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Marlborough Groundwater and Connected Surface Water Nitrate State of the Environment Report.

MDC Technical Report No: 21-003

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Executive Summary

Long term median Marlborough Nitrate-N concentrations in groundwater and hydraulically connected surface waters are relatively low by national standards and generally showing a declining trend with time consistent with a change to less intensive land-uses (vineyard). However long-term median Nitrate-N concentrations in groundwater at Wairau Valley, Tuamarina River Valley and Rai River Valley are moderately high from an aquatic ecology health perspective. A more detailed analysis of how recent Nitrate-N concentrations match the pMEP aquatic ecology targets will be contained in a follow-up 2021 MDC scorecard. Because of the diffuse way in which Nitrate-N enters groundwater, the most effective management approach to achieve pMEP quality targets are land use nutrient limits. Confined aquifers are natural sinks for Nitrate-N. The current pMEP permitted activity limit for Nitrate-N is much higher than current usage and probably historical usage also.

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1. Introduction

Nutrients are used in agriculture to maintain soil fertility and also come from human or natural decomposing wastes. A real issue for some New Zealand aquifer systems and their associated groundwater fed surface waterways is the nutrient nitrogen.

When we refer to nitrate and nitrate concentrations in water we are referring to Nitrate-Nitrogen concentrations, i.e. the nitrogen concentration of nitrate. The term used in this report is Nitrate-N to avoid confusion with European standards and literature or other forms of nitrogen.

Natural or pre-European levels of Nitrate-N in New Zealand aquifers were likely to be less than 1 g/m^3 (Rosen & White 2001). Nitrate-N levels in rivers draining pristine native bush catchments in Marlborough are much less than 1 g/m^3, which also reflects dilution by the large flows of rivers like the Wairau River.

The MDC state of the environment programme tracks the levels of other nutrients including phosphorus and sulphate. Phosphorus can affect the health of wetlands and rivers but to date MDC SoE survey results show most phosphorus is locked up in the soil layer as low levels are measured in Marlborough groundwaters. While there is a potential future risk to groundwater, its current immobility means it isn’t a priority for inclusion in this SoE report.

Sulphate is another nutrient measured as part of the SoE programme and is also a compound derived from sulphur used to control disease in vineyards. Its occurrence and fate in Marlborough aquifer systems is still to be analysed in detail and won’t be discussed in this report.

The focus of this document is nitrogen given its priority in the NPS for Freshwater Management, the presence of elevated Nitrate-N in some Marlborough aquifers relative to other nutrients, and its national profile in alluvial aquifers similar to those that occur locally.

High levels of Nitrate-N in Canterbury aquifers has been reported in the Christchurch *Press* newspaper for some time now and avoiding that situation from occurring in Marlborough should be a priority for MDC, the community and agriculturalists.

As well as satisfying the MDC requirements for annual reporting on the State of the Environment (SoE) monitoring programme for groundwater quality, this report was prepared in response to an internal request from MDC Assets and Services group for an update on Nitrate-N levels in Marlborough groundwater in relation to municipal water supply drinking guidelines.

Nitrate-N is expensive to treat in the quantities required for municipal supply. Prevention is the best approach by limiting rates of Nitrate-N added to the environment by human activities which is the main source.

Nitrous oxide (N_2O) is a nitrogen compound that is also a greenhouse gas so limiting the rate of artificial fertiliser use has other environmental benefits, not only protecting aquatic ecosystems or human health.

The focus of this report is the Wairau Plain where most of Marlborough’s aquifers and state of the environment (SoE) monitoring sites for groundwater quality and quantity are located. Knowledge of nutrient application rates and leaching on the river terraces of the Marlborough Sounds catchments is still in its infancy, with more records and observations needed to have a clear picture. Figure 1 shows the location of MDC groundwater quality SoE sites referred to in this report.

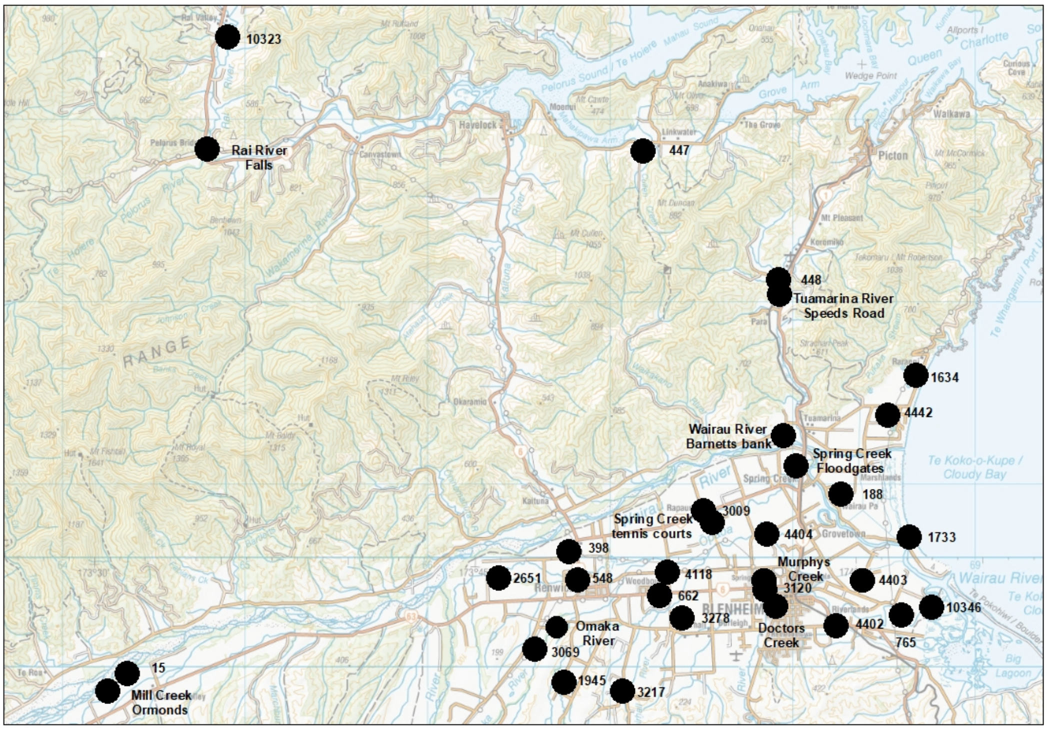


Figure 1: Map showing location and names of MDC SoE groundwater and surface water quality sites referred to in this report (MDC).

Notwithstanding this the report provides a district wide update of Nitrate-N levels and processes so the Marlborough Sounds catchments, Wairau Valley and Tuamarina River Valley are included. Apart from differences in rainfall and land use, the aquifer formations and Nitrate-N leaching processes are similar across Marlborough province.

2. Sources of Nitrate-N in Marlborough Groundwater

2.1. Marlborough Leaching Processes

Most of MDC’s knowledge and observations come from the Wairau Plain. This is the location of the Plant & Food Research field trials, where most MDC SoE sites are located and where MDC has the most comprehensive understanding of aquifer processes. However most hydrological concepts associated with the predominant alluvial aquifer type will apply regardless of their location in Marlborough.

Since about 2005 the Wairau Plain has effectively had a single agricultural crop type which is grape plants. As application rates of fertiliser for mature grape plants are likely to be similar regardless of vineyard location, this simplifies the study of Nitrate-N losses to groundwater in terms of nitrogen inputs (Figure 2).

Confirmation is needed of differences in fertiliser application throughout the life of a vineyard based on grower’s diaries and this is something MDC will work with Wine Marlborough on. Farm plans will be useful here also. It’s possible that young grape plants require more fertiliser to get them established.

Differences in aquifer Nitrate-N concentrations are likely to reflect spatial differences or temporal changes in climate, aquifer through-flow or soil type. While a single agricultural crop simplifies the analysis of the drivers of aquifer nitrogen levels in space and time, complex processes are at work, especially in the soil layer.

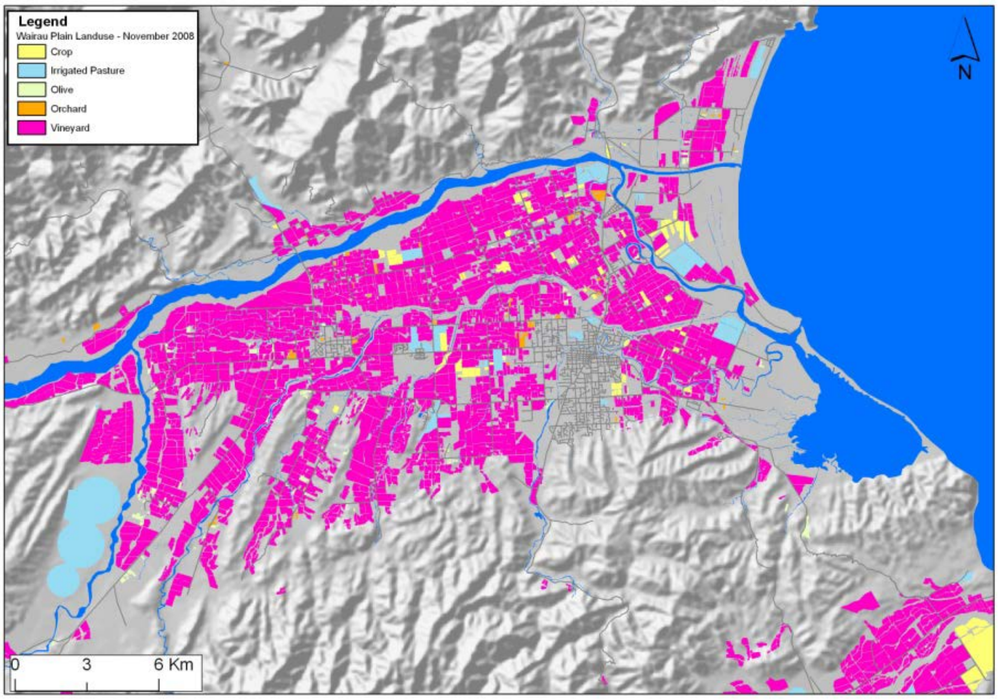


Figure 2: MDC map of Wairau Plain vineyard area 2008 produced by MDC based on ground surveys.

Plant & Food Research defined the Nitrate-N leaching losses for the main New Zealand agricultural crops for MDC in 2014 (Plant and Food Research - 2014). The research showed viticulture has the lowest leaching rates which are an order lower than irrigated dairying or arable cropping for the same land area (Figure 3). These Nitrate-N rates are generally accepted and based on direct field measurements under New Zealand conditions. The variation is larger for cropping and variants of dairying as the whisker lines show.

Irrigated vineyard leaches Nitrate-N and this is an important point meaning current practices are adding more nitrogen to the land than plants can take up or the soil processes can assimilate. Elsewhere in the province away from the Wairau Plain, pastoral farming is still an important land use and Nitrate-N leaching rates to groundwater will be higher based on the loss rates in Figure 3.

Because local hydrology is not as well investigated for the Marlborough Sounds catchments, Nitrate-N transfer pathways to groundwater and inter-connected surface water ways is not as well understood there yet.

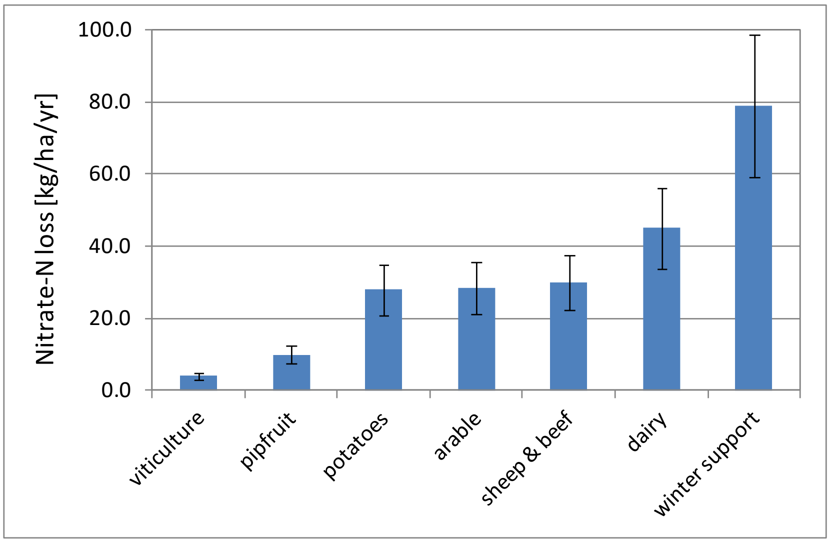


Figure 3: Nitrate-N loss for different land-uses/crops based on direct field measurements under New Zealand conditions (Plant & Food Research 2014).

The presence of elevated or high levels of Nitrate-N in groundwater is a sure sign of human activities. Most nitrogen is generated by intensive human settlement or farming activities at the land surface with Nitrate-N levels highest in shallow wells based on MDC SoE survey results (Figure 4).

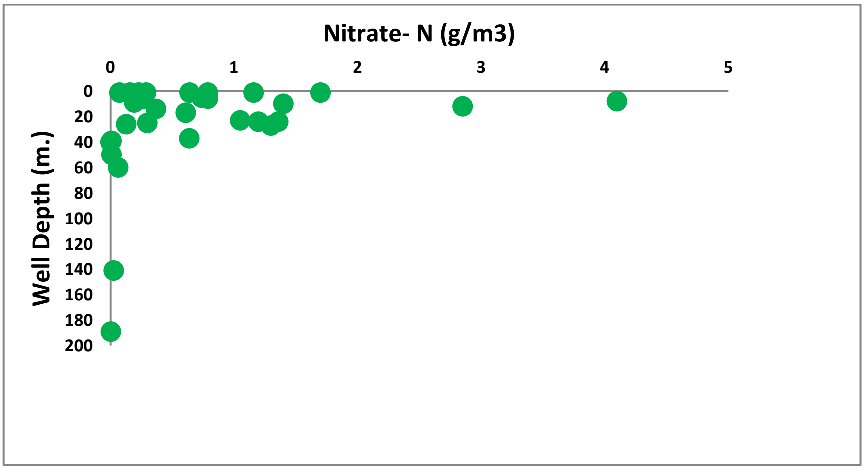


Figure 4: MDC SoE Programme Median Nitrate-N concentration versus well depth.

Conversely, denitrification results in low Nitrate-N concentrations in groundwater that has an absence of oxygen and organic matter, such as very deep groundwater or groundwater in the vicinity of peat deposits (as occur at Rarangi).

2.2. Wairau Plain Nitrate-N Drainage Measurements

In 2011 MDC commissioned Plant & Food Research to directly measure nutrient leaching rates under irrigated vineyard at a specially established drainage trial in Giffords Road on the northern Wairau Plain at Rapaura. This site represented the vineyard dominated area of the Wairau Plain overlying the unconfined and transmissive Wairau Aquifer. The lysimeters didn't intercept gravels and were above the groundwater table.

An array of drainage flow meters (DFM) were buried beneath the surface, but above the water table under the inter-row and beneath the grape plants (Figure 5). The drainage meters intercepted soil water and the mass of Nitrate-N was calculated based on laboratory analysis of the samples.

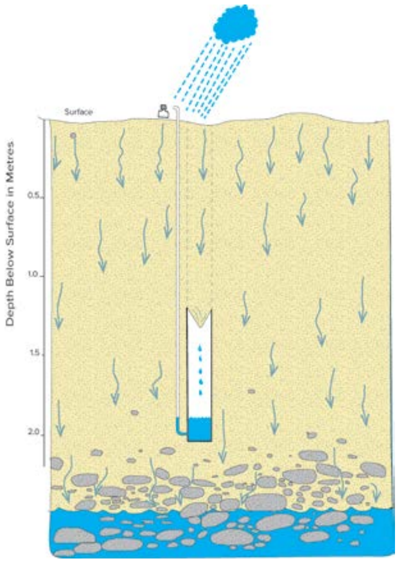


Figure 5: Section of Rapaura Plant & Food Research trial nutrient drainage collector (MDC).

Results showed Nitrate-N leaching does occur under irrigated vineyard but at low rates (Plant & Food Research - 2014) (Figure 6). Figure 6 shows the measured concentrations of Nitrate-N from the drainage array for the early part of the field trial.

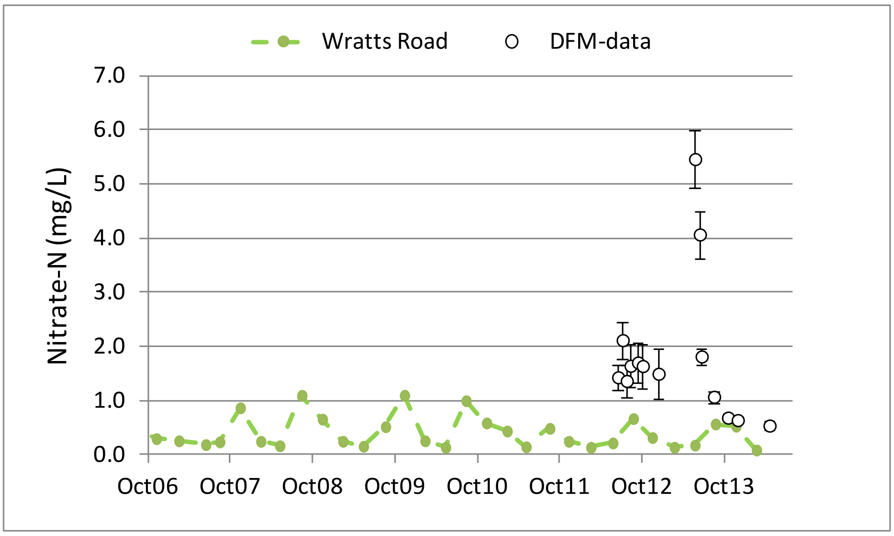


Figure 6: Measured concentration of Nitrate-N in soil water versus Nitrate-N (parts per million) in groundwater under irrigated vineyard at the downstream MDC Wratts Road well 3009. DFM stands for drainage flow meter (Plant & Food Research - 2014).

Nitrate-N concentrations in soil water are reduced by dilution as the soil water mixes with groundwater below the water table (Figure 6). This demonstrates the importance of understanding local differences in aquifer throughflow as they determine natural assimilative capacity in the saturated zone. Figure 7 shows the measured Nitrate-N losses expressed as a cumulative land surface application load. Less Nitrate-N is leaching to groundwater during drier months and drought seasons, demonstrating that while Nitrate-N application rates are the prime determinant, other factors are involved in mobilising it.

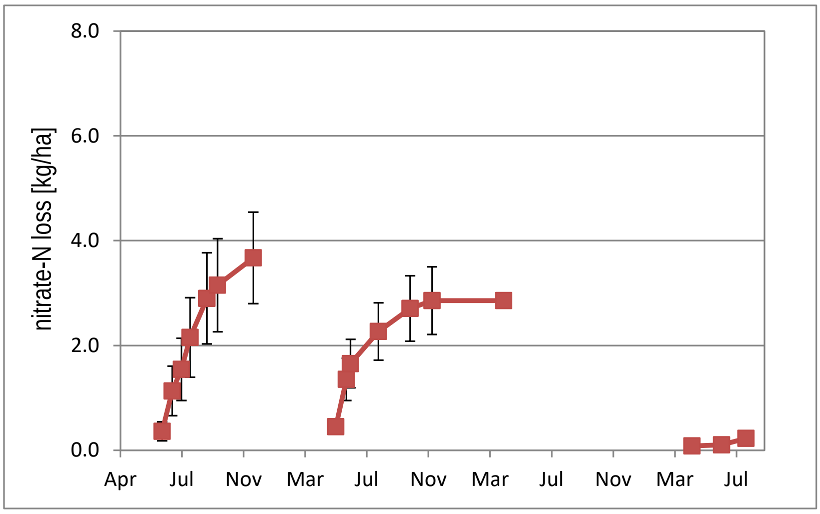


Figure 7: Cumulative Nitrate-N leaching rates expressed as equivalent mass of nitrogen applied per hectare at the land surface (Plant & Food Research - 2014).

The drainage rate of Nitrate-N was the equivalent of 4-5 kg/ha/year corresponding to an annual Nitrate-N application on the overlying land of around 15 kg/ha/year. Nitrate-N leaching is likely to occur under most Wairau Plain vineyards although at slightly different rates depending on the soil and climate at a particular site.

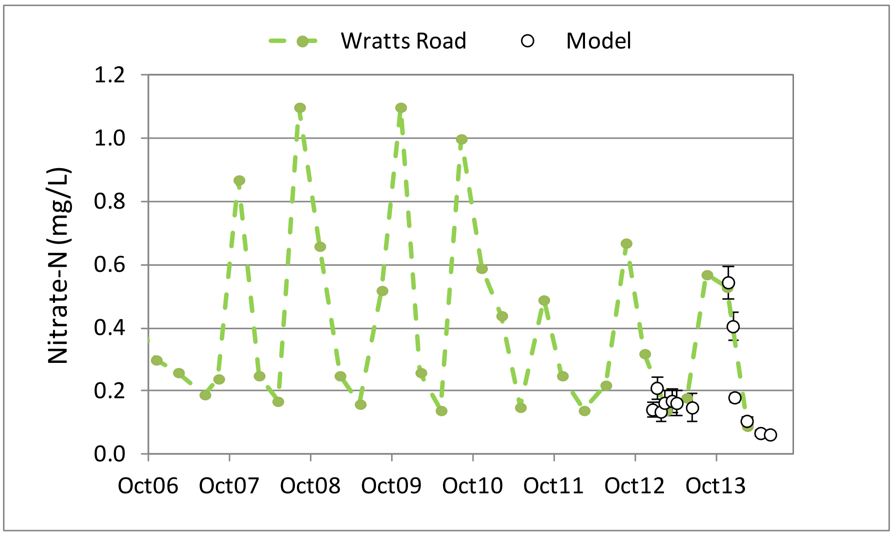


Figure 8: Modelled concentration of nitrate in soil water versus nitrate in groundwater at the downstream MDC Wratts Road well 3009 (Plant & Food Research - 2014).

Allowing for groundwater dilution and a travel time delay (Groundwaters of Marlborough – 2011), the Nitrate-N concentrations can be matched to those measured in groundwater at the downstream MDC Wratts Road monitoring well 3009 using an empirical approach (Figure 8).

2.3. Nitrate-N Use & Leaching Rates

It's a permitted activity under the proposed MEP (pMEP) to apply 200 kg of (total nitrogen) per hectare per year to the land surface, which will reduce to 190 kg under future national rules. This compares with typical applications of around 15 kg of Nitrate-N per hectare per year for the Spring Creek catchment based on known vineyard practice from the Plant & Food Research trial.

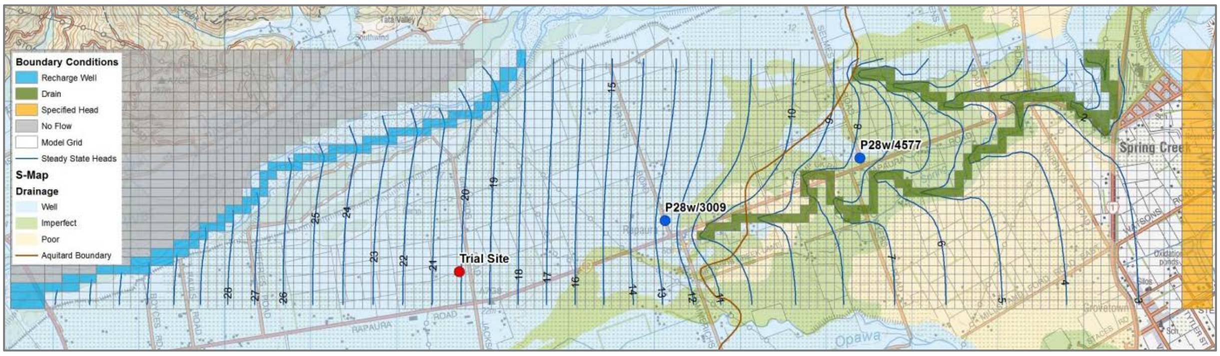


Figure 9: Plan view of Wairau Aquifer groundwater flow – contaminant transport simulation model domain (Lincoln AgriTech – 2015).

The current leached load can be calculated based on the known average concentration in groundwater of 0.3 g/m^3 Nitrate-N at MDC Wratts Road well 3009, multiplied by the average groundwater through-flow rate over a year. Figure 9 shows the aquifer plan area used to derive the Nitrate-N drainage rate. The map was part of the 2015 Lincoln Agritech Ltd report commissioned by MDC to investigate the sensitivity of Spring Creek channel flow to upstream land surface application rates of nitrogen. The map shows contours of groundwater elevation in metres above mean sea level.

The mean catchment flow rate based on gaugings at the Motorcamp site is 4 m^3/second or 126,144,000 m^3/year.

Land surface Nitrate-N leaching load = annual groundwater throughflow volume x groundwater Nitrate-N concentration

= 126,144,000 m^3/year x 0.3 g/m^3 Nitrate-N = 37,843,200 over 4200 hectares or 9,010 g Nitrate-N /ha/year (**~9 kg Nitrate-N /ha/year**)

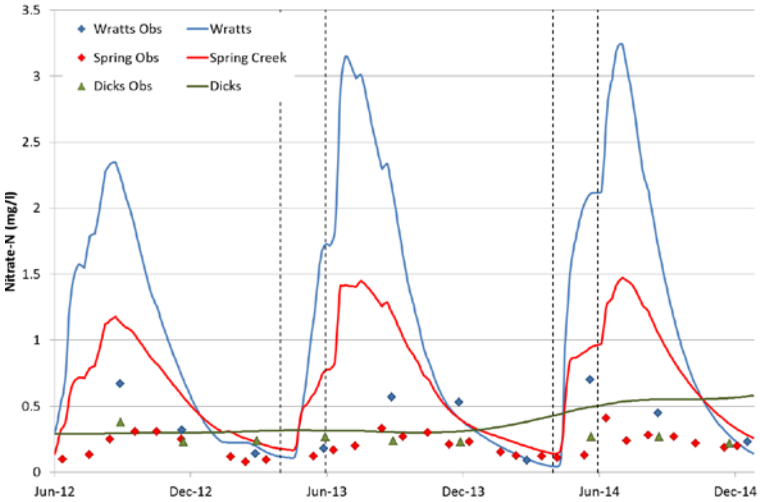


Figure 10: Northern Wairau Aquifer modelled nitrate concentration (Lincoln AgriTech – 2015).

An increase in land use intensity within the Spring Creek catchment was simulated by Lincoln Agritech by applying a hypothetical 50 kg Nitrate-N/ha/y to the soil (1/4 of permitted activity). The resulting concentration predictions based on MT3D simulations are graphed in Figure 10. The measured observations are marked by the discrete points and the continuous lines are the simulated values.

