BEFORE THE PROPOSED NATURAL RESOURCES PLAN HEARINGS PANEL

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER **AND**	of water quality provision
IN THE MATTER	of the submissions and further submissions set out in the S42A Officer Report

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STATEMENT OF PRIMARY EVIDENCE OF GRAHAM DAVID FENWICK ON BEHALF OF WELLINGTON REGIONAL COUNCIL

TECHNICAL – Water quality in regard to:
Objectives for aquatic ecosystem health and mahinga kai (Objective 025)

12 January 2018

TABLE OF CONTENTS

1. SUMMARY 1
2. INTRODUCTION 2
3. CODE OF CONDUCT 2
4. SCOPE 2
5. TECHNICAL BACKGROUND ON GROUNDWATER 3
6. NATIONAL DIRECTIVES FOR PROTECTING GROUNDWATER ECOSYSTEMS 11
7. WELLINGTON REGIONAL COUNCIL’S APPrOACH 12
8. EVALUATION OF WELLINGTON REGIONAL COUNCIL’S APPROACH 13
9. RESPONSES TO SUBMISSIONS 17
10. CONCLUSIONS 19
11. REFERENCES 20

1. SUMMARY

1.1 My name is Graham David Fenwick. I am a biologist with over 40 years' experience as a practicing researcher. My academic qualifications are a BSc, MSc and PhD, all in aquatic ecology, and a post-graduate Diploma of Business Administration. I have worked for NIWA as a scientist for 19 years (since 1998) and as a biodiversity scientist involved in environmental investigations since 1974. My specialist areas are aquatic invertebrate biodiversity and the ecology of aquatic sediments. A full list of my qualifications and experience is in **Attachment A** of my evidence.

1.2 I have been asked to provide evidence for the following specific matters/areas/schedules:

Background on groundwater and groundwater ecosystems.
National directives for protecting groundwater ecosystems.
Wellington Regional Council's approach

1.3 The scope of my evidence included providing my expert opinion on submissions relating to groundwater quality in the Proposed Natural Resources Plan for the Wellington Region (pNRP). My assessments involved considering each point raised, evidence presented and available via a desktop search and developing an expert opinion of the submitters' arguments.

1.4 I conclude that Wellington Regional Council's approach to managing groundwater quality in its proposed Natural Resources Plan (pNRP) is appropriate, given available science information.

2. INTRODUCTION

2.1 My name is Graham David Fenwick. I am a biologist with over 40 years' experience as a practicing researcher. My academic qualifications are a BSc, MSc and PhD, all in aquatic ecology, and a post-graduate Diploma of Business Administration. I have worked for NIWA as a scientist for 19 years (since 1998) and latterly in the role of Assistant Regional Manager, Christchurch. I have also worked as a biodiversity scientist involved in environmental investigations for Memorial University of Newfoundland (Canada), the Australian Museum (Sydney), and the University of Canterbury. My specialist areas are aquatic invertebrate biodiversity and the ecology of aquatic sediments. A full list of my qualifications and experience is in Attachment A to my evidence.

2.2 I have been engaged by Wellington Regional Council to provide evidence relating to Objective 25, Table 3.6 for Water Quality. My evidence relates to groundwater biodiversity and the effects of water quality on this

2.3 The penultimate draft of my evidence was peer-reviewed by Dr Michelle Greenwood, Freshwater Ecologist, and Dr Scott Larned, Research Manager – Freshwater, both at NIWA.

3. CODE OF CONDUCT

3.1 I have read the Environment Court of New Zealand Practice Note 2014 and have prepared this evidence in accordance with it. My evidence in this statement is within my area of expertise. I have not omitted to consider all material facts known to me that might alter or detract from the opinions which I express. I have qualified my opinions wherever I consider there is uncertainty.

4. SCOPE

4.1 I have been asked to provide evidence on the following specific matters:

(a) Technical background on groundwater,

(b) National directives for protecting groundwater ecosystems,

(c) Evaluating Wellington Regional Council's approach and making recommendations to amend, delete or add areas to the schedules in the Proposed Natural Resources Plan (pNRP); and

(d) Assessing submissions received on Objective O25, Table 3.6.

5. TECHNICAL BACKGROUND ON GROUNDWATER

Definition of groundwater

5.1 **Groundwater** is all water that occurs below the ground surface for either brief times or longer durations (Fenwick 2016). Groundwater can occur in the pore spaces between the grains of unconsolidated sediments, such as sand or gravel. Groundwater also occurs in the fractures of consolidated rock. Geological formations (e.g., sedimentary deposits, fractured bedrock, eroded limestone) that hold or transmit groundwater are termed **aquifers**. For the purposes of this evidence, groundwater is all water within an aquifer.

