Waikouaiti Metals – Investigation Report

DOCUMENT CONTROL

Date	Version	Author	Change Details	Approved By
08/07/2021	1.0	DCC 3 Waters	Final version	Tom Dyer, 3 Waters Group Manager
23/07/2021	2.0	DCC 3 Waters	Replaced Appendix C with revised Eurofins investigation report and modified text in section 5.4 and appendix title to reflect this. Modified table 5 to include number of inter-lab duplicate samples.	Tom Dyer, 3 Waters Group Manager

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DEFINITIONS

Determinand	A parameter that can be measured, or determined, by testing using an analytical method.
Distribution network	DCC-owned pipes and fittings that are used to transport potable water to customer supply points. Also known as a distribution system.
Distribution main	DCC-owned pipe which typically supplies multiple customers and to which service lines are connected.
Distribution zone	A distribution zone is a part of the distribution network in which all consumers receive drinking water of identical quality, from the same or similar sources, with the same treatment. The pressure is usually similar throughout a zone and the zone is usually clearly separated from other parts of the network (by location, layout, or composition of pipe). A distribution network in a water supply scheme may be separated into multiple distinct distribution zones.
Do Not Drink notice	A notice not to consume water including using tap water for drinking, cooking or preparing food.
Drinking water assessor	An individual appointed by the Director General of Health under section 69ZK of the Health Act 1956 to carry out the functions in section 69ZL of that Act, including assessing compliance of drinking water suppliers with the Act and the DWSNZ 2018. (see https://www.health.govt.nz/our-work/environmental-health/drinking-water/drinking-water-legislation).
Elevated results	For the purpose of this report, elevated results are considered to be laboratory results of a determinand in drinking water greater than the maximum acceptable value in the DWSNZ 2018.
Exceptional results	For the purpose of this report, exceptional results are considered to be laboratory results of a determinand from a water supply which are significantly above the typical value (see definition below) for a given sampling point.
Karitane Bowling Club	Customer in Karitane located at 106 B Stornoway St, Karitane.
Lead	A metal which has known adverse health effects when ingested.
Lead – Acid Soluble	Lead detected in a sample that is acidified with nitric acid upon sampling without filtration and analysed using ICP-MS. This measure of lead tends to include lead that is lightly adsorbed to particulates and is typically used for clean samples (drinking water samples) that has very little particulate

	matter. A modified version of APHA Online Edition method 3125 was conducted by Eurofins.
Lead – Dissolved	The lead detected in a sample after the sample has been filtered through a 0.45 micron filter and acidified to a pH < 2. This measure of lead is essentially the fraction of lead in a water sample that is not filterable (i.e. dissolved). A modified version of APHA Online Edition method 3125 was conducted by Eurofins.
Lead – Total	The total amount of lead in a water sample after a thorough digestion step in hot acid. This measure of lead is similar to acid soluble, but will extract more of the lead from particulates, if not all of it, and is typically used for raw water or sediment samples. A modified version of APHA Online Edition method 3125 was conducted by Eurofins.
Non-detectable results	Laboratory results showing a determinand is not present above the limit of detection for a test.
Local lead leaching	The ability of water to dissolve lead from lead-bearing materials.
Point of supply	The point at which customer plumbing is connected to the water supplier network.
Post-flush sample	A sample taken after flushing a tap for a designated amount of time (i.e. the protocol for metals sampling may include a directive to flush the tap before sampling for the flushed sample).
Pre-flush sample	A sample taken before flushing a tap, also known as the first flush sample, which may contain higher amounts of metals due to plumbosolvent waters causing leaching of lead or corrosion of fixtures and plumbing.
Service line	Pipework (and fittings) that connects a property to a distribution main. Service lines have been constructed of copper, galvanised steel, plastic, lead, or a mixture of these materials.
Tail piece	A fixture (lead has been used the past) that connects a service line (usually galvanised) to the distribution main.
Typical value	The average of more than 10 historical results for a determinand at a given sampling point.
Waikouaiti Golf Club	Customer located at 210 Edinburgh St, Waikouaiti.
Water supply scheme	A scheme consisting of all interconnected assets (pumps, treatment plant, pipes, fittings, etc) which gather raw water, treat raw water, and supply treated water to customers in a distribution network.

ACRONYMS AND ABBREVIATIONS

CRA	Catchment Risk Assessment
CSMR	Chloride-to-Sulphate Mass Ratio
DCC	Dunedin City Council
DNDN	Do Not Drink Notice
DWA	Drinking Water Assessor
DWSNZ	Drinking-water Standards for New Zealand 2005 – Revised 2018
ESR	Institute of Environmental Science and Research
ICP-MS	Inductively coupled plasma mass spectrometry
LOD	Limit of Detection
MAV	Maximum Acceptable Value
ORC	Otago Regional Council
PHS	Public Health South
T&T	Tonkin and Taylor
SS	Sampling Station
WSP	Water Safety Plan
WTP	(drinking) Water Treatment Plant

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EXECUTIVE SUMMARY

A number of elevated lead results were found in the Waikouaiti, Karitane, and Hawksbury Village water supply scheme between 31 July 2020 and 20 January 2021. On 2 February 2021, the Dunedin City Council issued a Do Not Drink Notice (DNDN) for this scheme. Since then, an investigation team has been working to understand the causes of the results and determine the risks to public health as far as practicable. A key aspect of this is to understand the cause of the exceptional values observed on 8 December 2020 (at Waikouaiti Golf Club and Karitane Bowling Club) and 20 January 2021 (in the raw water reservoir).

This report details the investigation team's findings about the source of the elevated lead results. The investigation included a review of potential lead sources and a high-level overview of potential sources/causes of high readings is included in the table below.

Considerations in Lead Investigation	Issue	Investigations Undertaken
Sample Methodology and Analytical Error	Sample collection	Review of sampling and analytical protocols. Duplicate samples and blanks.
	Laboratory Analysis	
Lead Leaching and Corrosion **(potential sources of internally derived lead contamination)**	Corrosivity of finished water	Review of water quality data including pH, alkalinity, CSMR.
	Distribution Network (DCC infrastructure)	Distribution main joints, service connections, backflow.
	Localised Lead Leaching (generally local plumbing fittings and pipework)	Review of sample data, review of local plumbing, stagnation tests and profile sampling.
Lead Ingress **(potential sources of externally derived lead contamination)**	Raw Water Contamination	Water quality analysis, Catchment risk assessment, review of raw water and gold mine data, network water age analysis.
	Water treatment plant	Plant operational review, chemical analysis, plant materials review and revision of tube settler operation.
	Backflow event	Review of low-pressure events (breaks) and connected properties.

Since the DNDN was issued on 2 February 2021, no instances of elevated lead in the distribution network have been observed in post-flush samples. However, elevated lead results have regularly been observed in pre-flush samples and are likely caused by water sitting within metallic fittings. The results of samples collected from raw water were at or below the limit of detection (LOD) in 351 out of 352 samples since DNDN was issued.

The data gathered indicated that lead is not persistently present in the Waikouaiti, Karitane and Hawksbury Village water supply scheme. To date, the abnormal or exceptionally high values observed on 8 December 2020 and 20 January 2021 have not been repeated.

The cause of exceptional readings on 8 December 2020 has been investigated. Here are the key findings.

- The most likely cause of exceptional results on 8 December 2020 is lead leaching from pipes and fittings in customer connections, not from the wider DCC drinking water network. The leaching may have been exacerbated by the length of time water was sitting in pipes and fittings, capture of particulate material in the sample or changes in water corrosivity. Lead readings from the customer taps used on 8 December 2020 displayed significantly higher lead levels than sampling from the distribution main close to these taps and high results were reproduced through stagnation testing with local fittings. High lead results were also obtained even when flushing for 10-20 minutes (during profile sampling) at both the Waikouaiti Golf Club and Karitane Bowling Club.
- The results on 8 December 2020 could also have been caused by sampling or analytical error, or be a result of catchment contamination. However, this appears less likely. Catchment contamination would have been a rare and relatively short-term event and would require any contamination to be from dissolved lead (rather than particulate) in order to have passed through the water treatment plant.

The cause of exceptional readings on 20 January 2021 has been investigated. Here are the key findings.

- The most likely cause of the exceptional result on 20 January 2021 in the raw water reservoir is lead in sediment from the raw water or the reservoir, or capture of particulate material from the sample tap. There was a spike in turbidity in the raw water on 20 January 2020 which coincided with the raw water reservoir running at low level. Most, if not all, particulate lead is removed by the water treatment process. Therefore, if the 20 January 2021 raw water result was caused by catchment contamination, it is unlikely that this would have resulted in lead-containing water being supplied to customers. Particulate material in raw water could be associated with sediment or lead bearing material stirred up in the river. The sample tap used on 20 January 2021 is a typical household tap and could be subject to corrosion.
- The results on 20 January 2021 could also have been caused by sampling or analytical error. However, this appears less likely.

A summary of the likelihood of potential causes of the exceptional readings on 8 December 2020 and 20 January 2021 is provided in the table below (see definitions used in likelihood assessment in Section 5.3).

	Potential Causes of Exceptional Lead Results		
Sample	**Likely**	**Unlikely**	**Very Unlikely**
Treated Water Waikouaiti Golf Club 8 December 2020	Localised Lead Leaching	Sampling Error, Lead Ingress (including from catchment), Network Lead Leaching	Backflow, Plant Related Event
Treated Water Karitane Bowling Club 8 December 2020	Localised Lead Leaching	Sampling Error, Lead Ingress (including from catchment), Network Lead Leaching	Backflow, Plant Related Event

Raw Water **20 January 2021**	Lead Ingress (including from catchment), Localised Lead Leaching	Sampling Error, Network Lead Leaching	Plant Related Event

1 INTRODUCTION

This report documents the investigation of elevated lead results observed from samples obtained in the Waikouaiti, Karitane, and Hawksbury Village water supply scheme. This follows the issue of a Do Not Drink Notice (DNDN) for Waikouaiti, Karitane and Hawksbury Village on 2 February 2021.

The results were part of a sampling programme initiated by DCC 3 Waters in July 2020. Lead was not regularly measured prior to this. The sampling programme is in addition to Drinking Water Standards for New Zealand (DWSNZ) requirements (1) (see section 7 for references), with regular lead monitoring not currently a requirement in this supply scheme. The additional sampling was primarily intended to inform a corrosion control strategy for the Waikouaiti Water Treatment Plant (WTP) as part of a planned upgrade to the WTP.

The first samples of the sampling programme were collected on 31 July 2020 and sampling is ongoing. Several elevated results were observed initially which the DCC acted on, including carrying out operational modifications and investigation. Exceptional results – lead readings 20 to 100 times higher than typical values – were observed at customer sampling taps in the distribution network on 8 December 2020 and in the raw water reservoir on 20 January 2021. The result at the raw water reservoir was the first elevated result (above regulatory limits—also known as maximum acceptable values or MAVs—for treated water) observed at the WTP and ultimately prompted the precautionary DNDN. On both occasions the subsequent samples were significantly lower (less than MAV based on DWSNZ).

Since the DNDN was issued, a dedicated investigation team has been gathering data, assisting the event response, working to understand the causes of elevated lead results and attempting to better characterise the risks to public health as far as practicable. A key aspect of this investigation was to understand the cause(s) of the exceptional values observed on 8 December 2020 and 20 January 2021.

An investigation plan was developed in February 2021 which outlines the objectives of the investigation (*Waikouaiti Metals Investigation Plan – Version 1 – 12 Feb 2021)*. A revised Waikouaiti Metals Recovery Phase Investigation Plan (2) documents the subsequent phase of the investigation.

This report effectively supersedes the Waikouaiti Metals – Response Phase Investigation Update Report (March 2021). The purpose of this report is to:

- provide a summary of lead data collected to date
- provide a summary of investigations and findings
- identify the most likely causes of elevated lead readings from water sampling at Waikouaiti and Karitane, including exceptional values observed on 8 December 2020 and 20 January 2021.

This report is not intended to:

- document other aspects of the DNDN response such as the operational workstream
- review the organisational response to the initial observation of elevated lead levels or the associated process and systems
- provide comprehensive details of any proposed mitigation measures.

This report was prepared by the DCC and peer reviewed by Tonkin and Taylor and Stantec.

2 BACKGROUND

2.1 Waikouaiti, Karitane and Hawksbury Village Water Supply Scheme Overview

The Waikouaiti WTP takes raw water from the Waikouaiti River. The Waikouaiti River has the third largest catchment in Otago and consists of a north branch and a south branch that converge approximately 8km upstream of the confluence with the Pacific Ocean (3). The larger north branch catchment extends into Macraes Flat, while the smaller south branch catchment extends towards Swampy Summit. The Waikouaiti WTP treats raw water taken from just downstream of the confluence of the north and south branches of the Waikouaiti River.

The Waikouaiti WTP treats water using membrane filtration with post treatment to condition water for consumption including chlorine for disinfection and soda ash for pH modification. After treatment, potable water is distributed to four distinct distribution zones, as shown in Figure 1 below. Hawksbury Village is supplied by a private distribution network via a metered connection from the DCC distribution network.

The network materials in Waikouaiti, Karitane, and Hawksbury Village consist of 39% asbestos cement, 21% PVC/oPVC/uPVC, 18% PE and 10% cast iron/galvanised iron. The remainder consist of ductile iron and concrete lined steel (as well as fittings and fixtures of various materials). Dedicated sampling stations (SS) have been installed throughout the distribution network recently to replace customer taps for sampling. The relative locations of these new and old sampling points are shown schematically in Figure 1 below.

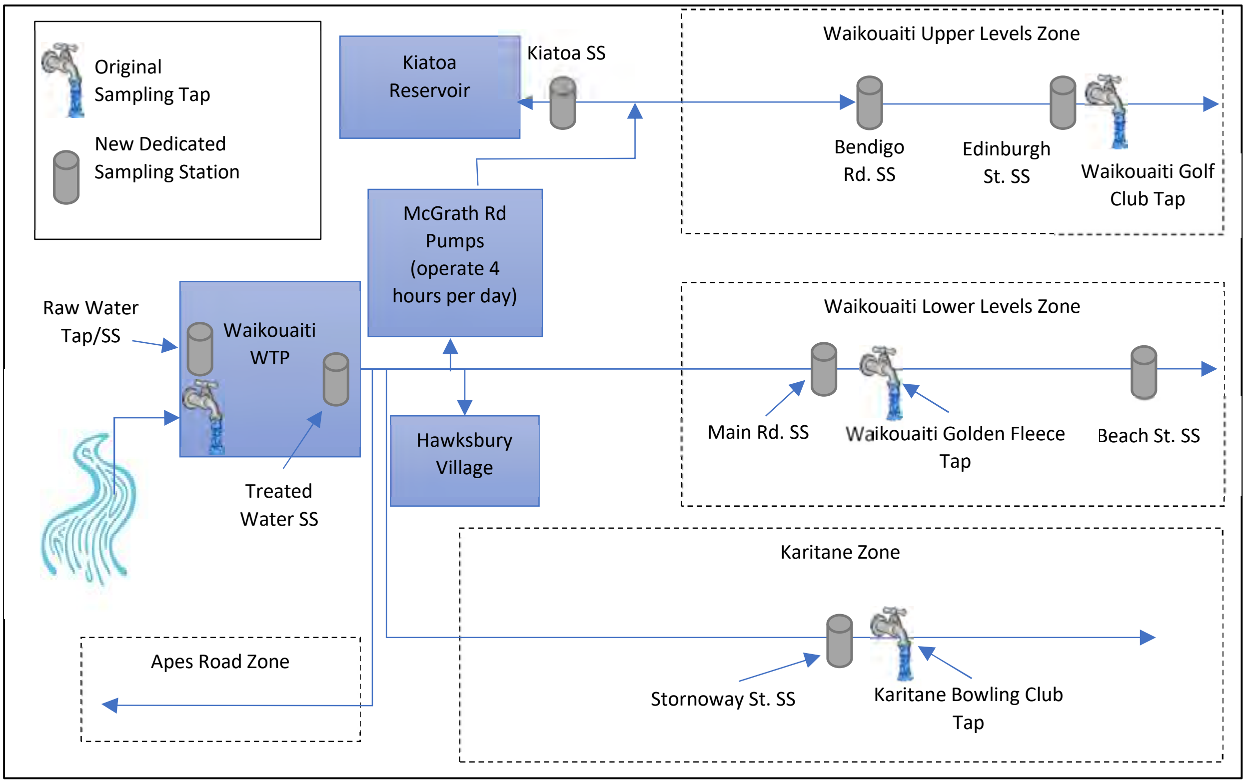

Figure 1: Waikouaiti, Karitane, and Hawksbury Village Water Supply Scheme

2.2 Lead in Drinking Water

2.2.1 Drinking water standards and compliance

The Health Act 1956 requires water suppliers to comply with the DWSNZ, which specifies determinands (further guidance available online (4)) that must be tested and the required frequency of testing. These determinands are categorised into groups according to their level of priority.

- Priority 1 (P1) determinands are microbiological (such as E. Coli) and protozoal (such as cryptosporidium) determinands. Drinking water suppliers are required to monitor for the effective removal of these determinands in all supplies as they present the highest level of health risk. The frequency of testing required for microbiological P1 determinands is dependent on the population being supplied and the elected compliance criteria. A distribution zone with a higher population requires more frequent sampling.
- Priority 2 (P2) determinands must be monitored regularly by drinking water suppliers and are assigned by the Ministry of Health. P2 determinands may include any chemical determinands, including heavy metals such as lead. There are no P2 determinands assigned for the Waikouaiti treatment plant or distribution zone (5).
- Priority 3 (P3) determinands do not require regular monitoring by drinking water suppliers and include all chemical determinands not assigned as P2 determinands. Drinking water suppliers may undertake discretionary monitoring of P3 determinands.

In 2020, the DCC approved funding for additional sampling in excess of DWSNZ standards from the 2020/2021 financial year. This budget funded the corrosivity sampling undertaken at Waikouaiti. Prior to July 2021, lead was not assigned as a P2 determinand for the Waikouaiti, Karitane and Hawksbury Village scheme and is therefore considered a P3 determinand. However, lead has been assigned as a P2 determinand from July 2021 and requirements for ongoing monitoring will be discussed and agreed with regulatory authorities.

2.2.2 Lead from the catchment / raw water supply

Water supplies that provide drinking water to a population of more than 500 in New Zealand are required to operate under a drinking water safety plan (WSP), which identifies risks of contamination in the water supply and ensures adequate measures are in place to treat water and provide safe drinking water. The level of treatment required for any water supply is a function of potential impurities in the feed water. Waikouaiti water supply is operated under a WSP, which includes a risk assessment of the catchment. This identified several risks associated with metals from the catchment and a range of controls. These controls include:

- Otago Regional Council (ORC) resource consents conditions require river water to be free of contaminants attributable to mineral processing and associated mining activities
- monitoring of discharge waters (quarterly and annually) conducted at the mine by Macraes staff under resource consent conditions
- online turbidity monitoring of raw water – high turbidity triggers an alarm
- raw water storage of 48 hours available during average demand.

2.2.3 Lead from the distribution network and local plumbing

The most common cause of elevated lead results in drinking water at customer taps is the corrosion of plumbing materials containing lead. (6) This local lead leaching is dependent upon plumbosolvency, which is the ability of water to dissolve lead from lead-bearing materials into water. Lead-bearing materials can include customer taps, brass fittings and fixtures, metallic pipework and, in some cases, distribution mains (lead pipes, lead jointing, some types of uPVC pipes).

The New Zealand Health website provides some technical notes on local lead leaching. These indicate that lead in drinking water in New Zealand is typically associated with metals from customer taps and service lines (connecting distribution mains to properties) rather than the distribution main. This is because most known pure lead pipework (lead pipes, lead service lines and lead tail pieces) has been removed from drinking water systems in NZ. (7) In Dunedin, known lead pipework has been replaced, as the opportunity arises, since the 1980s. However, some lead pipework is possibly still present, including unidentified lead service lines and lead tail pieces (typically found connecting distribution mains to galvanised service lines).

The amount of local lead leaching depends on a number of factors. These include the water chemistry (how corrosive it is), the pipe or fitting materials and the amount of time the water spends in contact with the pipe or fittings. (7)

Health guidance (7) identifies three options to reduce customer exposure to heavy metals in drinking water:

i) *Establishment of standards for the composition of materials that may be used in the manufacture of plumbing fittings.*

ii) *Adjustment of the chemistry of the reticulated water to minimise its local lead leaching.*

iii) *Encouragement of consumers to flush a small volume of water from the tap before drawing water for drinking, cooking or oral hygiene.*

The DWSNZ state that water suppliers servicing more than 500 people must follow the following procedures: (8; 1)

i) *Publish in a newspaper twice a year a public notice provided by the Ministry of Health.*

ii) *Provide this public warning to all consumers at least twice a year; for example, with each water supply bill or water rate demand.*

It is also possible to manage local lead leaching by dosing chemicals such as orthophosphate into drinking water. This is relatively common in some other countries, such as the UK, but uncommon in New Zealand. The risk profile of lead in water in NZ is understood to be quite different to that in the UK where lead water pipes are more common. (7)

3 DCC SAMPLING AND MONITORING

3.1 Water Metals Sampling Programme (2020)

DCC staff collect a significant amount of operational and compliance data at all WTPs, which assists in operating treatment plants and ensures safe water is provided to customers. This sampling also includes a broad range of testing to meet DWSNZ requirements. This testing has not previously included metals testing.

In July 2020, DCC 3 Waters initiated a sampling programme in the Waikouaiti, Karitane, and Hawksbury Village water supply scheme. This was primarily intended to inform a corrosion control strategy for the Waikouaiti WTP as part of a planned upgrade to the WTP. Additional data would allow optimisation of soda ash dosing at the plant which is intended to increase pH and alkalinity of treated water and reduce the potential for corrosion in the network. Improved corrosivity control would potentially extend the life of assets in the Waikouaiti distribution network and reduce the potential for pipe failures. This sampling programme is in addition to DWSNZ requirements and included samples from a range of locations across the distribution network and at the WTP. Analysis was undertaken for a broad range of parameters.

The first sample from Waikouaiti was collected on 31 July 2020 and indicated higher than anticipated levels of lead at Waikouaiti Golf Club (210 Edinburgh St). This resulted in an immediate review and expansion of the sampling in this scheme and investigation into the potential causes.

3.2 Additional Sampling and Monitoring Following DNDN

A further augmented sampling and monitoring programme was established following the DNDN. This was subject to discussion with and feedback from PHS and ESR and is documented in a 'Sampling Plan' (see Appendix A). The enhanced programme includes:

- **Additional quality assurance measures** for laboratory sampling analysis including duplicate samples (to be analysed at a second laboratory) and blanks (to identify potential contamination during transport or analysis).
- **Increased sampling frequency** (daily at most sites) with additional sampling locations added in the network, catchment and at the WTP.
- **Autosampler installation** at the river intake which collects samples every 15 minutes to evaluate the risk of potential short duration peaks of lead in river water.
- **Installation of a continuous lead monitor,** which would be the first known unit in New Zealand and provide continuous monitoring (analysis every 20 minutes) of raw and/or treated water.
- **Use of handheld lead analysers,** which were sourced from USA and could eventually be used for quick checks of lead in the field (as a crude indication of presence of lead for some field tests and not as a replacement for laboratory sampling).
- **A data sharing process** was implemented to ensure access to up to date lead data for DCC, other agencies (PHS, DWA), and the public. This included a page on the DCC website which presented all lead data and the submission of weekly data summaries to PHS and DWA. Raw data being received by the laboratory is not in an immediately useful format for the purposes of sharing with the public. Data must be checked, plotted, rechecked, and presented with appropriate messaging and context so the risk of misinterpretation is low. Data packages were also shared with technical specialists from numerous organisations in New Zealand and abroad to assist in the investigation.

3.3 Sample locations and sample taps

The initial metals sampling plan for the Waikouaiti, Karitane and Hawksbury Village water supply scheme allowed 'one off' samples at three locations in the distribution network and a number of samples at the WTP. The sampling plan was expanded to weekly sampling following review of the initial data. Following issue of the DNDN, a more comprehensive sampling programme was developed (as noted in section 3.2).

3.3.1 Distribution network sampling

Sampling in the distribution network was initially carried out at Waikouaiti Golden Fleece Hotel (Waikouaiti low levels zone), Waikouaiti Golf Club (Waikouaiti high levels zone) and Karitane Bowling Club (Karitane zone), which are customer taps attached to customer pipework. Figure 1 on page 2 shows the relative location of these taps in their respective distribution zones and a map is provided in Appendix B. These taps do not provide ideal conditions for water testing, typically because they cannot be sterilised easily which is required for microbiological testing.

The sample protocol included collecting pre-flush and post-flush samples. Pre-flush samples are collected immediately upon opening a sample tap, whilst post-flush samples are collected after the tap has been flushed for five minutes (or two minutes for dedicated sample stations after March 2021). Pre-flush samples are expected to be contaminated by the sample tap (where water has been standing since the last time the tap was used). Post-flush samples are intended to be representative of the water in the distribution main; however, this is not always the case (e.g. if the customer service line has lead-bearing pipework that contaminates the sample). Comparison of pre-flush and post-flush samples can provide insight into the source of contamination.

The DCC undertook a project to install new dedicated sample stations (SS) across the city which began in April 2020 and to date has installed approximately 100 new dedicated sampling stations. Appendix E contains the design specification and drawings of the sampling stations. The new sampling stations allow for sterilisation of taps for microbiological sampling and sampling results to be more conclusively representative of the distribution network. The new sampling stations are typically connected directly to the distribution main which eliminates the potential for contamination from customer plumbing.

The new sampling stations at 192 Main Road and 210 Edinburgh Street (Waikouaiti) and 99 Stornoway Street (Karitane) were activated on 4 February and replaced Waikouaiti Golden Fleece Hotel, Waikouaiti Golf Club and Karitane Bowling Club respectively. The new dedicated sampling stations are all close to the original sample taps but located on the distribution main. The intent of activating new dedicated sampling stations was to ensure ongoing sampling was not affected by contamination from customer plumbing and that results were representative of the water supply and distribution network.

Three additional sampling stations were installed in the distribution network in February 2021 at:

- Beach Street (intersection with Stewart Street), to provide data representative of the Waikouaiti lower levels zone
- Bendigo Road, which is upstream of Edinburgh Street and would assist in understanding the source of lead readings at the Waikouaiti Golf Course
- Kiatoa Reservoir, which supplies the Waikouaiti upper levels zone (including Edinburgh Street)

3.3.2 Treatment plant and raw water sampling

Water samples were collected from a range of locations at the WTP as well as from the raw water (multiple locations). This included the raw water intake/pump station, raw water reservoir, treated water reservoir and a number of locations throughout the WTP.

The sampling plan was updated in conjunction with PHS and ESR and is documented in the Sampling Plan (see Appendix A).

4 INITIAL REVIEW OF LEAD DATA

This section provides an initial overview of lead results observed at Waikouaiti and Karitane. Further detailed review of exceptional values is provided in sections 4.3 and 4.4.

4.1 Summary of lead data and initial observations

Figure 2, 3 and 4, show lead results from Waikouaiti Golden Fleece/192 Main Road, Waikouaiti Golf Club/210 Edinburgh Street and Karitane Bowling Club/99 Stornoway Street respectively. Figures 2-4 show both pre-flush and post-flush lead results which are described in section 3.3.1. Figure 8, Figure 10, and Figure 11 present lead results from the Waikouaiti River, raw water reservoir, and treated water reservoir, respectively.

Logarithmic scaling is used in order to show low and high results on the same plot. Care should be taken in comparing results on different days as logarithmic scaling can make high results appear closer to lower results than if they were presented on a linear scale.

Results that were below the limit of detection (LOD) are presented as being at the LOD (i.e. if the result is reported by the lab as <0.001 mg/L, it is reported here as 0.001 mg/L).

Analysis was undertaken for a broad range of metals (based on DWSNZ). However, only lead data is described in this section and generally in this report. The MAV for lead is 0.01 mg/L and the LOD is 0.0005 mg/L in treated water. The LOD for raw water is 0.001 mg/L which is higher than that for treated water because a slightly different analytical test is required. This is due to higher concentrations of other matter such as particulate material and organics. Results consist of a mixture of total, acid-soluble, and dissolved lead. Where more than one test is performed on a given date, the highest result is shown.

Table 1 provides a summary of lead results from all sample points including some which were conducted for specific assessments as part of this investigation. Specific assessments include profile sampling and stagnation testing (amongst other things) which are discussed further in section 5.

Table 2 provides acid-soluble lead results from sediment from Kiatoa Reservoir. The reservoir was drained, cleaned, and inspected in February 2021. Samples were taken on 24 February 2021 after the reservoir had been drained but before it had been cleaned and inspected. While the material was sediment from the bottom of the tank, the solids content was relatively low and was therefore analysed on a wet basis.

