WHAT IF ALLOWABLE DRINKING-WATER NITRATE LIMITS ARE REDUCED TO ADDRESS EMERGING HEALTH EFFECTS?

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ABSTRACT

Recent epidemiological evidence has found an increased risk of colorectal cancer and preterm births at nitrate-nitrogen concentrations as low as 1 mg/L in drinking water. This is much lower than the current maximum acceptable value of 11.3 mg/L for nitrate-nitrogen in the Drinking-water Standards for New Zealand and the World Health Organization Guidelines on Drinking Water Quality. The current limit is set to prevent the risk of blue baby syndrome. There is no limit set to prevent the health effects of long-term (for colorectal cancer) or prenatal nitrate exposure (for preterm births). One meta-analysis combining eight studies estimated that 1-8% of colorectal cancer is attributable to nitrate in drinking water.

This paper will discuss the health and economic implications of setting a nitrate limit based on the emerging evidence using a case study from Plan Change 7 of Environment Canterbury's Land and Water Regional Plan. The average nitrate-nitrogen concentration in Christchurch aquifers is 0.7 mg/L. However, elevated nitrate-nitrogen concentrations in deep bores north and west of Christchurch have been found, indicating anthropogenic sources of nitrate are already affecting Christchurch aquifers. Groundwater modelling found that it was likely that water north of the Waimakariri River contributes to the deep aquifers beneath Christchurch, and that nitrate from land intensification would likely lead to increased nitrate-nitrogen concentrations, with increases ranging from 0.9 – 7.6 mg/L (5^{th} and 95^{th} percentile scenarios).

We estimate there could be an additional 32.7 (95% confidence interval (CI) 8.9, 53.0) colorectal cancer and 9.8 (95%CI 8.0, 11.5) preterm births per year in the Christchurch City and Waimakariri District under the 5^{th} percentile scenario. Under the 95^{th} percentile scenario, this increases to an estimated 72.1 (95%CI 21.9, 107.2) and 23.9 (95%CI 19.9, 27.9) cases of colorectal cancer and preterm births, respectively. The estimated economic burden of these nitrate attributable health outcomes per year is between NZ$21 million under the 5^{th} percentile scenario and NZ$47.8 million under the 95^{th} percentile.

If water had to be treated to remove nitrate, ion exchange is the most likely treatment method, as this is well-proven and more cost-effective than other methods. However, this would be challenging in Christchurch due to the large number of pump stations where treatment plants would need to be installed. This could cost in the order of $610 million to construct and $24 million per year to operate. By way of comparison, this equates to 19 years of planned capital expenditure by Christchurch City Council on water supply and would result in a 75% increase in operational costs.

Nitrate-nitrogen concentrations above 1 mg/L have been found in many groundwater supplies around the country. The impact of lowering the limit in the drinking water standards would be significant in terms of source water risk management, restricting land use and increased water treatment requirements. However, not lowering the limit could result in higher rates of adverse health outcomes and other negative impacts on aquatic ecology.

KEYWORDS

Nitrate-nitrogen, colorectal cancer, preterm birth, drinking water standards, public health, nitrate treatment

NOMENCLATURE

Odds ratio (OR): a measure of association between an exposure and an outcome. The OR represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure.

Confidence interval (CI): the probability with which an estimated interval will contain the true value of the parameter.

PRESENTER PROFILE

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1 INTRODUCTION

Nitrate is one of the most common drinking water contaminants in New Zealand (NZ), largely driven by agricultural activity (nitrogen fertiliser application and livestock urine) (Morgenstern & Daughney, 2012). Nitrate leached into water from dairy farming has doubled since 1990 (Statistics New Zealand, 2019b). Emerging evidence has suggested a link between nitrate in drinking water and a range of adverse health outcomes (Manassaram et al., 2006; Temkin et al., 2019; Ward et al., 2018). The strongest evidence on these adverse health outcomes relate to colorectal cancer (Schullehner et al., 2018) and preterm births (Sherris Allison et al., 2021). The association between nitrate and adverse health outcomes have been observed as low as 1 mg/L nitrate-nitrogen. The current maximum acceptable value (MAV) for nitrate-nitrogen in the Drinking Water Standards for New Zealand (DWSNZ) (Ministry of Health, 2018a) and the World Health Organization (WHO) Guidelines on Drinking Water Quality is 11.3 mg/L (World Health Organization, 2017).

The current average nitrate-nitrogen concentration in Christchurch water supply bores is 0.7 mg/L (Christchurch City Council, 2021). However, elevated nitrate-nitrogen concentrations in deep bores north and west of Christchurch have been found, indicating anthropogenic sources of nitrate are already affecting Christchurch aquifers (Thorley, 2020). Groundwater modelling found that it was likely that water north of the Waimakariri River contributes to the deep aquifers beneath Christchurch, and that nitrate from land intensification in the Waimakariri District would likely lead to increased nitrate-nitrogen concentrations. The modelled increases ranged from 1.2 – 7.9 mg/L depending on which land use management and groundwater modelling scenario is used (Kreleger & Etheridge, 2019).

In this paper, we discuss the health and economic implications of setting a nitrate limit based on the technical reports and evidence prepared for Proposed Plan Change 7 of Canterbury's Land and Water Regional Plan.

1.1 THE MAXIMUM ACCEPTABLE VALUE FOR NITRATE

The current maximum acceptable value (MAV) for nitrate in the DWSNZ is 50 mg/L (which equates to 11.3 mg/L nitrate-nitrogen). This follows the Guidelines for Drinking-water Quality (World Health Organization, 2017) which are based on the risk to infants of developing methemoglobinemia (blue baby syndrome) and do not consider any other possible health conditions (Ward et al., 2018). Methemoglobinemia is a condition that affects infants where ingested nitrate causes the conversion of haemoglobin to methaemoglobin. Increased levels of methaemoglobin interfere with the blood's oxygen carrying capacity which restrictions oxygen delivery to cells in the body. Infants do not possess the enzymes necessary to facilitate the quick conversion of methemoglobin back to haemoglobin so are at heightened risk.

