RE-ASSESSMENT OF THE RISKS OF PROTOZOA IN NEW ZEALAND'S NATURAL WATERS

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ABSTRACT

The publication of the 1995 and 2000 editions of the Drinking Water Standards New Zealand (DWSNZ) expanded the focus of drinking water treatment onto the risks of protozoa. A large portion of the costs of the upgrading work on New Zealand's treatment plants since then has been in response to the addition of the protozoal requirements.

National baseline monitoring for protozoa in our natural waters has been going on since 2009, funded by the Ministry of Health and undertaken by Massey University. Over an 8.25 year period 28 sites across New Zealand were tested, including representative groundwater wells and springs, bush catchments, intermediate rivers and lowland rivers. The results show that:

- None of the samples collected from shallow groundwater/spring sites have contained protozoa although 8% of samples contained *E. coli*. These sites were deliberately selected because they were shallow or not secure, and had a history of occasionally containing *E. coli.*
- Less than 3% of bush catchment samples and less than 5% of intermediate river samples contained protozoa.
- No supplies sourcing water from lowland rivers would be required to achieve more than 3-log removal of *Cryptosporidium* oocysts for protozoal compliance.

The Catchment Risk Categorisation approach in DWSNZ (for supplies serving up to a population of 10,000) requires that shallow groundwater/spring sources need to achieve 3 log credits, intermediate river samples need to achieve 3 or 4 log credits, and lowland rivers need to achieve 4 log credits. Although DWSNZ allows for a water supplier to collect and analyse 26 samples over the course of a year to determine their source's specific protozoal risk, the $25,000 cost of this alternative approach can be a significant barrier for smaller water suppliers. The eight years of protozoal monitoring is showing that by using the Catchment Risk Categorisation approach, the risks of protozoa in a source water are likely to be overstated, particularly in groundwater.

The paper presents the results of the New Zealand monitoring for protozoa, considers this in the context of what has been found in the USA and elsewhere, discusses international legislative and best practice requirements and offers some provisional guidance on whether DWSNZ is too conservative. With DWSNZ likely to be revised as an outcome of the Havelock North Drinking Water Inquiry, this paper helps inform that revision process and may thereby reduce upgrading costs for smaller water supplies - particularly those that have groundwater as their source.

KEYWORDS

Drinking water, protozoa, source water, DWSNZ

PRESENTER PROFILE

Kathryn Jessamine is an environmental engineer with nine years of experience in the water industry in New Zealand, the United Kingdom and Canada. She also has a post-graduate diploma in public health and is particularly interested in the ways in which health, engineering and the environment are inextricably linked.

1 INTRODUCTION

Protozoa are a class of parasitic microorganism commonly found in surface waterways in New Zealand (Government Inquiry into Havelock North Drinking Water, 2017) and globally (US Environmental Protection Agency, 2002). Exposure to protozoa such as *Giardia* and *Cryptosporidium* can cause illness even in healthy individuals, usually acute gastrointestinal illness lasting two or more weeks (US Environmental Protection Agency, 2002; Ministry of Health, 2017). Exposure generally occurs from consuming food or water contaminated with protozoan oocysts originating from animal or human faecal matter. *Giardia* and *Cryptosporidium* are endemic in livestock, birds and domestic and feral animals in New Zealand (Government Inquiry into Havelock North Drinking Water, 2017) and diseases associated with these organisms are globally recognised as among the most common waterborne diseases (US Environmental Protection Agency, 2002). Due to the nature of gastrointestinal illness, many people do not seek medical attention and therefore a significant proportion of cases go unreported or unidentified (Ball, 2006).

Protozoa present a particularly difficult risk for water supplies because they can be infectious even at low levels of contamination. Only a single organism can cause illness (Boak & Packman, 2001; Bouchier, 1998). Oocysts can survive in adverse conditions (including anaerobic conditions), are resistant to conventional disinfection methods such as chlorination, are difficult to detect at such low concentrations, and are not well indicated by other indicator microorganisms (Craun, et al., 1998; Moulton-Hancock, et al., 2000; Bouchier, 1998; Rose, et al., 1991; Government Inquiry into Havelock North Drinking Water, 2017; Khaldi, et al., 2011). Oocyst viability in cold water or soil is estimated to be months or as much as a year (Dworkin, et al., 1996; Bouchier, 1998; Schmoll, et al., 2006).

The publication of the 1995 and 2000 editions of Drinking Water Standards New Zealand (DWSNZ) shifted the focus of drinking water treatment onto the risks of protozoa as a potential cause of illness. A large portion of the costs of the upgrading work on New Zealand's treatment plants since then has been in response to the addition of the protozoal requirements. Despite this, in 2016-2017, only 83.1% of the New Zealand population on networked drinking water supplies serving greater than 100 people were receiving drinking water that complied with the protozoa requirements of DWSNZ. Achievement against these requirements is more difficult for smaller water supplies, and this is reflected by lower compliance rates for water supplies serving 5,000 or fewer people (Ministry of Health, 2018).

Protozoa are generally considered to be a surface water problem because the filtering action of soil provides protection for groundwater sources (Boak & Packman, 2001; Schmoll, et al., 2006; Merkle & Macler, 2000; Howard, et al., 2006). This lowered risk for groundwater is acknowledged in the DWSNZ (Ministry of Health, 2018). However, Stage 2 of the Havelock North Drinking Water Enquiry reported that "*there is a wide body of* *evidence in the literature that Cryptosporidium outbreaks associated with groundwater supplies can and do occur*" (Government Inquiry into Havelock North Drinking Water, 2017). Monitoring of New Zealand's groundwater sources has yet to find evidence of protozoan contamination, and it may be that the current requirements for addressing the risks of protozoan contamination of drinking water in some groundwaters are overly onerous.

