MARLBOROUGH DISTRICT COUNCIL

# Riverlands Aquifer Combined Groundwater Quantity and Quality State of the Environment Report

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Report Prepared by:
**Peter Davidson**
Environmental Scientist – Groundwater
Environmental Science & Monitoring Group

Report Approved by:
**Alan Johnson**
Environmental Science & Monitoring Group Manager
Marlborough District Council

Marlborough District Council
Seymour Square
PO Box 443
Blenheim 7240
Phone: 520 7400
Website: [www.marlborough.govt.nz](http://www.marlborough.govt.nz)

# Executive Summary

This State of the Environment Report reviews groundwater monitoring data from the Riverlands Aquifer area and compares it to the environmental limits defined in the proposed Marlborough Environment Plan (pMEP), which are designed to ensure sustainable management of the resource, including the avoidance of sea-water intrusion effects.

There are no signs of seawater intrusion having occurred based on continuous observations of groundwater electrical conductivity and level at the MDC Lagoon monitoring sentinel wells since 2001. This demonstrates current rates of abstraction are broadly balanced by recharge, although the geographical distribution of most consented abstraction inland and away from the coast is a mitigating factor.

In most summer seasons Riverlands Aquifer levels approach the minimum 1.25 metres above mean sea level elevation cutoff threshold showing the resource is fully committed.

Changes in Riverlands Aquifer levels are demand driven, meaning the most appropriate way of avoiding low aquifer levels and maintaining acceptable levels of reliability for existing water users is through the pMEP volumetric allocation limit. The purpose of pMEP cutoffs is to temporarily govern seasonal demand during periods of naturally low recharge, not as the prime management method.

Not all groundwater specified in the pMEP as being available for allocation has been either consented or used. The MDC hold a significant paper allocation that is currently not fully utilised. If this unused quota were abstracted, it is likely to cause low groundwater levels that breach the limits set in the proposed Marlborough Environment Plan and potentially lead to seawater intrusion.

Riverlands Aquifer levels are predicted to increase in response to sea-level rise, but there is no apparent rise in groundwater levels so far based on Marlborough District Council State of the Environment monitoring network results.

Riverlands groundwater quality largely reflects natural evolution processes with few signs of human inputs either because they are minor, or the effects are masked by natural assimilation processes. The values or concentrations of a significant number of groundwater quality parameters are increasing with time consistent with Riverlands groundwater becoming more evolved.

Abstraction induced changes in aquifer flow patterns are likely to modify natural groundwater quality/chemistry. Natural events such as Wairau River or Ōpaoa River floods are also likely to influence groundwater quality in a similar way.

The process of implementing the NPSFM 2020 provides MDC with an opportunity for the matters raised in this report to be considered further.

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# 1. Introduction

Groundwater is crucial to many parts of Marlborough, especially the Wairau Plain where the largest aquifers are associated with the thick alluvial gravels forming the Wairau River deposited floodplain. All irrigation water in the Marlborough Sounds catchments is sourced from wells, although the aquifer forming alluvial gravels of the river valley floors are thin and do not store much groundwater. The East Coast and Awatere River catchments do not have the extensive floodplains to form aquifers and rely on channel flow sourced from infiltration galleries.

All water used on the Wairau Plain for drinking, processing wine or other food crops and most of the water for irrigating crops is sourced from underground aquifers. The base-flow of all surface waterways east of Hammerichs Road including those running through Blenheim represent upwelling groundwater.

Groundwater fed springs are aesthetically important to residents. They also form a unique cold-water habitat which is home to fish, plants and animals including many rare native species. Groundwater flow forms a barrier with the Pacific Ocean maintaining seawater at a safe distance from wells.

It is estimated that groundwater benefits the Wairau Plain economy to the tune of $800 million dollars a year through its servicing of horticulture and for human consumption in the main settlements or rural areas. Actively managing this valuable natural resource is a key role for Marlborough District Council (MDC) as the regulator.

A key measure of aquifer health are the observations supplied by the MDC State of the Environment (SoE) groundwater monitoring network representing the main aquifers underlying the Wairau Plain and smaller systems in the Marlborough Sounds, Wairau Valley and Flaxbourne River Catchment. The network consists of dedicated MDC wells along with privately owned water wells.

The MDC SoE network produces a wealth of monitoring information used for assessing the quality and quantity of groundwater resources at any point in time. Three decades of record now exists at many MDC Wairau Plain SoE monitoring sites with some having discontinuous record stretching back four to eight decades.

This information allows MDC to identify seasonal patterns, short to medium length cycles and long-term trends in groundwater behaviour. In conjunction with other information like metered water use, land use or climate; MDC can link changes in groundwater quality or quantity with changes to either human or natural drivers. Key to understanding cause and effect is catchment hydrology.

A key application of SoE data by MDC is for setting and refining limits, especially for abstraction of groundwater. While limits have been specified for all the major aquifer systems, the effects of actual use have only recently been measured directly through flow metering. External drivers like climate change complicate the picture for analysts.

Experience has shown that in many areas it can take a minimum of 20 years of continuous records of the behaviour of water resources to isolate cyclical seasonal patterns from human activities and identify any longer-term trends that might be present. There is no substitute for long uninterrupted time series with supporting climate or land use information.

# 2. Purpose

Given the importance of groundwater to the economic, aesthetic, and ecological wellbeing of Marlborough and in particular the Wairau Plain, MDC produce an annual report on the state of Marlborough's aquifer resources. Every five years a more comprehensive report is produced with more in-depth analyses. This report represents a more detailed review of the state of the Riverlands Aquifer.

SoE reports are a priority for MDC to gauge the effectiveness of pMEP rules/policy, impact of drought conditions such as during the 2018/19 - 2019/20 summer irrigation seasons and the effects of storms like the 2021/2022 events, on leaching land surface pollutants to groundwater.

The 2021 SoE report focused on groundwater quality and in particular levels of nitrate-nitrogen in Marlborough groundwaters. This is a topical issue at a national level for New Zealand. The 2022 review of groundwater quantity provided a regional scale overview of stress on groundwater systems and their related springs.

The Riverlands and south-eastern coastal area is the subject of this first geographically based focus report based on its heavily committed allocation status. This report is a comprehensive review of aquifer state and trends.

The aims of this report are to:

- assess the current state of groundwater resources in terms of its quality and quantity;
- identify seasonality, medium term patterns or longer-term trends in groundwater quality or level;
- attribute changes in groundwater quality/quantity between natural processes, climate change or human activities;
- identify which drivers can be managed or regulated versus those that constitute natural processes;
- review current state of Riverlands Aquifer allocation and appropriateness of pMEP volumetric limit; and
- update MDC, water users and the community on the state of aquifer resource.

# 3. Methodology

Central to this report was the analysis of MDC monitoring data to determine the existence of trends or patterns in groundwater quantity/quality time series and where possible identify their drivers. Data from the two MDC level monitoring wells representing the Riverlands Aquifer along-with metered water use was the primary source of information for the study. This data was assessed to determine:

- existence of long-term trends, intermediate cycles and seasonality;
- current state relative to ecological (pMEP) or human health thresholds (Drinking Water Standards for New Zealand Regulations & Aesthetics Values for Drinking Water Notice 2022);
- spatial changes in current state between the six MDC groundwater quality monitoring sites to understand groundwater evolution processes;
- influence of hydraulically connected surface water or local climate;
- influence of distant versus local land uses;
- influence of abstraction; and
- influence of aquifer structure, mineralogy and biochemical processes on groundwater quality.

Different software was used to analyse the MDC datasets. The Time Trends suite of statistical methods was used to test for statistically significant trends, in particular the Seasonal Kendall test. HILLTOP was used for graphing and comparing time series, calculating median values and correlating hydrological and water chemistry observations using scatter plots. ArcGIS was used for making maps and displaying information in plan view.

To understand sub-regional scale Riverlands Aquifer patterns, median concentrations of each chemical parameters were mapped to identify spatial patterns. The chemistry of river recharge sources was compared with that of groundwater to see how much of any change over time they accounted for versus local aquifer processes or land uses.

Groundwater chemistry/quality is strongly influenced by aquifer hydrology and abstraction patterns. Pumping has a greater influence on local groundwater levels and flow patterns than other Wairau Plain aquifers because of the very low storage characteristics of groundwater near the Cloudy Bay coast, including the Riverlands Aquifer.

# 4. MDC State of the Environment Monitoring Network

The report relies on observations from the MDC State of the Environment (SoE) monitoring well network of groundwater level recorder sites and groundwater quality sample sites (*Figure 1* and *Figure 2*).

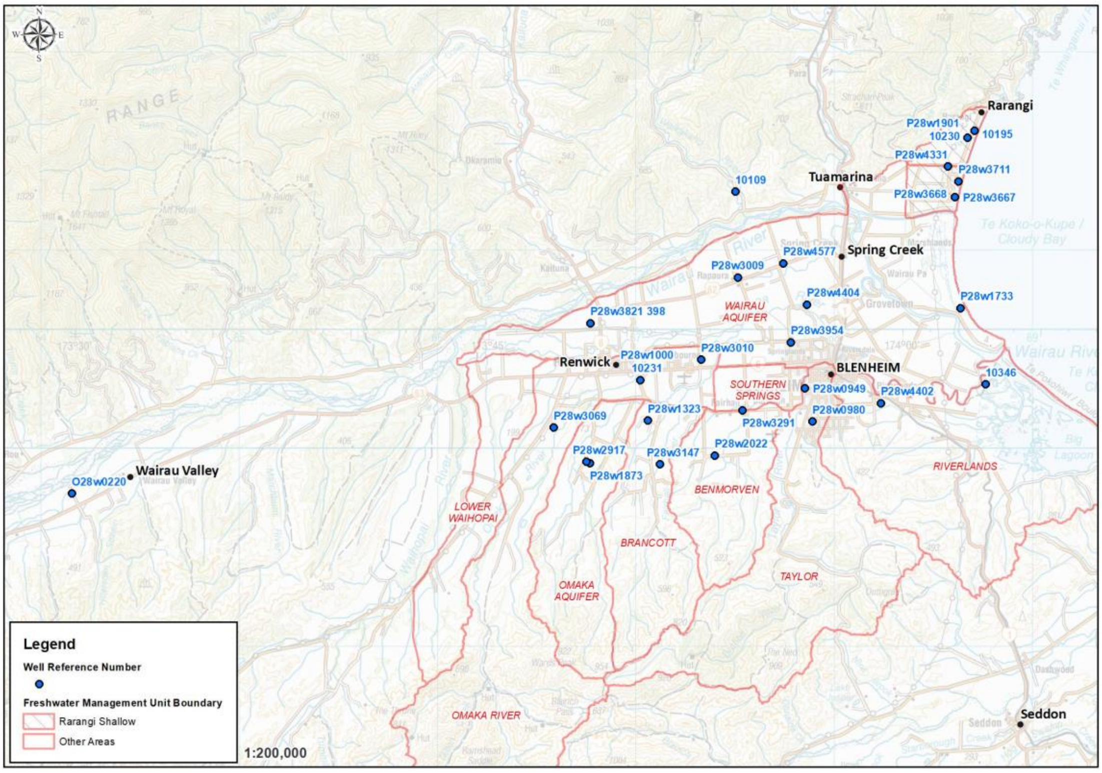



***Figure 1: MDC groundwater quantity state of the environment monitoring network.***

The Riverlands Aquifer can be subdivided into two parts based on proximity to the coast and potential risk from seawater intrusion. The coastal area has less consented abstraction, but pumping can directly affect the position of the seawater interface. Inland areas have the largest concentration of groundwater abstraction, which is creating a seasonal groundwater low, but is distant from the seawater interface. The MDC SoE network was established to represent both inland and coastal areas.

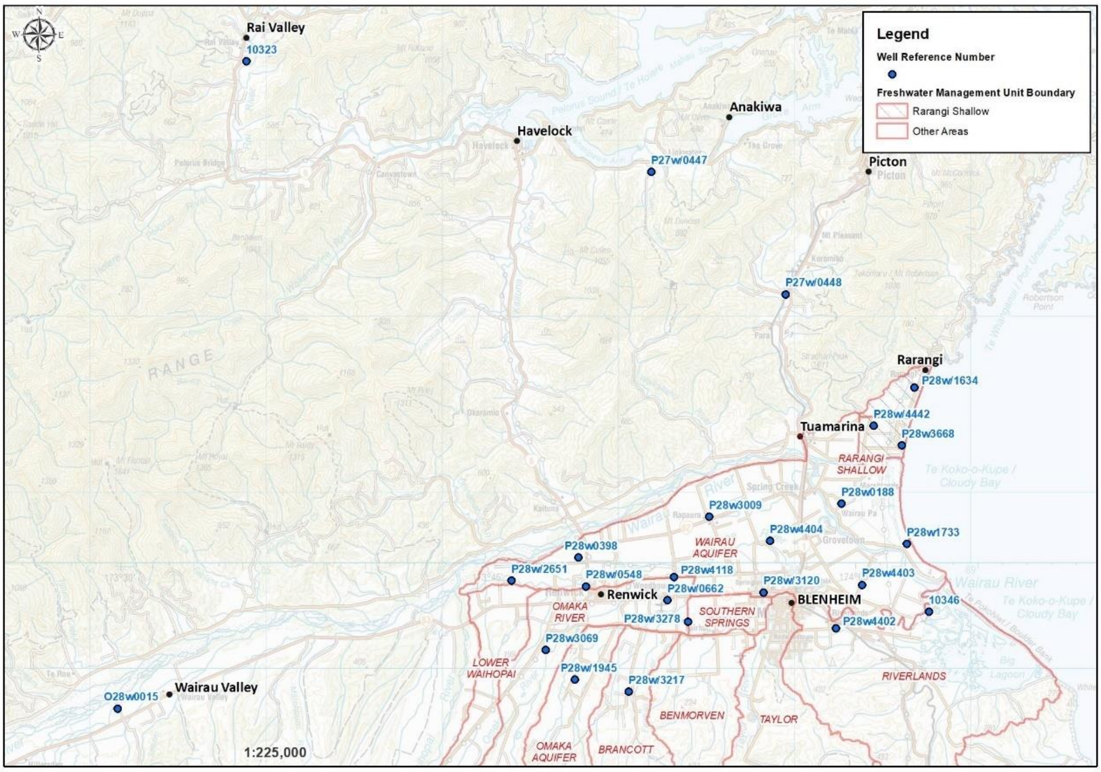



***Figure 2 : MDC Groundwater Quality State of the Environment Monitoring Network.***

MDC operate two permanent monitoring wells to observe variations in the quality and quantity of Riverlands Aquifer groundwater (wells 10346 and P28w/4402 on *Figure 2*). The prime purpose of the Lagoon Replacement well 10346 located near the coast within the MDC municipal effluent treatment area is to provide early warning of seawater intrusion (*Figure 3*).

This well and its predecessor Lagoon well 708, have provided continuous level record since the year 2000. Well 10346 is screened from 42.5 to 43.5 metres depth below the surface while the original Lagoon well 708 is 42.7 metres deep (*Figure 3*).

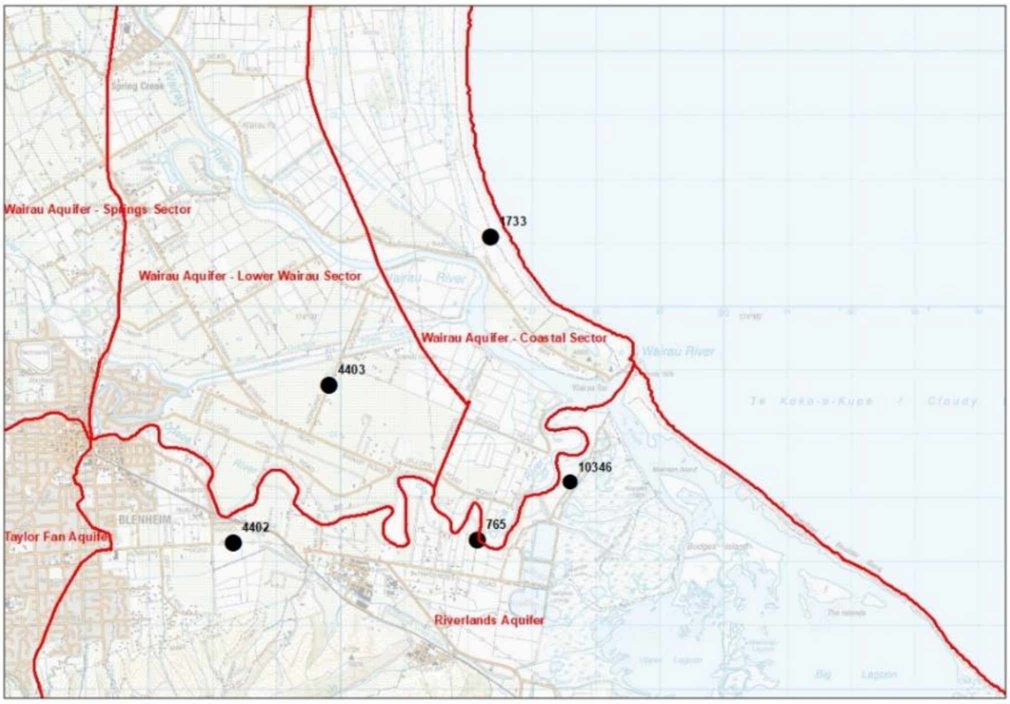



***Figure 3 Closeup of MDC State of the Environment (SoE) Monitoring Network location map representing the south-eastern Wairau Plain. The five MDC monitoring sites shown represent three different Freshwater Management sectors: Coastal Wairau Aquifer Sector, Riverlands Aquifer and Lower Wairau Sector. Well 765 is no longer an active MDC SoE site.***

MDC have continuous observations of groundwater electrical conductivity dating back to 2001 across both Lagoon wells. Because the two wells intercept slightly different parts of the aquifer, electrical conductivity is also different, meaning it is not valid for MDC to concatenate the records.

MDC established the permanent groundwater level and state of the environment quality monitoring well (Alabama Road well 4402) off the eastern end of Alabama Road in 2004 to observe the direct effects of pumping and define the groundwater gradient towards the coast (*Figure 3*). This well is screened between 22.3 and 25.5 metres depth below the surface. Due to the concentration of consented demand in the general area, summer groundwater levels are lower than near the coast.

As part of this report, groundwater quality data was sourced from the MDC Vernon well 765 and the southern most of the two wells making up the MDC Hardings Road wellfield which supplies the Cloudy Bay Business Park (Hardings Road south well 1147) to provide an historical perspective of changes in groundwater chemistry and how abstraction may have been affecting aquifer dynamics. Hardings Road south well 1147 is screened between 35 and 41 metres below the ground and located 110 metres north-west of well 765 (*Figure 3*).

The MDC Vernon well 765 is 38 metres deep and was sampled as part of the MDC SoE survey between 2007 and 2014. Both the Vernon and Hardings Road South wells are screened at the same depth meaning they should exhibit similar groundwater levels and chemistry at the same instant in time.

# 5. Hydrogeology

## 5.1. Aquifer Structure, Boundaries and Recharge

The focus of this report is the Riverlands Aquifer underlying Riverlands in the south-east corner of the Wairau Plain. To provide context, the report includes monitoring information from MDC wells representing the neighbouring aquifer systems.

The Wairau Aquifer is the largest of the Wairau Plain groundwater systems in terms of storage and throughflow rate. The Riverlands and Wairau Aquifers are hydraulically contiguous and have been bundled together to provide an overall appreciation of sub-regional flow dynamics.

All three coastal Wairau freshwater management units (Coastal Wairau Aquifer Sector, Riverlands Aquifer and Lower Wairau Sector) units have a confined aquifer structure and the same potential water management issues. Recharge water enters a significant distance upstream to the west, originating as channel losses from the Wairau River and to a lesser extent Taylor River. Some recharge water is also likely to originate along the boundary with the Wither Hills.

Considerable uncertainty remains over how groundwater discharges from the confined aquifers at the Cloudy Bay coast. Irrespective of the pathway, these flows are an order of magnitude lower than those of the main spring belt draining the unconfined Wairau Aquifer to the west.

