NITRATE CONTAMINATION IN NEW ZEALAND DRINKING WATER AND COLORECTAL CANCER RISK

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ABSTRACT

Exposure to nitrate in drinking water has been associated with an increased risk of colorectal cancer at nitrate levels far lower than the Maximum Acceptable Value of 50 mg/L. This project aimed to review nitrate concentrations in New Zealand drinking water and undertake a preliminary assessment of their potential effect on colorectal cancer rates.

Nitrate data was collected from water suppliers for more than 3.9 million people (~84% of the population) and exposure was extrapolated for an additional 600,000 people. Based on international dose-response estimates, 7 - 17% of the population may be exposed to potentially harmful nitrate levels and 0.6 – 5.6% of colorectal cancer cases may be attributable. Exposure to nitrate in drinking water is likely to be a significant risk factor for colorectal cancer in New Zealand.

These preliminary results warrant further study in New Zealand and warrant taking practical, precautionary steps to reduce nitrate levels in drinking water.

KEYWORDS

Nitrate, Drinking Water, Water Quality, Colorectal Cancer, New Zealand

PRESENTER PROFILE

Jayne is a Senior Environmental Engineer and manager of Fluent Solutions' Queenstown office. She has more than 10 years' experience in various aspects of environmental engineering, including three-waters design and construction contract management in Otago, operations management of water and wastewater services in remote communities in Western Australia and humanitarian engineering.

1.0 INTRODUCTION

There is increasing evidence for an association between nitrate levels in drinking water and colorectal cancer (e.g. Espejo-Herrera et al., 2016, Schullehner et al., 2018). This association has been found to occur at nitrate levels far lower than 50 mg/L which is the current World Health Organisation (WHO) Guideline Value (WHO, 2016) and the 'Maximum Acceptable Value' (MAV) in the Drinking-water Standards for New Zealand 2005 (revised 2018) (DWSNZ) (MoH, 2018).

Colorectal cancer rates in New Zealand are significantly higher than the global average and are amongst the highest in the world (Ferlay et al., 2018).

New Zealand drinking water suppliers are not required to routinely monitor or report on nitrate levels if levels have been previously found to be below 25 mg/L (50% of the MAV) (MoH, 2018) and there is no national repository of data that can be reliably used to estimate exposure to nitrate in drinking water for the population. This situation means that there is limited understanding of the scale of the potential public health risk posed by nitrate levels in drinking water. It is not clear whether the high colorectal cancer rates in New Zealand can be partially attributed to exposure to elevated nitrate levels in drinking water or whether incidences of colorectal cancer could be reduced through management of nitrate loads to drinking water sources or nitrate reduction at the treatment plant level.

The aim of this project was to review nitrate concentrations in New Zealand drinking water and their potential effect on colorectal cancer rates in the country. The objectives of the project were to:

1. Review literature linking nitrate with colorectal cancer
2. Develop a preliminary database of nitrate concentrations in New Zealand drinking water
3. Undertake a preliminary characterisation of population exposure to nitrate in New Zealand drinking water over time and place
4. Develop an initial estimate of the potential population burden of colorectal cancer attributed to nitrate exposure from drinking water

This paper presents a summary of the Author's Master of Science Dissertation, completed in June 2020.

1.1 NOTES ON UNITS OF MEASUREMENT

Nitrate concentrations in drinking water are typically reported in mg/L as either NO_3 (the nitrate ion) or NO_3-N (the nitrogen component of the nitrate ion). This study refers to the concentration of the nitrate ion (NO_3) in accordance with the units used in the DWSNZ (MoH, 2018). NO_3-N concentrations have been multiplied by 4.4267 to convert them to NO_3 for this study.

2.0 BACKGROUND

2.1 COLORECTAL CANCER INCIDENCE RATES AND RISK FACTORS

Colorectal cancer is New Zealand's third most prevalent cancer with 3,219 registrations of colorectal cancer recorded in 2016 (MoH, 2019). Based on 2016 data, the age standardised incident rate is 41.9 per 100,000 people; significantly higher than the global average of 19.7 per 100,000 and amongst the highest in the world (Ferlay et al., 2018). Colorectal cancer rates vary significantly throughout the country, with the highest incident rates in South Canterbury, Southern, Taranaki and Nelson/Marlborough District Health Boards (DHBs) (HQSC, 2019) (based on 2009 – 2013 data).

Known risk factors for colorectal cancer include the non-modifiable risk factors of age, personal history of polyps, family history of colorectal cancer and inflammatory bowel disease and the modifiable risk factors of obesity, physical

inactivity, high consumption of red meat, high consumption of processed meat, heavy alcohol consumption and smoking (Richardson et al., 2016).

Population Attributable Fractions (PAFs) have been estimated for known modifiable colorectal cancer risk factors in New Zealand by Richardson et al. (2016) (refer **Table 1** below). PAFs estimate the proportion of disease in a population that could be prevented if the modifiable risk factor (or exposure) was eliminated/reduced (Webb, Bain and Page, 2017). PAFs provide an indication of the relative importance of modifiable risk factors in a population. Due to the high rates of colorectal cancer in New Zealand, even small changes in the prevalence of risk factors could result in a significant reduction in registrations (Richardson et al., 2016).

PAFs can be estimated using Relative Risk Ratios (RRs) which are calculated based on the risk of disease in one group divided by the risk of disease in a reference group (e.g. Webb, Bain and Page, 2017). A RR greater than one indicates a positive association between exposure to the risk factor and the risk of disease. As an example, a RR of 1.15 indicates a 15% increased risk of disease associated with exposure. RRs are typically described with 95% confidence intervals (CIs).

The PAFs were estimated by Richardson et al. (2016) based on the following:

$$PAF = \frac{Pe(RR-1)}{Pe(RR-1)+1} \; x \; 100\%$$

$Where \; Pe = the \; prevalence \; of \; exposure \; to \; the \; risk \; factor$

$RR = the \; relative \; risk$

Table 1: Estimated PAFs for colorectal risk factors in New Zealand (based on Richardson et al. (2016))

Risk Factors	RR (95% CI)	Estimated prevalence of Risk Factor in New Zealand	Estimated PAF in New Zealand (95% CI)	Estimated No. Attributable Cases*
Heavy alcohol consumption	1.44 (1.25 – 1.65)	16.1% of adults have hazardous drinking pattern	6.6% (3.6 – 9.6)	212
High consumption of red meat	1.35 (1.21 – 1.51)	14.4% eat red meat more than 5 times per week	4.8% (2.6 – 7.0)	154
Obesity	1.33 (1.25 – 1.42)	29.9% obese (BMI ≥ 30)	9.0% (6.7 – 11.2)	289
Physical Inactivity	1.32 (1.23-1.39)	14.3% adults physically inactive (<30 mins physical activity / week)	4.4% (2.6 – 7.0)	141
High consumption of processed meat	1.31 (1.13 – 1.51)	8.6% eat processed meat more than 5 times per week	2.6% (0.9 – 4.3)	83
Smoking	1.15 (1.00 – 1.32)	17.2% (smoke at least once per month)	2.5% (0.0 – 5.2)	80

** Extrapolated by the Author based on the number of registrations of colorectal cancer in New Zealand in 2016 (3,219) (MoH, 2019)*

Obesity and heavy alcohol consumption were found to be the most significant modifiable lifestyle risk factors for colorectal cancer in New Zealand (Richardson et al., 2016). Exposure to elevated nitrate in drinking water was not taken into consideration as a modifiable risk factor by Richardson et al. (2016), most likely because there was inconclusive evidence and a limited number of studies at the time of publishing.