2 MONITORING OF AQUATIC PROTOZOA IN NEW ZEALAND

National baseline monitoring for protozoa in New Zealand's natural waters has been going on since 2009, funded by the Ministry of Health and undertaken by Massey University. Up to the end of March 2018 a total of 660 quarterly samples had been collected from 28 sites across New Zealand. The sites include representative groundwater bores and springs, bush catchments, intermediate rivers and lowland rivers. The results of this monitoring are summarised in Table 1 below.

Table 1: Summary of Massey University Protozoa Monitoring 2009-2018

Catchment Type	**Number of Sites as of 2018**	**% Samples Containing *Cryptosporidium***	**% Samples Containing *Giardia***
Groundwater/springs	8	0%	0%
Bush Catchments	No longer monitored[i]	1%	3%
Intermediate Rivers	7	1%	5%
Lowland Rivers	5	43%	59%

Analysis of the results shows that:

- None of the samples collected from shallow groundwater/spring sites have contained protozoa although 8% of samples contained *E. coli*. These sites were deliberately selected because they were shallow or not secure, and had a history of occasionally containing *E. coli.*
- Although over 80% of samples from bush catchments and intermediate rivers contained *E. coli*, less than 3% of bush catchment samples and less than 5% of intermediate river samples contained protozoa.
- Although 43% of lowland river samples contained *Cryptosporidium* and 59% contained *Giardia*, no supplies sourcing water from lowland rivers would be required to achieve more than 3-log removal of *Cryptosporidium* oocysts for protozoal compliance.

In 8.25 years of monitoring, no protozoa have been found in groundwater/springs and very few samples from bush catchments or intermediate rivers have contained protozoa. Even though *Cryptosporidium* was found more frequently in lowland rivers, the concentrations of oocysts were less than 2.5 oocysts per 100mL, and were not high enough to require greater than 3 log removal. Most of the *Cryptosporidium* oocysts were found in autumn and spring.

We note that the samples are only taken quarterly and therefore, on the face of it, do not provide the same rigour of characterisation as the fortnightly sampling required in DWSNZ.

However, for those sources which have been in the sampling programme for the full 8.25 years, 33 samples have been taken, in excess of the 26 required by DWSNZ.

Under the current DWSNZ, non-secure groundwater/springs would require 2-5 log removal for protozoa depending on the surrounding catchment characteristics. However, this monitoring indicates that this may be overly conservative since no protozoa have actually been found in New Zealand groundwater/springs in eight years. The remainder of this paper focuses on the risks of protozoa contamination of groundwater.

3 MANAGING PROTOZOA IN GROUNDWATER

Groundwater is widely used as a drinking water source internationally, as it is considered to be of *"generally good microbial quality in its natural state"* (Schmoll, et al., 2006). In the UK, 28% of drinking water comes from groundwater sources (Schmoll, et al., 2006) and in the USA, groundwater is commonly used for smaller water supplies and is often untreated (Macler, 1996; Murphy, et al., 2016; Schmoll, et al., 2006; Wallender, et al., 2014). In New Zealand, groundwater is a relatively common source of drinking water, with an estimated 45% of networked supplies serving more than 25 people having a groundwater source.

There is an argument that protozoa should not occur in 'true' groundwaters because their relatively large size (compared to bacteria and viruses) enables them to be entrapped within the layers of soil (Merkle & Macler, 2000; Ministry of Health, 2018). However, several recent reports acknowledge that contamination can and does occur (Bouchier, 1998; Schmoll, et al., 2006). Groundwater is sometimes referred to as the 'hidden sea' because the pollution pathways and processes are not visible, and are subsequently less well understood (Schmoll, et al., 2006).

3.1 NEW ZEALAND'S LEGISLATIVE REQUIREMENTS

In New Zealand the drinking water system is administered by the Ministry of Health primarily through the Health Act (1956) and DWSNZ. Following the Government Inquiry into the Havelock North drinking water contamination event, many aspects of the DWSNZ are under review.

Currently under the DWSNZ, protozoa are considered a priority 1 determinand and treatment is required for all water sources covered by the DWSNZ except for secure bore water. Bore water is considered secure if it can be demonstrated that contamination by pathogenic organisms is unlikely, including demonstrating that the source is not directly affected by surface or climatic influences through proving the age of water in the aquifer (greater than one year) or that the chemical composition of the water is stable. The bore itself must be satisfactorily constructed and sampling of water must prove absence of *E. coli* contamination (Ministry of Health, 2008).

For all other water sources (including non-secure groundwaters) compliance with the protozoa criteria is achieved when *"the treatment process used meets specified performance requirements"* (Ministry of Health, 2008). The minimum level of treatment required for groundwaters is 2 log removal for protozoa. The default log credit requirements are based on catchment type and are summarised for groundwaters in Table 2 (Ministry of Health, 2008).

