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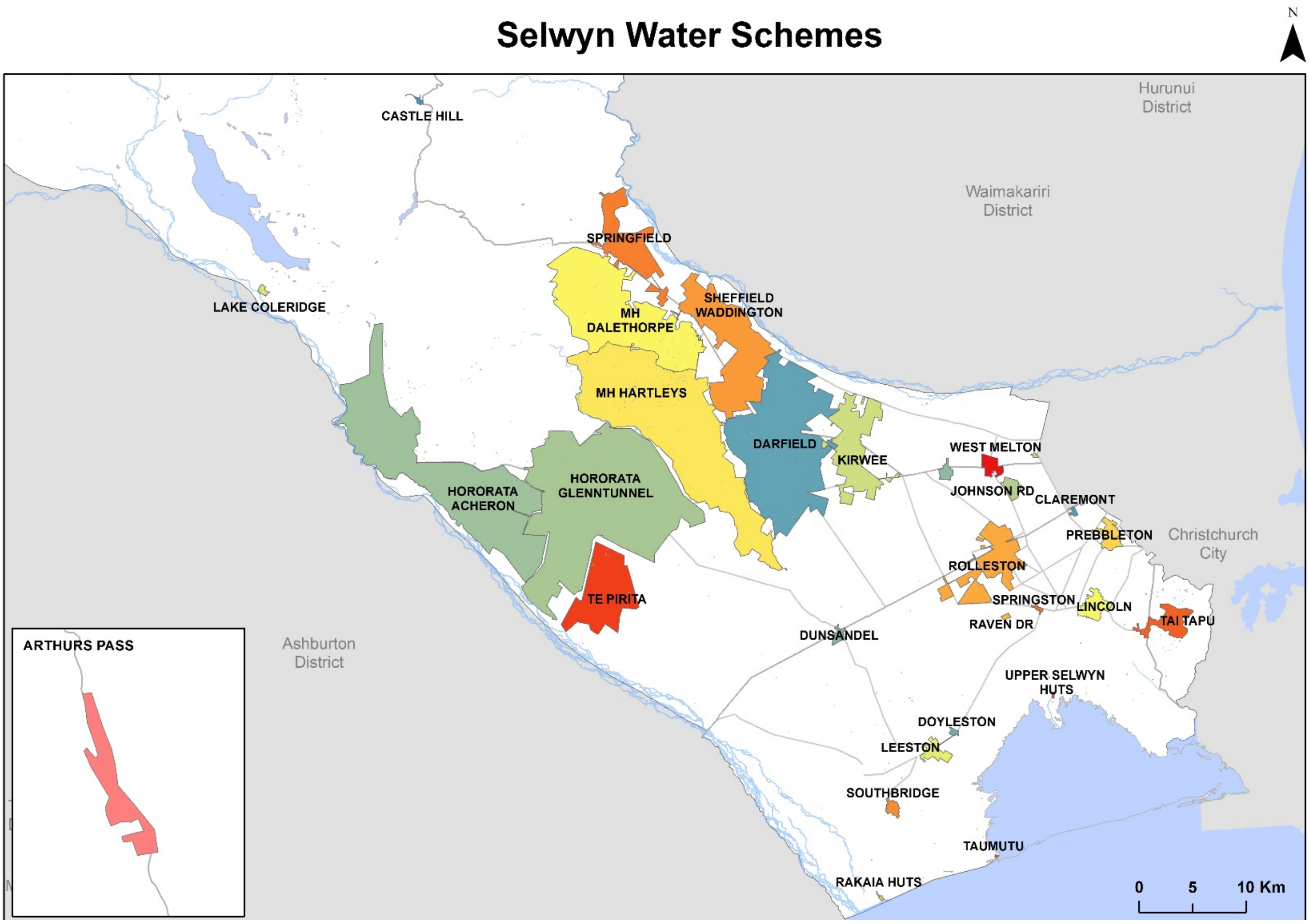
Report

Water Supply Chlorination - A Risk Based Approach

Prepared for Selwyn District Council

Prepared by Beca Limited

26 October 2018



Revision History

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A	Lisa Mace	Updated version of previous report titled "Risk Assessment of Water Supplies and Need for Treatment (Working Draft)" Draft issued for review by SDC 28 September and 18 October 2018 Final issued for publication 26 October 2018	26 October 2018

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Prepared by	Lisa Mace	[signature]	26 October 2018
Reviewed by	Andrew Watson	[signature]	26 October 2018
Approved by	Becky Macdonald	[signature]	26 October 2018
on behalf of	Beca Limited		

Executive Summary

In 2017 Selwyn District Council (SDC) commissioned an assessment of the bacterial contamination risks to its 30 rural and urban water supplies. This assessment looked at the source, treatment, reticulation and end users of each scheme. The main aim was to assess the need for the addition of chlorination treatment. The prompt was the detection of *E. coli* in some of SDC's supplies which had previously been deemed as secure groundwater as well as the findings from the August 2016 Havelock North drinking-water contamination event. SDC is planning for the eventuality that:

- Secure bores in non-confined aquifers, or semi-confined aquifers, will become non-secure (SDC has already seen issues in semi-confined aquifers)
- Wells in confined aquifers that are less than 30m deep will become non-secure.

This report summarises the second stage of the assessment. The first stage was completed in November 2017 and is summarised in the report titled *Risk Assessment of Water Supplies and Need for Treatment (Working Draft)*. This initial assessment included:

- A workshop to summarises the key bacterial risks associated with the SDC supplies
- An analysis of past *E. coli* transgressions for each supply
- Preparation of a risk matrix which provides a ranking for each risk, based on probability and consequence
- Application of the risk ranking to each supply, noting this should be carefully reviewed by SDC with Sicon
- High level costing for chlorination of three selected supplies

This initial assessment has been revisited with the aim of refining the risk matrix. The results of this refinement are presented in this report. Costing is no longer included in the report as that information has already been used for budget planning purposes.

The revisiting and refinement of the initial risk matrix was carried out through a further four workshops with representatives from SDC, Beca, Sicon (the WTP operators), Food and Health and the Drinking Water Assessor. As a result, a robust risk matrix was developed. The results are summarised below. It is recommended that chlorination occurs in order of priority as listed in the table below. Priority 1 supplies have been identified as the highest risk of bacterial contamination.

The following recommendations are made:

- Continue to review and update the Chlorination Risk Matrix as changes are made to the supplies
  - This includes updating the matrix as renewals and repairs are made, new treatment is installed and new risks are identified
  - If the structure/methodology of the matrix is modified then a committee with representatives from SDC, the operator, CDHB and other drinking-water experts should be brought back together to discuss and agree on the changes
- Chlorinate the supplies in order of priority ranking (i.e. Priority 1 supplies first)
  - Note that for some supplies (i.e. Arthurs Pass) there are plans to upgrade which will change the risk ranking once completed
  - If SDC does not decide to chlorinate all supplies, then a review and implementation of international best practice is recommended
  - It will be important to engage with communities early on and to clearly communicate the advantages of chlorination, drawing from the information presented in Section 2.

Water Supply Scheme	Risk Ranking	Priority
Acheron	58.8	Priority 1
Malvern Hills, Hartleys Rd	57.1	Priority 1
Hororata	55.6	Priority 1
Dalethorpe	53.2	Priority 1
Arthur's Pass	51.7	Priority 1
Upper Selwyn Huts	38.0	Priority 1
Sheffield/ Waddington	35.3	Priority 2
Springfield	34.1	Priority 2
Castle Hill	32.7	Priority 2
Rolleston	31.4	Priority 2
Lake Coleridge	30.0	Priority 2
Darfield	27.3	Priority 2
Tai Tapu	24.8	Priority 3
Te Pirita	24.8	Priority 3
Taumutu	23.8	Priority 3
Prebbleton	23.3	Priority 3
West Melton	23.1	Priority 3
Springston	22.4	Priority 3
Lincoln	21.7	Priority 3
Johnson Rd, West Melton	21.6	Priority 3
Southbridge	21.5	Priority 3
Leeston	20.6	Priority 3
Kirwee	17.9	Priority 3
Jowers Road	17.8	Priority 3
Raven Drive	14.8	Priority 4
Dunsandel & Sherwood Estate	14.8	Priority 4
Rakaia Huts	13.6	Priority 4
Claremont	8.4	Priority 5
Edendale	7.1	Priority 5

Shaded supplies are already chlorinated or planned for chlorination.

Contents

1 Introduction

1.1 Background

In 2017 Selwyn District Council (SDC) commissioned an assessment of the bacterial contamination risks to its 30 rural and urban water supplies. This assessment looked at the source, treatment, reticulation and end users of each scheme. The main aim was to assess the need for the addition of chlorination treatment.