The Coastal Sector of the Wairau Aquifer opposite Bar well 1733 is thought to discharge to surface springs via diffuse upwards flow, and possibly offshore flow to Cook Strait. An active discharge from that sector is indicated by moderately low residence times showing groundwater is not stationary. There is also marine geophysical evidence whereby the permeable gravels forming the Wairau Aquifer extend offshore and intercept the Cook Strait seafloor. The occurrence of seafloor springs has not been confirmed, however.

The more evolved state of Riverlands aquifer groundwater implies no active outlet may exist, or if it does flow rates are small. It is difficult to observe or measure these processes directly. This uncertainty is the reason the interface and direct effects of abstraction can’t be modelled yet.

The Riverlands Aquifer has a well-defined southern boundary represented by the geologically impermeable Wither Hills. The northern and western boundaries of the Riverlands Aquifer merge with the Wairau Aquifer and Taylor Fan Aquifers, but with no hard or definitive delineation.

For aquifer management purposes the northern boundary of the Riverlands Aquifer is defined in the Marlborough Environment Plan as the Ōpaoa River channel, which is not a hard boundary meaning the influence of pumping or recharge processes can cross the boundary line in both directions.

Vertical flows play a fundamental role in the behaviour of these aquifers. It is likely based on similar geological basins elsewhere in New Zealand that deeper aquifer systems exist beneath the currently defined hydro-geological formations, but deep drilling is required to describe and map them. Because of the dominant vertical flow gradient, the role of any deeper water bearing layers that exist is important in explaining processes closer to the surface.

## 5.2. Groundwater Level Fluctuations and Drivers

### 5.2.1. Aquifer Characteristics

Is necessary to understand why aquifer levels change to distinguish between human and natural drivers for management purposes. To do this requires an understanding of aquifer hydrology and abstraction to interpret patterns or trends. Well levels change constantly in response to natural and human induced stresses, especially in coastal areas of the Wairau Plain due to a confined structure.

The confined structure of the Riverlands Aquifer and Coastal Wairau Aquifer makes them more responsive to stresses like well pumping and loading from river floods than the porous open gravel type aquifers further inland.  Low storativity ($10^{-4}$ -$10^{-5}$) means they store small volumes of water with some changes in groundwater level representing pressure effects, not mass exchanges.  The confinement makes them closed systems with very low oxygen content which strongly influences groundwater chemistry.

Abstraction from wells, changes in barometric pressure, Wairau River/Ōpaoa River floods and sea tides squeeze or inflate these confined aquifers which affect well levels.  The Riverlands Aquifer is demand-driven meaning most seasonal change in groundwater level is caused by abstraction.  In the absence of pumping, groundwater levels do not vary by much reflecting their relative isolation from the main Wairau River recharge source, proximity to the stable sea boundary and a confined structure with limited groundwater outflow.

Conversely unconfined parts of the Wairau Aquifer are dominated by natural Wairau River recharge processes or spring discharge.  Wells at Riverlands are as productive as anywhere on the Wairau Plain, but drawdown cones are more extensive and can generate interference effects.  Artesian well levels are common but does not mean the aquifers are high yielding as commonly thought.

## 5.2.2. Seasonality

Figure 4 is an envelope plot of daily average aquifer elevation over a water year from July to July based on records dating back to the late 1980s for the Bar well 1733 (below) and 2004 for Alabama Road well 4402 (above).  The purpose is to show how groundwater levels vary seasonally across the study area and the influence of abstraction.

The vertical scale is the same for both graphs with a three-metre range.  The red line is the average elevation for each day and the blue line is what has happened since 1 July 2022 in the current water year.  The green shaded central area of each graph represents the middle 60% of daily readings.  The lighter shaded yellow outer areas represent the remaining 40% of high or low values.


***Figure 4: Comparison of groundwater level range between Bar well 1733 & Alabama Road well 4402.***

The annual hydrograph is characterised by relatively high levels in winter and early spring, interspersed with lower levels caused by abstraction that vary in range depending on proximity to pumping wells.  The variation in groundwater level at Bar well 1733 is small at around 1.5 metres whereas the range at Alabama Road well 4402 is over two metres (*Figure 4*).

The Bar well 1733 has a relatively small annual variation in aquifer level being close to the ocean and relatively distant from direct pumping effects, whereas the Alabama Road well 4402 is close to the centre of pumping over summer. Outside that period the natural seasonal variation is probably similar at both wells.

The natural or non-pumping annual range in aquifer level for the Riverlands Aquifer is estimated to be less than 1 metre based on continuous level record from Old House well 1372 pre-1975 (*Figure 5*). Historically the Riverlands area has always relied on groundwater abstractions so there has never been a period when the natural variation could be precisely observed.

## 5.3. Groundwater Level Trends and Patterns

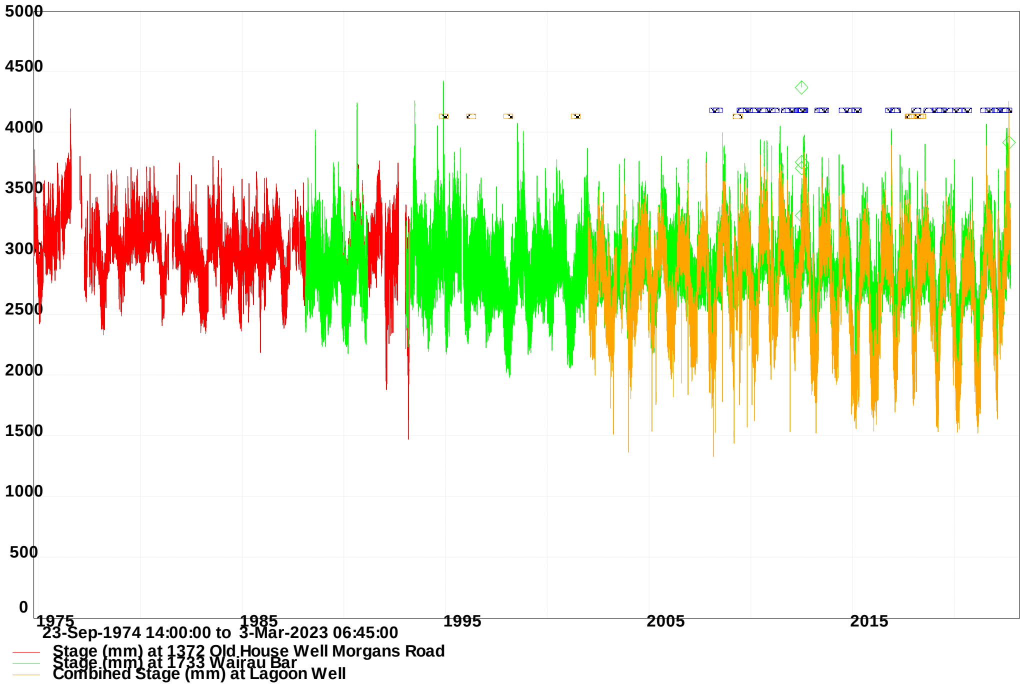



***Figure 5: Comparison of seasonal groundwater elevation range for Riverlands Aquifer based on combined Lagoon well versus central Coastal Wairau Aquifer Sector (Bar well 1733 & Old House well 1372) 1974 – 2022.***

Riverlands Aquifer groundwater levels have varied over time based on concatenating record from the Bar well 1733 with the closed Marlborough Catchment Board monitoring well 1372 (Old House well) providing 47 years of observations dating back to 1974 to use as an index of natural coastal aquifer state (*Figure 5*).

The vertical scale shows elevation in millimetres above mean sea-level (MCB/MDC R & D datum). The red line representing Old House well P28w/1372 groundwater level is strongly correlated with groundwater level at the Bar well 1733. Old House well 1372 is in Morgans Road around 2000 metres to south of Bar well 1733. The Lagoon Replacement well 10346 trace is orange and the Bar well 1733 is green (*Figure 5*). The most obvious difference over time is the larger seasonal summer drawdown at the Lagoon well compared to the Bar well 1733/Old House well 1372.

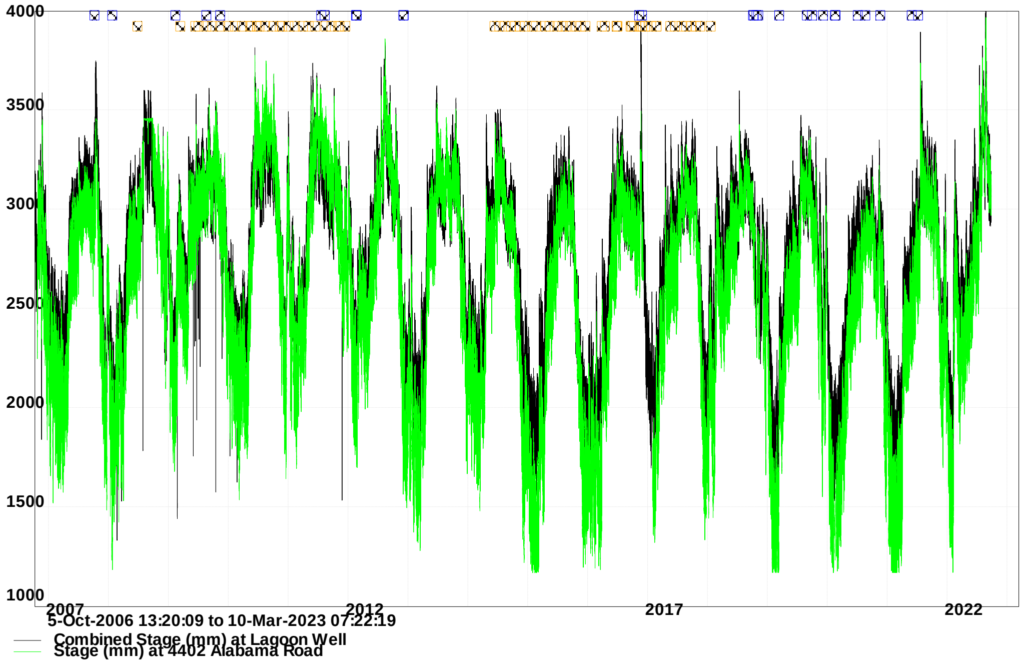



***Figure 6: Comparison of groundwater elevation difference between Lagoon Replacement well 10346 in black and well 4402 at Alabama Road in green. The mean sea-level elevation datum is MCB/MDC R & D).***

Figure 6 compares the groundwater elevation at the coastal combined Lagoon well with Alabama Road well 4402 to illustrate the larger pumping influence inland, nearer where most abstraction occurs. Groundwater levels at both wells tend to recover each year, but levels at the Alabama Road well 4402 (green) are around 0.5 metres lower in summer than levels at the Lagoon well 10346 (black).

### 5.3.1. Short term groundwater responses to stressors

Metering is compulsory for all Riverlands Aquifer water permits regardless of the size of consent, but not all meter readings are available to MDC in an electronic form. An allowance of 20% of the metered data was made for un-metered groundwater use as part of this study to reflect that around 80% of water permits were metered. Real time water use data is best for generating a cumulative total to compare against changes in groundwater level. Consented demand is appropriate for pMEP limit setting, but actual use is necessary to define cause and effect.

The localised impact of summer abstraction is easily identified in MDC monitoring time series by the seasonal divergence of groundwater levels between sites, or distortion of the tidal level cycle. Figure 7 shows the sinusoidal groundwater level pattern caused by ocean tides in Cloudy Bay during September 2022 for the three MDC monitoring wells, with nearby pumping drawing levels down and distorting three cycles of the Alabama Road well 4402 (blue) record only.

The range in tidal cycle is a function of distance from the sea, aquifer transmissivity and storativity. These fluctuations are most pronounced for confined aquifers but do show-up in the some Rarangi Shallow Aquifer well records for sites very close to the coast.

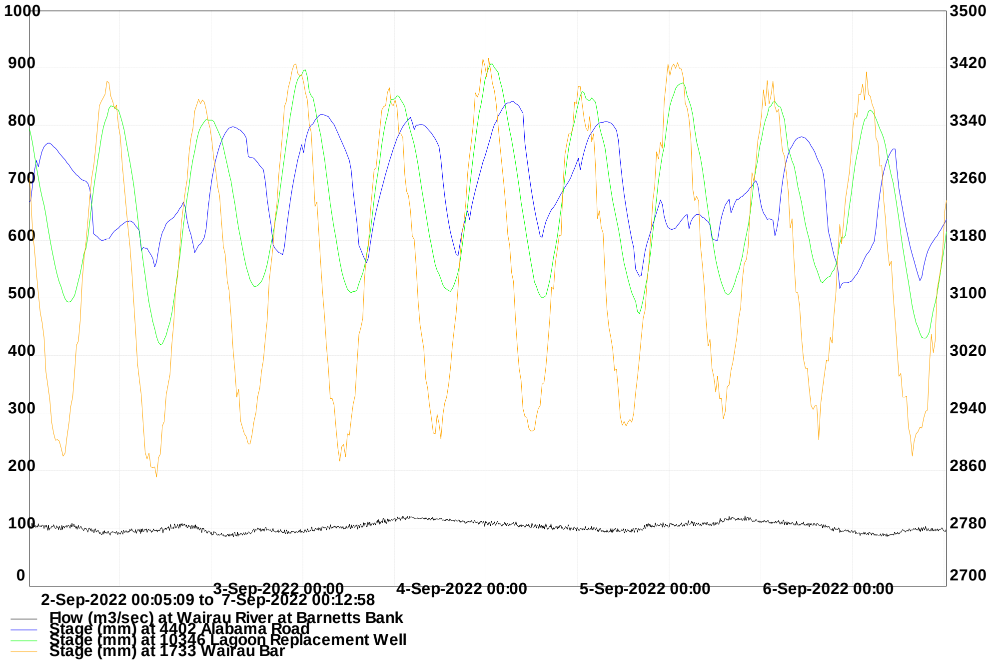



***Figure 7: Comparison of spring 2022 groundwater levels between Alabama Road well 4402 (blue), Bar well 1733 (orange) & Lagoon Replacement well 10346 (green).***

When abstraction increases groundwater levels fall and vice versa which is illustrated by well level record from early 2019 (*Figure 8*). Figure 8 shows Wairau River flow at Tuamarina (black) on the left-hand vertical axis, groundwater elevation on right hand inner axis (Bar well 1733 orange, Alabama Road well 4402 blue and Lagoon Replacement well 10346 green) and cumulative metered abstraction for the Riverlands Aquifer (purple) shown on right hand outer vertical scale.

The Bar well 1733 is least affected by pumping while the Alabama Road well 4402 experienced the largest drawdowns indicating it is closest to the greatest concentration of pumping (*Figure 8*). Conversely the Bar well 1733 is furthest from pumping effects. Under natural conditions groundwater elevation would be similar across all three wells.

A sure sign of interference effects from nearby pumping wells at the Alabama Road well 4402 is the distorted tidal cycle compared with the regular shaped waves exhibited by Bar well 1733 and Lagoon Replacement well 10346 (*Figure 8*). Drawdown events at Alabama Road well 4402 have been correlated with metered pumping records for the ANZCO wells, MDC Malthouse wellfield, amongst other nearby wells.

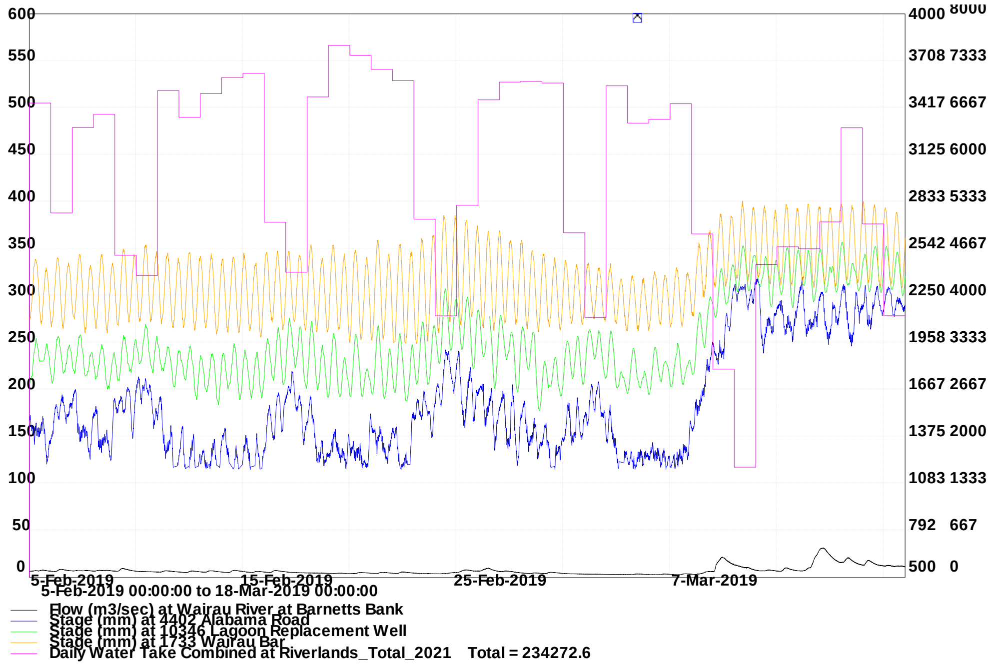



***Figure 8: Comparison of summer 2019 pumping versus MDC monitoring well levels at Alabama Road well 4402, Bar well 1733 & Lagoons Replacement well 10346.***

From about the 8 March 2019, aquifer abstraction reduces and groundwater levels at all three monitoring wells recover, and levels start converging (*Figure 8*). Rebound reflects less abstraction from the Riverlands Aquifer along with increased loading from the Wairau River/Ōpaoa Rivers coinciding with increased rates of recharge from the Wairau and Taylor Rivers associated with higher channel flows.

Groundwater levels rise in response to floods in the Wairau/Ōpaoa Rivers and corresponding low atmospheric pressure. Figure 9 shows the response of the three MDC monitoring well levels to the July 2019 Wairau River flood of 500 $m^3$/second at Tuamarina/State Highway 1. Aquifer levels rise rapidly at all three wells, then fall as the flood wave passes through. Floods are a loading effect and do not add water to these aquifers which are confined by overlying low permeability sediments. Figure 9 shows that by winter 2019, well levels at all three monitoring sites have converged meaning they are near their natural state with demand at its annual minimum.

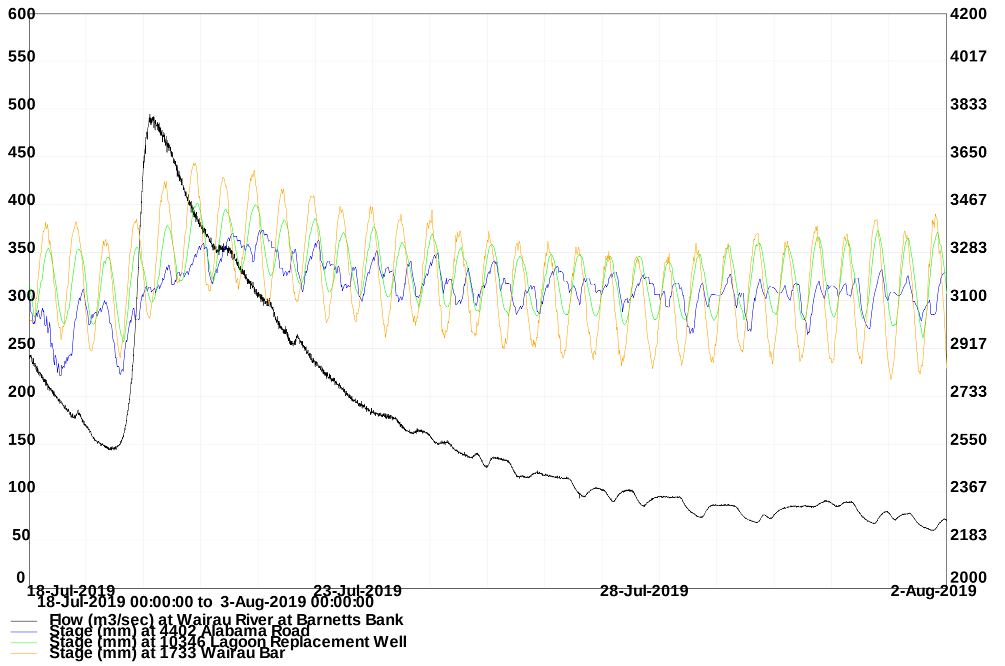



***Figure 9: Comparison of winter and flood induced differences in well levels between Alabama Road well 4402 blue), Bar well 1733 (orange) & Lagoon Replacement well 10346 (green) for mid-2019.***

Aquifer pressures appear to recover each winter or spring at all three MDC monitoring wells, showing the Riverlands Aquifer is being actively recharged, however seasonal abstraction driven drawdowns are large at the inland Alabama Road well 4402. The biggest change since MDC observations began is the increase in seasonal drawdowns, especially since around 2014/15 corresponding with increased abstraction (*Figure 6*).

