Non-achievement of the *Drinking-water Standards for New Zealand*: *E. coli* transgressions

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EXECUTIVE SUMMARY

The presence of *E. coli* (*Escherichia coli*) in drinking water (a transgression) is an indication that it has been faecally contaminated. Consequently, there is the potential for the water to contain pathogenic microorganisms, which is a risk for anyone drinking the water.

Supplies that routinely use chlorination have a lower likelihood of discovering *E. coli* in their drinking water than supplies that do not. The use of disinfection is a protective factor against *E. coli* transgressions.

This report presents the findings of a mixed-method study into *E. coli* transgressions by drinking water supplies. The aim of the study was to review data from the annual survey of drinking water quality to see if there was evidence that maintaining a chlorine residual could overcome occasional *E. coli* transgressions, and evidence of the cause of these transgressions.

Risk factors that increase the probability of *E. coli* transgressions in drinking water supply zones include, history of previous transgressions, *E. coli* detected leaving the plant and the use of secure bore water. Supplies serving smaller populations tend to have higher transgression rates than supplies serving larger populations.

Once a transgression is discovered, generally it is the water supplier who notifies the drinking-water assessor (DWA); sometimes it is the laboratory. The requirements for notifying DWAs, of both s69ZZ(2) of Health Act 1956 (requiring notification by the laboratory) and the *Drinking-water Standards for New Zealand* (the Standards) (requiring notification by the water supplier), appear to be rarely met.

Generally, it is the drinking water supplier who carries out investigations into transgressions. They do so in line with the Standards, but there are exceptions, including water suppliers not immediately notifying the DWA of a transgression. Some water suppliers, due to their geographical isolation, are reluctant to take the required number of clearance samples because of the time (resources) required in taking the samples.

Often the investigation identifies the cause of the contamination. It appears easier to identify the cause in supplies that use disinfection than supplies that do not. However, not all causes are identified and there are examples of the cause being misidentified.

Some types of corrective actions, such as the use of chlorination (to protect public health) in unchlorinated supplies can hinder the identification of the likely cause of a transgression and whether the problem has been fixed.

There is a wide variety of causes of transgressions including change in source water quality, treatment failing or being overwhelmed, and the ingress of raw water into the reticulation post treatment.

Even when the cause is identified, some water suppliers cannot readily address the problem. Access to capital investment or human resources, which can take time or simply be out of reach, may compromise the ability of some, particularly suppliers serving a small population, to respond adequately. This can result in these failures being repeated.

Even though secure bore water is a risk factor, it does not appear to be riskier than other sources. Rather supplies using secure bore water are less likely to use disinfection, which provides protection from contamination of the water after abstraction from the source. In the case of supplies serving a small population, water suppliers have had difficulty in successfully operating a disinfection system. This contributed to transgressions being less likely in small supplies using secure ground water sources than supplies disinfecting surface water. Improved management of chlorination systems should help to improve the statistics for small chlorinated supplies.

1. INTRODUCTION

1.1 BACKGROUND

The *Annual Report on Drinking-water Quality in New Zealand* (the Annual Report) and its predecessor (focussing solely on the microbiolgoical quality of New Zealand's drinking water), have been published by the Ministry of Health (the Ministry) since 1995. Before 2008, publication of the Annual Report was one of the tools used by the Ministry to encourage compliance with the voluntary *Drinking-water Standards for New Zealand* (the Standards). In 2008, an amendment to the Health Act 1956 (the Act) (s69V) made it a legal requirement for water suppliers "to take all practicable steps" to comply with the Standards, and also placed a legal responsibility on the Director-General of Health to publish the Annual Report (s69ZZZB).

The data on which the Annual Report is based are collected by the annual survey of drinking waters (the Survey). The Survey collects data from all networked water supplies throughout New Zealand that serve more than 100 people. In the July 2015–June 2016 year, this provided information on the quality of water received by approximately 3,791,000 people in 653 water supply zones (zones).

Integral to the collection and collation of the data through the survey are quality assurance measures, which provide a very high confidence in the quality of the information.

As well as fulfilling the s69ZZZB requirement, the purpose of the Annual Report is to present a readily understood summary of the extent to which the water supplies meet the requirements of the Standards and comply with the Act. This provides a national overview of the quality of the country's drinking-water. The statistics in Annual Reports have shown that too many transgressions are a major reason for water supplies failing to meet the bacteriological and chemical drinking-water standards. In the case of the bacterial standard, a transgression occurs when a sample exceeds the maximum acceptable value of one *E. coli* in 100 mL of sample.

In 2015, the first in a planned series of studies making a more detailed examination of the data collected by the Survey (Mattingley et al 2015) (the 2015 report) than is provided in the Annual Report was undertaken to gain a better understanding of the reasons for non-achievement of the *E. coli* (*Escherichia coli*) and chemical requirements of the Standards. It found that although the corrective actions to address transgressions were, in the great majority of cases, considered adequate by those completing the Survey, a number of supplies continued to experience transgressions over several years.

One of the conclusions of the 2015 report was that maintaining a residual disinfectant in zones appeared likely to improve the level of achievement of the *E. coli* requirements of the Standards. The report also found that water suppliers' inability to determine the cause of a transgression was likely to contribute to further *E. coli* transgressions. The intermittent detection of low levels of *E. coli* was likely to make investigation of the cause difficult, which in some cases led suppliers to attribute *E. coli* detection to errors in sampling or at the laboratory.

1.2 THE REPORT'S PURPOSE

The present report focuses on understanding the reasons for *E. coli* transgressions in zones using relevant findings of the 2015 report to direct the study. It reviews the Survey dataset for evidence that maintaining a chlorine residual helps in overcoming intermittent detection of *E. coli* in zones. The study also looks to understand the reasons for these intermittent occurrences of *E. coli*.

This understanding should lead to better public health risk management of the country's water supplies and improved national levels of achievement of the Standards.

1.3 LAYOUT OF THE REPORT

Section 2 of the report lays out the multi-methodological approch used in the report to analyse and investigate the reason behind trangressions and any evidence that disnfection, such as chlorine, may overcome intermittent detections of *E. coli.*

Section 3 provides the output of a statistical analysis of multiple years of data from the Survey.

Section 4 provides a discussion of the outputs of a series of interviews with drinking-water assessors (DWAs) about trangressions, their causes and the investigations.

Section 5 discusses the results from sections 3 and 4 and identified the key findings.

1.4 EXPLAINATION OF SOME TERMS

A drinking water supply is made of a number of components, zones, plants and sources. Zone or distribution zones are part of the drinking-water supply where consumers recive drinking-water of identical quality. The plant is the treatmentment plant supplying water to the zone. Source is the river, groundwater or other source which the water is taken. A supply can have one or more zones. A zone may be served by one or more plant and a plant may obtain its water from one or more source.

2. METHODS

A two-pronged mixed-methods approach was adopted to investigate the reasons for *E. coli* transgressions in zones. The first approach was statistical analysis of Survey data. The second approach was a series of semi-structured interviews with DWAs.

The objective of the statistical analysis was to describe the level of *E. coli* transgressions and the factors associated with them. The data came from a dataset containing seven years' annual survey data covering the period 2009/10 - 2015/16. Only networked supplies serving more than 100 people were included. The data were subjected to a series of descriptive and inferential statistical techniques using the R statistical language[1].

The Survey collects a wide range of information about the compliance of supplies with the Standards and legislative requirements. However, information on individual transgressions, such as the timing, likely cause and corrective actions taken in response to a transgression are not generally recorded in the Survey. This information was sought through a small number of semi-structured interviews.

The zones selected for the interviews were a subset of zones that had at least one transgression in 2015/16 and transgressions recorded in a minimum of three out of the previous six surveys. These zones were chosen because of their on-going transgression problems. Supplies that had been extensively studied elsewhere, such as Havelock North, were excluded from the selection. The resulting selection included 13 zones and 27 transgressions.

A wide range of stakeholders, water suppliers (and their contractors), laboratories and DWAs were associated with these zones. For practical reasons, including keeping the project to a manageable size, this study focused on DWAs for the interviews. The assumption was that DWAs would have a reasonable understanding of transgressions in their area. However, it is accepted that the study did not include other stakeholders, with valuable insights and possible alternative points of view.

Eight DWAs, with responsibility for the selected supplies/zones, took part in interviews. Prior to the interviews taking place, the DWAs were given a consent form which informed them of the purpose of the interviews, how the information would be used and the fact that neither they, nor the zones discussed, would be identified.