The PAFs estimated by Richardson et al. (2016) demonstrate the importance of consideration of both the relative risk and the prevalence of a risk factor when considering the potential population burden of the risk factor. Whilst there is published literature on the relative risk of colorectal cancer associated with exposure to nitrate in drinking water from international studies, there is no data on the prevalence of levels of exposure in New Zealand.

2.2 LINK BETWEEN INGESTED NITRATE AND CANCER

In 2006, the International Agency on Cancer Research (IARC) concluded that "*ingested nitrate or nitrite under conditions that result in endogenous nitrosation is probably carcinogenic to humans (group 2A)*" (IARC, 2010). The process of endogenous (i.e. internal) nitrosation is summarized in **Figure 1** below. Ingested nitrate can be reduced to nitrite by the action of bacteria in the mouth (WHO, 2016). Nitrite can react with nitrostable compounds in the acidic conditions of a healthy human stomach to produce N-nitroso compounds, many of which are probable human carcinogens. The N-nitroso compounds produced in the stomach can act as carcinogens in the colon and rectum.

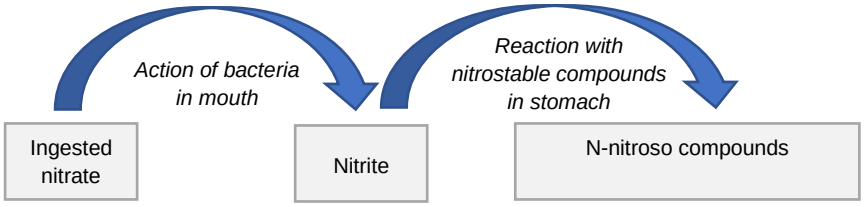

Figure 1: Summary of endogenous nitrosation

Vitamin C and other antioxidants have been found to inhibit the process of endogenous nitrosation (Grosse et al., 2006). Vegetables are the highest source of ingested nitrate through diet in New Zealand (Thomson, Nokes and Cressey, 2007) but are also a strong source of vitamin C and other antioxidants (Grosse et al., 2006). Therefore the formation of N-nitroso compounds from nitrate ingested in vegetables may be inhibited by the concurrent ingestion of vitamin C and other antioxidants in the vegetables (Grosse et al., 2006). Nitrate in drinking water is typically ingested without concurrent ingestion of vitamin C and antioxidants and may therefore result in greater formation of the probably carcinogenic N-nitroso compounds compared to ingestion of nitrate through vegetable consumption (Grosse et al., 2006).

2.3 NITRATE IN DRINKING WATER AND COLORECTAL CANCER

The WHO drinking water guideline value for nitrate of 50 mg/L (as nitrate ion) was established to protect bottle-fed infants from the acute condition Methaemoglinaemia, or 'blue baby' syndrome (WHO, 2016). This potentially fatal condition can occur when nitrite, endogenously converted from the consumed

nitrate, interacts with haemoglobin, reducing the efficiency at which oxygen is transported by blood (WHO, 2016).

A guideline value based on chronic (long term) health effects has never been established for nitrate in drinking water by the WHO or Ministry of Health (MoH) due to insufficient evidence of associations with chronic effects (MoH, 2017). Studies into the chronic effects of consumption of water with elevated nitrate levels have assessed associations with various cancers and birth defects and have yielded various and sometimes inconsistent results (Ward et al., 2018).The strongest potential association appears to be with colorectal cancer and there is increasing evidence to support this association (Ward et al., 2018, Temkin et al., 2019).

The results of identified published epidemiological studies (n=7) on the association between exposure to nitrate in drinking water and colorectal cancer are varied, but the majority suggest a positive association at levels significantly below the MAV of 50 mg/L. Statistically significant associations have been identified for nitrate concentrations as low as 1.59 mg/L (Weyer et al., 2001). The results indicate that the association may be stronger for colon cancer than rectal cancer and is likely to be stronger for subgroups including those with high red meat consumption and those with low vitamin C intake.

Two recent epidemiological studies in Denmark (Schullehner et al., 2018) and Spain and Italy (Espejo-Herrera et al., 2016) with different study designs contribute significantly to the body of evidence supporting this association, due to the large populations studied, the resulting statistical power and the detailed exposure assessments undertaken. Both studies assigned participants with average annual nitrate exposure levels using residential history and data from water suppliers and found increased risk of colorectal cancer with increased long-term exposure to nitrate in drinking water at levels significantly below current guidelines.

For the purpose of this preliminary study, the results from published studies most relevant to the New Zealand population are considered to be Espejo-Herrera et al. (2016), Schullehner et al. (2018) and Temkin et al. (2019) (a meta-analysis). The results of these studies indicated the following dose response relationships:

- A 49% increase in risk with exposure greater than 7.1 mg/L (RR=1.49 (95% CI: 1.24 – 1.78)) (Espejo-Herrera et al., 2016)
- An 11% increase in risk with exposure to 3.87 mg/L – 9.25 mg/L (RR=1.11 (95% CI: 1.02 – 1.20)) and a 15% increase in risk associated with exposure to more than 9.25 mg/L (RR=1.15 (95% CI: 1.07 – 1.24)) (Schullehner et al., 2018)
- A 4% increase in risk with every 4.43 mg/L increase in nitrate concentration above 4.43 mg/L (Temkin et al., 2019).

Based on these results and for the purposes of this study, nitrate concentrations in drinking water of greater than 5 mg/L are considered to be ‘elevated’.

2.4 NITRATE CONTAMINATION IN NEW ZEALAND WATER WAYS

Nitrate is highly soluble in water and nitrate in the soil that is not taken up by plants is readily leached to the groundwater, where it can be subsequently transported to surface water systems. Due to often slow groundwater movement rates, the environmental and human health impacts of current land use practices

may not fully arise for years or decades into the future (MFE and Stats NZ, 2019).

The largest source of dissolved nitrogen in New Zealand waterways is estimated to be from pastoral farming areas and specifically from intensive dairy farming (Elliott et al., 2005). Fertilizer application to pasture results in increased nitrogen content of the fodder, increased nitrogen intake for the animals and a subsequent increased return of nitrogen to the land via animal urine patches (Vogeler, Lucci and Shephard, 2015). The uneven distribution of the highly concentrated urine patches around a paddock results in patches of excess soil nitrogen that cannot be taken up by plants and are leached into the groundwater. This indirect leaching of nitrate from urine patches is the largest source of nitrate contamination from pastoral farming. Direct leaching of nitrate from fertilizer application is typically small unless the fertilizer application is poorly timed, such as a few days before a high rainfall event (Vogeler, Lucci and Shephard, 2015).

Other sources of nitrate contamination in New Zealand include human wastewater, market gardens, forestry activities, effluent disposal systems, stock feeding yards (MFE and Stats NZ, 2019). Site specific factors such as local climate, hydrogeology, soil management an significantly affect groundwater nitrate concentrations at the local scale (McLay et al., 2001).

