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Nitrates in drinking-water

A webpage from the Prime Minister's Chief Science Advisor, Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia.

Webpage content

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Nitrates in Drinking-water in Aotearoa

In recent years, the issue of nitrates in drinking water has received increasing attention. This resource summarises what we know, what we don't know, and what we need to know about nitrates in drinking-water. We link to additional resources throughout, which provide more in-depth details in particular areas.

Overview

- Nitrates is a term commonly used to describe substances that contain the nitrate ion (NO_3^-). Nitrates form naturally in the environment, with microorganisms in the soil converting nitrogen (N_2) from the air into nitrogen-containing compounds, which are then taken up by plants and support plant growth.
- Nitrates also form in the environment from decomposition of waste from plants and animals (which get their nitrogen from plants), for example, from animal urine.
- Human activities have increased the level of nitrates in the environment. For example, farming introduces nitrates through the use of synthetic nitrogen fertilisers to increase crop growth, urine patches from livestock, and tilling the ground. There has been a reported 627% increase in nitrogen fertiliser use in Aotearoa between 1990 and 2019. Nitrate is water soluble and can leach into groundwater. Other sources of nitrates can include wastewater, landfills and industrial waste.
- Humans ingest nitrates through both food and water, as well as producing nitrate endogenously (within the body). Bacteria in the mouth and gut can transform ingested nitrates into other compounds during digestion, some of which may be beneficial while others may be harmful. Typically, around 90% of our nitrate consumption is from fruits and vegetables.
- Aotearoa's Maximum Acceptable Value (MAV) for nitrates in drinking-water is set at a level that is intended to prevent Blue Baby Syndrome, in alignment with the World Health Organization's guidelines. The MAV is 50 mg/L nitrate. Blue Baby Syndrome is a serious condition in infants that leads to reduced oxygen availability and can cause death. The majority of New Zealanders have access to drinking-water that meets this standard through reticulated town or district water supplies. However, up to 14% of the population may get their drinking-water from unregistered supplies, where nitrate content is often not tested.
- In recent years, an association between nitrate levels in drinking-water supplies and bowel cancer risk in adults has been identified in some overseas studies, but the evidence base is not conclusive with respect to whether the relationship is causal or coincidental.
- In those studies that found an association, the concentration of nitrates in drinking-water associated with bowel cancer was lower than Aotearoa's MAV. The studies have sparked some public concern, particularly for areas of the country where agricultural activities mean nitrates are more highly concentrated in drinking-water sources.
- A study commissioned by the NZ Food Safety Science Research Centre and undertaken by researchers at ESR considered the toxicokinetics of ingested nitrate and estimated New Zealanders' dietary exposure to nitrate from both food and water. The study estimated nitrate intake from drinking-water based on registered water supply data, thus the conclusions may not apply to those on unregistered supplies. The authors' conclusion, that it is highly unlikely that nitrates in drinking-water or the diet present an increased risk of cancer, has been challenged by epidemiologists.

- As with all complex factors involved in long term disease, it is difficult to design a sufficiently robust case-control or cohort study that would establish whether any correlation between bowel cancer and nitrates in drinking-water is causal or coincidental at nitrate levels observed in Aotearoa. There is limited current and historic data available on individual nitrate exposure and diet in Aotearoa, which adds to the challenge. Historic data on exposure is important as most cases of bowel cancer are found in those over 60 years old and unaccounted risk factors are likely to decrease the ability to detect a statistically significant effect of nitrate on bowel cancer. There is no clear evidence to suggest people who have high nitrate in drinking-water have a higher distribution of any of these other risk factors (e.g. heavy alcohol and red meat consumption). However, this requires further investigation.
- Another recent concern has been a potential association between nitrates in drinking-water and adverse reproductive outcomes – particularly low birth weights and preterm births. A meta-analysis exploring nitrate contamination and adverse reproductive outcomes concluded that there was 'no consistent evidence of a relationship between nitrate in drinking-water and adverse reproductive outcomes.' The authors note that high quality, large epidemiology studies are needed to further assess any associations with nitrate exposure from drinking-water and pregnancy, birth and infant outcomes (the Health Research Council of New Zealand has recently announced funding for a study investigating the association between nitrate in drinking water and preterm births). With this in mind, pregnant women may take a precautionary approach and consider an alternative water supply. While no one should be drinking water with nitrate levels above the MAV it is particularly important during pregnancy.
- Evolving evidence on a possible relationship between nitrates and bowel cancer, reproductive outcomes, or any other adverse health events should continue to be monitored in Aotearoa New Zealand. The Ministry of Health provides policy advice on MAVs, with Taumata Arowai (the new water regulator) responsible for implementing those standards, and undertaking compliance and monitoring. Where the technical expertise sits to inform policy in the restructured health system is yet to be established.
- Monitoring and compliance with the current MAV should be prioritised. Regular testing of nitrate levels in drinking-water is important for families with formula-fed babies that use private groundwater bore or well supplies.

Note we refer to the Maximum Acceptable Value (MAV) for nitrate in drinking-water as 50 mg/L nitrate throughout this webpage (consistent with the NZ Drinking-Water Standard and WHO guidance). Some of the literature cited uses a different measure for nitrate in drinking water, "nitrate-nitrogen", which we have converted to nitrate where needed. For reference, 50 mg/L nitrate is equivalent to 11.3 mg/L nitrate-nitrogen.

Nitrogen and nitrates

The nitrogen cycle is a natural process crucial for plant growth and ecosystem health. Nitrates are formed naturally as part of this process.

A source of nitrogen is essential for all living things. While the atmosphere is around 80% nitrogen, nitrogen gas (N_2) is chemically inert. Biologically, conversion of nitrogen into a form appropriate for sustaining life requires a select group of microorganisms in a process known as nitrogen fixation, and usually results in the creation of ammonia (NH_3).[1] The ammonia can then be taken up by plants as ammonium ions (NH_4^+), or converted to nitrate, which is also readily taken up by plants, by a variety of microbial processes. Animals, including humans, consume nitrate through their diet. Humans obtain most of their nitrate from fruits and vegetables. Where there are greater inputs of nitrogen into this cycle (see 'The use of nitrogen in agriculture') the result can be an increase in leaching of nitrates into groundwater.