The 2016 Kaikōura earthquake caused the general land surface to rise which affected groundwater levels and the earthquake corrected data will be introduced later in the report in relation to examining long-term aquifer level trends.

# 6. Hydrological Issues

## 6.1. Background

The largest influence on Riverlands Aquifer levels is consented abstraction. Currently inputs appear stable, however rates of recharge originating as Wairau River channel losses have experienced a declining trend since 1973 and if this continues, coastal groundwater levels will eventually be affected. Rising sea-level will tend to increase confined aquifer pressures locally, however.

At Riverlands groundwater is abstracted for a broader range of end uses than is typical of the wider Wairau Plain. As well as being used for irrigating vineyard, groundwater supplies rural residential subdivisions, individual rural domestic lots and is used for food processing.

A significant portion of the Marlborough grape crop is processed at the Cloudy Bay Business Park or Riverlands industrial estate, which were zoned by MDC for this purpose and are close to the MDC municipal effluent treatment works. Another long-standing major user of groundwater at Riverlands is the ANZCO freezing works which operates year-round except for a closedown period between July and September.

For the past decade or more grapes have been the predominant irrigated crop in this area compared to 30 years ago when it was vegetables, fodder crops or grains. On an area basis, historic crops would have required more irrigation water than grapes, but with rotation of crops the same paddock may not have been irrigated every summer.

There has been reduction over time in groundwater abstracted for crop irrigation with more water used at a different time for processing that crop into wine and to meet growth in rural residential settlement in the Cob Cottage Road/Hardings Road areas.

There is no overlap between irrigation of grape plants and their processing into wine meaning demand for groundwater is spread across the year from October to June. Unlike the Lower Wairau and Coastal Wairau Aquifer sectors, groundwater abstraction from the Riverlands Aquifer is not restricted to the traditional summer irrigation season from October to April with many industrial uses operating for most of the year like the ANZCO freezing works.

Care is needed to make sure year-round demand matches natural recharge and instantaneous rates are sustainable. MDC use instantaneous limits in the pMEP for surfacewater use to avoid drying up individual river reaches, and the limited channel storage to buffer abstraction is analogous to the naturally low storage characteristics of the Riverlands Aquifer.

Historically a major juncture in terms of abstraction from the Riverlands Aquifer occurred in 2002 with the closure of the PPCS meat processing works at Riverlands. The water supply for the plant came from two wells within a southern meander bend of the Ōpaoa River, north of Hardings Road. The plant began operation in 1984 and abstracted groundwater at a significant rate between those years, although not all year round.

Based on the weekly actual pumping totals supplied to MDC by PPCS between 1997 and 2002, the maximum instantaneous flow rate from the two wells at Hardings Road was 67 l/s, but for much of the time the abstraction rate was around half of this rate.

## 6.2. Seawater Intrusion

The prime potential water management issue for the area is seawater intrusion. To date there has been no sign of it having occurred based on 23 years of continuous groundwater level and chemistry monitoring at the MDC network of sentinel wells along the Cloudy Bay coastline.

Riverlands is a backwater groundwater area compared with those aquifers underlying northern and central areas of the Wairau, with much lower groundwater flow rates and storage capacity. The grade of the groundwater table driving underground flow is low with the dominant gradient becoming more vertical as the coast is approached. Sufficient offshore pressure is currently being exerted by freshwater to maintain seawater in a safe position based on stable values of electrical conductivity observed at MDC sentinel wells.

As far back as 1978 a seasonal summer depression centred on the inland Riverlands area existed based on the 1978 composite groundwater piezometric survey of the entire Wairau Plain carried out by the Marlborough Catchment Board to map regional flow patterns. A groundwater crater existed at that time and has persisted ever since, even as groundwater abstraction patterns have changed. There are risks to having low aquifer levels, but to date there have been no obvious consequences.

Automatic recorders at the base of each MDC sentinel well measure groundwater level and electrical conductivity to monitor the seasonal risk of sea-water intrusion from pumping wells. Electrical conductivity is a more direct measure of an increase in salinity however aquifer level is easier to measure precisely.

Thresholds have been set in the proposed Marlborough Environment Plan (pMEP) restricting water users when either groundwater levels are low, or groundwater electrical conductivity is high as there is an increased risk from seawater intrusion. The level threshold is 1.25 metres elevation above mean sea-level (Marlborough Catchment Board/MDC Rivers & Drainage datum). The conductivity threshold is 600 micro-Siemens/cm for the deeper aquifers, including the Riverlands and Coastal Wairau Aquifer management sectors. These thresholds are based on trying to keep groundwater levels and groundwater quality within their historical operating range.

## 6.3. Groundwater Quality

High quality groundwater for drinking is essential for human health. The chemistry of groundwater provides insights into the hydrology and flow dynamics of aquifers, especially those influenced by abstraction such as the low storage systems underlying the south-eastern Wairau Plain.

A significant MDC record of groundwater chemistry/quality now exists for the Riverlands Aquifer and the neighbouring Lower Wairau and Coastal Sectors of the Wairau Aquifer. There are also discontinuous measurements for the previous MDC coastal SoE Vernon well (P28w/0765) dating back to 1988.

This is a valuable record as it straddles a long period corresponding with significant land-use change locally and in upstream recharge areas, but it requires careful interpretation as changes in abstraction patterns over time are likely to have affected groundwater chemistry. The chemical nature of Wairau River recharge water has also changed slightly with time and the flow-on effects are subtly evident in the chemical nature of Riverlands groundwaters.

Abstraction from wells has a significant effect on groundwater levels due to the low storage characteristics of these aquifers. Because pumping can induce changes in underground flow in this border area between old, mineralised groundwater and dilute Wairau Aquifer groundwater; time differences in chemistry provide indirect information on aquifer hydraulic properties. Whether water becomes more concentrated or dilute in response to pumping depends on local conditions.

A secondary issue at Riverlands identified in about the year 2000 was the presence of arsenic and manganese in groundwater at levels which posed a risk to human health. Their occurrence was linked to pockets of highly mineralised groundwater. Slow moving groundwater in contact with aquifer forming rocks over long periods of time becomes mineralised through water – rock interaction processes. Reducing groundwater conditions make any mineral present more soluble in groundwater. Common minerals that become naturally dissolved in groundwater are arsenic, manganese and iron which can potentially be abstracted via drinking water wells.

The reason MDC is in the process of moving its principal wellfield from Malthouse Road to St Andrews is to improve water quality by reducing levels of naturally occurring manganese and iron in groundwater. Treatment can reduce concentrations to safe levels if well owners are aware of a problem. Microbial contamination is a low risk for these confined aquifers underlying the south-eastern Wairau Plain as the water is old and these organisms are subjected to attenuation and die-off over time.

MDC manually monitor the quality/chemistry of groundwater each season as part of a long-term state of the environment (SoE) programme. Figure 2 and Figure 3 show the locations and numbers of wells sampled including the five MDC SoE monitoring wells representing the Riverlands Aquifer, Lower Wairau and Coastal Aquifer Sectors of the Wairau Aquifer.

Pumping from wells tapping these confined aquifers is likely to modify flow dynamics with corresponding changes in groundwater chemistry patterns. While pumping can induce short lived changes in groundwater chemistry, the main driver of natural changes in groundwater quality for highly confined parts of the confined Riverlands or Coastal Wairau Aquifer are natural biochemical reactions and evolution. Knowledge of the effect of pumping is necessary for explaining chemistry/quality patterns or time series.

Groundwater chemistry changes over short distances or well depths. This was demonstrated by significant differences in chloride levels between the original and replacement MDC Lagoon monitoring wells despite being only 50 metres apart. Natural evolution explains the differences in chemistry between the two Lagoon wells.

Nearer the western edge of the confining layer, groundwater quality will reflect local land use and rainfall influences, but these diminish as water travels further into the confined aquifer. This is especially true for redox sensitive compounds: arsenic, iron, manganese, sulphate and nitrate-nitrogen. A feature of these aquifers is water cannot enter them locally from the surface as its confined structure and pressurised nature prevents it.

# 7. Summary

The detailed analysis of state, trends and seasonality is contained in the Appendices. The following two sections summarise the findings split between the topics of quantity and quality.

## 7.1. Groundwater Quantity

The variation in groundwater elevation is mostly demand driven with the lowest levels in spring and summer due to crop irrigation. Seasonal drawdown is approaching the threshold elevation in the pMEP of 1.25 metres above mean sea level showing the Riverlands Aquifer is fully committed.

Levels may fall further due to factors other than consented abstraction. An allowance needs to be made for the declining trend in upstream Wairau Aquifer levels to provide free-board. Conversely, rising sea-level at the Cloudy Bay coast should be inducing higher confined aquifer pressures and related spring flows, but that isn't the case based on MDC state of the environment monitoring observations.

Significant groundwater remains available for allocation from the Riverlands Aquifer through the pMEP, mostly for MDC use. If this groundwater were abstracted, it is likely aquifer levels during peak irrigation season would fall below the pMEP restriction threshold of 1.25 metres above mean sea level and there would be an unacceptably high risk of seawater intrusion.

The primary management tool for avoiding seawater intrusion is the Riverlands Aquifer annual volumetric limit in the pMEP. The elevation and electrical conductivity cutoff thresholds in the pMEP are only intended to govern abstraction during times of naturally less recharge, not as the prime control. The Riverlands Aquifer is fully allocated in terms of actual demand, and it is appropriate for MDC to review the pMEP volumetric limit.

## 7.2. Groundwater Quality

Most of the SoE chemistry results for the south-east Wairau Plain (including the Riverlands area) fit the conceptual model of a closed system driven primarily by natural evolution processes rather than the influence of human activities. Symptomatic of this is groundwater becoming more evolved and mineralised with increasingly reduced aquifer conditions along its flow path towards the coast/Lagoons. Sulphate may be an exception although increases could reflect local oxidation processes.

Levels of most compounds increase with groundwater residence time (*Table 1*). The exceptions were calcium/magnesium due to ion exchange processes and nitrate-nitrogen due to natural reduction processes. Microbes are virtually non-existent, however naturally occurring problem species like arsenic, iron and manganese are common. The lack of variability of well depth to represent potentially different water bearing strata limits MDC knowledge of vertical flow processes and chemical gradients to two dimensions.

There are shorter-term fluctuations in many compounds and parameters. Sulphate and nitrate-nitrogen show strong seasonality, while iron varies over a shorter time span possibly reflecting pumping induced changes in groundwater flow or redox potential. Human and land surface inputs appear to be having a limited influence on groundwater or are being assimilated by natural processes.

***Table 1: Summary of geochemical state and trends.***

| Parameter | Dominant evolution pattern or process | Overall trend |
|---|---|---|
| Bromide | natural evolution | no change |
| Dissolved reactive phosphorus | natural evolution | decreasing |
| Ammoniacal-nitrogen | natural evolution | no change or increasing |
| Nitrate-nitrogen | natural reduction | decreasing |
| Sulphate | Landuse inputs/sulphate oxidation | increasing |
| Fluoride | natural evolution | no change or decreasing |
| Boron | natural evolution | increasing |
| Silica | natural evolution | increasing |
| Arsenic | natural evolution | no change |
| Manganese | natural evolution | increasing |
| Iron | unclear | No change or decreasing |
| Alkalinity | natural evolution | increasing |
| Magnesium | natural reduction | increasing |
| Calcium | natural reduction | increasing |
| Potassium | natural evolution | no change or increasing |
| Sodium | natural evolution | decreasing |
| pH | natural evolution | no change |
| Chloride | natural evolution | no change or increasing |
| Dissolved oxygen | natural reduction | no change |
| Electrical conductivity | natural evolution | increasing |

# 8. Conclusions

The Riverlands Aquifer is finely balanced in terms of the effects of consented abstraction on groundwater levels and is unlikely to be able to sustain further increases in actual use without exceeding the sustainable aquifer yield and risking seawater intrusion.

The pMEP volumetric limit should be reviewed to bring it into line with current actual use and an instantaneous limit introduced to manage over-stressing the Riverlands Aquifer in either time or space.

Groundwater quality varies spatially from moderately dilute in the north and west, to being highly evolved elsewhere which largely reflects natural biochemical processes associated with the confined aquifer structure.

Gaps in MDC knowledge still exist and the most pressing for management of local groundwater is a comprehensive set of abstraction figures to compare with observed changes in aquifer levels for a range of seasonal conditions.

# 9. Appendices

## 9.1. State, Seasonality & Trends

This section assesses the current state of the groundwater resources, describes seasonal variability, identifies the existence of longer-term patterns or trends and where possible explains their drivers. Key to evaluating state and trends of both groundwater quality and quantity is a sound understanding of aquifer hydrology and abstraction rates. Also, the chemical signature of recharge or input waters and how these change over time.

### 9.1.1. Groundwater Quantity

#### Background

The 2016 Kaikōura earthquake raised land surface levels at Riverlands. Based on precise surveys, the MDC Replacement Lagoon and Alabama Road monitoring wells rose by 59 mm and 117 mm respectively (*Figure 1: MDC groundwater quantity state of the environment monitoring network.Figure 1* & *Figure 2*). This made groundwater elevations following the earthquake appear lower relative to sea-level than they were.

Groundwater level record at the two MDC monitoring wells was corrected for the effects of the Kaikōura earthquake and at the same time a version was created in terms of the New Zealand vertical datum 2016 (NZVD2016). NZVD2016 is the new national topographic elevation datum that MDC is transitioning to. Currently all resource consent elevation conditions are expressed in terms of the MCB/MDC R & D datum which is the same as the Nelson 1955 elevation datum.

#### Groundwater Abstraction

Abstraction from the Riverlands Aquifer is strongly correlated with groundwater level observed at the MDC Riverlands Aquifer monitoring wells. This is illustrated by Figure 10 showing daily abstraction ($m^3$/day) in red inverted on the left-hand axis, versus groundwater level at Lagoon Replacement well 10346 on the right-hand axis.

This period was selected for analysis as it has the most telemetered meters available with the highest quality meter data. Not all abstraction is metered yet as older consents may not require them or have issues with data quality or completeness. It is estimated that a further 20% of water meter data are missing meaning abstraction is higher by this amount. This translates to a maximum abstraction rate of 132 l/s (*Figure 10*).

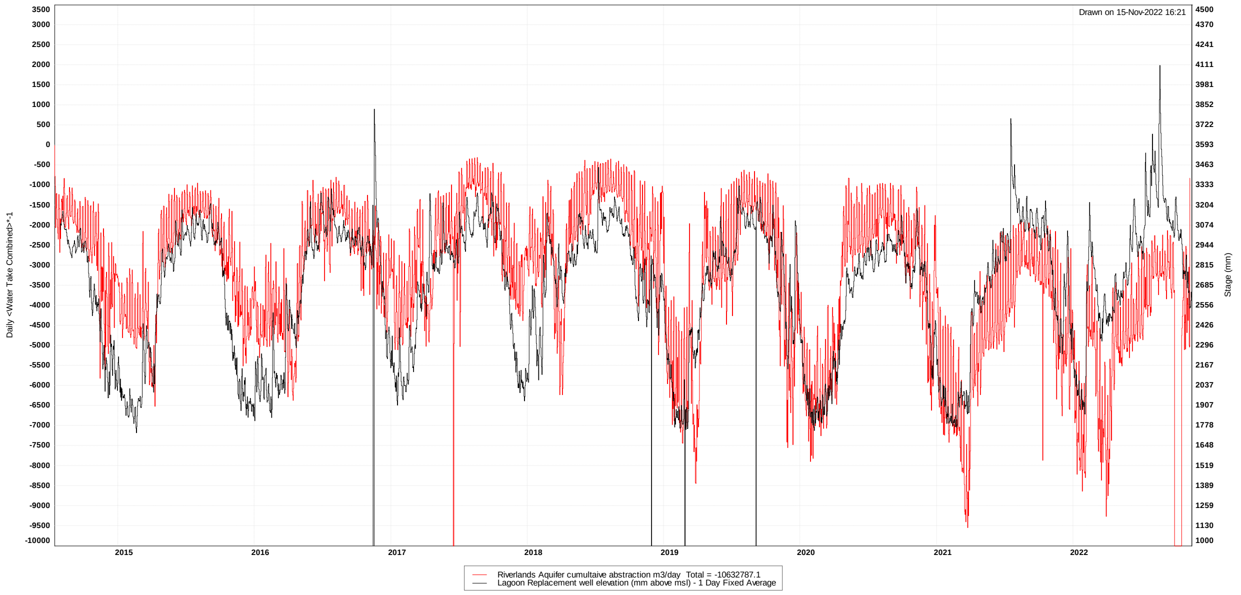



***Figure 10: Riverlands Aquifer daily total actual (metered) use (red) versus Riverlands groundwater level at Lagoon Replacement well 10346 (black). The left-hand vertical axis shows abstraction increasing downwards. Groundwater elevation is shown on the right-hand.***

Figure 11 is a scatter plot of total weekly abstraction for the Riverlands Aquifer versus groundwater level (stage) at the Lagoon Replacement well 10346 showing groundwater level falls with increased abstraction as expected. The average drawdown is 1.5 metres for a weekly abstraction of 60,000 m$^3$ or an average instantaneous pumping rate of around 100 l/s (*Figure 10*). Part of the two-metre seasonal range in groundwater level will be natural, not pumping induced, but is the minor component.

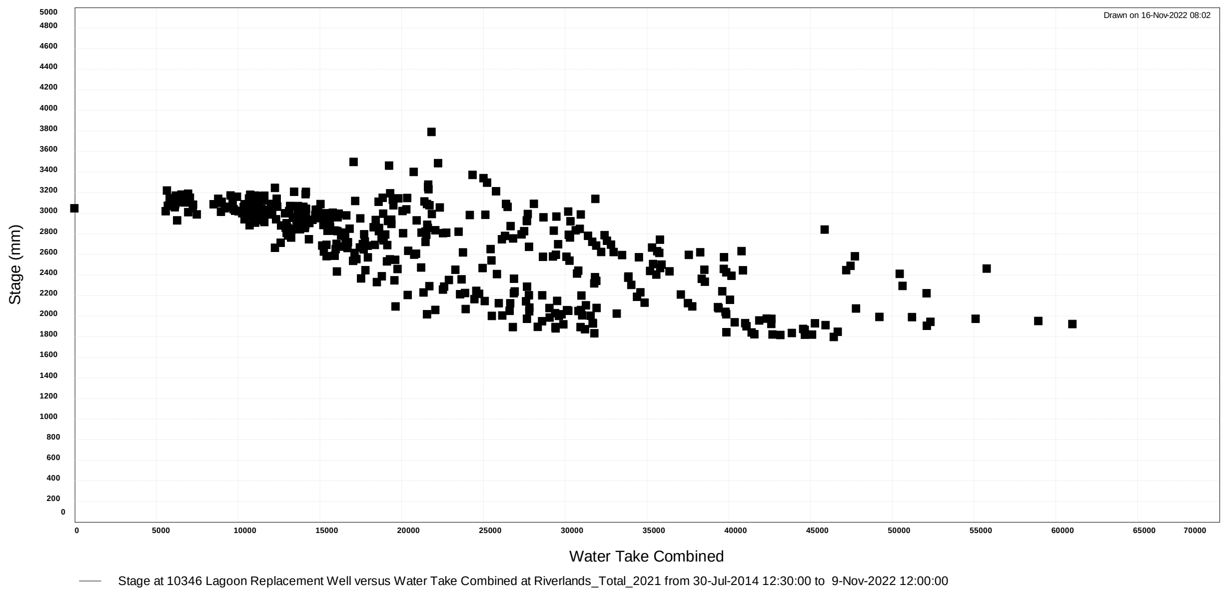



***Figure 11: Seven-day average groundwater elevation at Lagoon Replacement well 10346 versus Riverlands Aquifer cumulative weekly groundwater abstraction.***

In 2008 MDC commissioned Water Matters Ltd to develop a model of the Riverlands Aquifer for limit setting (Water Matters - 2008). A key finding of the report was that for a simulated abstraction rate of 100 l/s, groundwater levels near the Riverlands Aquifer coastal boundary would fall to 1.25 metres above mean sea level.

