Public health risk assessment of sewage disposal by onsite wastewater treatment and disposal systems in the Darfield and Kirwee Communities

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by

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DISCLAIMER

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SUMMARY

[This report deals with the public health risk associated onsite wastewater treatment and disposal systems, which, for brevity are termed "onsite systems".]

{Key points in the summary are highlighted with grey shading.}

Introduction

The Selwyn District is the fastest growing district in New Zealand. Movement west from Christchurch following the 2010 and 2011 earthquakes has contributed to the growth.

Despite this growth there are relatively large population centres, such as Darfield and Kirwee, in the district without reticulated sewerage systems. Wastewater is treated and disposed of through onsite systems. As a consequence, Community and Public Health has a concern that discharge of minimally-treated wastewater to ground may pose an unacceptably high public health risk.

To better understand the public health risk associated with the onsite treatment and disposal of sewage, this project, composed of three sub-projects, has been undertaken. The first subproject (Burbery 2014) was a critical assessment of the groundwater monitoring system presently used to detect contaminant plumes from the onsite system disposal fields. This included a description of the hydrogeology of the area. A sanitary survey undertaken by Community and Public Health (Mulrine 2014) was the second subproject. It investigated the operation and maintenance of the onsite systems in the Darfield community. Summaries of these subprojects are presented in the first two sections of this report.

The third subproject, reported here, draws on the findings of the first and second studies to make an assessment of the public health risk presented by the sewage treatment and disposal systems used in Darfield and Kirwee.

Potential Impact of onsite system discharges on groundwater quality (summary of Burbery 2014 and additional commentary)

Nitrate is considered by Burbery (2014) to be the groundwater contaminant of greatest concern from onsite sewage disposal in this area. The great thickness of the vadose zone[1] is expected to result in very high reductions in the levels of microbial contaminants before sewage reaches the water table. *Escherichia coli* bacteria have been detected in groundwater sampled at a depth of almost 125 m. However, contamination originating from land-based practices and preferential vertical flow paths produced by bore-drilling methods are suspected of having led to bacteria from the surface reaching the aquifer. This effect was unrelated to onsite systems.

The loading of nitrogen (kg-N/ha/yr) from the onsite system clusters of Darfield and Kirwee is calculated to add amounts of nutrients to the groundwater similar to those added by intensive agricultural activities in the area.

[1] The unsaturated zone above the water table.

Burbery (2014) concluded that **at a regional scale**, there is no clear evidence that decentralised treatment systems in Darfield and Kirwee, with their present population densities (Darfield, 5.7 people/ha; Kirwee 3.7 people/ha), are greatly affecting overall groundwater quality) This conclusion was based on the relatively minor contribution made to the **overall** nitrogen budget by onsite systems compared with intensive agricultural land use, and the low likelihood of microbial contamination of the groundwater because of the great thickness of the vadose zone.

However, **at the township scale**, the present population densities **may** add enough nitrate to the background concentration in the water to exceed nitrate's maximum acceptable value at the water table. Burbery estimated the "sustainable" population density to be 1.8 people/ha [2]. Although, the present densities exceed the most probable value of 1.8 people/ha, this value has a large uncertainty. The estimated upper bound of the sustainable density is approximately 12 people/ha[3].

Based on 2006 Census data, the average allotment size at a sustainable density of 1.8 people/ha would need to be approximately 1.44 ha for Darfield and 1.56 ha for Kirwee. For comparison, the Selwyn District Plan sets an average allotment size of 650 m^2 (0.065 ha) and 800 m^2 (0.08 ha) for Living Zone 1 within Darfield and Kirwee respectively.

Although calculated nitrogen inputs into groundwater are high, the impact on human health depends on the nitrate concentration at the abstraction point of water supply bores. The vulnerability of these bores is reduced by virtue of their screen depths[4] normally being more than 35 m below the water table (where the calculations of contaminant impacts usually focus).

While the sustainable population density is uncertain, it is clear that an increase in population density will increase the likelihood of nitrate exceeding its maximum acceptable value given in the *Drinking-water Standards for New Zealand 2005 (revised 2008),* **in groundwater below the onsite systems, or down gradient from them**. **The towns' bores do not presently draw water from these zones**.

Sanitary survey (summary of Mulrine 2014)

The sanitary survey undertaken in Darfield between December 2013 and February 2014 included 106 residences. Most were mid-sized (650–2000 m^2), built in the last 60 years, and had a median of two residents.

Many residents had a poor knowledge of their onsite systems. Approximately one-third of residents had not had their onsite tank emptied in the previous five years.

A little over 29 percent of residents had experienced some sort of system failure which included blockages (leading to the overflow of indoor amenities in some cases), ponding of water, slow draining of indoor amenities and odour.

[2] The "sustainable" density is the density Burbery calculated would result in the nitrate concentration at the groundwater table equalling nitrate's maximum acceptable value set in the *Drinking-water Standards for New Zealand 2005 (revised 2008).* It takes into account dilution of nitrogen inputs from onsite wastewater systems with natural soil drainage water (which carries a nitrogen load of its own).
[3] This figure is not given by Burbery (2014), but is derived by extrapolating the data used to produce Figure A3 in his report.
[4] The depth at which the water is drawn from the aquifer.

Onsite inspections showed that on most sites the tank vent could be clearly seen. The disposal field was usually under a lawn or garden. A small number of minor problems or system failures were observed, but no liquid on the ground surface or discharges to ditches or creeks were noted.

While some residents were happy with the current onsite system on their property, others wanted a reticulated system in Darfield.

Only a small number of non-residential properties were surveyed. As a result of this, and the unique use of each property, general conclusions about onsite systems on non-residential properties could not be reached.

Public Health Risk Assessment

Mulrine's report offers qualitative guidance to help in comparing the public health risk associated with onsite disposal with that of a reticulated system.

Hazard identification

In addition to nitrate, five pathogens that have been found in sewage and are of public health significance (*Campylobacter, Salmonella, Giardia, Cryptosporidium* and norovirus) are identified as hazards of interest. This selection is based primarily on the rates of reported illness associated with each pathogen in the Canterbury region.

Exposure assessment

Possible exposure pathways to sewage originating from onsite systems are identified. They are divided into two categories: those leading to direct exposure to sewage and those leading to indirect exposure (through drinking water).

Residents in Darfield and Kirwee receive their drinking water from the reticulated community water supply in each town. The Darfield bore draws water from depths between 189 m (approximately 54 m below the water table) and 243 m. The nitrate concentration in the water is approximately 26 mg NO_3/L. The bore is too new to assess a trend. The Kirwee bore draws water from depths between 112 m and115 m (up to 49 m below the water table). The highest nitrate concentration measured in samples taken since 1980 is 21 mg NO_3/L (1998). In both townships, the bores are up-gradient or cross-gradient from the onsite system clusters.

Consideration of **indirect** exposure pathways that could lead to contamination of the town bores shows that likelihood of exposure through this pathway is very low in the case of Darfield because the cluster of onsite systems is outside the bore's capture zone[5]. In Kirwee, the closest onsite systems may be within the community water supply bore's capture zone. However, measurement of nitrate concentrations in the bore water shows that this contaminant does not currently present a risk to public health. The likelihood of infection by pathogens from the sewage is found to be low because of attenuation in pathogen concentrations as they pass through the vadose zone and aquifer.

Exposure to contaminants of residents obtaining their drinking-water from private bores on properties down-gradient of the townships cannot immediately be ruled out on the grounds of capture zone delineation. However, the results of previous modelling show that both the nitrate and pathogen concentrations, in groundwater,

[5] Capture zone: the total area that contributes groundwater to the bore.

arising from the onsite system clusters are unlikely to reach levels of public health significance.

Exposure to sewage from onsite systems by **direct** pathways, that is, during system maintenance, or as the result of system failure (ponding or overflow of indoor amenities) is possible.

Calculations based on the concentration of nitrate (and other forms of nitrogen that can be oxidised to nitrate) in sewage show that the volume of sewage that would have to be ingested to be of potential health concern, because of nitrate, is unreasonably large.

A large number of parameter values are required to characterise direct exposure to **pathogens**, in terms of quantity and probability of exposure. Estimates of the values for some of the parameters can be made. However, scientifically defensible values are unavailable for many parameters. As a result, quantitative exposure estimates are not made.

A limited modelling exercise shows that on any given day **some** onsite systems in Darfield are expected to contain at least one pathogen species.

From considering exposure during system maintenance we conclude that awareness of the risks associated with working with sewage is likely to reduce the probability, and levels, of exposure. Adults are the population group most likely to be exposed through these pathways.

Onsite system failure is more likely to lead to direct exposure to sewage than system maintenance. While awareness of the risk associated with contact with sewage may reduce the likelihood of exposure in some cases of system failure, there are pathways by which people may be unaware of their exposure. An example is a pet coming into contact with ponded sewage, and then the owner coming into contact with the pet, but being unaware that the animal's fur or hair may be carrying pathogens. All groups within the population are potentially vulnerable to these exposure pathways.

Risk characterisation

In the absence of quantified exposure, this phase of the assessment explores what qualitative statements can be made about the public health risk associated with onsite systems.

The possible exposure pathways that are identified for onsite systems do not exist in a well-operated reticulated sewerage system that does not receive storm water input. Residents do not have to undertake system maintenance, nor does system failure leading to exposure to sewage occur. Given the absence of these pathways, the risk to public health from a reticulated system will be less than that of onsite systems.

Although possible pathways of exposure are identified for onsite systems, it does not necessarily follow that they will make an unacceptably high contribution to the level of disease in the community.

Exposure pathways consist of a series of events. For a pathway to lead to infection, all of the events in the chain must occur although none of the events is certain to occur. While the likelihood of exposure via a particular pathway cannot be quantitatively determined, consideration of the nature of the events in these pathways leads to the conclusion that the overall likelihood of ingestion of sewage through direct exposure from onsite wastewater systems is not high.

The rates of campylobacteriosis in districts and towns in Canterbury are consistent with this conclusion[6]. Despite uncertainties in calculating the diseases rates, the data show that the rate of campylobacteriosis for Darfield (excluding the outbreak in 2012, which arose from animal contamination of the town's old water source) does not stand out as being markedly different from other centres or areas. This is despite Darfield being the only town (of those for which rates have been determined) relying solely on onsite wastewater treatment and disposal.

Conclusion

Based on the available information, it is unlikely to very unlikely that onsite systems in Darfield and Kirwee contribute to illness in the towns, or properties down-gradient, through drinking-water contamination.

The very low likelihood of residents in the Darfield-Kirwee area becoming ill through indirect exposure to contaminants from the clustered onsite systems in the townships results from a combination of favourable factors, particularly the great thickness of the vadose zone in the area. **It must not be assumed that this finding is applicable to all situations in which onsite systems are clustered**. The combination of favourable factors may not exist elsewhere. The risk of contamination has to be assessed for each individual situation.

Town residents are more likely to come into direct contact with sewage (through maintenance or system failure) from onsite systems than they would if the towns had reticulated sewerage systems. While direct exposure pathways to sewage from onsite systems exist, it does not necessarily follow that these pathways make an unacceptably high contribution to illness in the communities. This contribution cannot be quantified, but the likelihood of exposure to sewage from onsite treatment and disposal systems is not high.

Implications for future development

It is difficult to assess how an increased population in Darfield-Kirwee will influence the likelihood of infection through **direct** contact with sewage from onsite systems. An accompanying increase in population density may increase effluent loading rates and with them the likelihood of system failures. On the other hand, the improved design of new systems should tend to reduce the likelihood of system failure and therefore infection, provided they are properly maintained and operated.

Exposure through the **indirect** pathway of drinking-water may lead to an increased likelihood of infection if growth in the townships results in onsite systems being established within the capture zones of the community water supply bores, or closer to the bores than what they are now. Provided disposal fields are not permitted

[6] *Campylobacter* is used for this comparison because it is the waterborne pathogen with the highest reported rate of disease in New Zealand. This increases the likelihood that small centres, such as Darfield, will have enough cases to allow comparisons. Illness caused by waterborne viruses, which are not notified, may be predominant where exposure to human waste is the main concern.

within the capture zones of the public water supply bores, a population increase is not expected to lead to an increased likelihood of contamination of the drinking-water.

An increase in the density of onsite systems in the Darfield and Kirwee townships will result in an increase in the nitrate concentration in the groundwater beneath the townships. This is expected to affect residents in the towns and those down-gradient differently.

- The increase in the groundwater nitrate concentration poses a potential risk to the quality of water from bores down-gradient of the townships.
- Provided onsite systems are not established within community supply captures zones, the quality of the townships' water supplies will not be adversely affected.

These conclusions concerning future development only take account of public health risk. They do not consider any other factors that may make it undesirable for a growing community to remain reliant on the onsite treatment and disposal of wastewater.

Recommendations

This report has been prepared to inform the debate between stakeholders about wastewater management in the Darfield-Kirwee area. The recommendations below follow from the report's findings and aim to protect public health given the present circumstances. They do not attempt to direct decisions about the appropriate approach to wastewater management.

Recommendation 1:

> To minimise the likelihood of onsite system failure and community residents being exposed to the microbiological hazards in sewage the Selwyn District Council, perhaps in conjunction with Environment Canterbury, should review possible mechanisms for ensuring that onsite systems are properly maintained or redesigned to meet current standards.

Recommendation 2:

> To maintain the safety of the community drinking-water supplies for Darfield and Kirwee planning by the Selwyn District Council for development of the townships, if onsite sewage treatment and disposal is to be retained, should ensure that onsite systems are not established within the capture zones of public water supply bores. The planning would need to take account of changes in the size of the capture zone resulting from increased water abstraction, and section sizes should be set to include reserve areas for a new disposal field should it be required (see AS/NZS 1547:2012).

1 INTRODUCTION

[This report deals with the public health risk associated onsite wastewater treatment and disposal systems, which, for brevity are termed “onsite systems”.]

The Selwyn District is the fastest growing territorial authority area in New Zealand (Stats NZ 2013). Following the 2010 and 2011 earthquakes, the growth of the district has been boosted by a population movement west from Christchurch.

Two of the largest population centres in the district are Darfield and Kirwee, with present populations determined by the Selwyn District Council (personal communication of Selwyn District Council data to E Moriarty by J Williamson, Community and Public Health) to be 2755 and 1081 people, respectively. Although both centres have reticulated water supplies, neither has a reticulated sewerage system. Residential and non-residential buildings rely on onsite systems.

Onsite systems may be an appropriate means of wastewater disposal for individual dwellings and small settlements. However, Community and Public Health has had a concern for some time that the disposal of minimally treated sewage to ground by populations the size of those in Darfield and Kirwee may present a risk to public health.

