in the 2010 guidelines.

The virus removal rates for the specific soils and the generic soil types are given in Tables 2 and 3. Bacterial removal rates in a range of soils are given in Table 4 from a recent review

(Schijven et al. 2017). Multiplication of these removal rates (log10/m) by the soil thickness gives the extent of microbial reduction in the soil (a log10 value).

Table 2. Virus reduction for specific soil types (Moore et al., 2010).

Soil identification	Virus removal $\log_{10}.m^{-1}$
Netherton clayey soil	1.0
Hamilton clay	1.8
Waikiwi silt loam	2.3
Waikoikoi silt loam	2.3
Lismore shallow silt loam over gravels	2.0
Templeton silt loam	2.0
Manawatu fine sandy loam	3.0
Waitarere sandy recent soil	2.5
Atiamuri pumice soil	16.6
Waihou allophanic soil	20

Table 3. Virus reduction for generic soil orders (Moore et al., 2010).

NZSC Feature	Virus removal $\log_{10}$ m^{-1}
Organic soils	1.0
Ultic soils	1.0
Granular soils	1.0
Melanic soils	1.0
Podzol soils	1.0
Gley soils	1.0
Brown soils	2.0
Pallic soils	2.0
Oxidic soils	2.0
Raw & Recent soils	2.5
Semiarid soils	2.5
Pumice soils	16
Allophanic soils	20

Table 4. The efficiencies of bacterial removal in different soils (after Schijven et al ., 2017, Table 3).

Soil Type	Contamination Source	Microbe	Removal Rate (Log_{10}/m)		
			Mean	Minimum	Maximum
Allophanic soil	Dairy shed effluent	Faecal coliforms	5.48	5.22	5.75
Allophanic soil	Dairy shed effluent	E. coli	5.34	5.04	5.63
Allophanic soil	Dairy shed effluent	Enterococci	5.16	5.05	5.28
Bare sandy loam	Cow manure	Faecal coliforms	2.41	NR	NR
Clay	Septic tank effluent	Faecal streptococci	6.04	NR	NR
Clay	Septic tank effluent	Faecal coliforms	3.67	NR	NR
Clay loam	Dairy shed effluent	Faecal coliforms	2.64	2.08	3.17
Clay loam	Cow manure	Faecal coliforms	0.46	NR	NR
Clay loam	Septic tank effluent	Faecal streptococci	1.75	NR	NR
Clay loam	Septic tank effluent	Faecal coliforms	0.81	NR	NR
Clayey silt loam	Cow manure	E. coli	0.54	0.42	0.65
Clayey silt loam	Dairy shed effluent	Faecal coliforms	0.55	0.4	0.69
Clayey silt loam	Dairy shed effluent	Enterococci	0.27	0.2	0.33
Clayey soil	Dairy shed effluent	Enterococci	0.79	0.72	0.86
Clayey soil	Dairy shed effluent	E. coli	0.34	0	0.69
Clayey soil	Dairy shed effluent	Faecal coliforms	0.41	0	0.83
Deep silt loam	Dairy shed effluent	Faecal coliforms	4	0.12	6.25
Fine sandy loam	Dairy shed effluent	Faecal coliforms	9.34	8.88	9.56
Loam	Septic tank effluent	Faecal streptococci	5.5	NR	NR
Loam	Septic tank effluent	Faecal coliforms	4.89	NR	NR
Loam	Dairy shed effluent	Faecal coliforms	0.75	0.43	1.06
Loamy sand	Septic tank effluent	Faecal coliforms	4.02	1.38	6.66
Loamy sand	Septic tank effluent	Faecal streptococci	3.72	1.37	6.07
Pumice sand soil	Dairy shed effluent	Faecal coliforms	Complete Removal in 0.7 m (> 10 log/m)		
Recent sandy soil	Dairy shed effluent	Faecal coliforms	2.34	1.96	2.77
Sandy loam	Septic tank effluent	Faecal streptococci	3.87	2.24	5.17
Sandy loam	Septic tank effluent	Faecal coliforms	3.7	2.63	5.13
Sandy loam	Dairy shed effluent	Faecal coliforms	2.78	2.24	3.31
Shallow silt loam	Dairy shed effluent	Faecal coliforms	4.04	2.42	6.49
Silty clay loam	Dairy shed effluent	Faecal coliforms	3.61	2.77	5.16
Silty clay/clay	Tracer	E. coli	0.34	0.32	0.36
Silty clay/clay	Septic tank effluent	Faecal streptococci	2.76	NR	NR
Silty clay/clay	Septic tank effluent	Faecal coliforms	2.44	NR	NR
Silty sands and gravel	Sewage	Faecal coliforms	8.28		
Silty sands and gravel	Sewage	Faecal streptococci	4.81	2.31	8.58
Stony silt loam	Cow manure	Faecal coliforms	2.48	1.61	2.69

3.4 UNSATURATED (VADOSE) ZONE TYPE AND PROPERTIES

The vadose zone might provide substantial virus removal. The methodology of how the parameters for the vadose zone contaminant transport and virus removal modelling were derived is described in detail in Moore et al. (2010) Section 5.6.2. Bacterial removal rates in a range of vadose zone media are given in Table 5 from a recent review (Schijven et al. 2017).

The types of aquifers and associated vadose zone materials considered by the tool are:

- Alluvial gravel
- Alluvial sand
- Pumice sand
- Coastal sand
- Sandstone and non-karstic limestone
- Karst and fractured rock
- Silt
- Clay
- Ash
- Peat

Table 5. The efficiencies of bacterial removal in different vadose zone media (after Schijven et al., 2017, Table 5).

Vadose Zone Media	**Contamination Source**	**Microbe**	**Removal Rate (Log$_{10}$/m)**		
			Mean	**Minimum**	**Maximum**
Coarse gravels	Septic tank effluent soak holes	Faecal coliforms	0.44	0.27	0.5
Fissured chalk	Sewage discharge through soakage	Faecal coliforms	0.32	0.31	0.36
Fissured chalk	Sewage discharge by drainage	Faecal coliforms	0.16	0.14	0.19
Pumice sand	Septic tank effluent	Faecal coliforms	2.66	NR	NR
Sand (d=0.18 mm)	Sewage effluent	Faecal coliforms	0.84	NR	NR
Sand with high Silica	Sewage effluent soakage basins	Faecal coliforms	0.53	NR	NR
Silty clay loam	Leaking deep pit of pig manure.	Faecal Streptococci	0.88	NR	NR
Very fine uniform dune sands	Wastewater infiltration basins	Faecal coliforms	NR	0.52	NR
Very fine uniform dune sands	Wastewater infiltration basins	Faecal Streptococci	NR	0.45	NR

3.5 AQUIFER TYPE AND PROPERTIES

Groundwater flow and pathogen transport through aquifers are influenced by aquifer hydraulic properties (i.e., hydraulic conductivity and porosity) as well as the thickness of the aquifer (see Section 3.6) and the pathogen removal rates, which are a result of the physical and chemical properties of the aquifer media. Bacterial removal rates in a range of aquifer types are given in Table 6 from a recent review (Schijven et al. 2017).

The Microbial Risk Assessment Tool will be developed for a range of hydrogeological settings found in New Zealand. The types of unconfined aquifers for which the tool will provide separation distances are:

- Alluvial gravel
- Alluvial sand
- Pumice sand
- Coastal sand
- Sandstone and non-karstic limestone
- Karst and fractured rock

Hydraulic properties and their variances that will be used as input data for the MRA Tool (Table 7 and Table 8) were taken from the 2010 guidelines (Moore et al., 2010). The hydraulic properties (transmissivity, hydraulic conductivity, porosity), sourced from regional authorities and small-scale tracer tests conducted by ESR at the time, were generally in the same range as values from the literature, and no major change is expected for the mean and variances with the addition of more data.

In general, aquifers can be very heterogeneous, and hydraulic properties can vary over several orders of magnitude even if measured at wells in close proximity to each other. Too few field data are available to allow aquifer heterogeneity to be precisely described. The accepted approach to overcoming this difficulty is to determine the variability in the aquifer's hydraulic properties and use this as the basis of a statistical model of the aquifer. This allows aquifer properties to be simulated at every unsampled point. Geostatistical models are used to describe the spatial variability of a property. Variograms are one version of a geostatistical model. Transiograms provide an alternative geostatistical model and are useful where the connectivity of high permeability flow paths are pervasive, such as in alluvial gravel aquifers. These geostatistical models allow hydraulic property values to be interpolated to locations without any observed values. A semi-variogram shows the semivariance as a function of the distance between two locations. The semi-variogram properties for the aforementioned aquifer types are listed in Table 8. Further information on the development of the semi-variograms is provided in the 2010 guidelines (Moore et al., 2010). A transiogram describes the juxtapositional properties of different facies at increasing separation distances. This is then used to describe the spatial disposition of permeable and less permeable aquifer material. Variograms will be used to describe the heterogeneity of most of the aquifer materials listed in Table 8, but transiograms will be used for alluvial gravels.

