tasman district council

Te Kaunihera o te tai o Aorere

Technical Report

Waimea Groundwater Quality Survey 2021

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WAIMEA GROUNDWATER QUALITY SURVEY 2021

June 2023

A technical report presenting results of the Tasman District Council's groundwater quality synoptic survey undertaken in the Waimea Plains. The report draws on various monitoring data collected by Tasman District Council, including that collected for the Institute of Geological and Nuclear Sciences Ltd as part of the National Groundwater Monitoring Programme and the Institute of Environmental Science and Research as part of the national survey of pesticides, glyphosate and emerging organic contaminants.

Prepared By:

Melanie Westley[1]

Reviewed By:

Andrew Fenemor[2]
Magali Moreau[3]
Uwe Morgenstern[3]
Joseph Thomas[1]

[1] Tasman District Council
189 Queen Street
Private Bag 4
RICHMOND

[2] Manaaki Whenua Landcare Research
PO Box 69040
LINCOLN

[3] Institute of Geological and Nuclear Sciences Ltd
PO Box 30-368
LOWER HUTT

EXECUTIVE SUMMARY

Groundwater is an essential part of our environment, in our economy and a shared resource within a catchment. Elevated nitrate-N concentrations caused by land use have been measured in parts of the Waimea Plains groundwaters since the 1970's, though isotopic (age) data suggests the initial nitrate-N contamination dates back to the 1940s. An intensive piggery operation is thought to be a major contributor to historic nitrate-N contamination, alongside diffuse nitrate-N inputs from horticultural and agricultural activities. The piggery closed in the mid-1980's and Tasman District Council has been monitoring nitrate-N movement across the aquifers since. This report summarises the findings of the latest groundwater quality survey in the plains (October to December 2021) which aims to understand the relationship between groundwater recharge, receiving water quality and an update and comparison to data from the previous surveys.

The 2021 survey involved the sampling of 137 bores/wells and 9 spring samples across the four main aquifer systems: Appleby Gravel Unconfined Aquifer (AGUA), Hope Minor Confined and Unconfined Aquifer (HU), Upper Confined Aquifer (UCA), Lower Confined Aquifer (LCA). In addition, samples were collected at 3 river sites to assess the quality of the river recharge and receiving waters. Samples were analysed for a suite of parameters, including nitrate and pathogen indicator (*Escherichia coli*). The analytical results were then compared to the previous surveys in the Waimea Plains to monitor nitrate movement with time through all four aquifer systems (1986, 1994, 1999, 2005, 2016 and 2021). In this report, the results of the national groundwater pesticide, glyphosate and emerging organic contaminants undertaken in the past in the plains are also summarised.

The highest groundwater nitrate-N concentrations in 2021 were found at the intersection of Bartlett Road/Ranzau Road West (31 g/m^3-N) and along Blackbyre Road (30 g/m^3-N) where the UCA and the AGUA merges together and becomes hydraulically indistinguishable. All bores/wells sampled between these two locations exceeded the maximum acceptable value (MAV) in the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 (11.3 g/m^3-N). Discharge of the historic nitrate-N contamination from the UCA into the AGUA is estimated to be between 11 to 16 g/m^3-N. In this area the aquifers are vulnerable to surface contamination, therefore additional inputs of nitrate-N from overlying land use activities between Bartlett Road and Blackbyre Road adds to the nitrate-N discharging from the UCA, resulting in measured nitrate-N concentrations well above 20 g/m^3-N in both of the aquifers.

Groundwater nitrate concentrations north of Brightwater in parts of both sides of the Waimea River were near or above 50% of the MAV for nitrate-N (5.6 g/m^3-N) in areas of overlying horticultural and agricultural activities. This suggests that present-day activities contribute to nitrate-N entering in the groundwater in all four aquifers. There are also many parts of the Waimea Plains where nitrate-N concentrations are less than 50% of MAV. Of the 137 bores/wells sampled in the Waimea Plains, 56 sites (41%) had nitrate-N below 50% of the MAV, 42 sites (31%) were between 50% of the MAV and the MAV, and 39 sites (28%) were above the MAV.

Towards the coast, groundwater emerging as springs varies in quality, and had higher nitrate compared with the rivers, with the values averaging between 4.6 and 7.6 g/m^3-N for Borck Creek and 1.7 and 4.1 g/m^3-N for Neimann Creek. This puts these springs in the Attribute State of C and D for nitrate-N from the National Policy Statement for Freshwater Management 2020 (Revised 2023) (NPSFM). These spring-fed environments have hard water which reduces the nitrate toxicity experienced by their ecosystems (Hickey, 2015), however nitrate-N concentrations in these spring-fed streams still exceed the NPSFM ecosystem criteria. River water quality (main source of recharge for the AGUA, UCA and LCA) is also of good quality, with nitrate-N concentrations averaging below 1.5 g/m^3-N.

Trend analysis of nitrate-N shows:

- AGUA: decreasing trend in the AGUA south of Brightwater. North of Brightwater, east of the Waimea River between Blackbyre Road and State Highway 60, there is a strong increasing trend. East of Swamp Road, nitrate-N becomes indeterminate.
- HU: decreasing trends in southern reaches. Approaching Bartlett Road, northeast of Pugh Road, nitrate-N becomes indeterminately increasing.
- UCA: Eastern edge, decreasing trend following northwards along the historic nitrate-N plume. Western edge, from Edens Road northwards, strong increasing trend. Increasing trend no longer detected from Edens Road/Pugh Road intersection through to Bartlett Road and northwards.
- LCA: decreasing trend at Lower Queen Street. Strong increasing trend at Bells Island. Outside of these two areas, no trends were exhibited.

Aside from nitrate-N, the 2021 survey showed that most other groundwater quality attributes in the Waimea Plains were well below the Aesthetic Values and Maximum Acceptable Values from the New Zealand Drinking Water Notice and Standard respectively (Taumata Arowai 2022 a and b; New Zealand Government 2022).

All pesticide residues detected by the Institute of Environmental Science and Research in 2018 were well below the MAV. Emerging Organic Contaminants were detected at one bore in the Waimea Plains; the effects of those compounds are largely unknown but it is likely to be of low toxicity to humans. No glyphosate was detected in any of the selected Tasman region bores.

The 2021 water quality survey identified various contaminant risks for groundwater which could have risks to public health if the resource is used for drinking water purposes. These include inappropriate sitting of bores/wells and bore/well heads not fully sealed which could result in localised contamination of *Escherichia coli*. In most instances these were not intentional but more a lack of knowledge of the bore/well landowners.

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GLOSSARY / LIST OF ABBREVIATIONS

AV	Aesthetic Values. The AVs are threshold concentrations for determinands above which arise a concern on water taste, odour, appearance and in some instances its feel (Taumata Arowai, 2022a).
Council	Tasman District Council
DWSNZ	Refers to the combined quality standards of Maximum Acceptable and Guideline Values set by the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 and Aesthetic Values for Drinking Water Notice 2022
E.coli	*Escherichia coli* (a faecal indicator bacteria). This indicator is used as a proxy for occurrence of pathogens in water. Pathogens can cause illness for anyone to ingests them and should not be present in drinking water.
EOC	Emerging Organic Contaminant. EOCs include pharmaceuticals, personal care and veterinary products, industrial compounds, pesticides, food additives and nano-materials as well as metabolites and transformation products of these. EOCs are classed as “emerging” owing to their recent detection due to related advances in analytical techniques and better monitoring. There is growing concern that the occurrence of EOCs may have adverse effects, human and aquatic health, including in the groundwater receiving environment.
ESR	Institute of Environmental Science and Research Ltd
FMU	Freshwater Management Unit
LAWA	Land Air Water Aotearoa
MAV	Maximum Acceptable Value. The MAV is defined as the highest concentration of a determinand in drinking water that, on the basis of present knowledge, is considered not to cause any significant risk to the health of the consumer over 70 years of consumption of 2 litres per day of that water (Ministry of Health 2005, revised 2018).
NPSFM	National Policy Statement for Freshwater Management 2020 (Revised 2023). The NPFSM sets out the objectives and policies for freshwater management under the Resource Management Act 1991.
SoE	State of the Environment. Monitoring and reporting undertaken by Council required under the Resource Management Act 1991.

STATEMENT OF DATA VERIFICATION AND LIABILITY

Tasman District Council recognises the importance of good quality data. This assessment of groundwater quality across the Waimea Plains aquifer system provides interpretation of results from the Council's groundwater quality monitoring programme and other relevant data available at the time of producing the report. Data collection and management systems follow systematic quality control procedures. International Accreditation New Zealand (IANZ) laboratories carried out sample analysis excluding field analysis.

While every attempt has been made to ensure the accuracy of the data and information presented, Tasman District Council does not accept any liability for the accuracy of the information. It is the responsibility of the user to ensure the appropriate use of any data or information from the text, tables or figures. Not all available data or information is presented in the report. Only information considered reliable, of good quality and of most importance to the readers has been included. All tables and figures have been created by the author unless otherwise stated.

ACKNOWLEDGEMENTS

I would like to acknowledge the assistance provided by the Tasman District Council Environmental Information department. In particular, Joseph Thomas (Senior Resource Scientist) and Mark Steele (Environmental Monitoring) for sampling the Council telemetered bores for this survey, Matt Ogden (Environmental Data) for statistical analysis of the nitrate-N data and producing the summary and figures in Appendix IV and VII, and the Environmental Monitoring team and summer students involved in the collection of the long-term water quality information throughout the years.

I would like to thank Andrew Fenemor from Manaaki Whenua Landcare Research and Magali Moreau and Uwe Morgenstern from the Institute of Geological and Nuclear Sciences Limited for their constructive reviews of the report.

And finally, a special thank you to the many landowners who provide access to groundwater and river monitoring sites.

1 INTRODUCTION

1.1 Background

Groundwater is an essential part of our environment and economy and a shared resource within a catchment. In the environment it supports river flows, lakes and wetlands, especially through drier periods. Springs are outcropping groundwater. The flow of groundwater into rivers as seepage through the riverbed, known as baseflow, can be essential to aquatic health.

Groundwater is found beneath the ground surface and can be accessed through springs and bores/wells. When it rains, some of the rainwater infiltrates (soaks) into the soil and travels downwards into the ground. It fills cracks in rocks and pore spaces between grains of sand and gravel until the ground is saturated, creating an underground body of water called an aquifer. Groundwater in an aquifer does not stay still. It flows through the aquifer from the recharge area (area where water seeps into the aquifer) to the discharge area (area where groundwater emerges back onto the ground surface as springs or seeps into rivers or the sea). Where groundwater and surface water are connected, rivers and streams can gain or lose water to the underlying aquifers. The mixing of water from groundwater and surface water systems leads to the mixing of their water qualities (LAWA, 2020a).

Aquifers can be unconfined, semi-confined or confined. Unconfined areas are located where water can soak straight down into the aquifer. An aquifer can also extend into an area where layers of impermeable material (typically silt and/or clay layers) prevent the aquifer from being recharged directly from the ground surface, referred to as the confined area. In practice, this means that in unconfined areas, water in the bore/well will remain at the level it was struck at moving with changes to recharge and atmospheric pressure and in confined aquifers, water will rise above the level at which it was struck. In the area transitioning between the unconfined and the confined status, the aquifer is referred to as semi-confined. The confinement status of an aquifer has implications on the water that is stored and flows within the aquifers, which has implication on the available volumes and water quality.

Groundwater quality is naturally influenced by a range of hydrogeological processes occurring inside the aquifer along the flow path. Some examples of such processes include mineral dissolution, mineral precipitation, mixing and ion exchange. Groundwater quality can also be affected from human activities. Water soaking through the soil can dissolve and/or leach fertilisers (particularly nitrate-N) and pesticides and carry them downwards to the underlying aquifer. Faecal matter from animals, livestock and wastewater systems can cause pathogens and bacteria to be carried through the soil into the groundwater.

Most of the Waimea Plains is currently used for intensive horticulture and agriculture activities, with much of the available arable land (land capable of being ploughed and used to grow crops) being irrigated. Early land use in the Waimea Plains was predominantly pastoral farms, with limited irrigation usage. From the 1950s to today, land use has intensified largely through irrigation of horticultural land. As the use of the water resources in the Waimea Plains increased over time, the awareness of the impacts of intensification on water quality grew. In particular, the impacts of groundwater quality and nitrate-N contamination of the groundwater within the Waimea Plains aquifer systems.

The largest settlement in the Waimea Plains is Richmond, with approximately 15,400 people (Tasman District Council, 2021). Properties in the urban areas of the Waimea Plains (e.g. Richmond, Brightwater, Wakefield etc) are connected to a Tasman District Council (Council) reticulated water supply (groundwater piped from various well fields in the Waimea Plains) and connected to Council reticulated wastewater network (Tasman District Council, 2022a). A well field in the Waimea Plains also supplies water to the coastal settlements of Mapua and Ruby Bay which are located outside of the Waimea Plains. Council reticulated water supplies are managed so that the nitrate-N concentrations are below half of the Maximum Acceptable Value (MAV) from the New Zealand Drinking Water Standard (New Zealand Government, 2022). Away from the urban areas in the Waimea Plains, properties source water from their own private bores/wells and rainwater collection. They rely on private wastewater disposal systems (such as septic tanks). On the eastern side of the Waimea Plains (east of the Waimea/Wairoa/Wai-iti rivers), there is a private water scheme (Waimea East Irrigation Scheme) which supplies properties with water sourced from the Wairoa River. This scheme is meant for irrigational purposes, though some properties also use this water for domestic purposes.

For private household bores/wells (where the water supply is used only by the people on that property) there is no requirement from Council for the property owner to regularly test the water quality. In the Waimea Plains, most of these household water supplies are either 'pile driven' bores or dug wells and are shallow (4 – 8 m deep). Because they take water close to the ground surface, wells and driven bores are considered insecure for drinking water purposes and it is common for them to often breach the Drinking Water Standards from various contamination sources.

Councils have responsibilities under the Health Act 1956, Section 69U and the Water Services Act 2021 to take reasonable steps to contribute to the protection of the source of drinking water. Assessing the water quality and bore details of private bores and wells in the Waimea catchment, provides a better understanding to the risks to groundwater from these bores/wells and is relevant to Council as it operates water supply bores that abstract from the same aquifers. In the case of various Council water supply bores located within the Waimea Plains, Council has a duty to monitor its source water for the various Council water supplies and within the distribution network. Under the Tasman Resource Management Plan (2022b), the water resources in the Waimea Plains are separated into various Water Management Zones. The Water Management Zones are not necessarily aligned to the known aquifer boundaries.

Elevated nitrate-N concentrations have been measured in the Waimea Plains groundwaters since the 1970's, though isotopic data suggests the initial nitrate-N contamination dates back to the 1940s (Stewart et al, 2011; Stewart, 2011). An intensive piggery operation is thought to be a major contributor to historic nitrate-N contamination, alongside diffuse nitrate-N inputs from horticultural and agricultural activities. The piggery closed in the mid-1980's and Tasman District Council has been monitoring nitrate-N movement across the aquifers since (Fenemor, 2020).

Several comprehensive groundwater quality surveys have been undertaken by the Council in the Waimea Plains over time (1986, 1994, 1999, 2005, 2016 and 2021) to monitor changes in nitrate-nitrogen (nitrate-N) concentrations across the aquifers (Stanton and Martin, 1975; Spencer, 1981; Fenemor, 1987; Edie, 1995; Ware, 1999; Stevens, 2005 and 2017; Fenemor, 2020). The 2021 survey included a focus on investigation nitrate-N concentrations. These surveys are referred to as synoptic because a higher density of samples than the regular State of the Environment (SoE) monitoring are collected within a short time frame to provide a catchment-wide, time-based information about the groundwater quality. To remain cost-effective, Council undertakes synoptic surveys through rotations between catchment, complemented by more frequent (quarterly to annually) regional SoE monitoring. These contribute to a better understanding of our groundwater quality.

1.2 Scope of this Report

The aim of the survey is to understand the relationship between groundwater and recharge water quality and to provide an update from the previous surveys, with a focus on nitrate-nitrogen (nitrate-N). This report summarises the water quality results of the 2021 synoptic survey. It compares the results with previous surveys and reports on the 2018 national pesticide survey. This report is intended for public use and a glossary and list of acronyms was included into this effect.

This report has a focus on nitrate-N in the Waimea Plains. Elevated nitrate-N in drinking water is a contaminant associated with methemoglobinemia (blue baby syndrome), a serious condition in infants that leads to reduced oxygen availability and can cause death (Prime Minister's Chief Science Advisor, 2023). Regular testing of nitrate-N levels in drinking water to check if concentrations are above the recommended Ministry of Health limits (MAV) is important for families with formula-fed babies that use private groundwater bore or well supplies. In recent years, an association between nitrate-N concentrations in drinking water supplies and bowel cancer risk in adults has been identified in some overseas studies. However, the evidence is not conclusive with respect to whether the relationship is casual or coincidental and at the time of writing this report, the guidance from the Office of the Prime Minister's Chief Science Advisor is to monitor and assess compliance with the current MAV (Prime Minister's Chief Science Advisor, 2023). The MAV in the Drinking Water Regulations 2022 is as per the previous levels of 11.3 g/m^3-N nitrate-nitrogen.

Naturally occurring nitrate-N concentrations in New Zealand groundwater are typically low. Madison and Burnett (1985) found that nitrate-N concentrations above 3 g/m^3-N are indicative of human impact in United States groundwater. In 2005, Daughney and Reeves using multivariate statistics on groundwater quality time series from the national groundwater monitoring programme (c. 100 sites across the New Zealand) determined that in New Zealand groundwaters, nitrate-N concentrations below 1.6 g/m^3-N were most likely a result of natural processes. Concentrations of nitrate-N higher than 3.5 g/m^3-N are "almost certainly indicative of human impact". Subsequent studies combining hydrochemistry, groundwater and age from the national monitoring network suggested a nitrate-N concentration thresholds for land-use impacted water to be 0.25 g/m^3-N for low intensity and 2.5 g/m^3-N for high intensity (Morgenstern and Daughney, 2012).

2 HYDROGEOLOGICAL SETTING

The Waimea Plains is located in the Moutere Depression, a 30 km wide system of valleys between the Tasman Mountains and the ranges of east Nelson (Ratterbury et al., 1998). The valley floor consists of an extensive Pliocene-early Pleistocene clay bound gravel sheet, called the Moutere Gravel. Since the mid-Pleistocene, these gravels have been locally cut into (incised) and reworked by several river systems and subsequently infilled with more recent alluvial (river deposited) gravels and sands.

The Waimea Plains occupies a 75 km^2 portion of the Moutere Depression (see Figure 1). It is located on the eastern edge of the Moutere Depression and is bounded to the southeast by the Waimea/Flaxmore Fault system, to the east by the eastern hills (Mt Hesslington and Barnicoat Ranges) and to the west by outcrops of Moutere Gravel (Spooners Range) along the Moutere Hills. The Waimea Plains extends northeast to the coast and is bounded by the Waimea estuary and barrier islands in the Tasman Bay. A number of small spring-fed coastal streams discharge directly into the Waimea estuary. In the northeast, the drainage is dominated by the Wairoa and Wai-iti rivers.

The Waimea Plains were formed during the Quaternary, though a succession of erosive periods, followed by infilling with alluvial gravels from the Wairoa/Wai-iti/Waimea rivers, have resulted in the deposition of the Hope Gravel (Figure 2 and 3). The Hope Gravels consist of poorly sorted, tight clay bound gravel, with lenses of better sorted gravels. To the southeast and adjacent to the eastern hills, the Hope Gravels are overlain and interdigitated (interlocked) with the Stoke Fan Gravel fan deposits (Dicker et al, 1992). The present flood plains have resulted in the deposition of the Appleby Gravel, overlying the Hope Gravel in part of the Waimea Plains. A terrace riser, known locally as "Burkes Bank", separates the Hope Gravels from the recent flood plain of the Waimea River (Beck, 1964). For a more detailed description of the general form and nature of these Quaternary deposits that comprise the Waimea Plains, please refer to Dicker et al (1992).

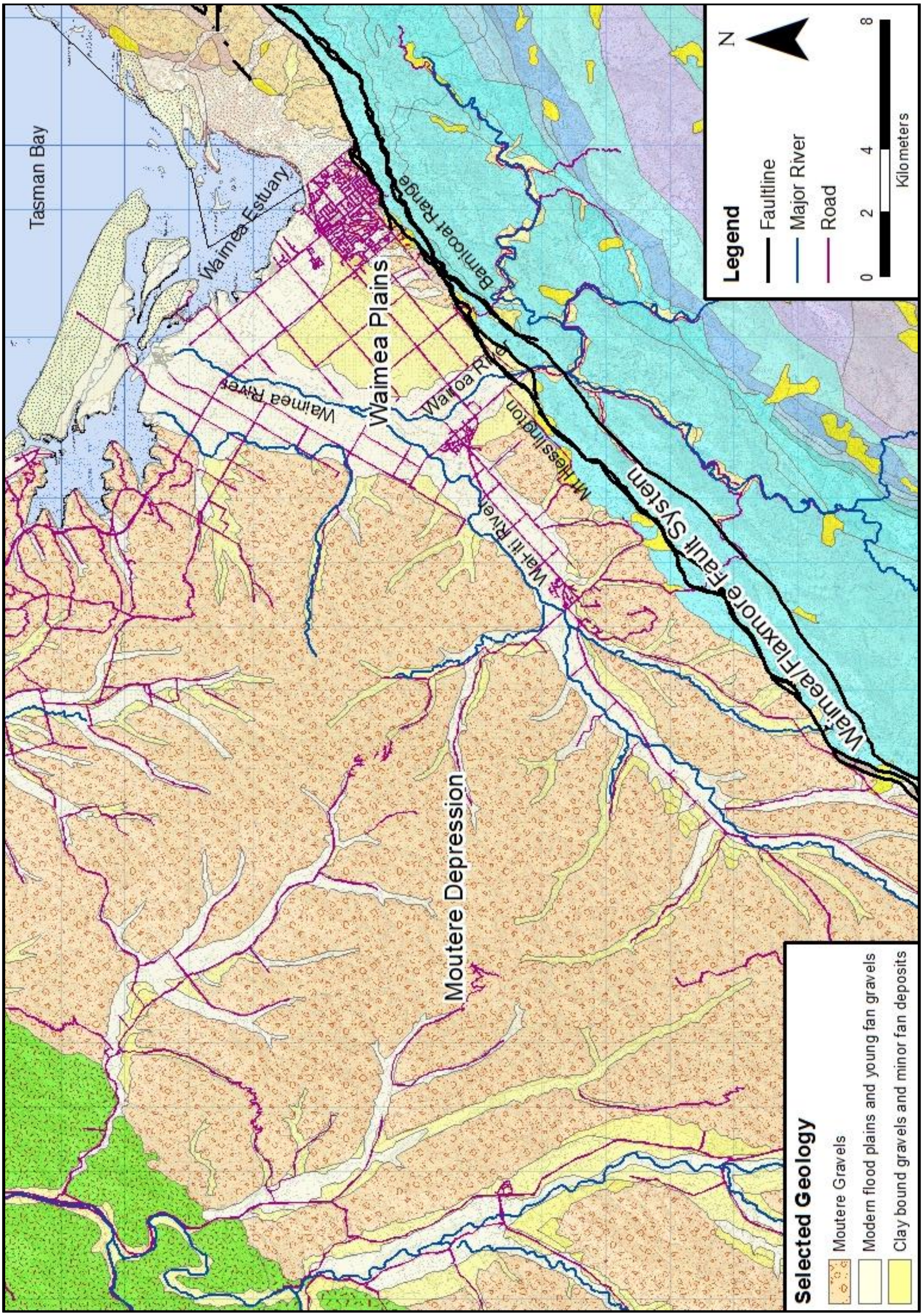

Figure 1: Geological map of the Moutere Depression showing the Waimea Plains to the northeast.

There are four principal aquifers in the Waimea Plains (see Figures 2 and 3), listed from shallow to deep below. The Moutere Gravel is regarded as the hydrogeological basement.

- The Appleby Gravel Unconfined Aquifer (AGUA)
- The Hope Minor Confined and Unconfined Aquifer (HU)
- The Upper Confined Aquifer (UCA)
- The Lower Confined Aquifer (LCA)

The AGUA is the present flood plain of the Waimea, Wairoa and Wai-iti rivers, cutting into the Hope Gravel. It comprises of recent well sorted gravels and sand and varies in thickness: thickest at the coast (up to 15 m), thinning and becoming shallower inland (Dicker et al, 2001). Groundwater level in the AGUA is typically 2 to 3 m below ground level. The AGUA is recharged by leakage from various surface water courses, as well as infiltration of rainfall and irrigation on the Waimea Plains. The AGUA also receives water from the UCA in the area between Bartlett Road and State Highway 60 where the two aquifers merge and become hydraulically indistinguishable (connected).

The HU consists of finer grained material and fan gravels deposited by small creeks draining the Barnicoat Range located at the eastern margin of the Waimea Plains. This material has intermingled with the Hope Gravel, causing sporadic isolated lenses of better sorted, water bearing gravels along the southeastern edge between the Wairoa Gorge and Richmond. These lenses are not laterally continuous (layers of sediment is not deposited in all directions) and are perched in places. The collection of these confined and unconfined aquifers forms the HU. The many HU aquifers are generally less than 0.5 m thick and most occur within the first 15 m below the ground surface. The HU is recharged by infiltration of rainfall and irrigation on the Waimea Plains, as well as infiltration of surface flows from the hills into their fans to the southeast. Dicker et al (2001) describes the HU to discharge to the underlying UCA and LCA close to the foot of the eastern hills and laterally to the AGUA north of Stage Highway 60. Fenemor (1988) suggests there is substantial water storage in the Barnicoat Range, potentially concentrated towards the southern end via the Waimea Fault (A Fenemor, pers comms) contributing recharge to the HU.

The UCA comprises well sorted gravel associated with a paleoriver channel, beginning at the mouth of the Wairoa Gorge flowing towards the sea in the north. However, the northern extent of the UCA is poorly defined, but thought to discharge through a paleo delta close to the existing coastline of the Waimea Estuary (Dicker et al, 2001). The confining layer thins out to the north (in the area between Bartlett Road and State Highway 60) where the UCA becomes unconfined and merges with the overlying AGUA. The UCA is typically between 18 to 32 m below the ground level, with the paleo river channel gravels up to 12 m thick in places. The UCA is recharged by leakage from the Wairoa River where it exits the Wairoa Gorge, as well as surface infiltration through the overlying HU aquifers along the base of the eastern hills near Haycock Road.

The LCA also consists of a deeper paleoriver channel, beginning from the mouth of the Wairoa Gorge and the Wairoa River to near Brightwater and extends in a north-northeast direction through the Waimea Inlet. The LCA discharges through a paleo delta underlying the Waimea Inlet north of Rabbit Island (Dicker et al, 2001). It is unknown how far offshore the LCA effectively ends (A Fenemor, pers comms). At the southern end (near Clover Road), the LCA is typically about 24 m below ground level. The LCA increases in depth to around 40 m below ground level towards the present-day coastline (near Lower Queen Street). The LCA varies in thickness: thickest at the coast (up to 14 m), thinning and becoming shallower inland towards the Wairoa Gorge. The LCA is recharged by leakage from the Wairoa River between the Wairoa Gorge and Brightwater, as well as surface infiltration through the overlying HU aquifers along the base of the eastern hills.

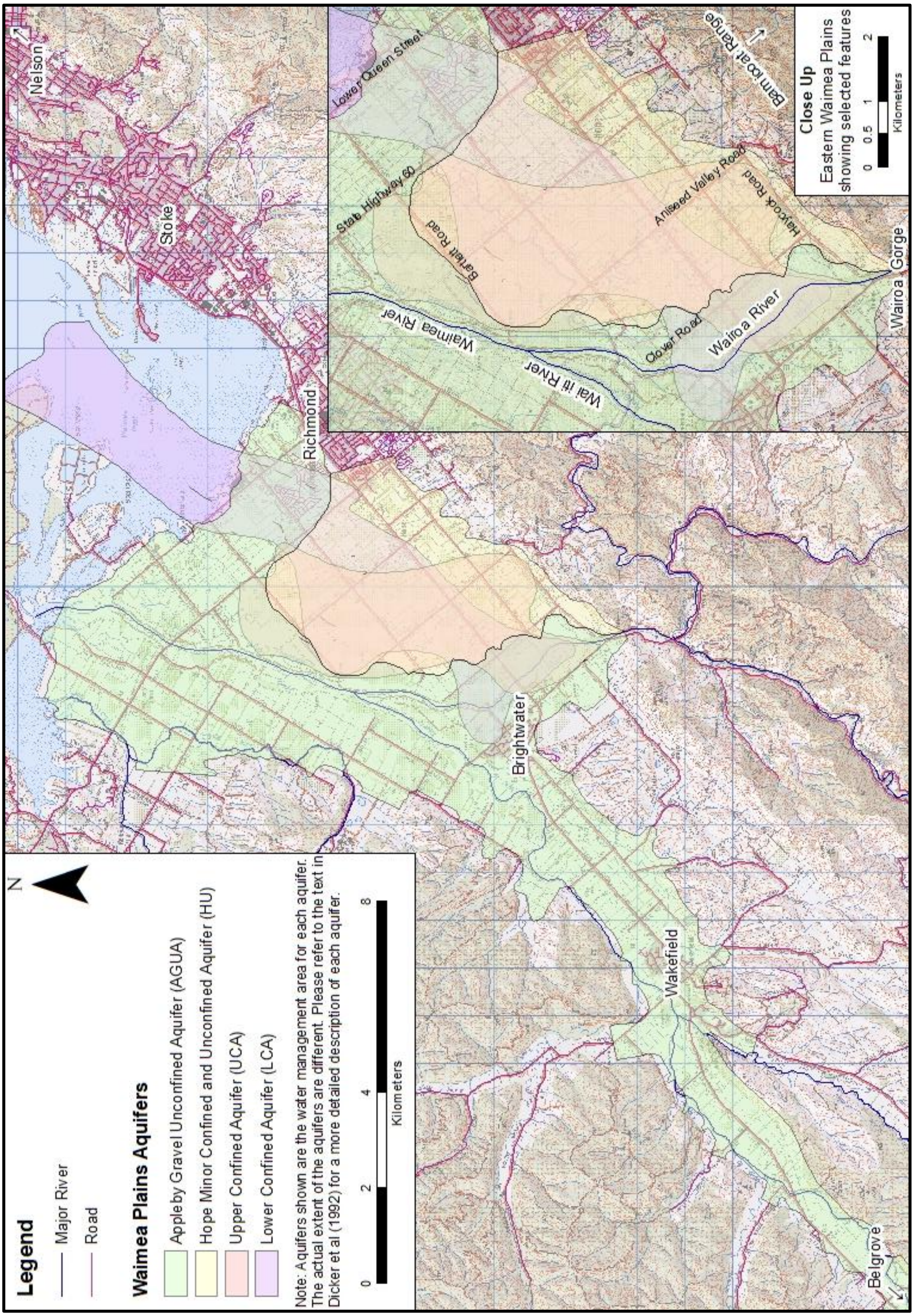

Figure 2: Waimea Plains aquifers.

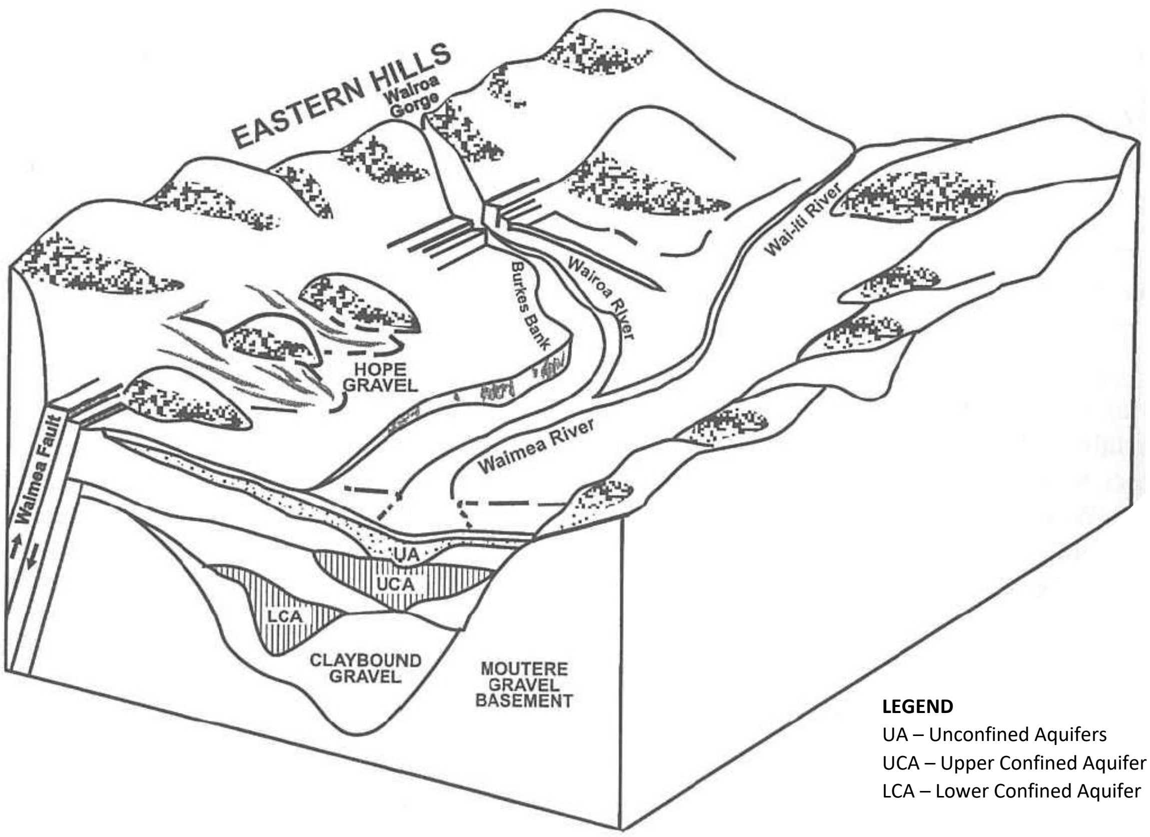

Figure 3: Three-dimensional hydrogeology of the Waimea Plains. Reproduced from New Zealand Hydrological Society (2001). Unconfined aquifers (UA) in this schematic includes the Hope Minor aquifers (HU) and the Appleby Gravel (AGUA).

