Wellington Water

Waterloo Wellfield
Water Quality Contamination Investigations

PART 1

August 2017

Our water, our future.

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Executive Summary

Safe and reliable drinking water is vital to the health and prosperity of our region and its people. Wellington Water are responsible for making sure that the water supplied to Hutt City, Porirua, Upper Hutt, and Wellington is clean and safe to drink.

This report documents the result of our multiple reviews, technical assessments, analysis of incident reports, and advice from independent experts relating to the changes in water quality within the Waterloo Wellfield.

About us

We manage the delivery of drinking water to our customers on behalf of our client councils – Greater Wellington Regional Council (**GWRC**), Hutt City Council (**HCC**), Wellington City Council, Upper Hutt City Council, and Porirua City Council.

In our role as a trusted advisor, we have service level agreements in place with all of our client councils. Our agreement with GWRC is to manage its bulk water supply network on their behalf, and our agreement with HCC is to manage its reticulation system. Each council retains ownership of their respective assets. All of our client councils have agreed that our number one priority is to ensure our customers are provided with safe and healthy drinking water.

Water supply and treatment processes

The Waiwhetu Aquifer is one of the region's key sources of fresh water, and can supply up to 70 per cent of the region's drinking water at certain times of the year. Unlike the other sources of fresh water, the water drawn from the Waiwhetu Aquifer, and subsequently supplied by the Waterloo Water Treatment Plant (**Waterloo WTP**), is not normally treated with chlorine to help manage waterborne pathogens. This is because the aquifer's natural filtration processes and confined environment have been relied upon to remove or inactivate (disable) waterborne pathogens. The bores used to draw water from the aquifer have *secure* status under the current New Zealand Drinking Water Standards 2005 (Revised 2008), and have held similar status under the previous drinking water standards that have applied in New Zealand.

The drinking water delivered by the Waterloo WTP supplies most of our customers in Hutt City (with the exception of Manor Park, Stokes Valley and Wainuiomata), which is an average total of about 74,000 customers per day. In addition, and in combination with drinking water supplied from the Wainuiomata Water Treatment Plant, the Waterloo WTP supplies drinking water to about 81,000 customers per day in Wellington City. Although the drinking water supplied to our Hutt City customers is not normally treated with chlorine to help manage waterborne pathogens, the water supplied to our Wellington customers is chlorinated.

Water quality sampling results

In almost four decades of monitoring, water quality samples taken from bores in the Waterloo Wellfield have never returned a positive *E. coli* recording. However, since December 2016, positive test results for *E. coli* have been received from two bores, and one from the Naenae Reservoir inlet main (the pipeline immediately 'downstream' from the Waterloo WTP). At around the same time, there was a significant increase in the number of total coliform bacteria being detected in water drawn from the bores in the wellfield, and at other locations that draw water from the aquifer, such as the Buick Street water fountain in Petone. These test results indicated that investigation into the sources of the contamination, and water treatment responses was required.

Taking action

To ensure we took all practical steps to continue to provide safe and healthy drinking water to our Hutt City customers (those who normally received unchlorinated water), we decided to continuously chlorinate the water supplied by the Waterloo WTP in April 2017. This decision was taken as a precautionary measure in response to positive *E. coli* test results and the increase in total coliforms. Further to this decision, we also decided to install ultra-violet (**UV**) units to provide further protection against waterborne pathogens – this work will be completed by December 2017. We made these decisions in collaboration with GWRC and HCC as well as Hutt Valley District Health Board's Regional Public Health (**RPH**) whilst we completed the investigations discussed in this report.

As a part of our response to the positive *E. coli* test results we also recommended to HCC that the Buick Street and Dowse Square water fountains be closed until each could be fitted with on-site filtration and UV treatment systems. Fit out work for the Buick Street fountain has recently been completed, and it has been switched back on. For the Dowse Square water fountain, fit out work is due to be completed in August 2017.

Previous investigations

Since April, we have reviewed our incident reports and investigations into the potential sources of the positive *E. coli* test results, in particular the Colin Grove bore and Naenae Reservoir *E. coli* incidents reports, as well as completing the Waterloo Wellfield and Collector Main - Water Quality Security Report (June 2017). Prior to April, we had also undertaken a 'lessons learnt' review of our unchlorinated water system (the system that supplies drinking water to most of our Hutt City customers as described in this report) following the *gastroenteritis* outbreak in Havelock North in August 2016.

This report documents the results and outcomes of all investigation work we have undertaken into the possible reasons for the *E. coli* test results and the detection of high total coliforms.

Key findings

Our investigations have involved a variety of assessments. These have included assessing the condition of the bores in the Waterloo Wellfield (and other asset assessments); the potential for contamination exposure in the Waterloo WTP collector main; the potential for problematic leaks from our wastewater and stormwater pipes; whether a mistake in the sampling process had been made; and, whether the 'shaking effects' of the Kaikoura Earthquake was a contributing factor. In spite of our detailed investigations we have not been able draw any definitive conclusions regarding the possible sources of the *E. coli* contamination and significant increase in the number of total coliform bacteria being detected.

Our detailed bore and asset assessments did identify some minor maintenance improvements that could be made to the bore equipment. We have either completed these improvements, or are in the process of doing so. However, we do not believe that these ongoing maintenance activities are material to the potential source of the *E. coli* contamination or increase in total coliforms.

Another possibility that we can't completely rule out is that the water in the Waiwhetu Aquifer itself might be contaminated. This report discusses the possibility that a breach in the aquitard (the layer of clay that seals and confines the aquifer) coupled with the large localised hydraulic drawdown in the aquifer could be drawing in contaminated water that may be located above the aquitard. There has also been some suggestion that poorly constructed (or maintained) non-community water supply bores or building piles that penetrate the aquitard might also be contributing to the contamination of the aquifer. Again, we cannot be definitive about these possibilities, and note that GWRC's Waiwhetu Aquifer Science Study is expected to investigate such possibilities further.

Independent Advice and Havelock North Drinking Water Inquiry

We have sought independent expert advice on the results of our investigations, and on our recommendations to be put forward for consideration by GWRC and HCC. Both independent experts advise that they believe there are public health and safety risks associated with water that is sourced from aquifers which is not subsequently fully treated for waterborne pathogens. They recommend that the water supplied by the Waterloo WTP should be treated through a combination of chlorine and UV in order to protect the water supply against waterborne pathogens.

It is noted that the findings of Stage 1 of the Havelock North Drinking Water Inquiry, and the early themes of the submissions from Stage 2, also suggest there is uncertainty associated with any water that is sourced from aquifers which is not subsequently fully treated for waterborne pathogens.

Conclusion and recommendations

Our investigations into the possible sources of the *E. coli* contamination and increase in total coliforms have not drawn any definitive conclusions. However, they have identified that there are significant risks that can't be eliminated or effectively managed if we continue to supply drinking water from the Waiwhetu Aquifer without fully treating it for waterborne pathogens at the Waterloo WTP.

Our priority is to continue to provide safe and healthy drinking water to our 74,000 Hutt City customers who normally receive unchlorinated water. We therefore, and after consideration of different treatment options, recommend that we continue to chlorinate the drinking water supplied from the Waterloo WTP, and to also treat it with UV, in order to manage the waterborne pathogen risk. We consider this recommendation to be in accordance with international best practice.

The *gastroenteritis* event in Havelock North in late 2016 demonstrated the risks associated with supplying drinking water that is not fully treated against waterborne pathogens. By treating the water supplied by the Waterloo WTP with chlorine and UV we will be ensuring our Hutt City customers, who had previously been receiving unchlorinated drinking water, will continue to receive safe and healthy drinking water into the future.

Contents

1. Purpose

In May 2017, we announced that we would be reviewing our investigations into the positive *E. coli* test recordings, and the increase of total coliforms in water being drawn from the Waiwhetu Aquifer and subsequently supplied by the Waterloo WTP. The purpose of this report is to document the results and outcomes of this investigation work.

The findings of our work are reported in the following two parts:

- **Part 1** (this report) documents and discusses the investigations that were undertaken in response to the positive *E. coli* test results and increase in total coliforms
- **Part 2** includes the various supporting investigation reports and key decision-making papers described in Part 1 (this report will be made available upon request).

1.1 Methodology for Part 1

Part 1 has been prepared based on the following investigation reports:

- Colin Grove Water Supply Bore December 2016 *E. coli* Incident Investigation Report (the **Colin Grove Report**) and our associated decision-making documents. This report was initiated immediately following the incident in December 2016, and was ultimately completed in early March 2017. It includes information on our inspections of the Waterloo Wellfield dating back to 2015, as well as a number of recommendations for remedial works and other investigative actions
- The Naenae Reservoir Inlet Main Positive *E. coli* Result Report – 3 February 2017 – Incident Report (the **Naenae Reservoir Report**). This report summarises the investigations we undertook in response to this incident
- Waterloo Wellfield and Collector Main, Water Quality Security – Investigations Report - June 2017 (the **Water Quality Security Report**). This report summarises our investigations into the condition of the Waterloo Wellfield's physical assets, including an independent third party inspection undertaken by Griffiths Drilling (NZ), as at June 2017.

2. Background

In April 2017 we recorded a third positive *E. coli* test result from the water drawn from the Waiwhetu Aquifer and supplied to our Hutt City customers via the Waterloo WTP. The first positive result had been recorded from the Colin Grove bore in December 2016. This was the first time on record that we had detected *E. coli* in water samples taken from any of the Waterloo Wellfield bores.

Following receipt of the third *E. coli* result, we made the decision to continuously treat the water supplied by the Waterloo WTP with chlorine.[1] We have since made an additional decision to treat the water with UV to further manage the waterborne pathogen risk.[2] Prior to this, and with the exception of emergency chlorination, most of our Hutt City customers[3] were receiving unchlorinated drinking water with no UV treatment. Chlorination has been continuous since our decision in April, and installation of UV units at the Waterloo WTP will be completed by December 2017.

At the same time we decided to chlorinate the water supplied by the Waterloo WTP, we recommended to HCC that its Buick Street and Dowse Square water fountains be closed. This was because testing of water samples from the Buick Street fountain had showed an increase in total coliform results. The Buick Street fountain was re-opened in June following installation of UV treatment equipment on-site, and a similar unit is expected to be operating at the Dowse Square water fountain shortly.

2.1 Water Supply System – a brief summary

The water supply system we manage for our client councils consists of three main components: the water source; treatment plants; and distribution systems. The water sources are:

- Hutt River
- Wainuiomata River
- Orongorongo River
- Waiwhetu Aquifer.

From these sources, water is processed at the Te Marua, Wainuiomata, Gear Island, and Waterloo treatment plants before entering the water supply distribution network (reticulation networks and reservoirs) and into the customer's 'tap'. **Figure 1** summarises our water supply processes.

[1] The water at the Waterloo WTP is currently chlorinated to a level of 0.4g/m3.
[2] It is noted that UV manages the protozoa risk, whereas chlorine on its own only manages bacteriological and viral risks.
[3] As described further in Section 2.2, our customers in Manor Park, Stokes Valley and Wainuiomata receive chlorinated water.

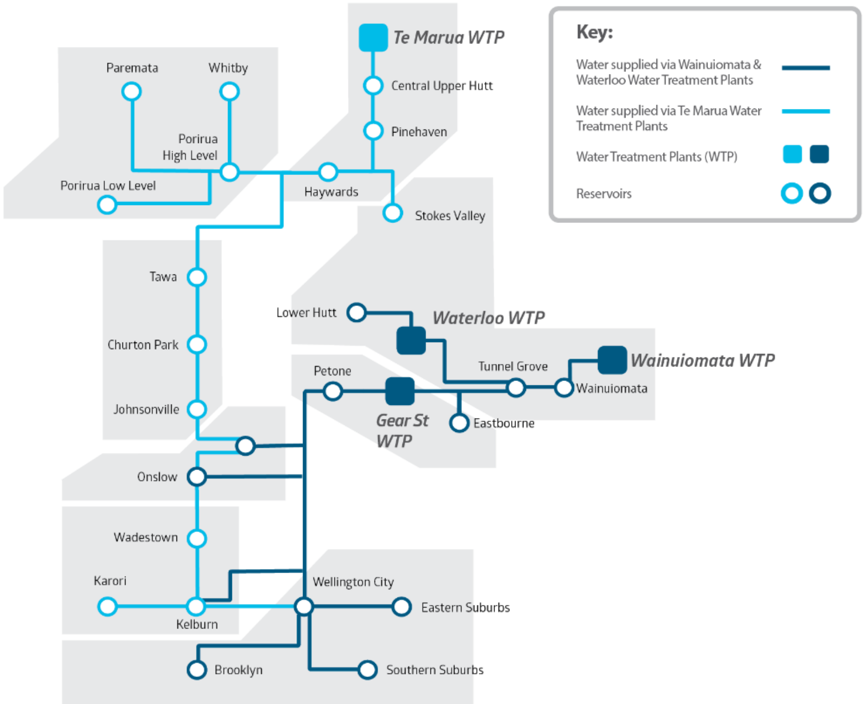


Figure 1 Water supply – 'source to tap'

The water supplied by Te Marua, Wainuiomata, and Gear Island treatment plants is treated with chlorine to help manage waterborne pathogens. However, the water supplied by the Waterloo WTP to Hutt City customers has not historically been treated with chlorine,[4] as we (and as did GWRC and HCC before us) have relied on the Waiwhetu Aquifer's natural filtration processes and confined environment to manage the risks associated with waterborne pathogens. This approach is specifically allowed for under Drinking Water Standards for New Zealand 2005 (**DWSNZ**) (Revised 2008).

2.2 Waiwhetu Aquifer and the Waterloo Water Treatment Plant

The Waiwhetu Aquifer is a vital water source for the region. Typically, about 40 per cent of our customer's drinking water is sourced from the aquifer, but this can be up to 70 per cent during the summer.

The Waiwhetu Aquifer is a natural underground water system located beneath the Hutt Valley and Wellington Harbour. It is generally located between 20m and 70m below ground level and is 'fed' by a combination of river and rainwater seeping into the ground and becoming confined beneath its

[4] It is noted that the water supplied by the Waterloo WTP is corrected for pH with lime. The Waterloo WTP has an automatic chlorine dosing system in place for emergency purposes, which uses either a sodium hypochlorite solution or calcium hypochlorite granules mixed with water to form a chlorine solution. This chlorine dosing system differs to the systems used at the Te Marua, Wainuiomata and Gear Island Treatment Plants. These treatment plants automatically dose the water with chlorine gas. It is also noted that the Te Marua and Wainuiomata water treatment plants include coagulation and filtration in their treatment processes.

aquitard.[5] Layers of gravel trapped below the aquitard allow for water to flow underground as an aquifer. **Figure 2** provides a high-level illustration of the aquifer and associated processes.