5.2 Groundwater originates from the passage of surface water into aquifers, a process referred to as **recharge**. A significant fraction of groundwater is recharged from rainfall that seeps through soil into aquifers. Another significant fraction of groundwater is recharged from rivers, where river water seeps through the river bed into an underlying aquifer. Groundwater can also be recharged during irrigation or other agricultural or industrial land-use practices.

5.3 Groundwater within the **saturated zone** (part of an aquifer filled with water) flows through small or large spaces (interstices, pores, cracks, cavities, etc., <1 mm to >100 mm) from higher to lower elevations and pressures (i.e., along **hydrostatic gradients**). In some cases, groundwater may be trapped in an aquifer and remain underground indefinitely.

5.4 The process by which water from an aquifer enters or becomes a surface water body is known as groundwater **discharge**. Human extraction of groundwater from aquifers, for example for irrigation or water supply, is also a form of discharge that is often termed **abstraction**.

Groundwater attributes

5.5 Groundwater and surface water are best regarded as dynamically interconnected parts of a single water resource, but interactions between the two vary widely in timing, rate, volume and location, even within small sub-catchments (Hatton & Evans 1998, Winter et al. 1998).

5.6 Groundwater can be dramatically affected by human interventions. For instance, groundwater or surface water abstraction can affect groundwater pressure gradients and alter groundwater flow rates and directions. Also, as in rivers, groundwater velocities decrease when water levels are lowered.

5.7 As water moves over the land surface and through soils and rock, including through an aquifer, it picks up numerous dissolved substances and fine particulate matter, including bacteria and other microscopic organisms. Although there may be some physical filtration and chemical transformations *en route* to and within an aquifer, most of these substances enter the groundwater.

5.8 Thus, land-use activities can markedly change the quantities and types of dissolved and fine particulate matter entering groundwater, and these substances may have important effects on groundwater quality.

5.9 Unlike surface water bodies, there are no photosynthetic plants in aquifers because there is no sunlight for their growth. Most life in aquifers, therefore, depends upon energy from surface environments, mostly imported as **dissolved organic carbon** (**DOC**). In special situations, plant roots may contribute organic carbon directly to groundwater.

5.10 Oxygen is another dissolved substance important for sustaining healthy aquatic ecosystems in many aquifers, as well as strongly influencing biogeochemical processes within an aquifer. It is carried into an aquifer by recharge water. Without photosynthesis and direct mixing with air, there is little or no re-oxygenation of groundwater within an alluvial aquifer. Consequently, dissolved oxygen concentrations tend to decrease with groundwater’s time underground and along an aquifer’s flow path (Griebler 2001, Helton et al. 2012) (except in limestone (or karst) systems). Deeper aquifers containing older groundwater tend to have little (**hypoxic**) or no (**anoxic**) dissolved oxygen.

Groundwater biodiversity and groundwater-dependent ecosystems

5.11 Most shallow aquifers support significant biodiversity. Bacteria, Fungi and Archaea (microbes) are amongst the most universal forms of life, and inhabit almost all aquatic habitats, including both oxic and anoxic aquifers.

5.12 Aquifers throughout New Zealand, including within the Wellington Region, contain significant biodiversity. Research shows a high microbial biodiversity (>250 likely species) in New Zealand aquifers, including those in the Wellington Region (Van Bekkum et al. 2006, Sirisena 2014, Sirisena et al. 2014).

5.13 Bacteria and other microbes in groundwater are mostly closely associated with **biofilms**, thin layers of bacteria and self-produced organic (polymeric) substances (Brunke & Gosner 1997) that coat essentially all surfaces (clay grains to boulders) within an aquifer.

5.14 The composition of these microbial communities appears determined primarily by the availability of dissolved oxygen within the aquifer (Griebler 2001). These different microbial communities profoundly affect groundwater quality by transforming dissolved substances into different chemicals, depending on oxygen availability (Chapelle 2000, Griebler 2001).

5.15 Animal life (unicellular Protozoa and multicellular metazoan invertebrates) also inhabits aquifers world-wide (Griebler & Lueders 2009). Groundwater metazoans, referred to as **stygofauna** (Humphreys 2000), are invertebrates adapted to life underground (i.e., no body pigments, no or reduced eyes, elongated bodies, elongated antennae) (Gibert et al. 1994, Coineau 2000, Gibert 2001). Small body size is another adaptation to subsurface, interstitial life, but some New Zealand stygofaunal macroinvertebrates grow to 20 mm long (Wilson & Fenwick 1999).