3.0 NITRATE DATA COLLECTION AND DEVELOPMENT OF NITRATE DATABASE

Nitrate data and supply information were requested from the 66 District Councils and from 119 private (non-territorial authority) water suppliers for which MoH had contact details for in early 2020. Nitrate data for water sources used for domestic or community supply was requested from Regional Councils with the aim of obtaining information on nitrate levels in drinking water for people who are not served by a registered drinking water supply. Water samples were collected and analysed for nitrate by the Author from 20 unregistered or self-supplies in the Southland District in late 2020.

The nitrate data and supply information collected was compiled into the ‘nitrate database’. The current nitrate concentration for each registered water supply was calculated based on the average of 2018-2020 nitrate results, or the most recent result if no data was available from the 2018 – 2020 period. Nitrate samples from the reticulation or water treatment plant were used in preference to raw source water samples. Where a water supply is supplied from multiple water sources with differing nitrate levels and no reticulation or water treatment plant results were available, the nitrate level for the supply was calculated as a weighted average based on the proportional contribution of each source. If the proportional contribution of each source could not be provided by the supplier it was assumed that each source with available nitrate data contributed evenly. If different supply zones in a water supply were supplied by different water sources, separate nitrate concentrations were calculated for each zone and the zones were entered into the database as separate entries. If a nitrate result was less than detection it was listed as 50 percent of the detection level. Nitrate data provided as Dissolved Inorganic Nitrogen or Total Dissolved Nitrogen were assumed to be equivalent to NO3-N.

Exposure to nitrate in drinking water for those not served by a registered supply was estimated based on the nitrate data collected from the sampling in Southland and from the data provided from the Regional Councils. Regional Council data was only included from water sources recorded as being for domestic, school, eatery or community supply. Water sources were estimated to serve three people if they were identified as being for domestic supply and 25 people if they were identified as being for school, restaurant, or community supply. The nitrate levels for the water sources in the Regional Council supplied data were calculated based on the average of the 2018 to 2020 results for each source. The nitrate data collected from Regional Councils was excluded from the nitrate database due to lower reliability of the data (compared to the nitrate data from water suppliers) associated with uncertainties around whether the water sources are still used for drinking water.

4.0 RESULTS AND DISCUSSION

4.1 NITRATE DATA COLLECTED AND NITRATE DATABASE

Nitrate data was collected for a total of 3,969,964 people for inclusion in the nitrate database. The data collected is summarised in **Table 2** below. The full nitrate database is available from the Author.

Table 2: Summary of data collected for nitrate database

	Number in nitrate database	Total Number in Register*	Percentage covered by the nitrate database
District Council Suppliers	60	66	90.9%
Private Suppliers	18	319	5.6%
Suppliers Total	78	403	19.4%
Registered Supplies	382	677	56.4%
People served by registered supplies	3,969,562	4,096,189	96.9%
People served by unregistered supplies**	402	603,566	0.1%

	Total number of people in nitrate database	Total New Zealand Population***	Percentage of population covered by the nitrate database
	3,969,964	4,699,755	84%

** Register of drinking Water Suppliers for New Zealand of Drinking Water Suppliers for New Zealand (ESR, 2020a)*
*** The total number of people served by unregistered supplies (603,566) was estimated by subtracting the number of people served by registered drinking water supplies from the 2018 New Zealand population.*
**** Based on 2018 census data (Stats NZ, 2020)*

The nitrate database developed in this study covers a large percentage of the New Zealand population (84%) (and 97% of people served by registered supplies) and provides an excellent indication of current exposure to nitrate in drinking water. Nitrate data was available from 60 out of the 66 District Councils but was not available for all of the supplies operated by these Councils. There

was a low response rate from private (non-Territorial Authority) suppliers and the database only includes data from ~6% of the private suppliers.

4.2 EXPOSURE TO ELEVATED NITRATE DRINKING WATER

Based on the nitrate database developed, a total of 8.2% of the population were found to be exposed to more than 5 mg/L and 2.2% were found to be exposed to more than 10 mg/L. A total of 4,459 people (0.1% of the population) were found to be exposed to more than 25 mg/L (greater than 50% of the MAV). The number of people in New Zealand exposed to each nitrate concentration range is shown in **Figure 2** below. The number of people for whom there is no available nitrate data in the database are also shown, separated into those served by registered supplies and those served by unregistered supplies.

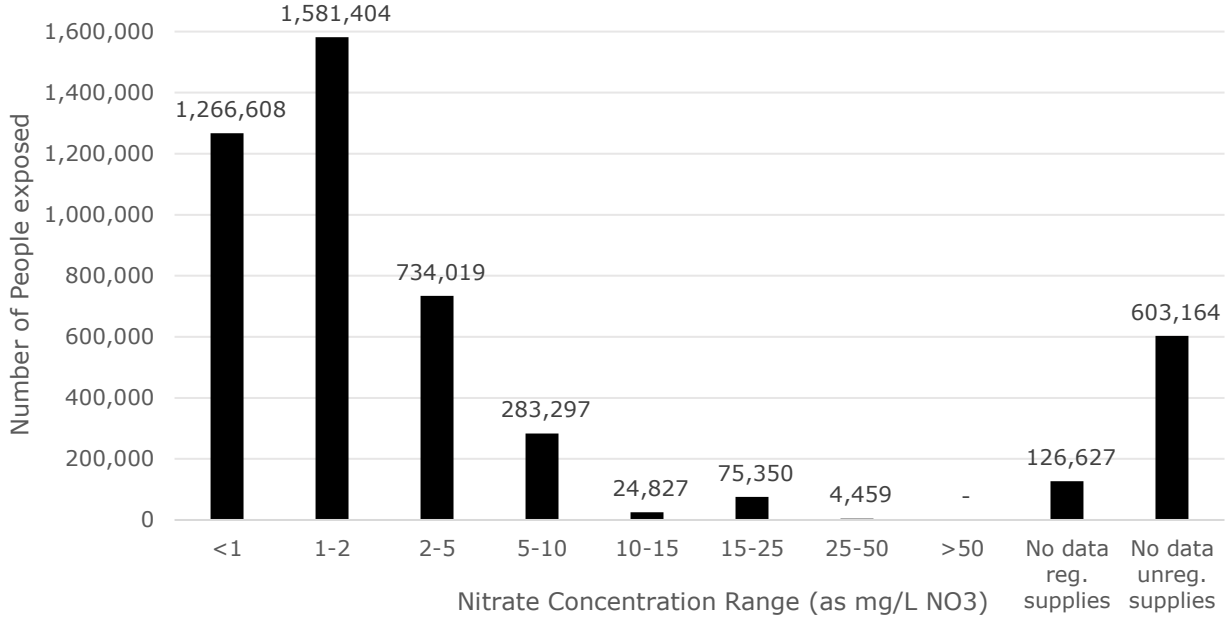

Figure 2: Nitrate levels in New Zealand drinking water

Based on nitrate database and Stats NZ (2020)

Exposure to nitrate in drinking water varied across the 20 District Health Boards (DHBs) (refer **Figure 3**). The DHBs with the largest number of people exposed to more than 5 mg/L were Canterbury (72,314 people) and Southern (71,703 people). Canterbury DHB also had the largest number of people exposed to more than 10 mg/L (48,898), more than 15 mg/L (31,475) and more than 25 mg/L (3,215). Nelson-Marlborough DHB, Waikato DHB and Southern DHB also had high numbers of people exposed to more than 15 mg/L (16,490, 14,749 and 11,884 respectively). Waikato had the highest number of people with unknown exposure levels (117,624 people). The percentage of the DHB population exposed to greater than 5 mg/L was highest in South-Canterbury DHB (51.5%) and also high in the Hawke's Bay DHB (39.1%) and the Northland DHB (34%). Exposure to nitrate levels greater than 10mg/L and greater than 15mg/L as a percentage of the DHB population was highest in Nelson-Marlborough (11.1% for > 10 mg/L and 10.9% for > 15 mg/L) and in Canterbury (9.1% for > 10 mg/L and 5.8% for > 15 mg/L). The percentage of the DHB population with unknown exposure levels was highest in Northland, at 44%.