This report is the third part of a suite of three studies undertaken to better understand the public health risk to the residents of Darfield and Kirwee presented by onsite disposal of sewage. The first of the studies, which was undertaken by ESR (Burbery 2014), was a critique of the groundwater monitoring system presently used to detect contaminant plumes from the onsite systems. It included a description of the hydrogeology of the area. The second study was a sanitary survey undertaken by Community and Public Health to investigate the operation and maintenance of the onsite systems in the community (Mulrine 2014).

This document draws on the findings of the first and second studies, and combines this information with data from the literature, to make an assessment of the public health risk presented by the onsite systems used in Darfield and Kirwee.

{Key messages in the report are highlighted with grey shading.}

Report structure

Section 2	Summary of the findings of the critical assessment by ESR of the groundwater monitoring network used by the Selwyn District Council.
Section 3	Summary of the findings of the sanitary survey by Community and Public Heath of onsite systems in Darfield.
Section 4	The assessment of the public health risk to the Darfield and Kirwee communities arising from the onsite treatment and disposal of the towns’ wastewater.
Section 5	The conclusion of the study including a brief discussion of the implications of the study’s findings for future development in the area.

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2 THE POTENTIAL IMPACT OF ONSITE SYSTEM DISCHARGES IN DARFIELD AND KIRWEE ON THE LOCAL GROUNDWATER QUALITY AND CURRENT ASSESSMENT METHODS

2.1 Introduction

This section summarises the findings of the ESR report (Burbery 2014) that reviewed the hydrogeological setting in the Darfield-Kirwee area, and assessed the vulnerability of the aquifer underlying the central Canterbury Plains to water quality impacts from the clusters of onsite systems. Some additional commentary is also provided.

[The full report should be consulted if detail beyond that provided in the following summary is needed.]

2.2 Nitrate

Nitrate is the chemical groundwater contaminant of primary concern from onsite systems in the Darfield-Kirwee area. Water in the local aquifer contains elevated nitrate concentrations (up to 71 mg NO_3/L)[7] before it receives any input from the Darfield and Kirwee wastewater disposal fields. Consequently, the regional groundwater system has a limited capacity to dilute nitrate impacts sourced from the clusters of onsite systems in Darfield and Kirwee.

The concentration of nitrate in undiluted septic effluent in an aerated environment is predicted to be within the range of 244–354 mg NO_3/L[8], most likely closer to 288 mg NO_3/L. On a local scale at the water table, in the absence of dilution effects, this is the magnitude of increase in nitrate concentration in the groundwater that could be expected.

Nitrogen mass loading rates determine the amount of nitrogen entering the ground and consequently are a factor influencing the groundwater nitrate concentration. The nitrogen mass load from the onsite systems in operation at Darfield is predicted to be in the range of 9.1–35.6 kg N/ha/yr, but most likely closer to 27 kg N/ha/yr. Nitrogen loads attributed to effluent generated in Kirwee are predicted to be in the range of 6.9–23.1 kg N/ha/yr, but most likely closer to 18 kg N/ha/yr, because of the lower population density. Conceptually, onsite systems in Darfield and Kirwee contribute similar nutrient loads, in terms of nitrogen mass, to the groundwater system as intensive agricultural land uses, notably dairy farming (Lilburne et al 2010).

Nitrogen mass loading rates from onsite systems are proportional to population densities. The current population densities are approximately 4.2–5.7 people/ha in Darfield and 3.2–3.7 people/ha in Kirwee. Considering the cumulative nitrate impact of nitrogen leached from the **land and onsite system effluent**, Burbery (2014) predicts that a 'sustainable' human population density in Darfield-Kirwee might be just 1.8 people/ha. This is the density at which the nitrate concentration in the groundwater at the water table equals nitrate's maximum acceptable value given in

[7] Burberry expresses nitrate concentrations in units of mg NO_3-N/L. This report expresses the nitrate concentration in units of mg NO_3/L to be consistent with the *Drinking-water Standards for New Zealand 2005 (revised 2008).*

[8] Calculated from the average daily per capita production of nitrogen of 11–16 g N/day (Sedlak 1991; USEPA 2002; McCray et al 2005) and the typical daily production of wastewater by a New Zealand resident of 200 L (ARC 2004).

the *Drinking-water Standards for New Zealand* 2005 (revised 2008). The figure of 1.8 people/ha is the most probable value for a sustainable density. However, there is a large uncertainty in the parameter values used in the calculation. As a result, it is possible that the maximum acceptable value could be exceeded even in the absence of onsite systems. Conversely, the maximum acceptable value may not be exceeded until the population density reaches approximately 12 people/ha[9].

The 2006 census found that the Kirwee housing occupancy was 2.8 people/dwelling. To achieve a sustainable population density of 1.8 people/ha, this would require an average minimum allotment of 1.56 ha[10]. A similar calculation for Darfield yields a minimum allotment size of 1.44 ha. For comparison, the Selwyn District Plan[11] requires minimum average allotment sizes for Living Zone 1 in Darfield and Kirwee of 650 m^2 (0.065ha) and 800 m^2 (0.08ha), respectively.

Currently the standard governing onsite systems (AS/NZS 1547:2012) does not limit the density of discharges nor indicate the level at which density may be a concern. Instead, it provides guidance on how to design, install and maintain systems so that adverse effects are avoided. The Auckland Regional Council's guideline document *Onsite Wastewater Systems: Design and Management Manual Technical Publication 58* (Ormiston and Floyd 2004) states:

> Cumulative effects need to be considered where a number of separate onsite systems are located in close proximity (e.g. more than one dwelling per 3,000 m^2 of total site area). In such situations the cumulative (combined) effects from a number of separate onsite systems can become significant.

No rationale is given for the limiting density of one wastewater system per 3000 m^2 (0.3 ha).

2.3 Hydrogeological setting

The thick vadose zone[12] in the Darfield-Kirwee area is likely to prevent most, if not all, microbial contaminants from effluent reaching the saturated zone. Nonetheless, there have been several positive detections of *Escherichia coli* in local groundwater sampled at depths of almost 125 m. This suggests the aquifer is not entirely immune to microbial contamination originating from land-based practices, and preferential vertical transport pathways caused by the installation of water wells are suspected to have contributed to the positive *Escherichia coli* detections.

A comprehensive review of microbial (predominantly bacteria and viruses) removal rates in natural porous media conducted by Pang (2009) reports removal rates in the order of 0.1 $\log_{10}$/m in the vadose zone for clay, sand-gravels and coarse gravel media, and removal rates in the order of 0.001–0.01 $\log_{10}$/m in gravel aquifers, which includes the system underlying the Canterbury Plains. Lower removal rates generally apply in situations, such as Darfield-Kirwee, where high contaminant loads are sustained.

[9] This figure is not given by Burbery (2014), but is derived by extrapolating the data used to produce Figure A3 in his report.
[10] Obtained by dividing 2.8 people/dwelling by 1.8 people/ha.
[11] https://www.selwyn.govt.nz/services/planning/district-plan
[12] The unsaturated zone above the water table

The removal rates, quoted by Pang (2009), for gravelly vadose zones generally range from 0.05 to 0.5 log_{10}/m. They were obtained from studies monitoring strata shallower than 10 m. Use of these values in estimating removal rates assumes they also apply to the 60 m thickness of strata under Darfield-Kirwee. Through this thickness of material, the overall removal would range from 3 to 30 log_{10} units. The *Escherichia coli* concentration in onsite system effluent is reported to range from 10^8 to 10^{10} cfu/100 ml[13] (Burbery 2014). To reduce this concentration to a value less than 1 cfu/100ml (the maximum acceptable value of the *Drinking-water Standards for New Zealand 2005 (revised 2008)),* the required removal rate would be 0.13–0.17 log_{10}/m. This is well within the range of removal rates reported by Pang (2009) for this matrix.

On the basis of this evidence, it is unlikely that viable pathogens will reach the water table under Darfield-Kirwee from onsite systems. The subsurface removal of microorganisms is further discussed in Section 4.3.4.4.

It is also important to recognise that the risk to human health depends on the contaminant impacts experienced at drinking-water supply wells, rather than their impacts on the aquifer in general. The vulnerability of the groundwater as a drinking-water resource in the Darfield-Kirwee area is significantly reduced, because water supply wells in the region normally draw their water from 35 m or more below the water table.

2.4 Conclusion

Overall, although the existing onsite wastewater practices in the Darfield and Kirwee area may make **locally significant** contributions to the overall nitrate-nitrogen mass budget, their contribution is similar to that rising from extensive and increasingly intensive agricultural land use across the Canterbury Plains.

At a regional scale, Burbery (2014) concluded that there is no clear evidence that decentralised treatment systems in Darfield and Kirwee, **with their present population densities** (Darfield, 5.7 people/ha; Kirwee 3.7 people/ha), are greatly affecting overall groundwater quality. This conclusion was based on the relatively minor contribution made to the overall nitrogen budget by onsite systems compared with intensive agricultural land use, and the great thickness of the vadose zone which will make microbial contamination of the groundwater very unlikely.

At the township scale, the present population densities may add enough nitrate to the background concentration in the water to exceed nitrate's maximum acceptable value at the water table. Burbery (2014) calculated a "sustainable" population density at which this might occur (1.8 people/ha), but there is a large uncertainty on this density. Moreover, changes in nitrate concentration in the groundwater may lag behind changes in the nitrogen input from onsite wastewater treatment systems. Burbery estimates that effluent may take months to years to pass through the vadose zone.

Although the sustainable population density is uncertain, it is clear that an increase in the density will certainly increase the **likelihood** of the nitrate concentration in the groundwater exceeding its maximum acceptable value.

[13] cfu- colony forming unit

The observations, above, concerning **groundwater at the township scale, relate to the quality of the groundwater below the onsite systems, or down gradient from them**. As will be shown later, the towns' bores do not presently draw water from these zones.

2.5 Key Points for a public health risk assessment

a. Based on available data, nitrate is the primary groundwater chemical contaminant of concern associated with onsite systems in the Darfield-Kirwee area. Under the pH and redox conditions in the gravel aquifers any heavy metals present are likely to adsorb to clay surfaces. No data on toxic organic contaminants are available from New Zealand onsite systems to allow an assessment of their health significance.

b. The concentration of nitrate in undiluted septic effluent is predicted to be close to 288 mg NO_3/L, although by the time effluent has permeated to the saturated zone and mixed with natural recharge waters, local nitrate impacts at the water table are expected to be in the realm of 89 mg NO_3/L (ie, in addition to the existing background of 71 mg NO_3/L, which exceeds the maximum acceptable value of 50 mg/L).

c. The nitrogen mass load from the onsite systems in operation at Darfield is predicted to be about 27 kg N/ha/yr

d. Microbial removal rates in alluvial outwash material, such as underlies Darfield-Kirwee, are in the order of 0.1 log_{10}/m for unsaturated material and 0.001–0.01 log_{10}/m for saturated material.

The risk to human health depends on the contaminant concentrations present at drinking-water supply wells, rather than the concentrations in the aquifer in general. The risk is significantly reduced in the Darfield-Kirwee area, because water supply wells in the region normally draw their water from 35 m or more below the water table.

3 SANITARY SURVEY OF ONSITE SYSTEMS IN DARFIELD

3.1 Introduction

Community and Public Health (C&PH) is concerned about communities without reticulated wastewater systems because of the public health risk that sewage and wastewater disposal in large unsewered communities may pose.

There is a risk to public health if septic plumes from onsite systems intersect with the groundwater. Such events are more likely when the volume of sewage per unit area produced in an unsewered community increases with increasing population density. Surface ponding of wastewater on properties, as a result of the failure of onsite systems, also presents a direct health risk to people via potential contact with effluent.

At present, no data to assess the operation of onsite wastewater treatment systems in the Darfield area are routinely collected. To fill this information gap, C&PH conducted an onsite wastewater treatment system survey in Darfield as part of the larger project assessing the public health risk associated with the un-reticulated disposal of wastewater in the Darfield and Kirwee townships.

The purpose of the survey was to gather information on the systems currently in use. The survey provides information about the immediate public health risks to residents, and the risk of discharge contamination, by investigating the number of residents potentially having direct contact with effluent via onsite system failure.

The report of the findings of this survey, which was undertaken between December 2013 and February 2014, was published in 2014 (Mulrine 2014). This section summarises the sanitary survey report.

[The full report should be consulted if detail beyond that provided in the following summary is needed.]

3.2 Methodology

An onsite wastewater treatment system questionnaire was developed by the Protection Team of C&PH. The questionnaire was completed in an interview with a resident of the property (for residential properties) or the property owner, caretaker or manager (for non-residential properties). A visual inspection of the site was also undertaken by the interviewer.

The survey site (Darfield) was visited and areas were categorised according to the age of the properties:

- original (greater than 30 years old),
- older (built within the last 5–30 years approximately), or
- recent (built within the last 5 years).

The 106 residential properties included in the survey were mostly med-sized properties (600–2000 m^2) built in the last 60 years. Most households included 1 to 3 residents (median of 2 residents), which is similar to the average household density of 2.8 reported in the 2013 census. More than half (57%) of the residents surveyed were over the age of 40. In comparison, 48 percent of residents in Selwyn District are over the age of 40, suggesting that the survey probably represents a population group that is slightly older than the general Selwyn District population.

All residences (except one) had one onsite system on their property, and most were less than 60 years old. The median age of the systems was 35 years.

3.3 Findings

3.3.1 Residential property assessment

3.3.1.1 System maintenance

Knowledge of the onsite system on their property was low for many residents, which may suggest that problems are not frequently encountered. Most systems had been emptied in the last 5 years (66.5%), but 5 respondents stated that their tank has never been emptied. Regular service or maintenance of the system was not undertaken by a large proportion of residents (92.6 %) with only 5 residents reporting doing any. This consisted of tasks such as checking the system, adding bacteria to the tank, digging drains, and flushing filters.

When asked whether servicing or maintenance of the onsite system was conducted by a contractor, 44.2 percent (n=23) of the 52 residents that responded stated that some was, and the remainder (55.8%, n=29) stated that none was. However, no response was recorded for approximately half of residents (n=53).

Service or maintenance of the system (by either the resident or a contractor) was conducted every 3-5 years for approximately a third of the 60 residents who responded to this question (36.7%, n=22), or never, for the remainder (63.3%, n=38).

A small number of residents (11.8%, n=11) stated that repairs had been made to their system, and the majority (88.2%, n=96) stated that none had been done. Most repairs were related to fixing/moving/upgrading pipes, leakage, and repairing the boulder pit. Three people mentioned that repairs were necessary due to damage caused by earthquakes. Responses were missing for 12 residents.

3.3.1.2 System failure

Over two thirds of residents (70.6%, n=72) had never observed a failure or blockage of their onsite system. However, 29.4 percent of residents (n=30) had experienced some sort of failure, which included blockages (n=19, and in three cases blockages led to the overflow of indoor amenities), ponding of water outside/boggy ground (n=9), slow draining of indoor amenities (n=5), and odour (n=5). Some residents mentioned more than one problem. In some instances, problems were attributed to greater than usual numbers of people staying at the residence at the time (n=3) and tree roots (n=3). No system problems were reported by residents to be on-going. Responses were missing from three surveyed residents.