SDC has 30 water supply schemes; all operated and maintained by SDC's maintenance contractor, Sicon. Chlorine is currently added to seven of these water supplies but there are a number of non-secure, non-chlorinated supplies that have no form of residual disinfection.

In recent years *E. coli* was detected in some of SDC's supplies which have previously been deemed as secure groundwater. SDC is planning for the eventuality that:

- Secure bores in non-confined aquifers, or semi-confined aquifers, will become non-secure (SDC has already seen issues in semi-confined aquifers)
- Wells in confined aquifers that are less than 30m deep will become non-secure.

This report is an update of the earlier report titled "Risk Assessment of Water Supplies and Need for Treatment (Working Draft)" and dated 2 November 2017.

1.2 Scope

The scope of the assessment described in this report includes:

- Review of information on SDC's 30 supplies:
  - Water Safety Plans
  - Spreadsheets of *E. coli* transgressions at the source, treatment plant and in the reticulation
  - Master spreadsheet that consolidates all relevant data for each supply
- Analysis of information gathered in an initial half-day workshop with Council staff (Workshop 1)
- Compilation of background material on chlorination
- Preparation of a chlorine risk matrix for determining the chlorination priority of supplies
- Concept and high level estimates of probable cost for adding chlorination to three example supplies (now removed from the report)
- A further four workshops to refine the previously developed chlorine risk matrix

2 Chlorination Advantages and Disadvantages

2.1 Introduction

This section of the report has been prepared for SDC to aid consultation when it is proposed to add chlorine to a supply. It provides a balanced summary of the advantages and disadvantages of chlorination together with a review of scientific literature regarding actual or perceived health and aesthetic effects. New Zealand requirements and guidelines with regards to disinfection are documented as well as risk management options for non-disinfected water supplies, particularly associated with natural hazards such as earthquakes. NB: If this section is extracted from the report and used elsewhere, the glossary and reference section should be included.

2.1 Disinfection of Water

2.1.1 Why Disinfect Water?

Water is disinfected to inactivate micro-organisms in the water that can cause illness (these are known as pathogens). These pathogens may be bacteria, protozoa or viruses. Sterilisation is a process related to disinfection, however during the sterilisation process all micro-organisms are killed, both harmful and harmless micro-organisms. In municipal water treatment, the correct term is disinfection.

To ensure that water is microbiologically safe for drinking, water supplies are generally treated and this often includes disinfection as a final step. Rather than relying solely on the disinfection step to achieve safe water, other treatment processes like sedimentation and filtration might be used to remove suspended solids (including micro-organisms) from the water before disinfection. After the water leaves the treatment plant, the distribution system needs to be well managed to prevent post-contamination of the water.

The need for disinfection is dependent on the characteristics of the source water and the water distribution system. For example, a groundwater that is shown to be secure (i.e. free from pathogens and protected from contamination) may not need to be disinfected.

2.1.2 Disinfection with Chlorine

Chlorine is the most commonly used disinfectant for water both in New Zealand and overseas. Disinfection of water using chlorine is often referred to as chlorination. Water supplies are chlorinated using chlorine gas (Cl_2), solid calcium hypochlorite ($Ca(OCl)_2$) or a solution of sodium hypochlorite (NaOCl). Chlorine is also used to disinfect pipes and reservoirs after construction or maintenance work to ensure their cleanliness.

The chlorine compounds that are formed when chlorine is added to water rupture cell membranes and inhibit vital enzymic activities resulting in microbial death (Ratnayaka *et al.*, 2009). Chlorine is only used to inactivate bacteria, viruses and, if the dose is high enough, *Giardia* cysts. Treatment plants must include other treatment processes to remove or inactivate *Cryptosporidium* oocysts (e.g., particle removal and/or a stronger disinfectant). *Giardia* and *Cryptosporidium* are the protozoan pathogens regulated by the Drinking-water Standards for New Zealand (DWSNZ).

2.1.3 Chlorine Chemistry

Chlorine is a highly reactive chemical and is a strong oxidant. When chlorine is added to water, hypochlorous acid (HOCl) and hydrochloric acid (HCl) are formed. The hypochlorous acid is further dissociated to hypochlorite (OCl^-).

Hypochlorous acid and hypochlorite together are known as free available chlorine (FAC). Hypochlorous acid is a much more potent disinfectant than the hypochlorite ion. The relative concentrations of these two molecules are controlled by the pH and temperature of the water, with more hypochlorous acid at lower pH values and lower temperatures.

Chlorine will also oxidise iron and manganese in the water and can form a wide range of chlorinated compounds with any natural organic matter present in the water. Chlorine is consumed by these reactions with inorganic and organic matter, and the amount of chlorine consumed is known as the chlorine demand.

If sufficient chlorine is added to the water (i.e., more than the chlorine demand) there will be a chlorine residual in the water. This residual minimises regrowth of micro-organisms in the distribution pipes and reservoirs, and also minimises the impacts of contamination that might enter the distribution system.

2.1.3.1 Effectiveness

The effectiveness of chlorine disinfection depends on:

- Residual chlorine concentration – the free chlorine concentration that remains after the chlorine has reacted with any contaminants in the water
- Contact time – the time the chlorine residual is in the water
- pH
- Temperature
- Turbidity – microbes can be shielded by particles in the water that cause turbidity and are protected from the effects of the disinfectant

Problems controlling these factors can result in inadequate disinfection of the water.

Disinfection efficiency (Ct) is the product of residual disinfectant concentration (C) and the contact time (t) of chlorine in the water. Generally, inactivation of organisms increases with increasing Ct.

2.1.4 Typical Dose

The amount of chlorine added to drinking waters varies from water supply to water supply. The dose is usually set to give a minimum residual of 0.2mg/L at the extremities of the distribution network. Typical chlorine dosages to final treated water are in the range 0.2 – 2.0mg/L of free available chlorine (Ratnayaka *et al.*, 2002). Lower doses tend to be used on clear groundwaters, while higher doses are typically required for poorer quality surface waters with more organic and inorganic matter. The dose rate will also vary depending on the season due to temperature effects.

The dose levels are usually controlled by monitoring the water flow rates and the residual chlorine in the water leaving the water treatment plant. Waters for which the chlorine demand and the flow through the treatment plant are almost constant can be chlorinated adequately by manual control. Additionally, the chlorine residual in the distribution system can be monitored to ensure that the dose added to the water at the treatment plant is in the correct range.

2.1.5 Disinfection By-Products

Disinfection by-products (DBPs), sometimes referred to as chlorination by-products, are formed during treatment through the reaction of chlorine with natural organic matter in the water. The organic material primarily comes from decomposition of vegetation (humic compounds).

The most common of these by-products are trihalomethanes (THMs) which are halogen-substituted single-carbon compounds with the general formula CHX_3 (where X = chlorine or bromine). The four THMs of importance to drinking water are bromodichloromethane, bromoform, chloroform and dibromochloromethane (MoH, 2005).

Another class of disinfection by-products are haloacetic acids (HAAs). These are acetic acids in which one or more of the hydrogen atoms in the methyl group has been replaced by a halogen atom (e.g. chlorine, bromine).

The level of disinfection by-products is dependent on the amount of natural organic matter in the source water. River and lake waters generally contain more organic matter than groundwaters.

Disinfection by-products have suspected health effects which are discussed further in Section 2.3.3. All chemical disinfectants used in drinking water can be expected to form by-products that could affect human health. In general, less is known about the by-products of other disinfectants (e.g. ozone) than about chlorination by-products. According to the US EPA (2009), water disinfected with monochloramine contains lower concentrations of regulated DBPs compared to chlorinated water but may contain higher concentrations of unregulated DBPs.

A comparison of the estimated risk from known pathogens in untreated surface water and chlorination by products concluded that the risk of death from pathogens is at least 100 to 1,000 times greater than the risk of cancer from DBPs and that the risk of illness from pathogens is at least 10,000 to a million times greater than the risk of cancer from DBP (Regli, Berger , Macler, & Haas, 1993).

2.1.5.1 Disinfection with Chlorine Gas

Chlorine is contained as a liquid under pressure in 900 or 1000kg drums or 70 or 100kg cylinders. Liquefied chlorine gas (Cl_2) is a greenish-yellow gas/amber liquid with a pungent and irritating odour. It is about 2.5 times heavier than air.

Chlorine gas is drawn via a vacuum regulating valve and made into a chlorine-water solution by means of an auxiliary water flow passing through an eductor which at the same time creates the operating vacuum.