The simulated Spring Creek concentrations shown in red are predicted to increase to just under 1.5 g/m^3 during winter for a 50 Kg Nitrate-N/ha/y load. The median Spring Creek Nitrate-N concentration remains below 1 g/m^3, but the groundwater Nitrate-N concentration median in blue is likely to exceed the pMEP ecological threshold of 1 g/m^3. Levels in the confined aquifer east of SH1 are shown in green and are predicted to increase only slightly.

It's a useful exercise to manually calculate the Nitrate-N concentration of Wairau Aquifer groundwater if the MEP permitted activity loading of 200 kg/ha/year was actually used in the capture zone/groundwater catchment for Spring Creek assuming 50 kg/ha/year leached.

50 kg Nitrate-N over 4200 hectares = 210,000,000 kg/year

Diluting this mass of Nitrate-N by the annual groundwater throughflow of the groundwater catchment would result in an average concentration in groundwater or connected surface water of 1.7 g/m^3

= 210,000,000 g/ Nitrate-N year **/** 126,144,000 m^3/year

= 1.7 g/m^3 Nitrate-N

This is similar to the concentration derived from the modelling.

3. Nitrate-N limits in Groundwater

This section provides background to the Nitrate-N concentrations that are of concern and why. These are:

- The Maximum Allowable Value for drinking-water supplies based on the health effects during pregnancy and for bottle fed infants. The Maximum Allowable Value (MAV) for Nitrate-N is 11.3 g/m^3 (DWSNZ 2005/2018).

  The drinking water standard is under review and recent publications suggest a substantially lower value might be needed to prevent increased incidence of bowel cancer (e.g. Schullehner et al. 2018). However in 2019 in a letter to the NZ Ministry of Health, the World Health Organisation (WHO) didn't consider the evidence from various studies it had reviewed warranted a change to the DWSNZ 2005/2018 MAV of 11.3 g/m^3 Nitrate-N (WHO – 2019).

- Aquatic health guidelines in surface waterways that are sourced from groundwater. The Nitrate-N objective in the proposed Marlborough Environment Plan (pMEP) has an annual median concentration of less than or equal to 1 g/m^3 and an annual 95 percentile of less than or equal to 1.5 g/m^3 as measured by the MDC State of the Environment monitoring programme (Objective 15.1b). The 2 thresholds are shown in Figure 11 in relation to Nitrate-N measurements for MDC SoE site 447 at Linkwater in the Marlborough Sounds.

  Nitrate-N pollution of shallow aquifers layers in Canterbury is a real issue and affects similar alluvial aquifer systems to those that exist in Marlborough. These shallow aquifer layers supply most of the flow of spring fed streams.

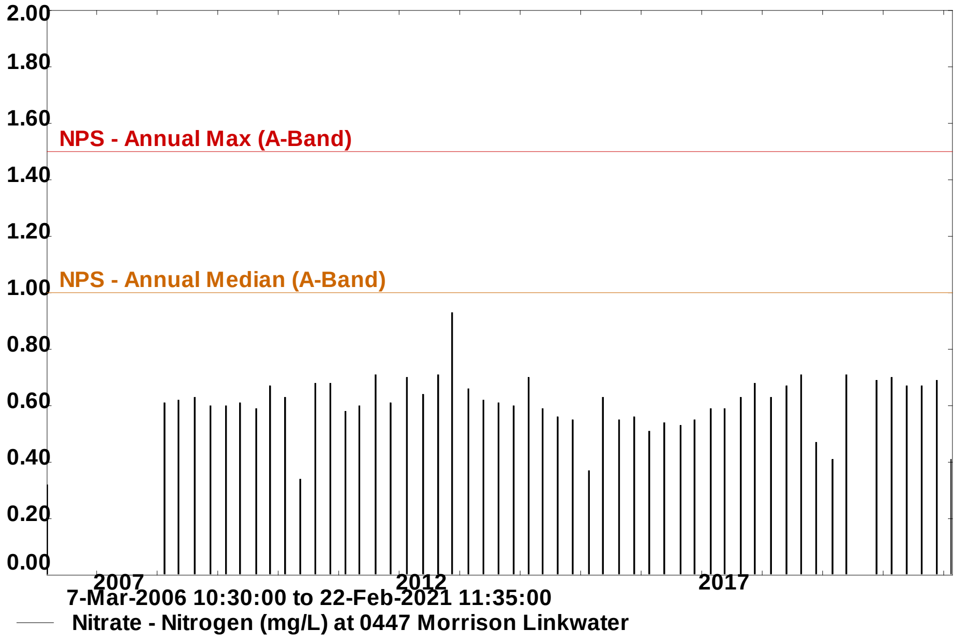


Figure 11: Proposed Marlborough Environment Plan (pMEP) surface water related ecological thresholds applied to MDC SoE groundwater quality monitoring site 447 at Linkwater 2006 – 2021.

4. Spatial Patterns of Nitrate-N in Marlborough Groundwater

4.1. Nitrate-N Levels in Marlborough Groundwater

Results from the MDC SoE programme show levels of Nitrate-N in Wairau Plain aquifers are relatively low by national standards, although they have been higher historically reflecting changes to less intensive agricultural land uses and drier climatic conditions in recent times.

Alluvial aquifers in provinces dominated by irrigated dairying or arable farming in Canterbury have significantly higher Nitrate-N values than the Wairau Plain aquifers based on recent 2021 articles in the Christchurch *Press* newspaper.

Notwithstanding this there are and have been occurrences of elevated to high values of Nitrate-N in groundwater in most local aquifer systems, including those beneath the Wairau Plain. High levels appeared to reflect a development phase of an agricultural system.

The SoE groundwater quality network away from the Wairau Plain isn’t currently representative enough and doesn’t have sufficient length of record to make definitive statements about the state/trends in groundwater Nitrate-N levels.

In particular MDC don’t have a complete picture of Nitrate-N levels in the river terrace and valley floor riparian aquifers of the Marlborough Sounds catchments. Measurements over a range of seasons and at several more SoE survey sites are required to provide a baseline picture.

While aquifer hydraulic properties and groundwater through-flow rates vary across New Zealand and between Marlborough aquifer systems, difference in Nitrate-N levels in groundwater are mostly explained by land use, in particular the surface loadings of artificial fertilisers or stock effluent/human waste.

Figures 12 and 13 show the median Nitrate-N concentration and range in Nitrate-N concentration respectively in groundwater and spring fed streams based on all MDC state of the environment (SoE) survey measurements.

The median Nitrate-N concentrations shown in Figure 12 are based on the entire record for that site and not just the most recent results. This is an important point as many Wairau Plain sites are showing downwards trends in Nitrate-N levels with time. The (pMEP) aquatic ecologic median limit in Section 3 is for annual periods. A separate report will report on the annual Nitrate-N statistics.

Each observation in Figures 12 and 13 marks the location of an SoE well used for sampling as part of the MDC groundwater quality State of the Environment monitoring programme. The well number or name of a hydraulically connected surface waterway is shown next to the symbol. The shortened version of MDC well numbers are referred to throughout this report (for example 188 refers to well 188 or P28w/0188 in full).

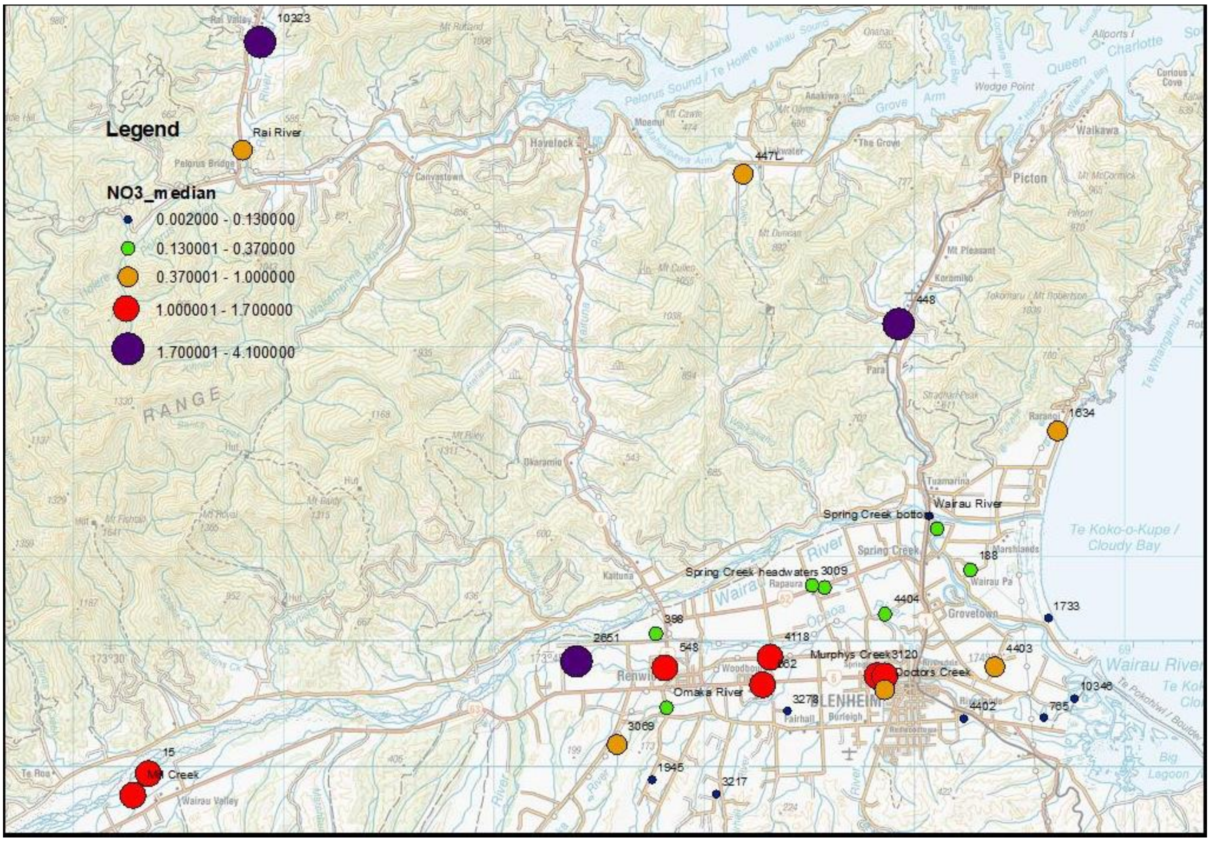


Figure 12: **Median Nitrate-N concentration in groundwater and hydraulically connected surface waters based on varying lengths of record depending on site. Annotations are MDC well number or name of connected surface water resource.**

There are low Nitrate-N levels across the northern Wairau Plain, with higher values straddling central areas, and low levels in the confined or semi-confined aquifers of the Southern Valleys catchments or coastal fringe. Median levels at Wairau Valley, Tuamarina River Valley and Rai River Valley are high. Median Nitrate-N levels are an order of magnitude lower than the human health Maximum Allowable Value (MAV) in the Drinking Water Standards for New Zealand (2005/2018) of 11.3 g/m^3 Nitrate-N for all sites.

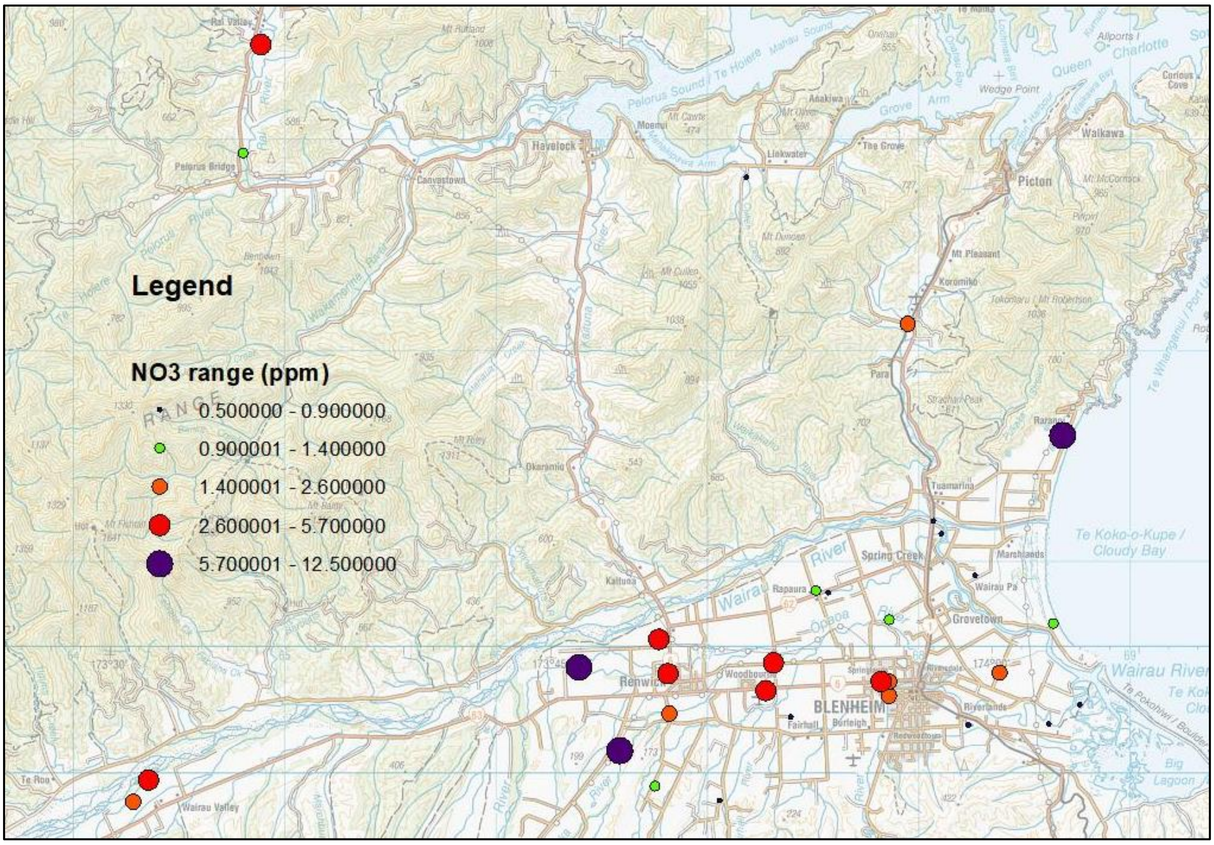


Figure 13: Range in Nitrate-N concentration in groundwater and hydraulically connected surface based on varying lengths of record depending on site. Annotations are MDC well number or name of connected surface water resource.

The seasonal and historic variation in Nitrate-N for a well or aquifer is important for understanding the land-use and climate drivers of leaching processes. Figure 13 shows the observed range in Nitrate-N values. This pattern mimics the median concentration in Figure 12.

A numbers of factors will be contributing to the range in Nitrate-N (Figure 13) both human and natural. Individual wells are not always representative of whole aquifers and reflect nearby land-use practices. The largest variations are associated with unconfined aquifers or in boundary areas with low transmissivity and less diluting or assimilative capacity (Figure 13).

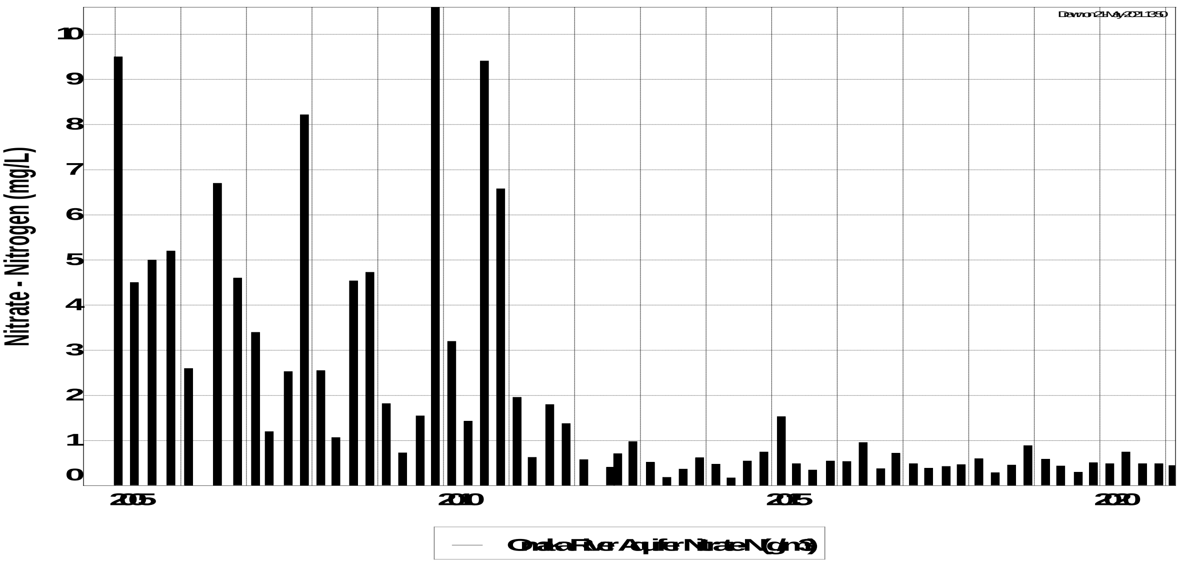


Figure 14: Seasonal Nitrate-N variation 2005-2020 for unconfined Omaka River Aquifer SoE well illustrating likely variability in fertiliser use over time (2005-2020).

There are also changes in fertiliser practice with time some of which are systematic such as those relating to crop maturity, and others that are likely to reflect personnel differences in agronomic philosophy between vineyards or wine companies.

An example of large changes in Nitrate-N leaching rates over time in an unconfined aquifer which are likely to be independent of physical processes is shown by Figure 14. Between 2005 and 2010 Nitrate-N concentrations measured in groundwater were excessively high and approached the human drinking water standard MAV of 11.3 g/m^3 Nitrate-N, while since then levels have been low.
The pattern doesn’t match the variation in natural drivers of Nitrate-N leaching or what has been observed at other SoE sites, and is likely to reflect changes in fertiliser practice as grape plants mature.

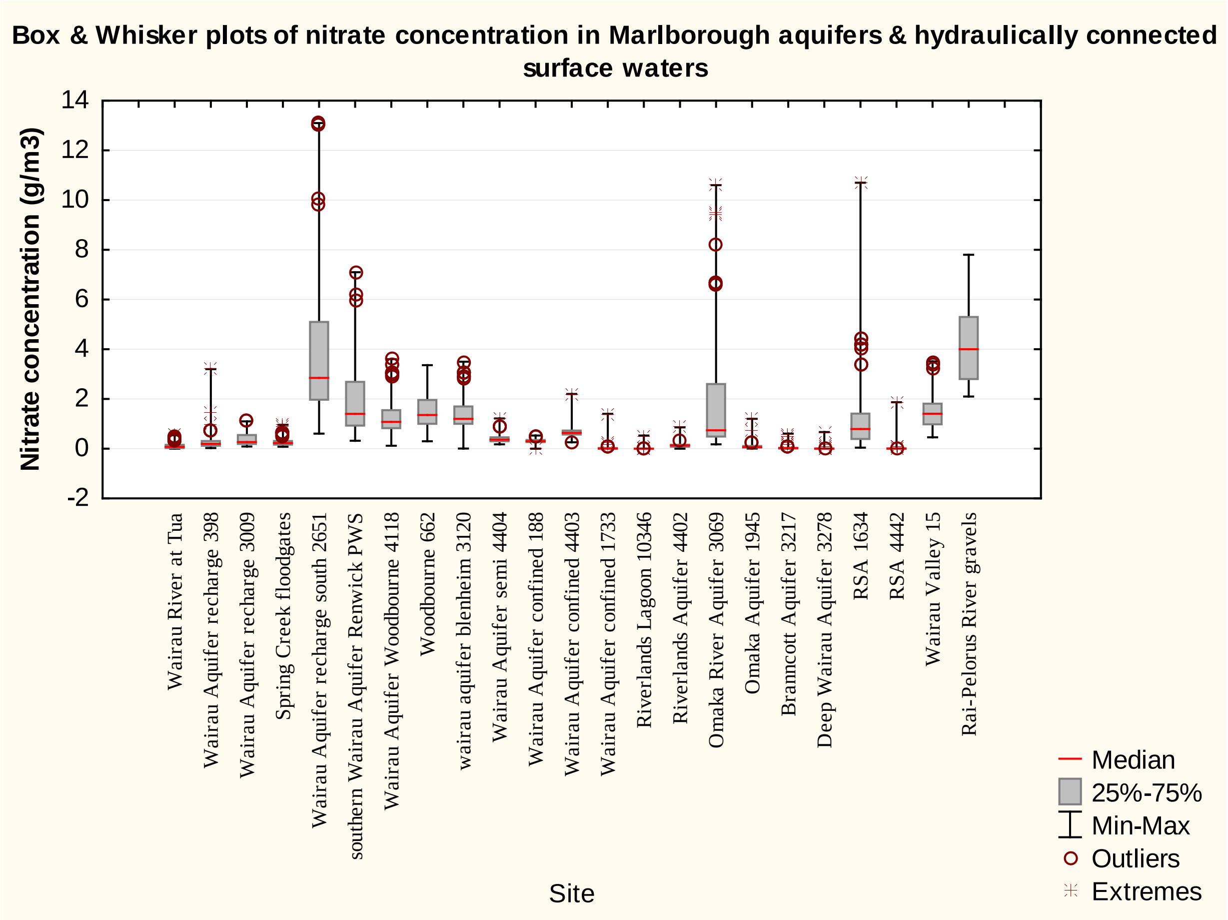


Figure 15: Median Nitrate-N concentration and range for MDC groundwater SoE network.

A visual way of assessing the relationship between Nitrate-N levels and water resource characteristics is by using box whisker graphs. Figure 15 features a series of box whisker plots showing the range in Nitrate-N levels signified by the length of the whiskers and median value marked by the red horizontal dash.

The box whisker plots are grouped together by aquifer or Freshwater Management Unit (FMU). Within each grouping the box whisker plots are ordered from left to right in the order of groundwater evolution. On the left hand side of Figure 15 is the Wairau River - Wairau Aquifer sequence beginning with dilute channel water which provides most Wairau Aquifer recharge.

The first 15 sites from the left map Nitrate-N concentration in groundwater along the travel path through the unconfined aquifer, groundwater fed streams/spring belt and confined aquifer at the Cloudy Bay or Riverlands coastal boundary to the east. Sites to right of and including “Omaka River Aquifer 3069” represent the Southern Valleys Aquifer suite, Rarangi Shallow Aquifer and Wairau Valley/Marlborough Sounds wells.

Figure 15 shows median Nitrate-N levels in groundwater are relatively low in Marlborough with the exception of sites along the southern boundary of the Wairau Aquifer, Tuamarina River Valley, Rai-Pelorus River Gravels and at Wairau Valley.

As expected, Nitrate-N levels and their ranges are low in the confined aquifers mainly because of natural denitrification processes, but also their relative isolation with the lack of external influences buffering changes. The degree of denitrification broadly reflects residence time. Groundwater in the deeper layers of the Southern Valleys Aquifer suite can be decades to tens of thousands of years old. The residence time of groundwater in the confined Wairau Aquifer and coastal Riverlands Aquifer is decades to hundreds of years old, which compares with a turnover time of less than a year for the unconfined Wairau Aquifer (GNS Science – 2019).

The box whisker plots show significant variations in measured Nitrate-N concentration within the unconfined parts of the Wairau Aquifer, Rarangi Shallow Aquifer and Omaka River Aquifer (Figure 15). This reflects a number of factors including Nitrate-N inputs running off from neighbouring catchments, changes in fertiliser practice over time and the response of unconfined aquifers to rainfall leaching.

4.2. Hydrogeological Influences

For the flat alluvial floodplain of the Wairau Plain or valley floors of the smaller catchments in Marlborough, rainfall induced gravity drainage is the main pathway for Nitrate-N reaching groundwater. Soil processes can modify what is leached and aquifer throughflow rates change the concentration of Nitrate-N in groundwater, but the primary determinant of aquifer Nitrate-N content is land-use. It follows that to limit groundwater Nitrate-N to acceptable levels at a regional catchment/aquifer scale requires landuse controls on agricultural activities and wastewater disposal practices.

Aquifer contamination from land surface activities is a diffuse process. Unlike rivers there is no simple way to intercept surface contaminants accompanying natural soil drainage to groundwater over large areas like the Wairau Plain or flood plains of river valleys. The most effective management approach is to limit the rate of Nitrate-N application to match plant needs, and avoid excess that can leach to groundwater.

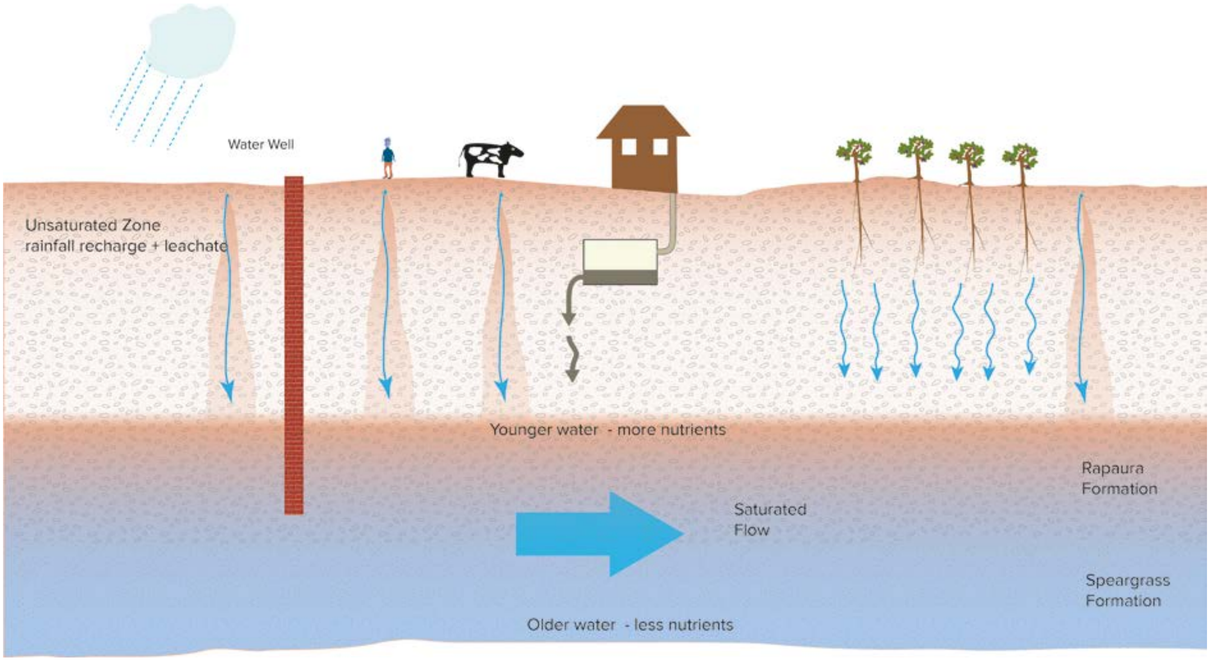


Figure 16: Diffuse nature of Wairau Plain nitrate transfer to groundwater with minimal runoff transfer pathways reflect flat terrane and relatively low to moderate rainfall.