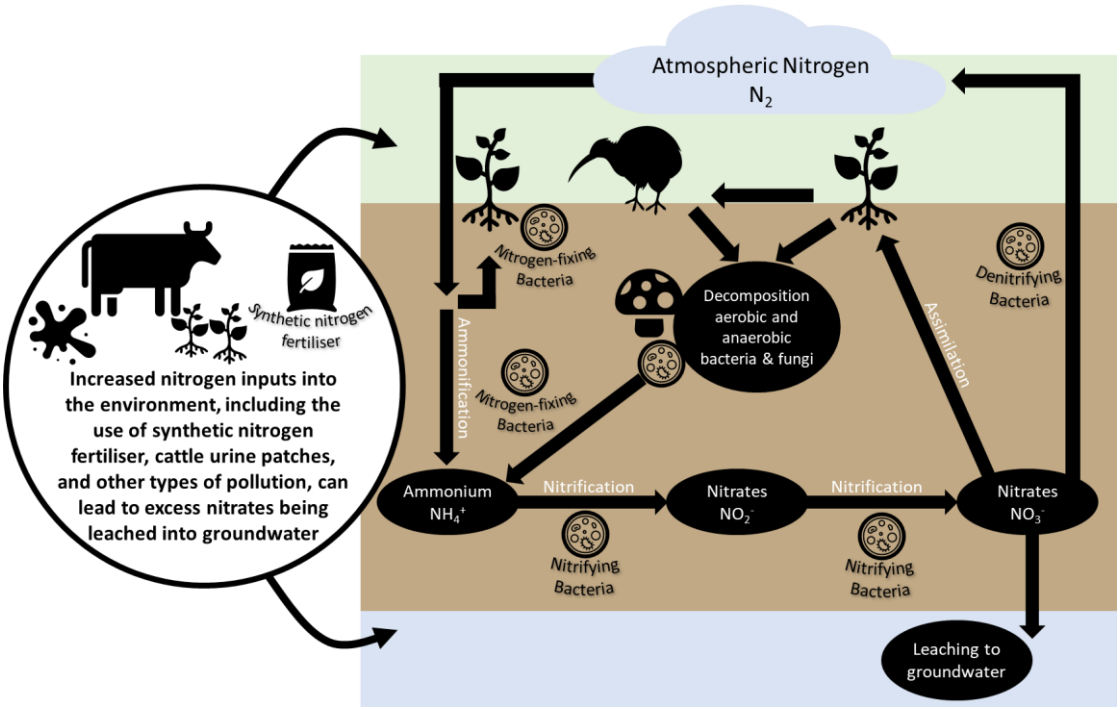

Figure 1 Key components of the nitrogen cycle (simplified).

[1] Masclaux-Daubresse, C., Daniel-Vedele, F., Dechorgnat, J., et al. (2010). Nitrogen uptake, assimilation and remobilization in plants: challenges for sustainable and productive agriculture, Annals of Botany, 105(7):141-1157. https://doi.org/10.1093/aob/mcq028

The use of nitrogen in agriculture

The availability of nitrogen in well-developed agricultural soils is typically the limiting factor in terrestrial plant growth.[2] Historically, as the global human population grew and needed more crops for food, people began deliberately using animal waste as fertiliser, to provide a source of nitrogen, either from their own animals (or themselves), from mining guano (ancient deposits of animal droppings, mostly from seabirds and bats) and also from minerals high in nitrate such as saltpetre.[3]

Today, the main nitrogenous fertiliser used in Aotearoa is synthetic nitrogen from ammonia made by the Haber-Bosch process, which can then be made into other fertilisers including manufactured urea, diammonium phosphate and sulphate of ammonia.[4] Stats NZ data shows a 629% increase in nitrogen fertiliser use in Aotearoa between 1991 and 2019.

In situations where the amount of nitrogen added to soil is greater than the amount that can be processed by soil microorganisms and taken up by plants, there can be a build-up of nitrates. Generally being water soluble, excess nitrates can be washed into rivers or, more usually, leached into aquifers. Urine patches from livestock such as cattle contain a substantial amount of nitrogen, which is easily leached into groundwater during rainfall.[5] Nitrate levels in water vary regionally and can fluctuate seasonally.[6] This can be due to intensity of agriculture, but also due to topography, soil type, land-use intensification and rainfall. Other sources of nitrates can include wastewater, landfills and industrial waste.

Credit: Katie (alaskahokie) (CC BY-NC 2.0)

[2] Bernhard, A. (2010). The nitrogen cycle: Processes, players, and human impact. Nature Education Knowledge, 3(10):25 https://www.nature.com/scitable/knowledge/library/the-nitrogen-cycle-processes-players-and-human-15644632/ Accessed 26 April 2022.

[3] Hignett, T.P. (1985). History of chemical fertilizers. In: Hignett, T.P. (eds) Fertilizer Manual. Developments in Plant and Soil Sciences, 15:3-10. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-1538-6_1

[4] Stats NZ. (2019). Nitrogen and phosphorus in fertilisers – published April 2019. https://www.stats.govt.nz/indicators/nitrogen-and-phosphorus-in-fertilisers Accessed 18 May 2022

[5] Waikato Regional Council. Managing farm nitrogen. https://www.waikatoregion.govt.nz/environment/land-and-soil/managing-land-and-soil/managing-farm-nutrients/managing-farm-nitrogen/ Accessed 29 April 2022.

[6] Waikato Regional Council. Nitrate in groundwater. https://www.waikatoregion.govt.nz/environment/water/groundwater-monitoring/gw1-report/ Accessed 26 April 2022

Environmental and freshwater health

The Ministry for the Environment's freshwater work programme is responsible for restoring and protecting the health of our waterways. Te Mana o Te Wai – the life-supporting capacity of freshwater – is the fundamental concept of the National Policy Statement for Freshwater Management. If the goals are achieved, they will help protect the health and wellbeing of people and the environment.[7] Regional Councils, communities, and tangata whenua will determine how Te Mana o Te Wai is applied locally in freshwater management.[8] Regulations such as national environmental standards for drinking-water and freshwater help provide protection.

