PRELIMINARY HEALTH RISK ASSESSMENT OF NZ GROUNDWATER WITH PARTICULAR REFERENCE TO INFANT METHAEMOGLOBINAEMIA

Dr Jim Cooke and Dr Ngaire Phillips – Streamlined Environmental Ltd, PO Box 21-250 Rototuna, Hamilton

ABSTRACT

The short-term maximum acceptable value (MAV) for drinking water in NZ is 11.3 mg/L nitrate-N, which follows the accepted World Health Organization (WHO) Guideline Value. Risk maps have been produced which show that groundwater sites with nitrate concentrations that breach health standards are found in most regions, but are most common in dairying regions. In the Waikato, elevated nitrate concentrations have also been attributed to market gardening in areas where free-draining soils overlie a shallow water table.

However advice notes to the latest (4th edition) of WHO Drinking Water Guidelines make it clear that where water is microbiologically safe, water can be safely ingested (even by bottle fed infants) at concentrations up to 100 mg/L nitrate (equivalent to 22.6 mg/L NO_3-N). In this paper we re-examine data from 3 regions, as well as a national data set, and determine new risk maps based on both *E. coli* (a faecal indicator bacteria) and nitrate concentration.

KEYWORDS

Nitrate, groundwater, methaemoglobinaemia, risk, *E. coli*

1 INTRODUCTION

In a recent review Cooke (2014) examined international literature and guideline documents on nitrate in drinking water aimed at protecting infants (<3 months) from methaemoglobinaemia (a condition that causes impairment of oxygen transport to tissues) leading to cyanosis (blue discolouration of the skin – hence blue baby syndrome). Cooke (2014) noted that the weight of evidence was that the role of nitrate exposure alone in causing infant methaemoglobinaemia is minor and not sound justification for the present WHO Guideline Value (GV) in drinking water (50 mg/L equivalent to 11.3 mg/L NO_3-N). In contrast, there is evidence for a strong association between infant methaemoglobinaemia and microbial pollution of water and/or some other gastrointestinal disorder causing diarrhoea (Avery, 1999).

Yet, despite the general agreement amongst researchers that nitrate in drinking water per se has only a minor role in causing infant methaemoglobinaemia, the latest edition of the WHO Drinking Water Guidelines (WHO, 2011) retains the 50 mg/L nitrate guideline value (GV). However, in notes to the last two editions of the Drinking Water Guidelines WHO does recognize recent research stating: "...and that if water is microbiologically safe it can be used for bottle-fed infants if the concentration is between 50 and 100 mg/l (but not above 100 mg/L – equivalent to 22.6 mg/L nitrate-N). Thus the WHO has effectively doubled the nitrate GV provided the water is microbiologically safe. WHO's reticence in relaxing the general GV is understandable because in much of the developing world, drinking water is not microbiologically safe.

In New Zealand, our drinking water guidelines (NZ MoH, 2013) adopt the WHO nitrate GV as the maximum acceptable value (MAV). It is important to note that whereas most chemical MAVs reflect consumption of water with that maximum concentration for a life-time (70 years), the MAV for nitrate is only short-term (designed to protect bottle-fed infants). In other words, except for this vulnerable subgroup, there is no MAV at all.

However, because of the difficulties of having separate water supplies for infants and the rest of the population, water suppliers (and MoH) accept that the short-term MAV is, in reality, still a long-term MAV.

Nitrate levels in NZ municipal supplies are low and generally well below the MAV. High nitrate (>MAV) in drinking water is therefore only an issue in unregulated supplies, generally from groundwater. While there are reports of increasing trends of nitrate levels in NZ groundwater, there is no evidence of similar trends in microbial contamination. This may be because there is insufficient data to establish a trend, but published reports suggest that the incidence of microbial pollution in groundwater wells is low. For example the latest report on nitrate concentrations in Canterbury groundwater (ECAN, 2013) showed that 7% of wells sampled (305) had nitrate concentrations greater than the WHO GV, with about 60% in total having nitrate concentrations greater than 'background'. In contrast, only 10% of wells had *E. coli* (faecal indicator bacteria) even detected (detection limit 1 cfu/100mL), although the percentage detected was higher in shallow wells (18% in wells < 20 m deep). *E. coli* were detected in only one well > 50 m deep.

With the promulgation of the National Policy Statement Freshwater Management (2014) the scientific validity of the nitrate MAV has even more significance, as some Councils are using the MAV as one justification for setting limits (e.g. Scott, 2013). Similarly, MfE and some Councils are posting 'risk maps' in which median NO_3-N > 11.3 mg/L are coloured red, indicating a high risk to infants drinking water from that supply. Our view is that if authorities are publishing such risk maps, they should reflect the true risk of drinking that water.