Karst and fractured rock aquifers were treated differently as it was not possible with existing knowledge to define the heterogeneity of the discrete fracture networks within the karst or fractured rock in a probabilistic sense (e.g., generation of stochastic realisations of the fracture networks). This work is beyond the budget and scope of this current guideline project. In the interim, a conservative approach was adopted where the spatial removal rate distributions were simply applied to a range of distances. This simple approach tends to inflate the calculated separation distances required, but this conservatism is appropriate in the face of scarce data.

It is noted that while there are few data in the literature, what is reported indicates very high values of hydraulic conductivity can occur in this setting (up to 1000 m/day), associated with flow within the fractures.

Table 6. The efficiencies of bacterial removal in different aquifer media (after Schijven et al ., 2017, Table 7).

Aquifer Media	Contamination Source	Microbe	Removal Rate (Log_{10}/m)		
			Mean	**Minimum**	**Maximum**
Coarse gravel	Sewage effluent	B. stearothermophilus	0.003	NR	NR
Coarse gravel	Sewage effluent	E. coli	0.005	0.004	0.01
Coarse gravel	Sewage effluent	Faecal coliforms	0.003	NR	NR
Coarse gravel	Tracer	B. subtilis spores	0.031	NR	0.045
Coarse gravel	Tracer	E. coli J6-2	0.21	NR	NR
Coarse gravel	Tracer	Faecal coliforms	0.003	NR	NR
Coastal sand	Septic tank effluent	Faecal coliforms	0.159	NR	NR
Dune sand	Sewage effluent	Faecal coliforms	0.014	NR	NR
Dune sand	Sewage effluent	Streptococci	0.005	NR	NR
Fine sand	Septic tank effluent	C. perfringens	0.024	NR	NR
Fine sand	Septic tank effluent	Clostridium	0.044	NR	NR
Fine sand	Septic tank effluent	Coliforms	0.05	NR	NR
Fine sand	Septic tank effluent	E. coli	0.048	NR	NR
Fine sand	Septic tank effluent	Enterococci	0.025	NR	NR
Fissured chalk	Sewage effluent	Faecal coliforms	0.023	0.004	0.067
Fractured gneiss	Tracer	E. coli	0.115	0.087	0.143
Fractured limestone	Sinkhole	Clostridium	0	NR	NR
Fractured limestone	Sinkhole	E. coli	0.001	NR	NR
Fractured limestone	Sinkhole	Faecal coliforms	0.001	NR	NR
Fractured limestone	Sinkhole	Streptococci	0.001	NR	NR
Gravel and sand	Tracer	E. coli	0.004	0.003	0.004
Karst limestone	Creek	Enterococci	0.017	0.001	0.215
Karst limestone	Creek	Faecal coliforms	NR	0.052	0.067
Limestone	Pig manure pit	Faecal streptococcus	0.016	0.015	0.017
Pumice sand	Sewage effluent	Faecal coliforms	3.847	NR	NR
Pumice sand	Tracer	E. coli	1.54	1.46	1.61
Sandstone	Pig manure pit	Faecal streptococcus	0.041	NR	NR
Sandy gravel	River bank filtration	Aerobic spores	0.145	0.08	0.27
Sandy gravel	River bank filtration	Bacillus	0.052	0.015	0.081
Sandy gravel	River bank filtration	Clostridium	0.053	0.015	0.126
Sandy gravel	River bank filtration	Faecal coliforms	0.102	0.031	0.148

Table 7. Summary of aquifer properties adopted in the MRA Tool (from Moore et al., 2010).

Aquifer type	Transport porosity	Hydraulic conductivity (m/day)
Alluvial gravel (for permeable channels)	0.0032	1300
Alluvial (coarse) sand	0.2	80
Pumice sand	0.3	80
Coastal Sand	0.2	10
Sandstone and non-karstic limestone	0.1	0.01
Karstic and fractured rock (e.g. basalt and schist)	1 and 0.1 for matrix and fractures respectively	1000

Table 8. Summary of the exponential semi-variogram properties for hydraulic conductivity used to represent the selected aquifer types – sill values in log10 (from Moore et al., 2010).

Aquifer type	Sill for $\log_{10}$ hydraulic conductivity	Sill for porosity	*a* value (1/3 Range)	Anisotropy
Alluvial (coarse) sand	1.2	0.0025	170	2:1
Pumice sand	0.01	0.002	100	1:1
Coastal sand	0.33	0.014	100	1:1
Sandstone and non-karstic limestone	0.44	0.014	100	1:1
Karstic and fractured rock (e.g. basalt and schist)	None assumed			

3.6 SOIL, VADOSE ZONE AND SATURATED ZONE THICKNESS

3.6.1 Soil thickness/depth

Soil depth is entered by the user, or if unknown, is assumed to be 1 m in accordance with the 2010 guidelines and Pang et al. (2009).

3.6.2 Vadose zone thickness

Vadose zone thickness can be entered by the user directly into the tool. A value of zero can be entered for situations where there are very high groundwater tables and no significant reduction is expected in the vadose zone.

3.6.3 Saturated zone thickness

Saturated thickness for the different aquifer types will be assumed to be 10 m greater than the well screen depths shown in Table 1.

3.7 OTHER ASSUMPTIONS AND LIMITATIONS OF THE FLOW SCENARIOS

Other assumptions that apply to the flow scenarios are:

- Water is abstracted at the screens for each type of well – domestic, small town and municipal.
- As described above, single wells pumping from an unconfined aquifer will be considered as within scope for this tools project as the inclusion of pumping interferences and of variable confinement status, would introduce significant complexity, requiring individualised site information. For such cases, a more detailed site-specific assessment should be undertaken. An assessment based on an unconfined aquifer would be expected to be conservative.
- The effect of boundary conditions (other than the pumping well and the surface loading) will not be considered in the tool. When such boundaries are in proximity to the source or are expected to affect the flow patterns or microbial transport and removal characteristics, a site-specific assessment should be undertaken.
- The soil and vadose zone directly below the OWMS disposal field are constantly saturated. The modelling has been undertaken assuming the maximum typical effluent disposal design flux of 10-50 mm/day. This flux is more than three orders of magnitude greater than most rainfall recharge rates.
- The vast majority of microbial transport through the soil occurs at saturated or near-saturated conditions (Close et al. 2008; 2010) so the transport of microbes has been simulated for near-saturated conditions and the frequency of those conditions for each land use is used to estimate the total microbial transport.

4. MICROBIAL LOADING AND REMOVAL RATE SCENARIOS

For the land-use scenarios modelled in the MRA tool, microorganisms were chosen that best represented the risk to groundwater resources and public health. The type of microorganism and why it was chosen is explained in the following sections. The collation and quantification of the source microbial loading inputs was reported by Humphries et al. (2020) and is used to estimate the microbial loading rates for each land-use in this section.

4.1 HUMAN RELATED LAND-USE SCENARIOS

Out of the eight land uses in the MRA tool, two land uses involve human faecal sources:

- Multiple domestic on-site wastewater management systems
- Community size on-site wastewater management systems

Since rotavirus was included in the 2010 setback distance guidelines as a modelled viral pathogen it was again considered for the MRA tool. However, on 1 July 2014 Rotarix®[1], an oral vaccine given at 6 weeks, 3 months and 5 months of age, was added to the New Zealand national childhood immunisation schedule (ESR, 2016). The introduction of a rotavirus vaccination in Australia resulted in a 70% decrease in rotavirus hospitalisations in under 5-year olds in the two and a half years following the vaccines introduction (ESR, 2016). A similar decline (85%) was reported following the first year of the vaccine's introduction to New Zealand (ESR, 2016). Due to the rotavirus vaccine being included on the national immunisation schedule, contracting rotavirus is now not as common as it once was. For the MRA tool rotavirus was therefore not considered to be a suitable microorganism to be modelled.

A viral pathogen that is not included in the national immunisation schedule and poses a risk to the community however is norovirus. Norovirus was chosen as the most suitable viral pathogen for the MRA tool with regards to the human related land-use scenarios. Values for norovirus shedding during illness are taken from a study by Borchardt et al. (2011).

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[1] The immunisation Advisory Centre https://www.immune.org.nz/vaccines/available-vaccines/rotarix

We have also included E. coli as a bacterial indicator as this is a good indication of faecal contamination, it is often monitored, and it is the indicator in the Drinking Water standards (Ministry of Health, 2018).