The increased focus on freshwater health aligns with New Zealanders' increasing concerns about the state of our freshwater.[9] In 2018, Stats NZ reported through their General Social Survey that 4 out of 5 New Zealanders were concerned about freshwater quality.[10] Many Māori have this concern, which is embedded through te ao Māori understanding of the relationship between people and water. In the book *Mountains to Sea: Solving New Zealand's Fresh Water Crisis*, Tina Ngata speaks to this relationship saying there is an "inherent understanding that many Māori carry, which is 'Ko wai mātou – we are water'", where water plays a central role in Māori sense of identity and well-being.[11] This relationship has been more widely recognised in recent years with the emergence of some co-governance and co-management structures and models for the resource management of freshwater.[12]

Water is a crucial resource for all and past instances of contamination, such as the Havelock North Campylobacter crisis in 2016, have had a significant impact on how New Zealanders think about the safety of their water supplies. Another incident involved elevated levels of lead being detected in some Dunedin water supplies in 2021.[13] Commentary and concerns on the issue of increasing levels of nitrates in our drinking-water sits within this general context. While not specifically addressed in this summary, the presence of higher levels of nitrates in drinking-water is often associated with microbial contamination in private water supplies.[14]

Under the Water Services Act 2021, Taumata Arowai has prepared new proposed Quality Assurance Rules which set out requirements for water suppliers to test source waters for nitrate. This will allow the regulator to maintain a national database of a range of contaminants in drinking-water sources, including nitrate.

[7] Ministry for the Environment. (2022). Government freshwater work programme. https://environment.govt.nz/what-government-is-doing/areas-of-work/freshwater/work-programme/ Accessed 22 April 2022.

[8] Ministry for the Environment. (2021). Te Mana o Te Wai implementation. https://environment.govt.nz/assets/Publications/Files/essential-freshwater-te-mana-o-te-wai-factsheet.pdf

[9] Joy, M. (2015). Polluted inheritance New Zealand's fresh water crisis. Bridget Williams Books, Wellington. https://doi.org/10.7810/9780908321612

[10] Stats NZ. (2019). Freshwater quality Kiwis' biggest environmental concern. https://www.stats.govt.nz/news/quality-kiwis-biggest-environmental-concern Accessed 24 May 2022.

[11] Ngata, T., (2018). In: Mountains to Sea: Solving New Zealand's Freshwater Crisis. Ed. Mike Joy. Bridget Williams Books, Wellington. https://doi.org/10.7810/9781988545431

[12] Harmsworth, G. Manaaki Whenua – Landcare Research. Te Ao Māori/mātauranga Māori to address regional council Research, Science and Technologies (RS&T) strategies and priorities. Envirolink Grant: 2141-NLCC117. Prepared for Nelson City Council on behalf of the regional councils and unitary authorities in New Zealand. https://www.envirolink.govt.nz/assets/2141-NLCC117-Te-Ao-Maori-matauranga-Maori-to-address-regional-council-RST-strategies-and-priorities.pdf

[13] Dunedin City Council. Waikouaiti/Karitane/Hawksbury Village residents can drink tap water again. Last updated April 2022. https://www.dunedin.govt.nz/news-and-events/public-notices/can-drink-tap-water-again Accessed 7 June 2022.

[14] World Health Organization. (2017). Guidelines for drinking-water quality, 4th edition, incorporating the 1st addendum https://www.who.int/publications/i/item/9789241549950

The Land, Air, Water Aotearoa (LAWA) Groundwater Quality National Picture Summary 2022 considered data from almost 1,000 wells and revealed groundwater nitrate concentrations exceed the MAV in around 6% of wells tested.[15] LAWA stated that generally the wells found to have higher nitrate concentrations were located in areas of intensive animal grazing or horticultural production. Of the wells tested, it is not known how many are used for drinking-water or what further treatment systems might be in place.

A recent study found that of the 575 groundwater monitoring sites in Aotearoa that had sufficient data to be analysed, 22% displayed trends that were inferred to be the result of human impacts, mostly evidenced by increasing trends in nitrate concentration.[16] Regional councils tend to monitor groundwater quality in known problem areas, which means that the available data may show a higher proportion of groundwater monitoring sites with signs of human impacts than exists across the whole groundwater resource. Canterbury is the region with the highest proportion of sites with trends inferred to be caused by human impact. Environment Canterbury reporting highlights similar trends and states that nitrate concentrations in groundwater are likely to still be increasing.[17]

Nitrates in the human body

The impacts of nitrate in the body are complex. Ingested nitrates from food and water are processed in the body to a range of different compounds which may have both positive and negative health impacts.

Positive impacts of nitrate are plausible via a potential associated increase in the level of nitric oxide (NO). Nitric oxide is made in the body from the amino acid L-arginine and acts as a rapid, short-term vasodilator and immunomodulator, among other effects.[18] Long considered inert end products of this reaction sequence, in 2008 it was discovered that nitrite and nitrate can be recycled into the pathway and as such could have beneficial effects in heart attacks, strokes and hypertension as well as improving sports performance, although these effects have not been shown definitively.[19,20,21,22,23]

One adverse health condition associated with nitrate in drinking-water, methaemoglobinemia or Blue Baby Syndrome, has been widely confirmed by the scientific community (see section ‘methaemoglobinemia (Blue baby syndrome)’).

[15] Land, Air, Water Aotearoa. Scientists release updated summary of NZ groundwater quality. https://www.lawa.org.nz/get-involved/news-and-stories/national-news/2022/march/scientists-release-updated-summary-of-nz-groundwater-quality/ Accessed 2 June 2022.