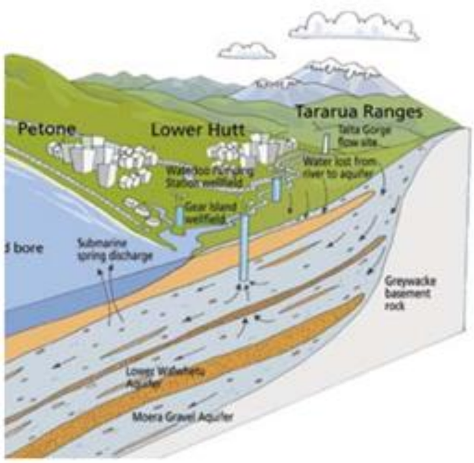
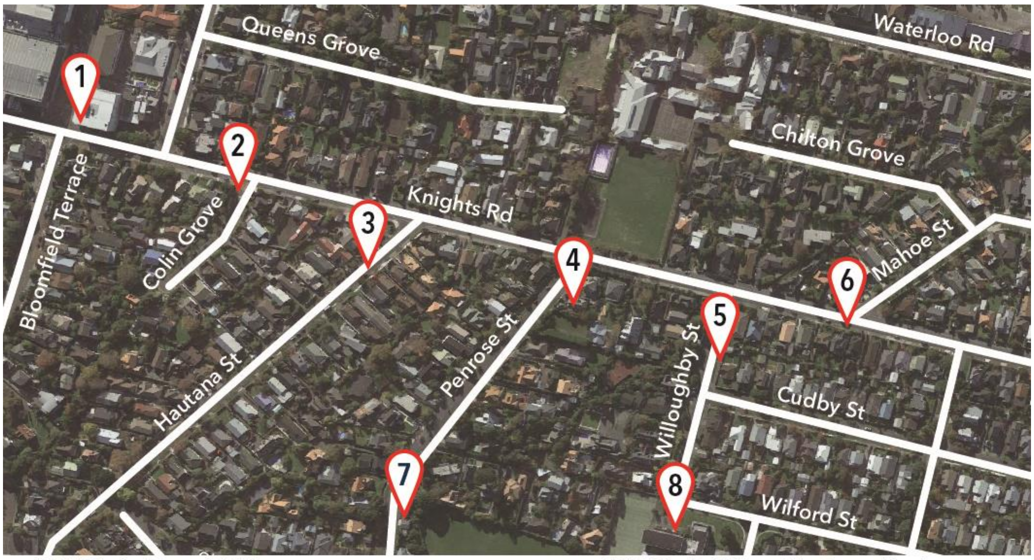


Figure 2 Waiwhetu Aquifer and associated processes

Water sourced from the Waiwhetu Aquifer is drawn from eight bores located along the "Knights Road spine" (collectively known as the **Waterloo Wellfield**) and transferred to the Waterloo WTP via the Waterloo collector main. The bores are approximately 40 metres deep with the bore head and chambers located underground. Six of the bores were installed in 1980[6] and two further were added in 1989[7]. The location of the eight bores is shown in **Figure 3**.



Well No.1 - Bloomfield Terrace
Well No.2 - Colin Grove
Well No.3 - Hautana Street
Well No.4 - Penrose Street North
Well No.5 - Willoughby Street North
Well No.6 - Mahoe Street
Well No.7 - Penrose Street South
Well No.8 - Willoughby Street South

Figure 3 Location of Waterloo Wellfield Bores

[5] The Waiwhetu Aquifer's aquitard is a layer of dense clay that acts as a barrier or a confining layer preventing surface water mixing with aquifer water. It's about one metre thick.
[6] Well No.1 – Bloomfield Terrace, Well No.2 – Colin Grove, Well No.3 – Hautana Street, Well No.4 – Penrose Street North, Well No.5 – Willoughby Street North, Well No.6 – Mahoe Street.
[7] Well No.7 – Penrose Street South, Well No.8 – Willoughby Street South.

The Waterloo WTP was commissioned in 1981. It processes about 70 million litres of drinking water per day on average, but has a production capacity of up to 120 million litres per day.

As set out in **Figure 4**, the Waterloo WTP normally supplies drinking water to about 155,000 customers per day on average. Of these, about 74,000 customers located in Hutt City normally receive unchlorinated drinking water,[8] with the remaining 81,000 customers located in Wellington City receiving chlorinated water. The process of chlorinating the drinking water supply to Wellington City occurs at the Gear Island Treatment Plant, where it is also "topped" up with chlorinated drinking water from the Wainuiomata Water Treatment Plant to ensure a sufficient amount of drinking water reaches Wellington City on a daily basis.

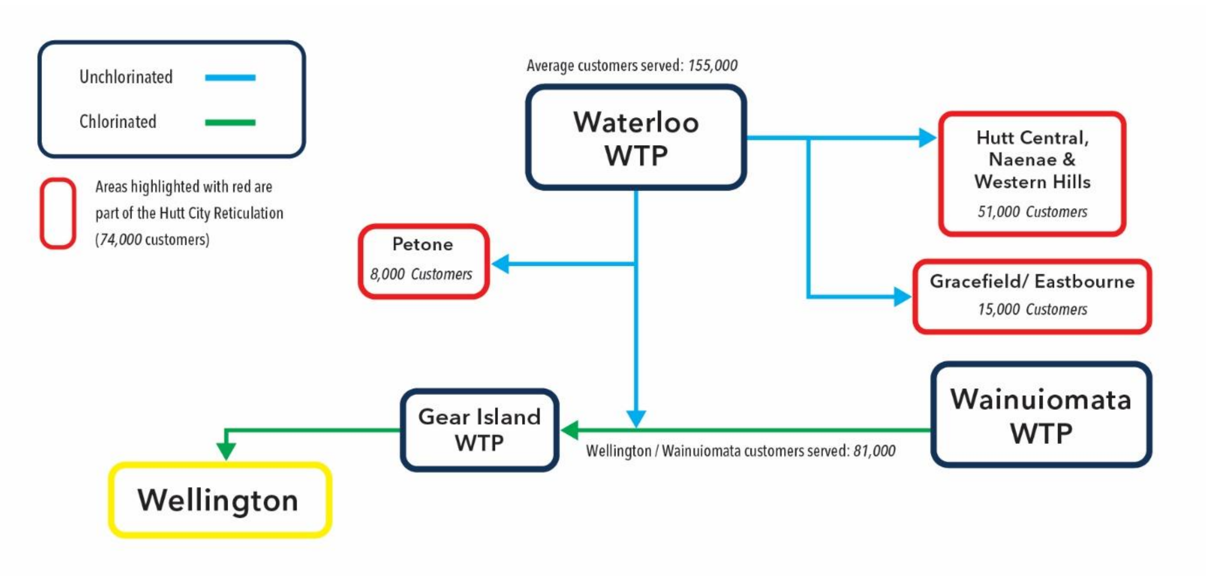


Figure 4 Waterloo WTP's unchlorinated and chlorinated water supplies

The decision to supply unchlorinated water from the Waterloo WTP to our Hutt City customers was made when the treatment plant and the Waterloo Wellfield were first commissioned in the early 1980s. This decision was premised on the information of the risks and benefits of supplying unchlorinated water that existed at that time.

Since the 1980s, the decision to supply unchlorinated water has been considered by both HCC and GWRC at various times. In 1996, GWRC undertook an assessment of the risks of supplying unchlorinated water, and considered on balance that water to be supplied by the Waterloo WTP should be chlorinated. At the time, the final decision to chlorinate was made by the HCC, who ultimately elected not to proceed with chlorination. The matter was considered again in 2003, and the decision not to chlorinate remained in place.

In 2017, the decision on the management of the waterborne pathogen risk in the drinking water to be supplied by the Waterloo WTP is to be made by GWRC – in consultation with HCC. It is noted that GWRC are the owner of the region's bulk water supply system and are the registered bulk water supplier under the Health Act 1956. We manage the bulk water supply on behalf of GWRC via a service level agreement.

[8] This excludes the suburbs of Manor Park, Stokes Valley and Wainuiomata. Customers in Manor Park and Stokes Valley are supplied with chlorinated drinking water from the Te Marua Water Treatment Plant. Customers in Wainuiomata are supplied with chlorinated drinking water from the Wainuiomata Water Treatment Plant.

In addition, it is noted that despite the recent *E. coli* test results, the water supplied by the Waterloo Wellfield bores to the Waterloo WTP is considered secure[9] under DWSNZ. The water supplied by the bores has also been considered secure under the previous drinking water standards that have applied in New Zealand.

2.3 *E. coli* and Recent Coliform Results

The three positive *E. coli* results we have received are briefly summarised as follows:

1. The first positive *E. coli* result was taken from the Colin Grove bore on 1 December 2016. We immediately took this bore offline and chlorinated the water supplied from the Waterloo WTP. Chlorination ceased after three days of negative *E. coli* tests. This bore currently remains offline until we are satisfied that the monitoring and testing requirements under the DWSNZ have been met
2. The second positive result for *E. coli* was taken from the Naenae Reservoir inlet pipeline on 4 February 2017. We immediately chlorinated the water supplied from the Waterloo WTP for three days. Further sampling of water at the inlet has tested negative for *E. coli*
3. The third positive result was taken from the Mahoe Street bore on 12 April 2017. We immediately took this bore offline and chlorinated the water supplied from the Waterloo WTP (which remains in place). A further sample of water from the bore has tested negative for *E. coli*. This bore currently remains offline until completion of this investigation.

From April 2017, we continued to sample water supplied from the Waterloo Wellfield, with increasing total coliforms at the Willoughby Street South bore being particularly noticeable. As this increasing coliform trend continued during early May 2017, we decided to take this bore offline in late May as a precaution. A similar trend was subsequently detected at Penrose Street South bore, and we also took this bore offline in mid-June 2017. We have also detected positive total coliform results from the Buick Street water fountain in Petone, which draws water directly from the Waiwhetu Aquifer. **Figure 5** below sets out the current operational status of Waterloo Wellfield bores.

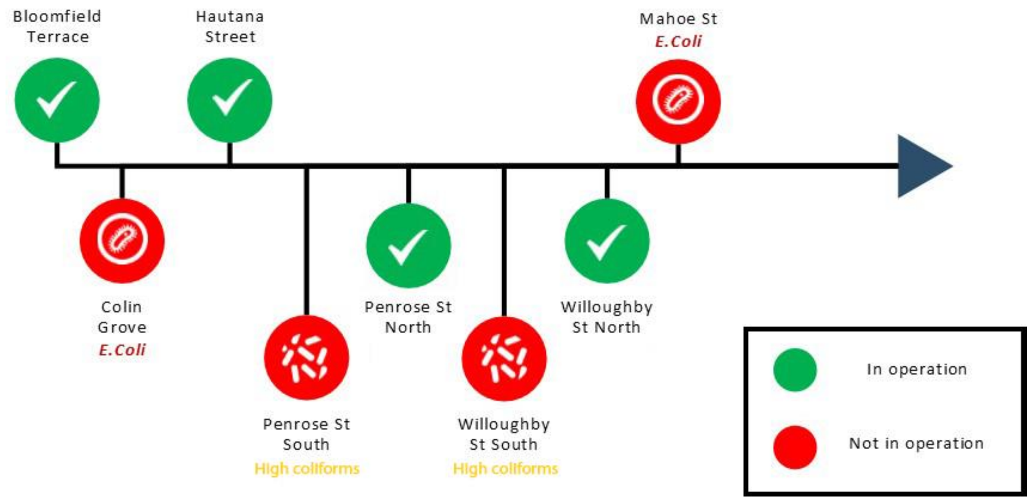


Figure 5 Current operational status of the Waterloo Wellfield Bores (as at July 2017)

[9] The DWSNZ's definition of *secure* status is discussed in Section 3.1.3 of this report.

In summary, four bores are currently offline due to either positive *E. coli* or high total coliforms readings. Consequently, all of our treatment plants are at maximum utility in order to meet daily customer demand for drinking water.

We believe the *E. coli* results are significant, as they are the first time on record that we have detected *E. coli* in water samples taken from any of the Waterloo Wellfield bores.[10] The recent total coliform results taken from the Willoughby Street South and Penrose South bores (as well as from the Buick Street water fountain) are further evidence that we needed to investigate the water quality in and around the Waiwhetu Aquifer.

Reinforcing the need for additional investigational work is the uncertainty created by the potential impacts from the Kaikoura Earthquake (November 2016), and the potential impacts of future significant earthquakes, on our water supply network. The Kaikoura Earthquake occurred two weeks prior to the Colin Grove bore positive *E. coli* result.

[10] It is noted that in 1991 a seagull entered the Waterloo WTP (via an open access hatch). This resulted in an increase in faecal coliforms in the water supplied by the treatment plant throughout Hutt City. At the time, all residents and businesses were required to boil their water as a precautionary measure.

3. Regulatory Context

3.1 Multiple Barrier Approach to Safe Drinking Water

Having a number of "barriers" in place to safeguard drinking water quality is considered international best practice. This approach recognises that by having more than one barrier in place, the risk of contaminated water being supplied to consumers decreases. It is noted that the importance of having a robust barrier system in place was recently highlighted by the Havelock North Drinking Water Inquiry (Stage 1) decision, [11] which is discussed further below in Section 3.1.5.

The following barriers need to be in place in order to provide a safe water supply system:

- Water source protection (measures to prevent contaminants entering water source)
- Effective treatment (filtration of particles and disinfection processes)
- Secure distribution (regular checks to make sure there are no leaks in the pipes)
- Effective monitoring (regular and robust water quality sampling regimes)
- Effective responses to adverse effects (timely and appropriate operational responses).

In New Zealand, the regulatory framework that supports the above barrier system is provided through a combination of the Resource Management Act 1991 (**RMA**), Local Government Act 2002 (**LGA**), and the Health Act 1956 (**Health Act**). As discussed below, the Building and Food Acts also apply to 'self (water) suppliers'.

The following commentary summarises key aspects of legislation relevant to drinking water. It is not meant to be an exhaustive examination of the legislation, but rather is provided to give a broad understanding of the regulatory framework for drinking water in New Zealand.

