# TOTAL COLIFORMS IN PUBLIC WATER SUPPLIES: CASE STUDIES IN THE PURSUIT OF THE ELIMINATION STRATEGY

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**ABSTRACT**

A key lesson learnt following the Havelock North Drinking Water Contamination Event is the importance that total coliforms can play in understanding the health and integrity of a public water supply. A drinking water quality parameter previously given little focus has now become a key metric in guiding responses and targeting attention in the management of drinking water systems.

This paper presents case studies in how total coliform detections have been used in practice to address issues of biofilm development, and reservoir integrity improvements that otherwise may have either gone unnoticed for years, or become pre-cursors to more serious contamination events.

Two normally unchlorinated supplies were monitored for coliforms, and through analysis of results changes in the systems were detected. With guidance from recently developed Incident Response Plans, and with expert external input, responses to the events were put in place. This included the implementation of emergency chlorination systems, trouble shooting and diagnostics of the root causes, communication with the affected communities, elected members and Taumata Arowai. Regular meetings were held with a core team of asset managers, operational staff, contractors, and senior management representatives throughout the process, until the issues had been resolved.

This approach has highlighted the benefits of applying an "elimination strategy" towards coliforms, as targeting a baseline of no non-zero detections allows any deviations from this to be easily identified and promptly acted upon.

There were many lessons learnt through these events, which are reflected on throughout this paper. This includes the importance of having sound monitoring, alerting, and response systems, a contractor with a good understanding of their supplies, and the ability to quickly and easily adapt systems to different modes of operation to help optimise the response.

**KEYWORDS**

Water Quality, Safety, Coliforms, Incident Response, Emergency Chlorination, Water Contamination Pre-Cursors.

**PRESENTER PROFILE**

I am responsible for managing 12 public water supplies in the Waimakariri District, serving a population of about 50,000. As a professional engineer, I am passionate about my role in public health providing safe and reliable drinking water to the community.

# INTRODUCTION

This paper presents two case studies of events within the 2022 year in which the monitoring of total coliforms on public water supplies was used as a primary mechanism to gain a deeper understanding of the supply, and guide responses.

This is not presented as a paper in best practice, nor is it an example of "what not to do". Rather it is intended as to provide an overview of both the benefits of coliforms as an indicator organism, their limitations, the challenges in responding to events and data in real time, to help share learnings and inform wider discussions on this topic.

To help provide a context for the responses, this paper begins by looking at the evolution in the change in response in the years following 2016 when the New Zealand drinking water landscape changed forever. Following this the events of 2022 are described, the responses explained, and some of the challenges and lessons learnt are discussed.

# BACKGROUND

The Waimakariri District has 12 public water supplies. In general, the larger urban supplies are unchlorinated, supplying deep and "secure" groundwater to the majority of the district's population. The rural restricted schemes also supply mostly secure groundwater, but with the addition of chlorine.

Prior to the initial recommendations from the Havelock North Drinking-Water Inquiry (the Inquiry) report, monitoring of total coliforms and *E. coli* was by presence absence test only, and it was only the *E. coli* results that were given any significant focus or attention.

Following some of these initial recommendations from the Inquiry, testing changed from presence / absence to enumeration, and the results of the total coliforms testing started to be paid attention to and reported on. Over the years since, the focus from the sampling results has shifted from simply being a means of demonstrating bacterial compliance with the drinking water standards, to a rich data source providing valuable information about the health and integrity of the supplies.

With this increased level of scrutiny given to results, and the increased information provided by counts of coliforms, comes the need to respond to what these results were telling us. Throughout the following sections, some of the key changes in approach are first described, leading to two key case studies of events, and the subsequent responses.

The focus of this paper is on un-chlorinated supplies. This is purely because in our experience in recent years, these are the only supplies in which there are any coliform detections. It is less likely to receive coliform detections on an unchlorinated supply as the chlorine treats the coliforms, and on these suppliers a different type of water quality indicator may be more useful. If a water supplier did receive coliform detections on a chlorinated supply, the lessons from this paper could just as easily apply.

## WHAT IS A GOOD LEVEL OF COLIFORMS?

The change in approach described above has not so much been a drastic shift overnight, but rather an evolution over the months and years since the total coliform data started being closely reviewed.

Initially, the data was simply reviewed and collected, to establish an understanding of baseline patterns. Once these typical patterns began to be understood, the next natural step was to look deeper at what the data meant, and how it should be responded to. An initial challenge was to determine what an acceptable level of coliforms is, and when a response should be triggered. The New Zealand Drinking Water Standards of the time did not provide a clear threshold, with only a guideline value provided, and no maximum acceptable value.

