E. COLI CONTAMINATION IN “SECURE” GROUNDWATER SOURCED DRINKING WATER SUPPLIES

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ABSTRACT

The Drinking-water Standards for New Zealand 2005 (Revised 2008) define a secure groundwater source based on the absence of surface or climatic influences, the security of the bore head and an absence of *E. coli* from regularly collected water samples. However, in some instances, apparently “secure” bores are still at risk of *E. coli* contamination. This paper provides examples of two such incidences.

Potential migration pathways for shallow contaminated groundwater into apparently secure boreholes include joins in the casing, possible migration down the borehole annulus and/ or an artificially increased hydraulic gradient through the natural strata. Based on the mixing model calculations used to define a secure groundwater source in the DWSNZ, some sources with high *E. coli* concentrations can still cause a threat of contamination to “secure” supplies. Detections of total coliforms are also an indicator of risk from surface contaminants that should not be ignored.

These risks need to be managed through appropriate controls on land use activities and discharges that occur within the contributory capture zones around water supply bores and through careful review of regularly gathered water quality monitoring data.

Keywords

E. coli, groundwater, drinking-water, contamination,

1 INTRODUCTION

The Drinking Water Standards for New Zealand 2005 (Revised 2008) (DWSNZ) define a secure groundwater source based on a demonstration that contamination by pathogenic organisms is unlikely because the bore water is:

- not directly affected by surface or climatic influences, as demonstrated by an absence of young water or a stable pattern of water quality determinands that are linked to surface effects, and

- abstracted from a bore head that is sealed from any inflow of surface water.

An ongoing sampling programme must demonstrate an absence of *E. coli* from regularly collected water samples to confirm the bore is accessing a secure groundwater source.

Public water supply bores that abstract from a secure groundwater source require a lower frequency of monitoring and can avoid treatment requirements that apply to other water sources. This is based on the reasonable expectation that they will not be affected by *E. coli* contamination.

However, some recent instances of *E. coli* contamination have shown that this is not necessarily the case. Occasional, one-off, detections of *E. coli* are not uncommon, particularly during wet weather sampling and there is always uncertainty as to whether they really indicate the presence of *E. coli* in the groundwater source or whether they result from sample collection and handling issues. However, there are some instances where repeat detections at elevated concentrations have occurred that imply the presence of *E. coli* within the groundwater source that is used by the bores.

This paper describes two such examples and considers the likely reasons for the detections and strategies to minimise the contamination risks.

2 EXAMPLE A. MIDDLE RENWICK ROAD BORE FIELD, BLENHEIM, 2008

2.1 THE ABSTRACTION BORES

The Middle Renwick Road (MRR) bore field comprises three bores that provide water to the Blenheim reticulated water supply during periods of high demand (typically in the months from September-May). The location of the bore field is shown in Figure 1. All three bores are screened from around 20 – 25 m deep in alluvial gravel strata.

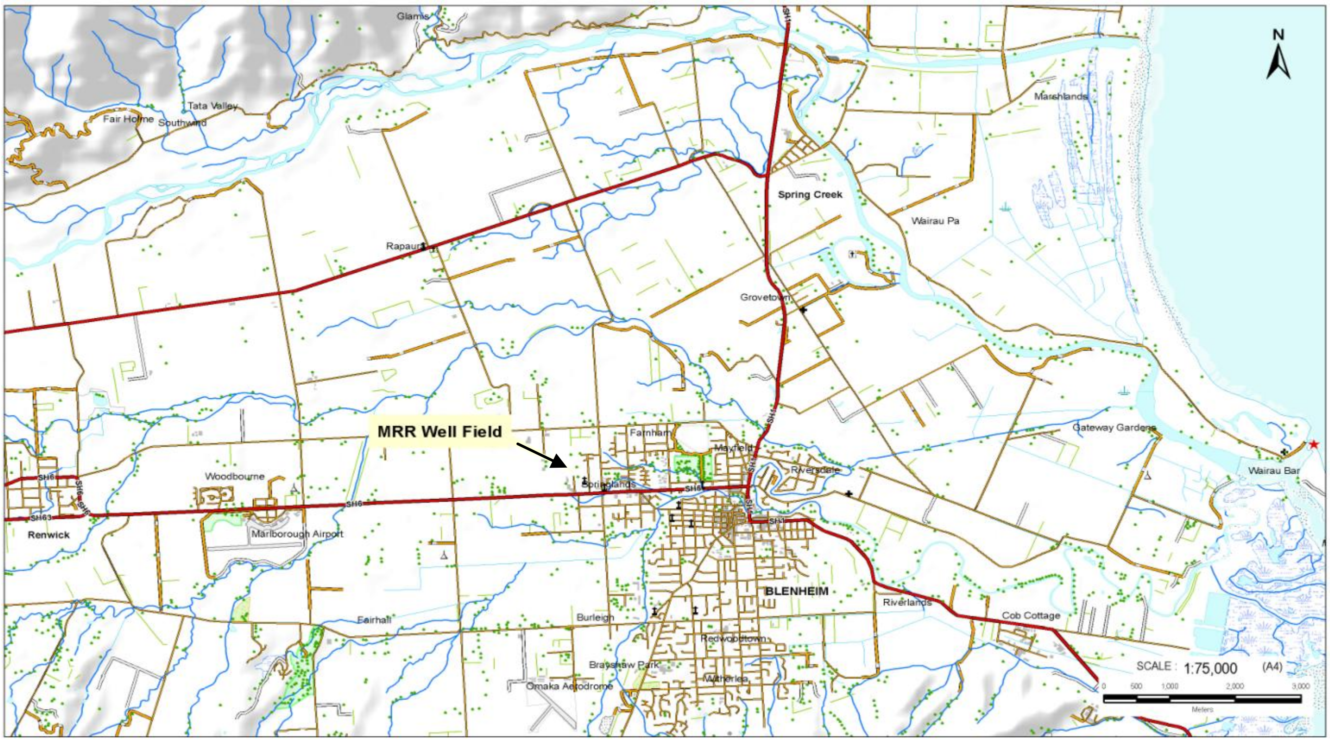

Figure 1: Location map

The bore field occurs within the extensive and high yielding Wairau aquifer. The primary source of recharge to this aquifer is the subsurface seepage from the Wairau River. The inland section of this aquifer (to the west of the MRR bore field) is unconfined and permeable strata extend to the ground surface. As a result, rainfall or any liquid contaminants can drain down into the aquifer, thereby providing a secondary source of recharge to the aquifer. However, from around the western edge of Blenheim, the Wairau aquifer becomes confined by a surface layer of finer grained lower permeability strata that overlies the gravel aquifer and becomes thicker in an eastwards direction. Figure 2 shows the inland (western) extent of this wedge of surface fine grained sediments. The MRR bores occur near the western (inland) edge of this surface confining layer.