3.1.1 Resource Management Act

The RMA is targeted at protecting the sources of drinking water – the first barrier. It assigns primary responsibility for protecting water sources to regional councils and through a National Environmental Standard for Sources of Human Drinking Water.[12] The latter is primarily the responsibility of the Ministry for the Environment, although its practical implementation falls to regional councils.

The purpose of the RMA is to promote the sustainable management of natural and physical resources, including water. It does this through the use of national environmental standards, national policy statements, regional policy statements and regional plans, district plans, individual resource consents and monitoring and enforcement mechanisms.

Regional councils have primary responsibility for maintaining and enhancing the water quality in their regions. They exercise these functions by: preparing, implementing and administering regional policy statements and regional plans; assessing and issuing resource consent applications for activities that would otherwise contravene the RMA and regional plans; and through ongoing

[11] Havelock North Drinking Water Inquiry: Stage 1, May 2017, page 29, paragraphs 112 – 122.

[12] Under this national standard, a human drinking water source is a natural water body such as a lake, river or groundwater that is used to supply a community with drinking water. The standard applies to water before it is treated and only sources of water used to supply human drinking water (i.e. not stock or other animals).

monitoring and enforcement action. Drinking water suppliers must obtain a resource consent from the regional council to take water, which regional councils then assess against the criterion specified in its planning documents.

District plans must give effect to any national and regional policy statements, and must not be inconsistent with a regional plan.

With regard to the Waiwhetu Aquifer, its guardianship comes under the jurisdiction of GWRC.

3.1.2 Local Government Act

Local authorities, that is both regional, city/district councils, have duties and powers under the LGA. The LGA requires local authorities to have regard to the contribution that water services make to their communities, to assess and plan for the future needs of their communities, and to take a sustainable development approach. Local authorities may also utilise bylaws to give effect to these responsibilities.

The LGA makes local authorities accountable to their communities through long-term and annual plan processes, consultation and regular reporting on performance. The level of service (e.g. performance targets) to be provided by each local authority is determined in consultation with their communities.

Further, a local authority that provides drinking water must continue to provide and maintain its capacity to provide drinking water. They must assess the provision of their water services, from a public health perspective, to ensure they are adequate and comply with all regulatory requirements.

District/city councils are generally responsible for the extraction, treatment, distribution, and monitoring of water to customers - barriers two to five. These responsibilities are generally undertaken in conjunction with the local district health boards (via the public health unit) and regional councils.

Wellington Water provides these water services on behalf of our client councils, although each council retains ownership of their respective water networks. With regard to public health, we execute these services with oversight from RPH and all client councils.

3.1.3 Health Act

Part 2A of the Health Act, and the DWSNZ, are the primary mechanisms for promoting safe drinking water under this legislation.

The Ministry of Health is responsible for improving, promoting, and protecting public health. The Ministry effectively designates RPH to perform some of its key duties under the Act with respect to the promotion of safe drinking water.

Local authorities, such as GWRC (as the water supplier) and HCC (as the owner of the local distribution network in Hutt City) have certain obligations under the Health Act regarding the supply of safe drinking water as well. These are namely to:

- Take all practicable steps to ensure an adequate supply of drinking water is in accordance with DWSNZ and to carry out remedial action if water quality is not in compliance
- Take reasonable steps to protect raw water sources from contamination, and to protect all aspects of the drinking water supply system from pollution

- Monitor the drinking water supplied in accordance with the DWSNZ and to detect and assess public health risks
- Prepare and implement a water safety plan (these plans set out procedures for managing contaminants entering the water supply network, including emergency response plans)
- Keep records and investigate/remedy complaints
- Provide assistance to Drinking Water Assessors (**DWAs**), designated officers, and medical officers of health.

Laboratories and testing fall within the scope of the Health Act. All tests and analyses of raw water and drinking water must be undertaken by accredited laboratories in accordance with the DWSNZ. Water sampling is either carried out by laboratory staff or personnel outside of laboratories (such as council officers) provided that such sampling is in accordance with the DWSNZ.

With regard to the testing of water sourced from the Waiwhetu Aquifer, this process is undertaken by Eurofins ELS who are accredited by International Accreditation New Zealand (**IANZ**). Eurofins is also a Recognised Ministry of Health laboratory for the sampling and testing of *E. coli* and other micro-organisms.

Drinking Water Standards NZ - Groundwater

The DWSNZ[13] was updated in 2008. In summary, the standard specifies how to assess the quality and safety of water, including the requirements for monitoring and testing of contaminants and providing treatment and/or responding to transgressions.

With respect to the extraction of groundwater, Section 4.5 of the DWSNZ sets out the relevant provisions for bore water security and compliance.[14]

In summary, bore water is considered *secure* when it can be demonstrated that contamination is unlikely because the bore water is:

- Not directly affected by surface or climate influences
- Abstracted from a bore head that provides satisfactory protection.

The requirements of bullet point 1 can be met if water younger than one year is not evident from testing, or if there is a lack of significant variability in determinants linked to surface effects. In addition, the absence of *E. coli* needs to be clearly demonstrated (e.g. through robust monitoring regimes).

The satisfactory protection of a bore head is determined as follows:

- The bore is to be assessed and judged to be secure by an expert
- The bore head is to be sealed at the surface
- The casing must not allow ingress of shallow water
- Animals must be excluded from within 5 metres of the bore head
- Bore construction must comply with the environmental standard for drilling soil and rock (NZS 4411, Standards New Zealand (2001)), including providing an effective backflow prevention mechanism, unless exempted by a DWA

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[13] http://www.health.govt.nz/publication/drinking-water-standards-new-zealand-2005-revised-2008.

[14] Page 42, http://www.health.govt.nz/publication/drinking-water-standards-new-zealand-2005-revised-2008

- The water safety plan must address contaminant sources and contaminant migration pathways
- Potential sources of contamination such as septic tanks or other waste discharges must be situated sufficiently far away from the bore so contamination of groundwater cannot occur.

Section 4.5.3 of the DWSNZ sets out the monitoring regime for drinking water supplies that come from multiple bores, including requirements for reduced monitoring. In order to justify reduced monitoring, it must be shown that: the bores draw from the same aquifer under similar conditions; the aquitard is continuous; the chemical character of the water from each bore is similar; and each bore head meets bore water security criterion.

With regard to our monitoring regime, we have historically undertaken sampling every second day from the 'sampling point' on the Waterloo WTP collector main. However, from early September 2016 and as consequence of our Havelock North lessons learnt review, we increased our sampling to daily. In addition, the sampling method for *E. coli* and total coliforms was changed from the presence/absence method to the enumerated method (which determines the Most Probable Number (**MPN**[15])).

Following the Colin Grove *E. coli* test result, we continued to take samples on a daily basis[16] from the bores that remained in operation, and after obtaining independent specialist advice,[17] we started taking samples to test for protozoa from both the Waterloo collector main and Gear Island Water Treatment Plant on a fortnightly basis.

Since the Naenae *E. coli* test result, we have undertaken *E. coli* sampling at the Naenae Reservoir inlet every two days. *E. coli* sampling at the Gracefield, Point Howard and Rahui Reservoirs, and all of the remaining reservoirs, occurs weekly, and sampling at each of Hutt City's local reticulation sample points occurs once a quarter.

Section 4.5.4 of the DWSNZ sets out the ongoing compliance for a secure bore. With regard to this particular section of the standard, and prior to the Colin Grove *E. coli* event, we undertook bore head protection assessments on a five-yearly basis, with the last formal assessment undertaken in July 2015. We also undertake three-monthly well pump and well chamber checks, which have recently been modified to include vacuum cleanouts of chambers and sumps, and leakage testing of penetrations.

Section 4.5.5 of the standard sets out the response processes for when *E. coli* is detected in the water supply system.

3.1.4 Building and Food Acts

Although water suppliers and carriers are required to be registered with the Ministry of Health, not all 'self-suppliers' are. Furthermore, the Health Act only applies to potable water in reticulated networks. As such, water taken from the Waiwhetu Aquifer for private use is thought to fall under the jurisdiction of the Building Act 2003 and/or the Food Act 2014. Monitoring of these water takes

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[15] MPN is a counting method that estimates the number of coliforms through a combination of probability tables and the number of positive reactions.

[16] This included enumerated *E. coli* and total coliforms sampling from each bore, the Waterloo WTP collector and outlet mains.

[17] The specialists were Jason Colton (Lutra Ltd, formerly H_2ope Ltd), and Dr Dan Deere (Water Futures Pty Ltd).

falls under the responsibility of the relevant city and regional councils as well as the Ministry for Primary Industries.

3.1.5 Havelock North Drinking Water Inquiry

The findings of the Havelock North Drinking Water Inquiry have provided additional background context for development of this report, in particular as the *campylobacteriosis* outbreak was ultimately traced back to water drawn from Te Mata Aquifer. This aquifer had been previously thought to be secure, and the associated water supply was not receiving treatment for the management of waterborne pathogens.

In August 2016, there was a widespread outbreak of gastroenteritis in Havelock North. An estimated 5,500 people became ill with *campylobacteriosis*.

In September 2016, the Government announced that an inquiry into the *campylobacteriosis* outbreak would be held. In May 2017, Stage 1 of the inquiry reported back (Stage 2, which is briefly commented on below, is due to be fully completed by the end of 2017).[18]

Havelock North Drinking Water Inquiry – Stage 1

Some of the key findings from the Stage 1 Report include:

- It is highly likely that contaminated water from a nearby stream/pond entered the Te Mata Aquifer, which was ultimately pumped into the reticulation system. A less likely scenario was that water from the contaminated stream/pond flooded the bore chambers via the road drainage system. Water then 'tracked' its way down the bore's cables into the aquifer where it was then pumped into the water supply system
- The regional council was found to have failed to meet its responsibilities under the RMA. It lacked knowledge and awareness of aquifer and catchment contamination risks. This included through its resource consent processes; its management of the many uncapped or disused bores in the vicinity; its state of the environment and resource consent monitoring work; and its liaison with the district council
- The district council was found to have not implemented the high standard of care needed for a public drinking water supplier, particularly in light of its experience of a similar outbreak in 1998, and the significant history of transgressions (positive *E. coli* test results). Consequently, it made key omissions, including in its assessment of risks to the drinking water supply, and breach of the DWSNZ
- The district council's mid-level managers delegated tasks but did not adequately supervise or ensure their implementation. This caused unacceptable delays to the preparation of a Water Safety Plan, which was fundamental in addressing the risks of an outbreak of this nature
- The district council did not properly manage the maintenance of plant equipment or keep records of that work; and it carried out little or no supervision of necessary follow-up work. Specifically, it was slow to obtain a report on bore head security, a key factor in source water security, and it did not promptly carry out recommended improvements
- The inquiry found that there was a critical lack of collaboration and liaison between the regional and the district councils
- The DWAs were too hands-off in applying the DWSNZ

[18] For the Stage 1 report see: https://www.dia.govt.nz/Government-Inquiry-into-Havelock-North-Drinking-Water#Report-1.

- Technical advisers failed to competently assess and report on the security of the bore heads.

Following the Havelock North outbreak, and as a provider of an unchlorinated water system, we undertook a series of lessons learnt workshops (in September 2016) to identify any risks from this incident that we might not have been previously been aware of.

As a result of our workshops, and as discussed above, we implemented daily sampling of the Waterloo Wellfield (from September 2016). We also increased the number of maintenance inspections of the bores and reviewed/improved communication channels with key stakeholders (e.g. RPH).

We also identified some ongoing actions from the workshops, including:

- the need for a better understanding of the water source
- the need for a better understanding of management of the distribution and reticulation networks
- how contamination could get into the water supply network.

These actions are either underway, or will be included in the new regional water safety plan. Furthermore, some of these actions are no longer applicable because of our decision to treat the water supplied by the Waterloo WTP with chlorine and UV.

It is noted our water safety plan currently consists of each our client council's previous water safety plans. As noted above, we have started developing a single regional water safety plan that will be completed by December 2017.

Havelock North Drinking Water Inquiry – Stage 2

Stage 2 of the Havelock North Drinking Water Inquiry has recently commenced. To date, there have been a number of submissions and/or evidence presented that have raised general concerns over the ongoing security of water extracted from aquifers for drinking purposes that is not subsequently treated to manage waterborne pathogens.[19]

[19] https://www.dia.govt.nz/Stage-2-Submissions.

4. Microbiological Contaminants and Monitoring

The barrier system discussed in Section 3.1 is designed to prevent microbiological contaminants entering the water supply system and causing significant public health problems, as was seen in the recent Havelock North incident, as well as overseas.[20] The DWSNZ recognises three classes of micro-organisms that may cause disease: bacteria, viruses, and protozoa. Each are briefly described below:

4.1.1 Bacteria

E. coli is an indicator organism used to assess the likelihood of recent faecal contamination. It is found in high numbers in the gut of all warm-blooded animals. Fresh faeces always contains *E. coli*, although it may not survive in the environment as long as some pathogens (or others indicators) do. When *E. coli* is detected in water, it shows that there has been recent faecal contamination of the water, and that the likelihood of pathogens being present is significantly increased. The types of pathogen, and their concentrations, will depend on the nature of the organisms infecting the animals or humans that are the source of the faeces, and the amount of animals or humans that are infected.

4.1.2 Viruses

Viruses that cause waterborne diseases tend to be enteric viruses (that is, they infect the gastrointestinal tract and are excreted by infected humans). Some human and animal viruses are highly infectious. Faecal polluted water can harbour viruses (viral pathogens). The presence of *E. coli* in water, although a bacterial indicator, indicates that bacterial, viral, or protozoan pathogens may be present.

4.1.3 Protozoa

Protozoa (e.g. *giardia and cryptosporidium*) are common causes of infection and disease in humans and other animals. To safeguard water supply against *giardia and cryptosporidium* appropriate water treatment processes (e.g. coagulation and conventional filtration, membranes or UV light) are required to be put in place. This is particularly true for *cryptosporidium* which is completely resistant to chlorine at the concentrations used in water treatment.

[20] A number of examples were cited in the Havelock North Drinking Water Inquiry: Stage 1 (May 2017). See page 8, paragraph 28.

4.1.4 Summary

Some common waterborne pathogens are set out in **Table 1** below.