3.3.1.3 Onsite inspections

All residents except one allowed an interviewer to undertake a site inspection of their property. Hard surfaces (including the main residence, other buildings, paths and paving) covered one quarter to half of most sites.

Information on features of onsite systems was gathered through the questionnaire and by direct observation. There were many missing responses in this part of the questionnaire; therefore, the number of observed features (rather than the percentage) is reported. Three types of system features were observed on the sites. On most sites (n=102), the system vent could clearly be seen. On at least eight sites the interviewer noted that it was not possible to see any of the system features apart from the vent.

Disposal fields (n=24) and boulder pits (n=9) were also observed on some sites. The mean age of onsite systems that had observable disposable fields was 38 years (SD=18 years, range=4-71 years, n=16). The disposal field (including the boulder hole and drainage field) was (or was presumed to be) usually under a lawn or garden. Only two sites had a reserve disposal field. Two thirds of sites (66.7%) had room for a reserve disposal field, while 29.5 percent did not.

No unused systems, outhouses/cesspools, long-drop toilets, old disposal fields or old boulder pits were observed on any of the sites.

From a brief visual inspection, a small number of minor problems/system failures were observed. These included slightly sunk/uneven ground near the system (9 sites), odour (5 sites), slow plumbing/drainage (2 sites), boggy ground (1 site), many trees growing over the system area (1 site), greener grass over the tank area (1 site), and a loosely-fitting hatch (1 site). No liquid/discharge on the ground surface or discharges to a ditch/creek or low point was observed on any of the sites. The relatively small number of systems with problems observed during the survey may be due in part to the time of the survey. Summer is a time when onsite systems are expected to experience fewest failures[14].

3.3.1.4 Miscellaneous observations

All residents sourced their household drinking water from the reticulated Darfield supply, and eight residents reported that a member of their household had experienced a gastrointestinal-type illness in the 30 days preceding the survey.

While some residents were happy with the current system on their property, others wanted a reticulated system in Darfield. In some cases this was due to concern about population growth and the impact that this rapid development may have on the current onsite systems. However, the perceived high cost of a new reticulated system was raised as an issue by several residents.

3.3.2 Non-residential (commercial, industrial and school) property assessment

3.3.2.1 General observations

A range of functions were included in the eight non-residential properties surveyed. Interviewees tended to be relatively knowledgeable about the system on their property and reported having them emptied regularly (in particular, at properties with a high wastewater load). Few onsite system problems were reported by the interviewees, or observed during the site inspection.

All properties had an onsite system. Six properties had one system, one property had two systems, and another property had six systems. The properties with two and six systems were used by a larger number of people.

[14] Observation by authors of this report, not Mulrine.

Five interviewees estimated the age of the system on the property – four systems were less than 30 years old, and one was 88 years old.

3.3.2.2 System maintenance

All interviewees who answered the question (n=6) stated that the onsite system had been emptied in the previous 2 years – two in 2014, three in 2013, and one in 2012.

Most interviewees (n=7) reported doing no service or maintenance themselves on the onsite system, and four interviewees reported that a contractor undertook service or maintenance on the system. Service or maintenance of the system (by either the interviewee or a contractor) was conducted annually for two properties, every 3–5 years for two properties, and never for one property. Three interviewees did not respond to this question.

Three interviewees stated that repairs had been made to their system, and these repairs were related to an overloaded system and new rodding eye installation. Only one interviewee reported a failure of the system, which was related to on-going blockages due to tree roots. The remaining seven interviewees reported no system failures or blockages.

3.3.2.3 Onsite inspections

From a brief visual site inspection, no signs of onsite system failure were observed.

3.3.2.4 Conclusions

Due to the small number of non-residential properties surveyed, and the unique use of each property, it is not possible to draw general conclusions about the onsite systems of non-residential properties.

3.4 Key Information for public health risk assessment

a. The median age of the residential systems was 35 yrs.

b. 44.2 percent of respondents had service or maintenance of the onsite system conducted by a contractor.

c. 11.8 percent of respondents stated that repairs had been made to their system.

d. 29.4 percent of respondents (n=30) had experienced some sort of failure, which included blockages (n=19, of which three cases led to the overflow of indoor amenities), ponding of water outside/boggy ground (n=9), slow draining of indoor amenities (n=5), and odour (n=5).

e. Disposal fields (n=24) and boulder pits (n=9) were also observed on some sites. The disposal field (including the boulder hole and drainage field) was (or was presumed to be) usually under a lawn or garden. Only two sites had a reserve disposal field. Two thirds of sites (66.7%) had room for a reserve disposal field, while 29.5 percent did not.

f. All respondents sourced their household drinking water from the reticulated Darfield supply.

g. Regular service or maintenance of the system was not undertaken by a large proportion of respondents (92.6%) with only 5 respondents reporting doing any. This consisted of tasks such as checking the system, adding bacteria to the tank, digging drains, and flushing filters.

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4 ASSESSMENT OF THE LEVEL OF RISK TO PUBLIC HEALTH ARISING FROM ONSITE SYSTEMS IN DARFIELD AND KIRWEE

4.1 Introduction

The purpose of this section of the report is to draw together the relevant information from the first two reports of the project (Burbery 2014; Mulrine 2014), as well as information from the literature to undertake a public health risk assessment.

There are four phases in undertaking a standard risk assessment.

a. Hazard identification – which in this case identifies the microorganisms and chemicals of primary concern in domestic sewage. The consequences of exposure to these hazards are also identified.
b. Exposure assessment – in which exposure pathways are identified and possible levels of exposure to hazards arising from these pathways is estimated.
c. Dose response – which, from information gathered from the literature, allows an estimate of the probability of a health outcome (such as illness) given exposure to a known dose of a hazard.
d. Risk characterisation – the phase that brings together the information from the three previous steps to estimate the probability of infection or illness in the Darfield and Kirwee townships resulting from the onsite treatment and disposal of their wastewater.

In an ideal situation, sufficient information is available in all phases of the assessment to undertake a quantitative risk assessment. However, there are gaps in the available information that preclude a **quantitative** assessment of the risk posed to public health by the use of onsite sewage disposal in Darfield and Kirwee. Despite this, this report offers qualitative guidance to help in comparing the public health risk associated with onsite disposal with that of a reticulated system.

The risk assessment provided here only considers the risk arising from onsite systems. The risk to health arising from background contaminant levels in groundwater resulting from agricultural activities up-gradient is not considered. This background contribution to contaminant levels will remain irrespective of the use of onsite systems.

4.2 Hazard identification

4.2.1 Introduction

The hazards present in domestic sewage that need to be considered in the risk assessment are microbiological and chemical. Section 4.2.2 identifies and describes the key microbial pathogens that could be present in domestic wastewater. The chemical hazard of primary public health concern in domestic sewage is nitrate. This is discussed in Section 4.2.3. The corrosion of materials within plumbing could release heavy metals into domestic wastewater. Apart from the first 100–200 ml of water flushed from a tap after water has been standing in it, the concentrations of these metals in drinking-water are usually below the maximum acceptable values set in the *Drinking-water Standards for New Zealand 2005 (rev. 2008)* (Nokes 1999). Consequently, their concentration in sewage is also expected to be low.

4.2.2 Microorganisms of public health significance in domestic sewage

Microorganisms of potential public health significance in domestic sewage are listed in Table 1 (based on United States Environmental Protection Agency information (USEPA 2013)). Also presented in the table are the rates of reported disease for New Zealand and Canterbury in 2013 (ESR 2014) and Selwyn District in 2012[15].

Disease rates are included in the table to show the relative importance of the various pathogens with respect to the reported incidence of the disease they cause. The data show that reported disease resulting from infection by many of these organisms is rare, or of low incidence. The pathogens considered likely to be of greatest potential health significance in the sewage of Darfield and Kirwee are indicated by grey shading in the table. They are discussed in more detail in Appendix 1.

The selection of pathogens of greatest concern is based largely on the notified disease incidence rates, but there are some additional considerations. Except for Hepatitis, no waterborne viral diseases are specifically named in the annual report of notifiable and other diseases (ESR 2014). Despite this, some virus species will have contributed to the rates of disease generically classed as “gastroenteritis”. In a quantitative microbial risk assessment for Napier City Council’s ocean sewage outfall, McBride (2011) restricted his consideration of viral risk to norovirus because:

a. The concentrations of norovirus in sewage are one to two orders of magnitude greater than those of other viruses
b. The virus is highly infective.

For these reasons, this study restricts its interest in viruses to norovirus.

[15] New Zealand Public Health Observatory website URL: http://www.nzpho.org.nz/NotifiableDisease.aspx (accessed 1 August 2014)

Table 1 Sewage-borne microorganisms of public health significance
('-' denotes notifiable disease, but fewer than 5 cases reported; a blank entry denotes a non-notifiable disease, or a disease that cannot be attributed to a specific pathogen)

Pathogen	Main disease or health effect	Reported cases in New Zealand 2013 per 100,000	Reported cases in Canterbury Health District 2013 per 100,000	Reported cases in Selwyn District 2012[a] per 100,000
Bacteria				
Campylobacter sp.	Campylobacteriosis	152.9	157.9	302.6
Pathogenic *E. coli*	VTEC/STEC infection	-	5.3	-
Legionella pneumophila	Legionellosis	-	11.4	-
Leptospira sp.	Leptospirosis	-	-	-
Salmonella sp.	Salmonellosis	25.6	28.0	35.5
Salmonella typhi	Typhoid fever	-	-	-
Shigella sp.	Shigellosis	-	1.4	-
Vibrio cholerae	Cholera	-	-	-
Yersinia enterolitica	Yersiniosis	10.8	19.9	-
Helminths				
Ascaris lumbricoides	Ascariasis			
Enterobius vernicularis	Enterobiasis			
Fasciola hepatica	Fasciolosis			
Hymenolepis nana	Hymenolepiasis			
Taenia sp.	Cysticercosis			
Trichuris trichiura	Trichuriasis			
Protozoa				
Balantidium coli	Balantidiasis			
Cryptosporidium oocysts	Cryptosporidiosis	30.1	37.6	23.6
Entamoeba histolytica	Amebiasis			
Giardia cysts	Giardiasis	38.7	35.7	30.7
Viruses				
Adenoviruses	Respiratory disease [b]			
Enteroviruses	Gastroenteritis			
Hepatitis A virus	Infectious hepatitis	-	9.1	-
Noroviruses [c]	Gastroenteritis			
Rotavirus	Gastroenteritis			

[a] Data for 2013 were unavailable at the time of report preparation.
[b] Adenoviruses can also cause pneumonia, eye infections and gastroenteritis.
[c] Formerly known as Norwalk-like viruses.

4.2.3 Chemicals of public health significance (nitrate)

The nitrate concentration in raw sewage is very low, approximately 0.9 mg of NO_3/L (Burbery 2014). Most of the inorganic nitrogen present in sewage is in the chemically reduced form of ammonia/ammonium. However, once in an aerated environment, ammonia undergoes nitrification to nitrate through microbiologically mediated oxidation. This could result in a nitrate concentration ranging from 244 to 354 mg NO_3/L (Burbery 2014).

Bottle-fed infants are the most vulnerable group within the community to nitrate. The maximum acceptable value for nitrate in the *Drinking-water Standards for New Zealand 2005 (revised 2008*) is set to protect this subpopulation. Elevated concentrations of nitrate in the water used to prepare infant formula can potentially lead to the development of methaemoglobinaemia ("blue-baby" syndrome) through the reaction of nitrate with haemoglobin in the blood. This reaction forms methaemoglobin, which binds oxygen thereby stopping oxygen transport (WHO 2011). The maximum acceptable value for nitrate is based on epidemiological findings showing that cases of methaemoglobinaemia are not found in waters with nitrate concentrations below 50 mg/L. Provided the water is microbiologically safe the World Health Organization considers that water with nitrate concentrations up to 100 mg/L can be used for bottle-fed infants[16]. The *Drinking-water Standards for New Zealand* retain the value of 50 mg/L for nitrate's maximum acceptable value because of uncertainty over the microbiological quality of the water in some water supplies.

4.3 Exposure pathways and levels of exposure

4.3.1 Introduction

The first part of this section identifies possible pathways by which the hazards discussed in Section 4.2 can be transferred from sewage to residents of the Darfield and Kirwee townships.

Sections 4.3.2 and 4.3.3 discuss the pathways by which the residents of Darfield and Kirwee, respectively, may be exposed to the hazards noted in Section 4.2. Although several pathways are identified in these sections, closer examination shows that not all are plausible. These are omitted from further consideration.

The intention of Section 4.3.4 is to estimate the levels of exposure of the residents in the Darfield and Kirwee communities to the hazards identified in Section 4.2. There are difficulties in making these estimations, which are discussed in the section.

[16] There has been a debate for some time over the role played by nitrate in the development of methaemoglobinaemia (Cooke 2014). As a consequence, some consider New Zealand's maximum acceptable value, and therefore the World Health Organization guideline, overly protective with respect to methaemoglobinaemia. It is outside the scope of this report to participate in this debate. However, the use of the maximum acceptable value in the risk assessment will ensure public health is protected.

4.3.2 Exposure pathways potentially affecting the Darfield community

4.3.2.1 Introduction

Figure 1 gives an overview of the pathways by which residents in the Darfield community might be exposed to chemical and microbiological hazards in sewage. This study restricts its consideration to exposure pathways leading to ingestion as this is regarded as the main infection pathway associated with onsite systems (Water UK 2006). There is sufficient difficulty in assessing the risk arising from ingestion that the minor pathways of skin contact, inhalation, and injection (through puncture wounds) are not included in the study.