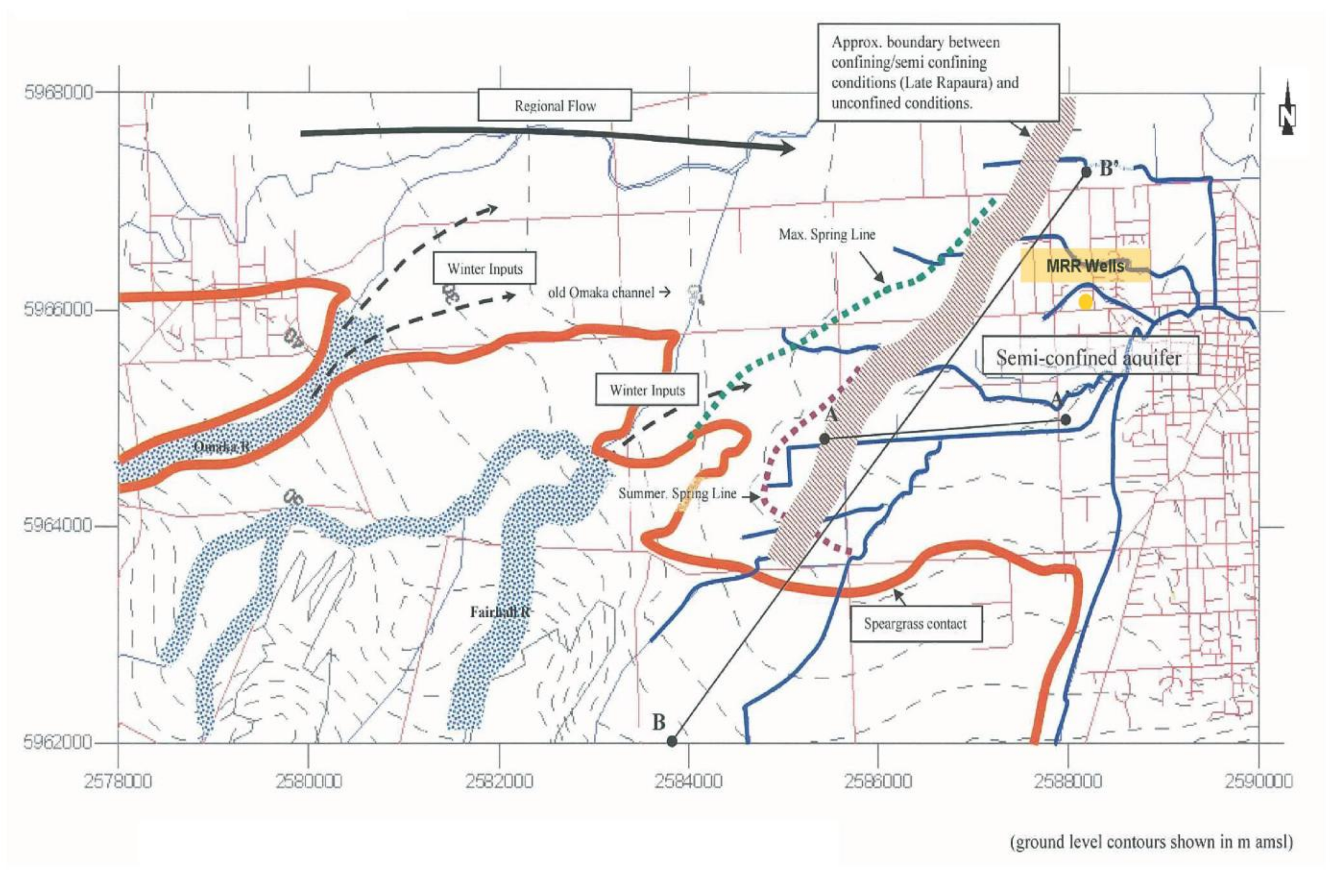

Figure 2: Conceptual Hydrogeological Model – Southern Springs (PDP, 2008)

Evidence to indicate that the MRR bore field occurs just within the western edge of the confined section of the aquifer is:

- the presence of clay and sand recorded in the drillers logs overlying the screened gravel strata;
- the static water level recorded in the drillers logs indicates an upward hydraulic gradient, which is consistent with the presence of nearby spring fed streams;
- MDC have reported a small tidally induced fluctuation that is apparent in water level records (with amplitude of around 20 mm). This is a characteristic of a confined aquifer system that extends out beyond the sea coast;
- MDC's analysis of a pumping test at this bore field had a low storage coefficient (1.1×10^{-4}), which is another characteristic of a confined aquifer system.

However, whilst the lower permeability clay and sand described in the drillers' logs will impede the vertical movement of water from the ground surface downwards into the aquifer, the strata is not completely impermeable and the drillers' logs indicate that most of the finer grained strata are mixed in with shingle (gravels).

The lateral gradient for groundwater movement in this area is generally from west to east. Therefore, the water that enters the bore screens is likely to mainly be water moving laterally from the area to the west of the bores in addition to a smaller zone of water that is captured by the drawdown cone around the bores, which will create some downwards and eastward flow in the vicinity of the bore head, due to the combined pumping effect of the three MRR bores, as demonstrated by the modelled drawdown cone shown in Figure 3.