Table 1 – Common waterborne pathogens

Bacteria (0.3-10µm[21])	Virus (0.005-0.3µm)	Protozoa (4-14µm)
Typhoid Cholera Legionella Yersina *E. coli 0157:H7* Campylobacter	Polio Adenovirus Rotavirus Hepatitis A and E Norovirus	*Giardia* *Cryptosporidium*

4.1.5 Microbiological Monitoring of the Waiwhetu Aquifer

As set out in Section 3.1.3, our monitoring/sampling regime focuses on total coliform and *E. coli* identification as the prime indicators of water quality degradation in the Waiwhetu Aquifer. Our total coliform tests are always accompanied by a test for *E. coli*.

Coliform bacteria are often used as "indicator organisms" because their presence can indicate that a possible contamination pathway exists between a source of the bacteria (e.g. animal waste) and the water supply.

Total coliforms are a diverse collection of bacterial *genera* that include two commonly used subsets. The term "faecal coliforms" is a misnomer, but is intended to include the four genera most commonly seen in human faeces, namely *Escherichia, Klebsiella, Citrobacter* and *Enterobacter.* With the exception of *Escherichia,* these genera may be derived from faeces or may originate from other sources. Conversely other genera may fall into the group "faecal coliforms" which is more correctly named "thermotolerant colifors" as this describes the phenotypic characteristics of the organisms that fall into the group.

As noted above, as *E. coli* is not generally found naturally in the environment, it is therefore considered to be the best indicator of faecal pollution and that pathogens might be present. However, there are instances where pathogens may be present in the absence of *E. coli.* *E. coli* survives in water for a shorter period of time than many other organisms, including total coliforms and *cryptosporidium,* as well as many viruses. Therefore, *E. coli* may die off after a faecal contamination event but pathogens may still be present. While total coliforms are not specific indicators of faecal pollution, they are more numerous than *E. coli* in faeces and survive longer in water. Therefore, detecting total coliforms in water is still an indicator that faecal contamination may have occurred.

Section 6.3.2 of the Guidelines for Drinking Water Quality Management for New Zealand[22] states:

"Total coliforms have limited interest in their own right, but with one important exception: when total coliforms are detected in the absence of E. coli, it is important that the source be investigated, as their presence may be indicative of a barrier failure or biofilm development."

[21] Micrometre (µm) is the unit used to measure the size of microbiological entities. For comparison purposes, the width of a single human hair ranges from between 10 to 200 µm.
[22] See http://www.health.govt.nz/publication/guidelines-drinking-water-quality-management-new-zealand.

Coliform bacteria are much more common in springs and shallow wells, rather than in deep wells, such as aquifers. This is because bacteria are naturally filtered out by the soil and rock above the aquifer, as surface water infiltrates into the ground. Coliform bacteria can still contaminate deeper wells (greater than 30 metres) if they are poorly constructed or suitable environmental growth conditions exist (e.g. access to food).

4.1.6 Recent Monitoring Results

As noted previously, since Colin Grove bore *E. coli* test result on 1 December 2016, we have recorded two further positive *E. coli* results from the water drawn from the Waiwhetu Aquifer. As set out in **Figure 6**, total coliforms in this water have also been increasing since October 2016. The upward trend has been particularly noticeable since February 2017, and is continuing despite progressively taking four of the eight bores in the Waterloo Wellfield offline due to either positive *E. coli* test results or high total coliform test results.

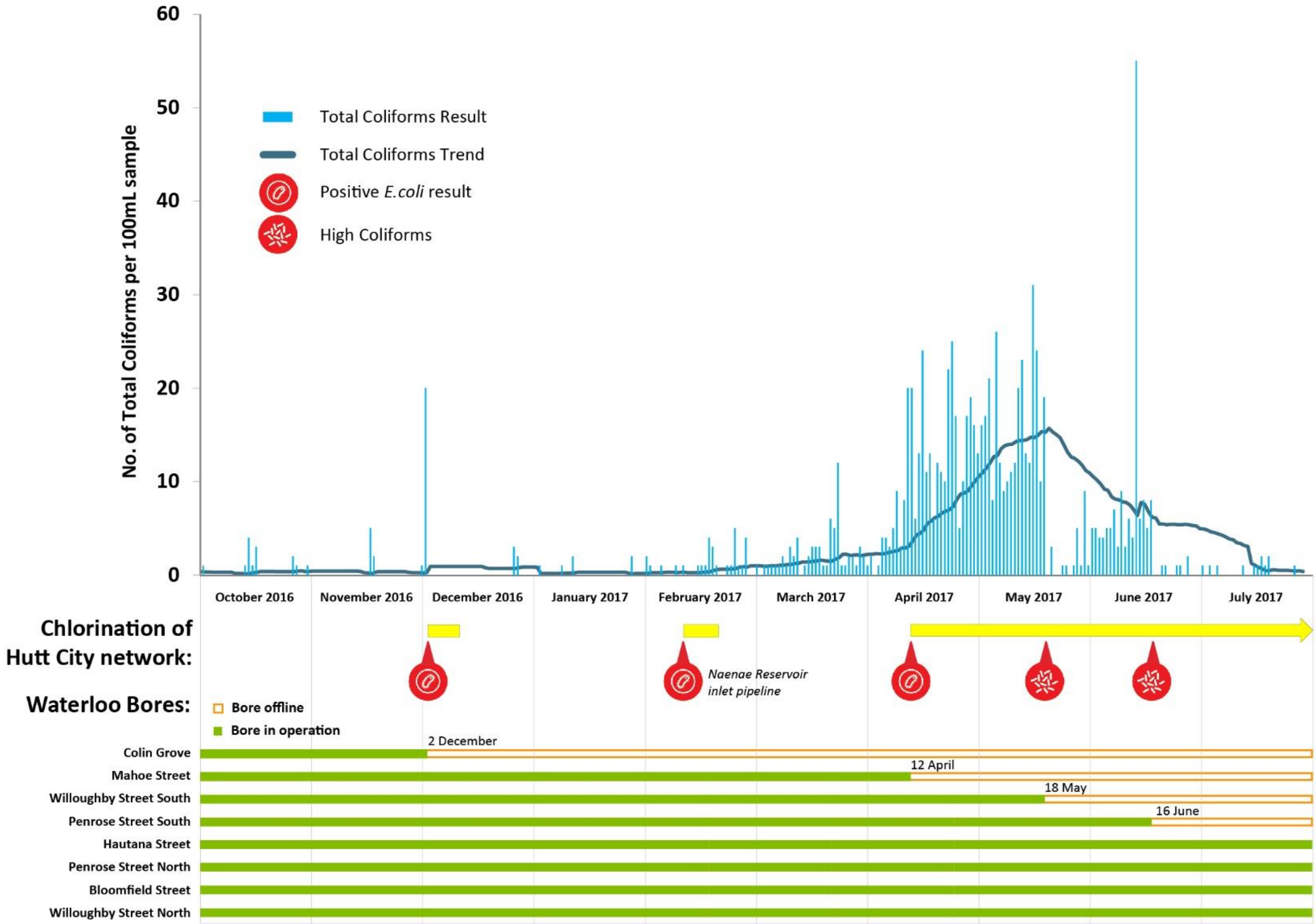

Figure 6 ***E. coli*** **and total coliform recordings – October 2016 to July 2017**

5. Source Investigations

Protection of the Waiwhetu Aquifer is under the stewardship of GWRC, and its primary protection tools are the planning controls it has under the RMA as discussed previously in Section 3.1.1.

Our investigations did reveal that there is some uncertainty regarding the condition of some the private bores and building piles that penetrate the aquitard and into the aquifer - in particular those built before the introduction of the RMA in 1991. Specifically, our Colin Grove investigations revealed that there are more than 50 private wells and/or building piles known to be penetrating the aquitard within one kilometre of the Colin Grove bore. There is also a distinct possibility that more might exist in similar proximities to the other seven bores in the Waterloo Wellfield. Further to this finding, and as discussed in Section 6.1, is the discovery that the hydraulic drawdown in the Waiwhetu Aquifer is far more extensive than previously anticipated. This suggests that there is a possibility that there might be a number of private bores and building piles located further afield that could also be potential sources of contamination as well. Therefore, it is possible that the source of the contamination could be linked to more than one private bore or building pile.

GWRC have a number of actions underway that are of relevance to our investigations. These are as follows:

- Waiwhetu Aquifer Science Study

  This study is investigating the recent changes to water quality in the aquifer. It will also seek to improve the knowledge of the aquifer and recommend potential improvements to decision-making and resource management practices. Investigation into the increase in total coliforms is expected to be undertaken as part of this study.

- Information and adaptive management approach

  GWRC are currently seeking to add to its information base on private bores, and to further develop its adaptive management practices.

With regard to the Waiwhetu Aquifer Science Study, and as noted below in Section 6, our review of the Colin Grove and Naenae Reservoir inlet main *E. coli* reports identified some activities that could be included in the scope of this study (or in its ongoing resource management activities), including:

- Undertaking inspections of non-community water supply bores
- Installing multi-level hydrostatic monitoring wells upstream of the Waterloo Wellfield.

Our investigations also identified that the GWRC resource management team may benefit from further information regarding drinking water standards, and that there might be opportunities for us to work more closely with this team on resource consent applications for activities that penetrate the aquitard.

5.1.1 Recommendations and Actions

In terms of water source protection, and the role we play in supporting GWRC as the steward of the Waiwhetu Aquifer, it is recommended that we:

- Support and provide resources for the Waiwhetu Aquifer Science Study
- Provide support to the GWRC resource management team on drinking water standards if needed
- Determine if any improvements can be made to existing processes with GWRC that might be of assistance to them when processing resource consent applications for activities that penetrate the aquitard.

We are also participating in the resource management hearings for the proposed Natural Resources Plan, including providing submissions on the importance of Waiwhetu Aquifer as a drinking water resource.

6. Asset Investigations

This section of the report briefly summarises our investigations on the Waterloo Wellfield following the Colin Grove and Naenae Reservoir inlet main *E. coli* test results. It is noted that the Mahoe Street bore positive *E. coli* test result has been subject to similar investigations.

6.1 Colin Grove *E. coli* Investigations

The first positive *E. coli* test result was returned from routine water sampling of the Colin Grove bore on 1 December 2016. Although this bore remains offline it has been given “provisional secure” status by RPH and therefore requires 12 months of intensive monitoring and negative *E. coli* results before it is brought back into service and secure status can be obtained.

Our investigations into this event are fully documented in the Colin Grove Report, which can be found in Part 2. The key findings of this report were presented to our 3 Waters Decision Making Committee on 30 March 2017.

Overall, the Colin Grove Report did not reach any definitive conclusions on the probable causes of the positive *E. coli* sample. The key investigations, and the status of the recommended actions in this report, are summarised below:

1. Assessment of the potential contamination of the water sample

Following the positive *E. coli* test result, we asked Eurofins ELS to confirm its sampling processes and to review the potential for contamination of the sample results. On 23 December 2016, they confirmed that all of the correct sampling procedures had been followed.

2. Detailed site inspection and testing of the wellhead

We undertook a detailed site inspection of the Colin Grove wellhead on Thursday 8 December 2016. The source of the contamination was not evident from the inspection. However, a number of possible locations that could potentially allow a small volume of contaminated water to enter were identified. We followed up our findings with a leakage test on 16 December 2016 and identified two minor leaks in the threaded portion of the power cable gland and at the sample valve. These leaks were sealed and the sample line was capped.

We subsequently undertook leakage testing of all of the bores in the Waterloo Wellfield between December 2016 and January 2017 to identify any faults, and to confirm that surface water could not be drawn into the well casings of the other bores. The inspections identified a number of areas where improvements to wellhead chamber security could be made generally. However, no items identified were considered to be the possible causes of the contamination.

This work has also identified that wellhead security would benefit from replacing the existing cable glands with more robust steel glands. Replacement of the cable glands will be completed in January 2018 when the aquifer pressures will be at levels that will allow for replacement. We do not believe this maintenance improvement is material to the positive *E. coli* test results.

3. **Review of the 2015 bore head security assessment (undertaken by H_2ope Ltd)**

A wellhead security check was completed by H_2ope Ltd[23] in July 2015. This security check was completed in support of our five-year bore security checks that are required to comply with the DSWNZ.

H_2ope Ltd recommended several remedial actions be undertaken following its inspection, which have been completed. However, as a consequence of this review, we identified the following additional improvements:

- Investigations into bentonite[24] levels undertaken in 2015 had shown that they were low, especially at the Penrose South bore (these were subsequently increased to the appropriate 420mm level). Bentonite levels were measured again in 2016, and had generally dropped to an average of 370mm. As such, we are now considering a further 'top up' of bentonite in the wellfield. Prior to 2015, bentonite inspections had not been regularly undertaken, but we are now carrying out annual inspections
- We plan to replace the plastic caps that cover the hydrant standpipe connections at the wells with aluminium sealing caps and gaskets to provide a more robust seal. This work will be completed shortly
- We need to confirm that 100-year flood levels are below the bore's air vent level (noting that the existing air vents are above ground). We will be using information recently collected by GWRC's flood protection investigation team to confirm flood and air vent levels. Notwithstanding this, the feasibility of relocating the non-return valves to a location below aquifer pressure is being assessed to further reduce risks (as well as the hydrant risk) by ensuring the delivery pipework is full of water when the pumps are shutdown
- We plan to install permanent non-return valves on the bore drawdown valves (that is, the 100 mm diameter valve branch on the well casings inside the wellhead chamber). Currently these non-return valves are only required when the drawdown pipelines are in use (and are manually attached by the operator)
- We are sealing the penetrations in the concrete floors at the Hautana Street, Penrose North, and Mahoe Street bores.

Some other minor wellhead security activities were also identified during the assessment. These activities are to be considered in more detail during the development of the regional water safety plan.

4. **Assessment of the potential for contamination of the wellfield collector main**

Under normal operation, the pressure in the Waterloo collector main is sufficient to prevent ingress of contaminant because it is under constant pressure from the Waterloo WTP Reservoir. It is only when the collector main is dewatered for maintenance purposes that there is an opportunity for ingress of contaminants at air valves and/or hydrants.

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[23] H_2ope Ltd now trades under the name of Lutra Ltd.

[24] Bentonite is a thick mud filler used to fill the void between the inner and outer casing of each well. It is naturally heavy and is used under the premise that its weight will seal any potential discrete pathways that may open in the aquitard as the well casing transitions through the aquitard layer.

The constant pressure maintained in the collector main, together with regular inspections, maintenance of the air valves, and appropriate shutdown procedures is considered sufficient to mitigate the potential risk of contaminants entering the collector main.

To this end, it is noted that prior to the *E. coli* test result, we had dewatered the eastern end of the Waterloo WTP collector main, but had kept the western end (where Colin Grove bore is located) charged. The Colin Grove Report concluded that this activity was highly unlikely to have been the source of any contamination.