Figure 16 shows conceptually how Nitrate-N at the surface is flushed to groundwater by rain or excessive irrigation water for local Marlborough alluvial aquifers. Irrigation induced leaching is less likely with the local vineyard dripper systems which are very efficient. Soil water entrains Nitrate-N which mixes with groundwater below the water table, where its concentration changes due to dilution and dispersion processes.

Nitrate-N concentrations in groundwater are also a function of local aquifer properties. Lower Nitrate-N levels are associated with the more transmissive gravels forming the northern Wairau Aquifer compared with the less permeable geology of southern areas of the Wairau Aquifer. Aquifers that receive river recharge tend to have lower Nitrate-N concentrations due to the diluting effect of the surface water also with low Nitrate-N.

Once Nitrate-N reaches the water table it moves at the same velocity as groundwater until reaching the break in land surface slope coinciding with the emergence of the mid-plain aquifer fed springs belt, becoming surface water. Aquifer structure strongly influences Nitrate-N pathways to groundwater. Unconfined aquifers have no physical barriers to pollutants like Nitrate-N draining from the land surface, except the assimilative capacity of the unsaturated zone/organic soil layer.

Figure 17 shows that for well 398 the highest Nitrate-N concentrations correspond with the highest groundwater elevations when rainfall/drainage rates peak and the water table is closest to the surface. Shallow groundwater has higher Nitrate-N concentrations.

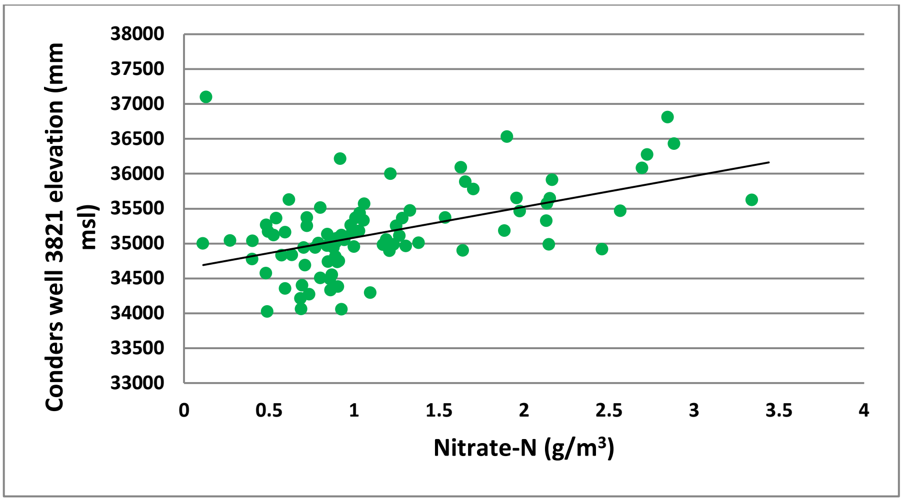


Figure 17**: Wairau Aquifer groundwater elevation in mm above mean sea level versus Nitrate-N concentration reflecting higher rates of leaching during wetter seasons when water table is closer to surface. Groundwater elevations from automatic recorder readings at MDC Conders permanent monitoring well 3821-398 corresponding with seasonal SoE surveys.**

Confined aquifers consist of a natural low permeability layer forming a barrier to surface pollutants. For example well P28w/0188 tapping the confined Wairau Aquifer in Dicks Road (Figure 18) receives recharge that left the surface approximately 5 kilometres upstream to the west. Because the aquifer is pressurised, the hydraulic gradient is upwards at depth.

Figure 18: Confined Wairau Aquifer well P28w/0188 at Dicks Road east of Spring Creek naturally free-flowing under artesian pressure.

Nitrate-N is the dominant form of nitrogen in the unconfined, oxygenated aquifers underlying the western half of the Wairau Plain. Conversely, groundwater beneath the eastern Wairau Plain is flowing through semi-confined or confined aquifers with natural reducing conditions where ammoniacal forms of nitrogen dominate (Figure 19). While recharge increases aquifer throughflow and the dilution effect, it is more than offset by rainfall leaching processes otherwise MDC wouldn't observe the spikes in Nitrate-N concentration in groundwater via its SoE surveys.

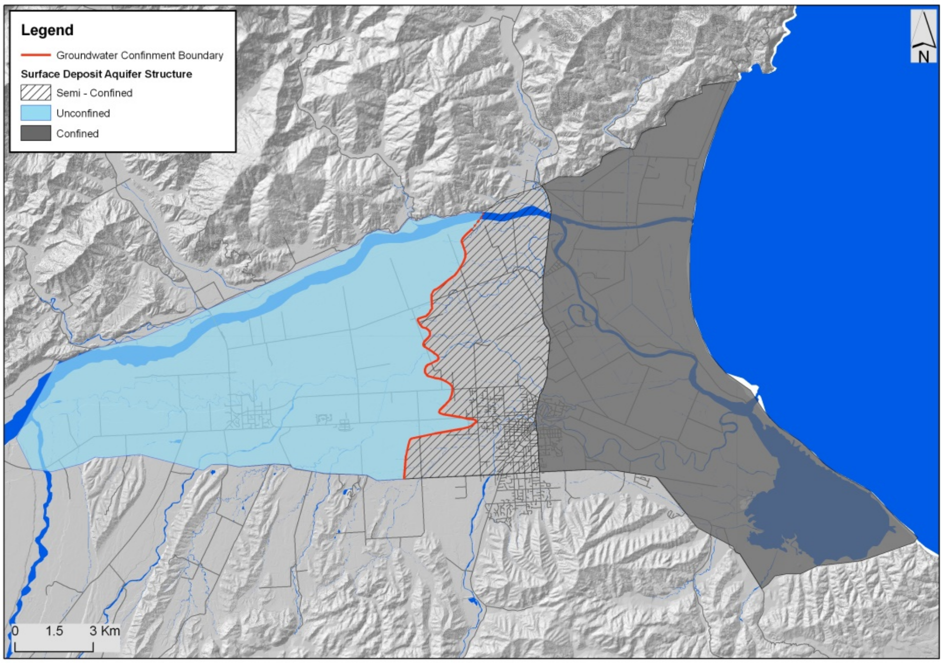


Figure 19: Northern Wairau Plain aquifer structure. Unconfined structure coloured light blue, confined structure in grey and semi-confined structure with grey cross-hatching (Groundwaters of Marlborough - 2011).

4.3. Accumulated Nitrate-N Concentrations Along Wairau Aquifer Flowpaths

As groundwater flows beneath the Wairau Plain from its recharge source in the west near Renwick, eastward to SH1 where most water re-emerges as spring flows; Nitrate-N would be expected to accumulate. This is because nutrients are added by land-use activities along the way, but the rate of underground flow and diluting capacity stay constant.

To check out the degree to which accumulation occurs and whether this needs to be incorporated into a future limit setting or nutrient allocation system, the Nitrate-N concentrations for each MDC SoE survey were over-plotted for a northern and a southern groundwater flow path depending on the well or river/stream/spring location.

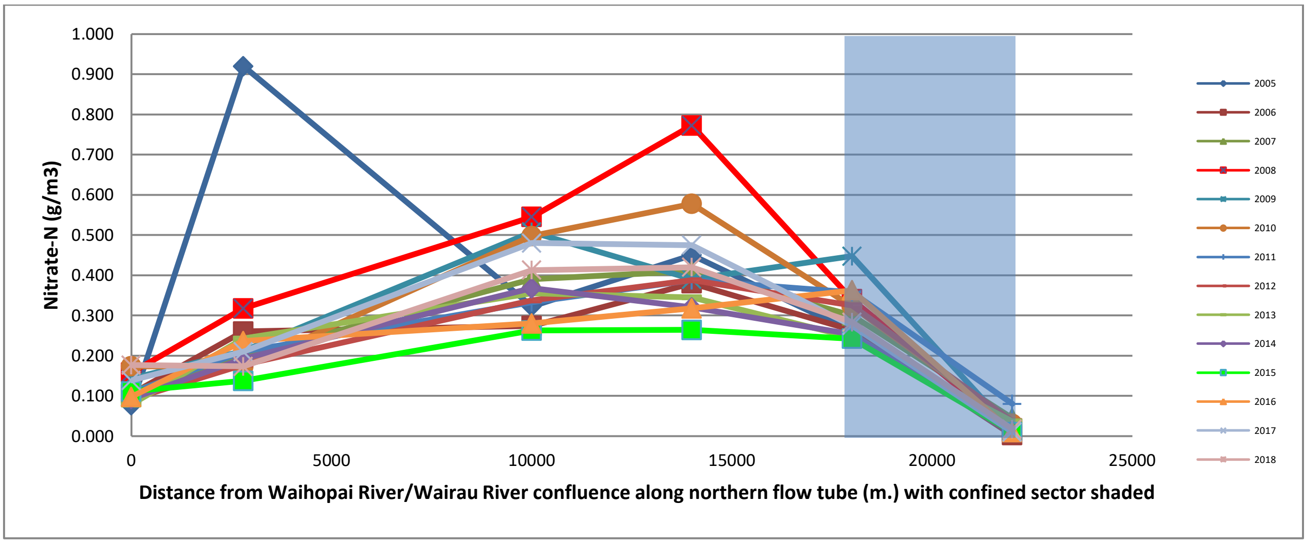
The wells comprising the northern flow path were: Wairau River at Tuamarina, MDC Conders well 398, MDC Wratts Road well 3009, MDC Mills & Ford Road well 4404, Dicks Road well 188 and MDC Bar well 1733. The wells comprising the southern flow path were: Wairau River at Tuamarina, well 2651, MDC Renwick well 548, Woodbourne well 4118, MDC Blenheim well 3120 and MDC Morgans Road well 4403.

The overplot of SoE surveys for the northern and southern Wairau Plain flowpaths is shown by Figure 20. The blue shaded area represents the confined part of the flowpath where denitrification processes dominate and Nitrate-N concentrations decrease naturally with distance inside the aquifer.

Part of the reason for lower Nitrate-N concentrations in the coastal confined aquifers of the Wairau Plain is due to the shallower Nitrate-N rich groundwater from the west being skimmed off into spring-fed streams and removed from the groundwater system before it reaches the deeper layers.

The coastal decrease in Nitrate-N is most apparent for the northern Wairau Aquifer flow-path as groundwater flow doesn’t change with no cross-boundary inputs of Nitrate-N from neighbouring catchments, as is the case for the Southern flow path.

As would be expected Nitrate-N levels decline within the confined portion of the aquifer for both flow-paths due to denitrification. The starting point for both flow paths is low Nitrate-N recharge water from the Waihopai or Wairau Rivers.



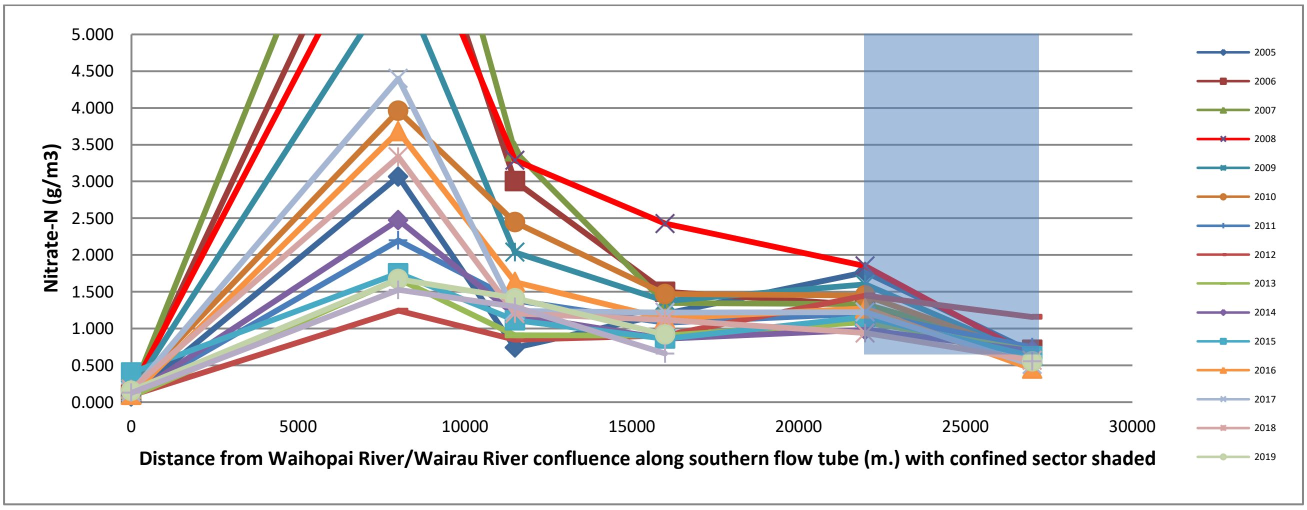


Figure 20: Overplot of groundwater Nitrate-N concentration by survey for Wairau Aquifer flow tubes. Northern flow tube at the top and Southern flow tube at bottom.

The concentration of Nitrate-N in groundwater transiting the southern flow tube is higher than for the northern flow path. This pattern reflects extra Nitrate-N originating from land surface activities in the neighbouring Southern Valleys catchments in conjunction with the reduced diluting capacity of lower groundwater through-flow rates for the southern flowpath. There is far less dilution from Wairau River recharge along the southern flow-path. Some Nitrate-N peaks can be traced through the confined layer but this doesn’t apply to the unconfined aquifer as leaching occurs simultaneously everywhere.

4.4. Natural Denitrification

Nitrate-N is the dominant dissolved form of nitrogen in groundwater where there is plentiful oxygen which is the case for the vast majority of local unconfined aquifer systems. This aquifer type dominates the western Wairau Plain and the upper/shallow layers of aquifers in most other parts of Marlborough. The exceptions are parts of the Rarangi Shallow Aquifer and Flaxbourne River Gravels which are oxygen deficient due to organic and biological activity associated with wetlands (Figure 21).

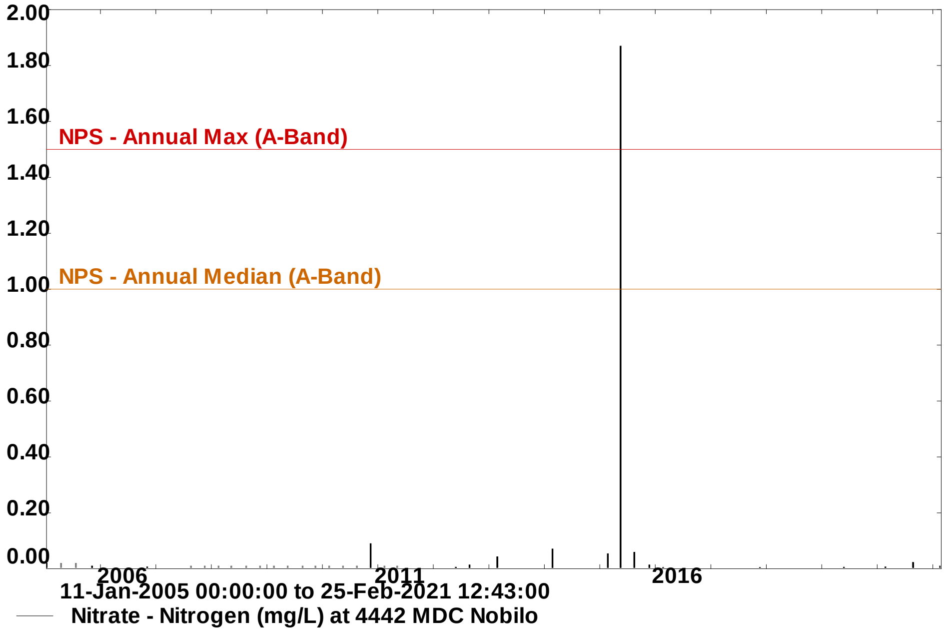


Figure 21: Rarangi Shallow Aquifer MDC well 4442 groundwater Nitrate-N 2005-2021. Generally low levels of Nitrate-N due to natural denitrification.

In confined aquifers and shallow aquifers with significant biochemical activity, ammonia is the dominant form of dissolved nitrogen. Nutrients like Nitrate-N and sulphate are redox sensitive meaning their stability changes in relation to pH and oxygen content of water. The good news is that Nitrate-N is consumed by the biochemical processes associated with the oxygen poor, reducing conditions naturally found in confined aquifers; making these aquifers a natural sink.

For example the confined Wairau Aquifer east of SH1 through to the Cloudy Bay coast converts Nitrate-N to nitrogen gas if the chemical process goes to completion, which is harmless to the atmosphere. Because most groundwater exits the Wairau Aquifer via the belt of mid-Wairau Plain springs rather than entering the confined aquifer, only a small fraction of groundwater is subjected to this natural treatment however.

The source of Nitrate-N is referred to throughout this report as the land surface as this is where artificial fertilisers are applied and the leaching process begins, however Nitrate-N is usually generated in the soil zone.

4.5. External Influences

The water budget for the northern Wairau Plain is dominated by groundwater recharged at a steady rate from Wairau River channel losses, with limited input from rainfall recharge (Taylor et al 1992 & GNS Science - 2019).

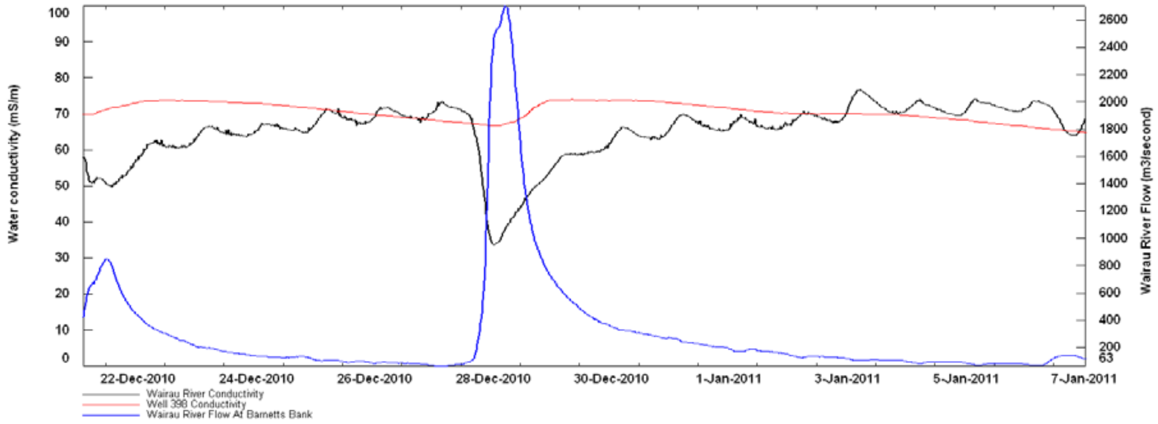


Figure 22: Electrical conductivity and flow of Wairau River at MDC Barnetts Bank recorder site (Tuamarina) 2009-2011 versus Electrical conductivity of MDC Conders well 398 groundwater representing Wairau Aquifer unconfined Recharge Sector.

This is supported by the chemistry of groundwater in shallow wells near the Wairau River being virtually identical to channel water, with the exception of low pH caused by local rainfall and soil zone infiltration processes. Figure 22 shows the electrical conductivity of river and groundwater are similar except during floods such as the December 2010 event when a flow of 2600 m^3/second delivered a pulse of dilute water down the channel.

Due to its distance from the Wairau River channel, well 398 wasn't directly influenced by the dilute recharge water, with an increase in electrical conductivity caused by local rainfall infiltration associated with the weather that generated the flood.

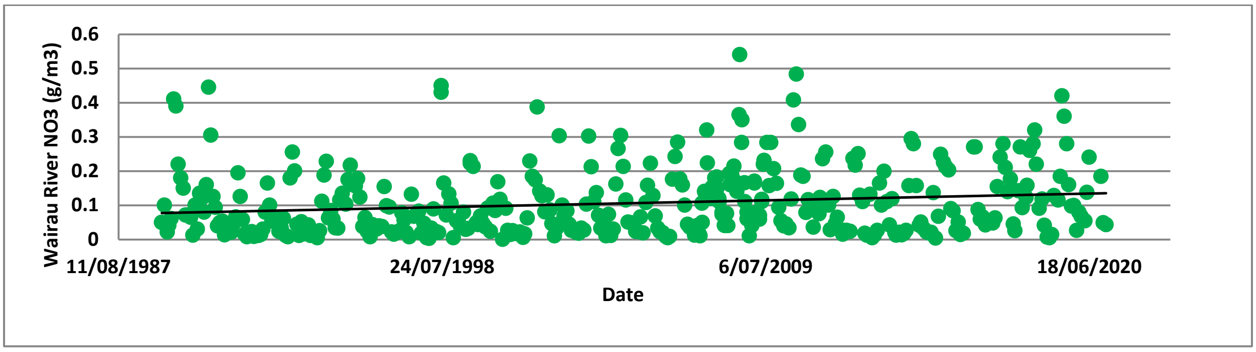


Figure 23: Nitrate-N concentration in Wairau River at Tuamarina 1987-2020.

Figure 23 shows an upwards trend in the Nitrate-N content of Wairau River water at SH1/Tuamarina at the bottom of the catchment since 1987. The cause is likely to be land-use intensification as channel flow is stable or has declined only slightly since 1960. The increasing trend in Nitrate-N is statistically significant based on the Mann-Kendall trend method (Appendix C). The median concentration of Nitrate-N in Wairau River water at this site is 0.077 g/m^3 which is very low which in part reflects the high median flow of the Wairau River at SH1/Tuamarina of 60 m^3/s.

Changes in the dissolved chemistry of Wairau River channel water are imparted on Wairau Aquifer groundwater. When analysing the cause of changes in Wairau Aquifer groundwater quality, the nature of Wairau River recharge water has to be subtracted to isolate land surface impacts on groundwater.

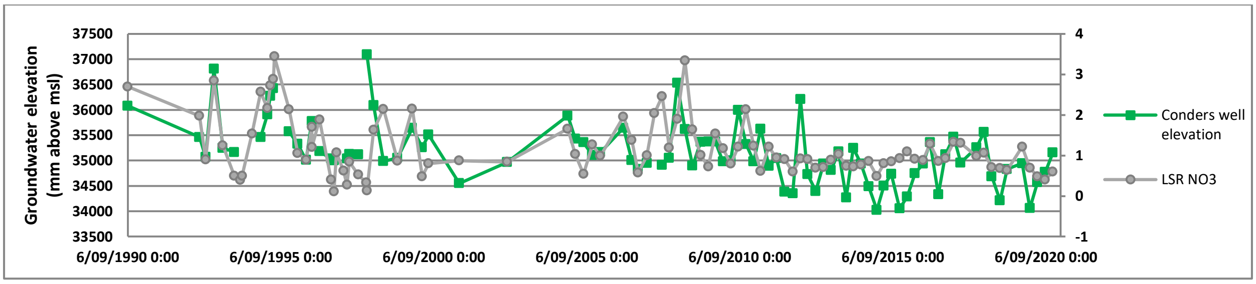


Figure 24**: Comparison of land surface Nitrate-N contribution to groundwater at MDC Wairau Aquifer Recharge Sector well P28w/1156-4118 with groundwater elevation at MDC Conders well P28w/0398. Grey line = Nitrate-N estimated from land surface recharge (ie, difference between Wairau Aquifer unconfined groundwater and Wairau River water). Green line = groundwater fluctuation at MDC well 398 approximately 1500 m. from Wairau River channel.**

The difference in Nitrate-N content between Wairau River and Wairau Aquifer water before most emerges via the mid-plains belt of springs, represents the land surface contribution. The grey line in Figure 24 shows the difference in Nitrate-N concentration of the Wairau River versus groundwater for well 1156/4118 north of Woodbourne from 1990 to 2020. Nitrate-N concentration is shown on the right hand vertical axis. Groundwater elevation at the MDC Conders well (398-3821) is marked in green and the scale is shown on the left hand axis in mm above msl.

Nitrate-N concentrations have declined slightly over time since 1990. There is a reasonable correlation between Nitrate-N concentrations and the variation in groundwater levels, with less leaching in drier periods and more in wetter seasons (Figure 24).

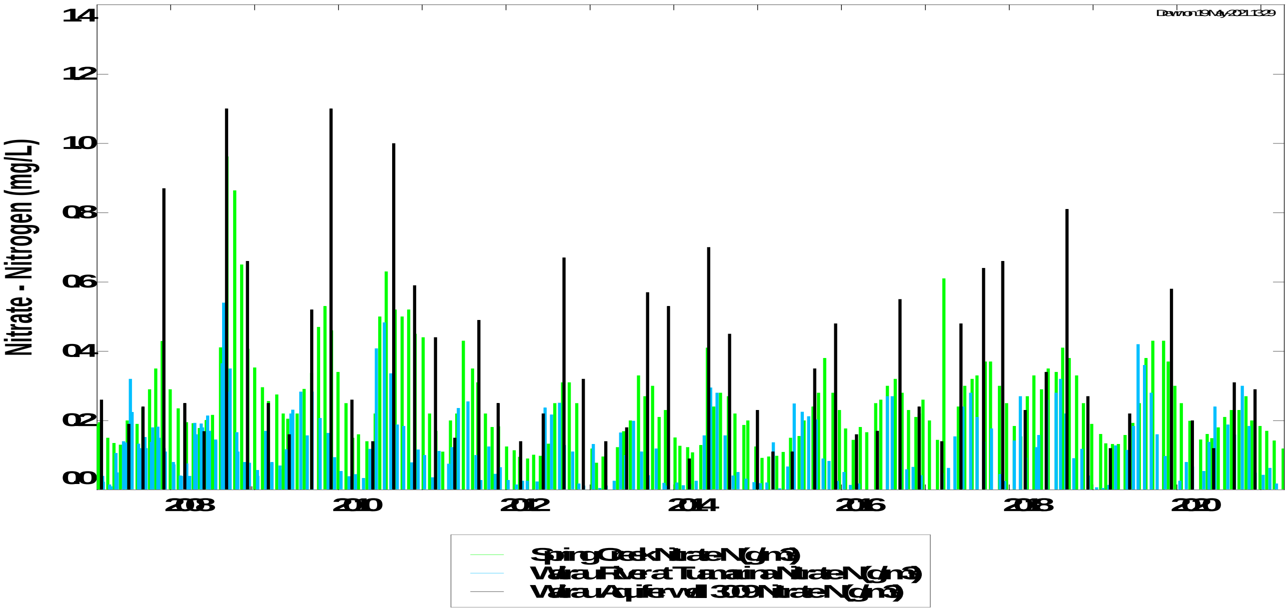


Figure 25: Seasonal pattern of Nitrate-N concentration in Wairau River at Tuamarina, lower reaches of Spring Creek at floodgates & Wairau Aquifer Recharge Sector groundwater at MDC Wratts Road well 3009.