3 DATA COLLECTION

Between October and December 2021, a water quality survey was undertaken in the Waimea Plains. The 2021 synoptic survey included 137 bores and wells, 9 spring-fed and 3 river sites. Figure 4 details the location of the sampling sites. Sampled bores and wells are used for a range of purposes (i.e., domestic household consumption, Council operated reticulated water supply, irrigation, commercial, industrial, piezometer/monitoring and stock water).

Samples were collected following appropriate protocols depending on the sampling point (shallow bores/wells, deep bores, surface water). Individual sample collection methodology is included in Appendix I. Groundwater temperature, dissolved oxygen concentration, pH, electrical conductivity (denoted as conductivity in this report) and where possible oxidoreduction potential were measured in the field as these parameters change once groundwater is removed from the aquifer. Water samples were subsequently dispatched to Hill Laboratories where they were analysed for nitrate-N, E.coli and total coliforms. A subset of samples (38 groundwater sites (selected for spatial coverage) and for all 12 river/spring-fed stream sites) were also analysed for major ions and dissolved metals. The full suite of parameters is provided in Appendix II.

During the field visit, the integrity of the bore/well head were assessed and discussed with the property owner.

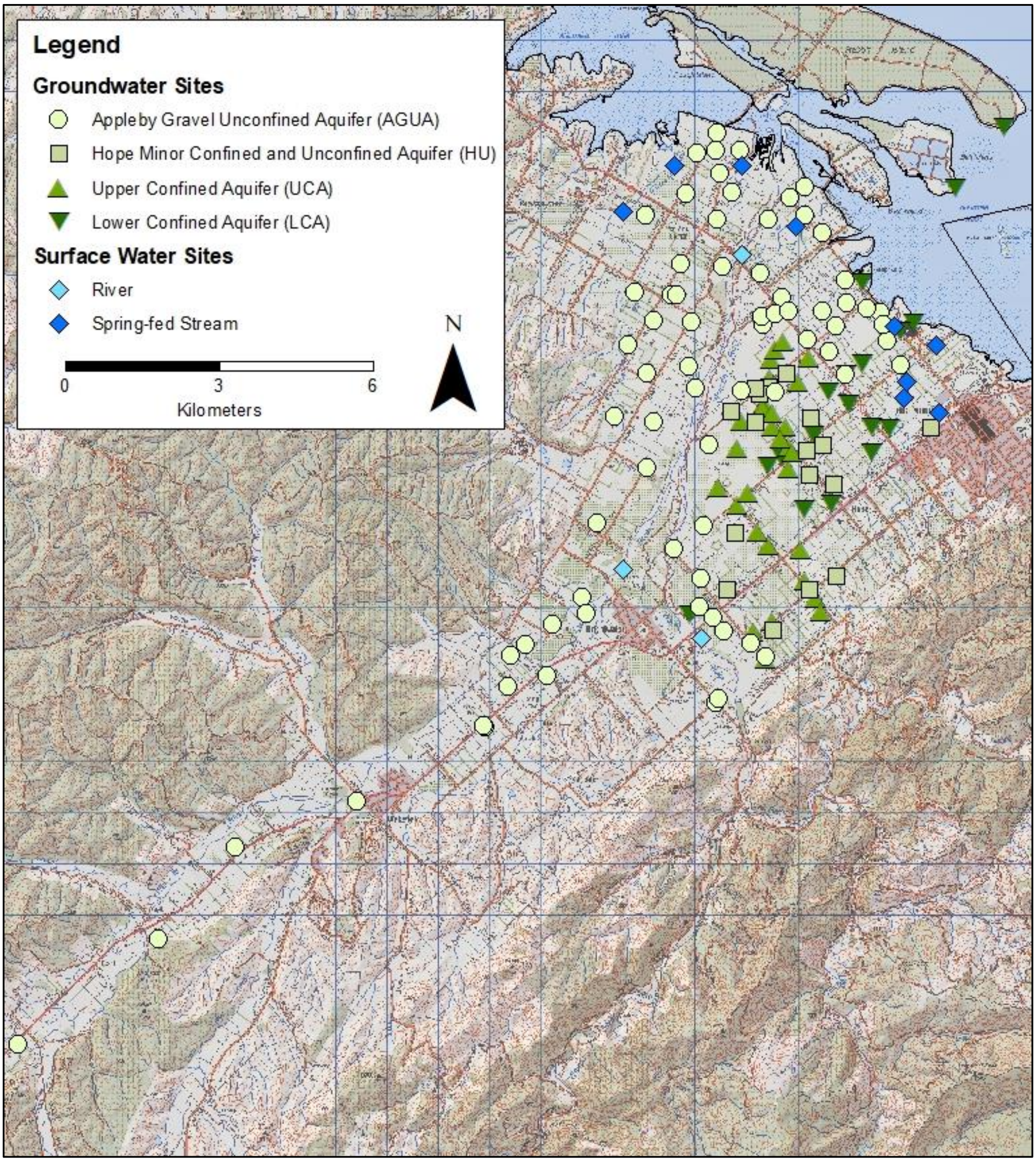

Figure 4: Location of all bores, wells, rivers and spring sites sampled in the 2021 Waimea Plains water quality survey.

4 GROUNDWATER QUALITY

4.1 Groundwater Chemistry

The water quality results were compared against the Water Services (Drinking Water Standards for New Zealand or DWSNZ) Regulations 2022 (New Zealand Government, 2022) and Aesthetic Values for Drinking Water Notice 2022 (Taumata Arowai, 2022a)[1]. Health significant substances have a Maximum Acceptable Value (MAV). Please refer to Appendix III to see the distribution of selected chemical parameters across the Waimea Plains.

[1] The two national water quality standard documents will be referred to in this report jointly as the Drinking Water Standards of New Zealand (DWSNZ).

The most common exceedance of the DWSNZ health significance parameter (out of the parameters that were tested for, see Appendix I) was nitrate-N. The sampling found that nitrate-N was elevated (above 50% of the MAV or exceeded the MAV) in parts of the Waimea Plains. Breakdown of nitrate-N can be found in Table 1.

Table 1: 2021 nitrate-N sampling results per aquifer

2021 Nitrate-N sampling results	Breakdown of sites per aquifer				
	AGUA	HU	UCA	LCA	All Sites
Below 50% of MAV (< 5.6 g/m^3-N)	44	4	4	4	56
Between 50% of MAV and MAV (5.6 - 11.3 g/m^3-N)	13	6	13	10	42
Above 50% of MAV (> 5.6 g/m^3-N)	28	12	27	14	81
Above MAV (> 11.3 g/m^3-N)	15	6	14	4	39
Total sites sampled in 2021	72	16	31	18	137

The highest nitrate-N concentrations were found at the corner of Bartlett Road/Ranzau Road West (31 g/m^3-N) and along Blackbyre Road (30 g/m^3-N) in the unconfined aquifers (HU and AGUA). Bores/wells sampled between these two locations were all exceeding the MAV at the time of sampling. This is the area where the UCA merges with the AGUA and becomes hydraulically indistinguishable and both aquifers are unconfined, therefore vulnerable to surface contamination, particularly during long duration and/or high intensity rainfall events. The area of Blackbyre Road is outside of the UCA reach, however it is likely to be receiving water from the Bartlett Road/Ranzau Road West area due to the flow of groundwater through the AGUA as it progresses towards the coast.

On the eastern side of the Waimea Plains (east of the Waimea/Wairoa/Wai-iti rivers), the majority of the bores/wells in all four aquifers were above 50% of the MAV (5.6 g/m^3-N or higher). This is expected due to the high intensity of horticultural and agricultural activities across the whole eastern side of the Waimea Plains. On the western side of the Waimea Plains (northwest of the confluence of the Wairoa and Wai-iti rivers to form the Waimea River), there is an area with nitrate-N above 50% of the MAV (5.6 g/m^3-N or higher). This area (Cotterell Road/Moutere Highway/River Road/Waimea West Road) corresponds with overlying horticultural and agricultural land uses. The findings indicate that regardless of historic nitrate-N contamination, there is an ongoing input from present-day land use activities (horticultural and agricultural) occurring across the Waimea Plains.

Aside from nitrate-N, there were *Escherichia coli* (*E.coli*) MAV exceedances for health significance in a number of bores/wells in the Waimea Plains. The majority of *E.coli* exceedances were found in shallow sites (wells or driven bores), regardless of their location (coastal or inland). The exceedances do appear to be localised, with contamination thought to be occurring due to inappropriate bore/well siting where the bore/well was located in close proximity with activities involving faecal matter (see Figure 5) or poor bore/well head protection (see Figures 6 and 7). Images of bores/wells shown in this report were taken on the day that the bore/well was sampled.

Wells and driven bores are sourced by shallow groundwater close to the ground surface above it and it is common for these to breach the MAV for the bacteriological pathogen indicator *E.coli*. Most the bores/wells with bacteriological exceedances did not meet the safe water take requirements (Section 2.4 from the Drinking Water Acceptable Solution for Spring and Bore Water Supplies (Taumata Arowai, 2022b)) and the bore construction requirements (Chapter 16, Clause 16.12 under the Tasman Resource Management Plan (Tasman District Council, 2022b)). Contamination can include seepage from stagnant water near the bore/well, localised seepage along the edges of the bore/well, animal faecal contamination, septic tank seepage and runoff/seepage following rainfall into the bore/well.

Figure 5: Bore located in paddock with no fencing to prevent stock from accessing the bore. Though the riser is above the ground surface, the bore itself is located in a low-lying area where water tends to pool with no concrete pad to prevent soakage. Contamination is likely to soak into the ground near the bore or have floodwaters flow directly down the bore.

Figure 6: Well with no adequate well head protection. Contamination can easily enter into the groundwater by falling directly into the well.

Figure 7: Bore located in low lying area without adequate bore head protection. Contamination can easily enter into the groundwater from the bore.

Drilled bores access deeper groundwater (typically in the Waimea Plains this is bores accessing the UCA and LCA or deeper AGUA/HU sites). Most of the groundwater from the bores had no detections of *E.coli* at the time of sampling, with the majority having good bore head protection and were appropriately sited away from potential contamination sources. Drilled bores can also access semi-confined and confined aquifers, which have a confining layer which prevents contamination from seeping directly from the ground surface above the bore. However, semi-confined and confined groundwater are still susceptible to contamination in areas which recharge those aquifers. The deeper the groundwater is abstracted from the aquifer, the more natural filtration and die-off of pathogens occurs. Figure 8 shows an example of bore located in the Waimea Plains that is appropriately sited, with good bore head protection.

Figure 8: Bore with a sealed bore head located above the ground to prevent stormwater runoff entering the bore. Backflow prevention device installed to prevent contaminated water flowing back into the aquifer. Concrete pad to deflect stormwater and prevent direct soakage into the bore.

Conductivity is a measure of the amount of total dissolved solids content in water (LAWA, 2020b). A range of hydrogeological processes, such as water-rock interaction, mixing or leaching of contaminants from the ground surface and sea water intrusion induced by abstraction can effect conductivity. Sea water has conductivity significantly higher than fresh water from rivers and groundwater (c. 50,000 uS/cm). Encroachment of sea water (intrusions) is normally noticed when background levels near the coastal bores/wells show an increasing conductivity trend. Although there is no MAV for conductivity, it is important indicator to detect contamination in an aquifer system. Elevated conductivity can also cause harm to household pipes/plumbing through chemical build up or deterioration.

At the coast, unconfined bores/wells near the coast are expected to have higher conductivity than inland bores due to salt deposition on the ground by sea spray. The shallow coastal bores/wells in the Waimea Plains all showed higher conductivity compared with inland bores/wells (south of Brightwater) that were not impacted from agricultural/horticultural ionic inputs.

Dissolved oxygen is an indicator of the physico-chemical ((physical and chemical) status of groundwater which influence some in-situ chemical processes such as mineral precipitation or oxydo-reduction (chemical reaction that involves a transfer of electrons between two chemical species, sometimes called a redox reaction). Coastally, on the eastern side of the Waimea River (between Lower Queen Street and State Highway 60) groundwater in the AGUA exhibits low dissolved oxygen level (less than 50%). Parts of the LCA (from Lower Queen Street and extending into the Waimea Estuary) also show low dissolved oxygen. This suggests that reducing conditions may be present in the AGUA and LCA in these areas. Under reducing conditions, nitrate-N is naturally converted into nitrite and further into nitrogen gas (the oxygen from the nitrate-N is consumed) (Martindale et al., 2019). Low oxygen levels also impact on dissolved iron and manganese concentrations, as they become more mobile under reducing or low oxygen levels however, iron and manganese were not detected in high concentrations in the AGUA and LCA. This suggests that the low oxygen zone has not yet reached reducing conditions. This means that where present, nitrogen in the Waimea Plains aquifer systems is in the form of nitrate-N.

On the eastern side of the Waimea River (east of the Waimea/Wairoa/Wai-iti rivers), groundwater is higher in magnesium concentrations and the water is harder compared with the western side. This is likely to be linked to the lithology of the source rocks (Dun Mountain Ultramafic Group), located in the catchment of the Wairoa River (Dicker et al, 1992). This geological group is rich in serpentinised minerals, that natural weathering through exposure to water (rainfall and/or rivers) results in magnesium ions being released. Water hardness is a measure of primarily calcium and magnesium ions. There are limited calcium ions present in the Waimea Plains (small lenses of limestone in the Maitai Group located also in the Wairoa River catchment) however the greater natural contribution to the water hardness is the magnesium ions from the ultramafic rocks. Magnesium is also a component in fertilisers, and as there is extensive horticultural and agricultural activities occurring on the Waimea Plains, there is likely a contribution of magnesium ions from these activities. This has resulted in hard water on the eastern Waimea Plains. The harder the water, the lesser the nitrate toxicity is experienced by the spring-fed ecosystems (Hickey, 2015).

4.2 Comparison to Previous Synoptic Surveys and State of the Environment Monitoring

Elevated nitrate-N concentrations[2] in the Waimea Plains was identified in the 1970's, prompting ongoing monitoring programmes and investigations into the source of initial contamination. Isotopic (age) testing of elevated nitrate-N groundwaters of the Waimea Plains suggests that the initial nitrate-N contamination in the UCA and LCA could date back as far as the 1940s (Stewart et al, 2011; Stewart, 2011).

An intensive piggery operation located between Haycock Road/Aniseed Valley Road (recharge area for the HU, UCA and LCA) is thought to be a major contributor to historic nitrate-N contamination in

[2] The term "elevated nitrate-N concentration" is used in this report to describe nitrate-N concentrations that are above the Maximum Acceptable Value in the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 of 11.3 g/m^3-N.

the HU, UCA and LCA. The operation was closed in the mid-1980s. While the piggery was operational, compost made from combining sawdust with the pig effluent (a 2:1 mix) was used by the market gardeners along Aniseed Valley Road (Fenemor, 2020). There was an effluent collection pit at the northwest corner of the piggery (see Figure 9).

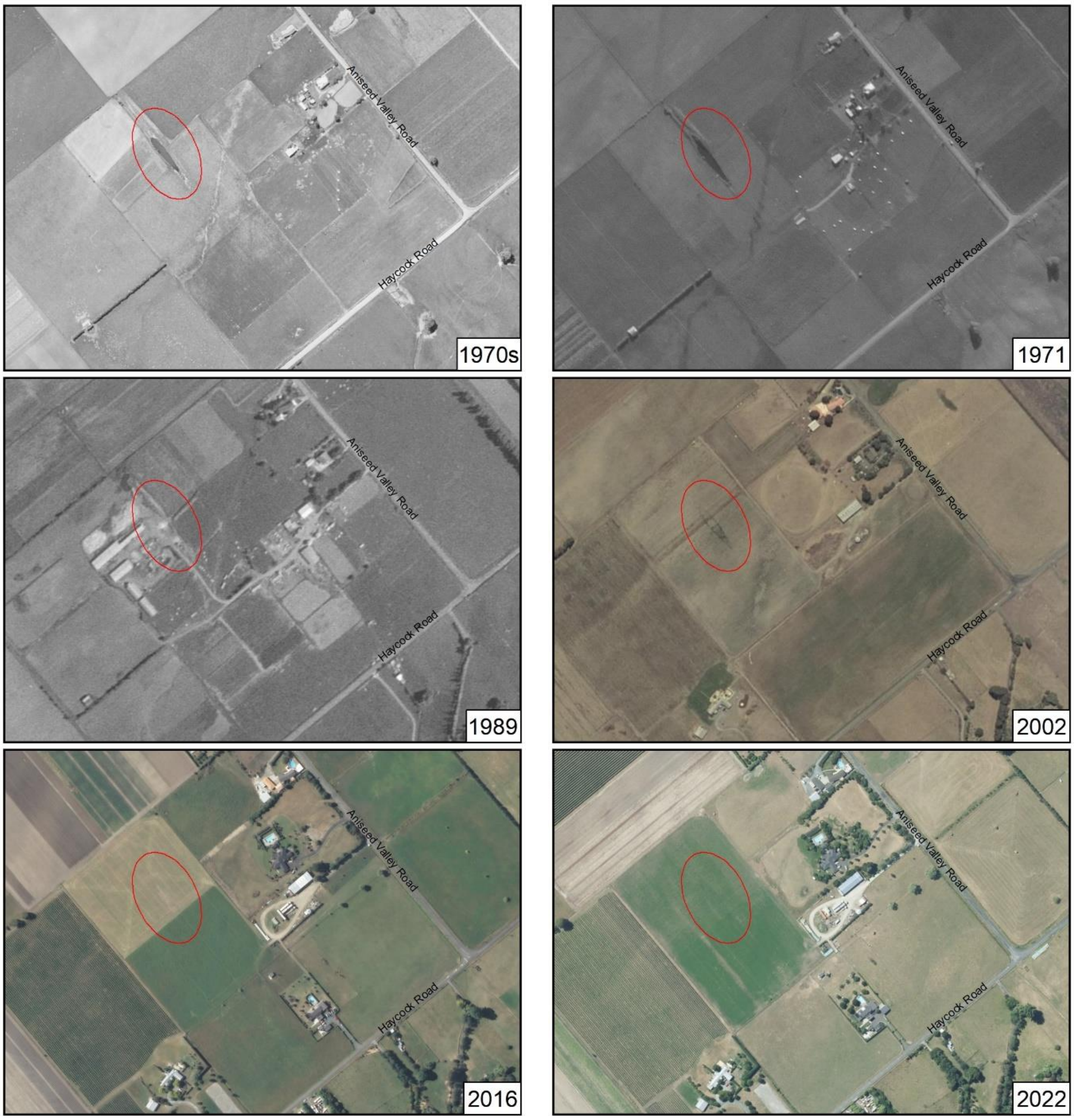

Figure 9: Aerial imagery showing historic effluent pit over time. Imagery sourced from http://retrolens.nz and licensed by LINZ CC-BY 3.0.

After the closure of the piggery, the pit was backfilled with soil and it is thought to have been released nitrate-N into the groundwater since then. As pig effluent is highly mineralizable (Eghball et al, 2002), the effluent from the pit should have "substantially degraded" over time (Fenemor, 2020).

The first published evidence of elevated nitrate-N concentrations in the groundwater of the Waimea Plains was reported by Stanton and Martin (1975) and Spencer (1981) as part of wider investigations into understanding the groundwater resource in the plains. These surveys indicated that elevated nitrate-N concentrations were present in the confined and semi-confined aquifers at the recharge zone along the eastern hills by the Wairoa Gorge. Elevated nitrate-N concentrations were found in areas of intensive land use, the highest concentration (50 g/m^3-N) was recorded from a well beside Main Road Hope midway between Richmond and Brightwater (between Edens Road and Ranzau Road). Nitrate-N with concentrations above 20 g/m^3-N were recorded in bores/wells along Aniseed Valley Road (between Patons Road to Main Road Hope) and continued northeast to just past the Pugh Road/Ranzau Road/Ranzau Road West intersection. The elevated nitrate-N concentrations found at many sites in the shallower groundwater between Aniseed Valley Road/Main Road Hope/Ranzau Road suggest that the source of the nitrate-N is not solely linked to the historic piggery operation but rather originates from broader-scale land use. The relatively slow throughflow of each aquifer had resulted in nitrate-N to move slowly through the aquifer, creating plumes of contamination to extend out from the source areas in a northerly direction, and remaining in the aquifer for some time (Stanton and Martin, 1975; Spencer, 1981).

Concern over the findings from Stanton et al and Spencer prompted the Council to undertake various actions, including several comprehensive synoptic surveys in the Waimea Plains to monitor the plume of nitrate-N through all four aquifer systems. Such surveys were undertaken in 1986, 1994, 1999, 2005, 2016 and 2021. The breakdown of groundwater sites per synoptic survey is summarised in Table 2.

Note that water quality investigations undertaken prior to 1986 did not separate the bores/wells into the specific aquifer system that the groundwater was abstracted from. Stevens (2005) identified a number of bores/wells from previous investigations that were reported abstracting from a particular aquifer, however when reassessing the bore logs containing driller remarks it was found to be abstracting from a different aquifer. The 2005, 2016 and 2021 water quality investigations grouped the groundwater bores/wells together based on the aquifer system that the groundwater is abstracted from.

Table 2: Council groundwater quality investigation sites sampled per aquifer.

Year / Aquifer	1986	1994	1999	2005	2016	2021
AGUA sites	11	15	28	46	74	72
HU sites	12	12	12	11	16	16
UCA sites	24	21	19	18	24	31
LCA sites	16	16	21	18	19	18
Total groundwater sites sampled	**63**	**64**	**82**	**93**	**133**	**137**

Care is required in interpreting the results which are used to describe trends. The six long-term monitoring bores in the Waimea Plains (GW 32 – TDC, GW 802 – Waiwest, GW 114 – TDC Roadside, GW 1392 – Spring Grove, GW 37 – Gardner (now GW 471) and GW 997 – McCliskies) are sampled every three months, which provides adequate long-term data to analyse temporal trends. However, most of the additional private bores/wells are only tested as part of synoptic surveys, which means up to six times since monitoring began. Despite being less variable than surface waters, groundwater quality can vary seasonally due to a range of factors including changes in rainfall patterns (intensity and volume), river recharge and land use practices throughout the year. This means the results from the synoptic investigations could also be a reflection of the timing of the sample was taken in the year and not an overall groundwater quality trend.

The 1986 investigation included 63 bores/wells; the results of the sampling were reported in Fenemor (1987). This investigation provided a spatial distribution of nitrate-N concentrations across the Waimea Plains but was limited by the available data to provide comment on any trends in nitrate-N concentrations over time. Elevated nitrate-N concentrations occurred locally in all four aquifers. Fenemor compared the results to the studies undertaken by Stanton et al and Spencer and found nitrate-N concentrations in the LCA remaining steady, decreasing concentrations in the HU, and increasing concentrations in the UCA, AGUA and spring-fed streams. The highest nitrate-N concentration was 28 g/m^3-N located along Ranzau Road West by Main Road Hope. Fenemor concluded that the most likely cause of the elevated nitrate-N concentrations was from nitrate-N leaching from fertilisers and animal wastes into the aquifer, particularly in the recharge areas of the aquifers. Fenemor also notes that other sources of nitrate-N may be contributing to the elevated nitrate-N concentrations (including point source discharges from septic tanks, offal pits etc).

The 1994 investigation sampled 64 bores/wells; the results of the sampling were reported in Edie (1995). 50 of the bores/wells sampled in 1986 were able to be resampled. Edie concluded that nitrate-N concentrations in the Waimea Plains have remained unchanged, with the exception of the shallow unconfined aquifer where nitrate-N concentrations increased in the Patons Road/Ranzau Road area where the highest nitrate-N concentration was located (24 g/m^3-N). Edie referred to the aquifer in this area as the AGUA, however analysis of the bore logs determines this to be the HU.

The 1999 investigation sampled 82 bores/wells; the results of the sampling were reported in an unpublished BSc (Honours) thesis by Ware (1999). 57 of the bores/wells sampled in 1994 were able to be resampled. Ware found that elevated nitrate-N concentrations continued along the LCA and UCA. The highest nitrate-N concentrations were in the UCA from the northern part of the Aniseed Valley Road to the corner of State Highway 60/Swamp Road (27 g/m^3-N). Ware concluded that the principal source of nitrate-N to the aquifer systems occurred in the Hope area, where groundwater recharges from the HU to both the LCA and UCA. The AGUA had the lowest nitrate-N concentrations due to recharge primarily from the rivers (which have low concentrations of nitrate-N). Ware identified localised elevated nitrate-N concentrations on the western side of the Waimea River (along Cotterell Road and River Road) and summarised this to be contamination from overlying land use activities.

The 2005 investigation sampled 93 bores/wells; the results of the sampling were reported in Stevens (2005). 69 of the bores/wells sampled in 1999 were able to be resampled. Stevens identified a slow and gradual increase in nitrate-N concentrations close to the coast in the LCA and a slight decrease in the mid-plains area. The UCA showed an overall decreasing trend in nitrate-N concentrations, however concentrations remained elevated along the length of the UCA, from the recharge area along the Richmond foothills to State Highway 60 where the confining layer thins to merge with the AGUA. The highest nitrate-N concentrations were in the UCA in the Aniseed Valley Road/Patons Road area (26 g/m^3-N). The AGUA had relatively low nitrate-N concentrations near the rivers. However, areas of elevated nitrate-N concentrations in the AGUA were found near State Highway 60 and Swamp Road (where the UCA confining layer thins and merges with the AGUA), and also localised elevated nitrate-N concentrations including along State Highway 60 between Bartlett Road/Blackbyre Road suggesting additional nitrate-N inputs other than leakage from the UCA. The HU also showed a decreasing trend, however nitrate-N concentrations remained elevated.

The 2016 investigation sampled 133 bores/wells; the results of the sampling were reported in Stevens (2017). 85 of the bores/wells sampled in 2005 were able to be resampled. Stevens confirmed elevated nitrate-N concentrations (up to 24 g/m^3-N) where the UCA discharges into the AGUA (Ranzau Road/Bartlett Road), further north in the AGUA (Bartlett Road/Blackbyre Road/State Highway 60), the low terrace adjacent to Clover Road (between Paton Road/Haycock Road), and on the western side of the Waimea River at the northern end of Redwood Road. The highest elevated nitrate-N concentrations were located along State Highway 60 opposite Blackbyre Road (28 g/m^3-N). There was also a localised high nitrate-N (31 g/m^3-N) from a shallow well at the intersection of Mt Heslington Road/River Terrace Road which was adjacent to a chicken coop. Elsewhere, nitrate-N concentrations in the AGUA were stable or decreasing. As well as the discharge area with the AGUA, elevated nitrate-N concentrations were also increasing along the UCA near Edens Road. The HU is also increasing along Bartlett Road near the intersection of Ranzau Road West. The LCA remains stable along much of its extent, with a few sites showing a small declining trend.

The 2021 investigation sampled 137 bores/wells, 112 of which were repeats from the 2016 survey. There were 30 sites which had been sampled in all six Council groundwater quality investigations. 81 sites had been sampled in three or more previous investigations. There were 57 bores/wells sampled in 2021 which had sufficient data to undertake trend analysis on (methodology and figure of trend results can be found in Appendix IV).

Trend analysis in the unconfined aquifers have a very strong decreasing trend of nitrate-N in the AGUA south of Brightwater. North of Brightwater, west of the Waimea River the AGUA trends are indeterminate, with indeterminate increasing along Golden Hills Road and Cotterell Road. East of the Waimea River, there is a strong increasing trend of nitrate-N around Blackbyre Road and State Highway 60. East of Swamp Road, the trend in the AGUA becomes indeterminate. There is strong and very strong decreasing trends in the southern reaches of the HU. Northeast of Pugh Road, the trend becomes indeterminately increasing as it approaches Bartlett Road.

Towards the eastern edge of the UCA, nitrate-N trend analysis shows a very strong decreasing trend following northwards along the historic piggery plume. Towards the western edge of the aquifer, from Edens Road northwards, there is a strong increasing trend of nitrate-N, which is no longer detected from the Edens Road/Pugh Road intersection through to Bartlett Road and northwards.

In the LCA, most sites do not exhibit trends for nitrate-N. There is a very strong decreasing trend of nitrate-N at Lower Queen Street, which switches to a strong increasing trend at Bells Island.

Contour plots of the nitrate-N concentrations for these six surveys can be found in Appendix V. Please note that plots from those drawn in Fenemor (1987), Edie (1995), Ware (1999) and Stevens (2005) have been redrafted based on the original nitrate-N data to incorporate the current knowledge of the aquifer constraints and the improved accuracy of bore locations in recent years.

Alongside the six SoE bores in the Waimea Plains, monthly nitrate-N sampling has also been undertaken in three bores since 2017 (see Figure 10), in response to landowner concerns following the release of the 2016 report. These three bores in the Bartlett Road/Ranzau Road West/Blackbyre Road area (area of highest nitrate-N concentrations in the 2016 investigation) were sampled by AgFirst (on behalf of Council). As of the release of this report, the monthly sampling is still being undertaken on these three bores.

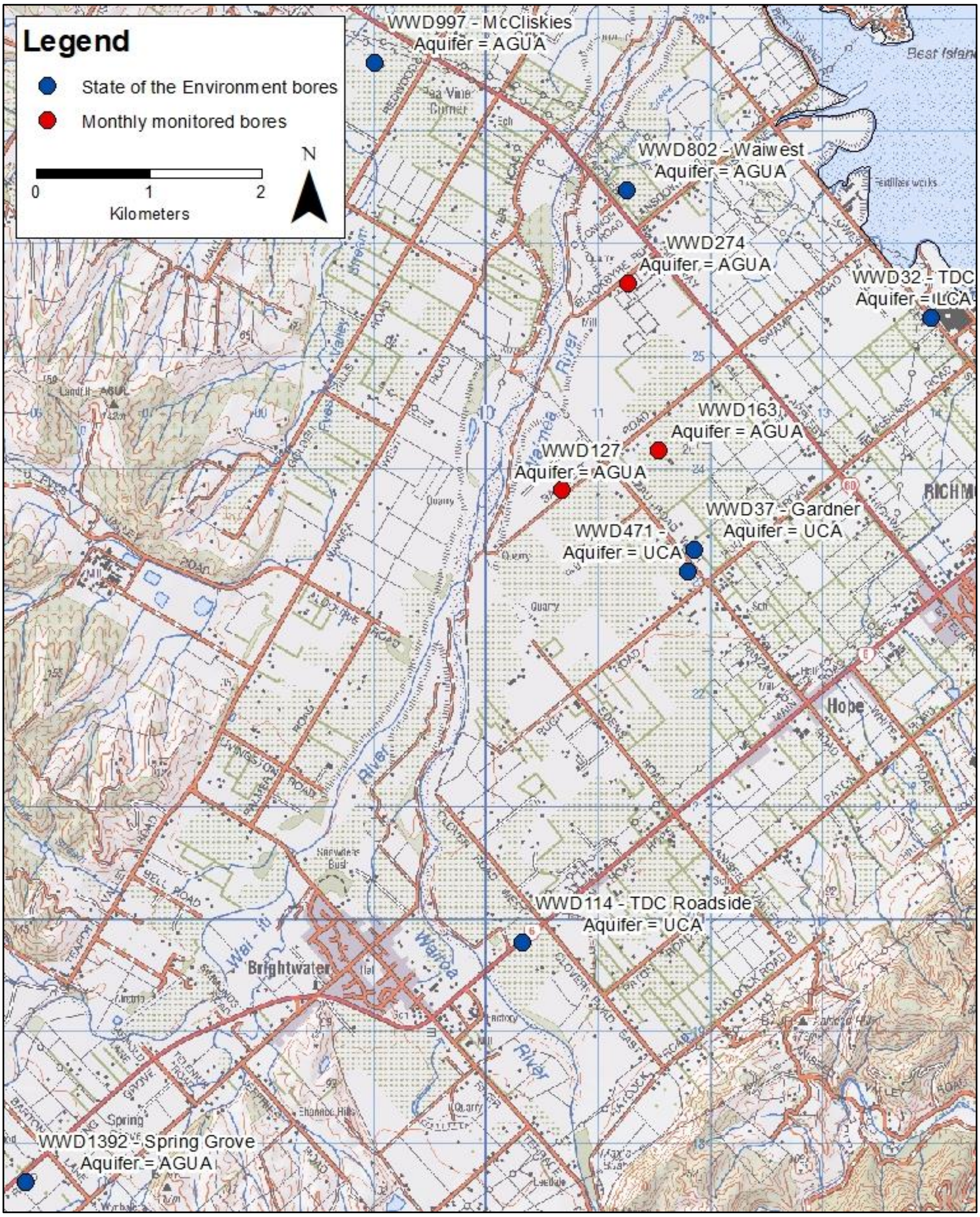

Figure 10: State of the Environment and monthly monitored bores in the Waimea Plains.

Please note sampling of the original UCA SoE bore (WWD 37 – Gardner) ended in December 2020 due to site access issues. When access resumed in November 2021, the submersible pump had ceased due to inactivity (likely caused from iron rust) and it was unable to be recovered and repaired. WWD 471 was chosen as the UCA SoE replacement due to the similar bore depth and close proximity to WWD 37 - Gardner. Sampling records for the UCA resumed in December 2021 from WWD 471. Figure 11 shows the nitrate-N concentrations measured at the Waimea Plains SoE bores.