Colorectal cancer includes cancers of the colon or rectum, commonly referred to as bowel cancer. Colorectal cancer is the second highest cause of death in New Zealand (Ministry of Health, 2018c). New Zealand has one of the highest colorectal cancer rates in the world (Bray et al., 2018). Within New Zealand, South Canterbury, Southland, Wairarapa and Nelson Marlborough District Health Boards (DHBs) have the highest rates of colorectal cancer (Health Quality and Safety Commission of New Zealand, 2019). Canterbury DHB has an average rate of colorectal cancer incidence compared to other DHBs but has the highest number of colorectal cancer cases in New Zealand.

An estimated 90% of colorectal cancers (CRC) are sporadic (non-hereditary), meaning they develop after birth due to a range of modifiable risk factors (Purcell et al., 2017). A NZ study has estimated the colorectal cancer rates attributable to known risk factors including obesity (9%), alcohol (7%), physical inactivity (4%), smoking (3%), consumption of red meat (5%) and processed meat (3%) (Richardson et al., 2016). Emerging international evidence has suggested that nitrate contamination in drinking water is another potential risk factor for colorectal cancer (Temkin et al., 2019).

A recent meta-analysis that pooled the results from eight epidemiological studies reported a 4% increase in CRC risk per mg/L increase in nitrate-nitrogen concentrations (odds ratio (OR) 1.04, 95%CI 1.01, 1.07) (Temkin et al., 2019). Population-based studies in Denmark, USA, Spain and Italy have reported an increased risk of CRC from nitrate concentrations >0.87 mg/L (Schullehner et al., 2018); >1.01 mg/L (Weyer et al., 2001); >1.61 mg/L (Espejo-Herrera et al., 2016); >5.00 mg/L (De Roos et al., 2003). However, some studies have produced mixed results with null findings or non-linear relationships between nitrate in drinking water and colorectal cancer (De Roos et al., 2003; Jones et al., 2019; McElroy et al., 2008; Weyer et al., 2001). Some limitations of these studies producing null or inconsistent findings were 1) overly specific populations such as older women aged 55-69 (Jones et al., 2019; Weyer et al., 2001) or rural populations (McElroy et al., 2008); 2) lacking statistical power due to small samples when split across multiple exposure groups (McElroy et al., 2008); and 3) unreliable exposure measurements for nitrate.

The two most methodologically rigorous studies conducted to date on nitrate contamination and colorectal cancer are Schullehner et al. (2018) and Espejo-Herrera et al. (2016). Schullehner (2018), commonly referred to as "the Danish Study," was a nation-wide, cohort study across the Danish population (n = 3 million, with 44 million observed person-years) with individual-level exposure data linked to their residential histories back to 1978. This one study is larger than all other cohort studies combined. Espejo-Herrera (2016) was a case-control study with 1,869 CRC cases matched with 3,530 controls in Spain and Italy with individual-level exposure data linked to participant's residential history and accounted for key confounders (sex, age, socioeconomic status, physical activity, smoking and family history of CRC). Like Schullehner, this one case-control study is larger than all other case-control studies combined. However, these two studies did not provide a linear estimate (e.g. increased risk of colorectal cancer per mg/L increase in nitrate) so we have opted for the Temkin estimate in our analyses.

The proposed mechanism ingested nitrate impacts cancer is through a process of endogenous nitrosation. Ingested nitrate is reduced to nitrite by nitrate-reducing bacteria in saliva (Sinha et al., 2021). Nitrite under acidic gastric conditions reacts with nitrosatable compounds to generate N-nitroso compounds (NOC) which are known carcinogens (International Agency for Research on Cancer, 2010). NOC can induce DNA-damaging metabolites, which could lead to cancerous lesions in cells (Zhu et al., 2014). A recent study identified this specific DNA damage in biopsies from a cohort of 900 colorectal carcinoma cases (Gurjao et al., 2021). Red meat consumption was associated with the alkylating signature in colorectal cancer sites which provided molecular evidence of the mutagenic impact of dietary nitrite via the NOC pathway (Gurjao et al., 2021). A randomised-controlled trial with human participants showed nitrate in drinking water increased bio-makers of NOC formation in faeces (van Breda et al., 2019), which supports human feeding studies focusing on dietary nitrate consumption (Hughes et al., 2001; Rowland et al., 1991).

1.2 NITRATE AND PRETERM BIRTHS

Any birth that occurs before 37 weeks is defined as a preterm birth. In NZ, preterm birth is the leading cause of mortality in infants (23% of all deaths in 2017) and children under 5 years (22% of all deaths in 2018) (Ministry of Health, 2018c). Surviving preterm infants have higher rates of chronic health conditions including neurological and developmental disabilities, mental health, emotional and respiratory problems (Frey & Klebanoff, 2016). The impacts of prematurity worsen with lower gestation ages, with the most severe outcomes experienced by early preterm birth (Frey & Klebanoff, 2016).

Two narrative reviews assessing the impact of nitrate in drinking water on birth outcomes concluded there was evidence linking nitrate with preterm births, albeit with some limitations (Manassaram et al., 2006; Ward et al., 2018). Addressing some of these limitations, a recent retrospective cohort study of 4.6 million births in California from 2000-2011 observed an increased risk of early preterm birth (<32 weeks) for mothers exposed to nitrate >5 mg/L (OR 1.49 95%CI 1.42, 1.56) and >10 mg/L (OR 1.34 95%CI 1.12, 1.60) compared to mothers exposed to <5.0 mg/L (Sherris Allison et al., 2021). The authors also conducted a within-mother analysis of exposure-discordant consecutive births which controlled for inter-participant differences. The within-mother analysis showed pregnancies exposed to >5 mg/L (OR 1.47 95%CI 1.29, 1.67) and >10 mg/L (OR 2.52 95%CI 1.49, 4.26) had increased odds of early preterm birth compared to pregnancies exposed to <5 mg/L.

Established risk factors for preterm birth include maternal tobacco use, age, socio-economic status and obesity (Frey & Klebanoff, 2016). Several environmental exposures have been suggested as additional risk factors for preterm birth including air pollution (Shah & Balkhair, 2011) and nitrate contamination in drinking water (Sherris Allison et al., 2021). One proposed mechanism for nitrate impacting preterm birth is through oxidative stress. Oxidative stress is an imbalance of oxidants and antioxidants, which can cause accelerated ageing of fetal cells (Menon, 2014). The aging of fetal cells generate biomolecular signals that can trigger the labour process (Menon, 2014). One biomarker of oxidative stress is high methaemoglobin levels from the conversion of haemoglobin to methaemoglobin (a by-product of nitrate metabolism) (Bryan & Loscalzo, 2017). Elevated methaemoglobin levels have been observed in umbilical cord blood of pregnant women exposed to nitrate (Tabacova et al., 1998).