Figure 25 shows Nitrate-N concentrations in groundwater at the Wratts Road well 3009 are slightly higher than the Nitrate-N content of Spring Creek channel water at the floodgates, and significantly higher than Wairau River recharge water. The difference between the Nitrate-N content of Wairau

River, groundwater and spring fed stream flow is the land use impact. The timing of Nitrate-N highs and lows are slightly advanced for the Wairau River, but similar for groundwater and Spring Creek (Figure 25).

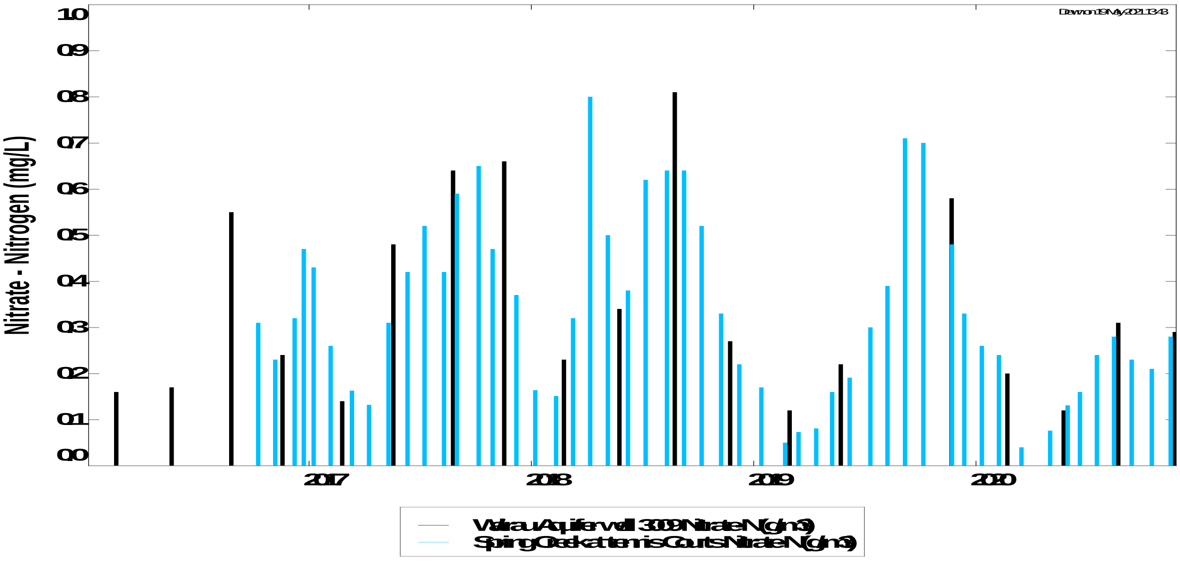


Figure 26: Seasonal pattern of Nitrate-N concentration in Wairau River, Spring Creek headwaters at tennis courts & Wairau Aquifer Recharge Sector groundwater at MDC Wratts Road well 3009.

Figure 26 shows a much closer match exists between Nitrate-N concentrations of Spring Creek headwaters (tennis courts) compared with groundwater from MDC Wratts Road well 3009; than for the lower reaches at the Floodgates, confirming they are the same water body. Further downstream where Spring Creek enters the Wairau River, Nitrate-N levels are lower due to inflows of pressurised, older groundwater that has taken a deeper flow-path with less land-use influence.

The consistency between groundwater and surface water concentrations shown in Figure 26 indicates the contribution of Nitrate-N running off is relatively small. This is consistent with Wairau River water being the dominant flux and recharge source based on isotope tracers (Taylor et al 1992), and the relatively small riparian land area compared to the total aquifer area.

Because the residence time of groundwater flowing through the northern Wairau Aquifer is very short (less than 1 year), any Nitrate-N present reflects current land uses, meaning legacy issues from historical land-uses can be ruled out (GNS Science - 2019). This demonstrates the importance of understanding the hydrology of an aquifer and the mean residence time for a catchment when interpreting water quality results.

4.6. Nitrate-N Concentrations in Groundwater Versus Hydraulically Connected Surface Waters

The baseflow of all northern Wairau Plain surface water-ways, with the exception of the artificially re-watered Ruakanakana (Gibson Creek) is re-emergent groundwater. During summer or dry seasonal conditions at any time of year, the quality/chemistry of groundwater and hydraulically connected surface water is similar for a particular location.

There are fewer direct perennial connections between surface water and groundwater in the Southern Valleys catchments of the Wairau Plain. This is because surface waters become hydraulically disconnected from groundwater.

A distinctive feature of groundwater fed springs is their clarity reflecting their groundwater origin. This contrasts with the turbid appearance of Ruakanakana (Gibson Creek) channel water caused by sediment rich Waihopai River, and to a lesser extent Wairau River inputs. Even when in flood the urban springs of Blenheim (Murphys Creek, Fultons Creek and Waterlea Creek) flow clear.

The degree of hydraulic connection between surface and ground waters in other parts of Marlborough is more varied than for the aquifer dominated Wairau Plain. This contrast can be explained by local hydrology, in particular the quantum difference between the moderately large flows of rivers versus underground flow, and its influence on solute concentration.

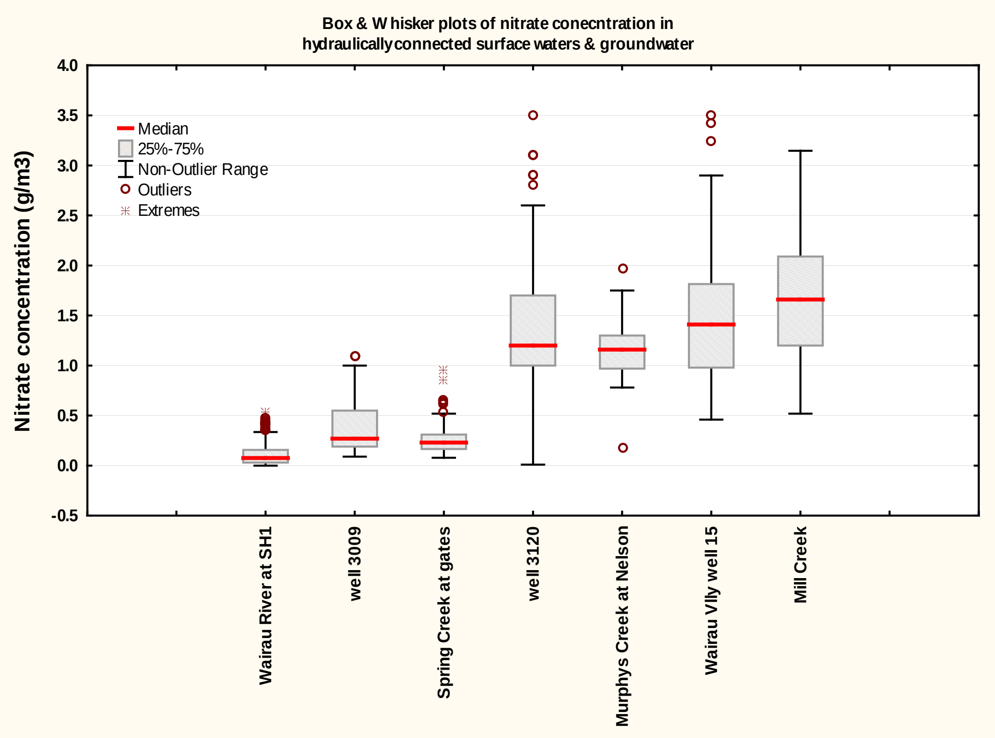


Figure 27: Three examples of interconnected water bodies exhibiting similar median Nitrate-N concentrations.

The box and whisker plots in Figure 27 show the similarity in median Nitrate-N levels for 3 groups of interconnected water bodies. The first group of 3 sites represents the shallow circulation of water associated with the northern Wairau Plain. The cycle begins with Wairau River recharge water moving underground into the Wairau Aquifer before re-surfacing again as Spring Creek flow. Well 3009 is used to represent shallow Wairau Aquifer groundwater (Figure 27).

Wairau River water contains the lowest median Nitrate-N concentration and smallest range. Shallow groundwater and Spring Creek water have similar median Nitrate-N concentrations of about 0.2 g/m^3, slightly higher than river water reflecting differences in land-use inputs.

The next group to the right feature shallow groundwater emerging as springs in the western outskirts of Blenheim (Figure 27). The median Nitrate-N levels of Murphys Creek channel water in central Blenheim is the same as groundwater from the MDC Middle Renwick Road public water supply wellfield (well 3120).

Interestingly the range is higher for the well than the spring, perhaps because pumped groundwater is induced from a larger radius than the catchment of the spring. Nitrate-N values are higher than for the Wairau River group because of the less transmissive gravels forming the southerly aquifer flow path and less diluting capacity.

The final pairing on the far right hand side is a Wairau Valley example involving shallow groundwater and Mill Creek channel flow. The median concentration of Nitrate-N for Mill Creek at the Ormond site is slightly higher than groundwater at the MDC Wairau Valley municipal well O28w/0015 (15), but the reason is unclear. The range in Nitrate-N concentration is the same for groundwater and surface water.

The message is that to preserve the quality of aquifer fed springs means maintaining the quality of groundwater by managing the effects of overlying land uses. The next analysis involves comparing the median Nitrate-N concentration for all sites in the MDC groundwater quality SoE programme, including related surface water sites monitored for Nitrate-N. In Figure 28 water bodies with the same colour belong to the same FMU and are hydraulically connected.

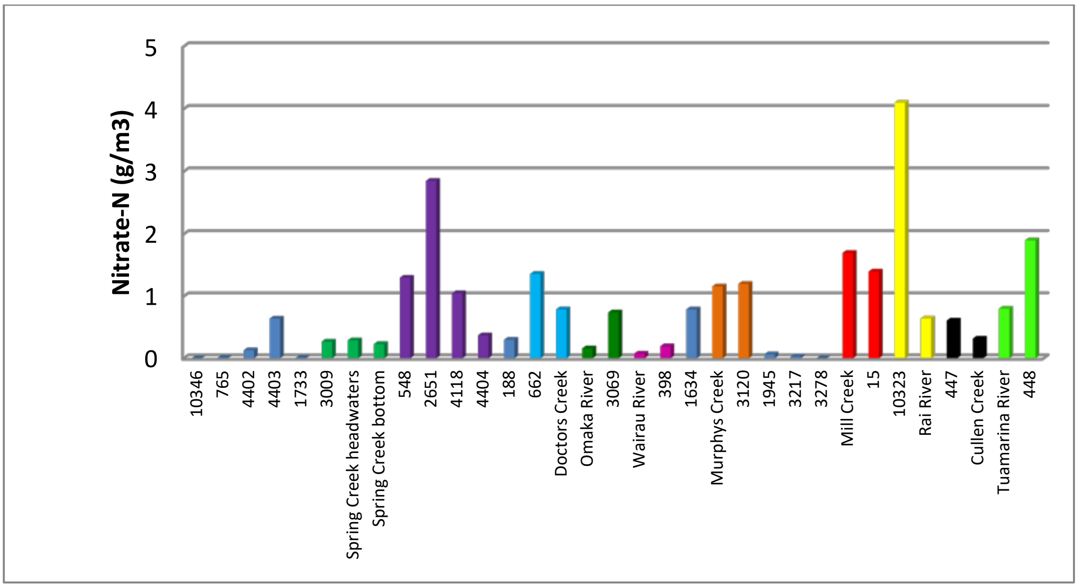


Figure 28: Median Nitrate-N concentration for Marlborough hydrologically paired water bodies with colour denoting those belonging to same FMU.

Not all water bodies sharing the same FMU have matching median Nitrate-N concentrations (Figure 28). For example well 2651 (purple) tapping the Wairau Aquifer west of Renwick exhibits much higher Nitrate-N levels than its neighbouring wells. This is thought to reflect drainage from the neighbouring Delta area introducing extra Nitrate-N into the aquifer along-with the low transmissivity of the southern boundary areas of the Wairau Aquifer.

Examples of where Nitrate-N concentrations are significantly different in groundwater versus surface water are the Rai River and Tuamarina River catchments (Figure 28). The terrace aquifer gravels transmit small flows of groundwater compared to the much large channel flows and as a consequence Nitrate-N levels are diluted in the Rai and Tuamarina Rivers. The dilution ratio is much higher for the Rai River due to its higher flows.

Nitrate-N levels are extremely low for sites representing confined aquifers shaded grey-blue (Figure 28). The land use overlying these aquifers is vineyard with the same Nitrate-N loading, but the confined aquifers are effectively natural sinks for Nitrate-N because of the chemical transformations that take place.

5. Temporal Trends in Nitrate-N

5.1. Seasonality

Aquifer through-flow rates and land-use Nitrate-N inputs are relatively constant, whereas leaching rates are variable. Nitrate-N leaching rates are strongly correlated with aquifer land surface recharge rates and in turn the depth to the groundwater table.

Average Wairau Plain rainfall is fairly evenly distributed throughout the year as Figure 29 shows; but potential evapotranspiration rates vary, resulting in limited land surface drainage during the drier months. Rainfall excess which is rainfall minus potential evapotranspiration drives leaching of land surface pollutants.

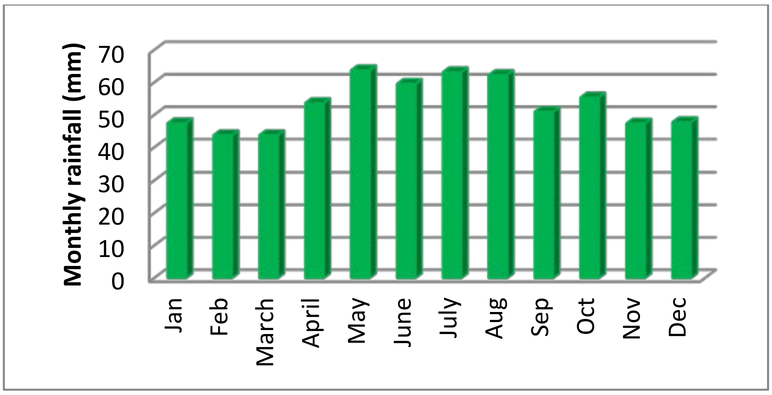


Figure 29: Marlborough Research Centre Grovetown long-term mean monthly rainfall.

This is illustrated by Figure 30 showing the monthly average rainfall for Blenheim in the top graph versus seasonal Nitrate-N concentrations at the MDC Wratts Road well 3009. The highest Nitrate-N concentrations were measured in the period from 2008 to 2010 following a period of high rainfall.

The current seasonal SoE surveying doesn’t provide the frequency for understanding shorter term relationships between rainfall intensity, duration and delayed response times for Nitrate-N leaching to groundwater. MDC have tried real time measurements of Nitrate-N using an automated probe in shallow wells at Rarangi with limited success and more work is needed in this area under Marlborough conditions.

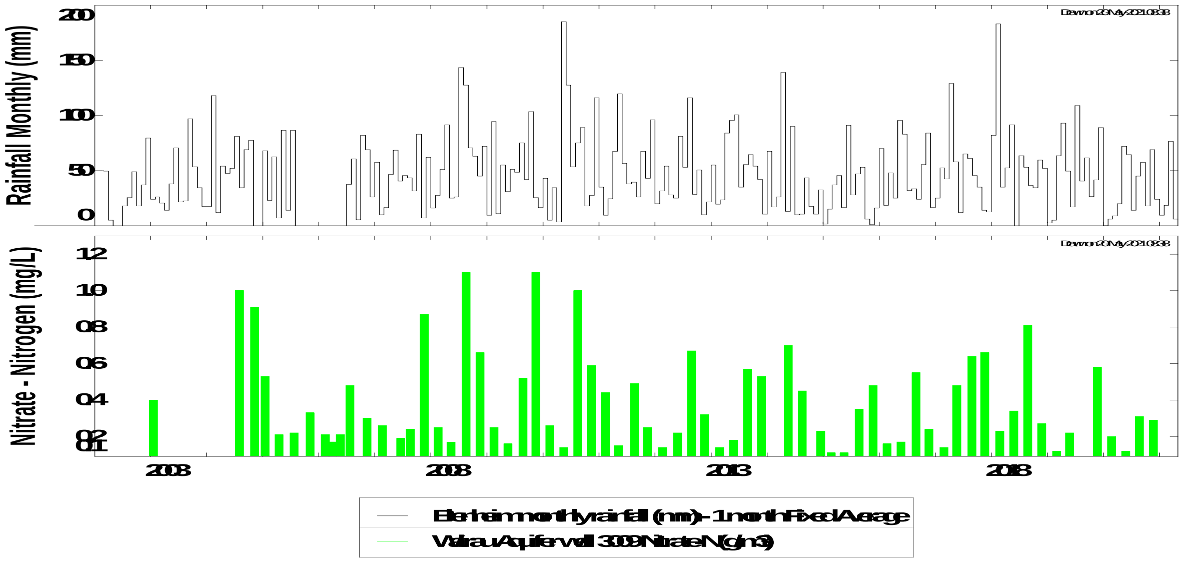


Figure 30: Monthly Blenheim rainfall versus seasonal groundwater Nitrate-N concentration at unconfined Wairau Aquifer MDC Wratts Road well 3009 from 2002 to 2021.

MDC groundwater quality SoE results show most Nitrate-N is leached to groundwater in spring and to a lesser extent in winter. Figure 31 shows the distribution of Nitrate-N in groundwater at the MDC Wratts Road well 3009 grouped as seasons for 17 years of record. The seasonal distribution is shown as this is the frequency of MDC groundwater quality SoE surveys.

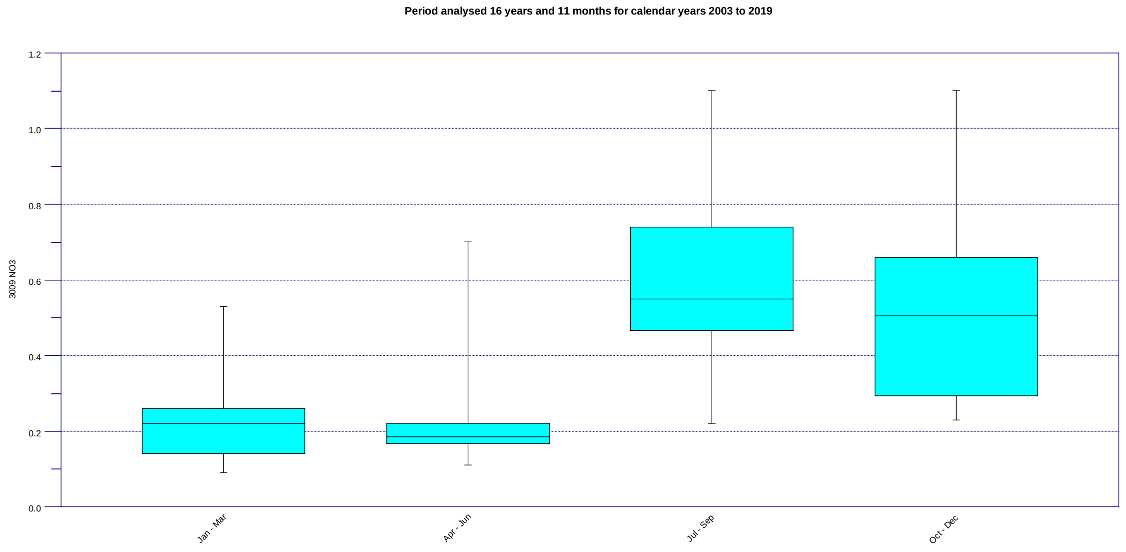


Figure 31: Seasonality of Nitrate-N leaching for groundwater at MDC Wratts Road well 3009 representing semi-confined Sector of Wairau Aquifer in the mid Wairau Plains area.

The dry summers experienced by the Wairau Plain mean there is normally little if any land surface recharge over this period with most Nitrate-N accumulating at the land surface until there is sufficient excess rainfall in winter or spring to drain downwards to the water table. Figure 31 describes the groundwater seasons slightly differently from the calendar seasons based on Marlborough groundwater conditions.

A similar pattern is seen at the Cloudy Bay shallow coastal sea-level intrusion wells where electrical conductivity values peak in winter or spring when rainfall is highest, and leaches sea salts that have accumulated on the sand dunes over summer/autumn (Figure 32).

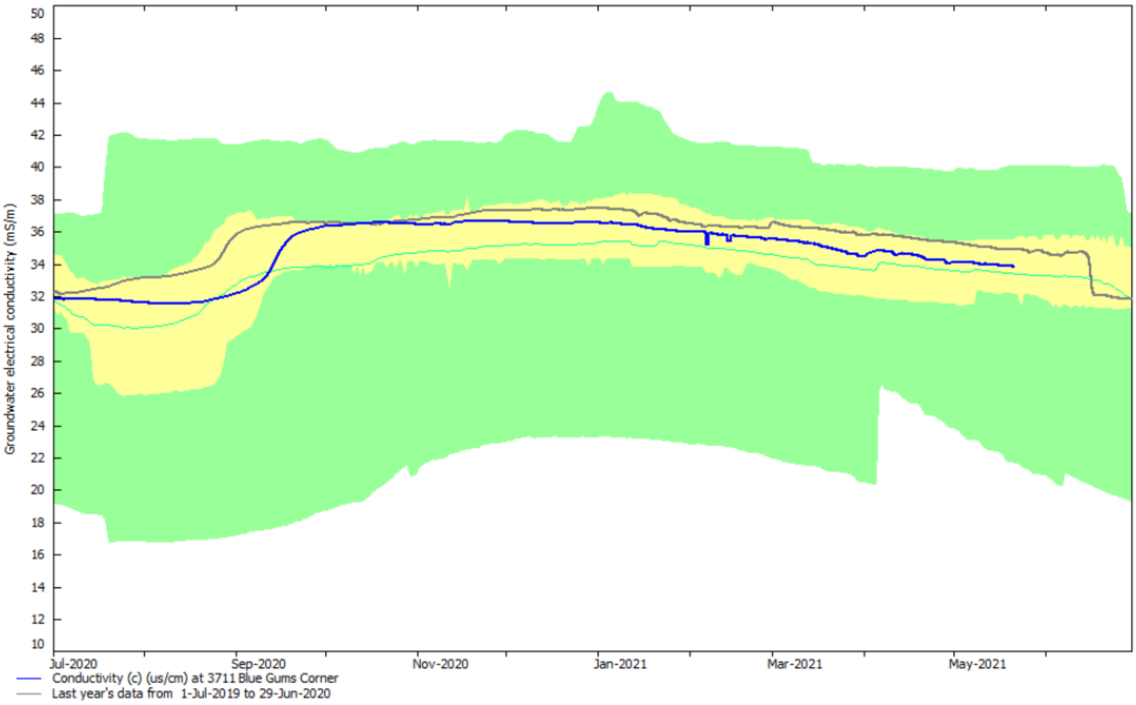


Figure 32**: Envelope plot showing electrical conductivity of shallow groundwater at MDC Rarangi Shallow Aquifer seawater intrusion early warning well 3711 representing unconfined groundwater near Cloudy Bay coastline 2001 – 2021. Levels peak in the wetter periods of the year not the drier months when abstraction peaks showing the influence of excess rainfall leaching sea salts to groundwater during spring.**

Land use primarily determines the Nitrate-N load at the surface available to leach as the Plant & Food Research field trials show. Rainfall or excess irrigation mobilises its movement downwards to groundwater. Observations show Nitrate-N leaching is sensitive to rainfall excess with low rates during summer or droughts and higher rates in wetter periods such as the mid 1990’s, 2007 to 2010 and spring 2001.

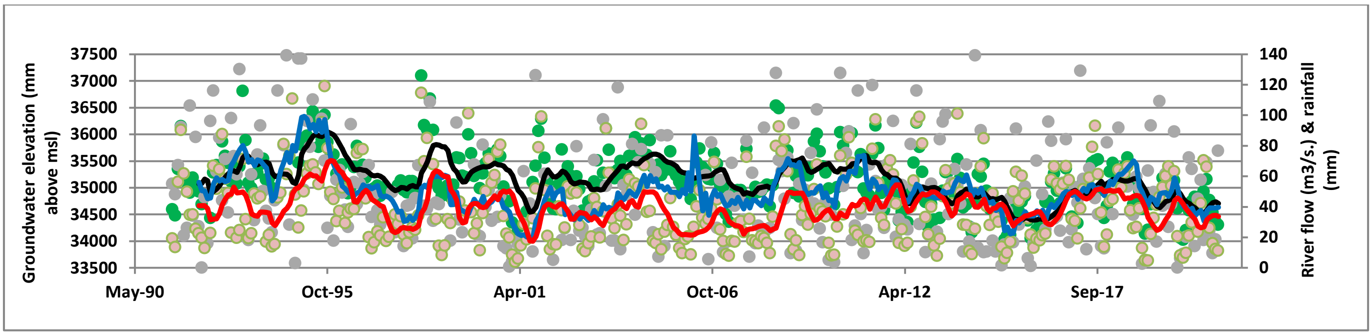


Figure 33: Comparison of variation in Wairau Plain rainfall, groundwater level and Wairau River baseflow 1990 to 2020. Mean monthly MDC Conders well elevation marked by green dots, Wairau River baseflow at Tuamarina marked by brown dots & Blenheim rainfall marked by grey dots from 1990-2021. Lines show moving means (groundwater elevation marked by black line, rainfall by blue line & river flow by red line).

Figure 33 shows average monthly Blenheim rainfall, Wairau River baseflow at Tuamarina and groundwater elevation at the MDC Conders well 398. This shows the influence of rainfall and Wairau River flow on groundwater levels in the unconfined section of the Wairau Aquifer. It also demonstrates the uniform nature of weather systems affecting the Wairau Plain.

This means the same Nitrate-N leaching rates through the unsaturated soil zone and groundwater attenuation processes in the saturated zone below the water table, will generally apply universally at any point in time. Rainfall, runoff and evapotranspiration rates will vary between the Wairau Plain and catchments north of the Wairau River however.

There is a rainfall gradient across the Wairau Plain. Blenheim and the south-eastern Wairau Plain has the lowest mean annual rainfall of 650 mm/year with increasing rates towards the north and west Wairau Plain.

In higher rainfall areas (greater than 1000 millimetres/year) of Marlborough north of the Wairau River, managing irrigation rates won’t reduce Nitrate-N leaching rates as natural drainage will tend to flush land surface pollutants to groundwater anyway.