The loading rates adopted for these two pathogens are:

- Human norovirus loading rate range: 1 x 10^{4} – 1 x 10^{10} viruses/L
- Human *E. coli* loading rate range: 4.3 x 10^{5} – 1.4 x 10^{7} cfu/100 mL

4.2 ANIMAL RELATED LAND-USE SCENARIOS

Out of the eight land uses in the MRA tool, five land uses involve animal faecal sources:

- Dairy farming
- Sheep and beef farming
- Stockyards
- Animal effluent/manure application to land
- Wildfowl

According to Moriarty et al. (2008) and Devane et al. (2005) *Campylobacter* has been widely recorded in cattle faeces throughout New Zealand. In a Canterbury study 97.8% and 93.9% of samples from composites of five dairy and beef cattle respectively, were reported to contain *Campylobacter* (Devane et al., 2005). During the Havelock North outbreak groundwater was found to be contaminated with sheep faecal matter which was subsequently identified as *Campylobacter* (Gilpin et al., 2020). Due to its widespread prevalence in dairy cows, beef cattle and sheep, and the high rate of infections within the New Zealand population, *Campylobacter* was considered the most appropriate organism to be used for agriculture related land-use scenarios in the MRA tool. The prevalence of *Campylobacter* in wildfowl faeces has been estimated for 4 different wildfowl species in New Zealand (Black swans, Canada Geese, ducks and gulls) by Moriarty et al (2011). These data have been collated, along with international studies, by Humphries et al (2020).

At this stage we have just indicated a range of *Campylobacter* concentrations for each agricultural land use. We will use the collated data on microbial concentrations and loading rates (Humphries et al. 2020) to derive an appropriate range and probability distribution that will be used with the stochastic simulations to provide the assessment of microbial risk.

We have also included E. coli as a bacterial indicator as this is a good indication of faecal contamination, it is often monitored, and it is the indicator in the NZ Drinking Water standards (Ministry of Health, 2018).

The loading rate ranges adopted for the agricultural animal sources are:

Campylobacter: 10^4 - 10^8 MPN/species/day

E. coli: $10^{7\,-}\,10^{11}$ MPN/species/day

Table 9 shows the raw mean/ranges of *Campylobacter* and *E. coli* in various livestock and in wildfowl. Ranges or means of the loading rate of each target microorganism are provided as concentration per animal per day. Loading rates include the prevalence (frequency of detection within a specified herd size) of each target microorganism in an animal species, as not all animals in a herd carry a particular microorganism. Data are taken from NZ studies unless otherwise indicated.

The loading rate ranges adopted for the wildfowl sources are:

Campylobacter: 10^4 - 10^6 MPN/bird/day

E. coli: 10^6 – 10^{10} MPN/bird/day

Table 10 shows the raw mean/ranges of *Campylobacter, E. Coli, Giardia and Cryptosporidium* in dairy farm effluent. Ranges of the loading rate of each target microorganism are provided as concentration per animal/day or hectare/day.

Table 9: Raw (pre statistical processing) loading rates for Campylobacter and E. coli in various livestock and in wildfowl.

Microorganism	Animal type	Loading rate	Units
Campylobacter	Dairy cow	10^{4} - 10^{10}*	**MPN/cow/day
	Beef cattle***	10^{5} – 10^{8}*	MPN/cow/day
	Sheep	10^{5} – 10^{8}	MPN or [€]CFU/sheep/day
Campylobacter jejuni	Dairy cow	10^{4} – 10^{7}	MPN/cow/day
	Beef cattle***	10^{8}	CFU/cow/day
E. coli	Dairy cows	10^{7} - 10^{10}	MPN/cow/day
	Beef cattle***	-	-
	Sheep	10^{10} - 10^{11}	MPN/sheep/day
Wildfowl			
Campylobacter	Black swans	10^{4}	MPN/bird/day
	Canada Geese	10^{6}	MPN/bird/day
	Ducks	10^{4}	MPN/bird/day
	Geese[¥]	10^{7}	CFU/bird/day
	Gulls	10^{4}	MPN/bird/day
E. coli	Black swans	10^{8}	MPN/bird/day
	Canada Geese	10^{6}	MPN/bird/day
	Ducks	10^{10}	MPN/bird/day
	Geese[¥]	10^{6}	CFU/bird/day
	Gulls	10^{8}	MPN/bird/day

*This highest range could be indicative of high shedding periods of the year such as spring during the calving season

**MPN = most probable number culturing method

***Data based on international studies as no NZ studies of concentration of *Campylobacter* or *E. coli* (only STEC) in beef cattle faeces

[€] CFU = colony forming units

[¥] International studies

Table 10: Raw (pre statistical processing) loading rates for Campylobacter, E. Coli, Giardia and Cryptosporidium in dairy farm effluent

Microorganism	**Environmental sample type**	**Concentration**	**Units**
Campylobacter	Dairy farm effluent	10^{4}- 10^{6}	MPN/cow/day
E. coli		10^{7}- 10^{8}	MPN/cow/day
E. coli		10^{6}- 10^{8}	*E. coli*/hectare/day
Giardia		ND by qPCR	
Cryptosporidium		ND by qPCR	

4.3 STORMWATER SYSTEMS

The remaining land-use scenario is stormwater systems which can be a mixture of sewage and septage (from leaks or overflows) and animal faeces, with the first flush of stormwater often approximating a weak sewage. Most routine monitoring of stormwater measures *E coli* and *enterococcus* (Humphries et al. 2020), but there are some measurements of pathogens including *Campylobacter* and viruses. In view of the mixed human and animal sources for stormwater we are proposing to simulate *E. coli*, *Campylobacter*, and Norovirus.

At this stage we have just indicated a range for various microorganisms in stormwater. We will use these ranges with an appropriate probability distribution for the stochastic simulations to provide the assessment of microbial risk. Table 11 shows the raw mean/ranges of *Campylobacter, E. coli, Giardia and Cryptosporidium* in stormwater. Norovirus concentrations in small and medium wastewater treatment systems ranged between 10^2 and 10^5 genome copies/L (Hewitt et al., 2011) and these values were reduced by a factor of 10 to approximate the "weak sewage" effluent for the stormwater simulations. Ranges of the loading rate of each target microorganism are provided as concentration per volume.

Table 11: Raw (pre statistical processing) loading rates for Campylobacter, E. coli, Giardia and Cryptosporidium in stormwater.

Microorganism	**Environmental sample type**	**Concentration**	**Units**
Campylobacter	Stormwater€	10^0- 10^2	**MPN/100 mL
Campylobacter jejuni	Stormwater	≤ 5	***GC/100 mL
E. coli¥	Stormwater	$10^1 – 10^7$	CFU or MPN /100 mL
Giardia	Stormwater	10^2- 10^5	Cysts /100 L
Cryptosporidium	Stormwater	10^1- 10^4	Oocysts/ 100 L

€ very little data on viruses but what is there has low prevalence e.g., 0.02%

*Data based on international studies as no NZ studies of concentration or loading rate in stormwater
**MPN = most probable number culturing method

***GC = gene copy

¥ $10^3 – 10^4$ could be useful means to model

The loading rate ranges adopted for the stormwater sources are:

E. coli: $10^3 – 10^4$ MPN/100 mL

Campylobacter: $10^0 – 10^2$ MPN/100 mL

norovirus: $10^0 – 10^3$ copies/100 mL

4.4 MICROBIAL LOADING AND REMOVAL RATES

Loading rates based on the previous report and removal rate scenarios for each receiving environment were estimated based on a review of the international literature and experimental data from New Zealand. The international literature has been recently reviewed by Schijven et al. (2017). With respect to microbial removal rates in soils, the vadose zone and groundwater types, they summarise the data from Pang (2009) as the most comprehensive source of removal rates. As there is no new data and the rates from Pang (2009) were used in the 2010 guidelines it follows that we can also use the same summarised viral removal rates. The bacterial removal rates are taken from Pang (2009) and Schijven et al. (2017). The virus and bacterial removal rates have been given in Sections 3.3 to 3.5

In general, reductions in microbe concentrations take place in each of the following four components of the transport process (Figure 1 & Figure 2):

1. the wastewater treatment plant or input source for other land-use scenarios
2. the land application system (LAS) and the soil, if any, beneath the disposal field for OWMS scenarios or soil layer for other land-use scenarios
3. the unsaturated (vadose) zone above the water table and
4. the groundwater as it flows through the aquifer.

The initial concentration of microbes entering the sewage tank or that are introduced from a specific land use, compared to the maximum acceptable concentration in the well water, determine the overall reduction that must be achieved by the total of the four components.