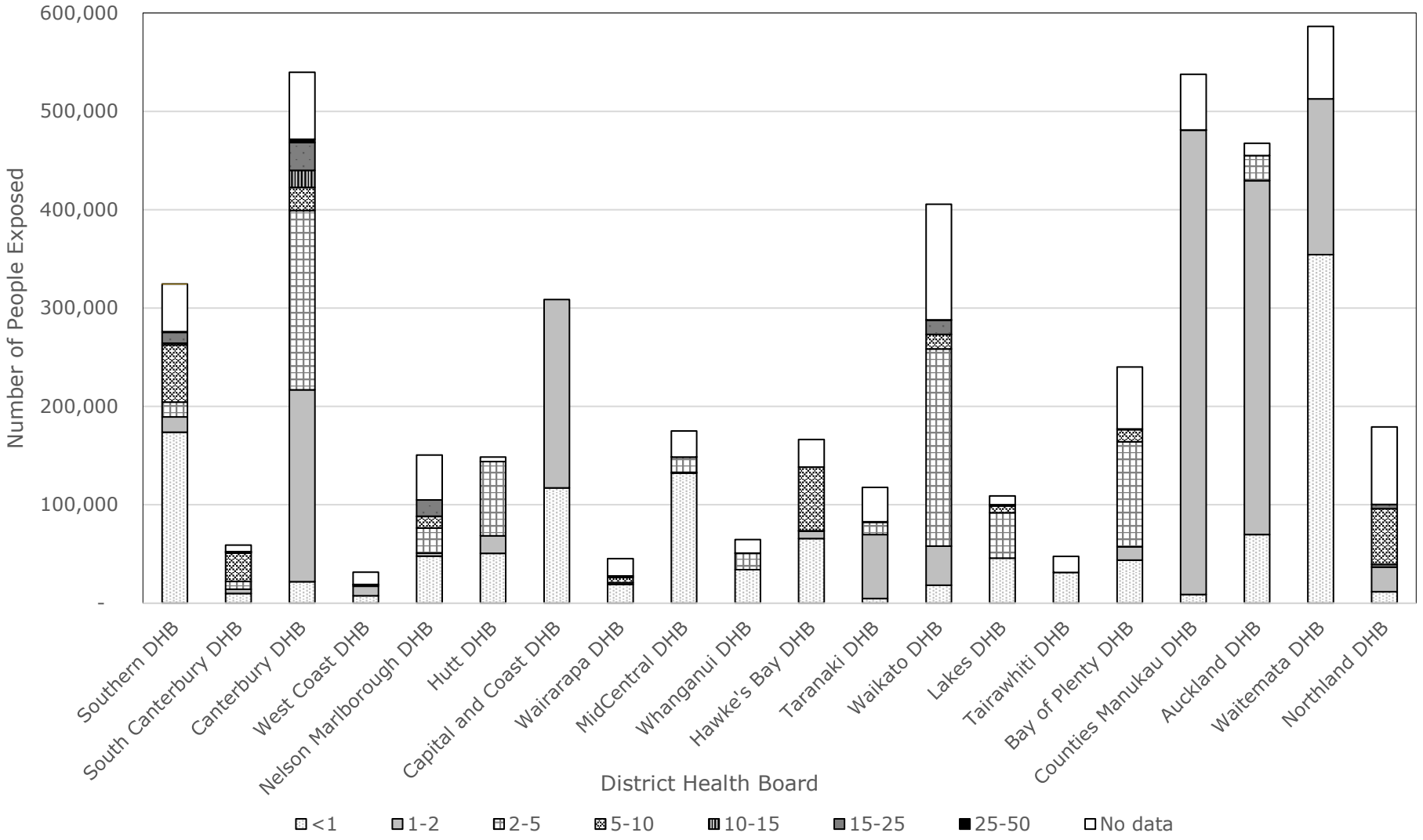

Figure 3: Exposure to nitrate levels (mg/L NO3) by District Health Board

Based on nitrate database and population data from Stats NZ (2020)

4.3 SPATIAL VARIABILITY OF DRINKING WATER NITRATE LEVELS

Nitrate levels in drinking water were found to have significant variation across New Zealand and within each DHB. Some supplies in close proximity to each other were found to have significantly different nitrate levels. **Figures 4** and **5** below display the location and nitrate concentration band of all registered water supplies (and supply zones) in the nitrate database.