[1] R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

The interviews took place in early 2017. To reduce the problem of recall bias, the focus was on transgressions that occurred in 2015/16, the most recent complete survey year at the time of the interviews, rather than previous years. During the interviews, DWAs were encouraged to consult their notes on the transgressions.

To ensure the quality and comparability of the data from the interviews, a *pro forma* was created. Two generic frameworks helped to inform the *pro forma*. The first was the immediate action, as laid out in “Response to a transgression in a drinking-water supply distribution zone” Figure 4.2 of the Standards. The second framework, provided a structure to the possible causes of *E. coli* being reported in zone. If routine monitoring determines that *E. coli* is present, or the disinfectant concentration is inadequate, immediate action is required. The Standards provide guidance as to what constitutes immediate action. Immediate action includes: inform drinking-water assessor (DWA); inspect plant/source; collect samples at plant for *E. coli* test; enumerate *E. coli*; investigate cause; take remedial action. Only responses for the presence of *E. coli* in the water, not an inadequate disinfectant concentration, were considered here.

The 2015 report identified a number of possible causes of *E. coli* being reported in samples taken from zones. In this work, the causes were expanded and described as:

- *E. coli* genuinely present in the drinking-water zone:
    - *E. coli* present in the source water and not removed by treatment/no treatment
    - *E. coli* enters reticulation system post treatment
    - Growth/regrowth of *E. coli* in biofilm.
- Methodological error:
    - Sampler error
    - Laboratory error
    - False positive, ie, the assay incorrectly indicates the presence of *E. coli.*

The *pro forma* sought information on how the transgression was investigated and the likely cause of the transgression.

3. REVIEW OF ANNUAL SURVEY DATA - A STATISTICAL ANALYSIS

3.1 INTRODUCTION

This section provides the results of a statistical analysis of *E. coli* transgression data reported in the Survey.

Firstly, there is a discussion of *E. coli* samples, transgressions and monitoring. A description of the overall rates of transgressions as measured in zones and at plants over seven years follows. The exploratory analysis delves into factors that may influence transgressions, including the size of supply and barriers, before focusing on the role of disinfection and secure bore water status in influencing transgression rates.

3.1.1 *E. coli* monitoring and transgressions

The greatest risk to consumers of drinking water is consuming pathogenic microorganisms (Hrudey 2017). Pathogenic microorganisms are generally derived from human or animal faecal matter. As it is impractical to sample for disease-causing pathogens in drinking water, the presence of *E. coli* is used as an indicator of faecal contamination instead.

The Standards set the maximum acceptable value (MAV) for *E. coli* as less than 1 in 100 mL of sample. If *E. coli* is found in a 100 mL drinking water monitoring sample, the sample has transgressed the MAV. This MAV differs from many of the chemical MAVs in that it is not based on the likelihood of an adverse health outcome. Instead, it simply indicates a hazard; the drinking water has been faecally contaminated. There has been some form of failure in the drinking water system and the presence of pathogens in the water must be assumed.

The Standards specify the minimum number of *E. coli* monitoring samples a supplier must take, at treatment plants and in zones, in order to comply with the bacteriological components of the Standards[2], though a supplier is free to collect more samples than that required by the Standards. Generally, the greater the population served the more samples must to be taken. The Standards also specify the maximum number of transgressions a supply can have while still complying with the Standards[3].

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[2] Continuous monitoring for *E. coli* is not yet possible

[3] The allowable number of MAV exceedances is calculated on the basis that there is 95 percent confidence that a determinand exceeds its MAV no more than five percent of the time. The fact that the number of samples required depends on population in effect means that it easier for large supplies with a low level of contamination to comply with the Standards than a smaller supply with an equivalent quality of water.

There are certain situations in which a water supplier can reduce *E. coli* monitoring:

- continuous monitoring of the disinfectant at the treatment plant is substituted for *E. coli* sampling
- free available chlorine measurements in the distribution zone are substituted for *E. coli* sampling
- or the water is sourced from a secure bore[4].

3.1.2 *Results*

Over the seven years (2009/10 to 2016/17), water suppliers have reported an average of 42,000 and 29,000 *E. coli* compliance monitoring samples taken per year in the zone and treatment plant (plant) respectively. The difference between these two figures is probably in part a consequence of the Standards allowing the replacement of *E. coli* monitoring and the fact that there are fewer plants than zones.

The fraction of zone monitoring samples with *E. coli* transgressions has fallen from 0.58% of monitoring samples taken in 2011/12 to 0.29% in 2015/16. At plants, the level has fallen from 0.55% in 2012/3 to 0.35% in 2015/16. However, over the years, the level of transgressions has gone up as well as down. Overall, transgressions are a relatively uncommon phenomenon with approximately one in 300 samples returning a positive result in a plant or the zone, on average. Although some water supplies have much higher transgression rates, many have none in any one year.

Table 1: Combined count of *E. coli* monitoring samples and transgressions taken in the zone, from the Survey

	Zone		Plant	
Survey Year	Transgression count	Transgression rate, %	Transgression count	Transgression rate, %
2009/10	201	0.49	123	0.44
2010/11	201	0.53	114	0.41
2011/12	247	0.58	144	0.51
2012/13	205	0.48	156	0.55
2013/14	198	0.46	118	0.44
2014/15	144	0.33	97	0.30
2015/16	128	0.29	108	0.35

[4] See Compliance criterion 2A and Compliance criterion 5 of the Standards for examples.

3.1.3 *Transgression rate by size of supply*

Focussing on the water quality measured in the 653 active distribution zones in the survey year 2015/16 year, approximately 60% of those zone had no recorded transgressions in any of the previous seven years, 19% had transgressions in one of those years, 9% transgressions in two years, 5% transgressions in three years and 8% of supplies had transgressions in four or more of the last seven years.

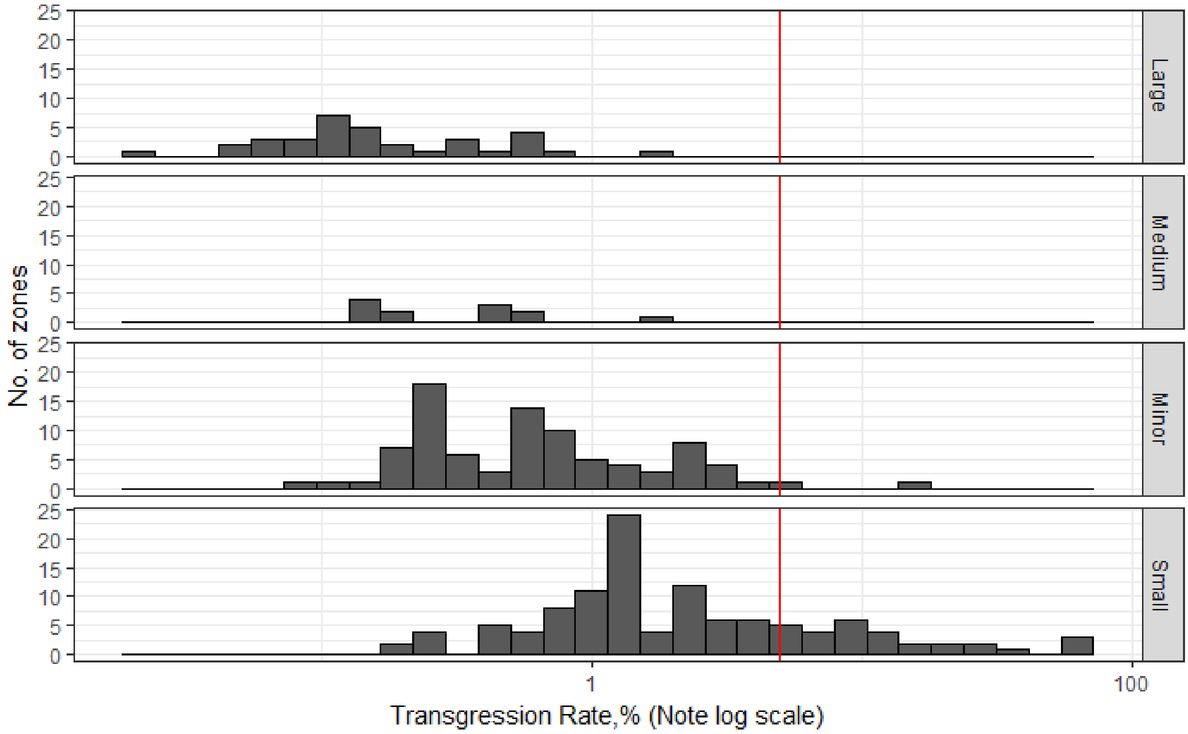
Though large zones[5] are more likely to comply with the Standards, they are also more likely to record transgressions. In 2015/16, 14%, 10%, 11%, 11% of large, medium, minor and small zones, respectively, recorded one or more *E. coli* transgressions.