As well as there being no maximum threshold for coliforms, there is no common publicly available data source to at least provide a source to compare results against that of other suppliers. Thus, initially coliform levels were only able to be compared with results from previous years to understand whether levels were either increasing or decreasing from previous years' results. This proved a reasonable mechanism to at least understand whether new issues were emerging or conditions improving, it did not help provide reassurance about whether the state of the supply was in line with international best practice in the first place, only whether the state of the supply was improving or declining.

Standards and guidelines from other countries were then reviewed to try to then understand what threshold levels there may be in other standards. Again, the information readily available was limited, and at times inconsistent between different countries. In the American Water Works Association (AWWA) Manual of Water Supply Practices M68 Water Quality in Distribution Systems Table 1-6 refers to no more than 5% of samples being positive for total coliforms as per the USEPA, while Table 1-7 requires that no more than 10% of samples be positive for coliforms as per Health Canada. These were the only examples found where a limit or threshold had been set.

Within the initial years, as there was still no clear understanding of what an appropriate target was, the initial focus was to work on continuous improvement on the levels on existing supplies, until an appropriate target could be established.

Throughout more recent events, it has become apparent that any tolerance for coliforms should be avoided wherever possible. While some initial jurisdictions' standards seemed to accept a certain level of coliforms, it has become apparent that by permitting some coliforms to be present in a supply, it is very difficult to then maintain a specific target level, without either risk of future exceedances of this target, or without risk of other more harmful organisms also entering the supply. Therefore, the conclusion has been reached that the target should be to have no coliform detections. Where water is sourced from deep and secure groundwater sources, the starting point in the raw water is zero coliforms. Any detections are therefore indications of something having occurred within the water supply system.

There are some parallels between this approach and the "road to zero" approach adopted by Waka Kotahi with respect to road deaths, or similarly the Zero Suicide programme, or with the elimination strategy adopted in the early stages of the COVID-19 pandemic in New Zealand. In all cases, while the zero target may not be achieved initially or seen as an overly ambitious goal in some cases, it is difficult to accept a target level any greater than zero in these situations.

## MANAGEMENT TOOLS

A number of management tools have been developed to assist in responding to coliform detections. These tools are founded on having a system to alert staff of the results, guide them how to respond, and work towards identifying and resolving the root cause. This is not an approach specific to coliform detections, but one that can be applied generically to any water quality indicator.

The following paragraphs walk through some recent system improvements that were made, which were essential precursors to being able to respond to detections in a timely and effective manner.

### NOTIFICATION OF RESULTS

With it being established that any detection of coliforms should be treated as a reason to respond, a key management tool required is one that enables a fast and effective response to any such detections. While in pre-2016 times, coliform results were reported only via monthly laboratory PDF reports, in the years following an automated system was developed to alert 3 Waters staff of any detection at the time that the results were generated by the laboratory. These types of systems are becoming commonplace in New Zealand now, and in hindsight anything less should be considered insufficient.

Any coliform detection when entered into the water supply laboratory automatically generates an email to 3 Waters operational staff informing them of what the level of the detection was, and where from. Staff can then access the results database to review past results, and other water quality parameters measured at the same time as the coliforms were detected (i.e. conductivity, turbidity, chlorine levels where applicable, and pH). Also available are all past results, such that historical results can quickly be reviewed to detect any patterns that may be emerging.

This fast and automated notification of results, combined with easy availability of the full database is the first tool required.

## INCIDENT RESPONSE PLANNING

With a system established to alert staff of the detections, the next obvious question is what to do when a notification is received. Pre-2016 Water Safety Plans typically had contingency plans, however these were generally limited to guiding responses to contamination events, and did not include any guidance on responses to lower level events. For example, triggers to initiate the contingency plans generally started with the detection of *E. coli*, but responses were not generally triggered by other parameters such as changes in total coliforms, pH, turbidity, or extreme weather events. This often meant that it was not until contamination of the water supply had occurred that a response was initiated, rather than in response to early warning signs, prior to any contamination actually occurring.

Following the release of the Water Safety Plan Framework and Associated Handbook in 2018 by the Ministry of Health, what were once contingency plans have now evolved into Incident Response Plans (IRPs). These IRPs have 5 levels, from minor issues that can be resolved through normal operational procedures at Level 1, right through to full scale emergencies at Level 5.

Typical total coliform responses generally fit around Level 2 in the IRP system, however can escalate to Level 3 if the level of coliforms escalates, the frequency of detections increases and/or the cause cannot be explained, with this uncertainty warranting a higher level response.

Generally initial responses involve a combination of review of other recent results, targeted flushing, repeated sampling, review of any maintenance activities on the supply, and consideration of any other known asset information (such as results of reservoir inspection reports, or well inspections, if relevant).

If the initial results can be explained, and the root cause resolved, this may be sufficient to close out the event at Level 2. However, if the coliform levels are high (>10), repeated, and unexplained, a more thorough response is warranted. The IRPs provide thorough guidance on factors to consider, and available options to consider as part of the initial response.