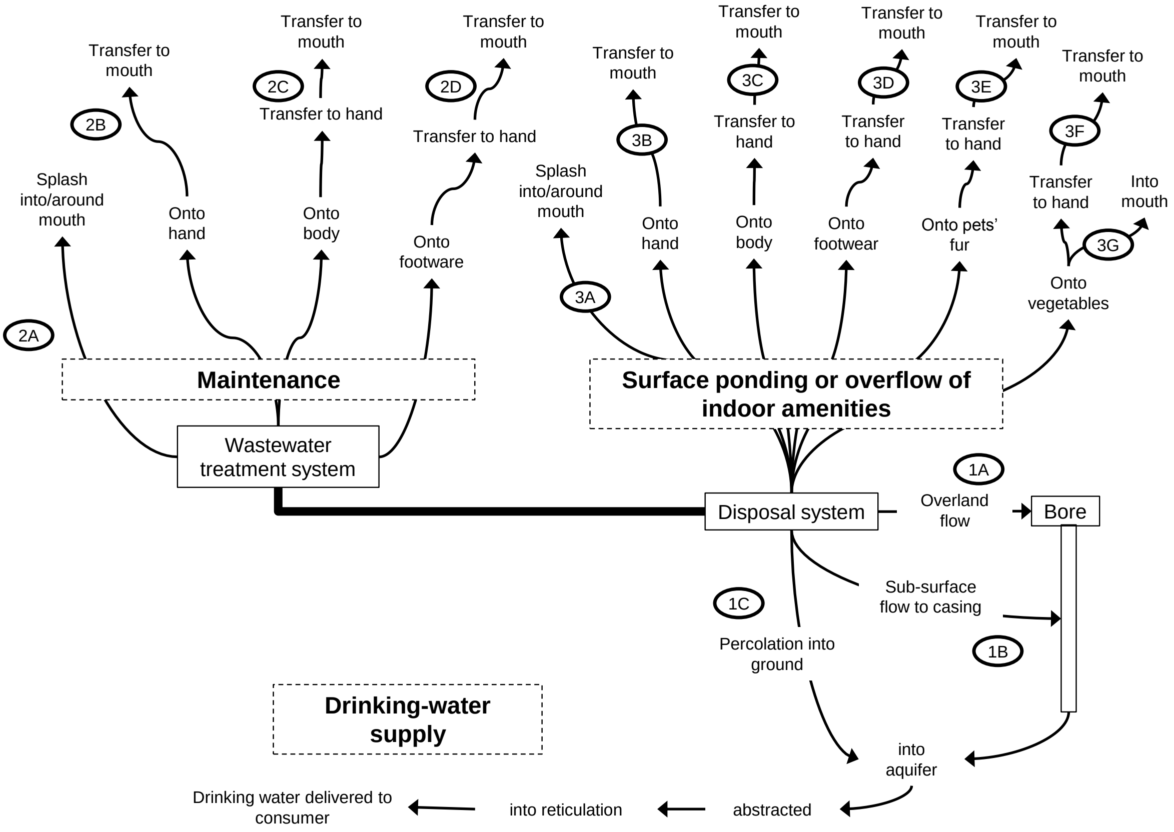

Figure 1 Possible pathways by which Darfield and Kirwee residents may be exposed, by ingestion, to the chemical and microbiological hazards in sewage

The figure shows that there are two types of exposure pathway: direct and indirect. Direct exposure pathways are linked to the operation of the onsite systems through either their maintenance or their failure. Reasons for sewage reaching the land surface, where people could be exposed to the sewage, include:

a. exceedence of the water-holding capacity of the media in the disposal field (as the result of high rainfall for instance), or,

b. pipe blockage resulting in tank overflow.

The indirect exposure pathways bring residents into contact with hazards in sewage through contamination of their water supply.

4.3.2.2 Exposure pathways through drinking-water – Darfield township

There are three pathways by which residents in Darfield town might be exposed through their drinking-water supply to contaminants in the effluent from their onsite systems. The conditions that have to be met for each pathway to make a significant contribution to exposure are listed in Table 2. The factors in the physical environment that will influence the importance of these pathways are listed in Table 3.

Table 2 Conditions necessary for exposure pathways associated with drinking-water to become significant

Pathway			Conditions for this pathway to be significant
1A	Overland flow of sewage to the well head	a.	The wellhead must be unsecure, that is, there must be an entry point that will allow sewage to reach the well casing and from there flow down the casing to the screen, where it can be drawn into the water being abstracted.
		b.	One or more onsite systems must have failed, leading to sewage seeping to the surface and possibly ponding
		c.	The failed system(s) must be close enough to the well that the surface ponding can reach the well head
		d.	The failed system(s) must be in a location that will allow sewage on the surface to flow towards the well head.
1B	Subsurface flow carrying sewage down the bore casing	a.	Onsite systems are located in a position where effluent can migrate horizontally to intercept the well casing
		b.	Drilling of the bore has left an annulus surrounding the casing that will allow effluent to flow down the casing to the groundwater.
1C	Percolation of sewage into the groundwater	a.	The bore must be in a location where it can draw in contaminated water when the bore is pumped.
		b.	There is no confining aquitard above the aquifer.

Table 3 Factors relevant to sewage exposure through drinking water in the Darfield community

a.	The water table under Darfield town is approximately 80 m below ground level (Burbery 2014).
b.	The primary source of the Darfield community's water supply is a 245 m deep bore screened below a depth of 189 m and abstracting water from 54 m below the water table (Burbery 2014).
c.	The water supply bore is approximately 1000 m from the township's onsite system cluster and about 485 m from the nearest individual system (Burbery 2014).
d.	The bore is cross-gradient from the town, as is the nearest onsite system (but in the opposite direction) (Burbery 2014).
e.	The Environment Canterbury (ECan) well card for the Darfield community water supply bore[17] indicates that the drilling method used was air rotary/percussive with no bentonite seal applied around the well casing, making it potentially vulnerable to subsurface flow.

[17] http://ecan.govt.nz/services/online-services/tools-calculators/pages/well-detail.aspx?WellNo=BX22/0006

Table 3 Factors relevant to sewage exposure through drinking water in the Darfield community (cont.)

f.	The wellhead of the town's bore is secure against the ingress of contaminants.
g.	The aquifer from which the township draws its water is unconfined.
h.	The sanitary survey found that although there was no evidence of surface ponding at the time of the survey, some participants reported that there was sometimes ponding and, at times, other signs consistent with system failure.

Pathway 1A

Responses to the sanitary survey indicate that onsite system failures do occur, and ponding was reported by some survey participants. Consequently, there are times when there is a source of contaminants that might follow this pathway. However, the distance between the bore and the closest onsite system (over 400 m), and the secure condition of the wellhead (assessment by C&PH), make it extremely unlikely that contaminants from sewage will reach the groundwater through this pathway. Surface ponding may spread over a few tens of metres but will not spread to a wellhead that is cross-gradient and over 400 metres away.

Pathway 1B

The air rotary method used to drill the bore is expected to have physically disrupted the aquifer and may induce a skin effect that could lead to effluent being conducted down the outer surface of the bore casing to the aquifer. However, considering the substantial depth of the bore and weathered nature of the sediments it penetrates, the likelihood of skin effects being effective at promoting contaminant transport in this situation is very low. Also, for this pathway to be significant, the effluent source must be reasonably close to the well (within a few tens of metres). For the reasons discussed with respect to Pathway 1A, the nearest onsite systems are too far away, and tangential to the direction of natural groundwater flow. As a result, this pathway does not present a realistic route by which contaminants might enter the water being abstracted.

Pathway 1C

Onsite systems may discharge into the ground, through a sophisticated dripper system or a boulder pit. Therefore, a potential source of contaminants exists. There is no known confining layer between the surface and the water table, and consequently contaminants could reach the groundwater through this pathway.

For the bore to draw in contaminated water, the disposal fields must lie within the bore's capture zone. Knowledge of the extent of the capture zone is the first step in determining whether it is reasonable to expect this pathway to contribute to contamination of the town's drinking-water.

In Appendix 2, a uniform flow equation calculation is described, which is used to obtain an indication of the capture zone dimensions. The assumptions on which this model is based make the calculated dimensions conservative. As a result, if an onsite system lies outside the calculated capture zone, this is very likely to be correct. Conversely, discharges that appear to be inside the capture zone may not be.

Monte Carlo modelling is used to try to take account of the uncertainties associated with field measurements for parameters required in the calculation of capture zone dimensions. At the 95 percent level of confidence, the modelling shows that the capture zone is expected to extend approximately 270 m down-gradient from the bore and 430 m across-gradient, at the maximum consented abstraction rate (6,000 m^3/day). The closest onsite discharge is 485 m from the bore placing it outside the estimated capture zone. On the basis of these results, it is almost certain that contaminants from onsite systems will not be drawn into the Darfield bore.

Overall, exposure of the Darfield township residents through their drinking-water to contaminants (microbiological or chemical) in the effluent from their own onsite systems can be ruled out as a potential cause of illness. Further inclusion of Pathways 1A, 1B and 1C in the risk assessment is not required.

The above assessment of the contribution that exposure through Pathways 1A and 1B make to the risk of illness in the Darfield township takes no account of extraordinary situations. Such situations might include extensive surface flooding because of prolonged heavy rain. Even in these situations, where for example, Condition c in Pathway 1A might be met, the likelihood of contamination is still low because the wellhead is secure (Condition a is not met). In addition, during extraordinary situations such as heavy flooding, the heightened risk to the water supply should be evident to the water supplier, and appropriate measures taken to mitigate the risk of waterborne infection.

4.3.2.3 Exposure pathways through drinking-water – properties down-gradient from Darfield

The conditions listed in Table 2 are also relevant to exposure pathways affecting properties down-gradient from Darfield township. Exposure pathways from private onsite wastewater systems to private bores are a possibility and may pose a risk to the health of those using the bores as drinking-water sources. However, this assessment is concerned only with contaminants originating from the township's cluster of onsite systems.

All three exposure pathways identified for the township are potential pathways for private bores roughly down-gradient from the town tank cluster. For the same reasons identified for the township, Pathways 1A and 1B will be insignificant contributors to exposure, that is, the private bores are too far from the town's disposal fields (at least 1.7 km), and are not considered further.

Pathway 1C, on the other hand, does need consideration (which is done in Section 4.3.4), because of the bores being approximately down gradient of the township.

4.3.2.4 Pathways leading to direct exposure to sewage

The possible pathways causing direct exposure to sewage are labelled 2A–2D and 3A–3G in Figure 1. Pathways through surface ponding (and water-logged soil) resulting from system failure are diagrammatically linked to the onsite system's disposal field. They could also arise from blockage leading to overflow from the sewage tank itself.

The sanitary survey (Mulrine 2014) shows that maintenance is not undertaken by the great majority of tank owners, and onsite system failures do occur in Darfield. The survey found that 5.3 percent of residents undertook their own maintenance. Consequently although transport of contaminants through Pathways 2A–2D is possible, only a small percentage the community will be exposed to contaminants through these paths. There was no evidence of onsite system failure at the time of the survey visit, but 30 respondents (29.4 %) stated that they had experienced system failures of various types. Nine (8.8 %) respondents had experienced ponding or the ground becoming boggy, indicating that pathways 3A–3G are also possible.

For any of the pathways shown in the diagram to pose a risk of infectious disease, one or more pathogenic species must be present in the sewage. Contact with sewage that is free of pathogens, while unpleasant, will not lead to infection.

Exposure to pathogens through all the direct pathways is a **possibility** and all need to be considered until their relative importance can be established.

4.3.3 Exposure pathways potentially affecting the Kirwee community

4.3.3.1 Introduction

The potential exposure pathways for the Darfield township, identified in Figure 1, are also applicable to Kirwee.

4.3.3.2 Exposure pathways through drinking-water – Kirwee township

The conditions necessary for exposure via Pathways 1A, 1B and 1C to be important are the same as set out in Table 2. The factors relevant to assessing exposure to sewage through drinking-water in the Kirwee community are different and are provided in Table 4.

Table 4 Factors relevant to sewage exposure through drinking water in the Kirwee community

a. The water table under Kirwee is estimated to be 65 m below ground level (Burbery 2014).

b. The primary source of the Kirwee community's water supply is a 115.2 m deep bore screened from 112.2–115.2 m and abstracting water from approximately 32–49 m below the water table (Burbery 2014).

c. The water supply bore is approximately 240 m from the nearest onsite system cluster and approximately 130 m from the nearest onsite system, cross-gradient. The closest up-gradient onsite systems are more than 1200 m away.

d. The bore is directly up-gradient from residences in one part of the town, but cross-gradient from those in another part of the town.

e. The ECan well card for the Kirwee community water supply bore[18] indicates that the drilling method used was cable tool.

f. The aquifer from which the township draws its water is unconfined.

g. The security of the town bore's wellhead against contaminant ingress is presently uncertain.

[18] http://ecan.govt.nz/services/online-services/tools-calculators/pages/well-detail.aspx?WellNo=L35/0191

Pathway 1A

The security status of the wellhead of the Kirwee Township's supply bore is presently uncertain (personal communication from C&PH). Irrespective of the wellhead security, the nearest onsite system is too far away (130 m) for overland flow to the wellhead.

Pathway 1B

The cable tool method used to drill the bore (cable tool) is considered less likely to produce an annulus about the bore casing that will lead to skin effects than the air rotary drilling method used to sink the Darfield bore. In addition, the distance of the bore from the nearest onsite system is too far for subsurface flow to the bore casing to be significant. Both factors together make it very unlikely that the groundwater will be contaminated by this pathway.

Pathway 1C

There is a greater potential for this pathway to contribute to contamination of Kirwee's drinking-water than was the case for Darfield. The bore is up-gradient of parts of the town and cross gradient from other disposal system clusters in the town. The Kirwee bore is closer to onsite systems than is the Darfield bore, and the depth of the water table at Kirwee is estimated to be at least 15 m shallower than at Darfield. The markedly smaller maximum consented abstraction rate for the Kirwee bore (2,092 m^3/day) compensates for this to some degree, as it results in a capture zone of reduced size.

The uniform flow equation calculation (Appendix 2) shows that at Kirwee's maximum permitted abstraction rate, and at the 95 percent confidence level, the capture zone extends approximately 90 m down gradient and 140 m cross-gradient at the bore. While the nearest cluster of onsite systems is 240 m away, and therefore well outside the capture zone, the closest individual system is 130 m cross-gradient. Although this appears to show that the closest system lies within the capture zone, as noted in Section 4.3.2.2, this may not necessarily be the case because of the conservative nature of the calculation.

The possibility of contaminants from an onsite system being drawn into the bore cannot be ruled out on the basis of the capture zone calculations. A closer examination of the possible level of exposure through this pathway is made in Section 4.3.4.2

The caveat given with respect to extraordinary situations for Pathways 1A and 1B in Darfield is also relevant for Kirwee.

4.3.3.3 Exposure pathways through drinking-water – properties down-gradient from Kirwee

The pathways by which residents in the Kirwee area, but down-gradient of the township, may be exposed to hazards in their drinking-water from the township's onsite system cluster are the same as those identified for Darfield. The separation distances are too great for Pathways A and B to be a concern, but Pathway C cannot be as readily dismissed and it is considered further in Section 4.3.4.2.

4.3.3.4 Pathways leading to direct exposure to sewage

The exposure pathways leading directly from onsite systems to people in the village are the same as for Darfield. All comments provided in Section 4.3.2.4 also apply to Kirwee, except that no sanitary survey was undertaken for Kirwee. However, it is reasonable to assume that people in Kirwee will behave in a similar way to those in Darfield, and consequently that the survey's findings that few householders undertake their own maintenance and that systems fail, sometimes leading to ponding, will also apply to Kirwee.

4.3.4 Estimated exposure

Section 4.3.2 has shown that a physical link via drinking-water between the discharge from onsite systems in Darfield and the town's residents is extremely unlikely. Section 4.3.3 has shown that while Pathways 1A and 1B are unlikely to present a risk in Kirwee, there is uncertainty about the risk presented by Pathway 1C in this township.