4.5 WHAT VIRUS CONCENTRATIONS IN DRINKING WATER CAN BE TOLERATED?

Figure 3 shows an overview of the approach used to determine the tolerable virus concentration in drinking water and follows the approach outlined in the 2010 guideline (Moore et al. 2010). Briefly, the tolerable daily probability of infection has been set at 1 in 10,000 following the level set out by USEPA in 1989 and adopted widely internationally. A dose response curve is used to relate the number of infective organisms ingested by an individual to the likelihood of that induvial becoming infected. The number of infective organisms ingested on a daily basis is the product of the concentration of infective organisms in the water and the amount of water consumed. Data from two New Zealand surveys have been used for the water consumption values in this modelling; the details of the distribution of values used are given in the Technical Appendix of the 2010 guidelines. The surveys indicate a median daily intake of 600 mL of unboiled water for people older than 15 years (Moore et al. 2010).

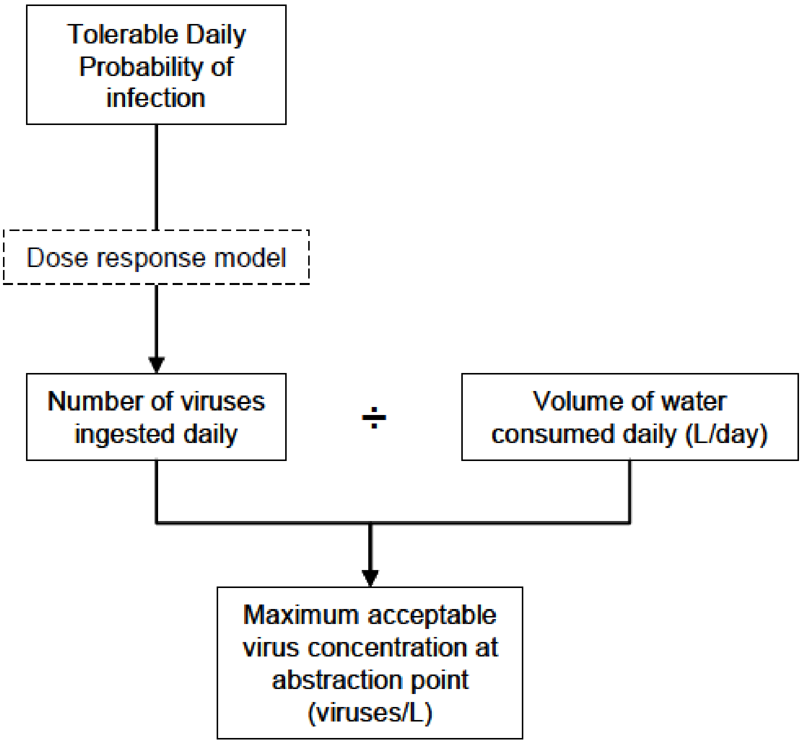

Figure 3. Algorithm for calculating the tolerable virus/microbe concentration in water in a well.

5. MODELLING APPROACH

A modular approach is adopted, whereby the soil, vadose zone and saturated zone modelling components are decoupled. The outputs of each modelling component are the log reduction in the pathogen concentration achieved with increasing transport distances, which is combined to achieve a total log reduction that is achieved as the pathogen moves through the soil, vadose and saturated zone. This approach provides significant computational advantages, while it allows the assessment of microbial risk from multiple interacting sources.

5.1 SOIL MODELLING

As microbial transport is order of magnitudes greater under saturated conditions, we only consider saturated conditions for the soil layer, considering the probabilities that such conditions may occur. This is achieved using a simple water balance model with daily steps, using rainfall and PET as parameters for a number of representative soil and hydrological conditions. As described above, we have used the Irricalc model for these calculations. The log10 reduction in the microbe concentration in the effluent as it percolates through the soil is calculated by multiplying the log10 reduction/m obtained from Table 2 by the depth of soil through which the effluent passes. As described in Section 3.6.1, if no soil depth information is available, a depth of 1 m is assumed. The removal rates for *Campylobacter* transport through soil are taken from Pang (2009). Because of the modular modelling approach adopted, the option of a more detailed soil modelling approach could be implemented if required and then incorporated with the vadose and groundwater modelling modules described below.

5.2 VADOSE ZONE MODELLING

The modelling of one-dimensional solute transport through the vadose zone will generally follow the methodology described in more detail in the 2010 guidelines. It is based on the 1D, mixing cell model described by Bidwell (2000), run in conjunction with @RISK® (providing Monte Carlo calculation capability) to allow some input parameters to take a range of values (Table 12). More complex models, such as Hydrus (Simunek et al. 1999), are available for vadose zone modelling. However, the required input data are not available for a national assessment and there would need to be significant simplifying assumptions for the application of these complex models.

Exploring a range of values is required to represent both the natural variability in the parameter and the uncertainty of parameter values due to data scarcity. From the Monte Carlo calculations a distribution of possible $\log_{10}$ reductions predicted to be achieved within the vadose zone was obtained.

Table 12. Input parameter values used for vadose zone modelling[1] (from Moore et al., 2010).

Hydrogeological setting	Infiltration rate (m/day)	Macropore flow contribution to total flow	Transport porosity Θ		Péclet Number		Longitudinal dispersion[2]		Retardation factor	Removal Rate ($\log_{10}$/m)	
			Matrix flow	Macropore flow	Matrix flow	Macropore flow	Matrix flow	Macropore flow		Matrix flow	Macropore flow
Alluvial gravel	0.050	25–50%[3]	0.1–0.2	0.005–0.015	20	20	5%	5%	1	0.05–0.61	0.05–0.61
Alluvial sand (coarse)	0.035	1–10%[3]	0.35–0.40	0.01–0.05	20	80	5%	1%	1	0.15–1.5 0.74[4]	0.15–1.5 0.74[4]
Pumice sand	0.030	0%	0.25–0.36		7–20		5–15%		1	1.3–4.0	
Coastal sand (fine)	0.030	0%	0.35–0.40		7–20		5–15%		1	0.43-2.1	
Sandstone – non-karstic limestone	0.020	0%	0.01–0.03		7–20		5-15%		1	0.014– 0.043	
Fractured rock and karstic geology	0.050	50–70%	0.01–0.03	1	7–20	80	5–15%	1%	1	4.0 x 10^{-4}–12.2 x 10^{-4}	4.0 x 10^{-4}–12.2 x 10^{-4}
Clay (cracking)	0.010	85–95%	0.45–0.65	0.015–0.035	7–20	80	5–15%	1%	1	0.78–2.4	0.78–2.4
Silts	0.020	0.5–2%	0.15–0.25	0.0025-0.0075	7–20	80	5–15%	1%	1	0.43–1.3	0.43–1.3
Peat	0.020	0%	0.35–0.55		7–20		5–15%		1	0.52–1.5	
Ash	0.020	0.5–2%	0.05–0.15	0.0025-0.0075	7–20	80	5–15%	1%	1	0.43–1.3	0.43–1.3

Notes:

[1] The @RISK distributions used are “uniform” for all parameters except those for alluvial sand for which a “triangular” distribution was assumed.
[2] Dispersion values are calculated from the Péclet Number and observation depth.
[3] Linearly decreased to 0% between 7 and 12 m.
[4] “Most likely value” for @RISK “triangular” distribution.

5.3 SATURATED ZONE MODELLING

The modelling of groundwater flow and pathogen transport for the Microbial Risk Assessment Tool will follow the methodology described in detail in the 2010 guidelines (Moore et al., 2010). This methodology is summarised in Figure 4.