5.16 New Zealand's stygofauna is widespread and diverse. Exploratory collecting revealed stygofauna in aquifers throughout the country (Fenwick 2000). More than 50 species are known from one intensively investigated shallow alluvial aquifer (the Selwyn) in

Canterbury (Fenwick 2016). Several species are known from the Waimea aquifer near Nelson and the five known collections from the Wellington Region (two species, Masterton groundwater management zone; one species, Hutt Valley; two species, near Porirua) contained four species of stygofaunal amphipods.

5.17 New Zealand's stygofauna comprises genera and species mostly endemic to this country (Scarsbrook et al. 2003). It includes some remarkable, ancient lineages (e.g., Barnard & Barnard 1983) moulded by our unique geological history, similar to weta, tuatara and kiwi.

5.18 Stygofauna appears restricted to oxygenated (oxic to hypoxic) aquifer habitats. The presence of macroinvertebrate stygofauna in anoxic aquifers in New Zealand is poorly known.

5.19 Groundwater life is rarely seen because these environments are difficult to access and because wells or bores are usually designed to exclude all but water. Because groundwater biodiversity is largely hidden and difficult to access, there is limited understanding of the extent of groundwater biodiversity and its contribution to the ecology of fresh waters (Gibert et al. 1994).

5.20 Despite this very incomplete knowledge, it is now well-established that life in an aquifer comprises a natural, functioning ecosystem, termed a **subsurface groundwater-dependent ecosystem** (**SGDE**)(DLWC 2002, Serov et al. 2012). SGDEs are communities of microbes and stygofauna that interact with each other and with their non-living environment, performing natural ecological processes in the absence of light.

Groundwater ecosystem services

5.21 As part of their natural functioning, these SGDEs modify their environment, providing **ecosystem services** that benefit the wider environment and humans. Biofilms within alluvial SGDEs capture and process dissolved and fine particulate matter (including bacteria), a vital part of natural bioremediation or cleansing that occurs in aquifers (Chapelle 2000, Handley et al. 2013, 2015, Wrighton et al. 2014). These biofilms utilise DOC and other substances, resulting in net losses of carbon from the ecosystem via aerobic respiration (Williamson et al. 2012, Di Lorenzo & Galassi 2013, Wrighton et al. 2014).

5.22 Biofilm bacteria also transform several other substances that would otherwise degrade water quality (e.g., polyaromatic hydrocarbons, such as naphthalene, from coal, tar and incomplete combustion of organic matter (Madsen et al. 1991)). In particular, they also facilitate denitrification, the transformation of nitrate into nitrogen. Bacterial denitrification appears to occur principally at hypoxic to anoxic microsites within aerobic aquifers (e.g., Koba et al. 1997, Gold et al. 1998, Rivett et al. 2008), and can result in significant (mean 50%, range: 29-75%) nitrate attenuation within some aquifers (e.g., Stenger et al. 2013, Elwan et al. 2015).

5.23 The stygofauna delivers additional ecosystem services. Stygofauna ingest and digest bacteria (Sinton 1984, Fenwick et al. 2004) keeping finer aquifer pore spaces open and water flowing through these pore spaces (Boulton et al. 2008).

5.24 While grazing biofilm and moving within an aquifer, stygofauna mechanically tills or disturbs the aquifer particles, turning them, abrading adhering biofilm, reworking and repositioning finer particles, and probably altering sediment matrices (Fenwick et al. 2004). This process, termed **bioturbation** and widely known in aquatic ecosystems (e.g., Mermillod-Blondin 2004, Wilkinson et al. 2009, Kristensen et al. 2012), is akin to the role of earthworms in healthy soils. In groundwater, bioturbation both stimulates microbial activity, leading to biogeochemical transformation of contaminants, and reduces any clogging to facilitate water flows (bioirrigation) that replenish dissolved oxygen (bioaeration) (Boulton et al. 2008) and maintain aerobic, oxidising conditions with improved water quality.

5.25 The overall effects of these SGDE processes, termed **ecosystem services**, include improving groundwater quality and its suitability for human uses, and maintaining an aquifers’ ability to conduct water and its yield of water for abstraction. These effects sustain many of the human values associated with groundwater, notably human health and economic values. These effects also contribute to the natural and human values associated with many rivers and streams, which receive smaller to larger contributions from groundwater.

Threats to SGDEs and groundwater values

5.26 Surface water quality is well-known to affect **aquatic ecosystem health** (**AEH**), with numerous dissolved and suspended substances degrading AEH when beyond critical limits (shortages and over-supplies) (e.g., Hynes 1972, Davies-Colley & Wilcock 2004). This applies equally to groundwater and SGDE AEH (e.g., Notenboon et al. 1994, Korbel et al. 2013, Korbel & Hose 2015, Espanol et al. 2017).