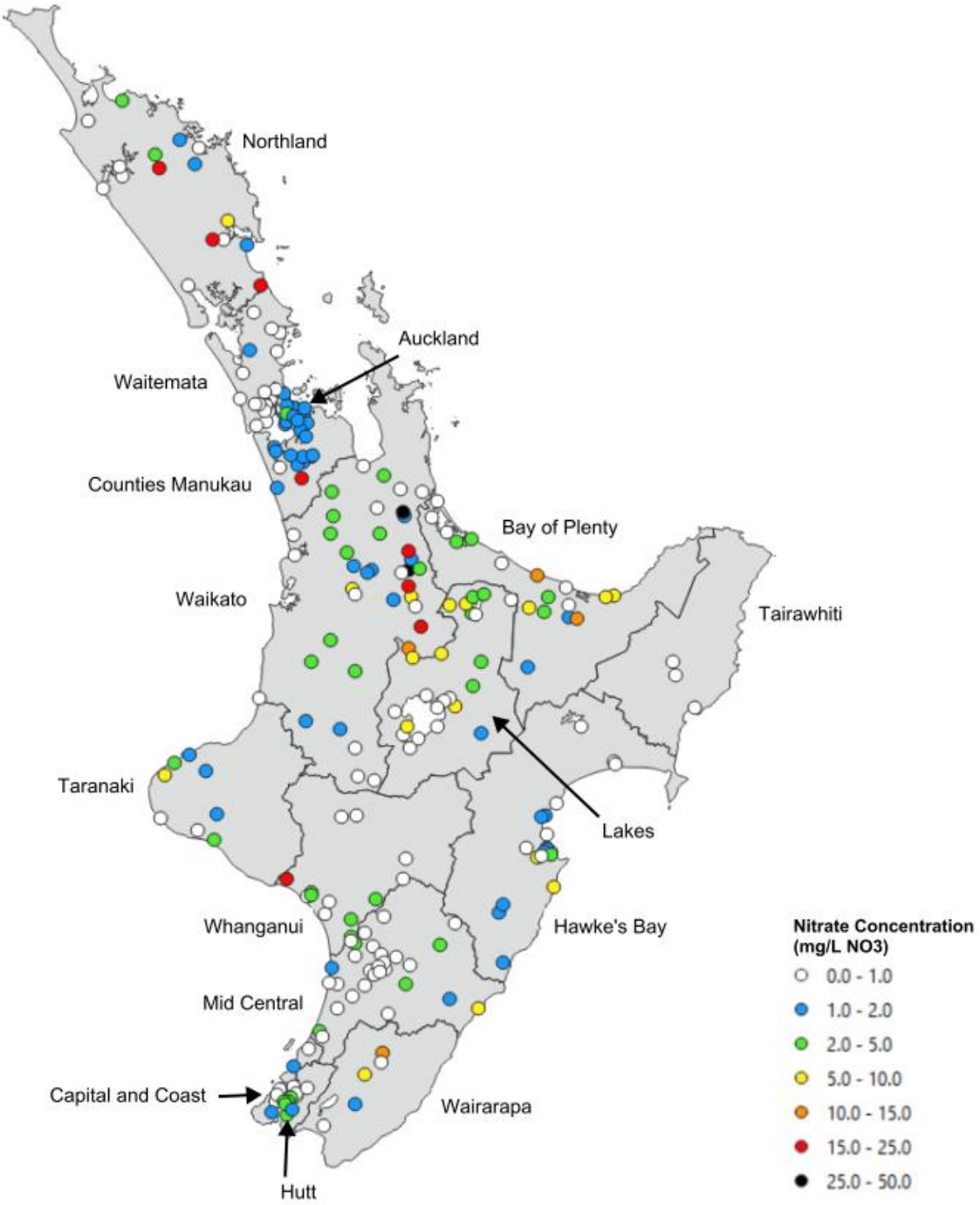

Figure 4: Nitrate levels in registered drinking water supplies, North Island

Map based on data from nitrate database and Creative Commons 3.0 New Zealand 2012

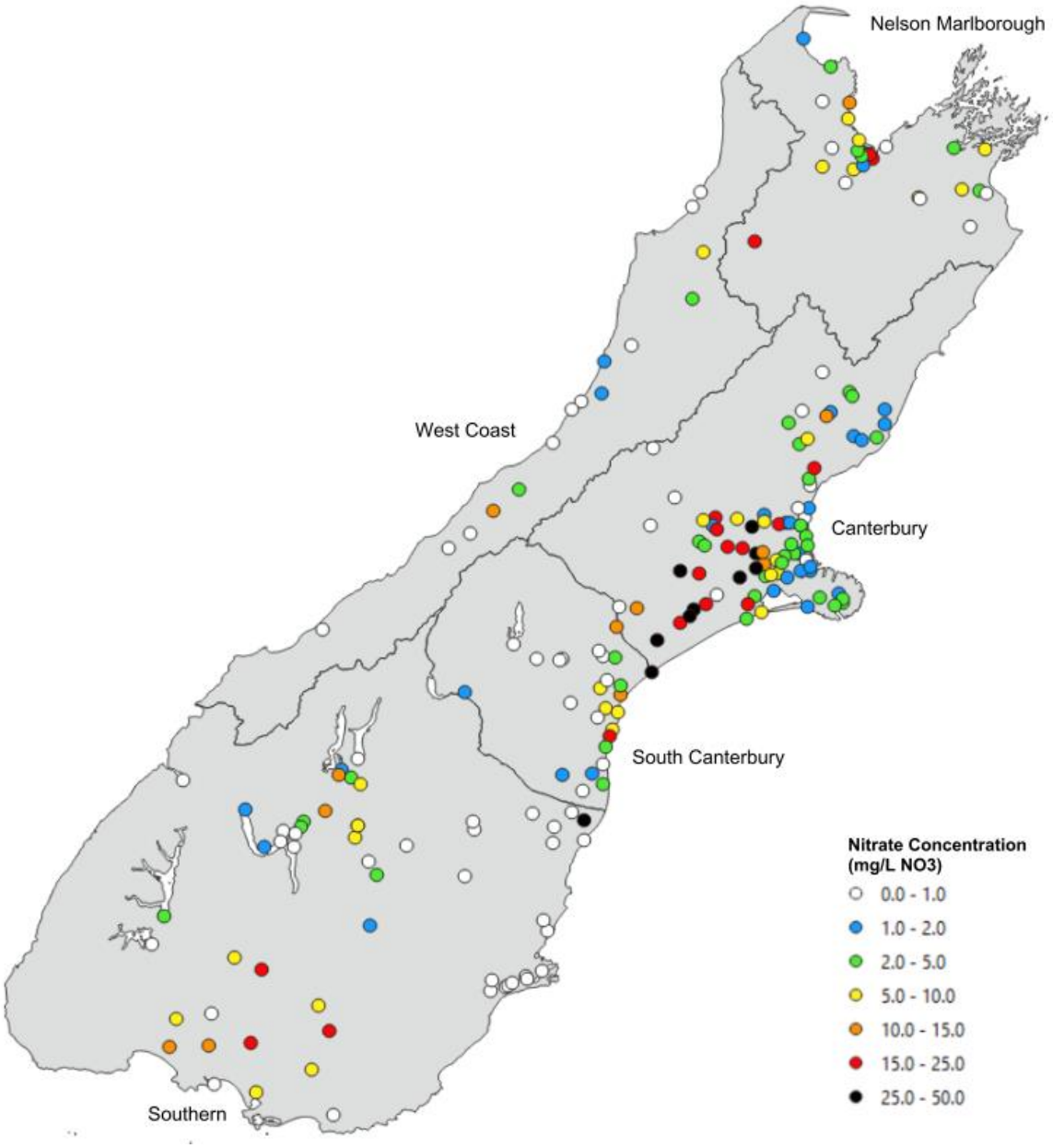

Figure 5: Nitrate levels in registered drinking water supplies, South Island

Map based on data from nitrate database and Creative Commons 3.0 New Zealand 2012

These maps clearly indicate clusters of drinking water supplies with elevated nitrate levels in the south of Canterbury, the south of Southland, Nelson Marlborough, Waikato and Northland. The maps also indicate clusters of drinking water supplies with low nitrate levels, such as in the Auckland, Waitemata, Counties Manukau, Tairawhiti, Hawke's Bay, Mid Central, Capital and Coast and Hutt District Health Boards.

The clusters of drinking water supplies with elevated nitrate levels (>5mg/L) in the south of Canterbury, the south of Southland, Waikato and Northland appear to be associated with areas of high cattle density. The typically low nitrate levels in drinking water supplies located in Taranaki and the western Waikato despite the high cattle intensity in these areas is considered to reflect the dominance of surface water sources supplying water supplies in the nitrate database in these areas and the flushing effects of high stream flows.

4.4 VARIATION IN NITRATE LEVEL BY WATER SUPPLY SIZE

The proportion of people exposed to the highest nitrate concentration bands varied considerably by the water supply size category (based on the size categories in ESR, 2019). The percentage of people exposed to greater than 10, 15 and 25 mg/L was highest in the smallest supply categories (Neighbourhood and Small) and lowest in the largest supply categories (Medium and Large).