Wairau Plain irrigation rates for grape plants are relatively low (average of 1 mm/day depending on soil type) and today are commonly scheduled based on actual farm soil moisture measurements. This leads to efficient irrigation use. Excessive irrigation water leading to Nitrate-N leaching is unlikely to be a major issue for the Wairau Plain based on current crops and management practices.

Figure 34 illustrates the close match that exists between Blenheim monthly rainfall, groundwater level at the MDC Wratts Road well 3009 and groundwater Nitrate-N at well 3009 since 2007. Rises in well 3009 level are mainly driven by Wairau River recharge rather than rainfall, however at a catchment scale when there is river channel activity it is normally also raining.

Nitrate-N concentrations in Wairau Plain groundwaters closely mimic rainfall. The seasonality is very evident for MDC well 3009 in Wratts Road with peaks in winter or Spring each year (Figure 34). Under typical summer or autumn conditions there is little rainfall recharge to groundwater.

For instance during the late 2015 dry spell and the 2018/19 and 2019/20 summer droughts, Nitrate-N levels in groundwater were low and at similar concentrations for several months. Sources of Nitrate-N were relatively immobile at the surface or moving through the soil zone (Figure 34).

Conversely, Nitrate-N levels were high in the 2008 – 2010 period due to high rainfall and runoff generating drainage which leached Nitrate-N to the water table (Figure 34).

Another possible contributing factor to lower Nitrate-N concentrations in groundwater recently could be due to stable soil N, increased root network capturing more Nitrate-N from the soil rather than leaching. Land contouring and establishment of vineyard are likely to cause a large flush of Nitrate-N from the soil system.

A minimum rainfall intensity is required to mobilise surface pollutants and initiate leaching to groundwater. The intensity will vary depending on soil depth and depth to the water table, which also vary in time and space.

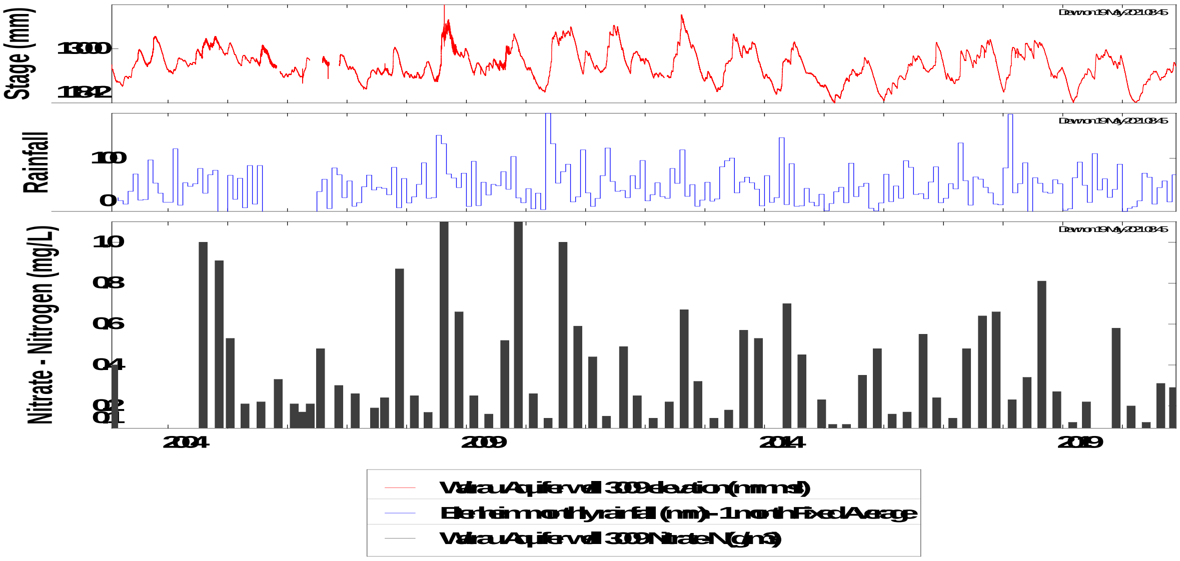


Figure 34: Seasonal Nitrate-N concentration and groundwater elevation (stage) at MDC Wratts Road well 3009 versus monthly Blenheim rainfall in mm/month.

In the case of the MDC Wratts Road well 3009 where groundwater is within 1 to 3 metres depth of the land surface, soil leachate doesn't have a deep unsaturated zone to transit, with drainage in most winters and spring seasons (Figure 34).

In western areas of the Wairau Aquifer the unsaturated zone depth can be up to 8 metres below the surface and will have a bearing on the drainage time of Nitrate-N. There will be a longer lag between rainfall at the surface and peaks of Nitrate-N in groundwater, compared to eastern areas of the Wairau Aquifer. The analysis of land use impact on groundwater quality is simplified by the short residence time of north-eastern Wairau Plain groundwater flow between the Wairau/Waihopai Rivers and the spring fed streams of less than a year.

This is based on recent analysis of monthly measurements of stable isotope values in the Wairau River and Wairau Aquifer wells (GNS Science - 2019). We can confidently say that any pollutant in groundwater has come from recent land use activities and isn't a legacy of land-uses decades previously.

5.2. Nitrate-N Trends Versus Land Use Change

There have been major changes in Wairau Plain land use since European settlement in the 1840's. During pre-European times and the early days of settlement, the Wairau Plain was covered in grasses, wetland and occasional stands of Kahikatea (Figure 35).

From a historical perspective the greatest land-use change occurred around this time when land was cleared, drained and used for grazing animals or growing crops. The surrounding lowland hills of the Richmond Range were cleared of bush and used for animal grazing (Figure 35).

Since 1970 and the establishment of government plantation forestry on the north bank, the majority of these lowland hills are at some stage of a 3 decade growth or harvesting cycle which causes large changes in rainfall runoff rates with implications for nutrient mobilisation.

Figure 35: Painting of coastal Wairau Plain looking south from Tuamarina at time of early European settlement on left and example of cleared northbank foothills at Top Valley in 1961 showing bare land now in exotic plantation forestry.

The second most significant land conversion occurred within recent memory. Before 1985 the main Wairau Plain land uses were mixed farming (cropping/sheep grazing), vegetables in the Lower Wairau, pip-fruit/stone fruit at Rapaura and dairying on the heavier coastal or former wetland soils. After this time vineyard gradually replaced these land uses until it was universal by about the year 2005.

Figure 36: Mosaic of Wairau Plain pre-vineyard land uses (MDC photographs).

Figure 36 show typical scenes from the late 1980’s and 1990’s within a clockwise direction: un-farmed gravelly soils near Renwick, mixed farming land at Rapaura, irrigated dairy pasture at Fairhall and unirrigated foot hills/Fairhall River terraces in the Southern Valleys catchments.

Figure 37: Typical Wairau Plain vistas in 2021 dominated by vineyard.

Effectively the Wairau Plain is one large vineyard interspersed with towns and rivers channels or floodways. The environmental advantages of vineyard as an agricultural land use is irrigation water use is around 20% of that used for dairying, while the nutrient load per hectare is around 10% of arable or dairying (Figure 37).

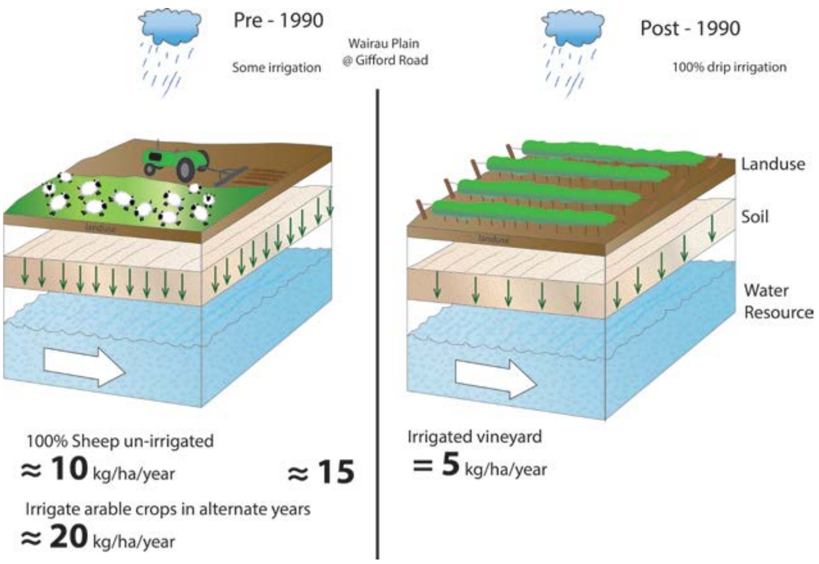


Figure 38: Comparison of estimated historic Wairau Plain agricultural Nitrate-N leaching rate versus measured current rate for Wairau Plain irrigated vineyard (MDC).

Figure 38 illustrates the concept of diffuse drainage of Nitrate-N from Wairau Plain land surface activities to an unconfined aquifer, and how leaching rates have reduced over time for the Wairau Plain from mixed farming prior to 1985 to irrigated vineyard since then.

Current Wairau Plain mature vineyard Nitrate-N land application rates are likely to average 15 kg Nitrate-N per hectare per year, leaching of 5 kg/ha/year (Figure 38). Rates of historic fertiliser and stock effluent Nitrate-N load can only be estimated and the task is complicated by fallowed land in some seasons and variable stocking rates.

A leaching rate equivalent to 15 kg/ha Nitrate-N was estimated based on the combination of land uses/crop types (Figure 38). A reduction in the leaching rate from around 15 to 5 kg/ha/year approximately matches the declining trend in Nitrate-N concentrations in groundwater observed across MDC Wairau Plain SoE monitoring wells.

5.3. Long-Term Nitrate-N Trends

Long-term hydrological trends take a minimum of 30 years to recognise based on the experience of MDC hydrologists when analysing Wairau River flow frequency since 1960. It takes this long to confidently separate out short and medium term climate driven patterns or land use cycles.

MDC have several groundwater level time series of this length, but fewer groundwater quality datasets. The water quality time series commonly have gaps in the early time data making it harder to be sure of the significance of a time trend.

All of MDC’s long time series of Nitrate-N in groundwater are for wells located on the Wairau Plain. MDC monitoring wells were established in other areas like the Marlborough Sounds or Wairau Valley in more recent times and the length of record doesn’t exist yet to comment on trends.

Figure 39 shows the temporal trends in Nitrate-N levels for the MDC SoE wells. Green represents a decreasing trend, red an increasing trend and grey means either no change over time, or insufficient length of record exists to identify temporal changes.

For the unconfined areas of the Wairau Aquifer, Nitrate-N values are declining with time. This trend is not apparent in the confined aquifers. The only site exhibiting an increasing trend are the medium depth layers of the Omaka Aquifer (Figure 39).

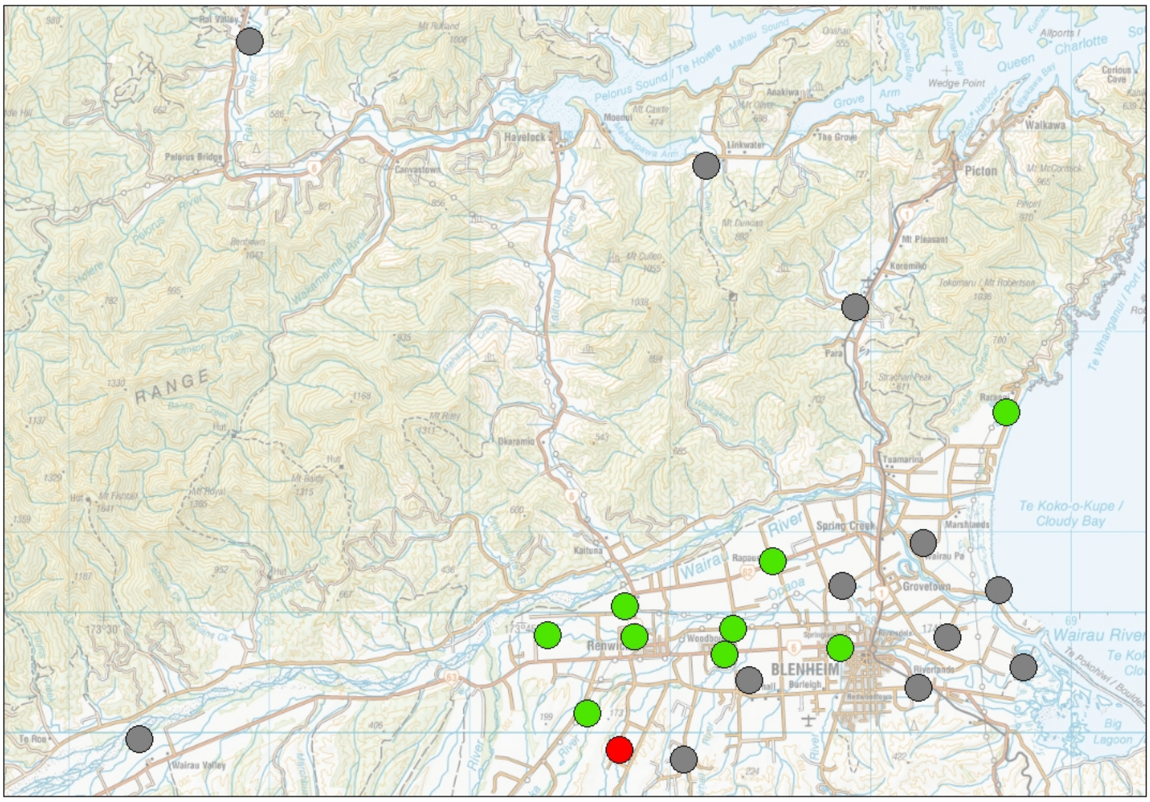


Figure 39: Summary of Nitrate-N temporal trends where green indicates a decline, red an increase and grey means no change over time or record is too short to identify changes yet.

The summary in Figure 39 is based on the long term groundwater quality datasets in Appendix B. For some very early laboratory analyses the Nitrate-N concentration may be less precisely expressed than in 2021 which will contribute to any apparent declining trend. Shorter time series are also shown in Appendix B as they represent useful information.

6. Climate Change Impacts on Nitrate-N Leaching

The 2021 NIWA climate change report commissioned by MDC, predicts greater variability in Marlborough river flows and rainfall runoff. Floods and droughts will be more frequent with for example Wairau River summer low flows predicted to halve by 2090.

The question is how are these changes in hydrological processes likely to affect Nitrate-N leaching and assimilation processes. It isn’t easy for MDC to be definitive because the forecasts are still too general to model their consequences on aquifer processes. The key task for MDC is to maintain good monitoring networks to identify the possible consequences of climate change on Nitrate-N leaching processes.

The forecast is for more extreme weather which may result is no net change if drier periods immobilise the Nitrate-N at the surface and balance wetter periods generating more runoff and leaching. More intense rainfall does not necessarily equate to more leaching as this will only occur if soil moisture is at the same level of saturation as current levels when rainfall occurs, which is unlikely to be the case with the increase in rainless periods and higher temperatures.

More intense rainfall events are likely to be translated into more intense surface runoff with a potential increase in sediment concentration and mobilisation. However a large component of the rain is unlikely to make its way through the soil column.

7. Conclusions

1. *Irrigated mature vineyard under Wairau Plain conditions leaches Nitrate-N but at low levels relative to other land uses.*

2. *Long-term median Nitrate-N concentrations in groundwater at Wairau Valley, Rai River Valley and Tuamarina River Valley are moderately high from an aquatic ecology perspective.*

3. *More detailed analysis of how recent Nitrate-N concentrations match the pMEP aquatic ecology targets will be contained in a follow-up MDC scorecard in 2021.*

4. *Nitrate-N concentrations at all SoE sites are less than the Maximum Allowable Value for human consumption in the Drinking Water Standards for New Zealand.*

5. *The highest measured Nitrate-N levels in Marlborough water resources are found in groundwater and mimicked in connected springs or aquifer fed streams.*

6. *Levels of Nitrate-N in groundwater are primarily driven by landuse activities, particularly artificial fertiliser use and stocking rates.*

7. *Soil type, climate and irrigation rates influence Nitrate-N leaching rates and their timing, but aren't the prime drivers of excessive Nitrate-N levels in Marlborough groundwater.*

8. *Managing excessive levels of Nitrate-N in groundwater can only be effectively achieved by managing land use and limiting nutrient limits.*

9. *Nitrate-N enters groundwater in a diffuse manner meaning it can't be intercepted by riparian management tools like fencing or planting channels.*

10. *The current MEP permitted activity Nitrate-N application rate of 200 kg/ha/year is an order of magnitude higher than current usage and probably historical Wairau Plain loadings averaged over the Wairau Plain land area.*

11. *For those Wairau Plain aquifer SoE sites where sufficient length of record (30 years or more) exists, there is generally a long-term declining trend in groundwater Nitrate-N levels and those of connected streams.*

12. *This decline is consistent with the dominant Wairau Plain agricultural land-use changing from mixed farming (sheep and arable) to vineyard from the mid-1980s onwards.*

13. *Recent Nitrate-N concentrations since 2014 have tended to be lower for the Wairau Plain probably because of the drier climatic conditions experienced leading to reduced rainfall leaching.*

14. *Confined aquifers act as natural sinks for Nitrate-N due to their reducing biochemical conditions, and the further inside the confined part of the aquifer the more assimilation occurs.*

15. *Climate change predictions are still too vague to translate into implications for Nitrate-N leaching to aquifers 60 years out.*

8. References

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8. Plant and Food Research (Green. S, Agnew, R. & Greven, M.): 2014 - *Monitoring Nitrate Loss Under Vineyard Soils on the Wairau Plains, Marlborough.*

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9. Appendices

9.1. Appendix A: Comparison of Nitrate-N levels of Groundwater and Hydraulically Connected Spring Fed Streams

The following is a detailed comparison of Nitrate-N time series for hydraulically connected sites with oxygenated water where there are no denitrification processes potentially influencing Nitrate-N concentrations. The paired surface and connected groundwaters in the same FMU are summarised in Table 1 and discussed below.

Locality	Surface water survey site	Groundwater survey site	Separation distance
Renwick	Wairau River at Tuamarina	MDC well P28w/0398 at Conders (398)	~ 1500 m. from active river channel assuming water quality same as at Tuamarina
Mid-Wairau Plain	Spring Creek/Awarua at floodgates	MDC well P28w/3009 at Wratts Road (3009)	~6,500 m. (~500 m. to Spring Creek headwaters at Tennis Court)
Blenheim	Murphys Creek at Nelson Street	MDC well P28w/3120 at Middle Renwick Road municipal wellfield (3120)	~350 m.
Fairhall	Doctors Creek upstream of Taylor River	RNZAF Base Woodbourne P28w/0662 (662)	~5,800 m.
South-western Wairau Plain	Omaka River at Hawkesbury Road	Well P28w/3069 near Lower Waihopai Valley Road (3069)	~3,000 m.
Tuamarina River Valley	Tuamarina River at Speeds Road	MDC Picton municipal supply well 448 at Speeds Road (448)	~250 m.
Wairau Valley	Mill Creek at Ormonds	MDC well O28w/0015 at Wairau Valley municipal wellfield (15)	~1,200 m.
Rai Valley	Rai River at Falls	Terrace monitoring well	~5,500 m.
Linkwater	Cullen Creek at main highway	Terrace well P27w/0447 (447)	~650 m.

Table 1: Paired groundwater – surface water bodies monitored by MDC as part of SoE programmes for Nitrate-N content.

For each paired water resource the electrical conductivity (EC) and Nitrate-N content is compared. EC or Nitrate-N units are shown on the left hand axis of each graph. EC was used as a measure of the natural similarity or degree of evolution of the 2 waters. Surface flows will tend to be more dilute. EC reflects Nitrate-N content, but is a minor contributor.

If waters have the same EC over time, but different Nitrate-N concentrations, then it implies a land-use influence. If the water bodies have different EC values it is likely that dilution is occurring as described above.

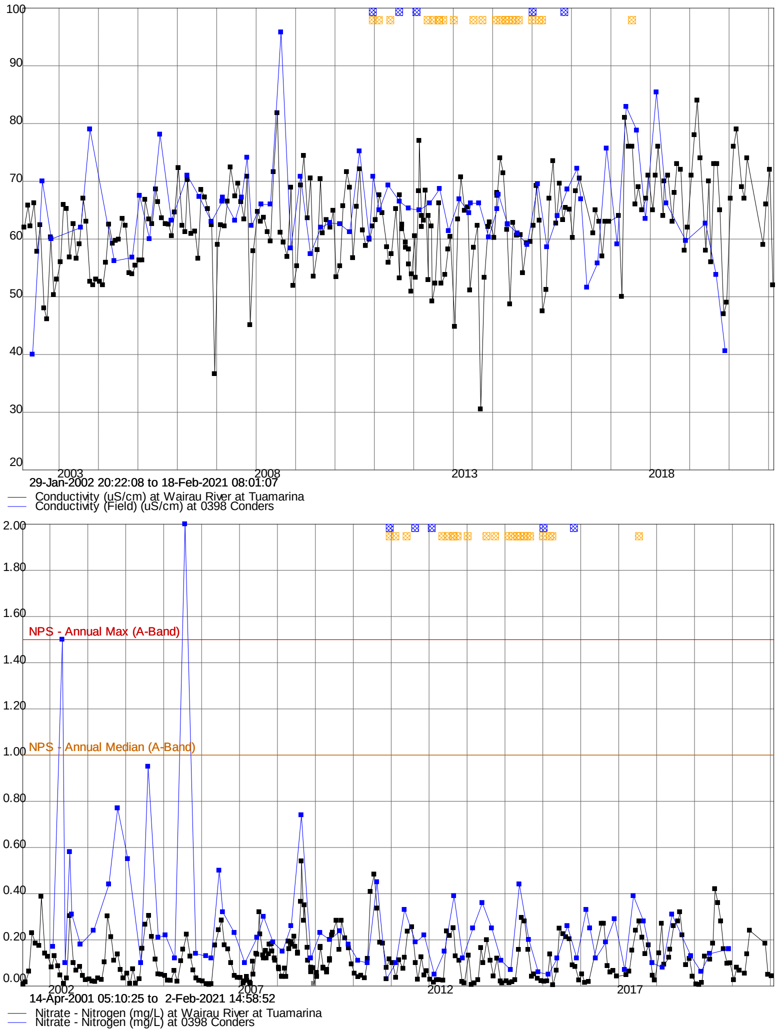


Figure 40: Nitrate-N and electrical conductivity for Wairau River at Tuamarina versus groundwater at MDC Conders well P28w/0398 in Wairau Aquifer Recharge Sector.

The first paired sites are well 398 representing the Recharge Sector of the Wairau Aquifer and Wairau River water Tuamarina (Figure 40). From many other pieces of hydrological information, MDC know for certain groundwater is recharged predominantly by Wairau River leakage and this is supported by the EC time series which overlap (MDC – 2011). Both waters are dilute.

Since 2006 Nitrate-N levels in Wairau Aquifer Recharge Sector groundwater at MDC well 398 have been very similar to Wairau River channel water, but prior to this, levels were higher in groundwater, perhaps due to higher fertiliser use coinciding with the conversion of pine plantation to vineyard near the well (Figure 40).

Nitrate-N levels are normally higher in groundwater for the same period. This is consistent with the drainage of land surface Nitrate-N to the more dilute Wairau River recharge water as it enters the aquifer. The underground flowpath for recharge water to reach well 398 from the Wairau River channel is likely to be around 1500 metres based on MDC research, but will vary seasonally.

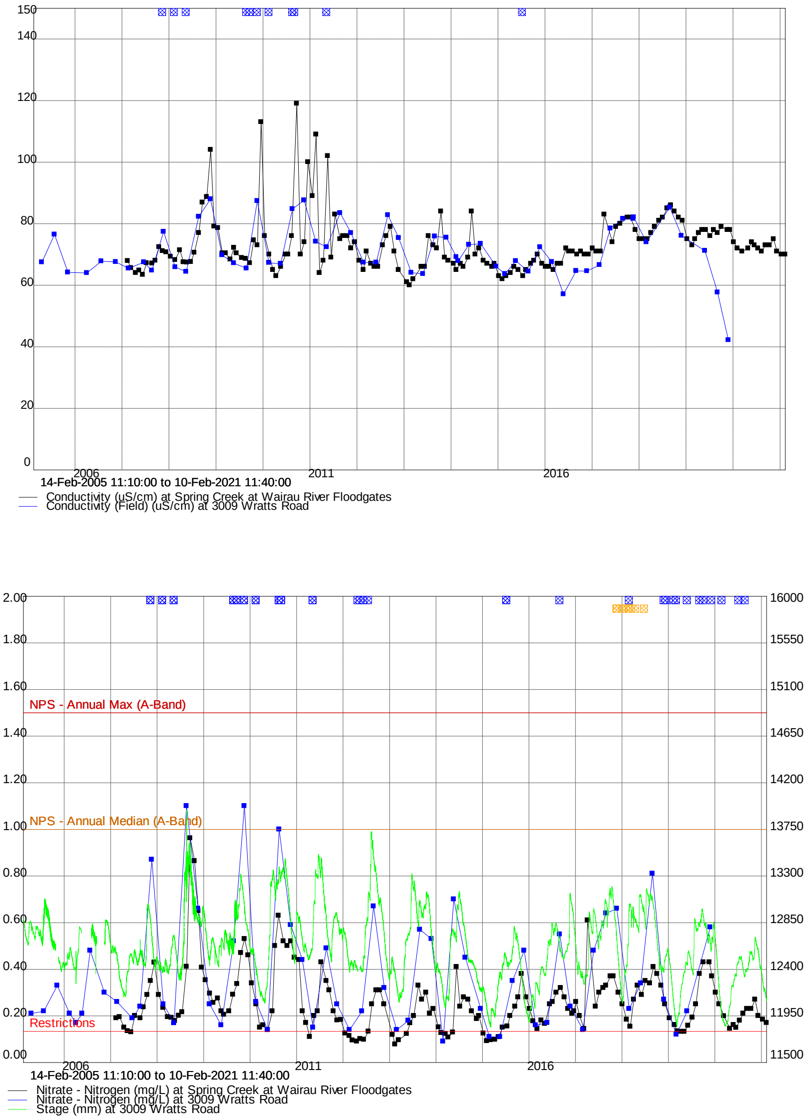


Figure 41: Nitrate-N and electrical conductivity for Spring Creek/Awarua at flood gates versus MDC Wratts Road well P28w/3009 in Recharge Sector. Variation in well elevation in mm shown in green on left hand vertical axis.

The second pairing is for Spring Creek at Floodgates versus the MDC Wratts Road well 3009. MDC measure the quality of Spring Creek water at the floodgates site just upstream of its confluence with the Wairau River (Figure 41).

The EC of Spring Creek channel water exactly matches the EC of groundwater at the MDC monitoring well 3009 at Wratts Road, representing the groundwater catchment for Spring Creek, demonstrating they are the same water resource (Figure 41). The fall in EC in 2019 is not real and reflects a problem with the MDC field meter.