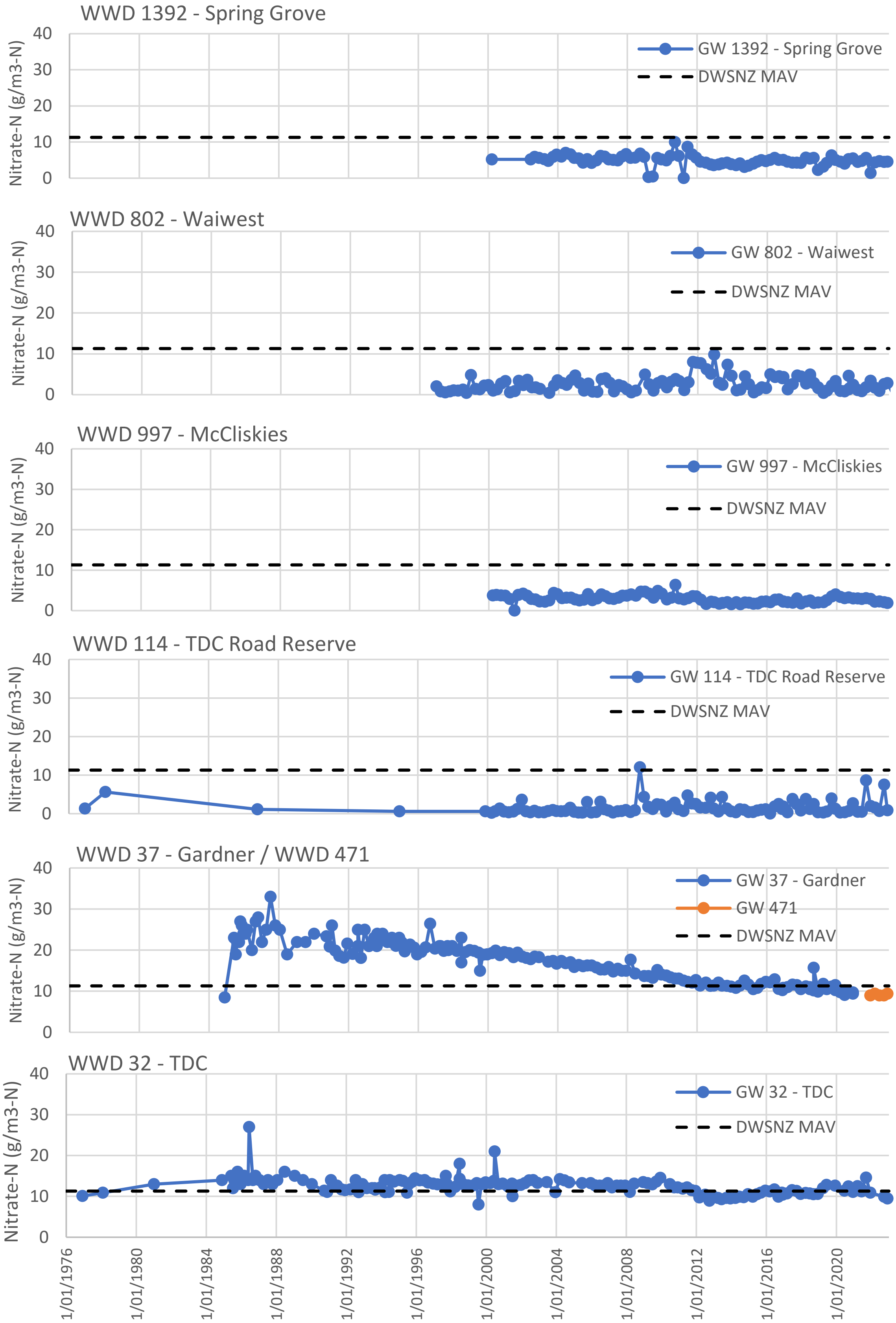

Figure 11: Measured groundwater nitrate-N concentrations over time in the Waimea Plains State of the Environment bores.

The three SoE bores from the AGUA all show low to medium nitrate-N concentrations (below the MAV). There appears to be no significant seasonal variation. From trend analysis, Spring Grove and McCliskies show a decreasing trend, with Waiwest showing an increasing trend. For all three SoE AGUA sites there is little variation from the mean throughout the years, suggesting that despite a strong trend (increasing or decreasing) resulting from the trend analysis, the actual movement of the trend from the mean is small. The average nitrate-N concentration for these bores are as follows:

Table 3: Mean nitrate-N concentration of the State of the Environment AGUA bores.

State of the Environment Bore (AGUA)	Mean nitrate-N concentration
WWD 802 - Waiwest	2.5 g/m^3-N
WWD 997 - McCliskies	2.9 g/m^3-N
WWD 1392 - Spring Grove	4.9 g/m^3-N

There are two SoE bores from the UCA (WWD 114 – TDC Roadside and WWD 37 – Gardner, now WWD 471). WWD 114 – TDC Roadside shows an increasing trend. The bore is semi-confined, receiving significant recharge from the overlying AGUA (A Fenemor, pers comms). WWD 37 – Gardner/WWD 471 shows a very strong decreasing trend of nitrate-N overtime. This bore is confined, with sampling in recent years showing the nitrate-N concentration to be at the MAV (or slightly below the MAV), compared to previously up to above 30 g/m^3-N. Nitrate-N concentrations at this site has little fluctuation from the general trend. This is due to the mixing of the multiple sources of nitrate-N and variable transit times for the recharge water to reach this confined part of the aquifer (Fenemor, 2020).

The SoE bore from the LCA (WWD 32 – TDC) shows a decreasing trend, with nitrate-N concentrations averaging at 12.6 g/m^3-N in recent years. As with the UCA, due to the confined nature of this aquifer, there is no seasonal fluctuation experienced at this bore.

Compared with the SoE bores, the monthly monitored bores provide greater temporal details highlighting nitrate-N changes to seasonal variation and rainfall pattern (see Figure 12) because of this connection to land surface activities.

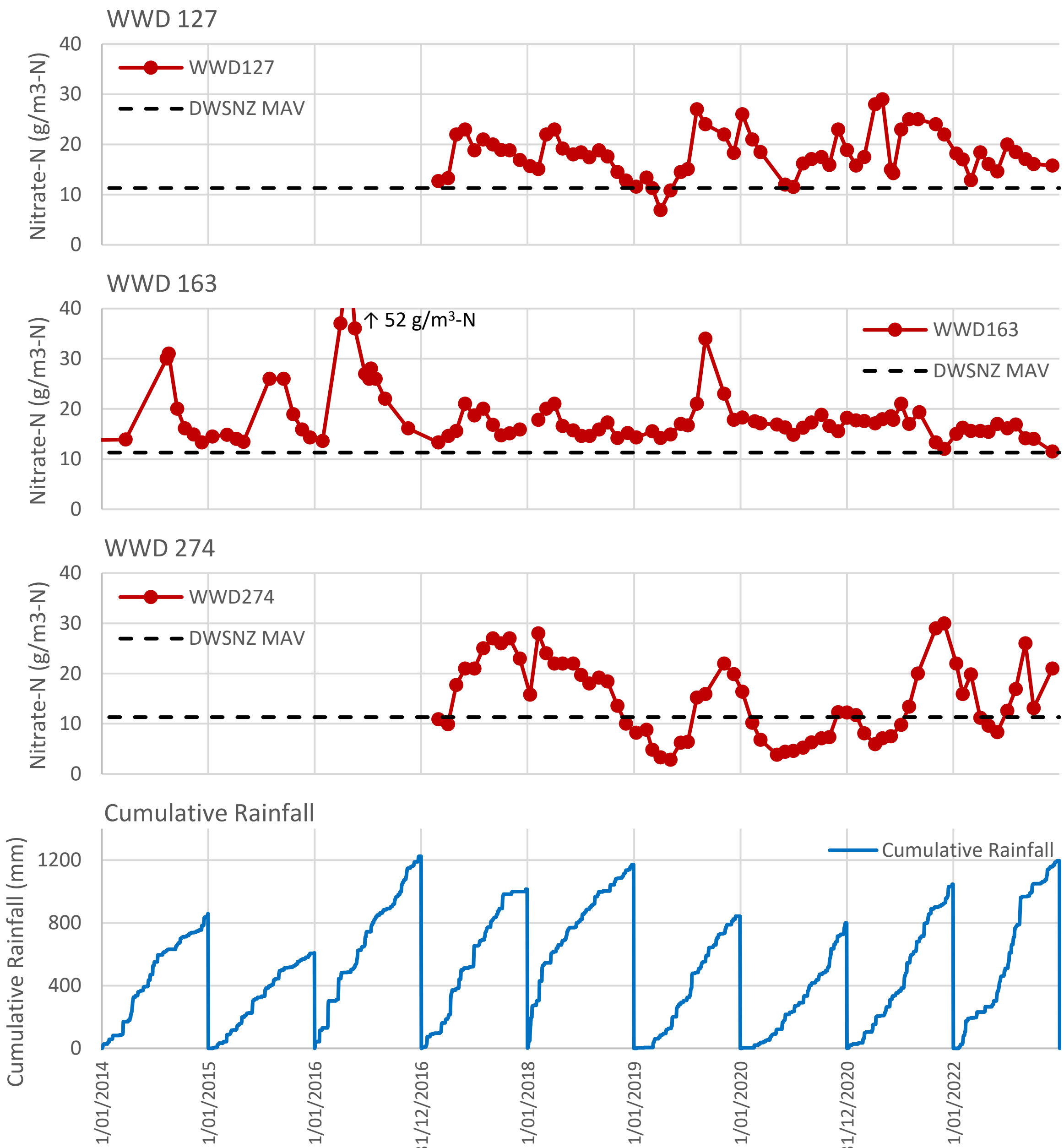

Figure 12: Measured groundwater nitrate-N concentrations over time in the Waimea Plains monthly monitored bores.

WWD 127 appears to be quite reactive to rainfall, suggesting leaching of nitrate-N from the surrounding land use is likely occurring after specific rainfall events. Comparing nitrate-N concentrations against daily rainfall at WWD 127 indicates that high volume/intensity rainfall events result in an increase in nitrate-N concentrations at the bore (see Appendix VI). Nitrate-N concentrations outside of the peaks remain elevated at around 10 g/m^3-N indicating that the there is a diffuse steady background in elevated nitrate-N inputs (possibly UCA discharge due to the locality of the bore and/or wider surrounding land use) occurring in the groundwater near WWD 127. This means water used from this area for irrigational purposes already has elevated nitrate-N concentrations, which then soaks into the ground and is abstracted back through the bore again in a process called recycling. A combination of recycling, and intensive horticultural and agricultural practices in the surrounding land throughout the years has resulted in loading of nitrate-N in the soil media. Waimea River dilution effects are likely being masked by leaching from surrounding land use.

WWD 163 shows the least seasonal variation and the least reactivity to rainfall events compared to the other monthly monitored bores. Nitrate-N concentrations do fluctuate more than would be typical for a bore in the UCA, with WWD 163 showing events of sharp increases of nitrate-N indicating that the bore is semi-confined. The nitrate-N tends to spike in winter months. However, nitrate-N concentrations outside of these peaks remain reasonably stable at around 16 g/m^3-N. This indicates that there is a fast flow path (preferential flow path, possibly a paleoriver channel), from a recharge area with high nitrate-N loading. Most of the time the bore discharges water from a deeper well-mixed groundwater. At times of high rainfall, shallower flow paths are activated which flush high nitrate-N water into the bore. WWD 163 is located in a well-established apple orchard. Nitrate-N application is strictly managed on-site as high nitrate-N affects fruit maturity and storage quality (Fenemor (2020) and D Easton, pers comm). This suggests that there is a component of diffuse steady elevated nitrate-N inputs (possibly UCA discharge due to the locality of the bore and/or wider surrounding land use) occurring in the groundwater at WWD 163.

WWD 274 appears to have the strongest seasonal variation, with nitrate-N concentrations increasing in late winter to peak in spring, then fall during summer to their lowest in autumn. WWD 274 is located close to the Waimea River and it is likely that this bore receives greater recharge from the Waimea River than the other two bores. During the summer months, the Waimea River (which has low nitrate-N) loses water to AGUA close to the river and thus the recharge waters received by WWD 274 is low in nitrate-N. During late winter to spring, there is usually an increase in rainfall and therefore WWD 274 likely receives a higher component of recharge from water that has soaked directly from overlying land use activities. This is similar to WWD 163, where shallower flow paths are activated in winter with flushing nitrate-N into the well. The underlying groundwater (discharged during drier periods when the shallow flow paths are not active) is river recharged, with low nitrate-N.

These monthly monitored bores show that nitrate-N between Bartlett Road and Blackbyre Road vary in concentration and can react significantly to changes in seasons and rainfall patterns. The data shows that nitrate-N concentrations sharply increase after leaching events (with a delay as the water soaks through the soil to enter the groundwater) and recover to background concentrations reasonably quickly. This is important as even though one sample from each site is taken every month, the nitrate-N result for each site may not be reflective of the highest nitrate-N concentration according to the nearby land use activities because the water is diluted by river water.

4.3 National Groundwater Pesticide, Glyphosate and Emerging Organic Contaminants Investigation

Since 1998, the Institute of Environmental Science and Research (ESR) has conducted a groundwater investigation sampling every four years for pesticides in bores across New Zealand. In 2018, ESR sampled for glyphosate (commonly known as 'RoundUp' or 'Drexel') and emerging organic contaminants (EOCs) for the first time, alongside the pesticide sampling. Seven bores in the Waimea Plains were sampled in 2018 as part of this investigation (Close & Humphries, 2019), see Figure 13.

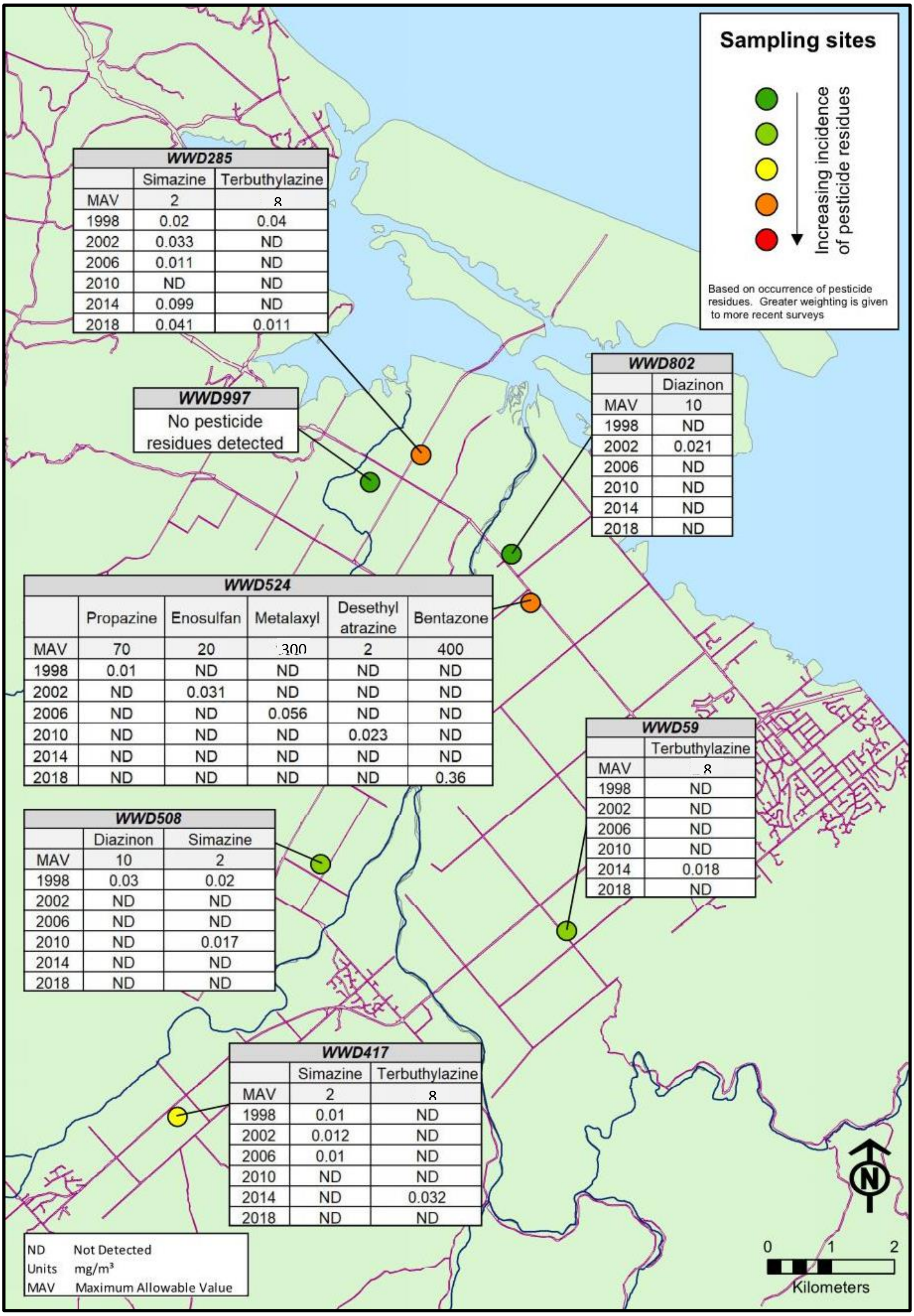

Figure 13: Combined pesticide results: ESR national groundwater pesticide survey (1998 to 2018).

ND means no detection. Measured in µg/L – this is equivalent to 0.000 000 001 g per litre (1 part per billion).

Two bores (out of the seven sampled in the Waimea Plains) had detections of pesticides in 2018: WWD524 (bentazone) and WWD285 (simazine and terbuthylazine). Bentazone, simazine and terbuthylazine are agrichemicals (AgriMedia, 2020) which are commonly used in the Waimea Plains. Bentazone is a selective post-emergence herbicide and used in a range of crops including grass seed crops, new pasture, onions, peas and potatoes (AgriMedia, 2020). Simazine is a selective pre-emergence herbicide used for weed control in orchards, vineyards and horticultural crops (AgriMedia, 2020). Terbuthylazine is a selective herbicide for grass and broadleaf weed control used in certain orchard crops, maize, sweetcorn and peas (AgriMedia, 2020).

Pesticide residue detections throughout the years do not exceed the MAV from the DWSNZ. All pesticide residues detected by ESR in 2018 were well below the maximum acceptable values in the DWSNZ.

In 2018, ESR also tested a selection of the bores for emerging organic contaminants (EOCs). EOCs are components or active ingredients in products that are commonly used by humans. WWD524 and WWD802 were selected for EOC sampling in the Waimea Plains. As this was the first time testing for EOCs, no comparisons to previous results can be made. WWD524 had two positive detections of EOCs: oxybenzone (ultraviolet filter/stabiliser) and sucralose (artificial sweetener). There was no EOCs detected in WWD802 at the time of sampling. The effects of EOCs are largely unknown and they do not have MAVs from the DWSNZ. As the compounds detected in WWD524 are in nanogram concentration (0.000 000 001 g), the EOCs are likely to be of low toxicity to humans. However, the impacts of EOCs in the environment and ecological systems are largely unknown.

ESR also tested for glyphosate (commonly known as RoundUp or Drexel) in a selection of bores for the first time in 2018. Glyphosate was not detected in any of the bores tested in the Tasman region (WWD524, WWD802 and WWD997 were tested from the Waimea Plains).

5 SURFACE WATER QUALITY

The major surface water recharge for the Waimea Plains aquifers are the rivers. It is important to monitor the river water quality as this is the baseline source for the groundwater quality. Figure 14The Wai-iti, Wairoa and Waimea rivers all provide significant recharge to the underlying aquifer system in the Waimea Plains. These three rivers, along with two spring fed streams, are monitored monthly as part of Councils State of the Environment river water quality monitoring programme. Seven additional surface water sites were sampled in 2021 as part of the synoptic survey (see Figure 14).

As for the groundwater sites, various chemical parameters for the surface water sites were tested, see Appendix I and II for the full suite of parameters tested for and the sampling methodology respectively. The surface water sites were analysed against a selection of attribute states in the National Policy Statement for Freshwater Management 2020 (Revised 2023) (NPSFM) (2020) for the protection of river ecosystem health. Appendix 1B Part 2 of the NPSFM requires the FMU or part of the FMU has "water quality and quantity [that] is sufficient for water to be taken and used for drinking water supply" (NPSFM, 2020). The results of the 2021 sampling were compared against the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 for the MAV parameters. Please refer to Appendix III to see the distribution of selected chemical parameters across the Waimea Plains.

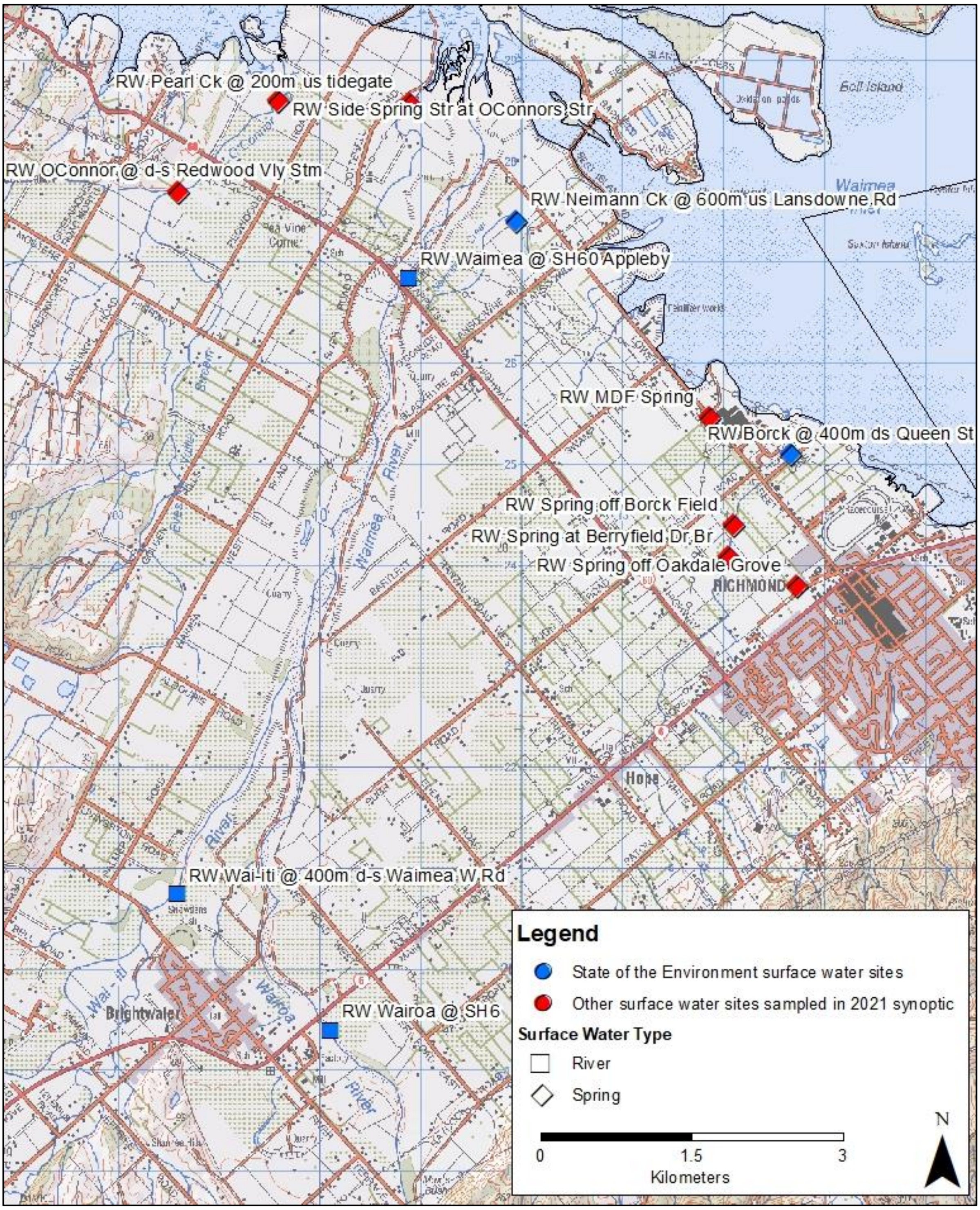

Figure 14: Rivers and spring-fed stream sites sampled in 2021 investigation.

Care is required in interpreting the results. Most of the NPSFM parameters require multiple samples to be taken throughout the year to determine the appropriate attribute state. For most of the synoptic survey springs, this was the first time that they have been sampled. The results are representative of the water quality that was present on the day and time that the sample was taken (can be thought of as a snapshot in time of the water quality). Water quality can vary seasonally due to a range of factors including changes in rainfall patterns (volume and intensity) and land use practices throughout the year. It is impossible to establish water quality state or trends from a single sample.

On average the surface water sampled in the 2021 survey was of good quality when compared to NPSFM attribute state values and the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 MAVs. Most of the rivers appear to have a water quality state for nitrate-N aligned with the NPSFM attribute state A[3]. The springs appear to have a lower water quality state, and aligned mostly with attribute state B and C. Most of the NPSFM attribute states require long term monitoring to produce annual median or annual 95th percentile results. For seven of the spring-fed sites involved in the 2021 survey, this was their first time being sampled so these sites did not have sufficient data to provide analysis for determining NPSFM attribute states. The three rivers and two spring-fed streams which are monitored monthly as part of Councils State of the Environment river water quality monitoring programme do have sufficient data to determine NPSFM attribute states.

The Waimea and Wairoa rivers have generally good water quality (NPSFM attribute state A for all parameters investigated which are in the NPSFM; James and McCallum, 2023).

The Wai-iti River has "likely degrading trends" identified for nitrate-N, dissolved reactive phosphorus and ammonia over the last five years, with nitrate-N in the NPSFM attribute state B. Nitrate-N was found to be increasing over the last five years at a rate of 0.136 g/m^3 per year. This is the highest rate of increase for surface water observed after Borck Creek for the Tasman Region (James and McCallum, 2023).

Borck Creek is a spring-fed creek which is quickly becoming urbanised in recent years. The creek has consistently high nutrient concentrations, low dissolved oxygen levels in summer and fine sediment deposits in the stream (James and McCallum, 2015, 2023). Isotopic analysis indicates that the source of nitrate-N in Borck Creek is a combination of effluent and fertiliser (Van der Raaij and Baisden, 2011). This is likely to have changed in recent years as the catchment has become urbanised and investigation work is underway. Both nitrate-N and ammonia concentrations seem to be higher in June and July

[3] Breakdown of the NPSFM attribute states for nitrate-N is below. Table reproduced from NPSFM (New Zealand Government, 2020)

Nitrate-N Attribute State	Annual Median	Annual 95th Percentile	Description
A	≤1.0 g/m^3-N	≤1.5 g/m^3-N	High conservation value system. Unlikely to be effects even on sensitive species.
B	>1.0 to ≤2.4 g/m^3-N	>1.5 to ≤3.5 g/m^3-N	Some growth effect on up to 5% of species.
National Bottom Line	**2.4** g/m^3-N	**3.5** g/m^3-N	**National Bottom Line**
C	>2.4 to ≤6.9 g/m^3-N	>3.5 to ≤9.8 g/m^3-N	Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects.
D	>6.9 g/m^3-N	>9.8 g/m^3-N	Impacts on growth of multiple species, and starts approaching acute impact level (that is, risk of death) for sensitive species at higher concentrations (> 20 g/m^3-N).

which is consistent with the time of year when plant uptake is the least. James and McCallum (2023) suggest this could be due to the growing of winter crops on Ranzau soils.

Neimann Creek is a spring-fed creek with similar issues to Borck Creek. Neimann Creek has high nutrient concentrations, low daily minimum dissolved oxygen and excessive fine sediment deposits in the stream bed (James and McCallum, 2015). Nitrate-N concentrations have been improving in the last five years (trend rate of -0.58 g/m^3 per year), with nutrient concentrations not changing much with increases in flow. Dissolved reactive phosphorus is much lower in spring and summer, which could be due to aquatic plant uptake. E.coli is in the NPSFM attribute band E, with concentrations highest in November and December and lowest during winter. E.coli does not survive long in groundwater so the source of contamination is likely to be close by. The source of E.coli could be from pukeko, which nest along the waterway and breed during November and December.

The prolific growth of aquatic plants in the spring-fed streams in the Waimea Plains result in very low summertime dissolved oxygen concentrations and high levels of organic-rich sediment on the bed. The spring-fed streams are likely to be limited by phosphorus rather than nitrogen based on the ratios of nitrogen to phosphorus. They conclude that increases in nitrogen concentrations is unlikely to result in increased growth or biomass of nuisance algae within the spring-fed streams. However, it can be difficult to predict if one particular nutrient is limiting.

Water in the spring fed creeks is hard, which means that the impact of nitrate toxicity experienced by the ecosystems in the spring fed creeks is lessened (Hickey, 2015) but the current levels still exceed the NPSFM ecosystem criteria. The spring-fed streams have high nitrate concentrations as the source water is from groundwater in the Waimea Plains. With the long residence time in the groundwater system, these sites are unlikely to recover anytime soon. If action was taken immediately to reduce nitrate inputs into the springs, it could still take up to 15 to 20 years before nitrate concentrations reduce to acceptable levels (James and McCallum, 2023).

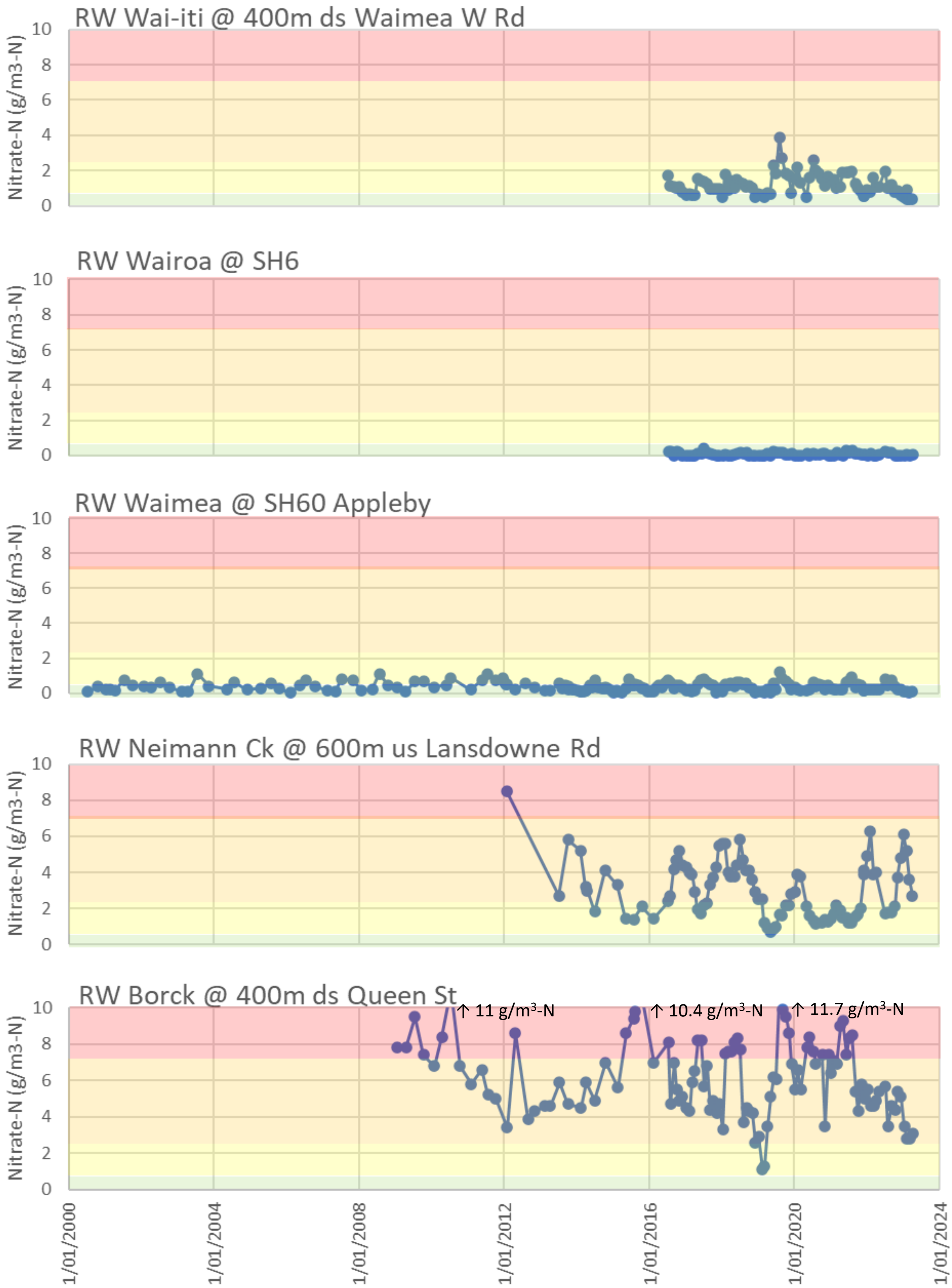

Figure 15: Measured surface water nitrate-N concentrations over time in the Waimea Plains State of the Environment surface water sites.

Green, yellow, orange and red colour highlights NPSFM attribute states from A to D, in increasing order.

6 DISCUSSION

Elevated nitrate-N concentrations have been measured in the Waimea Plains since at least the 1970’s, though isotopic data suggests that the initial nitrate-N contamination in the UCA and LCA could date back as far as the 1940s (Stewart et al, 2011; Stewart, 2011). An intensive piggery operation located between Haycock Road/Aniseed Valley Road (recharge area for the HU, UCA and LCA) is thought to be a major contributor to historic nitrate-N contamination in the HU, UCA and LCA. The piggery closed in the mid-1980’s. As pig effluent is highly mineralizable (Eghball et al, 2002), effluent resulting from the piggery operation should have substantially degraded over time (Fenemor, 2020).

The first published evidence of elevated nitrate-N concentrations in the groundwater of the Waimea Plains was reported by Stanton and Martin (1975) and Spencer (1981). Elevated nitrate-N concentrations were found at many wells in the shallower groundwater between Aniseed Valley Road/Main Road Hope/Ranzau Road, suggesting that the source of elevated nitrate-N was not solely linked to the historic piggery operation. Stanton et al and Spencer summarised that the relatively slow throughflow of each aquifer had allowed nitrate-N concentrations to gradually increase, creating plumes of contamination to extend out from the source areas in a northerly direction.