In the smallest supply categories, 21% of people with data (Neighbourhood) and 16% (Small) were exposed to greater than 10 mg/L, compared to 5% (Medium) and 1% (Large). The total number of people supplied by each category increases with increasing supply size (with the exception of Minor and Medium), ranging from 10,851 in the Neighbourhood category to 3,434,362 in the Large category. These results are presented in **Figure 6** below. Data coverage also increased with increasing supply size, ranging from 18% for neighbourhood supplies to 100% for Large supplies.

The data collected from Regional Councils for unregistered supplies (and considered to be less reliable) and the data collected in Southland has been included in the unregistered supply category in **Figure 6** to provide a comparison of potential exposure levels between unregistered and registered supplies. An estimated 5% of the people with available nitrate data in this category may be exposed nitrate levels greater than 50 mg/L, while 22% may be exposed to greater than 25 mg/L.

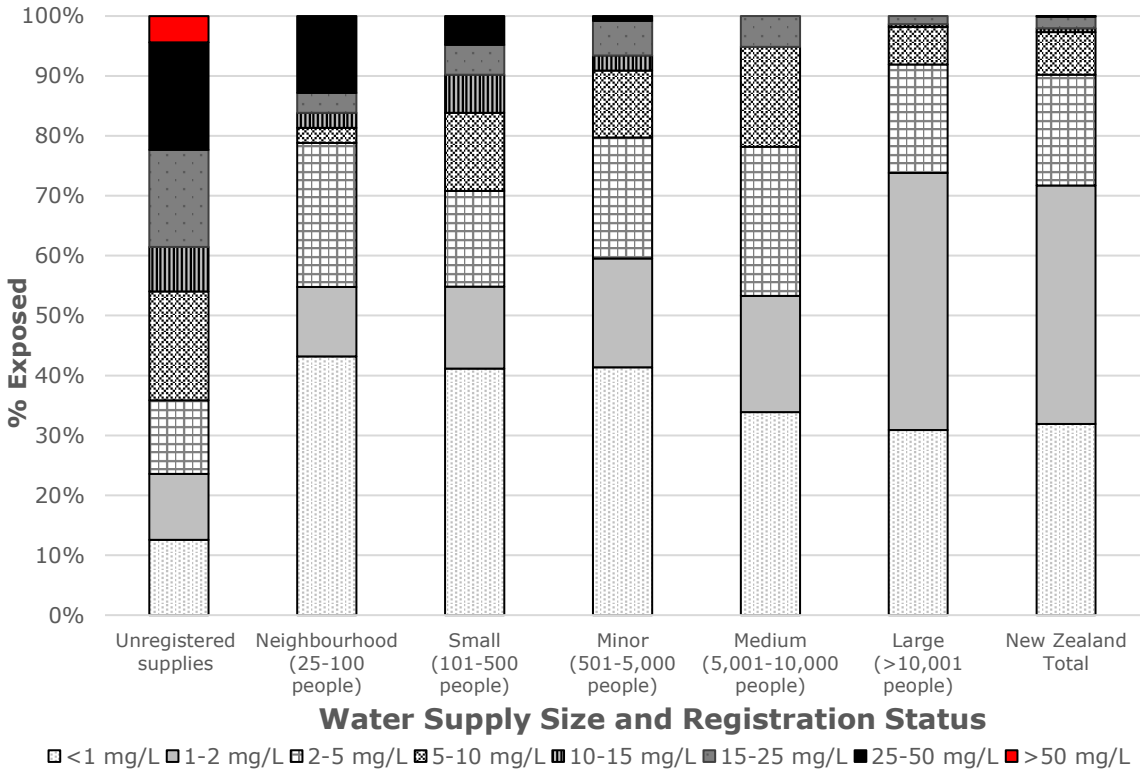

Figure 6: Drinking water nitrate levels by supply size and registration status

Based on nitrate database, data from Regional Councils and data collected in Southland

The results clearly indicate that people served by unregistered supplies and the smallest categories of registered drinking water supplies are more likely to be exposed to higher nitrate levels in drinking water than those supplied by the

largest supply categories. This is an important finding given that data coverage in the nitrate database is also lowest for the smallest supply categories and unregistered supplies. Based on current MoH policy, P2 determinands are typically only assigned to water supplies with greater than 500 people. This policy appears to exclude registered supplies with the greatest risk of elevated nitrate levels.

4.5 NITRATE EXPOSURE ESTIMATE FOR THOSE WITHOUT DATA

The ~600,000 people served by unregistered supplies are the largest group of people without available nitrate data in the nitrate database. Water sources used for unregistered supplies are likely to vary around New Zealand depending on rainfall and availability and quality of groundwater however there is currently no available estimate for the proportion of people served by unregistered supplies who rely on rainwater, compared to those who use groundwater or surface water for their drinking water. In the absence of any available national estimate, extrapolation of the water sources used by suppliers registered as specified self-suppliers and Networked Suppliers to less than 25 people (parts 3 and 4 of ESR 2019a) is considered to provide the most robust estimate for water sources used by people served by unregistered supplies. These registers cover more than 1,016 supplies and an estimated 153,102 people and the water source for each supply is classified as either rainwater, surface water or groundwater.

A total of 75% of the people in Parts 3 and 4 of the Register are supplied by a groundwater or surface water source, with the remaining 25% served by rainwater. Extrapolating these percentages to the people served by unregistered supplies without any available nitrate data would result in an estimated 451,403 people supplied by groundwater or surface water sources and 149,570 people supplied by rainwater. Extrapolating exposure levels based on Regional Council data and the results of the sampling in Southland (data for 2,593 people) would result in the additional number of people in each nitrate concentration band shown in **Table 3** below. Based on the results of the sampling in Southland, those served by rainwater supplies are assumed to be exposed to negligible levels of nitrate (<1 mg/L).

Table 3: Estimated exposure for unregistered supplies with no data

Based on data from Regional Councils, data collected in Southland and Stats NZ (2020)

Nitrate Exposure Range (mg/L)	Extrapolated no. of people* exposed served by unregistered supplies	No. people exposed (registered supplies in nitrate database)	Total	% of 2018 NZ Population
<1.0	206,648	1,266,608	1,473,256	31.3%
1.0 - 2.0	49,899	1,581,404	1,631,303	34.7%
2.0 – 5.0	55,852	734,019	789,871	16.8%
5.0 – 10.0	82,465	283,297	365,762	7.8%
10.0 – 15.0	33,791	24,827	58,618	1.2%
15.0 – 25.0	73,361	75,350	148,711	3.2%
25.0 – 50.0	81,590	4,459	86,049	1.8%
>50.0	19,960	-	19,960	0.4%
Total	**603,566**	**3,969,964**	**4,573,530**	**97.3%**

This extrapolation indicates that although there are only approximately 603,000 people served by unregistered supplies (compared to approximately 4,096,200 served by registered supplies), the total number of people served by unregistered supplies exposed to > 50 mg/L, 25 – 50 mg/L and 10-15 mg/L may be higher than the total number of people exposed who are supplied by registered supplies. This extrapolation also indicates that a significantly higher percentage of the population (up to 14.4%) may be exposed to greater than 5 mg/L than found by the nitrate database (8.2%).