[16] Moreau, M., Daughney, C. (2021). Defining natural baselines for rates of change in New Zealand’s groundwater quality: Dealing with incomplete or disparate datasets, accounting for impacted sites, and merging into state of the-environment reporting, Science of The Total Environment, 755(2) https://doi.org/10.1016/j.scitotenv.2020.143292

[17] Environment Canterbury. (2022). 8.3. Long term trends – groundwater and surface water. Natural Environment Committee report. https://api.ecan.govt.nz/TrimPublicAPI/documents/download/4489475 Accessed 24 May 2022

[18] Wink, D., Hines, H., Cheng, R., et al. (2011). Nitric oxide and redox mechanisms in the immune response. Journal of Leukocyte Biology, 89(6):873–891. https://doi.org/10.1189/jlb.1010550

[19] Lundberg, J.O. (2008). The nitrate-nitrite-nitric oxide pathway in physiology and therapeutics, Nature Reviews Drug Discovery, 7:156-167 https://doi.org/10.1038/nrd2466

[20] Bryan, N. S., & Loscalzo, J. (Eds.). (2017). Nitrite and nitrate in human health and disease, 21-31. Cham Switzerland: Humana Press. https://doi.org/10.1007/978-3-319-46189-2

[21] Hord, N.G. et al. (2009). Food sources of nitrates and nitrites: the physiologic context for potential health benefits, American Journal of Clinical Nutrition. 90(1):1-10 https://doi.org/10.3945/ajcn.2008.27131

[22] Bonilla Ocampo, D., Paipilla, A., Marín, E., et al. (2018). Dietary nitrate from beetroot juice for hypertension: a systematic review. Biomolecules, 8(4):134. https://doi.org/10.3390/biom8040134

[23] Jackson, J., Patterson A., MacDonald-Wicks, L., et al. (2018). The role of inorganic nitrate and nitrite in cardiovascular disease risk factors: a systematic review and meta-analysis of human evidence. Nutrition Reviews, 76(5):348-371. https://doi.org/10.1093/nutrit/nuy005

A number of studies have investigated associations between nitrates and other adverse health impacts. Findings from these studies are, to date, generally inconclusive; they are discussed further in the following sections (see section 'Evidence for adverse health impacts associated with nitrate in drinking-water').

Dietary sources of nitrates

Water is not the only source of nitrate in the human diet and is rarely the major source.

Water is not the only source of nitrate in the human diet and is rarely the major source. Because of their ubiquity in the soil and high solubility, nitrates are found in most fruit and vegetables, which account for over 80% of nitrates in the typical diet.[24,25]

Fruits and vegetables also contain compounds, such as anti-oxidants, which may inhibit a reaction that turns the nitrates into compounds that may cause cancer in humans. In contrast, other foods such as preserved meats (like ham, bacon and some salamis) contain nitrates which can be more readily converted to nitrites inside our bodies (or already contain nitrite as a preservative). These nitrites may then react to form compounds that may be carcinogenic.[26,27] Overall, preserved meats are estimated to contribute a very small amount of nitrate to most New Zealanders' diets.[28]

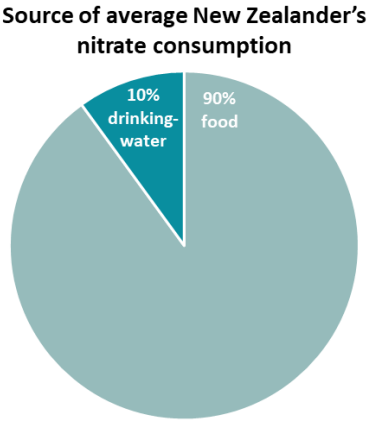

Figure 2 On average, New Zealanders consume around 10% of their nitrates from drinking water and the remainder from foods. Variation between individuals was not assessed.

As with soil microbes, commensal microbes in the human mouth and intestine can convert nitrate into nitrites and nitric oxide.[29] This means that the impact of nitrate intake is likely to vary between individuals.

In August 2021, the New Zealand Food Safety Science and Research Centre (NZFSSRC), released a report prepared by the Institute for Environmental Science and Research (ESR), on nitrates in the diet of New Zealanders.[30] This report was co-funded by Fonterra and the Ministry of Business, Innovation and Employment. It used information from national nutrition surveys that asked around 8,000 New Zealanders about their eating and drinking habits to estimate how much nitrate came from food and how much from drinking-water. The authors also tried to estimate how much water was consumed together with food, or within a short time of eating (when water is consumed close to eating then it is difficult to separate the exposures when considering risk). They estimated the amount of nitrates the cohort ingested in a day and found that on average, the nitrate New Zealanders take in

[24] Ma, L., Hu, L., Feng, X., et al. (2018). Nitrate and nitrite in health and disease, Aging and Disease, 9(5):938-945. https://doi.org/10.14336/AD.2017.1207

[25] Cressey, P., Cridge, B. (2022). Exposure to nitrate from food and drinking-water in New Zealand. Can these be considered separately?. Food Additives & Contaminants, A:1-15. https://doi.org/10.1080/19440049.2022.2037725

[26] Ferguson, L. (2010). Meat and cancer, Meat Science, 84(2):308-313, https://doi.org/10.1016/j.meatsci.2009.06.032

[27] International Agency for Research on Cancer. 2010. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 94. Ingested nitrate and nitrite, and cyanobacterial peptide toxins.
464. https://www.ncbi.nlm.nih.gov/books/NBK326544/pdf/Bookshelf_NBK326544.pdf

[28] Cressey, P., Cridge, B. (2022). Exposure to nitrate from food and drinking-water in New Zealand. Can these be considered separately? Food Additives & Contaminants, A:1-15. https://doi.org/10.1080/19440049.2022.2037725

[29] Gonzales-Soltero, R., Bailén,M., de Lucas, B., et al. (2020). Role of oral and gut microbiota in dietary nitrate metabolism and its impact on sports performance, Nutrients, 12(12):3611 https://doi.org/10.3390/nu12123611

[30] Cressey, P., Cridge, B. (2021). *Nitrate in food and water.* Wellington (NZL): Institute of Environmental Science and Research. https://nzfssrc.org.nz/assets/Project-Reports/Report_CSC21025_Nitrate_in_food_and_water_FINAL..pdf

from food and water add up to about 25% of the internationally agreed acceptable daily limit, with less than 10% coming from drinking-water. However, the study estimated nitrate intake from drinking-water based on registered water supply data, thus the estimates may not apply to people drinking from unregistered supplies (around 14% of the population).