There is a balancing act that is required to be found in the preparation of an IRP however, between providing clarity to the users of the plan in terms of how to respond, without being excessively prescriptive to a point that may be limiting in terms of allowing the user of the plan to use their own judgement with any given event. It is difficult to articulate or define exactly how this balance is best found, and a degree of flexibility is often necessary for a given event. A key lesson is that the IRPs can require refinement over time. Often following a post event review, updates to the IRP are made to adjust the response plans for future events based on learnings from the most recent event.

Where IRPs are implemented in response to coliform detections, there can be a tipping point between Level 2 and Level 3 where a decision must be made about implementing the emergency chlorination system. This is necessary where public health cannot be assured, but there are downsides to implementing chlorination too early. Coliforms in our experience have been by far the most powerful indicator of an issue, and once chlorine is implemented it has been very effective at treating the coliforms and managing the public health risk, but conversely also masking what is often the one useful indicator.

The approach that has been adopted is to always prioritise public health, and therefore not hesitate to activate the emergency chlorination system when there is a degree of uncertainty with regard to the safety of the system. However, a key initial step when the chlorination system is implemented is that in parallel with starting up the chlorine system, sampling staff undertake a comprehensive sampling run throughout the network to gather as much coliform data in the moments before the chlorine enters the supply. This is done as the last chance to gather this crucial information (required as part of the diagnostics and resolution stages) before it is neutralized.

The above processes (notification of results, and IRPs to guide responses) paved the way for the case studies presented below where coliforms were detected and responded to in two of the Waimakariri District's supplies in early 2022. What made these responses more challenging was that the events occurred within a matter of days of each other, with the responses overlapping each other.

# EVENT 1 - WOODEND

## WOODEND BACKGROUND 2016 - 2021

Of the two events covered in this paper, this is the more straightforward event to understand, and probably more typical of other events faced by water suppliers elsewhere. There are however some more unique characteristics of the Woodend supply that has most likely impacted upon the interpretation of coliform results on this supply previously.

The Woodend supply sources its water from deep (>200m) and secure groundwater wells, with very good microbiological history, and clear separation between the source water and activities on the surface. These sources do however contain iron and manganese. While the iron and manganese are now treated effectively, historically treatment has been inconsistent. This has meant that over previous decades, a manganese and iron biofilm has built up on the inside walls of the pipework.

This biofilm is managed to a point through quarterly comprehensive flushing of the reticulation network. This has been successful in resolving almost all discoloration complaints that used to occur on the supply, however not in removing biofilms entirely.

The significance of this is that these biofilms had been thought to give a place where nonpathogenic coliforms can survive within the pipe walls, leading to reasonably frequent but low level (1-2 coliforming units per 100mL sample) coliform detections.

Also of significance in understanding the supply is that the water is treated with biological manganese removal filters, which allow manganese and iron to be removed by naturally occurring microbes in the water that develop in a sand filter. While very successful at treating manganese, it has also been suspected that these biological filters provide an opportunity for coliforms to live and exist in the filters, given they are living systems. The prior thought process has been that the specific characteristics of a biological manganese removal filter, and biofilms on pipe walls, had led to coliform detections on this supply at greater frequencies than other supplies.

While this has not been thought to present a public health risk, the main downside has been thought to be that the occurrence of coliforms due to the reasons listed above has partially removed the usefulness of coliforms as a detector for any legitimate deficiencies in the system that may present a public health risk and warrant investigation.

As part of the ongoing investigations into coliforms on the Woodend supply, diagnostic sampling and analysis of results indicated that the frequency of coliform detections was the same in the reticulation system as it was in the water leaving the Chinnerys Road treatment plant. To assist with the following explanation, the schematic below should be referred to.