It is important to note that the Regional Council data may overestimate exposure to elevated nitrate levels in unregistered drinking water supplies due to uncertainty of whether the water sources are still in use, potential household treatment and potential use of multiple sources. For these reasons the Regional Council Data was not included in the nitrate database. Nonetheless, this extrapolation indicates the potential for significant exposure to elevated nitrate levels in drinking water from unregistered supplies across New Zealand and warrants further investigation in the next phase of this study.

4.6 PRELIMINARY ESTIMATE OF POPULATION BURDEN OF COLORECTAL CANCER ATTRIBUTABLE TO NITRATE IN DRINKING WATER

Based on the results of the nitrate database and the results of relevant international studies, the number of New Zealanders currently exposed to potentially harmful levels of nitrate in drinking water may range from approximately 317,000, based on Espejo-Herrera et al. (2016) to more than 505,000, based on Schullehner et al. (2018). This is equivalent to 6.7 – 10.8% of the population. Based on the calculation of the Population Attributable Fractions (PAFs) these preliminary results indicate that between 0.6% and 3.2% of colorectal cases in New Zealand may be attributable to exposure to nitrate in drinking water. This is equivalent to approximately 19 – 103 cases, based on the number of new registrations in 2016 (3219) (MoH, 2019). These results assume that the people without any available nitrate data (a total of 729,791 people or 16% of the population) are not exposed to potentially harmful levels of nitrate in drinking water (as only the data from the nitrate database is used). These estimates are shown in **Table 4** below.

Inclusion of exposure estimates for approximately 600,000 people not served by a registered supply with no available data (extrapolated from Regional Council data) would increase the estimated number of people potentially exposed to harmful levels of nitrate in drinking water to between 568,810 and 804,122 (12.1 – 17.1 % of the New Zealand population). The inclusion of these exposure estimates would increase the estimated PAF to between 1.75% (based on Temkin et al., 2019) and 5.6% (based on Espejo-Herrera et al., 2016) and would increase the estimated number of attributable cases to between 56 and 180 cases per year. As described in Section 4.5 the Regional Council data and extrapolated exposure estimate for people served by unregistered supplies is considered to have lower reliability and is therefore a preliminary estimate for hypothesis generation only.

Table 4: Number of people estimated to be exposed to potentially harmful levels of nitrate in drinking water, estimated PAFs and estimated number of attributable colorectal cancer cases

Study	Exposure Range (mg/L NO3)	RR	No. people exposed	% of 2018 population	PAF (%)	Est. no. cases
Espejo-Hererra et al., 2016	≥7.1	1.49	317,213	6.75%	3.20	103.1
	Total	**-**	**317,213**	**6.7%**	**3.20**	**103.1**
Schullehner et al., 2018	3.87 - 9.25	1.11	390,221	8.30%	0.91	29.1
	≥ 9.25	1.15	115,206	2.45%	0.37	11.8
	Total	**-**	**505,427**	**10.8%**	**1.28**	**40.9**
Temkin et al., 2019*	4.43 - 8.85	1.04	283,131	6.02%	0.24	7.7
	8.85 - 13.28	1.08	21,088	0.45%	0.04	1.2
	13.28 - 17.71	1.12	47,019	1.00%	0.12	3.9
	17.71 - 22.13	1.16	31,215	0.66%	0.11	3.4
	22.13 - 26.56	1.20	13,523	0.29%	0.06	1.9
	26.56 - 30.98	1.24	1,683	0.04%	0.01	0.3
	30.98 - 35.41	1.28	238	0.01%	0.00	0.0
	35.41 - 39.84	1.32	2,000	0.04%	0.01	0.4
	39.84 - 44.27	1.36	265	0.01%	0.00	0.1
	Total		**400,162**	**8.5%**	**0.59**	**18.8**

** The exposure ranges and RRs have been extrapolated from Temkin et al. (2019) based on the estimated 4% increase in risk for every 1 mg/L NO3-N (or 4.43 mg/L NO3)*

Table based on current exposures in the nitrate database (excludes extrapolation for those without data)

This study has developed the first estimate of the potential contribution of exposure to nitrate levels in drinking water to colorectal cancer cases in New Zealand. Although the results are preliminary, they indicate that exposure to nitrate in drinking water is likely to be a significant contributing factor to colorectal cancer cases in New Zealand. Exposure to nitrate in drinking water may have a similar significance to the established risk factors of high consumption of red meat, physical inactivity, high consumption of processed meat and smoking, that have estimated PAFs between 2.5 and 4.8% in New Zealand (refer **Table 1**). The established risk factors of heavy alcohol consumption and obesity may be more significant risk factors than exposure to nitrate in drinking water due to the high Relative Risk Ratios (RRs) and high prevalence rates of these risk factors.

4.6 PRELIMINARY COMPARISON OF ELEVATED NITRATE LEVELS WITH COLORECTAL CANCER INCIDENCE RATES

The location of registered water supplies with elevated nitrate concentrations (greater than 5 mg/L) and the 2009 – 2013 age-adjusted colorectal cancer incidence rates by DHB are shown in **Figure 7** for the purpose of hypothesis generation only. High rates of colorectal cancer in the Southern, South Canterbury, Canterbury and the Nelson Marlborough DHBs coincide with clusters of elevated nitrate levels in drinking water. The high rates of colorectal cancer in the West Coast, Waiarapa, Taranaki and Waitemata DHBs do not appear to coincide with elevated nitrate levels in registered drinking water supplies based on the available data, indicating the strong influence of other risk factors.