Table 2: Default DWSNZ Protozoa Risk Assignment by Groundwater Type

Type of Groundwater	Log Credits Required
Springs and non-secure bore water 0 to 10 m deep are treated as requiring the same log credit as the surface water in the overlying catchment	3-5
Bore water drawn from an unconfined aquifer 10 to 30 m deep	3
Bore water drawn from deeper than 30 m	2
Secure, interim secure, and provisionally secure bore water	0

Alternatively, waters suppliers can collect and analyse 26 samples over the course of a year to determine their source's specific protozoal risk, however the $25,000 cost of this is a significant barrier for smaller water suppliers.

The Health Act also requires water supplies providing drinking water to more than 500 people to develop and maintain a water safety plan. A water safety plan is intended to describe the management of the water supply using quality assurance and risk management principles and to cover all aspects of the supply including source water issues, potential contaminant sources and pathways, and actions to be taken in the event of monitoring transgressions or treatment failures.

The DWSNZ relate to the performance of water supply systems, and does not contain specific requirements for the siting and security of bores, however extensive guidance is provided in the Guidelines (Ministry of Health, 2018).

3.2 INTERNATIONAL BEST PRACTICE

The requirements for addressing the risk of protozoa contamination in DWSNZ have largely been based on the US Environmental Protection Agency's (EPA) Surface Water Treatment Rule (1989), Long Term 2 Enhanced Surface Water Treatment Rule (2006) and Groundwater Treatment Rule (2006) because of the extensive work done in the USA in quantifying and investigating drinking water risk. The World Health Organisation (WHO) also provides guidance on the risks of protozoa in groundwater, and the concept of Water Safety Plans was adopted in New Zealand (as Public Health Risk Management Plans) prior to the release of the WHO Guidance. Elsewhere, many countries have been working on best practice guidelines for managing risks, including in the UK.

3.2.1 USA

In the USA the EPA considers the presence of protozoa in groundwater to indicate the risk of surface water contamination. Consequently, the EPA's Groundwater Rule does not include requirements for testing or treating for protozoa. Under the Groundwater Rule, limestone (karst), fractured bedrock and gravel aquifers are defined as 'sensitive' (US Environmental Protection Agency, 2006), and for these sources, the State must prove the presence of a hydrogeological barrier e.g. confining layer or carry out faecal indicator source water monitoring to retain 'true' groundwater status (Schmoll, et al., 2006).

Groundwaters not able to meet the Groundwater Rule requirements are covered by the Surface Water Treatment Rule (SWTR), and are referred to as groundwater under direct influence (GWUDI). The SWTR defines GWUDI as "*any water beneath the surface of the ground with* (Department of Health Drinking Water Section, 2005)*:*

1. *"significant occurrence of insects or other microorganisms, algae or large-diameter pathogens such as Giardia, or*
2. *significant and relatively rapid shifts in water characteristics such as temperature, conductivity, turbidity, or pH which correlate closely with climatological change or surface water conditions."*

This definition implies that the groundwater source is located close enough to a surface water source that it can receive direct surface water recharge and is therefore at risk of contamination from protozoa which are not normally found in 'true' groundwaters.

Each State is responsible for determining the conditions that signify GWUDI. Two examples of the approach taken by States, from Connecticut and Ohio, are summarised below. Connecticut carries out a preliminary assessment to determine if a groundwater source is potentially GWUDI (Department of Health Drinking Water Section, 2005). The assessment considers:

- Distance from surface water sources
- History of disease outbreaks
- Monitoring history for indicator organisms
- Turbidity
- Construction of bore

If an existing or new groundwater source fails to meet any of the criteria in the preliminary assessment, it is considered to potentially be under the influence of surface water. That source must then carry out further testing to prove that it is not GWUDI, carry out remedial works so that the preliminary assessment criteria are met, or provide treatment in accordance with the SWTR.

Ohio determined that a "*standard, but flexible*" approach to determining the potential of aquifer contamination is best. The resultant prescriptive process is designed to promote uniform application across all sites (Ohio EPA, 2014). The risk assessment process is triggered by positive *E. coli* results or persistent total coliforms in existing groundwater wells or in new well approval samples. A Hydrogeologic Sensitivity Assessment (HSA) is then carried out. If required, the HSA may recommend that further investigation, in the form of an Assessment Source Water Monitoring (ASWM) is carried out.

The HSA is a risk assessment process, that produces a "*relative ranking of the source water sensitivity to pathogen contamination*" (Ohio EPA, 2014). The HSA assigns positive or negative scores based on the hydrogeologic barriers and recharge pathways identified at the supply site. This produces a 'barrier index' which provides a relative measure of the risk of contamination at that site. The HSA scores for the following criteria:

- Source water susceptibility
- Vadose zone characteristics
- Saturated zone characteristics
- Aquifer characteristics
- Potential for induced recharge
- Well construction

Based on the barrier index, a source is classified as 'pathogen sensitive', 'Intermediate Sensitivity' or "Pathogen Non-Sensitive". This classification then guides how the source catchment should be managed.