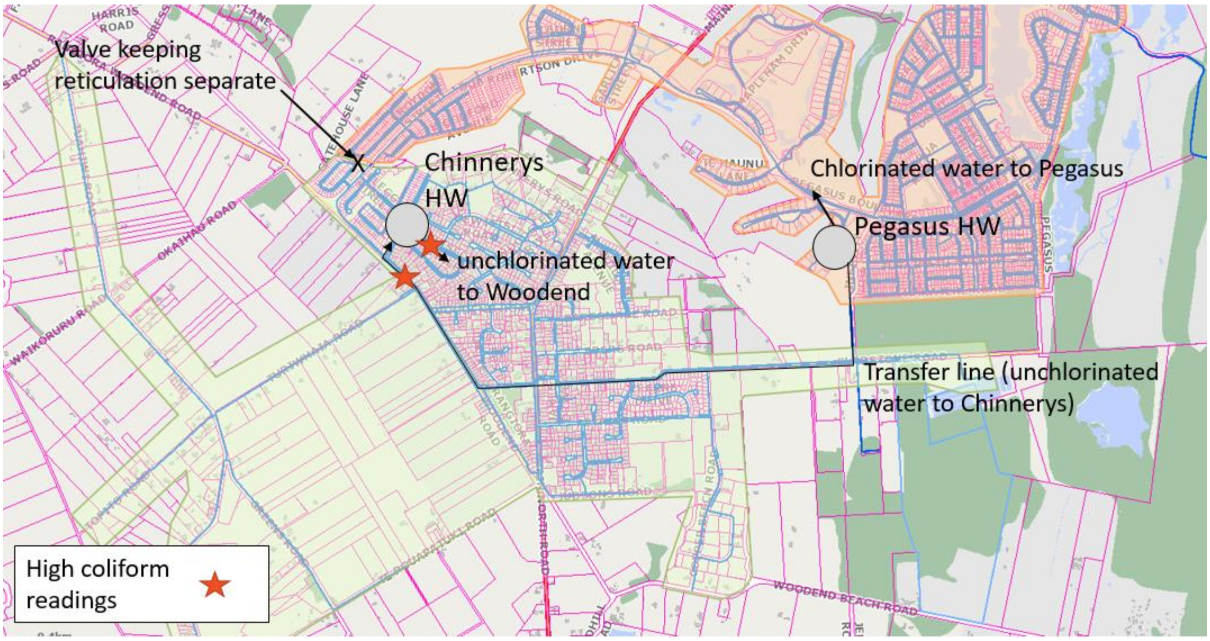


*Figure 1: Woodend-Pegasus Water Supply Overview*

Prior to 2018, it was thought that the biological manganese filter at the Chinnerys Road headworks was most likely the cause of the coliforms. In 2018, the Chinnerys Road filter was decommissioned, and the Chinnerys Road headworks reconfigured such that it started receiving treated water from the Pegasus headworks.

It was initially thought that decommissioning of this biological filter at Chinnerys Road would have stopped the coliform detections. This was not the case, and detections continued after the joining with the Pegasus supply.

The next line of investigation was the Chinnerys Road reservoirs. There are two reservoirs at the site; each was individually drained, comprehensively inspected using a "demonstrably safe" set of criteria, and each defect addressed before bringing each reservoir back into service.

The above process was successful in identifying a number of potential vulnerabilities and addressing them, which in itself made this a worthwhile step in the process to have undertaken. However, it wasn't successful in eliminating the coliform detections on the supply. Further diagnostic testing was undertaken which went further upstream with samples taken from the transfer line between Pegasus and Woodend, the outlet of the Pegasus reservoirs, the filter outlets, and the source water.

This next stage of testing identified that the coliforms were coming from somewhere within the Pegasus site, either from the manganese removal filter at Pegasus or the Pegasus reservoirs. This conclusion coincided with the extension of the demonstrably safe reservoir inspection to the Pegasus site. These inspections were done again by external specialist engineers who thoroughly inspected the reservoirs and filters externally, with internal inspections done by drone in this case to allow the reservoirs and filters to remain in service.

It was during the reservoir inspection and repair process that the higher coliform detections occurred, leading to the key event on this supply. This is discussed in the following section.

## 2022 HIGH COLIFORM EVENT

As part of the 2022 inspections, a gap approximately 10mm in size was found at some points between the top of the walls and the reservoir roof. This was not immediately obvious from past inspections from the top of the roof, or from the ground below, due to the height of the reservoir making it difficult to distinguish this precise weak point. They would however be identified with the use of scaffolding during the detailed inspections.

With the plant configured such that this reservoir was unable to be taken offline easily, repairs to this defect in the roof to wall joint were done with the reservoir still in service. At the time it was thought that this could be completed with minimal risk to the live system, and was preferred over some of the complications thought to be associated with taking the reservoir out of service.

The key reason for the reluctance to take the reservoir out of service was that this could only be done by feeding the Woodend system (usually unchlorinated) from the reservoir at the Pegasus plant that was chlorinated. The key reservation was around the impact that chlorinated water would have on the biofilm in the Woodend pipework, based on experience from other water suppliers where the introduction of chlorine to pipework with manganese biofilm had resulted in very high levels of discoloration in the water, in some cases for extended periods of time.

Following the above assessment, the repairs were completed with the reservoir in service. These were successful in that the immediate risk was resolved, and the weakness in the reservoir addressed with full sealing around the perimeter. Following the completion of the repairs, further sampling was undertaken downstream of the reservoir in the transfer line between Pegasus and Woodend, and within the reticulation in the Woodend system. This sampling led to coliform counts in the order of 40 per 100mL sample, far higher than past detections in the order of 1 – 2 per 100mL sample. As a result of these detections, the following steps took place:

- An alert was received by 3 Waters staff as soon as the results became available;
- The IRP was reviewed and enacted as a Level 2 event.
- Comprehensive sampling instructed at all reticulation sample points, headworks, reservoir, filter and source.
- Key staff were consulted including operations, asset management, team leaders and the department and unit managers. As a result of these discussions, it was concluded that the source of the coliforms could not be easily explained, and as such the uncertainty in the

source led to the conclusion that the safety of the supply could not be assured without the addition of chlorine. As such chlorination of the Woodend supply was instructed in order to manage the safety of the supply in the immediate term, while allowing further time to investigate, identify the cause, and remediate it.