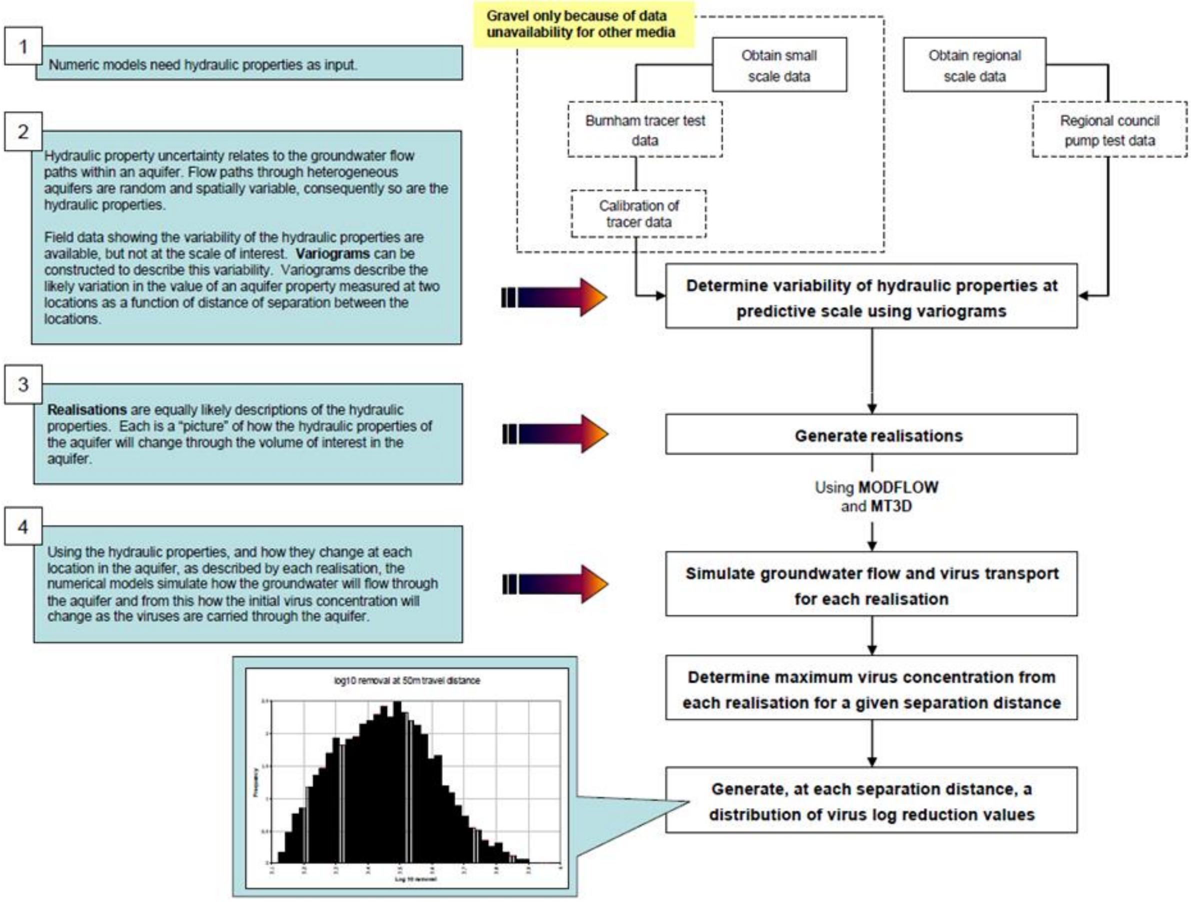

Figure 4. Overview of the saturated zone modelling.

The contaminant transport and pathogen removal will be addressed in a stochastic framework. For each aquifer type multiple realizations of the heterogeneous hydraulic conductivity field will be generated (Figure 5). The generation of these stochastic realisations will be based on field variograms and transiograms from earlier studies, as appropriate for each aquifer type. The steady-state flow solution for each heterogeneous realization will be generated using MODFLOW for each pumping rate and depth.

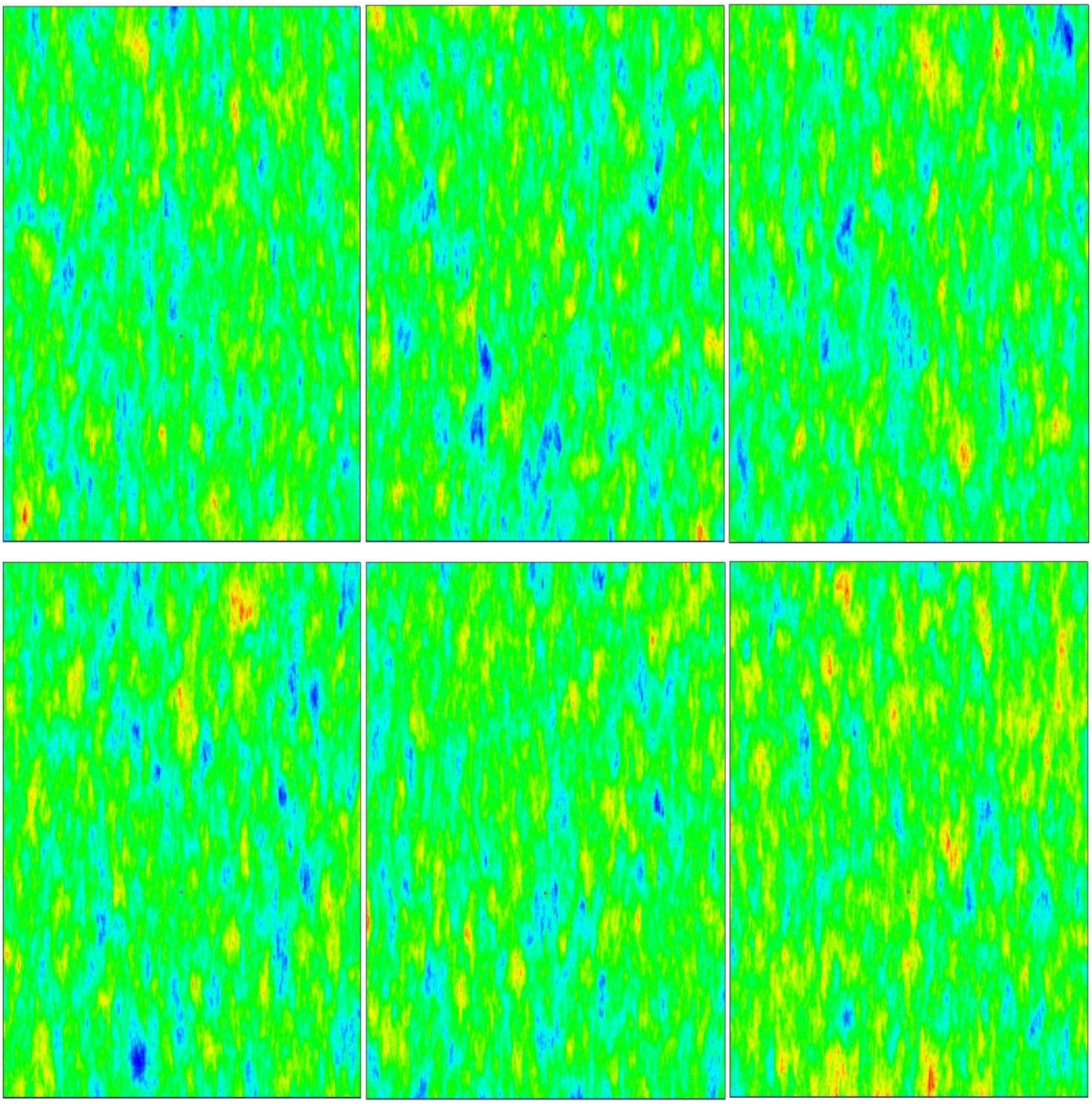

Figure 5. Top layer view of six realizations of a 3D heterogeneous hydraulic conductivity field.

The contaminant log-removal will be calculated using the inverse transport solution, using MT3DMS. Contaminant removal will be simulated as a first-order irreversible reaction quantified by a reaction constant. This approach will allow multiple sources to be considered in the calculation of risks of microbial contamination, by superimposing solutions which will be included in the tool outputs. For multiple OWMS, this approach will simply be the superposition of the multiple locations of the multiple OWMS. For a dairy land use grazing a paddock of 7 ha, the approach will be to superimpose the solutions from multiple inputs located throughout the diffused source area.

The outputs from the MT3DMS transport solutions incorporating all realizations will be compiled and form the basis of the probabilistic description of the microbial log-removal that is achieved in the aquifer.

6. OUTPUT OVERVIEW

In addition to a report, there will be an MRA tool comprising a user interface (e.g. an Excel or Python enabled interface) which will provide a rapid and simple analysis of the microbial risks in any selected context.

The interface will enable a user to select options for the site context details from menus. The option details would include the following:

- Microbial risk scenario being explored (e.g. Onsite Wastewater, Wildfowl etc) as well as an option for combinations of these scenarios
- Water supply being explored (e.g. single dwelling, community or municipal supply)
- Soil type and thickness of soil profile
- Vadose zone material and thickness
- Saturated zone material and disposition of the site compared to the prevailing groundwater flow direction
- Confidence limit, and/or risk tolerance, desired for setback distance.

The selected confidence limit option will allow a user of the guidelines to select a continuum of risk tolerant to risk averse for the microbial risks. This is unlike the 2010 guidelines, where a very conservative (or risk averse) confidence limit option was hardwired into the guidelines.

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APPENDIX 1: SURVEY QUESTIONS & SUMMARY OF FEEDBACK

1. Survey Responses

Question 1

Report Section 2.1 and Section 4.1 Do you feel comfortable with the scenario for multiple OWMS and associated assumptions such as loading rates that will be used for the Microbial Risk Assessment Tool?

