8.7 Groundwater nitrates

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State of knowledge of the “Groundwater Nitrates” attribute: Good / established but incomplete – general agreement, but limited data/studies

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

Elevated concentrations of nitrate are known to impact subterranean aquatic organisms (composed mainly of small crustaceans, oligochaetes, nematodes, acari, and molluscs, less than 1 mm to several centimetres in body size) and microbial communities that inhabit underground aquifers and springs. Collectively known as stygofauna, these organisms are adapted to complete darkness and restricted space and exhibit an unexpectedly high biodiversity, which is recognised but poorly documented [1, 2], The invertebrates and fish that inhabit spring-fed streams (including their hyporheic zones), lakes, wetlands and caves (karst ecosystems) are also known to be sensitive to elevated nitrate [3-7]. Effects include chronic and acute toxicity and impacts on microbial biogeochemistry and overall ecological functioning. Additionally, elevated nitrate in groundwater discharges to surface water impact on aquatic organisms and their interrelationships in receiving waters [8], and contribute to eutrophication and associated problems such as proliferation of algae and toxic cyanobacteria.

Elevated concentrations of nitrate in drinking water sources from groundwaters via wells, bores, springs and spring-fed streams are known to affect human health. Impacts range from methemoglobinemia or blue baby syndrome in infants to adverse reproductive and birth outcomes, thyroid disease and a range of cancers, particularly colorectal [9-14].

A2. What is the evidence of impact on (a) ecological integrity or (b) human health? What is the spatial extent and magnitude of degradation?

(a) Evidence is strong for effects on aquatic organisms, based on New Zealand and international ecotoxicity studies [2-7]. Evidence for ecosystem-level effects on spring-water fed freshwaters is moderate, while effects on subterranean groundwater communities is poor, primarily due to a lack of (and difficulties accessing) ecosystem-level monitoring and assessment below-ground, and lack of baseline ecological records. It has often proved difficult to detect ecosystem level responses to elevated nitrate in spring fed streams where multiple compounding factors interact [15, 16].

(b) Evidence is moderate to strong for impacts of groundwater nitrate on human health, with assessments carried out in multiple countries including New Zealand, and systematic reviews and metanalyses undertaken [9-14, 17]. Effects on new-born babies fed milk formula prepared from nitrate-rich water are widely accepted, but there is still some contention regarding the wider risks from nitrate in drinking water [17-19], given significant additional exposure from food. Neither the WHO nor USEPA (or the NZ government) has yet revised drinking water guidelines to account for such risks, but evidence is mounting.

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

In 2020 StatsNZ [20] reported nitrate levels in 49% of monitored sites (128 of 262) sites were likely or very likely improving, and 35% (92 out of 262) were likely or very likely worsening. Continued upward trends in nitrate concentration have continued or accelerated in many aquifers across the country, particularly those associated with intensifying agriculture including vegetable growing and horticulture. Natural baseline for groundwater nitrate concentrations and longer-term trends have been assessed in the National Groundwater Monitoring Programme using isotopic tracing techniques [21, 22]. More recently assessments have been made using both the National Groundwater Monitoring Programme and council monitoring results compiled by LAWA using hierarchical cluster analysis, relationships to groundwater age, and regression against a measure of land-use impact [23]. There can be long lags in response of groundwaters to contamination due to the size and complexity of underground aquifers and associated travel times between source and monitoring site. These issues can be better understood and accounted for by aging groundwaters and modelling aquifer recharge and flow rates.

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

Groundwater quality (including nitrate) is monitored at the regional level as part of council State of the Environment (SOE) monitoring programmes[1]. At a national level, regional authorities collaborate with GNS Science as part of the National Groundwater Monitoring Programme[2]. This monitoring data is made publicly available on the LAWA[3], MfE[4] and GNS[5] websites and summary data presented by StatsNZ [20]. This long-term research and monitoring programme involves sample collections across New Zealand by council staff following standard protocols, and analysis by the GNS Science laboratory. LAWA presents data from the NGMP as well as from wider council monitoring programmes. Overall groundwater sampling and analytical methods are generally comparable between the NGMP dataset and the LAWA dataset. Regional council staff collect samples following

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[1] https://www.lawa.org.nz/learn/factsheets/groundwater/monitoring-groundwater-in-new-zealand#:~:text=Groundwater%20quality%20is%20monitored%20by%20regularly%20collecting%20groundwater,samples%20are%20sent%20to%20accredited%20laboratories%20for%20analysis.