3.2.2 WORLD HEALTH ORGANISATION

The World Health Organisation has a Framework for Safe Drinking-Water based on three key requirements (Schmoll, et al., 2006):

- Health based targets based on an evaluation of health concerns
- Development of a Water Safety Plan
- A system of independent surveillance that verifies that the system is operation properly

Water Safety Plans are considered a means of "*comprehensive risk assessment and risk management….that encompasses all steps in the water supply from catchment to consumer*" (World Health Organisation, 2017). There are three key components of a water safety plan:

- System assessment to determine if the water supply can deliver water of a quality (and quantity) that meets targets
- Identifying operational control measures to identify changes in water quality
- Management and communication plans

Specific to the risks of protozoa in groundwater, WHO guidance recognises that groundwater is often of good microbial quality but the potential for contamination exists if the protective measures provided by natural filtering mechanisms of the soil are short circuited (above or below ground), and that contamination is more widespread than previously believed (Schmoll, et al., 2006; World Health Organisation, 2017). However, the WHO guidance also acknowledges that although a *"significant percentage of groundwater sources are contaminated"*, bacteria and viruses are the main agents of contamination and recognises that *"in developed countries…viruses can be regarded as the most critical microorganisms with respect to groundwater contamination and health risks"* (Schmoll, et al., 2006).

Shallow groundwater is assumed to be at the greatest risk of contamination because of the potential for it to be under direct influence of surface water, and treatment is generally for these sources is recommended. Deeper and confined aquifers are regarded as being at lesser risk of contamination and are generally considered to be well protected from contamination without treatment (World Health Organisation, 2017).

The WHO also provides extensive guidance on assessing the potential for groundwater contamination and managing agricultural, social and industrial sources of pollution. The guidance is intended to indicate the scope and scale of assessment, rather than technical guidance. The WHO promotes the use of water safety plans, groundwater protection zones and sanitary surveys as tools to protect groundwater sources.

3.2.3 ELSEWHERE

Suggested best practice management for contamination of groundwater is similar to that provided in Guidelines (Ministry of Health, 2018) and generally includes the following aspects (Merkle & Macler, 2000; Wallender, et al., 2014):

- Source water protection barriers (e.g. location in relation to surface water and sewage sources)
- Well and water system integrity barriers
- Septic system design and maintenance
- Operations and system maintenance barriers
- Disinfection requirements.

Some larger water suppliers have established protocols for assessing the risk of protozoan contamination in groundwater supplies. At Southern Water in the UK, the risk assessment procedure identifies ten key factors for protozoan contamination (Boak & Packman, 2001). For each factor, the appropriate risk level for a particular supply is selected from a hierarchy which gives a score for each factor. Each factor is weighted slightly differently to produce a final overall risk score. The ten key factors are:

- Land use (intensity of livestock)
- Sewers and septic tanks (intensity)
- Geology/hydrogeology (aquifer type and cover)
- Potential for rapid bypass of aquifer unsaturated zone
- Potential for induced recharge from surface water bodies
- Site drainage
- Borehole construction/integrity
- Headworks
- Historic water quality
- Treatment level

The final risk score allows the sources to be prioritised (high, medium and low) and is used to determine which sources should have continuous Cryptosporidium monitoring and for more detailed investigation and, if required, remedial action should take place.

4 OUTBREAKS OF WATERBORNE PROTOZOAN ILLNESS

Outbreaks of waterborne, protozoan illness in New Zealand are relatively common, however there is insufficient information available to be able link these outbreaks with groundwater supplies. Overseas there are a number of reported outbreaks of cryptosporidiosis and giardiasis associated with groundwater supplies, however many of these have clear system and/or hydrogeological shortfalls that have led to contamination of the source.

Factors contributing to potential for contamination of groundwater have been identified in the literature. Several of these have been identified as likely causes of contamination in outbreak reports. The main contamination factors are listed below, and generally match with the management best practices discussed earlier (Macler, 1996; Bouchier, 1998; Hynds, et al., 2014; Ministry of Health, 2018):

- Quality of bore construction
- Proximity to contamination sources e.g. septic tanks, livestock
- Security of bore heads (poorly constructed bores three times more likely to have protozoan contamination (Hynds, et al., 2014))
- Hydrogeologic conditions including karst or fissure-dominated flow conditions, connections to river aquifers, shallow vadose zone, shallow aquifer depth
- Proximity to surface water
- Heavy rainfall events

Several studies have shown that attack rates for waterborne protozoan illness are often higher in communities with groundwater supplies compared to communities with surface water supplies (Frost, et al., 1997; Craun, et al., 1998; Wallender, et al., 2014). This may be due to endemic presence of protozoa in surface waters leading to a certain level of resistance amongst individuals who regularly consume that water. In contrast, in groundwater supplies, contamination is more of a transient event, and those drinking the contaminated water do not have a tolerance and are therefore more susceptible to developing illness as a result of the contamination.

4.1 NEW ZEALAND

Giardiasis and cryptosporidiosis are notifiable diseases in New Zealand and the numbers of outbreaks in New Zealand are reported on each year. In 2014, 2015 and 2016 (the latest three years where information is available), *Giardia* and *Cryptosporidium* were the top two causes of waterborne disease outbreaks in New Zealand (by number of outbreaks), as summarised in Table 3 (ESR, 2018; ESR, 2016; ESR, 2015). However, there is insufficient information to be able to attribute the outbreaks to a specific type of water (surface or ground) supply.

Table 3: Waterborne Protozoa Outbreaks in New Zealand

Year	2014	2015	2016
Number of Giardiasis and Cryptosporidiosis outbreaks	33	12	8
Total number waterborne outbreaks	42	19	14
Number of notified cases of Giardiasis and Cryptosporidiosis	103	73	25
Total number of notified cases of waterborne illness	131	89	1007[ii]

The following is a list of historic outbreaks of waterborne illness caused by protozoa (Ball, 2006; Ministry for the Environment, 2007). Only one, at Peketa in 1996, is known to have had a groundwater source. For the remaining outbreaks, the source of drinking water is surface water or unknown.