One UK study estimated the average health care costs and loss of family earnings at age 18 of an extremely early preterm birth (<28 weeks) and early preterm birth (<32 weeks) were NZ$248,000 and NZ$161,000, respectively (Mangham et al., 2009). In New Zealand, there is an average of 775 early preterm births each year which would be equivalent (based on the UK study,(Mangham et al., 2009) to an extra cost of NZ$150 million per year.

1.3 CANTERBURY GROUNDWATER QUALITY

1.3.1 CURRENT STATE OF CANTERBURY GROUNDWATER QUALITY

The median nitrate-nitrogen concentration in Canterbury's groundwater in 2019 was 3.4 mg/L, with values ranging from <0.05 to 23 mg/L (Environment Canterbury, 2020). Nine percent of monitoring wells exceeded the maximum acceptable value of 11.3 mg/L in the Drinking-water Standards for New Zealand (see Figure 1). Forty percent of wells had likely increasing or very likely increasing trends of nitrate-nitrogen concentrations (see Figure 2).

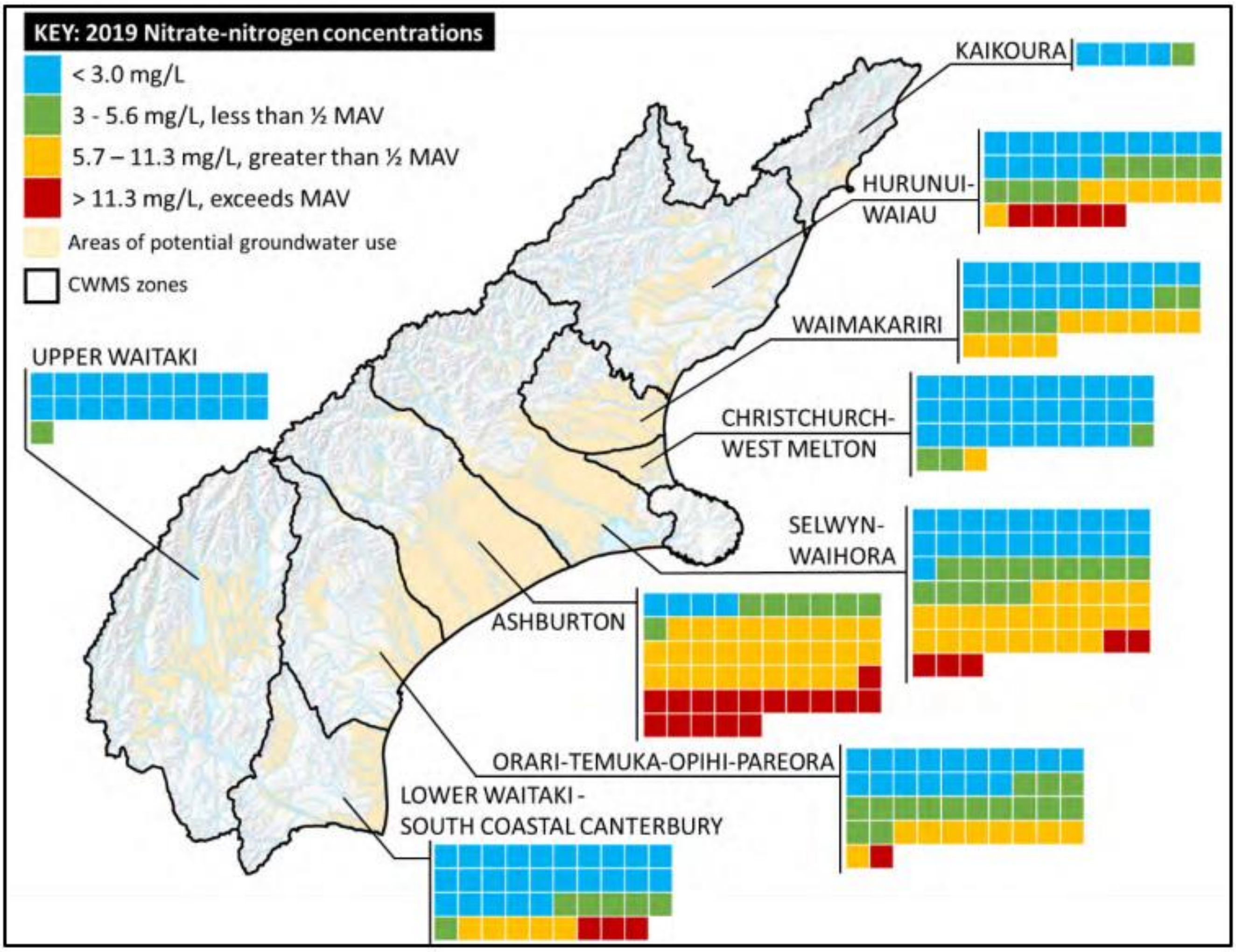

Figure 1: Summary of nitrate-nitrogen concentrations sampled in the 2019 annual survey (Figure 4 from Environment Canterbury (2020))