5.27 As with surface water ecosystems, there is good evidence that human land-use activities frequently affect SGDE health by changing water quality and/or groundwater hydrology (e.g., Sinton 1984, Boulton et al. 2008, Stein et al. 2010, Hartland et al. 2011, Di Lorenzo & Galassi 2013, Korbel et al. 2013).

5.28 Harmful concentrations of common freshwater pollutants are known for many surface water organisms and habitats, and there are established limits or guideline concentrations for several common contaminants for sustaining the ecological health of surface water ecosystems.

5.29 Such limits have not been determined for SGDEs because harmful concentrations of common pollutants (e.g., nitrates) are unknown for any stygofauna world-wide and in New Zealand. One study indicated that stygofauna were more sensitive to some pollutants than their surface water equivalents (Mosslacher 2000), but robust evidence is largely lacking.

5.30 Surface water ecosystem health limits, guideline or trigger concentrations (concentrations above which harmful effects are likely, and the converse for other substances, e.g., dissolved oxygen) are based mostly on toxicities of individual substances to readily accessible species, and usually include some species known to be more sensitive than others (e.g., Hickey 2016). They tend to overlook sublethal effects, some of which interfere with natural reproduction and other important physiological or behavioural processes (e.g., Hickey 2016).

5.31 Surface AEH guideline concentrations usually overlook any combined or synergistic effects of contaminants on individual species, although there is some recent information on the effects of some substances in reducing toxicity (e.g., nitrate toxicity is reduced in hard water or when chloride is present) (Hickey 2016).

5.32 Guideline or trigger concentrations based on toxicities for selected species have unknown relationships to ecosystem health. However, a conservative approach dictates that ecosystem health is best assured by maintaining ambient contaminant concentrations well below known toxic concentrations, and below those known to induce sublethal effects on any of its species.

5.33 Nitrate is a key contaminant of aquifers in the Wellington Region (e.g., Tidswell et al. 2012, Daughney & Reeves 2003). Experience elsewhere shows that high concentrations of nitrate can occur in groundwater over large areas (Hayward & Hansen 2004) and persist for decades (Stewart et al. 2011).

5.34 Although there is no unequivocal evidence that nitrate is harmful to stygofauna and SGDEs, its widely known toxicity to surface water invertebrates at low concentrations (e.g., Hickey 2013b, MfE 2017) almost certainly means that nitrate is similarly harmful to SGDE health.

5.35 The physiology of crustaceans, the dominant invertebrates in most SGDEs, is impaired by nitrate (and its other hypoxic states: nitrite and ammonia) (Alonso & Camargo 2003, 2006, Soucek & Dickinson 2012, Hickey 2013a). Some evidence indicates that crustaceans are more sensitive than other invertebrate groups to nitrate, whereas other evidence suggests the opposite (e.g., Soucek & Dickinson 2012).

5.36 Reduced oxygen concentrations appear to act synergistically with nitrite and with ammonia (NH_3) (nitrate is generally reduced to these substances in low oxygen environments) to affect the physiology crustaceans in acute, six-hour exposure (Broughton et al. in prep.). Thus, low dissolved oxygen concentrations in groundwater probably exacerbate the effect of chronic exposure to nitrite and ammonia on at least some stygofauna.

5.37 This information indicates the need for conservative limits for nitrate (and nitrite) in groundwater, as well as managing groundwater to sustain near-natural dissolved oxygen concentrations.

5.38 Dissolved oxygen is essential for sustaining most stygofauna and aerobic SGDE health. Its concentrations differ naturally between aquifers, are typically moderate to low in most aquifers, and some groundwaters lack dissolved oxygen (i.e., are anoxic) (Rosen 2001). Concentrations within most shallower aquifers vary seasonally and spatially (e.g., Larned et al. 2015) and generally decrease along an aquifer’s flow-path.

5.39 Because there is very limited re-oxygenation of water within an aquifer (Boulton et al. 2008), changes in groundwater velocity will affect ambient dissolved oxygen concentrations (Hoehn 2001).

5.40 Water level differences or hydrostatic gradients drive velocities of water movement through an aquifer. Thus, reduced groundwater levels, caused by reduced recharge and/or groundwater abstraction, can result in slower replenishment and lower dissolved oxygen (and DOC) concentrations, potentially compromising SGDE health.

5.41 Most groundwater is naturally low in available food (dissolved organic carbon (DOC)) (e.g., Coineau 2000, Poulson & Lavoie 2000, Williamson et al. 2012, Larned et al. 2015). Beyond some undefined limits, increased DOC and/or reduced oxygen availability will affect the ability of stygofauna to control biofilm development (Boulton et al. 2008). Uncontrolled growth of biofilm may clog progressively larger pore spaces within an aquifer, reducing water velocities and dissolved oxygen replenishment, at least at finer scales (Baveye et al. 1998, Seifert & Engesgaard 2007, Bottero et al. 2013).