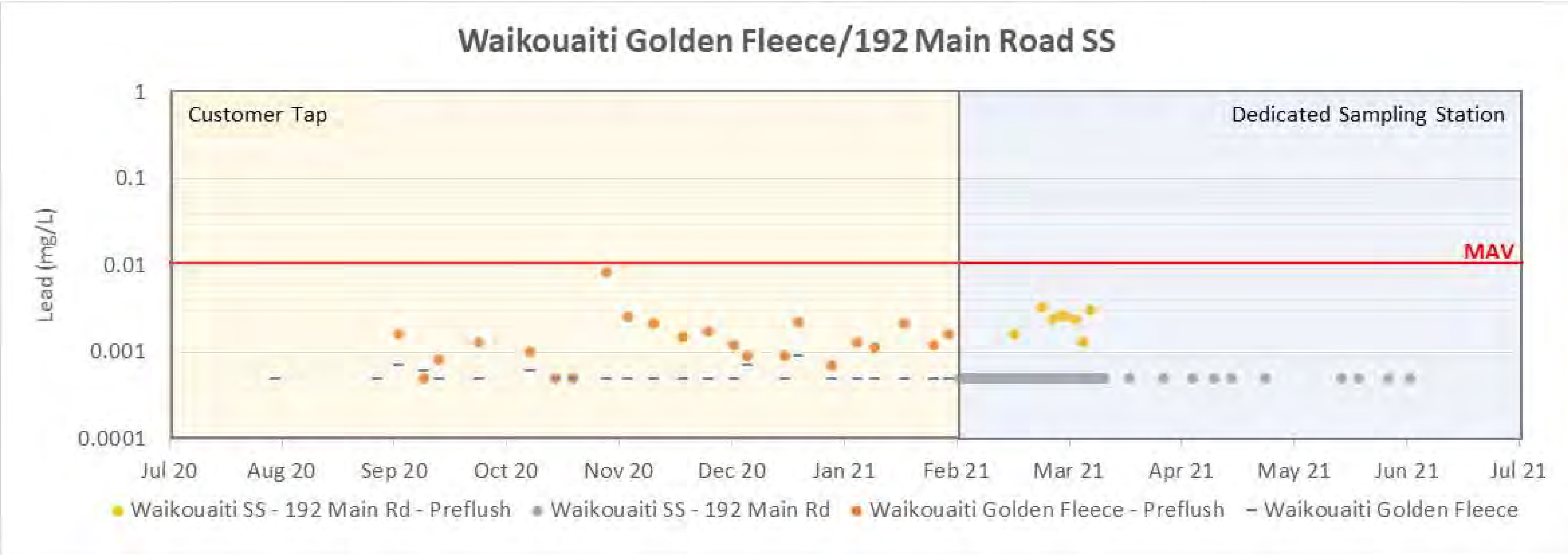

Figure 2: Lead Measurements at Waikouaiti Golden Fleece and 192 Main Rd SS (31/7/20 – 8/6/21)

Note: The continuous grey line from early February 2021 to mid-March 2021 is due to high frequency (daily) samples which were all at the same level (i.e. less than LOD)

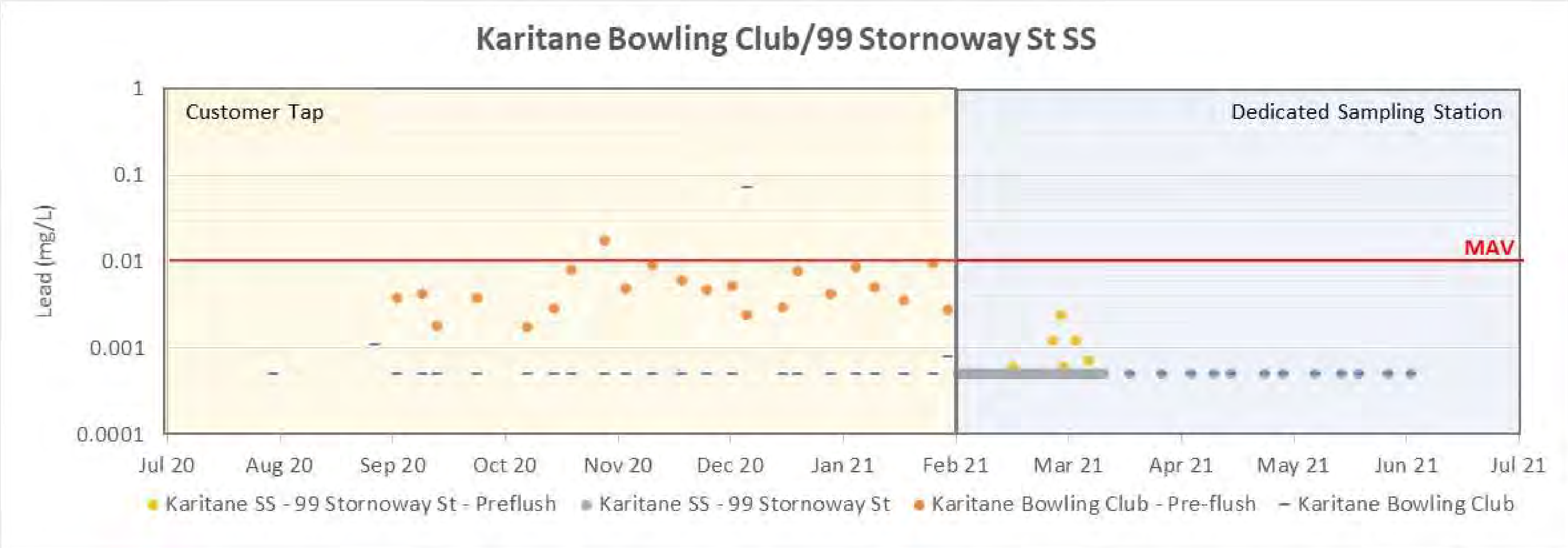

Figure 3: Lead Measurements at Karitane Bowling Club and 99 Stornoway St SS (31/7/20 – 8/6/21)

Note: The continuous grey line from early February 2021 to mid-March 2021 is due to high frequency (daily) samples which were all at the same level (i.e. less than LOD)

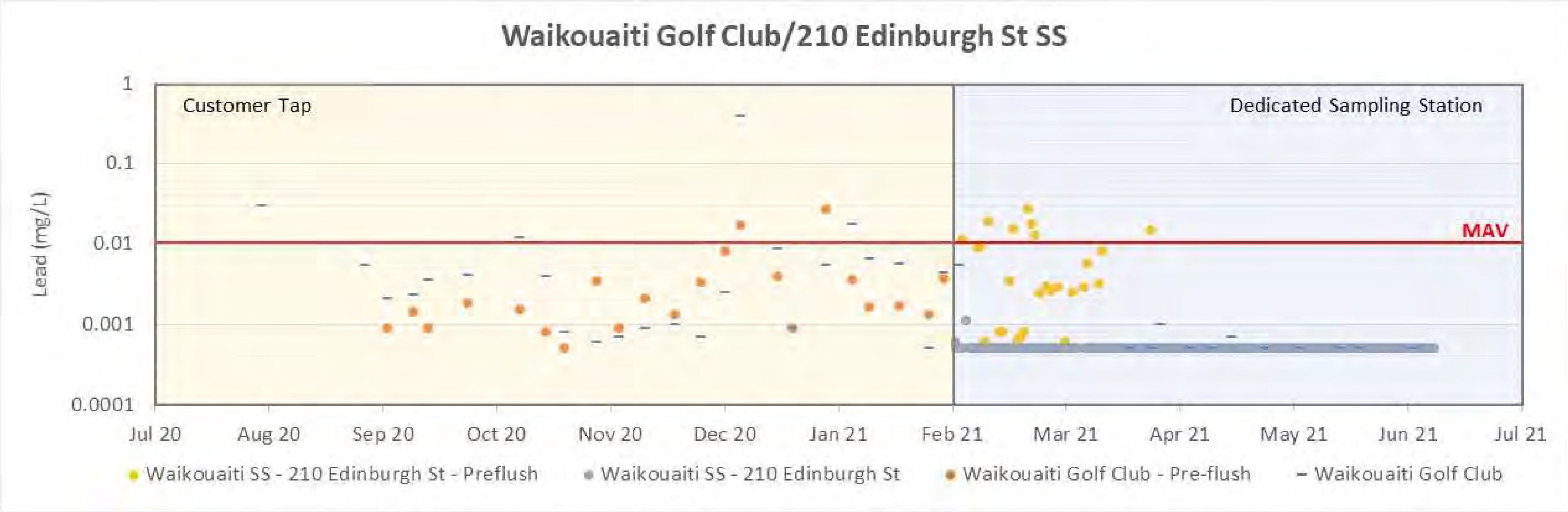

Figure 4: Lead Measurements at Waikouaiti Golf Club and 210 Edinburgh St SS (31/7/20 – 14/6/21)

Note: The continuous grey line from early February 2021 to June 2021 is due to high frequency (daily) samples which were all at the same level (i.e. less than LOD)

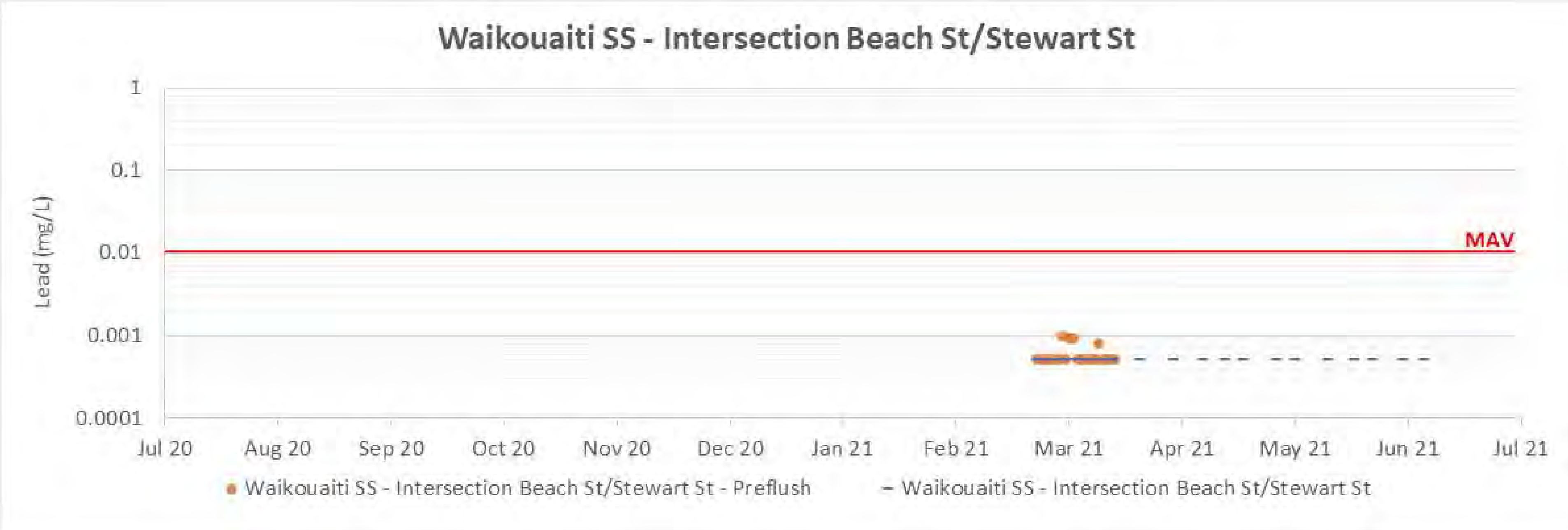

Figure 5: Lead Measurements at the Intersection of Beach St and Stewart St SS (23/2/21 – 8/6/21)

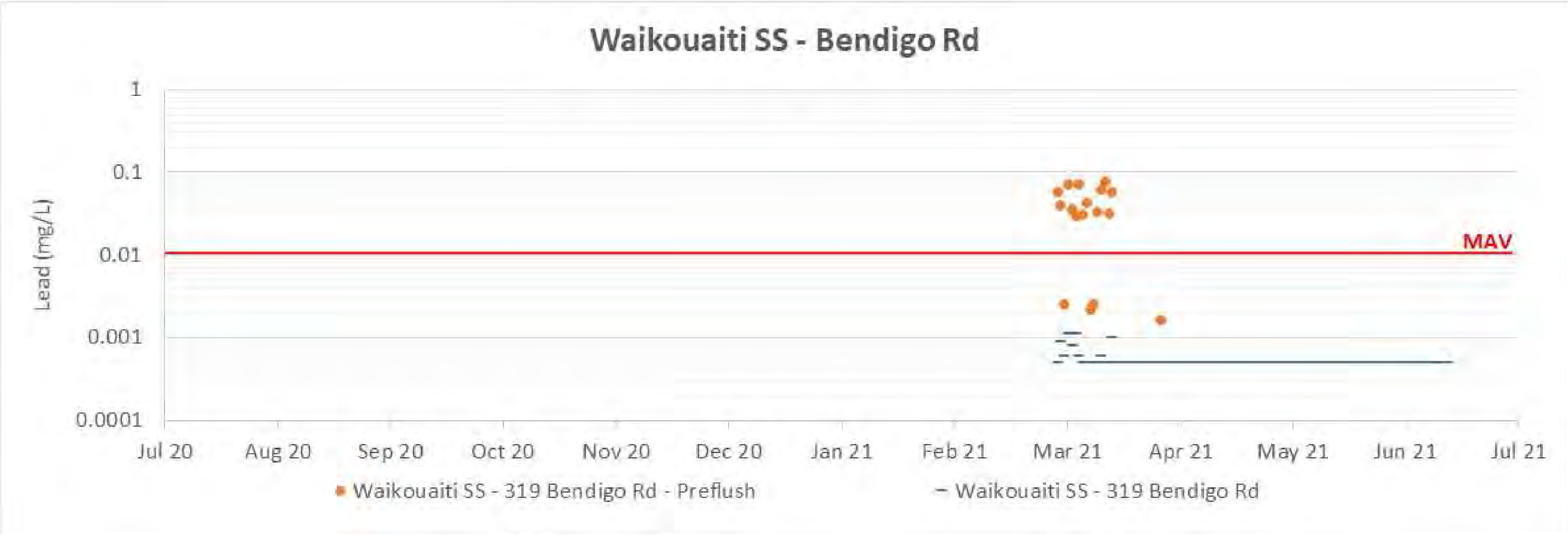

Figure 6: Lead Measurements at Bendigo Rd SS (1/3/21 – 15/6/21)

Note: The continuous blue line from early February 2021 to late May June 2021 is due to high frequency (daily) samples which were all at the same level (i.e. less than LOD)

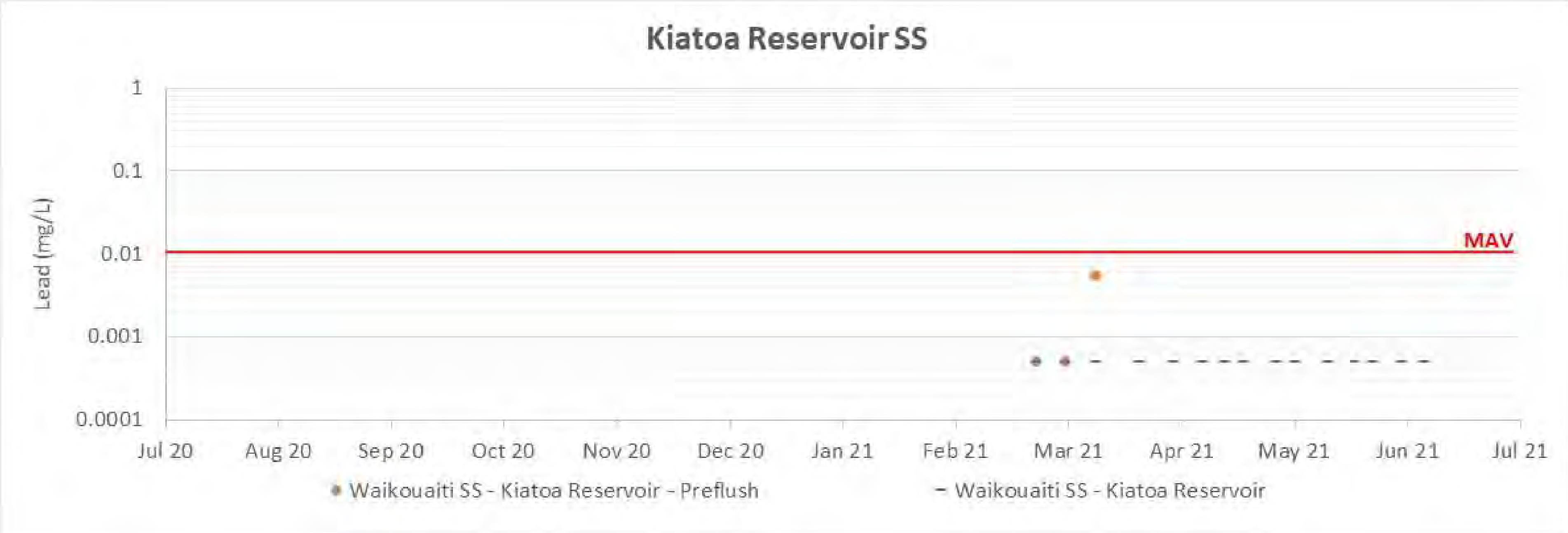

Figure 7: Lead Measurements at Kiatoa Reservoir SS (23/2/21 – 8/6/21)

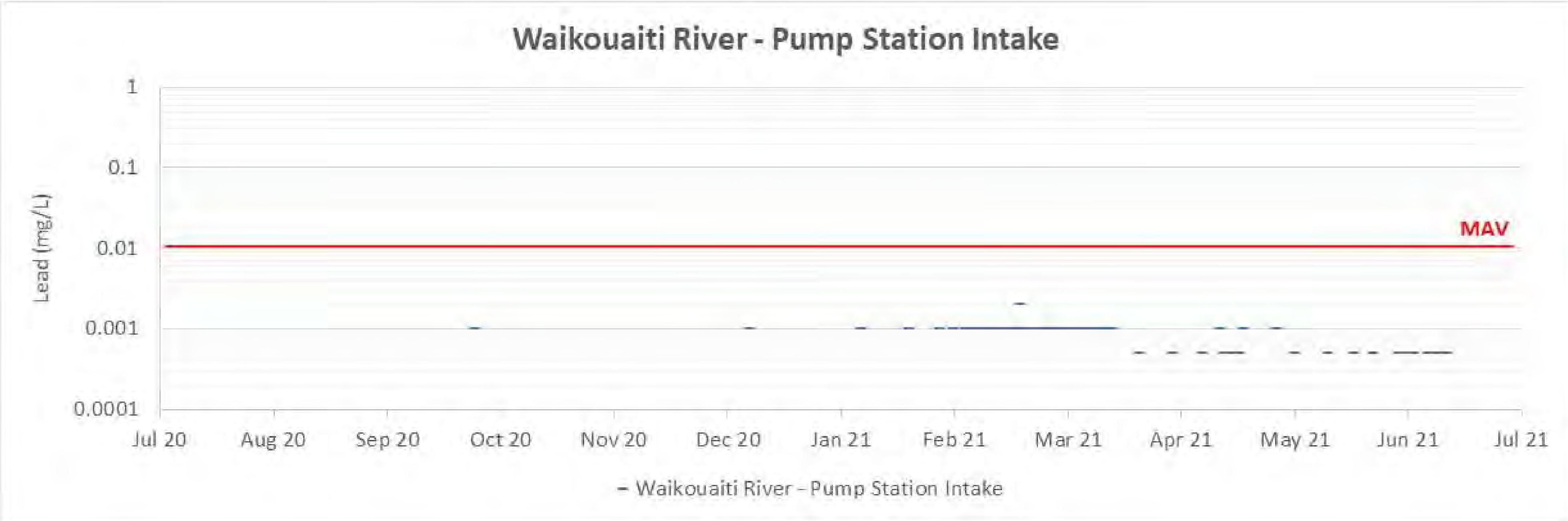

Figure 8: Lead Measurements at the Pump Station Intake (25/9/20 – 14/6/21)

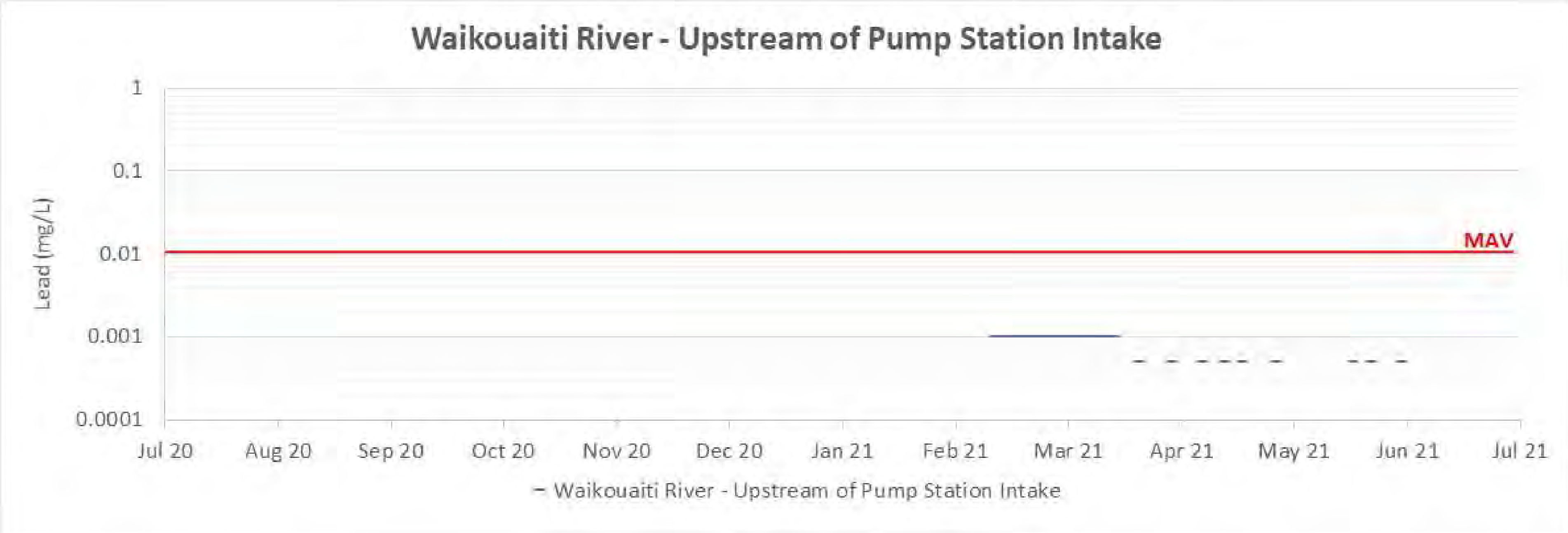

Figure 9: Lead Measurements Upstream of the Pump Station Intake (12/2/21 – 2/6/21)

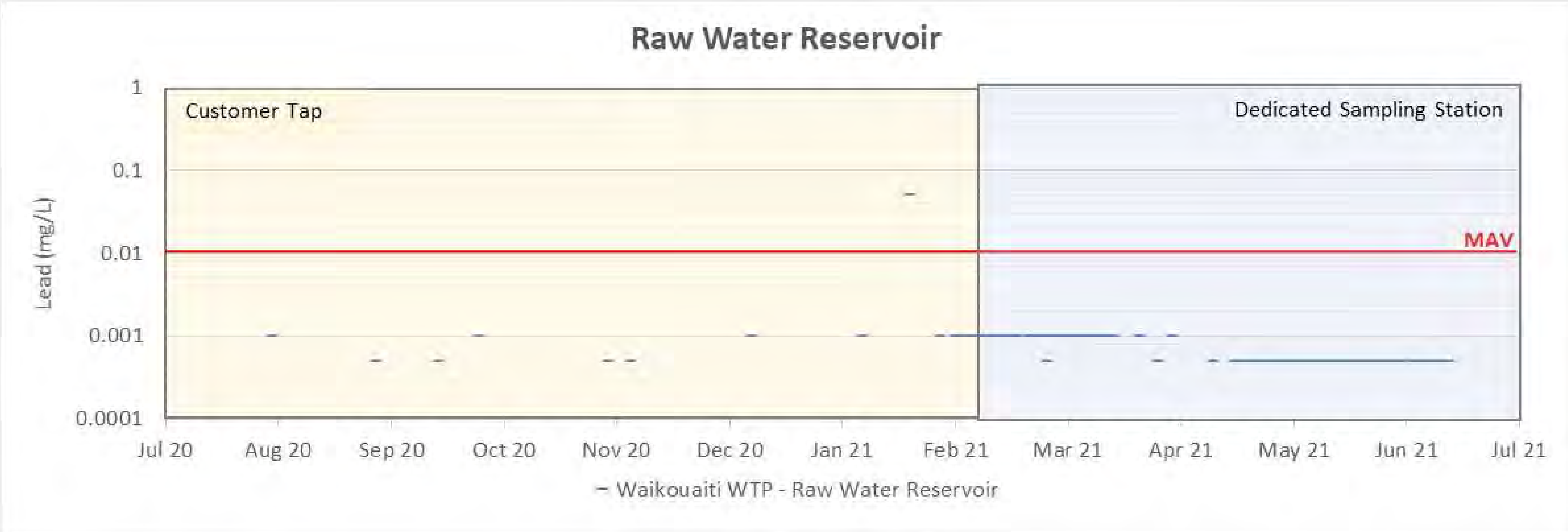

Figure 10: Lead Measurements at Raw Water Reservoir (31/7/20 – 14/6/21)

Note: The continuous blue line from early February 2021 to mid-March 2021 is due to high frequency (daily) samples which were all at the same level (i.e. less than LOD). The continuous blue line from mid-April 2021 to mid-June 2021 is due to high frequency (daily) samples which were all at the same level (i.e. less than LOD and noting a slightly different test was undertaken with a lower LOD than previously used).

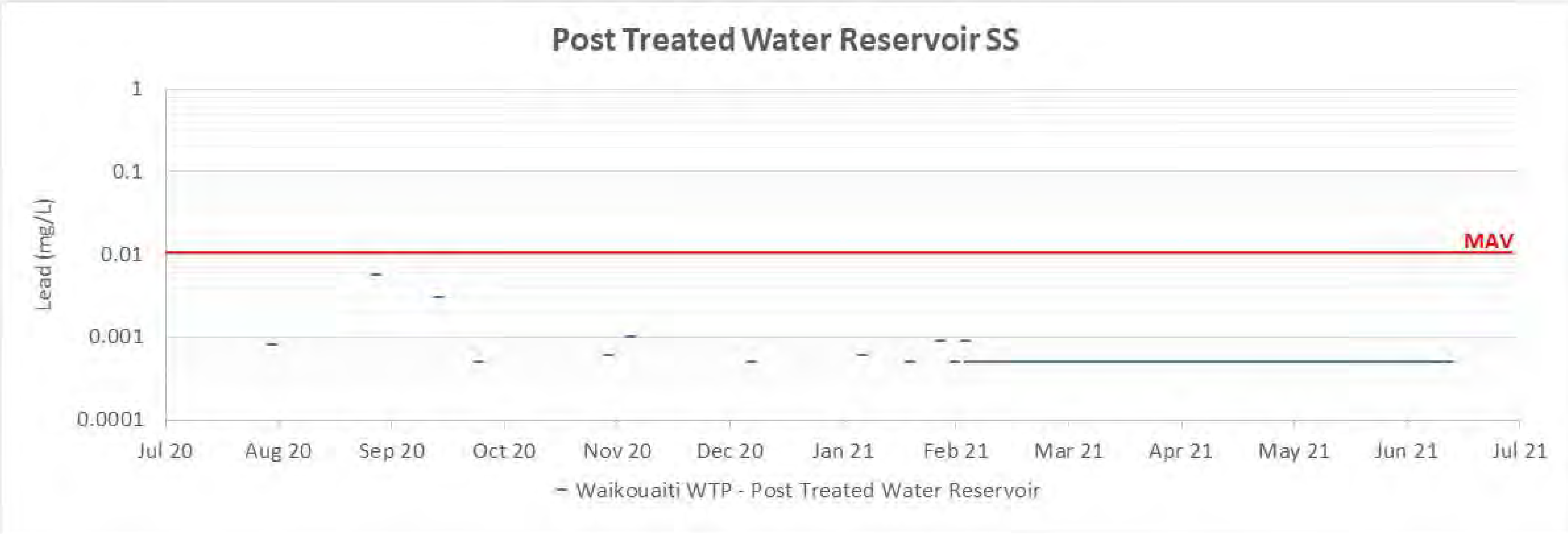

Figure 11: Lead Measurements at the Treated Water Reservoir (31/07/20 – 14/6/21)

Table 1: Summary of Lead Results by Sample Location (31 July 2020 – 15/06/2021)

Sample Location	Samples Processed	Results > LOD	Results > 50% MAV	Results > MAV
Distribution Network and Sample Taps				
Golden Fleece Hotel (Pre-flush)	22	19	1	0
Golden Fleece Hotel (Post-flush)	25	5	0	0
Waikouaiti SS - 192 Main Rd (Pre-flush)	82	12	0	0
Waikouaiti SS - 192 Main Rd (Post-flush)	94	0	0	0
Karitane Bowling Club (Pre-flush)	22	22	9	1
Karitane Bowling Club (Post-flush)	31	3	1	1
Karitane SS - 99 Stornoway St (Pre-flush)	82	6	0	0
Karitane SS - 99 Stornoway St (Post-flush)	100	1	0	0
Waikouaiti Golf Club (Pre-flush)	22	21	3	2
Waikouaiti Golf Club (Post-flush)	34	26	9	4
Waikouaiti SS - 210 Edinburgh St (Pre-flush)	81	42	13	7
Waikouaiti SS - 210 Edinburgh St (Post-flush)	173	3	0	0
Waikouaiti SS - Beach St/Stewart St (Pre-flush)	44	4	0	0
Waikouaiti SS - Beach St/Stewart St (Post-flush)	54	0	0	0
Waikouaiti SS – 319 Bendigo Rd (Pre-flush)	33	31	23	22
Waikouaiti SS – 319 Bendigo Rd (Post-flush)	123	13	0	0
Waikouaiti SS - Kiatoa Reservoir (Pre-flush)	6	1	1	0
Waikouaiti SS - Kiatoa Reservoir (Post-flush)	18	0	0	0
River and Water Treatment Plant Samples				
Catchment - Waikouaiti River - pump station intake	132	1	0	0
Waikouaiti WTP - Waikouaiti River Upstream	78	0	0	0
Waikouaiti WTP - Raw Water Reservoir Feed to Plant - Old Tap	11	1	1	1
Waikouaiti WTP - Raw Water Reservoir Feed to Plant - SS	146	0	0	0
Waikouaiti WTP - Post Treated Water Reservoir	209	9	1	0
Miscellaneous Investigation Results				
Waikouaiti WTP - Raw Water Reservoir Feed to Plant - Lead Investigation	3	2	0	0
Waikouaiti WTP - Raw Water Reservoir Feed to Plant - Profile Sample	11	1	0	0
Waikouaiti WTP - Raw Water Reservoir Feed to Plant - Profile Sample Old Tap	11	1	1	1
Karitane Bowls Club - Customer Tap - Profile Sample	22	11	2	0
Waikouaiti Golf Club - Alternate Tap 1 - Profile Sample	11	11	1	1
Waikouaiti Golf Club - Customer Tap - Profile Sample	22	22	10	2
Waikouaiti SS - 210 Edinburgh St - Profile Sample	11	1	0	0
Waikouaiti SS - 319 Bendigo Rd - Profile Sample	5	5	3	2
Waikouaiti SS - 319 Bendigo Rd - Plastic Tap - Profile Sample	4	0	0	0
Waikouaiti SS - 210 Edinburgh St - Plastic Tap (Pre-flush)	9	0	0	0
Waikouaiti SS - 210 Edinburgh St - Plastic Tap (Post-flush)	9	0	0	0
Waikouaiti SS – 319 Bendigo Rd - Plastic Tap (Pre-flush)	9	0	0	0
Waikouaiti SS – 319 Bendigo Rd - Plastic Tap (Post-flush)	9	0	0	0
Karitane Bowls Club - Toby and Meter - Stagnation Test	5	5	5	5
Waikouaiti Golf Club - Double Check Valve and fittings - Stagnation Test	8	8	8	5

Waikouaiti Golf Club Metals Investigation	25	0	0	0
Waikouaiti WTP - Containerised Plant Filtrate	84	0	0	0
Waikouaiti WTP - Tube Settler	146	8	1	1

Note: results include totals for all lead analysis tests including total, acid soluble and dissolved/soluble

Table 2: Kiatoa Reservoir Samples - Lead Results (24/05/2021)

Kiatoa Reservoir Sediment Acid-soluble Lead Results
0.0031 mg/L
0.0082 mg/L
0.0024 mg/L
0.0055 mg/L
0.0047 mg/L
0.012 mg/L

Figure 2 - Data from Waikouaiti Golden Fleece Hotel/192 Main Road. Key observations are:

- When samples were collected from Waikouaiti Golden Fleece Hotel, lead was detected in 19 of 22 pre-flush samples (all less than MAV) and was detected in 5 of 25 post-flush samples (all below 0.001 mg/L).
- Pre-flush samples are collected immediately upon opening a sample tap, while post-flush samples are collected after the tap has been flushed for five minutes (or two minutes for dedicated sample stations after March 2021). The intent of flushing is to provide post-flush samples which are representative of the water in the distribution main however, this is not always the case e.g. if the customer service line has lead-bearing pipework that contaminates the sample.
- Lead results in pre-flush samples and post-flush samples indicate lead was probably associated with the sample tap and local pipework in the pre-flush samples.
- Since the dedicated sample station was activated, post-flush lead results have been below the limit of detection in all 94 samples. This supports the theory that pre-flush lead results from Waikouaiti Golden Fleece Hotel are caused by localised lead leaching associated with the sample tap and associated pipework and fittings.