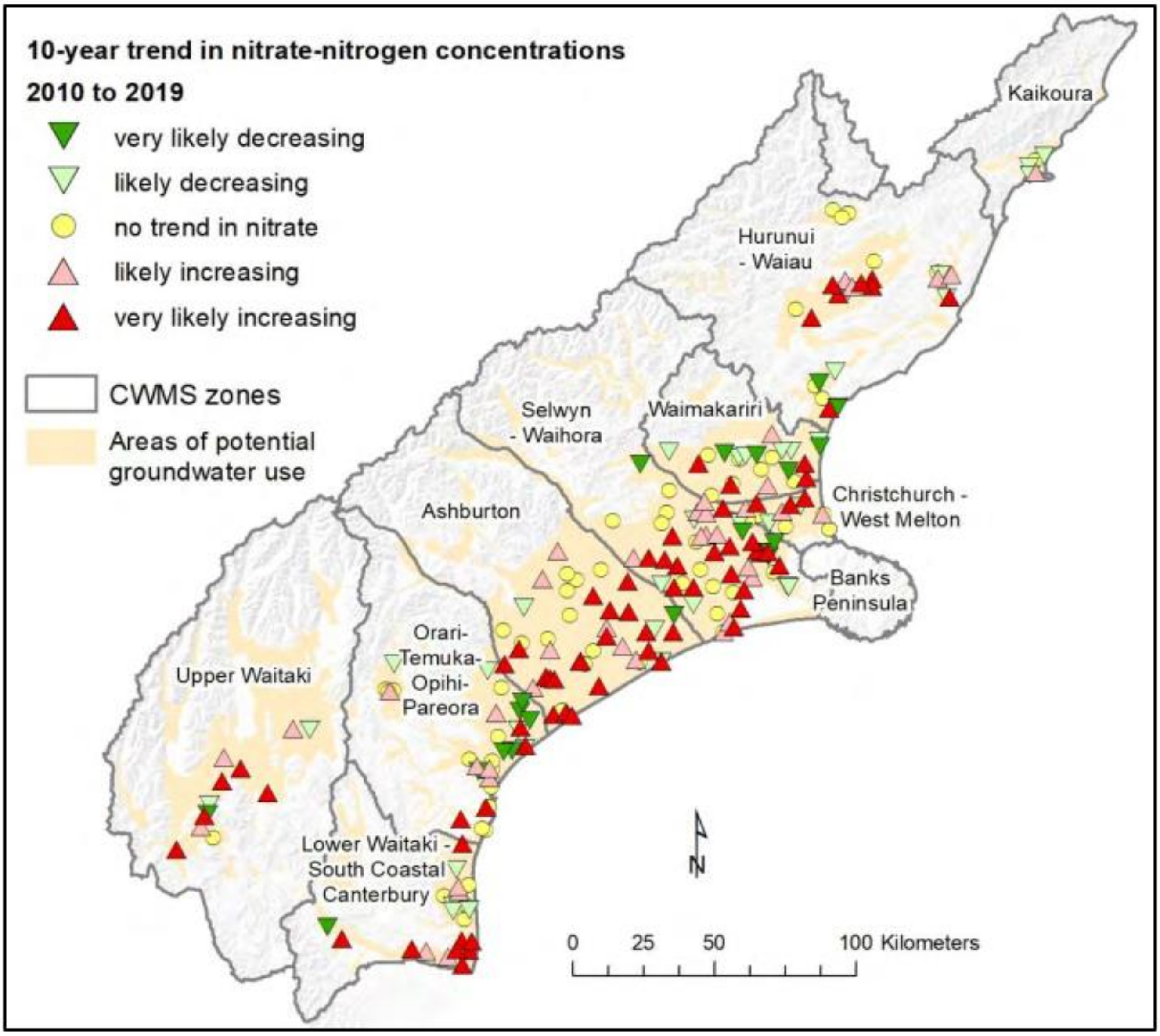

Figure 2: Ten-year trends (2010 – 2019) in nitrate-nitrogen concentrations in annual survey wells (Figure 6 from Environment Canterbury (2020))

1.3.2 CHRISTCHURCH WATER SUPPLY AND GROUNDWATER QUALITY

Christchurch is fortunate to have a very high quality groundwater source for the residents and businesses of the city and Lyttelton Harbour. This is the sole water supply source for Christchurch, Brooklands, Kainga, Lyttelton, Governors Bay and Diamond Harbour (total population 342,000).

There are 48 water supply pump stations spread across Christchurch city, which pump water from 142 wells directly into the water supply network. The water supply network is divided into eight water supply zones, with between two and 16 pump stations supplying each zone.

Recharge of the Christchurch groundwater system occurs in the unconfined areas primarily from drainage from the Waimakariri River and rainfall on a small area of the plains northwest of Christchurch. About three quarters of groundwater is recharged by Waimakariri River, with rainfall derived infiltration providing most of the remainder.

Another contributing source of groundwater to the deep aquifers in the north of Christchurch is deep flow beneath the Waimakariri riverbed from north of the Waimakariri

River. This is based on groundwater modelling undertaken by GNS for Environment Canterbury (Kreleger & Etheridge, 2019). The source area north of the Waimakariri River is shown in Figure 3. Therefore, increased nitrate leaching from land use intensification in the Waimakariri District would likely lead to increased nitrate-nitrogen concentrations in the deep Christchurch aquifers.