Total responses = 11

- Yes = 8
- No = 3

Comments (x8 responses)

1) Not entirely comfortable with the assumption that all systems are performing as expected. Darfield survey found close to 30% has reported some failure https://www.cph.co.nz/wp-content/uploads/darfieldwastewatersystemssurvey.pdf . I think it would be better for a conservative assessment of cumulative effects to assume some of the systems will not be achieving optimum removal before discharge.
2) The assumed volumes appear to be reasonable. The performance of OWMSs is variable based on the level of maintenance undertaken. Most systems will operate sub-optimally as there is a tendency to only respond when the system has failed. Consideration should be given to assessing the risk of sub-optimal conditions and/or performance to assist in understanding how the risk increases as OWMS performance decreases. The microbial loading and removal rate values seem reasonable and are based on an extensive review of international literature. However, it is likely that they will need to be amended to better match contaminant concentrations observed in groundwater sources.
3) Draft methodology appears well based and supported
4) It seems reasonable to me within my scope of knowledge regarding OWMS's
5) Multiple OWMS represent to greater risk and has not been adequately assessed to date, this would be a welcome addition to the toolbox
6) More or less same answer as #2
7) The assumption of correct operation and maintenance of OWMS is probably reasonable for purposes of the tool, but needs to be acknowledged as likely unrealistic and some effort taken to quantify the effects of reduced performance due to poor or no maintenance of a proportion (x%) of systems
8) Don't understand

Question 2

Report Section 2.2 and Section 4.1 Do you feel comfortable with the scenario for community size on-site wastewater management systems and associated assumptions such as loading rates that will be used for the Microbial Risk Assessment Tool?

Total responses = 11

- Yes = 10
- No = 1

Comments (x7 responses)

1) It would also be good to include a scenario of smaller clusters than 250. Most of the consent applications for multiple systems are subdivisions of around 10 to 20 sites close together.
2) In regard to loading rates, it is necessary to consider how these communities access water as this will have an impact on wastewater flows and loads. e.g. community based water supply or individual self supplies.
3) Larger systems should have specific info
4) As above
5) Sizes seem reasonable and logical and loading base on Norovirus is appropriate and accounts for worst case scenario.
6) Without checking in detail, seems consistent with my experience and relevant standards regarding allowance volume of effluent generated.
7) Maybe a good idea to include regional park facilities and other public toilets that can receive high loads

Question 3

Report Section 2.3 and Section 4.2 Do you feel comfortable with the scenario for dairying (irrigated and non-irrigated) and associated assumptions such as loading rates that will be used for the Microbial Risk Assessment Tool?

Total responses = 11

- Yes = 9
- No = 2

Comments (x6 responses)

1) The assumptions and limitations in the model are understandably necessary, however, may not result in the desired amount of precaution being exercised. For example, assumptions around the use of stand-off pads and feed lots; and also how Farm Dairy Effluent (FDE) is managed relies on effective enforcement of, and compliance with, FDE requirements is assumed; in reality there is evidence of non-compliance and this substantially increases risks to groundwater. The model needs to be able to assess the increased risk for poor performance to guide users in the assessment of risk if there is a failure of a system or systems. Knowing what could eventuate when an adverse situation occurs is essential.
2) More than a single loading option is helpful
3) As above - within my scope of knowledge the scenarios seem reasonable
4) Might need clarity around daily loading rates compared to annual (per ha basis)
5) I don't actually feel "uncomfortable" with it; neither fully comfortable, and you have no other option. Would have preferred a third option called "pass". I will ask a colleague of mine who has great experience and strong opinions on this to answer your survey.
6) Insufficient subject experience to offer substantive critique

Question 4

Report Section 2.4 and Section 4.2 Do you feel comfortable with the scenario for Sheep & Beef and associated assumptions such as loading rates that will be used for the Microbial Risk Assessment Tool?

Total responses = 11

- Yes = 9
- No = 2

Comments (x5 responses)

1) Consideration of the proximity of waterways and drains to farming activities will influence the transportation of contaminants from land to waterways and into groundwater.
2) Although the majority of sheep and beef in Taranaki would be in the hillier areas and we have very little information regarding groundwater use in these areas so it might be good to expand on this at a later date.
3) Same as item 3. Pass.
4) Is there sufficient evidence to exclude hill country areas as a recharge zones to groundwater? Does this apply consistently across the country? Perhaps best to identify limitations of the model for certain areas where hill country is an important recharge area.
5) extra comments

Question 5

Report Section 2.5 and Section 4.2 Do you feel comfortable with the scenario for Wildfowl and associated assumptions such as loading rates that will be used for the Microbial Risk Assessment Tool?

Total responses = 11

- Yes = 8
- No = 3

Comments (x5 responses)

1) Wildfowl populations should be evaluated on the size and extent of wetlands, ponds and lakes.
2) I think that the large flock numbers is probably the safest way to go as the numbers would be difficult to determine
3) Bioresearches has done some figures for us on Rotorua lakes - will send through
4) No idea. Some other answers are "neither comfortable nor uncomfortable, pass". This is "no idea, pass".
5) Insufficient subject experience to offer substantive critique

Question 6

Report Section 2.6 and Section 4.3 Do you feel comfortable with the scenario for Stormwater systems and associated assumptions such as loading rates that will be used for the Microbial Risk Assessment Tool?

Total responses = 11

- Yes = 8
- No = 3

Comments (x5 responses)

1) I think stormwater from residential and commercial areas could be looked at separately because I expect the microbial sources and level of risk may not be the same.
2) Although stormwater systems are included in the land-use scenarios, there is no consideration of catastrophic events, such as flooding, which can mobilise significant volumes of contaminated water, including sewage or effluent storage overflows. Heavy rainfall and/or surface flooding has been implicated in high-profile drinking water contamination events (e.g., Havelock North; Walkerton, Ontario). It would be helpful if the assessment framework proposed for the MRA tool could incorporate such event-based scenarios.
3) I think this is a reasonable approach due to so many unknowns

4) Will need to be careful to factor in the heterogeneity of stormwater soakage and not to double dip with wastewater sources
5) What you present here is consistent with my prior experience for variability and paucity of data. As you say, it can be like weak sewage. How is it comfortable to make vast generalisations based on numerical artistry to make much of little. And I don't think the approach to simulation is likely appropriate, at least arguably difficult to defend on objective basis.

Question 7

Report Section 2.7 and Section 4.2 Do you feel comfortable with the scenario for Stockyards and associated assumptions such as loading rates that will be used for the Microbial Risk Assessment Tool?

Total responses = 11

- Yes = 5
- No = 6

Comments (x5 responses)

1) Loading rates need to be determined on the maximum stock capacity on any one day as that is when the peak effluent volumes will be occurring. The adequacy of onsite wastewater systems is assumed however thought should be given to adverse events (flooding) where contaminants can then be discharged into the environment.
2) seems like a reasonable approach
3) Same as item 3. Pass.
4) Insufficient subject experience to offer substantive critique
5) Happy

Question 8

Report Section 2.8 and Section 4.2 Do you feel comfortable with the scenario for animal effluent application to land and associated assumptions such as loading rates that will be used for the Microbial Risk Assessment Tool?

Total responses = 11

- Yes = 9
- No = 2

Comments (x5 responses)

1) Could include some consideration of leaking directly from storage ponds.
2) The main concern is where the land is overloaded either through excess application or significant rain events that can cause overtopping of effluent ponds and increased transport of contaminants into groundwater.
3) Yes with reservations- although due to all the assumptions it would be good to maybe have some warnings when using the tool as a reminder of what is not covered as I think a lot of these assumptions are not followed
4) Same as item 3. Pass.
5) Insufficient subject experience to offer substantive critique

Question 9

Report Section 5 Do you feel comfortable with the modular approach for soil, vadose zone and saturated zones that will be used for the Microbial Risk Assessment Tool?

Total responses = 11

- Yes = 9
- No = 2

Comments (x4 responses)

1) 2.4.1 Section 5.3: Saturated zone modelling
   • The use of Gaussian Random Fields generated using the FIELDGEN method may introduce some bias in the modelling of microbial transport in the saturated zone. These types of random fields do not exhibit the same connectivity of high-permeability zones that have been reported in hydrogeological studies. Therefore, preferential pathways (and associated contaminant breakthrough curves) may not be appropriately represented using the MRA tool approach.

   • It is unclear where the modelled pumping bores will be placed in the saturated zone models. Pumping bores are typically screened in the most permeable zones to maximise well yields, and these high-permeability facies can be extensively connected. If the modelled bores are randomly located, including in low-permeability zones, this is likely to bias the distribution of virus log-reduction values outputted by the saturated zone model ensemble.