5.42 A shift towards hypoxic and anoxic conditions will change microbial communities (e.g., Cheung et al. 2014), favouring bacteria that use different metabolic pathways and produce different respiratory end-products (i.e., from CO_2 to H_2S) (Chapelle 2000). Such changes may significantly degrade water quality, initially at smaller (<10-100 mm) scales. Conceivably, this process, unchecked, may compromise the health of larger parts of a SGDE, degrade water quality further and reduce groundwater yield from the aquifer

(Boulton et al. 2008, Fenwick 2016).

6. NATIONAL DIRECTIVES FOR PROTECTING GROUNDWATER ECOSYSTEMS

6.1 New Zealand's groundwater biodiversity has a high intrinsic value because of its global uniqueness and it ancient origins (e.g., Barnard & Barnard 1983). Although poorly known, Wellington Region's groundwater biodiversity is a significant subset of this globally important groundwater biodiversity.

6.2 Even though the biodiversity within New Zealand's aquifers is poorly known, the New Zealand Conservation Act 1987 and the New Zealand Biodiversity Strategy require regional councils to ensure that the intrinsic and other values of all biodiversity (including that of "underground aquifers") are adequately maintained and safeguarded for future generations (DoC 2000: 45).

6.3 The ecosystem services delivered by groundwater biodiversity are integral to sustaining groundwater and surface water resources, cultural identities and economies at local, regional and national levels (e.g., Boulton et al. 2008, Fenwick 2016, Robertson et al. 2017).

6.4 The Resource Management Act 1991 (and amendments) requires regional councils to ensure the sustainability of these ecosystem services (safeguard "the life-supporting capacity of air, water, soil, and ecosystems" by "avoiding, remedying, or mitigating any adverse effects of activities on the environment" to ensure that the needs of future generations are met (NZG 1991: Section 5).

6.5 Currently, there are no national numerical directives (defined concentrations) specifically for managing SGDEs for aquatic ecosystem health (AEH). However, the Ministry for the Environment's National Policy Statement for Freshwater Management 2017 (MfE 2017)(and its precursor (MfE 2014) explicitly includes aquifers as "freshwater" (p. 4) and implicitly throughout the NPS-FM as "water", "fresh water", "freshwater resources", "the resource", "water body", "waterway", "freshwater management unit" (MfE 2017: 4, 5, 7-10). The repeated use of "associated ecosystem" (or similar) within Objectives A1, B1, C1 and

D1, and their associated policies, is a clear signal that SGDEs are within the scope of this policy statement, and no less important than surface water bodies. Certainly, there is no exclusion of aquifers, groundwaters or SGDEs, either explicit or implied.

6.6 The NPS-FM Appendix 1 sets out national values and uses for freshwater, which explicitly includes "aquifer" as one "freshwater body type" (MfE 2017: 26). These compulsory national values for ecosystem health are:

- *The freshwater management unit supports a healthy ecosystem appropriate to that freshwater body type (river, lake, wetland, or aquifer).*
- *In a healthy freshwater ecosystem ecological processes are maintained, there is a range and diversity of indigenous flora and fauna, and there is resilience to change*.
- *Matters to take into account for a healthy freshwater ecosystem include the management of adverse effects on flora and fauna of contaminants, changes in freshwater chemistry, excessive nutrients, algal blooms, high sediment levels, high temperatures, low oxygen, invasive species, and changes in flow regime. Other matters to take into account include the essential habitat needs of flora and fauna and the connections between water bodies.*

6.7 For these reasons, I consider that SGDE biodiversity in the Wellington Region, and throughout New Zealand, requires specific protection.

7. WELLINGTON REGIONAL COUNCIL'S APPrOACH

7.1 Groundwater in the Wellington Region is used extensively for potable and stock drinking water supplies, and for irrigation and industrial uses. It comprises 33% of all freshwater takes for the Wellington Region (414 million m^3/year) (Keenan et al. 2012), and up to 70% of the water supplied to the greater Wellington urban area during summer (Wellington Water 2017). Groundwater provides baseflow to the region's rivers, streams and wetlands. It also discharges at the land surface, and into coastal waters, as natural springs or seeps. Protecting these groundwater-fed surface water ecosystems requires careful management of the quality and quantity of the underlying groundwater (Tidswell et al. 2012).

7.2 Recognising that SGDEs are vital freshwater resources with significant cultural, social, biodiversity and ecological values, SGDEs were included in the pNRP under Objective O25, Table 3.6. Narrative objectives were proposed for both water quality and water quantity to safeguard AEH of both SGDEs and ecosystems in connected surface waters because there are no scientifically-derived, numerical limits, guidelines or bottom lines specifically for assessing and/or managing SGDE health.