A minimum groundwater level of 1.25 m. above mean sea level was considered to provide sufficient protection against seawater intrusion and was incorporated in the pMEP along with an annualised abstraction volume equivalent to the instantaneous rate of 100 l/s. A threshold range of 1.5 to 1 metre above mean sea-level is common in other regional plans, however there are few examples of the minimum elevation being defined for local conditions except where problems have occurred for a known pumping rate.

For the purposes of deriving a yearly volumetric limit in the pMEP the instantaneous safe yield derived by modelling was annualised by MDC by simply multiplying through by the number of seconds in a year. In hindsight this approach was too simplistic and has resulted in too high an annual volumetric limit in the pMEP that should be corrected.

This is a complex physical system and the exact level of risk of seawater intrusion may never be known. The cumulative instantaneous abstraction rate corresponding to groundwater levels at the coast of 1.25 metre elevation was defined by computer modelling. An instantaneous abstraction rate limit was considered by MDC staff but was not included in the pMEP.

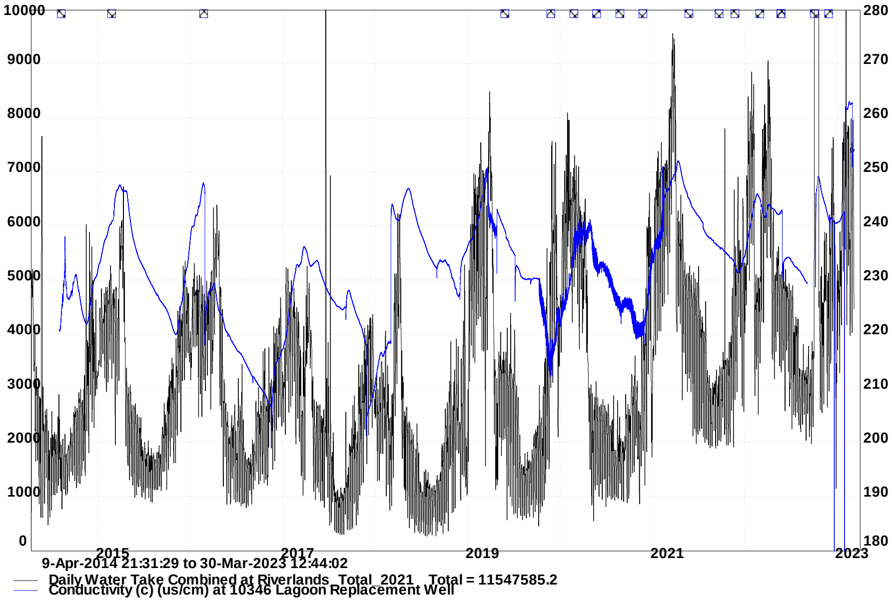



***Figure 12: One day average groundwater conductivity at Lagoon Replacement well 10346 versus Riverlands Aquifer cumulative daily groundwater abstraction.***

Groundwater electrical conductivity (EC) is a better measure of the onset of seawater intrusion; however, it is more difficult to accurately measure remotely and in real time. Figure 12 shows that groundwater EC at well 10346 is strongly correlated with Riverlands metered abstraction, although there is a time lag between pumping and a resultant change in EC. Figure 13 shows the time series plotted against each with a 30-day lag and shows a strong positive correlation.

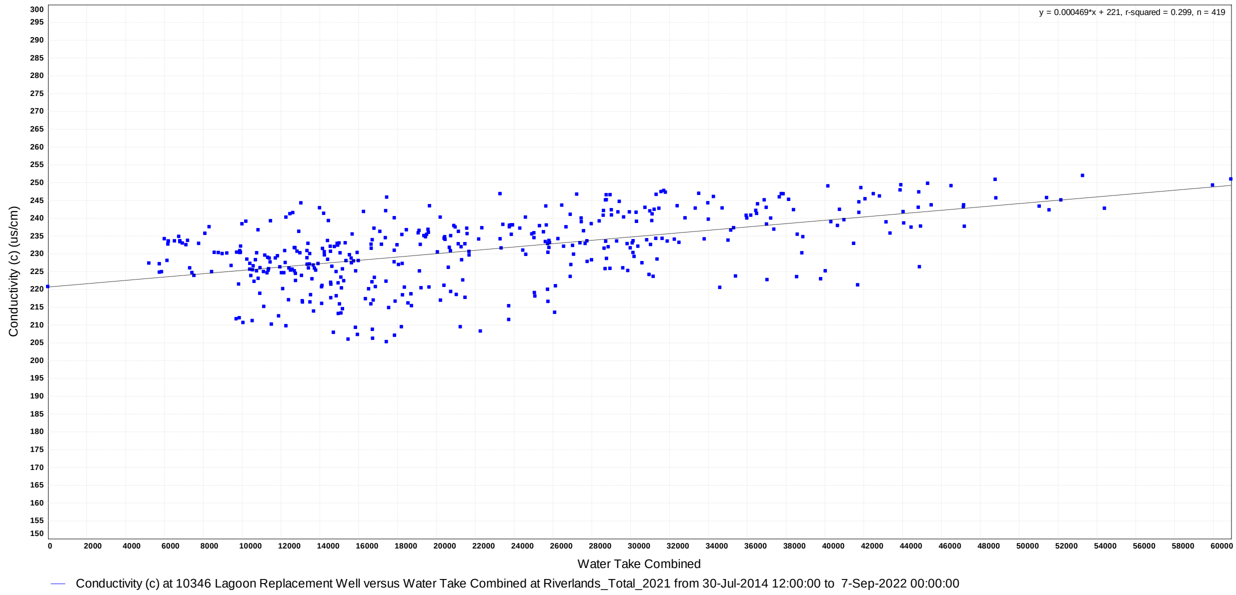



***Figure 13: Seven-day average groundwater conductivity at Lagoon Replacement well 10346 versus Riverlands Aquifer cumulative weekly groundwater abstraction with 30 day lag.***

Figure 14 shows the strong negative correlation between EC and groundwater elevation with the same 30-day lag applied showing lower aquifer levels causes EC to increase.

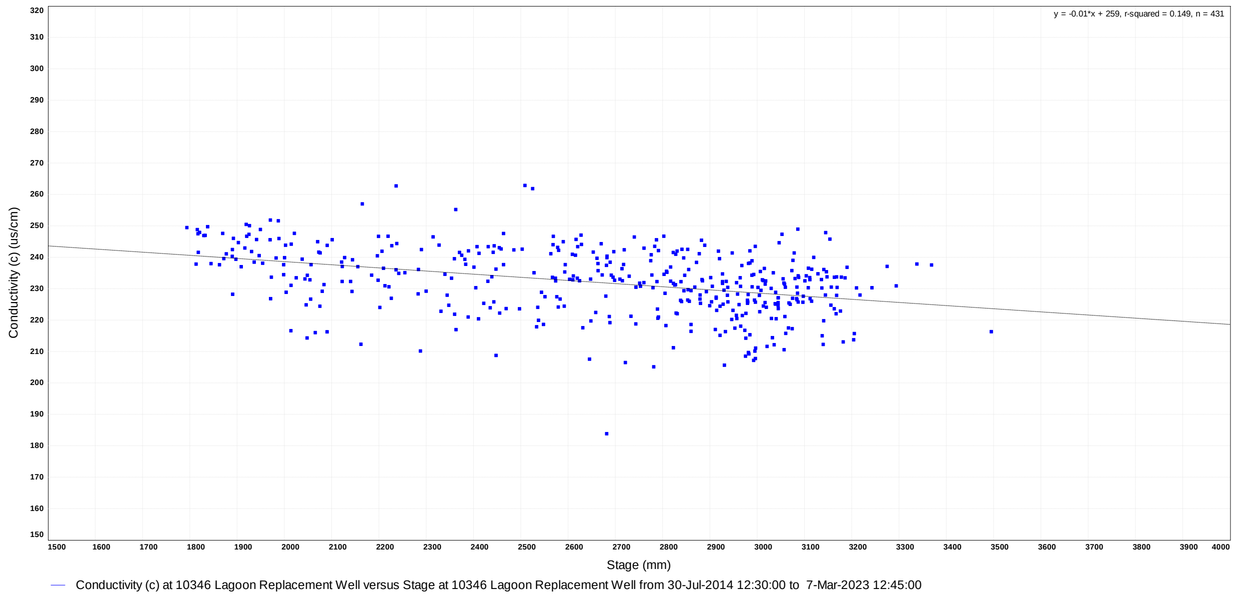



***Figure 14: Seven-day average groundwater conductivity at Lagoon Replacement well 10346 versus Riverlands Aquifer cumulative weekly groundwater abstraction with 30 day lag.***

## Coastal Riverlands Aquifer

The coastal area is represented by MDC Replacement Lagoon well 10346 located near the Wairau Lagoon and MDC sewerage treatment ponds in Hardings Road.

## Patterns & Trends

Figure 15 shows groundwater elevation at the combined Lagoon well from 2002 to 2022 in terms of the NZVD2016 datum and corrected for uplift from the 2016 Kaikōura earthquake. The equivalent cut-off elevation for water permits of 1250 mm above mean sea-level (MCB/MDC R & D datum) in the proposed Marlborough Environment Plan is shown by the blue horizontal line.

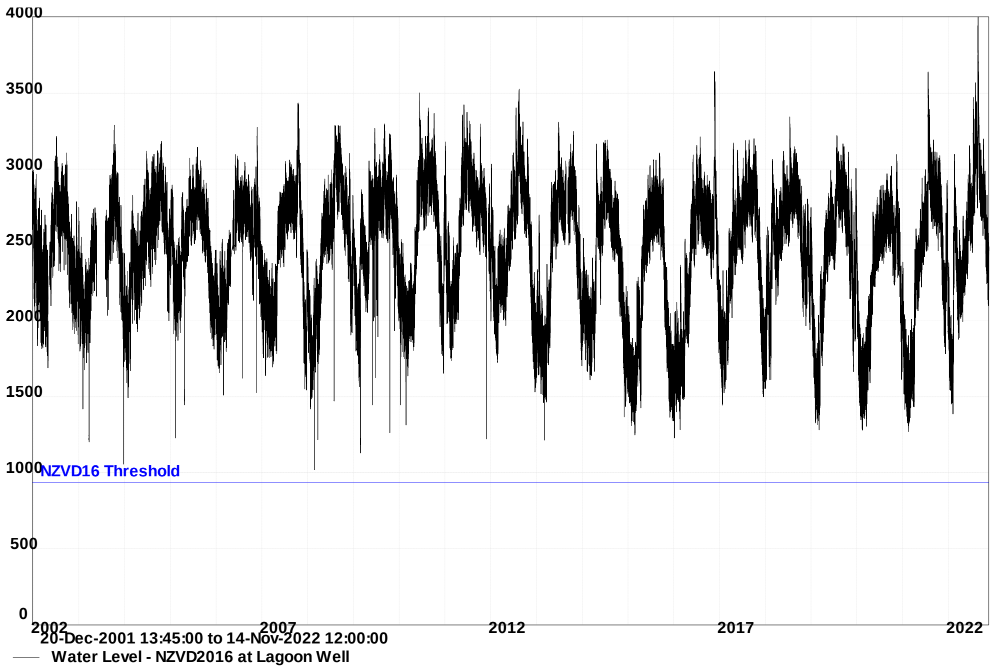



***Figure 15: Groundwater elevation for MDC combined Lagoon monitoring well 2002-2022 earthquake corrected and in terms of NZVD2016 including cut-off threshold.***

There is a definite pattern of larger seasonal variations in groundwater level since about 2015 with groundwater levels lower due to pumping in summer through to early autumn (*Figure 15*). Figure 16 shows aquifer levels peak in August and reach their minimum in February.

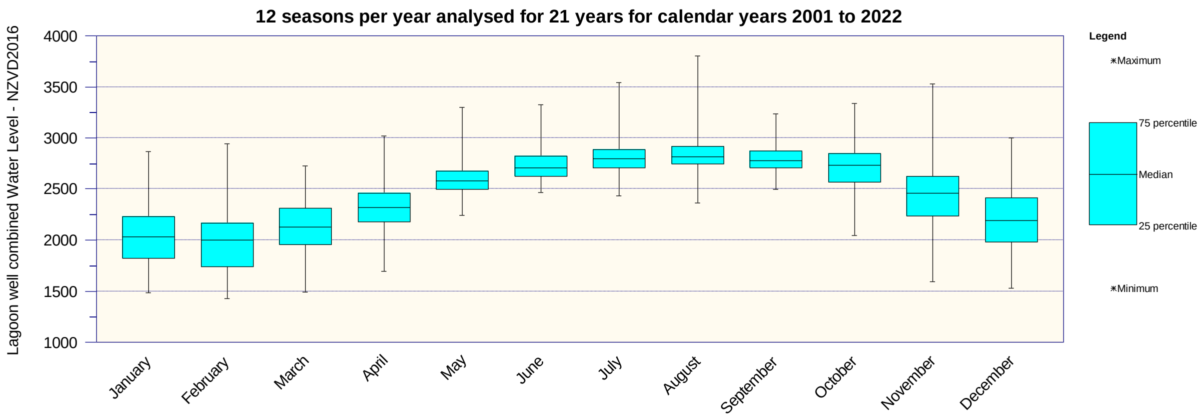



***Figure 16: Monthly variation in groundwater level for MDC combined Lagoon well.***

Combined Lagoon well groundwater level was statistically tested for the presence of trends. The Mann-Kendall test found a trend was unlikely based on a P statistic of 0.7 which was not significant at the 95% (0.05) confidence level used (*Figure 17*). The blue trend line is horizontal indicating the absence of a trend.

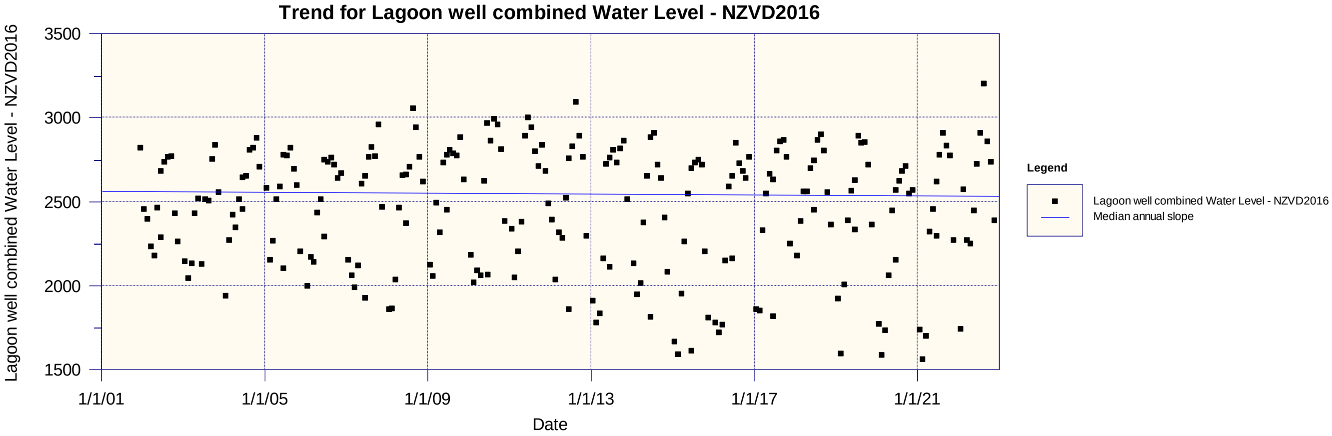



***Figure 17: MDC combined Lagoon well groundwater level trend line using Mann-Kendall test (2002-2020 earthquake corrected NZVD2016).***

The mid 2022 storm and Wairau River flood raised Riverlands aquifer levels to record highs. The sensitivity of trends in the groundwater level record to the 2022 storm was tested by removing this period of data and re-running the Mann-Kendall test, which showed a trend was about as likely as not based on a P statistic of 0.4.

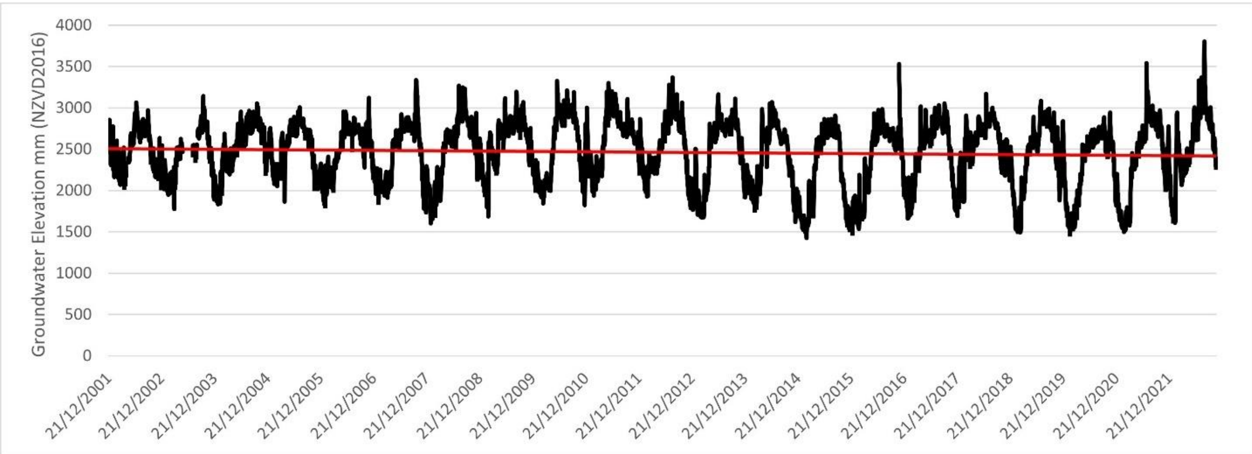



***Figure 18: Groundwater level for MDC combined Lagoon monitoring well with XL trend line fitted (2002-2022 earthquake corrected NZVD2016).***

As a check on the Mann-Kendall test results, an XL trend line was fitted to the same combined Lagoon well dataset. Figure 18 shows the trendline suggests a slight downwards trend.

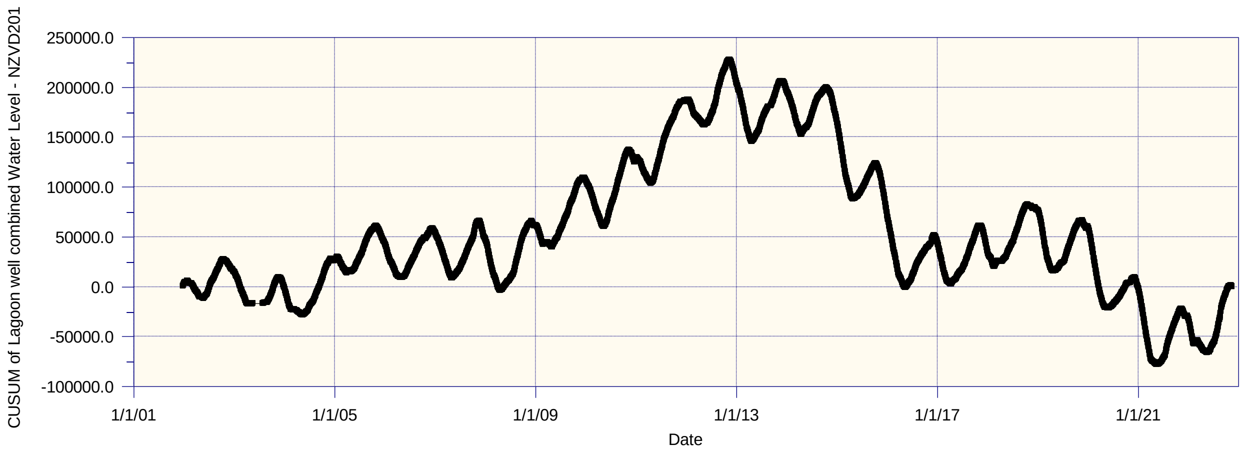



***Figure 19: Cumulative deviation from mean level for MDC combined Lagoon monitoring well (2002-2022 earthquake corrected NZVD2016).***

The cumulative deviation from the mean (CUSUM) is another measure of change with time. Figure 19 shows a rise with time meaning a declining trend in groundwater level which is at odds with the Mann-Kendall test result and XL trend analyses.