There are also bores on properties approximately down-gradient from each township. The capture zone of these bores contains onsite systems in the townships. Consequently, exposure of down-gradient residents to contaminated drinking-water from these bores is a possibility. This section assesses the likely level of exposure.

Residents of both townships may also be directly exposed to sewage from the clusters of onsite systems in the towns.

This section examines exposure through both the indirect (drinking-water) pathways that have not been ruled out as a concern and direct pathways.

4.3.4.1 Exposure of Kirwee residents through drinking-water – nitrate

The Kirwee community water supply bore (L35/0191) has been annually sampled for nitrate since 1980. Hanson (2002) reported a long-term increasing trend in the nitrate concentration when he reviewed the data available in 2002. The maximum nitrate concentration in water from this bore, recorded in the Environment Canterbury (ECan) database, is 21 mg NO_3/L (1998).

Section 4.3.3.2 has already shown that the nearest onsite system to the Kirwee bore may lie within the bore's capture zone. The nitrate concentration measured in the bore water results from the combined contribution of any nitrate inputs from onsite system and the diffuse sources up-gradient of the bore. Comparison of historical nitrate results from L35/0191 and L35/0575 (up-gradient and screened at a similar depth), shows that a large fraction of the nitrate in the water is from up-gradient sources[19].

Therefore, we conclude that, at present, as well as the total nitrate concentration in Kirwee's water supply not exceeding 50 percent of the maximum acceptable value (25 mg NO_3/L), any input of nitrate from the town's onsite systems must also to be too low to pose a public health risk.

4.3.4.2 Exposure of Kirwee residents through drinking-water – pathogens

The estimated extent of the capture zone for the Kirwee community water supply bore (Section 4.3.3.2) indicates that the disposal fields of some onsite systems may

[19] L35/0191: 8 October 2006 – 3.4 mg NO_3/L; 10 October 2007 – 3.2 mg NO_3/L. L35/0575: 7 December 2006 – 2.4 mg NO_3/L; 7 May 2007 – 3.2 mg NO_3/L.

lie within the bore's capture zone, although towards the zone's margin. This section considers factors that will influence the concentration of pathogens reaching the bore, if onsite systems are indeed within the capture zone.

The concentration of microbes within the effluent from onsite systems will be attenuated as they pass through the materials of the vadose zone and aquifer. The *Guidelines for separation distances based on virus transport between onsite domestic wastewater systems and wells*[20] (the *Guidelines*; Moore et al 2010) provides tables that estimate the extent of this attenuation under a range of conditions (subsurface media, vadose zone thickness and separation distance).

Viruses, which were used as the basis for deriving these guidelines, can survive for long times in the environment and being the smallest pathogens are difficult to remove by physical processes, such as filtration, that occur in subsurface media (WHO 2011). Consequently, virus attenuation is expected to provide a conservative estimate of the attenuation of other pathogen types in sewage (ie, bacteria and protozoa).

Burbery's report (2014) states that the subsurface media include clays, silts, sand and gravels, in both the saturated and unsaturated zones. Of these media, gravel provides the poorest removal of pathogens. Therefore the $\log_{10}$ reductions tabulated in the *Guidelines* for this medium should provide a conservative estimate of general microbial removal.

At a horizontal separation of 130 m (the distance between the bore and the closest onsite system) and vadose zone thickness of 65 m, the *Guidelines* estimate the attenuation in the concentration of a virus passing through a gravel matrix to be 12–13 $\log_{10}$. This will be an underestimate of the extent of removal in the Kirwee case for two reasons. Firstly, sand and clay are also present in the matrix. These finer materials will increase the attenuation beyond that calculated for gravel alone (the *Guidelines*). Secondly, the log reductions tabulated in the *Guidelines* are calculated at the water table. Dilution between the water table and the bore's screen (the abstraction depth) will further reduce the pathogen concentration.

Norovirus concentrations in raw municipal sewage have been reported at up to 10^7 genome copies/L (Nordgren et al 2009). Using the conservative estimate of a 13 $\log_{10}$ reduction in the virus concentration, the concentration of a virus at the bore may be of the order of 10^{-6} genome copies/L.

The calculation in Appendix 3 shows that a norovirus concentration in the abstracted water of 10^6 genomes/L will result in an annual probability of infection of the same order of magnitude as the USEPA's tolerable annual probability of infection of 10^{-4} (Chapt. 10, WHO 2001).

On the basis of these calculations, even if the closest onsite system lies within the capture zone, the likelihood of an infective dose of pathogens being ingested with Kirwee's drinking-water is low.

Overall, although the likelihood of being exposed through their drinking-water to pathogens from their onsite systems is greater for Kirwee residents than Darfield

[20] These guidelines were produced by an Envirolink-funded project to provide regional councils, primarily, with separation distance values that have more scientific basis than the separation distances used by local authorities at that time.

residents, the likelihood of this happening is still low. Further inclusion of Pathways 1A, 1B and 1C for the Kirwee risk assessment is not required.

4.3.4.3 Exposure of down-gradient residents through drinking-water – nitrate

Burbery (2014) records a study by Pattle Delamore Partners (PDP 2011) which modelled the nitrate plume originating from the onsite system clusters of the two townships. The modelling showed that nitrate impacts on the groundwater were only likely to exceed the maximum acceptable value for nitrate at distances within 45 m and 225 m of the Darfield and Kirwee system clusters, respectively. Burbery (2014) considers, after review of the hydraulic gradient in the area, that the extent of the Darfield plume may have been underestimated. He suggests that the Darfield plume's extent may be similar to that of Kirwee's plume.

The nearest bores down-gradient of the onsite clusters of Darfield and Kirwee are no closer than 1.7 km to either township (Burbery 2014). This separation distance is well in excess of the estimated 225 m extent of the plume from the clusters. Consequently, any contribution that the onsite system clusters make to the nitrate concentration in these wells is expected to be less than the maximum acceptable value.

4.3.4.4 Exposure of down-gradient residents through drinking-water – pathogens

The *Guidelines* (Moore et al 2010) can be used to assess the likelihood of exposure to pathogens through drinking-water from down-gradient bores. The *Guidelines* show that processes acting to attenuate microbes in the unsaturated and saturated zones are sufficient to achieve a high log reduction in the microbial concentrations over the distance between the onsite system clusters and their nearest bores.

The nearest private bores used for water supply are at least 1.7 km down–gradient from the onsite system clusters of both Darfield and Kirwee. The depth to the water table depth is variable. Burbery's (2014) estimated minimum vadose zone thickness of 65 m for the Kirwee area (which is less than the estimated thickness of 80 m for Darfield) is used here to make a conservative estimate of microbial attenuation.

The log reduction tables in the *Guidelines* for gravel give an approximate $\log_{10}$ reduction of 17 for a 65 m thick vadose zone and 1 km horizontal separation (maximum tabulated distance). The 17 $\log_{10}$ reduction still substantially underestimates the overall log reduction. Given that the 1 km horizontal separation contributes approximately 5 $\log_{10}$ to the overall 17 $\log_{10}$ reduction, a further 3 to 4 $\log_{10}$ might be expected if the *Guidelines* calculations were extended to the full 1.7 km distance. The finer material in the matrix (eg, sand) can be expected to contribute to further virus attenuation as will the depth of the bore screen below the water table.

There is another factor to consider in assessing the possible level of exposure in the nearest down-gradient bore. The *Guidelines* calculations are based on the assumption that the aquifer is receiving effluent from a single septic tank. The 2013 Census (Stats NZ 2014) recorded 747 dwellings in Darfield. This figure provides an approximately value for the number of domestic onsite systems discharging effluent into the ground.

No modelling studies to estimate the cumulative effect of clusters of sewage disposal systems are available. However, consideration of the situation suggests that the risk to health remains low. The number of systems in the cluster will increase the volume of effluent entering the ground by two to three orders of magnitude, but the **concentration** of viruses in the discharged effluent remains the same. Consequently, the 17 log_{10} reduction will still be sufficient to ensure the probability of infection is tolerable given that 13 log_{10} was found to be adequate in Section 4.3.4.2.

Overall, exposure of people getting their drinking-water from bores down-gradient from the Darfield and Kirwee to pathogens from onsite system clusters is unlikely.

4.3.4.5 Direct exposure to sewage – nitrate

Ingestion of nitrate is the only chemical risk associated with direct exposure to sewage that is being considered. The level of exposure to nitrate through the direct pathways is very unlikely to be sufficient to present a public health risk. This is shown by the data in Table 5.

The table shows, for the population categories of adult and child: the volume of water they are assumed to drink daily for the purposes of setting maximum acceptable values; the amount of nitrate this volume represents if the water contains nitrate at its maximum acceptable value; and the volume of sewage that would have to be ingested to result in the same intake of nitrate. The category of “Infant” is not included in the table for although this sub-population is the most vulnerable to nitrate, infants would not be expected to be exposed to sewage through maintenance or ponding.

Table 5 Data showing the volumes of sewage that would have to be ingested to provide the same dose of nitrate as the daily ingestion of water containing nitrate at the maximum acceptabe value

	Assumed daily intake of drinking-water (L)	Daily intake of NO_3 at the MAV[1] concentration (mg)	Volume of sewage to be ingested to yield the same intake of NO_3[2] (mL)
Adult	2	100	280 – 420
Child	1	50	140 – 210

[1] Maximum acceptable value

[2] Calculated on the basis of the NO_3 concentration in onsite system effluent ranging from approximately 240 to 355 mg/L (Burbery 2014)

Ingestion of the volumes of sewage listed in the right-hand column of Table 5, by either an adult or child through any of the direct pathways of Figure 1 is unrealistic. Consequently, no further assessment is made of the risk arising from direct exposure to nitrate in the sewage on onsite systems.

4.3.4.6 Direct exposure to sewage – pathogens

Parameters that influence the **quantity of pathogen** ingested and the **probability** of that ingestion characterise exposure to the pathogen. They are needed for quantitative modelling of exposure through the pathways shown in Figure 1. As an example, Table 6 lists parameters needed to model exposure via the direct pathways arising from the maintenance of onsite systems (Pathways 2A–2D). The purpose of Table 6 is to show the type of data required; it may not be exhaustive. Many of the parameters in Table 6 have to be determined from other parameters that are not included in the table.

The starting point in developing a model for exposure via the direct pathways is to characterise the pathogen source, that is, to estimate the probability that the sewage in an onsite system contains pathogens, and if so, their concentration. The model would require information about[21]:

a. The probability that a person in the town is shedding pathogens, for how long, and in what numbers,
b. Possible clustering (infected people being more likely to be in the same household), which would increase the amount of pathogen being shed into individual sewage tanks, but reduce the probability that an individual tank is contaminated.

The values, or estimated values, of some parameters in Table 6 are known or can be calculated. For the majority of parameters, particularly probabilities, values cannot be assigned without further investigation. This compromises our ability to characterise the exposure to pathogens quantitatively. Monte Carlo modelling would allow a distribution of values to be assigned to parameters but this would still result in output values with a large uncertainty.

To show the uncertainty associated with estimating possible exposure to sewage containing pathogens, a small simulation study is presented in Appendix **4**.

[21] There are practical difficulties in direct measurement of pathogen concentrations in onsite systems, because of needing to be informed when a household member is shedding and then getting access of the tank for sampling.

Table 6 Parameters needed for modelling direct exposure to sewage resulting from the maintenance of onsite systems. Labelling in brackets refers to exposure pathways in Figure 1

Maintenance pathways

Probabilities

- Probability of a given onsite system receiving waste from an infected person
- Probability of maintenance being carried out on the onsite system
- Probability of sewage being splashed into the mouth of the person undertaking the maintenance (2A)
- Probability of the individual getting sewage on their hand (2B)
- Probability of the individual getting sewage on their body (2C)
- Probability of the individual transferring sewage to their hand from their body (2C)
- Probability of the individual getting sewage on their footwear (2D)
- Probability of the individual transferring sewage to their hand from their footwear (2D)
- Probability of the individual transferring sewage to their mouth from their hand (2B, 2C, 2D)

Other parameters

- Concentration of the target pathogen in the sewage in the onsite system
- Volume of sewage(or number of organisms) splashed into the mouth (2A)
- Volume of sewage(or number of organisms) the individual gets on their hand (2B)
- Volume of sewage(or number of organisms) the individual gets on their body (2C)
- Volume of sewage(or number of organisms) the individual gets on their body (2D)
- Volume of sewage(or number of organisms) transferred from the body to the hand (2C)
- Volume of sewage(or number of organisms) transferred from the footwear to the hand (2D)
- Volume of sewage(or number of organisms) transferred from the hand to the mouth (2B, 2C, 2D)
- Rate of pathogen die-off in onsite system's tank.
- Rate of pathogen die-off on hand or body
- Rate of pathogen die-off on footwear or clothing
- Period before transfer from hand to mouth (2B, 2C, 2D) - linked to pathogen survival
- Period before transfer from body or footwear to hand (2C, 2D) – linked to pathogen survival

4.3.4.7 Later steps in the exposure pathways

The simulation in Appendix 4 shows the large uncertainty in a single probability needed to characterise the exposure. Similar, or greater, uncertainties in other parameter values will increase the uncertainty in estimates of the level, and probability, of exposure. This section considers what qualitative statements can be made about the exposure.

Probability of exposure

The simulation provides a range of values for the probability of a given onsite system's tank containing *Campylobacter* on any given day. Having the pathogen enter the tank is only the first event that must occur for an individual to become ill. For someone to be exposed to the pathogen, every other step or event along the pathway must also occur.

The overall exposure probability is the product of each of the individual step probabilities, assuming that the probability at each step is conditional on the probability of the previous step. None of these steps is certain to occur. Therefore, the probabilities of all steps will be less than unity. As each probability is less than unity, the probability of reaching a particular point along the pathway decreases with each step. If the probability of each step were similar, then exposure via a pathway with several steps would be less probable than a pathway with few steps. However, the probabilities of the steps are unknown and may be markedly different.

For example, Pathway 2A requires only one step. There are no subsequent steps that may further decrease the probability of exposure arising through that pathway. However, sewage splashing directly into the mouth seems intuitively to be a low probability event. On the other hand, although Pathway 3E (which depends on an individual having a pet or coming into contact with one) has several steps, the first step, of a dog for example splashing through ponded sewage, seems more likely than the single step of 2A.

In conclusion, the probability of exposure is decreased by every step along a pathway. However, no reliable generalisation can be made that provides a qualitative guide to the extent to which the overall probability of exposure may decrease along a pathway.

Level of exposure

The amount of pathogen to which an individual may be exposed is decreased by each transfer step along the pathway, assuming that none of the steps will allow microbial growth. The difficulty arises in knowing how much of the pathogen may be lost from the pathway with each step.