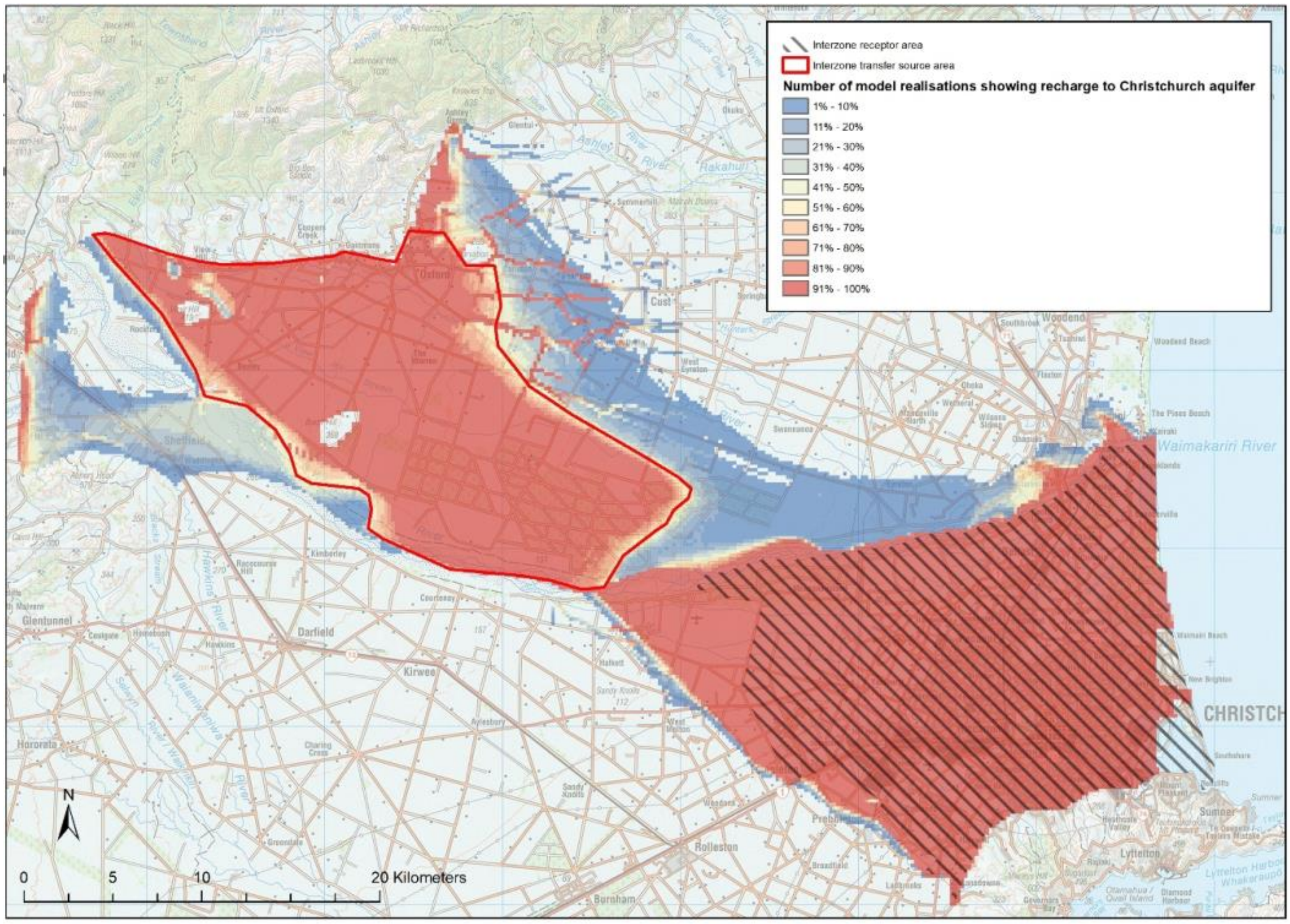

Figure 3: Waimakariri recharge sources of the Christchurch groundwater system (Figure 3-8 from Kreleger and Etheridge (2019))

The average nitrate-nitrogen concentration in Christchurch water supply bores in 2021 is 0.7 mg/L (Christchurch City Council, 2021). Elevated nitrate-nitrogen concentrations in deep bores in the northwest of Christchurch have been found where the current average concentration is 1.4 mg/L, indicating anthropogenic sources of nitrate are already affecting these aquifers (Thorley, 2020). Maximum nitrate-nitrogen concentrations measured in active water supply wells for the period 2008 – 2020 is shown in Figure 4, with values up to 4.2 mg/L.

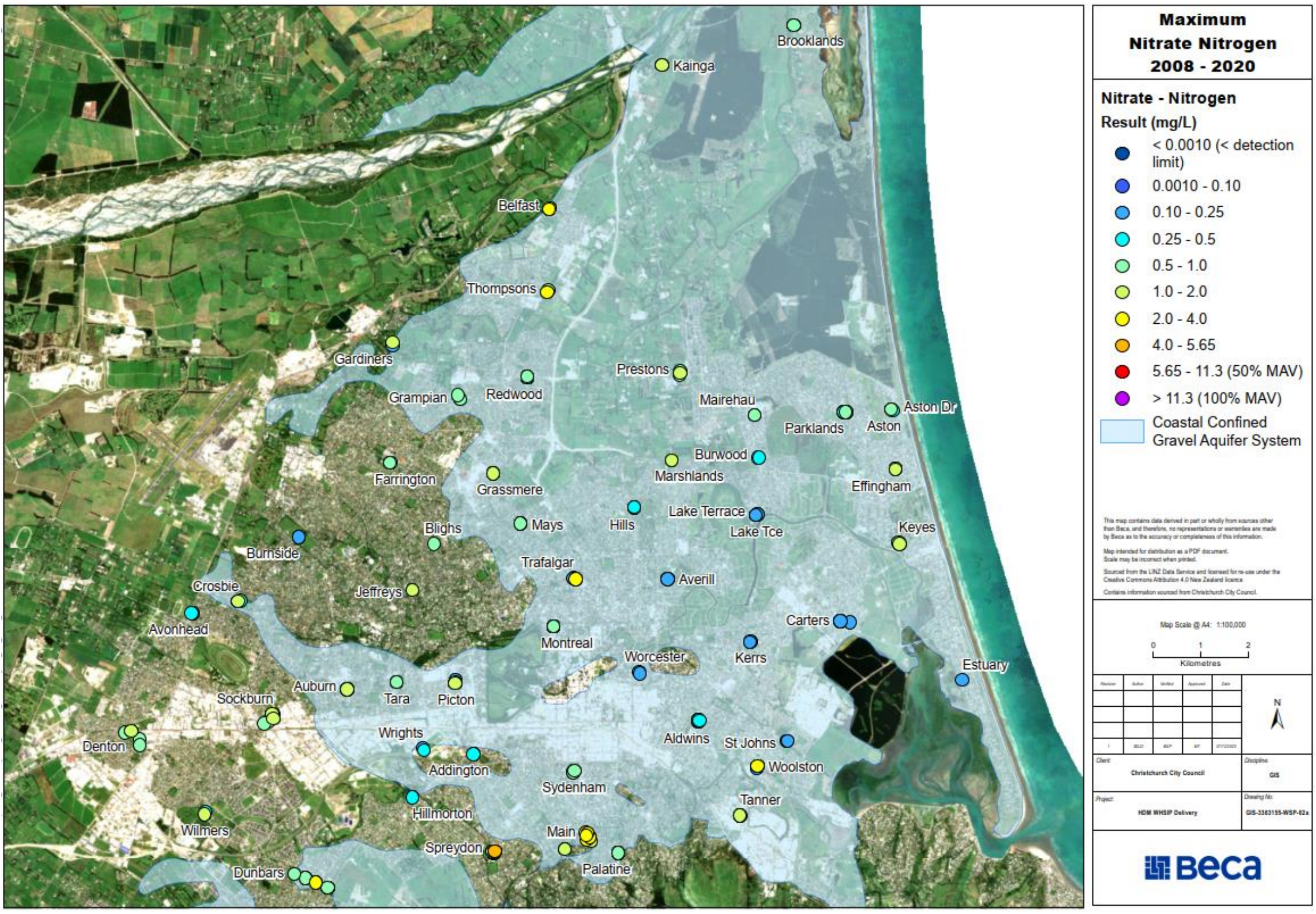

Figure 4: Maximum in nitrate-nitrogen concentrations in active water supply wells in Christchurch 2008 - 2020 (Christchurch City Council, 2020)

1.3.3 WAIMAKARIRI DISTRCT WATER SUPPLY

The Waimakariri District also relies on groundwater for its water supply. 53,800 people are served by water supplies owned and operated by the Waimakariri District Council. There are approximately 2,750 active private water supply wells in the district, with an estimated 6,900 people using these wells. The average nitrate-nitrogen concentration in Waimakariri District Council water supplies was 1.9 mg/L and in private water supply wells was 3.5 mg/L (Kreleger & Etheridge, 2019). The maximum nitrate-nitrogen concentrations in Waimakariri private water supply wells is shown in Figure 5.