## Inland Riverlands Aquifer

Inland areas of the Riverlands Aquifer are represented by well 4402 located east of the sharp bend in Alabama Road near Riverlands School. There are no pMEP restrictions applying to inland resource consent holders as cumulative abstraction is unlikely to directly affect confined aquifer levels at the coast, induce seawater intrusion or restrict the ability of neighbouring well bores to achieve their yield provided they are using submersible pumps.

## Patterns & Trends

There is a greater variation in aquifer level at the Alabama Road well 4402 compared to Lagoon well due to the greater concentration of groundwater pumping inland from the coast as discussed earlier (*Figure 20*).

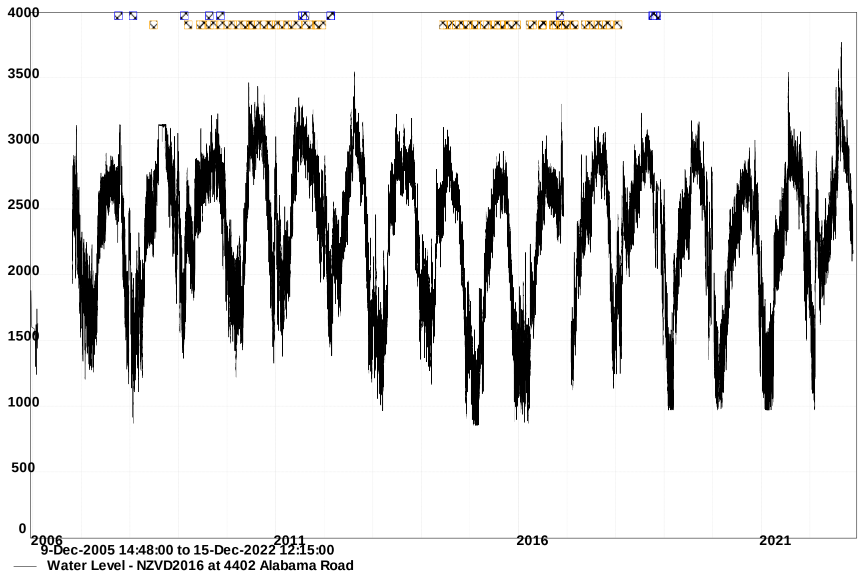



***Figure 20: Groundwater elevation for MDC Alabama Road well 4402 (2005-2022 earthquake corrected NZVD2016).***

There are greater seasonal drawdowns from 2013 onwards due to higher rates of abstraction since that time (*Figure 20*).

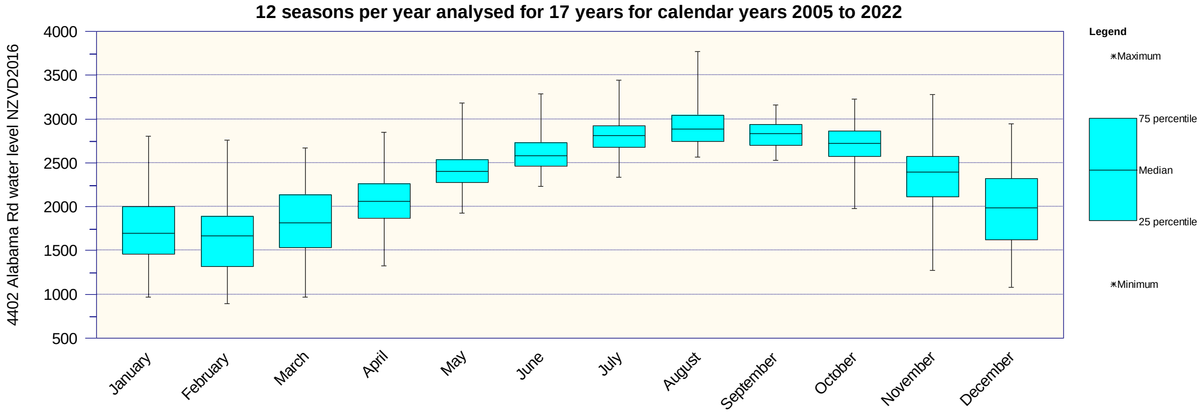



***Figure 21: Monthly variation in groundwater level for MDC Alabama Road well (2005-2022 earthquake corrected NZVD2016).***

Inland groundwater levels peak in August and reach their annual minimum in February which is the same as for the coastal Lagoon monitoring well (*Figure 21*).

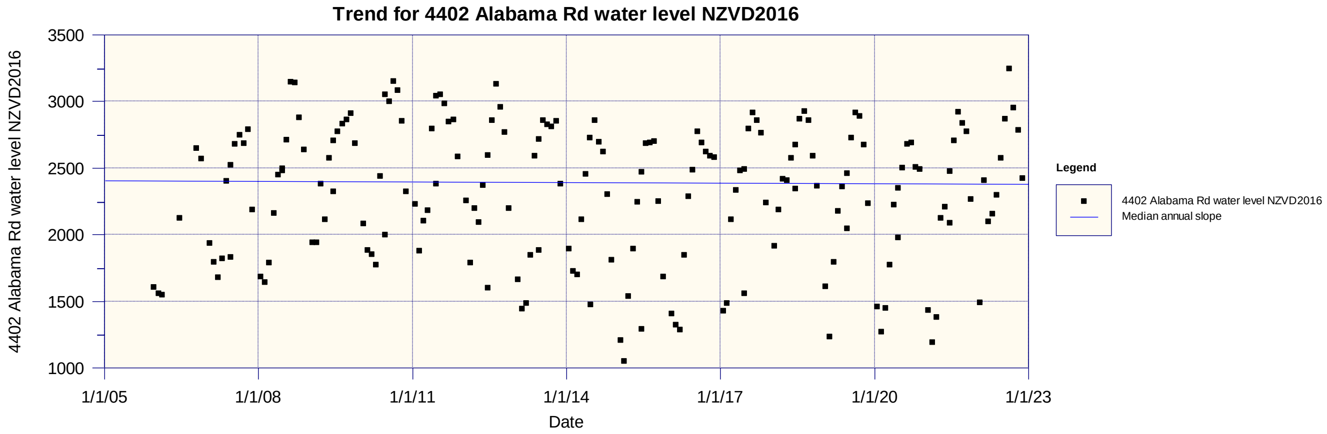



***Figure 22: MDC Alabama Road 4402 groundwater level trend line using Mann-Kendall test (2005-2022 earthquake corrected NZVD2016).***

The Mann-Kendall test found a trend in groundwater level was unlikely based on a P statistic of 0.9, although the blue trend line implies a downwards trend (*Figure 22*).

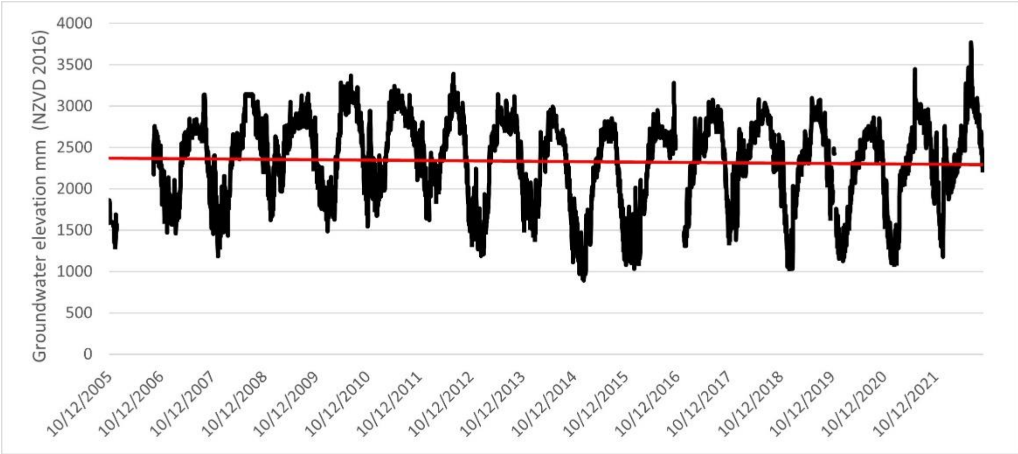



***Figure 23: Groundwater level for MDC Alabama Road well 4402 with XL trend line fitted (earthquake corrected NZVD2016)***

The XL fitted trend line indicated the presence of a slight decreasing trend in groundwater level (*Figure 23*).

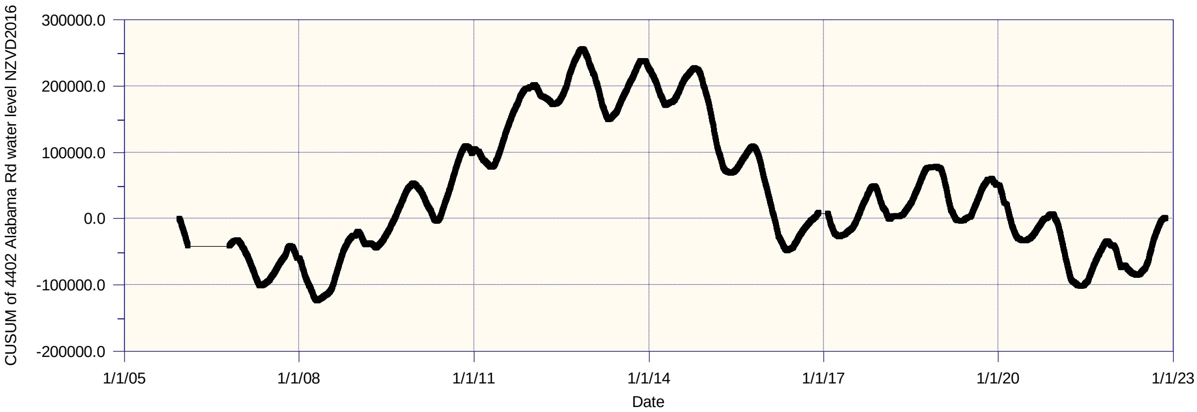
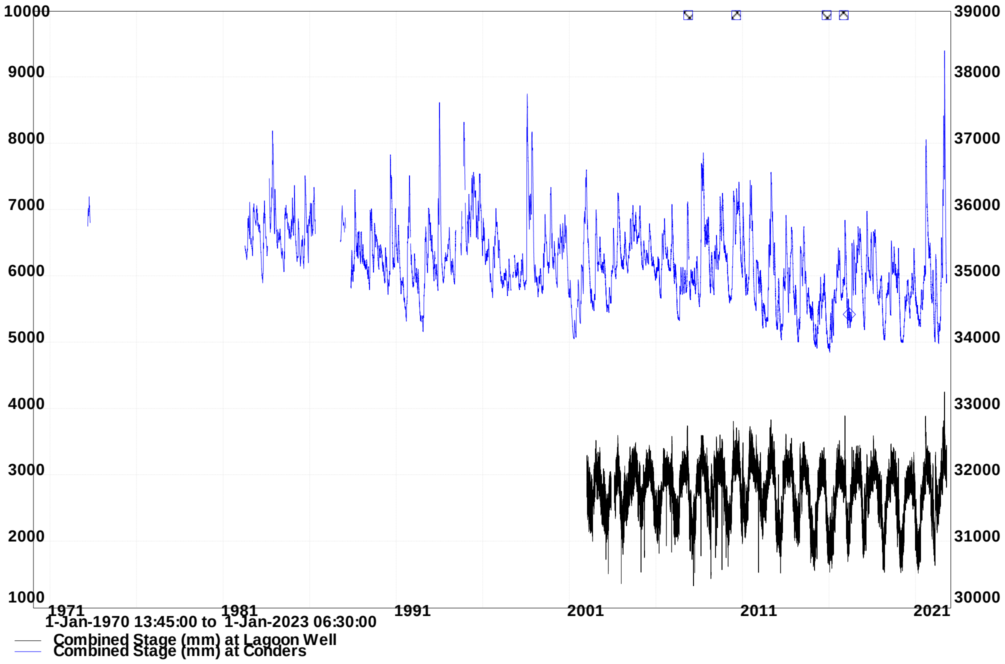



***Figure 24: Cumulative deviation from mean groundwater level for MDC monitoring well P28w/4402 at Alabama Road (2002-2022 earthquake corrected NZVD2016)***

The cumulative deviation from the mean groundwater level for Alabama Road well 4402 shows the same declining pattern in groundwater as at Lagoon Replacement well 10346, for the shorter period from 2005 to 2022 (*Figure 24*).




**F*igure 25: Comparison of variation in well levels upstream and downstream of springs 1973-2020. Left hand vertical axis shows groundwater elevation at Replacement Lagoon well 10346. Wairau Aquifer elevation from 1973 in blue with scale on right hand vertical axis. Elevations in terms of MCB/MDC R & D datum.***

A potential future issue is whether the current declining trend in Wairau Aquifer levels upstream of the springs will affect coastal confined aquifer levels at some stage. Currently only the groundwater fed springs representing overflow that cannot be accommodated in the confined aquifer are impacted. Declining Wairau Aquifer levels at the Conders well 398/3821 is shown by the blue time series in Figure 25 with the black line representing the replacement Lagoon well 10346 level. However, provided that the springs maintain their baseflow, it is unlikely that a declining inland water level will impact on the coastal confined aquifers.

### 9.1.2. Groundwater Chemistry-Quality

### Background

Most chemical parameters either measured regularly in the field or analysed in the laboratory as part of the MDC SoE monitoring programme are described in this section. The emphasis is on identifying and explaining patterns or trends, especially those with implications for seawater intrusion. Groundwater chemistry was used in the first instance to understand stress from consented abstraction as the MDC focus for the Riverlands Aquifer is on refining the sustainable yield, with quality not a big issue.

To provide context and an overall appreciation of groundwater quality across the south-eastern corner of the Wairau Plain, time series for each chemical parameter at the three active MDC SoE sites representing the Riverlands Aquifer and neighbouring Wairau Aquifer were plotted together.

Results from the MDC Wairau Aquifer Springs Sector well in Middle Renwick Road (well 3120) were included to define the chemical nature of upstream recharge water. This helped identify whether trends in Riverlands Aquifer groundwater chemistry were caused by local processes or resulted from changes in recharge water, or a combination.

# Electrical Conductivity

The electrical conductivity (EC) of groundwater is a measure of its total dissolved salt content of naturally occurring elements like chloride or calcium, and compounds from human activities like nitrate-nitrogen. EC provides a measure of how dilute or evolved a particular groundwater is at a particular time.

MDC also use electrical conductivity as its key indicator of seawater intrusion. Automatic loggers installed at the base of coastal sentinel wells take EC measurements at 15-minute intervals. The chemical properties of groundwater are the best measure of the onset of seawater intrusion.

Low groundwater levels mean an increased risk of seawater intrusion, but the true test is a significant increasing trend in the EC of groundwater in response to abstraction. Drainage of evaporated sea spray salts and effluent disposal field leachate can also contribute chloride to groundwater in winter or spring raising groundwater EC values, but not for the pressurised, confined type aquifers present at Riverlands.

Certain elements and compounds have a greater influence on EC than others. These include chloride and sodium which occur in high concentrations in seawater. Manganese, iron, and arsenic on the other hand do not contribute significantly to EC. EC is a powerful index of how dilute or evolved a groundwater is with the added advantage of being easy to measure accurately in the field using a hand-held meter.

## Regional Patterns

Most groundwater at Riverlands and in neighbouring aquifers begins life as Wairau River water which is very dilute with low dissolved salts meaning it has low EC (*Figure 26*). The EC of Wairau River water decreases with increasing flow due to dilution (*Figure 26*). During a flood, channel water is more dilute but has a high suspended sediment content and is turbid as a result.

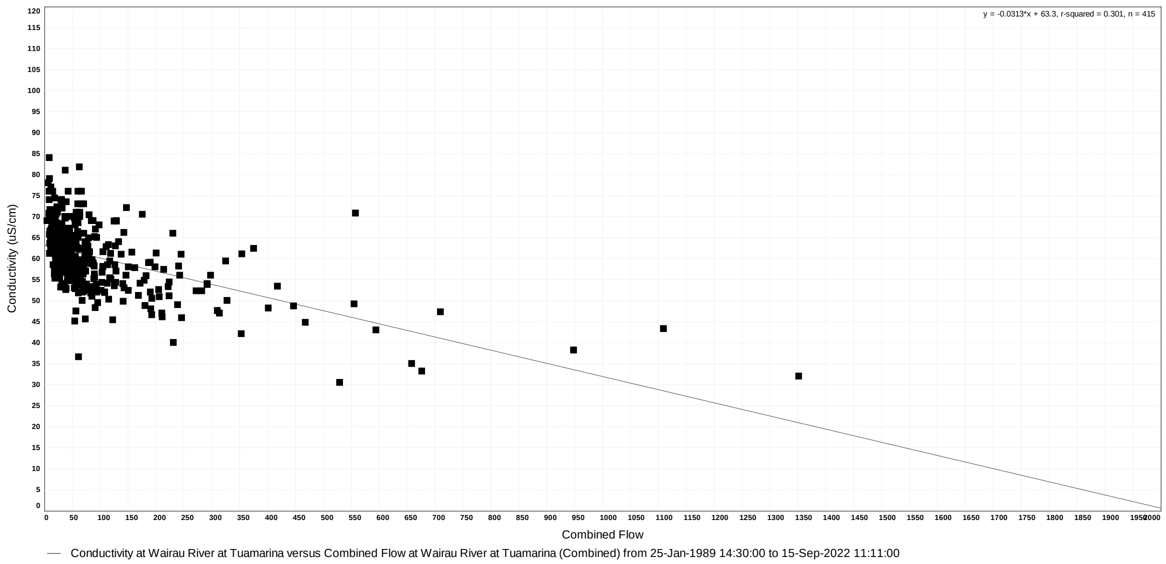



***Figure 26: Wairau River electrical conductivity versus flow at Barnetts Bank (upstream of Tuamarina/State Highway 1) 1990-2022.***

There has been an increasing trend in Wairau River water EC at the bottom of the catchment at Tuamarina/State Highway 1 consistent with a slight decline in lower catchment channel flows since 1989, although land use influences have changed over that time also (*Figure 27*). The green line shows the EC values for recently recharged groundwater at well P28w/0398 located north-west of Renwick is almost identical to the EC of Wairau River water as would be expected (*Figure 27*).