Figure 3 - Data from Karitane Bowling Club/99 Stornoway Street. Key observations are:

- When samples were collected from the Karitane Bowling Club, lead was detected in all of the pre-flush samples (22 out of 22, with one of these above MAV) and in a small fraction of the post-flush samples (31 samples with 3 above LOD), typically at very low levels except for 1 value above MAV. The remainder of post-flush samples were less than limits of detection. This indicates lead was probably associated with the sample tap and local pipework.
- An exceptional reading greater than 100 times typical values was recorded on 8 December 2020 (0.072mg/). The following reading on 18 December 2020 showed a return to typical levels. Typical values of all post-flush results from the Karitane Bowling Club were observed to be less than LOD (more than 90% were less than LOD). Potential causes for the exceptional reading are discussed further in sections 5 and 6.
- Since the dedicated SS was activated, post-flush lead results have been below the LOD in 99 out of 100 samples. This supports the theory that lead results from the Karitane Bowling

Club tap (potentially except for the abnormal value on 8 December) are caused by localised lead leaching associated with the sample tap and associated pipework and fittings. 6 out of 82 pre-flush samples were above LOD.

Figure 4 - Data from Waikouaiti Golf Club/210 Edinburgh Street. Key observations are:

- When samples were collected from the Waikouaiti Golf Club, lead was detected in almost all the pre-flush samples (22 samples with 21 > LOD, 2 > MAV) and in many of the post-flush samples (34 samples with 26 above detectable levels and 4 > MAV).
- In a number of cases pre- and post-flush results were greater than the MAV and initial indications suggested that pre-flush samples would be associated with localised plumbing and post-flush values would indicate lead present in the distribution network. However, further investigation, which is discussed in section 5.6.3, indicates that the post-flush values may have been caused by localised lead leaching (i.e. from local pipework).
- An exceptional reading, greater than 20 times typical values, was recorded on 8 December 2020. The next sample on 18 December 2020 returned a significantly lower value (less than MAV). Potential causes for this exceptional reading are discussed in sections 5 and 6.
- Since the new SS was activated, lead has been frequently detected in pre-flush samples (81 samples with 42 > LOD and 7 > MAV) and less frequently in post-flush samples (173 samples with 3 >LOD and a maximum of 0.0011 mg/L). This indicates lead associated with the new dedicated SS but not the distribution network.
- The presence of lead in pre-flush samples taken from the new SS was unexpected and results of further investigation are discussed in section 5.6.3.2.
- The network upstream of the Waikouaiti Golf Club/210 Edinburgh Street tap and SS has cast iron pipework with lead joints. While this would not typically be expected to leach significant quantities of lead, the lead joints is a possible, but very unlikely, source of lead in the post-flush samples from the Waikouaiti Golf Club tap. Findings from this investigation stream are presented in section 5.5.
- The absence of lead in post-flush samples from the dedicated sample tap could indicate that lead in post-flush Waikouaiti Golf Club samples were either caused by localised plumbing or lead no longer being present in the distribution network after 4 February. If lead levels in the main had been largely eliminated, this could be because of increased flushing in the distribution network (reducing stagnation time in the main) and/or changes in water chemistry – see section 5.2.2.

Figures 5-7 - Data from three new dedicated sampling stations in the Waikouaiti High Levels and Low Levels Zones, installed in the weeks after the DNDN was issued. Key observations are:

- A total of 186 post-flush samples were collected between 31 July 2020 and 15 June 2021. 173 of these samples were less than limit of detection (LOD) and all were less than 50% of MAV.
- All detectable, but low (near LOD), lead results from post flush samples, were observed at the Bendigo Rd SS in the Waikouaiti upper levels.
- Lead was found in pre-flush samples (83 samples of which 36 were above LOD and 22 were greater than MAV), which was found to be associated with stagnation in the tap and affected a small volume (less than 1.5l).
- The absence of lead in most post-flush samples from these dedicated sampling stations shows no sign of significant lead sources upstream of these sites.

- The presence of lead in pre-flush samples taken from the new sampling stations was unexpected and results of further investigation are discussed in section 5.6.3.2.

Figure 8-11 - Data from the Waikouaiti River pump station intake, a location just upstream of the intake, the raw water reservoir, and the treated water reservoir. Key observations are:

- 209 out of 210 samples taken directly from the river are below LOD and the detectable result was near the LOD.
- 177 out of 182 samples taken from the raw water reservoir outlet were below the LOD. Four of the five detectable results were expected as they were part of the lead investigation. Two above LOD were due to intentional mishandling and poor sampling technique intended to replicate a high result. Another two results were above LOD, but below the MAV were pre-flush samples. The exceptional result was the 0.05 mg/L sample from January 20, 2021. Therefore only 1 of 182 samples was above LOD with no initial explanation.
- 200 out of 209 samples taken from the treated water reservoir outlet were below the LOD. All detectable results were below the MAV and most were at or near the LOD.

Table 2 shows the acid-soluble lead results for samples containing a mixture of water and sediment taken from Kiatoa reservoir on 24 February 2021. The samples are acidified and can sit for several days awaiting testing. The sediment contained in the sample may contribute significantly to the acid-soluble metals (including lead) measurements. Key observations are:

- The samples indicate lead above 50% of the MAV with one sample above the MAV, however, this may be explained by the relatively high amount of sediment stored under acidic conditions.
- None of the flushed samples from the dedicated sampling stations downstream of Kiatoa reservoir have ever returned values above 50% of the MAV, including a sample taken on 23 February 2021 (the day before the sediment/water samples were taken), which would support a theory that levels in the sediment are associated with particulate materials.
- The small amount of sediment that accumulated was observed in the reservoir likely accumulated over at least the past two years. Due to the relatively low flow through Kiatoa reservoir, particulate matter would settle in the reservoir and accumulate over time. The amount of particulate material in the water passing through the reservoir is very low owing to upstream membrane treatment. However, there are several possible explanations for the source of this particulate material/sediment:
    - Sediment from water treated prior to the installation of solid separation at the WTP, settled in upstream pipes and subsequently flushed to the reservoir.
    - Particulates from cement pipes and metal fixtures/fittings upstream of the reservoir.
    - Undissolved sediment from soda ash dosing at the WTP (which is downstream of membranes).

A summary of the initial data inspection is as follows:

- The probable cause of frequent, low-level pre-flush lead concentrations at both Waikouaiti Golden Fleece Hotel and Karitane Bowling Club is localised lead contamination (due to

corrosion/leaching caused by local lead leaching) from lead-bearing plumbing and fixtures associated with the customer sample tap.
- The probable cause of frequent, relatively low-level lead concentrations (excluding 8 December) at Waikouaiti Golf Club is localised lead contamination (from lead leaching/corrosion of local pipes or fittings due to local lead leaching) or low-level contamination caused by cast iron pipework with lead joints on the Edinburgh Street main. If these were caused by other mechanisms (catchment contamination or backflow) then they would be expected to be seen at other locations in the distribution network more regularly.
- The abnormal elevated results of lead on 8 December 2020 (at both Karitane Bowling Club and Waikouaiti Golf Club) and 20 January 2021 (at the raw water reservoir) are unexplained and are exceptional (i.e. not typical). These exceptional results may have been caused by a different mechanism of lead contamination to other readings. The hypothesis that a common mechanism was the cause of these exceptional readings (such as a distinct contamination event) was investigated and findings are summarised in sections 5 and 6.

4.2 Potential explanations for changes in lead readings at Waikouaiti Golf Club

There appears to be a step change in the magnitude of low-level lead results at Waikouaiti Golf Club between 1 February (the last sample taken at the customer side tap) and 4 February (the first sample from the dedicated sampling tap). Following 4 February 2021 almost all of the flushed samples have been less than LOD. There are several factors which may have contributed to this:

- Increased distribution main flushing was initiated following the DNDN being issued on 2 February. Flushing reduces the time water has in contact with potential sources of lead in the distribution network. If lead in the distribution network is a contributing factor to lead in the water, then flushing can lower lead levels in the water.
- The chloride-to-sulphate mass ratio (CSMR) appears to have decreased since early January 2021 which also corresponds to a temporary drop in alkalinity. Both the CSMR and alkalinity are important parameters that influence the corrosivity of water with respect to plumbing materials. Threshold limits of 0.2 and 0.5 (9) for CSMR have been established in previous studies and water with a CSMR below these values is less corrosive than water with CSMR above these values, in terms of the potential for galvanic corrosion of lead. If the alkalinity drops below approximately 50 mg/L, water can become increasingly more corrosive, especially when the CSMR is also high. (10) Initial analysis indicates that the CSMR was greater than 1 in December 2020 and dropped to less than 0.4 in February 2021 due to changes in the raw water chemistry. Alkalinity is generally around 70 mg/L but drops during a rainfall event, which occurred in early January 2021. Changes in lead levels appeared to correspond with the rise and fall of CSMR which is discussed further in section 5.2.2.
- Customer-side sample taps and local plumbing materials are probable sources of lead results prior to the DNDN being issued. Local plumbing could impact both pre- and post-flush samples from the Waikouaiti Golf Club if the sample flushing is not sufficient to provide samples representative of the distribution main. Although a contributing factor, this alone does not indicate that local plumbing was the sole cause of the exceptional value on 8 December 2021.

Further investigation into these potential causes is presented in section 5 and the most likely cause of the change in lead readings at or close to the Waikouaiti Golf Course is presented in section 6.

4.3 Potential causes of abnormal / exceptional readings on 8 December 2020

A comparison of data on the 8 December 2020 at Waikouaiti Golden Fleece Hotel, Waikouaiti Golf Club and Karitane Bowling Club provides the following observations:

- As noted in section 4.1, it would appear likely that the abnormally high values on 8 December 2020 at both Karitane Bowling Club and Waikouaiti Golf Club are related because they occurred on the same day and lead has not been seen at these levels in any other samples. However, two unrelated coincidental events could have also caused the results.
- Initial analysis of other metals in both of these samples indicated a common profile between the two samples on 8 December 2020. This is different to the profile on other days (when lead levels were not high). This was initially believed to support a theory that the mechanism for the 8 December 2020 readings was different to typical levels observed. This is investigated further in section 5.6.4.
- Both samples recorded much higher lead concentrations in post-flush than pre-flush samples. These lead results could have been associated with water in the distribution network (rather than localised pipework). Further investigations to better establish the likelihood of a potential contamination event occurring are presented in section 5.7.
- The Waikouaiti Golden Fleece Hotel was also sampled on 8 December 2020 and results were below LOD. This does not contradict the possibility of a contamination event and could be explained because the water age at the Karitane Bowling Club and the Waikouaiti Golf Club is similar (approx. 15 hours from the WTP), but the water age at the Waikouaiti Golden Fleece Hotel is lower by approximately five hours. A high concentration pulse of water could have already passed through the Waikouaiti Golden Fleece Hotel. The findings of a model tracer study are given in section 5.7.4.
- The Waikouaiti Golden Fleece Hotel, Waikouaiti Golf Club and Karitane Bowling Club are all on separate branches of the distribution network. If the cause of these was a common contamination event, then this could only have occurred at (or upstream) of the location where these distribution networks diverge from one another (close to the McGrath Road pump station, near Hawksbury Village). This includes the catchment, WTP and the distribution main between the WTP and Hawksbury Village.

There are several potential explanations for the elevated values on 8 December, which are discussed further in sections 5 and 6.

In summary:

- **Sampling Methodology or Analytical Error** is discussed further in section 5.4. Whilst sampling or analytical error is possible, there are a number of protocols in place to prevent this. It may initially seem unlikely to have caused unreliable readings at two distinct locations on the same day, without impacting any other samples collected on the same day (four other samples were collected). Other similar sampling or analytical errors have not been observed in any of the other samples analysed for lead (in all three forms i.e. total, acid soluble or dissolved) collected between 31 July 2020 and 15 June 2010.
- **Distribution main or other network lead leaching** is discussed further in section 5.5.

- **Localised lead leaching/corrosion** is discussed further in section 5.6. This would indicate local lead release in two separate locations which could be exacerbated by changes in raw water chemistry.
- **Changes in Raw Water Chemistry** is discussed further in section 5.2.2 and refers to changes in raw water chemistry affecting treatability of raw water or corrosivity of treated water resulting in localised lead release at the Waikouaiti Golf Club and Karitane Bowling Club.
- **Raw Water Contamination** is discussed further in section 5.7 and could be a common source of lead at both the Waikouaiti Golf Club and Karitane Bowling Club on 8 December 2020. This would represent a distribution-wide contamination event.
- **Plant Operation** is discussed further in section 5.8. If plant operational issues caused elevated lead on 8 December 2020, this would likely have been a distribution wide contamination event.
- **Backflow** is discussed in section 5.9. If backflow caused elevated lead on 8 December 2020, this would likely have been a distribution wide contamination event.

4.4 Potential causes of abnormal/exceptional readings on 20 January 2021

Key observations associated with exceptional results observed at the raw water reservoir on 20 January 2021:

- The exceptional result measured in the raw water reservoir did not coincide with elevated levels elsewhere in the Waikouaiti, Karitane and Hawksbury Village water supply system.
- 1 unexplained elevated (above MAV) result out of 182 samples indicates the potential for an isolated or infrequent contamination event, localised contamination or sampling error.
- Initial analysis of other metals present on 20 January 2021 indicated different compositions to other days (relatively higher copper and relatively lower iron).
- The raw water tank has a theoretical retention time of approximately 1-2 days, and it might be expected that contamination would persist for some time. However, the tank is known to have poor mixing characteristics and, potentially, a short-term pulse of high concentration material could have passed through relatively quickly.
- If lead was particulate material, this would have been removed in the membrane plant and would not have been present in treated water. Analysis undertaken on 20 January 2021 was for total metals only (which includes both particulate and dissolved lead).

There are several potential explanations for the elevated values on 20 January 2021. These are similar to the potential causes on 8 December 2020 with the exception that distribution main lead leaching (due to local lead leaching), plant operation or distribution network backflow could not have caused elevated lead in the raw water reservoir.

- **Sampling Methodology or Analytical Error** is discussed further in section5.4. While sampling or analytical error is possible there are a number of protocols in place to prevent this.
- **Localised Lead Leaching/Corrosion** is discussed further in section 5.6.
- **Changes in Raw Water Chemistry** is discussed further in section 5.2.2.
- **Raw Water Contamination** is discussed further in section 5.7.

5 INVESTIGATION OF LEAD SOURCES

5.1 Overview of Mechanisms of Elevated Lead Results

Several mechanisms for the elevated and exceptional levels of lead observed are possible. This section presents the observations, evidence, and findings of the investigation that are related to these mechanisms.

Table 3 presents specific potential sources of lead categorised into three main categories: Sampling Methodology and Analytical Error, Lead Leaching and Corrosion, and Lead Ingress.

Table 3: Potential Sources of Lead by Category

Considerations in Lead Investigation	Issue	Specific Examples
Sample Methodology and Analytical Error	Sample collection	Location, protocol, QA/QC
	Laboratory Analysis	Transport, sample preparation, detection method, QA/QC
Lead Leaching and Corrosion **(potential sources of internally derived lead contamination)**	Corrosivity of finished water	Treatment process trends, pH, alkalinity, CSMR
	Distribution Network (DCC infrastructure)	Distribution main joints, service connections, backflow
	Localised Lead Leaching (generally, private infrastructure)	Galvanized pipe, lead solder, lead containing fixtures and fittings (brass, bronze, steel)
Lead Ingress **(potential sources of externally derived lead contamination)**	Raw Water Contamination	Mine operations, landfill, fly tip, soil, ground water
	Water treatment plant	Treatment chemicals, tube settler operation, plant discharge
	Backflow event	Industry using lead or significant lead material in connected property/system

5.2 Water Chemistry and Data Analysis

This section outlines the findings of the water chemistry analysis, which was fed into the assessments of the likelihood of each potential source. By investigating the chemistry of the water in depth, DCC was able to assess the likelihood of each of these potential sources.

Lead chemistry is a complex subject and a number of water chemistry parameters can affect corrosivity of water and leaching rates in distributions systems and customer plumbing. Several investigations have been undertaken to identify if changes in water chemistry could have contributed to the elevated levels of lead observed on 8 December 2020 or 20 January 2021 or if any water chemistry parameters show a strong correlation with lead levels in Waikouaiti water.

5.2.1 Bivariate analysis

Bivariate analysis of sample results for lead against various parameters are presented in this section. Only the results from customer taps (results obtained before 4 February 2021) are used in these analyses, which help to determine whether a correlation exists between lead and water quality parameters that can play a role in corrosivity of water. These plots also show whether the post-flush results on 8 December 2020 (pink crosses) were abnormal from other Waikouaiti network results including both pre-flush (orange dots) and post-flush (blue dots) results of samples taken from the Waikouaiti Golf Club, Karitane Bowling Club, and Waikouaiti Golden Fleece Hotel.

5.2.1.1 Calcium and Magnesium

Calcium and magnesium contribute to hardness of water and assist water suppliers in knowing whether their water is scale forming or not. The total hardness of Waikouaiti water is generally less than 100 mg/L and is considered soft to moderately hard. The bivariate plots for calcium and magnesium shows relatively stable levels and no correlation with lead.

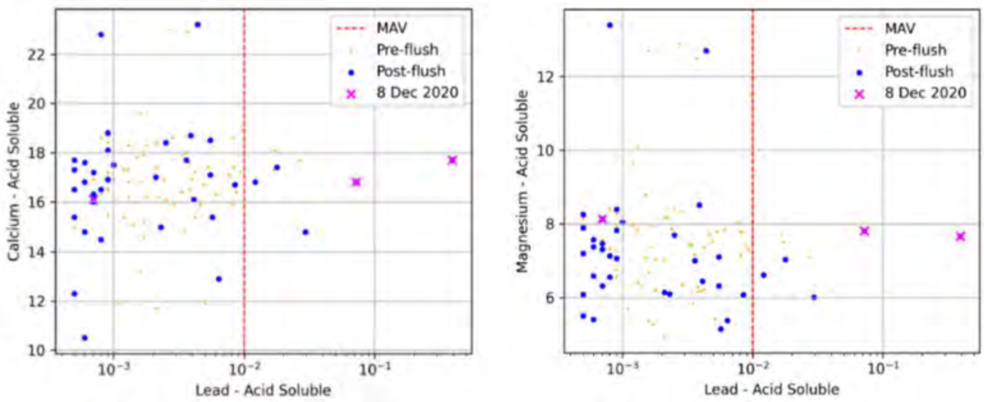

Figure 12: Bivariate Plots of Calcium and Magnesium versus Lead

5.2.1.2 Alkalinity and Dissolved Inorganic Carbon

The levels of dissolved inorganic carbon (DIC) and alkalinity (which are inherently related to each other) play a critical role in forming (or not forming) scales in pipes and the corrosivity water towards metallic materials. However, these bivariate plots show no apparent correlation between lead and alkalinity or DIC.

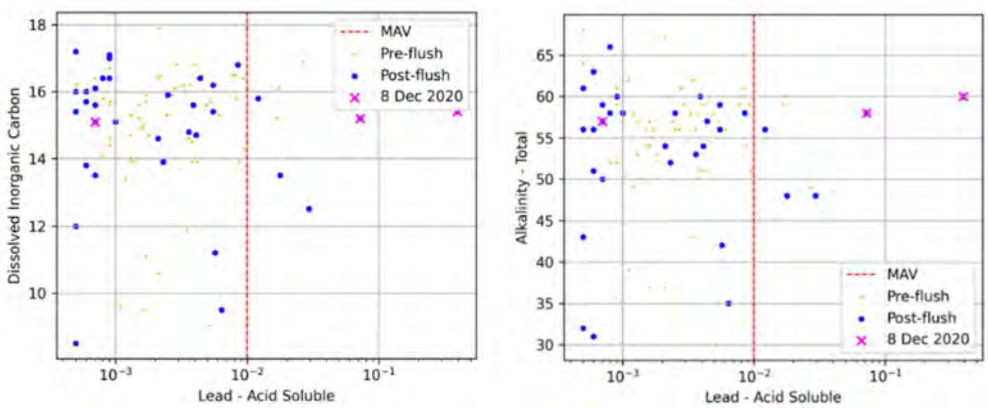

Figure 13: Bivariate Plots of Alkalinity and Dissolved Inorganic Carbon versus Lead

5.2.1.3 Chloride and Sulphate

Chloride and sulphate levels have been shown to affect galvanic corrosion of lead and other metals (10). The highest lead levels were observed at relatively low sulphate levels although there was a spread of lead concentrations across the full range of sulphate concentrations observed and there is no strong correlation. The chloride-to-sulfate mass ratio (CSMR) is generally used to help understand the risks of local lead leaching in a water supply. The CSMR is discussed later in section 5.2.2.

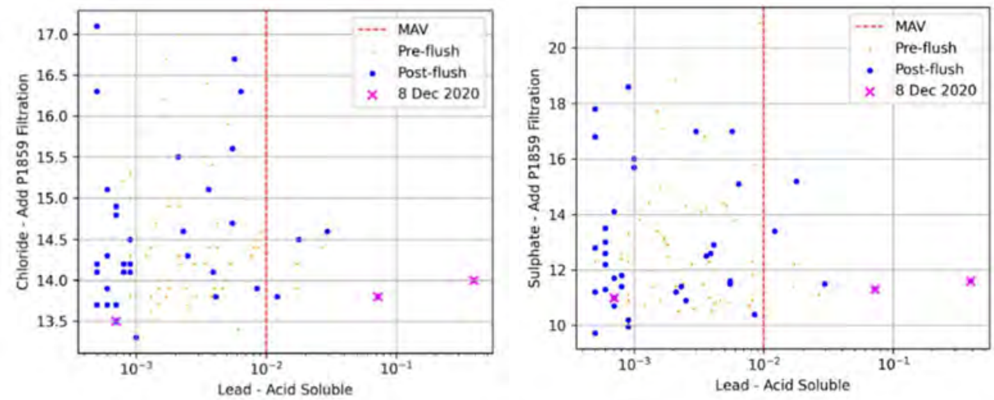

Figure 14: Bivariate Plots of Chloride and Sulphate versus Lead

5.2.1.4 Chlorine and Dissolved Oxygen

In drinking water chlorine dominates the oxidation-reduction potential (ORP) which plays an important role in local lead leaching and corrosivity. Higher chlorine levels can keep lead in the insoluble state or oxidise soluble lead into an insoluble state. As seen in the plots below, the chlorine at the Waikouaiti Golf Club was quite low and is consistent with a trend of elevated lead at lower chlorine levels. However, the chlorine at the Karitane Bowling Club was high and the corresponding high lead result is an exception to this trend. Oxygen does not dominate oxidation-reduction potential when chlorine is present, so it was expected to have little effect, no trend is apparent in the plot on the right.

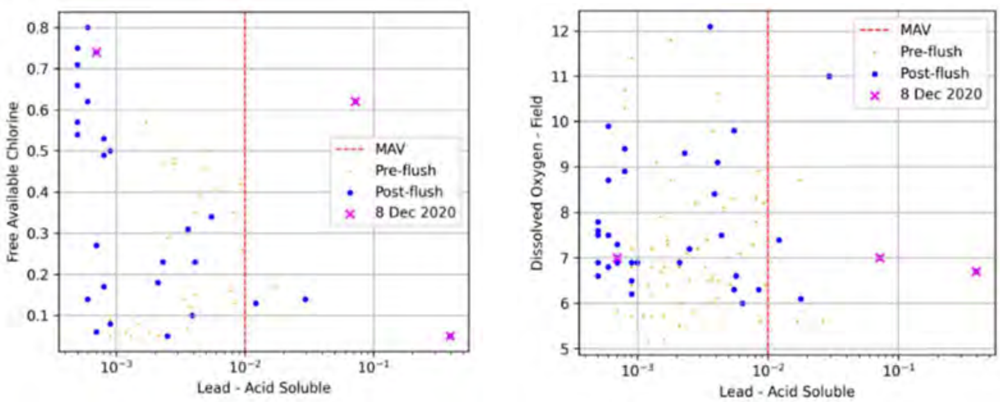

Figure 15: Bivariate Plots of Free Available Chlorine and Dissolved Oxygen versus Lead

Chlorine can be used as an indicator of retention time (or stagnation time) because chlorine decays in a network at a certain rate. Lower chlorine can indicate low consumption rates (among other things). If there were lead-bearing materials present in the distribution network which were contributing to levels of lead in the water, increased stagnation times would be expected to cause higher levels of lead.

Lower chlorine can also mean biological growth is more active in the network. Biological growth on the inside of pipes is common and the formation of biofilms can also enhance degradation of pipes as they can lower the pH near the surface of the pipes which in turn enhances corrosion and/or lead leaching.

5.2.1.5 Other Metals

The plots below show lead versus other metals i.e. iron, manganese, zinc, aluminium, and copper. A number of metals, including lead, undergo complex corrosion reactions in water. Metals are present in drinking water due to dissolution of particles containing metals or from corrosion of metallic materials. The following trends are examined to assess if changes in water chemistry may have caused the exceptional lead readings on 8 December 2020.

It appears that iron and manganese are particularly low on 8 December 2020 compared to other results as there is a weak positive correlation between lead and other metals. Aluminium appears to be low on 8 December 2020 compared to other post-flush samples, but may follow a similar trend to pre-flush samples. It is unclear whether zinc follows a trend without more detailed analysis.

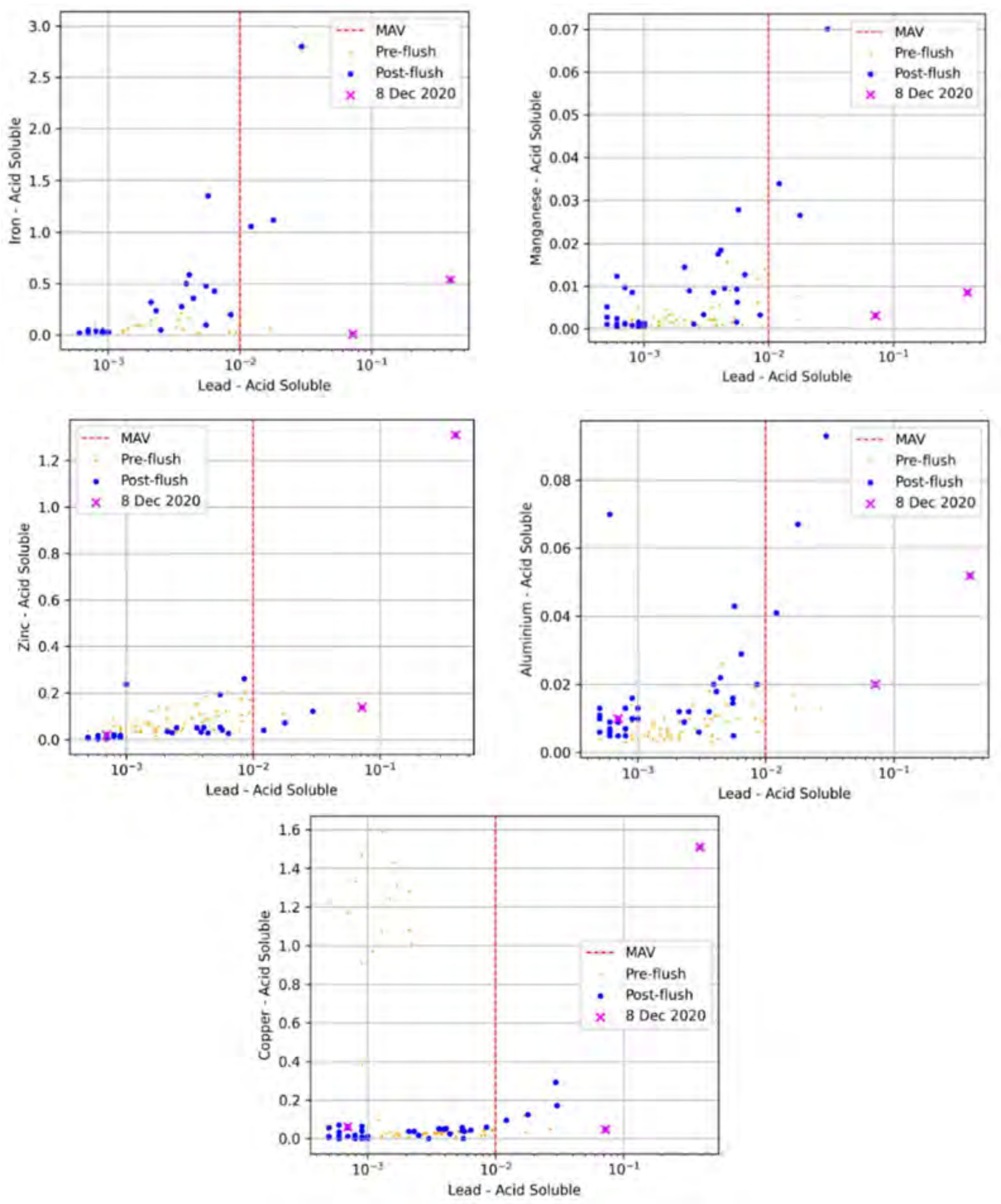

Figure 16: Bivariate Plots of Iron, Manganese, Zinc, Aluminium, and Copper versus Lead

Overall the bivariate analysis shows:

- No correlation with magnesium, calcium, dissolved inorganic carbon, or alkalinity.
- Chloride and sulphate levels that are favourable for galvanic corrosion of lead (to be discussed in section 5.2.2).
- The Waikouaiti Golf Club had low chlorine levels at the time of the 8 December 2020 results, which could affect the corrosivity of water, further complicated by the possibility of microbial growth.
- The metals profile of the samples taken on 8 December 2020 from the Waikouaiti Golf Club and Karitane Bowling Club were similar. Zinc and copper were also raised in the samples. Feedback from water quality specialists at Stantec (global water consultants) indicate that the presence of elevated lead, copper and zinc all in the same sample would be a strong indicator that the sample is representative of corrosion or leaching associated with local plumbing rather than distribution system water quality.

5.2.2 Corrosivity Indicators

Lead in the Waikouaiti system is largely present in a solid form including in the catchment (e.g. in sediment from rock such as schist) and the water treatment and distribution system e.g. as a component of metallic fixtures. This lead can be dissolved if the water is corrosive. Typically, this is a relatively slow process and water which is flowing past a solid lead source is less likely to accumulate high levels of lead. However, if corrosive water stands (stagnates) in contact with a lead source, then concentrations can increase.

Many factors contribute to corrosivity including pH, alkalinity, chloride and sulphate concentrations, presence or absence of biofilms and scales, and dissolved and total solids. The corrosion potential of treated water can be measured by several indices. These indices were reviewed in the catchment as part of the Catchment Risk Assessment (CRA) and are assessed in the treated water in this section.