Nitrate-N levels are fluctuating seasonally mimicking the cycle at the Wratts Road well 3009. The explanation why Nitrate-N levels are normally slightly higher in groundwater is probably because the Wratts Road well located several kilometres upstream of the surface water site intercepts shallower groundwater (Figure 41).

Spring Creek at the bottom of its catchment receives a fraction of older, upwelling groundwater containing less Nitrate-N. The concentration of Nitrate-N being leached to groundwater correlates well with rainfall or groundwater level as the green line shows (Figure 41).

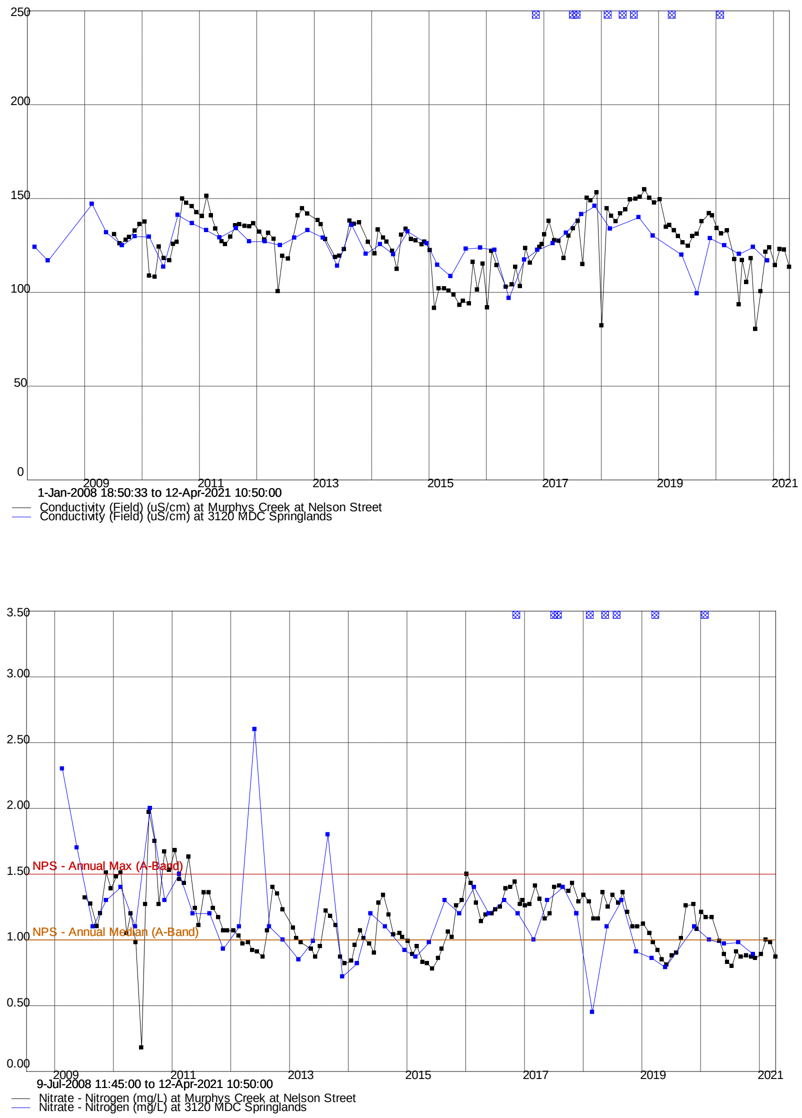


Figure 42: Nitrate-N and electrical conductivity for Murphys Creek at Nelson Street versus groundwater at MDC municipal wellfield well P28w/3120 in Springs Sector.

The next pairing involves Murphys Creek channel water at Nelson Street in the western suburbs of Blenheim and groundwater from well 3120 at the MDC Blenheim municipal wellfield nearby on Middle Renwick Road (Figure 42). The EC of Murphys Creek channel water exactly matches that of groundwater at well 3120, indicating the same water resource (Figure 42). Nitrate-N levels are also similar suggesting the urban contribution from runoff is small with most Nitrate-N arriving in groundwater and originating further west in the capture zone.

There are a few points where Nitrate-N concentrations are quite different. Groundwater Nitrate-N levels are higher than for surface water in 2012, 2013; and lower in 2018 which may be related to rainfall, stormwater or sewer contributions. Nitrate-N concentrations prior to 2010 are relatively high and variable.

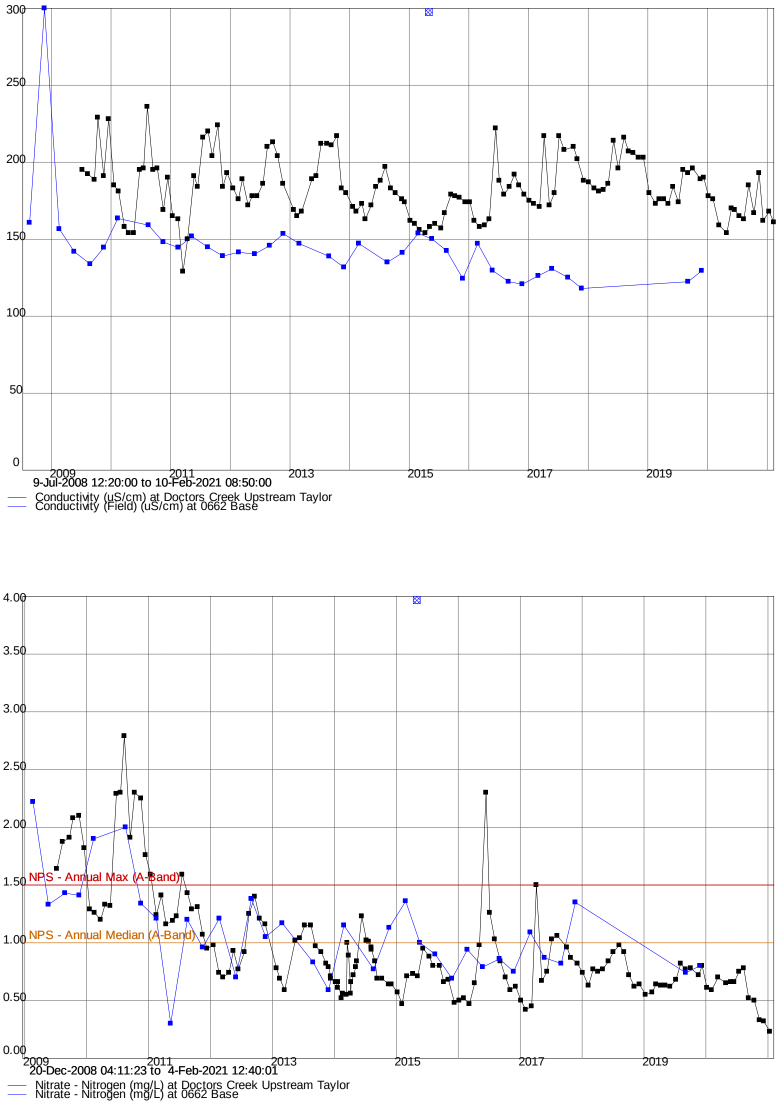


Figure 43: Nitrate-N and electrical conductivity for Doctors Creek upstream of Taylor River versus groundwater at Woodbourne well P28w/0662.

The next pairing in the series is for the water resource draining the most western of the Southern Valleys catchments, with some contribution for Wairau River water at Woodbourne. Doctors Creek flow at the SoE survey site upstream of the Taylor River confluence represents groundwater baseflow combined with significant seasonal quick flow generated from hill runoff (Figure 43).

The two sites used were RNZAF Base Woodbourne well 662 and Doctors Creek upstream of the Taylor River. While these sampling sites are a significant distance apart and there is a significant quickflow contribution to the water balance in the catchment, it is useful to compare their chemical signature and nutrient footprint.

Figure 43 shows that EC is higher in Doctors Creek, perhaps reflecting its groundwater baseflow and localised inputs of natural salts. There appears to be limited diluting effect from flood flows on the total dissolved salt concentration. The EC of the two water bodies are not as closely matched as other pairs in the study however (Figure 43). Interestingly Nitrate-N concentrations are a closer match.

Nitrate-N concentrations are still relatively high considering the peaty strata in the Bells/Battys Road area. The field drains might be diverting enough shallow groundwater direct to the Fairhall/Co-op Drain or Doctors Creek.

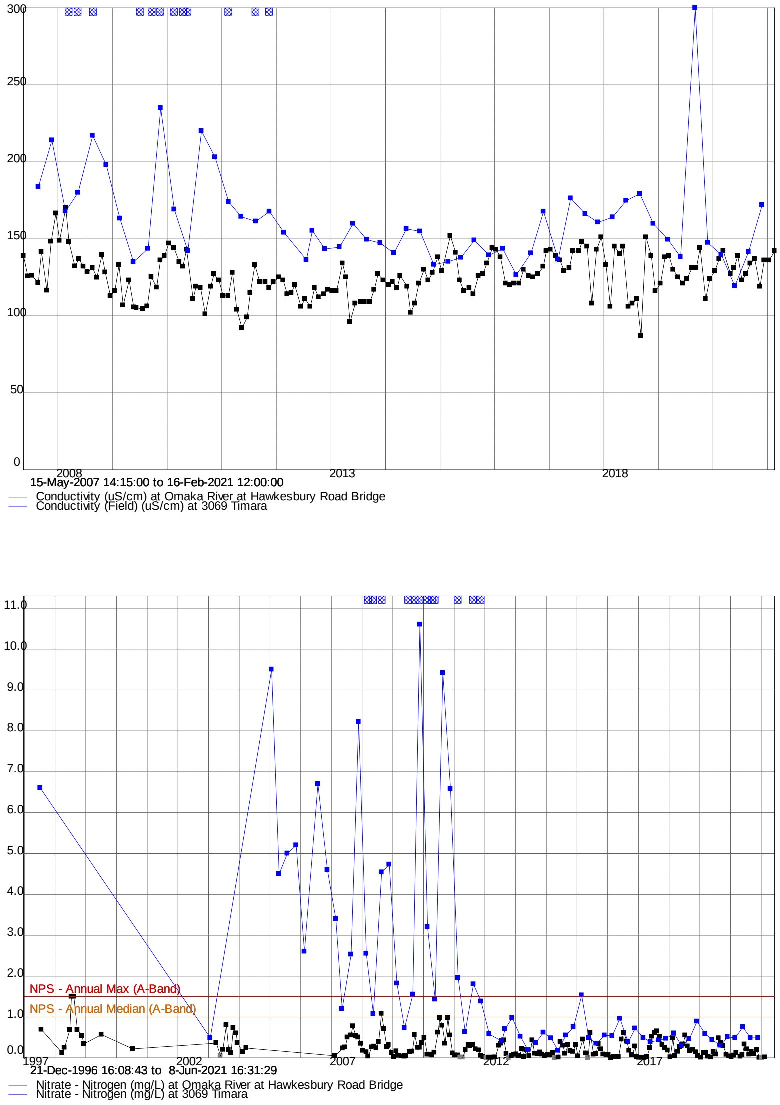


Figure 44: Nitrate-N and electrical conductivity for Omaka River at Hawkesbury Road versus groundwater at terrace well P28w/3069 representing Omaka River Aquifer.

The next pair of water bodies relate to the Omaka River catchment located southwest of Renwick and forming part of the Southern Valleys catchment suite. MDC well 3069 is located in a vineyard and intercepts shallow groundwater (Figure 44). The surface water SoE site representing Omaka River flow is at Hawkesbury Road bridge, the point at which most channel flow is lost to groundwater.

During the initial period of record, EC of shallow groundwater is significantly higher than for Omaka River water, but values have largely converged in recent times mimicking the Nitrate-N pattern (Figure 44). The Nitrate-N concentration of shallow groundwater has been low since 2012 and consistently low for Omaka River channel water. The crop type hasn't changed neither has rainfall so other factors are driving the variation, probably rates of fertiliser use in relation to crop maturity. Nitrate-N levels in groundwater up to 2010 were approaching the human health limit but have now declined to low concentrations relative to the pMEP aquatic ecological thresholds (Figure 44).

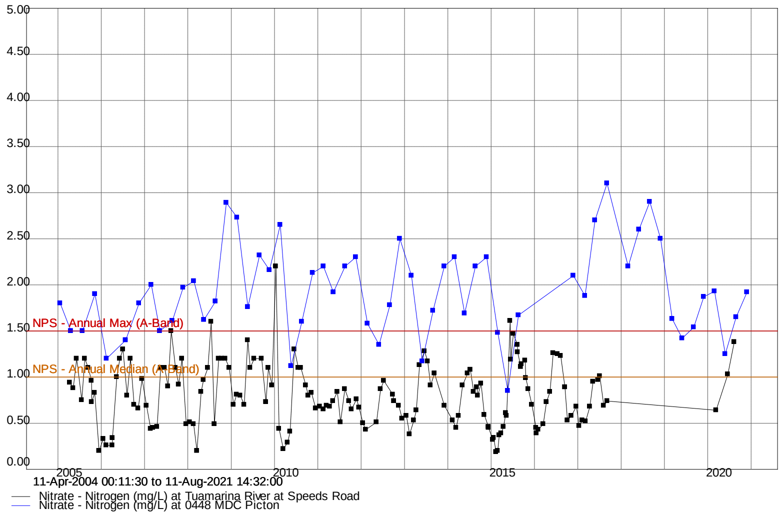


Figure 45: Nitrate-N for Tuamarina River at Speeds Road versus groundwater at Picton municipal supply well P27w/0448 representing the Tuamarina River Gravels Aquifer.

The next pairing shown by Figure 45 involves the Tuamarina River catchment where groundwater and surface water are known to be hydraulically connected (Groundwater – 2011). The groundwater table is close to the land surface. This finding is based on testing of the Blue Hole Spring in the early 1970's and analysis of the response to municipal pumping from the Picton municipal wellfield on Tuamarina River flows by MDC hydrological staff and consultants acting for the Assets and Services Department in recent times.

Groundwater is sampled seasonally by MDC from the Picton municipal wellfield in Speeds Road. There are no long-term EC observations for Tuamarina River channel water in the reach opposite the wellfield however.

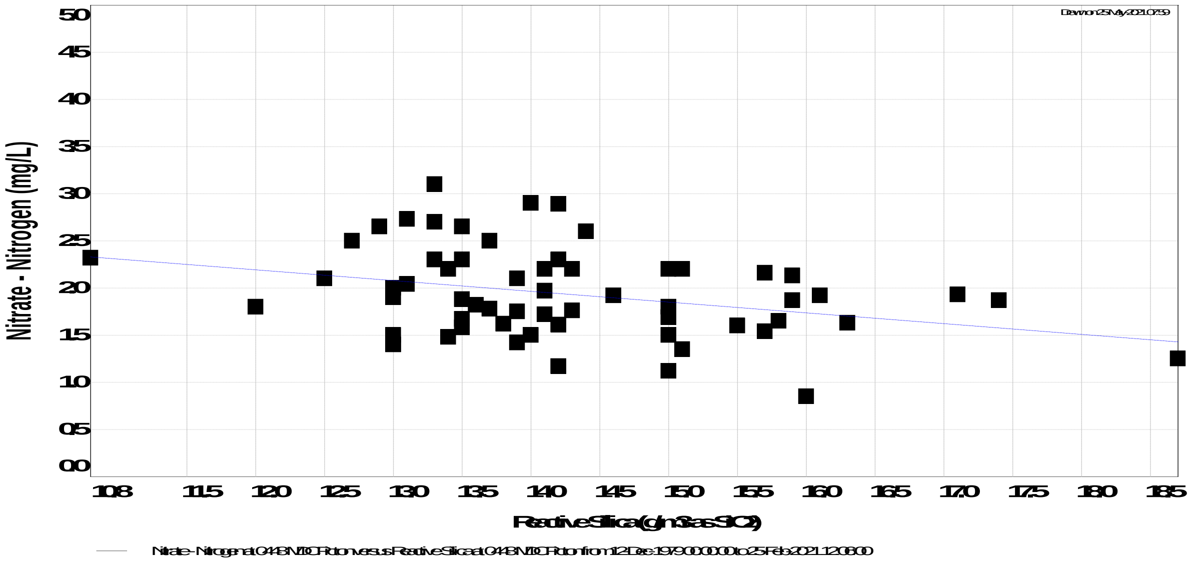


Figure 46: Nitrate-N concentration versus reactive silica concentration for MDC Picton municipal wellfield 1979-2020.

It is likely that the relatively large channel flow compared to underground throughflow has a diluting effect which is certainly the case for Nitrate-N (Figure 45). Consequently, Nitrate-N levels are expected to be higher in groundwater.

Nitrate-N values in groundwater at the Picton municipal wellfield often peak in summer which is unusual as the driver for leaching is normally winter or spring rainfall. A possible explanation is the Nitrate-N peaks are generated in spring, but take several months to become apparent in groundwater (Figure 45). Alternatively irrigation is generating Nitrate-N leaching on the river flats which provides baseflow to the Tuamarina River in summer when the channel gains flow downstream.

Figure 46 shows Nitrate-N concentration in groundwater is highest when silica is lowest. High silica normally indicates longer residence time underground, inferring the Nitrate-N peaks are associated with young water.

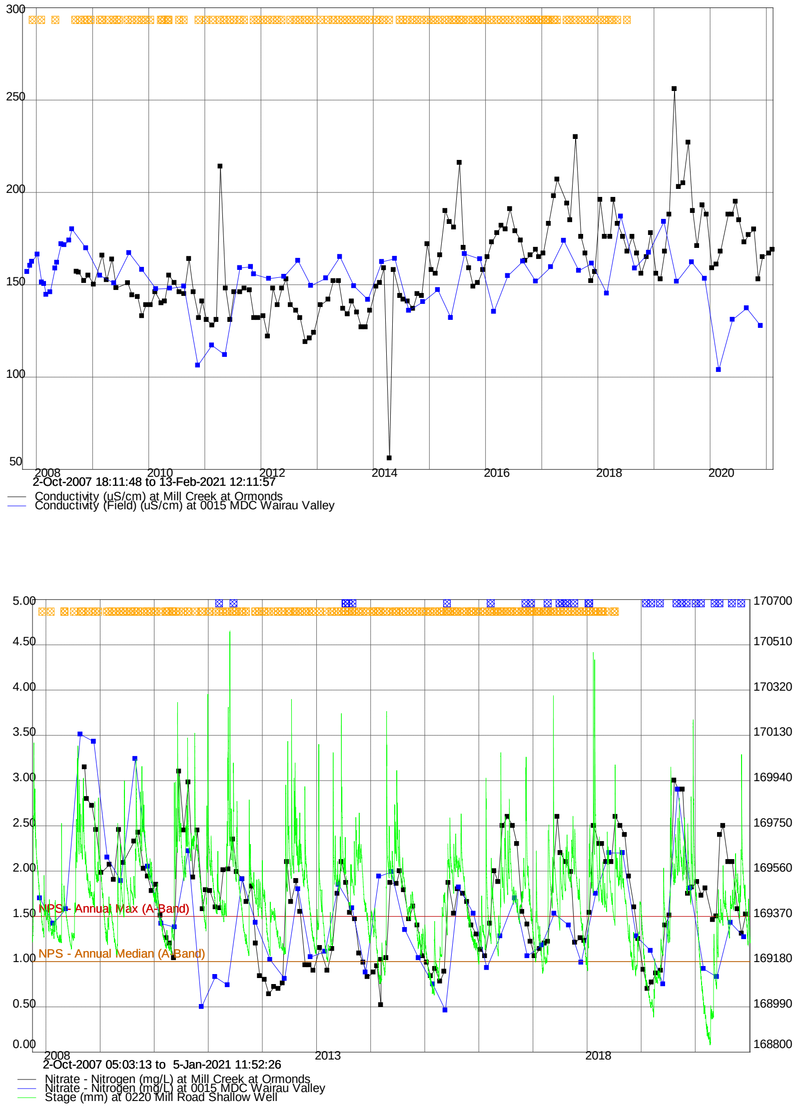


Figure 47: Nitrate-N and electrical conductivity for Mill Creek at Ormonds (Wairau Valley) versus lower terrace MDC public water supply well O28w/0015. Variation in well level elevation shown in green.

The next pairing shown by Figure 47 is the shallow circulation on the lower Wairau River terrace at Wairau Valley where Mill Creek is known to gain flow from groundwater (Groundwater – 2011). Groundwater is sampled seasonally at the MDC Wairau Valley community water supply well O28w/0015 (well 15) (Figure 47). Surface water quality is sampled at Mill Creek at the Ormond flow recorder site, upstream of well 15.

EC values are relatively well matched and high (~170 microS/cm), but interestingly over time groundwater has become more dilute than Mill Creek water, but the reasons are uncertain. Changes in the saline wedge, runoff or land-use contamination would affect both water bodies equally. The water bodies are likely to be highly connected hydraulically based on observations.

Nitrate-N levels are similar in groundwater and surface water (Figure 47). Nitrate-N levels are relatively high compared to the ecological limits and fluctuating seasonally. The timing of Nitrate-N peaks is strongly correlated with the variation in groundwater level at the MDC well O28w/0220 located in Mill Road (Figure 47). Groundwater elevation is shown on the right hand axis in Figure 47.

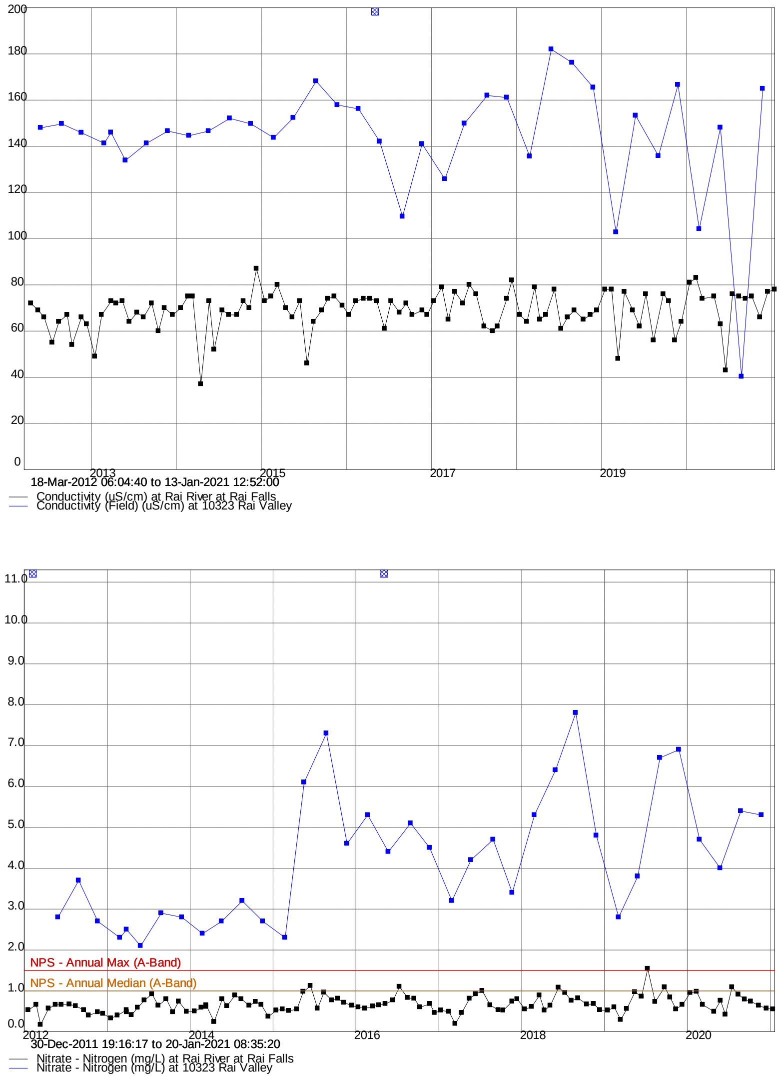


Figure 48: Nitrate-N and electrical conductivity for Rai River at Falls versus groundwater at terrace well.

The next comparison is for the Rai River catchment based on surface water measurements at Rai Falls and the river terrace well near Rai Valley township (Figure 48). The significant difference in EC values between the 2 water bodies emphasises the diluting effect of the relatively large river channel flows (Figure 48).

Nitrate-N levels are significantly higher in groundwater than river water. The rise in groundwater Nitrate-N levels is independent of the Rai River, indicating a local driver (Figure 48). Groundwater is draining towards the Rai River channel based on the topographic contours and radon measurements by MDC/ESR.

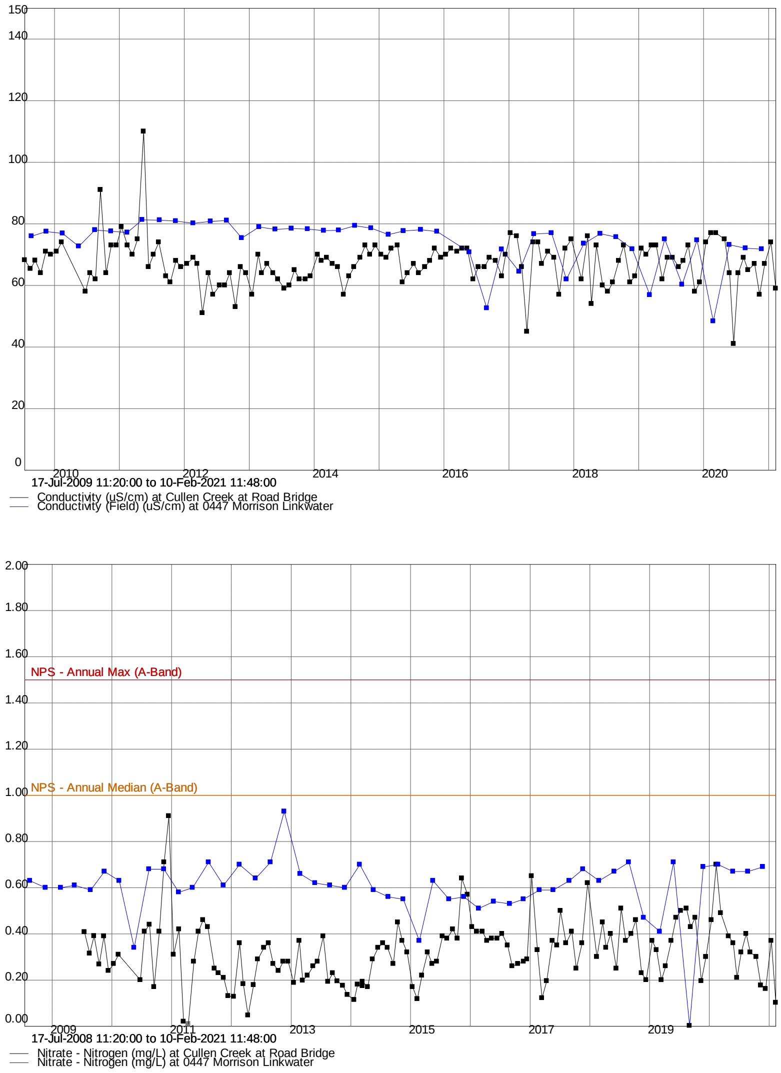


Figure 49: Nitrate-N and electrical conductivity for Cullen Creek at highway versus groundwater at Cullen Creek Gravels P27w/0447.