In this paper we propose alternative criteria for presenting risk based on WHO's notes to their guidelines cited above. Based on these criteria we present a preliminary risk assessment for infant methaemoglobinaemia, based on nitrate and *E. coli* (an indicator of faecal indicator bacteria) levels in groundwater wells from three regions across New Zealand (Waikato, Taranaki, and Canterbury). We also used this approach to re-analyse national data presented in the 2009 update of the status of national groundwater quality indicators (Daughney & Randall, 2009).

2 METHODS

2.1 DATA

Groundwater monitoring data were obtained from three regional councils (Waikato, Taranaki and Canterbury). In addition, a re-analysis of data used in the report "National Groundwater Quality Indicators Update: State and Trends 1995-2008" (Daughney & Randall, 2009) was undertaken. Only sites where measures of both nitrate (in mg N /L) and *E. coli* (measured as cfu/100mL only) were available were included in our analyses. Table 1 provides details of the data used. It should be noted that the number of sites used in any one year varied. Values were averaged within each year for each site and then median values were calculated across years, to provide an annual average median value for each site. Median values for the period 1995-2008 for the New Zealand data were used as provided (Daughney & Randall, 2009; https://www.mfe.govt.nz/publications/ser/groundwater-quality-trends-2008/).

Table 1: Details of data used in analysis

Region		**Taranaki**	**Canterbury**	**Waikato**	**New Zealand**
Date range		2004, 2006-2007, 2011-2014	2004-2013	Mostly 2004 and 2008	1995 – 2008
Number of sites	All	82	354	45	683
	Shallow (<20 m)	57*	161	30	353*
	Deep (≥20 m)	11	193	15	291
Nitrate (mg/L)	Average	3.27	4.40	6.93	3.34
	Median	2.30	3.80	4.54	2.10
	Range	0.01 – 21.4	0.03 – 21.8	0.025 – 27.0	0 – 22.7

Region		Taranaki	Canterbury	Waikato	New Zealand
***E. coli* (cfu/100mL)**	Average	24.40	4.74	20.67	21.05
	Median	2	0.5	0.5	0.5
	Range	<1 – 505	<1 – 1234.5	<1 – 801	<1 -– 2400

* Depth data missing for some sites

2.2 RISK CATEGORIES

We defined risk categories for infant methaemoglobinaemia based on the presence of both nitrate and bacterial contamination (1 or more cfu/100ml *E. coli*). We also adopted the WHO recommendation of up to 22.6 mg/L nitrate-N in the absence of bacterial contamination (i.e., <1 cfu/100mL *E. coli*). On this basis, we assessed the regional and national datasets on the basis of the risk categories defined in Table 2.

Table 2: Risk categories for methaemoglobinaemia

Risk Category	Nitrate-N	Nitrate-N + *E. coli*
Low	<5.65 mg/L	<22.6 mg/L, <1 cfu/100ml *E.coli*
Moderate	5.65 - 11.3 mg/L	<11.3 and > 5.65 mg/L + ≥ 1 cfu/100ml *E. coli*
High	>11.3 mg/L	>11.3 mg/L and ≥ 1 cfu/100ml *E. coli* OR >22.6 mg/L, <1 cfu/100ml *E. coli*

2.3 ANALYSIS

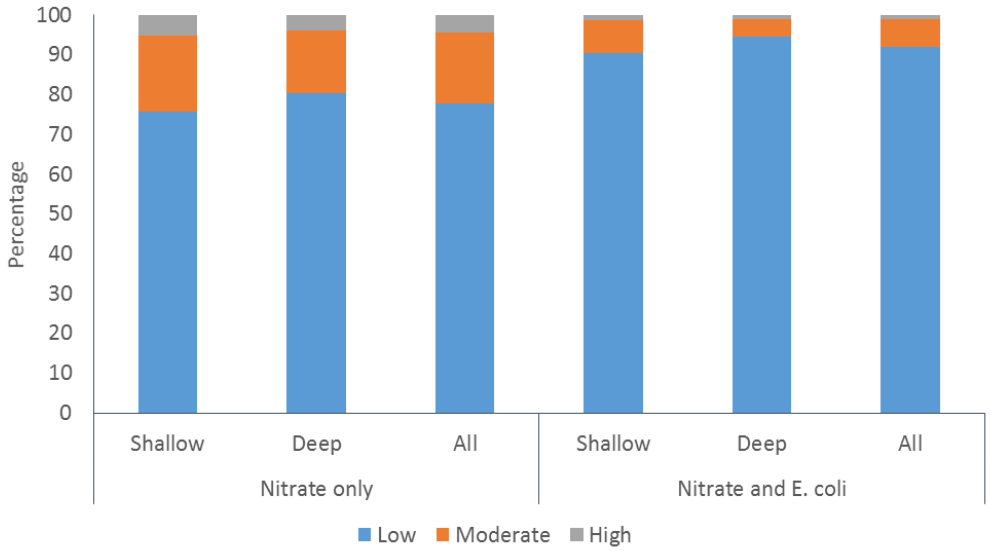
We examined the difference between the two approaches (nitrate only and nitrate + *E. coli*) for a) all sites and b) sites with a well depth ≥20m (deep) or <20m (shallow). Wilcoxon paired samples tests were used to test for statistical significance of differences between the percentage of sites in each risk category based on nitrate and on nitrate + *E. coli*. Significance was set at a p value of 0.05 or less.