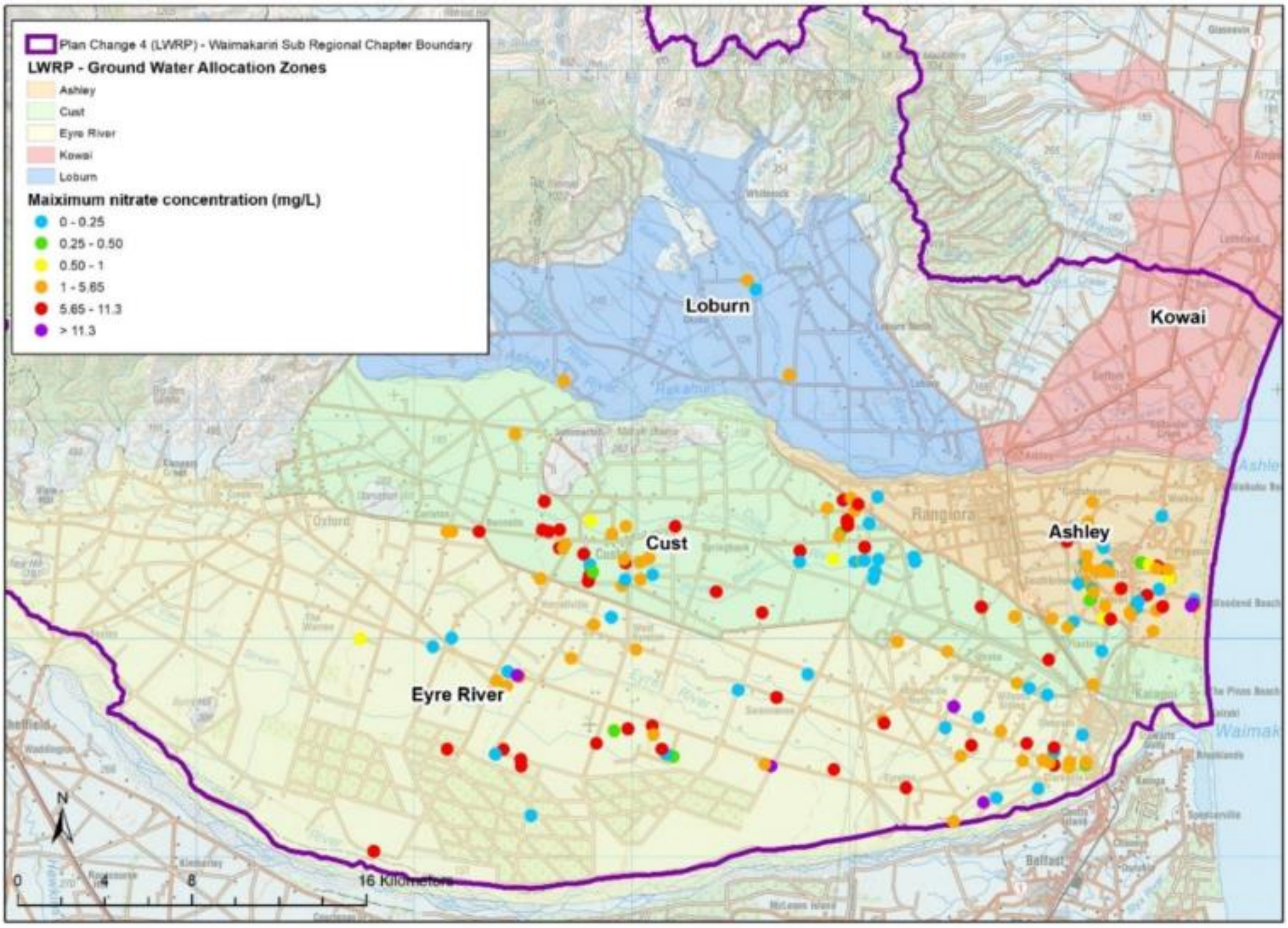

Figure 5: Measured maximum nitrate concentrations in private water supply wells in the Waimakariri District (Figure 2-11 from Kreleger and Etheridge (2019))

1.3.4 REGIONAL PLAN CHANGE SCENARIOS

ECan's Waimakariri Zone Committee set target nitrate-nitrogen concentrations for the Waimakariri and Christchurch aquifers to inform the Proposed Plan Change 7 of the Canterbury Land and Water Regional Plan. For the Waimakariri District, the target was 5.65 mg/L, which is half the DWSNZ MAV. For Christchurch aquifers the target was 3.8 mg/L, to protect the 90% of aquatic species, recognising the interconnectivity of the aquifers with spring fed streams.

Environment Canterbury and its consultants undertook extensive modelling and analysis to assess various land use scenarios that were considered for the proposed plan change. For simplicity, this paper focuses on the good management practice scenario, which is defined as the practices described in Industry-Agreed Good Management Practices Relating to Water Quality dated 18 September 2015 (Kreleger & Etheridge, 2019).

The aims of this paper were to:

1. Estimate the potential health burden attributable to nitrate in Christchurch and Waimakariri District under ECan Plan Change 7 Scenarios

2. Estimate the cost of the health burden attributable to nitrate and the cost of different nitrate treatment processes.

2 METHODS

We used the 5th, 50th and 95th percentile groundwater modelling nitrate predictions results for the good management practice scenario for ECan's Plan Change 7 to provide a range of possible groundwater quality scenarios in Christchurch and the Waimakariri District (Kreleger & Etheridge, 2019). Nitrate-nitrogen levels for the Waimakariri District were provided for community and private water supply wells, while only community wells were provided for Christchurch. Thus, we have three exposure groups for analyses. We took the current average nitrate-nitrogen for each exposure group reported as our current state. The input data used in our analysis is shown in Table 1.