Combining the last seven years of *E. coli* monitoring data, approximately 54%, 68%, 66% and 60% of large, medium, minor and small zones recorded no *E. coli* transgressions. Of those supplies that did, the overall transgression rates (proportion of samples collected that tested positive for *E. coli*) are shown in Figure 1. For the subset of supplies that have had a transgression, there is a tendency for larger supplies to have a lower average transgression rate than small supplies. Some caution needs to be exercised in interpreting differences between supply sizes. For example, it is not possible for small supplies to record the very low rates reported for the large supplies[6]. This is simply due to the fact that smaller supplies generally take fewer samples than large supplies.

[5] Large zones serve more than 10,000 people, medium zones serve between 5001 and 10,000 people, minor zones 501 and 5000 people and small zones 101 to 500 people inclusive.

[6] In brief, transgression rate is a ratio of the transgressions to monitoring samples. As the number of monitoring samples goes up for a given value of transgressions, the ratio goes down. The greater the number of monitoring samples the lower the ratio can be for single transgression.

Figure 1: **Histogram of the overall transgression rate of supplies based on seven years results (2009/10 to 2015/16) Supplies with no transgressions not plotted. Vertical red line indicates 5%.**



3.1.4 *Barriers*

All zones are not the same. They differ in numerous ways, including the level of transgressions experienced, the type of source water and the disinfection process (if any) used. The question is: could any of these indicators account for the variation in transgressions between zones?

The survey contains information about many potential indicators. To make sense of the multitude of potential indicators, indicators were classified according to barrier type. A barrier being one of the five barriers proposed by the Walkerton Inquiry (O'Connor 2002). A sixth barrier, Management/Risk management, which has been added to the list by other workers is also included here. There has been debate as to what can be regarded as a barrier and what is not a barrier (Hrudey 2017). The definition is beyond the scope of this paper and not considered further. Only indicators, which in the opinion of the authors, using their expert knowledge, could be associated with a barrier type were included. In addition, to keep the number of indicators manageable, the study focused on disinfection rather than other forms of treatment, such as filtration. A total of 22 indicators were identified.

This framework of indicators was analysed using a retrospective cohort approach and the idea of relative risk. Relative risk is the probability of a transgression occurring when an indicator was present (exposed group), compared with the probability of a transgression occurring when the indicator was absent (or non-exposed group). Essentially it splits the data into two mutually exclusive groups. The approach provides a framework for comparing various indicators to investigate if some, or any, of the barriers were associated with higher or lower levels of relative risk. Following customary convention, the level of significance was set at $\alpha = 0.05$[7]. Note, evidence of association does not imply causation. Neither does this approach consider confounding factors such as when barriers interact with one another. Only transgressions occurring in the 2015/16 year were considered, with a single exception discussed below.

In brief, out of the 21 indicator ratios investigated (see Table 2), seven were significant at α = 0.05. These are grouped by barrier type and discussed below.

- ***Source protection.***
  - Secure bore water sources relative to all other sources (RR=1.79) and secure groundwater relative to surface sources (RR=1.79) both have relative risk ratios greater than one and $p < 0.05$ implying a higher risk of *E. coli* transgression in zones using secure sources than other sources. So the use of secure bore water is a risk factor.
- ***Treatment***
  - Disinfection vs no disinfection (RR=0.45) and chlorination vs no disinfection (RR=0.31) both have risk ratios less than one implying that disinfection is protective against *E. coli* transgressions. Chlorination is by far the most common disinfection system and was used in 489 zones.
  - UV irradiation is the next most common disinfectant (used by 187 zones). Though it is protective (RR=0.62) relative to no disinfection, the p value of 0.082 indicates the RR value is not statistically significant according to the criterion of α = 0.05.
  - Having a transgression at the plant is a risk factor (RR=4.23) for having a transgression in the zone. Again, this illustrates the importance of the treatment barrier; if treatment fails then there is a possibility that contamination will make its way into the zone. Note that by definition, plants that do not take *E. coli* monitoring samples (as they may not be required to do), will have no *E. coli* transgressions at the plant.

[7] Based on the asymptotic p-value.

- ***Distribution system***
  - Only one indicator was associated with the distribution system. However, it was noted that transgressions in the previous survey year were a risk factor (RR=5.35), suggesting historical performance is a predictor of future performance. Though historical transgressions cannot be the cause of current transgressions, the possibility that they have a common cause should be considered.
- ***Monitoring programmes***
  - Monitoring is key to obtaining information about *E. coli* transgressions, however though overall the relative risk (RR=0.71) was lower for supplies that monitored in accordance with the Standards, this was not statistically significant (p=0.247). Obviously there is a difficulty in interpreting the data. If the supplier did not sample in accordance with the Standards this would be expected to reduce the probability of recording a transgression if the water was contaminated.
- ***Response***
  - Complying with the requirements of the Standards for responding to transgressions is protective (RR= 0.16), however a supply with no transgressions complies by default. This indicator relates to the duty of a supplier to take corrective action if the Standards are breached (s69ZF). Note this duty refers to both chemical and microbiological transgressions, which explains why it is possible to fail this duty and have no *E. coli* transgressions.
- ***Management/Risk management***
  - Most supplies complied with their duties for Adequacy of supply, Water Safety Plan (WSP), complaints and record keeping. None of these values were statistically significant.

Though a number of other indicators were not identified as statistically significant, it does not prove that these indicators or their related factors are unimportant or ineffective. It would be logically wrong to interpret the above results as saying that management/risk management was unimportant. It may be that there is insufficient evidence to draw conclusions due to the small sample size. Alternatively, it may be these indicators, in combination with the test do not provide a robust test of the hypothesis. For example, the indicators for WSP test only whether a water supply has a WSP and has started implementing the plan. It neither assesses the quality of the plan nor whether its implementation is on track.

In summary, the significant indicators that differentiate zones with transgressions from zones that don't have transgressions are the type of source, disinfection, remedial actions and their history of previous transgressions. Having a secure bore water source increases the risk of a transgression whereas disinfection, particularly chlorination, decreases the probability of a transgression. Though historical transgressions cannot be the cause of current transgressions, historical transgressions are predictive, possibly due to a common root cause of current and past transgressions. No attempt has been made to correct for confounding factors.

The indicators that appear to be significant, with the exception of remedial action and historical performance, are analysed further below.