   • It is unclear whether the saturated zone numerical models will be two- or three-dimensional, or whether the solute transport model will account for dispersion. Solute transport in three dimensions has been shown to increase dispersion and dilution effects. If the underlying saturated zone models in the MRA are modelled in two dimensions and without dispersion, the setback distances may be conservatively large.
2) Adds flexibility
3) Consistent with Separations distance guidelines
4) This is a step back for me. It is not representative of system's behaviour, the current state of model complexity, or the current availability of cpu, the lack of which drove the use of decoupled models long ago. The vadose zone model is particularly oversimplified - and based on an old paper that, in all these years has been cited 3 times? Since the vadose zone is the key to the city. and, re defensible... I have not been following this project - do you have any large amount of field data that rigorously justifies model predictions?

Question 10

Report Section 3.2 In Table 1 we indicate some pumping rates and well screen depths for domestic, small town and municipal wells. Can you confirm whether these pumping rates and assumed well screen depths are reasonable?

Total responses = 11

- Yes = 5
- No = 6

Comments (x8 responses)

1) If the table is correct, you are assuming single dwelling wells are screened 20 m below the water table. In my experience private wells are usually screened very close to the water table/have screens intercepting the water table.
2) Table 1 in the Draft for Comment has assumed pumping rates in m3/d for small community and larger community supplies. For the larger community supplies, pumping rates of 200 m3/day are assumed which seems to be very low. Even for small community supplies, the pumping rate of 50-100 m3/d is also low. These conservative rates will underestimate the zone of influence around wells. The model also assumes pumping rates are constant, which

is very unlikely as most small water supplies are heavily influenced by daily demand cycles. Adopting a peak pumping rate will provide a degree of conservatism within the model. The screen depths shown in Table 1 for single dwellings and small community supplies are 20 m and 30 m, respectively. Many small supplies are screened at very shallow depths. Using deeper screen depths could lead to under-estimation of microbial concentration values at shallow bores.

3) Not unreasonable for unconfined systems
4) I think the aquifer types need to be increased. Taranaki shallow aquifer is volcanic and very variable so a few more options would be good. we also have a permitted take at 50m3/day which will be increasing to 100 m3/day so it would be good to have a few more scenarios
5) Table is not clear. 20m3/day seems high but guess ok for worst case, cone of depression will need to be based on max pump rate (l/s).
6) Sorry to be so difficult with the discomfort levels here in response. The pumping rates in this table are bang on in theory and consistent with permitted and/or projected for models. I am not sure if you could call the data here, and other places that I have worked, robust - many gaps in knowledge. Here, I have the sense that, in practice, most pumpers pump less or up to this, however, in some spectacular circumstances the floodgates open. Therefore, personally, I would think of this as another data gap; but you did a great job to assemble numbers that are reasonable on paper.
7) Why would pumping rates be different for geology types in a community supply scenario - and only the community supply scenario? I.e. why would a community need twice as much water if they live over a gravel aquifer vs a sand aquifer? Also, why would the depths of unconfined aquifers change depending on the dwelling or community composition? Drilling best practice dictates that wells fully penetrate an aquifer, so most wells in an unconfined aquifer should be at similar depths. The water use amount should be similar for a similar supply system (single, small, large) and the depth of wells should be similar across unconfined aquifers unless there is a demonstrable difference in well depths between supply purposes (e.g. single dwellings pay as little as possible, so generally have shallower wells vs community supplies who try to meet best practice.)
8) Very good

2. Additional Email Responses

Environment Canterbury:

“I looked through this document and from what I can tell they covered everything I would like to see modelled. The only thing I would check, is if there is scenario that looks at no vadose zone removal? I have had a couple of consents with very shallow water table (~ 1m bgl).

I would be keen to see their results. “

Waikato Regional Council, John Hadfield:

“I appreciate the work that has already been done in the draft methodology and the start provided in 2010. It is definitely useful to expand the tool. Also a soft copy output / ”emulator” is a useful addition. I’m interested in the connection between this “tool” and other measures being introduced such as in the review of the NES by MfE and requirements for SPZs with guidance for uniformity. These are likely to require, for microbial protection (SPZ2), a travel time delineation (probably one year - with an upper distance of ~ 2.5 km). I see that uncertainty can be considered / varied in your output which again warrants some discussion with other e.g. MfE initiatives. Other aspects not addressed such as confinement would likely provide additional protection. Given there is a balance between land-use constraint and protection though such aspects may make for an overly cautious approach dependent on application. Lastly (for now given Christmas) I am less comfortable with the fractured rock & karst system category which is very difficult and should be approached cautiously – am sure you appreciate that.”

Ministry for the Environment, Adrian Young:

“Thanks for the update on this work. It looks like a really useful tool for informing RMA consent decisions.

I will have to defer to councils to provide feedback on the technical aspects of this work, as that is not really something MfE is in a good position to provide on (we used to have some groundwater scientists in-house, but most of them have moved on).

But from a policy perspective I see this work as being very complementary to the work we are doing to make amendments to the Drinking Water NES. As you would be aware, we are looking at setting requirements around the use of source water risk management areas/protection zones and controls on activities in those zones, and this tool would clearly help councils assess risks and make decisions whether to grant consents.

Do you have a timeframe for completion of this project? It would be good to stay connected as this progresses and to consider how it might form part of a wider implementation package for supporting councils to implement the Drinking Water NES (once amended).“

WaterNZ, Noel Roberts:

“The modelling assumes household application rates of 300 - 400 L/p/d which is twice what is normally accepted.

Also it is based upon near saturated soils which will not always be appropriate. I am unsure on what basis household effluent virus numbers were based upon, but this clearly depends on whether there is a sick person in the house. Statistical assessments need to be made, particularly for a cluster community.

I totally agree with the water use, national average for a networked water supply is around 250 – 260 l/p/d. 200 l/p/d is commonly used for onsite wastewater system design purposes."

Environment Bay of Plenty, Paul Scholes:

"Great to see this tool being progressed, when do think there will be a working version ready?

Have attached a Bioresearches report done for us a while ago on water fowl, which may or may not be useful. Also please find attached a draft report I have put together looking at separation distances for a council plan change.

Fiona Ambury, Whiterock Consulting and Andrew Dakers. ecoEng Limited:

Fiona and Andrew have prepared a 4 page response to the report. I have included the text of the response but not the figures.

"**Background**

Whiterock Consulting and ecoEng have been invited to review the ESR draft proposal: Model scenarios for a microbial risk assessment tool, prepared by Murray Close, Bronwyn Humphries, Conny Tschritter, Theo Sarris, and Catherine Moore, November 2020.

This is a joint submission, and our focus will be on on-site wastewater management systems only.

Both ecoEng Ltd and Whiterock Consulting provide independent engineering design services to clients requiring on-site wastewater management systems (OWMS). ecoEng has been actively providing this service for 20 years and Whiterock Consulting for 6 years . We apply best practice with reference to key standards and accepted guidelines. The key New Zealand standard we use is AS/NZS1547:2012, which is a risk management and amenity standard, as relevant to OWMSs.

One of the important services ecoEng and Whiterock Consulting provide for their clients is site specific risk assessment in relation to the proposed OWMS(s). This risk assessment is necessary for the following reasons:

- to determine fit-for-purpose risk mitigation measures and specifically the design specifications and required management, monitoring and servicing required of the preferred OWMS;
- to prepare support documentation for the required compliance application(s) (in particular RMA and Building Act requirements)

There are a number of hazards and consequent risks that we are required to address when designing an OWMS. Figure 1 illustrates some of the key hazards.

Whiterock Consulting and ecoEng are well aware of the many sites in New Zealand rural areas with high groundwater, where OWMSs are required in the midst of a number of both private and sometimes community drinking water bore. Unlike some other countries, the treated wastewater must be applied into or onto land within property boundaries and is not permitted to be discharge to surface waters or stormwater systems. Assessing pathogen hazards is a key requirement in the work we, and other designers, do and therefore we welcome the development of the microbial risk assessment (MRA) tool.

We recognise that OWMSs are complex systems, with several interacting and interrelated components. Refer to Figure 2.

Review comments

1. Figure 2 in the draft report labels the treatment plant as the OWMS. This is incorrect. While we knowledge there is no authoritative definition of an OWMS it is generally accepted that it is a system and the typical system components include some or all of; wastewater source facilities, the treatment plant, the dosing device and a land application system (refer to Figure 2).

2. On p11 reference is made to the 3-bedroom dwelling producing 1500-2000 L/day. This is significantly higher than what is typically accepted as a daily volume from a 3-bedroom dwelling. The most authoritative source for this information would be AS/NZS1547:2012 Table H3 (screen print below).