- A communications plan was also enacted which included:
    - Email / text alert to supply members to inform them of the event and activation of the emergency chlorine system.
    - News story published on the Council website and Facebook page.
    - Senior managers, Councilors, Community Board members, and Taumata Arowai were notified.

In this case, based on the configuration of the Woodend and Pegasus supply, the chlorination of the Woodend supply was able to be done as easily as opening a valve to connect the Pegasus reticulation system into the Woodend reticulation system, the isolation of a reservoir and pumpset, and the isolation of the Chinnerys Road headworks. This had the following benefits:

- The parts of the system where the coliforms originated (Pegasus Reservoir B) were immediately taken out of service;
- The chlorination was as quick as possible, with no need to start up temporary chlorination equipment, but rather it was as simple as opening a valve, and turning off some pumps.

The previous day's testing indicated that the coliforms originated from the Pegasus Reservoir B, and not further upstream in the system. This conclusion was based on the general thought process being the origin of the coliforms is the most upstream point in the system where they are detected. Following this, the reservoir in question was fully drained and inspected internally. No further defects were found during the internal inspection however.

At this stage possible causes were discussed. The most probable cause was that as part of the repair process in which sealant was installed around the reservoir perimeter some organic material must have been dislodged which had dropped into the reservoir, leading to it being detected downstream. Conversations were held with the repair contractor, and while they did not believe they had done anything to cause this, it was understood that they would not necessarily have known had they inadvertently done this.

With the cause thought to be identified, but still not 100% confirmed, the part of the system that had been taken out of commission was carefully re-commissioned, in a staged way. This included super chlorination of the system from Pegasus Reservoir B through the transfer pipe, and into the Chinnerys Road reservoirs. This chlorine was then neutralized, the system, drained, then re-filled, and testing for coliforms undertaken again prior to recommissioning.

Once a satisfactory number of clear results had been obtained, this part of the system was put back into service, with the Woodend reticulation system once again receiving chlorine free water. Following this, more frequent sampling was undertaken to monitor water quality results in the days and weeks following the recommissioning.

The positive outcome was that not only did the high level of coliforms not re-occur, the low level coliform detections that had been thought to be 'normal' for the supply also reduced significantly. This likely showed that the original root causes of the coliforms that were once accepted (i.e. biofilms and the biological filter) were likely not the true root cause, as if this were the case, the reservoir repairs that were undertaken would not have been successful in significantly reducing the level of coliform detections. The other possibility may have been that the super-chlorination of the reservoirs and transfer pipeline, and the chlorination of the Woodend reticulation, may have sterilized coliforms that had previously been allowed to live and exist in these parts of the system.

## WOODEND CONCLUSIONS

The following conclusions can be drawn from the Woodend event, in terms of things that could have been managed better:

- The previous attitude of accepting low level but frequent coliform detections as a result of manganese biofilm in the pipework combined with the biological filter meant that other possible causes were not explored as early, or as thoroughly as they could otherwise have been. While there were some reasonable theories behind the early assumptions, this should not have been sufficient reason not to explore other possible options more thoroughly as well.
- Had a zero target towards coliforms been adopted earlier, it is likely the reservoir defects would have been identified earlier, and resolved in a more timely manner.

Despite the above, there were also several lessons learnt in terms of things that worked well, not with the pre-cursors to the event, but in terms of the event management and response:

- The readiness and flexibility of the scheme to swiftly take a reservoir out of service, and provide the unchlorinated section of the reticulation system with chlorinated water was pivotal in the speed and ease at which the initial transition was made.
- The thorough understanding to the system and skill of operators to isolate, inspect and quickly super chlorinate the relevant part of the system, while maintaining normal operation in the live part of the system was also a key factor in the success of the response. Had operators not had the commitment, or the system knowledge, this part of the process could have been much more challenging to manage.
- The fast and open communication with the public, including the use of the email / text alert system helped mitigate the negative public

response associated with the unexpected change in the water, at short notice.

# EVENT 2 - KAIAPOI

## KAIAPOI BACKGROUND 2016 - 2021

The Kaiapoi township is supplied from two main headworks (Darnley Square and Peraki Street), each site fed by 3 separate deep, secure and artesian wells. The headworks and wells have very good microbiological history, and are considered very high quality groundwater sources.

The reticulation system of Kaiapoi too generally has very good microbiological water quality, with the exception of samples taken from the northern part of the town, which at times has had low level coliform detections.