Tasman District Council has undertaken several comprehensive synoptic surveys in the Waimea Plains to monitor the plume of nitrate-N through all four aquifer systems. The most recent sampling investigation was in spring 2021. Of the 137 bores/wells sampled in the Waimea Plains, 56 sites had nitrate-N below 50% of the MAV (below 5.6 g/m^3-N), 42 sites were between 50% of the MAV and the MAV (between 5.6 and 11.3 g/m^3-N), and 39 sites were above the MAV (above 11.3 g/m^3-N).

The highest nitrate-N concentrations in 2021 were found at the intersection of Bartlett Road/Ranzau Road West (31 g/m^3-N) and along Blackbyre Road (30 g/m^3-N). All bores/wells sampled between these two locations exceeded the MAV for nitrate-N (11.3 g/m^3-N). The area between Bartlett Road and State Highway 60 is where the UCA and the AGUA merges together and becomes hydraulically indistinguishable. Any discharge of nitrate-N from the UCA would be noticed here and would be contributing to the elevated nitrate-N concentrations at the Bartlett Road/Ranzau Road West intersection. Blackbyre Road is outside of the UCA reach, however water from Bartlett Road is likely to travel towards Blackbyre Road as the flow of groundwater progresses towards the coast. Trend analysis shows that nitrate-N is strongly increasing in this area.

Discharge of the historic piggery nitrate-N contamination from the UCA to the AGUA in the area between Bartlett Road to State Highway 60 is estimated to be between 11 to 16 g/m^3-N (based off the background concentrations measured at the monthly and SoE monitoring bores in the area). As this area is unconfined, additional inputs of nitrate-N from overlying land use activities between Bartlett Road and Blackbyre Road adds to the background nitrate-N discharging from the UCA, resulting in the elevated nitrate-N concentrations reaching well above 20 g/m^3-N. In the southern extent of the historic piggery plume, trend analysis shows a strong decreasing trend, indicating that nitrate-N originating from the historic contamination in the UCA and overlying HU is decreasing overtime.

The monthly monitored bores (which are located between Bartlett Road and Blackbyre Road) show that nitrate-N in this area varies in concentration and can respond quickly to seasonality and rainfall patterns. Nitrate-N concentrations are expected to be highest during spring months due to this season usually having more frequent and intensive rainfall events that correspond in leaching. The monthly monitored sites show that nitrate-N concentrations increase rapidly after leaching events and recover to background concentrations reasonably quickly. This is important as even though the nitrate-N sample taken from each site for the 2021 synoptic investigation was during spring, the nitrate-N result for each site may not be the reflective of the highest nitrate-N concentration experienced at these sites.

Unconfined groundwater south of Brightwater shows a very strong deceasing trend of nitrate-N, with the majority of sites samples being well below 50% of the MAV (5.6 g/m^3-N). North of Brightwater on both sides of the Waimea River, nitrate-N was near or above 50% of the MAV. East of the Waimea River and east of Burkes Bank, the majority of all four aquifers were near or above the MAV. West of the Waimea River, bores/wells in the AGUA along Cotterell Road/Moutere Highway/River Road/Waimea West Road were also near or above 50% of the MAV. Trend analysis on the western side of the Waimea River shows an indeterminate increasing trend of nitrate-N in this area. It was expected for these areas to have higher concentrations of nitrate-N due to the overlying horticultural and agricultural activities. The large number of samples where nitrate-N concentrations are near/above 50% of the MAV across the main horticultural and agricultural areas on the Plains clearly demonstrate that there is a combined input from present-day activities which are contributing to nitrate-N entering in the groundwater in all four aquifers.

Apart from nitrate-N concentrations, groundwater in the Waimea Plains is of good quality with regards to other water chemistry attributes. The 2021 survey found the majority of the chemical parameters for groundwater were well below the MAV and AV. Spring-fed streams varied in quality, and had higher nitrate-N compared with the rivers. Borck Creek ranges on average between 4.6 and 7.6 g/m^3-N (NPSFM Attribute State C and D for nitrate-N), with the highest value in the last 12 months for this site of 5.7 g/m^3-N in July 2022. Neimann Creek ranges on average between 1.7 and 4.1 g/m^3-N (NPSFM Attribute State B or C for nitrate-N), with the highest value in the last 12 months for this site of 6.1 g/m^3-N in January 2023. The hard water in these spring-fed environments reduces the nitrate toxicity experienced by their ecosystems, nevertheless these nitrate concentrations exceed the NPSFM ecosystem criteria (Hickey, 2015). River water quality (main source of recharge for the AGUA) is also of good quality, with nitrate-N concentrations averaging under 1.5 g/m^3-N (NPFSM Attribute State A and B).

Groundwater in the majority of the Waimea Plains have dissolved oxygen above 50%. Coastally, on the eastern side of the Waimea River (between Lower Queen Street and State Highway 60) groundwater in the AGUA has low dissolved oxygen (less than 50%). The LCA (from Lower Queen Street and extending into the Waimea Estuary) also has low dissolved oxygen. Iron and manganese mineralisation is common in waters with low dissolved oxygen, if these ions are present in elevated concentrations then reducing conditions may be occurring. Under reducing conditions, nitrate-N concentrations are typically low as the nitrate (NO_3) is converted into nitrogen gas (N_2). Iron and manganese were not detected in high concentrations in these lower dissolved oxygenated areas of the AGUA and LCA. This suggests that conditions are not completely reducing, meaning nitrates in the aquifer systems are most likely to be in the form of nitrate-N.

All pesticide residues detected by ESR in 2018 (out of the seven bores that were sampled) were well below the MAV in the DWSNZ. ESR detected EOCs at one bore in the Waimea Plains; the effects of those EOCs are largely unknown and do not have MAVs from the DWSNZ. However, as the EOCs detected were at nanogram concentration (0.000 000 001 g), the EOCs are likely to be of low toxicity to humans. No glyphosate was detected in any of the selected Tasman region bores.

The 2021 water quality investigation did identify various risks to the security of the groundwater source which could have risks to public health. These include inappropriate sitting of bores/wells and bore/well heads not fully sealed. In most instances these were not intentional but more a lack of knowledge from the bore/well landowners.

Localised contamination of E.coli was common in the shallow groundwater sites, both inland and coastal sites. E.coli contamination is likely occurring due to inappropriate bore/well siting where the bore/well was in close proximity with activities involving faecal matter (e.g. runoff from milking sheds or seepage from septic tanks). Poor bore/well head protection where the bore/well head was not sealed could also be a pathway for contamination to enter into the aquifer.

Most of the groundwater abstracted from deeper in the aquifer (bores deeper than 10 m below ground level or accessing confined groundwater) did not have detections of E.coli at the time of sampling. The majority of the deep bores had good bore head protection and were appropriately sited away from potential contamination sources.

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APPENDIX I Groundwater and surface water sampling methodology

Groundwater sampling methodology:

Each sample was taken directly from the sampling tap or pump outlet. The supply was left to run either from an existing pump or a portable pump, via a hose or directly to the ground, for a minimum duration of five but preferably up to 10 minutes for the shallow sites. Deeper groundwater sites were pumped for a minimum of three full purge volumes. Using a YSI ProDSS, conductivity, dissolved oxygen and temperature (and if possible, pH and oxydo-reduction potential) were measured by filling (and overflowing) a bucket so the probes received constant flow over the sensors.

After pumping, the sampling tap/outlet was cleaned using a paper towel sprayed with methylated spirits, followed by disinfection using flame (where possible). The tap/outlet was then run for a few seconds to allow any water impacted by the cleaning process to flush out. The water sample was filled directly into the bottles from the tap/outlet. Unpreserved bottles were filled directly to the top of the bottle. Preserved bottles were filled to 1 cm below the rim of the bottle so none of the preservative which coated the inside of the bottle was lost by overfilling for spilling.

The filled bottles were then labelled and bagged to keep all the bottles from each site together. Once bagged, the samples were placed in a chilly bin, kept cool with ice packs and couriered overnight to Hill Laboratories. Samples which required filtering for analysis were filtered by Hill Laboratories directly.

River and spring sampling methodology:

The river and spring samples were taken using a simple grab method, where the sample bottles and lid were dipped into the water until they were filled. The lid was screwed underwater to avoid any surface water scum entering the sample. The field measurements were taken by dipping the probes into the main flow of the water.

Each groundwater and surface water site had three bottles which required filling.

Table 4: Sample bottle treatments

Bottle	Material	Preservative
Groundwater site		
1 x 500 mL (UP500)	Polyethylene	None
1 x 100 mL (NWU100)	Polyethylene	None
1 x 400 mL (SterThio)	PET container, PP lid	$Na_2S_2O_3$
Surface Water site		
1 x 500 mL (UP500)	Polyethylene	None
1 x 100 mL (NWU100)	Polyethylene	None
1 x 400 mL (SterThio)	PET container, PP lid	None

APPENDIX II Water quality parameters and sample bottle treatments

All 137 groundwater sites were analysed for the following parameters:

- Escherichia coli
- Nitrite-N
- Nitrate-N
- Total Coliforms

38 groundwater sites and all 12 river/spring-fed stream sites were tested for the above parameters as well as a comprehensive water chemistry suite:

- Acidity
- Bromide
- Chloride
- Dissolved Calcium
- Dissolved Iron
- Dissolved Magnesium
- Dissolved Manganese
- Dissolved Potassium
- Dissolved Reactive Phosphorus
- Dissolved Sodium
- Electrical Conductivity
- Free Carbon Dioxide
- Fluoride
- Reactive Silica
- Sulphate
- Total Alkalinity
- Total Ammonical-N
- Total Hardness

The summary of methods is provided by Hill Laboratories.

The following table gives a brief description of the methods that will be used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses will be performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Table 5: Hill Laboratory summary of methods

Test	Method Description	Default Detection Limit
Total anions for anion/cation balance check	Calculation: sum of anions as mEquiv/L calculated from Alkalinity (bicarbonate), Chloride and Sulphate. Nitrate-N, Nitrite-N. Fluoride, Dissolved Reactive Phosphorus and Cyanide also included in calculation if available. APHA 1030 E 23rd ed. 2017.	0.07 meq/L
Total cations for anion/cation balance check	Sum of cations as mEquiv/L calculated from Sodium, Potassium, Calcium and Magnesium. Iron, Manganese, Aluminium, Zinc, Copper, Lithium, Total Ammoniacal-N and pH (H^+) also included in calculation if available. APHA 1030 E 23rd ed. 2017.	0.05 meq/L
% Difference in Ion Balance	Calculation from Sum of Anions and Cations. Please note: The result reported for the '% Difference in Ion Balance' is an absolute difference between the 'Sum of Anions' and 'Sum of Cations' based on the formula taken from APHA. This does not indicate whether the 'Sum of Anions' or the 'Sum of Cations' produced a higher value. APHA 1030 E 23rd ed. 2017.	0.10 %
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 4500-H^+ B 23rd ed. 2017. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units
Total Acidity (pH 8.3)	Titration to pH 8.3 with standard sodium hydroxide solution, phenolphthalein indicator. APHA 2310 B 23rd ed. 2017.	1.0 g/m^3 as $CaCO_3$
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2320 B (modified for Alkalinity <20) 23rd ed. 2017.	1.0 g/m^3 as $CaCO_3$
Free Carbon Dioxide	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO_2 D 23rd ed. 2017.	1.0 g/m^3 at 25°C
Total Hardness	Calculation from Calcium and Magnesium. APHA 2340 B 23rd ed. 2017.	1.0 g/m^3 as CaCO3
Electrical Conductivity (EC)	Conductivity meter, 25°C. Analysed at Hill Laboratories - Chemistry; 101C Waterloo Road, Christchurch. APHA 2510 B 23rd ed. 2017.	1 µS/cm
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.02 g/m^3
Dissolved Manganese	Filtered sample, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.0005 g/m^3
Bromide	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.05 g/m^3
Chloride	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3
Fluoride	Direct measurement, ion selective electrode. APHA 4500-F^- C 23rd ed. 2017.	0.05 g/m^3

Total Ammoniacal-N Trace	Phenol/hypochlorite colorimetry. Flow injection analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500-NH_3 H 23rd ed. 2017.	0.005 g/m_3
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_{3-} I (modified) 23rd ed. 2017.	0.002 g/m_3
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House	0.0010 g/m_3
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_{3-} I (modified) 23rd ed. 2017.	0.002 g/m_3
Dissolved Reactive Phosphorus (trace)	Filtered sample. Molybdenum blue colorimetry. Flow injection analyser. APHA 4500-P G 23rd ed. 2017.	0.0010 g/m_3
Reactive Silica	Filtered sample. Heteropoly blue colorimetry. Flow Injection Analyser. APHA 4500-SiO2 F (modified) 23rd ed. 2017.	0.10 g/m_3 as SiO_2
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m_3
Total Coliforms	MPN count using Colilert (Incubated at 35°C for 24 hours), or Colilert 18 (Incubated at 35°C for 18 hours). Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9223 B 23rd ed. 2017.	1 MPN / 100mL
Escherichia coli	MPN count using Colilert (Incubated at 35°C for 24 hours), or Colilert 18 (Incubated at 35°C for 18 hours), Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9223 B 23rd ed. 2017.	1 MPN / 100mL

APPENDIX III Distribution of selected chemical parameters across the Waimea Plains

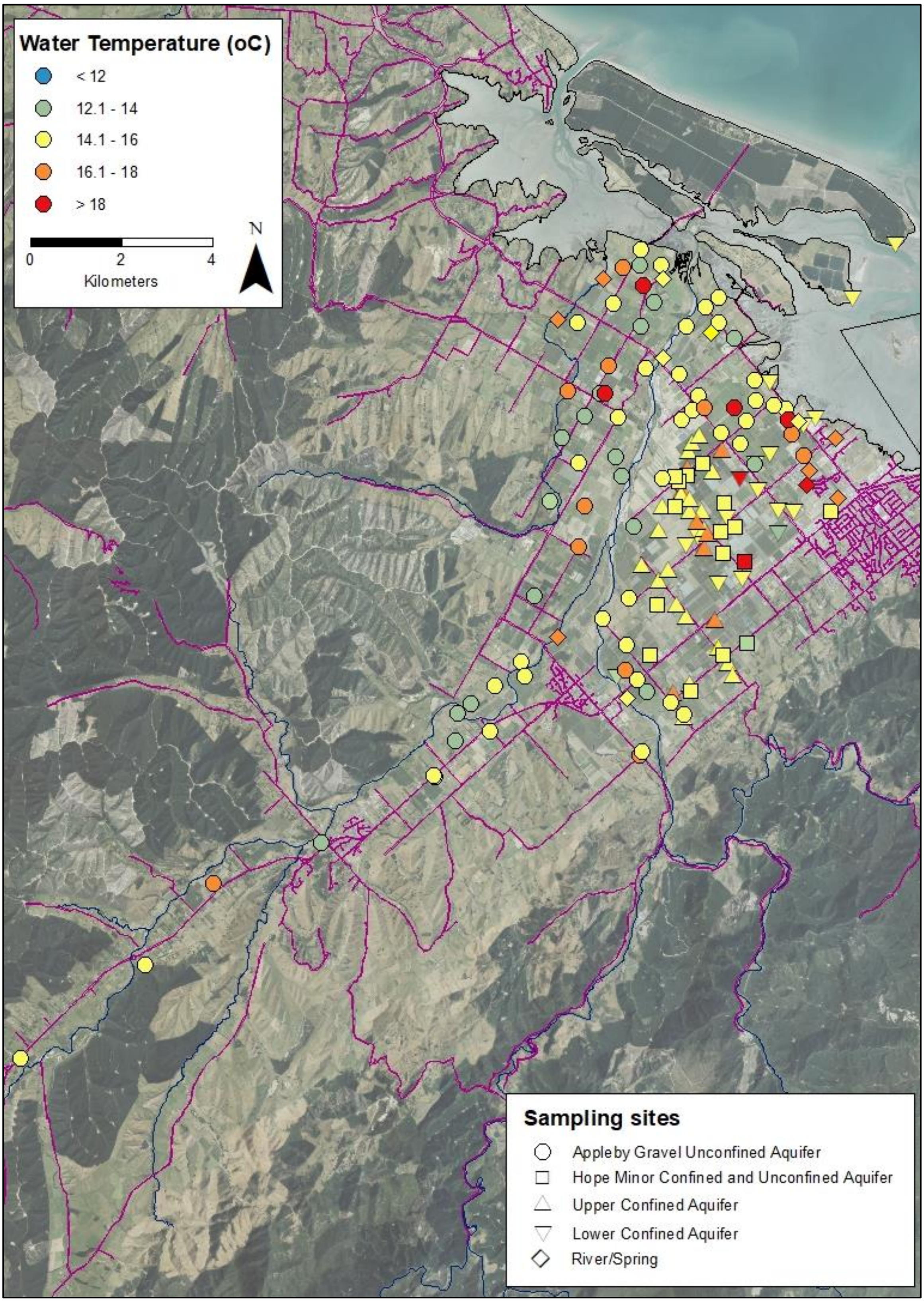


Figure 16: Distribution of temperature across the Waimea Plains from 2021 survey.

There is no MAV from the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 or AV from the Aesthetic Values for Drinking Water Notice 2022 for temperature.

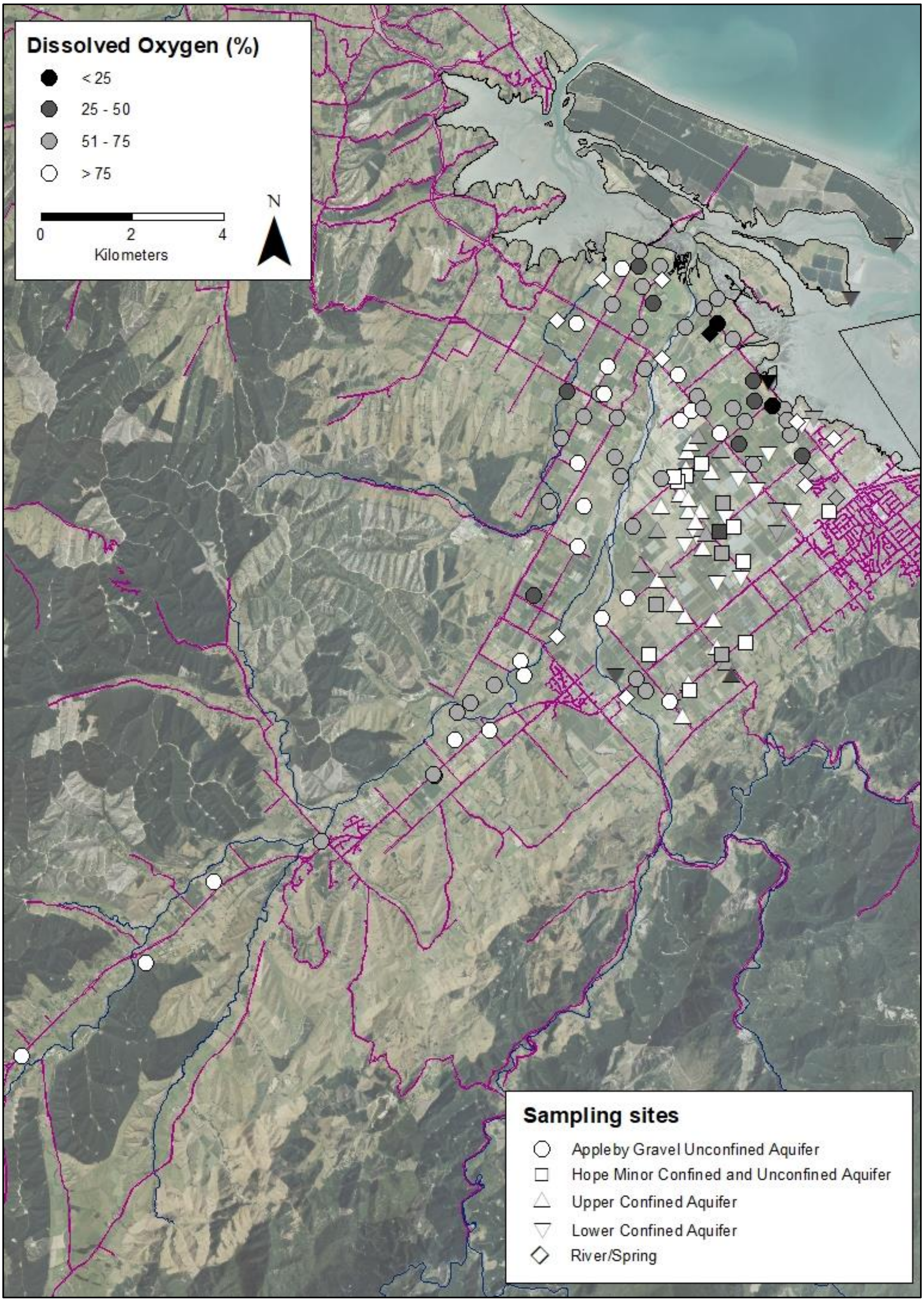


Figure 17: Distribution of dissolved oxygen across the Waimea Plains from 2021 survey.

There is no MAV from the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 or AV from the Aesthetic Values for Drinking Water Notice 2022 for dissolved oxygen.

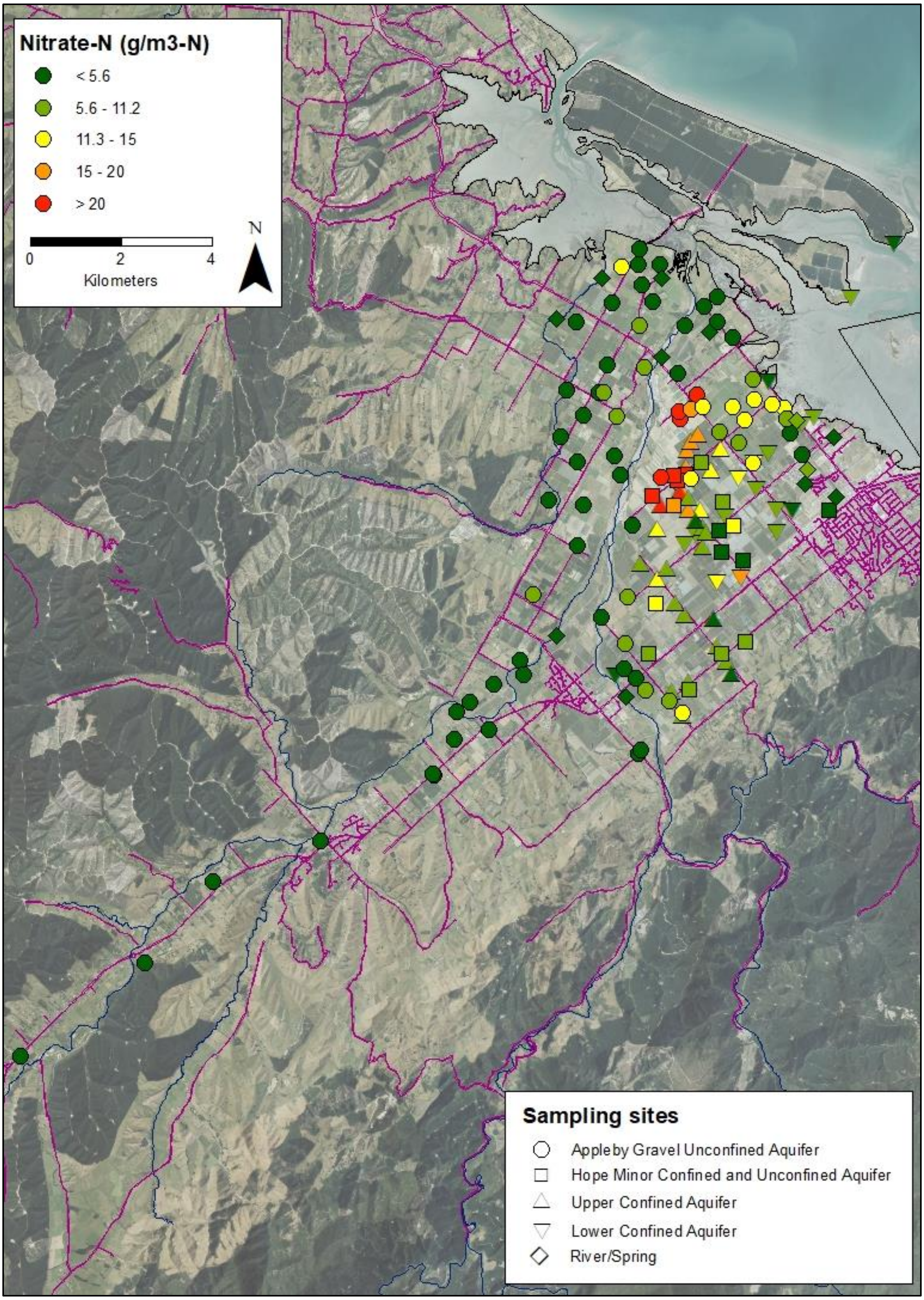


Figure 18: Distribution of nitrate-N across the Waimea Plains from 2021 survey.

The MAV from the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 for nitrate-N is 11.3 g/m^3-N. Yellow, orange and red highlights concentrations measured above the MAV, in increasing order.

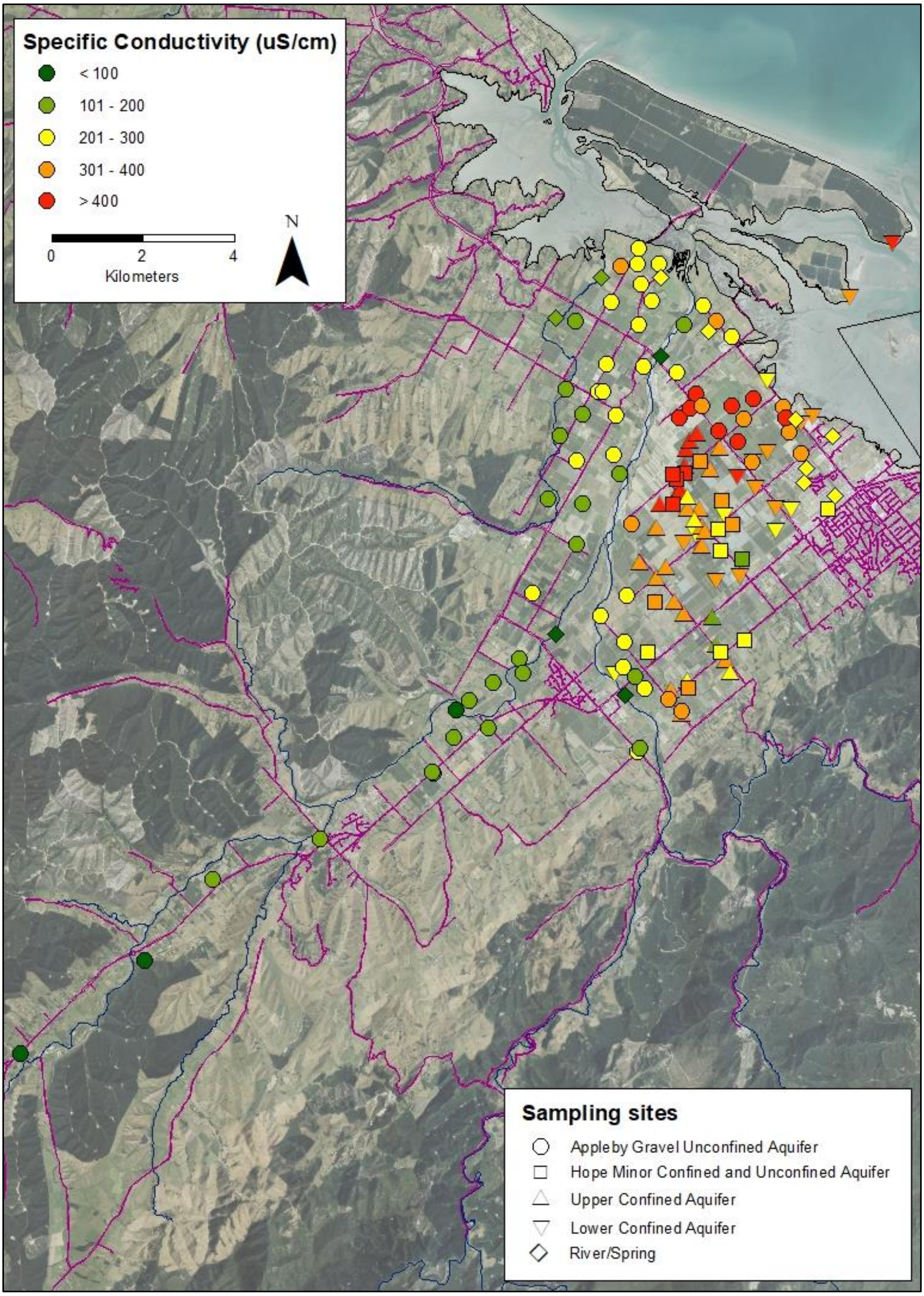


Figure 19: Distribution of conductivity across the Waimea Plains from 2021 survey.

There is no MAV from the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 or AV from the Aesthetic Values for Drinking Water Notice 2022 for conductivity.

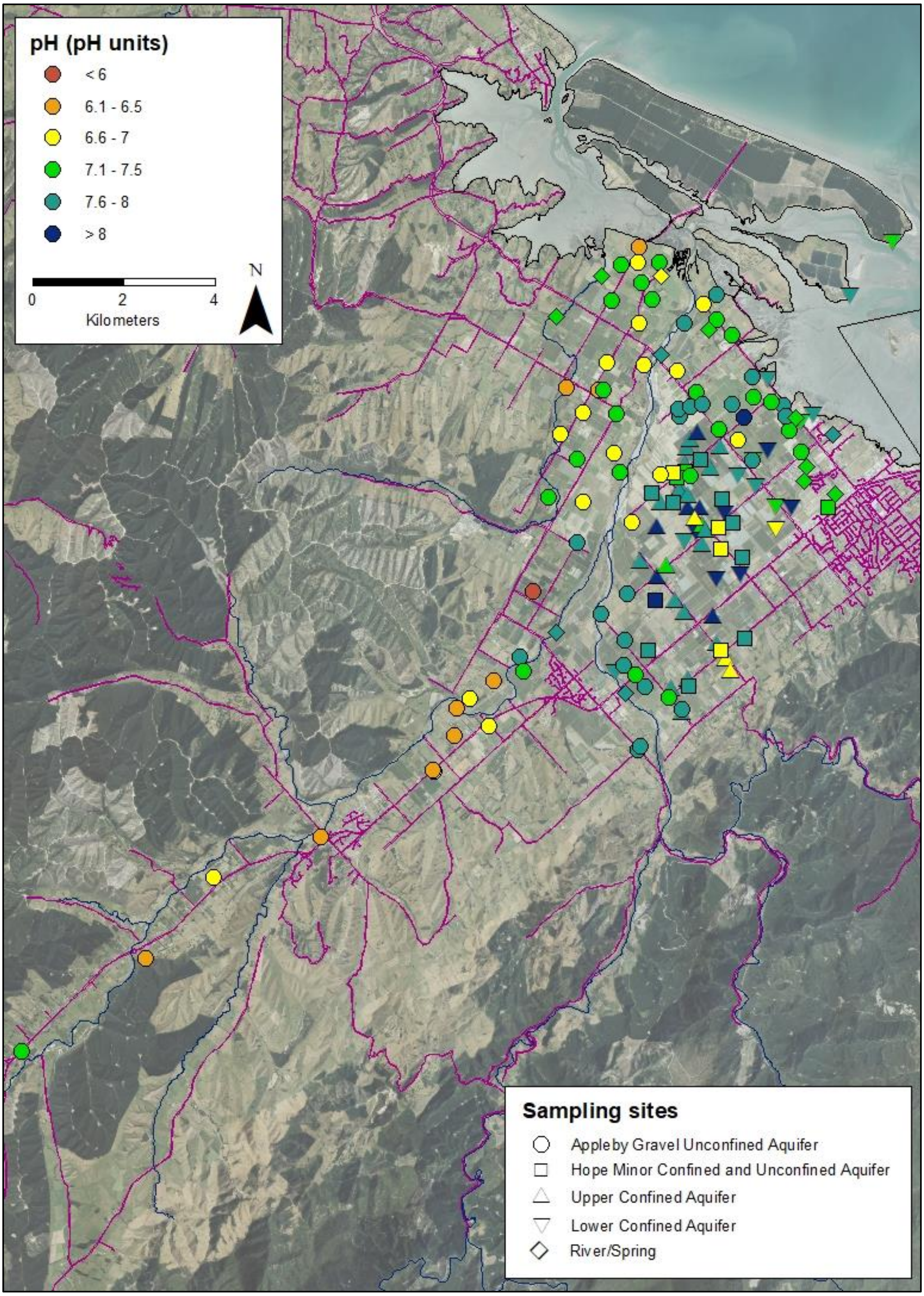


Figure 20: Distribution of pH across the Waimea Plains from 2021 survey.

The AV from the Aesthetic Values for Drinking Water Notice 2022 for pH is between 7.0 and 8.5 pH units.