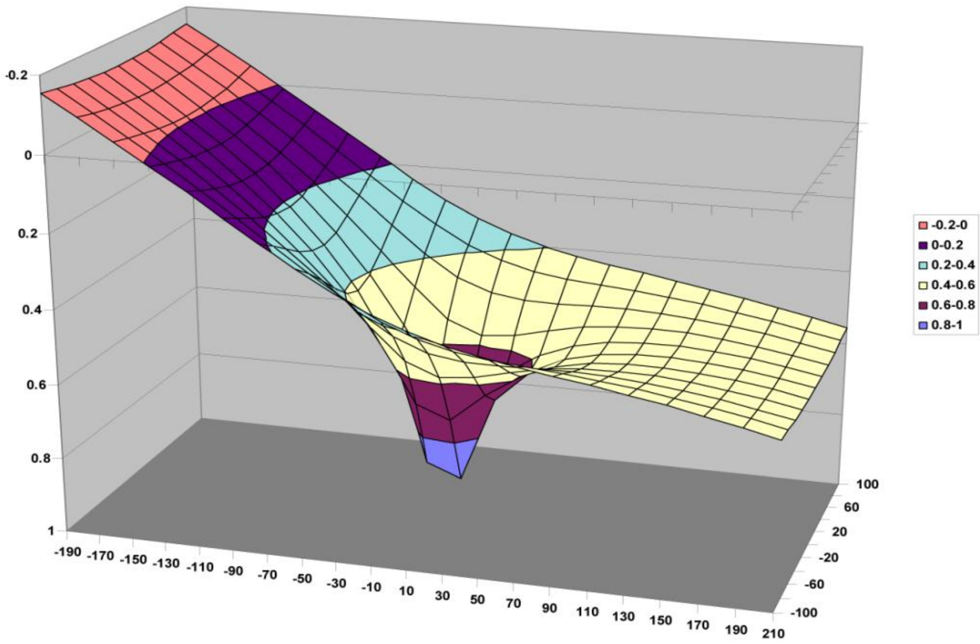

Figure 3: Three-dimensional Representation of Drawdown Around MRR Well Field Superimposed on Regional Water Table Gradient (PDP, 2008)

Static groundwater levels in the area are around 1 – 3 m deep and the pumping from these bores creates a drawdown at the bores amounting to an additional decline of around 1 – 2 metres.

Occasional measurements of electrical conductivity, chloride and nitrate-nitrogen have historically been made in the MRR bores and show some variability, as presented in Figure 4. The recorded values are all relatively low (nitrate-nitrogen < 4 mg/L, chloride < 7 mg/L and conductivity <20 mS/m), indicating good quality groundwater. However, the variation of measurements over time also provides a clear indication of shallower near surface groundwater having a greater influence on the MRR bores at certain times of the year.

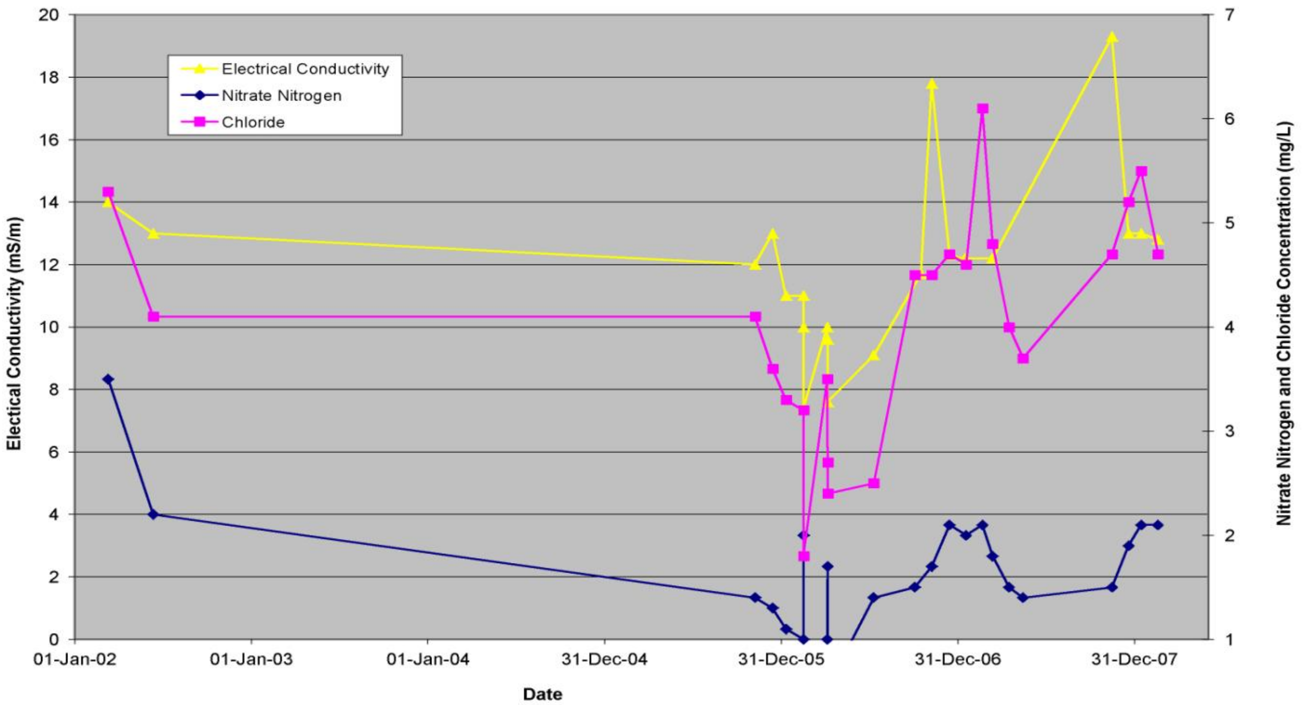

Figure 4: General Chemical Indicators (PDP, 2008)

Sampling has also been carried out at the MRR bores to determine the age of the groundwater, however the results were inconclusive due to the presence of low levels of CFCs within the groundwater. However, given the seasonal variation in nitrate-nitrogen and chloride within the bore and the relatively shallow depth from which the groundwater is abstracted (19-25 m), it is most likely that the Ministry of Health would classify the MRR bores as "non-secure" and vulnerable to bacterial contamination. Despite this, the bores have been in use for many years. One bore was drilled in 1965 and the other two in 1997. So they have a long history of use with no indication of water quality problems.