Because of chlorine's acute toxicity and corrosivity when it is a gas, considerable safety and isolation measures must be incorporated in the design and layout of chlorine installations to safeguard the operators and the public from leaks at the water treatment plant. Safety issues associated with leaks do not occur through the reticulation as it is no longer in its gas phase.

2.1.5.2 Disinfection with Sodium Hypochlorite

Sodium hypochlorite is a clear light-yellow aqueous solution available in bulk or in 1000L containers, and is frequently used in place of chlorine gas for safety reasons. It is manufactured at between 14.8% and 16.5% (and can be up to 18%) free available chlorine by volume (i.e. 14.8 – 16.5kg FAC/100L of product).

Sodium hypochlorite is added to water by a dosing pump or an injector.

Sodium hypochlorite decomposes and consequently loses its chlorine strength when exposed to atmosphere or sunlight. Decomposition produces an increase in chlorate ion (ClO^{3-}) concentration. Good manufacturing techniques and proper storage of sodium hypochlorite will give a shelf life of at least 12 months, but the FAC content will decrease during this time (Opus, 1997).

At the commonly procured concentration of 13 – 15%, sodium hypochlorite solution is corrosive and will affect the skin and eyes on contact. This means that operators are required to wear appropriate person protective equipment and follow operating procedures. These effects are not seen when diluted into the water supply. SDC use 1% sodium hypochlorite solution to reduce the risk to operators.

2.1.6 Effect on Livestock

Questions may be raised by consumers about how the addition of chlorine to water may affect livestock health and whether it puts animals off consuming the water. Chlorine is not listed as a water quality parameter of concern for livestock drinking water quality in the Australian and New Zealand Guidelines for fresh and marine water quality (2000).

Chlorination is routinely practised in rural water supply schemes in New Zealand, and dates back to a condition of the government subsidies and loans given to such schemes when they were being established between the late 1950s to the mid-1980s recognising that the water was also being used for domestic purposes. It has also been recorded that "…. this process [chlorination] is also helpful in facilitating control of waterborne stock disease. A correctly monitored and maintained chlorine residual must have some preventative affect with the spread of stock diseases." (Lincoln College, November 1975).

High levels of chlorine in water may affect the efficiency of the rumen microbial population (Olkowski, 2009) meaning that in ruminant livestock such as cows, metabolic impairment of rumen function may occur. Although Olkowski does not record the concentration of chlorine that could be considered as "high" the context of his remark suggests it is several times what would be regarded as a normal chlorine residual. Olkowski also notes that monogastric livestock will likely be less affected by direct effects of chlorine, and most affected by pathogens in drinking water, so more aggressive water disinfection may be beneficial in this class of farm animals in situations where risk of bacterial contamination is high.

New Zealand's now has a long history of chlorinating rural water supplies. There is no evidence of adverse health outcomes or a disinclination to drink chlorinated water by livestock, as long as the chlorine residual is well controlled within accepted limits. Chlorination should therefore not be of concern for livestock health, and the evidence actually points to the benefits of chlorination.

2.2 Chlorination in New Zealand Context

2.2.1 Health (Drinking Water) Amendment Act 2007

The Health Act 1956 was amended by the Health (Drinking Water) Amendment Act in October 2007 and aims to protect public health by improving the quality of drinking water provided to communities. The Act does the following:

- Requires drinking-water suppliers to take all practicable steps to ensure they provide an adequate supply of drinking water that complies with the DWSNZ
- Requires drinking-water suppliers to introduce and implement public health risk management plans
- Ensures drinking-water suppliers take reasonable steps to contribute to the protection from contamination of sources from which they obtain drinking water
- Requires officers appointed by the Director-General of Health to act as assessors to determine compliance with the Act and to have their competence internationally accredited
- Requires record keeping and publication of information about compliance
- Provides for the appropriate management of drinking-water emergencies
- Improves enforcement by providing an escalating series of penalties for non-compliance.

2.2.2 Drinking-Water Standards for New Zealand

The Drinking-water Standards for New Zealand 2005 (revised 2008) (DWSNZ) specify water quality standards and compliance criteria for microbiological, chemical and radiological contaminants (determinands) in drinking water. The DWSNZ give highest priority to health risks arising from microbial contaminants because they can lead to rapid and major outbreaks of illness. Control of microbial contamination is of paramount importance and must not be compromised in an attempt to correct chemical problems.

In terms of microbial contaminants, standards and compliance criteria are set for bacteria and protozoa. There are no standards or compliance criteria for viruses because there is too little information available and no suitable viral indicator to set standards or compliance criteria. It is considered that if there is no human effluent in the catchment, viruses will not pose a risk to public health.

The DWSNZ do not require disinfection for drinking-water supplies. Rather, the DWSNZ require monitoring of water quality or performance parameters in accordance with the various compliance criteria to demonstrate the water treatment plant consistently produces water of good quality (i.e. meets the standards), and there is no degradation in water quality as it passes through the distribution system from the treatment plant to the consumer.

2.2.2.1 Secure Groundwater

The DWSNZ recognise that the microbiological quality of groundwaters is often better than that of surface waters because concentrations of microbes in the water are reduced by processes such as filtration, adsorption and natural die-off of micro-organisms as the water percolates into the ground and moves through the aquifer.

The time the water travels underground is a key factor in improving the microbial quality of the water, as longer times allow for larger numbers of microbes to die. Where groundwater is shallow, there is little opportunity for these processes to improve the water quality, so the microbial quality of the water may vary in response to weather events at the surface in much the same way as surface water quality may vary. Therefore, for monitoring purposes, these shallow groundwaters are treated as surface waters.

Groundwater sources that are isolated from surface or climatic influences, because of their depth or protection by impermeable overlying strata, and abstracted via a bore head demonstrated to provide protection from contamination by pathogenic micro-organisms are termed “secure”. A secure status allows a marked reduction in monitoring requirements for *Escherichia coli* (*E. coli*) and no additional treatment is needed to achieve compliance with the DWSNZ with respect to protozoa. Monitoring of the distribution system is still required for secure groundwater sources.

A secure status is only an indicator of good microbial, not chemical, water quality.

2.2.2.2 Bacterial Compliance

The indicator organism *E. coli* is used in the DWSNZ to assess the bacterial quality of water. The bacterial quality of treated water is deemed satisfactory if the *E. coli* concentration is less than 1 organism per 100mL.

a. Water Leaving the Treatment Plant

Direct *E. coli* monitoring is required at all treatment plants, except where treatment includes continuously monitored disinfection. To show compliance with the DWSNZ in these treatment plants, the water supplier can monitor performance parameters that show the treatment process is operating properly.

For secure groundwaters to demonstrate continued bacterial compliance, the water must be monitored, preferably at the borehead but before any treatment or storage, at a minimum specified frequency and detect no *E. coli*. The DWSNZ specify the response procedure if *E. coli* is detected.

b. Distribution System

For unchlorinated supplies (or when the residual maintained in the distribution system is less than 0.20mg/L FAC) the following requirements must be met:

- The water in the distribution system is monitored for the presence of *E. coli*
- The sampling sites and frequency of sampling for *E. coli* meet the DWSNZ requirements
- The number of 100mL samples in which *E. coli* is found is equal to, or less than, the allowable exceedances given by DWSNZ
- DWSNZ compliant sampling and analytical procedures are used.

If chlorine disinfection is not used, a higher frequency of *E.coli* monitoring is required than for chlorinated supplies, as chlorinated supplies may partially substitute *E. coli* monitoring by FAC monitoring.

2.2.2.3 Protozoa Compliance

Giardia and *Cryptosporidium* are the protozoa of primary concern in drinking waters. As testing for these protozoa is expensive, compliance is based on the ability of the treatment plant to remove protozoa, and more particularly, to remove *Cryptosporidium* which is a more difficult task than removing *Giardia*. The approach to basing protozoal compliance on the treatment process and its performance requires knowledge of:

- The concentrations of *Cryptosporidium* in the source water
- The efficiency of the treatment plant processes at removing or inactivating *Cryptosporidium*.

Comparing these two shows whether the treatment plant can remove or inactivate enough of the protozoa in the source water to produce safe drinking water.

Treatment processes that may protect against protozoa are:

- Processes designed to physically remove particles from the water e.g. sedimentation and filtration
- Disinfection processes that inactivate the organism; i.e. chlorine dioxide, ozone and UV radiation. The percentage of the organism that these disinfectants inactivate depends on their concentration (or intensity, in the case of UV radiation) and the time that the *Cryptosporidium* is exposed to the disinfectant. Chlorine is relatively ineffective against *Cryptosporidium* and cannot be used for protozoal compliance.