Some information is available about the efficiency of fomite[22]-to-hand transfer and hand-to-mouth transfer. Rusin et al (2002) report the transfer percentages for two bacteria species and a virus from hand to mouth as being 30–40 percent. They found similar transfer efficiencies for transfer from hard surfaces, such as taps or phone receivers, but porous surfaces, such as fabrics, had transfer efficiencies of less than 1 percent, and in many cases less than 0.01 percent.

These data show that loss in the number of pathogen cells at the hand-to-mouth transfer step in each of the pathways is likely to be low. However, where transfer

[22] Inanimate objects or surfaces

from a porous surface is involved, for example, the transfer of pathogens from clothing onto a hand, high pathogen loss can be expected.

The quantity of microbes transferred in each step is only one of the factors influencing the eventual level of pathogens to which an individual is exposed. Factors such as the ability of pathogens to survive[23] during the journey along the exposure pathway will also affect the eventual dose.

The level of exposure through Pathways 2A and 3A will depend on the volume of sewage entering the mouth. These pathways will not suffer from significant reductions in pathogen concentration through die-off (because of the rapid transfer) or poor transfer efficiencies. The complicating factor is the extent to which exposure is reduced by the reaction to spit out a drop entering the mouth.

4.3.4.8 Exposure arising from maintenance (Pathways 2A to 2D)

As well as the onsite system needing to contain pathogens for these pathways to lead to exposure, people in the Darfield community must be undertaking maintenance of their systems. The sanitary survey found that 36.7 percent of respondents reported that their system was serviced or maintained (either by themselves or a contractor) every three to five years. However, only 5.3 percent undertook the servicing or maintenance themselves. This small percentage will further reduce the probability of exposure of an individual through Pathways 2A to 2D.

There is insufficient information to establish definitively which of the pathways (2A to 2D) is most likely to lead to exposure. An important factor that will reduce the probability and level of exposure through all of these pathways (2B to 2D) is awareness, that is, knowledge that infection during the maintenance of the system is possible because of the nature of the activity.

Awareness could have two effects. First, it may reduce the **probability** of the hand to mouth transfer step occurring. People working with sewage will be aware of the risk of infection this brings. For some individuals, unconsciously bringing their hand into contact with their mouth area may still make this transfer step a possibility. The second effect of awareness is reducing the **level** of exposure, because it will encourage an individual to wash their hands directly after undertaking the maintenance. While it cannot be assumed that everybody undertaking their own system maintenance will conscientiously wash their hands, it is a reasonable assumption that this mitigating action will reduce the number of pathogens to which the average individual is exposed.

Summary: The possibility of exposure resulting from direct contact with sewage during maintenance cannot be ruled out. However, given awareness of the risk associated with working with sewage, and the care people are likely to take to avoid infection, the probability of exposure occurring during maintenance is not high.

4.3.4.9 Exposure through contact with ponded sewage or overflowing amenities (Pathways 3A to 3G)

Exposure to sewage resulting from ponding or overflowing amenities also depends on the presence of pathogens in the onsite system. It is influenced by the probability

[23] The term "survive" here includes the possibility of growth for bacteria.

of the system failing in a way that leads to sewage appearing on the ground surface, overflowing from indoor amenities or being present in saturated soil.

The sanitary survey found that 29.4 percent of participants (n= 30) had experienced some type of onsite system failure[24]. Of the 30 who had experienced a failure, only nine (9%) had observed surface ponding and three (3%) overflow of amenities. Thus exposure via Pathways 3A to 3G is a possibility. The relatively permeable stony soils in the area will be a factor tending to reduce the likelihood of ponding.

Obtaining a qualitative estimate of the probability of exposure through these pathways is more complex than for the pathways resulting from maintenance, because all sub-populations (young to old) may be exposed to pathogens.

Compared with exposure through maintenance, some residents exposed to surface ponding may be unaware of the risk. Young children who are attracted to water (clean or otherwise), may be unaware of the risk, and in some circumstances adults may not recognise that puddles of water have arisen from their onsite system.

Pets are another group within the community that may come into contact with ponded sewage, and for which the restraining effect of awareness does not exist. All members of a household, irrespective of age, may be unaware that a pet has been in contact with ponded sewage. Consequently, awareness is unlikely to be a factor that will reduce the probability of transmission by pathway 3E.

When residents are aware of the hazard of ponding sewage (or overflowing amenities) it is likely that adults will stay away from the hazardous area, and will tell their children to do that same. Both actions will reduce the overall probability of exposure resulting from Pathways 3A to 3D. Of course, some children may not heed the warning.

As well as the possibility of ponding contaminating vegetables, the gradual saturation of soil, before ponding occurs, may lead to their contamination (particularly root vegetables) and also go unnoticed (Pathways 3F and 3G). Preparation of the vegetables, even if only by rinsing under running water may reduce the potential level of exposure to some degree.

Summary: Exposure of Darfield or Kirwee residents to sewage because of failure of their onsite system is possible. The factor that can lead to all age groups being exposed to the risk of infection from failed systems is lack of awareness that they have been exposed to an infection source. Some groups within the community, particularly children, are less likely to be aware of sewage ponding being a health risk. As a result, they are less likely to avoid exposure or take other steps to protect themselves from infection, such as additional care to ensure they wash their hands.

Factors, such as the low probability of some steps, and the poor transfer efficiency in some steps, will act to reduce the overall probability of exposure to an infectious dose of pathogens. However, the possibility of reduced awareness of exposure to sewage from system failures appears to make exposure through these pathways more likely than exposure arising from maintenance.

[24] The Ministry for the Environment estimates that failure rates are between 15 and 50 percent. http://www.mfe.govt.nz/publications/rma/nes-onsite-wastewater-systems-discussion-jul08/html/page4.html (accessed 14/6/14).

4.3.4.10 Conclusion

The simulation in Appendix 4 shows the magnitude of the uncertainty associated with one of the parameters needed to quantify exposure through the direct pathways. For other parameters, such as the probability of sewage being splashed into the mouth of someone undertaking system maintenance, no data are available to allow an estimate of the value for the probability.

Crude estimates of values to allow modelling could be made, but the compounding uncertainties would not allow scientifically defensible estimations of exposure.

Awareness of the risk of infection associated with exposure to sewage is likely to be an important factor influencing the probability and level of exposure to pathogens. Exposure to sewage during maintenance seems a less significant exposure pathway than exposure resulting from system failure, because of the awareness factor.

4.4 Dose-response functions

A quantitative risk assessment requires collation of dose-response information for the target pathogens. From this information and exposure data it is possible to estimate the probability of infection, following intake of a given dose of a pathogen, and from this, the probability of illness.

Although reliable estimates of the amount of pathogen ingested cannot be made in this study (see Section 4.3.4.10), dose-response information is given in Table 7 to show the relative infectivity of the pathogens considered likely to be most significant here.

For the pathogens in Table 7 the relationship between the dose and the probability of infection, P_{inf}, can be described by one of three mathematical models: the Beta-Poisson model, given approximately by

$$P_{inf} = 1 - [1 + N/\beta]^{-\alpha}$$

the exponential model given by

$$P_{inf} = 1 - e^{-rN}$$

and the beta-binomial model for disaggregated norovirus

$$P_{inf} = 1 - [B(\alpha, \beta+i)/B(\alpha, \beta)]$$

where N is the average pathogen dose, I is an individual's pathogen dose, α and β are shape and scale parameters, r is the probability of infection given a single oocyst, cyst or virus particle, B is the standard beta function.

The median doses, at which half the exposed population is expected to become infected (N_{50}), for the bacteria and protozoa in Table 7, can show the relative infectivity of the pathogens. The two bacteria require substantially greater doses to cause infection than the protozoa. For norovirus, interpretation of the N_{50} value is complicated by the shape of the dose response function, which rises steeply at low doses and levels off before reaching the N_{50} value. Norovirus is highly infectious to some people, others have a high level of immunity and in some cases total immunity (McBride et al 2013; Teunis et al 2008).

Table 7 Dose-response information for the pathogens of interest in his study

Pathogen	Dose-response model	α	β	r	N_{50} [1]	Reference
Campylobacter	Beta-Poisson	0.145	7.58		896	Haas et al 1999
Salmonella	Beta-Poisson	0.33	139.9		1003	McBride et al 2013
Cryptosporidium	Exponential			0.05	14	McBride et al 2013
Giardia	Exponential			0.0199	35	Haas et al 1999
Norovirus	Beta-binomial	0.04	0.055		26	McBride et al 2013

[1] The median dose expected to result in infection in half the exposed population. For the exponential model this is given by $-\log_e(0.5)/r$ and for the Beta-Poisson model by $\beta(2^{1/\alpha} - 1)$.

4.5 Risk characterisation

4.5.1 Introduction

The risk characterisation phase of a risk assessment typically draws together the information assembled in the hazard identification (Section 4.2), exposure assessment (Section 4.3) and dose-response (Section 4.4) phases of the work. In this case, because exposure cannot be quantified, quantitative risk characterisation is not possible.

The purpose of this section is to explore what qualitative statements can be made about the public health risk arising from onsite treatment and disposal of sewage.

4.5.2 Qualitative risk characterisation

4.5.2.1 Introduction

A primary motivation for this project is to provide information about the acceptability of onsite systems in Darfield and Kirwee from a public health view point. The information delivered by the project should help inform decisions about the future provision of sewerage services. This section considers differences in the public health risks associated with onsite and reticulated wastewater systems.

4.5.2.2 Exposure probability

Figure 1 shows direct pathways that could **conceivably** lead to infection because of the onsite treatment and disposal of sewage. In a well-operated reticulated sewerage system that does not receive storm water input these exposure pathways do not exist. Residents do not have to undertake system maintenance, nor does system failure leading to exposure to sewage occur. Given the absence of these pathways, the risk to public health from a reticulated system will be less than that of onsite systems.

Although possible pathways of exposure are identified for onsite systems, it does not necessarily follow that they will make an unacceptably high contribution to the level of disease in the community. Without a quantitative risk assessment the level of this contribution cannot be readily determined. In these circumstances, risk characterisation relies on what can be surmised about exposure.

The probability of illness, P_I, due to a specific pathogen via a specific exposure pathway can be written as:

$$P_I = P_{Inf} \times P_{I,Inf} \times P_E \quad [1]$$

where the probability of infection given exposure, P_{Inf}, is a function of the pathogen dose and the pathogen's dose-response function, $P_{I,Inf}$ is the probability of a specific illness[25] given infection, and P_E is the probability of exposure to the pathogen (which includes the probability of the sewage containing the pathogen).

In the case of direct exposure to sewage through the pathways of Figure 1 the value of P_E may have a significant influence on P_I, because it could be substantially less than unity. Even if the probabilities P_{Inf} and $P_{I,Inf}$ were to be close to unity, if exposure to pathogens is improbable, the probability of illness will be low.

The simulation in Appendix 4 has determined a daily probability for *Campylobacter* being in a given onsite system's tank. This is only one of the components of P_E. It provides an estimate of the **upper bound** for the probability of an individual becoming ill with campylobacteriosis as a result of exposure through one of the pathways of Figure 1[26] (ie, if $P_{Inf} = P_{I,Inf} = 1$). For a complete assessment of the levels of disease associated with direct exposure to sewage from onsite systems, Equation 1 needs to be evaluated for all pathways and for each pathogen that may be present.

Had the probability estimate from the simulation been a low value, it would have shown that the probability of illness is low[27]. However, the daily probability of a system containing *Campylobacter* was calculated to be approximately 2 percent, which is relatively high[28]. Other probabilities contributing to P_E may be low resulting in a low overall P_E value, but we cannot be certain of this.

A possible approach is to assume worst case values for all parameters to allow a worst case estimation of P_I. However, what constitutes the worst case value for some of these parameters is unknown. Such an approach could lead to either an under- or overestimation of the level of illness.

4.5.2.3 Summary of information relevant to characterising risk

Previous sections contain information that has a bearing on the risk characterisation.

[25] Gastroenteritis is the primary concern with the pathogens considered in this assessment.
[26] P_I is the product of several probabilities (Equation 1) including the component probabilities of P_E, of which the probability determined by the simulation is one. The maximum value of any of the probabilities that contribute to P_I is unity. Therefore, even if all other probabilities equal 1, P_I cannot be greater than the probability determined from the simulation.
[27] With the caveat that the probability would probably be slightly greater than the simulation value because of illness from other pathogens needing to be taken into account.
[28] The daily probability of 0.02 is equivalent to an annual probability of approximately 0.99. The USEPA's tolerable annual probability of infection is 0.0001 (Chapt. 10, WHO 2001).

a. On any given day **some** onsite systems in Darfield are expected to contain at least one pathogen species.

b. Some residents in Darfield undertake their own system maintenance. If this maintenance is being undertaken on a system containing pathogens, there is the possibility of infection and subsequent illness through Pathways 2A–2D.

c. Ponding of sewage and the overflow of amenities do occur in Darfield. If these events happen on a day in which pathogens are in the onsite system, there is the possibility of infection and subsequent illness through Pathways 3A–3G.

d. Awareness of the possibility of infection by the person undertaking system maintenance seems likely to reduce the probability of infection via these pathways.

e. Adults are the population sub-group at greatest risk from exposure during system maintenance.

f. Awareness of the possibility of infection is less likely to reduce the probability of infection via the pathways associated with system failure than it is for tank maintenance. This is because those being exposed (including pets) are less likely to be aware[29] that they have been exposed, and will not take measures to prevent infection.

g. Members of any age group in the population could become infected from sewage ponding and amenity overflow, because of being unknowingly exposed to sewage.

Conclusion: The public health risk associated with onsite systems is greater than that from a well-operated reticulated sewerage system (without storm water input) because exposure pathways for onsite systems do not exist for a reticulated system. The difference in the level of risk cannot be robustly quantified.

For illness to occur as the result of exposure via a given pathway a series of events, none of which is certain to occur, must **all** take place. Taking this, and a–g above into consideration, it is reasonable to conclude that the overall likelihood of ingestion of sewage from onsite wastewater systems is not high.

Epidemiological data presented in Table 8 are consistent with this conclusion. The table contains case numbers for campylobacteriosis from the Episurv database (data extracted 14 July 2014). It lists, for a group of Canterbury districts and towns, the population of the area or town, the number of cases of campylobacteriosis reported in the period from 1 January 2013 to 14 July 2014[30] in that area or town, the rate of campylobacteriosis expressed as a rate per 100,000 of population, and whether the sewerage system in the area or town is reticulated.

There is substantial uncertainty in the rates in Table 8. This needs to be taken into account when reaching conclusions about the relationship between the sewage disposals systems and disease rate.