The final pairing is for Linkwater in the Marlborough Sounds involving a comparison of Cullen Creek water with groundwater at well P27w/0447 located approximately 50 metres from the Cullen Creek channel (Figure 49). Electrical conductivity values are low at both sites (~80 microS/cm) indicating dilute water. EC values are similar indicating the same water resource which is consistent with previous hydrological research by GNS Science and MDC (Figure 49).

Cullen Creek EC values fluctuate for the whole period of record, but groundwater levels were very stable up to 2016. The groundwater pattern changes from a stable value of 80 microS/cm to being more variable, probably reflecting its change in use from an unpumped well to being used for domestic supply (Figure 49).

Nitrate-N values are slightly higher in groundwater than Cullen Creek channel water. This is likely to reflect a combination of less through-flow beneath the terrace gravels compared to the nearby channel and direct drainage of Nitrate-N from the land surrounding the well. Overall Nitrate-N values are low.

9.2. Appendix B:

9.2.1. Long Nitrate-N Time Series

The following section contains graphs and analysis of the long times series of Nitrate-N available to MDC.

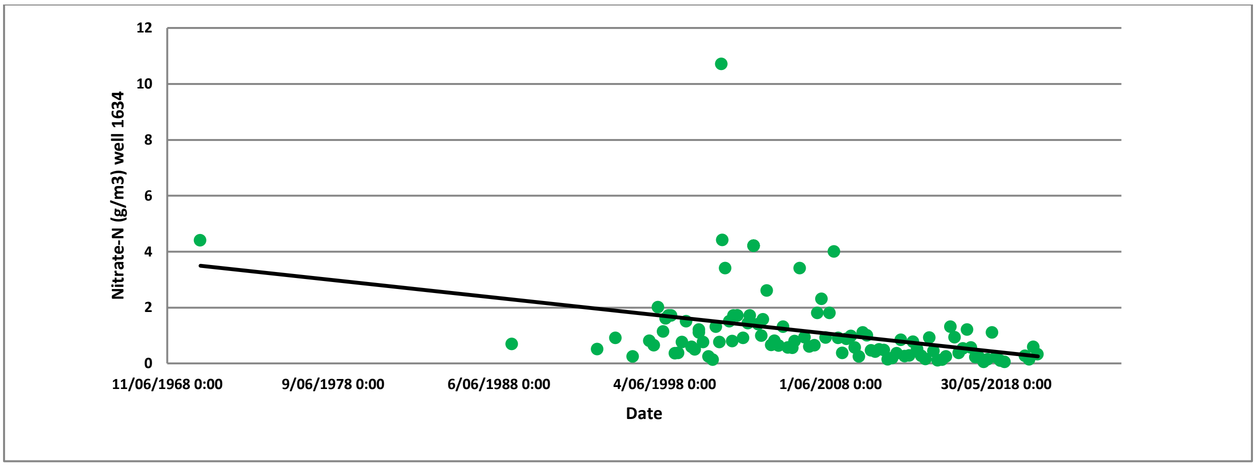


Figure 50: Nitrate-N concentration at unconfined Rarangi Shallow Aquifer well P28w/1634 1970-2020.

The Rarangi Shallow Aquifer (RSA) extends to a depth of 10 metres below the surface and is hosted by fine marine gravels near the Cloudy Bay coast, north-east of Blenheim. These fine gravels are extremely free draining making the groundwater resource susceptible to land use contaminants. The RSA is the source of drinking water for the local community and maintains the health of hydraulically connected rare, coastal fen wetlands.

Figure 50 shows up until 2009 RSA Nitrate-N concentrations fluctuated significantly, reflecting wetter periods such as spring 2001 and 2008 to 2010, and most probably differences in land practices such as fertiliser use at the golf course. There is an overall declining trend in Nitrate-N levels since 2009, however concentrations are near the pMEP aquatic ecology limit. Figure 50 demonstrates how sensitive Nitrate-N values in groundwater are to land use practices, which can change quickly.

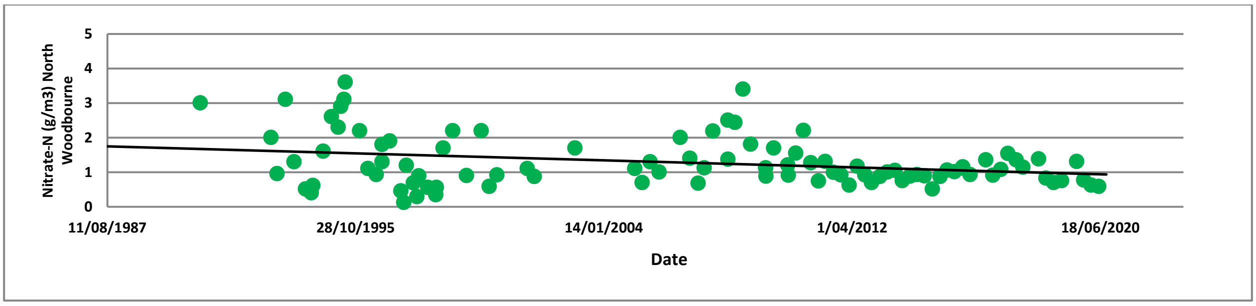


Figure 51: Nitrate-N concentration at unconfined Southern Wairau Aquifer/Woodbourne combined well P28w/1156-4118 combined 1990-2020.

Old Renwick Road represents the boundary between the highly transmissive gravels to the north recharged by Wairau River leakage, and the less permeable gravels to the south which receive recharge from the Southern Valleys catchments as well as the Wairau River (Figure 51).

Figure 51 shows a declining trend in Nitrate-N concentrations since the late 1980s from 1.75 to about 1 g/m^3. The permanent rewatering of the Ruakanakana system from the Wairau River may have increased dilution, although this isn't supported by a declining trend in Wairau Aquifer levels since the introduction of the Southern Valleys Irrigation Scheme (SVIS) in 2004. Land use change from mixed farming to vineyard probably accounts for a large part of the downwards trend (Figure 51).

Median Nitrate-N concentrations have been around the MEP ecological threshold of 1 g/m^3 since 2011, but were higher previous to this date (Figure 51). The record for Figure 51 comes from two wells side by side and the data has been concatenated. The more modern well is slightly deeper and may intercept slightly lower Nitrate-N concentrations.

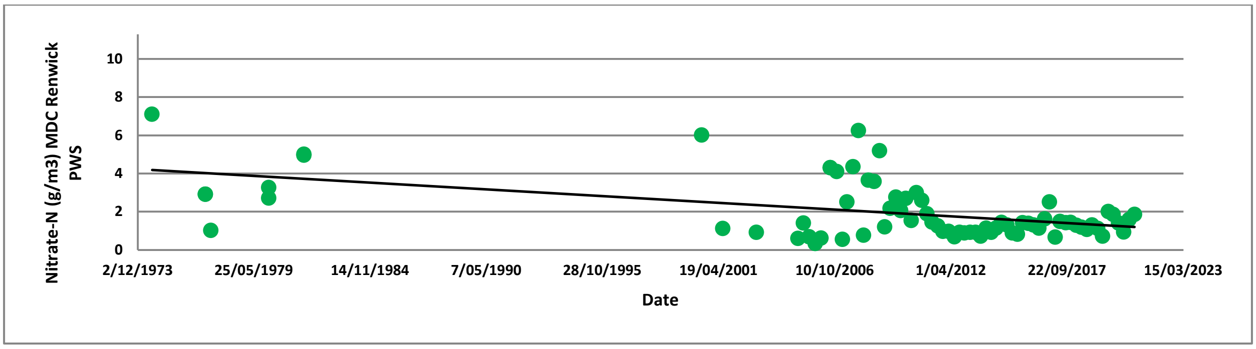


Figure 52: Nitrate-N concentration at unconfined Wairau Aquifer MDC Renwick municipal wellfield wells P28w/0548-0547 combined 1974-2020.

Renwick municipal water is supplied from a wellfield of 3 wells located near the river terrace just west of SH1 (Figure 52). Well 548 is normally sampled as part of the SoE programme. This part of the unconfined Wairau Aquifer consists of the thinnest, least transmissive gravels located furthest from the Wairau River recharge source.

As a consequence there is less dilution than further north in the Wairau Aquifer and drainage from land on the upper terrace introduces Nitrate-N into the Wairau Aquifer as runoff. The channel of nearby Ruakanakana is not as leaky as it was historically meaning less surface water enters groundwater, with relatively low Nitrate-N content (Figure 52).

Figure 52 implies a decline in Nitrate-N concentrations in groundwater, although the large gap in data during the 1980s and 1990s means the graph is only indicative. Notwithstanding this a decrease in Nitrate-N is consistent with the other Wairau Aquifer long-term time trends.

Concentrations have definitely declined noticeably over the past decade (Figure 52). This probably reflects conversion of former cropping/grazing land both on the Delta and overlying the Wairau Aquifer to the west to vineyard, along-with drier conditions meaning less mobilisation of Nitrate-N. From a human water supply perspective Nitrate-N levels are low, but near the median threshold in the MEP to preserve aquatic ecological values.

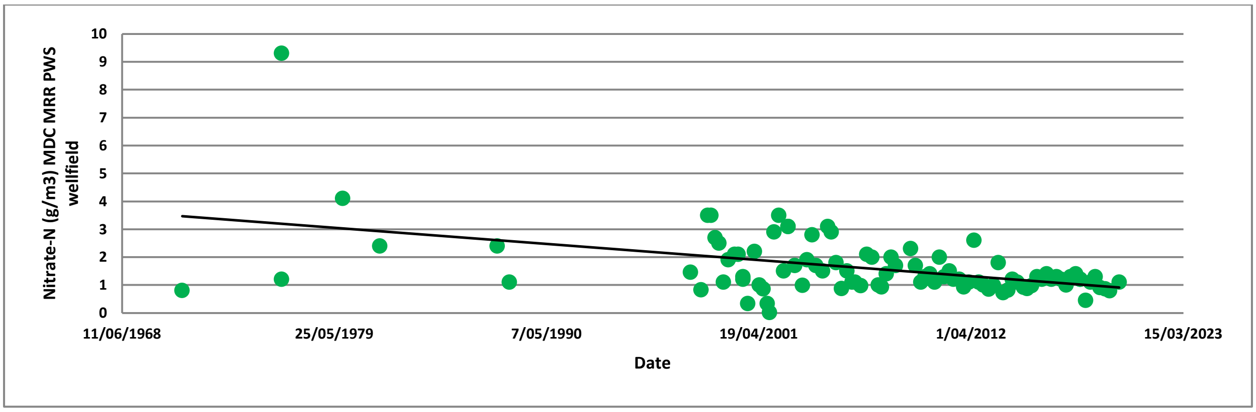


Figure 53: Nitrate-N concentration at semi-confined Wairau Aquifer Middle Renwick Road wellfield P28w/0612-3120 combined 1971-2020.

A long (50 year) but interrupted Nitrate-N history exists for MDC wells tapping the semi-confined Wairau Aquifer in the western suburbs of Blenheim (Figure 53). The existence of multiple springs in the suburb of Springlands reflects the emergence of groundwater at the surface caused by the existence of the confining layer and change of land surface slope.

Because of the high pump rate of the wells supplying groundwater to the municipal network, it is likely some groundwater has been induced from a significant radius including from groundwater fed springs like Murphys Creek. This is based on historic real time data logger record. Figure 53 shows a significant declining trend since 1997, although there are few data points available before this time. Current Nitrate-N levels are around 1 g/m^3 (Figure 53).

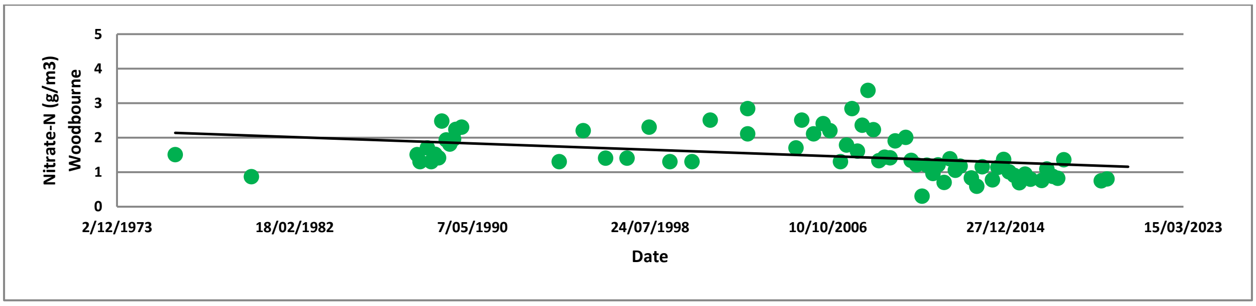


Figure 54: Nitrate-N concentration at semi-confined Woodbourne well P28w/0662 1976-2020.

The Woodbourne area of the central Wairau Plain around the RNZAF base/airport, experiences a large seasonal variation in well levels of around 10 metres reflecting the ephemeral nature of the rivers draining the Southern Valleys catchments (Figure 54). In summer the rivers normally dry-up and recharge northwards is small. Well 662 is a 24 metre deep former base supply well.

Figure 54 implies a significant long term fall in Nitrate-N concentration at Woodbourne well P28w/0662 from 1976 to 2020, although there are major gaps in the data prior to the mid-1990s which complicates the interpretation.

Higher values correspond with the wetter weather conditions experienced between 2008 and 2010. Lower values since 2014 are consistent with the warmer, drier Wairau Plain conditions which have tended to lock-up Nitrate-N at the surface. Average Nitrate-N levels in 2020 hover around the MEP aquatic ecology limit (Figure 54).

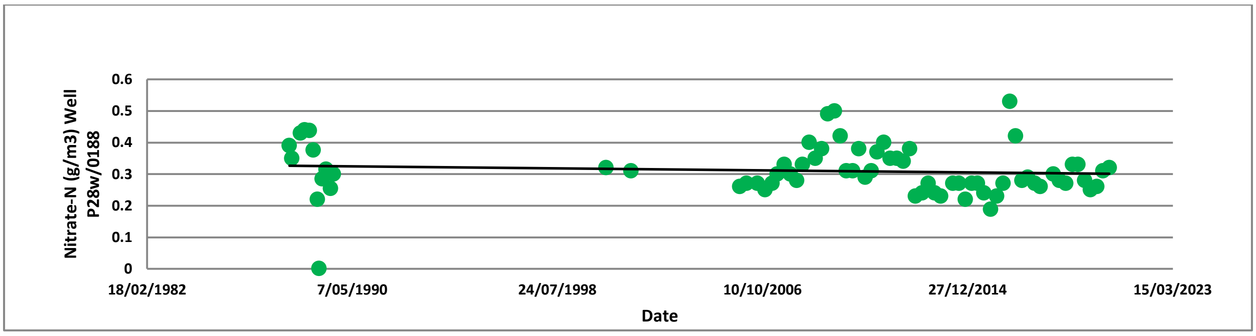


Figure 55: Nitrate-N concentration at confined Wairau Aquifer well P28w/0188 1987-2020.

Well 188 is a 24 metre deep well tapping the confined Wairau Aquifer seaward of Spring Creek township and the Wairau River (Figure 55). Well 188 free-flows which simplifies its field sampling by MDC. The well taps the confined portion of the aquifer which protects it from overhead land uses.

Natural reducing conditions are not sufficiently advanced that groundwater has become evolved at this stage in its flow path. When we refer to groundwater becoming mineralised in this report it means the natural evolution of dilute recharge water through water–rock interaction, not organic nitrogen mineralisation.

Figure 55 shows low and stable Nitrate-N levels since 1987 for well 188. Nitrate-N levels are lower overall compared to shallower Wairau Plain sites further west as a significant proportion has been removed by natural denitrification processes. There are gaps in the record making any conclusions on the existence of trends in Nitrate-N levels less certain.

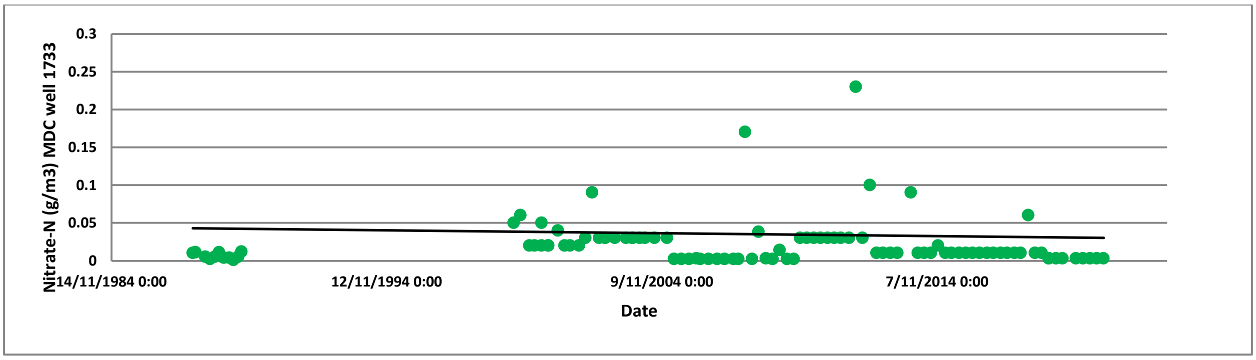


Figure 56: Nitrate-N concentration at confined Wairau Aquifer Coastal Sector well P28w/1733 1987-2020.

The Wairau Aquifer at the Cloudy Bay coast is highly confined and responds to cycles in ocean tidal loadings. Recharge water enters the system a significant distance to the west around Blenheim and during its passage beneath the surface denitrification processes actively reduce Nitrate-N levels.

Figure 56 shows Nitrate-N levels are relatively low as expected, however the fluctuations aren't consistent with its structure. What is surprising given the apparent isolated nature of the aquifer at the coast is the 2 orders of magnitude variation in Nitrate-N concentrations at well 1733 from 0.001 to 0.23 g/m^3.

Other MDC Wairau Plain SoE monitoring wells representing confined aquifer conditions have much smaller ranges in Nitrate-N levels. If concentrations of around 0.005 g/m^3 or less represent the biochemical conditions in this part of the confined Wairau Aquifer, what causes the higher values? (Figure 56).

It's likely to involve changes in redox conditions over time due to pumping inducing changes in flow patterns or other natural stresses. The purging of the well will be reviewed and a comparison with low flow sampling from near the screen trialled.

The mechanism is being explored in terms of Wairau River flood loadings inducing pulses of younger recharge water, differences in vertical flow rates and penetration of young; Nitrate-N rich recharge water from the west. This shows the importance of knowing the hydrology of a catchment in order to understand the nutrient chemistry.

9.2.2. Shorter Nitrate-N Time Series

9.2.2.1. Unconfined Aquifers

By definition unconfined aquifers are more vulnerable to land surface pollution. Marlborough's unconfined aquifer systems are generally oxygenated except for parts of the Rarangi Shallow Aquifer and at Flaxbourne, meaning Nitrate-N is the dominant form of nitrogen found dissolved in these groundwaters.

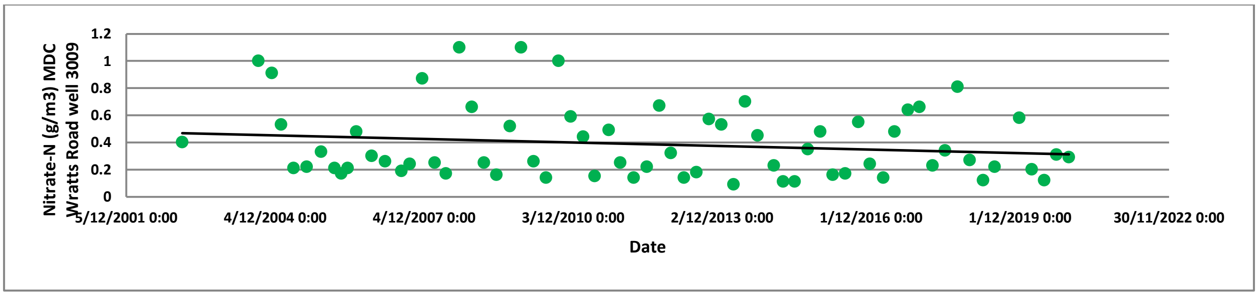


Figure 57: Nitrate-N concentration at unconfined Wairau Aquifer Recharge Sector Wratts Road well P28w/3009 2003-2020.

The unconfined, recharge sector of the Wairau Aquifer opposite the Wairau River floodway and north-west of Renwick, is where most recharge water enters the Wairau Plain groundwater systems. The recharge rate averages 7 m^3/second based on channel loss gaugings (MDC – 2011).

River recharge is a continuous process and it follows that the chemical nature of groundwater near the recharge reach is dominated by that of Wairau River water and relatively unaffected by landuse inputs at this early stage. This reflects the low Nitrate-N content of Wairau River recharge water and diluting effect of the high groundwater throughflow rate.

Figure 57 shows the Nitrate-N times series for MDC Wratts Road well 3009 from 2001 to 2020. The presence of a high groundwater table close to the surface and an unconfined aquifer structure means this site is the most responsive of the Wairau Plain SoE network to rainfall recharge, entraining any surface pollutants and leaching them to groundwater. The seasonality of Nitrate-N inputs from land uses is very apparent with low concentrations in recent times (Figure 57).

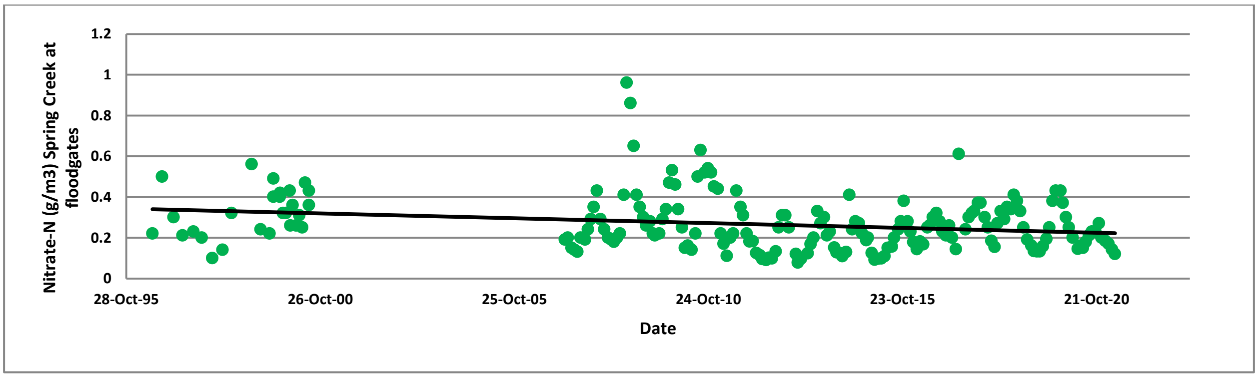


Figure 58: Nitrate-N concentration of lower reaches of Spring Creek at floodgates 1996-2021. Measurements exist for the period 2001 – 2006 but haven't been entered into MDC hydrological database yet.

The springs that emerge in a north-south belt in the mid plains area represent upwelling groundwater. Nitrate-N levels in Spring Creek at Floodgates and MDC Wratts Road well 3009 are the same order and exhibit the same distinctive seasonality (Figures 57 & 58). Annual median Nitrate-N levels are less than the MEP aquatic ecologic limit. There is a slight downwards pattern in Nitrate-N levels recently consistent with all other Wairau Aquifer SoE sites (Figure 58).

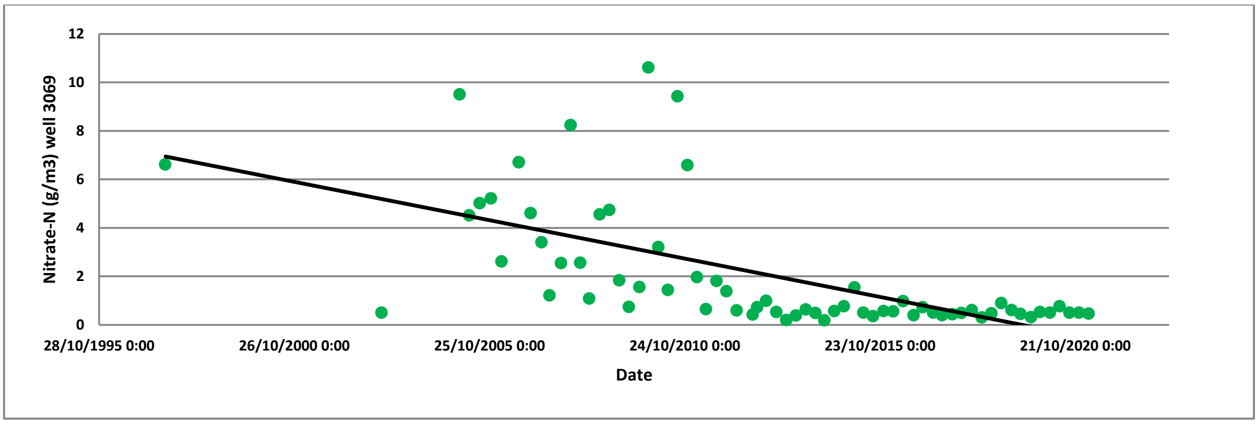


Figure 59: Nitrate-N concentration at unconfined Omaka River Aquifer well P28w/3069 1997-2020.

The Omaka River Aquifer which is recharged directly by Omaka River leakage is a shallow, riparian type gravel aquifer susceptible to land surface contamination because of its unconfined structure. Shallow groundwater levels are relatively stable compared to the related deeper layer at Woodbourne because of the moderating effect of continuous Omaka River recharge (Figure 59).

The high Nitrate-N levels observed between 2005 and 2010 probably reflected local agricultural practices compounded by high rainfall between 2008 and 2010 (Figure 59). Nitrate-N levels declined to a value of around 1 g/m^3 by 2011 and have remained low since then. Groundwater throughflow rates have haven't changed over that time so the explanation for the dramatic downwards trend must be local land-use practices and changes in Nitrate-N application rates.