Prior to enumerated samples being taken (i.e. pre 2017), a higher than normal proportion of coliform presences were detected at times from the northern Lees Road sample point, while the rest of the scheme had much more consistent absence detections. As these earlier samples were not enumerated, the specific level of coliforms at these times is unknown.

As noted previously, in the years prior to 2016, the presence of coliforms were paid little attention, and only if there was an *E. coli* detection was a more significant response triggered. However, around the 2017 and 2018 period, the pattern of coliform detections in Lees Road was noticed. The initial response was driven by operational staff who had noted during flushing that some sediment and gravels were flushed from the pipework. This was thought to be due to subdivisions from around 2010 where adequate hygiene practices were likely not in place during the construction of new pipework, and some sediment left in place.

In response to this, flushing of the northern part of Kaiapoi was undertaken, and it appeared to be successful in that the coliform detections in this part of the network significantly reduced and in the subsequent years there were no further incidents of note.

## 2022 EVENT

In late December 2021 and January 2022, the Lees Road sample point recorded some coliform readings in the order of 20 per 100 mL. The rest of the scheme's water quality remained very good.

Based on past experience and knowledge, the original theory was that much like past events, this must have been as a result of some remaining gravels in the pipework from the time of the construction of the subdivision around 2010. Given this issue had been successfully dealt with previously by flushing, the response was repeated, and the same result expected.

Given the strong theory that the coliforms were from a source about 10 years old in the pipework, and that it had only ever been coliforms and not *E. coli*, and given the expectation that the issue could be easily resolved by flushing, the emergency chlorination system was not activated initially. Had there been a suggestion of a breach of the integrity of the pipework, a different response may have been warranted.

This time however the result of the flushing was quite different. Instead of the flushing clearing out the material leading to the coliform detections, it had the opposite impact. Samples taken as the flushing was underway returned results of very high coliform counts (>200 mpn/mL), still without any *E. coli*. Although still with no indication of a system breach, the unexpected and at the time unexplained nature of the detections was sufficient justification to initiate the emergency chlorination system, which was in place within a matter of hours of the decision being made.

In the intervening hours just before the chlorinated water reached the water supply network, samples were taken not only from the scheme's registered sample points at the extremities of the network, but also from a number of hydrants throughout the network. Given earlier sampling had indicated that the coliforms were not associated with the source or headworks, but rather the reticulation network, the goal of this intensive sampling was to pinpoint where within the reticulation network the coliforms were entering the supply.

The results of the intensive sampling were however inconclusive, in that coliform detections were found right throughout the northern Kaiapoi reticulation system, but still not from the source or headworks. The first batch of results are summarised below:

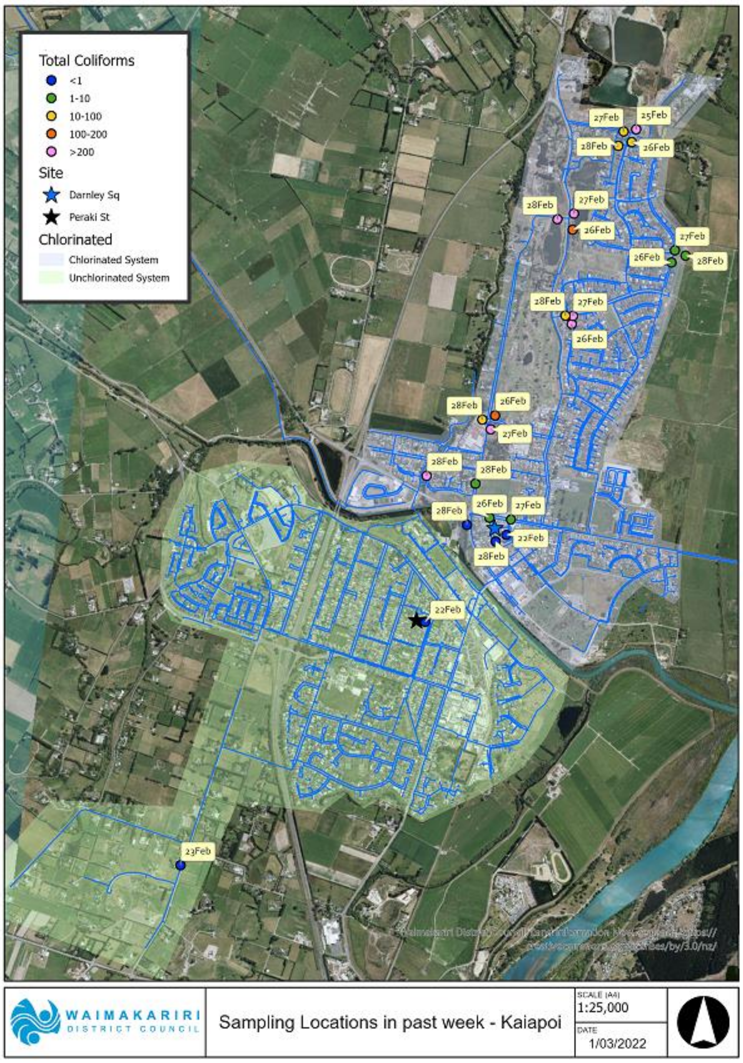


*Figure 2: Overview of Kaiapoi Scheme and Initial Sampling Results*

These results were more difficult to explain as they did not suggest a point source breach of the system (which would have had more limited spread throughout the wider system), but rather a simultaneous occurrence within the section of the reticulation network more generally. This type of event had not been experienced before.