- Dunedin, 1987-1988: Increased risk of giardiasis in micro-strained part of water supply compared with sand-filtered part in a surface water supply (Fraser & Cooke, 1991).
- Whangarei, 1990: increased incidence of giardiasis in the part of the city with unfiltered water
- Auckland, 1993: 34 cases of giardiasis.
- Tauranga, 1995: one notification of cryptosporidiosis at a school.
- Denniston, 1996: four cases of giardiasis in an unregistered, untreated, unprotected water supply
- Peketa (Kaikoura District), 1996: three cases of giardiasis, groundwater supply reported to be discoloured and faecal coliforms detected.
- Waikato (Ohinemuri, Morrinsville), 1996/97: 14 cases of giardiasis.
- Waikato district 1997: 170 cases of cryptosporidiosis. Associated with turbidity spikes in water supply originating from filter backwash and/or backflow from farms. No oocysts or faecal coliforms detected.
- Tauranga district, 1997: cryptosporidiosis from bore water source but illness associated with contamination of open storage tank
- Masterton, 2003: *Cryptosporidium* detected in water supply, but no cases of disease.

4.2 OVERSEAS

A review of international literature found a number of reported outbreaks of giardiasis and cryptosporidiosis associated with groundwater supplies. These are listed in Appendix A. In many of the outbreaks reported, it was either not possible to identify the relative security of the groundwater source from the information available or there was an easily identifiable route of contamination, generally because of poor bore construction or contamination from surface water. Many of the types of groundwater sources involved in the outbreaks, e.g. those with adits (infiltration galleries) (Bouchier, 1998) would be discouraged from use in New Zealand. In the USA, many outbreaks associated with protozoa in (assumed secure) groundwater supplies were later found to be under the influence of surface water (US Environmental Protection Agency, 2006). A study in Norway did not find protozoa to be the cause of any outbreaks associated with groundwater between 1984 and 2007 (Kvitsand & Fiksdal, 2010).

Many groundwater supplies are untreated, and several of the outbreak studies focused on untreated groundwater supplies. However, outbreaks were also reported in groundwater supplies with treatment, suggesting that poor aquifer management and bore security, rather than simply a lack of treatment, are significant factors in protecting groundwater supplies from protozoan contamination.

5 MONITORING OF PROTOZOA IN GROUNDWATER

Although monitoring of non-secure groundwater in New Zealand has not yet found protozoa, they have been found in the USA, the UK and elsewhere.

In general, the quality of monitoring data is limited unless details of the hydrogeological and bore construction conditions are known and can be linked directly to the number of samples testing positive for protozoa. In many cases this information is not available. Other sources have also noted that although they are aware of protozoa monitoring programmes, the data is not always published or available (Merkle & Macler, 2000). It may be that the monitoring data available is subject to publication bias where only those studies obtaining positive results (that being the unusual or unexpected result) making it to publication.

Monitoring results are also influenced by the sample methodology, sample volume (Boak & Packman, 2001) and testing methods. Some studies have found that protozoa counts are seasonal (Rose, et al., 1991; Gallas-Lindemann, et al., 2013; Ministry of Health, 2018), and others that protozoa is more likely to be found under continuous pumping conditions or with increased sampling frequencies (Khaldi, et al., 2011; Bouchier, 1998).

5.1 NEW ZEALAND

The results of the ongoing monitoring by Massey University for the Ministry of Health show that none of the 160 samples collected from eight shallow groundwater/spring sites over the last eight years have contained protozoa. These sites were deliberately selected because they were shallow or not secure, and had a history of occasionally containing *E. coli*. Details of the eight groundwater/spring sites are summarised in Table 4.

Table 4: Summary of Groundwater Monitoring Sites in Massey Study

Site number	Description
1	Fed by two springs in high-productivity pastoral area Depth <10 m at well head
2	Natural spring. Depth <10 m
3	Bore (not secure) in urban area. Depth 20 to 40 m
4	Bore in high-productivity pastoral area. Depth <10 m
5*	Spring: 3500 m3/d.
6*	Spring: 3300 m3/d.
7*	Well
8*	Rural bore

* Sites 5-8 added to study in September 2016

Earlier testing in 2008-2009 by Massey University for the Ministry of Health found no protozoa in 65 samples taken from seven shallow bores. Individual water suppliers have also been monitoring bores for protozoa and provided results to the Ministry of Health. A further 759 samples were collected from 29 non-secure bores around New Zealand did not find protozoa. Recent testing in Hastings (following the Havelock North outbreak) took 382 samples from 7 bores and did not find any protozoa.

A summary of all the available New Zealand monitoring data is provided in Table 5. No protozoa have been found in more than 1,366 samples taken from 51 non-secure and secure bores in New Zealand in the period 2005-2018.

Table 5: Summary of New Zealand Groundwater Protozoa Monitoring

Study	Number of Samples	Number of Sites
Massey 2009-2018 (ongoing)	160	8
Massey 2008-2009	65	7
Water Supplier Monitoring 2005-2018	759	29
Hastings 2016-2018	382	7
Total	1,366	51

5.2 OVERSEAS

A literature search for international monitoring for protozoa in groundwater found 15 studies and one pooled analysis across nine countries in North America and Europe. The results of these studies are summarised in Appendix B.