Secure bore waters are considered to comply with protozoal compliance criteria without any treatment.

2.2.2.4 Chlorine Standards

The Maximum Acceptable Value (MAV) for free available chlorine is 5mg/L as Cl_2. This is derived from a 'no observable adverse effects' level of 15mg/kg body weight per day. This is from a study which reported the absence of toxicity in rodents that received chlorine as hypochlorite in drinking water for up to two years. It should be noted that this value is conservative as no adverse effect level was identified in this study. Long-term animal toxicity studies have shown no specific effects from the ingestion of chlorine (MoH, 2017).

Based on aesthetic considerations, the DWSNZ give a Guideline Value (GV) for chlorine of 0.6-1.0mg/L. At free available chlorine concentrations in this range there is an increasing likelihood that some consumers may object to the taste or odour.

2.2.2.5 Disinfection By-Products

The DWSNZ have standards (MAVs) for the main disinfection by-products which may be produced by chlorination.

Monitoring for disinfection by-products is only required if a water distribution zone is assigned one or more disinfection by-products as a Priority 2 contaminant. The assignment of Priority 2 contaminants to a water supply distribution zone is a result of risk assessment and monitoring over a year. Contaminants that exceed 50% of their MAV in any sample taken during an assessment are recommended to the Ministry of Health for assignment to the supply as a Priority 2 contaminant. This requires the water supplier to monitor them if they are to comply with the DWSNZ.

Disinfection by-products are monitored in the distribution system rather than at the treatment plant because they continue to form after treatment. This reflects the continuing slow reactions between the disinfectant and the organic matter, with concentrations increasing as the water moves from the treatment plant out into the distribution system (Nokes, 2008).

2.2.3 Water Safety Plans

Drinking-water suppliers are required under the Health (Drinking Water) Amendment Act to prepare and implement Water Safety Plans (WSPs) for their supplies.

The WSP documents the things that can go wrong in the supply (source, treatment plant and distribution system) that present a risk to public health, what might cause them, and what measures should be in place to reduce the likelihood of them happening.

WSPs for drinking-water supplies that employ chlorine disinfection need to consider the following risks:

- Not enough free available chlorine to disinfect the water
- Too much free available chlorine, which may result in excessive levels of chlorine, possibly high levels of disinfection by-products and possible heavy metals (from corroded fittings) in the water supplied to consumers
- Excessive formation of disinfection by-products.

For the second and third bullet points above, the concentrations of disinfection by-products formed, and therefore the risk they present, will depend on the amount of natural organic matter in the water.

Operational health and safety risks in relation to chlorine storage and dosing are typically managed by way of health and safety plans rather than a WSP.

The WSP must be reviewed and renewed at least every five years.

2.2.4 Industry Practice

Chlorination is the most common means of drinking water disinfection in New Zealand, primarily through gaseous chlorine or sodium hypochlorite. Chlorination is used at 26% of the country's treatment plants[1], with 78% of people connected to registered drinking-water supplies receive chlorinated water (MoH, 2011).

Major water supplies (>10,000 people) in New Zealand that do not employ chlorination are:

-
- Blenheim, Marlborough District Council (unsecure groundwater source)
- Napier, Napier City Council (secure groundwater source)
- Hastings and Havelock North, Hastings District Council (secure groundwater source)
- Richmond, Tasman District Council (unsecure groundwater source)
- Kaiapoi, Waimakariri District Council (secure groundwater source)
- Mosgiel, Dunedin City Council (secure groundwater water source).

All of these supplies, with the exception of Blenheim and Richmond, have secure groundwater sources. In both cases, UV disinfection has been introduced for bacterial and protozoa compliance.

Note that the Christchurch water supply (Christchurch City Council) was classified as a secure groundwater source up until December 2017, when its secure status was revoked. Temporary chlorination was introduced early in 2018 to protect public health until work to upgrade the wellheads and address some other identified risks can be completed.

2.3 Chlorination Literature Review

2.3.1 Overview

This section provides a review of literature regarding the advantages and disadvantages of chlorination. The general themes are summarised in Table 2-1.

Table 2-1: Chlorination advantages and disadvantages

Advantages	Disadvantages
Inactivates pathogenic bacteria and viruses	Does not inactivate protozoa (e.g. *Cryptosporidum*)
Provides residual disinfection in distribution system	Forms DBPs when organic matter is present and these by-products may have health effects
Minimises impact of re-contamination	Can cause aesthetic (taste and odour) problems
Monitoring tool for distribution system integrity	Operational health and safety risks, especially with chlorine gas
Minimises biofilm growth in reticulation	

[1] A treatment plant is defined as the point where water enters the distribution system, irrespective of whether the water is treated or not.

2.3.2 Disinfection

2.3.2.1 Disinfection Effectiveness

The work of Butterfield (1943 – 46, cited in Ratnayaka *et al.*, 2009) showed that under nearly all conditions the typhoid bacillus and other enteric pathogenic bacteria are at least as susceptible to chlorination as *E. coli*. It is therefore practicable to assume that if *E. coli* is absent in a sample of disinfected water then the water is also free of pathogenic bacteria. The spores of bacteria are more resistant to the action of chlorine than bacteria, but fortunately the bacteria causing most waterborne diseases are not spore formers (Ratnayaka *et al.*, 2009).

Enteric viruses are generally more resistant to free chlorine than enteric bacteria. The DWSNZ do not regulate viruses, as there is not sufficient international regulatory guidance to draw on. Rather, they take the approach that if no human effluent is present in the source water, viruses will not pose a risk to public health.

2.3.2.2 Chlorine Residual in Distribution System

In the United States, primary and secondary disinfection are considered; primary disinfection refers to inactivation of pathogens in the source water, whereas secondary disinfection is the provision of a disinfectant residual to inactivate pathogens throughout the distribution system. While chlorination provides a residual, alternative disinfectants such as ozone and UV do not provide a residual.

Maintenance of a disinfectant residual throughout the distribution system may help to maintain the quality of water in the distribution system in the following ways:

- Inactivating pathogens in the distribution system
- Indicating a breach in the distribution system
- Controlling biofilm growth.

The USA and British practice is typically to maintain a disinfection residual. In Europe, the approach typically has been to manage the distribution system without a disinfection residual.

a. Disinfection within Reticulation

Pathogens can enter the distribution system via a variety of pathways, including, as referenced from the US EPA, 2002:

- Treatment breakthrough
- Leaking pipes, valves, joints, and seals
- Cross-connections and backflow
- Improper treatment of materials, equipment, or personnel before entry
- Intentional introduction of contaminants into distribution system.

As the distribution network gets larger, the likelihood of a contamination event increases, as does the consequence, as more people could be affected.

A chlorine residual in the distribution system assists in countering any low level microbiological contamination. However, contamination events in the distribution system can be as a result of a mains break, and will probably be too large for low levels of chlorine residual to deal with (MoH, 2017).

The disinfection effectiveness of a chlorine residual is dependent on a range of factors including the residual concentration, the system hydraulics, chlorine demand in system, the type of contaminant and temperature. Within the distribution system, the disinfectant residual can vary from pipeline to pipeline and from the pipe centreline to the pipe wall (US EPA, 2002?).

b. Monitoring Distribution System Integrity

Monitoring of FAC can act as an indicator of system security, as large and/or sudden changes in FAC levels may indicate ingress or contamination of some kind (MoH, 2017). However, this does not necessarily indicate whether or not the microbiological quality of the system has been compromised.

c. Controlling Biofilm Growth

Drinking water is not sterile and can contain low levels of micro-organisms that can survive through treatment and distribution. Micro-organisms can grow on the internal surfaces of distribution pipes forming a thin biofilm layer. Once biofilm development begins, subsequent material, organisms and contamination introduced to the distribution system can become entrained in the biofilm. Biofilms can contribute to various problems, including:

- Protect microbes from disinfection and allow microbes injured by environmental stress and disinfectants to recover and grow
- Increased disinfectant demand
- Pipe corrosion
- Adversely affect pipe hydraulics
- Deterioration of aesthetic water quality.

Material in the biofilm may subsequently be released into the flowing water under various circumstances. As a result, biofilms can act as a slow-release mechanism for persistent contamination of the water.

The presence of a disinfection residual can limit biofilm growth within the distribution system (Le Chevallier and Au, 2004 and Trussell, 1999).