- CSMR is the mass ratio of chloride ions to sulphate ions
- If CSMR < 0.2, then potential for galvanic corrosion (PPGC) of lead is low;
- If 0.2 <= CSMR <= 0.5, then PPGC is moderate;
- If CSMR > 0.5 and alkalinity > = 50, then PPGC is moderate; and
- If CSMR > 0.5 and alkalinity < 50, then PPGC is high.

CSMR, pH, and alkalinity are among the most important factors to consider when determining whether lead in drinking water might be originating from local lead leaching. This section reviews the historical data available from Eurofins results and regular DCC test results from handheld meters.

Figure 17 shows alkalinity and sulphate from samples taken at the Waikouaiti Golf Club. Changes in these parameters are mostly due to changes in source water rather than the treatment process.

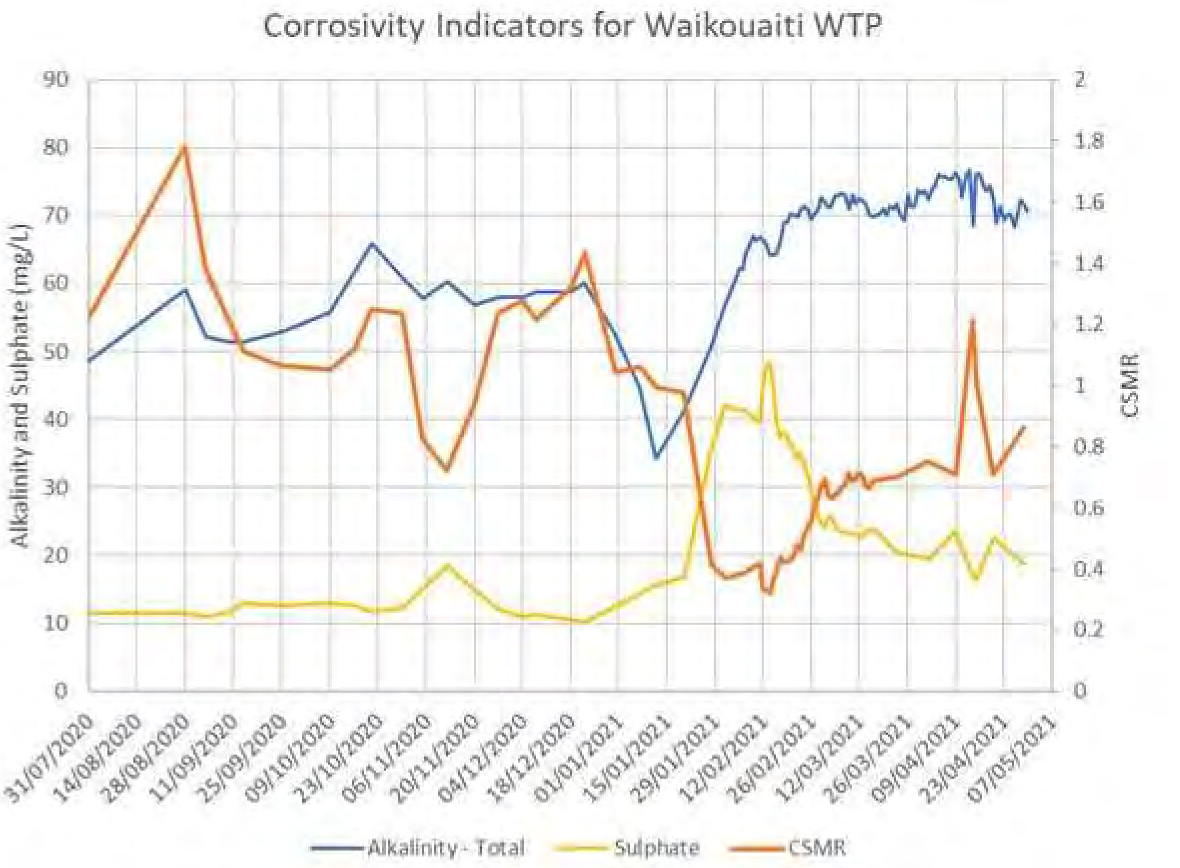

Figure 17: Alkalinity, CSMR and Sulphate

Sulphate increased significantly in late January 2021, and a drop in alkalinity occurred at the start of January. A large rain event occurred in early January and the drop in alkalinity can be caused by rainfall and runoff (which have low alkalinity) diluting the river water. The sulphate (and therefore CSMR, because chloride is relatively stable) experienced a step change shortly after the rain event in early January. Data analysis indicates that changes in the sulphate level typically correlate with mining-related activities in the catchment and potentially including a discharge from Fraser's Pit (part of Oceana Gold Macraes facility) from 15 January 2021 until 21 January 2021. Lab results from this discharge on 15 January 2021 showed undetectable dissolved lead concentrations. Additionally, Oceana Gold indicated that waste rock piles in the upper catchment can absorb water during heavy rainfall and gradually leach sulphates into the ground water after the rain event as well. More evidence to support this is included in the CRA attached in Appendix G. Sulphate is not a public health concern in drinking water until it reaches very high levels. In general metals from waste rock are less mobile than sulphate, so an increase in sulphate does not directly indicate that increased metals occurred too.

The sulphate and alkalinity data indicates that treated water had a moderate corrosion potential on 8 December 2020 (alkalinity approx. 60 mg/L and CSMR 1 to 1.3) and high corrosion potential in mid-January 2021 (CSMR > 1 and alkalinity <50 mg/L). The increase in sulphate in late January 2021 reduced the CSMR resulting in moderately corrosive water from February to April 2021.

Figure 18 presents a comparison of CSMR and lead results from the Waikouaiti Golf Club. There is a general reduction in lead levels after the DNDN which could be influenced by the reduction in CSMR although flushing and the change in sample tap could also be factors. Results before 4 February 2021 were taken from customer taps, while the later results were taken from dedicated stainless steel sampling stations. The trends of lead and CSMR before 4 February 2021 show a weak correlation but this may not be causal. A small rain event on 4 December 2020 could potentially have dropped the alkalinity slightly.

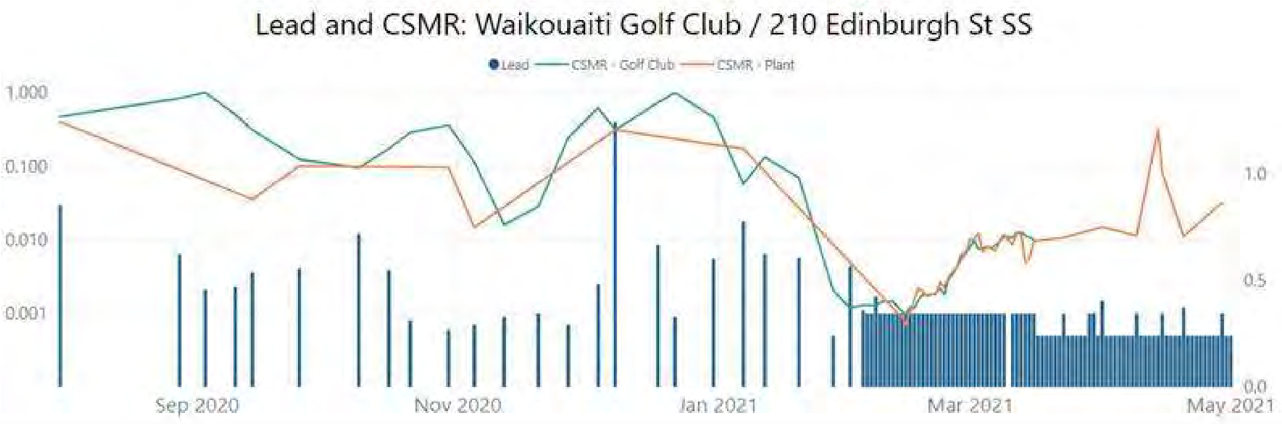

Figure 18: Lead and CSMR @ Waikouaiti Golf Club / 210 Edinburgh St SS

A review of treated water pH SCADA trends (see Figure 19) showed that the pH was generally between 7.2 and 7.85). In general, higher pH water is less corrosive to plumbing and there is little evidence that changes in pH caused a release of lead in the distribution network prior to 8 December 2020.

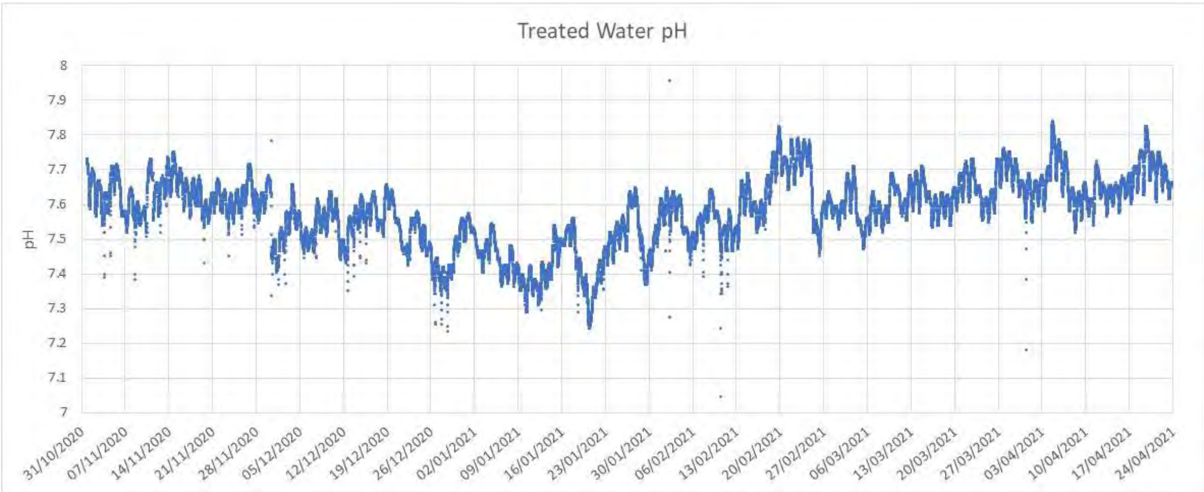

Figure 19: Waikouaiti WTP - Treated Water pH

5.3 Framework for Assessment of Likelihood

In documenting potential causes of lead contamination, the likelihood that any potential cause/event could have occurred was assessed based on the data and evidence collected through the investigation.

The framework for this is provided in Table 4.

Table 4: Investigation of Lead Sources – Assessment of Likelihood

Likelihood	Definition
Very Unlikely	Limited or no direct evidence or data to support this having occurred. No indication of abnormal operation or failed controls.
Unlikely	Some data support this having occurred. No indication of abnormal operation or failed controls.
Likely	Evidence and/or data indicates that this happens at a low frequency.
Very Likely	Evidence and/or data indicates that this happens on a reasonably high frequency and/or known controls had failed.

Throughout the assessment *possible* and *feasible* have been used to denote that something could have happened (i.e. it is not impossible or infeasible) and not specifically as a ranking of likelihood.

Most likely has been used to describe the cause believed to have the greatest possibility of having caused a specific event to occur (e.g. a high lead reading). The *most likely* cause could still be unlikely, in some cases.

5.4 Potential Source #1: Sampling Methodology or Analytical Error

Modifications or imperfections in sampling methodology or analytical error could result in elevated readings in several ways.

- A variation on the required sampling methodology (e.g. flushing taps for different lengths of time) could have resulted in abnormally high lead values caused by localised contamination at a specific location on the customer pipework.
- A variation to the sampling methodology could have resulted in detachment of particulate metal (corrosion of local materials) which could substantially elevate lead readings. The detachment of particulate lead may occur for reasons other than sampling or analytical error.
- Samples could potentially be contaminated in transit or on arrival at the laboratory.
- Variations in sample preparation or analysis could result in errors.

DCC has a long-term relationship with Eurofins to undertake sampling and analysis on behalf of DCC for both compliance and operational (or 'performance') monitoring. Eurofins are an IANZ accredited laboratory and experienced in both sampling and analysis.

DCC asked Eurofins to initiate a review of several factors associated with the sampling and analysis which was undertaken by Eurofins. This review was intended to better understand the likelihood of sampling or analytical error contributing to the elevated results on 8 December 2020. Eurofins investigation is attached in Appendix C. In summary, this is what the review found.

- The same, experienced sampler took all the samples on 8 December 2020 (at the Waikouaiti Golf Club, Karitane Bowling Club and four other locations in the Waikouaiti scheme).
- Samplers are all trained to level 2 for potable water sampling and samplers were following a protocol provided by the DCC for sampling.
- No specific training for metals sampling had been given at the time, though a protocol developed by the DCC was followed.
- GPS tracking showed the vehicle was parked in the correct location, which indicated the correct sample taps were most probably used.
- Eurofins is confident the sample protocol was followed and that the sample bottle did not contact the sample tap. If that had occurred, samplers are trained to discard the bottle to avoid potential contamination.

Following the DNDN a number of additions were made to the sampling and analysis protocol including the following.

- Storage of samples for at least one month for re-analysis purposes.
- Blind duplicates to be tested by Eurofins to determine repeatability (one duplicate per five samples).
- Trip blank – a sample of clean water included in each consignment of samples - to detect cross-contamination during preparation, transport and analysis of samples (one per consignment).
- Inter-lab duplicates to compare Eurofins results to Hill Laboratories results (one per consignment).
- Automatic verification of any sample that exceeds MAV – including retest of held sample.
- Analysis and reporting of results provided as soon as possible (due to sampling and shipping logistics timing cannot typically be reduced to less than 48 hours).
- All results which exceed a MAV or 50% of a MAV trigger an automatic alert to DCC.

Table 5 shows a summary of blanks and duplicates analysed prior to 1 May 2021. Abnormal results include blank samples that showed lead above the detection limit or duplicates that had >10% for any results over 0.010 mg/L or differ by more than 0.001 mg/L in the result.

Table 5: Blanks, Duplicates, and Retests

	# Samples Analysed	# Results Exceeding QA/QC Limits
Blind Duplicates	131	2
Trip Blanks	85	0
Inter-lab Duplicates	4	0

The two duplicate exceedances showed variability (up to 25% difference) in detectable results in pre-flush results. This variability is potentially due to the presence of particulates and/or the protocol for division of duplicates during pre-flush sampling.

The absence of results in blanks and infrequency of results which appear to be exceptional (or have no clear explanation) indicates that, while still a potential cause, sampling or analytical error are unlikely to have resulted in elevated lead being detected in water samples on 8 December 2020 and 20 January 2021.

5.5 Potential Source #2: Lead Leaching in Distribution Network

As discussed in section 2.2.3, plumbosolvent water may result in lead-bearing materials causing elevated lead results in water samples. Whether local lead leaching in the network is a cause of lead results (from section 4.1) depends on the network pipe materials upstream of the sampling station. If lead or lead-bearing materials were exposed to water in a low-flow area of a network, lead could potentially reach the low-levels seen in flushed samples from the Waikouaiti Golf Club. Moreover, if pipes have severe pitting, corrosion or other damage and those same pipes contain lead elements (like joints), the likelihood that lead leaches into the distribution network may increase.

This section describes a number of investigations which were undertaken to assess the potential for network corrosion caused by plumbosolvent water to cause the elevated and exceptional readings.

A review of pipe materials in the network was undertaken to identify potential sources of lead within the DCC-owned network and is discussed in section 5.5.1. Sections of pipe were excavated to confirm the presence of lead-joints connecting cast iron pipes in the Waikouaiti Upper Levels zone. Once confirmed, two sections of cast iron pipe containing lead joints were cut away and sent to WSP for pipe condition and lead joint integrity assessment.

5.5.1 Review of network materials

Figure 20 below shows the location of different pipe materials in the Waikouaiti, Karitane, and Hawksbury Village distribution network of relevance to this investigation. The majority of the pipework in the network is non-metallic, however, there are some areas with cast iron and other metals. Cast iron mains are limited to the Waikouaiti Upper Levels Zone (along Edinburgh Street to the right Figure 20) and a short section of cast iron in the Waikouaiti Lower Levels Zone (just above the centre of Figure 20). The Karitane zone (lower left of Figure 20) is not known to have any metallic pipes in the network.

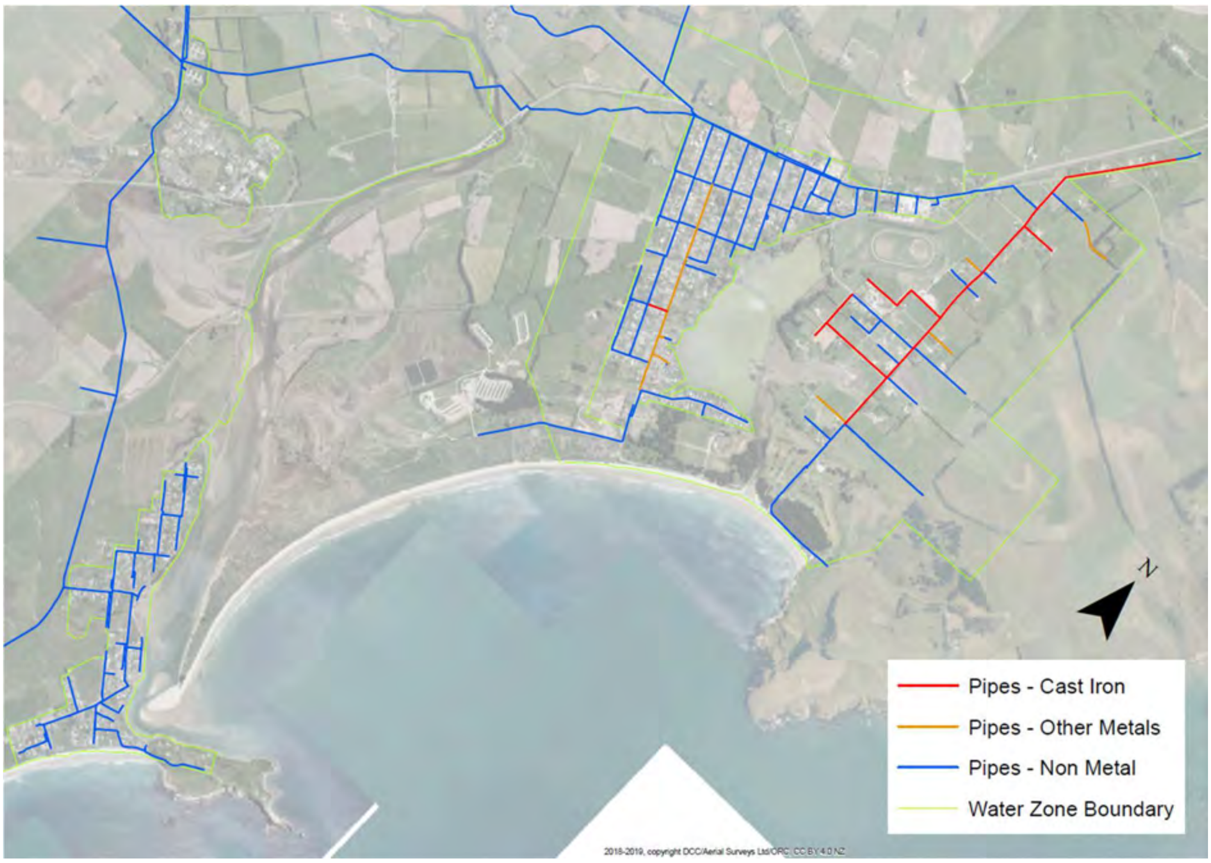

Figure 20: Partial Map of Waikouaiti, Karitane, and Hawksbury Village Distribution Network.

While network lead leaching is a potential cause of high lead readings in samples taken from the Waikouaiti Golf Club on 8 December 2020, the Karitane Bowling Club result on the same day could not be explained by this mechanism because there is no known source of lead in the distribution pipework upstream of this location. Furthermore, the elevated levels at the raw water reservoir on 20 January 2021 would not be explained by this mechanism due to the absence of lead bearing pipework upstream of the raw water reservoir.

5.5.2 Lead Jointing Investigation

Two sections of cast iron pipe with run-lead joints (see Figure 21 below) were removed from Edinburgh Street and Perth Street and sent to WSP for inspection. WSP assessed the pipes for age and integrity, and their findings are documented in Appendix D.

Figure 21: Sections of cast iron pipe sent to WSP for condition and lead joint integrity assessment from Waikouaiti Upper Levels zone.

In summary:

- The pipes were estimated to be installed in 1913 and assessed to be at the end of life stage and due for replacement.
- In the two pipe sections analysed, there were no signs that the lead was directly exposed to the water supply and the hemp rope that seals the connection (isolating the water supply from the lead) was packed tightly into the socket (see Figure 22).
- Lead joints are unlikely to have contributed to the exceptionally high results observed on 8 December 2020.
- It is possible (though unlikely) that other lead joints on the cast iron water mains in Waikouaiti may be exposed to water due to the hemp rope not being sufficiently packed prior to the pouring of the molten lead or subsequent damage or degradation.

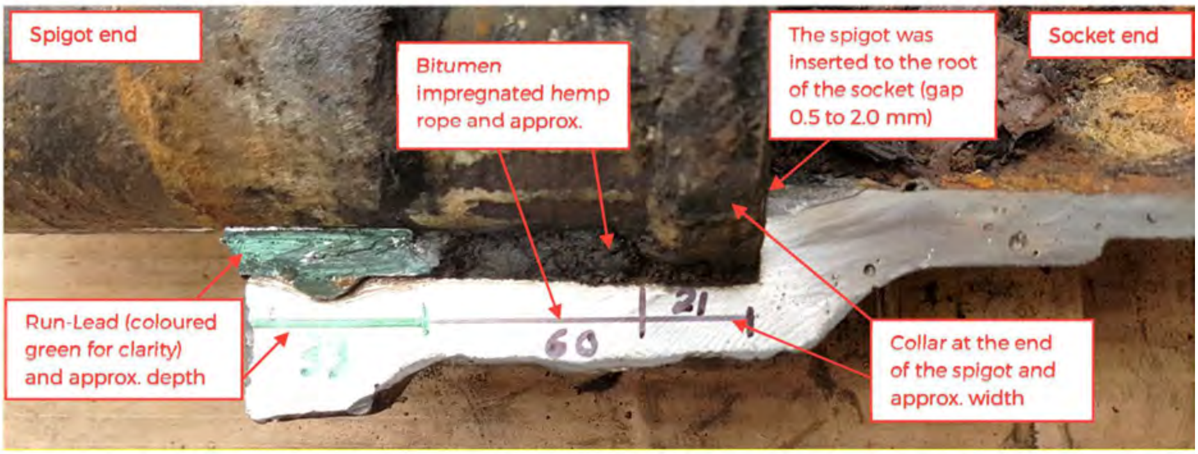

Figure 22: Cross-section of lead joint shows the tightly packed bitumen impregnated hemp rope blocking the direct contact of water with the lead joint.

5.5.3 Network lead data review

While a number of elevated lead results have previously been observed at the Waikouaiti Golf Club and indicated the possibility of elevated levels of lead in the network in the Waikouaiti High Levels zone (along Edinburgh St), 118 out of 119 samples collected at the Karitane Bowling Club (and subsequently nearby Stornoway Street) between 31 July 2020 and 30 April 2021 have indicated there is typically no elevated lead in the Karitane zone. Lead leaching in the distribution system due to local lead leaching might be expected to result in relatively consistent levels of lead in the water, unless substantial changes in water chemistry or residence time/water consumption rates occur. The exceptional value reported on 8 December 2020 at Karitane was very unlikely to have been caused by distribution network lead leaching because there is no evidence of substantial changes in water chemistry and no known lead-bearing pipework in the Karitane distribution network (with the exception of local plumbing fittings).

At the Waikouaiti Golf Club there were frequent detectable and elevated lead readings prior to the DNDN being issued. The post-flush results were initially thought to indicate network lead leaching because the samples were thought to have been flushed for enough time for the sample to be representative of the distribution main. Following the DNDN being issued, a new dedicated sample station was installed and, generally, very few detectable levels of lead have been observed at this location, which indicates that distribution network lead leaching is unlikely. Table 6 presents a summary of this data.

Table 6: Summary of Lead Detections at Waikouaiti Golf Club and 210 Edinburgh St

Post-Flush Only	Waikouaiti Golf Club – pre 4 February 2021	Waikouaiti Golf Club – post 4 February 2021 (inc. profile samples)	210 Edinburgh St. SS – post 4 February 2021
No. Samples	25	41	181
No. Greater than LOD	24	32	2
No. >MAV	4	1	0

This perceived drop in lead levels could also have been affected by changes to flushing regimes or changes in water corrosivity. However, tests at the Waikouaiti Golf Club tap on the same day as tests on the 210 Edinburgh St SS show lead in the former and not the latter, which is shown in Table 7.

Table 7: Comparison of Lead Readings at Waikouaiti Golf Club and 210 Edinburgh St SS

Date	Waikouaiti Golf Club	Waikouaiti SS – 210 Edinburgh St.
4 March 2021	0.0061, 0.006, 0.005, 0.0064, 0.0069, 0.0059, 0.0091, 0.0088, 0.0078, 0.0101, 0.0037	<LOD
8 March 2021	0.0261, 0.0043, 0.003, 0.0025, 0.0024, 0.0018, 0.0022, 0.0022, 0.0019, 0.0018, 0.0034	<LOD
23 March 2021	<LOD	<LOD
30 March 2021	<LOD	<LOD
1 April 2021	0.001	<LOD
9 April 2021	<LOD	<LOD
15 April 2021	<LOD	<LOD
20 April 2021	0.0007	<LOD
22 April 2021	0.0194, 0.0017, 0.0015, 0.0016, 0.0017, 0.0023, 0.0026, 0.0031, 0.0021, 0.001, 0.0009	<LOD
29 April 2021	<LOD	<LOD
9 May	<LOD	<LOD
20 May	<LOD	<LOD
25 May	<LOD	<LOD
8 June	<LOD	<LOD

Lead results from the Waikouaiti Golf Club did appear to be generally lower following the DNDN being issued, which could also be explained by changes in water chemistry that occurred in the Waikouaiti River, which is discussed further in section 5.6.

5.5.4 Network lead summary

The general lack of lead sources in the distribution pipework and data reviewed at sample points at, and close to the distribution mains indicates that distribution network lead leaching in this scheme is generally unlikely. This is a very unlikely cause of exceptional lead readings at the Karitane Bowls Club (where distribution mains are non-metallic) and an unlikely cause of lead readings at the Waikouaiti Golf Club (which has a cast iron main).

5.6 Potential Source #3: Lead Leaching in Local Plumbing

As discussed in section 2.2.3, plumbosolvent water may result in lead-bearing materials causing elevated lead results in water samples. Localised corrosion may be associated with lead bearings and fittings associated with service lines and customer connections. These have the potential for longer retention times than distribution mains particularly where supplies may be unused for an extended period e.g. overnight.

In order to assess the potential for localised elevated lead levels, a number of investigations were carried out including:

- a review of materials close to sampling points where high readings were observed,
- stagnation testing and
- profile sampling.

5.6.1 Review of local plumbing

Pipework and fittings at the Waikouaiti Golf Club and the Karitane Bowling Club were inspected to identify potential local sources of lead. In addition, the original sample tap at the raw water reservoir at the Waikouaiti WTP was inspected. It was found to be a domestic tap fitting attached to a short length of plastic pipework attached to the outlet to the reservoir.

A site investigation of the Karitane Bowling Club customer sampling tap identified:

- A largely plastic (MDPE) service line from the main to the customer connection point.
- A brass meter (potentially containing lead) at the interface between DCC supply and the customer pipework.
- Plastic (MDPE) pipework from the meter to the clubhouse and the outside tap used for sampling.
- Multiple connections on the customer-side main upstream of the sample tap including a connection to a header tank (presumably with an air gap), connections to the kitchen water supply and other connections (presumably to a toilet and other facilities).
- A connection to an irrigation system connected at an unknown location.
- The time to fill a bucket was measured and based on this, the flow rate from the sample tap at the Karitane Bowling Club was estimated to be 0.1 L/s. The total volume in the supply line to the tap was estimated to be 25 L (based on pipe length and diameter) therefore the time to flush one volume of water out of the supply line is about four minutes, just under the five minute flushing protocol that was used by Eurofins. However, this could vary with changes in water pressure and interactions with other aspects of the customer pipework. Flushing is a necessary, but not sufficient condition to produce a sample representative of the main, as lead present in flushed samples may still originate from local plumbing.

Figure 23 provides a schematic of this arrangement.

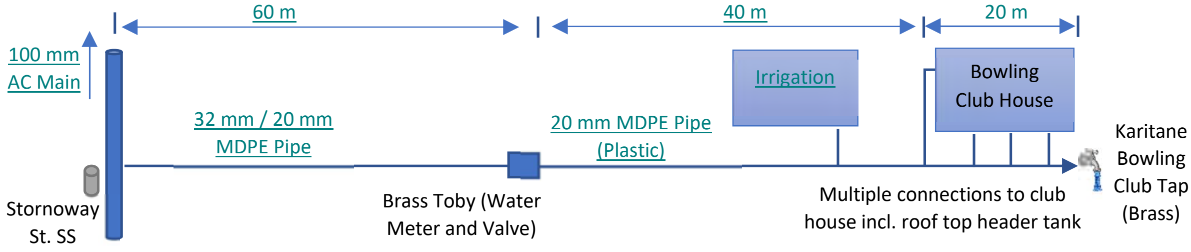

Figure 23: Karitane Bowling Club Sample Tap Schematic (indicative and not to scale)

A site investigation of the Waikouaiti Golf Club customer sampling tap revealed:

- A largely plastic (PE) connection from the distribution main to the customer connection point.
- A manifold comprising multiple brass fittings including isolation valves, meter and non-return valves. On inspection the non-return valves were passing water, so these were removed and replaced.
- A branch downstream of the manifold with PVC piping to the irrigation system.
- Plastic (MDPE) pipework from the manifold toward the clubhouse and the outside tap used for sampling.
- Multiple connections between the sample tap and the customer connection point.
- Multiple outdoor taps.
- Transition from plastic pipework to galvanised steel close to the clubhouse. Galvanised steel is reported to absorb lead and release lead under changing water quality conditions (if installed downstream of lead bearing materials).
- The time to fill a 10-litre bucket was measured and based on this the flow rate from the sample tap at the Waikouaiti Golf Club was estimated to be 0.5 L/s. The total volume in the supply line to the tap was estimated to be 110 L and therefore the time to flush one volume of water out of the supply line is just under four minutes, which is under the five minute flushing protocol that was used by Eurofins. However, this could vary with changes in water pressure and interactions with other aspects of the customer pipework.

Figure 24 provides a schematic of this arrangement.