Of the 15 studies found, only two reported not finding protozoa in the groundwater samples tested. In the pooled analysis, *Cryptosporidium* was found in 6 out of 9 studies and *Giardia* in 3 out of 10 studies. Eleven of the 14 studies contained sufficient information to estimate the number of samples that tested positive for *Giardia* or *Cryptosporidium*. Out of 507 groundwater samples taken, 73 tested positive for either *Giardia*, *Cryptosporidium*, or both[iii].

Some of the studies compared contamination in different types of groundwater. Unsurprisingly, infiltration galleries were found to be more likely to be contaminated than springs, with vertical wells least likely to be contaminated (Moulton-Hancock, et al., 2000, Hibler 1988 in Hancock, et al., 1998).

6 CONTAMINATION PATHWAYS

Although groundwater has previously been considered a 'safe' source of drinking water free from protozoa, recent literature has begun to highlight the potential risks of protozoan contamination of groundwater. There is growing recognition that *"not all groundwater is of consistently high quality"* and that there is possibility for rapid contamination of groundwater from surface water sources, especially after rainfall recharge (Bouchier, 1998). The previous sections have demonstrated that protozoan contamination of groundwater is occurring, and this section outlines the potential pathways through which contamination may be happening.

The structure of the aquifer and the soil layers above it affects how water and contaminants (including protozoa) are transported. The depth to water table and soil moisture are important factors in the ability of soil above the aquifer to provide a barrier to contamination by filtering out microorganisms. In aquifers with shallow cover, there is a shorter distance over which straining can occur, and soil moisture facilitates movement of contaminants as well as limiting adsorption in the soil. The ability of a soil matrix to filter out protozoa depends on the relative size of the oocysts to the pores. Entrapment of pathogens is most effective in the upper soil layers due to predatory organisms, competition from established microbial communities and sunlight and up to 99% of *Cryptosporidium* oocysts are retained in the upper soil layers (Schmoll, et al., 2006). This straining mechanism can be bypassed, for example by sewers located below the soil zone. Shallow groundwater sources are more likely to be impacted by heavy rainfall, due to direct surface water contamination and mobilisation of organisms in the unsaturated zone by water percolating. (Schmoll, et al., 2006).

The characteristics of the aquifer also influence the potential for protozoan contamination. In dual porosity type aquifers, water is mainly stored in interstices in the rock matrix, with flows occurring through fractures which are much larger than oocysts. Evidence suggests that these type of aquifers (fractured rock and karst with limited unconsolidated soil overlayers) allow protozoan contamination despite not being influenced by surface water (Merkle & Macler, 2000). Other aquifers are granular and these may provide improved straining of contaminants depending on pore size (Morris & Foster, 2000). Figure 1 shows that *Cryptosporidium* oocysts are larger than the typical 1μm pore size of chalk aquifers, but within the pore size range for other aquifer types e.g. sandstone (Bouchier, 1998).

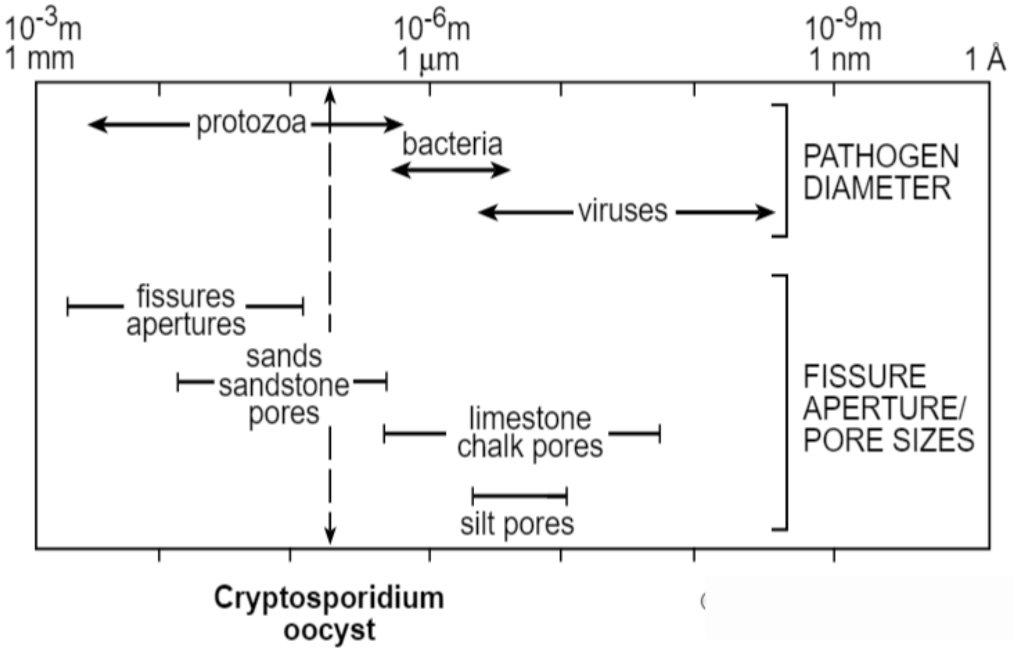

Figure 1: Pathogen diameters compared to aquifer matrix dimensions (taken from ARGOSS, 2001; British Geological Survey ©NERC in Schmoll, et al., 2006)

Aquifer vulnerability can be classified based on the level of confinement, aquifer attenuation ability and the travel time to the saturation zone. The residence time in aquifers can also be a barrier for contamination (if it exceeds the expected lifespan of an oocyst). In karstic aquifers the residence time is only weeks to months, whereas in sedimentary and deep aquifers the residence time is measured in years. The distance to the contamination source is also important. Contaminants can be transported long distances in karst or, highly fractured aquifers, but for other types of aquifer, the distance is limited to tens or hundreds of metres depending on the specific hydrogeology (Schmoll, et al., 2006).