Two factors influence the uncertainty in the figures. Firstly, the number of cases in the towns is small. Natural variation in this number by only one or two cases

[29] Or it is of no consequence to them as in the case of pets.
[30] Data for 2012 were not included because of the confounding factor of the campylobacteriosis outbreak in Darfield associated with contaminated drinking-water, unrelated to onsite system discharges, during that year.

represents a large percentage change and consequently a marked change in the rate.

Secondly, establishing the population that should be used to calculate the rate is not straight forward. All the population figures contained in Table 8 are taken from the 2013 Census except for the populations of the Selwyn District towns of Darfield and Leeston. For these towns, estimates of the town population come from the district council (personal communication of Selwyn District Council data to E Moriarty by J Williamson, Community and Public Health). The council's estimates are markedly different from the census estimates[31], but are considered more likely to represent the number of people to which the Episurv data apply.

When interpreting the data in Table 8, it must also be recognised that the campylobacteriosis cases reported are not specifically associated with infection from onsite systems.

With the above factors in mind, a safe conclusion to be drawn from Table 8 is that the rate of campylobacteriosis in Darfield does not stand out as being markedly different from other centres or areas for the period covered. This is despite Darfield being the only listed town relying solely on onsite wastewater treatment and disposal.

Table 8 Campylobacteriosis rates for locations in Canterbury showing that the rates do not clearly correlate with the type of sewage treatment and disposal system

Area/Town	Population[1]	Number of Cases	Calculated Rate (cases per 100,000)[2]	Reticulated Sewer
Canterbury DHB	539,436	1,218	226	Mixture
Waimakariri District	49,989	142	284	Mixture
Selwyn District	44,595	140	314	Mixture
Hurunui District	11,529	43	373	Mixture
Ashburton District	31,041	163	525	Mixture
Amberley (excluding Amberley Beach)	1,575	8	508	Yes
Darfield	2,755	10	363	No
Leeston	2,050	6	293	Yes
Methven	1,710	6	351	Yes
Woodend	2,679	12	448	Yes

1. Population figures are from the 2013 Census, except for the Darfield and Leeston population which were provided by the Selwyn District Council (personal communication of Selwyn District Council data to E Moriarty by J Williamson, Community and Public Health).
2. Note that these rates are calculated from cases occurring over approximately 18 months and cannot be compared with the more common annual incidence rates published elsewhere

[31] For example, the census population for Darfield is 1935, while the council's estimate is 2755, and for Kirwee (not contained in the table) the census figure of 3486 is greater than the council's estimate of 1081, and greater than that for Darfield, known to be a larger town. The reasons for differences are unclear.

5 CONCLUSION

The risk to the health of the residents in the Darfield and Kirwee communities (townships and down-gradient properties), through exposure to hazards in sewage from onsite systems has been assessed. Two types of exposure to sewage were considered:

a. **indirect exposure** through contamination of the groundwater and subsequent contamination of groundwater-sourced water supplies.

b. **direct exposure** that might occur during onsite system maintenance or through ponding or amenity overflow

Indirect exposure

Contamination of the towns' water supplies by effluent from onsite systems is extremely unlikely because of:

a. the location of each bore with respect the onsite system clusters

b. the distance of the bores from the nearest onsite systems

c. the depth of the bores/ the thickness of the vadose zone

d. the depth below the water table from which water is abstracted.

Consequently, in the absence of cross-connections between drinking-water and wastewater systems or other unforeseen incidents, at present there is a very low likelihood of exposure of the Darfield' residents to sewage through their water supplies and a low likelihood for Kirwee's residents.

Exposure of people, down-gradient of the townships, to chemical or pathogen hazards at concentrations of health concern is unlikely, because of factors b–d above.

The low to very low likelihood of residents in the Darfield-Kirwee area becoming ill through indirect exposure to contaminants from the clustered onsite systems in the townships results from a combination of favourable factors (a–d), particularly the great thickness of the vadose zone in the area. **It must not be assumed that this finding is applicable to all situations in which onsite systems are clustered**. The combination of favourable factors may not exist elsewhere. The risk of contamination has to be assessed for each individual situation.

Direct exposure

The public health risk resulting from ingestion of nitrate through direct exposure to sewage is negligible. The volume of sewage that would have to be ingested to cause illness is beyond what could be reasonably expected. This is particularly true for infants, the sub-population most vulnerable to the adverse effects of nitrate[32].

However, the high concentrations of pathogens that may be present in sewage mean that illness of microbiological origin resulting from direct exposure to sewage does need to be considered. Quantitative modelling of this risk requires the values of a

[32] Infants will not be involved in onsite system maintenance and it is unlikely that they will come in contact with sewage ponding or overflows resulting from system failure.

large number of parameters to be known. Estimates of some of these values are available, but the majority are not. Consequently a robust quantitative risk assessment cannot be made.

Exposure to sewage can occur during the maintenance of onsite systems and as the result of tank failure. The study concludes that the risk of illness associated with system failure is probably greater than the risk associated with system maintenance. Awareness of the risk during tank maintenance is considered to be an important factor influencing this likelihood. Adults are the sub-population primarily at risk during maintenance.

Pathways that may lead to the exposure of residents of Darfield and Kirwee to pathogens from their onsite systems are not present in a well-maintained reticulated sewerage system that has no storm water input. Consequently, the likelihood of illness arising from disposal of wastewater by onsite systems is greater than the likelihood of illness rising from reticulated sewage disposal. Although onsite systems are more likely to lead to illness than a reticulated sewerage system, the likelihood of illness arising from exposure to the content of onsite systems is not necessarily high enough to be of public health significance.

Examination of campylobacteriosis rates in various towns and districts within Canterbury does not show clear evidence of the rate of the disease being higher in Darfield than locations solely or partially reliant on reticulated sewerage systems.

Implications for future development

It is difficult to assess how an increased population in Darfield-Kirwee will influence the likelihood of infection through direct contact with sewage from onsite systems. An accompanying increase in population density may increase effluent loading rates and with them the likelihood of system failures. On the other hand, the improved design of new systems should tend to reduce the likelihood of system failure and therefore infection, provided they are properly maintained and operated.

The situation is different with respect to the possibility of infection through contaminated drinking-water. At present, despite a source of contamination existing in each town, there is a very low likelihood of contamination of the towns' water supplies because of the relative locations of the bores and the onsite system clusters.

The primary factors presently protecting the residents of Darfield and Kirwee from exposure to pathogens through their drinking-water are: the sewage sources being outside the capture zones of the bore (Darfield); the thickness of the vadose zone and the horizontal separation distance between the bore and sewage sources (Darfield and Kirwee).

Population growth in the area will not greatly affect the thickness of the vadose zone. However, **if** development of these townships were to allow onsite disposal fields to be established at locations within the bores' capture zones, and closer than the existing onsite systems, particularly in Kirwee, the likelihood of drinking-water contamination would increase.

An increase in the abstraction rate from the supply bore in each town, to meet increased demand, will increase the size of the capture zone around the bore. In this way, a disposal field that was initially outside the capture zone, may eventually be positioned within the capture zone. Such a possibility needs to be borne in mind when planning the development of the towns.

An increase in the **density** of onsite systems in the Darfield and Kirwee townships will result in an increase in the nitrate concentration in the groundwater beneath the townships. This is expected to affect residents in the towns and those down-gradient differently.

- The increase in the groundwater nitrate concentration poses a potential risk to the quality of water from bores down-gradient of the townships.
- Provided onsite systems are not established within community supply captures zones, the quality of the townships' water supplies will not be adversely affected.

These conclusions concerning future development only take account of public health risk. They do not consider any other factors that may make it undesirable for a growing community to remain reliant on the onsite treatment and disposal of wastewater.

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6 RECOMMENDATIONS

This report has been prepared to inform the debate between stakeholders about wastewater management in the Darfield-Kirwee area. The recommendations below follow from the report's findings and aim to protect public health given the present circumstances. They do not attempt to direct decisions about the appropriate approach to wastewater management.

Recommendation 1: To minimise the likelihood of onsite system failure and community residents being exposed to the microbiological hazards in sewage the Selwyn District Council, perhaps in conjunction with Environment Canterbury, should review possible mechanisms for ensuring that onsite systems are properly maintained or redesigned to meet current standards.

Recommendation 2: To maintain the safety of the community drinking-water supplies for Darfield and Kirwee planning by the Selwyn District Council for development of the townships, if onsite sewage treatment and disposal is to be retained, should ensure that onsite systems are not established within the capture zones of public water supply bores. The planning would need to take account of changes in the size of the capture zone resulting from increased water abstraction, and section sizes should be set to include reserve areas for a new disposal field should it be required (see AS/NZS 1547:2012).

[Section 4.3.4.3 refers to work undertaken by PDP (2011) to model the nitrate plume originating from the onsite system clusters. It also notes that Burbery (2014) believes that the extent of the plume at Darfield may be underestimated. A recommendation to undertake further work, particularly the sinking of new monitoring bores to obtained better information on the nitrate concentration in the groundwater, is not made here because of the comment made by Burbery (2014) in Section 5.5 of his report:

> "Although having monitor wells placed within the two perceived plumes of contamination would directly measure the impacts on groundwater quality from the septic tank operations at Darfield and Kirwee, the benefits of accruing this knowledge are offset by the financial costs and the risk that drilling boreholes close to the contaminant source may actually weaken the natural attenuation capacity of the aquifer. The cost of installing a 70-m deep monitoring well in the Darfield and Kirwee area is about $18,000, and about $200 for every extra metre beyond that (Iain Haycock, McMillan Drilling Services, personal communication, February 2014)."]

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APPENDIX 1

Information on likely pathogens in domestic sewage

Campylobacter spp.

Species of *Campylobacter* are the most common cause of notifiable gastrointestinal illness in New Zealand (ESR 2014). They are widespread in the environment and are carried by a range of animal hosts as well as humans (Percival et al 2004). In surface waters, *Campylobacter* concentrations are usually low compared with the high numbers in sewage. *Campylobacter* are reported to be able to survive in groundwater for several weeks (Percival et al 2004). Their survival increases with decreasing temperature.

The typical symptoms of campylobacteriosis are diarrhoea (often bloody), abdominal pain and fever (Ministry of Health 2012). Symptoms are of varying severity. The incubation period[33] ranges from one to ten days, with two to five days being more usual (Ministry of Health 2012). The pathogen is not usually shed in stools beyond 30 days, but asymptomatic carriage of the organism may continue for up to seven weeks (Heymann 2009).

Infected individuals usually recover in less than a week. In some cases, it may cause long-term consequences such as Guillain-Barré syndrome or reactive arthritis. Campylobacteriosis can be fatal, but deaths are rare.

The predominant transmission route is ingestion of contaminated, or cross contaminated, food. Infection may result from the consumption of unpasteurised milk, faecally contaminated water, or contact with farm animals. Person-to-person transmission is uncommon (Ministry of Health 2012).

Salmonella spp

In 2013, pathogens within the *Salmonella* group were the second most common cause of enteric illness caused by bacteria in New Zealand (ESR 2014).

Domestic and wild animals and birds, as well as humans, act as reservoirs of *Salmonella*. Animals and humans can be asymptomatic carriers, and while humans are rarely chronic carriers, it is common amongst birds and animals (Percival et al 2004). The bacterium is shed in animal faeces and survives well in soils. It has been isolated from sewage polluted surface waters (marine, estuarine and fresh) and groundwater (Percival et al 2004). Contamination of wells has been found, caused by seepage from onsite systems (Percival et al 2004). *Salmonella* bacteria are capable of surviving for long periods in environmental waters, and may even show regrowth in heavily polluted waters during warm periods (Percival et al 2004).

Gastroenteritis resulting from infection by *Salmonella* is characterised by abdominal pains, diarrhoea (occasionally bloody), fever, nausea and vomiting (Ministry of Health 2012). The infection, which may last from two to five days, is usually self-limiting. However, for some cases the severity of the diarrhoea may require hospitalisation. For these patients, the *Salmonella* infection may spread from the intestines to the blood stream and then to other parts of the body. In some cases, salmonellosis may have long-term consequences such as reactive arthritis. Death resulting from salmonellosis is rare.

[33] Time between ingestion of the organism and symptoms experienced.

The incubation period can range from 6 to 72 hours, but is typically 12–36 hours. The period over which the pathogen is shed in stools can range from a few days to several weeks, and in a small percentage of cases (1% of adults) shedding may continue for over a year.

Transmission of salmonellosis may result from ingestion of food (including meat products and milk) or water contaminated by faeces from infected hosts.

Cryptosporidium spp.

Cryptosporidium spp. are protozoan parasites, which are excreted in large numbers in the faeces of infected animals and humans. Livestock and humans are reservoirs of the pathogen.

The form of the organism that is shed into the environment, the oocyst, is thick-walled and capable of surviving for long periods outside a host (Percival et al 2004). As well as water, *Cryptosporidium* has been detected in a variety of matrices including foodstuffs. Primary and secondary sewage treatment provides no guarantee of inactivation of the pathogen, as it has been detected in the effluent of sewage treatment plants (Percival et al 2004). The occurrence of *Cryptosporidium* in environmental waters depends on the possible sources of the pathogen in the catchment. High densities of livestock, especially during calving, and high numbers of wildlife can increase the likelihood of the pathogen in the water.

Infection by *Cryptosporidium* spp. causes an acute illness with primary symptoms of diarrhoea (may be profuse and watery) and abdominal pain (Ministry of Health 2012). Fever, nausea and vomiting may also be experienced (Percival et al 2004). Symptoms tend to last for longer than with other common causes of gastroenteritis. Also, in some people, symptoms may seem to improve and then get worse again (relapse) before the infection clears fully. Infected individuals may be asymptomatic. The disease is self-limiting, provided the patient is immunocompetent, but the infection can be life-threatening for immunocompromised patients (Percival et al 2004).

The incubation period for cryptosporidiosis probably lies in range of 1 to 12 days with the average being seven days (Ministry of Health 2012). Oocysts appear in the faeces at the start of the illness, and shedding continues for a period ranging from 1 to 15 days after cessation of diarrhoea (Percival et al 2004). Symptoms usually last 1–2 weeks. Asymptomatic carriage beyond this period may lead to a continued risk of infection because of the possible relaxation of hygiene precautions.

Transmission of oocysts is via the faecal-oral route, including person to person, from infected animals or from contaminated water (including recreational waters) or food (Ministry of Health 2012). Person-to-person transmission is important in households and institutions (Percival et al, 2004).

Giardia spp.

Giardia spp. are protozoan parasites that infect humans and a range of other animals (wild and domesticated). In New Zealand, the highest rate of giardiasis occurs in children aged from one to four years of age (Ministry of Health 2012).

The cysts of *Giardia* are environmentally robust and have been found in dairy farm run-off, sewage plant effluent, sewer outfalls and in sewage contaminated drinking-water (Percival et al, 2004). Cysts have been found to remain viable in cold environmental and tap waters for up to three months.