In our analyses, we assumed 100% of the population were exposed to this level of nitrate. While the nitrate concentration varies depending on well location, as there appears to be a linear relationship between nitrate concentration and health effects, using the average concentration is appropriate at a population-based level.

Table 1: Population served and exposure scenarios for Christchurch and Waimakariri District drinking water supplies

Water supplies	Population Served[1] (n)	Percentage of Canterbury DHB[2] (%)	Current NO_3-N exposure (mg/L)	5th percentile scenario exposure (mg/L)[4]	50th percentile scenario exposure (mg/L)[4]	95th percentile scenario exposure (mg/L)[4]
Christchurch (community)	342,000	63	0.7[3]	3.0	5.2	7.6
Waimakariri (community)	53,800	10	1.9[4]	3.0	5.4	8.3
Waimakariri (private)	6,900	1.3	3.5[4]	3.1	6.3	10.2

[1] Retrieved from evidence in chief of Bridget O'Brien for Christchurch City Council for Land and Water Regional Plan Change 7 (O'Brien, 2020)
[2] Extracted from the 2018 Census
[3] Retrieved from Christchurch City Council water quality monitoring data 2021 (Christchurch City Council, 2021)
[4] Retrieved from Kreleger and Etheridge (2019)

2.1 COLORECTAL CANCER AND PRETERM BIRTH DATA

Colorectal cancer incidence data for the year 2017 was retrieved from the Ministry of Health from the New Zealand Cancer Registry (n=409) (Ministry of Health, 2018d). Early preterm birth (<32 weeks) incidence for the Canterbury District Health Board (CDHB) was retrieved from Ministry of Health Maternity Collection Database (n =496) (Ministry of Health, 2018b). We created a population-weighted colorectal cancer and preterm birth incidence for each study area. For example, Christchurch community supply served 63% of the CDHB population, thus we assigned 63% of the colorectal cancer and preterm cases to this supply (n=259 and n= 314, respectively).

2.2 POPULATION ATTRIBUTABLE FRACTION

Population attributable fractions (PAF) are used to estimate the proportion of disease in the population that could be prevented if the modifiable risk factor (or exposure) was eliminated (Webb et al., 2017). PAF analyses use the relative risk (RR) from epidemiological studies to estimate the potential population burden of a disease accounting for differences in exposure. To calculate the population attributable fraction for nitrate-attributable colorectal cancer and preterm births in our study areas, we first created an effective RR by multiplying the average exposure (or exposure scenario) by the relevant RR. For colorectal cancer we used the continuous RR from Temkin's meta-analysis (0.04 per 1mg/L increase) (Temkin et al., 2019). For preterm births we used Sherris' continuous RR (RR 0.01 per 1mg/L increase) (Sherris Allison et al., 2021). The effective RR was used in the standard PAF formula below in place of the RR:

PAF = $[P(RR-1)/Pe(RR-1)+1]$ x 100%

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

$RR = the\ relative\ risk$

Because we calculated an effective RR based on the average exposure, the prevalence of the risk factor was 100%. Confidence intervals (CI) were calculated using the lower and upper confidence intervals from Temkin (95%CI 1.01, 1.07) and Sherris (95%CI 1.009, 1.011).

2.3 DIRECT AND INDIRECT HEALTH-RELATED COSTS

To estimate the economic burden of nitrate contamination in drinking water we used available estimates of the direct and indirect costs of each colorectal cancer and preterm birth case. The economic cost of direct medical treatment for CRC in NZ is estimated to be NZ$43,000 per case (Blakely et al., 2015). The indirect costs (such as lost productivity) of each healthy year of life lost is estimated at NZ$69,000 (Temkin et al., 2019) while an estimated eight years of healthy life is lost per diagnosed colorectal cancer case (Ministry of Health, 2013). Thus, of each additional colorectal cancer case costs an estimated NZ$595,000 (indirect costs of $552,000 + direct costs of $43,000). One UK study estimated the average economic burden at age 18 of a preterm birth <28 weeks and preterm birth <32 weeks were NZ$248,000 and NZ$161,000, respectively (Mangham et al., 2009). Given our outcome only assesses preterm births 20 to 31 weeks, we took the average of these two figures (NZ$204,500).

3 RESULTS DISCUSSION

2.3 NITRATE-ATTRIBUTABLE COLORECTAL CANCER AND PRETERM BIRTHS

Table *1* shows the estimated burden of nitrate-attributable colorectal cancer and early preterm births in Christchurch and Waimakariri under ECan's nitrate management scenarios. Under current exposure, nitrate contamination in drinking water contributes to an estimated 6.6 (95%CI 1.7, 11.3) and 1.8 (95%CI 1.5, 2.2) colorectal cancer and early preterm cases per year in Christchurch, respectively. These rates rise to 60.4 (95%CI 18.3, 90.0) colorectal cancer cases and 20 (95%CI 16.6, 23.3) early preterm births in the 95th percentile scenario (7.5mg/L nitrate-nitrogen). While Waimakariri is projected to experience slightly higher nitrate exposure than Christchurch, its overall population contribution is low (3.5 colorectal cancer cases and one preterm birth per year under current exposure levels). However, Waimakariri rates of nitrate-attributable colorectal cancer are 2.8 times (community supplies) and 4.8 times (private supplies) higher than Christchurch under current scenarios. Differences in rates reduce under the ECan scenarios given the similarities in exposure estimates so are not reported here.