7 DISCUSSION AND CONCLUSIONS

The Havelock North Drinking Water Inquiry has focused attention on the vulnerability of groundwater and bores to microbial contamination. Eight years of monitoring of non-secure groundwater in New Zealand has not found any evidence of protozoan contamination, and suggests that the treatment requirements in New Zealand may be too conservative.

Internationally, outbreaks of waterborne protozoan illness and positive results for protozoa in groundwaters are being reported. However, from the information available, often the presence of protozoa in groundwater can be attributed to contamination occurring due to unfavourable hydrogeological conditions, or poor bore security and/or construction. Some of the geological conditions known to have the higher risks of contamination e.g. karst aquifers, are uncommon in New Zealand[iv]. International best practice uses the presence/absence of protozoa as an indication if a groundwater source is at risk of contamination from surface water, but the New Zealand data shows that even though E. coli was present in 8% of samples no protozoa were found

Currently the DWSNZ requires all non-secure groundwater supplies to provide treatment for protozoa (except for supplies serving up to 500 people who choose Section 10 compliance). This is particularly problematic for small water suppliers as even if they spend money to carry out testing and prove their source is at a reduced risk, a minimum of 2-log removal for protozoa is still required. The monitoring carried out to date suggests that these non-secure groundwater supplies in New Zealand may not be at risk of protozoan contamination. The WHO suggests that, based on their small size and longevity in the environment, viruses have the highest potential to be transported to and within groundwater and that bacteria and viruses should be the microbiological contaminants of priority for groundwater supplies (Schmoll, et al., 2006).

As a result of the Havelock North Drinking Water Inquiry, many aspects of the current drinking water system are being examined and with the expected changes to the DWSNZ there is a window of opportunity to make changes. At the time of writing, the Ministry of Health has already convened working groups to discuss, amongst a variety of other issues, the relative risks of protozoa in groundwater. The DWSNZ should balance the need to protect the health of New Zealanders against risks and costs, and identify priority microbiological contaminants. Based on the information presented in this paper, it would appear that the requirements for the control of protozoal risk as categorised in the current DWSNZ do not reflect the actual presence of this organism in New Zealand groundwater and should be managed with lower default controls compared to bacteria and viruses, which should continue to be areas of focus. In order to support this there are two recommended courses of action:

- Review US State guidance on determining risk of groundwater contamination
- Investigations into the transportation and entrapment of protozoa in New Zealand aquifers

The authors also recommend that the value of continuing the current protozoan monitoring programme should be re-assessed in the light of the results to date and the findings of this paper.

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[i] Previously seven sites were monitored. None had protozoa numbers high enough to require greater than 3-log removal

[ii] In 2016 there were a large number of notified cases due to a large outbreak of campylobacter in Havelock North

[iii] This is an estimate only as it was not always possible to determine whether positive results occurred simultaneously or separately for *Cryptosporidium* and *Giardia*

[iv] Information about aquifers in New Zealand can be found at https://data.mfe.govt.nz/layer/52675-location-and-extent-of-nzs-aquifers-2015/data/

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APPENDIX A – SUMMARY OF INTERNATIONAL OUTBREAKS OF WATERBORNE PROTOZOAN ILLNESS

Location	**Time**	**Outbreak details**	**Hydrogeological details**	**Contamination pathway**
Unknown - could be UK and/or USA	Unknown	5 of 11 cryptosporidiosis outbreaks (Lisle and Rose 1995 in Hancock, et al., 1998)	Groundwater or springs	Not detailed
USA	Unknown	33% of the 12 most recent waterborne outbreaks of cryptosporidiosis (Hancock, et al., 1997 in Morris & Foster, 2000)	Groundwater wells	Not detailed
North Thames, UK	1997	1 outbreak with 345 confirmed cases of cryptosporidiosis (Willocks, et al., 1998)	Deep chalk wells in a semi-rural area close to river	Suspect ingress through chalk interstices or surface water contamination through a bore fault. Unusual weather conditions (dry followed by rain)
USA	1971-2008 1971-2011	14 of 248 outbreaks associated with untreated groundwater were caused by *Giardia* (240 of 23,478 cases) (Wallender, et al., 2014) 13.3% of waterborne disease outbreaks caused by *Giardia* however in the more recent period 1990-2011 this has risen to 33.3% (Adam, et al., 2016)	Untreated groundwater (includes GWUDI)	Not detailed These two studies may use the same CDC data set
Washington State, USA	1994	1 outbreak (Dworkin, et al., 1996)	Two deep wells	Suspected contamination from adjacent treated effluent irrigation system due to poor condition of well and poor condition of irrigation system