The study used an acceptable daily intake of 0 – 3.7mg/kg of body weight per day (expressed as nitrate ion). An acceptable daily limit is the amount of a substance in food or drinking water that can be consumed over a lifetime without an appreciable health risk. With respect to nitrate in water supplies, this figure is particularly relevant for infants fed formula.

This is different than the MAV which is based on the concentration in drinking-water that is considered not to cause significant risk to health over a lifetime when consuming 2 litres of water a day.

Figure 3 Vegetables such as beetroot are naturally high in nitrates, as well as protective factors such as anti-oxidants. Credit: Adair Broughton (CC BY-NC-ND 2.0)

Evidence for adverse health impacts associated with nitrate in drinking-water

Methaemoglobinaemia (Blue Baby Syndrome)

Methaemoglobinaemia is an acute condition associated with nitrate ingestion. Nitrate initiates conversion of haemoglobin to methaemoglobin. Methaemoglobin cannot carry oxygen, which means that the blood carries less oxygen than usual and tissues in the body receive a reduced supply of oxygen. Signs of this condition can include headache, shortness of breath, poor muscle coordination, blue-coloured skin and other symptoms. Metheamoglobinaemia is serious and requires treatment.

Infants are particularly susceptible, especially in the presence of certain gastro-intestinal infections.

Infants are particularly susceptible, especially in the presence of certain gastro-intestinal infections.[31] As water that has higher levels of nitrate is also likely to have microbial contamination, this means the likelihood of methaemoglobinaemia is further raised.[32]

Methaemoglobinaemia is a risk for infants that are bottle fed with formula made up with drinking-water that is above 50 mg/L of nitrate. That led the WHO to set a guideline of 50 mg/L of nitrate measured as nitrate to act as a protective measure for bottle-fed infants and for other population groups. An MAV of 50 mg/L was adopted for nitrates in drinking-water in New Zealand's Drinking-water Standards.[33]

Cancer

In 2011, the WHO looked at the potential health risks of nitrates (and nitrites) in drinking-water, specifically focusing on evidence for carcinogenicity (largely for gastric cancer), impaired thyroid function, congenital malformations, and toxicity (largely through methaemoglobinaemia) in animal models and humans.[34] The review did not find sufficient or consistent evidence of harm to support adjusting the guideline value to less than 50 mg/L nitrate in drinking-water (which continues to be based on epidemiological evidence for methaemoglobinaemia in infants). This was a significant evidence synthesis with high methodological quality and peer review.

A systematic review and meta-analysis published in 2022 considered the association between dietary nitrate, nitrite intake, and site-specific cancer risk.[35] The meta-analysis showed thyroid cancer risk was higher and kidney cancer risk lower with higher nitrate intakes. The study suggests there are type and site-specific effects of cancer risks, including protective effects, from dietary intakes of nitrate (and nitrite). The study was limited by the few studies available for each type of cancer, inability to adjust for potentially confounding factors (like intake of vitamins and red or processed meat), and the wide range of nitrate intake values from different studies. The study did not consider drinking-water separately to other dietary intakes.

Colorectal or bowel cancer

Bowel cancer rates in Aotearoa are relatively high compared to many other countries although the incidence of bowel cancer is reducing.[36,37] Recently, the possibility of a correlation between nitrates in drinking-water and bowel cancer has been the focus of some studies. While some studies have found a correlation, others have been inconclusive or have not shown a correlation.

The mechanism for nitrate causing gastric cancers is thought to involve the reduction to nitrite which may then react with N-containing compounds in the gut to form *N*-nitroso compounds, widely shown

[31] Johnson, S. (2019). Methemoglobinemia: Infants at risk. Current Problems in Pediatric and Adolescent Health Care, 49(3):57-67. https://doi.org/10.1016/j.cppeds.2019.03.002

[32] Canterbury Community and Public Health. (2016). Nitrate in drinking water "Blue baby" syndrome https://www.cph.co.nz/wp-content/uploads/saf0025.pdf

[33] Ministry of Health. (2018). Drinking Water Standards for New Zealand 2005, Revised 2018. https://www.health.govt.nz/system/files/documents/publications/dwsnz-2005-revised-mar2019.pdf

[34] World Health Organization. (2011). Nitrate and nitrite in drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality. https://web.archive.org/web/20220401011445/ https://www.who.int/water_sanitation_health/dwq/chemicals/nitratenitrite2ndadd.pdf

[35] Said Abasse, K., Essien, E., Abbas, M., et al. (2022). Association between dietary nitrate, nitrite intake, and site-specific cancer risk: A systematic review and meta-analysis, 14(3):666. https://doi.org/10.3390/nu14030666

[36] Bowel Cancer NZ. About bowel cancer: Symptoms and statistics. https://bowelcancernz.org.nz/about-bowel-cancer/what-is-bowel-cancer/symptoms-statistics/ Accessed 12 April 2022.

[37] World Cancer Research Fund. Colorectal cancer statistics. https://www.wcrf.org/cancer-trends/colorectal- cancer-statistics/ Accessed 12 May 2022.

to be carcinogenic over the long term.[38] New Zealand researchers have also recently reported there is a likely biological pathway for nitrate in drinking-water to increase the risk of colorectal cancer.[39]

Attributing a direct link between nitrate in drinking-water and cancer is challenging because of the range of factors involved, including different dietary sources of nitrates and nitrites, different sources of *N*-nitroso compounds, impact of different physiological and gut microbial rates of conversion of nitrates to nitrates, and the presence of protective factors, such as vitamins A and E, in the diet. So, for example, fruit and vegetables are the most significant sources of nitrate in the diet, but contain high levels of protective factors such as vitamins and fibre.[40] There is also a time lag between the ingestion of nitrate and the potential development of colorectal cancer. In the last decade, there have been a small number of studies investigating the association between nitrate in drinking-water and cancer, which have assessed the association with varying degrees of rigour.

Attributing a direct link between nitrate in drinking water and cancer is challenging because of the range of factors involved.