2.2 THE CONTAMINATION INCIDENT

In recent years, daily sampling of the water from the MRR bore field for faecal coliforms and *E. coli* has been carried out by Marlborough District Council (MDC) during those times when it is in use. On 29 January 2008, the microbiological contaminant indicator *E. coli* was detected in groundwater from the bore field, resulting in a boil water notice being issued for all Blenheim water users. *E. coli* continued to be detected on the following days and the bores were taken out of service.

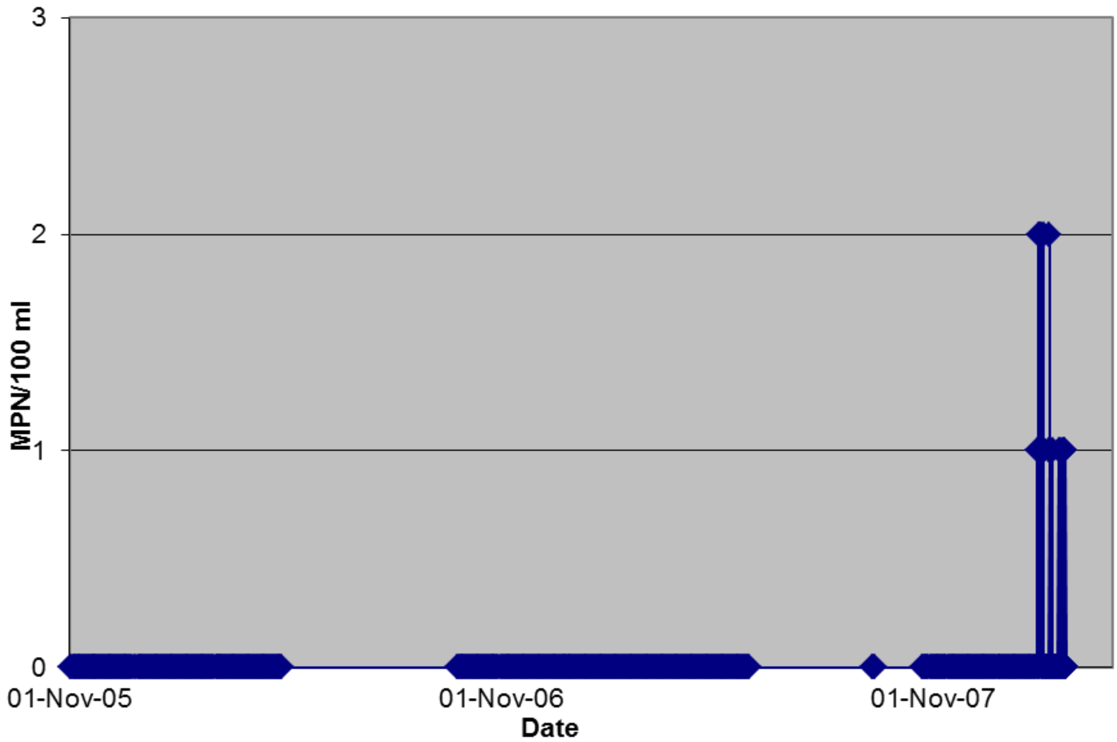

Figure 5: Historical Monitoring for E.coli Detections (PDP, 2008)

2.3 THE POTENTIAL CAUSE

The last two samples plotted in Figure 4 were collected on 14th January and 10 February 2008. The results show this was the time of year when land surface activities were having their greatest influence on the quality of the MRR bores, but the concentrations of nitrate-nitrogen and chloride were not unusually high compared to previous years. Similarly, the abstraction rate from the bores at the time of the *E. coli* detections was not unusually high.

Pumping test data from the MRR bore field was re-analysed to define a likely capture zone around the bore field from which the contamination is most likely to be derived. The zone was defined as extending about 165 m to the east of the MRR bore field, 260 m to the north and south and 1,200 m in a general westerly direction. Whilst the generally defined aquifer parameters indicate the average rate of movement of a particle through these strata occurs at a rate of 1-5 m/day, preferential flow channels for lateral migration within the gravel strata could be expected to occur at velocities up to around 200 m/day. Therefore the larger distance of 1.2 km in the general upgradient (westerly) direction is based on an assumption that *E. coli* could enter the aquifer and migrate along preferential flow paths to reach the bores. The length of this upgradient zone was based on work by Pang et al (2005), which indicates a 5-log reduction over 1220 metres of lateral flow in a contaminated gravel aquifer.

Potential contaminant sources such as those originating from human wastewater sources can have an *E. coli* concentration of around 1 x 10^6 MPN/100 ml and therefore require at least six log reductions to reach detectable concentration of 1 MPN/100 ml. However, at the very least it is assumed that one log reduction would occur as the contaminant migrates downwards to the 20 m depth of the bore screens and therefore no more than 5 log reductions would be required from lateral migration within the aquifer to achieve the observed concentrations.

On that basis, Figure 6 shows two zones around the bore:

- a highest risk zone at a distance of 90 m from the edge of the bore field;
- a lower risk zone extending out to 1,200 m in the upgradient direction from the bore.