2.3.3 Health Effects

2.3.3.1 Introduction

There are numerous scientific papers and articles that consider potential associations between chlorination of drinking water and health effects. Typically, review papers or information cited by authorities responsible for setting drinking water standards/guidelines (e.g. World Health Organisation (WHO), US EPA) have been consulted in preparing this document rather than individual scientific studies.

In terms of potential health effects associated with chlorinated drinking water, the chemicals of primary concern are disinfection by-products (DBPs) rather than chlorine itself (or hypochlorous acid and hypochlorites).

There are two main types of studies used to consider the health effects of chemicals such as disinfection by-products:

- Animal toxicological studies
- Epidemiological studies.

Animal toxicity studies tend to focus on a single DBP at high concentrations. Single-chemical animal toxicity studies are useful for determining the mechanism of action for a chemical's toxicity and establishment of toxicity thresholds, but they are inadequate to fully characterise the risk of DBPs in drinking water. This is because actual exposure is usually to a variable and complex mixture of chemicals, and human exposure to DBPs is typically at much lower doses.

Epidemiological studies look at the distribution and determinants of health-related states or events in specified populations. Such studies for DBPs can be unreliable because people are exposed to many chemicals in their daily lives and it is difficult to assess DBP exposure, particularly over a longer duration. If chlorinated drinking water does show a link or association to a health effect, the identity of the specific by-product(s) is often unclear.

Ingestion of drinking water may not be the only route of exposure to DBPs. DBPs have been shown to be absorbed through the skin and inhalation (PSR, no date) from activities such as showering and swimming.

Consequently assessments of the health risks of chlorinated water can be highly uncertain. In some cases, research results are contradictory; some studies show links to adverse health effects and others do not (US EPA, 2009).

Generally chlorination by-products have been well studied compared to the by-products of alternative disinfectants which are beginning to be studied. DBPs continue to be identified and research into their health effects is also ongoing.

2.3.3.2 Cancer

Animal research has shown that exposure to high concentrations of DBPs can increase the risk of cancer. There is particular concern about bladder cancer (AWWA Drinktap.org). In laboratory studies using rats and mice, THMs have been linked to cancers of the colon and kidney, and haloacetic acids have been linked to liver tumours (Boorman *et al.*, 1999).

While there is some evidence of possible health effects from DBPs, particularly possible cancer risks from chloroform and the other THMs and by-products, this evidence is based on high-dose animal studies. Epidemiological studies conducted to date do not provide any evidence that disinfectants and their by-products affect human health at the concentrations found in drinking water (WHO, no date).

WHO (2000) concluded "the hypothesis of a causal relationship between consumption of chlorination by-products and the increased relative risk of any cancer remains an open question." Further, "the small to medium relative risks for all the tumour sites studied and uncertainty related to the magnitude and type of human exposures make it difficult to conclude that real risks result from the ingestion of chlorinated drinking-water."

2.3.3.3 Reproductive & Developmental Effects

Some toxicological and epidemiological studies suggest a potential association between DBP exposure and adverse reproductive and developmental effects.

WHO (2000) concluded that data for reproductive and developmental effects are often conflicting. This review points out that early studies were often biased or suffered from methodological limitations. In general, WHO concluded that the evidence for an association between chlorinated drinking water and adverse pregnancy outcomes is inconclusive and that many of the weak associations could be due to confounding bias.

2.3.3.4 Respiratory Effects

It has been reported that asthma can be triggered by exposure to chlorinated water (Watson & Kibbler, 1993, cited in WHO 2003). This is an isolated reference and has not been picked up by any regulatory authority.

2.3.3.5 Dermatological Effects

Episodes of dermatitis have also been associated with exposure to chlorine.

Skin problems traceable to disinfected water are typically related to swimming pool use (US EPA, 2009). Trichloramine, which forms in swimming pools when chlorine reacts with ammonia from bodily fluids, has been linked to skin problems. Concentrations of chlorine used in swimming pools are much higher than those used in drinking water. Chlorinated swimming pools typically have a FAC concentration of 2.5 – 5.0mg/L (the desirable range given by NZS5826:2010 Pool Water Quality), compared to drinking water which typically has a FAC concentration of less than 1mg/L.

2.3.3.6 Other Health Effects

Epidemiological studies have not identified an increased risk of cardiovascular disease associated with chlorinated water (WHO, 2000).

Chlorine must be removed from water used in kidney dialysis machines (US EPA, 2009).

US EPA (2009) recommends that chlorine in water should be neutralised or removed if used in fish tanks.

2.3.4 Aesthetic Issues – Taste & Odour

Most individuals are able to taste or smell chlorine in drinking water at concentrations well below the DWSNZ MAV of 5mg/L (MoH, 2017). Many people can detect the odour of chlorine at around 0.2mg/L and the taste at around 0.4mg/L (MoH 2017). At a free available chlorine (FAC) concentration of between 0.6 – 1.0mg/L, there is an increasing likelihood that some consumers may object to the taste or odour. Some people are more sensitive to the taste and smell of chlorine than others.

If there are general taste and odour problems at a chlorine concentration less than approximately 0.5mg/L, they may be a result of interactions between chlorine and ammonia, or traces of phenolic substances naturally occurring in the water. Phenolic substances are often derived from algae, so surface waters is more likely to generate problems than groundwater. Surface waters containing ammonia often also contain traces of amino acids and other nitrogenous compounds that may react with FAC to cause chlorinous tastes and odours at quite low levels of measured FAC (MoH, 2017). Micro-organisms in the biofilm on pipe surfaces can also interact with FAC, sometimes causing tastes or odours.

Localised problems can result from an interaction of FAC with coatings or additives used in or on concrete or plastic piping. All materials used in the water supply system should be suitable for use with drinking water.

Water that has been in sunlight for some time (several hours) will usually show a large drop in the FAC level; boiling the water will also reduce the chlorine concentration (MoH, 2017). Chlorine can also be removed using point-of-use activated carbon filters, but it is noted that these can harbour large numbers of micro-organisms, so the supplier's instructions must be followed (MoH, 2017).

Many water supplies in the Canterbury area are not chlorinated, so it is expected that Cantabrians would be more highly sensitised to chlorine in drinking water than people from other regions where chlorination is more common.

2.3.5 Operational Health & Safety

2.3.5.1 Chlorine Gas

Chlorine is a severe eye, nose, throat and upper respiratory tract irritant, and can be fatal if inhaled.

If chlorine contacts combustible materials, fire or explosion may result.

Chlorine gas installations must comply with AS/NZS 2927:2001 The storage and handling of liquefied chlorine gas.

The siting of chlorine gas dosing facilities may be a potential concern raised by communities because of the risks associated with chlorine leaks. Water New Zealand are planning to publish a guideline document covering the preparation of emergency response plans for plants that use chlorine gas.

2.3.5.2 Hypochlorite

Sodium hypochlorite solution is corrosive and will affect the skin and eyes on contact.

There is a trend for WTPs located in built up areas to change to hypochlorite as a way of managing the risks of chlorine gas (Joslyn and Garris, 2001).

2.4 Risk Management

2.4.1 Managing Risks of Chlorinating

The risks of disinfecting with chlorine can be managed through the Water Safety Plan (WSP) process by a range of measures including:

- Testing the source water to determine whether DBPs are likely to form and their expected levels
- Reduce DBP precursors in the source water if these are at levels such that DBPs may form at concentrations greater than their MAV
  - This may include filtration ahead of chlorine addition to remove dissolved organic matter
- Maintenance of chlorine dosing equipment to ensure chlorine is not over or under-dosed
- Monitoring of chlorine residual to check that chlorine is not over or under-dosed.

Operational health and safety risks are minimised if chlorine equipment is installed, operated and maintained in accordance with good industry practice.

Consumers can purchase activated carbon filters to remove chlorine and its by-products if they find these objectionable.

If people experience aesthetic issues related to taste and/or odour, the tastes or odours can be reduced by keeping a jug of water stored in the fridge for drinking.

2.4.2 Managing Risks of Not Chlorinating

The risks of not disinfecting with chlorine can be managed through the WSP process by a range of measures including:

- Reticulation monitoring for *E. coli*

- Water asset management to make sure that the condition of distribution system assets (pipes, valves, reservoirs, etc.) is satisfactory, and that they upgraded or replaced before they corrode or break and allow contaminants to get in to the water supply
- Training and supervision of maintenance workers and contractors to ensure standard operating procedures in relation to hygiene are followed
- Regular inspections and maintenance of wellheads to ensure they remain secure
- Robust backflow prevention strategy with monitoring and enforcement
- Remedial action plans for when problems are identified.