7.3 The narrative objectives for water quality refer to nitrate concentrations only and provide broad guidance: “not cause unacceptable effects” on life and ecosystems in groundwater directly and indirectly connected to surface water.

8. EVALUATION OF WELLINGTON REGIONAL COUNCIL’S APPROACH

Water quality: nitrate

8.1 Nitrate is the focus for water quality to achieve Objective O25 for groundwater (Greenfield et al. 2014). This contaminant of groundwater has attracted substantial attention because it is toxic to several surface water organisms at low concentrations (e.g., < 6 mg NO_3-N/L, Hickey & Martin 2009).

8.2 There are no guideline concentrations for nitrate in New Zealand groundwater. However, surface water guidelines are considered directly relevant to protecting SGDE AEH, at least, because the above-ground values that they are aimed at protecting are mostly the same as those associated with groundwater when it arrives at the surface (ANZECC 2000). The earlier guideline (ANZECC 2000: 1-2) also noted that SGDEs “should be given the highest level of protection” because of “their high conservation value”.

8.3 The pNRP’s approach treats SGDEs as similarly vulnerable to contaminants as surface water organisms and ecosystems (Greenfield et al. 2014), consistent with the views of other workers (e.g., Tomlinson & Bouton 2010, Fenwick 2016, Robertson et al. 2017).

8.4 Following this reasoning, the council's technical report (Greenfield et al. 2014) recommended that "in the interim, the surface water nitrate chronic toxicity threshold is adopted as the closest relevant measure of protection", in the absence of any national guidance and paucity of stygofauna-specific information. The technical report adopted the NPS-FM (MfE 2014, 2017) guidance concentrations for intermediate protection (protect 95% of aquatic species[1]): annual median and 95th percentile concentrations of ≤2.4 and ≤3.5 mg NO_3-N/L, respectively, for managing the AEH of groundwater that is directly (Category A and B) and not directly connected (Category C) to surface water in the region (Greenfield et al. 2014). The pNRP neither refers to this guideline concentration, nor provides any numerical value. Instead, it specifies that nitrate concentrations shall "not cause unacceptable effects on groundwater-dependent ecosystems or … communities in connected water bodies" (pNRP, Table 3.6, p. 43).

8.7 Two key reports provide the most recent, authoritative information that is relevant to nitrate effects on SGDE AEH (i.e., concentrations below which risks of unacceptable effects are considered low). These reports, the latest in a succession of critical reviews (e.g., Hickey 2002, 2013a,b, Hickey & Martin 2009), incorporate all of the relevant empirical research evidence, plus new information and insights.

8.8 Both of these key documents defined guidelines for surface water bodies of differing conservation value or protection levels. The pNRP's supporting technical report (Greenfield et al. 2014) recommended an intermediate level of protection[2] for managing groundwater quality, in the absence of more specific, regionally relevant toxicological and biodiversity information, and as a compromise between the pNRP's precautionary approach (Policy P3, P41) and existing nitrate concentrations in the region's aquifers.

8.9 The first of these key reports, the NPS-FM 2014[3], set national maximum concentrations for protecting 95% of river species at an

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[1] Protect 95% of species or some growth effects on up to 5% of species.

[2] Protect 95% of species or some growth effects on up to 5% of species.

[3] There is no difference between the 2014 and 2017 versions of the NPS-FM in terms of nitrate limits for river water. The NPS-FM 2017 update (MfE 2017) was not available at the time that he technical report and pNRP were produced.

annual median concentration of 2.4 NO_3-N mg/L and an annual 95th percentile at 3.5 NO_3-N mg/L[4].

8.10 The NPS-FM (MfE 2014, 2017) also requires that water quality of a water body (including groundwater) is “to be maintained at its current level ... or improved” (MfE 2017: 5).

8.11 The second key work (Hickey 2016), a 2016 update of the Australian and New Zealand guidelines for fresh and marine water quality (ANZECC 2000), established an intermediate protection guideline concentration of 2.1 mg NO_3-N/L for protecting 95% of species inhabiting slightly to moderately disturbed surface waters.

8.12 Neither the NPS-FM (MfE 2017) nor the pNRP considered any potentially differing physiological vulnerabilities of stygofauna to nitrate compared with surface water invertebrates (Hickey & Martin 2009, Hickey 2013b). Nor did they consider the potential increased toxicity effects of nitrate under hypoxia (Camargo et al. 2005, Alonso & Camargo 2006, 2015).

8.13 I consider that the pNRP’s narrative objective is appropriate in the interim, because it seeks to ensure that the region’s groundwater resources are managed sustainability in the absence of more specific scientific information, while accommodating existing water quality within the region.