Table 1: Nitrate-attributable colorectal cancer and preterm births under ECan nitrate management scenarios

Area	Health outcome	Current	ECAN Scenario 5th percentile	50th percentile	95th percentile
Christchurch City[1]	Colorectal Cancer, n (95%CI)	6.6 (1.7, 11.3)	27.8 (7.5, 45)	44.6 (12.8, 69.2)	60.4 (18.3, 90)
	Preterm births, n (95%CI)	1.8 (1.5, 2.2)	8.3 (6.8, 9.7)	14 (11.6, 16.4)	20 (16.6, 23.3)
Waimakiriri community[2]	Colorectal Cancer, n (95%CI)	2.9 (0.8, 4.8)	4.4 (1.2, 7.1)	7.2 (2.1, 11.2)	10.2 (3.1, 15.0)
	Preterm births, n (95%CI)	0.8 (0.7, 1)	1.3 (1.1, 1.5)	2.3 (1.9, 2.7)	3.4 (2.8, 4.0)
Waimakiriri private[3]	Colorectal Cancer, n (95%CI)	0.6 (0.2, 1.0)	0.6 (0.2, 0.9)	1.1 (0.3, 1.6)	1.5 (0.5, 2.2)
	Preterm births, n (95%CI)	0.2 (0.2, 0.2)	0.2 (0.1, 0.2)	0.3 (0.3, 0.4)	0.5 (0.4, 0.6)
Total	Colorectal Cancer, n (95%CI)	10.2 (2.6, 17.4)	32.7 (8.9, 53.0)	52.9 (15.2, 82.0)	72.1 (21.9, 107.2)
	Preterm births, n (95%CI)	2.9 (2.4, 3.4)	9.8 (8.0, 11.5)	16.7 (13.8, 19.5)	23.9 (19.9, 27.9)

1 Current scenario = 0.65 mg/L N03-N; 5th Percentile = 3.0 mg/L N03-N; 50th Percentile = 5.2 mg/L N03-N; 95th Percentile = 7.6mg/L N03-N

2 Current scenario = 1.9 mg/L N03-N; 5th Percentile = 3.0 mg/L N03-N; 50th Percentile = 5.4 mg/L N03-N; 95th Percentile = 8.3 mg/L N03-N

3 Current scenario = 3.5 mg/L N03-N; 5th Percentile = 3.1 mg/L N03-N; 50th Percentile = 6.3 mg/L N03-N; 95th Percentile = 10.2 mg/L N03-N

Table 2 estimates the cost of nitrate-attributable colorectal cancer and preterm births under ECan's nitrate management scenarios. Current nitrate contamination costs an estimated NZ$6.7 million each year. The cost of 5th percentile scenario (3 mg/L) is NZ$21.5 million per year. The 95th percentile has direct and indirect health costs of NZ$47.8 million per year. The majority of the costs are associated with colorectal cancer but it should be noted the preterm birth estimates do not account for stillbirths or infant mortality associated with preterm births.

Table 2: Estimated cost of nitrate-attributable colorectal cancer and preterm births under ECan's nitrate management scenarios

Water Supply	Health outcome	Current	ECAN Scenario 5th percentile	50th Percentile	95th Percentile
Christchurch City and Waimakiriri district	Colorectal Cancer, $million (95%CI)[1]	6.1 (1.6, 10.4)	19.5 (5.3, 31.5)	31.5 (9.1, 48.8)	42.9 (13, 63.8)
	Preterm births, $million (95%CI)[2]	0.6 (0.5, 0.7)	2.0 (1.6, 2.3)	3.4 (2.8, 4)	4.9 (4.1, 5.7)

1 Each additional CRC case costs an estimated NZ$595,000 (indirect costs of $552,000 + direct costs of $43,000).

2 Economic burden at age 18 of a preterm birth <28 weeks and preterm birth <32 weeks were NZ$248,000 and NZ$161,000, respectively. Given our outcome only assesses preterm births 20 to 31 weeks, we took the average of these two figures (NZ$204,500).

2.3 WATER TREATMENT OPTIONS – COST

If water had to be treated to remove nitrate, ion exchange is the most likely treatment method, as this is well-proven and more cost-effective than other methods. However, this would be challenging in Christchurch due to the large number of pump stations where treatment plants would need to be installed. The cost of nitrate removal increases with the mass of nitrate to be removed. Evidence for Christchurch City Council considered the cost reducing a possible future nitrate concentration of 7.9 mg/L down to 5.65, 3.8 and 1 mg/L (half the DWSNZ MAV, the zone committee target and the target that CCC was requesting based on emerging health evidence respectively) (Birdling, 2020) The estimated capital and operating costs are shown in Table 4, along with net present value calculated over 100 years with a discount rate of 3%.

Table 4: Estimated cost of removing nitrate from the Christchurch water supply

	Target Future Nitrate-Nitrogen Concentration		
Cost Estimate	**5.65 mg/L**	**3.8 mg/L**	**1 mg/L**
Capital Cost	\$347M	\$461M	\$610M
Annual Operating Cost	\$13M	\$18M	\$24M
Net Present Value	\$829M	\$1,117M	\$1,507M

By way of comparison, the cost of the scenario to reduce future nitrate concentrations to 1 mg/L equates to 19 years of planned capital expenditure by Christchurch City Council on water supply and would result in a 75% increase in operational costs (O'Brien, 2020).

This compares with the cost to farmers of implementing the nitrate loss reductions in Proposed Plan Change 7, which had a net present value of \$457 million (Butcher, 2020).

4 CONCLUSIONS

Emerging health evidence has found links between nitrate-nitrogen concentrations much lower than the current DWSNZ MAV and colorectal cancer and preterm births.

We estimate there could be an additional 32.7 (95% confidence interval (CI) 8.9, 53.0) colorectal cancer and 9.8 (95%CI 8.0, 11.5) preterm births per year in the Christchurch City and Waimakariri District under the 5th percentile scenario. Under the 95th percentile scenario, this increases to an estimated 72.1 (95%CI 21.9, 107.2) and 23.9 (95%CI 19.9, 27.9) cases of colorectal cancer and preterm births, respectively. The estimated economic burden of these nitrate attributable health outcomes per year is between NZ\$21 million under the 5th percentile scenario and NZ\$47.8 million under the 95th percentile.

If water had to be treated to remove nitrate, ion exchange is the most likely treatment method, as this is well-proven and more cost-effective than other methods. However, this would be challenging in Christchurch due to the large number of pump stations where treatment plants would need to be installed. This could cost in the order of \$610 million to construct and \$24 million per year to operate. By way of comparison, this equates to 19 years of planned capital expenditure by Christchurch City Council on water supply and would result in a 75% increase in operational costs.

Across New Zealand, 19% of 433 monitoring sites exceeded the DWSNZ MAV for nitrate on at least one occasion between 2014 and 2018 in Statistics NZ’s analysis of groundwater quality (Statistics New Zealand, 2019a). If a lower DWSNZ MAV for nitrate-nitrogen was adopted to account for the emerging health evidence around colorectal cancer and preterm births, this would have a significant impact on land use in water supply catchments and treatment.

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