3 RESULTS

3.1 RE-ANALYSIS OF MFE DATA (1995-2008)

The inclusion of *E. coli* as a factor in determining risk of methaemoglobinaemia resulted in a statistically significant change in the percentage of all risk categories (Fig. 1) ($p<0.0001$), as well as when shallow ($p<0.0001$) and deep sites ($p<0.0001$) were considered separately. A decrease in the percentage of moderate and high-risk sites was observed across all sites and in shallow and deep sites separately. Concurrently, there was an increase in low risk sites across all sites, as well as in deep and shallow sites separately.

Figure 1 Percentage of sites in risk categories: New Zealand

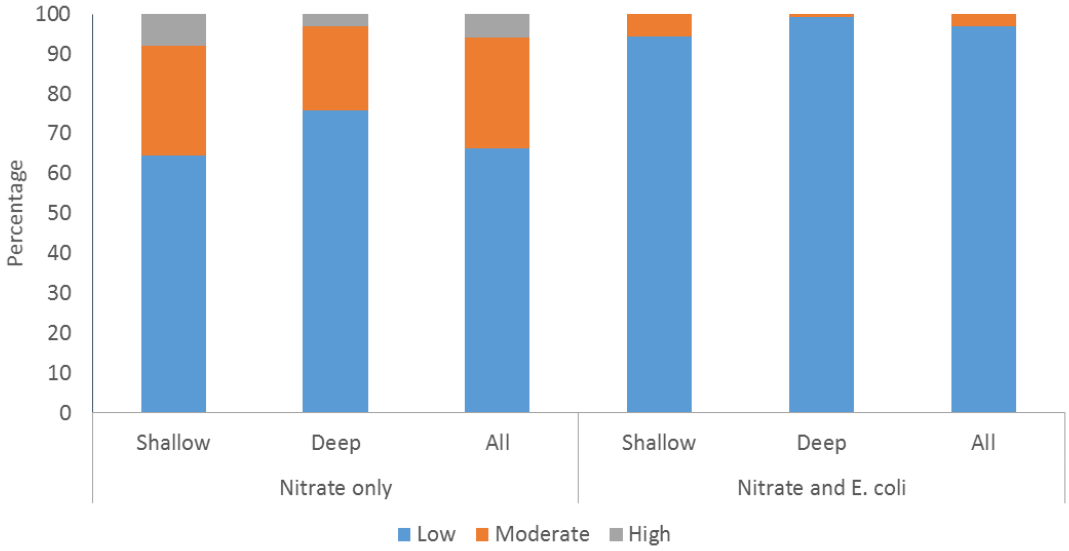


3.2 ANALYSIS OF REGIONAL DATA SETS

3.2.1 CANTERBURY

As for the New Zealand data set, the inclusion of *E. coli* as a factor in determining risk of methaemoglobinaemia resulted in a statistically significant change in the percentage of all risk categories (Fig. 2) ($p<0.0001$), and also when considered separately for shallow ($p<0.0001$) and deep ($p<0.0001$) sites. A decrease in the percentage of moderate and high-risk sites was observed across all sites and in both deep and shallow sites separately, with a concurrent increase low risk sites. The proportion of moderate and high risk sites was greater in shallow than in deep sites.

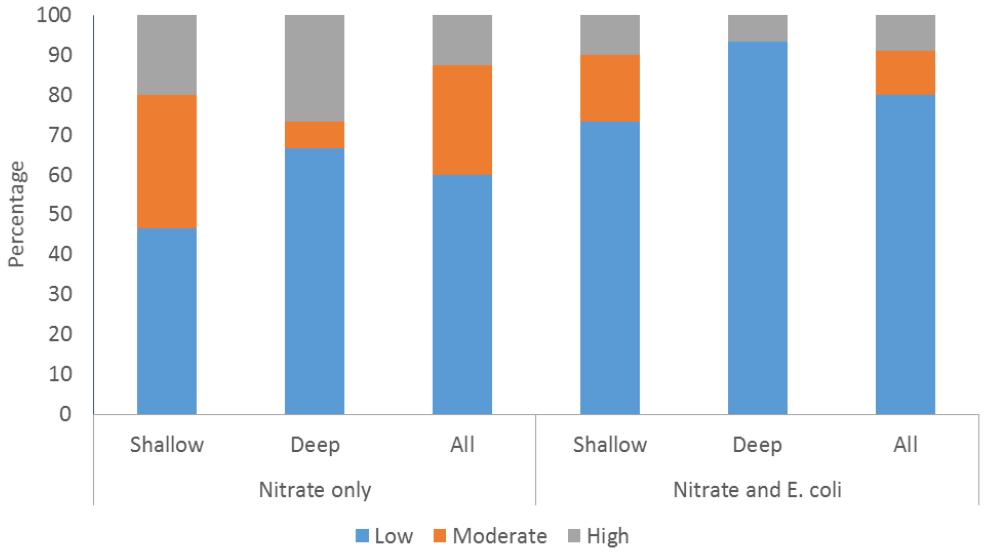
Figure 2 Percentage of sites in risk categories: Canterbury