Table 2: Relative risk associated with various indicators

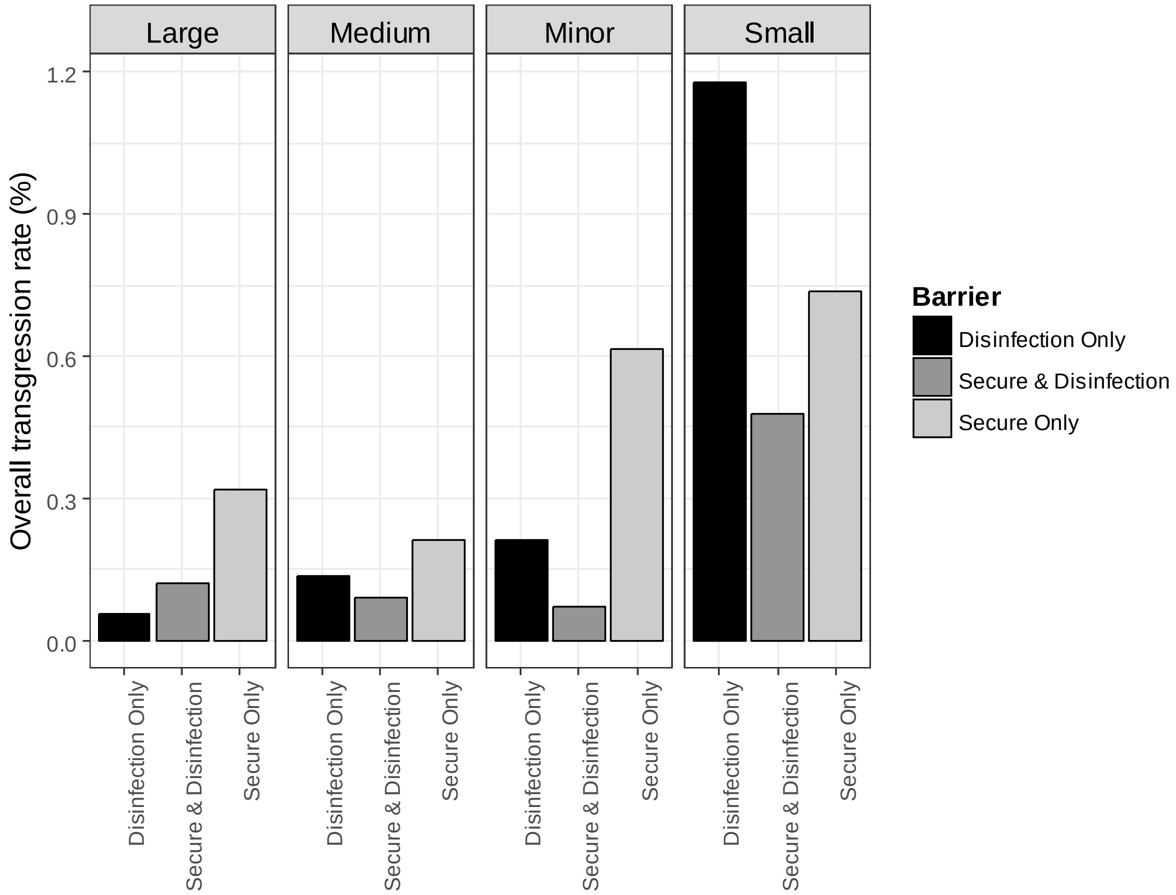
		Complied or first category		Non Comply or second category			
Barrier	**Indicator ratio**	**Zone Transgress**	**Zone No Transgression**	**Zones Transgress**	**Zone No Transgressions**	**Relative Risk**	**p**
Source Protection	69U Protection of Source water (Complied vs Non comply)	70	562	2	19	1.16	0.823
	Secure bore water relative all other source	***17***	***79***	***55***	***502***	***1.79***	***0.026***
	GW non secure relative to surface source	20	175	32	291	1.04	0.898
	Secure bore water vs surface	***17***	***79***	***32***	***291***	***1.79***	***0.039***
	Mixed vs surface only	3	36	32	291	0.78	0.659
Treatment	***Disinfection vs no disinfection***	***50***	***496***	***22***	***85***	***0.45***	***0.001***
	Chlorination vs no disinfection	***31***	***458***	***22***	***85***	***0.31***	***<0.001***
	Ozone vs no disinfection	0	12	22	85	0	NA
	UV vs no disinfection	24	163	22	85	0.62	0.082
	Transgression at plant vs no transgressions at plant	***24***	***45***	***48***	***536***	***4.23***	***<0.001***
Distribution	***Previous year had transgression in zone vs Previous year had no transgression in zone***	***32***	***27***	***39***	***346***	***5.35***	***<0.001***
Monitoring programmes	69Y Duty to Monitor (Complied vs Non comply)	60	512	12	69	0.71	0.247
	Bacteriological monitoring, (Complied vs Non comply)	61	527	11	54	0.61	0.114
	Days of the Week, (Complied vs Non comply)	67	541	5	40	0.99	0.985
	Interval, (Complied vs Non comply)	60	519	12	62	0.64	0.134
	Frequency, (Complied vs Non comply)	66	528	6	53	1.09	0.826
Response	***Remedial Actions (Complied vs Non comply)***	***58***	***570***	***14***	***11***	***0.16***	***<0.001***
Management/Risk management	Adequacy (Complied vs Non comply)	70	571	2	10	0.66	0.533
	WSP (Complied vs Non comply)	64	539	8	42	0.66	0.246
	Records (Complied vs Non comply)	72	581	0	0	NA	NA
	Complaints (Complied vs Non comply)	71	575	1	6	0.77	0.783

3.1.5 *Size, security and disinfection*

The indicators identified as being significant in the relative risk section as well as the finding that zone size is an important factor were investigated further. Seven years of *E. coli* monitoring results were combined and grouped together by size of supply, treatment and source protection barriers. The results are presented in Figure 2 and exclude supplies without disinfection and those not using secure bore water. This approach takes no account of intragroup variability. Overall, supplies with no disinfection and lacking secure sources had transgression rates of 0.55%, 0%, 1.34% and 7.44% for large, medium, minor and small supplies respectively.

Comparing supplies with disinfection only with those using secure bore water only, the transgression rates were lower for disinfection than secure bore water, the exception being small supplies. Supplies that used a combination of secure source and disinfection, had lower transgression rates than supplies that used one or the other. In this case large supplies are the exception to this finding.

Figure 2: Transgression rate by barrier type (disinfection and security) and supply size



- ***Disinfection and security***

In 2015/16 a total of 546 out of 653 (83.6%) of zones used disinfection. A total of 96 out of 653 (14.7%) had sources regarded as secure. Out of the 96 supplies that had a secure bore water source, 38 (39.6%) had disinfection as well. A total of 49 zones, (7.5%) of the total had no disinfection or secure source.

- ***Transgression at plants and in zones***

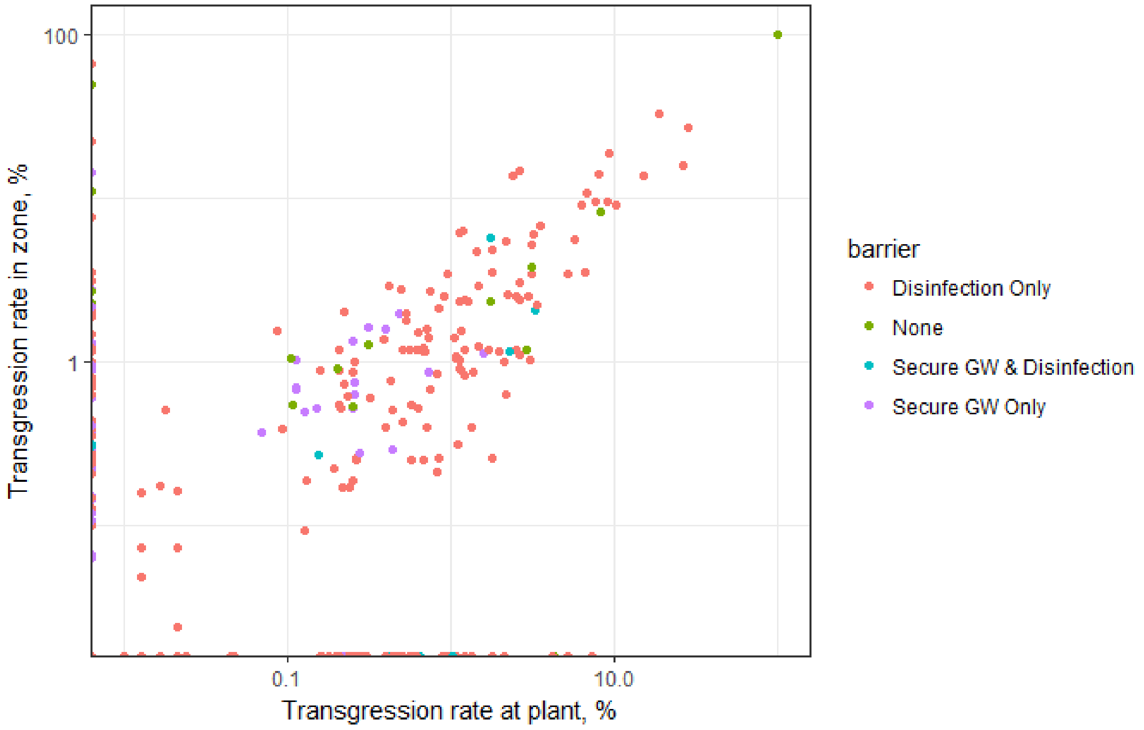
As identified in Table 2, the relative risk of a transgression in a zone was associated with transgressions in the plant. The preceding relative risk analysis did not distinguish between transgression rates, only the presence or absence of a transgression in 2015/16.

Focussing on transgression rates (proportion of monitoring samples that transgressed), Figure 3, there is a tendency for higher transgression rates in zones to be associated with higher rates in plants. However, there are cases where there are transgressions found at a plant and not in zones and vice versa. Of the 653 zones 594 were active in 2015/16 and had multi-year monitoring sampling data for both zone and the plant, 151 zones (25.4% of total) had transgressions at both the zone and plant, 75 had transgressions in zones and not at the plant (12.6% zones) and 67 had transgressions at the plant and not the zone (11.3% zones). As noted previously, there are different criteria for sampling at the zone and the plant. As the Survey does not collect comprehensive information as to the timing of individual samples, it is not possible to match up individual zone and plant samples, so there is no way of knowing if a transgression at a plant is directly associated with a transgression in the zone(s).