Giardiasis is characterised by diarrhoea, abdominal cramps, bloating, flatulence, nausea, weight loss and malabsorption[34] (Ministry of Health 2012). The infection may be asymptomatic. In immunocompetent patients the illness is self-limiting, but in immunocompromised (and occasionally with immunocompetent) individuals the disease may become chronic. In this event, symptoms relapse in short, recurrent bouts.

The incubation period ranges from 3 to 25 days, although the median period is 7–10 days (Ministry of Health 2012). Acute giardiasis typically lasts one to three weeks (Percival et al 2004). Cysts are shed all through the period of infection (typically 2–6 weeks).

The transmission route is faecal-oral. Transmission may occur through ingestion of faecally contaminated food or drinking-water, swallowing recreational water, exposure to faecally-contaminated environmental surfaces, and person to person.

Norovirus

Like most viruses, under normal conditions, noroviruses are species specific. Their presence in sewage (see Table A1) will result from human faecal material.

Table A1 Some published concentrations of norovirus in municipal sewage[1]

Norovirus Genotype	Concentration range in raw municipal sewage (log_{10} genome copies/L)	Reference
G I	2.11 – 4.64	Hewitt et al 2011
	2.05 – 4.76	Flannery et al 2012
	4.0 – 6.3	Nordgren et al 2009
G II	2.19 – 5.46	Hewitt et al 2011
	1.81 – 5.34	Flannery et al 2012
	<4 – 7.0	Nordgren et al 2009

1 This list is not exhaustive.

While they may survive for extended periods in the environment, they are unable to multiply outside living host cells (Percival et al 2004).

Noroviruses have been identified in sewage, effluent, river, groundwater and seawater samples. The presence of these organisms in samples is determined by molecular methods; they cannot be grown in the laboratory.

The predominant symptoms of norovirus infection are diarrhoea and vomiting (which may be projectile), accompanied by headache and myalgia (pain in one or more muscles). Although the symptoms may be incapacitating they usually resolve within 24–60 hours with dehydration being the most common complication (CDC 2011). Additional complications may arise in the immunocompromised. Up to 30 percent of infections may be asymptomatic (CDC 2011). Infection does not result in on-going

34 Poor intestinal absorption of nutrients

immunity to further infection so that an individual may become infected by noroviruses several times during a lifetime (CDC 2013).

The average incubation period of gastroenteritis associated with norovirus, ranges from 12 to 48 hours, with a median period of 33 hours (CDC 2011). Shedding of norovirus is usually up to seven days after the onset of symptoms, however shedding can last up to 56 days in some people (Atmar et al 2008).

Transmission is primarily by the faecal-oral route. Transmission may be person-to-person, or through ingestion of contaminated food, water, or contact with contaminated surfaces (CDC 2014).

APPENDIX 2

Well capture zone calculations for Darfield and Kirwee public water supply bores.

The uniform flow calculations below are used to obtain a first approximation of the extent of the capture zones around the water supply bores in the two towns. The assumptions made in deriving the equations make the calculations conservative, that is, they are likely to overestimate the dimensions of the capture zone.

For the simplified case of an abstraction well fully penetrating a homogenous, isotropic aquifer with a uniform regional flow field that is oriented in the x-direction, the margins of the well-capture zone are calculated from the equation (Moreau et al 2014):

$$x = \frac{-y}{\tan(2\pi kbiy/Q)}$$

where Q = the well's steady-state pumping rate (L^3/T), k = hydraulic conductivity (L/T), b = the aquifer thickness (L), i = the hydraulic gradient in the aquifer (L/L), and x and y are the distances from the pumping well at the origin to the boundary line in the x and y directions respectively.

The stagnation point in the x direction x_0 (ie, the distance the well will capture groundwater against the direction regional flow) is given by:

$$x_0 = \frac{-Q}{2\pi kbi}$$

The distance along the y axis from the pumping well to the capture zone boundary (ie, at coordinate $(0,y_0)$) is given by:

$$y_0 = \frac{\pm Q}{4kbi}$$

At an infinite distance up-gradient along the x axis, the distance in the y direction, which marks the maximum half-width of the capture zone boundary is given by:

$$y_{max} = \frac{\pm Q}{2kbi}$$

The accuracy of this approach is limited by the assumptions that the values for the parameters used in the calculation are independent of direction and that the aquifer material is homogeneous. Neither assumption is valid for the Darfield-Kirwee aquifer, which leads to the calculations being conservative.

The values for the parameters required for the calculations in the Darfield-Kirwee area, using conservative estimates for aquifer properties obtained from local pumping data, are given in Table A2.

Monte Carlo calculations (@RISK, Pallisade Corporation) were used to try to take account of uncertainty in the values determined from field tests in Table A2. All experimental parameters were assigned a triangular distribution with the base value (Table A2) being used as the most likely value. The minimum and maximum values for the distribution were taken from the range in the table. The model was run for 10,000 iterations.

Table A3 contains the results of the calculations. The results for x_o and y_o were obtained from the base values in Table A2. The 95th percentile values for the x_o and y_o values were obtained from the Mont Carlo calculations. There is a 95 percent confidence that the capture zone defined by these dimensions is no greater than the capture zone **that would exist if the assumptions underpinning the equations were valid,** that is, the aquifer is anisotropic and homogeneous. As these are conservative assumptions, the actual level of confidence that the capture zone is no larger than the dimensions given should be greater.

Table A2 Aquifer properties used in the delineation of capture zones

Aquifer properties (Lee Burbery personal communication)					
Parameter	Units	Darfield base value[1]	Range[2]	Kirwee base value[3]	Range[2]
Transmissivity, T	m^2/d	2300	200–4500	2500	200–4500
Aquifer thickness, b	m	26	5–45	13	5–45
Hydraulic conductivity (estimated), K = T/b	m/d	88		192	
Regional hydraulic gradient[4], i		0.0025	0.0025–0.0095	0.0025	0.0025–0.0095
Regional Darcian velocity, U = Ki	m/d	0.221		0.48	
Regional areal flux, Ub	m^2/d	5.75		6.24	
Pumping rate, Q	m^3/d	6000		2092	

1 Assumed transmissivity value derived from pump test results of well BX22/0006; aquifer thickness value reflects screened length of well rather than true aquifer thickness.
2 Range of values for parameters for which field values are available.
3 Assumed transmissivity value derived from pump test results of well L35/0685; aquifer thickness value reflects screened length of well rather than true aquifer thickness.
4 Shallowest hydraulic gradient reported for region assumed for the base value to provide a conservative result.

Table A3 Results of the capture zone delineation calculations

Bore	**x_o (Stagnation point)[1] (m)**	**Greatest extent of x_o (m) (95% certainty)**	**y_o[2] (m)**	**Greatest extent of y_o (m) (95% certainty)**
Darfield	166	270	261	430
Kirwee	53	90	84	140

1 The farthest point down-gradient from which water will be drawn into the bore.
2 The farthest distance directly cross gradient from the bore from which water will be drawn into the bore

APPENDIX 3

Estimation of the probability of norovirus infection in the Kirwee community well

From the **maximum** estimated concentration of norovirus of 10^{-6} genomes/L in the water abstracted from the Kirwee Community bore, arising from the nearest onsite system to the bore (Section 4.3.4.2), the daily probability of infection for someone drinking this water can be estimated from:

$$P_{inf} \quad = \quad 1 – [B(\alpha, \beta+i)/B(\alpha, \beta)]$$

where B is the standard beta function, α and β are shape and scale parameters and i is an individual's virus dose.

This form of the norovirus dose-response function is applicable when the viruses are disaggregated. In effluent from an onsite system, in which the sewage may have remained for some time before discharge, the virus particles may be clumped together (aggregated). The extent of aggregation is likely to change as the viruses pass from the disposal field to the down-gradient well, although we do not know how this will change. The equation above will overestimate the probability of infection when the virus is aggregated, and consequently irrespective of the degree of aggregation it provides a conservative estimate of the infection probability.

The dose N is calculated from the virus concentration and the volume of water ingested daily. An adults' daily consumption of water is assumed by the World Health Organization to be 2 L, giving a dose of 2×10^{-6} genomes /L. Substituting this value for N and the values of 0.04 for α and 0.055 for β (McBride et al 2013) into the equation, results in an estimated daily probability of infection of 1.5×10^{-5}.

As the typical shedding period for norovirus is seven days, the annual probability of infection ($P_{inf,yr}$), assuming infection of a household occurs only once a year, is given by

$$P_{inf,yr} \quad = \quad 1 – [1 – P_{inf}]^n$$

where n is the number of days of exposure to the virus. Setting n equal to the typical shedding period results in a value for $P_{inf,yr}$ of approximately 1.1×10^{-4}.

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APPENDIX 4

Simulation study to determine the number of onsite systems containing Campylobacter

A simulation study, which is based on infection with *Campylobacter*, illustrates the uncertainty associated with estimating the probability of an onsite system containing the pathogen. *Campylobacter* is chosen for the study because campylobacteriosis is the most frequently reported enteric disease in New Zealand (ESR, 2014). Norovirus may be a major cause of disease associated with human waste (McBride 2011). However, because disease arising from norovirus infection is not included in the notifiable diseases schedule, a simulation based on norovirus is not possible.

The aim of the simulation is to estimate the number of onsite systems in Darfield that could contain the pathogen on a given day of the year and uses the following model components:

a. From the Notifiable and Other Diseases in New Zealand Annual Report for 2013 (ESR 2014), the reporting rate for campylobacteriosis was 158 cases per 100,000 population in Canterbury. If the Darfield population is typical of Canterbury, then with a population of 1935, approximately three notified cases of symptomatic campylobacteriosis a year are estimated to be resident in Darfield.

b. Only a portion of people with symptoms will present to the health system and become notified. In addition, only a portion of people who become infected actually become ill and exhibit symptoms, although infected people without symptoms can still shed *Campylobacter* in their stools. A prospective UK study (Tam et al 2011) suggested a ratio of 1:9.5 of reported cases to total symptomatic cases of campylobacteriosis. Further, an estimated 20 to 50 percent of people infected with *Campylobacter* will develop symptoms, with the most likely value being around 33% (FAO/WHO 2009). Combining these two factors results in the minimum, most likely and maximum ratios of 1:19, 1:28.5 and 1:47.5 for converting between the numbers of notifications and infections. Using these conversion factors, the estimated number of people in Darfield infected with *Campylobacter* each year ranges from approximately 55 to 140.

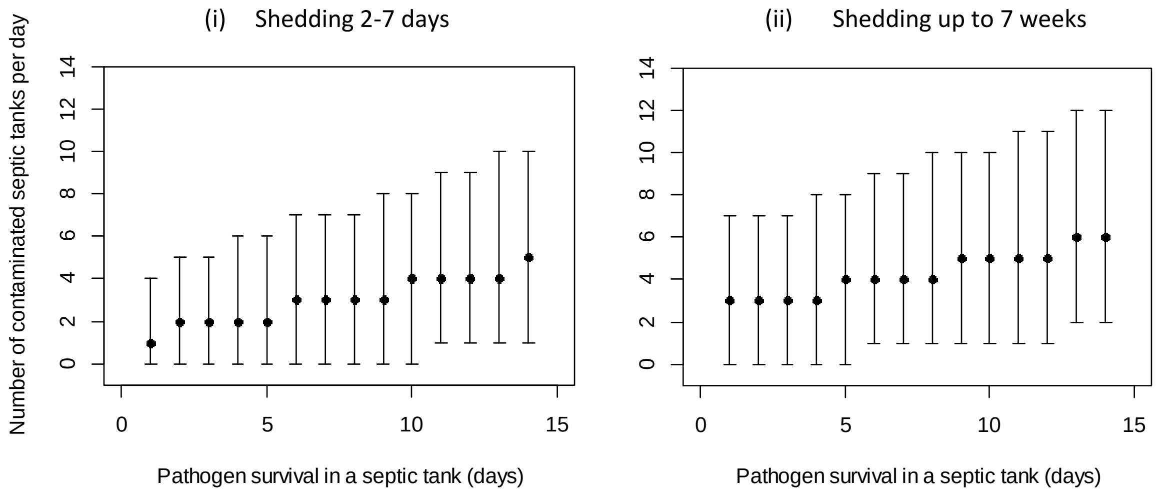
c. The period over which *Campylobacter* is shed by infected people who do not take antibiotics ranges from a few days to seven weeks (Heymann 2009). The Ministry of Health Communicable Disease Control Manual states that *Campylobacter* spp. may be shed in the stool for several weeks after infection (Ministry of Health 2012). Two distributions have been used to model the possible shedding periods of infected people.

    Distribution (i) - the duration of shedding occurs for between two and seven days and each duration is equally likely.

    Distribution (ii) - three quarters of infected people shed for between two and seven days duration and each duration is equally likely, plus a quarter of infected people may shed for longer periods up to 7 weeks. The probability of shedding for a period longer than a week decreases with increasing shedding period.

d. Only one person is assumed to shed into an onsite system at a given time and each systems is equally likely to be utilised by an infected person.

The simulation was coded using the R statistical package (R Core team 2012) and



results were obtained for 1000 one-year iterations to ensure convergence of simulation estimates.

Figure 2 Estimated number of onsite systems likely to have pathogen present on a day given pathogen survival time in the tank, and short and long shedding period scenarios. Bars represent the 95th percentile interval from simulations.

Figure 2 shows the estimated number of onsite systems in Darfield that could contain the pathogen on any given day, given different survival periods for the pathogen once entering the onsite system. The point estimates in the figure are the median number of contaminated systems on a given day from the simulations and the bars represent the estimated range of possible numbers of contaminated tanks on a day (95th percentile interval of simulation estimates). This estimate does not indicate the amount of pathogen that may be in an associated sewage sample, the probability of coming into contact with the sewage or the resultant risk to public health.

Figure 2 shows that with a maximum shedding period by infected cases of up to seven weeks, and long-term pathogen survival, less than 2 percent of the domestic onsite systems in Darfield contain *Campylobacter* each day. There are 747 occupied dwellings in Darfield (Stats NZ 2014), each is assumed to have one onsite system.

An estimate of the survival of *Campylobacter* in the sewage is available from an ESR study of microbial survival in sediment and the water column containing dilute sewage (results unpublished). The study found that the *Campylobacter* concentration decayed faster than that of the indicator bacteria and phage studied. The T_{90} value[35] obtained from the study for *Campylobacter* was 5.2 days. This value will probably be greater in undiluted sewage as the oxygen concentration in raw sewage, which will be lower than that in the study, will be more conducive to *Campylobacter's* survival. With a T_{90} value of 5.2 days, 14 days in the tank (the

[35] T_{90} is the time taken for a microbial population to decay to 90% of its initial concentration.

longest period given in Figure 2) equates to an approximately 2.7 log reduction in the *Campylobacter* concentration.

This simulation is based on a single bacterial pathogen with the properties described. The population of Darfield could also be infected with other pathogens (bacteria, viruses or protozoa), which could be shed into onsite systems.