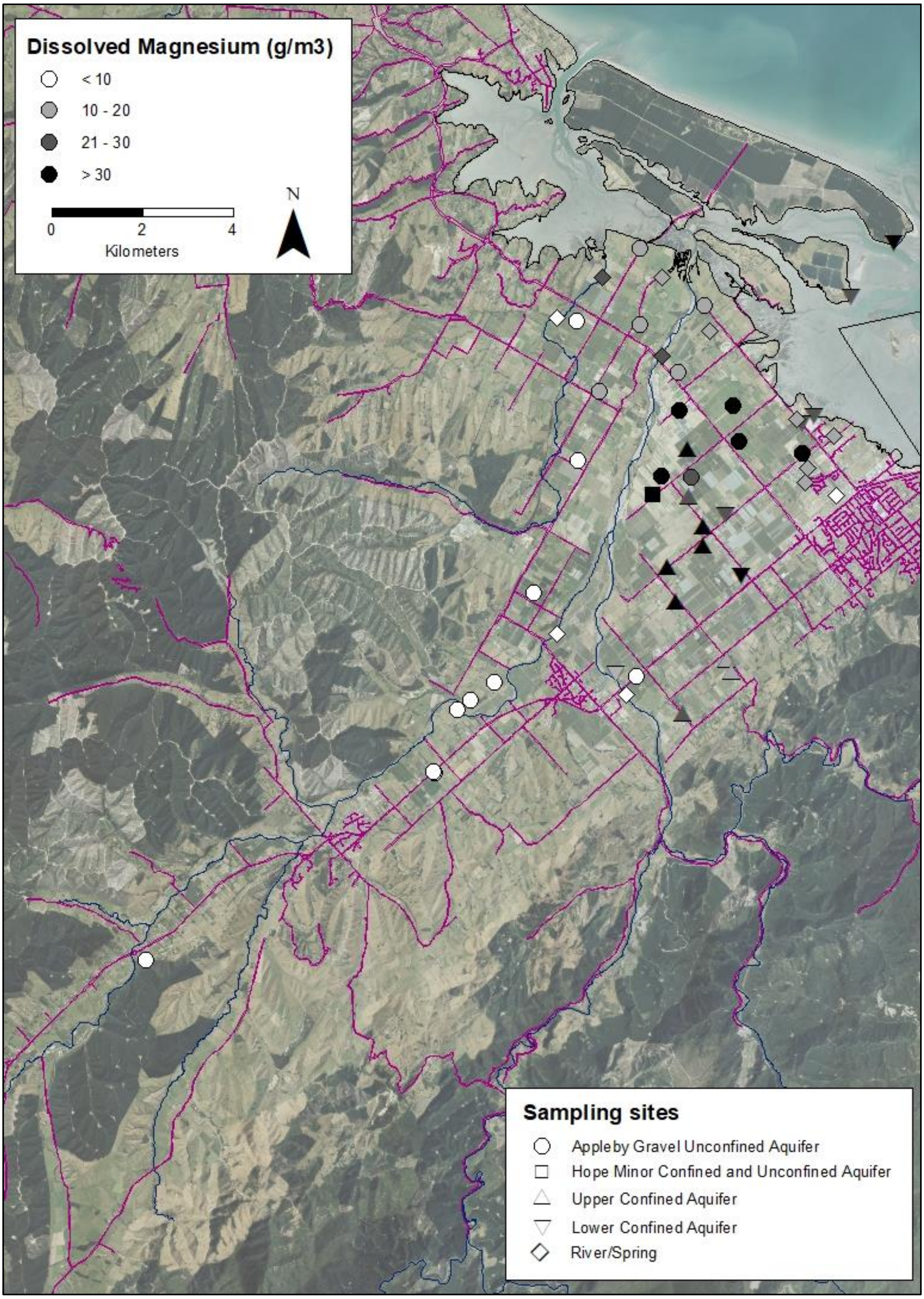


Figure 21: Distribution of dissolved magnesium across the Waimea Plains from 2021 survey.

There is no MAV from the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 or AV from the Aesthetic Values for Drinking Water Notice 2022 for dissolved magnesium.

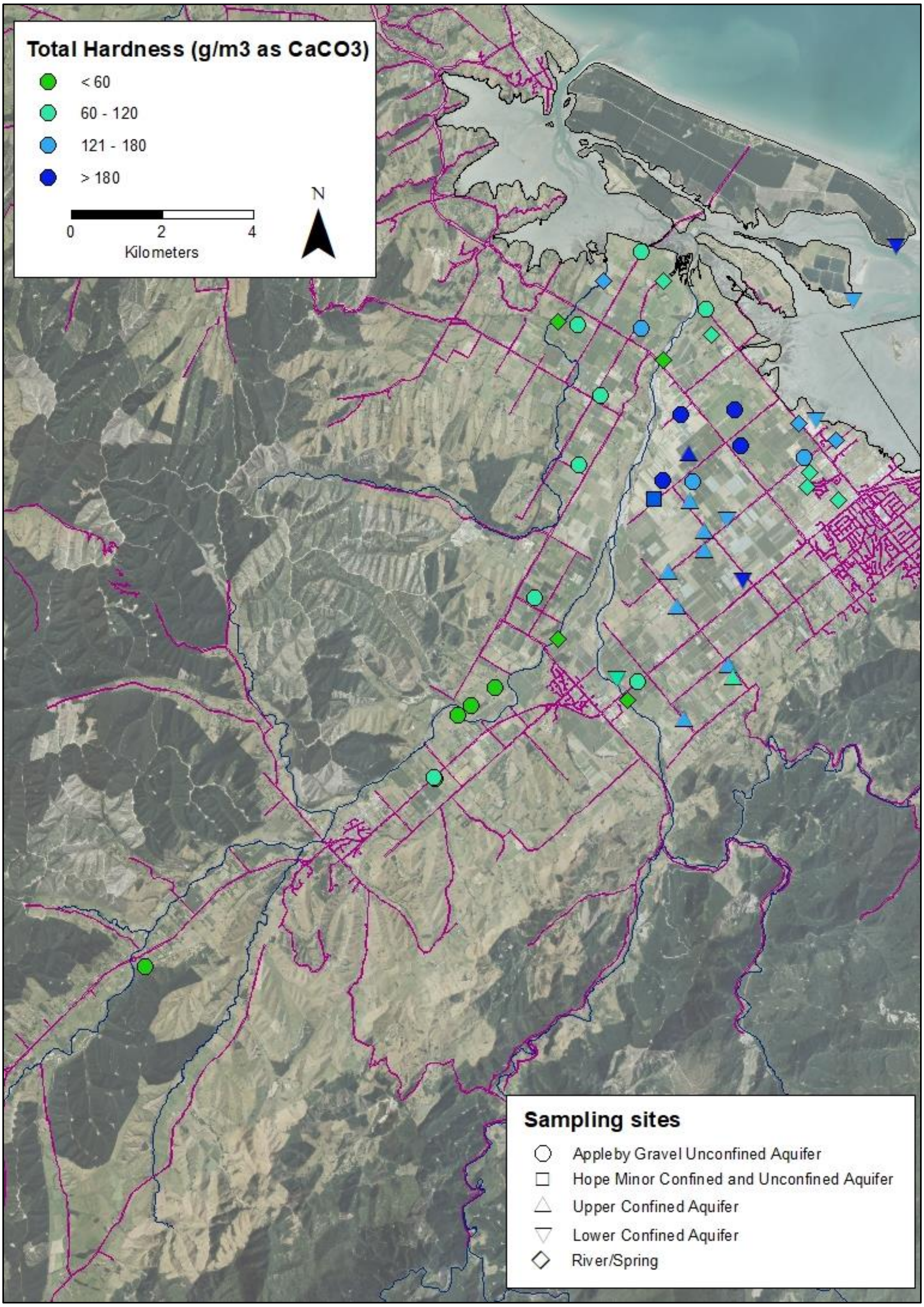


Figure 22: Distribution of total hardness across the Waimea Plains from 2021 survey.

The AV from the Aesthetic Values for Drinking Water Notice 2022 for hardness is 200 g/m^3 as $CaCO_3$. Taste threshold is 100 – 300 g/m^3 as $CaCO_3$.

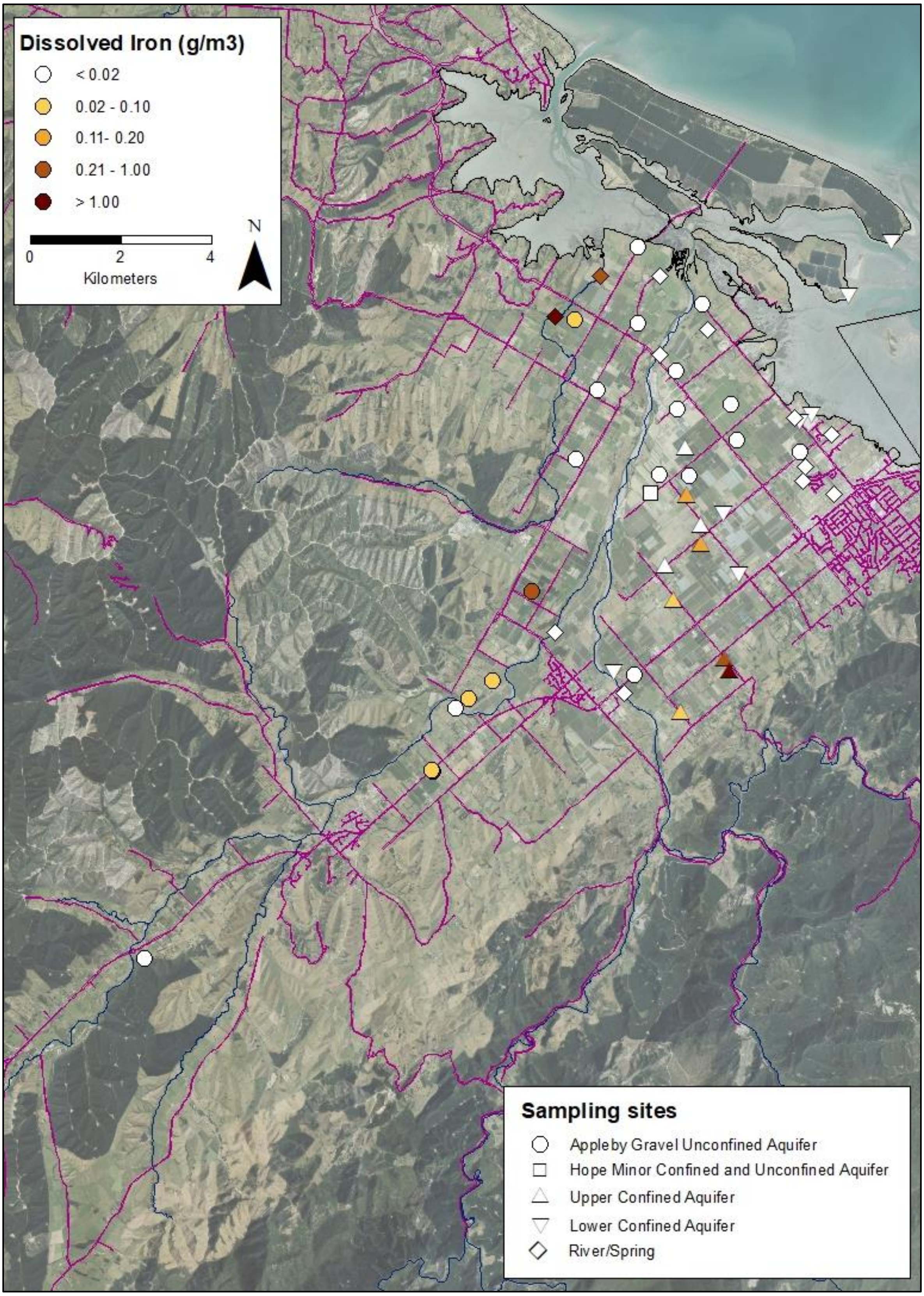


Figure 23: Distribution of dissolved iron across the Waimea Plains from 2021 survey.

The AV from the Aesthetic Values for Drinking Water Notice 2022 for iron is 0.30 g/m^3.

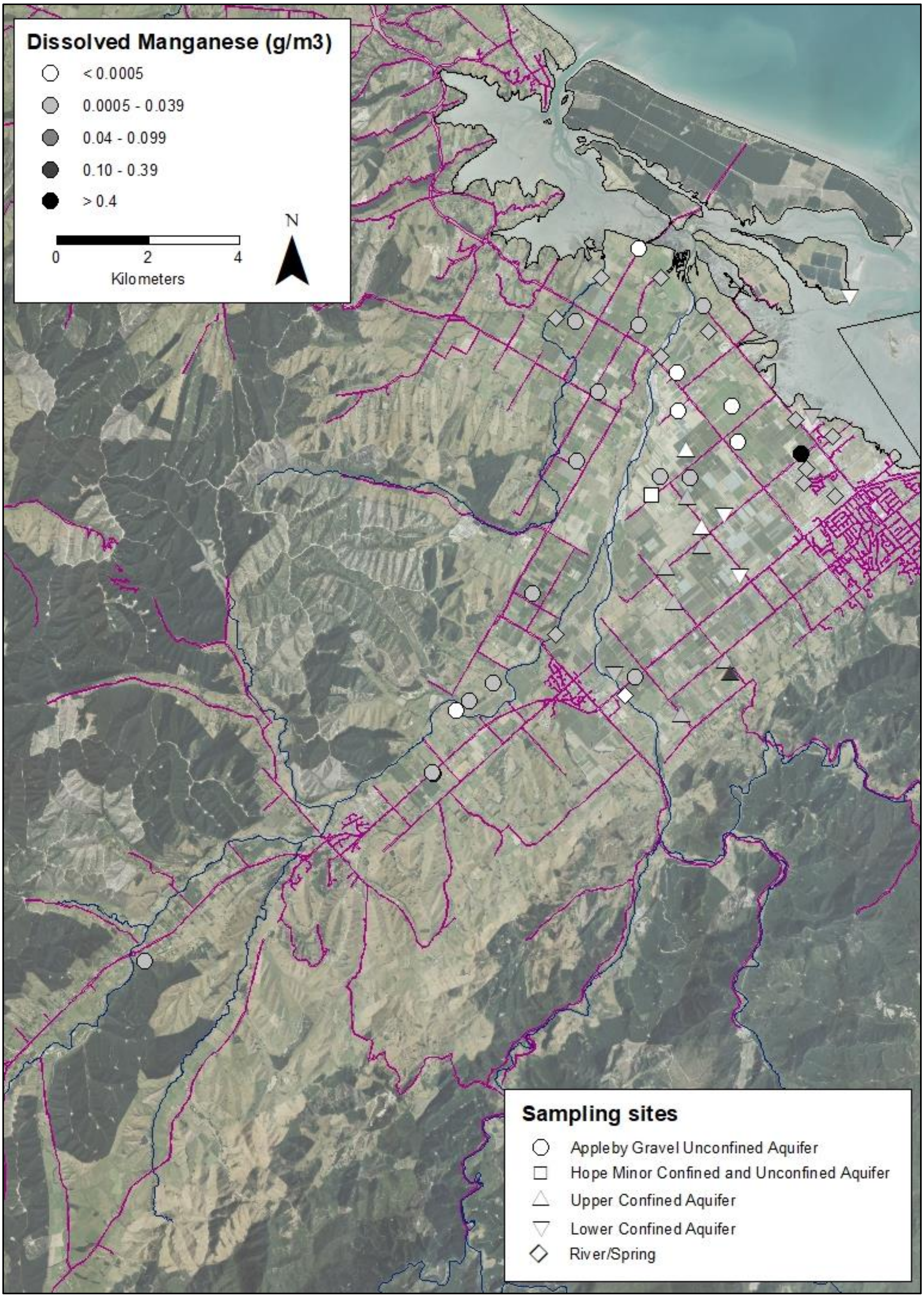


Figure 24: Distribution of dissolved manganese across the Waimea Plains from 2021 survey.

The MAV from the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 for manganese is 0.4 g/m^3. The AV from the Aesthetic Values for Drinking Water Notice 2022 for manganese is 0.04 g/m^3 (staining of laundry), 0.10 g/m^3 (taste threshold).

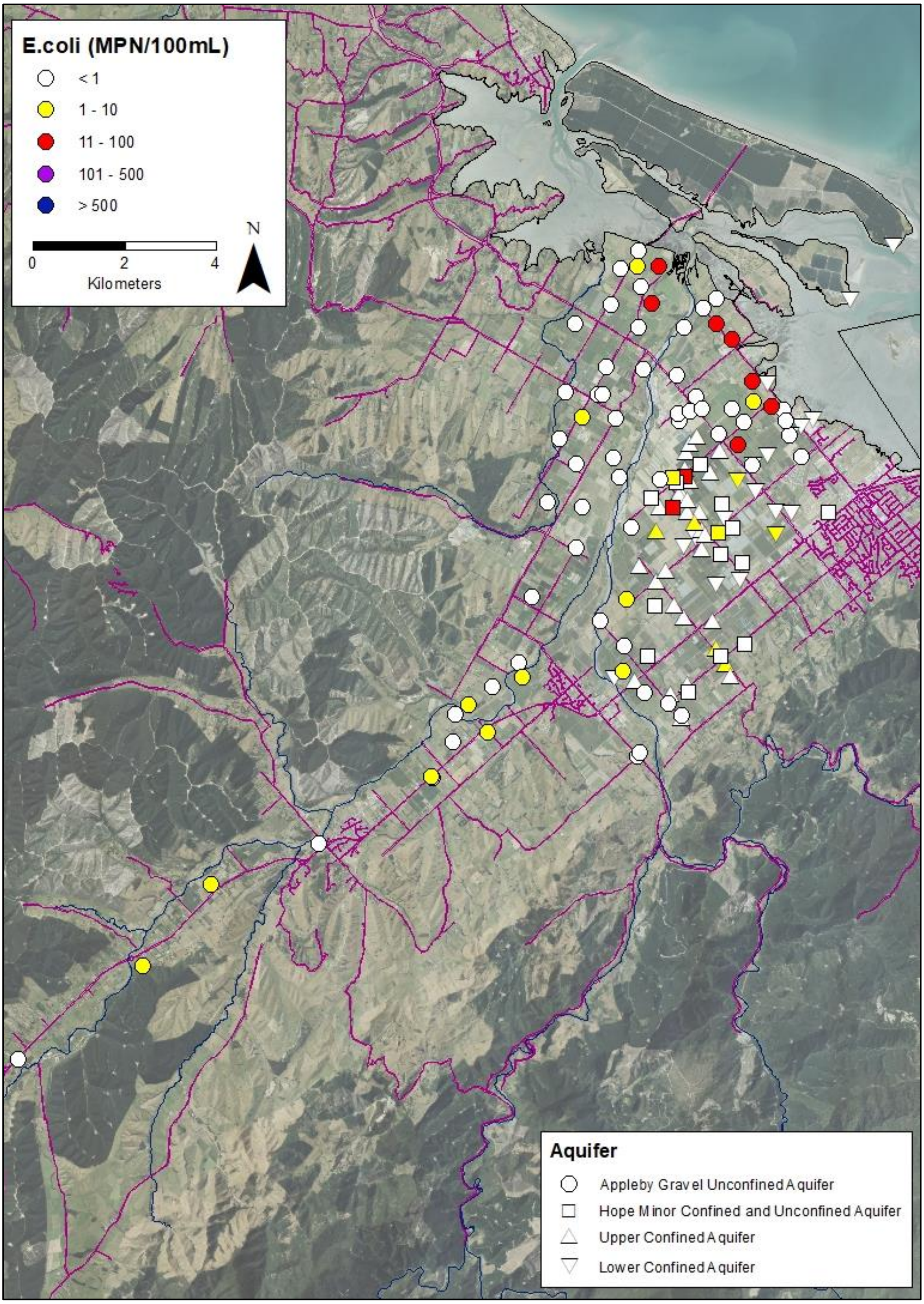


Figure 25: Distribution of E.coli across the Waimea Plains from 2021 survey.

The MAV from the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 for *Escherichia coli* is < 1 MPN/100mL. Please note the surface water samples were not received by the laboratory within the 24-hour period required for bacteriological analysis and therefore not included.

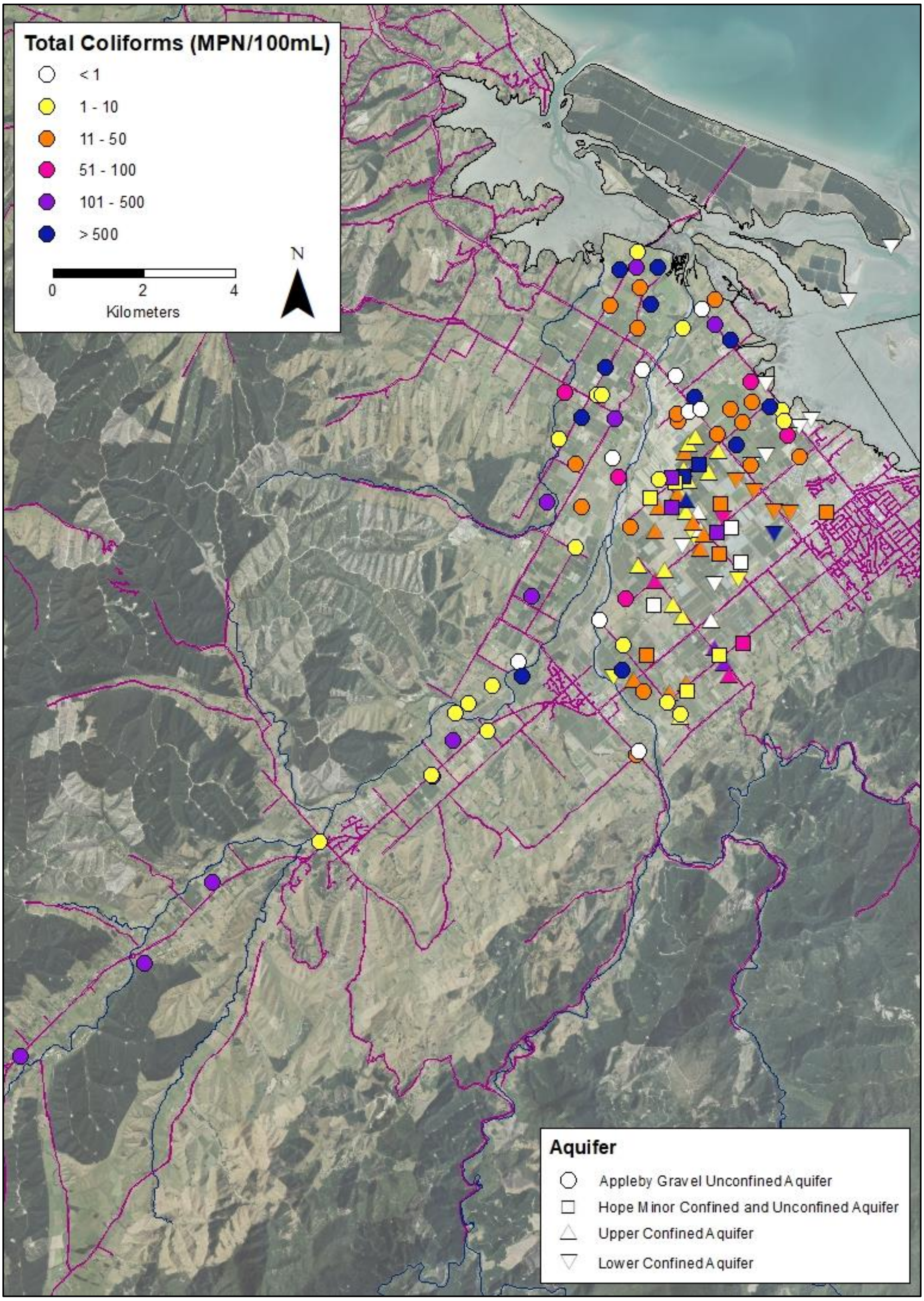


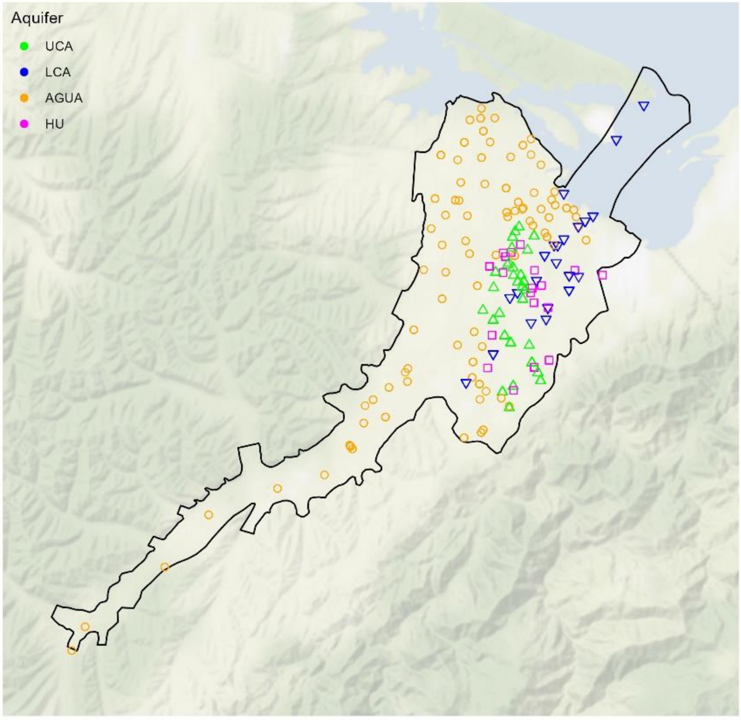
Figure 26: Distribution of total coliforms across the Waimea Plains from 2021 survey.

There is no MAV from the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 or AV from the Aesthetic Values for Drinking Water Notice 2022 for total coliforms. Please note the surface water samples were not received by the laboratory within the 24-hour period required for bacteriological analysis and therefore not included.

APPENDIX IV Nitrate-N trend analysis methodology and results

Prepared by Matt Ogden (October 2022).

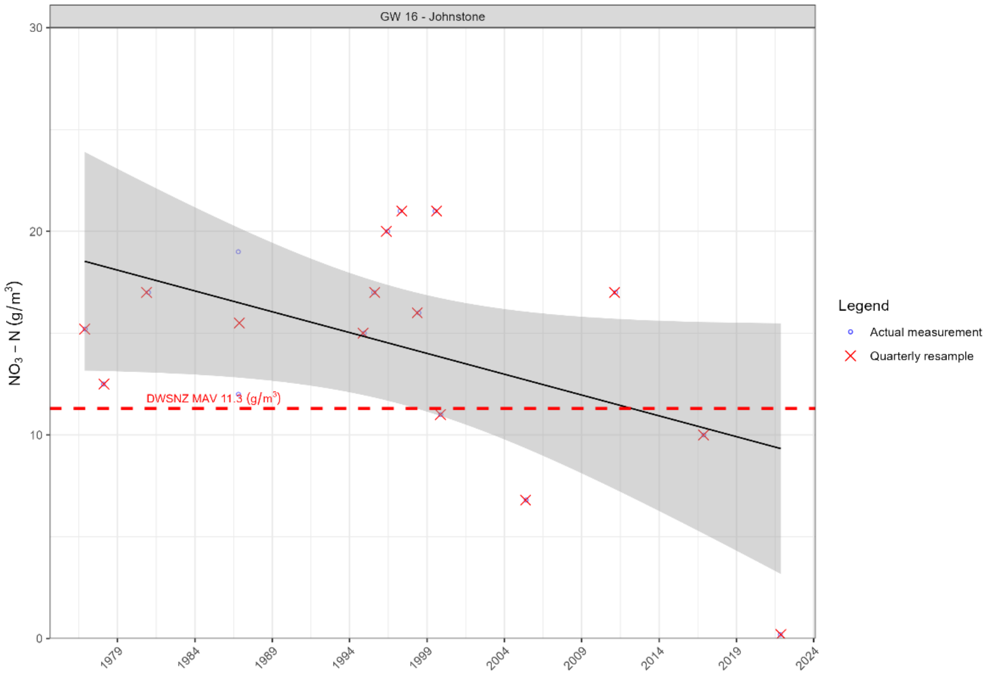
The purpose of this analysis is to explore long term trends in Nitrogen data captured at various sites throughout the Waimea Plains.



Waimea Plains bore sampling (Nitrate) sites

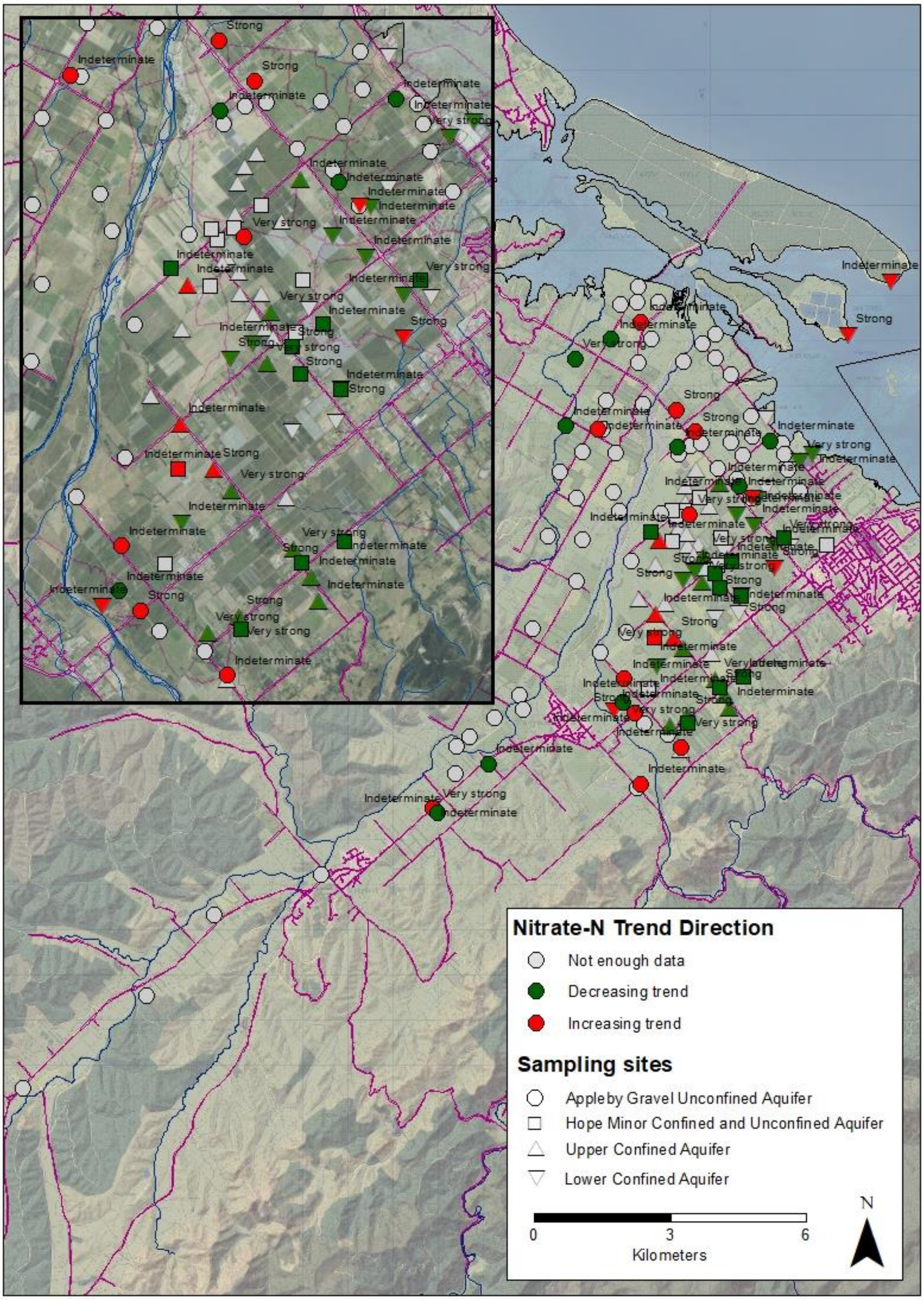
1. Data is loaded from ENVMON.
   (Test Name Group is Nutrients and Test Name is Nitrate-N, Total Nitrogen or Nitrate-N + Nitrite-N) OR (Test Name is Nitrate-N)
   The data is grouped by Sample Date and Site Id and a maximum value is taken to remove duplicates from the dataset.
2. Data is joined with aquifer information which was collated in a spreadsheet.
3. Paginated plots are created for each site, grouped by aquifer showing the Nitrate data over time.

4. Trend analysis is performed:
    - The dataset is resampled to a quarterly interval – where multiple values exist in a quarter, the median value is computed.
    - This resampled dataset is grouped by “site for analysis” (some sites are merged into one due to changes in sampling location e.g. GW 471 and GW 37 - Gardner).
    - Any sites which have less than 5 records are filtered from the subsequent trend analysis as they are considered to have insufficient data to draw any meaningful conclusions on the trend.
    - For each site, the **Man Kendall[4] Tau** and **Man Kendall Sl** is computed as the trend direction and trend confidence respectively.
    - A threshold of 0.1 is used for the trend direction – that is the trend direction is classified to **Decreasing** if the Man Kendall Tau is less than 0.1, **Increasing** if the Man Kendall Tau is more than 0.1, and **None** otherwise.
    - Thresholds of 0.01 and 0.1 are used for the trend confidence – that is the trend is confidence is classified to **Very Strong** if the Man Kendall Sl is less than 0.01, **Strong** if the Man Kendall Sl is less than 0.1, and **Indeterminate** otherwise.
5. The results are saved for subsequent visualisation.



site_for_analysis	aquifer	n_records	mann_kendall_tau	mann_kendall_sl	trend_direction	trend_confidence
GW 16 - Johnstone	HU	15	-0.16508	0.425824	Decreasing	Indeterminate

[4] The Mann Kendall Trend Test (sometimes called the M-K test) is used to analyse data collected over time for consistently increasing or decreasing trends (monotonic) in Y values. It is a non-parametric test, which means it works for all distributions (i.e. the data doesn't have to meet the assumption of normality).
[Mann Kendall Trend Test: Definition, Running the Test - Statistics How To]


Nitrate-N Trend Direction
Not enough data
Decreasing trend
Increasing trend
Sampling sites
Appleby Gravel Unconfined Aquifer
Hope Minor Confined and Unconfined Aquifer
Upper Confined Aquifer
Lower Confined Aquifer
0
3
6
Kilometers
N

APPENDIX V Contour plots of Waimea Plains nitrate-N investigations

Contour plots of Waimea Plains nitrate-N investigations 1986, 1994, 1999, 2005, 2016 and 2021.

Please note that plots from those drawn in Fenemor (1987), Edie (1995), Ware (1999) and Stevens (2005) have been redrafted based on the original nitrate-N data to incorporate the current knowledge of the aquifer constraints and the improved accuracy of bore locations in recent years.

Aquifer extents shown in the contour plots are the water management area for each aquifer. The actual extent of the aquifers is different. Please refer to the text in Dicker et al (1992) for a more detailed description of each aquifer.