Though further analysis is needed, a visual inspection of the data suggests that the interpretation that some zone transgressions could be the result of treatment failures (ie, *E. coli* passing through the plant to the zone), whereas others may be due to *E. coli* introduced post treatment, is plausible and consistent with the data.

Full statistical interpretation of the data is complicated by there being different *E. coli* monitoring sample sizes (counts of samples) between zones, some zones being served by multiple plants and there being little information about the timing or relative contributions of individual plants to a zone.

Figure 3: **Transgression rates in zone and plant for individual zones made up of seven years combined data. Barrier classified on 2015/16 data**



- ***Different forms of disinfection***

The two main forms of disinfection currently used are chlorination and UV irradiation (546 out of 653 zones used at least one of these forms of disinfection). In 2015/16, 489 (75%) and 187 (29%) zones were recorded as using chlorine or UV radiation to disinfect their water, respectively. Ozone is not widely used, 12 of 653 zones used this form of disinfection in 2015/16, so it is not considered further.

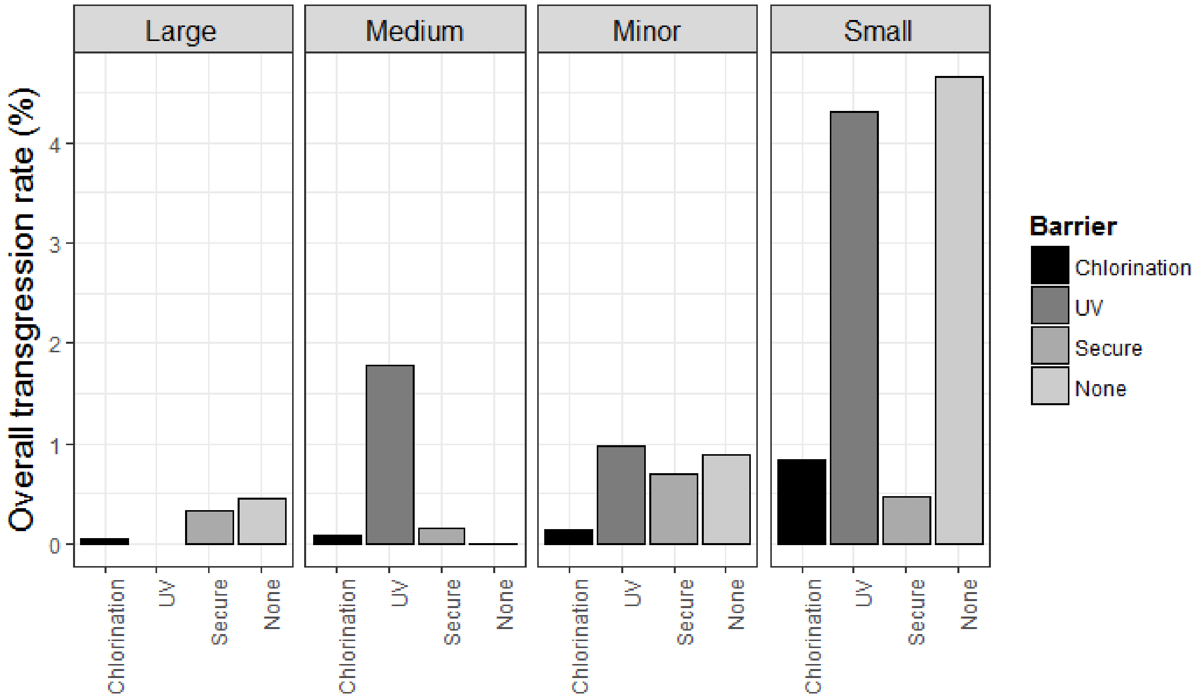
When considering treatment barriers, chlorination was identified as lowering the relative risk of a transgression vs no disinfection (relative risk 0.31, p <0.001). UV irradiation also had a lower relative risk compared with no disinfection (relative risk 0.62, p = 0.082), but because of its p-value was not considered statistically significant.

Information on which zones were using chlorination and maintaining a chlorine residual throughout the distribution system is limited. It is based on whether the supplier chose to use compliance criterion 6B of the Standards. This criterion allows suppliers to reduce monitoring provided they maintain a residual. As few suppliers chose this criterion, even when anecdotal evidence suggests supplies do maintain a residual it is doubtful this indicator can differentiate supplies with a residual from those without, so was not used.

There are various combinations of disinfection and groundwater security that are used. To keep the analysis simple, only zones which use either chlorination or UV irradiation were considered. To ensure the type of disinfection was the standard process, only zones in which the form of disinfection was the same for six or more years were considered. Secure bore water was included on the same basis. The "None" category consists of zones that had not had any combination of disinfection or groundwater security for 6 or more years. Some of these zones may currently have some form of disinfection. As a consequence, the rates in Figure 4 may differ from those in Figure 3. This is intentional and gives a different view of the data. For instance, changing treatment may result in initial difficulties with water quality or it may be in response to water quality problems, so cause and effect are unclear. Focusing on the results as representative of the longer-term performance of the barriers is expected to be more informative.

As noted previously, the transgression rates appear to be a function of the size of supply. Rates increase with decreasing supply size. No large zone relied solely on UV disinfection for six or more years. Of the other size categories, zones relying on UV disinfection had higher transgression rates than those using only chlorination or secure bore water. In addition to possible treatment failure (which may not be as readily detected in UV systems without sensors), UV offers no protection against recontamination in the distribution zone.

Figure 4: Overall transgression rates by zones which use UV disinfection, chlorination, secure bore water and those that do not use these barriers or a combination over the longer term. (Only zones having six or more years' data included)



3.1.6 *Secure vs disinfection*

The preceding analysis identified, among other things, secure bore water as a risk factor whereas disinfection was a protective factor against *E. coli* transgressions. However, the type of source water and the choice of disinfection, used or not, may be related.

An analysis of the relationship between transgressions, source water and disinfection is carried out in this section. To simplify the situation, the focus was only on supplies that either sourced all their water from secure bore water or from supplies that did not get any their water from secure borewater, and supplies that used chlorination with supplies that did not use disinfection. As in the preceding analysis only supplies active in 2015/16 were considered.

Of the 96 zones that sourced their water from secure sources, 38.5% used chlorination. Of the 536 supplies that used water that was sourced from non-secure sources 81.5 % were chlorinated. So, there is a tendency for supplies without a secure source to use disinfection.

Focusing on transgressions and the source of water, the results of a logistic regression model analysis estimate that odds of a transgression are 1.92 (p=0.031), that is, transgressions are more likely in supplies using a secure source than in those without. This is a similar result to that presented earlier in Table 2.

As it was noted that source water security and disinfection are related, what happens to the likelihood of a transgression with respect to source water if we control for disinfection? The odds of a transgression for supplies using a secure source relative to the others are 0.96, so supplies using a secure source are less likely to have transgression, controlling for disinfection. However, as p=0.906, this is statistically insignificant, meaning we cannot distinguish between the performance of supplies with secure sources and supplies without a secure source once we have controlled for disinfection. However due to the small sample size, some caution must be used when drawing conclusions from this analysis.

Overall, there is a tendency for supplies with secure sources to be more likely to have transgressions than supplies with non-secure sources. The difference appears to be more related to the fact that supplies with a secure source tend not to use disinfection, rather than secure sources being riskier than other sources.

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4. DWA INTERVIEWS

4.1 INTRODUCTION

The following section provides the results of a series of interviews with DWAs about individual transgressions. The interviews complement the statistical analysis, by accessing information and opinions not captured by the Survey.

The following sections discuss:

- monitoring
- notification of transgressions
- investigation of transgressions, including likely cause and follow-up sampling
- remedial actions taken.

4.2 MONITORING

Water suppliers are required to carry out routine *E. coli* monitoring. Though the DWAs could not provide information about the nature of the test methods used for all the supplies discussed, there was a mix of presence/absence *E. coli* testing and enumeration testing, with some suppliers having used a mix of presence/absence and enumeration.

In the light of information coming from the Havelock North Inquiry, one supplier started using enumeration for routine testing from the start of 2017, and in another district the public health unit (PHU) had been encouraging water suppliers to use enumeration for routine testing. This advice was not being followed at the time of the interview.

It may be that in-house laboratories tend to use presence/absence *E. coli* tests whereas commercial laboratories tend to use enumeration tests.

4.3 TRANSGRESSION NOTIFICATION

Figure 4.2 of the Standards requires water suppliers to inform the DWA of an *E. coli* transgression and section s69ZZ(2) of the Act requires laboratories to inform the DWA. The interviews revealed that in most cases, the PHU was notified of the transgression by the water supplier. In the remaining cases the laboratory notified the PHU. The DWAs were only ever notified by either the water supplier or the laboratory, never both.