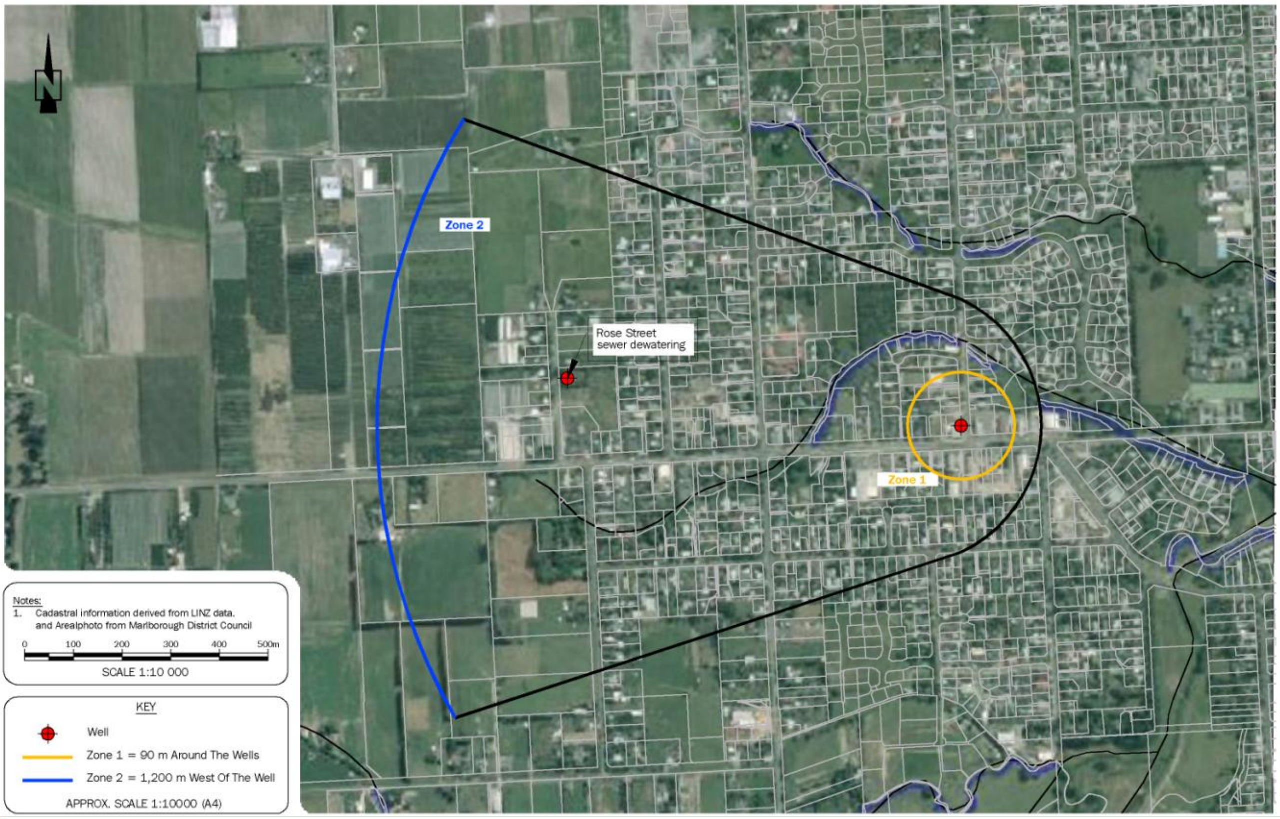

Figure 6 : Estimated Capture Zone For MRR Wellfield

Sources of contamination within this capture zone include leaky sewer pipes, septic tanks in the vicinity of Rose Street as well as some excavation works along Rose Street and their associated de-watering discharge that were taking place around the time that the contamination was detected. The Rose Street area is located around 800 m to the west (upgradient) of the MRR bore field and the de-watering discharge entered Murphy’s Creek via an open drain at a location around 400 m in a general westerly direction from the MRR bores.

Due to the history of good quality water being sourced from the bore field it was important to consider any changes that occurred at the time of the contamination. The findings of that analysis are summarized in Table 1.

Table 1: Summary of Sources and Pathways

<table>
<tr><th colspan="2">Potential E. Coli Source</th><th colspan="2">Potential Migration Pathways</th></tr>
<tr><th>Source</th><th>Likelihood of A Change in Late January 2008</th><th>Pathway</th><th>Likelihood of A Change in Late January 2008</th></tr>
<tr><td>Sewer leaks</td><td>Possible</td><td>Cracks in bore casing at shallow depth</td><td>Unlikely</td></tr>
<tr><td>Onsite sewage discharges</td><td>Possible</td><td>Migration down old bore casing at bore field</td><td>Unlikely</td></tr>
<tr><td>Rose Street sewer excavation</td><td>Yes</td><td rowspan="2">Drawdown into aquifer caused by bore pumping</td><td rowspan="2">Unlikely</td></tr>
<tr><td>Murphys Creek</td><td>Yes (due to discharge from Rose St de-watering)</td></tr>
</table>

As noted in Table 1, it seems unlikely that any of the migration pathways into the bores have changed significantly compared to previous years. Therefore, the most likely situation is that a new contaminant source (or an increase in an ongoing contamination source) has allowed *E. coli* to enter the groundwater along a flow path through which they can reach the MRR bores.

The Rose Street excavation de-watering activities are an obvious change that occurred at the time of the contamination, but the available information does not prove this conclusively and the development of a sewer leak or a failure of an onsite sewage discharge could have equally caused this situation.

The contaminants are expected to have entered the bores either through cracks in the bore casings at shallow depth or via the bore screens, with vertical migration to that depth caused either by leakage down an abandoned bore casing or migration through the gravel strata.

The frequency of detections reduced since the operational use of the water bores ceased, indicating that the drawdown of groundwater levels around the bore field during its summer operational pumping load was a contributing factor to the detections.

Given the uncertainty as to the contaminant source, the bores need to be managed on the basis that the MRR bore field could experience an ongoing risk of contamination incidents. This is what has transpired with continuous UV disinfection now in place.

3 EXAMPLE B: PRESTON DOWNS, WEST MELTON, 2012

3.1 THE ABSTRACTION BORES

Two water supply bores were drilled in 2008 to supply water to a residential subdivision in West Melton (around 10 km west of Christchurch). The location of the bores is shown in Figure 7 and they are known by their street locations as Elizabeth Allen Drive and Jacqueline Drive. The bores are drilled through semiconfined alluvial gravel strata and abstract water from around 95 - 101m deep. The water level is around 20m deep and the bores yield around 18L/s for a drawdown of 39m.