5. Assessment of contamination from the fire hydrants or air valves on well delivery pipework

We assessed the possibility that the source of the contamination is due to the air valves and hydrant locations.

The risk of contamination exists when the well pumps are not operating and air is drawn into the pipeline between the aquifer pressure level and the non-return valve downstream of each well chamber.

As indicated above, the source of the contamination is highly unlikely to have been from the air valve vents (which are well above ground level in cabinets) or the hydrants. However, we are considering the feasibility of relocating the non-return valves to a location below aquifer pressure to eliminate this risk by maintaining this pipe section full of water. We also removed the fire hydrant located near the Willoughby South bore as a precautionary measure.

6. Assessment of the potential for contamination of the aquifer from upstream wells and piles

Our assessment indicates that further assessments of non-community water supplies and building piles that penetrate the aquitard needed to be undertaken. These assessments are to be undertaken by GWRC.

7. Liquefaction assessment caused by the Kaikoura Earthquake (by Tonkin and Taylor)

In late 2016, we had Tonkin and Taylor assess the likelihood of potential links between the liquefaction caused by the Kaikoura Earthquake and the positive *E. coli* test results. Their main findings were:

- Degradation of the aquitard at the Waterloo Wellfield due to liquefaction was unlikely
- Differential dynamic displacement between well and ground (stiffness of well and curvature of ground) forming an annulus between ground and outer casing was not considered a likely scenario
- Liquefaction or other ground damage is not expected at the level of the seal (base of the double casing), and site observations indicated that the bentonite was in satisfactory condition.

Based on the above findings, we do not believe that liquefaction was likely to have contributed to the positive *E. coli* result.

8. Assessment of potential effects of the Kaikoura Earthquake on the Waiwhetu Aquifer (undertaken by Pattle Delamore Partners (PDP))

PDP undertook an investigation into the likelihood that the Kaikoura Earthquake was a contributing factor to the positive *E. coli* result. Ultimately, this assessment was inconclusive as to whether the earthquake was a contributing factor. However, PDP's report did recommend undertaking the following actions (the status of the actions are denoted in italics):

- Camera inspections of each of the wells. *These inspections were ultimately determined not to be needed. This was because there was no evidence (such as, a material drop in bentonite levels) to suggest that the double casings of wells had been compromised and thus warranted further detailed inspection.*
- Closely monitor turbidity in the wells and compare readings with pre-earthquake measurements. *Monitoring of pre and post-earthquake turbidity was completed, and indicated that there were no significant differences*
- Obtain GWRC well data within a 1km radius from the wellfield and identify wells that are likely to penetrate the confining strata through to the Waiwhetu Aquifer, and carry out inspections of wellheads from the wells identified by the well search, in particular any within close proximity to the wellfield. *Action incomplete. This recommendation is however expected to be completed by GWRC*
- Review and consider any known damage to the stormwater or sewer networks in proximity to the wellfield. *Sewer and stormwater inspections of Wellington Water's network are currently underway in the Knights Road area (which is the priority area). To date, several sewer main faults have been identified (and nine repairs completed). One fault in the stormwater main has been identified and subsequently repaired. Inspections of the sewers and stormwater drains in the wider Waterloo Wellfield area are expected to be completed shortly. For avoidance of doubt, we are not inspecting private laterals.*

9. Assessment of the potential for downward hydraulic gradients at the bores (by PDP and Earth in Mind)

A desktop hydrological investigation was undertaken by PDP and Earth in Mind to better understand the effects of the downward hydraulic gradients at the Waterloo Wellfield. This is a situation when the water table pressure is higher than the aquifer pressure when the bore pumps are running. This situation could potentially result in downward flow paths that might draw contaminated water located above the aquitard into the aquifer.

PDP and Earth in Mind's investigations noted that while a downward vertical gradient potentially allows for the flow of water into the Waiwhetu Aquifer, it is expected that the aquitard's confining properties are unlikely to have changed as a result of the Kaikoura Earthquake. Therefore, the risk of water leaking through the aquitard (and into the aquifer) near the wellfield is unlikely to have changed following the earthquake, but cannot be completely ruled out as discussed in Section 6.5.1 below.

Further study of the zone of influence[25] for the localised drawdown effects was recommended by PDP and Earth in Mind. We subsequently undertook hydraulic modelling, which indicated that the downward hydraulic gradient is larger than first thought and potentially extends well beyond the Waterloo Wellfield. **Figure 7** sets out an indicative plan to help explain the potential extent of the negative vertical hydraulic gradients caused by pumping at the Waterloo Wellfield further.

[25] This is the area of the Waiwhetu Aquifer affected by extraction. It is approximately about 2.5 to 3 square kilometres, and is generally located underneath central Lower Hutt.

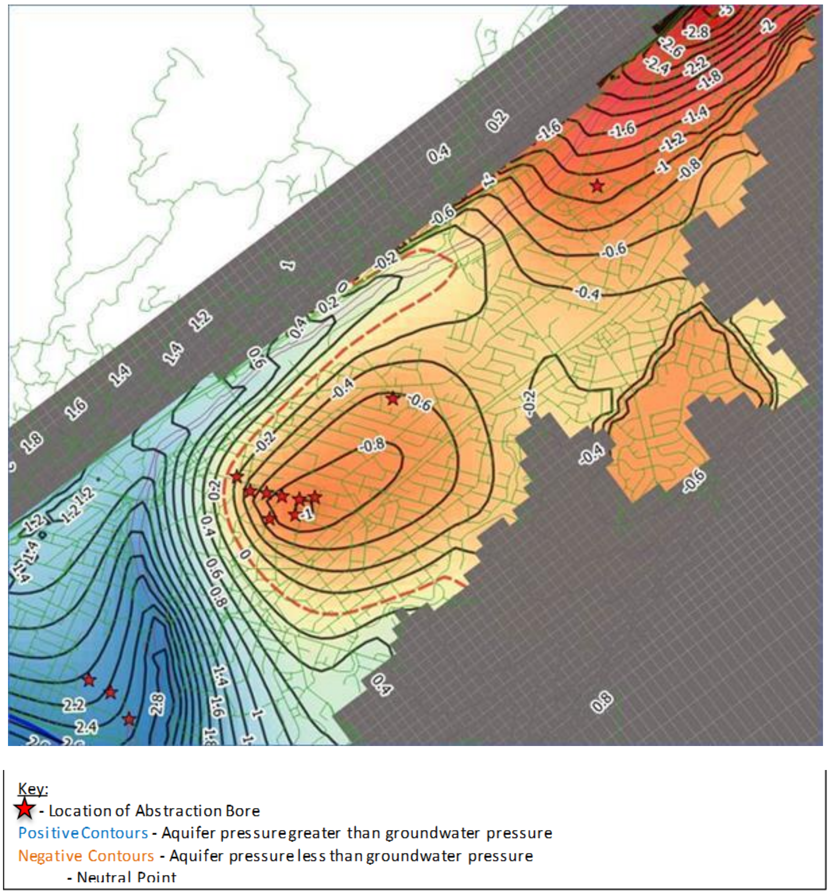

Figure 7 Potential extent of negative hydraulic gradients in Lower Hutt (north is up)

Both PDP and Earth in Mind also recommended that we consider installing pressure gauges and multi-level hydrostatic monitoring wells to further aid with the understanding of downward hydraulic gradients when the bores are pumping. It is noted that GWRC is installing multi-level monitoring wells at locations around the Waterloo Wellfield as part of the second stage of its Waiwhetu Aquifer Science Study. These wells will include equipment to measure the vertical hydraulic gradients as well as being capable of taking water quality samples from different depths. Following completion of the study, and if considered necessary, we will install pressure gauges.

10. Assessment of Waiwhetu Aquifer's water chemistry (by H_2ope Ltd)

H_2ope Ltd were asked to assess the water chemistry variation in the Waiwhetu Aquifer both prior to, and following the Kaikoura Earthquake.

Overall, the H_2ope Ltd assessment indicated that the Waiwhetu Aquifer's water chemistry is unlikely to have been affected by the Kaikoura Earthquake. However, localised effects may have had an impact on water quality at the Penrose Street North bore, and further investigations were recommended by H_2ope Ltd. These were subsequently completed.

11. Online monitoring trends of the Waiwhetu Aquifer and Colin Grove bore

We undertook a review of our online water data for the four weeks leading up to the positive *E. coli* result. Readings of pH, turbidity, conductivity, and temperature were steady, with the only unusual reading being a drop in nitrate levels from 0.80mg/l to 0.64mg/l, which was unrelated to the Colin Grove bore.

12. A review of historical bacterial test results for the Waterloo Wellfield

This involved assessing the historic bacterial results for the Waterloo Wellfield. As noted in Section 3.1.3, we started daily quantitative water sampling/testing for total coliform and *E. coli* directly from Waterloo Wellfield on 5 September 2016. For the three years prior to September, sampling had been undertaken from the Waterloo WTP collector main every second day and tested for presence or absence of total coliforms.

It is noted that for the three years prior to 5 September 2016, a total of 29 total coliforms had been detected in the 2,000 samples collected from the Waterloo WTP collector main. However, for the almost three-month period between 5 September and 1 December 2016, when 1,700 samples were collected under the new sampling regime, 19 total coliforms were detected. Most of the coliforms detected were in the range of 1 to 5 MPN/100mL, however, a sample taken from the Colin Grove bore on 24 September 2016 showed a very high total coliform reading of 613 MPN/100mL.

One observation from this review was the possibility that the presence of total coliforms, in the water drawn by the Waterloo Wellfield, had not significantly changed since construction of the bores in the 1980s, and that the recent upward trend that had been detected was due to increased sampling. However, and regardless of this observation, the fact remains that a high number of total coliforms along with *E. coli* have been recently detected in the water drawn by the bores.

13. Age Dating Report (by GNS Science)

In February 2016, GNS Science assessed the drinking water security of the Waterloo and Gear Island wellfields using groundwater age. Their report indicated that the age of the water drawn from the wells is greater than one year (which is in compliance with DWSNZ).

A recommendation to test the age of the aquifer water more frequently will be considered following completion of GWRC's Waiwhetu Aquifer Science Study. All of the other actions recommended by the GNS Science assessment have been completed, with the exception of the recommendation to site future water supply bores in locations that allow access to older water. This action will be undertaken as part of our planned wellfield replacement strategy as discussed below in Section 6.5.7.

6.1.1 Colin Grove Report - Overall Findings Review

Ultimately, the Colin Grove Report did not identify the possible source(s) of the *E. coli* contamination. The conclusions of the Colin Grove Report, along with our review of this report, are as follows:

- Collector main contamination from the earthquake is unlikely
- Contamination via the sampling process is unlikely, but can't be completely ruled out
- Wellhead penetration leakage testing identified a slight contamination risk (all leaks were subsequently confirmed as watertight)
- The bore head security assessment of the Waterloo Wellfield indicates that bore heads are unlikely to be the source of contamination

- Contamination of the Waiwhetu Aquifer due to upstream piles or non-community water supply bores upstream is possible. It is noted that GWRC is considering this risk in more detail
- Inspections of nearby sewer and stormwater mains indicated that faults existed, which is not an unusual situation (these leaks are either repaired or repairs are underway)
- There is a general catchment contamination risk due to the following:
  - the relatively shallow depth of the Waiwhetu Aquifer
  - the relatively young age of water in the aquifer
  - the likelihood of localised drawdown induced by the downward flow gradients near the wellfield. The downward gradients might be drawing surface water along the outer well casing into the aquitard. However, the outer casing terminates within the aquitard, and so drawdown of contaminants into the aquifer itself is considered unlikely.
- Analysis of the aquifer water quality and online monitoring trends (as of December 2016) did not indicate that there was a drawdown of water above the aquitard into the aquifer. In addition, there was no significant decrease in the bentonite levels within the outer casing to suggest disruption of the well casing/aquitard interface.

It is noted that the downward hydraulic gradient risks were discussed at the 3 Waters Decision Making Committee on 30 March 2017. The Committee ultimately identified that there was a need to collaborate with our client councils to help further their understanding of the risks to the aquitard from urban development/intensification. Modelling of the drawdown induced hydraulic gradients was also recommended, which was subsequently completed as discussed earlier in this section.

6.1.2 Colin Grove Report – Status of Ongoing Actions

The status of the actions that are in progress are as follows:

- The feasibility of relocating the non-return valves to a location below aquifer pressure is being assessed, and this will maintain the delivery pipework full of water when the pumps stop
- Replacing hydrant caps with more robust aluminium caps and sealing gaskets is in progress
- Sealing the penetrations of the concrete floors of the Hautana Street, Penrose North and Mahoe Street bores is underway
- Sewer and stormwater investigations and repairs are progressing, and are expected to be completed shortly.

6.2 Naenae Reservoir Inlet Main *E. coli* Incident Report

This positive *E. coli* test result[26] was taken from the inlet pipeline to the Naenae Reservoir on 4 February 2017. This result is significant for the Waiwhetu Aquifer because the Waterloo WTP connects directly to this pipeline. We immediately chlorinated the water supply from the Waterloo WTP for three consecutive days following receipt of the result, and manually dosed the Naenae and Rahui Reservoirs. Ultimately, our investigations into the possible sources of contamination at the Naenae Reservoir were inconclusive.

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[26] The result was >=1/100mL. This result was based on the presence/absence sampling test method.

A summary of the key findings of the Naenae Reservoir Inlet Main Report are described in this section.

6.2.1 Water Source (i.e. Waiwhetu Aquifer)

Our assessment referred to the findings of the Colin Grove Report on the possible effects of the Kaikoura Earthquake, noting in particular that it was unlikely that the earthquake had damaged the aquitard. With respect to the water source, no further actions were recommended.

6.2.2 Bore Heads

Our assessment referred to the wellhead security checks undertaken in support of the Colin Grove Report, and noted that no material issues had been identified by these security checks. With respect to the bore heads, no further actions were recommended.

6.2.3 Waterloo Water Treatment Plant Outlet

Our assessment concluded that the presence of total coliforms in the Hautana Street bore, and at the outlet of the Waterloo WTP on the day of the positive *E. coli* test result, tended to suggest that the contamination might be coming from the water source rather than the treatment plant. With respect to the outlet, no further actions were recommended.

6.2.4 Naenae Reservoir

We inspected the Naenae Reservoir on Saturday 4 February 2017. No issues with the security or integrity of the reservoir were identified at the time. We also identified that there was no backflow from the Naenae Reservoir into the inlet main.