One DWA noted that there was an agreement that the laboratory would be responsible for notifying the DWA of a transgression rather than the water supplier. Another DWA explained that one laboratory would not notify the PHU directly, because they did not have a system set up to do this.

In several transgressions covered by the interviews, the water supplier used their own in-house laboratory. In these situations, it could be argued that the supplier had fulfilled the requirements of the Act and the Standards, but neither water suppliers nor laboratory staff were interviewed in this work to support this speculation.

Had laboratory staff and water suppliers been interviewed they may have shed light on laboratory's' perceived legal position about providing results to a party (the PHU) other than the entity that had paid for the analysis.

The interviews focused on specific transgressions recorded in the Survey. Consequently, DWAs were expected to be aware of the transgressions discussed. However, there was a view expressed by one DWA that they may not hear about transgressions in some of the smaller supplies not run by a local authority. Otherwise, the non-reporting of transgressions, were not considered a problem by the interviewees.

Among the immediate actions a water supplier needs to take in response to an *E. coli* transgression, informing the DWA is one. There was evidence that some notifications were delayed. One DWA noted there was a delay in being informed because the wrong email address was used. As a result, by the time the PHU became aware of the transgression the follow-up sampling was complete. In another case, the PHU was notified on the Monday morning when the supplier had been notified by the laboratory of a transgression on the previous Saturday. Possibly the supplier did not realise that PHU staff work at weekends so that informing the DWA could have been more timely. Water suppliers in that PHU region have been reminded of DWA afterhours contact details.

4.4 THE INVESTIGATION

Upon finding a transgression, an investigation must be carried out. In all but one of the transgressions included in the study the water supplier undertook the investigation. In the case of the exception, a very experienced DWA undertook the investigation because the cause of a previous transgression in the same supply had been incorrectly identified. This had resulted in the further transgression. The DWA stepped in to ensure the problem was properly managed. In brief, there had been problems with maintaining a satisfactory free available chlorine (FAC) residual. The water supplier ascribed this to depletion of the chlorine supply. The chlorine supply was replenished and although the first follow-up sample was positive for *E. coli*, the next three were clear. The water supplier took this as evidence that the problem was rectified, but problems with low FAC residuals persisted. The DWA suspected that there was a further underlying problem that had not be identified. On investigation he found that the chlorine pump had failed.

Though DWAs generally do not get involved in the investigations, the circumstances that might lead to their getting involved included:

- Repeat transgression (similar to the situation described above).
- Water supplier lacking the necessary expertise and resources, as might be the case for a small private supply.
- Evidence of a possible waterborne outbreak.

Some DWAs noted that they check with their communicable disease team within their PHU for any evidence of waterborne disease. Presumably if a transgression coincided with a possible waterborne outbreak, then the DWA would get involved, irrespective of the supplier's size and resources.

There were several reasons DWAs did not get directly involved with an investigation.

- The DWA did not consider their involvement necessary when there were repeat transgressions, where the probable cause was known, the supplier was taking appropriate immediate action and future planned capital expenditure laid out in the WSP would solve the problem in the next few years,
- The cause of the problem appeared clear to the water supplier when they started the investigation, or the cause of the transgression had been identified and rectified before, or when the PHU was notified of the transgression. As noted above, a substantial delay before the PHU was informed of the transgression sometimes contributed to the cause being identified and remedial action taken before the PHU became aware of the transgression.
- The DWA had sufficient faith in the water supplier's competence in investigating the transgression that they did not consider their direct involvement necessary. The water supplier was going above and beyond what was required, keeping DWA informed, "taking things seriously" and "didn't need to be pushed". In fact, there was possibly a belief that DWA involvement would have hindered and distracted the supplier from putting their effort into the investigation.
- One DWA observed that the Standards (Figures 4.1 and 4.2) make the investigation the water supplier's responsibility; the supplier consults the DWA when required.
- The water supplier provided the DWA with information about the investigation. In some cases, this information was provided as the investigation unfolded. At other times it appears the information was provided once the investigation was complete. DWAs use their judgement as to whether this information is satisfactory and they may go back to the supplier for further information.

- In some supplies the investigation did not appear to end with three days of samples free of *E. coli*. The supplier continued their investigation, which effectively formed part of their remedial actions.

4.5 FOLLOW-UP SAMPLING

The Standards provide an outline of the immediate action that must be taken in response to a transgression in the zone. A number of these immediate actions include collecting samples for *E. coli* testing. The water supplier should resample the distribution system at the location that originally tested positive, at adjacent sites and at the plant. Samples should be enumerated for *E. coli.* Resampling should carry on daily in the distribution zone until the samples test free of *E. coli* on three successive days.

The number of follow-up samples following a transgression discussed during the interviews varied from none to more than 30 individual samples. Sampling was usually taken at the original location of the transgression, and other locations informed by sanitary surveys and other information. Of the supplies that carried out follow up sampling, all used enumeration techniques.

When the DWA was able to identify the test method, all testing was done by an enzyme substrate method. Despite total coliform data being available from the enzyme substrate method, there were some water suppliers who the DWAs said did not provide the total coliform result. This may have been because the total coliform result was redundant for compliance purposes.

Remoteness can be a factor in taking follow-up samples. For one zone, the DWA explained there was an historical agreement, between the water supplier and the previous DWA, that follow-up samples would not be taken when the cause of the problem had been identified (and presumably corrected). Given that the supply was on a permanent boil water notice and had chlorination remedial sampling was somewhat redundant and not necessarily a good use of limited resources.

Some water suppliers take follow-up samples over a four-, or more, day period to cover themselves against a failure with the initial sample. This is longer than the minimum of three days required by the Standards, assuming *E. coli* was not detected in any of the follow-up samples.

When a routinely unchlorinated system is chlorinated to ensure the absence of *E. coli*, a problem arises in deciding when to take the follow-up samples. Protection of public health indicates the need for a swift response, in chlorinating the system, for example. However, follow-up samples taken while the system contains chlorine may give a misleading indication of the safety of the water when chlorination ceases, if the cause of the problem has not been accurately identified and rectified.

A problem that was identified in relation to several transgressions was how to decide when, following a long trail of follow-up samples with intermittent failures, the further detection of *E. coli* should be regarded as a new transgression. This situation suggests that either the problem had not been properly identified or properly fixed, or that the cause of the problem was outside the water supplier's control with the treatment available (eg, elevated turbidity events in the source).

4.6 THE CAUSE

In 24 of the 27 transgressions studied, a cause was identified. Treatment failure was the most common reason mentioned for the transgression. The direct reasons for these failures was either a change in raw water quality (eg, increased turbidity), which compromised disinfection, or a combination of faecally-contaminated source water and a treatment problem (eg, exhaustion of the chlorine supply, airlock in the chlorinator), which resulted in *E. coli* reaching the reticulation system.

In a few cases, contamination of water post treatment was identified as the likely cause. For example, ingress of contaminated surface water into storage tanks was believed to be the cause of a number of transgressions in supplies without chlorination.

In identifying the cause of some transgressions, the DWA believed that the cause was the same as it had been previously. This was found both when a change in source water quality seemed linked to the transgression and when there was post-treatment contamination. The assumption is probably valid, but in some cases, it is unclear whether a check for other possible problems was made because of the assumption.

Transgressions arising from treatment failure tended to occur in small zones. The zones in which the cause was identified as post-treatment, or could not be identified at all, tended to be the larger zones.

As well as the immediate reasons for transgressions, various indirect reasons for the transgressions were identified.

- A community committee has responsibility for the operation of the supply. For example, checking on supply operation (eg, chlorine stocks) appeared to receive low priority.
- Resources not allowing alarms to be installed, or not allowing frequent enough visits by the operator to the treatment plant. The likelihood of transgressions occurring, or

higher *E. coli* concentrations being detected post-treatment, increases when these failures coincide with poor source water quality (eg, elevated turbidity), which was the case in more than one supply. The operator in one supply failed to check regularly the UV intensity of the disinfection unit. This particular community was able to afford the installation of telemetry to page the operator's cell phone when low UV intensity is detected, and this has since been implemented.

- The water supplier has no control of what is happening in the catchment. In the case of one supply, natural events, such as slips, occur and the bushed catchment is so impenetrable that the supplier is unable to check on the occurrence of such events, or take steps to control them. This water supplier is attempting to use drones to survey the catchment. The DWA also noted that there are unsubstantiated rumours the person who owns the land at the supply intake may be sabotaging the water supply operation.
- The length of the reticulation presents difficulties in maintaining a satisfactory chlorine residual. The estimated length of the reticulation in one rural supply was 80 km. In this supply, the high chlorine demand of the source water added to the challenge of maintaining a satisfactory residual all the way through the reticulation.