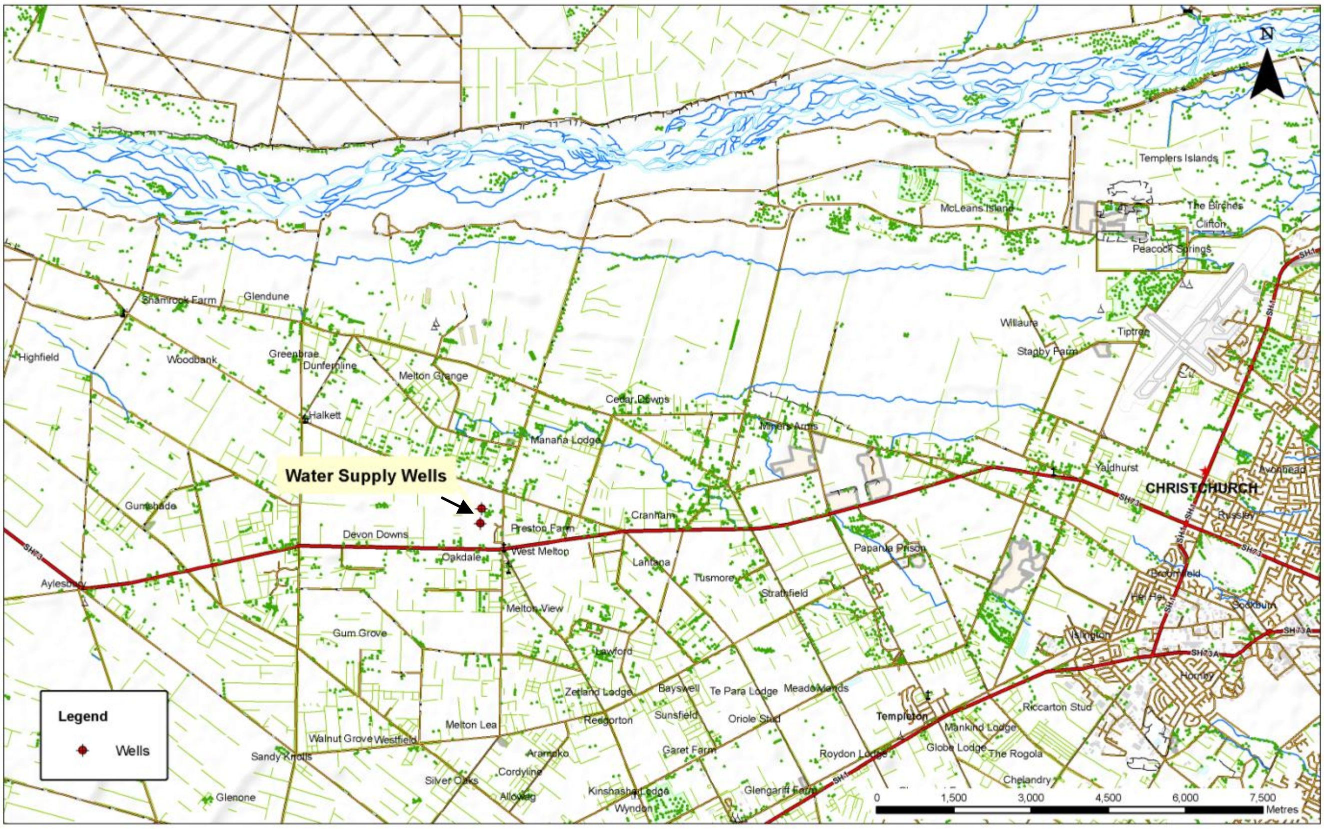

Figure 7: Location Map

Samples collected at the time of drilling indicated the bore is a source of good quality drinking water. *E. coli* were not detected, although total coliforms were present.

A groundwater age sample collected from the Jacqueline Drive bore produced variable information from the different tracers that were used. The results from the various tracers and the associated interpretive comments were:

- CFC-11: 29 years (+/- 3) - affected by diffusive exchange processes in the unsaturated zone resulting in the estimated age being a minimum
- CFC-12: <19 years – affected by contamination
- SF_6: 9.5 years (+/- 3.5) - affected by diffusive exchange processes in the unsaturated zone resulting in the estimated age being a minimum
- Tritium: 43 (+/- 6) - an ambiguous age depending on the parameters used in the mixing model

Whilst these results indicate a degree of uncertainty regarding the average groundwater age, the GNS mixing model associated with those groundwater age determinations showed that less than 0.005% of the water was younger than one year. The bore head was secure and on that basis the bore was given an interim secure status in accordance with DWSNZ.

3.2 THE CONTAMINATION INCIDENT

The bores commenced regular use for water supply purposes in September 2011. Sampling over this period has indicated variable instances of turbid water and total coliforms, as shown in Figure 8. The occurrence of elevated turbidity in these bores is typically associated with pump start-up or high rainfall events.