The following other investigations were undertaken, to help explain the water quality results:

- Review of backflow prevention practices throughout the network. No issues of particular concern were noted, however some properties that had been written to recently to require backflow preventers be installed had their installations fast tracked. The risks identified with these properties were more chemical in nature than microbiological, so were not considered to be of particular relevance to the issue.
- Review of other activities on the water supply network. There had been some developer connections to the network in recent weeks or months.

While an avenue worth pursuing, these were ultimately deemed as very unlikely to be a possible cause as:

- The connections were made to the side of a network, where modelling suggested that the flow paths could not have led the water from that point to travel to the other parts of the reticulation where detections were made.
- Audits undertaken during the cut-ins were reviewed and did not give any reason to suggest any contamination could have been possible.

- Pressure in the system was reviewed, both leaving the headworks, and also at a point close to one extremity where there is continuous pressure monitoring. This data suggested system pressure had been maintained in the weeks and months prior to the event. The maintaining of positive pressure is a key barrier in preventing any contaminants from entering pipework, so the pressure data made the theory of something from external to the pipes seeping in unlikely.
- Pressure transient loggers were placed in the network to identify if there were transients not able to be detected by more conventional pressure loggers. This data did not give any reason to suggest a low or negative pressure event would be expected on this supply.
- More pressure loggers were placed throughout the network to identify any increased pressure in the reticulation, greater than that leaving the headworks. This was to identify any activity inadvertently pumping into the reticulation (i.e. a cross connection with a private well). This data did not suggest any such activity was taking place.
- Other known activities in the area were reviewed. There had been a factory fire, resulting in a reasonable firefighting activity in the northern Kaiapoi reticulation. This had not caused any low pressure events (as per the evidence described above), however had caused larger than normal flows. Also discovered was that the fire service had put in place a system to suppress dust from the fire using water taken from a network fire hydrant, combined with air. While the fire service are permitted to access the network for firefighting, it was not anticipated that air might be added to the water being taken. This addition of air in itself did not present a contamination risk, however if some of this air could have traveled back into the network, this could have caused some turbulence within the immediate surrounding pipe network. This possible risk was addressed by providing the fire service with an RPZ backflow device fixed to a hydrant upstand such that they could continue suppressing dust without risk of air traveling back into the system.

From the above investigations, the fire appeared to be the activity identified that was the most suspicious, however this in itself did not suggest any pathway for anything other than potentially air to get back into the system. And in this case, the only risk was that the air could stir up some material already in the pipework. Further, the earliest coliform detection was found before the fire occurred. So at best the fire could have been an exacerbating factor, but not the root cause.

Given the difficulty in explaining the events that had taken place, despite the thorough investigations, advice from an external consultant with expertise in microbiological activity in water supply systems including biofilms was sought. This advice was sought early on in the event response stage, and regular meetings were held with a combination of operational staff, asset management staff, water compliance staff, and senior managers, as well as the expert consultant. Guidance was given in terms of what next steps to take, and to interpret recently obtained results.

Over the next weeks, through a process of elimination of any other conceivable theory, the last remaining plausible theory was that biofilms had been able to develop in the pipes over many years. The biofilms could be housing coliforms on the pipe walls, that could have been stable for many years, and then at a certain point in time begun sloughing off. First the firefighting flows, then the intensive flushing to try to clear possible debris in the pipework then could have exacerbated things by triggering more and more biofilm to slough off from the pipework, explaining why the initial flushing worsened the water quality results, rather than improving it, despite pulling through more high quality water from the headworks.

The reassuring part of this explanation was that harmful pathogens are not associated with the types of biofilms in this system, based on specialist advice received at this time. The less encouraging part was the limited options in dealing with such biofilms. While the biofilm itself was not seen to present a public health risk, the fact that it could lead to coliform detections meant that it could take away the effectiveness of the most useful indicator of a breach of the water supply's integrity. If a biofilm that contains coliforms is left in place despite regularly causing coliforms to be detected in the network, it would essentially result in the monitoring of coliform data being meaningless, thereby removing a powerful indicator of some other type of system breach. This alone was seen as reason enough to try to take further steps to remove the biofilm to a point that coliforms stopped being detected.