It is likely that there are other indirect causes for some of the zones not identified during the discussions. It is interesting to note that in the interviews discussing transgressions in non-disinfected water supplies, the lack of disinfection was not mentioned as a cause.

Overall, the level of confidence in correctly identifying the cause did appear to be associated with the nature of the cause. When the supply was disinfected and it could be shown there was a failure in a component of the disinfection system, this was regarded as definitively being the cause of the transgression. In other cases, the proposed explanations were plausible and made sense to the DWA, but they could not definitely be shown to be the cause. In other cases, no cause was identified.

In a number of instances, it was noted that the transgression was preceded by an identified environmental change. The changes included heavy rainfall causing a rise in turbidity of surface water sources or increased ingress of surface water into the post-treatment part of the system.

Methodological error (false positive)

Previous work and anecdotal evidence suggested that the cause of some transgression was a false positive. A false positive result could be caused by methodological errors introducing

E. coli during the sampling stage or within the laboratory. A false positive could also arise because the test assay incorrectly indicates the presence of *E. coli* when it is absent.

False positives caused by methodological error were not identified as the cause of any of the transgressions studied. However, for one transgression in which the investigation could find no indication of treatment failure or changes in source quality that may have resulted in the disinfection system being overwhelmed, no conclusion as to the cause of the transgression was provided by the water supplier. The DWA's comment was: "On this occasion they did not say sampling error.", which suggests that on other occasions when the reason for *E. coli* detection could not be found, sampling error may have been suggested as the reason.

Anecdotal comments made by a couple of DWAs suggested that suppliers were more likely to blame a result on sampling or laboratory error if these activities were contracted out. We have no evidence to support or refute this.

4.7 REMEDIAL ACTION

There were a variety of remedial actions taken by water supplies. These actions included boil water notices, temporary chlorination, draining and cleaning tanks, flushing, ensuring the treatment system was working, installing alarms and enhanced monitoring. In some cases, for example where the cause was not identified, no specific remedial actions were identified in the interviews.

Boil water notices are permanent in some of the zones studied. In other cases, they are readily issued and in one case, because the water supplier can be virtually certain that a transgression will arise when the turbidity is elevated, the boil water notice is issued on the basis of turbidity before bacteriological test results are available. Issuing and cancelling boil water notices appears a much more readily implemented public health response in small systems than in the larger ones.

In some (rural) communities in one district, relatively high chlorine doses (up to 2 mg/L) are readily tolerated by the community. In other communities, the use of chlorination may be less acceptable, as illustrated by a DWA referring to the use of a "dubiously low concentration" of chlorine. In one instance a probable cause of the transgression was found, a decision was made to stop chlorination before the cause was fixed. The supplier decided to manage the risk through increased monitoring (not just microbial monitoring) and activities such as spraying the outside of the apparently failed infrastructure with chorine solution.

Chlorination and or boil water notices was not an automatic response following a transgression. After a transgression in a large non-chlorinated supply, follow-up sampling was extensive; over 30 samples were taken, no cause was identified. One of these samples detected *E. coli*, other samples found elevated total coliforms. Remedial actions such as boil water notices and chlorination were not used in this instance.

Where a cause of failure has been identified, in principle, the water safety plan should be able to address the cause. But note that:

- small supplies struggle with resources to be able to implement necessary improvements (whether capital expenditure or staffing),
- a water safety plan may be approved, with an improvements schedule that notes the necessary improvements, but the planned implementation date may be some time off,
- supplies with continuing poor source water quality (eg, elevated turbidity) will continue to experience difficulties if the only barrier is a single disinfection step (ie, no particulate removal step).

4.8 DWA OVERALL ASSESSMENT OF THE TRANSGRESSION AND RESPONSE

Generally, the DWAs were satisfied with water suppliers' responses to the transgressions discussed.

Several reasons for an investigation's conclusion being considered correct (some of these the DWA noted directly, others are by inference) were identified.

- The reasons for the transgression were obvious (eg, chlorine exhausted), a definite explanation.
- The DWA was directly involved in the investigation.
- The DWA trusted the water supplier to undertake a thorough investigation – in one case, the supply had had on-going problems and the water supplier had provided a full description of what had been done. In another, the supplier took the issue very seriously, carrying out an extensive investigation and keeping the DWA informed.
- The cause of transgressions was well known and on-going, eg, the filtration system being overwhelmed so that UV disinfection was ineffective.
- There were plausible explanations for the investigation's findings, such as, following heavy rain, non-disinfected drinking water was contaminated by surface water entering a storage tank through cracks.
- In the case of one untreated groundwater sourced supply, the investigation found no likely source of contamination. The DWA was sufficiently satisfied with the adequacy of the water supplier's investigation, despite the absence of a conclusion.

5. DISCUSSION

5.1 INTRODUCTION

Several discussion points arise from the findings of this study. First we discuss limitations, with regard to both the statistical analysis and the qualitative analysis of interviews.

5.2 LIMITATIONS

Firstly, this is an observational study rather than an experimental study. Observational studies, such as the statistical analysis used here, can introduce various forms of bias, for example, when the outcome of interest, *E. coli* transgressions, can influence the risk factor, let's say the use of disinfection. So, cause and effect are intimately related and can potentially be misinterpreted and incorrect conclusions can be drawn when generalising the results. In an experimental study we would have greater control over variables and therefore would usually be able to draw stronger conclusions.

The interviews are a form of qualitative observational study. As well as the limitations mentioned above, there is a further complication with the small sample size. Only supplies that had repeat transgressions were included in the interview study. Consequently, there is little information about supplies that have had very infrequent transgressions over the last seven years.

Nevertheless, the findings can be treated as working hypotheses, some of which have stronger evidence than others. The use of multiple methods, interviews and statistical analysis together adds to the robustness of the findings.

5.3 OVERALL DISCUSSION

Overall, transgression appears to be an uncommon and transient phenomenon. Only about 0.3% of monitoring samples taken from zones resulted in *E. coli* detection. The observed rate of transgressions tends to be higher for smaller supplies than larger supplies. The fact that large supplies are more likely to report one or more transgressions during a year than smaller supplies reflects the fact that larger supplies are required to take more monitoring samples than smaller supplies.

Some supplies have significantly more transgressions in their zones than others. The variation of transgression rates in zone cannot be explained by chance. Certain indicators appear to be risk factors while others are protective against transgressions. These indicators include, history of previous transgressions, transgressions at the plant, disinfection and the nature of the source water.

One of the most significant risk factors for transgressions appears to be transgressions in previous years (RR=5.35). This suggests that there may be some common and underlying cause for past and current transgressions. There also appears to be an implicit assumption when transgressions are being investigated, that the cause of the current transgressions was the same as previous. This may be a reasonable assumption; however, it may also prevent suppliers investigating alternative explanations and causes.

Even though the cause may be identified, the supplier, for whatever reason, may be unable to mitigate the risk.

Disinfection is a protective factor against transgression (RR = 0.45). By far the most common form of disinfection is chlorination. The data do not provide a good picture as to the extent water suppliers maintain a residual in the reticulation system.

Secure source water appears to be a risk factor (RR = 1.79). Supplies using secure bore water have a higher likelihood of a transgression than those supplies that do not source all their water from secure sources. Delving deeper into the data suggests that source water and the use of treatment are related. Supplies that source their water from secure sources are less likely to use treatment than supplies that obtain their water from other sources. When an adjustment is made for disinfection, supplies using secure bore water are at no higher risk than other supplies.

This study did not investigate the reasons for water suppliers choosing type of treatment. The interviews and statistical data point towards:

- current format of the Standards used to assess risk
- criteria for assessing bore water security
- water safety plan process
- availability of human and financial resources
- expectations of customers (consumers of drinking-water)

are all expected to be factors.

Transgressions at the plant (RR = 4.23) are also associated with transgressions in the zone, though the data from the Survey cannot directly link transgressions in the plant to those in the zone. Results from the interviews suggest, that when the reasons were found, the most common cause of zone transgressions was treatment failure, which could be related to changes in source water quality and or treatment problems.

As well as treatment failure, some causes were tracked to post-treatment failures, with untreated and contaminated water entering some part of the reticulation system due to some form of infrastructure failure.

In many cases, it appears to be easier to identify failures in the treatment system when the supply has disinfection. There appear to be more challenges to identifying the cause of a transgression when it occurs post-treatment or in the absence of disinfection. At times it proves impossible to find the immediate cause of a transgression.