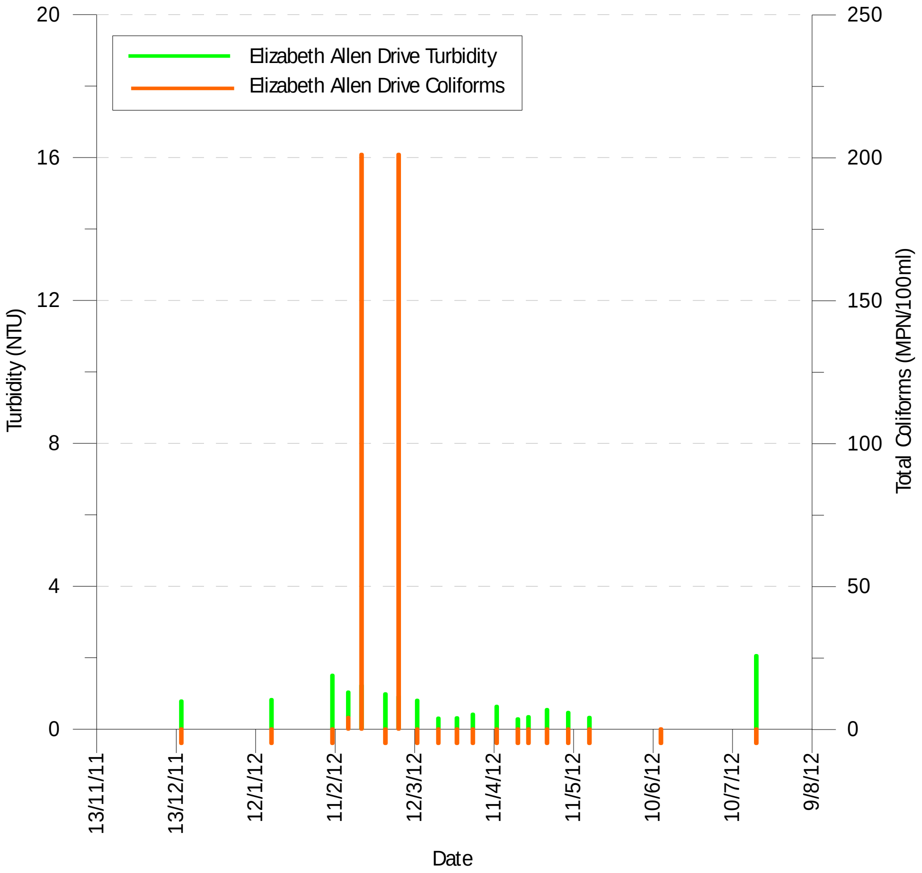

Figure 8: Elizabeth Allen Drive – Turbidity and Total Coliforms (PDP 2012)

No detections of *E. coli* occurred until a sampling round in August 2012 following turbid water being observed in the reticulation. The results are plotted in Figure 9 and as a result the bores were taken out of service.

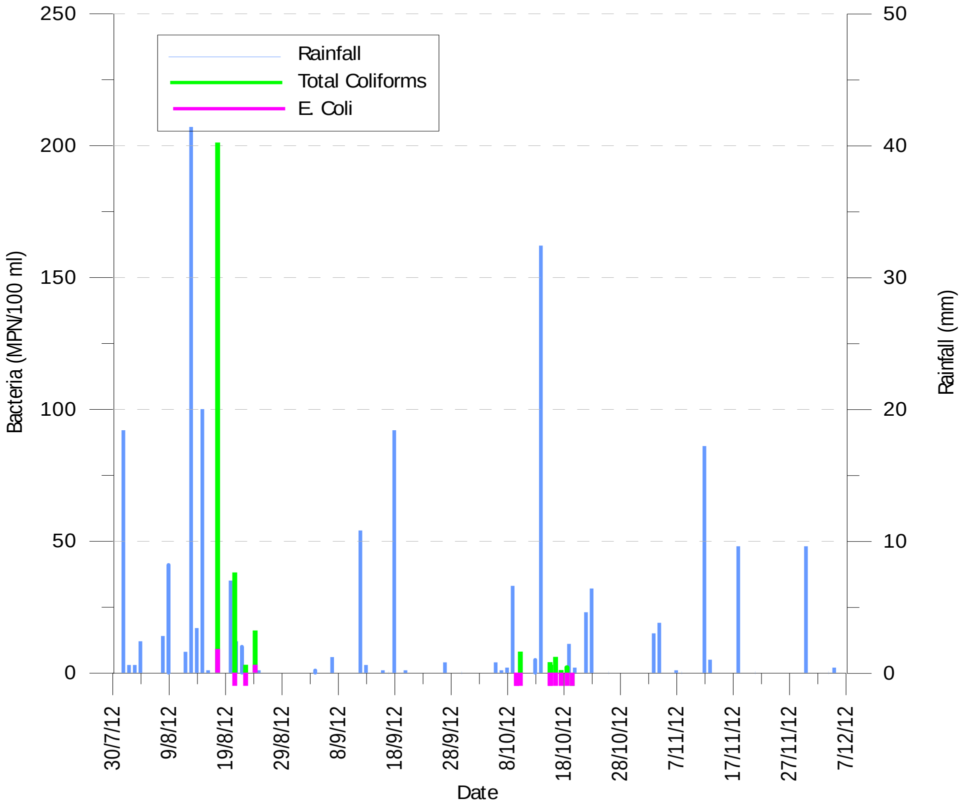

Figure 9: Bacteria counts and Rainfall for samples collected from Elizabeth Allen Drive well since first observations of poor water quality (PDP 2012)

3.3 THE POTENTIAL CAUSE

Inspections of bore heads and down hole camera inspections revealed no obvious pathway for contamination to enter the bore, although both these methods of inspection had limited resolution. Whilst the Christchurch and Darfield areas experienced significant earthquakes in late 2010 and 2011, the lack of *E. coli* detections since September 2011 give no indication of an ongoing problem arising from those disturbances. Nearby sources of contamination include stormwater soakage ponds, reticulated sewerage and stockwater race soakage. However, the occurrence of the *E. coli* detections does not always coincide with stormwater events.

The sewer reticulation is recently installed and should be of good quality with relatively few leakage problems.

There have been changes to the stockwater races that run in a southerly direction along the western Preston Downs subdivision boundary. The water race is sourced from the Waimakariri River which has reported *E. coli* concentrations ranging from 2 - 2000 MPN/100 ml and concentrations within the water race itself are likely to be greater due to land use and animal impacts along the water race channel. Previously these water races flowed into the paddocks and drained away through the soil over a relatively large area. However, during 2012 this surface soakage area was replaced by the construction of 4m deep soakage pits to intercept permeable gravels that provide a more rapid soakage pathway into the underlying strata. The soakage pits are located around 300 – 400 m to the west (upgradient) of the affected water supply wells. This change in soakage mechanism provides a possible source for the contamination incident.

However, since the original detections, a third deep water supply bore, located around 900 metres east of the Jacqueline Drive bore has also shown *E. coli* detections, which adds further uncertainty to the potential source mechanism. The water drawn from all three wells now receives UV treatment, with a series of automated valves that flush turbid water to waste and ensure the effectiveness of the UV treatment system.

Bacteria occur naturally in almost all groundwater systems, however coliform bacteria are generally not found in subsurface sediments (Chapelle, 2001). Coliform bacteria are naturally found in soil, vegetation and they are universally present in large numbers in the faeces of warm blooded animals. Therefore the presence of coliform bacteria in samples of water from deep bores implies the presence of a pathway between the shallow surface environment and the deeper groundwater intercepted by the bore (United State Geological Survey, Water Resources Division, Michigan District, 2007).