[2] https://www.gns.cri.nz/data-and-resources/national-groundwater-monitoring-programme/

[3] https://www.lawa.org.nz/explore-data/groundwater-quality

[4] https://data.mfe.govt.nz/table/104571-groundwater-quality-trend-1999-2018/

[5] https://www.gns.cri.nz/data-and-resources/gns-geothermal-and-groundwater-ggw-database/

the National Environmental Monitoring Standards (NEMS) for groundwater quality data[1], and samples are sent to accredited laboratories for analysis. Each well may be sampled annually, quarterly or monthly depending on the purpose of the monitoring. Monitoring tends to be focussed on areas where groundwater is used as a source of drinking water and there are concerns regarding its safety, primarily for human consumption.

A recent assessment of the NZ groundwater monitoring network [24] concluded that it was unfit for the purpose of detecting nitrate reductions within practical timeframes (5-10 years) or budgets. The need for information on mean residence time data was emphasized to provide additional information on lag and temporal dispersion effects.

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

Overall, there are minimal practical limitations to monitoring, except significant current reliance on existing wells and bores and the set depths that they source water from (i.e., not ideal in terms of monitoring for change). Modifying the monitoring network, as recommended to increase its ability to detect changes resulting from management actions [24], would mean starting again at a significant number of new sites where there will not be a baseline of historical information. Therefore, I would conclude that measuring this attribute is practical and feasible, but will require significant investment to redevelop a fit-for-purpose monitoring programme.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

A monitoring programme following standard procedures is already in place collecting samples from selected wells and bores. The spatial extent and frequency of measurements could be usefully increased. There is also potential for high frequency monitoring using sondes (Electrical conductivity, dissolved oxygen, redox, pH, temperature) and optical nitrate probes. These provide near continuous data enabling high temporal resolution to discern short-term, seasonal and long-term variability and trends to be discerned, However, they are relatively expensive to purchase and run and still require calibration, maintenance and careful quality assurance and control to achieve quality results.

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

We understand that Lincoln Agritech has worked with iwi/hapū/land trusts (e.g., Ngāti Tahu-Ngāti Whaoa in the Waiotapu Stream catchment) on groundwater nitrates as part of the Critical Pathways research programme funded by MBIE. It appears that the Section 33 transfer of certain water quality monitoring functions from WRC to Tūwharetoa Māori Trust Board in 2020 included: “Groundwater: Biannual groundwater quality monitoring at two schools (Kuratau and Waitahanui); and Groundwater: Six weekly groundwater level measurements at 62 sites in the Taupō catchment” [45].

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

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[1] https://bucketeer-54c224c2-e505-4a32-a387-75720cbeb257.s3.amazonaws.com/public/Documents/NEMS-Water-Quality-Part-1-Sampling-Measuring-Processing-and-Archiving-of-Discrete-Groundwater-Quality-Data-v1.0.0.pdf

The other key contaminants commonly impacting groundwater (in addition to nitrate) are faecal microbes (as commonly measured using the indicator bacteria *E. coli*,), ammonium-N, and phosphorus. Other persistent chemical pollutants such as pesticides, PFAS, PAHs, and estrogens may cause localised contamination of groundwaters. Pesticides are subject to targeted lower-level monitoring as part of the four-yearly national survey of pesticides in groundwater (since 1990), which in 2018 included analysis for emerging organic contaminants [26]. All are associated with agricultural or urban/industrial sources, but the relationships to nitrate are generally variable and indirect.

Recent studies in New Zealand [23] have found that land-use intensity provides a good predictor of nitrate concentrations in oxic (but not anoxic) groundwaters. Nitrate concentrations are reduced where groundwaters are anoxic [27], which promotes denitrification (conversion to gaseous forms of N emitted to the atmosphere). This would suggest that geochemical indicators of groundwater anoxia (e.g., redox state) would also be needed if using land-use as a predictor [28].