3.2.2 WAIKATO

The inclusion of *E. coli* as a factor in determining risk of methaemoglobinaemia resulted in a statistically significant difference in the percentage of sites in each risk category when examined across all sites ($p=0.002$) and in shallow sites ($p=0.012$), and a near-significant difference for deep sites ($p=0.068$) (Fig. 3). In all cases there was a significant increase in low risk sites, and a decrease in moderate and high-risk sites. A greater proportion of higher risk sites were recorded from shallow compared to deep sites.

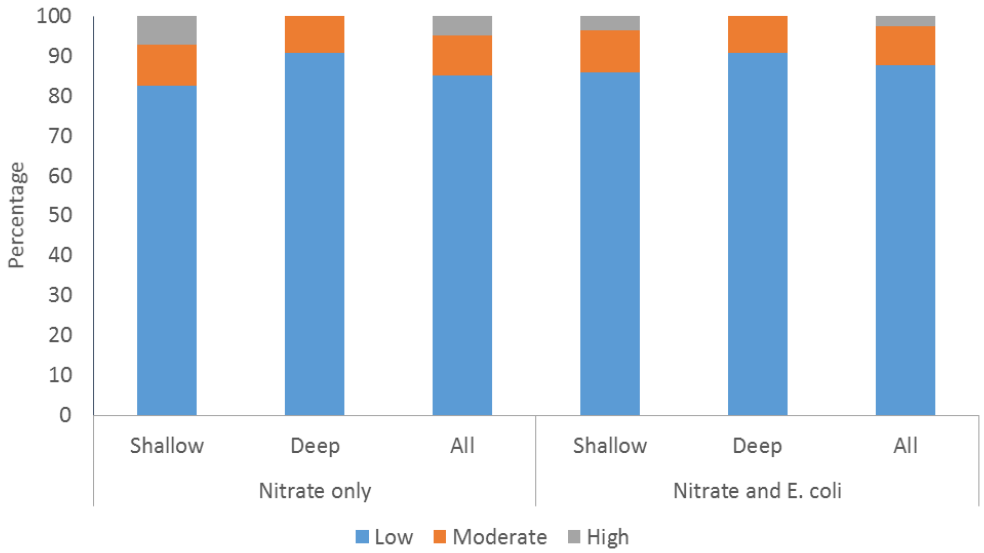
Figure 3 Percentage of sites in risk categories: Waikato



3.2.3 TARANAKI

There was no statistically significant difference in the percentage of sites in any risk categories when risk was defined using nitrate and *E. coli*, rather than just nitrate (Fig. 4) for all sites (p=0.18) or when shallow (p=0.18) sites were considered. There was no statistically significant difference in the number of deep sites in each risk category.

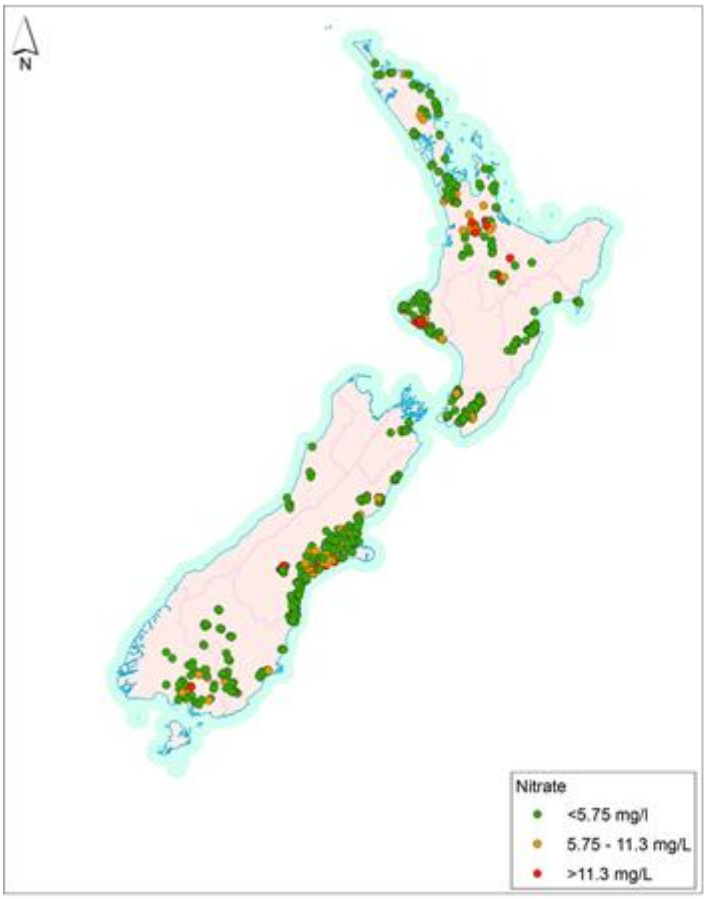
Figure 4 Percentage of sites in risk categories: Taranaki