The next steps taken to try to achieve this goal were:

- Increase of chlorine dose level to try to accelerate breakdown of biofilms on pipe walls;
- Further intensive flushing of the system to take advantage of the impact of the chlorine breaking down the biofilm, to try to scour this off and remove it from the system;
- Removal of chlorine from the system, followed by frequent sampling throughout the reticulation network.

The result of the above three steps were that the coliform detections almost disappeared entirely for the next approximately 6 months. The results in this time period following the event were better than during any other period on record in terms of the lack of coliforms in the system.

At the time of writing this paper however, the coliform detections have crept back in, following a very similar pattern to the earlier event. Chlorination is again in place, and this time the further step of genetic analysis of samples throughout the system is being undertaken to gain a higher degree of understanding of the origins of the coliforms. The hope is that rather than identifying biofilms as the cause through a process of elimination, genetic data could be used to ideally prove that this is in fact the origin beyond all reasonable doubt. Unfortunately this next stage of work was in the very early stages at the time this paper was written, so the outcomes of this next stage will need to be the subject of a future publication.

### KAIAPOI CONCLUSIONS

The events of the Kaiapoi water supply led to several conclusions being drawn:

- Past events are not necessarily an indicator for the outcomes of future events. While historically flushing had been successful in clearing coliforms from the network, in the 2022 event, flushing increased the level of coliforms.
- Coliforms appear to be able to live on biofilm for a number of years, even without a 'food source' in the form of organic material in the source water.
- In the case of the Kaiapoi events, all other water quality parameters that were measured were unable to detect a change, with conductivity, pH, turbidity and FAC levels (once implemented) all remaining stable through the event.
- An open mind is necessary at all times during the investigation stages, and all avenues should be explored thoroughly.
- The response to this event, like the Woodend one, was also reliant on the availability and experience of the in-house contractor (the Water Unit) in being available to undertake the flushing, sampling, activation of the temporary chlorination system, and on-going response.
- The response also benefitted in this case from regular meetings involving a range of parties, ranging from contractors, operators, asset management staff, senior managers, and expert consultants. This allowed a range of viewpoints to be considered, and the response to be regularly reviewed and adapted as new information came to light, or new results became available.

## CONCLUSIONS

While individual conclusions have been drawn from each event, there are some common themes which are summarised below:

- The monitoring of total coliforms is a highly powerful indicator that can be used to monitor the health of a water supply, and provide invaluable information regarding changes in the system. As an indicator, it appears to be much more sensitive to changes compared to other water quality parameters that can be easily measured. This conclusion applies more to non-chlorinated supplies than chlorinated.

- To make the monitoring of coliforms truly effective, it must be coupled with a fast and effective reporting system and robust response plans.
- For the implementation of the response plans to be effective, particularly for events where the cause is not immediately obvious, there must be regular review and adaptation of the response. Even when similar events have occurred in the past, the response that was successful for one prior event may not necessarily be successful for the next.
- The response in both cases was also reliant on a competent, skilled, and committed operational response. The use of the in-house contractor who have a large degree of both familiarity and ownership of the supplies was fundamental in these responses.
- The most effective way to manage coliform levels in a supply is to work towards a zero tolerance approach. Once a baseline of no detections can be established over an extended period of time, it makes it much more straightforward to first identify any deviations from this level, and therefore to trace back where the deficiency may have been such that it can be addressed. To achieve this, all possible 'entry points' to the system must be treated as critical barriers that must be protected at all costs.
- This kind of approach requires an ongoing commitment, with vigilance maintained over time. Even when one event is managed, this should not give rise to complacency as there is always the possibility of future events.
- Irrespective of coliform data, a multi-barrier approach is important to be maintained in any system. The ongoing monitoring and responding to coliform levels is not a barrier to contamination in itself, rather a tool in identifying where barriers may have been breached such that the breaches can be quickly identified and addressed.

While the current technology used to monitor coliforms has been highly effective in the case studies discussed in this paper, there is still a large amount of scope for further improvements over time. Emerging technology both in terms of real time monitoring, but also genetic analysis of coliforms provides huge potential to gain a greater depth of understanding of changes in a water supply. By knowing more about the type of coliforms that are in the supply, as well as a more precise time at which the water quality changed, the specific cause will likely be able to be identified much sooner than it would otherwise. This provides huge opportunities to continue to find ways to both improve understanding of the health and integrity of water supplies, and to inform more intelligent diagnostics and responses.


## ACKNOWLEDGEMENTS

All the Waimakariri District Council 3 Waters Unit, Project Delivery Unit, and Water Unit staff involved in the response, or the preparation of the plans and systems used to alert and guide the responses.

Heather Uwins-England (PhD, BSc, BEnvSc (Hons)) for the ongoing support through the Kaiapoi events.


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