Part B—Current state and allocation options

B1. What is the current state of the attribute?

We have a reasonably good understanding of the current state of groundwater nitrate across the motu from current monitoring networks, and this is reported regularly on LAWA. However, there is a bias towards collecting data in areas where groundwater is used for drinking water and there are concerns about safety (see A4i). Also, lag times for nitrate to be detected in wells and receiving waters i can be considerable so the ability of the current network to detect changes is relatively poor [24]. Additionally monitoring coverage tends to be clustered in alluvial aquifer areas (especially Canterbury) where nitrate contamination of ground water is known to be significant, and less common elsewhere [23]. Groundwater nitrate concentrations are trending steadily upwards in many New Zealand agricultural regions where monitoring is in place. Understanding is sufficient to use nitrate concentration as an indicator of human health and ecosystem integrity risk.

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

Natural reference states and rates of change have recently been defined across NZ [23, 29], The three different approaches compared all provided similar estimates [23].

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

No specific numeric bands have been identified specifically for groundwater nitrate. Ecosystem toxicity for groundwaters have generally been assessed using standards proposed for surface waters. For example, Moreau and Daughney[29] made comparison using trigger values from the ANZECC 2000 guidelines[1] (since superseded by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, 2018)[2]. Alternatively, the nitrate toxicity values in the National Objectives Framework (NOF) could also be applied, providing three attribute states (A-C) and a national bottom

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[1] https://www.waterquality.gov.au/anz-guidelines/guideline-values/default

[2] https://www.waterquality.gov.au/anz-guidelines

line (D) based on annual medians and 95th percentile values. The numeric nitrate guideline values for the NOF framework are based on the statistically-derived 'no observed effect concentration' (NOEC) and 'threshold effect concentration' (TEC) values for 22 surface-water species [7]. The applicability of these thresholds for groundwater fauna would need to be evaluated further, as it is unclear whether groundwater species are more [30] or less [31, 32] or similarly sensitive to nitrate-N. The relative stability of natural groundwater environments is characterised by low ecological trait variability, and low biomass and reproductive rate in stygofauna, This suggests that recovery potential following disturbance is likely to be poor [33] making groundwater fauna particularly vulnerable to flushes of high nitrate and other toxicants.

For drinking water the maximum allowable value (MAV) has been set at the WHO and NZ drinking water guideline standard of 11.3 mg Nitrate-N/L. Groundwater nitrate-N levels at or above this are generally noted as high risk, and levels below this medium or low risk (e.g., ECAN 2022 [34]), but no specific numerical bounds for the medium and low risk categories have been identified.

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity or human health?

Thresholds for toxicity of nitrate to different aquatic organisms have been identified for New Zealand [7], but are generally gradual rather than sharp tipping points. In New Zealand, the 20th and 80th percentiles are often used as thresholds to define default guideline values for surface water quality, and similar thresholds have also been proposed as an appropriate national-scale default threshold for groundwater quality.

Thresholds for nitrate in drinking water that pose unacceptable risk from methemoglobinemia in infants are reflected in the drinking water guidelines. Thresholds for other potential health risks are currently uncertain, although some meta-analysis studies have derived statistical thresholds.

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

There are variable lag times and legacy effects for groundwater nitrate that may affect aquatic ecosystems and human health. These relate primarily to the volume of aquifers relative to groundwater recharge rates and the travel times for groundwater flows to reach downslope sites where they are sourced (e.g., via groundwater bores) or mix with surface waters [23, 24]. Long-term climate cycles and trends may also affect the state and trends in groundwater aquifers with relatively short residence times.

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

A high standard of groundwater quality is an outcome sought by all iwi/hapū/rūnanga. In addition to discussing this attribute directly with iwi/hapū/rūnanga, in regards to groundwater nitrates, there is highly likely to be tikanga and mātauranga Māori relevant to informing bands, allocation options, minimally disturbed conditions and/or unacceptable degradation in treaty settlements, cultural impact assessments, environment court submissions, iwi environmental management and climate change plans, etc.