E.Coli bacteria are a subgroup (genera) of the overall coliform bacteria group. However, unlike the general coliform bacteria, *E.Coli* are almost exclusively of faecal origin (Foppen & Schijven, 2006), and therefore their presence in samples of groundwater indicate a connection with a nearby surface environment that is contaminated with animal faeces.

As bacteria move from their surface source through the soil zone their concentrations will reduce due to bacterial die off and filtration, often by orders of magnitude (Reneau & Pettry, 1975), although the types of soils present will influence the level of reduction. Further reduction also occurs within the groundwater environment itself (Pang et. al, 2005). As a result, detections of coliform bacteria (including *E.Coli*) in samples from deeper groundwater imply either;

a. a source with sufficiently high concentrations that concentrations are still observed in deeper bores; or

b. rapid movement from the source to the aquifer allowing limited bacterial reduction between the source and receptor.

Either one, or a combination of both, of these scenarios could allow coliform bacteria from the surface environment to reach a bore in measureable quantities. Therefore the detections of total coliforms and *E.Coli* in the Preston Downs bores may be somewhat inconsistent with the results from the groundwater age analysis indicating the occurrence of only a very small percentage of young water in the well.

4 DISCUSSION

Explanations for the occurrence of *E. coli* detections in water supply can rarely be provided with 100% certainty. The detections are typically quite variable and could be derived from a range of potential sources, either in the ground, at the bore head, or due to sampling procedures. Rainfall patterns, pumping rates and durations, groundwater levels and variable conditions of potential contaminant sources all contribute to the potential contaminant migration mechanisms and are all highly variable. In the two examples described above, the repeated detection of elevated *E. coli* indicates they are most likely derived from the groundwater source entering the bores. Furthermore, the fact that the detections occurred following an extended period of no detections indicates a change in conditions has occurred. That information leads to the identification of likely contamination sources, although they are not conclusively proven.

In both instances the Council staff were correctly implementing the DWSNZ and their rapid response to the detection of *E. coli* prevented any reported health incidences. However, despite these correct measures the contamination incidents still occurred in bores that had previously indicated an acceptably low level of risk, so it is helpful to consider what more could be done to avoid the problem.

The examples do indicate the importance of understanding the hydrogeological conditions around water supply bores and the potential migration pathways for contaminants originating from the land surface. It is interesting to note that the secure groundwater definition for young water in DWSNZ of 0.005% could still result in a breach of the Standards (detectable *E. coli*/100ml) for concentrations of 2.0 x 10^4 *E. coli*/100ml based on a simple mixing model. Such sources include domestic wastewater, many industrial wastewaters, stormwater generated from some land areas and some surface water bodies. Therefore additional attenuation is required to occur between the contaminant source and the bore intake screen to ensure that the DWSNZ limits are not breached.

Understanding the location of these potential sources, separation distances and potential migration pathways to wells can allow site specific identification of likely contamination sources for each water supply and whether any changes in these sources occur that might trigger an increased risk of contamination (such as excavations that create more rapid and deeper infiltration of contaminated water). Maintaining a register (as a living document) of these potential contamination sources that occur within the capture zone of a water supply well can help to identify any changes or situations of increased risk as they arise.

Variable results in groundwater age determinations indicate wells that may have a higher risk of contamination, as do the detections of total coliforms. For example, the USEPA (and others, including the WHO and the Canadian Ministry of Health) recommend the use of total coliforms as an indicator whereby no more than 5.0 percent of samples for total coliforms can be positive in one month (or for systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month). If a sample tests positive for total coliforms, the system must collect a set of repeat samples within 24 hours, and also analyze for faecal coliform or *E. coli.* The USEPA have adopted this policy because there have been water borne disease outbreaks where very low outbreaks of coliforms were found, suggesting that any level of coliform contamination indicates some health risk.

However, the presence of *E.coli* makes it very likely that other faecally derived bacteria (and viruses) are present (Krauss & Griebler, 2011). Given the occurrences of total coliform detections in the Preston Downs bore prior to the incidence of *E.coli* detection, active observation of total coliform concentrations in monitoring data may be a useful means of identifying where a bore is at risk, particularly where the age data is inconclusive.

Finally, the regular monitoring of water quality and review of sampling results to identify any changes that occur is vital to understanding the movement of water into the bore. The exact parameters and frequency of sampling should be determined on a case by case basis, but in addition to *E. coli* could include:

- Total coliforms, as an indicator of migration of organisms from surface soils
- Nitrate, chloride and electrical conductivity are conservative indicators that are elevated in land surface recharge and indicate variability in the effects of surface recharge throughout the year
- Electrical conductivity, as a general indication of total dissolved solids and how they vary throughout the year
- Turbidity – to determine its variability and potential cause

Variable results in some, or all, of these parameters, particularly when associated with rainfall events provides an indication of a higher risk of contamination, even in wells that have been classified as a secure groundwater source, or considered that way on the basis of many years of satisfactory performance.

5 CONCLUSIONS

The correct implementation of the DWSNZ, a long history of non-detectable *E. coli* and groundwater ages indicating no surface influence do not guarantee an absence of *E. coli* contamination. Such incidences can still occur due to the creation of new contaminant sources and/or more direct migration pathways within the capture zone of a water supply zone. Therefore, for all water supply sources (irrespective of their secure status) it is important to understand:

- the potential contaminant migration pathways into the bore, via the definition of capture zones that are specific to the bore
- the likely contaminant sources within that capture zone – which could be set out in a register that describes the time period over which the sources have existed
- the tracking of any changes to existing sources, or the introduction of new sources
- the regular sampling of groundwater quality to further understand the migration of near surface contaminants and how that migration pattern is changing between seasons and over longer time periods.

The active review of all this information is required to best manage the risks of water supply contamination, coupled with the implementation of appropriate controls on land use activities and discharges that occur within the capture zone of each bore.

6 ACKNOWLEDGEMENTS

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