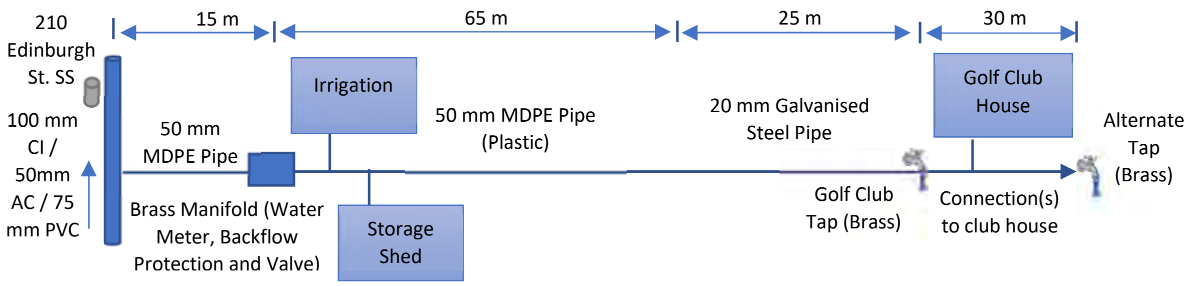

Figure 24: Waikouaiti Golf Club Sample Tap Schematic (indicative and not to scale)

The presence of lead bearing materials and unknown connection points led to further investigations to identify the potential for localised mobilisation of lead. Localised lead mobilisation could explain the lead readings on the 8 December. This testing is summarised in the following sections and included:

- Stagnation tests of actual fittings and fixtures that were present at the sites.
- Timed profile sampling of customer taps that the exceptional results originated from.

5.6.2 Stagnation Tests

Prolonged stagnation of water could be a contributing factor of the readings on 8 December 2020 if the samples collected an element of water which had been stagnating in lead-bearing plumbing materials. The brass manifolds from both the Waikouaiti Golf Club and the Karitane Bowling Club were removed and replaced (see Figure 25 below). Stagnation tests were done by allowing water to sit in capped manifolds for 24 hours to assess the manifolds as a potential source for elevated lead readings. Water was then carefully sampled directly from the manifolds into 500 mL plastic containers. These samples were then sub-sampled and sent to Eurofins for analysis (lead – acid soluble, amongst other metals). The remaining sample was analysed by handheld lead analysers and recorded.

Figure 25: The meter and toby from Karitane Bowling Club (left) and the meter and double check valve with associated fittings and fixtures from Waikouaiti Golf Club (right)

The results of stagnation tests are presented in Figure 26 and Figure 27 (which show Eurofins data and not handheld test data). The first stagnation test used water taken from the Waikouaiti distribution zone in February 2021 and had a CSMR of approximately 0.5, an alkalinity of approximately 70 mg/L and a pH of approximately 7.8. The second stagnation test used water taken from Mt. Grand WTP which is typically more corrosive (CSMR = 9.5; alkalinity = 10 mg/L; pH = approx. 6.5).

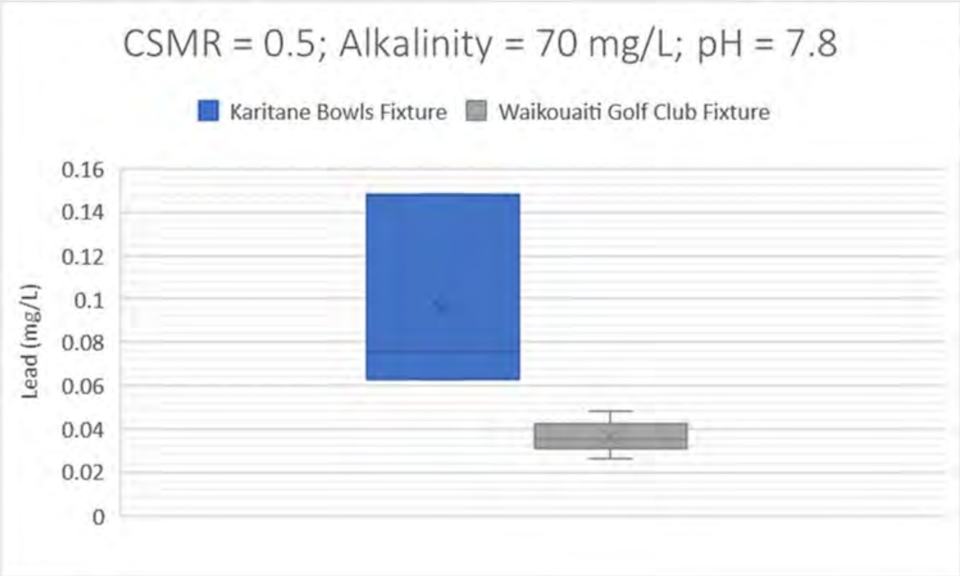

Figure 26: Stagnation Test Results from Fixtures with Treated Water from Edinburgh St SS

Figure 27: Stagnation Test Results from Fixtures with Filtered Water from Mt. Grand WTP

The results show that relatively high levels of lead (>10 times the MAV), like those seen on 8 December 2020 at the Karitane Bowling Club (0.072 mg/L) could originate from fixtures that are present at, or close to customer connections/local plumbing. Long stagnation times (>24 hours) are possible at both the Karitane Bowling Club and the Waikouaiti Golf Club, as the facilities are used periodically. However, it is not possible to identify the stagnation time on specific days.

The results show substantial variability between locations and samples from the Karitane Bowling Club manifold ranged from 0.06 mg/L to 0.14 mg/L. Samples which were observed to contain particulates returned higher acid-soluble lead results than samples without particulates. Lead containing particulates are known to contribute to high levels of lead in drinking water and are a likely cause of the 8 December 2020 reading at the Waikouaiti Golf Club.

The impact of CSMR on stagnation tests was not as expected with lower lead concentrations observed at apparently higher CSMR. This contradicts research (10) indicating the potential for increased local lead leaching if water in contact with plumbing has elevated chloride-to-sulphate mass ratio. However, other factors can affect local lead leaching and lead readings including presence of particulate material, stagnation times, other water chemistry factors as well as scale within the fittings. The manifolds were stored dry between the two tests and it is likely that material on the internal faces may have oxidised forming a layer which reduced leaching rates in the second stagnation test despite higher CSMR and lower alkalinity than the first stagnation test.

Stagnation testing indicated that it is feasible to obtain high lead readings from water stagnated in brass fittings for periods of 24 hours. This testing also highlights the variability and complexity in predicted rates of leaching or lead release.

Overall, these results indicate that it is very likely for local lead leaching (from fittings and pipework) to cause high lead (acid soluble) readings when using the customer taps in the Waikouaiti, Karitane, and Hawksbury Village distribution network. Whilst levels as high as 394 µg/L (also an acid soluble reading) have not been reproduced, tests have shown that concentrations are a function of multiple factors including stagnation time, presence of particulates and corrosivity and could vary widely. It is likely that with a higher CSMR (closer to that observed on 8 December 2020), higher lead levels could be obtained from these fittings.

The stagnation time on 8 December 2020 cannot be specifically identified. However, a review of golf club usage and rainfall trends does not indicate any abnormalities which may have resulted in increased stagnation times.

Based on this analysis localised lead leaching is considered to be a likely cause of the elevated and exceptional results observed on 8 December 2020. This is also supported by profile samples at the Waikouaiti Golf Club where lead was regularly detected from the customer tap and not detectable at the distribution main.

5.6.3 Profile Sampling

Profile testing (lead – acid soluble, amongst other metals) of customer taps and dedicated sampling stations was conducted to:

- assess changes in lead concentration in subsequent samples which may indicate the source of lead i.e. whether elevated lead concentrations are associated with local plumbing or the distribution network
- put previous flushed results from customer taps in context
- better understand how much time was required to access water from the distribution network from the customer supply point (i.e. required flushing times) and compare these results to estimates of time required to flush (presented in section 5.6.1).

Two types of profile sampling were undertaken - timed profile sampling and sequential volume profile sampling.

5.6.3.1 Timed Profile Sampling of Customer Taps

Timed profile sampling was undertaken by Eurofins (based on a protocol developed by DCC) at a range of locations. A 1 L pre-flush sample was collected immediately at the opening of the tap. The tap was left open and subsequent 1 L samples were collected every minute for 10 minutes. Each sample was analysed for a range of metals, creating a timed profile of the customer tap. The results of the first timed profile sample (samples taken at one-minute intervals for 10 minutes) are shown in Figure 28 and include:

- customer taps at the Waikouaiti Golf Club (4 March 2021) and the Karitane Bowling Club (3 March 2021)
- dedicated sample stations close to the customer taps (210 Edinburgh St, 5 March 2021)
- raw water reservoir sample taps (old tap and new dedicated SS).

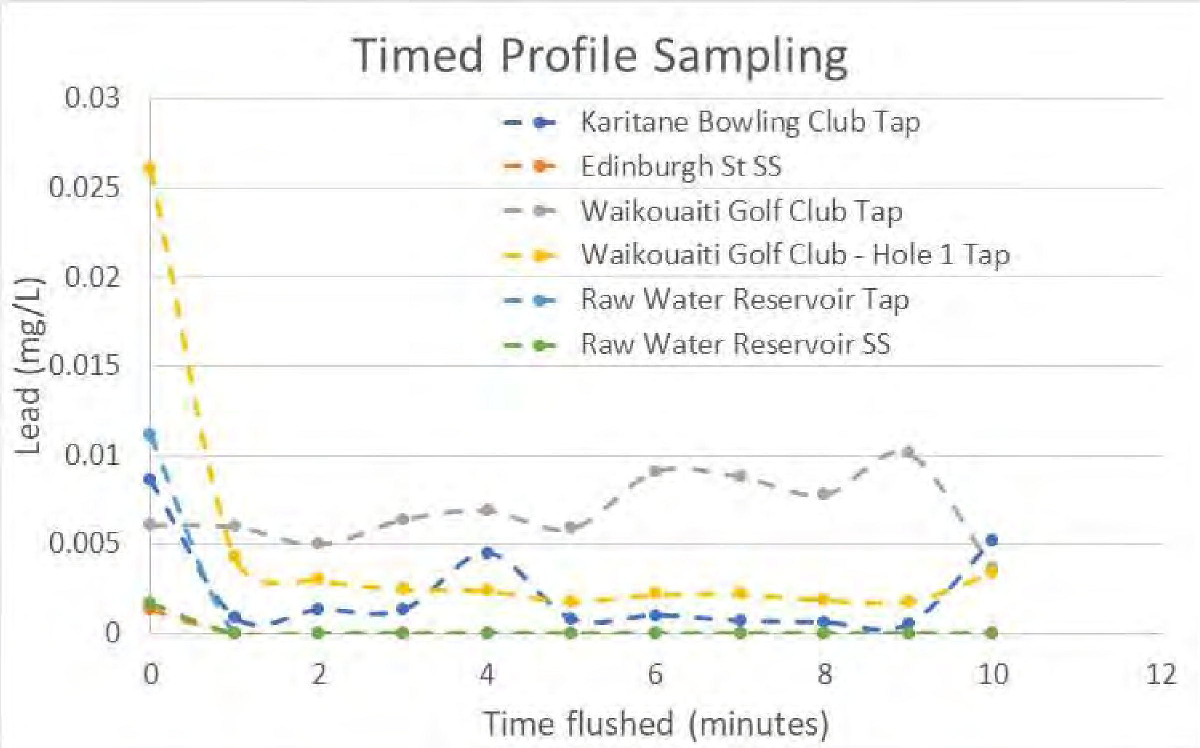

Figure 28: Timed Profile Samples. Dashed lines are shown as a guide only, not interpolation.

The Edinburgh Street dedicated sampling station (SS) takes a sample from the main via an approximately 1m long nylon hose. Lead was observed in the first flush sample from the dedicated SS, but all subsequent samples were less than LOD. The Waikouaiti Golf Club sample taps are located on the customer's property connected to the customer's plumbing. The persistent presence of lead between 50% and 100% of MAV from the golf club taps indicates contamination associated with local plumbing. The customer's connection to the main is within 10 – 20 m of the dedicated SS which showed no lead in flushed samples. This evidence suggests lead detected in flushed samples from the customer's taps was not originating from the distribution network.

Similarly sampling from the Stornoway Street SS did not present any detectable lead other than the pre-flush sample. In contrast sampling from the Karitane Bowling Club sample tap presented persistent detection of lead with peaks after four and 10 minutes of flushing. This evidence suggests lead detected in the flushed samples from the Karitane Bowling Club could have originated from localised lead leaching. The magnitude of these readings could be higher if water was more corrosive, it was stagnated for a longer period or if particulate material was captured.

These tests also indicate that 10 minutes of flushing was insufficient to provide a sample of water which was representative of water in the distribution network at either location. An extended timed profile sample was undertaken to identify if representative samples might be obtained after 20 minutes of tap flushing. Samples were taken every two minutes and the results are shown in Figure 28.

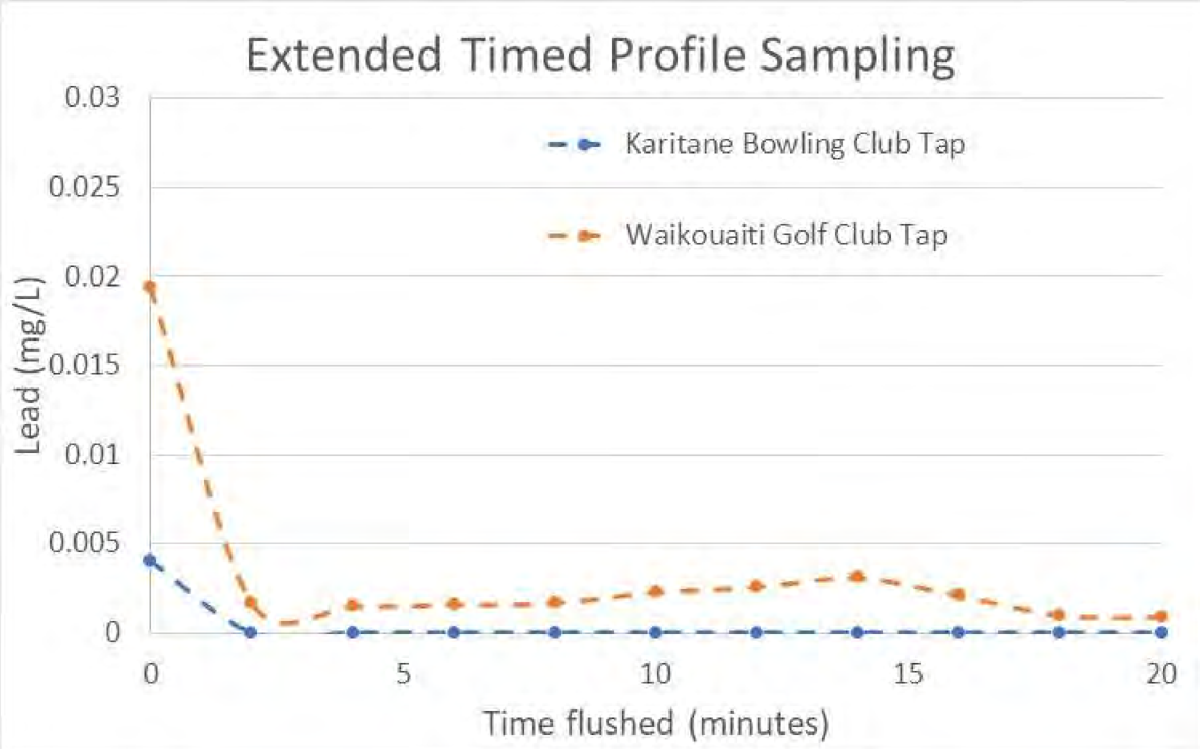

Figure 29: Extended Timed Profile Samples. Lines are shown as a guide only, not interpolation.

The results from the extended timed profile sampling show that samples from the Waikouaiti Golf Club still showed detectable lead after 20 minutes of flushing however, a flushed sample taken from the nearby dedicated SS (210 Edinburgh Street) showed detectable levels of lead in only 3 of 173 post flush samples. The extended profile from the Karitane Bowling Club returned non-detectable levels in all but the pre-flush sample. This is not consistent with the initial profile sample and could be due to changes in corrosivity or stagnation times. 100 samples from the sample station at 99 Stornoway Street have returned only one level above the LOD (which was actually at the LOD), with the exception of pre-flush samples.

Results from timed profile samples indicate that it is very common for samples taken from customer taps to contain lead associated with the local fittings (while there is no lead in the distribution network) and therefore this is a likely cause of elevated lead results observed in samples obtained from customer taps prior to the DNDN being issued (including 8 December 2020).

5.6.3.2 Elevated Pre-flush Readings - Lead in Samples from Dedicated Sampling Stations

Pre-flush results from multiple newly installed sampling stations regularly returned elevated lead results. This finding was unexpected because pre-flush samples from other dedicated sample stations did not regularly return detectable levels of lead. The dedicated sampling stations consist of stainless steel tubing, a stainless-steel ball valve, nylon tubing and fittings, and a nickel-plated ball valve as a shut-off valve. While stainless steel can contain low levels of lead (11) this was not expected to be significant because pre-flush samples at other taps did not indicate elevated lead levels. However, repeated elevated pre-flush results indicated lead was present.

In order to investigate the source of this lead, a fully plastic SS (shown in Figure 30) was installed next to the stainless steel station for comparison and volumetric profile sampling was undertaken at each of the taps.

It is noted that the SS is secured in a locked galvanised casing and is not accessible for public use. It is also noted that SS are fabricated from metallic components to allow sterilisation using a blow torch.

Figure 30: (a) Plastic Sample Station (left) and Steel (right) @ 210 Edinburgh St (also installed at Bendigo Rd.)   (b) Plastic tap connection to main

Figure 31 shows pre-flush and post-flush lead results from four sampling stations; a plastic SS and a stainless steel SS at 319 Bendigo Road, and a plastic SS and a stainless steel SS at 210 Edinburgh Street.

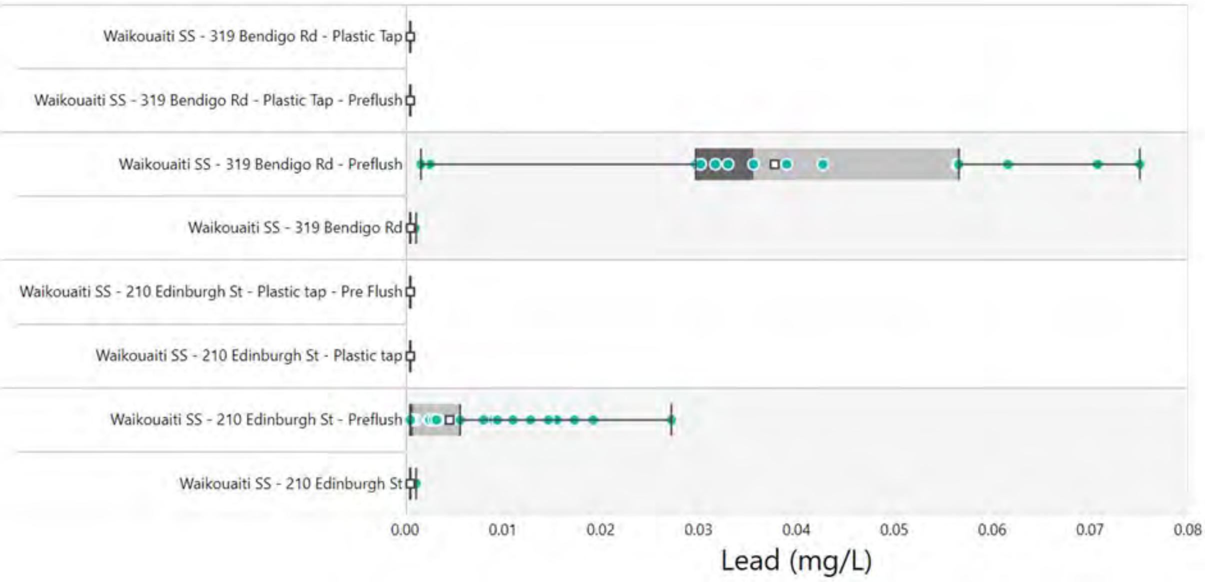

Figure 31: Pre-flush and post-flush results from sites with both stainless-steel SS and plastic SS

The results in Figure 31 show that in all cases plastic taps have undetectable amounts of lead in both pre-flush and post-flush samples, whereas the stainless steel taps have elevated levels of lead in the pre-flush samples and mostly undetectable levels of lead in the post-flush samples. This confirms the stainless steel taps themselves (or a component of the SS) as the source of lead.

To better understand where the lead was originating from in the stainless steel dedicated sampling stations and to understand how much flushing was required to sample water representative of the network, sequential volumes were collected from the sampling stations. The total volume of the sequential profile samples (about 2 L) was enough to sample the entire volume of the sampling stations' tubing/pipework and to sample water coming from the main. Samples were analysed immediately by a handheld lead analyser. Duplicate samples were also sent to Eurofins to validate the handheld test results.

Figure 32 shows Eurofins and handheld test results from profile sampling of the stainless steel tap and the plastic tap at 319 Bendigo Road.

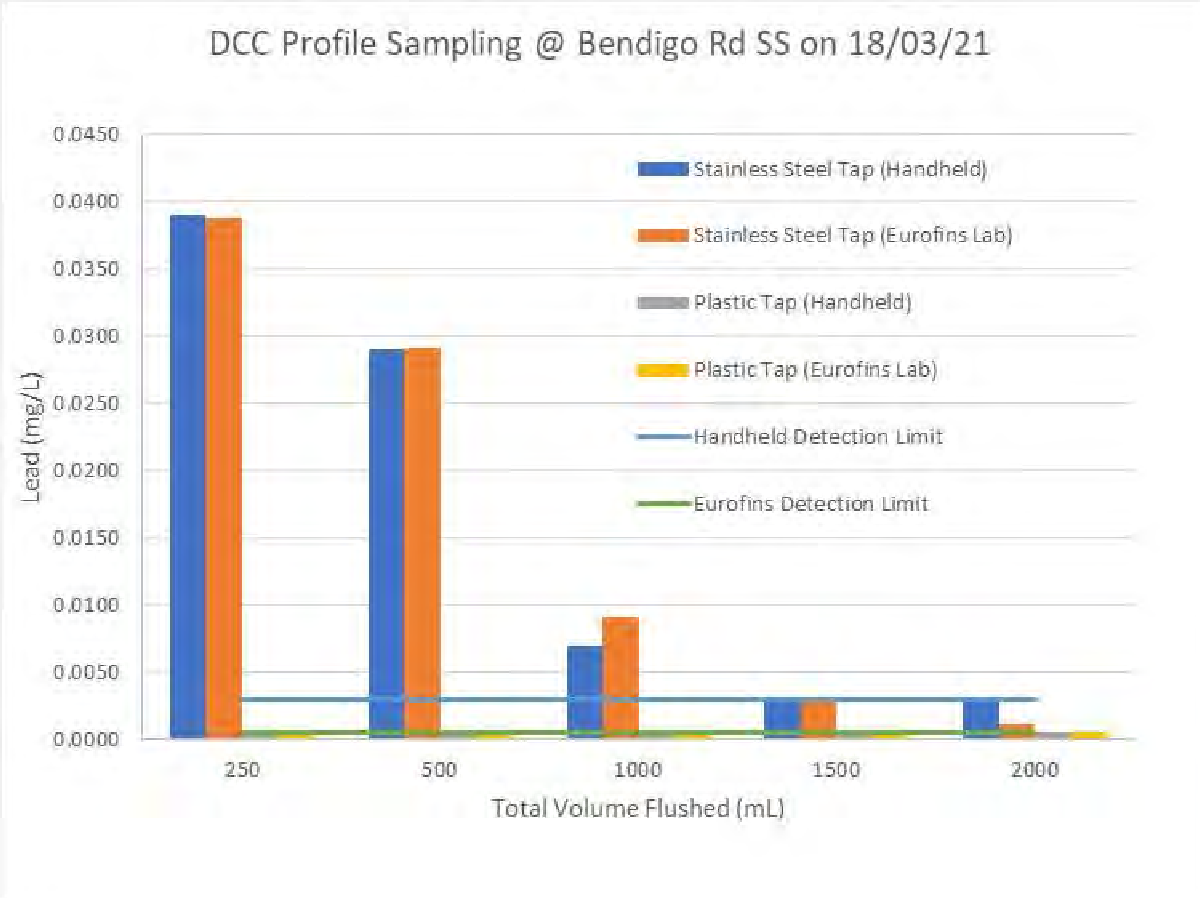

Figure 32: Profile sampling of Bendigo Road SS comparing Eurofins and handheld results

The results show that the highest level of lead was in the first volume which is held in the stainless steel tubing of the tap. The lead decreases to below 50% of the MAV after 1500 mL has been flushed. This evidence indicates that the stainless steel tubing is very likely contributing to the lead results detected in the pre-flush samples collected at the stainless steel SS. No lead was detected in any of the samples obtained from the plastic sampling station. Lead in pre-flush samples is not a hazard to public health because taps are locked and only used for sampling. These results also demonstrate that pre-flush samples are not representative of water in the distribution network and that at least 1500 mL should be flushed for 4-6 seconds from the dedicated SS to obtain a representative sample.

5.6.4 Metals Profile

In addition to lead, samples were analysed for other metals (aluminium, copper, iron, manganese, nickel, and zinc) by Eurofins. Figure 33 shows a metals 'fingerprint' for metals that were commonly found above detection limits in water samples. Metals results for several water samples that had particularly high lead results were selected for metal fingerprinting including:

- The two exceptional results observed in post-flush samples taken on 8 December 2020 at the Karitane Bowling Club and the Waikouaiti Golf Club (#1 and #4 in Figure 33).
- The moderately elevated results observed in pre-flush profile samples (see section 5.6.3.1) taken on 22 April 2021 at the Karitane Bowling Club and the Waikouaiti Golf Club (#2 and #5).

- The results from 24-hour stagnation tests (see section 5.6.2) of manifolds from the Karitane Bowling Club and the Waikouaiti Golf Club (#3 and #6).
- The results of a pre-flush sample taken on 7 March 2021 from a recently installed, stainless steel dedicated SS at 319 Bendigo Road (#7).
- The results from pre-flush profile samples (see section 5.6.3.1) taken on 23 April 2021 from an old sample tap (#8) and a recently installed, stainless steel SS (#9) at the raw water reservoir.
- Finally, the results from a post-flush sample taken from the old sample tap at the raw water reservoir on 20 January 2021 (#10).

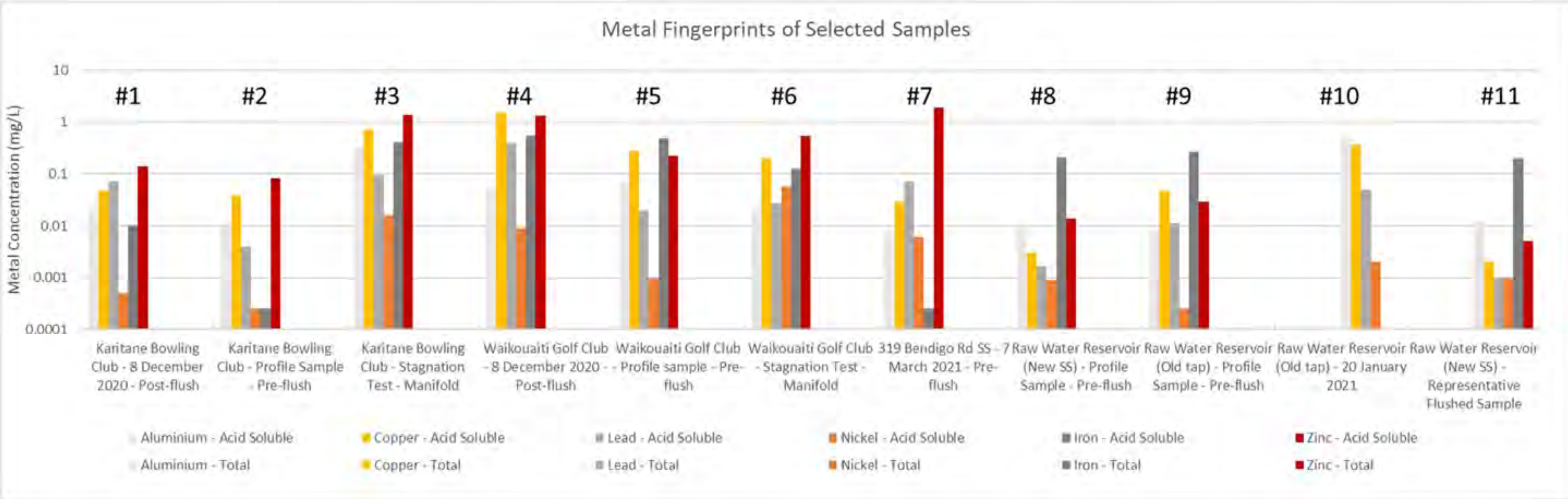

Figure 33: Metal Profile of Selected Samples

Notes:

- The raw water reservoir sample from 20 January 2021 was not analysed for iron and zinc measurements.
- Iron and manganese were present at similar ratios in most samples, so only iron is plotted for simplification purposes.
- Sample #10-11 results – the raw water reservoir sample from 20 January 2021 and a representative flushed sample – are 'total' metals results. The 'total' metals method follows a more rigorous acid-digestion method than "acid soluble" method used to prepare the other samples (#1-9).

Key observations from Figure 33 include:

- The post-flush sample profile (#1) from the Karitane Bowling Club (8 December 2020) shows elevated copper, lead and zinc, all of which are known to be corrosion products of fittings and plumbing materials (based on discussion with Stantec).
- The pre-flush profile sample (#2) from the Karitane Bowling Club shows elevated copper and zinc (slightly elevated lead), which are known to be corrosion products of plumbing materials including customer plumbing materials.
- A sample obtained from stagnating water for 24 hours in the manifold from the Karitane Bowling Club shows elevated results (#3) of all metals and indicates this manifold as a potential source of contamination that was actually present upstream of the sampling point at the time of the very high result from the Karitane Bowling Club (8 December 2020).
- The lead levels in sample #3 was the second highest lead result (14x MAV) in all samples (after the result from Waikouaiti Golf Club on 8 December 2020 – 40x MAV). This suggests high results could originate from common local plumbing fixtures. Notably Sample #3 also had visible particulates present in the sample. Particulates are known to cause very high lead results in drinking water samples.
- The post-flush sample results (#4) from the Waikouaiti Golf Club (8 December 2020) show all metals to be elevated and the metals profile is similar to #3. While #3 was from the Karitane Bowling Club, similar materials were found to be present in the Waikouaiti Golf Club plumbing.
- A sample obtained from stagnating water for 24 hours in the manifold from the Waikouaiti Golf Club shows elevated results (#6) for all metals. This sample contained the highest amount of nickel of all samples shown here. The manifold (#6), among other metallic plumbing present at the Waikouaiti Golf Club on 8 December 2020, could have contributed metals to the results in sample #4.
- Sample #7 from Bendigo Road had very low levels of iron and higher levels of other metals. The raised lead has been shown to be originating from the stainless steel tap itself.
- Samples #8 and #9 were pre-flush raw water reservoir samples obtained during profile sampling of the old tap and the new stainless steel SS. The pre-flush samples had generally elevated metals commonly associated with corrosion products of plumbing materials – the metals markedly decreased (not shown) upon flushing. This shows that the raw water reservoir tap can contribute to metals if the sample is not flushed.
- The lead in sample #10, a post-flush result from the old sampling tap off the raw water reservoir, was unusual. Iron and zinc were not analysed for in this sample.
- The samples from this particular sample (#10) were 'Total' and were digested following a more rigorous digestion process than acid-soluble samples of samples #1-9. This means if particulates were present in sample #10, they would have been more likely to be acidified than particulates present in the other samples. In general, the metals in sample #10 were elevated above the pre-flush samples #8 and #9.
- Aluminium in sample #10 is higher than any other sample in Figure 33 and is present at a level which is uncommon in the Waikouaiti River water (typically <0.05). A potential cause of this high aluminium result and the associated lead result is discussed more in the section 5.7.5.