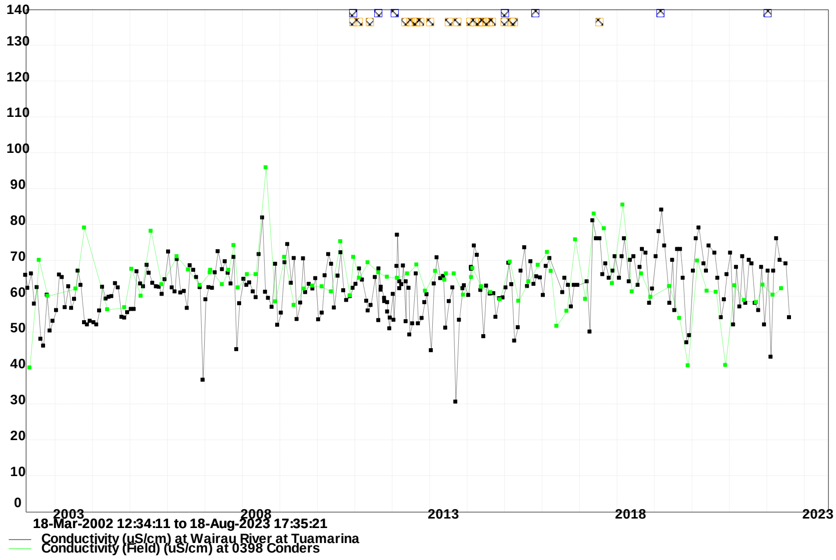



***Figure 27: Electrical conductivity of Wairau River water at Tuamarina (State Highway 1) (black) versus EC of aquifer recharge water at Conders well P28w/0398 (green) from 2002-2022.***

Along its natural flow path to the Cloudy Bay coast (and Riverlands), this base recharge water evolves through natural processes and surface influences to contain more salts with a correspondingly higher EC value (*Figure 28*).

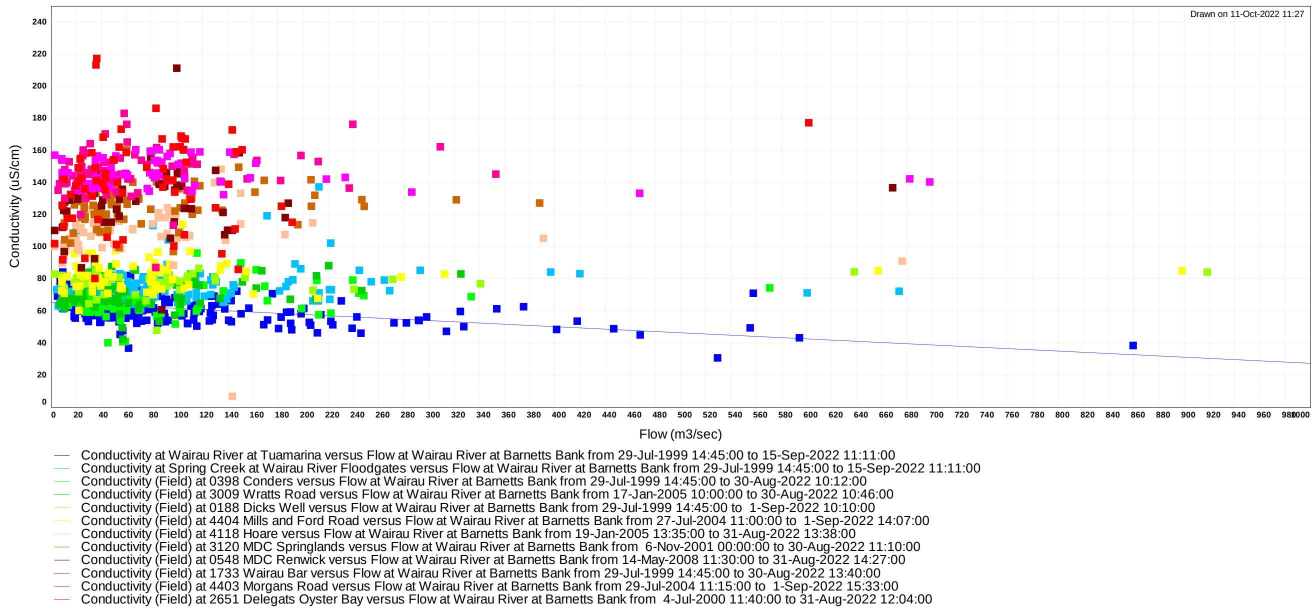



***Figure 28: Deviation of groundwater EC away from Wairau River water versus Wairau River flow at State Highway 1.***

Figure 28 shows field measurements of EC for Wairau River water in blue and in other colours for all Wairau Aquifer SoE monitoring well sites, plotted against Wairau River flow at State Highway 1/Tuamarina on the horizontal axis. The brighter colours indicate more evolved groundwater including an increased contribution from land surface recharge. There is a clear pattern of increasing EC in groundwater with distance from the Wairau River recharge source. EC is lower for a higher Wairau River flow for sites closer to the channel only (*Figure 28*).

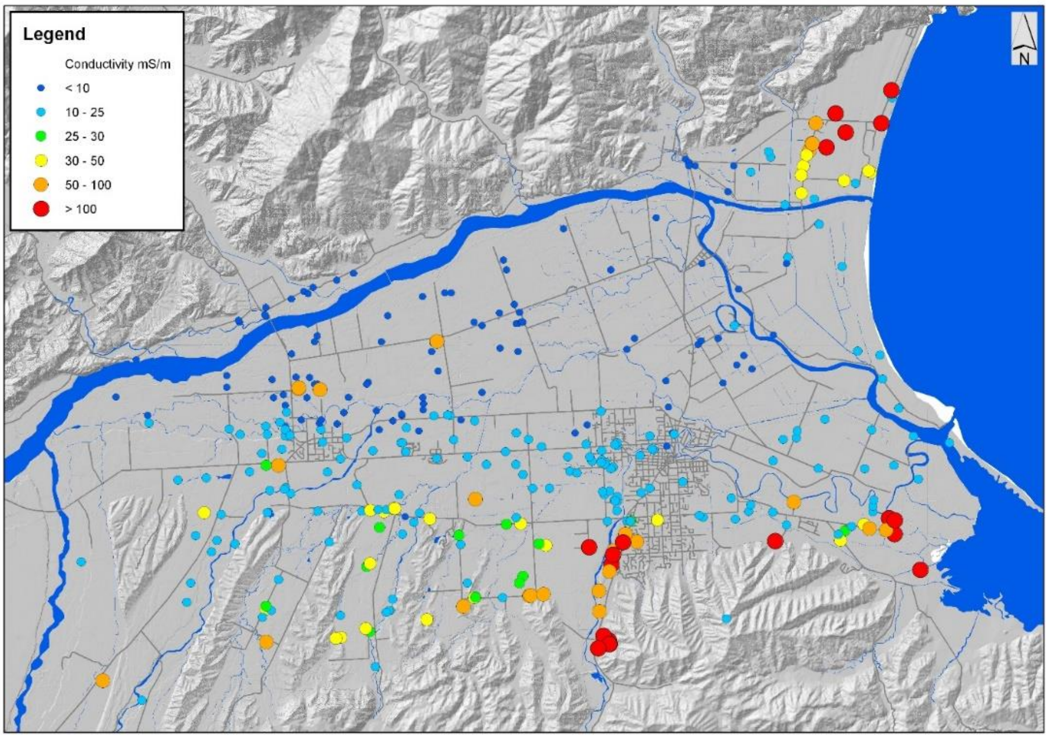



***Figure 29: Median electrical conductivity (g/m3) Wairau Plain excluding RSA (Groundwaters of Marlborough 2011).***

This divergence is driven by a combination of land use inputs, changes in groundwater flow rates and natural biochemical/evolutionary processes in groundwater. The regional Wairau Plain pattern is clearer to see in plan view (*Figure 29*).

## Local Values & Trends

EC is monitored continuously at the Replacement Lagoon well 10346, but only seasonally at the Alabama Road well 4402 as it is too far inland for pumping to directly affect the seawater interface. For the Wairau Aquifer Coastal Sector, EC is measured continuously at the Bar well 1733 as its prime role is seawater intrusion early warning. The MDC Morgans Road well 4403 representing the Wairau Aquifer Lower Wairau Sector is sampled seasonally as part of the groundwater quality SoE survey.

Median EC values for the MDC SoE sites in the study area are shown in plan view in Figure 30 with some wells having longer records than others. Figure 30 shows the most evolved groundwater occurs in the south-east, reflecting the relatively stagnant, backwater nature of this aquifer area. Conversely the most dilute groundwater is at Morgans Road well 4403 followed by the Bar well 1733, which is consistent with their location in more transmissive parts of the aquifer. Alabama Road well 4402 groundwater exhibits intermediate EC values.

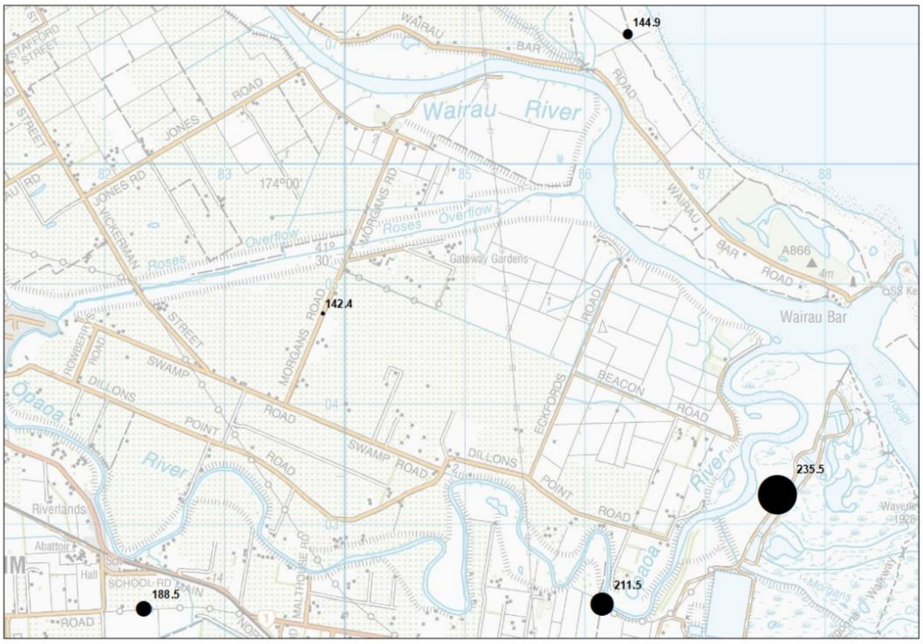



***Figure 30: Median electrical conductivity (microS/cm).***

Figure 31 shows the variation in EC for the five MDC SoE wells representing the study area. This hierarchy or its inverse for redox sensitive parameters (sulphate or nitrate-nitrogen), should apply to all groundwater quality parameters unless there are local anomalies or human influences.

EC values fall into two broad groups with younger, more dilute groundwater in the north-west and older, more evolved groundwater dominating the south-east (*Figure 31*). Gaps in the Bar and Vernon wells data series limit their usefulness but are still valuable indicators of long-term changes in or influences on groundwater chemistry.

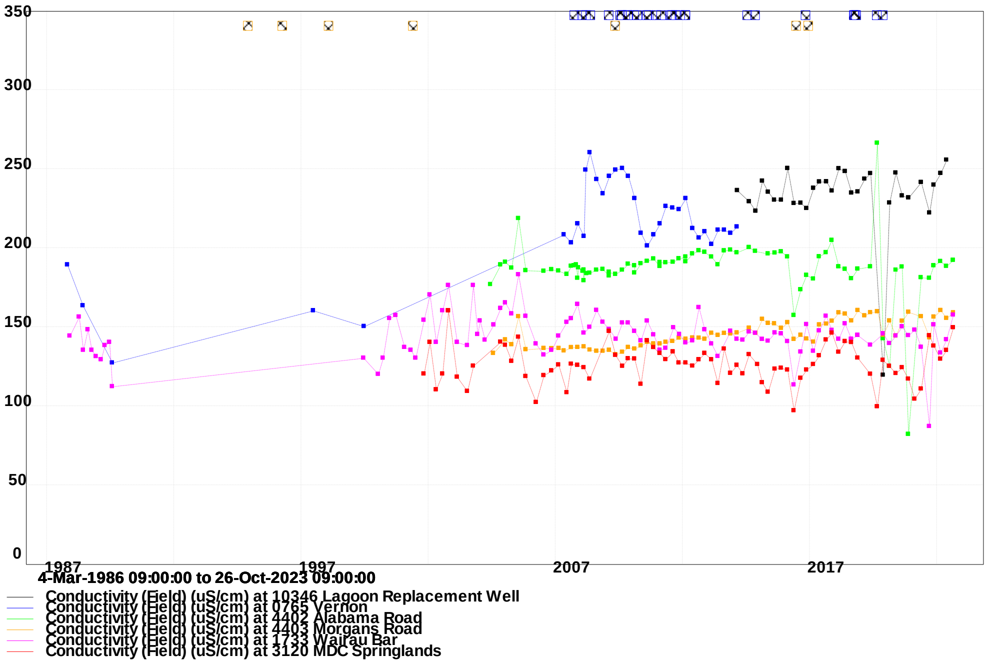



*Figure 31: Electrical conductivity 1987-2022.*

In terms of time trends there was a significant increase in EC at Vernon well 765 between 1987 and 2007, before sampling was transferred to the Replacement Lagoon well. There is an increasing trend in EC at the Morgan's Road well, but a decreasing pattern at Alabama Road well 4402 since 2016. EC values for Bar well 1733 and Springlands well 3120 groundwaters are variable (*Figure 31*).

The general rate of increase in groundwater EC for Alabama Road well 4402 and Morgans Road well 4403 cannot be explained by the increase in the EC of Wairau River recharge water alone showing it reflects local natural evolution processes too (*Figure 32*).

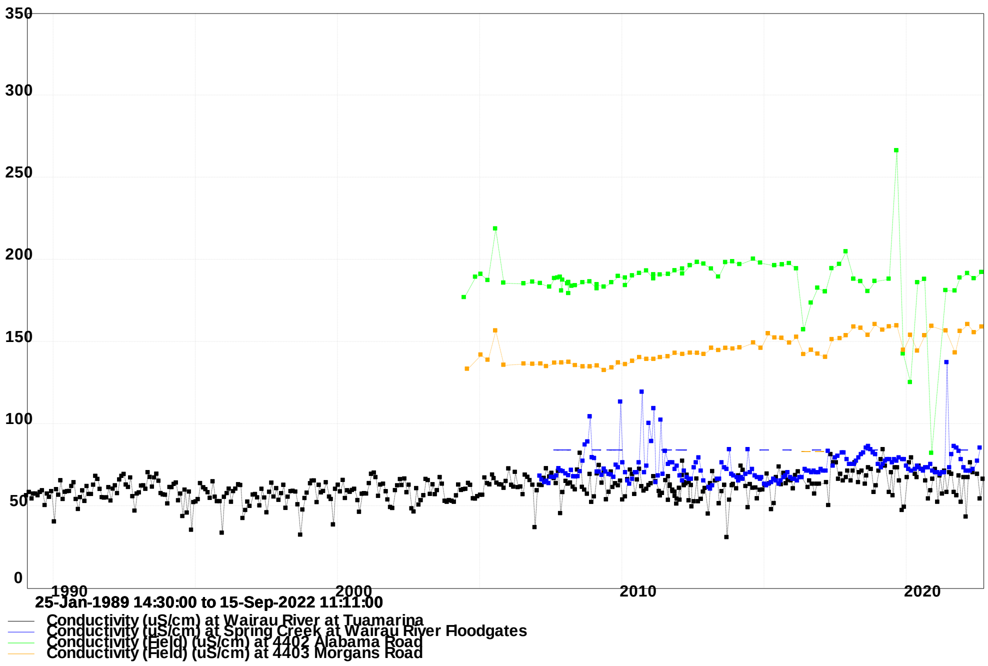



*Figure 32: Electrical conductivity at Alabama Road well 4402 (green) and Morgans Road well 4403 (orange) versus Wairau River at Tuamarina (black) and Spring Creek at floodgates (blue) 2004-2022.*

## Causes of Variability

As all wells in the study area intercept confined aquifers that are relatively isolated from surface influences, sharp changes in groundwater quality imply indirect effects or pressure responses to upstream inputs, disturbances or boundaries. Due to spatial differences in aquifer properties and flow paths, there could be time-lags whereby EC may increase at one SoE well but be decreasing elsewhere for the same aquifer conditions.

There is less variability in EC at the Morgans Road and Alabama Road wells than for the other sites suggesting more homogeneous groundwater conditions exist there. The largest concentration of groundwater abstraction is near the Alabama Road well 4402 and would be expected to draw more evolved groundwater from the south and dilute groundwater from the north. Since mid-2016 there has been increased fluctuations in EC at the Alabama Road well 4402 especially, which may be related to seismic activity associated with the Kaikōura earthquake or changing abstraction patterns (*Figure 31*).

Springlands well 3120 exhibits strong seasonality consistent with the seasonally varying recharge influence from the Wairau River and local land use impacts. The relatively low but variable EC of groundwater from Bar well 1733 reflects its central location beneath the Wairau Plain where gravels are most transmissive. The variability in EC may reflect differential surface loading and pressure effects from Wairau River sourced recharge or vertical mixing of groundwaters of different ages. These processes are being actively researched by GNS Science and MDC at well 1733.

EC observations at the Vernon well dating back to 1987 have been variable and given its proximity to a major MDC wellfield previously used to supply the now closed PPCS freezing works between 1984 and 2002, the possible effects were investigated as part of this report.

It is possible pumping from this PPCS wellfield may have induced more dilute groundwater from the north, with a return to the historical equilibrium when the plant closed. Unfortunately, MDC does not have sufficient groundwater quality record before 1984 when the PPCS works began operation to confirm what changes occurred over the life of the plant.

It is unlikely their operation explains all the variation in groundwater EC because abstraction rates are relatively low. Weekly abstraction reported by PPCS to MDC and expressed as an instantaneous flow show that while peak rates were close to the maximum consented of 60 l/s at times, mostly the freezing works were operating at abstraction rates of around 25 l/s.

Ocean tides have a direct loading effect on confined aquifer levels and EC. At high tide the aquifer loading increases (higher groundwater levels) causing higher conductivity coastal groundwater to have more influence at monitoring bores. Conversely, at low tide the reduced ocean loading (lower water levels) allows more lower conductivity inland groundwater to move towards the monitoring bore. Large Wairau River floods should have the opposite effect by lowering the EC of groundwater and Figure 33 shows this is the case for winter and spring 2022.

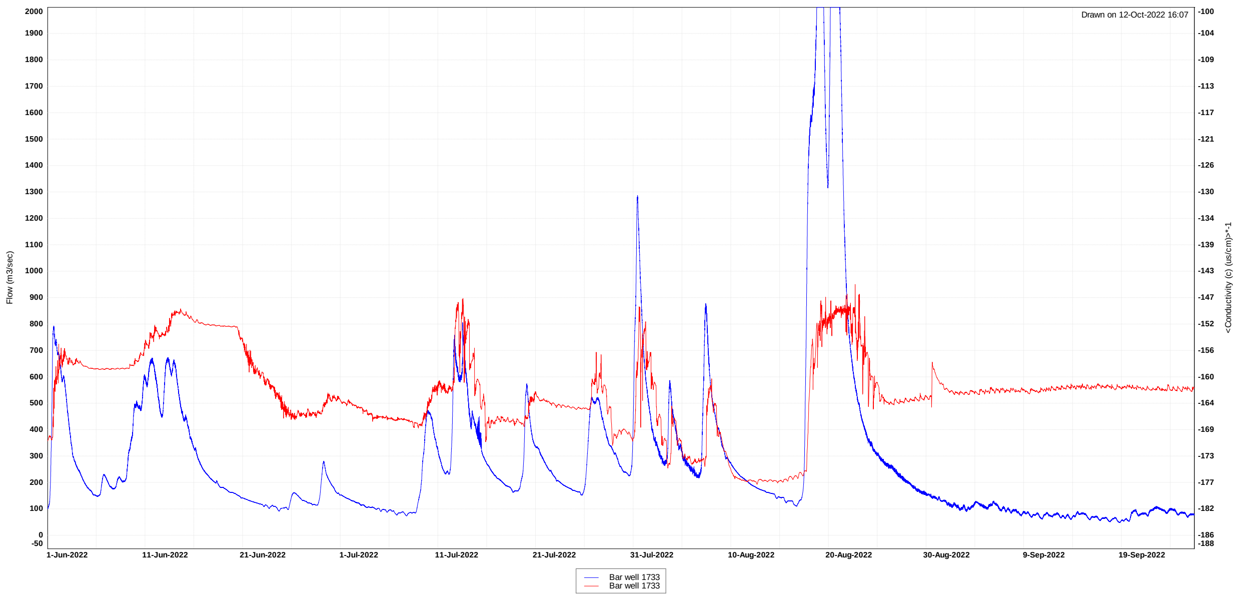


*Figure 33: Wairau River flow (m3/second) at Barnetts Bank (blue) on left hand vertical axis versus Bar well 1733 EC (microS/cm) inverted (red) on right hand vertical axis for June – September 2022.*

Based on continuous MDC downhole sensor observations groundwater, EC follows a twice daily cycle at Bar well 1733 and Replacement Lagoon well 10346, mimicking the ocean tide cycle (*Figure 34* & *Figure 35*).