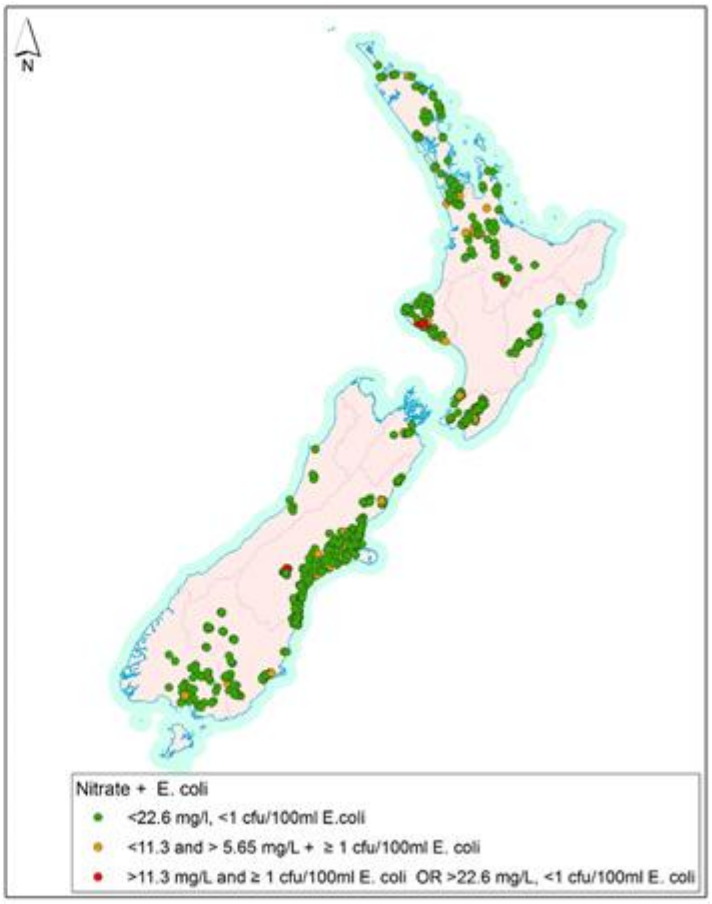


3.3 RISK MAPS

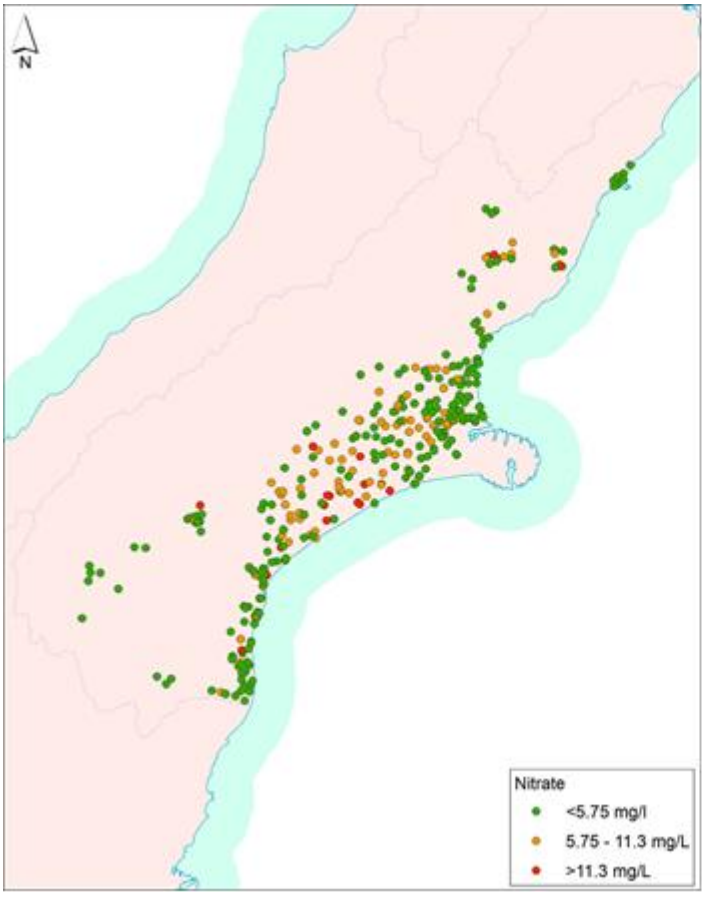
Based on the risk categories defined in Table 2, we have derived national and regional maps showing the risk of infant methaemoglobinaemia. These maps simply give a spatial representation of the data summarized in Figures 1 – 4. However they do illustrate how the perceived risk of drinking water containing nitrate can change dramatically by using the nitrate + E coli criterion (changes from high (red) to moderate (orange) and low (green) risk. This is especially evident in the Canterbury data where a large number of sites in mid-Canterbury change from high or moderate risk to low risk.