6.2.5 Contamination of the Sample

Following the incident, we asked Eurofins ELS to confirm its testing processes. It confirmed that there were no abnormalities with its sampling processes. However, our assessment at this time did make a general note that sample contamination can never be completely ruled out.

The report recommended that a study into total coliforms be undertaken. As noted in Section 5 above, this study is expected to be incorporated into the Waiwhetu Aquifer Science Study.

6.3 Waterloo Wellfield and Collector Main - Water Quality Security Report - June 2017

The Water Quality Security Report summarises the status of our investigations into the condition of the Waterloo Wellfield's physical assets as at June 2017 (and can be found in full in Part 2). Overall, this report did not reach any definitive conclusions on the probable sources of the water quality contamination. It did identify some areas where improvements could be made to wellhead chamber security more generally; however none of these areas are considered to be linked to the causes of the contamination.

As part of developing this report, we requested Griffiths Drilling (NZ) undertake an independent inspection of the Waterloo wellheads (which they completed on 16 June 2017). Their written report, which documents its inspections, examination of the bentonite levels, review of the current inspection regimes and advice on the likelihood of contamination from the wellheads, is attached as an appendix to the Water Quality Security Report.

Overall, the 'Griffiths Report' found that the bores are generally well maintained and are in good operational condition. A summary of the proposed actions from the Griffiths Report are as follows:

- Investigate water ingress into the well chambers, including testing the slime and mould build up
- Adjust the sump pumps to the correct activation levels to avoid build-up of water on the base of the chamber
- Investigate options for sealing the well chambers to eliminate the risk of contaminant ingress, such as using epoxy compounds, or raising the wellhead above ground level
- Pressure test all wells to further assess the integrity of the wells, and to identify any leaks in the wellheads, and include:
  - pressure testing as a regular maintenance procedure to be undertaken as soon as any ground movement occurs, such as an earthquake
  - steam cleaning the wellheads.
- Investigate the corrosion of the flanges, with the steel integrity to be tested to ensure excessive pitting has not occurred
- Take bentonite level measurements for both hydrated and un-hydrated levels in the future.

Some of the actions recommended by Griffiths have already been completed, such as pressure (leakage) testing of the wellheads. The remaining actions are to be completed in the near future. Overall, the actions listed above are not considered material to the causes of the water quality contamination.

6.4 Age of the Waterloo Wellfield Infrastructure

During the development of this report, it was identified that the design life of a bore is typically around 30 years. As noted in Section 2, six of the bores in the Waterloo Wellfield were built in 1980 (making them 37 years old) and two were built in 1989 (making them 28 years old). We discuss the implications of the age of the bores in the following section.

6.5 Discussion

The following section further considers the results of the asset investigations discussed above.

6.5.1 Design to Prevent Discrete Pathways Around Well Casings

The Waiwhetu Aquifer itself is a mix of artesian gravels that can be characterised as "dense sandy gravels with some silt". These gravels are typically found at a depth of 20 metres and provide sufficient transmissivity for water to flow underground.

Given that the aquitard is reasonably "thin" we asked ourselves: *What mechanisms are in place to prevent groundwater tracking down into the aquifer between the aquitard and interface with the well casing?* It is noted that the main mechanism utilised to prevent water tracking down each bore's duel casing is the bentonite. **Figure 8** shows the location of the bentonite in the well casings.

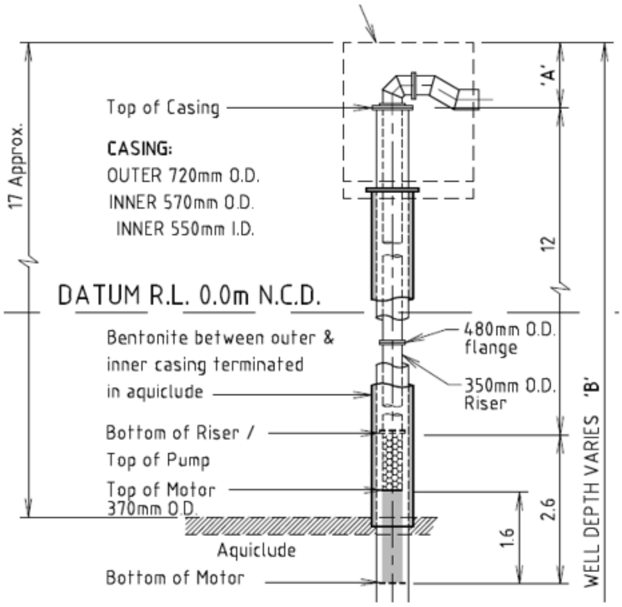

Figure 8 Bentonite location in the well casings (Extract of 1980 well design from drawing A3-10161-BS)

The outer casing of the well terminates at the aquitard, with a smaller well and associated casing drilled through the aquitard and into the Waiwhetu Aquifer. The void between the two casings is then filled with bentonite in order to prevent water tracking between the two well casings, and to plug any fissures that may develop between the aquitard and the casing of the well.

Bentonite is the main method of identifying and "plugging" any discrete pathways for water in each well's inner-casing. However, its effectiveness for plugging such pathways is uncertain due to various factors, including measurement sensitivities associated with human error. Accordingly, it is not possible to guarantee that the bentonite has plugged all of the possible pathways for contaminated water to travel. Furthermore, as noted in Section 6.1, the first bentonite inspection for the bores was only undertaken in 2015, which creates further uncertainty regarding the effectiveness of the bentonite in each well (as there is insufficient data to draw any material conclusions).

The Colin Grove Report highlighted that pumping from the wells induces a downward vertical gradient that could potentially allow for the flow of surface water into the Waiwhetu Aquifer. Whilst it is largely accepted that the risk of this occurring is likely to be the same prior to, and after, the Kaikoura Earthquake, there still remains a risk that there might be a discrete pathway near the well casings for contaminated water to enter the aquitard.

Based on the Colin Grove Report, it appears that the original well design used appropriate methods for managing the interface between well casing and the strata, thus preventing contaminated surface water ingress into the Waiwhetu Aquifer through discrete pathways. However, there is also sufficient evidence to suggest the following:

- There is no *certain* way to monitor for changes in the aquitard immediately surrounding each well, especially after an earthquake
- There is a *residual risk* that small changes have occurred in the aquitard immediately surrounding well casings that cannot be detected

- There is a *residual risk* that bentonite will not plug all discrete faults immediately around the interface between inner and outer well casings.

On balance, we believe the security of the aquitard around each well casing cannot be guaranteed to prevent groundwater intrusion. Furthermore, there is no definitive preventative measure that can be put in place that will guarantee such security.

6.5.2 Design to Prevent Groundwater Entering the Well Casing

During development of this report, we considered the possibility that the layer between the inner and outer well casing might be compromised, and therefore could provide a possible pathway for contaminated groundwater.

A historic failure at the Gear Island bore (where a hole developed in the inner casing) was ultimately detected through turbidity and presence of bentonite in the water extracted from the Waiwhetu Aquifer. This in turn demonstrated the effectiveness of bentonite for detecting large casing faults. However, this particular failure also demonstrated that the outer casing remained intact, therefore protecting the well from drawing in groundwater.

The Gear Island bore example suggests that any undetected cracks that might develop in the well casing are likely to be below the aquitard, and therefore would be associated with the inner casing of the well. Cracks in this position could draw in water from the Waiwhetu Aquifer itself, but this situation would be below the confining layer of the aquitard.

On balance, we believe there is a high degree of confidence that the well casings (to at least the bottom of the outer casing and some immediate depth thereafter) are secure due to the design of the well and casing system. Such design should prevent groundwater from being drawn into an operating well, provided that there are no discrete pathways for groundwater (located near the surface) to travel into the aquitard. If discrete pathways do exist, then groundwater can be drawn into an operating well.

6.5.3 Design to Prevent Groundwater Entering the Collector Main

The Waterloo WTP collector main runs at a pressure of approximately 10 metres, as a consequence of the Waterloo Wellfield pumping system. When the pumps are off, pressure from the reservoir inside the treatment plant maintains the pressure in the collector main. This means that it is highly unlikely that negative pressure might develop in the collector main, and draw in contaminated water from the surrounding environment.

Accordingly, we asked ourselves: *Can groundwater be drawn into the collector main through normal operation?* On balance, we believe this is very unlikely. And if it was occurring, contamination would be detected at the collector main sampling point and not the wellhead.

6.5.4 Buried Services Risks

CCTV inspections of our sewer and stormwater systems in the Knights Road area are nearing completion.[27] The inspections completed to date have identified several faults in both systems (which is not unusual). Most of these faults either have been fixed or will be in the near future. It is noted that despite most of the faults being fixed, total coliform results have continued to increase

[27] For avoidance of doubt, these inspections have not included inspections of buried services located on private properties (e.g. private sewer laterals).

after completing many of the repairs. Further, sampling has indicated that coliforms are likely to have originated from groundwater near the surface rather than from a leaking sewer system.

Accordingly, we asked ourselves: *Could leaking buried services be a potential cause of contamination?* On balance, we believe that our sewer and stormwater pipes are not likely to be the source of contamination, and if sampling had revealed that these pipes were a problem, then a discrete pathway through the aquitard must exist.

6.5.5 Maintenance Procedures

Routine maintenance can provide an opportunity for contaminated equipment to make contact with wellhead and pipe systems. As this contamination risk cannot be eliminated in its entirety, our maintenance procedures require a run-to-waste process to be undertaken following any disassembly or service outage. This process involves flushing the inside of the well by pumping water (from inside the well) through the nearby fire hydrant point and onto the street.

Accordingly, we asked ourselves: *Could maintenance procedures be a potential source of contamination?* On balance, we believe there is a very low risk that our procedures were the source of the contamination. It is noted that chlorine is not added to the flushing procedure between the bore and when the collector main is opened. Therefore, it is possible that some residual contaminant might still remain within the wellhead where vorticities in the water may have prevented a perfect flush. However, the probability of this occurring is considered extremely low.

6.5.6 Sampling Processes

We note that the Eurofins ELS field technician responsible for the collection of the positive *E. coli* samples has extensive field experience, including collecting samples from the Waterloo WTP collector main. As such, it is unlikely that positive *E. coli* results were due to lack of experience in the sampling process.

During our investigations, we confirmed that gloves aren't normally worn during field sampling because if the sampler interferes with the inside of the sampling container, or the water collected, the sample is immediately discarded.

It is noted that following the Colin Grove and Naenae *E. coli* incidents, we asked Eurofins ELS to review their testing procedures for both samples. As identified in each respective investigation report, Eurofins ELS confirmed that no abnormalities in their testing processes had been discovered.

Accordingly, we asked ourselves: *Could contamination be introduced as a result of human factors during sampling?* On balance, we believe this is unlikely, but it cannot be entirely ruled out. It is noted however that the continued increase in total coliforms readings over the past six months (at multiple bores) supports this conclusion.

6.5.7 Equipment at the Point of Sampling

We collect samples from a sampling tap located in an above ground cabinet. Samples must be collected using a sampling pump if the main well pump is off. Regardless of whether the main well pump is on or off, water collected from the sampling tap is always passed through the same plumbing.

Sampling taps are flushed for two minutes before each sample is taken. However, the taps themselves are not "environmentally sealed" and are therefore susceptible to possible contamination during the sampling process. As such, it is possible that the lack of "environmental tightness" of the cabinet might be a source of contamination. It is also possible that contamination could enter the sampling line and equipment, and not actually be present in the well itself. However, total coliform readings at each bore have been observed at the Waterloo WTP collector main, and this supports the assessment that the source of the coliforms is not a result of faulty sampling equipment.

6.5.8 Design Life Implications

As noted above, the typical design life for a bore is 30 years. As such, we asked ourselves: *Could the age of the Waterloo Wellfield bores be a contributing factor?*

Well assets comprise a number of mechanical and electrical components, which are maintained in varying states and capacities over the life of the well. Almost all components are ultimately accessible for replacement except for the outer well casing, and to some degree, the inner well casing.

Since the bores were constructed in the 1980s, they have been disassembled and rebuilt at various times, and the insides of their inner casings have been regularly inspected. The mechanical and structural components of the bores that are located "above ground" are generally accessible for observation, cleaning and/or replacement.

Ultimately, for an asset to be approaching its end-of-life there has to be some substantive and ongoing deficiency to justify its replacement (for example, whole-of-life costs have increased significantly). On this basis, we can make the following observations regarding the bores in the Waterloo Wellfield:

- The well chambers are located underground with a single point of access. They are therefore classified as a 'confined space' from a health and safety perspective, which adds to both the complexity and cost to undertake inspections and maintenance activities
- The design of the well structures below ground, and the associated chamber, may not meet modern assurances or requirements for environmental performance including:
  - Eliminating moisture in the environment
  - Being above long-term flood levels
  - Being sufficiently protected from external contaminants
  - Maintaining long-term asset condition
  - Accessing components for maintenance
  - Seismic performance against modern building standards.

With the possible exception of the seismic performance criteria, whilst the above factors contribute to increasing maintenance costs, they do not indicate that the wells are at their end-of-life. In addition, there is no equipment failure to suggest that replacement is required.

Whilst there is no single design standard for the life of a bore, it is commonly accepted that they have a design life of around 30 years. As such, we plan to develop a wellfield replacement strategy, with a view to progressive replacement of the wells.

6.5.9 Summary of Risks

Figure 9 and **Table 2** summarise the possible sources of contamination risk from a bore perspective. The most likely sources of contamination are as follows:

- The possible existence of discrete pathways for water to travel into the aquitard
- The possible existence of discrete pathways in the aquitard near the well casing
- The bentonite in the well casing is not flowing efficiently and filling voids
- Buried services leaking contamination into groundwater
- The above ground urban environment is affecting the performance of the well equipment.