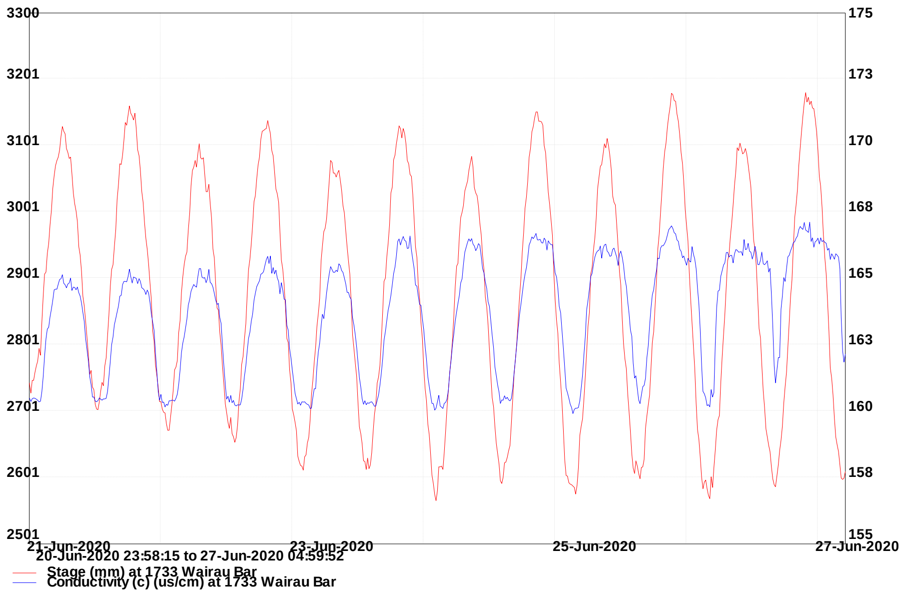


*Figure 34: EC versus groundwater elevation at Bar well 1733 for mid-2020.*

For June 2020, EC is delayed relative to ocean tides for Lagoon Replacement well 10346 and synchronised with the tidal cycle at Bar well 1733. This is likely to reflect the less transmissive nature of sediments near well 10346 meaning the tidal pressure wave takes longer to propagate through the aquifer.

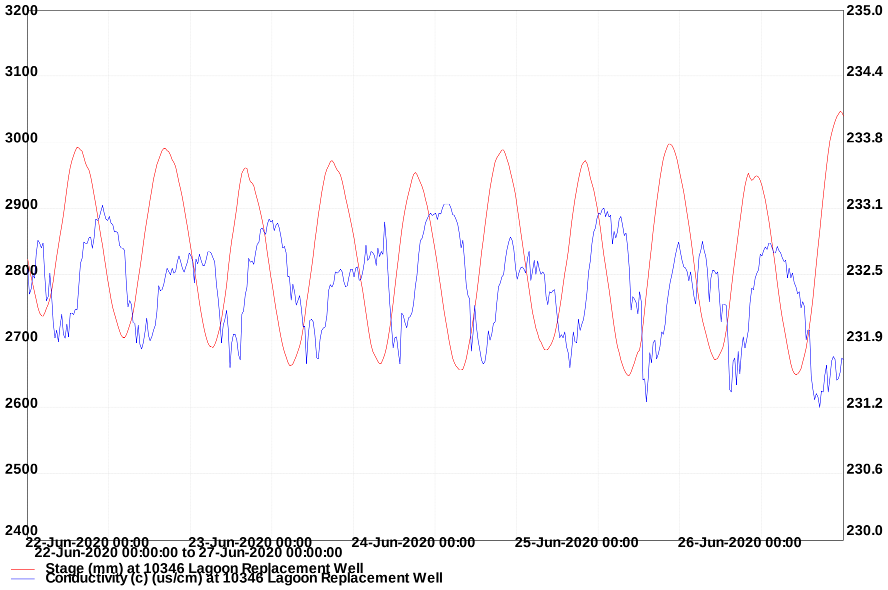



*Figure 35: EC versus groundwater elevation at Lagoon Replacement well 10346 for mid-2020.*

## Measurement Quality

Measuring EC accurately in real time isn't as straightforward as for other parameters. For the Replacement Lagoon well 10346 and Bar well 1733, a close match exists between EC measured in the field (black) compared with continuous, down-well automatic measurements (blue) (*Figure 36* and *Figure 37*). The low field measured value in late 2019 is anomalous. EC is higher during summer and correlates strongly with abstraction for Riverlands monitoring wells.

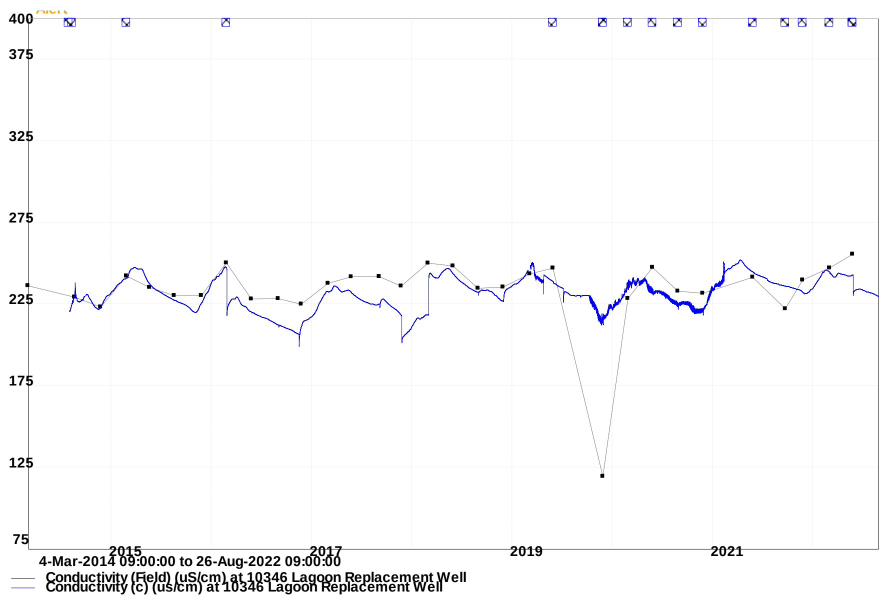



*Figure 36: Lagoon Replacement well 10346 EC measured automatically versus discrete seasonal SoE survey EC field measurements.*

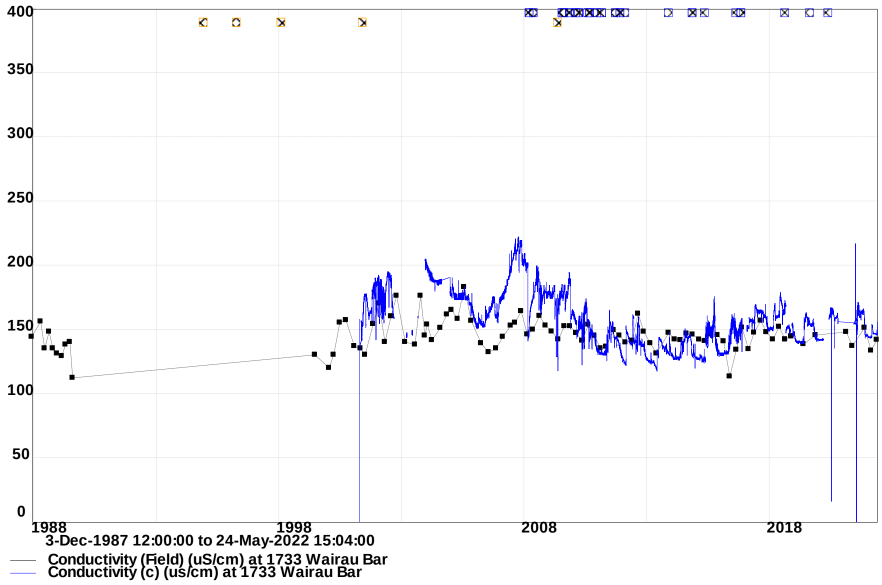



***Figure 37: Bar well 1733 EC measured automatically versus discrete seasonal SoE survey EC field measurements.***

The orange and red horizontal lines in Figure 38 show the alert threshold of 400 and Marlborough Environment Plan (MEP) cut-off threshold for resource consent holders of 600 microS/cm respectively. During the replacement of the original Lagoon well 708 by well 10346 in 2014, overlapping measurements of groundwater EC and level were made to see if the same aquifer strata was intercepted by both wells.

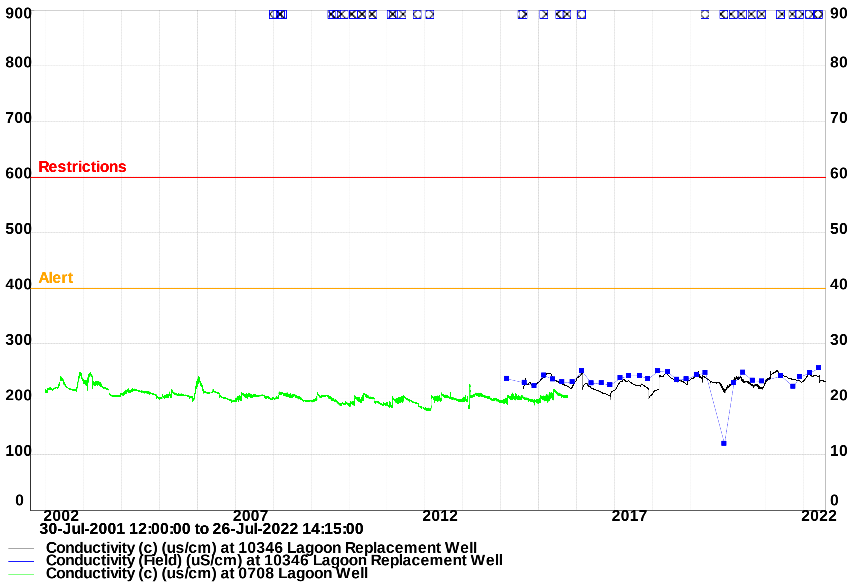



***Figure 38: Comparison of groundwater EC at original Lagoon well 708 (green) versus Lagoon Replacement well 10346 (blue/black) 2002-2022.***

Groundwater levels were identical, but EC was slightly higher at the Replacement Lagoon well 10346 (Figure 38). While the two wells are only around 50 metres apart, the new well intercepts more evolved groundwater. This is not surprising as large groundwater age gradients and corresponding differences in quality exist over short distances. Units of EC for the Replacement Lagoon well 10346 are microS/cm on the left-hand vertical axis and milliS/m the original well P28w/0708 on the right-hand vertical axis.

## pH

pH is a measure of the hydrogen ion ($H^+$) activity in water and has a major influence on most chemical reactions that occur in the closed coastal Wairau Plain aquifers especially those involving iron, manganese and arsenic which have human health implications. pH also reflects the by-products of biochemical reactions like alkalinity.

## Regional Patterns

At a regional Wairau Plain scale groundwater pH increases from very low values for unconfined aquifer areas in the north and western Wairau Plain, to values commonly above pH 8 in the Southern Valleys Aquifers and along the coastal boundary (Figure 39).

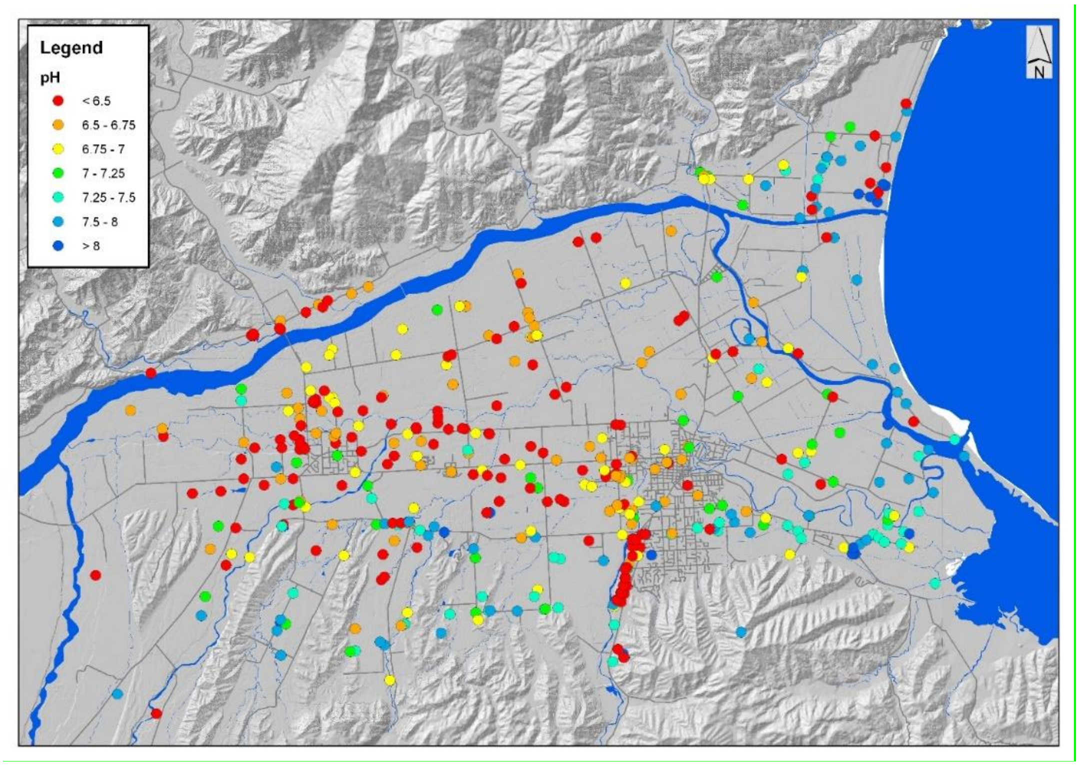



***Figure 39: Median pH Wairau Plain (Groundwaters of Marlborough 2011).***

Higher groundwater pH commonly reflects the presence of more alkalinity produced by the reduction type reactions predominating in the confined aquifer conditions. The pH of unconfined Wairau Aquifer groundwater underlying the western Wairau around Renwick has historically been low in the range from pH 6 to 6.5 due to leaching of atmospheric $CO_2$ to the groundwater table in the form of carbonic acid (Figure 39).

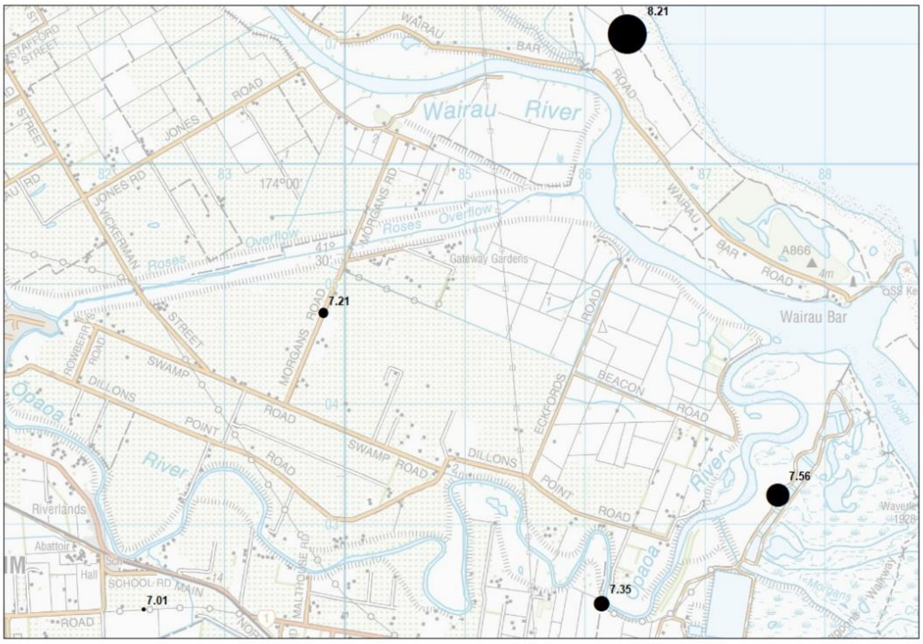



*Figure 40: Median pH.*

## Local Values & Trends

pH is highest near the edges of the study area corresponding with the most evolved groundwaters (Figure 40). Groundwater at the Alabama Road well 4402 has near neutral median pH while the reasons for Bar well 1733 having the highest median pH remain unclear. Groundwater at well 1733 is relatively young with a mean residence time (MRT) of 11 years and less evolved than Lagoon Replacement well 10346 groundwater. The Lagoon Replacement well contains no tritium meaning groundwater has been isolated from atmospheric influences for at least sixty years based on its half-life.

The age of groundwater from Bar well 1733 is stable over time based on the tritium content, however, $SF_6$, which has been measured twice, is consistently too low for a MRT 11 years. This suggests an unusual mixing of water from different flow paths.

Figure 41 shows pH does vary at all sites despite the confined aquifer conditions. There is no apparent seasonal pattern except for Alabama Road well 4402 which tends to peak in summer or spring, explaining the corresponding increase in iron as it becomes more soluble in groundwater.

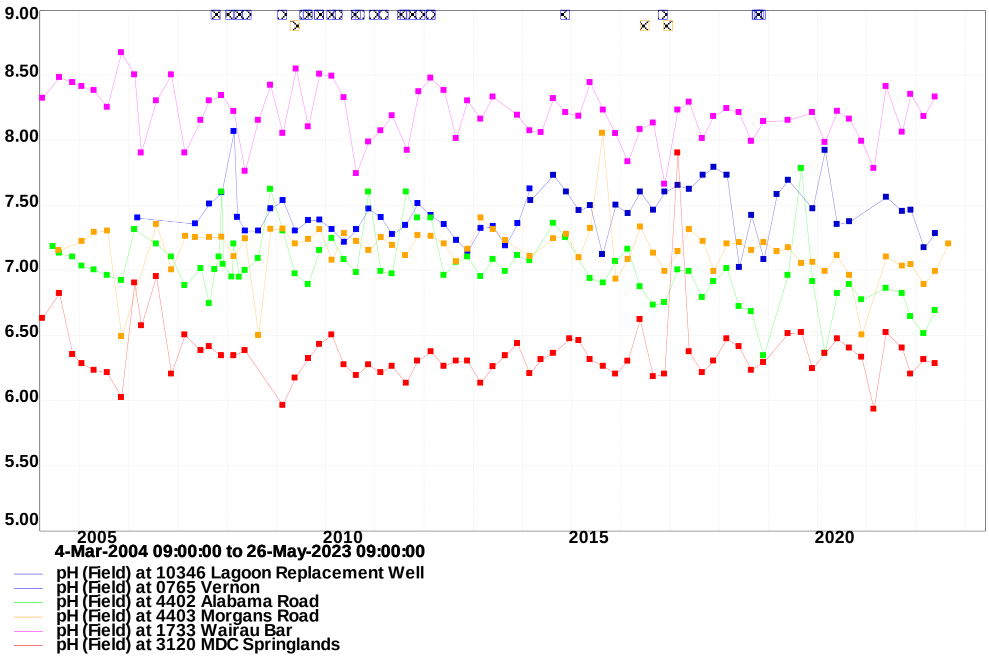



***Figure 41: pH measured in field 2004-2022.***

Figure 41 shows pH is increasing over time at the Lagoon Replacement well 10346 (blue), while decreasing at Bar well 1733 (purple), Morgans Road well 4403 (orange) and Alabama Road well 4402 (green). pH is lower and stable at the upstream Springlands well over the same period.