In 2016, a large case control (1,869 cases and 3,530 controls) study in Spain and Italy during 2008-2013 was published that showed a positive association between total nitrate consumption from both drinking-water and food sources over long periods and colorectal cancer, particularly amongst men, and subjects with high red-meat consumption and other risk factors.[41] Drinking-water nitrate levels ranged from 1.6 mg/L to 30.0 mg/L. There are a number of limitations described in the study including potential confounding factors (such as other water contaminants), variable response rates, and uncertainty around historic nitrate levels in the drinking-water and long-term dietary information.

In 2018 a large Danish population-based study undertook analysis of 1.7 million people using average drinking-water nitrate levels.[42] Records of adults included in the study were examined from 35 years of age until the onset of colon or rectal cancer, the end of the study, death, or emigration. The study did not examine differences in diet or lifestyle, which represents a significant limitation, but did control for education and socioeconomic status. The study showed a statistically significant increase in colorectal cancer with nitrate levels in drinking-water above 3.87 mg/L and for colon cancer alone at levels above 9.25 mg/L, both below the current 50 mg/L standard. The paper indicates that for every 10 cases of colorectal cancer expected in low nitrate areas (below 1.27 mg/L) there would be on average an additional 1 case in high nitrate areas. This is one of very few robust studies on this topic and so more research is needed.

There has been publicity in Aotearoa and scrutiny around these studies.[43] For example, an article in the Conversation in January 2019, in which the authors argued that the statistically significant

[38] Kobayashi, J. (2018). Effect of diet and gut environment on the gastrointestinal formation of *N*-nitroso compounds: A review, Nitric Oxide, 73: 66-73 https://doi.org/10.1016/j.niox.2017.06.001

[39] Chambers, T., Douwes, J., Mannetje, A., et al. (2022). Nitrate in drinking water and cancer risk: the biological mechanism, epidemiological evidence and future research. Australian and New Zealand Journal of Public Health, 46(2):105-108. https://doi.org/10.1111/1753-6405.13222

[40] Food Standards Australia New Zealand. (2011). Survey of nitrates and nitrites in food and beverages in Australia. https://www.foodstandards.gov.au/consumer/additives/nitrate/Documents/Survey%20of%20nitrates%20and%20nitrites.pdf

[41] Espejo-Herra, N., Gràcia-Lavedan, E., Boldo, E., et al. (2016) Colorectal cancer risk and nitrate exposure through drinking water and diet. International Journal of Cancer, 139(2):334-346. https://doi.org/10.1002/ijc.30083

[42] Schullehner, J. (2018). Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study, International Journal of Cancer, 143(1):73-79 https://doi.org/10.1002/ijc.31306

[43] Selvarajah, S. (2022). Is New Zealand drinking water nitrate standard fit for purpose to protect from colorectal cancer? A critical review. In: Adaptive Strategies for Future Farming. (Eds. C.L. Christensen, D.J. Horne and R. Singh). Occasional

increase in colorectal cancer at less than one tenth of the current standard merited a look at the standard, particularly in the light of the fact that in farming intensive areas across Aotearoa ground water wells used for drinking are contaminated with nitrates.[44]

In a paper published in March 2022, a group of researchers at the Otago School of Medicine reviewed the published effect ratios for studies of colorectal cancer and estimated the exposure of the public in Aotearoa to nitrate in drinking-water to determine potential impacts. They estimated that around 100 cases and 41 deaths per annum from colorectal cancer (around 3% of cases in Aotearoa) could be attributable to excess nitrate in drinking-water in Aotearoa.[45] A key limitation in the study is that it did not directly assess the relationship between individual exposure to nitrate and colorectal cancer (i.e. whether there was a causal relationship). There is also a need for more comprehensive testing data on nitrate levels and water sources used by unregistered supplies (which serve around 13-14% of the population).[46]

Others have emphasised that a focus on nitrate in drinking-water is not the top priority for bowel cancer prevention in Aotearoa.[47] Well-documented bowel cancer risks include obesity, diabetes, physical inactivity, smoking nicotine and alcohol. However, it is worth considering all sources of risk, particularly as we expect our drinking-water sources to be safe and we have limited alternative choices available.

The authors of the NZFSSRC 2021 report on nitrates in the diet of New Zealanders (see section 'Dietary sources of nitrate') concluded that it was not reasonable to separate nitrates ingested via food from nitrates ingested from water, and that there was unlikely to be an impact on cancer from total nitrate intake.[48] It was also published in part in a peer-reviewed journal.[49] The report does not explain regional differences in bowel cancer rates and their overlap with areas of high nitrates in drinking-water. Some health researchers reacted by pointing out that the evidence in the NZFSSRC report draws attention to the complexities of relating cancer incidence to nitrate intake from drinking-water but does not definitively rule out a relationship, and that the report is contrary to the current International Agency for Research on Cancer (IARC) position (that nitrate from dietary and drinking-water sources should be considered separately).[50,51]

Report No. 34. Farmed Landscapes Research Centre, Massey University, Palmerston North, New Zealand. https://www.researchgate.net/publication/358864025

[44] Joy, M., Baker, M. Drinking water study raises health concerns for New Zealanders. 25 January 2019. https://theconversation.com/drinking-water-study-raises-health-concerns-for-new-zealanders-108510 Accessed 26 April 2022.