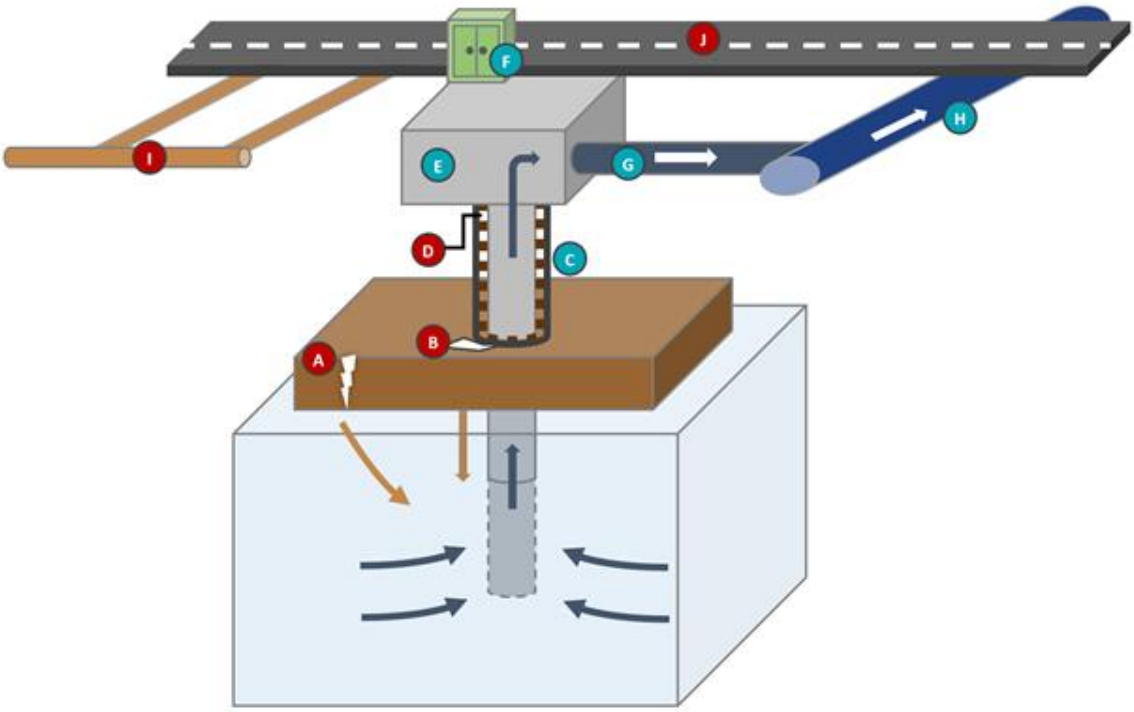

Figure 9 Location of possible wellhead contamination risks

Table 2 Analysis of possible wellhead contamination risks

Diagram Label	Possible risk	Can this risk exist?	Is this a contamination risk?	Can it be eliminated or managed?	Objective Contamination Risk
A	Discrete pathways in the aquitard	Yes	Yes	No	Residual Risk
B	Discrete pathways in the aquitard near the well casing	Yes	Yes	No	Residual Risk
C	Outer casing could be compromised	Yes	No	Yes	Unlikely Risk
D	Bentonite in the well cases is not flowing efficiently and filling voids	Yes	Yes	No	Residual Risk
E	Well head not adequately sealed	Yes	Yes	Yes	Unlikely Risk
F	Contamination introduced in sampling cabinet	Yes	Yes	Yes	Unlikely Risk
G	Well head pipework and valves not adequately sealed or performing correctly	Yes	Yes	Yes	Unlikely Risk
H	Collector main pipework and valves not adequately sealed or performing correctly	Yes	Yes	Yes	Unlikely Risk
F-H	Maintenance procedures allow contamination to enter collector main	Yes	Yes	Yes	Unlikely Risk
I	Buried services leaking contamination into groundwater	Yes	Yes	No	Consequence of 'Risk A' being present
J	The above ground urban environment is affecting the performance of the well equipment	Yes	Yes	No	Consequence of 'Risk A' being present

7. Peer Reviews

Mr Anthony Wilson and Professor Colin Fricker have independently reviewed our investigations, including the Colin Grove and Naenae Reports.

Both Mr Wilson and Professor Fricker are recognised water quality experts in New Zealand. Mr Wilson is a member of the Havelock North Drinking Water Inquiry's Panel, and Professor Fricker is providing expert advice to the panel.

The comments and findings of each peer review are attached as **Appendix 1** to this report, and are summarised below.

7.1 Anthony Wilson Review

Mr Wilson identifies the following matters in his review:

- **Regulatory context**

  There is a risk that the DWA may come to the conclusion that the aquifer cannot be regarded as secure and downgrade the status of all wells. This is because of the significant increase in total coliforms detected; the three positive E-Coli results; the relatively shallow depth of the aquifer; the thin aquitard (only one metre); the relatively young age dating of the water (over one year); and a greater understanding that in close proximity to the well casings there is a significant downward hydraulic flow gradient when the pumps are running.

  If this were to occur with the existing treatment at the Waterloo WTP, Wellington Water would then not be able to meet the requirements of DWSNZ for the water from the plant.

  It is recommended close liaison be maintained with the DWA to manage this risk.

- **Drinking-water Standards for New Zealand**

  The current standards - DWSNZ 2005 (revised 2008), are now over ten years old (the 2008 update was relatively minor amendments) and are based on science and practice that is at least 15 years old. In particular there are two matters relevant as follows:

  a) **Secure Status of Groundwater**

     The 2015 Australian and the 2011 Canadian standards (both of which were based on DWSNZ) take the pragmatic view that there is no such thing as a 'secure' groundwater source, except in exceptional circumstances subject to much more rigorous criteria than apply in NZ. They note that whereas it is theoretically possible to have secure groundwater, it is not so in practice, given the inevitable heterogeneous nature of any geologic formation including aquifers, and the realities of human modification of the environment. The USA and German standards can be interpreted to take the same stance.

     This position is well demonstrated by the existence of more than 50 known (and the possibility of more unknown) penetrations of the aquitard within 1km of the Colin Grove well.

Minute 8 issued by the Havelock North Drinking Water Inquiry, which sets out the matters to be investigated in Stage 2 of the Inquiry, makes specific reference to the need to examine this aspect of the current standards. Without predetermining the outcome of the Inquiry, one possibility is that any review of DWSNZ may adopt the Australian and Canadian position.

If this were to be the case, a return to the status quo at Waterloo WTP would no longer be an option.

b) Ultra Violet Light Efficacy on Protozoa

Scientific understanding of the effectiveness of UV on protozoa has advanced since the current DWSNZ was adopted. In simple terms, UV at low doses has been found to be much more effective than recognised in the standards, however DWSNZ 5.16.1 does allow a log credit of up to 3 log provided the reactor 'has been validated to achieve (up to 3 log) following the procedures and requirements specified in *Ultraviolet Disinfection Guidance manual (USEPA 2006b).* Further information on validation is given in 5.16.2 of the standard.

Without a detailed understanding of this equipment (i.e. the recently purchased UV equipment), it is possible that its validation was to a more recent standard than the USEPA 2006b standard then this may not be recognised by the current DWSNZ. If so, this raises the possibility of a technical non-compliance, and may require agreement with the DWA to recognise the validation certified in the first instance.

- **Below Ground Wellhead Facilities**

  The wellheads in the Waterloo field are below ground. This introduces an additional (and avoidable) risk of contamination.

  There is no mention of whether the water levels in the wellhead sumps or the operation of the sump pumps intended to remove any water entering the sumps are monitored by the supervisory control and data acquisition (**SCADA**) network. If they are not, it is recommend that such monitoring be installed as a matter of urgency, and that they have sufficient battery back-up to allow continuous monitoring in the event of power failure, a particularly high risk situation.

  It is possible that a future review of DWSNZ may require the progressive removal of below ground wellheads, and any well replacement strategy should take into account both the risks inherent in this form of construction and the possibility of a regulatory change.

- **Backflow**

  Backflow and back siphoning events are more common than most water suppliers and consumers realise or acknowledge.

  They represent a particular risk to a water supply which has no residual disinfectant in the water in the reticulation. This residual disinfectant is usually chlorine.

  There is another advantage in having a chlorine residual in that, if the residual is monitored, this can provide early warning of contamination in the network. Where there is a chlorine residual it is good practice to always measure the residual concentration when taking a sample. The result is instantaneous and if there is no residual, action can be initiated without having to wait 24 hours for the test result.

It is also possible to monitor the chlorine residual continuously, giving real time insight into what is happening within the reticulation.

- **Summary and recommendation - UV with chlorine treatment**

  In summary, UV and chlorine is considered the best option. Given the very low turbidity of the source water it will be an affordable, very effective and a highly reliable option that gives a high degree of confidence in the safety of the supply under all circumstances.

  A risk with this option is that, provided the equipment is sized correctly, it will provide satisfactory barriers to all three pathogen types. But if the source is determined not be secure, and to have a protozoa risk, then it may not satisfy the exact criteria of the current DWSNZ (depending on the validation certified).

  This risk only exists however if:

  - The source is deemed to be not secure
  - The source is assessed as being at risk of protozoa
  - The equipment has not been certified by USEPA 2006b.

  The risks associated with the current regulatory framework should be discussed with the DWA, and whereas it is recognised that they need to comply with the current regulations, the source has not yet been determined not to be secure (and it may not ever be), any proposal to provide additional barriers should be well received.

7.2 Colin Fricker Review

Professor Fricker's review is summarised as follows:

- **General**

  A much more in-depth study of the available data would be required to draw firm conclusions about the condition of the aquifer, the risk to public health, and the recommended treatment options. This would require a more in-depth look at monitoring data over a five to ten year period.

  The report mentions that Wellington Water has attempted to determine the causes of the positive *E. coli* results from the raw water. That is an impossible task given the low numbers of positives and the fact that the positives came from different sites. My sense is that there have been total coliforms present in the raw water for a considerable period despite the absence of *E. coli.* My interpretation is that the aquifer has not been (if it ever was) "secure" for many years. The whole concept of a secure groundwater is one that I and many other water professionals (including hydrologists) would question. Certainly the requirements of DWSNZ for demonstrating "security" would not be condoned by many, particularly the concept of water age testing every five years in a country with so much seismic activity. To that end, I would not consider any water system in New Zealand to be "secure" at this point in time, and I believe that it would take an extremely detailed study to demonstrate security. The USEPA groundwater rule would require much more monitoring to be performed, as well as sanitary surveys every time coliforms are detected in the raw water.

The presence of coliforms in the raw water demonstrates that the aquifer is impacted by surface water, but in the absence of *E. coli* detections then one might argue that the surface water was not contaminated with faecal material. There have now been a small number of *E. coli* detections and this has shown that there is some degree of faecal contamination (assuming that these organisms were truly *E. coli*. There are some non-*E. coli* coliforms that have been shown to produce ß-D-glucuronidase) albeit at apparently a low level. Regular monitoring with larger volume samples would determine the true frequency of faecal contamination.

The real issue is the safety of the raw water and whether or not it is making people sick when it is not disinfected. The answer to that question can be derived by two types of study, a Quantitative Microbial Risk Assessment (**QMRA**) and an epidemiological study. Typically, QMRA studies involve intensive sampling and testing for pathogens including bacteria, viruses and protozoa. Each pathogen group has different survival and transport characteristics. These studies are expensive and can take years to complete, and I am not advocating that a true QMRA study be undertaken. However, I do believe using the data currently available, together with some targeted monitoring, that a good assessment of the safety of the groundwater can arrived at.

Epidemiological studies are notoriously difficult and expensive to undertake. Given the fact that Wellington has different areas that receive treated and untreated groundwater, it may be possible for the medical profession to investigate the incidence of gastrointestinal disease in these different zones. That possibility should be investigated.

- **Summary**

  Groundwater sources where there is clear evidence of surface water infiltration should be treated with UV designed to inactivate protozoa, viruses and bacteria. The only question that remains then is whether to chlorinate to maintain a residual in the reticulation system. The required analyses has not be undertaken to provide a detailed answer to that question. However, there have been many bacteriological positives in the non-disinfected reticulation system. The important question there is whether the organisms concerned were in the raw water or whether they originated from ingress. If it can be shown conclusively that they originated in the raw water then it may be possible to arrive at the conclusion that a residual disinfectant is not required. However, proving the origin of the organisms is usually not easy. The safest treatment option is to treat the water with UV and then add a chlorine residual to protect against downstream contamination. World's best practice would be to include both forms of disinfection.

  In summary:

  - The aquifer is impacted by surface water which probably has a low faecal content
  - The risk of a disease outbreak is low at this point in time but that could change at any time
  - Most water professionals with expertise in this area would not deem the aquifer to be secure

- World's best practice would be to use UV (most likely medium pressure) plus chlorine.

7.3 Wellington Water responses

Table 3 sets out our responses to Mr Wilson and Professor Fricker's key recommendations.

Table 3 – Wellington Water's responses to the key recommendations of the peer reviewers

Recommendation	Peer reviewer's comments	Wellington Water response
Liaison with DWA (Mr Wilson)	Recommends close liaison with the DWA.	Agreed. We have a close and well established working relationship with the DWA.
Monitor water levels (in the wellhead sumps or sump pumps) with SCADA (Mr Wilson)	SCADA monitoring should be installed with sufficient battery back-up.	Agreed. A SCADA system was installed in July 2017.
Monitor residual chlorine (Mr Wilson)	Chlorine residual monitoring can provide early warning of contamination in the network and provides real time insight into what is happening within the reticulation.	Agreed. We currently monitor chlorine residual in the reticulation system. If chlorination becomes permanent, we will review sampling locations and frequency.
Confirm UV equipment compliance with DWSNZ (Mr Wilson)	Confirm that the UV equipment purchased for the Waterloo WTP complies with DWSNZ	Confirmed. Expert advice has confirmed that the UV equipment complies with DWSNZ.
Consider residual chlorine to the reticulation system (Professor Fricker)	Investigate this option.	Chlorine is currently in the reticulation system, and monitored as set out above.
In-depth study of the condition of the Waiwhetu Aquifer (Professor Fricker)	More in-depth studies of the available data are required to draw any firm conclusions about the condition of the aquifer, the risk to public health, and the recommended treatment options. Quantitative Microbial Risk Assessment and epidemiological studies are recommended.	GWRC's Waiwhetu Aquifer Science Study is underway. Any decisions on future studies on the aquifer will be made following completion of GWRC's Waiwhetu Aquifer Science Study.

Ongoing treatment for waterborne pathogens (Both Mr Wilson and Professor Fricker)	The best treatment option is UV and chlorine dosing	Agreed. This recommendation is consistent with the ultimate recommendation of this report. We have considered a range of treatment options, including: 1. Return to pre *E. coli* detection state (no chlorine) 2. Continue to chlorinate only 3. UV disinfection only (no chlorine) 4. UV disinfection with chlorine. Our selection of Option 4 (UV and chlorine) was premised on ensuring that safe and healthy drinking water would continue to be provided to our Hutt City customers, it would ensure compliance with the DWSNZ, as well as being cost efficient.