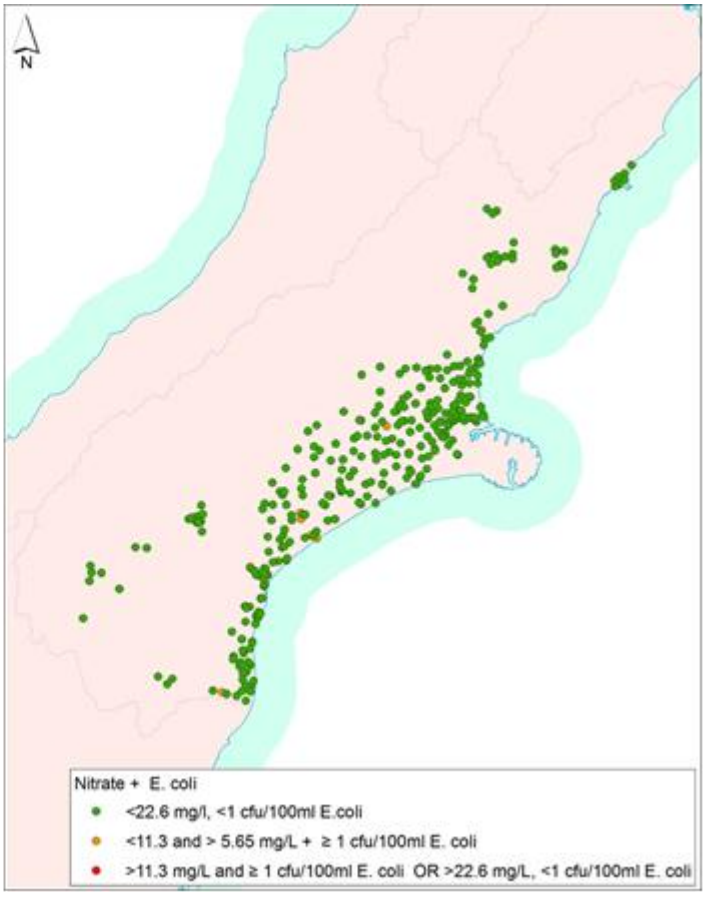
3.3.1 MFE DATA (1995-2008)