[45] Richards. J., Chambers, T., Hales, S., et al. (2022). Nitrate contamination in drinking water and colorectal cancer: Exposure assessment and estimated health burden in New Zealand. Environmental Research, 204(C):112322. https://doi.org/10.1016/j.envres.2021.112322

[46] Institute of Environmental Science and Research. (2020). Drinking Water for New Zealand. Institute of Environmental Science and Research, online. www.drinkingwater.esr.cri.nz Accessed 22 April 2022

[47] Selvarajah, S. Otago Daily Times. Better to focus on known cancer risks. Tuesday, 29 March 2022. https://www.odt.co.nz/opinion/better-focus-known-cancer-risks

[48] Cressey, P., Cridge, B. (2021) *Nitrate in food and water.* Wellington (NZL): Institute of Environmental Science and Research. https://mcusercontent.com/ac7d10ed90f765f0df9b564b7/files/0d6eaae9-6e25-328b-835e-10330f48888c/CSC21025_Nitrate_in_food_and_water_FINAL_13_August_2021.pdf

[49] Cressey, P., Cridge, B. (2022). Exposure to nitrate from food and drinking-water in New Zealand. Can these be considered separately? Food Additives & Contaminants, A:1-15. https://doi.org/10.1080/19440049.2022.2037725

[50] Chambers, T., Hales, S. (2021). Public health response to report on potential risk of nitrate from drinking water. Accessed 13 January 2022 https://blogs.otago.ac.nz/pubhealthexpert/public-health-response-to-report-on-potential-risk-of-nitrate-from-drinking-water/

[51] International Agency for Research on Cancer. (2010). *Ingested nitrate and nitrite, and cyanobacterial peptide toxins.* Lyon. https://publications.iarc.fr/_publications/media/download/2867/c9f9c85d6dd616d774bdbbe67bae77bddeb1b4de.pdf

Performing a definitive high-quality study of the impact of nitrates on colorectal cancer in Aotearoa would be very difficult due to our mobile population and the fact that much of the issue involves drinking water sourced from groundwater without long term monitoring of nitrate levels that would be required to understand the cumulative risk to an individual during the long time it takes to develop colorectal cancer.

Impacts on reproductive health

Studies have been published that have found associations between reproductive outcomes and nitrate exposure during pregnancy. One of these studies considered the Danish population and indicated a relationship between low birth weight and length of the new-born (but not head circumference) and drinking-water nitrate level.[52] The study identified a statistically significant but small effect that was unlikely to be clinically significant. The effect was strongest with increasing exposure up to 25 mg/L, and had a weaker association above 25 mg/L (although there were relatively few people in the study whose water supply contained nitrate at levels above 25 mg/L). There were some limitations in the study including a lack of data on individual dietary sources of nitrate, other water contaminants, level of water consumption, and uncertainty in water supply area.

Another study from a population in California showed a modest increase in incidence of preterm births where drinking-water contained 25-50 mg/L of nitrate.[53] The study concluded, "If future studies confirm the association between nitrate exposure below 10 mg/L [10 mg/L nitrogen-nitrate, is equivalent to 44 mg/L nitrate] and preterm births, the nitrate standard for drinking-water may need to be re-evaluated." Some of the limitations in this study included a lack of information on other risk factors such as maternal smoking or body mass index, other contaminants in drinking-water, and possible misclassification of exposure to nitrate levels in drinking-water.

In 2022, researchers at the Liggins Institute in Aotearoa completed a systematic international literature review and meta-analysis on nitrate contamination in drinking-water and adverse reproductive outcomes.[54] Five observational studies, assessed as high-quality, were included and most of which investigated levels of nitrate that are below the New Zealand MAV. The review found there is currently no consistent evidence of a relationship between nitrate in drinking-water and adverse reproductive outcomes. However, the review also concluded the number of studies suggesting possible relationships with specific congenital anomalies means that new evidence should be regularly reviewed and there should be ongoing nitrate exposure monitoring and reporting in Aotearoa. The Health Research Council of New Zealand has recently announced funding for a study investigating the association between nitrate in drinking water and preterm births.[55]

Since this systematic review, a further study from Denmark considered fecundability (time to pregnancy) and found there was no association with drinking-water nitrate (either in preconception

[52] Coffman, V., Søndergaard Jensen, A., Trabjerg, B., et al. (2021). Prenatal exposure to nitrate from drinking water and markers of fetal growth restriction: A population-based study of nearly one million Danish-born children, Environmental Health Perspectives, 129(2). https://doi.org/10.1289/EHP7331

[53] Sherris, A., Baiocchi, M., Fendorf, S., et al. (2021). Nitrate in drinking water during pregnancy and spontaneous preterm birth: A retrospective within-mother analysis in California, Environmental Health Perspectives, 129(5). https://doi.org/10.1289/EHP8205

[54] Lin, L., St Clair, S., Gamble, G.D. et al. (2023).Nitrate contamination in drinking water and adverse reproductive and birth outcomes: a systematic review and meta-analysis. *Sci Reports*, **13**. https://doi.org/10.1038/s41598-022-27345-x .

[55] In June 2022, the Health Research Council of New Zealand announced a funding grant for a retrospective cohort study investigating "The impact of nitrate in drinking water on preterm birth" to be undertaken over 36 months, led by Tim Chambers and Chris Daughney. See https://www.hrc.govt.nz/resources/research-repository/impact-nitrate-drinking-water-preterm-birth Accessed 21 June 2022.

or long-term exposure).[56] Another Denmark study considered the risk of childhood cancer and observed an association between central nervous system cancers and the highest category of nitrate exposure in drinking-water (more than 25 mg/L nitrate). This association was strongest for exposure preconception, but was also seen in prenatal and postnatal exposure.[57] There was no observed association with other childhood cancers, such as leukaemia or lymphoma.

The New Zealand College of Midwives has previously advised that pregnant women should consider an alternative water supply if nitrate levels exceed 22 mg/L nitrate (or 5 mg/L nitrate-nitrogen).[58] However, following the Liggins report, the College advise that this advice is currently being reviewed and is expected to be updated in the near future, so the website should be checked for the latest advice.