8.14 The intermediate guidance concentrations for nitrate in groundwater suggested in the technical report (Greenfield et al. 2014; taken from Hickey 2013b, adopted by MfE 2017 and very similar to Hickey 2016) are appropriate interim guidance for sustaining SGDE AEH, given prevailing nitrate nitrogen concentrations (Wellington Region medians <0.002 mg/L to 11 mg NO_3-N/L, maximum 16.0 mg NO_3-N/L (Tidswell et al. 2012)), existing land-use activities and the paucity of directly relevant information on the region’s SGDEs.

8.15 A much lower concentration was recently recommended as a trigger[5] for managing nitrate-nitrogen concentrations (0.40-0.50

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[4] Hickey’s 2013b values were adopted for and identical with MfE’s 2017 National Policy Statement – Freshwater Management ecosystem health nitrate limits for rivers.

[5] Triggers or trigger concentrations which, if reached or exceeded, should initiate management review of available information and decisions on management actions.

mg/L) within Golden Bay’s Te Waikoropupu Springs and contributing aquifer (Young et al. 2017). Such a low concentration was deemed appropriately precautionary given the springs’ very high biodiversity, cultural, spiritual, economic and other values, and documented changes in the springs’ water quality (increase in nitrate nitrogen concentrations by 30-70% since 1970, reduced water clarity, increased pH, probable decline in dissolved oxygen concentrations (Young et al. 2017)).

8.16 Also, this low trigger concentration for nitrate is consistent with the NPS-FM’s (MfE 2017) requirement that the water quality of a water body is maintained or improved.

Water quality: other substances

8.17 Other substances also affect the AEH of SGDEs, but their importances and critical concentrations for sustaining AEH are inadequately known, both within the region and internationally. Some of the more important substances are discussed briefly to ensure that nitrate is not perceived as the sole determinant of SGDE AEH.

8.18 Concentrations of these substances are all naturally variable and variously affected by human activities, either directly or indirectly.

8.19 Organic carbon, principally in dissolved form, can either stimulate or disrupt SGDE ecosystem functioning (e.g., Boulton et al. 2008). It is naturally variable and rarely monitored in groundwater.

8.20 Dissolved oxygen concentrations in groundwater tend to reduce with time underground and with increased microbial activity induced by increased organic carbon supply. Reduced water velocities due to water level reductions and/or aquifer clogging also result in lower oxygen concentrations due to reduced rates of replenishment.

8.21 Groundwater velocity, driven by hydrostatic gradients within an aquifer, determines rates of water movement in the aquifer. This is a major factor in replenishing organic carbon and dissolved oxygen to sustain AEH within groundwater (Hoehn 2001).

8.22 Given the paucity of knowledge of the effects of nitrate, dissolved oxygen, organic carbon, groundwater velocity/water level and the effects of interactions between these and other contaminants on SGDE AEH, the pNRP's narrative guideline for water quantity (Table 3.6) seems appropriate.

9. RESPONSES TO SUBMISSIONS

Federated Farmers of New Zealand S352/080

9.1 This submitter considered that no water quality objectives, other than protecting against salt water intrusion, were required.

9.2 Significant bodies of empirical research evidence make it very clear and widely accepted that nitrate (and nitrite) concentrations in groundwater should be managed for human health reasons (e.g., MOH 2008), as well as to protect aquatic ecosystems (e.g., Hickey 2016).

9.3 In my view water quality objectives for groundwater are required in the pNRP to facilitate managing aquatic ecosystem health..

Dairy New Zealand S316/033, Kaiwaiwai Dairies Ltd S119/009, New Zealand Fish and Game Council S308/144, Wairarapa Water Users Society Incorporated S124/005

9.4 Some submitters considered that the 2008 drinking water standards for New Zealand (DWSNZ) Maximum Acceptable Value (MAV) concentrations for inorganic determinands that are potentially significant to human health (MOH 2008) were suitable AEH thresholds for SGDEs within the pNRP's Table 3.6. Some submitters noted that pNRP's objective for nitrate in groundwater would better addressed using the DWSNZ MAV concentration (11.3 mg NO_3-N/L (MOH 2008)).

9.5 One submission considered that available evidence established the DWSNZ MAV for nitrate as "more conservative than any equivalent standard" (including surface water limits) for protecting SGDEs. This assertion appears to be based on Hickey's (2013a) evidence for the Board of Inquiry into the Tukituki Catchment proposal. His subsequent reports (Hickey 2013b, Hickey 2016) and the NPS-FM (MfE 2014, 2017) superseded the conclusions presented in that evidence.

9.6 I consider that use of the 2008 DWSNZ (MOH 2008) (MAV) for nitrate in drinking water (11.3 mg NO_3-N/L) to be inappropriate for ensuring SGDE AEH in the Wellington Region for the following reasons.