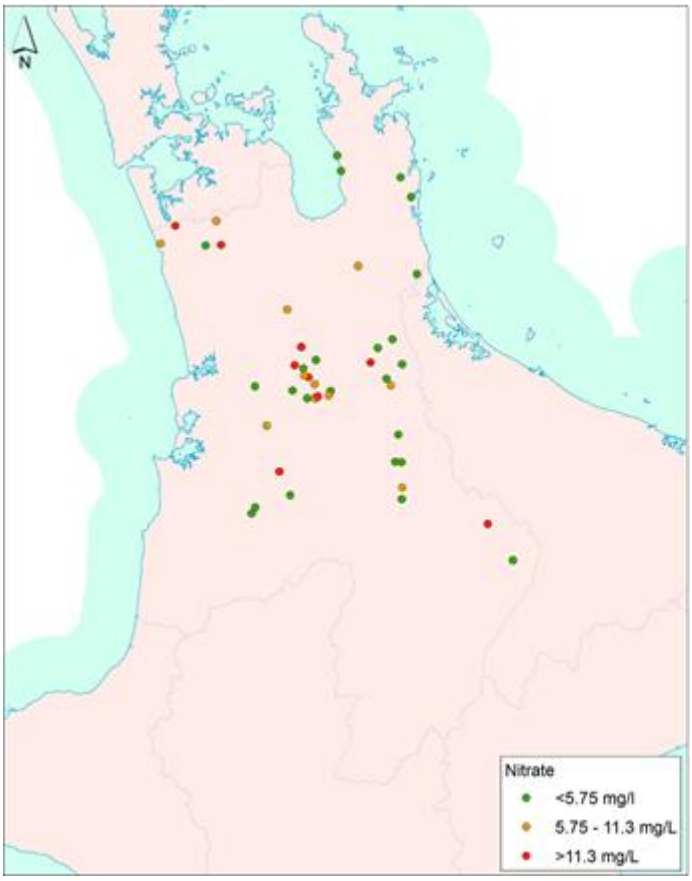


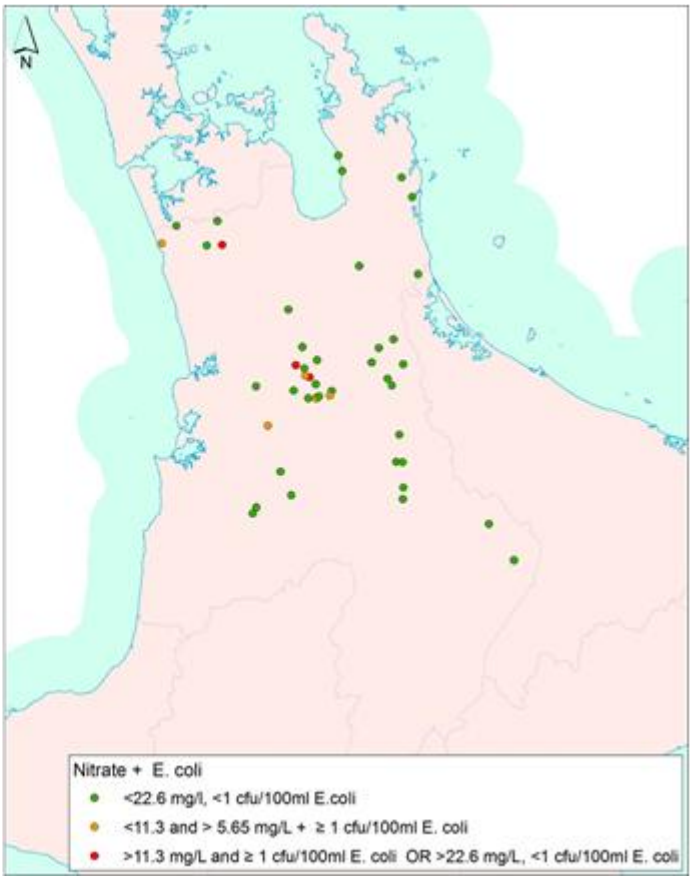
3.3.2 CANTERBURY



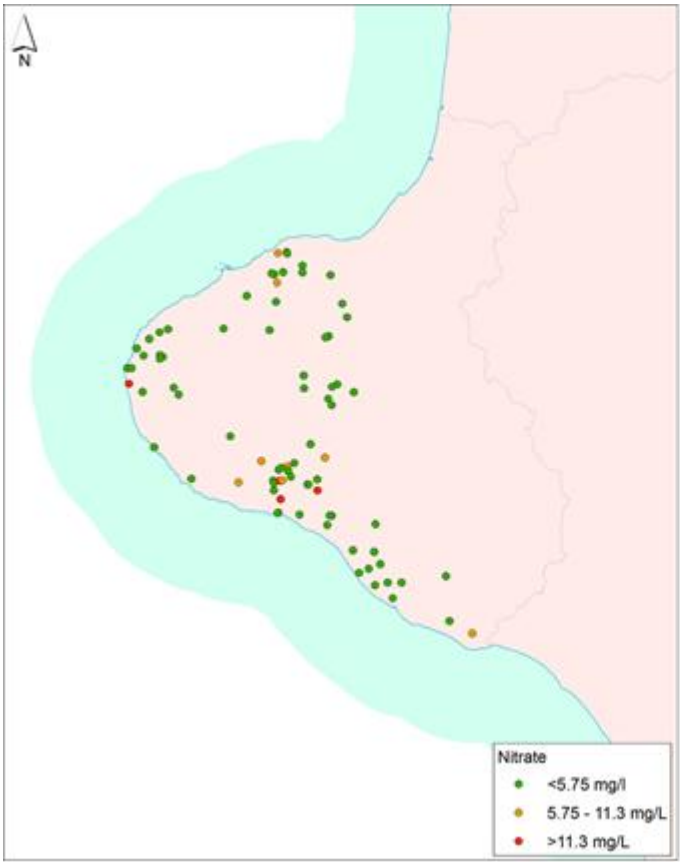


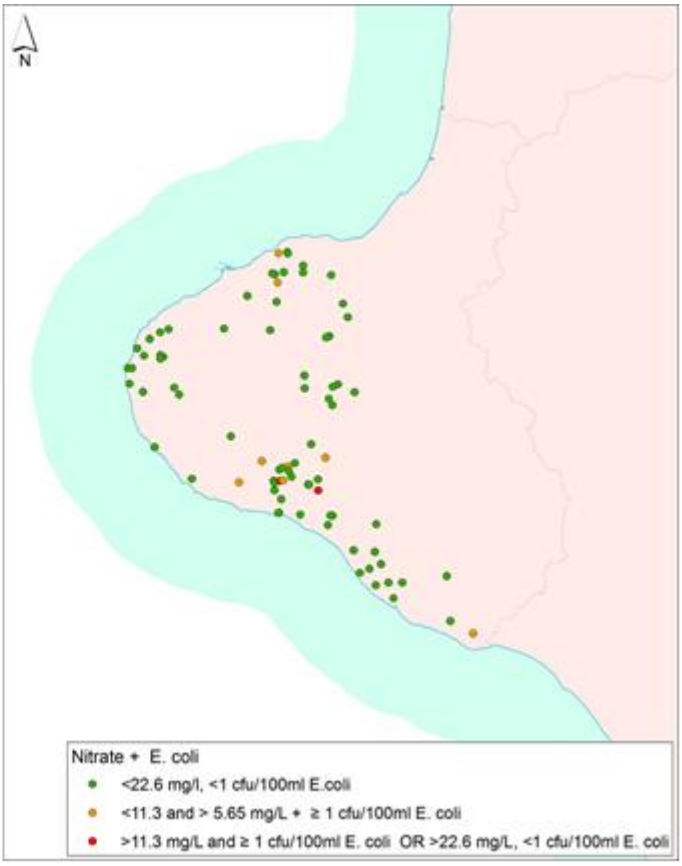
3.3.3 WAIKATO





3.3.4 TARANAKI





4 CONCLUSIONS

Our analysis shows that incorporating *E. coli* into the risk assessment for nitrate in groundwater results in a lower perception of risk than the criteria currently in use. There are generally significantly less wells that would be considered "high risk" than is the case using the standard WHO GV. It should be pointed out that our suggested criteria for including *E. coli* (≥ 1 cfu/100 ml) is conservative as much higher bacterial concentrations in drinking water have been associated with reported cases of infant methaemoglobinaemia (L'hirondel & L'hirondel, 2002). The overall lower level of risk is consistent with reported cases of infant methaemoglobinaemia in NZ (Cooke, 2014) and similar developed countries. For example Avery (1999) reported that cases of infant methaemoglobinaemia linked to contaminated drinking water are now virtually non-existent in the United States, despite estimates of some 660,000 infants exposed to drinking water nitrate concentrations in excess of the guideline value. In contrast, countries where microbially-contaminated water is common report a much higher incidence of the condition (Fewtrell, 2004).

The difference in perceived risk when including *E. coli* in the criteria is not universal. For example we noted a much higher decrease in risk in Canterbury wells than Taranaki wells when *E. coli* were included in the criteria. The difference is also more pronounced in deep sites, compared with shallow sites, with generally fewer high risk deep sites when *E. coli* is considered along with nitrate.