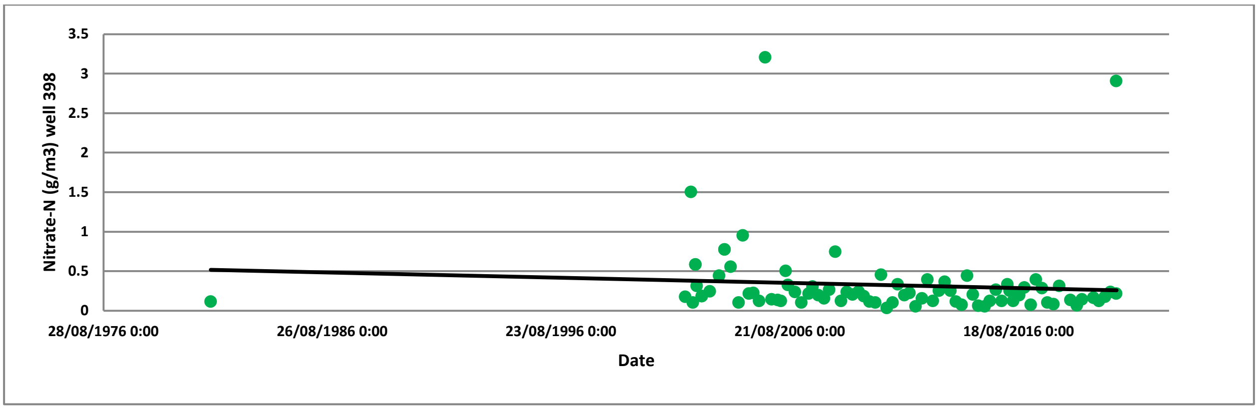


Figure 60: Nitrate-N concentration at unconfined Wairau Aquifer Recharge Sector well P28w/0398 1981-2020.

Well 398 is 10 metres deep and represents conditions in the shallow, unconfined layer of the Wairau Aquifer in the Recharge Sector where the Wairau River loses water underground. The well has been a permanent part of the MDC groundwater quality SoE/National Groundwater Monitoring Programme (NGMP) programme since 2001 (Figure 60).

Figure 60 shows Nitrate-N levels are low and as expected, mirror concentrations in the nearby Wairau River. Because of the large gaps in the early part of the time series, few conclusions can be made about the long-term trend.

What would have been of prime interest were levels in the 1970's corresponding with mixed farming on the Wairau Plain. Since 2005 it can be confidently stated that Nitrate-N levels are falling with time in-line with the observed pattern elsewhere on the northern Wairau Plain.

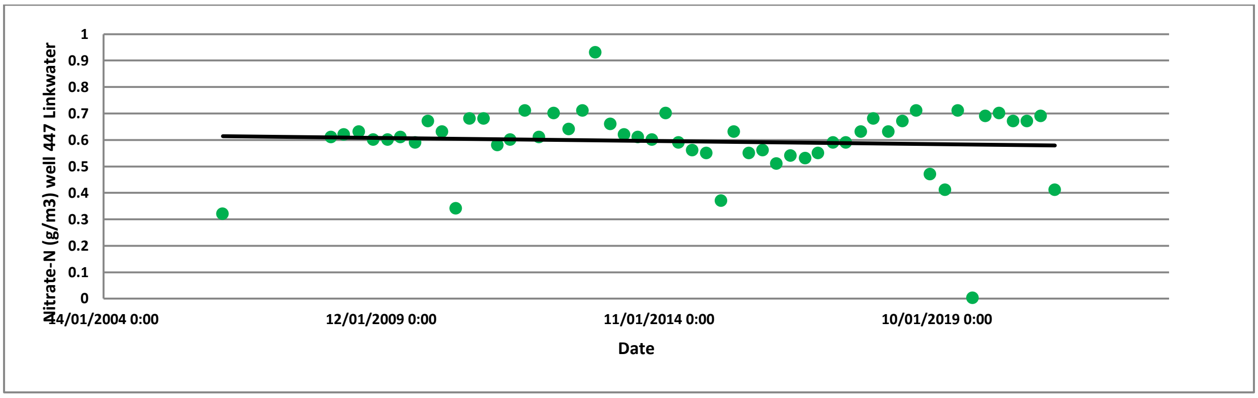


Figure 61: Nitrate-N concentration at unconfined Linkwater well P27w/0447 2006-2020.

The Linkwater Aquifer is known to be hydraulically connected to Cullen Creek based on gauged channel losses to groundwater and isotopic results (MDC – 2011). Well 447 is 11 metres deep and intercepts the shallow gravels associated with Cullen Creek (Figure 61). A shallow circulation system exists with water exchanging between Cullen Creek and shallow groundwater in both directions.

Nitrate-N levels are all less than 1 g/m^3 and stable over time suggesting constant inputs and dilution through the Cullen Creek alluvial fan (Figure 61). The median level is less than the pMEP aquatic ecological limit. The record is too short to comment on trends at this stage.

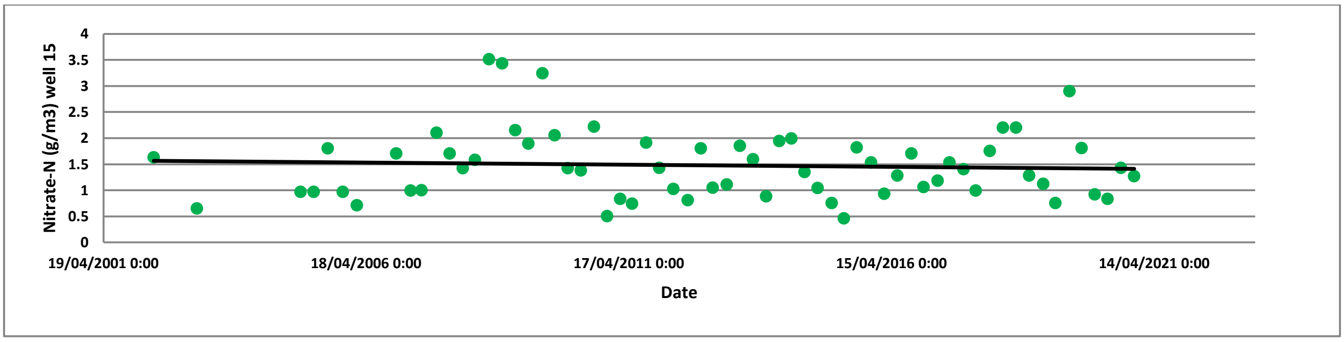


Figure 62: Nitrate-N concentration at unconfined Wairau Valley lower terrace aquifer MDC well O28w/0015 2002-2020.

The south-bank of the Wairau Valley receives recharge from rainfall runoff draining the southern ranges where there have been significant land-use changes since 1990. Plantation forestry on the hills and vineyard or rural residential subdivision on the lower terraces, have replaced semi-intensively grazing with occasional cropping. MDC sample the shallow Wairau Valley municipal supply well 15 each season as part of the SoE programme (Figure 62).

There is a large range in Nitrate-N concentrations from 0.5 to 3.5 g/m^3 reflecting changing land use practices or forestry harvest cycles and variations in rainfall/runoff (Figure 62). The peak value coincided with the wet conditions experienced across the province between 2008 and 2010, which mobilised Nitrate-N downwards to groundwater. The median Nitrate-N concentration of 1.4 g/m^3 exceeds the pMEP aquatic ecology and appears stable over time.

9.2.2.2. Confined & Semi-Confined Aquifers

By virtue of their structure, Nitrate-N levels in Marlborough's confined aquifers are relatively low, especially for groundwater that has been isolated for long periods with associated advanced reducing conditions. Local aquifers also have an abundance of organic matter (e.g. Kahikatea logs) which aids natural denitrification processes.

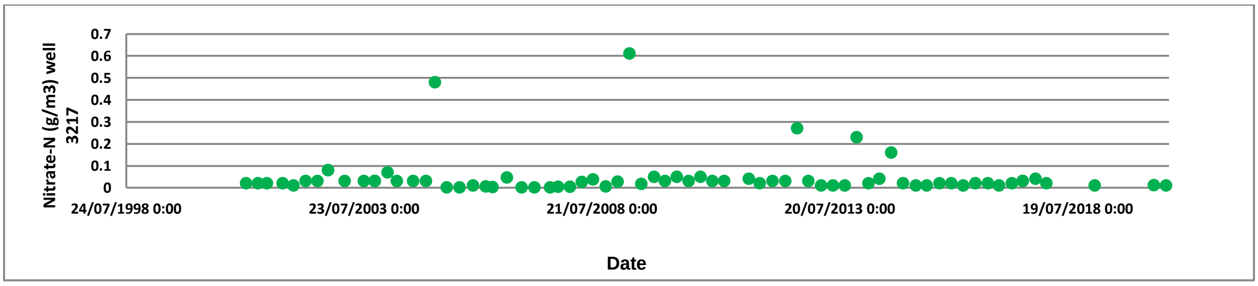


Figure 63: Nitrate-N concentration at confined Brancott Aquifer well P28w/3217 2001-2020.

Well 3217 is privately owned vineyard irrigation well near Wrekin Road at the south end of the Fairhall-Brancott valley. The well is 140 metres deep and intercepts the semi-confined Brancott Aquifer (Figure 63).

The well is screened across a large vertical range including strata close to the surface so Nitrate-N levels are expected to vary depending on which layer groundwater originates from. The overcommitted Southern Valleys Aquifers are only used when the local SVIS scheme is unavailable meaning there are periods of years when groundwater in not used for irrigation and its chemical nature changes with the arrival of younger recharge water.

Figure 63 shows that Nitrate-N concentrations in groundwater from 3217 are generally very low as would be expected given the semi-confined structure of the aquifer and depth of the well. However there is significant variation in Nitrate-N values probably related to pumping patterns, and whether aquifer levels are depressed or closer to the surface.

Even peak Nitrate-N values are relatively low and thought to represent periods when pumping induces younger, shallower groundwater into the deeper layers of the Brancott Aquifer. This is based on a comparison of aquifer and silica levels over time. There is no apparent long term temporal pattern to date (Figure 63).

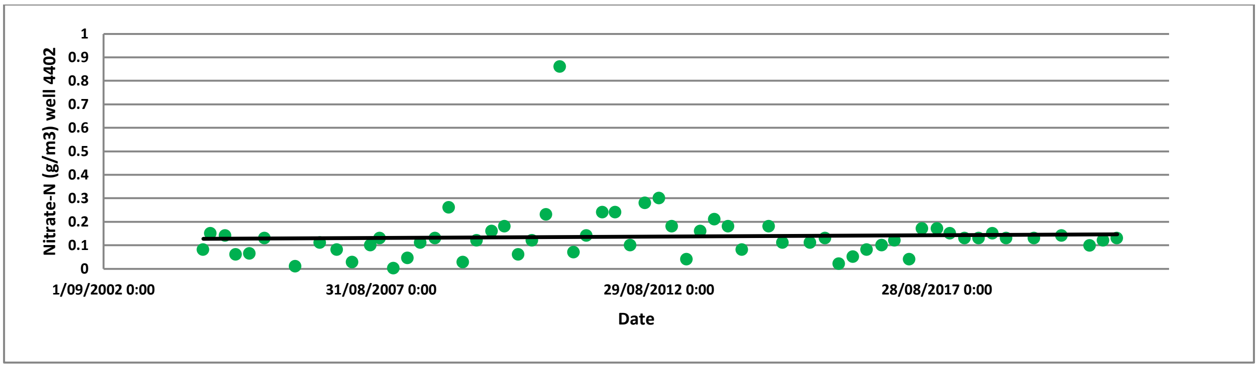


Figure 64: Nitrate-N concentration at confined Riverlands Aquifer MDC Alabama Road well P28w/4402 2004-2020.

Well 4402 was established by MDC to monitor the impact of inland seasonal abstraction on aquifer/wells levels in the south-eastern coastal area of the Wairau Plain. Well 4402 is 26 metres deep and penetrates the confined Riverlands Aquifer east of Alabama Road (Figure 64).

Nitrate-N levels for well 4402 are low and not showing any apparent long-term pattern (Figure 64). Up until 2015 there was a seasonal cycle to Nitrate-N levels, peaking in spring and reaching a minimum in summer. This may indicate the confining layer is thinner near well 4402, or the leading edge may be close by.

Since 2015 there has been a flattening of Nitrate-N levels, possibly reflecting drier surface conditions leading to less leaching, which is propagated through to the confined coastal aquifers including Riverlands (Figure 64). Alternatively the impact of the 2016 Kaikoura earthquake may have changed the aquifer structure and vertical flow paths and modified Nitrate-N related processes.

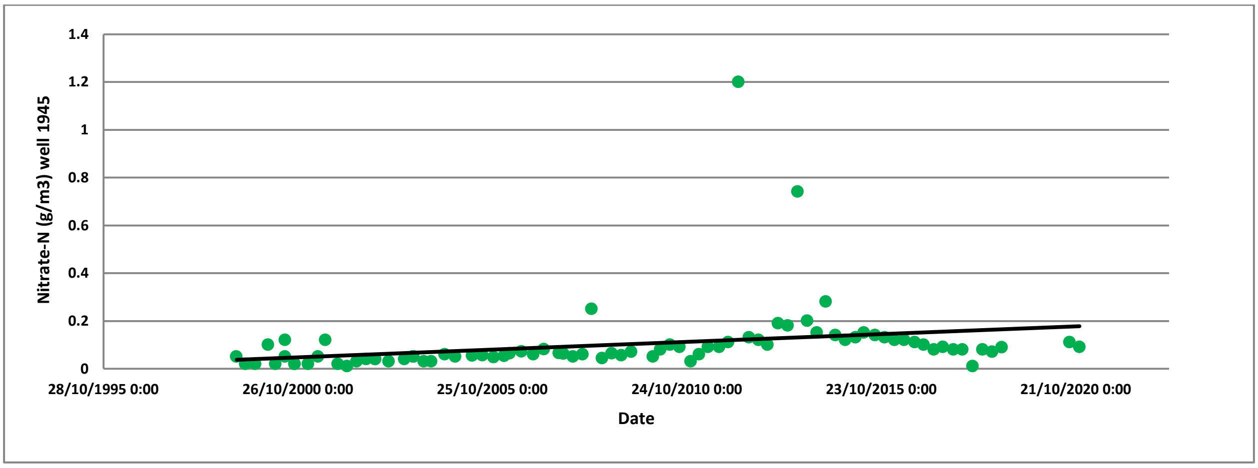


Figure 65: Nitrate-N concentration at semi-confined medium depth Omaka Aquifer layer well P28w/1945 1999-2021.

Well 1945 is a 60 metre deep irrigation well penetrating the medium depth layers of the Omaka Aquifer (Figure 65). Due to its long screen, well 1945 sources groundwater from across a wide depth and strata range.

The Nitrate-N content of groundwater is likely to vary with depth. Reducing conditions probably dominate deeper strata with shallower layers likely to contain oxygenated groundwater with an associated greater land-use influence.

The long screen-length of well 1945 means mixing of groundwater from different stratum is likely to be occurring which complicates the interpretation of redox sensitive results. This is the only SoE site where Nitrate-N concentrations are increasing. The likely reason is landuse intensification involving human settlement and agriculture. However historical Nitrate-N levels are low with a few exceptions (Figure 65).

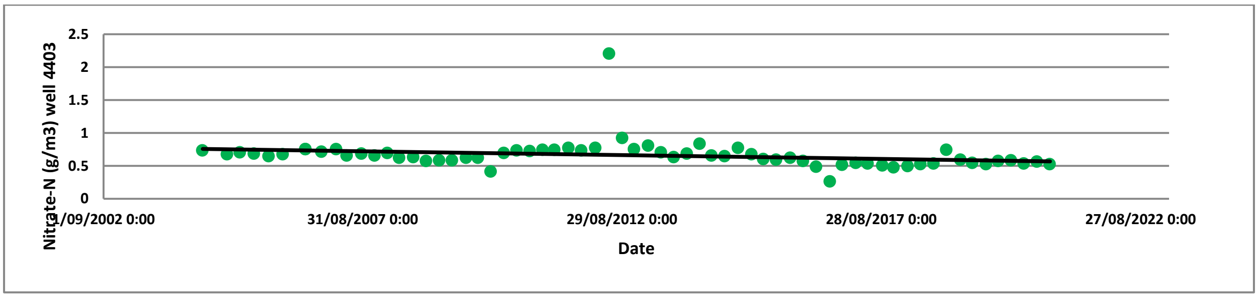


Figure 66: Nitrate-N concentration at confined Wairau Aquifer Morgans Road well P28w/4403 2004-2020.

MDC well 4403 in Morgans Road is a dedicated SoE groundwater quality monitoring well. It is screened between 34 and 37 metres below the surface and penetrates the confined Wairau Aquifer in the Lower Wairau Sector (Figure 66). The well exhibits an artesian standing static water level allowing it to be free-flowed by MDC for SoE sampling.

Figure 66 shows Nitrate-N levels are relatively low with an extremely small range. Well 4403 taps groundwater that has travelled a short distance into the confined aquifer with limited exposure to natural denitrification processes, but Nitrate-N levels are low. There is a slight declining pattern consistent with all other Wairau Aquifer SoE sites (Figure 66). Groundwater doesn't appear to be too denitrified as manganese levels aren't excessively high.

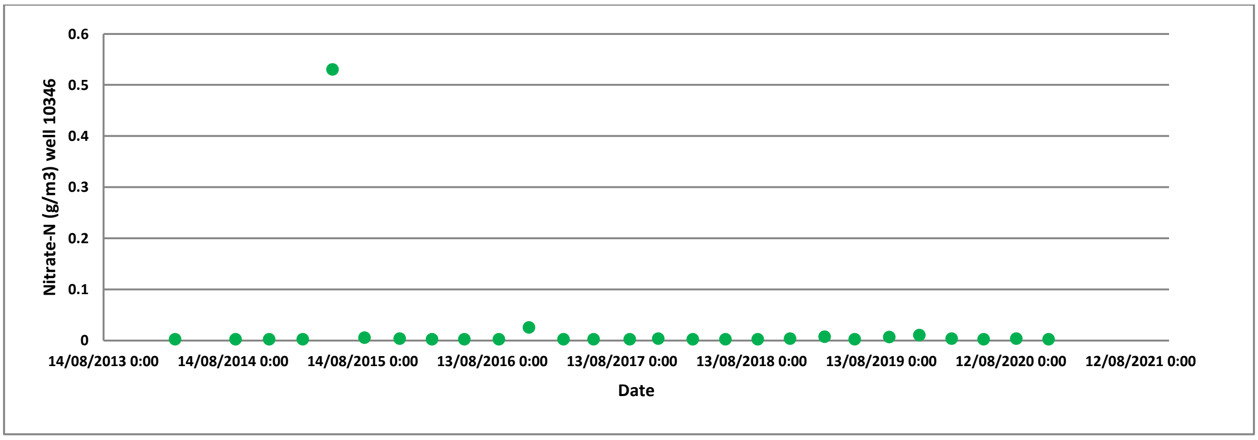


Figure 67: Nitrate-N concentration at confined coastal Riverlands Aquifer well 10346 2014-2020.

Well 10346 is used by MDC for seawater intrusion early warning well and for groundwater quality SoE monitoring. It is 44 metres deep and penetrates the confined Riverlands (Figure 67). The Riverlands Aquifer is heavily committed in terms of consented water demand.

Nitrate-N levels are extremely low at well 10346 which is expected given reducing conditions dominate this confined aquifer and cause groundwater to be highly mineralised with a distinctive H_2S odour during sampling. The exception is the sample taken in mid-2015 (Figure 67). Some but not all Nitrate-N values are less than the laboratory detection limit of 0.002 g/m^3.

Other symptoms of advanced reducing conditions are arsenic levels at 50% of the MAV, iron levels close to the Guideline Value of 0.2 g/m^3 and elevated manganese (DWSNZ – 2005/18). There is no seasonality or trend in Nitrate-N levels as would be expected for an isolated aquifer with stagnant conditions which act as a sink for Nitrate-N (Figure 67).

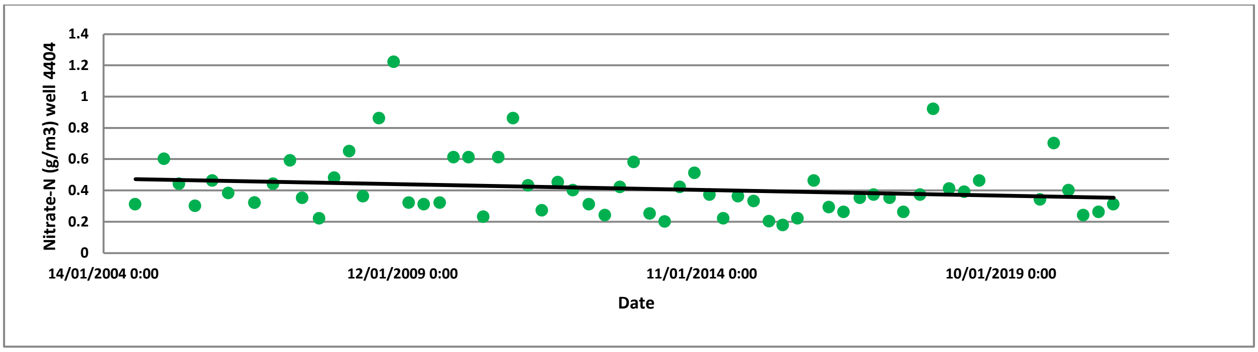


Figure 68: Nitrate-N concentration at semi-confined Wairau Aquifer well P28w/4404 Mills & Ford Road 2004-2020.

Well 4404 is a 14 metre deep well located at the end of Mills and Ford Road, east of the Opaoa River channel. It represents the semi-confined area of the Wairau Aquifer where groundwater breaks the surface as springs (Figure 68).

Nitrate-N concentrations are relatively low and there is a significant variation which may be related to the influence of the Opaoa River (Figure 68). There is a slight declining trend in Nitrate-N levels since samples were first taken in 2004 consistent with other Wairau Aquifer SoE site results.

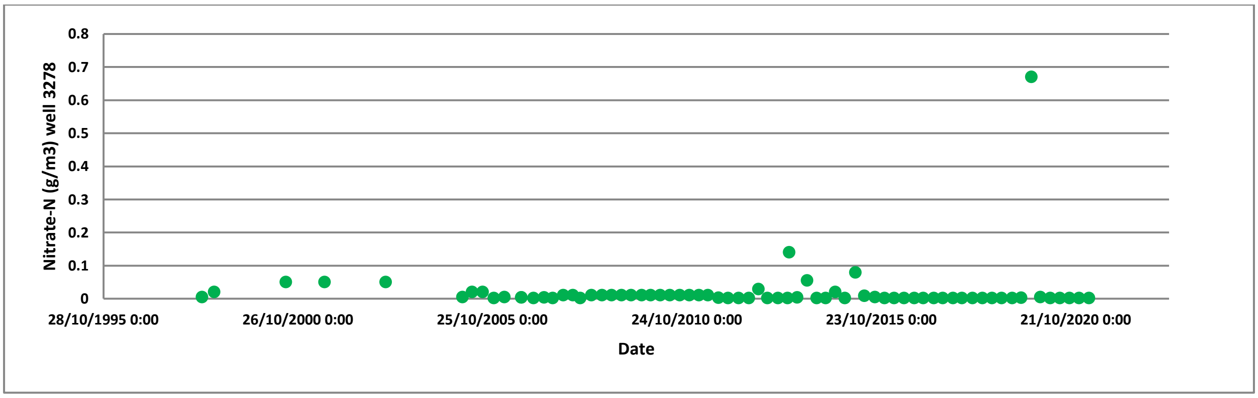
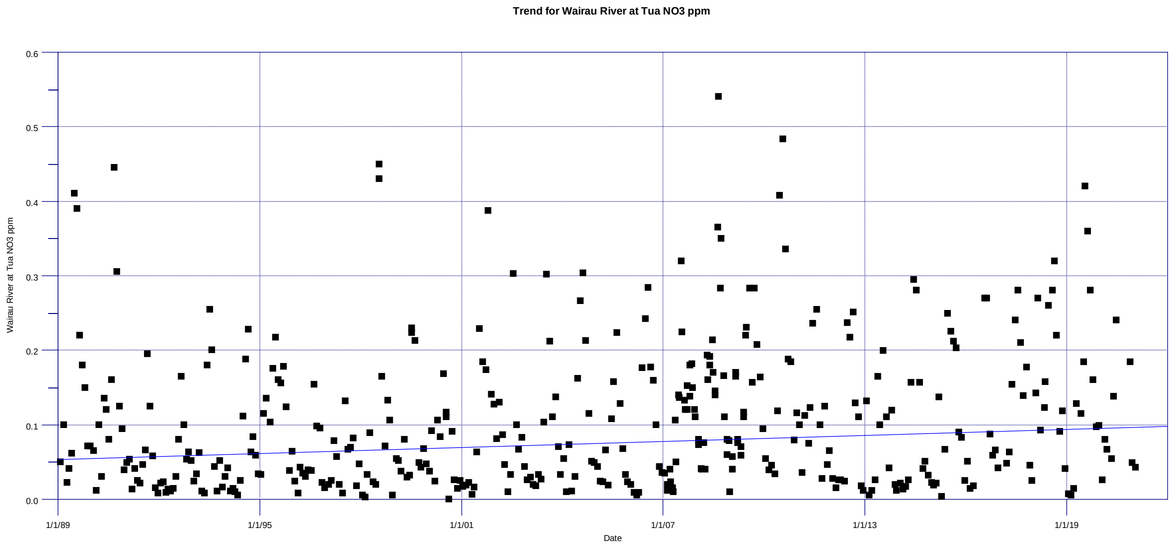


Figure 69: Nitrate-N concentration at confined Deep Wairau Aquifer well P28w/3278 1998-2020.

Well 3278 penetrates the Deep Wairau Aquifer beneath the Fairhall area at a depth of 200 metres and contains very old water recharged 20,000 years before present and as a consequence is highly mineralised (Figure 69).

Nitrate-N concentrations in groundwater are extremely low (Figure 69). The water bearing layer is confined by marine sediments and pressurised, meaning there is little likelihood of surface pollution. Any Nitrate-N present in groundwater is ancient and wasn’t generated by recent land uses.

9.3. Appendix C: Statistical Analysis of Trends



Mann-Kendall test using all values for Wairau River at Tua NO3 ppm

Seasons used in analysis are: Jan - Dec

Period analysed 32 years and 1 months for calendar years 1989 to 2021

413 observations from 25⁄1⁄89 to 12⁄1⁄21 with 217 ties and 32 time ties due to multiple values in time periods

Sample size greater than or equal to 10 and normal approximation used to determine P value

	Sample size	Median value	Kendall statistic	Variance	Z	P	Median Sen slope (annual)	5% confidence limit for slope	95% confidence limit for slope	Percent annual change
Unadjusted	413	0.08	10286.00	7844803.95	3.67	0.00	0.00	0.00	0.00	1.77

Figure 70: Mann-Kendall plot and statistics for Wairau River Nitrate-Nitrogen concentration at Tuamarina 1989-2021.