There are a number of water supplies in Europe that do not disinfect with chlorine and are able to reduce contamination risks through use of other measures. These measures include:

- Reducing leakage rates through the reticulation to around 3%
- Reducing pipe breakage rates by replacing reticulation pipes early
- Large source protection zones with very limited activity and infrastructure within them
- A high level of monitoring
- Vigilant backflow protection.

Considerable change would be required for a typical New Zealand water supply to achieve the high European standards for non-chlorinated supplies. This would include; major reticulation and reservoir renewals, greater control of land use and discharges in source protection zones, clean-up of contaminated sites, greater control of drilling and wells/piles upgradient of water supply wellfields; and there would be a substantial increase in the operational, maintenance and monitoring requirements. The costs to ratepayers would be significant.

Where a water source is not secure, alternative disinfection processes such as UV disinfection can be used instead of chlorine to inactivate pathogens, although UV does not provide a residual in the distribution system.

In disaster situations (e.g. floods and earthquakes), emergency chlorination is often used in the immediate response phase as a means of dealing with increased levels of contamination (e.g. sewage) that are usually associated with disaster events.

3 *E. coli* Transgressions

To aid in the risk assessment for each supply, historical *E. coli* monitoring results were considered. Data from annual compliance reports has been used. This includes data from July 2012 to June 2017. Figure 3-1 shows that a number of supplies have had positive *E. coli* counts in the source water.

The data show that the counts are greatly reduced after the treatment plant and in the reticulation as shown in Figure 3-2 and Figure 3-3, respectively. *E. coli* transgressions in the water leaving the treatment plant and in the reticulation are the most important to track, as they reflect what the consumer is receiving. Table 3-1 summarises the average and maximum *E. coli* transgression values. This table highlights a few supplies that have had high *E. coli* values in the past.

This information, as well as the knowledge of which supplies have had improvements (such as installation of UV) in recent years, have been used to aid in the risk analysis shown in Section 4.