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

Relationships of groundwater nitrate concentrations and their temporal trends to agricultural and urban land use pressures are well established for oxic (but not anoxic) groundwaters [20, 23, 35]. Nitrate concentrations tend to be reduced where groundwaters are anoxic [27], promoting denitrification (conversion to gaseous forms of N emitted to the atmosphere). This would suggest that geochemical indicators of groundwater anoxia (e.g., redox state) are also needed if using land-use as a predictor [28].

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

It has been estimated that implementation of farm mitigation actions between 1995 and 2015 driven by central and local government, and industry policies reduced the nitrogen losses (predominantly nitrate) per hectare from dairy land use that would have occurred in the absence of mitigation actions by 25-30% [36]. However, these reductions were only able to marginally off-set overall pastoral farming (Dairy and drystock) increases of N loss by ~25%, which mainly resulting from intensification and expansion of dairy land use over the same period [36]. This increased N loss occurred largely in irrigated, free-draining areas of the country which contribute disproportionally more to elevated groundwater nitrate loads. This suggests that farm mitigation actions driven by policy and industry actions are only partly ameliorating the problem.

C2-(i). Local government driven

Resource consenting processes, policies and rules, often selectively applied in recognised problem areas (e.g., sensitive lake and coastal catchments) or areas of high or increasing population density, are being used to promote greater treatment of domestic wastewaters (e.g., advanced on-site treatment systems) before land application and reticulation to communal treatment systems. Similarly, improved construction of farm effluent storage and treatment ponds (e.g., properly lined to reduce seepage to groundwater), and effluent land application practices (e.g., deferred and low-rate irrigation, reduced N application rates) are gradually being implemented that reduce the risk of nitrate losses to groundwater. Managed aquifer recharge is also being trialled to dilute groundwater contaminants and maintain stream flows. Overall, there is little specific evidence that these actions specifically are having significant effects on groundwater nitrate, although improving trends are common in some areas [20] as indicated by 49% of monitored sites with improving trends (see A3).

C2-(ii). Central government driven

Improvements to wastewater treatment infrastructure have been a concern of central government for a number of years. Labour's "Three waters"/Affordable water reforms, have been replaced with National's "Local Water done well" to address long-term under-investment and inaction on improved water and wastewater infrastructure. Fixing leaking sewerage networks, reducing wet-weather overflows, upgrading onsite and small community and town wastewater treatment systems, and improved design and management of land treatment systems will likely reduce localised hot-spots of elevated groundwater (and surface water) nitrate.

As part of the NPS-FM 2020, NZ $140 million per year was provided by government to aid implementation, 60% of which was focused on temporary Jobs for Nature projects under the COVID-19 Relief and Recovery Programme [37]. In addition, the One Billion Trees programme (NZ$24 million per year) supports native and exotic plantings that take social, environmental, cultural and economic priorities into account to help meet climate change objectives (Te Uru Rākau 2018; Climate Change Response (Zero Carbon) Amendment Act 2019, Public Act 2019 number 61). These government schemes provided support to catchment groups and supported a wide range of environmental projects with potential water quality co-benefits that could include mitigation of groundwater nitrate.

The NPS-FM 2020 instigated by the previous government also attempted to put controls on winter grazing, stock exclusion from watercourses, maximum N application rates, and requirements for farm management plans to address excess nutrient loads to ground and surface waters. This strengthening of freshwater management policy also influenced resource consenting decisions and associated requirements. With repeal of the Natural and Built Environments Bill, and the Spatial Planning Bill and introduction of the Fast-track Approvals Bill, there is uncertainty about central government future intentions.

C2-(iii). Iwi/hapū driven

Iwi/hapū trust farms are grappling with the challenge of protecting te taiao (the natural world) and safeguarding mahinga kai (cultural food resources and practices) as part of their kaitiaki (environmental guardianship) responsibilities, whilst generating income to support and advance the wellbeing of their iwi/hapū/whanau. Different iwi/hapū are at different stages along the path of reconciling and addressing these challenges.