In summary, this indicates that the metals profile on 8 December 2020 at both sites was similar to that observed from samples with high lead, which was known to be caused by local plumbing fittings (i.e. brass). Other plumbing/fixture metals that could contribute these metals include galvanized copper, chrome, brass. This indicates this is a likely cause of these exceptional readings.

5.6.5 Local Lead Leaching Summary

Detectable and elevated lead levels were regularly observed at sample taps which were remote from the distribution main (e.g. customer sample taps at Waikouaiti). High lead levels were reproduced through stagnation testing and profile sampling and were generally not observed on samples taken directly from the main network. Metal profiles from 8 December 2020 were similar to profiles from water stagnated in metallic fittings. This indicates that localised corrosion associated with lead-bearing fittings is a likely cause of the exceptional lead readings on 8 December 2020 (and a very likely cause of high lead readings at the Waikouaiti Golf Club and the Karitane Bowling Club in general).

It is acknowledged that the readings on 8 December 2020 were higher than those reproduced through other testing, profile sampling and stagnation testing - the higher levels could be explained by longer stagnation times, presence of particulate material or corrosivity of water.

5.7 Potential Source #4: Raw Water Contamination

Raw water contamination could be caused by the discharge of lead-bearing materials anywhere in the catchment and from a large range of potential sources. The risk of contamination of the river is considered in the Water Safety Plan. The WSP assessed this as a very unlikely event but is classified as high risk due to the potentially significant consequences.

Following the DNDN being issued, DCC engaged a team of technical specialists, Tonkin and Taylor (T&T) to undertake a preliminary Catchment Risk Assessment (CRA) with a specific focus on the risk of lead contamination. The T&T team includes specialists in hydrogeology and water contamination relating to public health. The Catchment Risk Assessment is provided in Appendix F and a summary is provided in section 5.7.1.

Further analysis of raw water quality data (including data collected since the CRA was issued) is provided in sections 5.7.2 and 5.7.3.

An analysis of water age and transfer within the distribution network was also undertaken to identify feasibility of a common contamination event resulting in elevated levels at the Waikouaiti Golf Club and the Karitane Bowling Club but not being identified elsewhere. This is described in section 5.7.3.2.

5.7.1 Catchment Risk Assessment (CRA)

Tonkin & Taylor were engaged to undertake a catchment risk assessment (CRA). The full CRA is in Appendix F.

The summary of findings from the CRA:

- DCC undertook an aerial survey of the Waikouaiti river and reported a range of potential contamination sources to the ORC who investigated them further. These were considered further by T&T in the CRA.

- T&T undertook a desk top review in addition to fieldwork and a survey of the river which included samples from river water and sediment in the river from near the intake all the way to Macraes Flat.
- The CRA found no evidence of elevated lead results in the river or sediment and concluded that sustained elevated discharges of lead within the Waikouaiti River catchment is unlikely.
- The CRA concluded that (if lead results were not caused by sampling error or localised plumbing contamination) short-term 'pulse(s)' of elevated lead are the most-likely explanations for the exceptional result in the raw water reservoir (and therefore potentially also in the distribution network on the 8 December 2020) and that the highest risks of catchment contamination were mining operations, the WTP itself (discussed further below), and a fly dump near Eldorado Station.
- A simple mass balance, which does not account for more complex catchment and chemical processes, shows that there is no evidence to indicate that discharges from the mine could lead to the concentrations of lead at the water intake that have been experienced.
- A further analysis of the impact of lead batteries, or lead containing petrol, being discharged to the river indicated that substantial quantities of either would be required to reach the high readings observed. If this had occurred, it is expected there would be some residual evidence of this, which has not been found to date.

Recommendations from Tonkin & Taylor included the following.

- Continue to monitor raw water for lead (total and dissolved) at high frequency, along with periodic sampling of sediment for lead (including event-based sampling also).
- Further discussion with the mine to establish whether further environmental monitoring data may be available.
- Further investigation of the fly-dump. Subsequent assessment by ORC indicated this was low risk.
- Investigation of Mahika Kai results. Subsequent investigation and analysis by the ORC, Ngāi Tahu and ESR did not indicate any cause for concern with lead levels. This included analysis of trout, shellfish and eels.

5.7.2 Review of additional Oceana Gold Mine data

Oceana Gold provided additional environmental data which included sulphates, pH, lead and other water quality parameters. Oceana Gold monitors the Waikouaiti catchment monthly at a number of different sites. They discharge from three locations intermittently, usually during or following heavy rain events. These discharges occur in the upper reaches of the catchment. A controlled event-based discharge from Frasers Pit occurred from 14 to 21 January 2021 due a heavy rainfall event in early January. An initial review of this data indicated that the discharge appeared to contribute to elevated levels of sulphate seen in mid-January, but no significant dissolved lead results (or metals) were observed in the monitoring that Oceana Gold undertook. Dissolved lead results do not account for particulate lead associated with the discharge. However, if particulate material was present it would be removed by the treatment plant. It is expected that particulate lead, if discharged, would largely remain in a particulate form in the natural waters of Waikouaiti River. The DCC will review the current monitoring associated with these discharges and provide feedback to the ORC.

5.7.3 Raw Water Quality

The CRA included a review of SCADA data including raw water quality (turbidity and colour), so is not repeated here. Following the DNDN, an online conductivity and pH monitor were installed at the raw water pump station and an autosampler was setup to take two-hour composite samples from the Waikouaiti River.

5.7.3.1 Raw Water pH and Conductivity

Figure 34 shows the online pH and conductivity monitoring at the raw water pump station. The pH and conductivity are not remarkable and did not show any significant fluctuations which could substantially affect water quality or downstream local lead leaching.

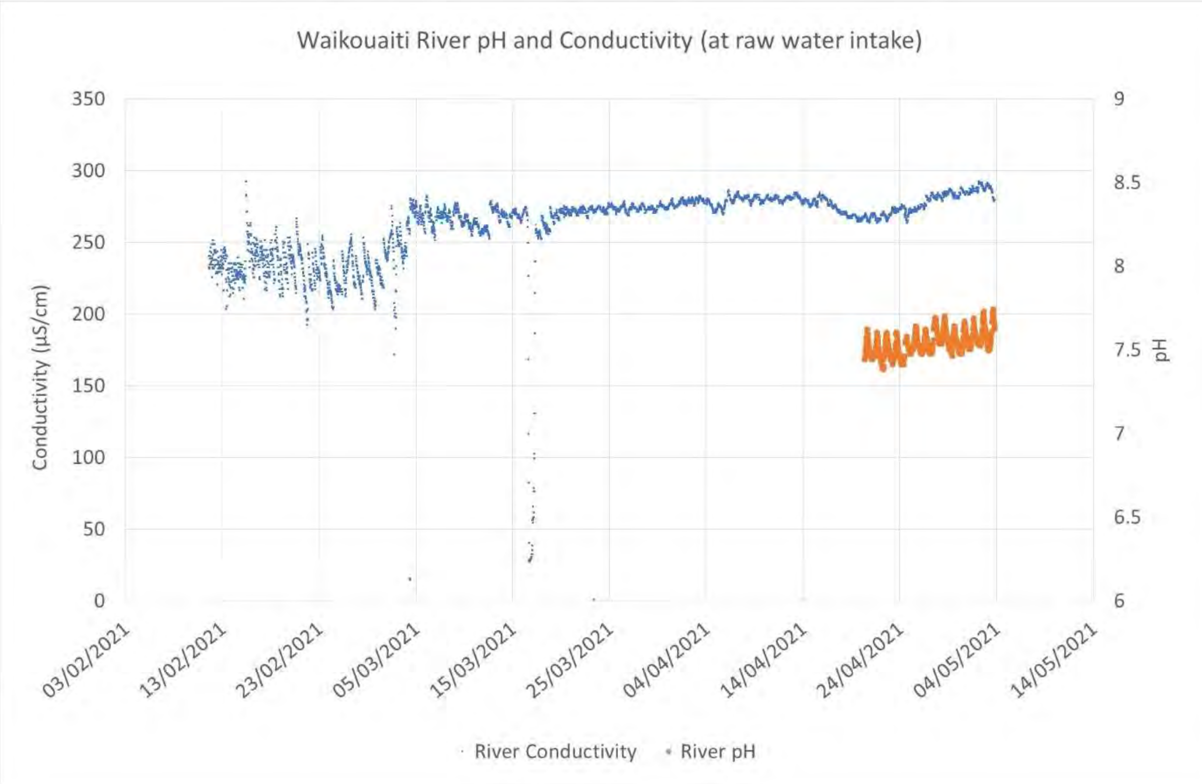

Figure 34: Waikouaiti River pH and Conductivity

5.7.3.2 Autosampler

An autosampler was installed at the raw water pump station. The autosampler collects samples from a continuously running sample line which draws from the raw water pump suction and discharges back to the river. The autosampler collects 24 two-hour composite samples by sub-sampling every 15 minutes. Samples were collected for between two and six days per week from mid-February. The samples were analysed for a range of acid-soluble metals using ICP-MS analysis at the University of Otago's Centre for Trace Element Analysis, which is a 'Class 10' (ISO 4) ultra-clean laboratory. The university was used instead of Eurofins due to a shorter turnaround time. While the university lab is not officially accredited, they specialise in measurement of trace levels of metals and have a lower limit of detection than Eurofins.

All sets of results from these analyses taken up to 9 May 2021 are shown in Figure 37. The analysis was all for total metals, i.e. the results include particulate as well as dissolved.

Of more than 500 river samples analysed, only two results were above MAV. The samples above MAV were 0.034 mg/L and 0.011 mg/L and were both from the first sample bottle in the autosampler. Samples from the first bottles tended to show significantly higher variation than any other sample bottles which indicates a potential systemic issue with one or more of the first sample bottles (four sets of bottles are used in rotation).

Figure 36 shows the systematically higher average (marked by the X and the line connecting the plots) concentration of lead in the first bottle.

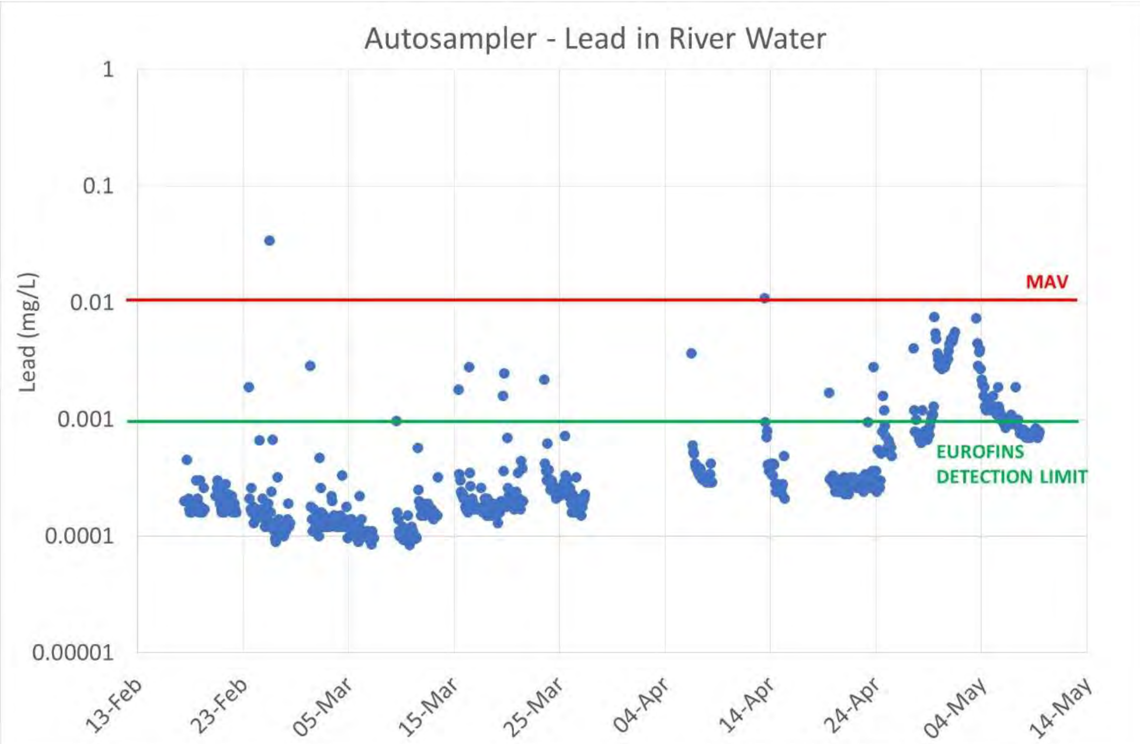

Figure 35: Autosampler – Lead in River Samples

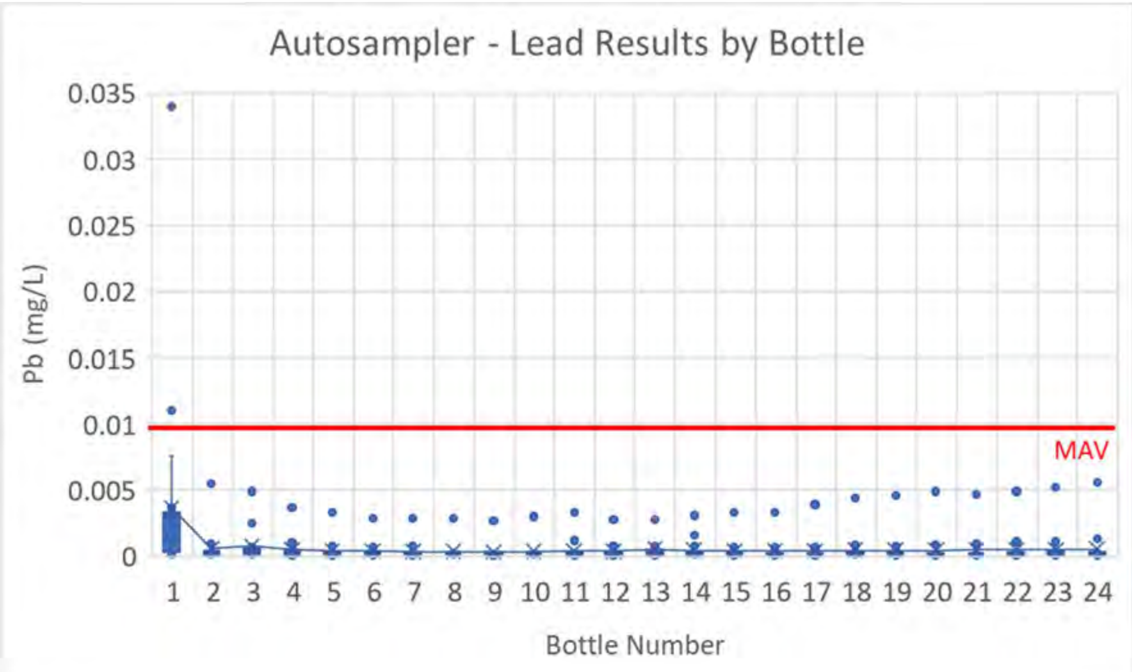

Figure 36: Autosampler -Lead Results by Bottle

The data does indicate a peak in lead levels (still below the MAV) which appear to increase gradually and lasted for approximately nine days. This could be associated with sediment in river water or potentially changes in raw water corrosivity which had an impact on lead dissolution from sample feed pipework (which includes a copper pipe). Further operational investigation will continue to analyse results, but is outside the scope of this report. However, this small peak was still below MAV and does not represent the type of short term intermittent high lead concentrations which could explain the readings on 8 December 2020 (or 20 January 2021). Furthermore, Eurofins sampling in this period did not detect any levels of lead in the raw water or at any stage in the treatment plant.

Figure 37 and Figure 38 show the lead results from the most recent two data sets as well as other metals results. This indicates that a range of metals all follow a similar trend.

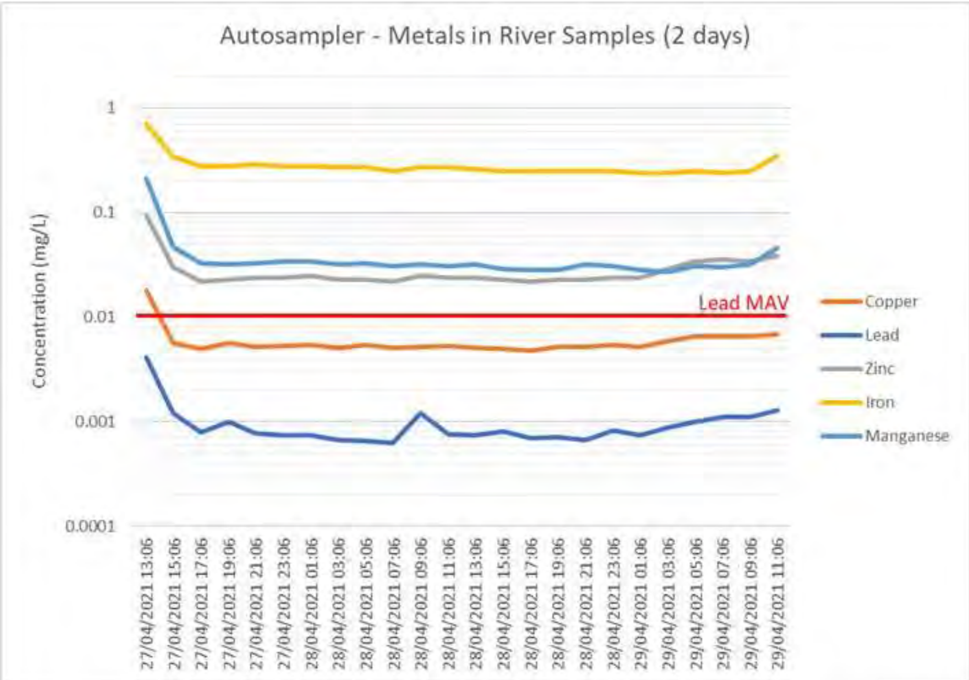

Figure 37: Autosampler – Lead in River Samples (27/04/2021 – 29/04/2021)

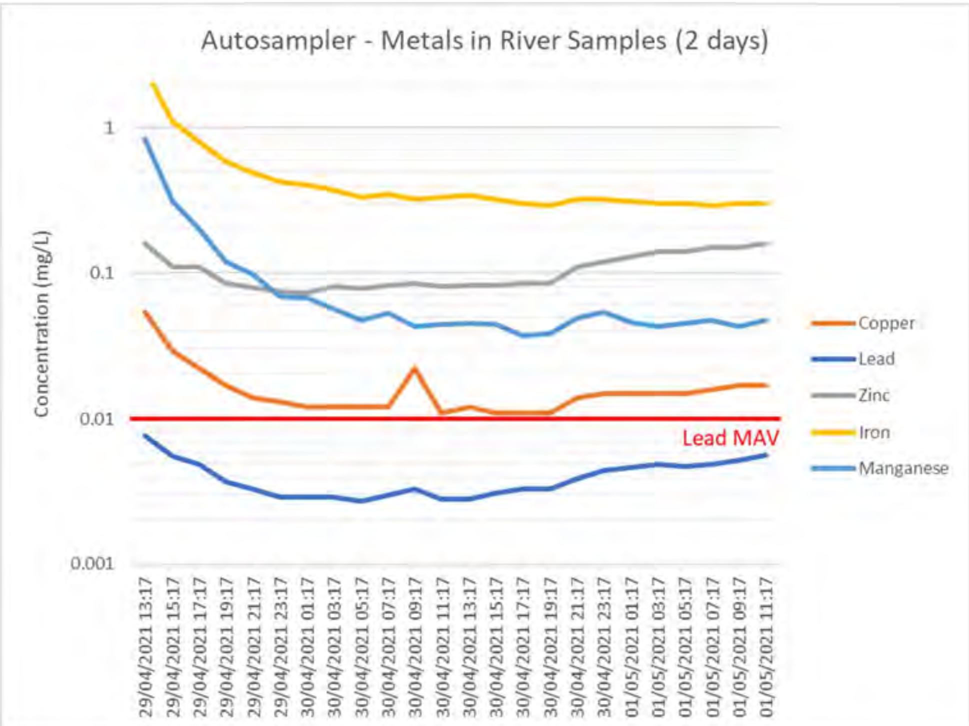

Figure 38: Autosampler – Lead in River Samples (29/04/2021 – 01/05/2021)

5.7.4 Network Water Age Analysis

A series of water age analyses were performed to investigate the feasibility of exceptional results from the Waikouaiti Golf Club and the Karitane Bowling Club on 8 December 2020 being caused by a common upstream contamination event, whilst being undetected on the same day at the WTP and the Waikouaiti Golden Fleece Hotel.

Infoworks WS Pro 4.0 was used to model lead transport in the network by building lead spikes in mg/l at various times of the day at the node closest to the WTP. Infoworks WS Pro 4.0 is a hydraulic modelling software used for water quality and quantity analysis of water supply networks. For this analysis a water distribution model covering Waikouaiti and Karitane networks was used.

A contamination event in the upstream system (catchment, plant or distribution upstream of Hawksbury Village) would have taken varying amounts of time to travel through the distribution and reach each of the sample locations. These locations are in different zones of the distribution network and are fed by separate mains which diverge close to Hawksbury Village, see Figure 1. The time taken for water to reach the Waikouaiti High Level Zone can be highly variable because this zone is either supplied from the Kiatoa Reservoir or directly from the McGrath Road pumps which are located close to Hawksbury Village. The pumps generally run through the night and when operational, the pumps fill Kiatoa Reservoir and supply the Waikouaiti Upper Levels Zone without passing through Kiatoa Reservoir. When the McGrath Road pumps are not running the Waikouaiti High Level Zone is supplied from Kiatoa Reservoir and as such the water age is much longer due to the storage time in Kiatoa Reservoir. The Waikouaiti Low Level Zone and Karitane Zone are both gravity fed from the treated water tank and water age is more consistent though still a function of demand.

A tracer model was configured to demonstrate the time taken for a pulse of material (nominal concentration/magnitude of one and duration of one hour) to reach each sample point at different times of the day. As noted above, this is variable depending on demand and whether the McGrath Road pumps are operating. The model makes a number of assumptions including that all material is conserved i.e. concentrations only reduce due to dilution and that tanks are fully mixed. The plots below show three scenarios to probe the variability of model results due to the timing of pumps running.

- Pulse starts at 7pm on 7 December 2020 - McGrath Road pumps are not operating throughout this pulse and as such Waikouaiti Upper Levels Zone is supplied by water already pumped to Kiatoa Reservoir the previous day. This is shown in Figure 39.
- Pulse starts at 11pm on 7 December 2020 - McGrath Road pumps operate and the pulse reaches Kiatoa Reservoir where it is diluted prior to subsequent release. Some material bypasses Kiatoa Reservoir and is supplied direct to Waikouaiti High Levels. This is shown in Figure 40.
- Pulse starts at 3am on 8 December 2020 - McGrath Road pumps operate and the pulse reaches Kiatoa Reservoir where it is diluted prior to subsequent release. Some material bypasses Kiatoa Reservoir and is supplied direct to Waikouaiti High Levels. This is shown in Figure 41.

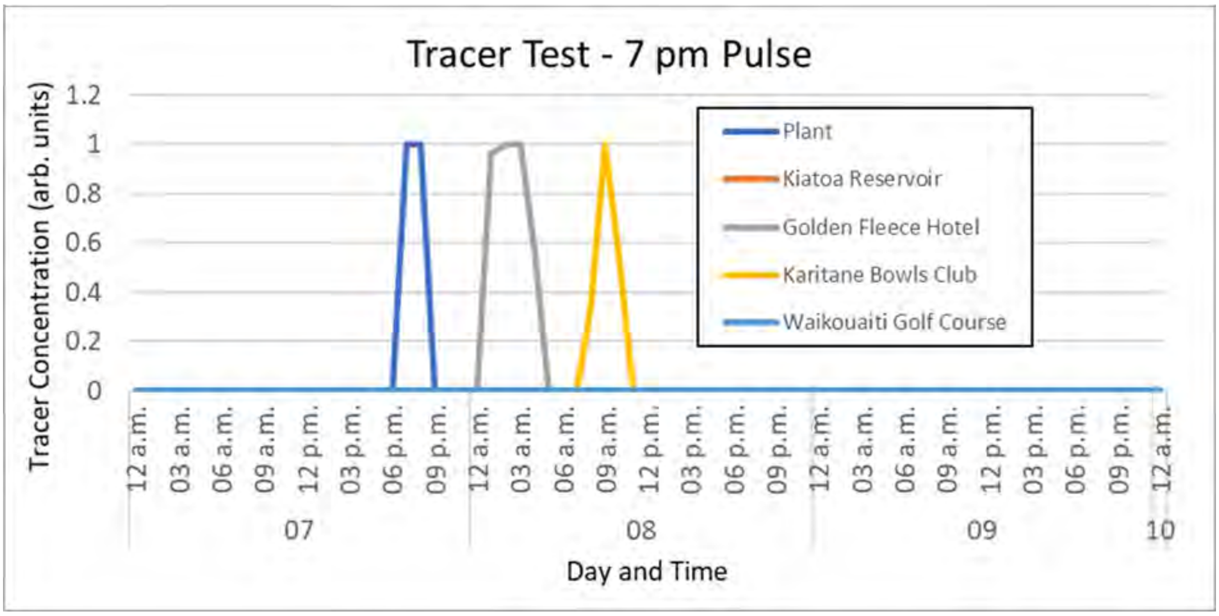

Figure 39: Tracer Test: 7pm on 7 December 2020

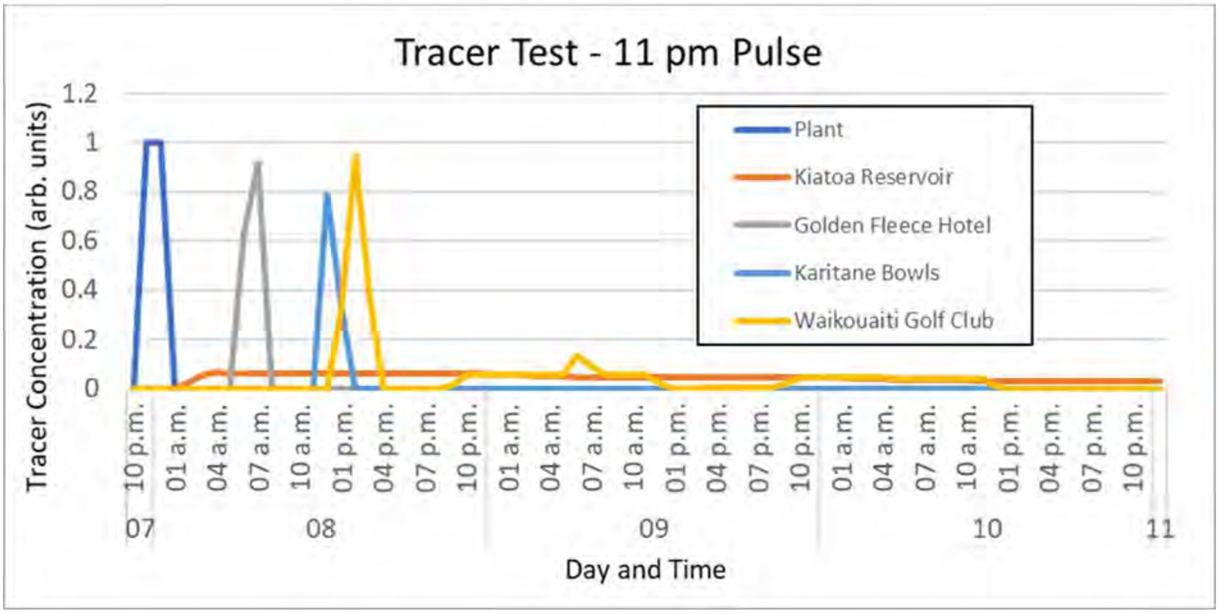

Figure 40: Tracer Test: 1 pm on 7 December 2020

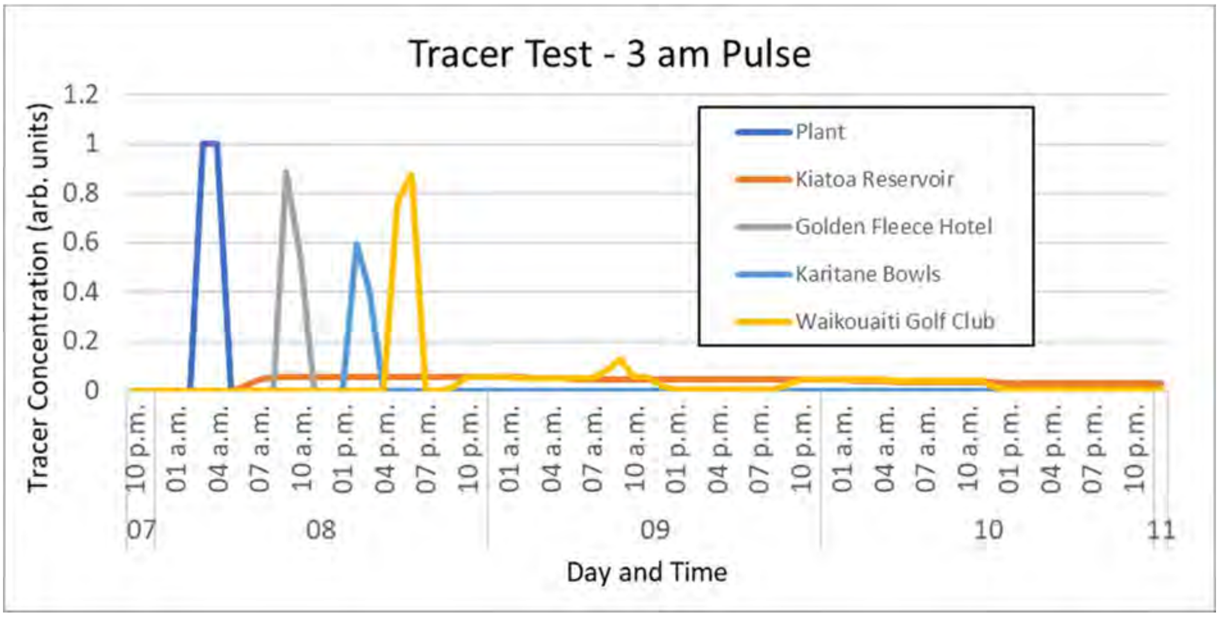

Figure 41: Tracer Test: 3am on 8 December 2020

These pulses all arrive at the Waikouaiti Golden Fleece Hotel first, followed by the Karitane Bowling Club approximately 5-6 hours later. If the McGrath Road pumps were running during the pulse, then the Waikouaiti Golf Club would receive the pulse a further 2-3 hours after the Karitane Bowling Club. There are subsequent lower level pulses in the Waikouaiti Golf Club which are due to the pulse contaminating Kiatoa Reservoir and being supplied across a number of days (the level is lower due to dilution in the reservoir).