Warrington, UK	1992-1993	1 outbreak with 47 reported cases (Bridgman, et al., 1995)	Sandstone aquifer with shallow cover. Deep vertical wells	Subsidence and fissures provide route for ingress of surface water. One of the wells also found to drain a nearby field
England, UK	1990-1998	11 suspected *Cryptosporidium* groundwater contamination events (Bouchier, 1998)	Wells and springs in a range of aquifer types including river gravels, sandstone, chalk and karstic limestone	Surface water contamination noted as possible contamination route for many
Texas, USA	1998	One outbreak of cryptosporidiosis with 89 confirmed and 1300-1500 unconfirmed cases (Bergmire-Sweat, et al., 1999 in Howard, et al., 2006)	Deep wells (>30m) in a karst aquifer. Wells located 400m from creek	Not detailed.
Pennsylvania, USA	1993	551 cases of cryptosporidiosis (Moore, et al., 1993 in US Environmental Protection Agency, 2006)	Karst aquifer	Not detailed.
Norway	1984 – 2007	None out of 102 outbreaks were associated with protozoa (Kvitsand & Fiksdal, 2010)	Various groundwater	Not applicable

APPENDIX B – SUMMARY OF INTERNATIONAL MONITORING OF PROTOZOA IN GROUNDWATER

Entries in bold have been included in the sample summary presented in Section 5.

Location	Findings	Comments
20 states in the USA	19 of 166 groundwater sites tested positive for *Giardia* and/or *Cryptosporidium* (Moulton-Hancock, et al., 2000): • 211 samples from 121 vertical wells. 5% sites positive • 48 samples from 31 springs. 23% sites positive • 80 samples from 10 horizontal wells. 40% sites positive • 44 samples from 4 infiltration galleries. 50% sites positive	Number of positive samples not provided (only sites) Note some of the data from this study may be included in the Hynds pooled analysis
17 states in the USA	• **1 of 18 groundwater sources positive for *Giardia*** (Hancock, et al., 1998) • **6 of 7 spring samples positive for *Cryptosporidium*** (Rose, et al., 1991) • **0 of 7 spring samples positive for *Giardia*** (Rose, et al., 1991)	**No further details available**
USA	17 of 74 wells tested positive for *Cryptosporidium* (Hancock, et al., 1997 in Morris & Foster, 2000)	No further details, including number of samples available
Ohio, USA	16 samples from 16 wells did not find protozoa (Fong, et al., 2007)	No further details available
Washington State, USA	**1 of 2 samples from 2 wells tested positive for *Cryptosporidium*** (Dworkin, et al., 1996)	**Deep Wells (150m and 180m) adjacent to wastewater irrigation system** **Note this study is included in the Hynds pooled analysis**
USA and Canada	*Cryptosporidium* found in 6 of 9 studies *Giardia* founds in 3 of 10 studies (Hynds, et al., 2014)	Karstified, unconsolidated, fractured bedrock, un-fractured bedrock and diverse. Limited information available to be able to link studies to number of samples or groundwater type

Unknown (possibly Canada)	• 5 of 36 springs and • 2 or 40 wells and • 5 of 16 infiltration galleries Tested positive for *Giardia* (Hibler 1988 in Hancock, et al., 1998)	Number of samples unknown Note this study may be included in the Hynds pooled analysis
England	**Approximately 8 out of 258 samples tested positive for *Cryptosporidium* at 3 of 6 sites** (National Cryptosporidium Survey Group, 1992)	**Positive results occurred in late spring. Sites chosen because they were considered 'safe' deep boreholes, or where quality was known to be affected by rainfall or surface water**
Italy	• **No *Giardia* or *Cryptosporidium* found in 14 samples at one site** (Briancesco & Bonadonna, 2005) • **2 of 18 groundwater samples positive for *Giardia* and 0 of 18 for *Cryptosporidium* (Lonigro, et al., 2006 in Giangaspero, et al., 2007)** • **2 of 14 groundwater samples positive for *Giardia* and 1 of 14 for *Cryptosporidium* (Di Benedetto, et al., 2005 in Giangaspero, et al., 2007)**	**No further details available**
Finland	**40 samples taken from 20 sites and 4 samples at 4 sites positive for *Giardia*** (Pitkänen, et al., 2015) • **1 driven in unconfined, sand and gravel aquifer, well depth 8m** • **2 dug in semiconfined sandy aquifers, well depth <5m** • **1 drilled in deep confined, bedrock aquifer, depth unknown**	**Well types selected based on high potential for contamination. Aquifer types varied. Positive results in autumn.**
France	• **8 of 9 spring samples positive for *Cryptosporidium* and 1 of 9 for *Giardia*** • **4 of 9 wellbore samples positive for *Cryptosporidium* and 0 of 9 for *Giardia*** • **9 of 9 continuously pumped wellbore samples positive for *Cryptosporidium* and 1 of 9 for *Giardia*** (Khaldi, et al., 2011)	**Site located in karst aquifer in area of agricultural land use plus direct influence of surface water**
Portugal	**1 of 39 samples from a single groundwater site positive for giardia and 23 of 39 positive for *Cryptosporidium*** (Lobo, et al., 2009)	**No further details available**

Norway	**20 samples taken from 20 groundwater sites** (Gaut, et al., 2008)**:** • **3 of 20 samples positive for *Cryptosporidium*** • **0 of 20 samples positive for *Giardia***	**Bedrock**
Germany	**5 of 66 groundwater samples positive for *Cryptosporidium* and 1 of 66 for *Giardia*** (Gallas-Lindemann, et al., 2013)	**Radial and vertical well(s) further detail unknown**