Though disinfection is a protective factor, it is not a panacea. Treatment can fail, either through treatment problems (eg, exhaustion of chlorine supply) or through changes in raw water quality (eg, turbidity) overwhelming the disinfection system. It appears particularly challenging for small suppliers to achieve satisfactory treatment. During the interviews it was suggests, this may arise because of lack of access to skills and expertise to manage the treatment system. In other cases, it may be poorer capital investment, meaning the systems lack the capability to manage challenges, which a large and sophisticated treatment system could withstand.

Reasons for failure associated with source water quality or treatment can be readily identified and, in principle, can be addressed by implementing water safety plans. Availability of resources appears to be a primary reason for these potential causes of transgressions not being addressed. Where small supplies are owned and/or operated, by their communities, questions of training, know-how, and prioritisation with respect to private responsibilities also appear to arise.

The extent to which DWAs are involved in investigations is mixed in the supplies serving smaller populations. The nature of the problem, the perceived competence of the water supplier to carry out the investigation, and the experience of the DWA influence the degree of DWA involvement.

With a few exceptions, DWAs are notified of transgressions by water suppliers, ie, they do not receive notification directly from the laboratory. Consequently, some laboratories, for whatever reason, are noncompliant with s69ZZ(2) of the Act, which requires the laboratory to notify the Director General (in practice the DWA) directly on finding a test result that fails an MAV set in the DWSNZ. Notification through the water supplier, rather than the testing laboratory, occurs with all sizes of water supply.

The 2015 report found sampling or laboratory errors being identified as the reasons for the detection of *E. coli* when intermittent *E. coli* detection was reported. These explanations were not offered for the transgressions examined in this study. Sampling and laboratory errors are not required to explain transgressions when other causes are evident, as was the case for the small supplies included in this study. The majority of supplies captured by the inclusion criteria in the earlier study used groundwater sources, often untreated. Reasons for transgressions, such as substantial increases in turbidity or the failure of the treatment system, were generally unavailable to explain their transgressions. This may have contributed to water suppliers turning more readily to attributing transgressions to sampling or laboratory errors.

In the transgressions studied in this work, DWAs were generally happy to let the water supplier undertake the investigation (which follows the responsibility assigned in the Standards). This appears to have worked in most instances. The skills and experience of the water supply staff have an influence on their ability to carry out satisfactory investigations. With the available information, it is difficult to determine how the water suppliers included in this study would have handled investigations had the causes not been as obvious as they were in most instances. Certainly, in the one case in which an experienced DWA stepped in to assist with the investigation, it appears that the water supplier had not been able to identify the second reason for the recurring transgressions.

The interviews showed there was diversity in the handling of transgressions. Constraints, such as geographical isolation, made it difficult for at least one supplier to undertake investigation. The more extensive resources available to larger suppliers apparently allows more wide-ranging investigations. This may relate to the type of corrective action the supplier chooses to use, for example, boil water notices appear to be more readily used by the smaller suppliers. However, this observation and inference needs to be validated with water suppliers.

Some responses, such as introduction of temporary chlorination, may interfere with the investigation into finding the cause of the transgression.

The interviews indicated Havelock North outbreak has led to a small increase, in the use of enumeration in the place of presence/absence testing for routine monitoring. The use of presence/absence testing for routine monitoring means that the concentration of *E. coli* in the initially transgressing sample is never known. Enumeration of follow-up samples cannot provide this missing information. The variability in microbial concentrations in water provides no assurance that the concentrations measured in follow-up samples are representative of the concentration in the initial sample. There is no direct association between *E. coli* concentration and the concentrations of pathogens in the water, but knowing the *E. coli* concentration provides an indication of the level of contamination. In turn, this indicates an appropriate level of response.

5.4 STUDY FINDINGS AND THE PRINCIPLES OF DRINKING WATER SAFETY

The *Report of the Havelock North Drinking Water Inquiry: Stage 2* (Government Inquiry into Havelock North Drinking Water 2017) identified six fundamental principles of drinking water safety for New Zealand.

Principle 1: A high standard of care must be embraced

Principle 2: Protection of source water is of paramount importance

Principle 3: Maintain multiple barriers against contamination

Principle 4: Change precedes contamination

Principle 5 Suppliers must own the safety of their drinking water

Principle 6: Apply a preventive risk management approach

Implementation of these principles should ensure the provision of safe drinking water; water in which determinand concentrations do not transgress MAVs. As this study was concerned with transgressions, does it provide evidence of the importance of these principles?

Information collected by the study does show the importance for some principles. For other principles, relevant information was not collected.

Figure 2 offers evidence of the benefit of multiple barriers (Principle 3). Although the concept of secure bore water is presently under review, generally, bore waters presently classed as secure are likely to be of better quality than surface waters and groundwaters not classified as secure. Abstraction of secure groundwater can be regarded as a barrier, albeit not one that can be controlled engineered treatment barriers. On this basis, the “Secure and Disinfection” barrier category in Figure 2 represents a water supply with two barriers, in contrast with the “Secure only” and “Disinfection only” categories in which only a single barrier is present. With the exception of the Large supplies, the transgression rates for the “Secure and Disinfection” category are lower than those of the other two categories.

Information from the interviews shows how water supplies are more vulnerable to transgressions during change (Principle 4). Several supplies experienced transgressions because of deterioration in source water quality following rain events. Generally, it was increased turbidity that compromised the efficacy of the disinfection process (either chlorine or UV irradiation).

The need for an improvement in water supplier’s standard of care (Principle 1) was also apparent from some discussions with DWAs. Small supplies, where regular checks are not made on the supply of chlorine or the UV lamp intensity, are vulnerable to transgressions through treatment failure.

The importance of source water quality or the protection of the source water could not be shown statistically in this study (Principle 2). When account was taken of disinfection the performance of supplies using secure groundwaters and those not sourcing secure groundwater could not be distinguished. However, the interviews showed that there were several instances of treatment systems being overwhelmed by increased levels of turbidity of chlorine demand during rain events. Better source protection in these situations would not necessarily reduce the threats created by turbidity or chlorine demand. Nevertheless, these findings show the consequences of poor source water quality on transgression occurrence and by implication the possible presence of pathogens.

5.5 POINTS FOR CONSIDERATION

- DWAs and water suppliers could be helped by providing advice on when and where follow-up samples should be taken after chlorination of a normally unchlorinated supplies in response to a transgression. Presently, there can be tension between the need to protect public health and the need to determine when remedial actions have been successful.

- The remoteness of some small supplies introduces practical difficulties in the use of follow-up samples for managing the response to a transgression. *Ad hoc* solutions have been agreed between DWAs and water suppliers in some situations. These agreements do not meet the requirements of the Standards, but may not necessarily create a risk to public health. Consideration should be given to modifying the requirements of the Standards to allow a practicable solution that does not place unnecessary demands on the resources of a small supplier while still protecting public health.

- Though the likely cause of a transgression may be found, water suppliers and DWAs should not discount alternative explanations. This should not be used as an excuse for not taking corrective action, or slowing down corrective actions, but the potential for alternative causes should be used to inform risk management.

- Chlorination is a protective factor against *E. coli* transgression; however, it is not a panacea. Disinfection can fail. Improved operation of chlorination in supplies drawing from surface waters is needed if transgression rates in these supplies are to be reduced to the levels observed in supplies abstracting from secure ground water sources.

- The Standards are set to ensure 95 percent confidence that a determinand does not exceed its MAV more than five percent of the time. The fact that the larger suppliers are required to take more samples than smaller suppliers (and that this can result in achievement of the Standards despite transgressions) means that suppliers serving smaller populations in effect need to have higher quality water to meet the Standards than a larger supply. Some consideration should be given to whether this aspect of the Standards makes public health sense.
- Although *E. coli* is an indicator of faecal contamination, its presence does not mean drinking-water contains pathogens, neither does its absence prove water is pathogen-free. However, its presence suggests a greater likelihood of the water being contaminated with pathogens than when it is free of *E. coli*. Water suppliers should not use *E. coli* as the only indicator of risk. They need to be vigilant against changes in the supply, or indicators, including, but not restricted to, heavy rainfall, turbidity and total coliforms, signalling an increased risk to water quality. Waiting for a positive *E. coli* result may not be a prudent course of action when other indicators suggest the possibility of contamination or heighted risk of contamination.
- Further work should be carried out to identify the role of treatment, other than disinfection, such as filtration, in influencing the likelihood of transgressions. In addition, it would be useful to review the results with water suppliers, particularly to understand the factors that influence how they investigate transgressions and manage risk.

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