As can be seen in the plots, whether a pulse enters the Kiatoa Reservoir depends on when the pulse started at the WTP. One of two scenarios seems to occur in these network tracer models:

- Timing of the pulse is such that the pulse only enters the Waikouaiti Lower Levels Zone (Waikouaiti Golden Fleece Hotel) and the Karitane Zone (Karitane Bowling Club), but is never pumped to Kiatoa Reservoir and the Waikouaiti Upper Levels Zone (Waikouaiti Golf Club).
- Timing of the pulse is such that the pulse can enter all three zones.
- The tracer reaches the Waikouaiti Golf Club and the Karitane Bowling Club at similar times.
- The tracer arrives at the Waikouaiti Golden Fleece Hotel consistently before it arrives at both the Waikouaiti Golf Club and the Karitane Bowling Club.
- The tracer remains in the Kiatoa Reservoir until the reservoir has sufficient turnover to dilute the tracer to negligible levels.

The results of this modelling indicate that it is possible for a contamination event to be detected at both the Karitane Bowling Club and the Waikouaiti Golf Club but not detected at the Waikouaiti Golden Fleece Hotel or the raw water reservoir.

The results also demonstrate the importance of Kiatoa Reservoir as a potential monitoring point as it can potentially preserve a contamination event for a number of days as long as the McGrath Road pumps were operational during the event.

5.7.5 Raw Water Reservoir Contamination

After the lead result of 0.050 mg/L at the raw water reservoir on 20 January 2021, catchment technicians drained and inspected the raw water reservoir and did not find any lead-bearing materials. There was a layer of mud/sediment a few centimetres deep on the bottom of the reservoir, which is not unusual as the raw water reservoir acts as a settling tank when the plant is not running.

The sediment on the bottom of the reservoir was sampled and returned low levels of lead (<20 mg/kg), but very high aluminium (>10,000 mg/kg). This may indicate aluminium from the WTP settling pond discharge is being recycled back into the WTP following discharge to the river. The WTP intake to the treatment plant is downstream of the WTP's settling pond discharge. Aluminium discharge to the river through the settling pond discharge is limited under the discharge consent. It is also possible that levels of aluminium in the river sediment are naturally relatively high as some local rocks contain high levels of aluminium oxide. Data provided by Oceana Gold noted rocks in the upper catchment of the Waikouaiti River can be >15% Al_2O_3. It is very likely that any aluminium or lead entering the reservoir is particulate.

5.7.6 River Water Turbidity and Raw Water Reservoir Operation

Water treatment plant SCADA trends were reviewed to identify any potential operational upset in the raw water reservoir on or around 20 January 2021. Figure 42 shows the level in the raw water reservoir and the river turbidity.

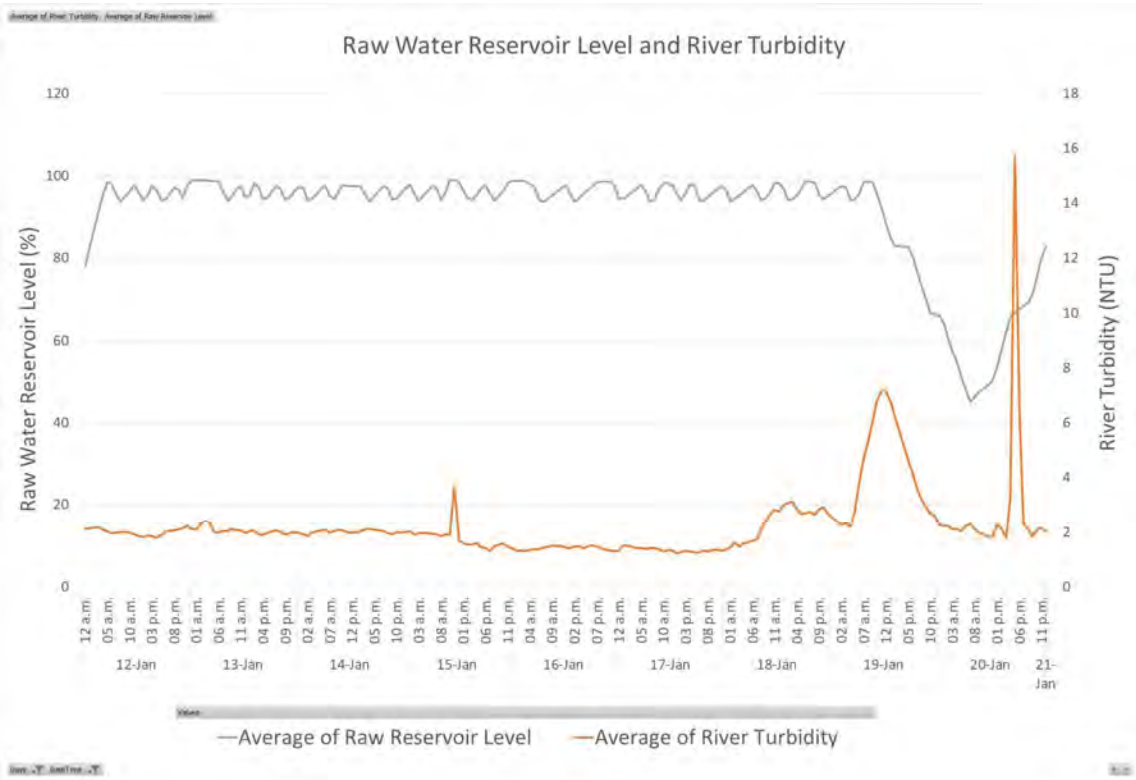

Figure 42: Raw Water Reservoir Level and River Turbidity

On 19 January 2021 the raw water reservoir level dropped from a typical level of 95% to less than 50%. The feed to the raw water reservoir stops at high turbidity to reduce the load on the WTP. High turbidity of river water on 19 January 2021 correlates with the drop in the raw water reservoir level. The raw water feed to the raw water reservoir was stopped for this reason. Turbidity is typically caused by higher levels of sediment and particulate material in the water and typically occurs at higher river flows e.g. in wet weather but can also be caused by disturbances to the riverbed like dredging.

A sharp spike in turbidity was recorded on 20 January 2021, the same day as the high lead result. The cause of this is unclear. This sharp spike appeared as raw water was being transferred to the raw water reservoir as the level can be seen to be increasing. While the source of the turbidity peak is unknown it is feasible that this is related to the high lead reading observed on 20 January 2021 for several reasons:

1. Changes in turbidity and river flow could result in increased particulate material in sediment or alternatively mobilisation of materials from other sources.
2. The reservoir is a top inlet, bottom outlet concrete cylindrical tank. At low tank levels (observed 19 – 20 January 2021) short-circuiting of flow through the reservoir could be significant (water traveling direct from inlet to outlet without mixing) and incoming flow may also stir up sediment from the bottom of the reservoir. If this sediment contained particulate lead this could be a cause of the high lead reading from the raw water reservoir on 20 January 2021. Sediment in the reservoir was measured and was 20 mg/kg, however this could potentially be variable.
3. The sample obtained from the raw water reservoir on 20 January 2021 had a relatively high aluminium content (as discussed in section 5.2.2). The sediment is known to have high aluminium content which could be caused by sediment from the raw water reservoir. The raw water reservoir level on 20 January 2021 was very low at the time of sampling.

Given the spike in turbidity and the river water pH, lead would most likely be present in a particulate form in the raw water on 20 January 2021. Particulate material, including lead, is removed by the membrane treatment process and would not contribute to lead in the water supplied to the distribution network i.e. would not present a public health risk.

5.7.7 Raw Water Contamination Summary

The Waikouaiti River is not expected to be a significant source of lead getting into the system although there is known to be lead in the sediment from the river. Lead which is present in the raw water is typically expected to be particulate and present at trace levels from sediment. The WTP removes particulate lead through a membrane filtration process which would therefore not be present in treated water.

It is unlikely that raw water contamination was the cause of the exceptional lead readings at the Karitane Bowling Club and the Waikouaiti Golf Club and there is no data to indicate a source of dissolved lead in the raw water. However, it is feasible that if an unknown source of dissolved lead was present in the raw water on 8 December 2020, it could have been subsequently detected at the Karitane Bowling Club and the Waikouaiti Golf Club, but not at the Waikouaiti Golden Fleece Hotel or raw water reservoir.

It is likely that the exceptional lead reading on 20 January 2020 in the raw water reservoir was associated with increased turbidity in the raw water and/or sediment from the raw water reservoir.

This would be expected to be particulate in nature (sampling on 20 January 2020 was analysed for 'total lead' rather than 'dissolved lead') and should be removed by the water treatment process.

5.8 Potential Source #5: Plant Operational Issues

5.8.1 Plant Operational Review

A review of the plant log did not show anything substantial although enhanced flux maintenances (EFMs) were performed on 7 December 2020 (typically conducted every two days). Plant technicians reported high turbidity in the river from approximately 27 December. Investigation by the catchment technician indicated this ran approximately 10 km upstream and could be associated with removal of river aggregate. However, this was after 8 December 2021 and more than three weeks prior to 20 January 2021. High turbidity is typically associated with rain events. The raw water feed to the plant (raw water pumps) is shut down in the event of high turbidity to reduce the solids load on the plant.

T&T processed plant SCADA data for the 12 hours and 100 hours prior to each elevated lead reading. This data is Appendix F. Analysis of these trends did not identify any common trends preceding elevated lead readings or any obvious abnormal operation.

SCADA trends were reviewed in further detail to identify any potential process upset at the plant before 8 December 2020. The first trend to look at is the turbidity of the water feeding the membrane plant. These were generally all normal however feed turbidity was noted as being unusual, which is discussed further below.

Figure 43 shows Raw Turbidity, Feed Turbidity, and Filtrate Turbidity. Raw Turbidity is measured at the raw water pump station and measures river water turbidity. The Feed Turbidity monitor is positioned after the floc tank (downstream of a return stream from the tube settler).

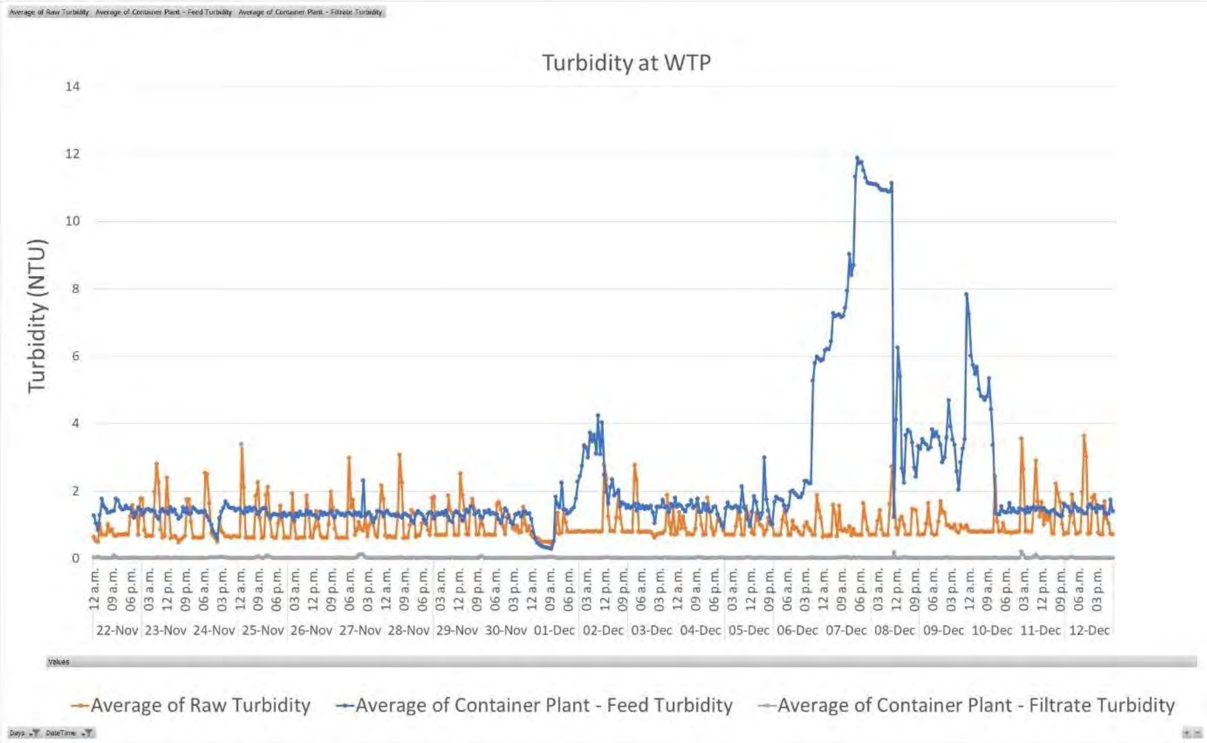

Figure 43: Raw Turbidity, Feed Turbidity, and Filtrate Turbidity

Figure 43 shows the feed turbidity rises on 7 December 2020 while raw water turbidity remained at a consistent level. Generally, the turbidity from the raw to the feed will increase due to floc forming and this can be seen in the baseline levels of both the raw and feed turbidity. However, the increase in turbidity on 7 December 2020 is significantly higher than typically observed. This could be caused by the carry over of solids from the tube settler (see section 5.8.2 for further discussion of the operation of this process unit). Turbidity caused by the carry over of solids from the tube settler would inherently be particulate material which should be removed by the downstream membrane process. It would not be expected to cause elevated lead levels in treated water. The dosed water in the floc tank does have slightly reduced pH (typically between 6.5 and 7). However, this is not expected to cause dissolution of lead.

The tube settler supernatant return will be modified to include online turbidity monitoring which will divert supernatant to the ponds in the event of high turbidity. This will control any future risk of this occurring.

A general review of plant operation and SCADA data indicates it is very unlikely for general plant operation to cause elevated lead levels in treated water.

5.8.2 Tube Settler Operation

Waikouaiti WTP has a process unit called a tube settler recycle which concentrates waste solids to reduce the volume of water discharged back to the river. A membrane filter backwash, called an Air Scour Reverse Flush (ASRF), is performed regularly with treated water mixed with air. The air and water scour the membranes, loosening blockages in the membrane pores which restores membrane efficiency. The backwash water from ASRF cycles (containing solids filtered by the membrane) is pumped to a backwash tank and then a tube settler (lamellar clarifier). As solids settle to the bottom, clarified supernatant is returned to the floc tank. It then mixes with the dosed water and undergoes filtration. Solids in the tube settler are drained periodically to a sludge pond. These solids are particulate material from the river in addition to coagulated material (colour and organics). If there is particulate lead in the raw water this would be removed by the membranes and ultimately concentrated in the tube settler.

The membrane treatment plant also undergoes two types of regular chemical cleans: enhanced flux maintenance (EFM, typically every second day) and clean-in-place (CIP, typically monthly). Both of these cleans use either acid or caustic to clean the membrane pores and aggressively reverse fouling of the membrane to restore membrane efficiency. When the clean is finished, the wash water from these recirculating cleans is pumped to a neutralisation tank as the plant and membranes are drained of this wash water. Generally, no pH adjusting chemicals should be able to enter the backwash water. The membranes then undergo flushing with treated water. This flush water enters the backwash tank, as opposed to the neutralisation tank. As a result, small amounts of citric acid (or sulphuric acid) or caustic (remaining in the pipework after a chemical clean drain down) could potentially be present in this first flush of the plant and membranes.

If acidic material from a wash was present in a backwash this material would be pumped to the tube settler. It is possible this could dissolve metals from particulate material in solids in the tube settler. This should not be possible given the acid washes are directed to the neutralisation tank not the backwash tank. Material in the neutralisation tank is neutralised then pumped directly to a sludge pond.

To understand if it is feasible for low pH material to be present in the tube settler the supernatant and post clean flush water pH were monitored during chemical cleans. Three samples were taken, and the pH of the water in these samples were all greater than 7.5. The pH of the tube settler supernatant did not drop below 7.6. Continuous pH monitoring of the tube settler supernatant was set up from 21 April 2021 and shows a stable pH between 7.6 and 7.8 when the backwash pumps are running as shown in Figure 44.

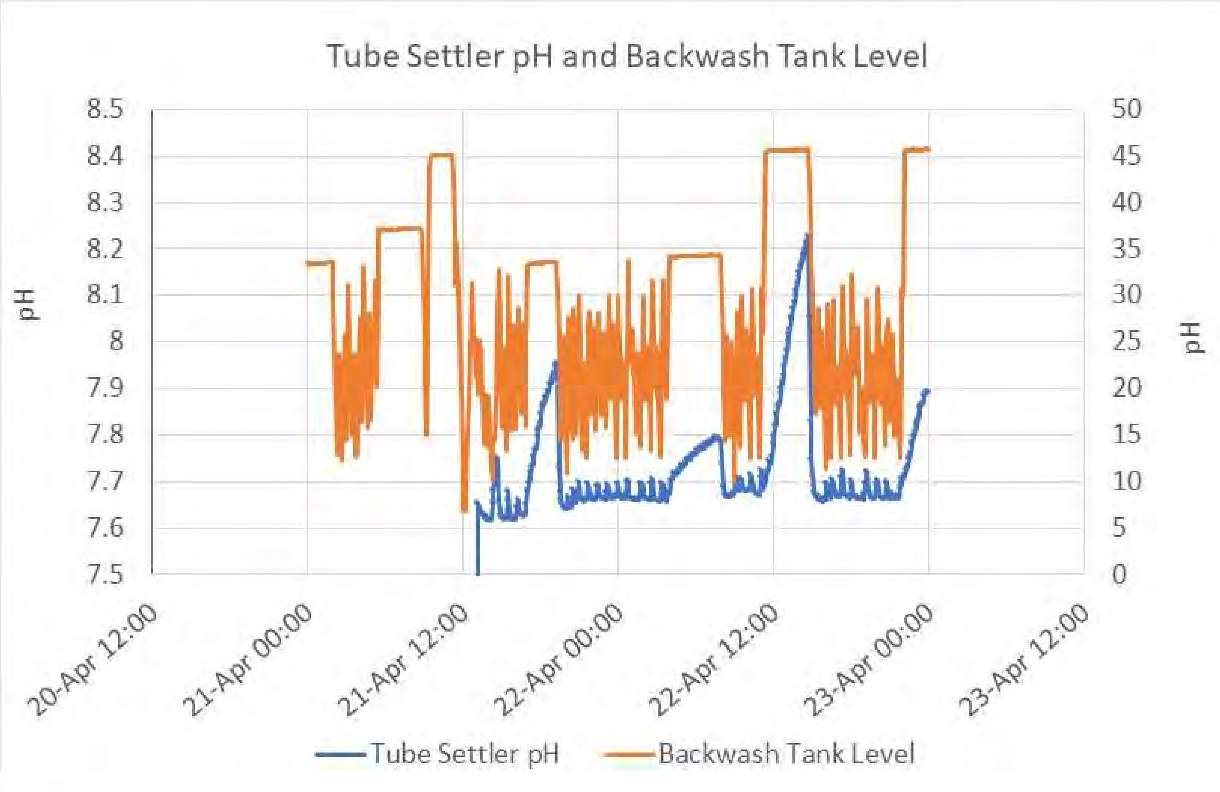

Figure 44: Tube Settler pH and Backwash Tank Level

Figure 44 shows a periodic increase in pH. The rises are almost certainly an artefact caused by the position of the pH probe in the tube settler and not representative of the actual pH in the tube settler. At these times the backwash tank level is flat meaning the WTP is not producing water. The backwash tanks pump intermittently and small pH rises can be seen in between backwash pump runs. As expected, there is no significant elevation of pH in the tube settler during acid cleans. It is very unlikely that this could be the cause of the elevated lead levels on 8 December 2020. unless there was some unidentified abnormal operation at the time which caused unusual changes in pH.

A second potential mechanism for lead release into the distribution network is that the tube settler operates sub-optimally, and bacterial growth creates acidic and/or anoxic (deficient in oxygen) conditions within the tube settler. This could cause the dissolution of particulate lead. This would not be expected and is very unlikely particularly because sludge is regularly removed from the tube settler using an automated sludge removal system (pump based on level). However, plant operations did note that:

- During a drain down of the tube settler in early February 2021, operators remember smelling a solvent-like smell coming from the tube settler. Bacteria can produce these types of odours under certain conditions.

5.8.3 Tube settler was running sub-optimally in January 2021 (and possibly in December 2020) with sludge carry-over photographed in late January 2021 Chemical Analysis

ACH and soda ash are two chemicals used in the Waikouaiti WTP process. It would not be expected that these should normally contribute any lead in drinking water. Both are standard chemicals used in water treatment, manufactured and supplied to appropriate standards. However, if either of these chemicals were contaminated this could be a potential source of introduction of lead to the water.

Samples of both chemicals were sent to both Eurofins and the University of Otago for laboratory analysis. Additionally, the Certificates of Analysis provided by the manufacture for ACH were reviewed. The lead results from all the tests were below their respective detection limits. A conservative calculation of the contribution of ACH to lead in treated water was performed. No more than 0.0001 mg/L of lead would be present in treated water due to ACH dosing at the plant (if lead content was at the limit of detection).

Operational parameters for ACH and soda ash dosing were checked for the two weeks preceding 8 December 2020 and no unusual events were observed.

Figure 45 shows the ACH dose rate which was within normal operating conditions up to 8 December 2020. The dose rate is directly linked to the colour of the raw water. A dose factor (not shown) is also entered manually by the operator to fine tune the coagulation step to reduce the filtered colour. The Dose Pump Speed is also shown, and the pump has been operating within the normal range.

Figure 46 shows soda ash dosing parameters. In the weeks preceding and days immediately after 8 December 2020, soda ash dosing is normal. The plant runs intermittently, so the dose rate is zero when the plant is not running. This is confirmed by ex-tank pH usually being higher than the filtered pH. Soda ash is added after filtration (filtered pH) and increases the pH of treated water (ex-tank pH). All pH trends are within normal range. A calibration was performed on November 30 2020 on the ex-tank pH meter.

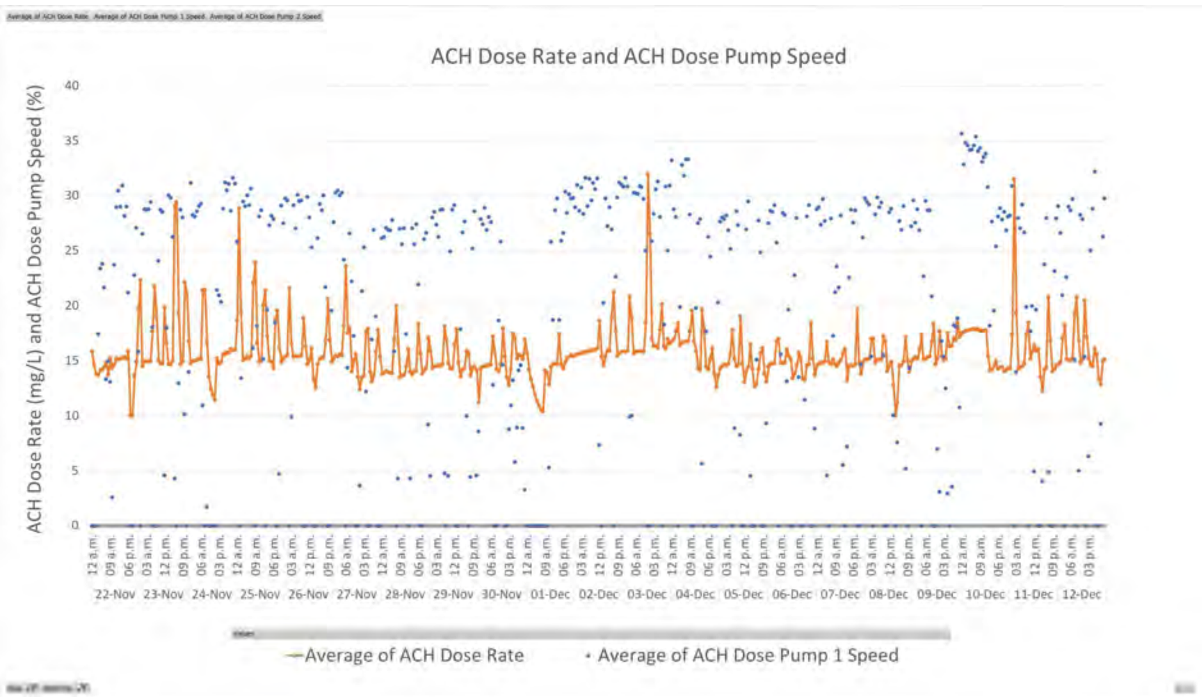

Figure 45: ACH Dose Rate and Pump Speed (22 Novemebr 2020 to 12 December 2020)

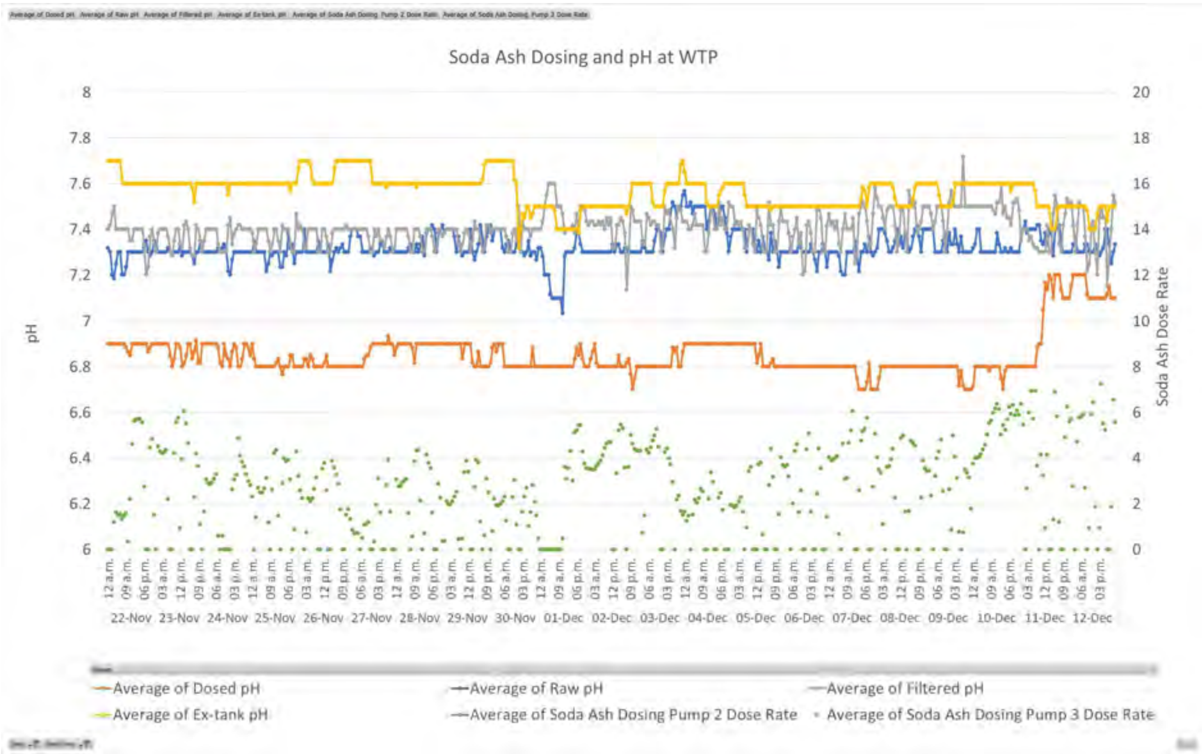

Figure 46: Soda Ash Dosing (22 November 2020 to 12 December 2020)

5.8.4 Plant Materials Review

The construction materials of the plant were reviewed to assess the potential for lead introduction from metallic plant components.

Figure 47 shows pipe materials at the WTP. These are all largely non-metallic. A disused membrane process uses largely stainless steel pipework however this would not be expected to be a source of lead and is currently isolated.

There are some metallic components in the raw water pump station including a brass/bronze pump impeller. These are all very unlikely to cause very high intermittent lead levels.

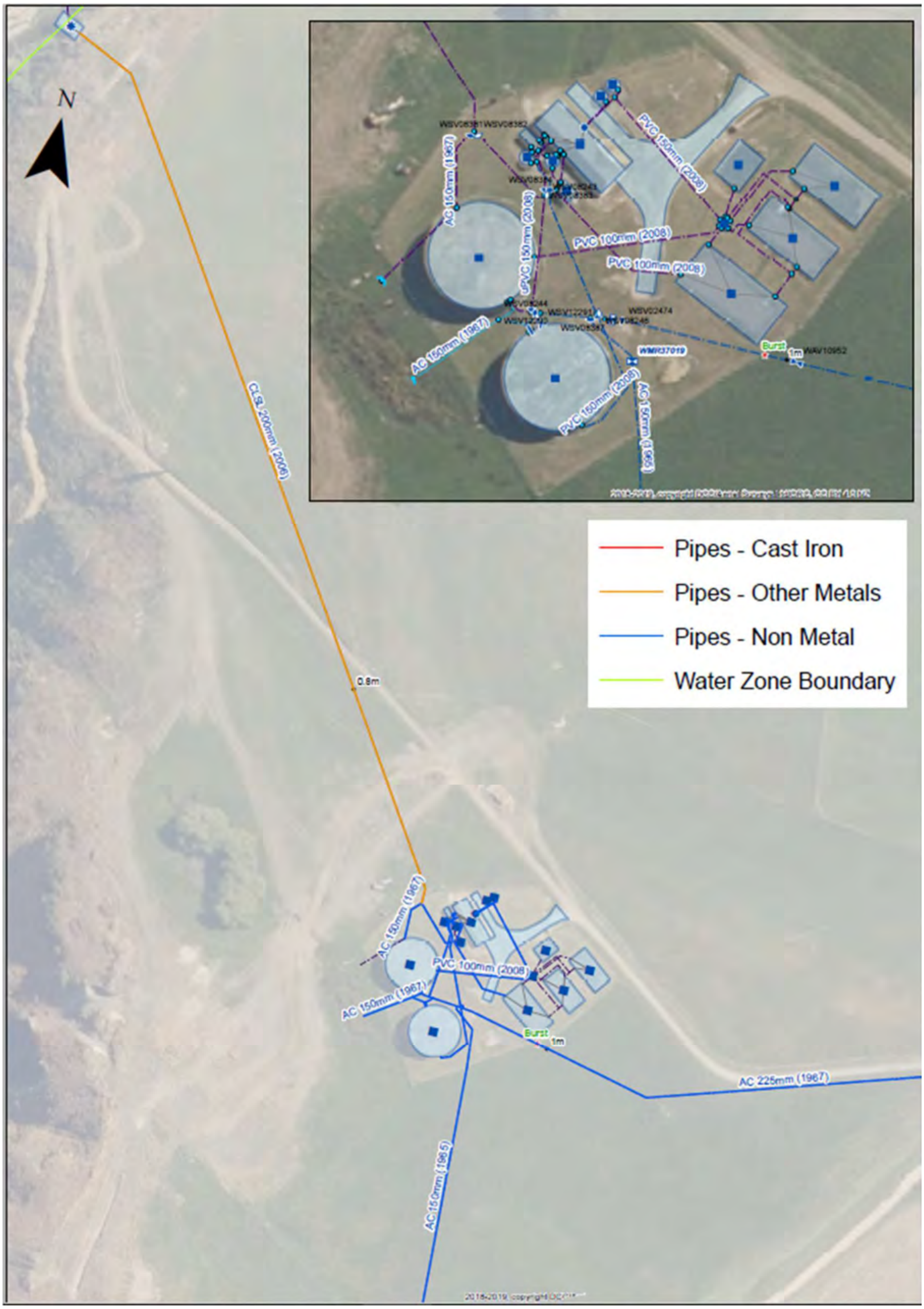

Figure 47: Map of Known Plant Materials

5.8.5 Plant Contamination Summary

It is very unlikely that the operation of the WTP is the cause of elevated lead levels in the treated water. Waste from chemical cleans is a very unlikely cause of the elevated lead detections. It is very unlikely that the operation of the tube settler is a cause of the elevated lead detections. Chemicals dosed at the WTP are very unlikely to be a cause of the elevated lead detections. Wetted materials at the WTP are very unlikely causes of the elevated lead detections.