Iwi/hapū consultation requirements under the RMA, and their involvement in co-management and co-governance including recognition of ownership of various river and lake beds, and incorporation of treaty obligations, guiding documents such as the Vision and Strategy for the Waikato River, establishment of legal personhood (e.g., Whanganui River), and concepts such as Te Mana o te Wai, have undoubtedly shifted the bar in terms of freshwater management expectations.

Overall, this has increased the emphasis on environmental protection above economic exploitation, and provided a more holistic approach to freshwater management than was possible under the largely site-by-site consenting approach taken under the RMA. Due to the normal long-term chronic nature of groundwater nitrate pollution, methods such as rāhui are unlikely to be effective. Overall, there is little tangible evidence that these actions specifically are having significant effects on groundwater nitrate, although improving trends are common in some areas [20] as indicated by improving trends at 49% of monitoring sites (see A3).

C2-(iv). NGO, community driven

Farmer and/or community catchment and river care groups undertake local actions to address environmental issues, including those affecting groundwater quality. These include riparian planting which can remove nitrate from shallow groundwater flows that pass through the vegetation root zone by plant uptake and by provision of organic soils which promote nitrate removal by microbial denitrification. It is also possible for protected and restored natural wetlands and constructed wetlands to remove nitrate from shallow groundwater that seeps into them.

C2-(v). Internationally driven

Many biodiversity protection and enhancement actions (as might be implemented as part of international conventions) also have potential co-benefits for surface and groundwater nitrate concentrations. The impacts are likely to be variable depending on hydrogeological characteristics, but overall considered to be relatively minor unless it involves large-scale retirement of agricultural land-use and conversion to native bush.

Part D—Impact analysis

D1. What would be the environmental/human health impacts of not managing this attribute?

Changes in the attribute state affect ecological integrity and human health as described in A1 above.

Not managing groundwater nitrate is likely to result in:

- Reduced ecological integrity of groundwater and spring-fed ecosystems, with potential repercussions for downstream freshwater, estuarine and coastal ecosystems.
- Reduced quality of groundwater-sourced water supplies with increased health risks and associated costs to ameliorate them; e.g., increased treatment requirements or provision of alternative water supplies/bottled water. There is potential for increased infant deaths and wide variety of human health effects and associated costs if not managed.

Once aquifers become contaminated, remediation becomes logistically challenging using current practical options, and will often require long timeframes for sustainable improvement due to enduring legacies of N loading within catchments [38].

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

Impacts would primarily be felt in vegetable growing areas (Pukekohe, Gisborne, Hawkes Bay, Horowhenua) with high fertiliser use, and in areas with intensive irrigated dairying (e.g., Canterbury). There is also evidence of nitrate-contaminated groundwater aquifers in the Waikato River catchment [46]. Groundwater nitrate contamination could also affect markets for products and prices obtained, where negative environmental and human health effects associated with production are incompatible with consumer and market preferences.

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Climate change effects on groundwater hydrology are complex [39, 40], and corresponding effects on contaminant levels in groundwaters still uncertain [41, 42]. Climate change will likely also lead to land use and management changes that will affect groundwater utilization and recharge and associated hydrological water balances and contaminant flows. Areas that become drier or experience more frequent droughts are likely to increasingly rely on irrigation to safeguard productivity and reduce uncertainty. Depending on the source of irrigation water (groundwater or river flows) and efficiency of its use, this is likely to affect the reliability of irrigation supply [43], the recharge of groundwater, rate of groundwater turnover and the accumulation of nitrate in the aquifer [44]. In areas where rainfall and/or its variability is likely to increase there is potential for greater leaching of nitrate to groundwater, but also greater denitrification losses back to the atmosphere (due to more saturated soil conditions), and greater dilution and flushing with low nitrate rainfall.

Generally, there is low confidence regarding the outcomes of climate change on groundwater nitrate. Further modelling studies are required for different NZ regions to better understand the likely effect of climate change on groundwater availability, transit times and nitrate concentrations and loads [40, 41].

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