9.7 First, the DWSNZ 2008 nitrate (and other determinand) MAVs were established to define limits for public (i.e., human) health protection (MOH 2008). Available research evidence (notably NPS-FM (MfE 2014, 2017) and Hickey (2016) empirically demonstrate that this standard, designed to protect human health, is inappropriate for ensuring the health of aquatic ecosystems and invertebrates under long-term exposure.

9.8 Second, international and New Zealand toxicological evidence (e.g., Kincheloe et al. 1979, ANZECC 2000, Hickey 2002, Camargo et al. 2005, Alonso & Camargo 2006, CCME 2012, Hickey 2013b) shows that concentrations of nitrate nitrogen required for ensuring surface water AEH are substantially lower than that of the DWSNZ (i.e., 2.1 mg NO_3-N/L cf. 11.3 mg NO_3-N/L)(Hickey 2016).

Dairy New Zealand & Fonterra Co-operative Group Ltd S316/033, Fertilizer Association of NZ Incorporated S302/018, Horticulture NZ S307/020, Minister of Conservation S75/027, Royal Forest and Bird Society of New Zealand Inc. S353/027

9.9 These submissions requested amendment of Objective O25 to replace narrative objectives for nitrate-nitrogen and groundwater quantity in Table 3.6 with unspecified or simpler numerical values, because the narrative objective was not sufficiently clear, “directive” or measureable.

9.10 The pNRP narrative objective provides broad guidance in the absence of robust science knowledge quantifying the effects of nitrate specifically on stygofauna and SGDEs. The technical report (Greenfield et al. 2014) provides more specific, albeit tentative, guidance, and the pNRP’s narrative accommodates the possibility of implementing such guidance as soon as it becomes available.

9.11 The narrative objective and associated technical report concentrations represent pragmatic interim guidance that acknowledges current nitrate concentrations in the region’s groundwater and important land use activities, yet are precautionary and heed the NPS-FM’s (2017) requirement for groundwater quality to be maintained or improved.

10. CONCLUSIONS

10.1 Based on available information on its region's SGDEs, their likely biodiversity and the toxicity of nitrate to aquatic organisms, I consider that Wellington Regional Council's pNRP takes an appropriate interim approach to managing SGDE AEH, with respect to groundwater quality.

10.2 The approach is also appropriate for managing threats posed to SGDEs by other common solutes likely to originate from land-use activities in the region.

10.3 The approach is appropriate to managing groundwater quantity for sustaining SGDE AEH within the Wellington Region.

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Attachment A
Qualifications and experience

Qualifications

1993	Dip. Business Administration, University of Canterbury.
1984	Ph.D., Marine Biology, University of Canterbury.
1975	M.Sc., Zoology, University of Canterbury.
1972	B.Sc., Botany & Zoology, University of Canterbury.

Experience:

2006-present	Assistant Regional Manager, NIWA, Christchurch.
Feb 2002-Oct 2006	Scientist/Principal Scientist and Group Manager, NIWA Christchurch.
July 1998-2002	Contract scientist to NIWA.
Jan-Dec 1997	Research and Teaching Associate, Department of Management, University of Canterbury.
Jan 1990-Dec 1996	Lecturer in Marketing (fixed term), Department of Management, University of Canterbury.
Feb 1989-Oct 1989	Marketing consultant to local businesses.
Nov 1986-Jan 1989	Marketing Consultant, Target Services Group Ltd and the Consulting Group of Horwath & Horwath (N.Z.) Ltd.
Nov 1985-Oct 1986	Research Associate, Department of Zoology, University of Canterbury.
Jan 1984-Oct l985	Post-doctoral fellow, Chemistry Department, University of Canterbury, funded by Sea Pharm Inc., Princeton, U.S.A.
Nov 1982-Oct 1983	Marine Biologist, University of Canterbury.
Jan 1980-Feb 1983	Ph.D. thesis research.
Sept 1977-Dec 1979	Marine Biologist, Department of Zoology, University of Canterbury.
Apr-Aug 1977	Assistant Curator (fixed term), Department of Coelenterates and Crustacea, The Australian Museum, Sydney, Australia.
Nov 1976-Mar 1977	Marine Scientist and Deputy Leader, University of Canterbury Snares Islands Expedition.
Jan-Nov 1976	Marine Benthic Ecologist, Estuarine Research Unit, Zoology Department, University of Canterbury.
Nov 1974-Oct 1975	Marine Biologist, Department of Biology, Memorial University of Newfoundland, St Johns, Canada.
Mar 1973-Oct 1974	M.Sc. thesis studies.
Nov 1971-Jan 1972	Research Assistant, University of Canterbury Antarctic Research Programme.