5.9 Potential Source #6: Backflow

The DCC has undertaken an investigation to:

- assess the likelihood that backflow could have contributed to the elevated lead levels detected at the Waikouaiti Golf Club and the Karitane Bowling Club on 8 December 2020; and
- identify controls to manage the risk of backflow in this area in future.

5.9.1 What is backflow and how can the risk be managed?

Backflow is the flow of water from private property back into the public water supply. This water can potentially contain contaminants. Backflow can occur due to:

- back pressure – this occurs when a property's water pressure is higher than the network's (e.g. where the customer's water pressure is greater than the pressure supplied by the network);
- back siphonage – this occurs when the water pressure drops in the network (e.g. due to a watermain shutdown, breakage or high-water use).

Backflow is a potential risk to public health because any contaminated water that flows back into the public water supply network could be consumed by the community.

Maintaining constant and adequate pressure in the reticulation network minimises the likelihood of a backflow event occurring or contaminants entering the water if there is a break in the main supply. Pressure within the water network is maintained using reservoirs.

Backflow risk is managed by installing a testable backflow prevention device at the point of supply for properties deemed to present a higher risk of backflow. A reduced pressure zone (RPZ) backflow prevention device provides the highest level of protection. Many points of supply also include non-testable check valves, which provide a basic level of protection against backflow that is considered adequate for low risk properties e.g. domestic residences. Backflow risk can also be managed by ensuring there is a physical disconnection between the public water supply and private plumbing where possible i.e. an air gap on a private water storage tank.

All service connections pose a degree of risk to the water supply in terms of backflow. To determine which type of backflow prevention device must be installed, the DCC considers each connection's potential to cause harm. This depends on the nature of the activity at a property and the likelihood of backflow occurring. Consequently, the DCC manages the risk of backflow from non-domestic and domestic connections differently. Backflow may also be managed differently on restricted flow water schemes. The area serviced by the Waikouaiti WTP is a mix of on-demand and restricted flow service connections.

Backflow prevention requirements are addressed on all new connections to the DCC drinking water networks. However, some existing connections do not have adequate backflow prevention measures in place, while others have no protection against backflow. The DCC has programmes in place to improve backflow protection on its networks. These programmes, as they relate to the Waikouaiti water supply, are detailed in section 3.6.5 of the Waikouaiti water supply (WAI015) Water Safety Plan (2020).

5.9.2 Waikouaiti Backflow Investigation 2021

To assess the likelihood that backflow could have contributed to the elevated lead levels detected at the Waikouaiti Golf Club and the Karitane Bowling Club on 8 December 2020, the DCC conducted:

- a desktop review of breakages in the DCC Waikouaiti drinking water network during the week prior to 8 December 2020;
- tested all known testable backflow prevention devices installed on service connections to the DCC Waikouaiti drinking water network; and
- a targeted backflow risk survey at Hawksbury Village.

5.9.3 Desktop review of breakages in the DCC Waikouaiti drinking water network during the week prior to 8 December 2020

Backflow can occur when water pressure changes in the network. The network can lose pressure as a result of maintenance e.g. watermain shut down, breakage e.g. burst main or heavy water use e.g. firefighting.

The DCC reviewed information about repairs carried out on the DCC drinking water network infrastructure in the area covered by the DNDN to assess the likelihood a breakage could have caused a backflow event that contributed to the elevated lead levels detected on 8 December 2020.

The DCC's network maintenance contractor carried out four repairs to the network during the week prior to 8 December 2020. These are set out in Table 8 below. Each repair has been assigned a likelihood rating. The likelihood rating denotes the DCC's assessment of the likelihood the repair caused a backflow event that could have contributed to the to the elevated lead levels detected in the Waikouaiti and Karitane distribution networks on 8 December 2020.

Table 8: Network Repairs Prior to 8 December 2020

	WORK ORDER NUMBER	DATE	LOCATION	BRIEF DESCRIPTION OF ISSUE AND REPAIR	LIKELIHOOD RATING (1 – 5)*
1	604008	3 Dec 2020	Karitane	Water observed seeping from the roadway. Contractor used a vacuum truck to expose the rider main. Contractor	1

	WORK ORDER NUMBER	DATE	LOCATION	BRIEF DESCRIPTION OF ISSUE AND REPAIR	LIKELIHOOD RATING (1 – 5)*
				found and repaired a hole in the 50mm MDPE rider main.	
2	604054	3 Dec 2020	Karitane	*Repair 1*: Water gushing in paddock. Contractor excavated and found a cracked 80mm AC water main. Contractor shut down the water main and replaced a length of the main.	1
3				*Repair 2*: Water observed bubbling out of the ground following Repair 1, approximately 10m from Repair 1. Contractor shut down the main again, excavated and found a ring crack on the 80mm AC water main. Contractor installed an 80mm leak clamp.	1
4	604157	4 Dec 2020	Karitane	Water observed gushing in roadway, flowing at a steady pace. Contractor arrived and saw the Talbot had been damaged by a third party. Contractor used a gate valve and installed a new Talbot. (100mm AC water main).	1

*1 = very unlikely; 2 = unlikely; 3 = possible; 4 = likely; 5 = very likely

Based on the information above, it is very unlikely that a breakage caused a backflow event that contributed to the elevated lead levels detected at the Waikouaiti Golf Club and the Karitane Bowling Club on 8 December 2020.

The DCC is not aware of any other events that could have led to a loss of pressure in the Waikouaiti drinking water network and caused backflow during the week prior to 8 December 2020. Fire and Emergency New Zealand (FENZ) has advised that DCC fire hydrants in the area were not used for firefighting purposes during the week prior to 8 December 2020 and DCC are not aware of any other uses at that time. The DCC's network maintenance contractor carried out its routine fortnightly flushing of fire hydrants in the area on 25 November 2020, 13 days before 8 December 2020. Routine flushing was carried out again on 9 December, the day after the water samples with elevated lead levels were taken.

The evidence suggests the water mains in the network were never in a state of negative pressure that could have created the conditions for backflow to occur during the week prior to 8 December 2020.

5.9.4 Testing of all known testable backflow prevention devices installed on service connections to the DCC Waikouaiti drinking water network

The DCC conducts annual testing of customer-owned backflow prevention devices. Up until February 2021 there were 11 testable backflow prevention devices on the DCC's testing schedule in Waikouaiti and Karitane. Of these, seven are located at the DCC wastewater pumping stations.

The DCC tested the 11 known testable backflow prevention devices in August 2020 and all passed.

The DCC tested all 11 known devices again in February 2021 after the DNDN was issued. Once again, all devices passed the test.

During testing in February 2021, DCC staff surveyed Waikouaiti and Karitane to identify any other testable backflow prevention devices not on the DCC's testing schedule. Staff found an additional testable device at a commercial property on Waikouaiti. This was tested and passed. This device will be added to the DCC's testing schedule.

Table 9 shows the results of backflow prevention device testing carried out in Waikouaiti and Karitane in 2020 and 2021.

Table 9: Backflow Prevention Devices

	Device location	2020	2021
1	Karitane No1 wastewater pump station (WWPS) – Coast Road	Pass	Pass
2	Karitane No2 WWPS – Stornoway Street	Pass	Pass
3	Karitane No3 WWPS – Bravas Street	Pass	Pass
4	Waikouaiti No1 WWPS – Henry Street	Pass	Pass
5	Waikouaiti No2 WWPS – Stewart Street	Pass	Pass
6	Waikouaiti No3 WWPS – Beach Street	Pass	Pass

	Device location	2020	2021
7	Waikouaiti No4 WWPS – Reid Street	Pass	Pass
8	Community Centre – 288 Main Road	Pass	Pass
9	Waikouaiti Recreation Reserve – Matanaka Drive	Pass	Pass
10	Private, Waikouaiti	Pass	Pass
11	Private, Waikouaiti	Pass	Pass
12	Private, Waikouaiti	Not tested	Pass

During testing in February 2021, DCC staff identified additional industrial and commercial properties in Waikouaiti and Karitane that may, subject to further on-site investigation and risk assessment, present a higher backflow risk and require installation of a testable backflow prevention device.

On a separate occasion, DCC staff found a testable backflow prevention device (double check valve) at the Waikouaiti Golf Club in a poor state of repair. This was subsequently replaced with an RPZ backflow prevention device. The new device will be added to the DCC's testing schedule.

It is very unlikely that backflow from one or more of these properties could have contributed to elevated lead levels in the drinking water network on 8 December 2020. As outlined above, the available evidence suggests the water mains in the area were never in a state of negative pressure that could have created the conditions for backflow to occur during the week prior to 8 December 2020.

5.9.5 Targeted backflow risk survey at Hawksbury Village

Drinking water produced at the Waikouaiti WTP is conveyed to a valve pit at McGrath Road adjacent to Hawksbury Village, via a single pipeline. Downstream of the valve pit, separate pipelines distribute drinking water to Waikouaiti (two pipelines), Karitane (one pipeline) and Hawksbury Village (two pipelines).

Service connections to pipelines upstream of, and immediately downstream of the McGrath Road valve pit are of interest because any water that flows back into the DCC network from serviced properties could be distributed to both Waikouaiti and Karitane townships.

In April 2021, DCC staff inspected service connections to the pipeline between the Waikouaiti WTP and the McGrath Road valve pit, and service connections to pipelines immediately downstream of the McGrath Road valve pit. These pipelines have not been in a negative pressure situation due to watermain shutdowns in the last decade.

Staff found seven service connections to the DCC drinking water infrastructure upstream of, and immediately downstream of the McGrath Road valve pit. Of the seven, five were to rural properties/farms. Of these five properties, four were found to have non-testable double check valves installed on their service connections. Staff installed non-testable double check valves into the fifth property's service connection during the inspection. This service connection was located upstream of the valve pit.

As outlined above, the available evidence suggests the water mains in the area were never in a state of negative pressure that could have created the conditions for backflow to occur during the week prior to 8 December 2020. Had a backflow event occurred, the non-testable double check valves installed on four of the seven service connections upstream and immediately downstream of the McGrath Road valve pit would have provided a rudimentary level of protection against backflow from those four properties entering the public network. Further on-site investigation and risk assessment is required to determine whether these properties present a higher backflow risk and require installation of a testable backflow prevention device.

The two remaining service connections inspected are large connections that supply water to Hawksbury Village's private drinking water reticulation network. Both connections are located immediately downstream of the McGrath Road valve pit and do not include testable backflow prevention devices. Due to the size of the private drinking water network and the range of activities serviced by it, the DCC undertook a targeted backflow risk survey at Hawksbury Village in May 2021.

Hawksbury Village is the site of the former Cherry Farm psychiatric hospital, opened in the mid-twentieth century. The site and buildings were owned and operated by the Otago Hospital Board until the 1980s, when they were decommissioned and subsequently sold to private parties. Today, Hawksbury Village is home to a range of residences and industrial/commercial premises. Some original buildings remain (in varying degrees of repair) while others have been demolished or renovated. New buildings have been constructed and further subdivision and development continues.

Hawksbury Village is serviced by its own drinking water reticulation network, drainage networks and wastewater treatment plant, roading network, and electricity distribution network. Hawksbury Village Management Limited (HVML) owns and operates the infrastructure and charges customers for its use.

The DCC provides drinking water to the Hawksbury Village network from the Waikouaiti drinking water network via two feeds located immediately downstream of the McGrath Road valve pit: a 225mm feed and a 100mm feed. Neither feed has any form of backflow prevention installed at the boundary between the DCC's network and the Hawksbury Village network. The DCC charges Hawksbury Village Management Limited for the water supplied. Use is measured by a meter located next to the McGrath Road valve pit.

During the targeted backflow risk survey undertaken in May 2021, a representative of HVML explained how Hawksbury Village's drinking water network works, and detailed work HVML is undertaking in relation to the network. Key points included:

- the water mains inside the village are primarily asbestos cement pipe. Service lines for potable water are primarily copper, with some galvanised pipework used for dedicated fire service lines.
- water supply to unused buildings is turned off where possible.
- water customers in the Village currently have a range of point of supply configurations. These include meters[1], tobies[2] and gate valves[3]. HVML is progressively upgrading residential points of supply to include a basic level of protection against backflow (non-testable dual check valves).

DCC staff visited five properties as part of the targeted backflow risk survey. The properties were identified by DCC staff and HVML as sites that may present a high backflow risk:

- Hawksbury Village wastewater treatment plant.
- A large-single story residential complex (estimated 60-70 years old) with two separate service lines: a potable water line and a dedicated fire sprinkler line.
- Three buildings used for non-domestic activities:
  - Two in active use.
  - One not in active use.

DCC staff found one testable backflow prevention device: a RPZ device installed within the boundaries of the wastewater treatment plant. Testing showed the device was in good working order. Staff did not identify any other supply lines to the wastewater treatment plant upstream of the RPZ.

DCC staff found water meters on the two non-domestic buildings in active use and the residential complex (potable water line) that staff assume – based on the age and type of the meter – contain built-in features (check valves) that can provide a rudimentary level of protection against backflow. However, the presence or absence of a check valve could not be confirmed by visual inspection of the exterior of the meter.

The fire sprinkler system at the large single-story residential complex was found to be turned off at the valve house inside the complex. However, the shut off valve located at the water main remains open.

While the building is not currently in use, the water supply to the third non-domestic building cannot be shut off because a neighbouring residential property (in use) shares the same service connection. No backflow protection was observed on the 50mm copper service with a gate valve. Staff observed a large metal tank on the roof of the building. The tank appeared to be vented and made of copper,

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[1] Some water meters may include built-in features that can provide a rudimentary level protection against backflow.
[2] Tobies include built-in features that can provide a rudimentary level of protection against backflow.
[3] Gate valves do not provide any protection against backflow.

but close inspection of the tank was not possible. Access to the interior of the building was not available at the time of the site visit.

Several other Hawksbury Village properties that may present a high backflow risk but that were not inspected during as part of the targeted backflow risk survey in May 2021.

In order for backflow from Hawksbury Village to have contributed to the elevated lead levels detected at the Waikouaiti Golf Club and Karitane Bowls Club on 8 December 2020, water containing dissolved lead would need to have been back-siphoned through the Hawksbury Village network to the McGrath Road valve pit and distributed to Waikouaiti and Karitane. A significant pressure drop in the DCC network outside of Hawksbury Village would be required to create such a backflow event. As outlined above, the available evidence suggests the water mains in the area were never in a state of negative pressure that could have created the conditions for backflow to occur during the week prior to 8 December 2020.

On this basis, it is very unlikely that backflow from Hawksbury Village contributed to the elevated lead levels detected at the Waikouaiti Golf Club and Karitane Bowls Club on 8 December 2020.

5.9.6 Backflow Summary

The investigation has found:

- It is very unlikely that one of the four breakages in the network during the week prior to 8 December 2020 caused a backflow event that contributed to the elevated lead levels detected at the Waikouaiti Golf Club and Karitane Bowls Club on 8 December

- All testable backflow prevention devices on the DCC's testing schedule were functioning properly in August 2020 and February 2021, which would have prevented backflow from these sites in the event backflow did occur;

- Other factors suggest it is very unlikely that backflow from other potentially high-risk properties that currently have low or no backflow prevention measures in place contributed to the elevated lead levels detected at the Waikouaiti Golf Club and Karitane Bowls Club on 8 December 2021. In particular, the available evidence suggests the water mains in the area were never in a state of negative pressure that could have created the conditions for backflow to occur during the week prior to 8 December 2020. However, this predominantly relates to the likelihood of backflow caused by back siphonage. A more detailed assessment of the likelihood of backflow caused by back pressure would require further site-specific investigation at the potentially high-risk properties identified through this investigation.

During the investigation, the DCC identified and tested two additional backflow prevention devices at particularly high-risk sites (a commercial property in Waikouaiti and the Hawksbury Village wastewater treatment plant). Continued testing and maintenance of these devices will mitigate against the risk of backflow occurring from these properties in future.

5.9.7 Future Improvements

The DCC has identified, for further consideration, the following actions to improve future management of backflow risk in the Waikouaiti, Hawksbury Village and Karitane area:

- Installation of RPZ backflow prevention devices on Hawksbury Village's two connections to the DCC drinking water network in McGrath Road.

- Continuation of the backflow prevention programmes set out in section 3.6.5 of the Waikouaiti water supply Water Safety Plan, including:

    - site-specific investigation and backflow risk assessment of existing commercial / industrial properties in Waikouaiti and Karitane identified through this investigation as currently having low or no backflow prevention measures in place; and

    - installation of testable backflow prevention devices on those properties identified as presenting a backflow risk – this, along with annual testing and maintenance, would mitigate against the future risk of backflow.

- Sharing the findings of the targeted backflow risk survey at Hawksbury Village with Hawksbury Village Management Limited (HVML), for consideration and implementation through its management of Hawksbury Village's drinking water network. Among other things, any advice to HVML should highlight the need for regular maintenance and annual testing of the RPZ backflow prevention device installed at the Hawksbury Village wastewater treatment plant.

6 SUMMARY OF LIKELY CAUSES OF LEAD READINGS

This section summarises the most likely cause of elevated and exceptional lead readings and takes into consideration the investigations presented in section 5.

6.1 Potential Explanations for Changes in Lead Readings at Waikouaiti Golf Club

As noted in section 4.2, there appears to be a step change in the level of low-level lead results at Waikouaiti Golf Club between 1 February 2021 (the last sample taken at the customer side tap) and 4 February 2021 (the first sample from the dedicated sampling tap). Following 4 February 2021 almost all of the flushed samples have been less than limit of detection, whereas prior to this detectable levels (some above MAV) were relatively frequent.

The available data indicates that it is likely that this apparent step change in lead readings at (or close to) Waikouaiti Golf club is due to the change from using the customer side sample tap at Waikouaiti Golf Club to sampling from a dedicated sample station (210 Edinburgh St SS). The dedicated sample station is located directly from the main with approximately 20m of the service line that supplies the golf club.

Comparison of samples from Waikouaiti Golf Club before and after 4 February 2021 suggest a reduction in lead levels from the Waikouaiti Golf Club. This could be associated with changes in water corrosivity with the CSMR indicating more corrosive water prior to 4 February 2021. However, these changes in corrosivity do not explain the presence of detectable levels from the Waikouaiti Golf Club tap after 4 February 2021 when the 210 Edinburgh St SS indicates lead levels less than LOD.

Profile sampling and stagnation tests both confirm that elevated levels are very frequently observed from samples taken downstream of meters and metallic customer pipework. Localised lead leaching due to local fittings associated with the customer tap is therefore a likely cause of the elevated lead levels observed prior to 2 February 2021.

6.2 Likely Cause of Abnormal / Exceptional Readings on 8 December 2020

There were two very high lead readings on the 8 December. A number of potential causes of these readings have been investigated.

- As noted in section 4.1, it was investigated as to whether the abnormally high values on 8 December 2020 at both Karitane Bowling Club and Waikouaiti Golf Club were related because they occurred on the same day and lead has not been seen at these levels in any other samples. It was also investigated as to whether two unrelated coincidental events occurred.
- The most likely cause (considered to be likely) of these results is **localised lead leaching** associated with local fittings and pipework. Lead readings of the same order of magnitude have been reproduced through stagnation testing and profiles sampling at these taps. The magnitude of lead readings depends on corrosivity of water which is complex but there is some evidence to suggest it was relatively corrosive on 8 December 2021. That is, there **may have been subtle changes in water chemistry** that day. The lead readings also depend on the extent of stagnation, presence of particulates, flushing duration and flushing flow rate which can all vary day to day.
- It is possible (considered to be unlikely) this was caused by catchment contamination which was untreated (soluble or dissolved lead) and conveyed through the distribution network. The duration of the contamination event would have been relatively short because there was no trace of this at any other locations including the raw water reservoir, treated water reservoir or Waikouaiti Golden Fleece Hotel sampling point. Any event which could have causes this has not been repeated in the past 3 months and a Catchment Risk Assessment found the likelihood of catchment contamination sufficient to cause the observed levels of lead as unlikely or rare. Additional controls have been proposed to further manage this risk.
- An alternative cause of this is sampling error. This is unlikely and there is no specific evidence or indication of this being the case, but still possible.
- It is considered very unlikely that this was caused by back flow or plant operation because a source of lead capable of causing this or suitable circumstances in which this could occur (abnormal events or failed controls), have not been identified.

6.3 Likely Causes of Abnormal / Exceptional Readings on 20 January 2021

The potential cause of exceptional lead on 20 January 2021 have been investigated.

- The most likely cause of this result is particulate material associated with either **the raw water, sediment in the raw water reservoir, or the sample tap**. Low levels in the raw water reservoir and the presence of aluminium in the sample (known to be in high concentrations in reservoir sediment) both indicate potential for this sample to have contained reservoir sediment). The **raw water at this time was highly corrosive** (based on CSMR) which could have caused localised lead leaching associated with the tap. Particulate lead **in raw water** poses minimal public health risk as it would be removed by the current membrane filtration plant.
- It is possible (unlikely) this was caused by catchment contamination which could have been soluble or particulate (in this scenario, particulate lead is more likely to have caused the result than soluble lead). The duration of the contamination event would have been relatively short or alternatively the material may have been removed in the treatment process because there was no trace of this at any other locations including the treated water reservoir or distribution sample locations. Any event which could have caused this has not been repeated in the past 3 months and a Catchment Risk Assessment found the likelihood of catchment contamination sufficient to cause the observed levels of lead as unlikely or rare. Additional controls have been proposed to further manage this risk. Given the evidence obtained to date, this possible cause poses minimal public health risk. This risk will be reviewed if further evidence (suggesting a catchment contamination event is more likely) is discovered.
- An alternative cause of this is sampling error. This would appear to be more likely a cause in this case than on 8 December 2020 because it would require only a single sample to be contaminated during the sampling or analysis process. However, there is no evidence to suggest this did occur and it is considered to be unlikely.
- It is not possible that this was caused by back flow or plant operation because the raw water tank is upstream of the treatment process.

If both abnormal levels on 8 December 2020 and 20 January 2021 were caused by the same mechanism, then the only potential causes would be sampling or analytical error or raw water contamination. This is considered to be very unlikely. **It is most probable that the readings obtained on 8 December 2020 and 20 January 2021 were a result of different causes (or mechanisms).**

6.4 Summary of all Lead Data and Likely Cause

DCC has analysed approximately 873 samples of treated water from the treated water reservoir or distribution network since July 2020 (post flush only and excluding profile samples). These are theoretically representative of the water supplied, though some of these are from customer taps which have been shown to be a likely cause of contamination. A further 1,147 samples were taken which included raw water, pre-flush samples, profile samples and samples for specific investigations.

Of 873 treated water samples (post flush and excluding profile samples), 814 (more than 93%) were less than LOD and more than 99% were less than MAV (868). Of the 59 samples above limit of detection 42 were in the Waikouaiti Upper Level Zone. Of 5 readings greater than MAV, 4 were from the Waikouaiti Golf Club (with the 5th from Karitane Bowls Club). The elevated samples above MAV are largely explained by localised lead leaching associated with sample taps and investigation had identified it is feasible to repeatedly see high lead readings from customer taps (particularly Waikouaiti Golf Club) whilst readings from the distribution network directly are less than LOD.

There are 2 out of 873 treated water samples which were considered to be exceptional, because they were abnormally high compared to previous readings at the same location. The cause of these appears to most likely be localised lead leaching (from local fittings or pipework), however other causes cannot be entirely ruled out. One further exceptional reading was observed in raw water.

There are a number of elevated lead readings from the pre-flush of dedicated sample stations. These have been investigated and are caused by lead present in the tubing of sample taps. These taps are not accessible for consumption. Post flush samples from these taps, representative of the distribution network, were almost all less than LOD in all locations.

There were a number of elevated readings associated with profile sampling at customer taps. These demonstrated that regardless of flushing duration it is possible to obtain elevated lead levels when sampling from customer taps.

Table 10 presents a summary of all of the readings above 50% of MAV and the most likely cause.

Figure 48 presents a cumulative frequency plot of all of the samples. This demonstrates that more than 99% of post flush samples were less than the MAV and more than 95% of all samples (including preflush) are less than MAV.

Table 10: Summary of Treated Water Lead Results (31 July 2020 – 15 June 2021)

					Potential Causes of Lead Results > 50% of MAV by Likelihood			
	Sample Point or Type	***# of Results > 50% MAV***	***# of Samples over MAV***	***Max Result (mg/L)***	***Very Likely***	***Likely***	***Unlikely***	***Very Unlikely***
Exceptional	*Treated Water Waikouaiti Golf Club 8 December 2020*	*1*	*1*	*0.394*	*N/A*	*Localised Lead Leaching*	*Sampling Error, Lead Ingress (including from catchment), Network lead leaching*	*Backflow, Plant Related Event*
Exceptional	*Treated Water Karitane Bowls 8 December 2020*	*1*	*1*	*0.072*	*N/A*	*Localised Lead Leaching*	*Sampling Error, Lead Ingress (including from catchment), Network lead leaching*	*Backflow, Plant Related Event*
Exceptional	*Raw Water (20 January 2021)*	*1*	*1*	*0.05*	*N/A*	*Lead Ingress (including from catchment), Localised Lead Leaching*	*Sampling Error, Network lead leaching*	*Plant Related Event*
Elevated and > 50% MAV	*Stagnation Tests*	*13*	*10*	*0.148*	*Localised Lead Leaching*	*N/A*	*N/A*	*N/A*
Elevated and > 50% MAV	*Treated Water SS - Pre-flush*	*37*	*29*	*0.0751*	*Localised Lead Leaching*	*N/A*	*N/A*	*N/A*
Elevated and > 50% MAV	*Profile Sampling - Sampling Station*	*3*	*2 (all Bendigo Preflush)*	*0.0388*	*Localised Lead Leaching*	*N/A*	*N/A*	*N/A*
Elevated and > 50% MAV	*Treated Water Customer Taps - Post-flush (excl. 8 December 2020)*	*8*	*3 (all Golf Club)*	*0.0295*	*Localised Lead Leaching*	*N/A*	*Sampling Error, Lead Ingress (including from catchment), Network lead leaching*	*N/A*
Elevated and > 50% MAV	*Treated Water Customer Taps - Pre-flush*	*13*	*3*	*0.0266*	*Localised Lead Leaching*	*N/A*	*N/A*	*N/A*
Elevated and > 50% MAV	*Profile Sampling Customer Taps*	*13*	*3*	*0.0261*	*Localised Lead Leaching*	*N/A*	*N/A*	*N/A*
Elevated and > 50% MAV	*Treated Water Reservoir SS - Post-flush (28 August)*	*1*	*0*	*0.0056*	*Localised Lead Leaching*	*N/A*	*Sampling Error, Lead Ingress (including from catchment), Network lead leaching*	*N/A*
Elevated and > 50% MAV	*Sub-total*	*91*	*53*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
< 50% MAV	*TOTAL OF 1308 PRE AND POST FLUSH TREATED WATER SAMPLES <50% MAV INCLUDING PROFILE SAMPLING*							

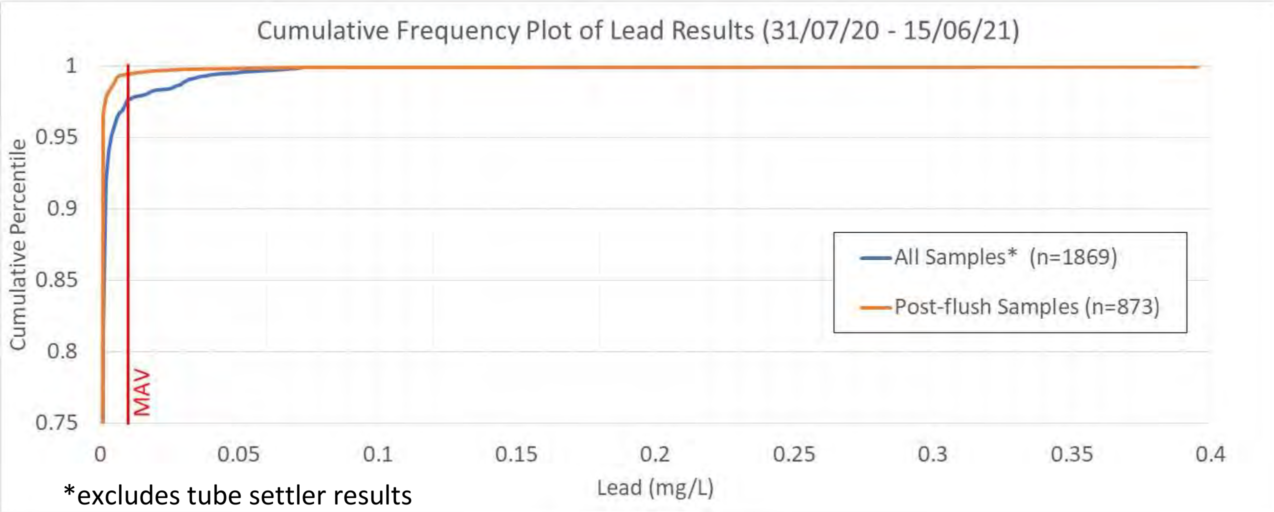

Figure 48: Cumulative frequency plot of lead results (31/07/20 – 15/06/21)

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8 APPENDICES

Appendix A

Waikouaiti Metals Sampling Plan_v2.pdf

Appendix B

SamplingPoints-all.pdf

SamplingPoints-wtp.pdf

Appendix C

Dunedin City Council Investigation Report Final 14 July 2021.pdf

Appendix D

WSP Pipe Condition and Lead Joint Integrity Assessment.pdf

Appendix E

190607 Draft No 3 WQ Sampling Stations 1207-01 to 1207-04.pdf

Standard & Specification Sampling Point Version 2.pdf

Appendix F

CRA report_15.03.2021.pdf

Appendix G

Sulphate Levels in Waikouaiti River