While this is only a preliminary analysis, it does indicate that a risk criterion that includes the presence of *E. coli* has some merit. The criterion is sanctioned in WHO (2011) and provides a more realistic assessment of risk than the official GV, which we note is just that – a guideline to assessed in the light of local circumstances. The inclusion of *E. coli* also serves as a reminder that the principal concern with respect to public health of water supplies remains microbial contamination.

ACKNOWLEDGEMENTS

Waikato, Taranaki and Canterbury Regional Councils for making their data freely available and answering our questions. We thank Graham McBride for his valuable review of this paper.

REFERENCES

Avery A.A. (1999). Infantile methemoglobinemia: reexamining the role of drinking water nitrates. Environ. Health Perspect. 107, 583.

Cooke, J.G. (2014) Are Rising Nitrate Levels in Rural Groundwater a public health concern? Water (Water NZ magazine) March 2014 p63-65

ECAN (2013). Annual Groundwater Quality Survey 2011. pp. 1–13.

Daughney, C.; Randall, M. (2009). National Groundwater Quality Indicators Update: State and Trends 1995-2008, GNS Science Consultancy Report 2009/145. 60p. Prepared for Ministry for the Environment, Wellington, New Zealand.

Fewtrell, L. (2004). Drinking-Water Nitrate, Methemoglobinemia, and Global Burden of Disease: A Discussion. Environmental Health Perspectives, 112(14), 1371–1374.

L'hirondel, J.-L., & L'hirondel, J. (2002). Nitrate and Man: Toxic, harmless or beneficial? CABI Publishing.

NZ Ministry of Health (MoH) (2013). Guidelines for Drinking Water Quality Management for New Zealand Chapter-10-Chemical-Compliance.

Scott, L. (2013) Hinds Plains water quality modeling for the limit setting process. Environment Canterbury Report R13/93

WHO (2011). Guidelines for Drinking Water Quality v4. World Health OrganisationOrganization.