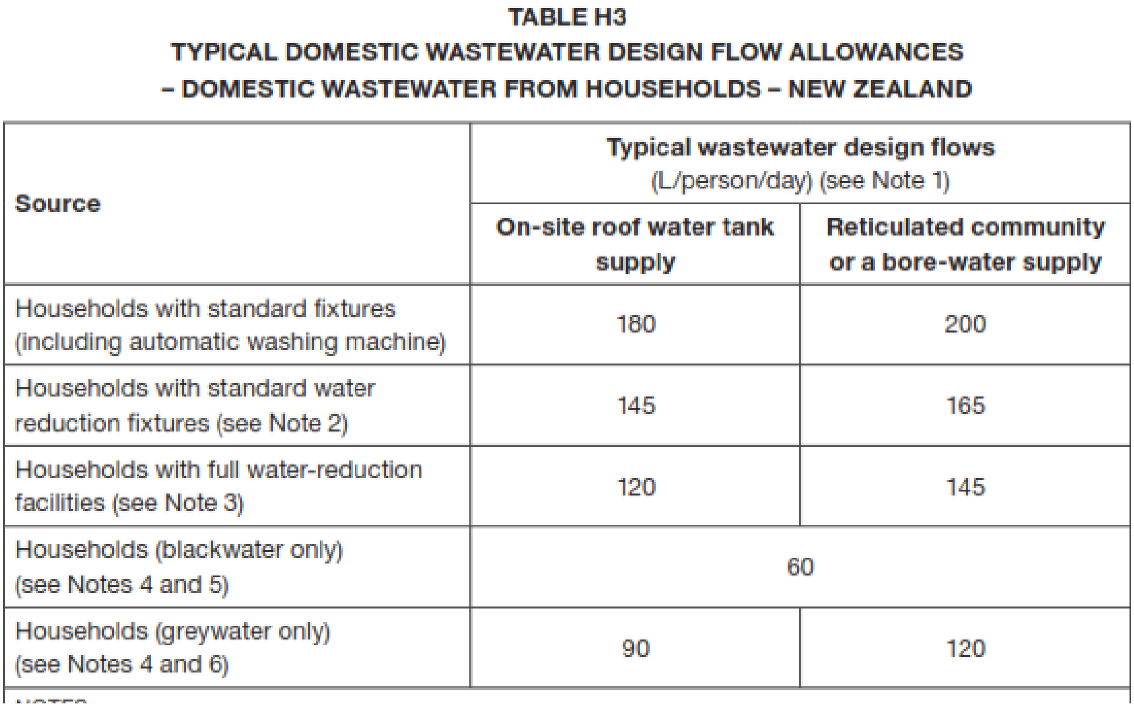

TABLE H3
TYPICAL DOMESTIC WASTEWATER DESIGN FLOW ALLOWANCES – DOMESTIC WASTEWATER FROM HOUSEHOLDS – NEW ZEALAND

Source	**Typical wastewater design flows** (L/person/day) (see Note 1)	
	On-site roof water tank supply	**Reticulated community or a bore-water supply**
Households with standard fixtures (including automatic washing machine)	180	200
Households with standard water reduction fixtures (see Note 2)	145	165
Households with full water-reduction facilities (see Note 3)	120	145
Households (blackwater only) (see Notes 4 and 5)	60	
Households (greywater only) (see Notes 4 and 6)	90	120

Based on Statistics New Zealand data, the average single dwelling occupancy is 2.5 to 3 adults per dwelling and at 180 L/day occupant the typical wastewater volume is likely to be 450 – 550 L/day per dwelling. For the purposes of design we would use a maximum possible daily flow per dwelling and this is a function of the number of bedrooms. For example, for a four bedroom dwelling we are likely to use a peak occupancy of 7 at a peak daily flow per capita of 200 L/day, therefore the peak daily design wastewater volume from the four bedroom dwelling would be 1400 L per day.

3. On p11 the report continues to confuse an OWMS with a treatment plant.

4. When referring to treatment plants the draft report suggests there are two types; primary and secondary treatment plants. We would suggest you consider at least three treatment categories:

a. Primary, septic tank (refer to AS/NZS1546.1:2008)

b. Secondary (refer to AS1546.3:2017 for definition of secondary treatment)

c. Advanced secondary (refer to AS1546.3:2017 for definition of advanced secondary treatment) (See bullet point #6)

5. Section 2.1 p11 change wording to: Primary treatment OWMS: solids settling tank followed by an effluent disposal field such as a soakage trench or subsurface LPED drip irrigation. Drip irrigation is not recommended post primary treatment but only post-secondary treatment.

6. Generally, it is accepted that we would not add a UV unit post primary or secondary treatment, because treated effluent turbidity and UVT would render the UV unit ineffective. We recommend adding UV units to advanced secondary (or better) treatment units only.

7. Section 3.2, p20, refers to a pumping rate of 20m3/day. This seems very high for a single rural dwelling. For example, the permitted activity take in Canterbury is 10 m3/day for a single dwelling.

8. The report assumes soils and the vadose zone are saturated (see Section 3.3 p 20 and Section 3.7 p 27). We agree that this is a reasonable assumption for land application systems (LAS) such as trenches and mounded systems where loading rates are necessarily relatively high. The loading rates to these LAS is a function of the soil type and should be in accordance with AS/NZS1547:2012 Table L1 and Table N1. However, in the case of pressure compensating drip irrigation PCDI fields and LPED irrigation fields, the loading rates are considerably less at 2 – 5mm/day, dependent on soil type and category as recommended in AS/NZS1547:2012 Table M1. It is possible that more than 60% of the OWMSs installed in the last 10 years throughout New Zealand are either PCDI fields and LPED irrigation fields. It is very unlikely that these low loading rates would saturate the soils or the vadose zone. This doesn’t, of course, allow for heavy rainfall events.

9. Section 3.6 refers to soil depth. The only type of LAS that would normally involve a soil layer, as defined in this report, would be the PDCI and LDEP irrigation fields. For all other types of LAS (trenches, mounds) it is very unlikely there will be a pre-existing soil zone and the point of discharge and it is more likely to be directly into the vadose zone (depths of 0.6 m to 1.0 m or deeper)

10. Table 12, p36, last 2 columns use log(e) rather than the more commonly used log(10). Is there a reason for this? Can be confusing.

Use of the tool by designers and regulators

As noted in Section 1 the service we offer our clients is the technical design of on-site wastewater management systems (OWMS). Clearly one of the primary objectives for an OWMS is to provide the owner with a convenient sustainable and effective wastewater service. Equally important is designing a site specific system to mitigate the identified risks. There are many types of hazards and consequent risks as mentioned in Section 1 of this report.

However, one of the key risks is to public and private health.

All OWMS must, by necessity, be the result from a “design” process. There are a whole range of designers operating in New Zealand, with diverse skills and knowledge. The situation is unlikely to change in the near future. Some are independent while others tied into a particular brand of treatment plant.

In providing a fit-for-purpose design for an OWMS, many sites will require an assessment of health risks to community and property occupiers. To identify such risks, the common pathogen/microbial indicator used in the local authority guidelines and rules, and a number of design texts, is the Faecal Coliform (FC) or E-Coli. Very rarely do these documents refer to other types of microbial pathogen. From what we have observed in the field, over the years, in unreticulated (rural) areas with relatively high groundwater and a number of neighbouring private and/or community bore water supplies, the health risks from OWMS discharges has been underestimated.

The typical pathogen risk assessment procedure by many designers is to assesses FC attenuation through the different components of the OWMS. For example, for the treatment plant component, a designer will commonly refer to either the manufacturer’s advice in terms of its capability for log reduction of FC and/or the log reduction advised by a testing facility such as OSET NTP (Rotorua), if the treatment plant has in fact been tested by this facility.

Typically, these FC log reduction values are mean values and not 90 or 95 percentile values. The designer will then, typically, apply FC, attenuation rates for the different stages through the OWMS, such as soil attenuation rate (if appropriate), the vadose zone and aquifer attenuation rates for the particular site layout and soil, geological and groundwater conditions, (refer to Figure 3). Based on this analysis the designer will determine the risk score from this particular hazard.

As noted earlier we are very encouraged and supportive that this tool is being developed. However, for this MRA tool to be adopted and widely applied by designers, and effectively audited by local authority officers, it will need to be not only a very user-friendly tool but will also need to be using hazard indicators that are consistent with those used in the local authority rules, regulations and guidelines. This is not the case at the moment.

We remain happy to continue to assist, if it is helpful, with the development of this very important, relevant and timely risk assessment tool.”