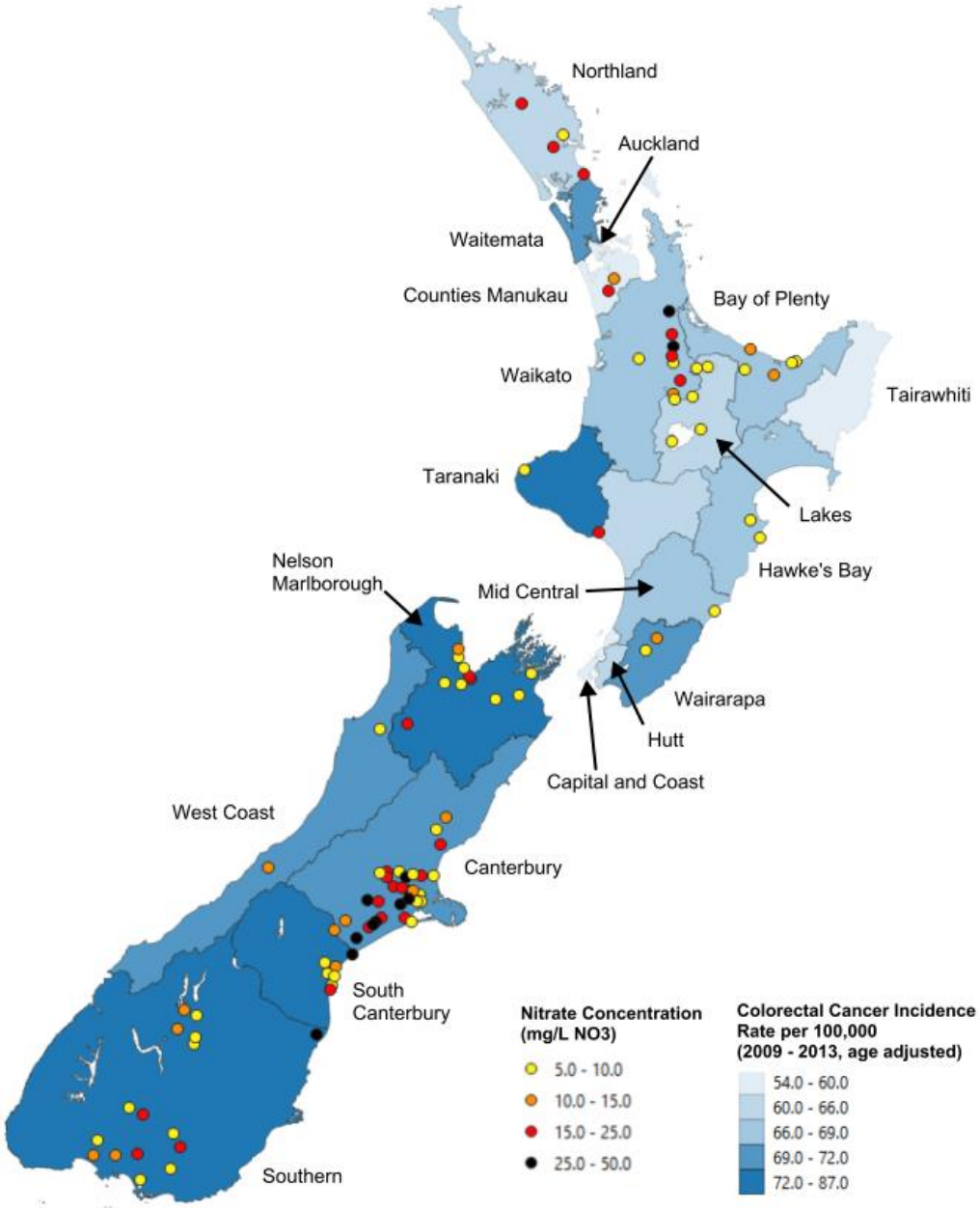

Figure 7: Elevated nitrate levels in registered drinking water supplies and colorectal cancer incidence rates within each District Health Board

Map based on data from nitrate database, 2009 – 2013 age adjusted colorectal cancer rates per DHB (HQSC, 2019) and Creative Commons 4.0 International (2019)

4.6 STUDY STRENGTHS AND WEAKNESSES

Despite being a preliminary investigation, there are a number of strengths associated with this study. These strengths include:

- High nitrate data coverage for the New Zealand population in the nitrate database (84%).
- High nitrate data coverage for the population served by registered water supplies in the nitrate database (97%).
- Estimated nitrate levels in drinking water for approximately 600,000 people not served by a registered supply have been considered.

- Nitrate data collected from multiple different sources.
- Nitrate levels in the nitrate database are estimated from multiple results from 2018-2020 where possible, rather than based on a single result.
- Results of multiple, peer-reviewed international studies have been applied, including the results of a recent meta-analysis (Temkin et al., 2019).

Due to the preliminary nature of the study there are a number of associated weaknesses. The most significant weaknesses are considered to be:

- Uncertainties in the dose-response relationship - this study is based on the implicit assumption that the dose response relationships published in the academic literature by Schullehner et al., (2018) and Espejo-Herrera et al., (2016) are applicable to the New Zealand population. The use of the dose response calculated in the meta-analysis by Temkin et al., (2019) attempts to address some of this uncertainty to some degree.
- Not considering the length of exposure.
- Co-founding factors for colorectal cancer not considered.
- Lack of data for unregistered, neighbourhood, small and private supplies.
- No consideration of consumption of multiple water sources or bottled water.

These weaknesses are planned to be addressed by the recently established Nitrate in Water Research Group in a follow-on epidemiological study on the association between nitrate in drinking-water and colorectal cancer in New Zealand.

CONCLUSIONS AND RECOMMENDATIONS

This study provides the first known attempt to characterise exposure to nitrate in drinking water across the New Zealand population and the first known attempt to estimate exposure to nitrate in drinking water for people who are not supplied by registered drinking water suppliers. This study provides the first estimate of the potential contribution of exposure to nitrate in drinking water to colorectal cancer rates in New Zealand.

Based on the results of this preliminary study, 320,000 to 800,000 people may be exposed to potentially harmful levels of nitrate in drinking water, equivalent to 6.7 – 17.1% of the New Zealand population. Exposure to nitrate in drinking water is estimated to be attributable for 0.6 – 5.6% of colorectal cancer incidences in New Zealand. The results of this study indicate that nitrate in drinking water is likely to be a significant contributing factor to colorectal cancer rates in New Zealand and may be of a similar significance as the established risk factors of consumption of red meat, consumption of processed meat, lack of physical activity and smoking. Nitrate in drinking water is unlikely to be as significant as the risk factors of obesity or heavy alcohol consumption.

Although the results of this study are preliminary only, they are significant and they strongly suggest that further research into nitrate levels in New Zealand drinking water is warranted, along with further research into the epidemiology of exposure to nitrate in drinking water and the association with colorectal cancer risk.

The results warrant application of the precautionary principal and suggest that practical steps should be taken to reduce exposure to elevated nitrate levels in drinking water. Practical steps may include using available water sources with

lower nitrate levels, blending sources to reduce nitrate levels or installation of nitrate treatment processes. This is recommended for both registered suppliers and unregistered suppliers. The results also support the implementation of drinking water source protection zones and land management rules that seek to reduce nitrate leaching to waterways.

It is recommended that Taumata Arowai:

- Consider the body of evidence for the association between nitrate in drinking water and colorectal cancer and if the evidence continues to increase, consider establishing a chronic MAV for nitrate based on an accepted one-in-one-hundred thousand cancer risk.
- Consider reviewing the requirements for minimum sampling frequency for chemical compliance in the next revision of the DWSNZ (MoH, 2018).
- Consider reviewing options to permit point-of-use treatment in the next revision of the DWSNZ (MoH, 2018) as it may be the most economical way to reduce drinking water nitrate levels for Neighbourhood and Small supplies.
- Consider assigning nitrate as a P2 determinand in supplies with less than 500 people where nitrate levels exceed 50% of the MAV.
- Consider improvements to water quality data reporting and data storage on a national level.
- Work with drinking water suppliers to ensure that they have adequate resources/expertise to safely manage Neighbourhood and Small water supplies.
- Consider establishing water quality monitoring programs for unregistered water supplies in conjunction with Regional Councils.

ACKNOWLEDGEMENTS

This work would not have been possible without the significant contribution of the drinking water suppliers who provided nitrate data and supply information for their water supplies and the Regional Councils that provided nitrate data and information on the use of bores for domestic consumption. Thank you also to ESR and the MoH for providing general information and advice throughout the project and for assistance in contacting private drinking water suppliers.

Thank you to my employer Fluent Infrastructure Solutions who have provided me the time and resources to complete this dissertation and thank you to the Nitrates in Water Research Group for your support, guidance and encouragement throughout the project.

FURTHER INFORMATION

For further information on the results of this preliminary study, please contact Jayne Richards: jayne@fluentsolutions.co.nz.

For further information on the proposed epidemiological study on the association between nitrate in drinking water and colorectal cancer in New Zealand please contact the Nitrate in Water Research Group: nitratesinwater@otago.ac.nz.

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