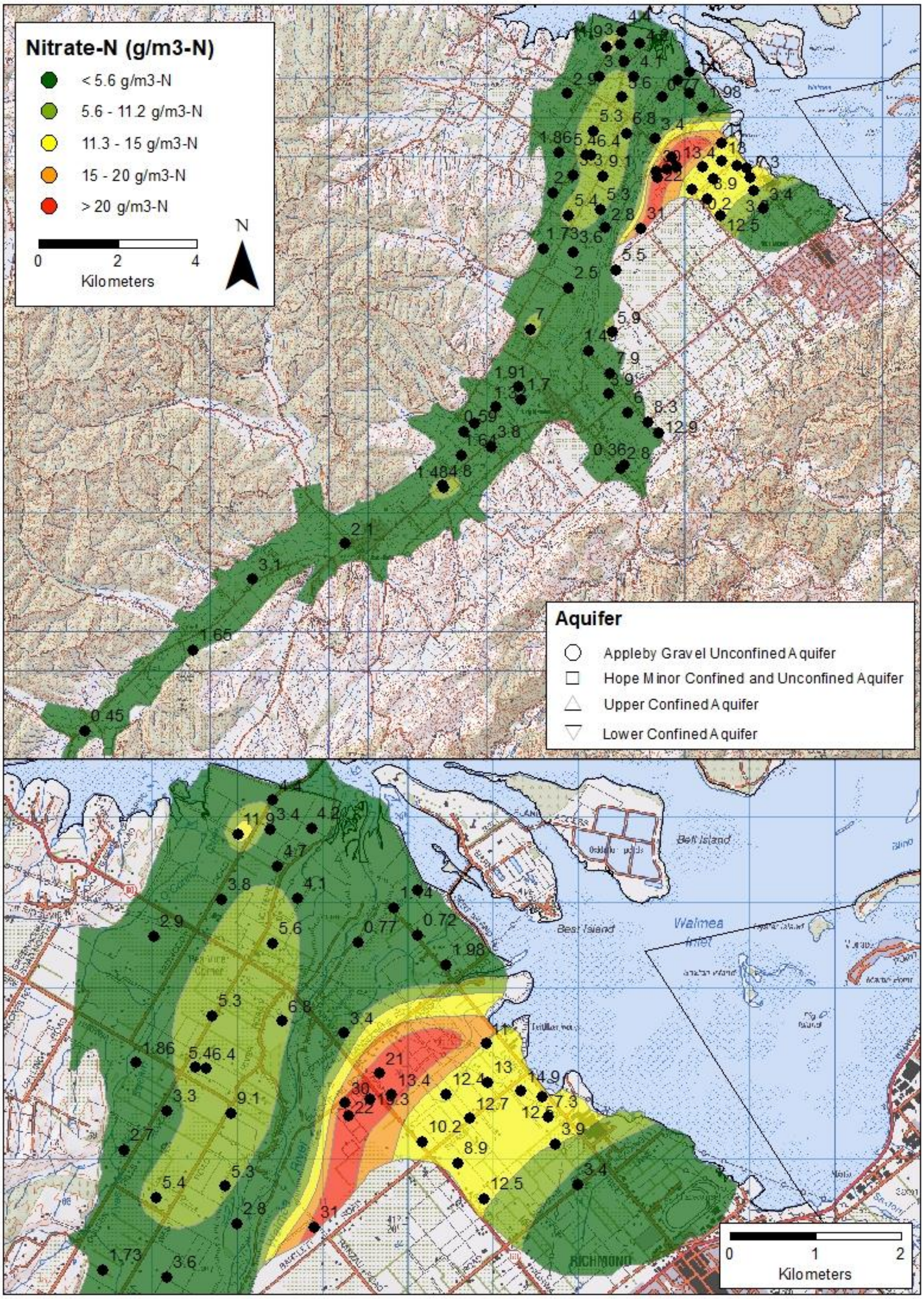


Figure 27: Contour plot for 2021 AGUA nitrate-N concentration.

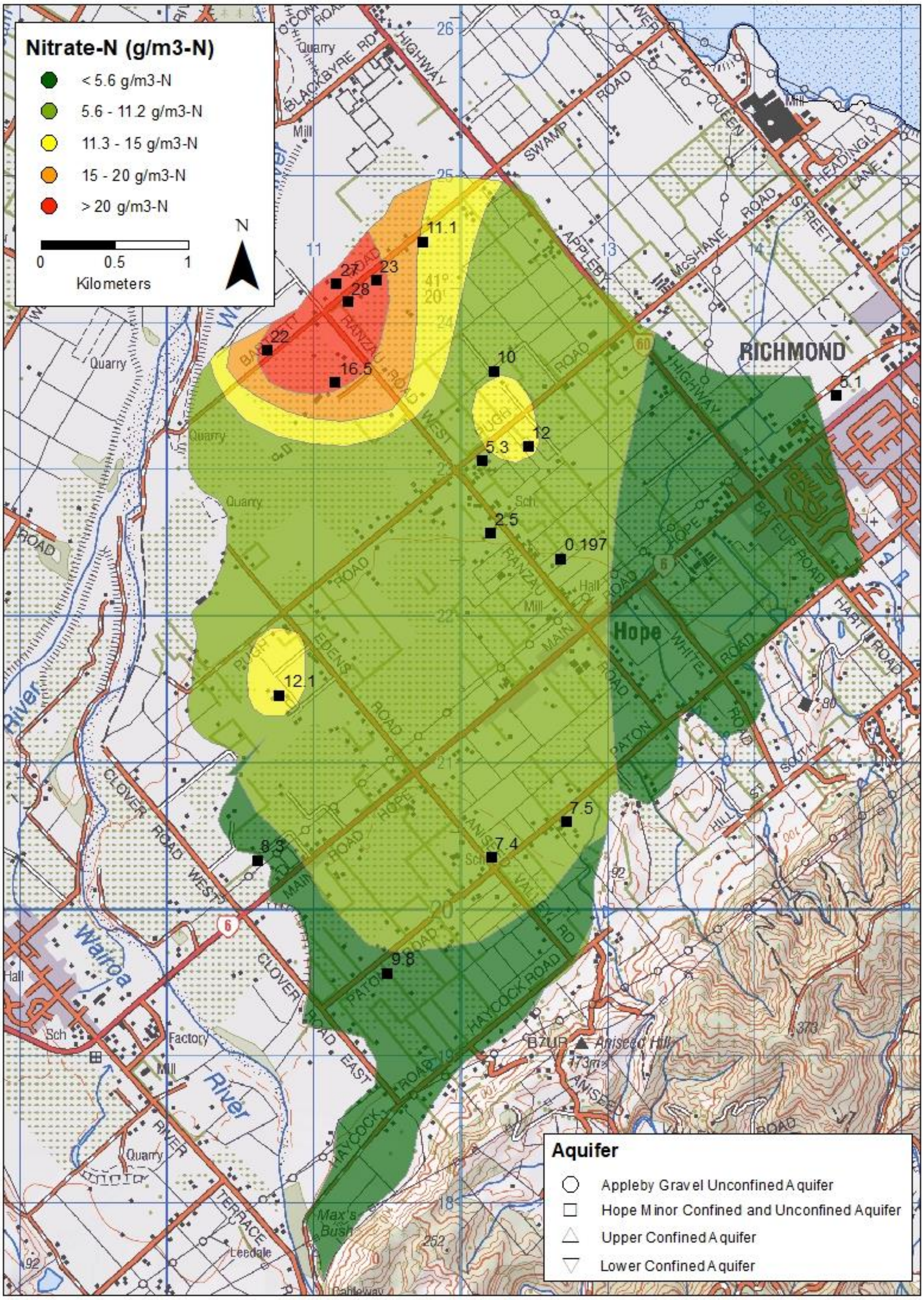


Figure 28: Contour plot for 2021 HU nitrate-N concentration.

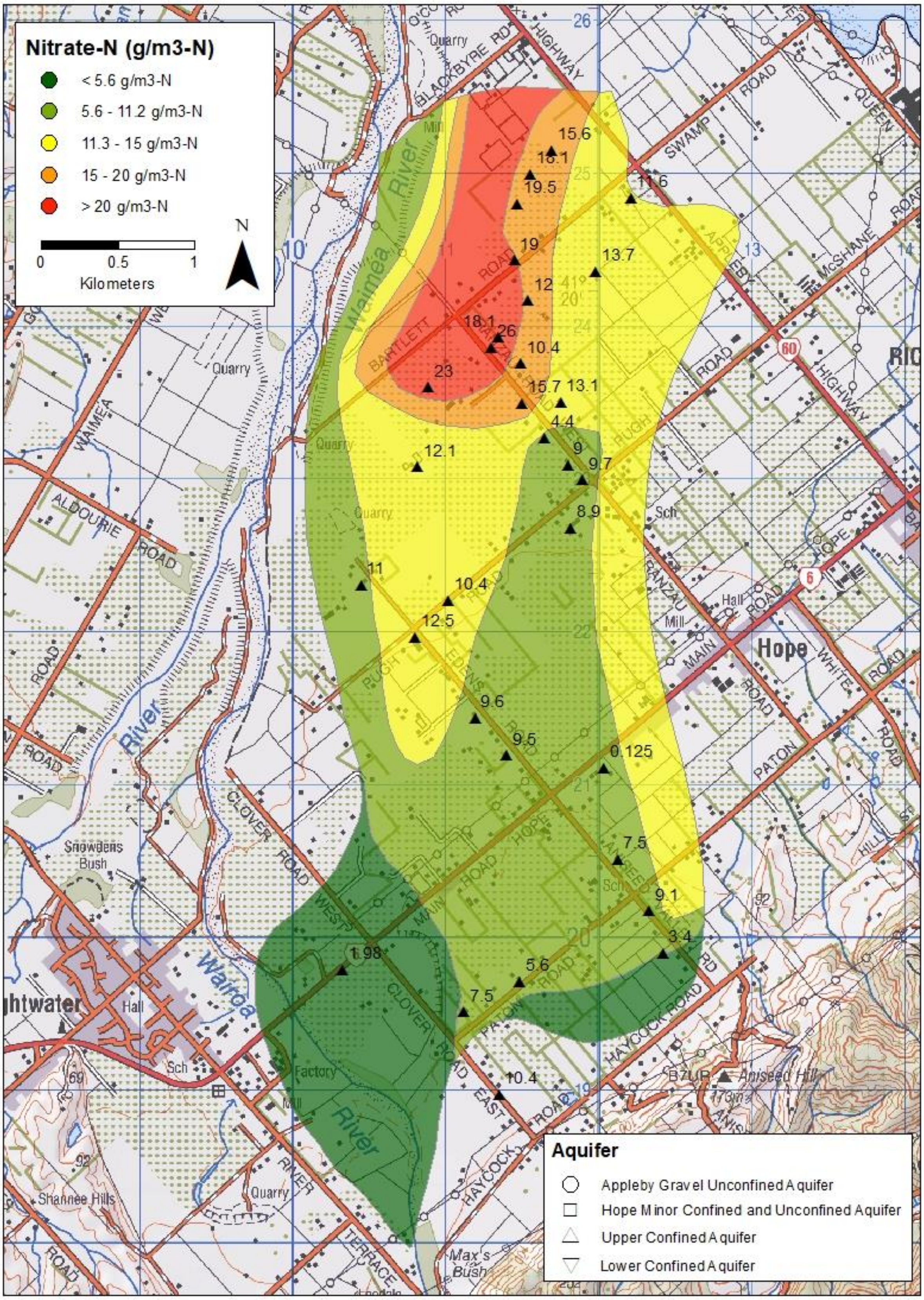


Figure 29: Contour plot for 2021 UCA nitrate-N concentration.

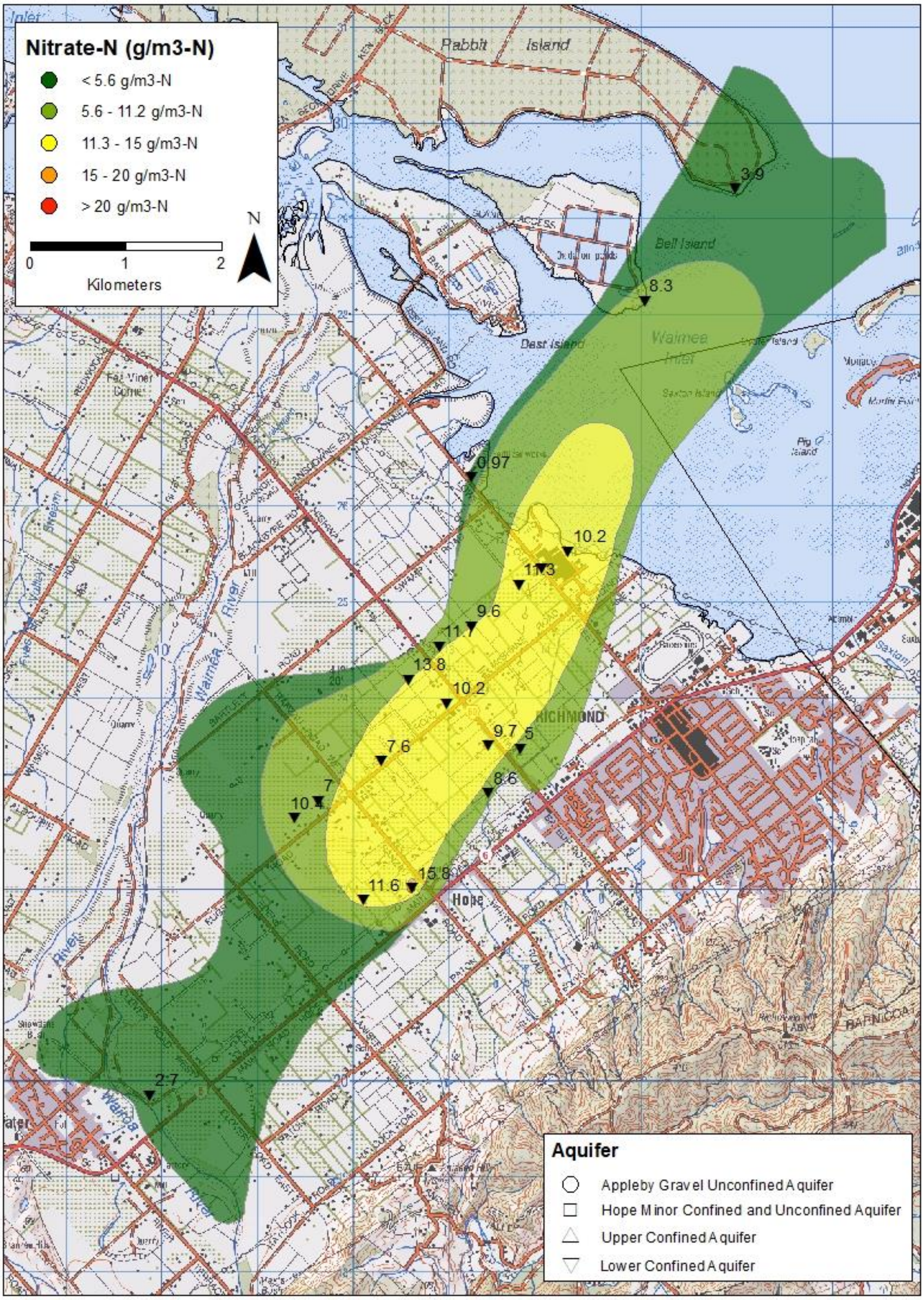
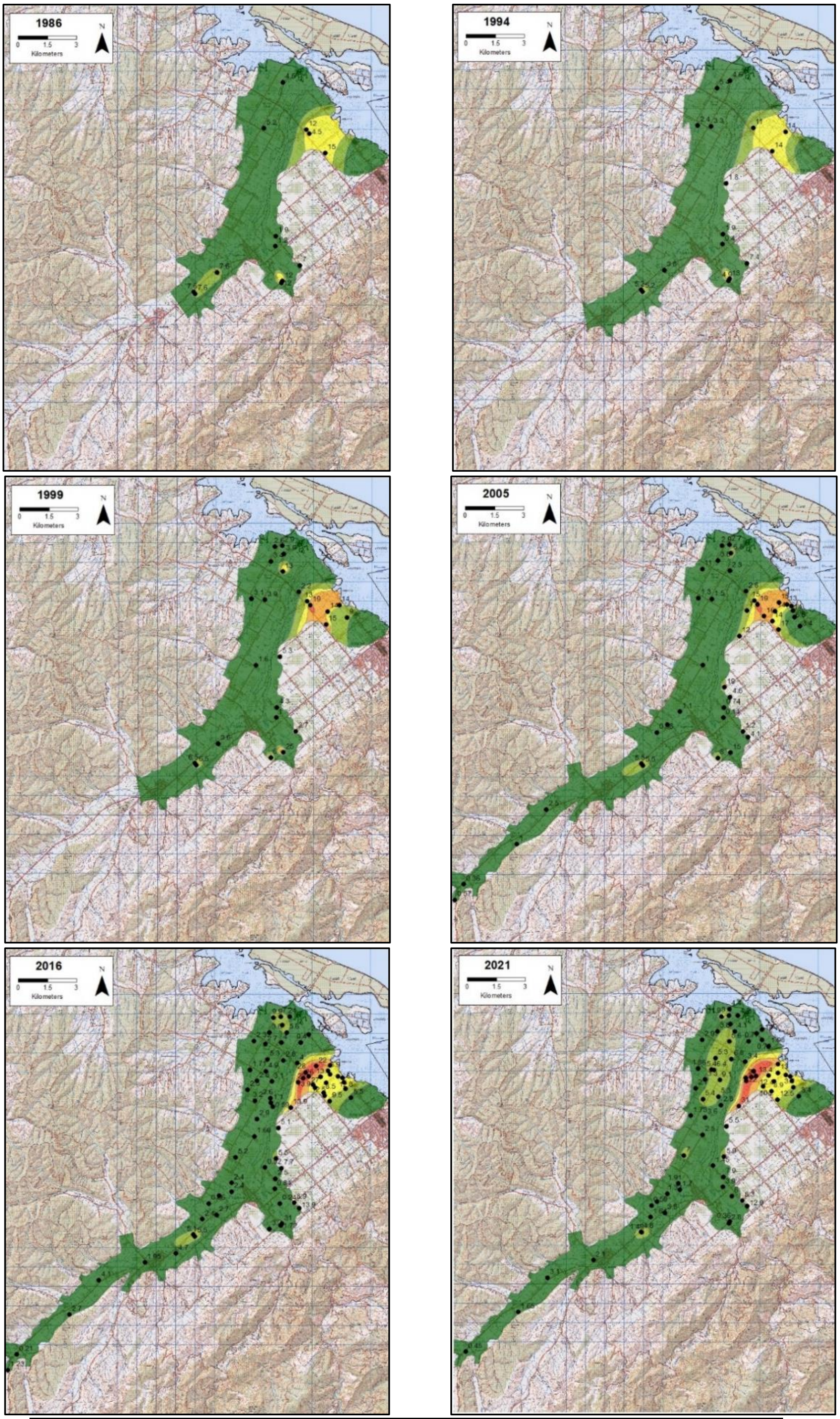
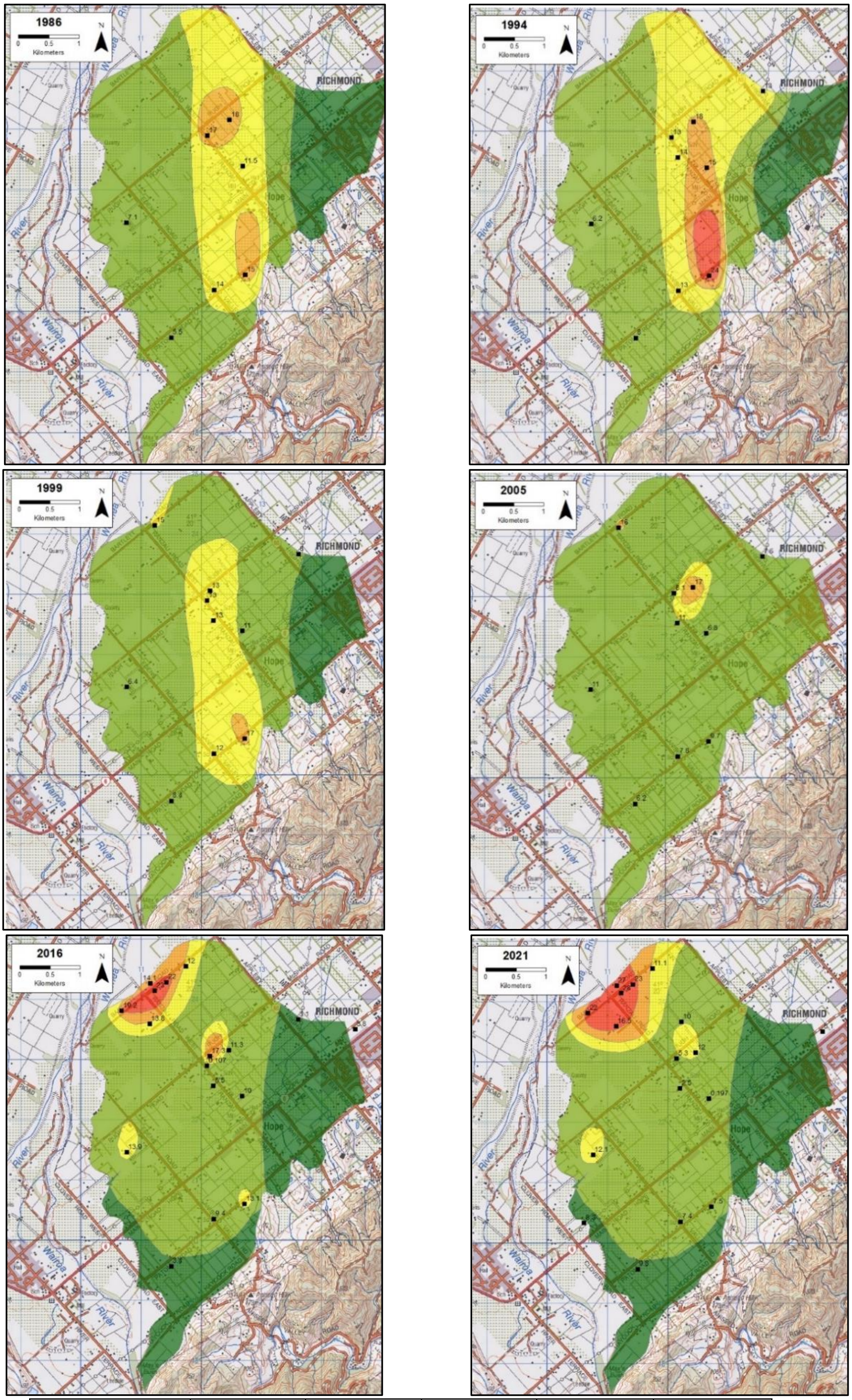


Figure 30: Contour plot for 2021 LCA nitrate-N concentration.



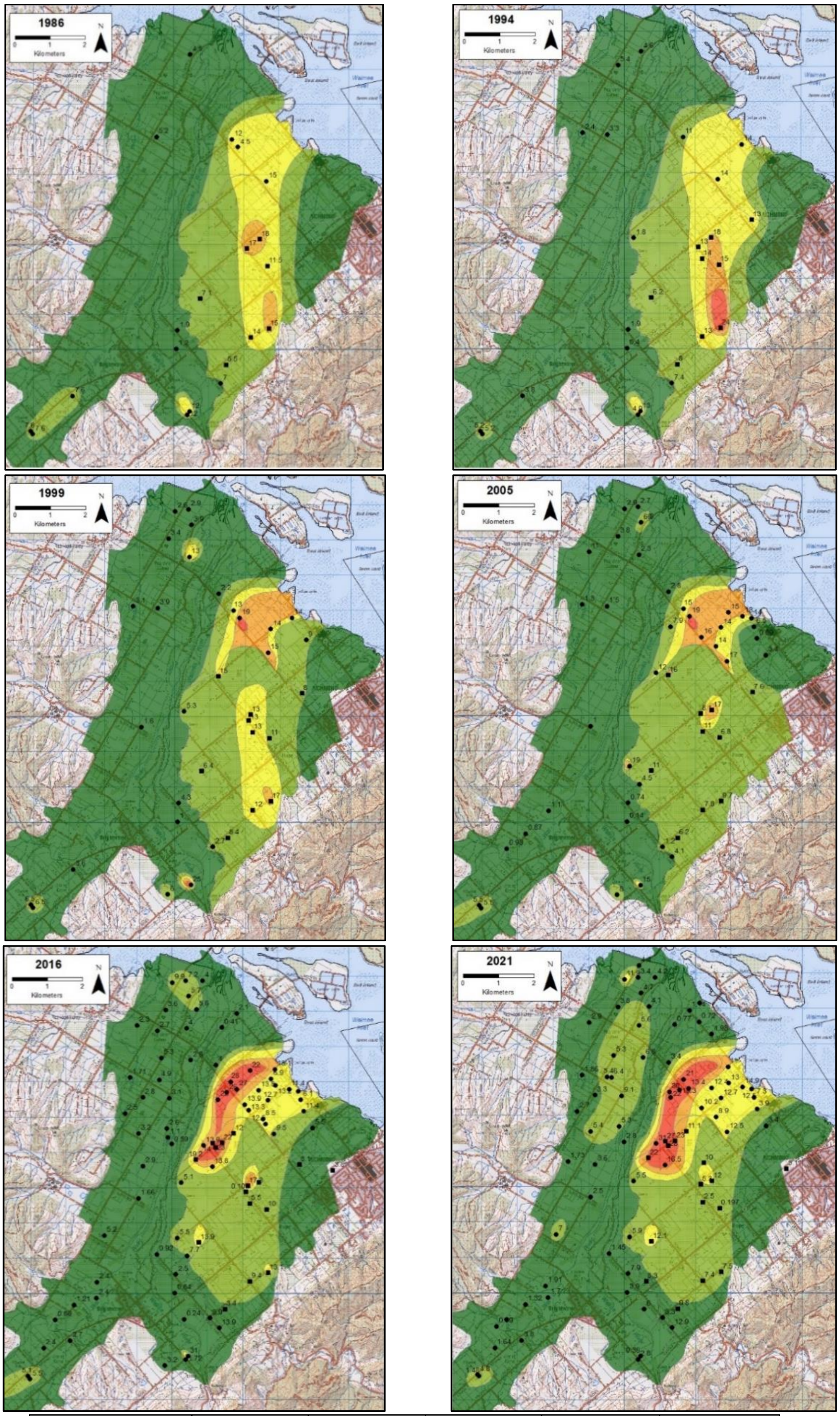
Legend					
Nitrate-N (g/m3-N)	< 5.6	5.6 – 11.2	11.3 -15	15.1 – 20	> 20

Figure 31: AGUA nitrate-N contours from 1986, 1994, 1999, 2005, 2016 and 2021 investigations.



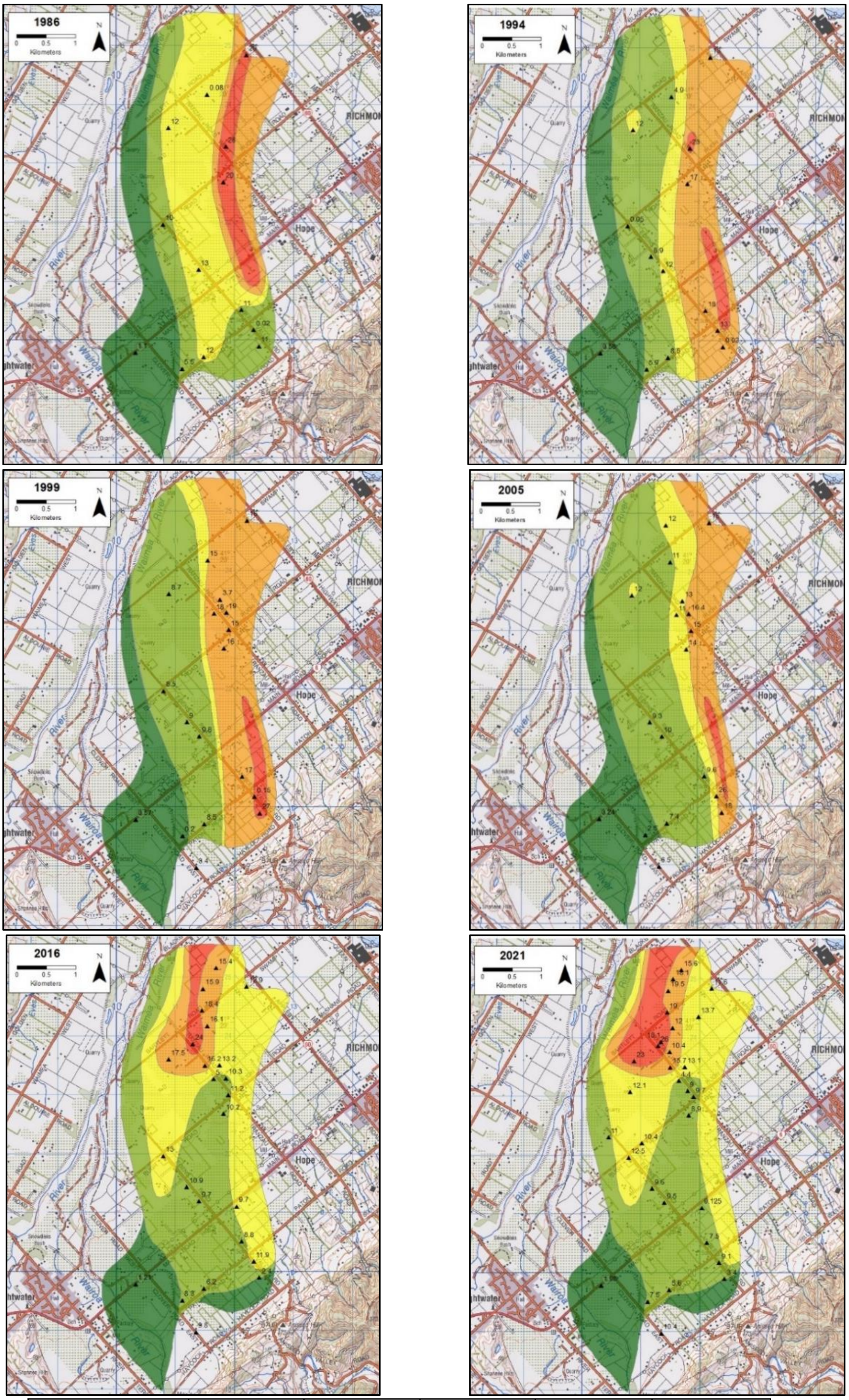
Legend					
Nitrate-N (g/m3-N)	< 5.6	5.6 – 11.2	11.3 -15	15.1 – 20	> 20

Figure 32: HU nitrate-N contours from 1986, 1994, 1999, 2005, 2016 and 2021 investigations.



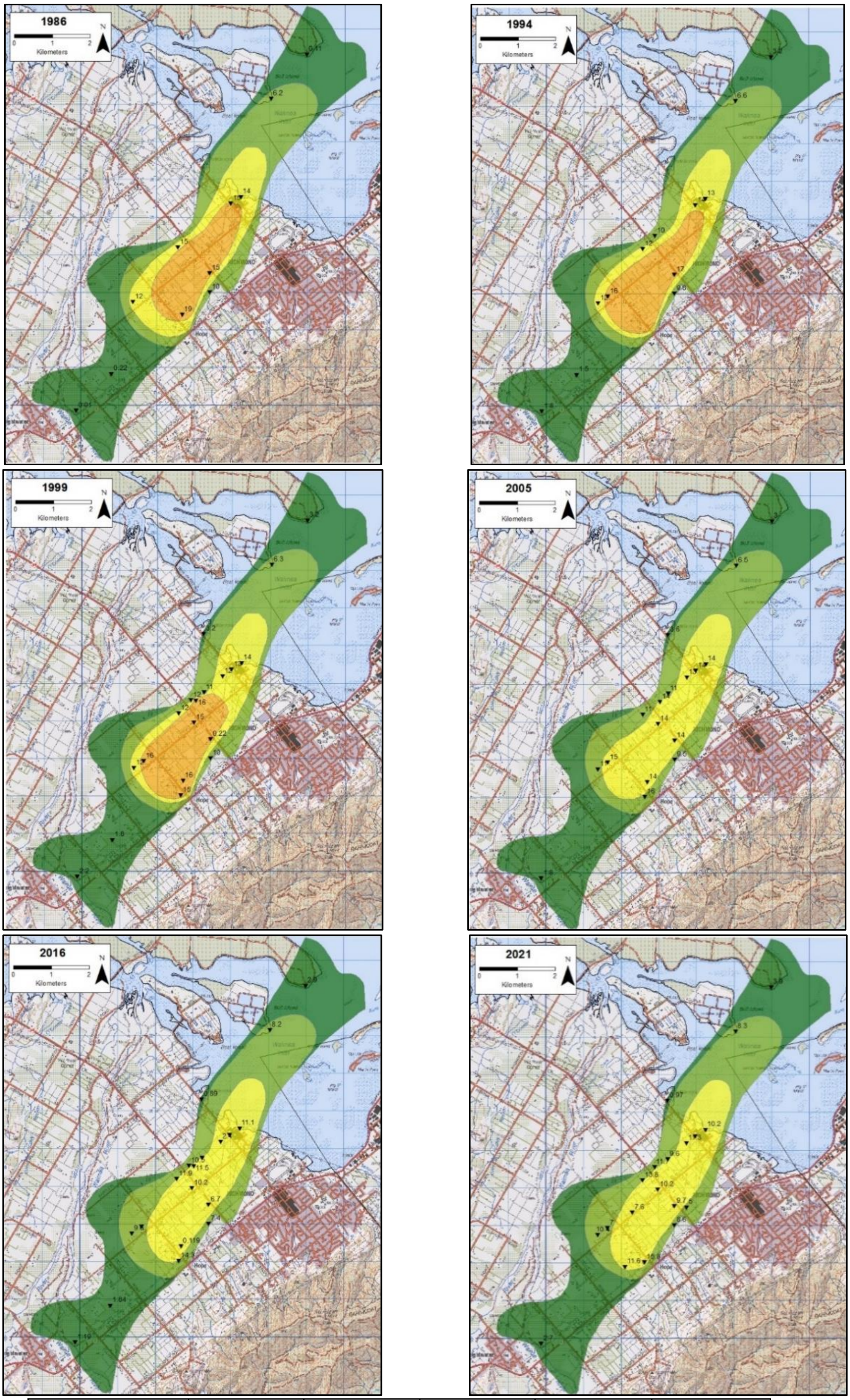
Legend					
Nitrate-N (g/m3-N)	< 5.6	5.6 – 11.2	11.3 -15	15.1 – 20	> 20

Figure 33: AGUA and HU nitrate-N contours from 1986, 1994, 1999, 2005, 2016 and 2021 investigations.