Advice for people with concerns about their drinking-water

The Ministry of Health advises the current evidence suggests that nitrate levels lower than 50 mg/L are safe. Drinking-water from registered water suppliers must be tested and maintained to ensure this level of nitrate is not exceeded.[59] However, drinking-water from private water supplies is not monitored. This means that testing groundwater bore or well water supplies for nitrate is important for families with formula-fed babies, and may be practised by other concerned individuals who choose to take a precautionary approach, for example during pregnancy. The Ministry of Health provides information on how people can test their drinking water.[60] There is also information available in the 'household water supplies' booklet.[61] The level of nitrate in water can vary throughout the year, influenced by factors such as rainfall and farming activities, which means sampling may need to occur multiple times a year.[62]

There is available advice on the Ministry of Health website for people who have drinking-water from a private source that is high in nitrate.[63] Nitrate is dissolved in the water and is not volatile and so cannot be removed by filtration or by boiling the water.[64] It is effectively removed by distillation or by either reverse osmosis or anion exchange. While devices can be obtained to treat domestic water

[56] Ebdrup, N., Knudsen, U., Schullehner, J., et al. (2022). Nitrate in drinking water and time to pregnancy or medically assisted reproduction in women and men: A nationwide cohort study in the Danish National Birth Cohort. 2022. Clinical Epidemiology,14:475-487. https://doi.org/10.2147/CLEP.S354926

[57] Stayner, L., Schullehner, J., Dige Semark, B., et al. (2021). Exposure to nitrate from drinking water and the risk of childhood cancer in Denmark, Environment International, 155. https://doi.org/10.1016/j.envint.2021.106613

[58] New Zealand College of Midwives. (2021). Nitrate levels in drinking water: risks for pregnant women and formula-fed babies. https://www.midwife.org.nz/wp-content/uploads/2021/05/Advice-to-member-Nitrates-May-2021-1.pdf

[59] Ministry of Health. Annual report on drinking water quality 2020-2021. Released 2022. https://www.health.govt.nz/system/files/documents/publications/annual-report-on-drinking-water-quality-2020-2021-mar22.pdf

[60] Ministry of Health Website. Nitrate in drinking-water. https://www.health.govt.nz/your-health/healthy-living/drinking-water/nitrate-drinking-water Accessed 26 April 2022.

[61] Ministry of Health and Institute of Environmental Science and Research. (2021). Household water

[62] Ministry of Health. Guidelines for drinking-water quality management for New Zealand. Released 2017. https://www.moh.govt.nz/notebook/nbbooks.nsf/0/B97E4331F0C1F869CC257C2E0072BAB9 Accessed 29 April 2022.

[63] Ministry of Health Website. Nitrate in drinking-water. https://www.health.govt.nz/your-health/healthy-living/drinking-water/nitrate-drinking-water Accessed 26 April 2022.

[64] Household Water Supplies; The selection, operation and maintenance of individual water supplies, 2021 update. Institute of Environmental Science and Research and Ministry of Health. https://www.esr.cri.nz/assets/WATER-CONTENT/ESR0940-Household-water-supply.pdf

supplies, it may be more cost effective to consider an alternative water source that is lower in nitrate.[65]

Undertaking nitrate removal at existing water supply stations in Aotearoa could have a high cost – estimates for Christchurch's water supply network have been made at a capital cost of more than $300 million, with significant ongoing costs.[66] Stabilising or reducing nitrate levels in water sources through environmental protections (see section 'Environmental and freshwater health') could minimise potential economic, environmental, social, and cultural costs. However, even if nitrate leaching is stopped now it will take many years to pass through some of the aquifers and return to natural levels.[67]

The long-term solution to nitrate in aquifers, rivers and lakes includes the more controlled use of synthetic fertilisers, and optimisation of farming practices so that animal waste, particularly cow urine, does not exceed the ability of the environment to absorb the nitrogen released, and nitrogen can be retained in the soils and improve plant growth.

Conclusion

Aotearoa's MAV of 50 mg/L for nitrates in drinking water is set at a level that is intended to prevent Blue Baby Syndrome, in alignment with the World Health Organization's guidelines. The majority of New Zealanders (around 86%) have access to drinking water that meets this standard through reticulated town or district water supplies. Farming and other sources of nitrogen have increased the level of nitrates in the environment and in our groundwater.

In recent years, an association between nitrate consumption and bowel cancer risk in adults has been identified in some studies, but the evidence base is not conclusive. In those studies that find an association, the concentration of nitrates associated with bowel cancer was found to be significantly lower than Aotearoa's MAV.

Another recent concern raised has been a potential correlation with adverse reproductive outcomes – particularly low birth weights and preterm births. A meta-analysis exploring nitrate contamination and adverse reproductive outcomes concluded that there was 'no consistent evidence of a relationship between nitrate in drinking water and adverse reproductive outcomes.' The authors note that high quality, large epidemiology studies are needed to further assess any associations with nitrate exposure from drinking water and pregnancy, birth and infant outcomes (the Health Research Council of New Zealand has recently announced funding for a study investigating the association between nitrate in drinking water and preterm births). Pregnant women may take a precautionary approach and consider an alternative water supply.

Evolving evidence on a possible relationship between nitrates and bowel cancer, reproductive outcomes or any other adverse health events should continue to be monitored in New Zealand by the Ministry of Health. The Ministry of Health provides policy advice on MAVs, with Taumata Arowai (the new water regulator) responsible for compliance and monitoring. Where the technical expertise

[65] Ministry of Health Website. Nitrate in drinking-water. https://www.health.govt.nz/your-health/healthy-living/drinking-water/nitrate-drinking-water Accessed 26 April 2022.

[66] Statement of evidence of Gregory Albert Birdling for the Christchurch City Council. Before the Canterbury Regional Council Hearing Commissioners. In the matter of the Environment Canterbury (Transitional Governance Arrangements) Act 2016 and in the matter of submissions on Proposed Plan Change 7 to the Land and Water Regional Plan and Proposed Plan Change 2 to the Waimakariri River Regional Plan. Dated 17 July 2020. https://api.ecan.govt.nz/TrimPublicAPI/documents/download/3909177

[67] Environment Canterbury. Nitrate in waterways – what's the story? https://www.ecan.govt.nz/get-involved/news-and-events/2019/nitrate-in-waterways-whats-the-story/ Accessed 14 April 2022.

sits to inform policy in the restructured health system is yet to be established. In addition, monitoring and compliance with the current MAV should continue to be prioritised. Regularly testing nitrate levels in drinking-water is important for families with formula-fed babies that have private groundwater bore or well supplies. If you own or operate a water supply (this includes private bores or wells) that is used for drinking water by people outside of your own home, you are legally a "drinking water supplier" and are responsible for ensuring the water meets drinking-water standards.[68]

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[68] Taumata Arowai. Mō ngā kaiwhakarato wai, For water suppliers. https://https://www.taumataarowai.govt.nz/for-water-suppliers/ Accessed 21 June 2022

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