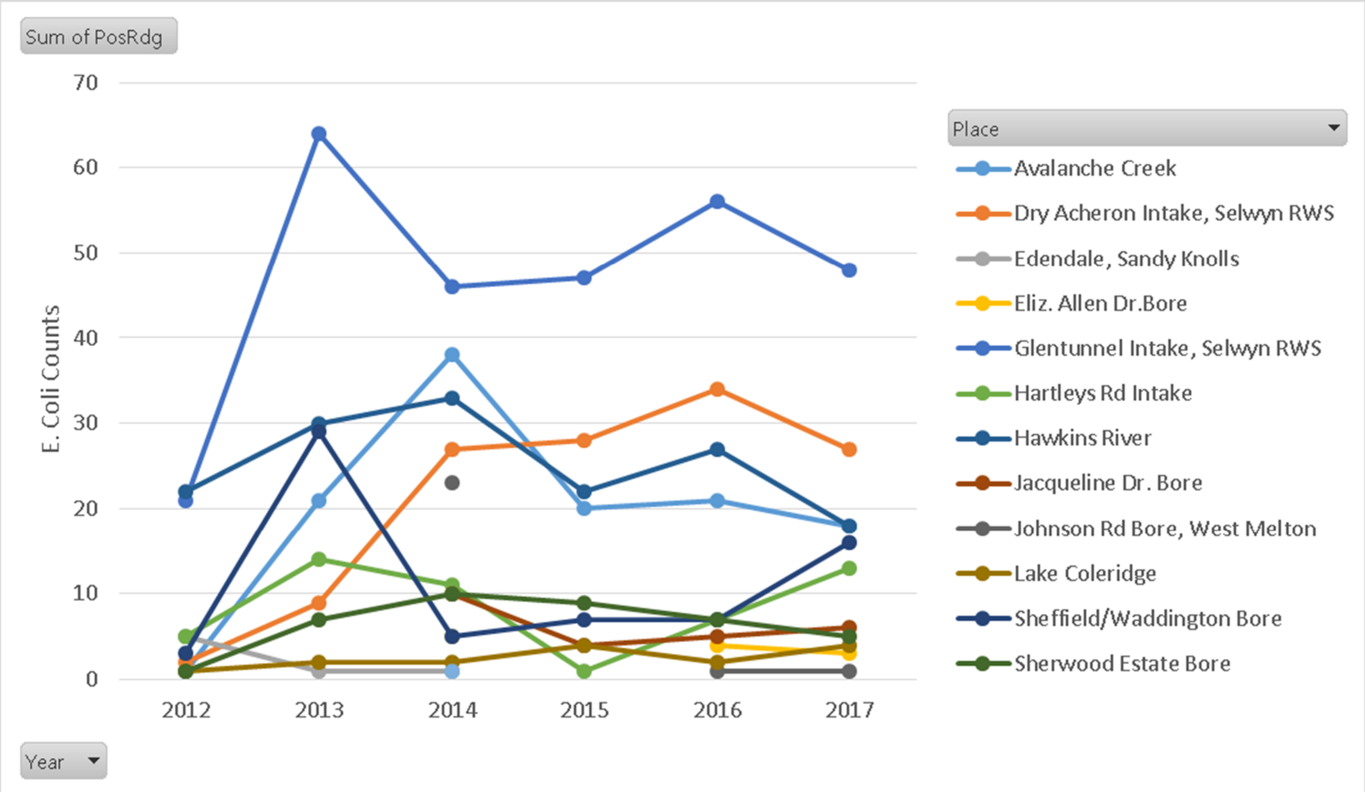

Figure 3-1: *E. coli* Counts in Source Water

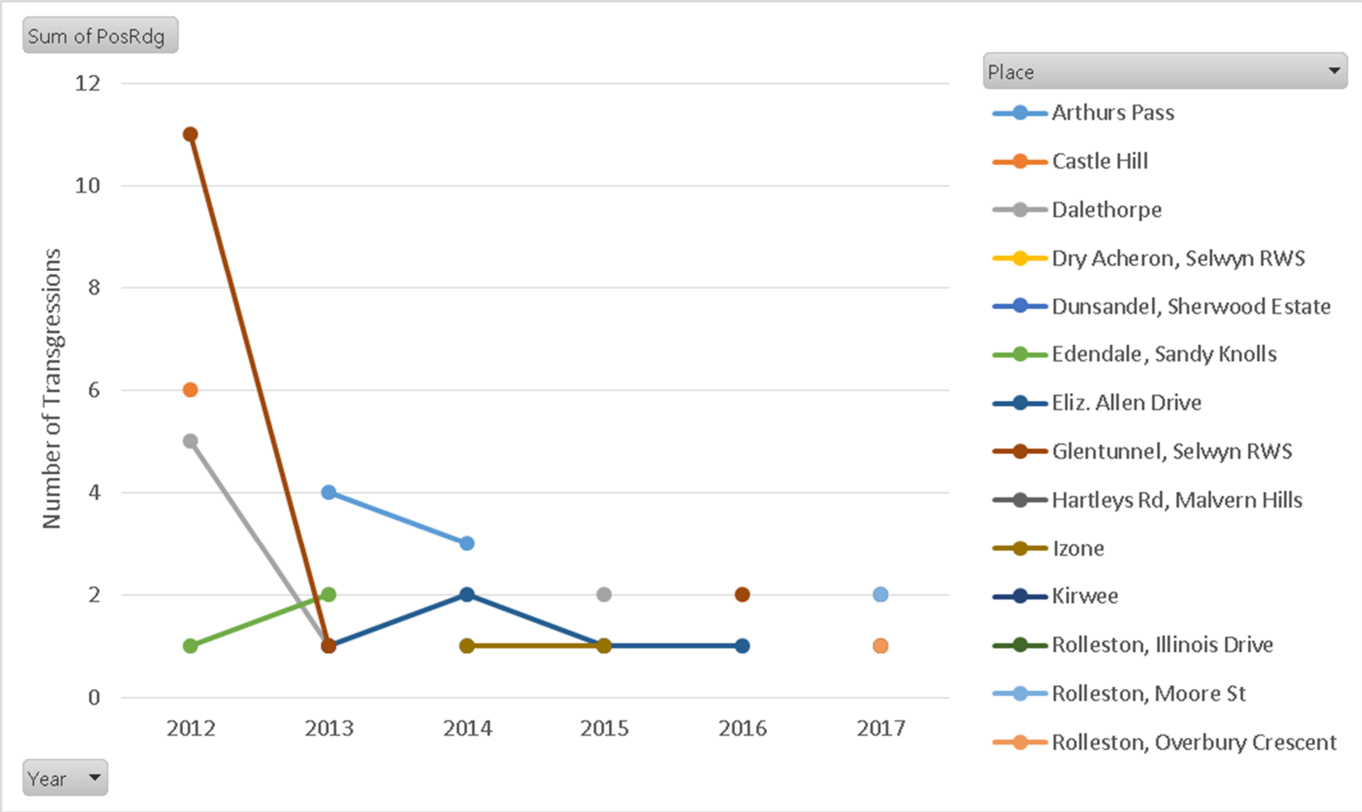

Figure 3-2: Annual Transgressions Following the Treatment Plant

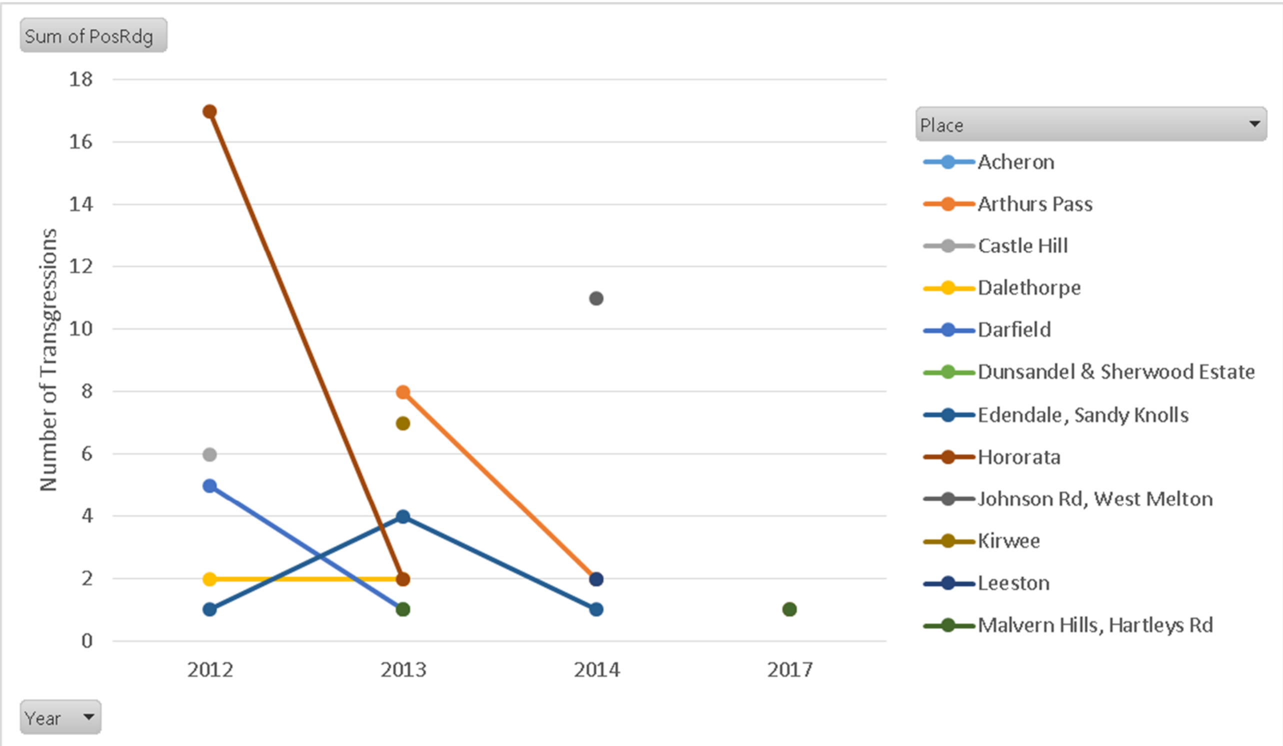

Figure 3-3: Annual Transgressions in the Reticulation

Table 3-1: Summary of Average and Maximum *E. coli* Transgression Readings in the Reticulation (July 2012 – June 2017)

	Average *E. coli* Concentration when a Transgression occurs (MPN/100mL)	Maximum *E. coli* Concentration when a Transgression occurs (MPN/100mL) [Date of sampling]
Acheron	5	9 [22 April 2014]
Arthurs Pass	2	11 [18 March 2013]
Castle Hill	2	4 [19 July 2012]
Dalethorpe	21	78 [12 November 2012] Before UV and chlorination upgrade
Darfield	30	70 [16 August 2012] From the now de-commissioned river source
Dunsandel & Sherwood Estate (before UV upgrade)	1	1 [3 January 2013]
Edendale, Sandy Knolls (before new bore and UV upgrade)	1	2 [13 & 17 July 2013]
Hororata	4	19 [10 October 2013]
Johnson Rd	18	83 [19 April 2014] Treatment bypass now de-commissioned
Kirwee (before new bore and UV upgrade)	3	8 [20 August 2013]
Leeston	1	1 [17 February 2014]
Malvern Hills, Hartleys Rd (before new bore and UV upgrade)	1	1 [26 November 2013]

4 Chlorination Priority Matrix Formation

4.1 General

A series of five workshops were completed to develop the Chlorination Priority Matrix. Each workshop included representatives from SDC, Beca, Sicon (the WTP operators), Food and Health (not at Workshop 5) and the Drinking Water Assessor (not at Workshop 1).

The aim of the workshops was to consider those risks that could potentially be mitigated by chlorination and so other contamination (including protozoa) was not considered. This is because chlorine is only effective against bacteria.

The sections below list the key activities completed in each workshop. An Excel spreadsheet was prepared and built on during each workshop.

4.2 Workshop 1

The first workshop occurred on 20 July 2017. The aim of this workshop was held to gain a greater understanding of the bacterial human health risks associated with each of the SDC water supplies. The workshop was structured by working through supply categories and identifying the known risks in a general sense as well as for each individual supply. The categories were:

- Secure groundwater supplies (larger supplies)
- Secure groundwater supplies (smaller supplies)
- Non-secure groundwater supplies (larger supplies)
- Non-secure groundwater supplies (smaller supplies)
- Surface water supplies.

There was also brief discussions on regulatory requirements, likely changes to come and fluoridation.

The bullet points below provide a high level summary of the workshop:

- The aim was to have a fresh look at risks. This was triggered by concern around a general deterioration in raw water quality in the Canterbury region. The workshop also aimed to gather information to help assess which supplies would benefit most from chlorination.
- Over the last 3 – 5 years the improvements undertaken have meant a large decrease in transgressions but there are still areas for on-going improvement on some schemes.
- Two key assumptions have been signed off by Council for inclusion in the next LTP:
  - Secure bores in non- or semi-confined aquifers will become non-secure – noting that SDC has seen issues in semi-confined aquifers already
  - Wells in confined aquifers that are less than 30m deep will become non-secure
- Some supplies could benefit from *Cryptosporidium* testing (i.e. reduced log-credit requirement). This does not have to be repeated every five years if risks are unchanged (a clarification to Drinking-water Standards for New Zealand (DWSNZ) that is documented in the Guidelines).

This workshop led to the first draft of the Chlorination Priority Matrix. This matrix is summarised in the report titled *Risk Assessment of Water Supplies and Need for Treatment*, dated 2 November 2017. This matrix was proof of concept and it was then developed further as a result of subsequent workshops.

4.3 Workshop 2

The second workshop occurred on 28 June 2018. The aim of this workshop was to review the previous matrix and consider how it could be improved to be made more robust. Discussion was focused around the objectives of the risk matrix and what it should include to adequately reflect each supply. Methods of quantifying likelihood, consequence and resulting risk were considered.

The risk factors determined in the previous risk matrix were divided into source/treatment and reticulation/end user and additional risk factors were collaboratively developed. It was decided that reticulation/end user risk factors should have a separate weighting from the source/treatment risk factors. This is because microbial contamination at the WTP is more likely to be identified and mitigated than contamination in the reticulation. As a starting point, it was decided that source/treatment carries 30% of the risk and reticulation/end user carries the remaining 70%. This was later changed to 40% source/treatment and 60% reticulation/end user, based on the experience and knowledge of the workshop attendees.

An initial version of the updated risk matrix was formed following this workshop. It was prepared in an Excel file with data input tabs feeding into the matrix tab. Subsequent workshops were focused on refining this matrix.

4.4 Workshop 3

The third workshop occurred on 7 August 2018. The focus of this workshop was to refine the risk factors previously identified and to identify information sources still required.

Some risk factors are binary (i.e. the risk exists, or it doesn't), but some risk factors carry varying degrees of likelihood or severity. During this workshop, criteria for each risk factor were discussed so that a consistent approach to determining the severity of the risk at each site could be made.

The vulnerable population risk factors were refined as it was found that supplies feeding preschools, primary schools and hospitals/rest homes were receiving compounding risk factors which unfairly moved these supplies to the top of the priority list.