Legend					
Nitrate-N (g/m3-N)	< 5.6	5.6 – 11.2	11.3 -15	15.1 – 20	> 20

Figure 34: UCA nitrate-N contours from 1986, 1994, 1999, 2005, 2016 and 2021 investigations.



Legend					
Nitrate-N (g/m3-N)	< 5.6	5.6 – 11.2	11.3 -15	15.1 – 20	> 20

Figure 35: LCA nitrate-N contours from 1986, 1994, 1999, 2005, 2016 and 2021 investigations.

APPENDIX VI Measured groundwater nitrate-N concentrations over time vs cumulative rainfall in the Waimea Plains monthly monitored bores

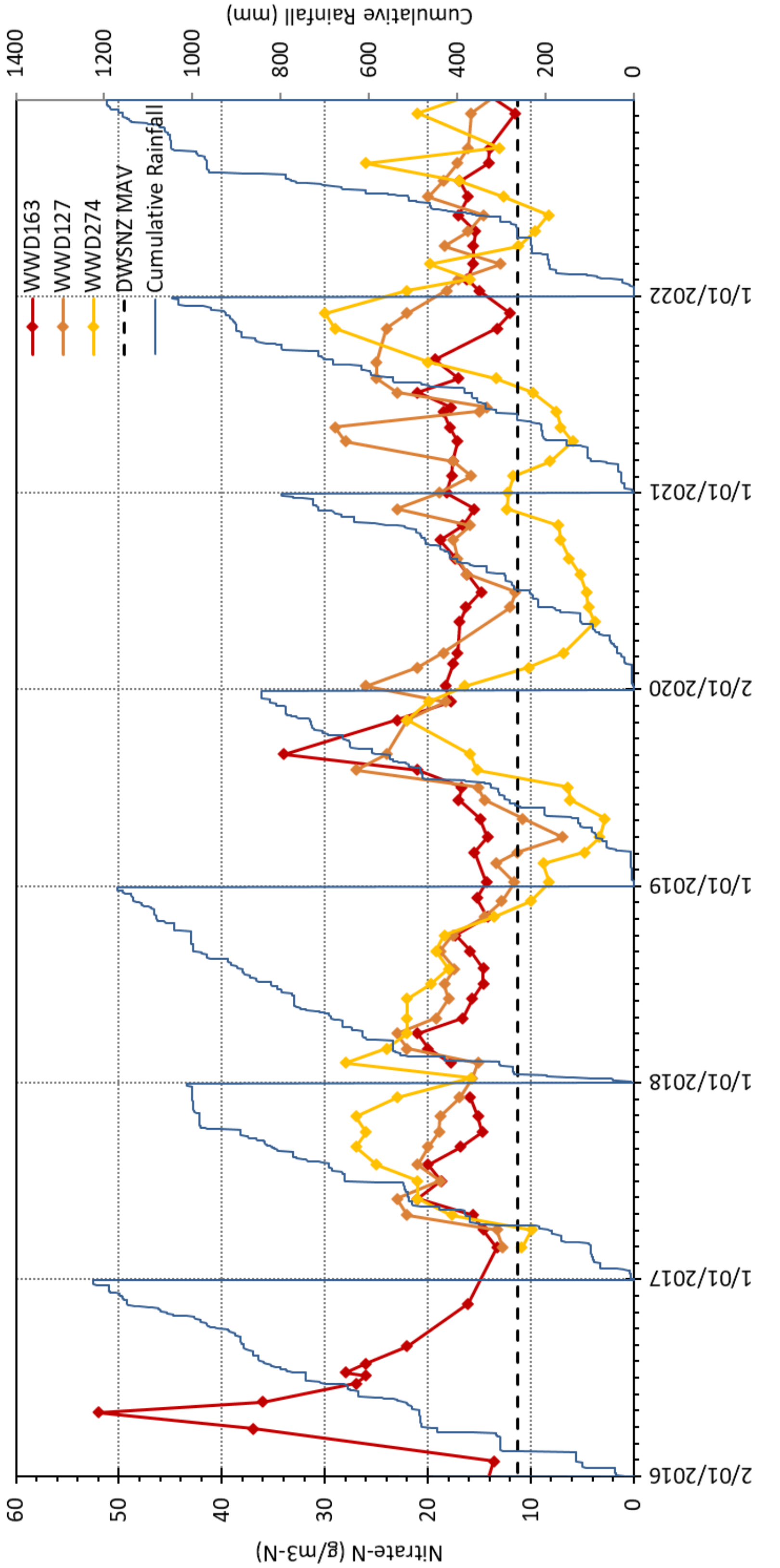


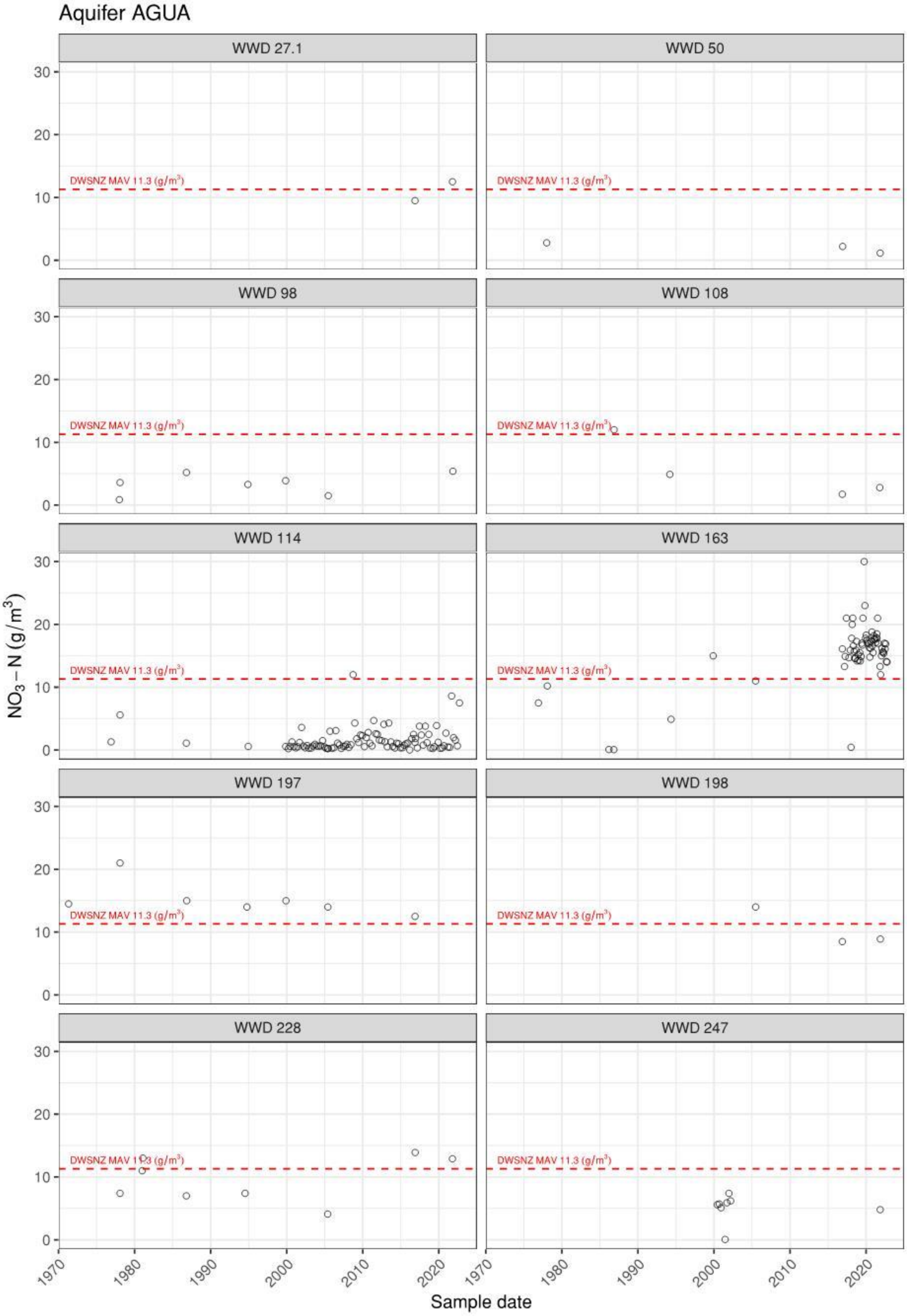
Figure 36: Measured groundwater nitrate-N concentrations over time vs cumulative rainfall in the Waimea Plains monthly monitored bores.

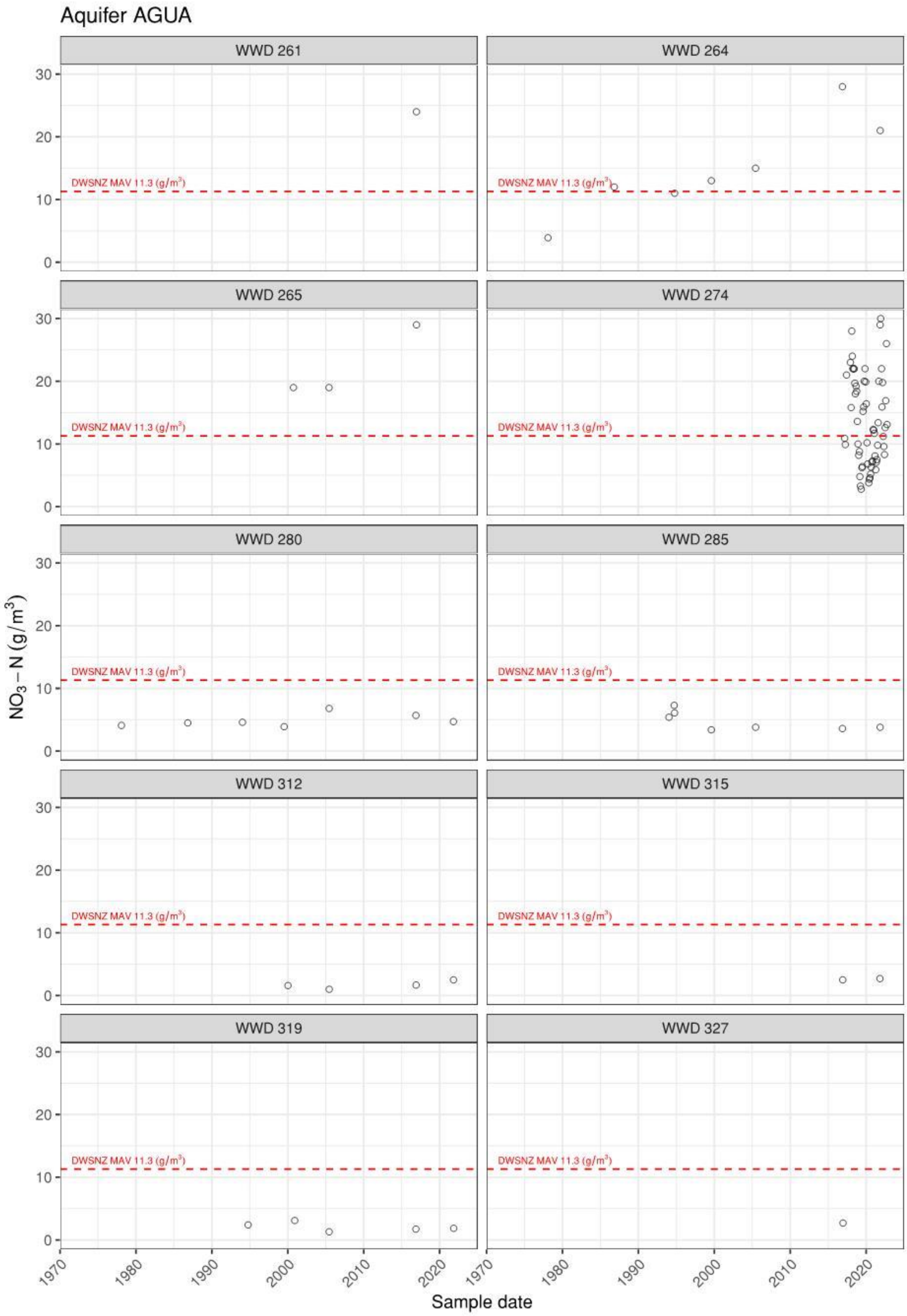
APPENDIX VII Measured groundwater nitrate-N concentrations over time for all bores/wells sampled in 2021

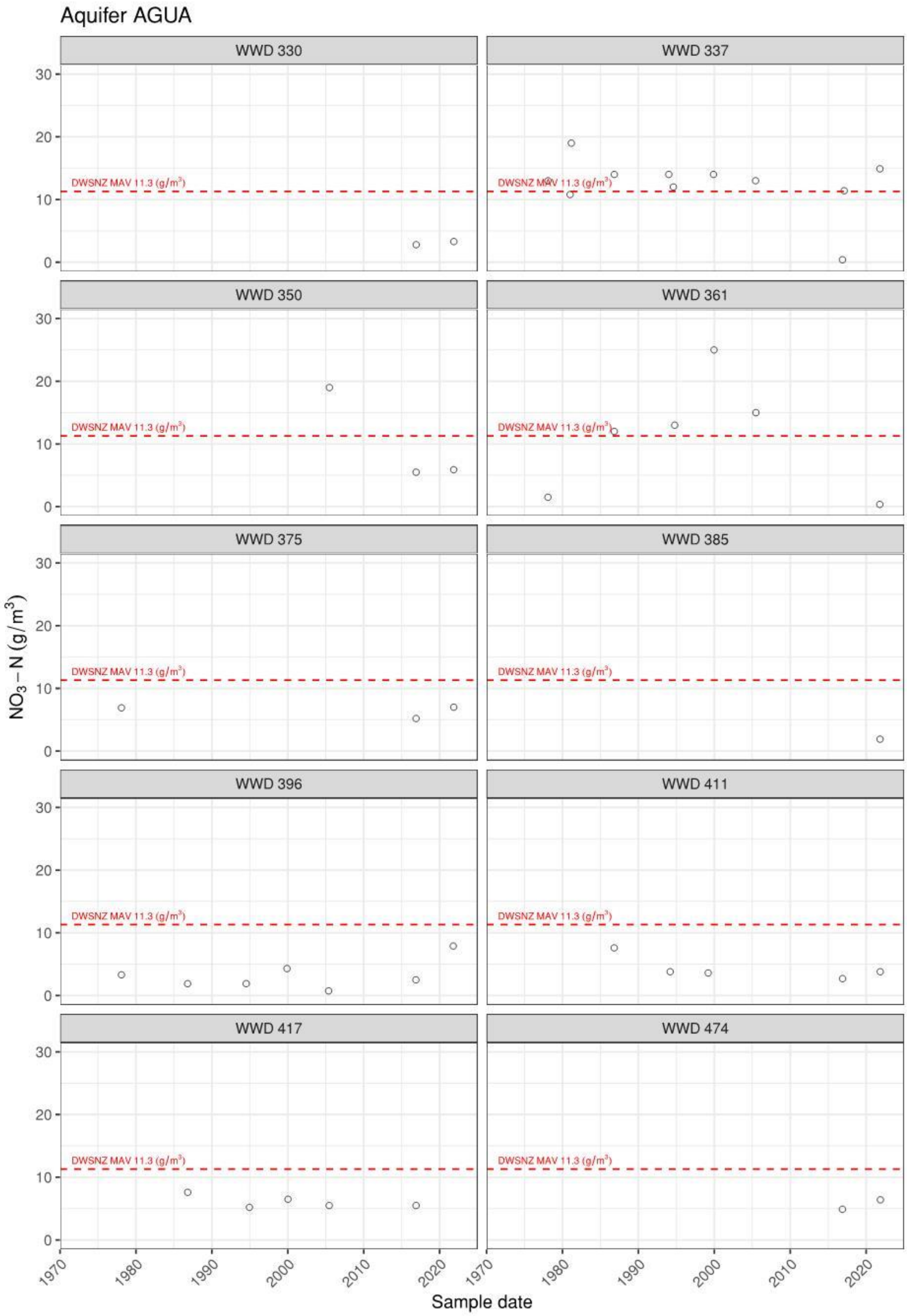
All historic data included up to October 2022. Sites grouped numerically into their corresponding aquifers.

Prepared by Matt Ogden (October 2022).

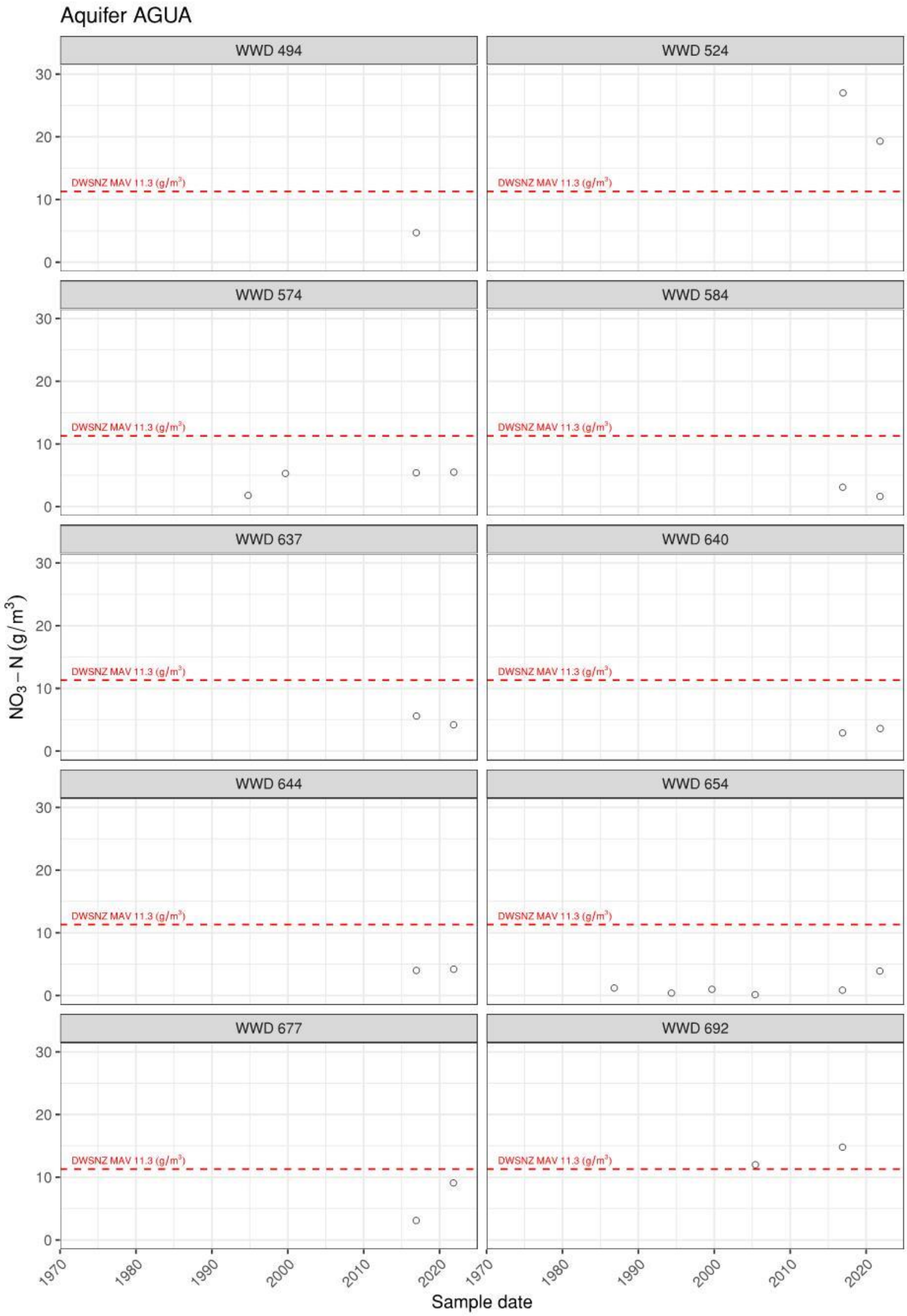
Aquifer AGUA

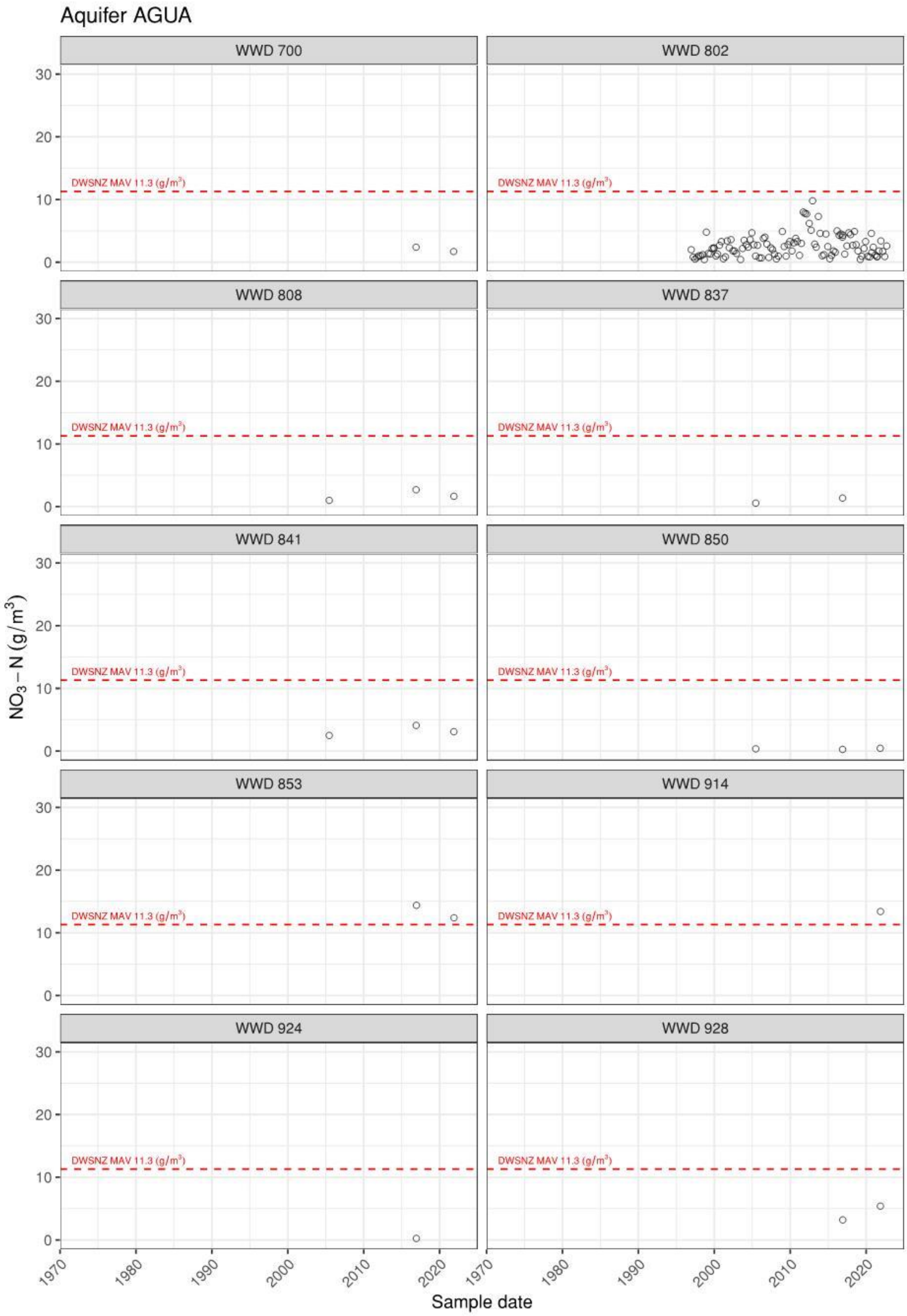


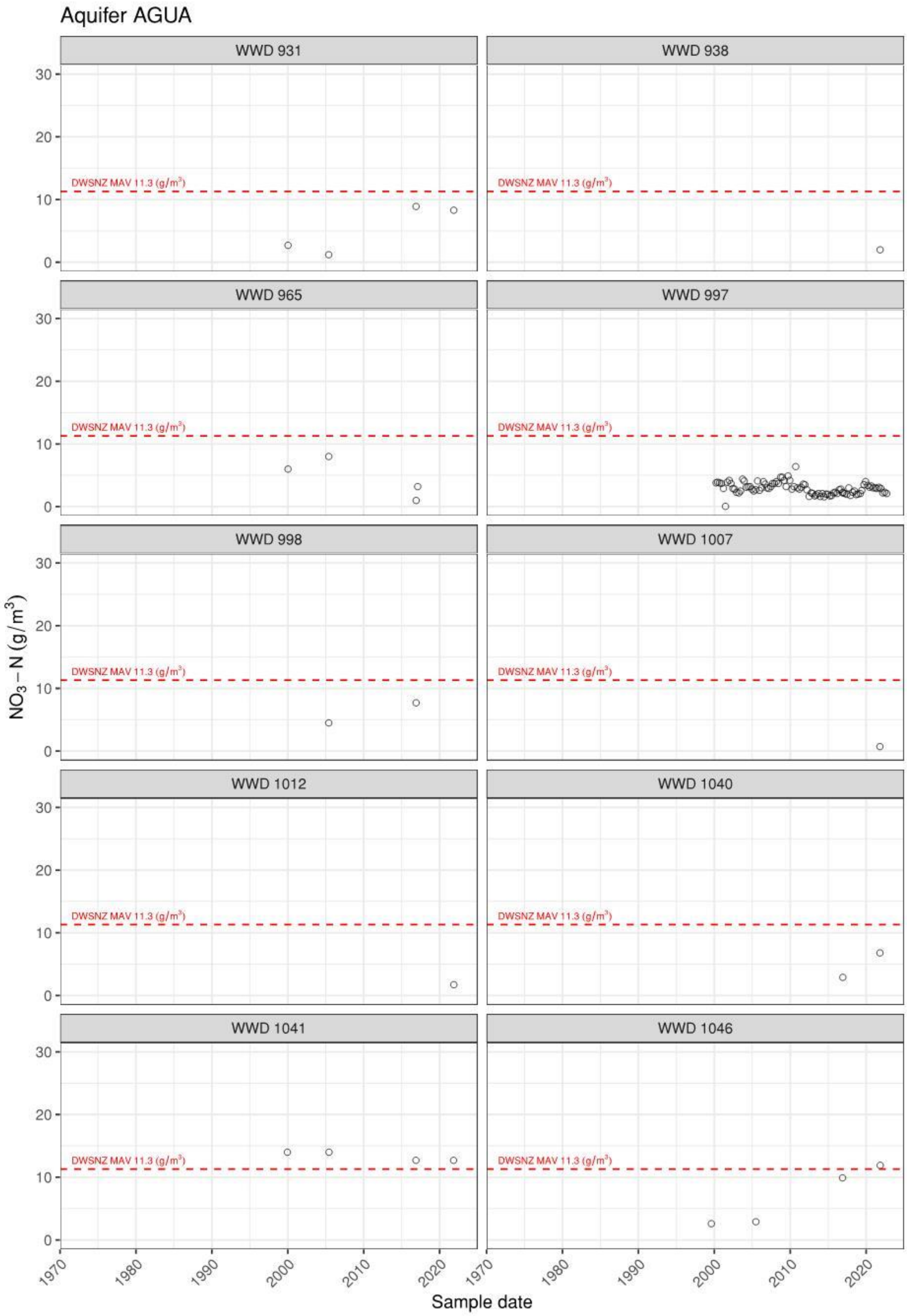

Aquifer AGUA
WWD 261
WWD 264
WWD 265
WWD 274
WWD 280
WWD 285
WWD 312
WWD 315
WWD 319
WWD 327
DWSNZ MAV 11.3 (g/m³)
NO3 – N (g/m³)
Sample date
30
20
10
0
1970
1980
1990
2000
2010
2020

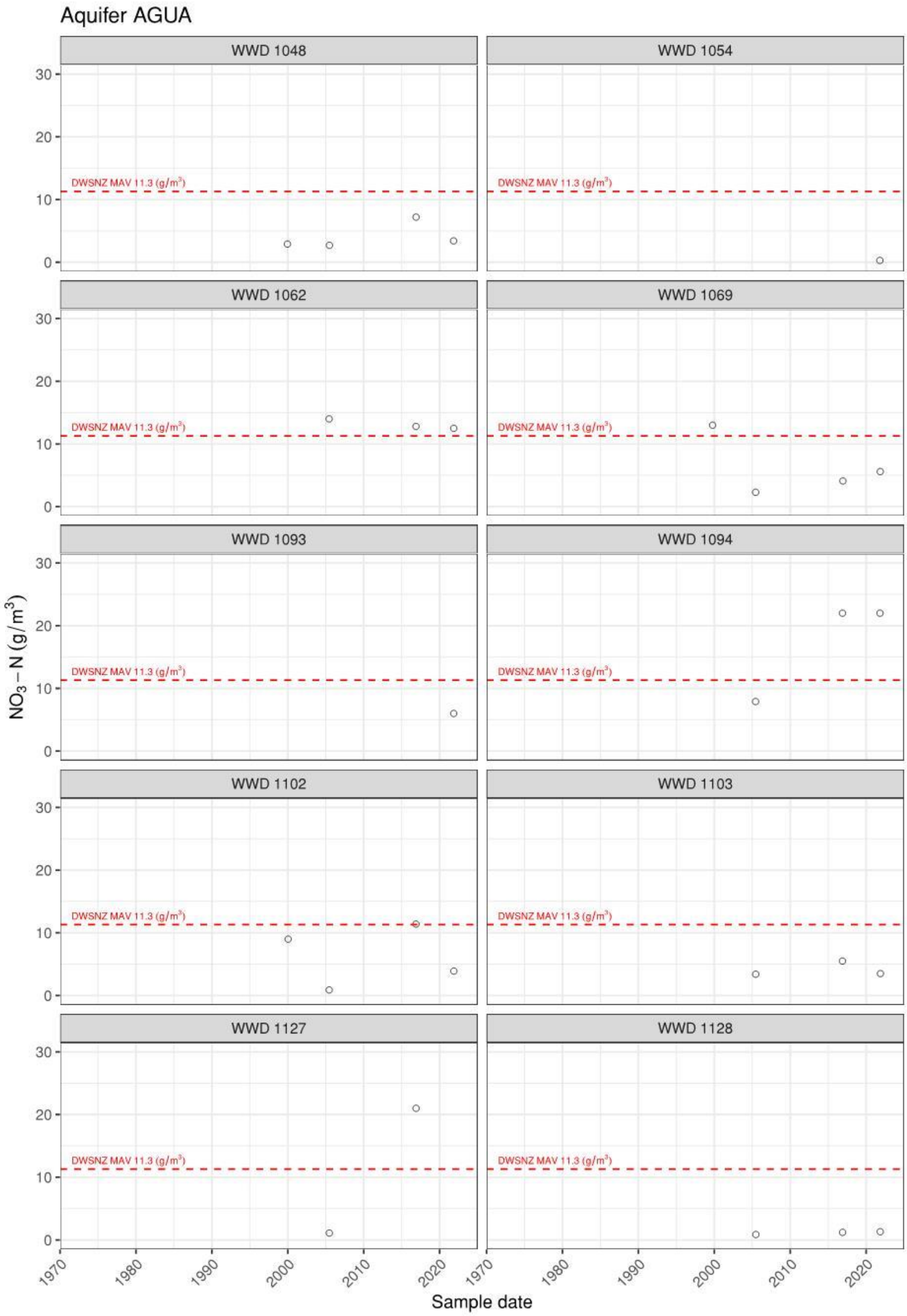


Aquifer AGUA
WWD 330
WWD 337
WWD 350
WWD 361
WWD 375
WWD 385
WWD 396
WWD 411
WWD 417
WWD 474
DWSNZ MAV 11.3 (g/m³)
$NO_3 - N$ (g/m³)
Sample date
0
10
20
30
1970
1980
1990
2000
2010
2020