8. Conclusion and recommendation

Results of our Waterloo Wellfield Water Quality Contamination Investigations highlight that the water supplied from the Waterloo WTP may be vulnerable to microbiological infections in the future. Ultimately, however, the conclusions of our investigations into the possible sources of *E. coli* are inconclusive – that is, no specific source of contamination has been identified.

Despite this overall conclusion, the detection of *E. coli* on three separate occasions, along with the increasing trend of total coliforms since February 2017, indicates that there is a concerning change in the quality of the water being drawn from the Waiwhetu Aquifer by the Waterloo Wellfield bores and processed by the Waterloo WTP. This change is an indicator that another bacterial event might occur, and therefore appropriate mitigation measures need to be put in place.

In summary, this report has identified the following:

- Our investigations into the condition of the bores and associated assets have shown that they are unlikely to be the source of the *E. coli* contamination
- Our investigations did identify that some minor improvements could be made to the bores and assets. These improvements either have been completed or are in the process of being completed. However, we do not believe that these improvements are material to the source of the *E. coli* contamination or the high total coliforms
- The 'shaking effects' of the Kaikoura Earthquake are unlikely to have be a contributing factor to the *E. coli* contamination
- There is a possibility that the water in the aquifer itself might been contaminated. In particular, there is some concern that poorly constructed (or maintained) non-community water supply bores or building piles that penetrate the aquitard might be potential sources of contamination.

We have sought independent expert advice on the results of our investigations, and on our recommendations to be put forward for consideration by GWRC and HCC. Both independent experts advise that they believe there are public health and safety risks associated with water that is sourced from aquifers which is not subsequently fully treated for waterborne pathogens. They recommend that the water supplied by the Waterloo WTP should be treated through a combination of chlorine and UV in order to protect the water supply against waterborne pathogens.

It is noted that the findings of Stage 1 of the Havelock North Drinking Water Inquiry, and the early themes of the submissions from Stage 2, also suggest there is uncertainty associated with any water that is sourced from aquifers which is not subsequently fully treated for waterborne pathogens.

Significant risks

Our investigations into the possible sources of the *E. coli* contamination and increase in total coliforms have not drawn any definitive conclusions. However, they have identified that there are significant risks that can't be eliminated or effectively managed if we continue to supply drinking water from the Waiwhetu Aquifer without fully treating it for waterborne pathogens at the Waterloo WTP.

Our priority is to continue to provide safe and healthy drinking water to our 74,000 Hutt City customers who normally receive unchlorinated water. We therefore, and after consideration of different treatment options, recommend that we continue to chlorinate the drinking water supplied from the Waterloo WTP, and to also treat it with UV, in order to manage the waterborne pathogen risk. We consider this recommendation to be in accordance with international best practice.

Finally, the *gastroenteritis* event in Havelock North in late 2016 demonstrated the risks associated with supplying drinking water that is not fully treated against waterborne pathogens. By treating the water supplied by the Waterloo WTP with chlorine and UV we are ensuring our Hutt City customers, who had been previously receiving unchlorinated drinking water, can continue to receive safe and healthy drinking water into the future.

8.1 Recommendation

In summary, this report's key recommendations are as follows:

1. Continue to chlorinate the water supplied by the Waterloo WTP as well as treating the water with UV. It is noted that further investigations into upgrading of the Waterloo WTP chlorination dosing system, the installation of run-to-waste systems (to comply with the Drinking Water Standards NZ), and the associated ongoing maintenance requirements will be needed.
2. Support and participate in the Waiwhetu Aquifer Science Study.
3. Consider Professor Fricker's recommendation to undertake Quantitative Microbial Risk Assessment and/or epidemiological studies at the appropriate time.
4. Provide support to the GWRC resource management team on drinking water standards if needed.
5. Work with GWRC, to determine if any improvements could be made to existing processes between Wellington Water and GWRC that might be of assistance to GWRC when processing resource consent applications for activities that penetrate the aquitard.
6. Complete the ongoing maintenance activities identified in Section 6.
7. Consider this report when developing the new regional water safety plan.

Appendix 1 – Peer Reviews

Infrastructure and Water
CONSULTANCY SERVICES LIMITED

4 July 2017 File: Cardno 17/001

CARDNO
IBM Building
Level 5, 25 Victoria Street
Petone, Lower Hutt 5012

Attention: Selwyn Blackmore

Dear Selwyn,

PEER REVIEW; WATERLOO WELLFIELD WATER QUALITY CONTAMINATIONS INVESTIGATIONS

I have read the draft Part 1 report (version 4.0 dated 7 July 2017) and the supporting reports and make the following comments:

1.0 Regulatory Environment

In the current Drinking-water Standards for New Zealand (DWSNZ) there is a lack of clarity as to who declares a water source to be 'secure'. It appears that the water supplier does so (by demonstrating compliance with the criteria set out in the standard) and that this becomes accepted unless the Drinking Water Assessor (DWA) objects.

What is clear however is that should there be concerns about the risk of influence by surface water, then the DWA can downgrade the status. The report notes that this has occurred for at least one well (Colin Grove) which has been classified as 'provisionally secure'.

Given the apparent significant increase in total coliforms detected; the three positive E-Coli results; the relatively shallow depth of the aquifer; the thin aquitard (only one metre); the relatively young age dating of the water (over one year); and a greater understanding that in close proximity to the well casings there is a significant downward hydraulic flow gradient when the pumps are running; there is a risk that the DWA may come to the conclusion that the aquifer cannot be regarded as secure and downgrade all wells' status.

If this were to occur then with the existing treatment at the Waterloo Water Treatment Plant (WWTP), Wellington Water Ltd (WWL) would not be able to meet the requirements of DWSNZ for the water from the plant.

I recommend that close liaison be maintained with the DWA to manage this risk.

2.0 Drinking-water Standards for New Zealand

The current standards - DWSNZ 2005 (revised 2008), are now over ten years old (the 2008 update was relatively minor amendments) and are based on science and practice that is at least 15 years old. In particular there are two matters relevant to the WWTP issue.

2.1 Secure Status of Groundwater

The 2015 Australian and the 2011 Canadian standards, (both of which were based on DWSNZ) take the pragmatic view that, in practice, there is no such thing as a 'secure' groundwater source, except

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in exceptional circumstances subject to much more rigorous criteria than apply in NZ. They note that whereas it is theoretically possible to have secure groundwater, it is not so in practice, given the inevitable heterogeneous nature of any geologic formation including aquifers, and the realities of human modification of the environment. The USA and German standards can be interpreted to take the same stance.

This position is well demonstrated by the existence of more than 50 known (and the possibility of more unknown) penetrations of the aquitard within 1km of the Colin Grove well.

Minute 8 issued by the Havelock North Drinking Water Inquiry (HNDWI), which sets out the matters to be investigated in Stage 2 of the Inquiry, makes specific reference to the need to examine this aspect of the current standards. Without predetermining the outcome of the Inquiry, one possibility is that any review of DWSNZ may adopt the Australian and Canadian position.

If this were to be the case, the status quo at WWTP would no longer be an option.

2.2 Ultra Violet Light Efficacy on Protozoa

Scientific understanding of the effectiveness of UV on protozoa has advanced since the current DWSNZ were adopted. In simple terms UV at low doses has been found to be much more effective than is currently explicitly recognised in the standards, however DWSNZ 5.16.1 does allow a log credit of up to 3 log, provided the reactor 'has been validated to achieve (up to 3 log) following the procedures and requirements specified in *'Ultraviolet Disinfection Guidance manual (USEPA2006b)'*. Further information on validation is given in 5.16.2.

Without a detailed understanding of the equipment recently procured it is possible that its validation was to a more recent standard that the USEPA 2006b standard, and as such not recognised by DWSNZ 2005/08. If so this raises the possibility of a technical noncompliance, and may require agreement with the DWA to recognise the validation certified.

2.3 Below Ground Wellhead Facilities

I note that the wellheads in the Waterloo field are below ground. This introduces an additional (and avoidable) risk of contamination. I also note that being 'enclosed spaces' that require controlled entry; this renders routine inspection, maintenance and cleaning more difficult.

The report makes no mention of whether the water levels in the wellhead sumps or the operation of the sump pumps intended to remove any water entering the sumps are monitored by the SCADA network.

If they are not, I recommend that such monitoring be installed as a matter of urgency and that they have sufficient battery back up to allow continuous monitoring in the event of power failure, a particularly high risk situation.

It is possible that a future review of DWSNZ may require the progressive removal of below ground wellheads, and any well replacement strategy should take into account both the risks inherent in this form of construction and the possibility of a regulatory change.

3.0 Backflow

Backflow and back siphoning events are more common than most water suppliers and consumers realise or acknowledge. See paragraphs 223 to 227 of the HNDWI Stage 1 report.

They represent a particular risk to a water supply which has no residual disinfectant in the water in the reticulation. This residual disinfectant is usually chlorine.

The discussion on future options should discuss the risks associated with backflow in Hutt City (there is an elevated risk in the higher suburbs) and the advantages of having a residual disinfectant.

There is another advantage in having a chlorine residual in that, if the residual is monitored, this can provide early warning of contamination in the network. Where there is a chlorine residual it is good practice to always measure the residual concentration when taking a sample. The result is instantaneous and if there is no residual, action can be initiated without having to wait 24 hours for the test result.

It is also possible to monitor the chlorine residual continuously, giving real time insight into what is happening within the reticulation.

When discussing chlorine it would be useful to dispel an urban myth about the taste and smell of chlorine. Chlorine is not normally detectable by humans at concentrations less than 1.0 mg/L. What is however able to be detected are the compounds formed when the chlorine reacts with organic material: 'chloro–organics'.

When networks are not normally chlorinated there are always some organics present in the pipes, typically as biofilms. The chlorine reacts with these and can produce detectable tastes and odours. It takes considerable time (many months and sometimes years) for the chlorine to oxidise all this material and reach equilibrium.

It may not be an easy message to sell to a community that is opposed to chlorine, but with time the tastes and odours they experience and perceive (as some will be psychosomatic) will gradually reduce.

4.0 Summary and Recommendations

In summary, UV and Chlorine is considered the best option. Given the very low turbidity of the source water it will be an affordable, very effective and highly reliable option that gives a high degree of confidence in the safety of the supply under all circumstances.

A risk with this option is that, provided the equipment is sized correctly, it will provide satisfactory barriers to all three pathogen types, But if the source is determined not to be secure, and to have a protozoa risk, then it may not satisfy the exact criteria of the current DWSNZ, (depending on the validation certified).

This risk only exists however if:

- The source is deemed to be not secure, and
- The source is assessed as being at of protozoa, and
- The equipment has not been certified by USEPA 2006b.

The risks associated with the current regulatory framework should be discussed with the DWA, and whereas it is recognised that they need to comply with the current regulations, the source has not yet been determined not to be secure (and it may not ever be), any proposal to provide additional barriers should be well received.

Infrastructure and Water
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4 July 2017

Wellington Water Well Field Report

A much more in depth study of the available data would be required to draw firm conclusions about the condition of the aquifer, the risk to public health and the recommended treatment options. This would require a more in depth look at monitoring data over a five to ten year period. Nonetheless I have attempted to draw some conclusions and make some recommendations for how the report could be improved.

The report mentions that WW have attempted to determine the root causes of the positive *E. coli* results from the raw water. That is an impossible task given the low numbers of positives and the fact that the positives came from different sites. My sense is that there have been total coliforms present in the raw water for a considerable period despite the absence of *E. coli*. My interpretation is that the aquifer has not been (if it ever was) "secure" for many years. The whole concept of a secure groundwater is one that I, and many other water professionals (including hydrologists) would question. Certainly the requirements of NZDWS for demonstrating "security" would not be condoned by many, particularly the concept of water age testing every five years in a country with so much seismic activity. To that end I would not consider any water system in New Zealand to be "secure" at this point in time and I believe that it would take an extremely detailed study to demonstrate security. The USEPA groundwater rule would require much more monitoring to be performed as well as sanitary surveys every time coliforms are detected in the raw water.

The presence of coliforms in the raw water demonstrates that the aquifer is impacted by surface water but in the absence of *E. coli* detects then one might argue that the surface water was not contaminated with faecal material. There have now been a small number of *E. coli* detects and this has shown that there is some degree of faecal contamination (assuming that these organisms were truly *E. coli*. There are some non-*E. coli* coliforms that have been shown to produce ß-D-glucuronidase) albeit at apparently a low level. Regular monitoring with larger volume samples would determine the true frequency of faecal contamination.

The real issue is the safety of the raw water and whether or not it is making people sick when it is not disinfected. The answer to that question can be derived by two types of study, a Quantitative Microbial Risk Assessment and an epidemiological study. Typically, QMRA studies involve intensive sampling and testing for pathogens including bacteria, viruses and protozoa. Each pathogen group has different survival and transport characteristics. These studies are expensive and can take years to complete and I am not advocating that a true QMRA study be undertaken. However, I do believe using the data currently available together with some targeted monitoring that a good assessment of the safety of the groundwater can arrived at.

Epidemiological studies are notoriously difficult and expensive to undertake. Given the fact that Wellington has different areas that receive treated and untreated groundwater, it may be possible for the medical profession to investigate the incidence of gastrointestinal disease in these different zones. That possibility should be investigated.

My personal feeling is that these groundwater sources where there is clear evidence of surface water infiltration should be treated with uv designed to inactivate protozoa, viruses and bacteria. The only question that remains then is whether to chlorinate to maintain a residual in the reticulation system. I have not yet undertaken the required analyses to provide a detailed answer to that question. However, there have been many bacteriological positives in the non-disinfected reticulation system. The important question there is whether the organisms concerned were in the raw water or whether they originated from ingress. If it can be shown conclusively that they originated in the raw water then it may be possible to arrive at the conclusion that a residual disinfectant is not required. However, proving the origin of the organisms is usually not easy. The safest treatment option is to treat the water with uv and then add a chlorine residual to protect against downstream contamination. However political pressure will undoubtedly be applied to attempt to prevent chlorination. World's best practice would be to include both forms of disinfection.

I hope that this covers what you need. It can be summed up in a few bullets:

- The aquifer is impacted by surface water which probably has a low faecal content
- The risk of a disease outbreak is low at this point in time but that could change at any time
- Most water professionals with expertise in this area would not deem the aquifer to be secure
- World's best practice would be to use uv (most likely medium pressure) plus chlorine

Prof. Colin Fricker PhD FRSB FRSPH
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