During this workshop, the relative risk ranking for each risk factor was considered. This was done by comparing the percentage of the category that each risk factor received. This lead to refinement of the rankings used.

4.5 Workshop 4

The fourth workshop occurred on 14 August 2018. The purpose of this workshop was to work through the inputs into each risk factor for each supply and confirm the accuracy. As in previous workshops, the personnel in attendance was key. Operators, SDC staff and the Drinking Water Assessor know each supply well and were able to comment on the data, any assumptions made, and any recent changes to the supplies.

4.6 Workshop 5

The fifth and final workshop was carried out to agree on the final version of the matrix, this report and the recommendations to be presented. This occurred on 24 October 2018. A few final additions and corrections were made to the matrix and the priority rankings were agreed upon.

4.7 Information Sources

Table 4-1 lists the key information sources for the matrix.

Table 4-1: Key Information Sources

Code	Risk	Information Source
Source and Treatment		
ST1	Well depth	From WSP and updated based on operator knowledge
ST2	Log Credit - Bore/surface water	From annual compliance reports
ST3	Treatment	From WSP and updated based on operator knowledge
ST4	High turbidity/low UVT issues unresolved	SDC SCADA data, operations knowledge
ST5	High risk of flooding/inundation at non-secure bore heads	Operations knowledge, historical evidence, SCADA
ST6	No stock exclusion in an area with livestock; i.e. stock can be within 5m of the bore heads	Operations knowledge, documented in WSP
ST7	Bacterial compliant WTP	Compliance reports, 14/15, 15/16 and 16/17
ST8	Specific operational risk (note: accessibility, sewer)	Operations knowledge
Reticulation / End User		
RE1	Population	From 2017 data provided
RE2	Tourist/moving population	Only applies to Arthur's Pass and Acheron (Terrace Downs)
RE3	Vulnerable population - hospitals/rest homes	SDC data, workshop
RE4	Vulnerable population - primary schools	School populations from Ministry of Education
RE5	Vulnerable population - preschools	Preschool populations from Ministry of Education
RE6	Reticulation runs through public or private land (private strikes)	SDC GIS asset data
RE7	Rapid growth in residential/trade/industrial connections resulting in a risk of contamination	Workshop information

Code	Risk	Information Source
	because of contractors striking pipes, take water from hydrant	
RE8	Commercial enterprise / industry with risk of microbial contamination or backflow risk	Based on knowledge of industries in town
RE9	Large number of Council reservoir sites and/or high risk of leaks in reservoir(s)	Based on number of reservoir sites and condition rather than number of reservoirs
RE10	Vulnerable reticulation with likely sources of ingress i.e. poor condition pipes/fittings and/or frequent breakages	Based on pipe condition assessments
RE11	Low pressure either intermittently or all the time in network	Operations knowledge
RE12	Reticulation passing through a town with septic tanks	SDC asset data, GIS
RE13	Private tanks	SDC asset data, rating system
RE14	Bacterial compliant reticulation	Compliance reports, 14/15, 15/16 and 16/17
RE15	Specific operational risk (note: accessibility, sewer)	Operations knowledge

4.8 Priority Rankings

Table 4-2 lists the risk rankings that were agreed on for each priority. A number of methods were considered (i.e. use of standard deviations) but a linear ranking system was determined as the most appropriate.

Table 4-2: Priority Rankings

Min Risk Ranking	Max Risk Ranking	Priority
35	+	Priority 1
27	35	Priority 2
18	26	Priority 3
9	17	Priority 4
0	8	Priority 5

5 Chlorination Priority Matrix

5.1 Risk Matrix

A robust risk matrix has been prepared as a result of the inputs and workshops described above. Preparation of this matrix was a collaborative approach by those that attended the workshops. The intention is for the matrix to remain a working file so that risk rankings can be updated as changes are made to each of the supplies.

Table 5-1 provides a summary of the matrix outcomes as of this report date. Those supplies that are already chlorinated (or there are plans to chlorinate shortly) are shown in blue. Six supplies are included in the Priority 1 group and four of these are already chlorinated/there are plans to chlorinate them. A further three of the five Priority 2 supplies are already chlorinated/there are plans to chlorinate them.

Table 5-1: Summary Priority Matrix

Water Supply Scheme	Risk Ranking	Priority
Acheron	58.8	Priority 1
Malvern Hills, Hartleys Rd	57.1	Priority 1
Hororata	55.6	Priority 1
Dalethorpe	53.2	Priority 1
Arthur's Pass	51.7	Priority 1
Upper Selwyn Huts	38.0	Priority 1
Sheffield/ Waddington	35.3	Priority 2
Springfield	34.1	Priority 2
Castle Hill	32.7	Priority 2
Rolleston	31.4	Priority 2
Lake Coleridge	30.0	Priority 2
Darfield	27.3	Priority 2
Tai Tapu	24.8	Priority 3
Te Pirita	24.8	Priority 3
Taumutu	23.8	Priority 3
Prebbleton	23.3	Priority 3
West Melton	23.1	Priority 3
Springston	22.4	Priority 3
Lincoln	21.7	Priority 3
Johnson Rd, West Melton	21.6	Priority 3
Southbridge	21.5	Priority 3
Leeston	20.6	Priority 3
Kirwee	17.9	Priority 3
Jowers Road	17.8	Priority 3
Raven Drive	14.8	Priority 4
Dunsandel & Sherwood Estate	14.8	Priority 4
Rakaia Huts	13.6	Priority 4
Claremont	8.4	Priority 5
Edendale	7.1	Priority 5

Shaded supplies are already chlorinated or planned for chlorination.

6 Recommendations

The main aim of the study was to aid SDC in gaining a greater understanding of the human health risks associated with each of the SDC water supplies and to establish a method for prioritising the chlorination of supplies. As a result of the workshops and the collaborative approach to developing the risk matrix, the following recommendations are made:

- Continue to review and update the Chlorination Risk Matrix as changes are made to the supplies
  - This includes updating the matrix as renewals and repairs are made, new treatment is installed and new risks are identified
  - If the structure/methodology of the matrix is modified then a committee with representatives from SDC, the operator, CDHB and other drinking-water experts should be brought back together to discuss and agree on the changes
- Chlorinate the supplies in order of priority ranking (i.e. Priority 1 supplies first)
  - Note that for some supplies (i.e. Arthurs Pass) there are plans to upgrade which will change the risk ranking once completed
  - If SDC does not decide to chlorinate all supplies, then a review and implementation of international best practice is recommended
  - It will be important to engage with communities early on and to clearly communicate the advantages of chlorination, drawing from the information presented in Section 2.

7 Glossary

DBP	Disinfection by-product
DWA	Drinking Water Assessor
DWSNZ	Drinking-water Standards for New Zealand
E. coli (*Escherichia coli*)	A bacterium used as an indicator of faecal contamination
Enteric	Related to the intestinal tract
Epidemiology	Studies of the factors that influence disease in human populations
Free available chlorine (FAC)	The chlorine present in chlorinated water in the form of hypochlorous acid and hypochlorite ion
Fluoridation CoP	Water New Zealand Code of Practice for the Fluoridation of Drinking-Water Supplies in New Zealand
Guideline value (GV)	In the DWSNZ the value for an aesthetic determinand that, if exceeded, may render the water unattractive to consumers
HAA Haloacetic acid.	A type of disinfection by-product in which one or more of the hydrogen atoms in acetic acid has been replaced by a halogen atom (chlorine or bromine).
MAV	Maximum Acceptable Value. The concentration of a determinand, below which the presence of the determinand does not result in any significant risk to a consumer over a lifetime of consumption.
MoH NZ	Ministry of Health
Natural organic matter (NOM)	Complex organic compounds that are formed from decomposing plant, animal and microbial material in soil and water. Total organic carbon (TOC) is often measured as an indicator of NOM.
Pathogen	An illness-causing micro-organism
PHRMP	Public Health Risk Management Plan
Protozoa	Free-living, aquatic, single celled micro-organism that is larger and more complex than bacteria, for example *Giardia* and *Cryptosporidium*
THM	Trihalomethane. A type of disinfection by-product in which three of the four hydrogen atoms of methane (CH_4) have been substituted by halogen atoms (chlorine or bromine)
WHO	World Health Organisation
WINZ database	Water Information New Zealand database
WSP	Water Safety Plan

US EPA	United States Environmental Protection Agency
UV disinfection	Disinfection using electromagnetic radiation (ultraviolet light) with wavelengths in the range of 200 – 400nm

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