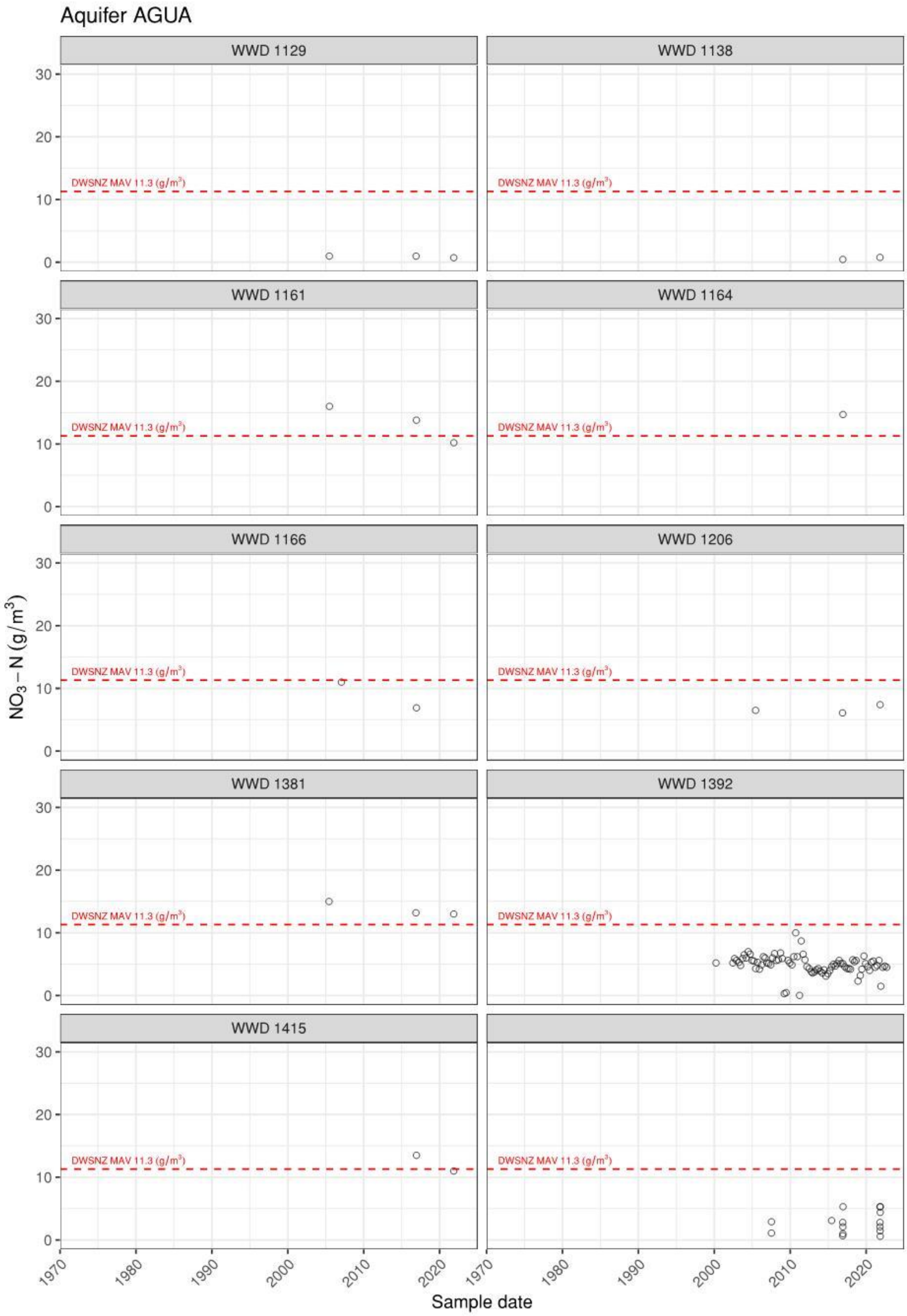

Aquifer AGUA
WWD 494
WWD 524
WWD 574
WWD 584
WWD 637
WWD 640
WWD 644
WWD 654
WWD 677
WWD 692
DWSNZ MAV 11.3 (g/m³)
0
10
20
30
1970
1980
1990
2000
2010
2020
NO3 – N (g/m³)
Sample date


Aquifer AGUA
WWD 700
WWD 802
WWD 808
WWD 837
WWD 841
WWD 850
WWD 853
WWD 914
WWD 924
WWD 928
DWSNZ MAV 11.3 (g/m³)
NO3 − N (g/m³)
0
10
20
30
1970
1980
1990
2000
2010
2020
Sample date

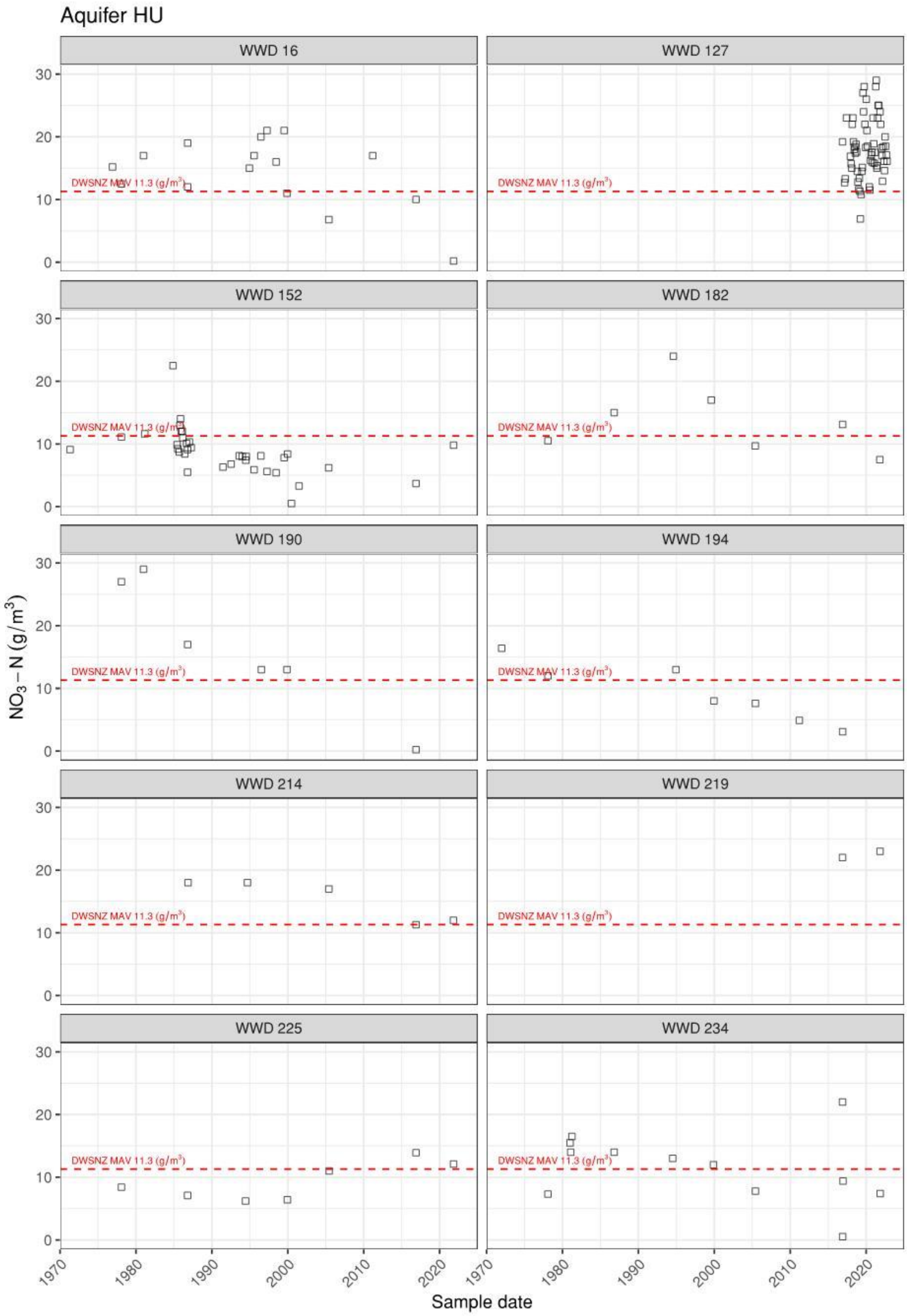

Aquifer AGUA
WWD 931
WWD 938
WWD 965
WWD 997
WWD 998
WWD 1007
WWD 1012
WWD 1040
WWD 1041
WWD 1046
DWSNZ MAV 11.3 (g/m³)
NO3 – N (g/m³)
Sample date
0
10
20
30
1970
1980
1990
2000
2010
2020



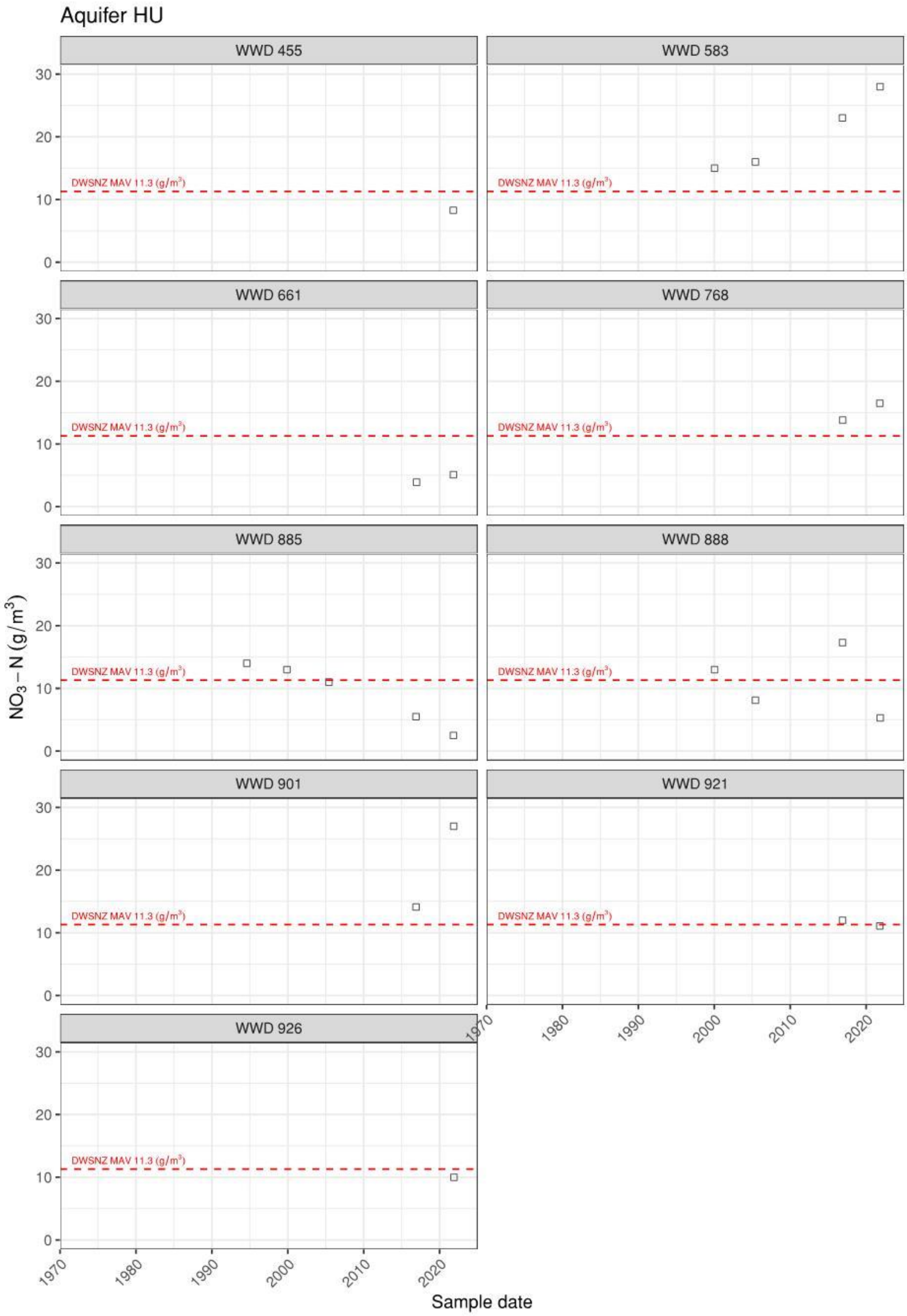
Aquifer AGUA
WWD 1048
WWD 1054
WWD 1062
WWD 1069
WWD 1093
WWD 1094
WWD 1102
WWD 1103
WWD 1127
WWD 1128
DWSNZ MAV 11.3 (g/m³)
$NO_3 - N$ (g/m³)
Sample date
0
10
20
30
1970
1980
1990
2000
2010
2020



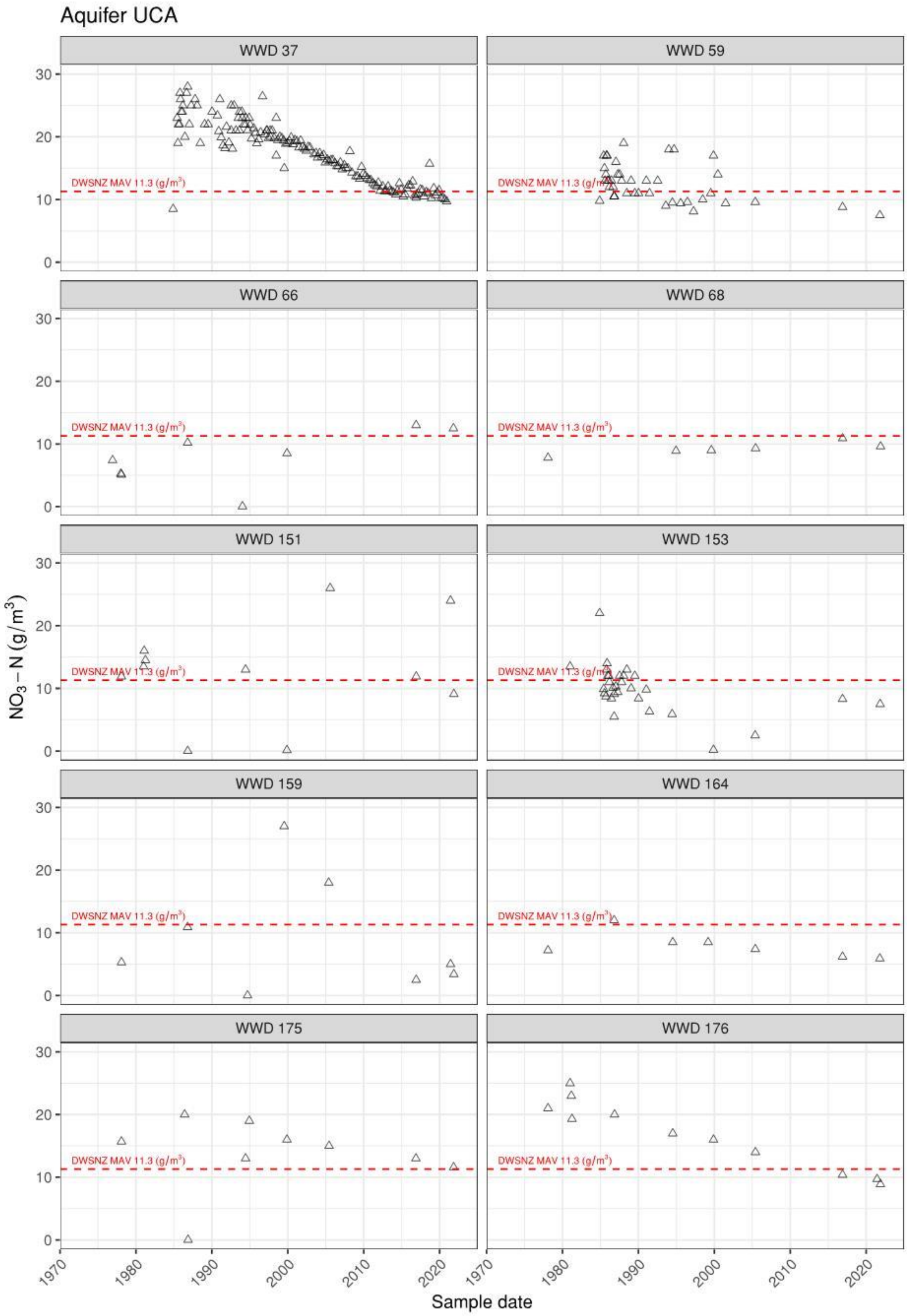
Aquifer AGUA
WWD 1129
WWD 1138
WWD 1161
WWD 1164
WWD 1166
WWD 1206
WWD 1381
WWD 1392
WWD 1415
DWSNZ MAV 11.3 (g/m3)
NO3 – N (g/m3)
Sample date
0
10
20
30
1970
1980
1990
2000
2010
2020

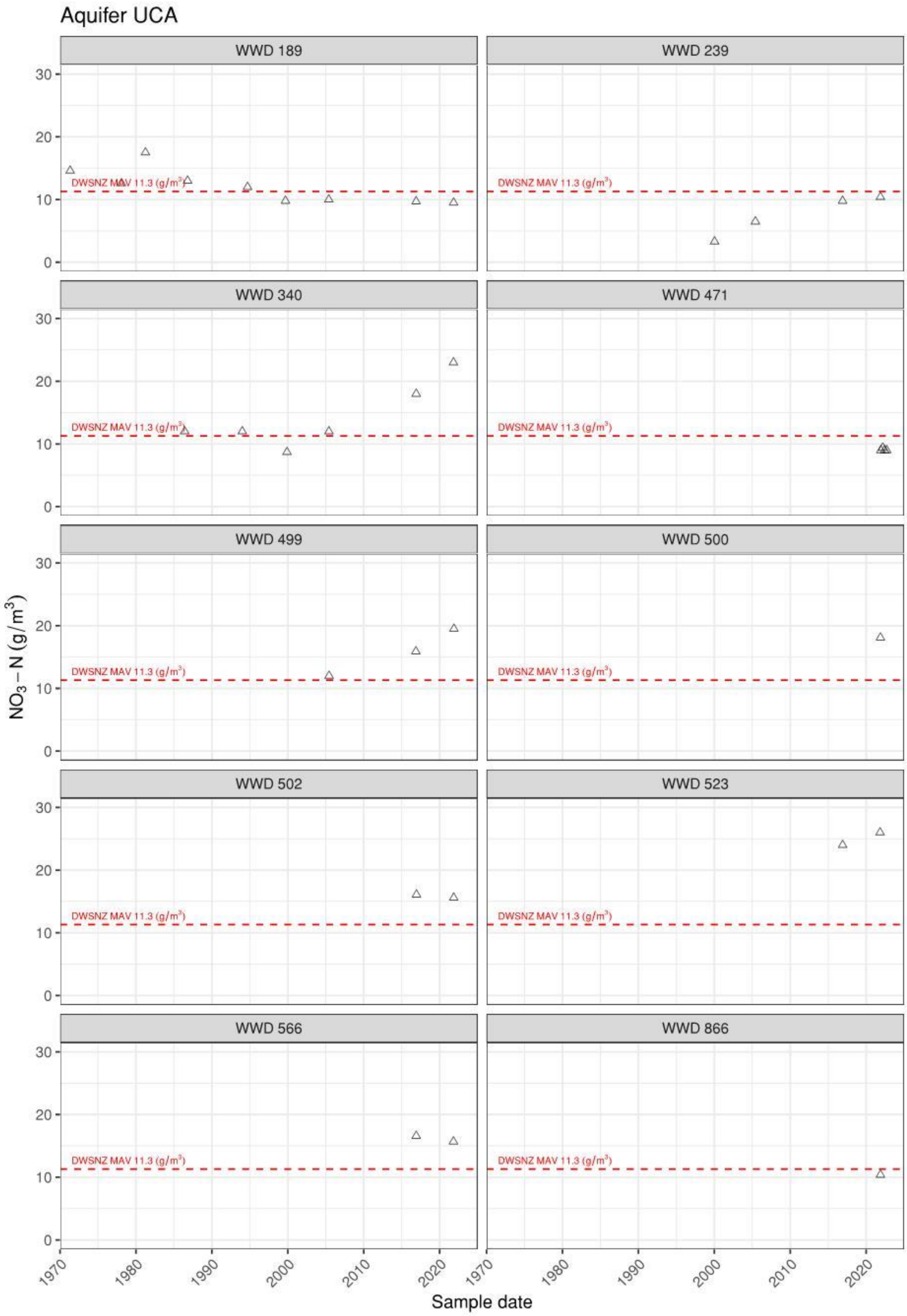


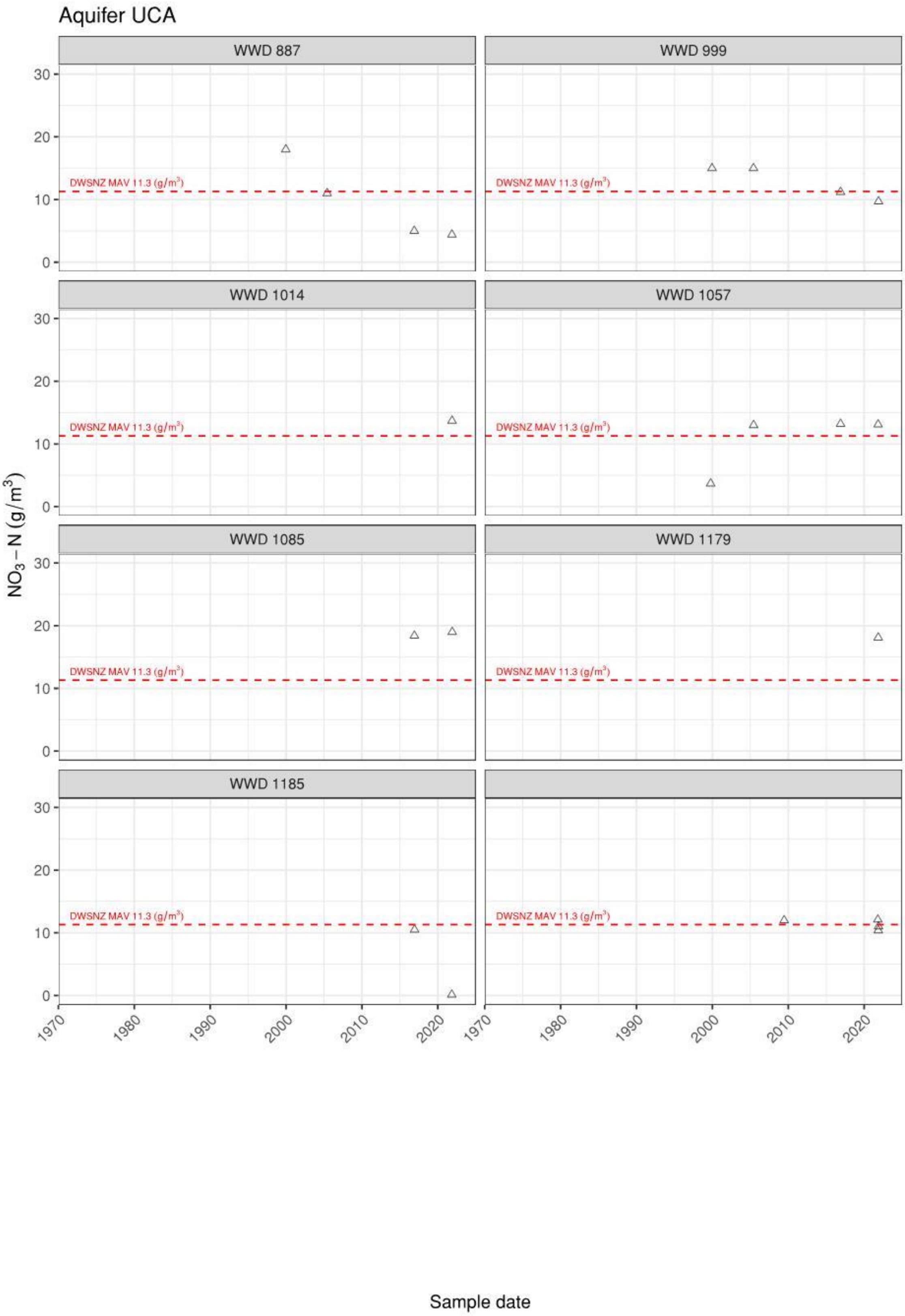
Aquifer HU
WWD 16
WWD 127
WWD 152
WWD 182
WWD 190
WWD 194
WWD 214
WWD 219
WWD 225
WWD 234
DWSNZ MAV 11.3 (g/m³)
NO3 − N (g/m³)
Sample date
0
10
20
30
1970
1980
1990
2000
2010
2020

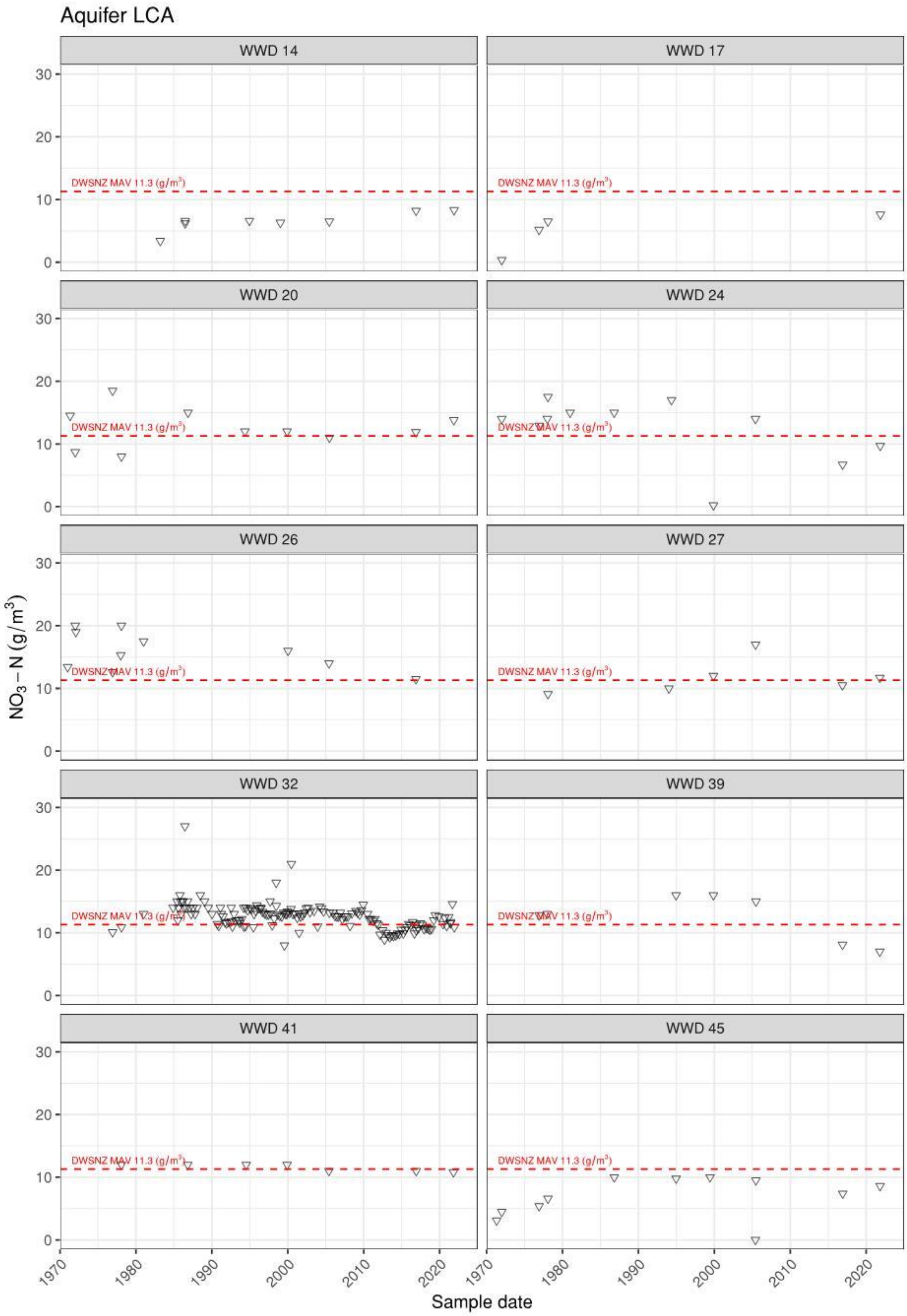


Aquifer HU
WWD 455
WWD 583
WWD 661
WWD 768
WWD 885
WWD 888
WWD 901
WWD 921
WWD 926
DWSNZ MAV 11.3 (g/m³)
NO3 – N (g/m³)
Sample date

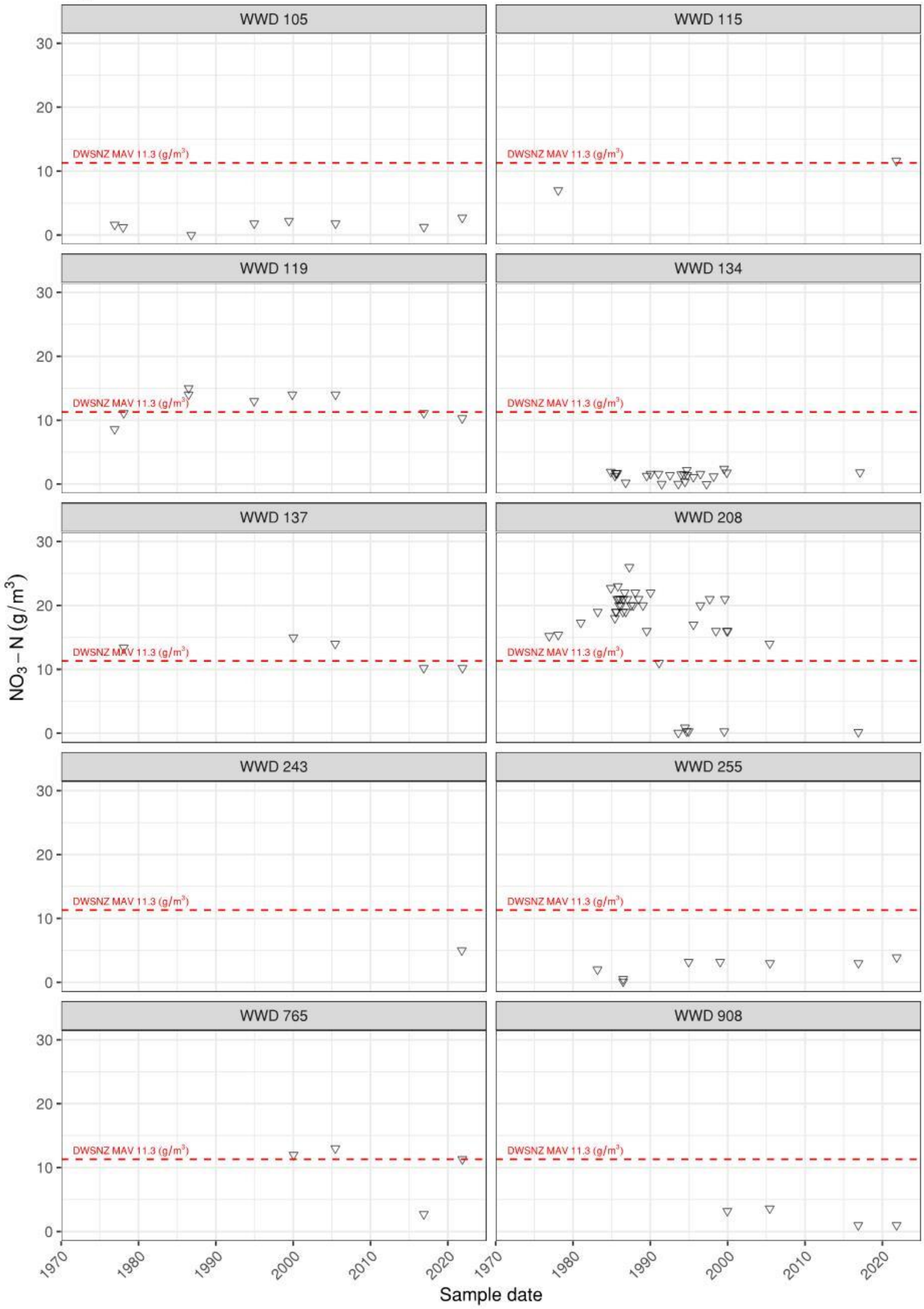

Aquifer UCA
WWD 37
WWD 59
WWD 66
WWD 68
WWD 151
WWD 153
WWD 159
WWD 164
WWD 175
WWD 176
DWSNZ MAV 11.3 (g/m³)
NO3 − N (g/m³)
Sample date
0
10
20
30
1970
1980
1990
2000
2010
2020


Aquifer UCA
WWD 189
WWD 239
WWD 340
WWD 471
WWD 499
WWD 500
WWD 502
WWD 523
WWD 566
WWD 866
DWSNZ MAV 11.3 (g/m³)
NO3 − N (g/m³)
Sample date
0
10
20
30
1970
1980
1990
2000
2010
2020

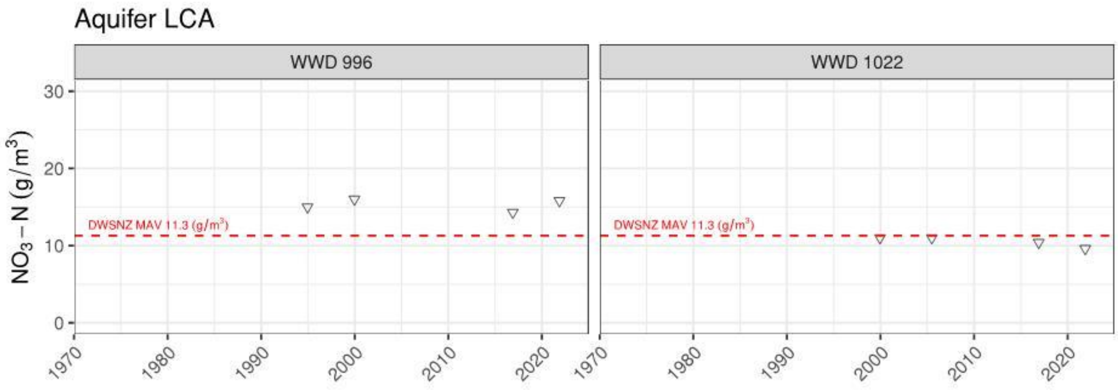

Aquifer UCA
WWD 887
WWD 999
WWD 1014
WWD 1057
WWD 1085
WWD 1179
WWD 1185
DWSNZ MAV 11.3 (g/m³)
NO3 − N (g/m³)
Sample date


Aquifer LCA
WWD 14
WWD 17
WWD 20
WWD 24
WWD 26
WWD 27
WWD 32
WWD 39
WWD 41
WWD 45
DWSNZ MAV 11.3 (g/m³)
$NO_3 - N$ (g/m³)
Sample date
0
10
20
30
1970
1980
1990
2000
2010
2020

Aquifer LCA



WWD 105
WWD 115
WWD 119
WWD 134
WWD 137
WWD 208
WWD 243
WWD 255
WWD 765
WWD 908
DWSNZ MAV 11.3 (g/m³)
NO3 − N (g/m3)
Sample date


Aquifer LCA
WWD 996
WWD 1022
DWSNZ MAV 11.3 (g/m³)
DWSNZ MAV 11.3 (g/m³)
NO3 − N (g/m³)
30
20
10
0
1970
1980
1990
2000
2010
2020

Sample date