## Causes of Variability

As discussed earlier, the relatively high pH of groundwater underlying the south-east Wairau Plain largely reflects natural weathering effects and reduction reaction products. While groundwater alkalinity values for the study area are increasing, their corresponding pH values are not. Median pH shows a strong negative correlation with median concentrations of nitrate-nitrogen and sulphate (*Figure 42*). The median sulphate concentration of just over 4 g/m$^3$ at Bar well 1733 is anomalously high for its pH however (*Figure 40 & Figure 42*).

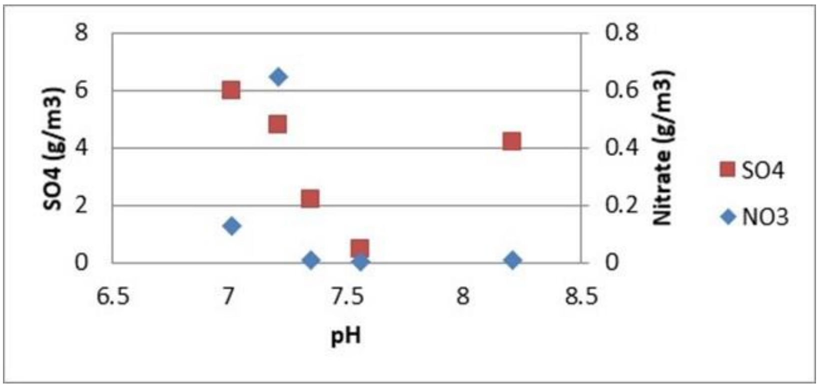



***Figure 42: Median pH versus median sulphate & nitrate concentration.***

There is also a strong correlation between the median pH of groundwater and median concentrations of potassium, magnesium and calcium. Concentrations of potassium increase with higher pH while calcium and magnesium decline (*Figure 43*). The relationships plotted in Figure 42 and Figure 43 are consistent with geochemical evolution processes dominating the study area. The wells corresponding to each data points can be identified by Figure 40.

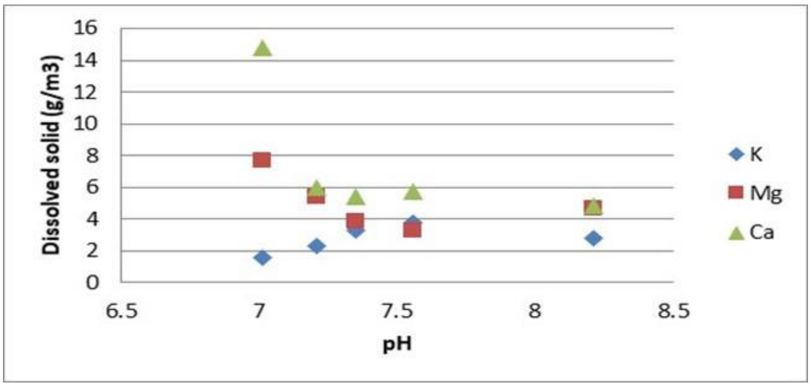



*Figure 43: Median pH versus median potassium, magnesium & calcium concentration.*

## Temperature

Groundwater temperature varies significantly for wells tapping the unconfined Wairau Aquifer. This is caused by the temperature variation of Wairau River recharge water for wells near the river channel. Groundwater in very shallow wells can be directly influenced by surface weather conditions. Conversely there should be limited variation in groundwater temperature for the confined aquifers featured in this report as they are closed systems isolated from direct surface influences.

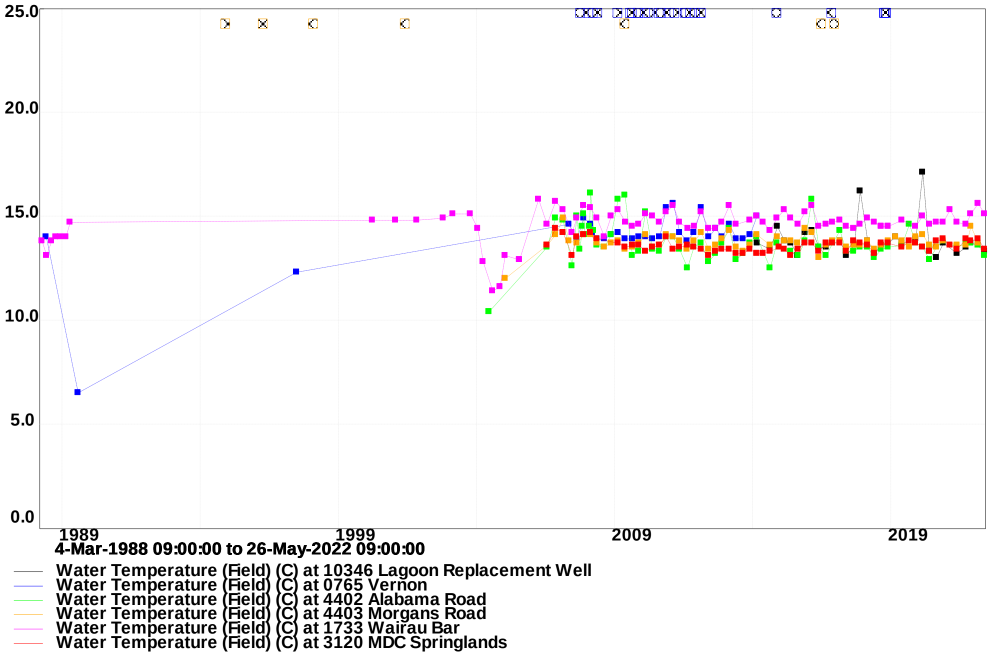



*Figure 44: Field measured groundwater temperature in degrees Celsius.*

## Local Values and Trends

The highest temperatures and most pronounced seasonality are associated with groundwater at Bar well 1733, with similar values at the other sites (*Figure 44*). This pattern is consistent with less confined conditions or more interaction between aquifer layers or surface processes at Bar well 1733.

There is an apparent seasonal variation in groundwater temperature at most sites, with warmer water in summer, but whether this is real or reflects measurement or instrument error is uncertain.

## Causes of Variability

Manual measurements require groundwater to be bought to the surface with the possibility of temperature changes as part of the sampling procedure. The advantage of measurements from automatic sensors at the base of deeper wells is they are direct and not influenced by surface temperatures.

For example, manual measurements for Bar well 1733 involves pumping groundwater up to a flow cell at the surface. Temperature changes could be imparted by the electric submersible sampling pump and the ambient air temperature affecting the flow cell, sample bucket, plastic delivery hose or steel well casing. The Lagoon Replacement well 10346 and Morgan's Road wells are normally flowing artesian so there is no need for a pump, but opportunities still exist for groundwater temperature to be modified, especially on hot days.

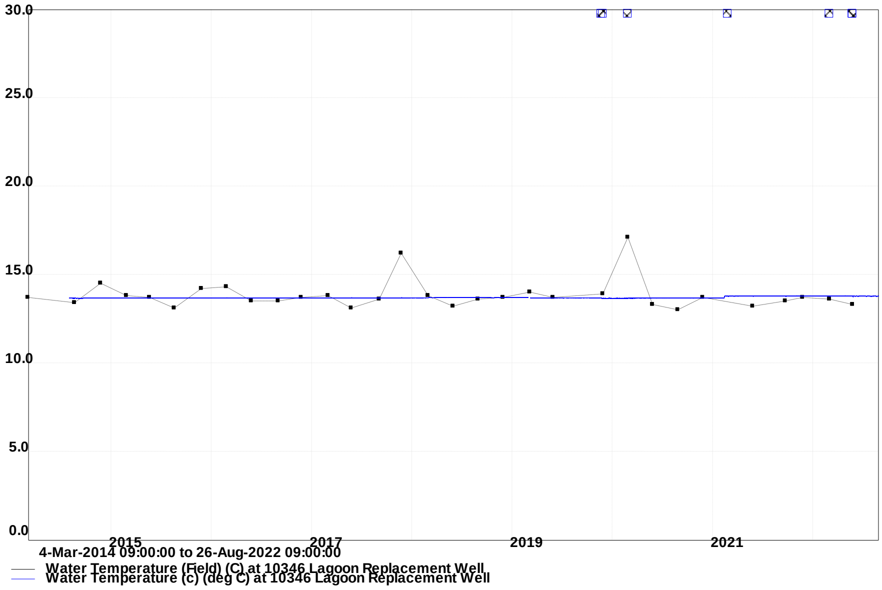



***Figure 45: Comparison of manual (black) versus automatic (blue) measurements of groundwater temperature for Lagoon Replacement well 10346 2014-2022.***

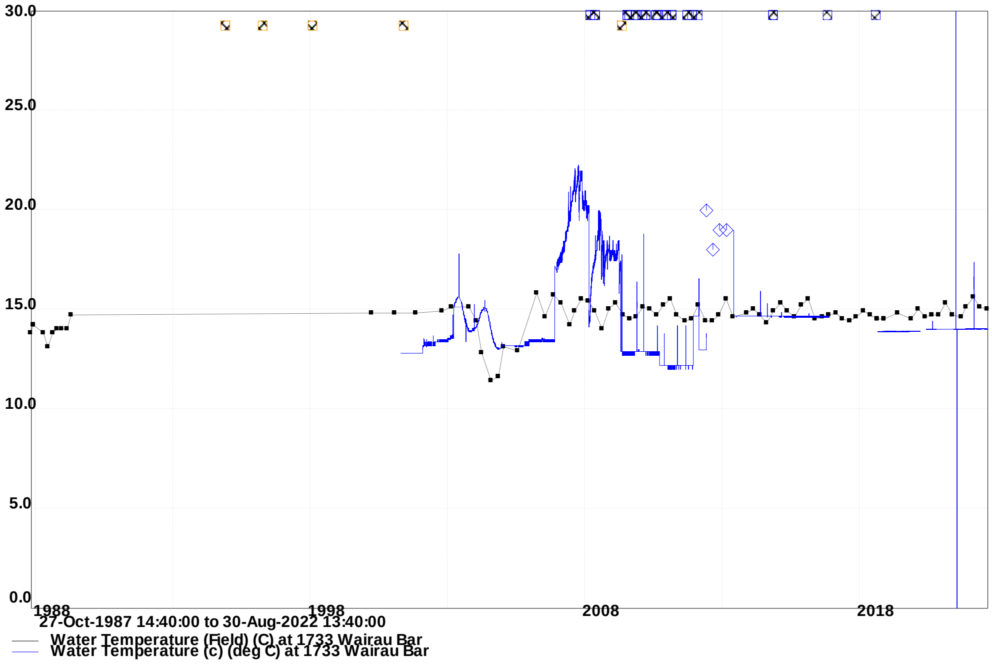



***Figure 46: Comparison of manual (black) versus automatic (blue) measurements of groundwater temperature at Bar well 1733 1987-2022.***

Figure 45 and Figure 46 compare field (black) with automatic sensor (blue) measurements of groundwater temperature for Lagoon Replacement well 10346 and Bar well 1733. Manual measurements are more variable than automated sensor readings at Lagoon Replacement well 10346, but the reverse applies for Bar well 1733. Variations in groundwater temperature affect derived values of electrical conductivity for automatic sensors, compounding any errors that exist. Uncertainty remains over the accuracy of MDC temperature data, but it is a cheap and powerful tool for understanding aquifer processes, especially vertical mixing.

## Dissolved Oxygen

Levels of oxygen dissolved in groundwater have not been measured by MDC for as long as other parameters. The growing DO record is proving very useful for understanding levels of redox sensitive parameters like iron, arsenic and manganese. The unit used in this report is percentage of saturation.

## Regional Patterns

Based on the well described Wairau Plain geochemical evolution pattern; younger, less evolved groundwater in the north and west were expected to correspond with higher dissolved oxygen (DO) levels and this is what is observed (*Figure 47*). Conversely dissolved oxygen levels are relatively low at Riverlands.

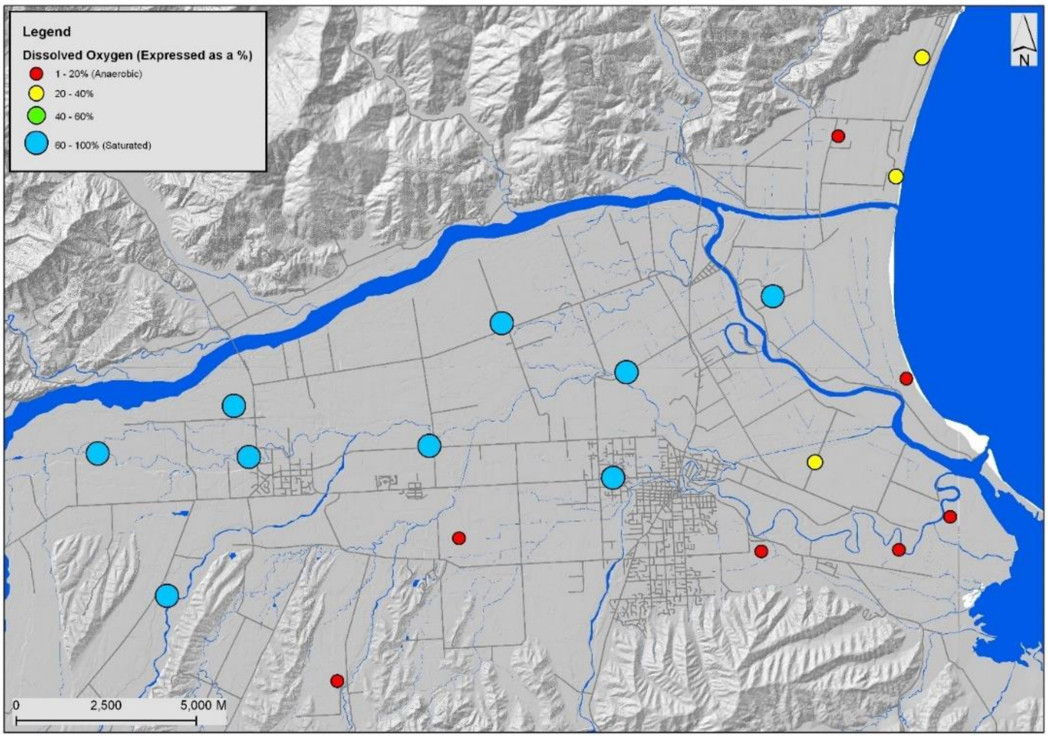



***Figure 47: Median dissolved oxygen concentration (g/m3) Wairau Plain.***

The closeup map view of Riverlands reveals the same DO pattern applies there with lower values associated with the most evolved groundwater on the edges of the aquifer (*Figure 48*).

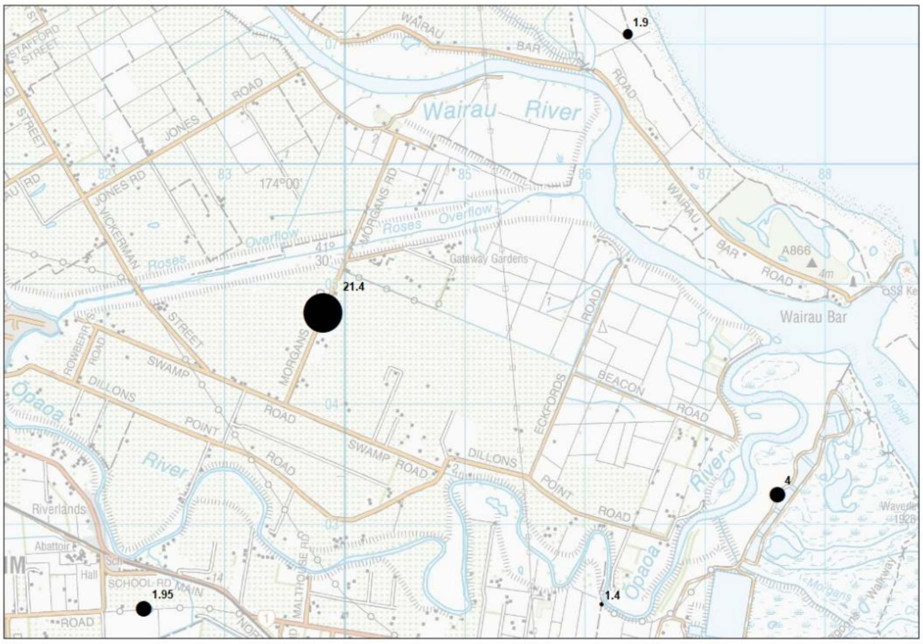



*Figure 48: Median dissolved oxygen concentration as percentage saturation 2007-2022.*

## Local Values and Trends

What is most interesting about the equivalent time series of DO are the significant fluctuations, especially leading up to and following the 2016 Kaikōura earthquake (*Figure 49*). The earthquake occurred just after midnight on the 14 November 2016 and the spring SoE survey occurred soon afterwards marked by the earlier large spike in Figure 49. The DO content of groundwater was previously thought to be relatively stable for the confined aquifer conditions present at Riverlands, but this is not the case based on seasonal SoE observations. Measurements of DO are subject to leaks in hoses and flow cells, however measurements made by free-flowing Alabama Road and Lagoon Replacement wells are likely to be reliable.

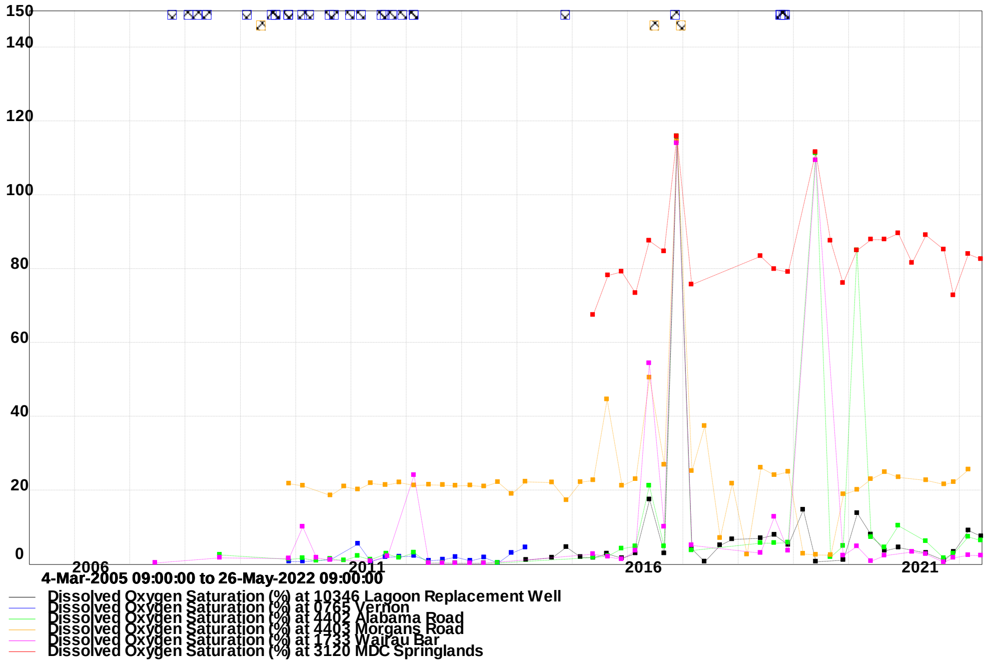



*Figure 49: Field measured dissolved oxygen as percent saturation 2008-2022.*

Springlands well 3120 has the most oxygenated groundwater followed by Morgans Road well 4403. As expected, DO levels at the Lagoon replacement well 10346, Alabama Road well 4402 and Bar well 1733 are mostly low consistent with their advanced reducing conditions (*Figure 49*). Since 2017, dissolved oxygen values have generally fallen consistent with the presence of more evolved groundwater.

## Causes of Variability

It is very likely the late 2016 Kaikōura earthquake caused structural changes to the confined aquifer resulting in different flow dynamics or interlayer mixing. Changed flow pathways and mixing patterns should establish new geochemical equilibrium conditions.

There have been no noticeable changes in redox sensitive parameters coinciding with the earthquake. At the Morgans Road well 4403 there was a fall in silica and electrical conductivity levels as oxygen levels rose consistent with the arrival of more dilute groundwater (*Figure 50*). A contributing factor to declining DO levels since 2016 may be less groundwater through-flow during the drier seasons compounded by higher abstraction.

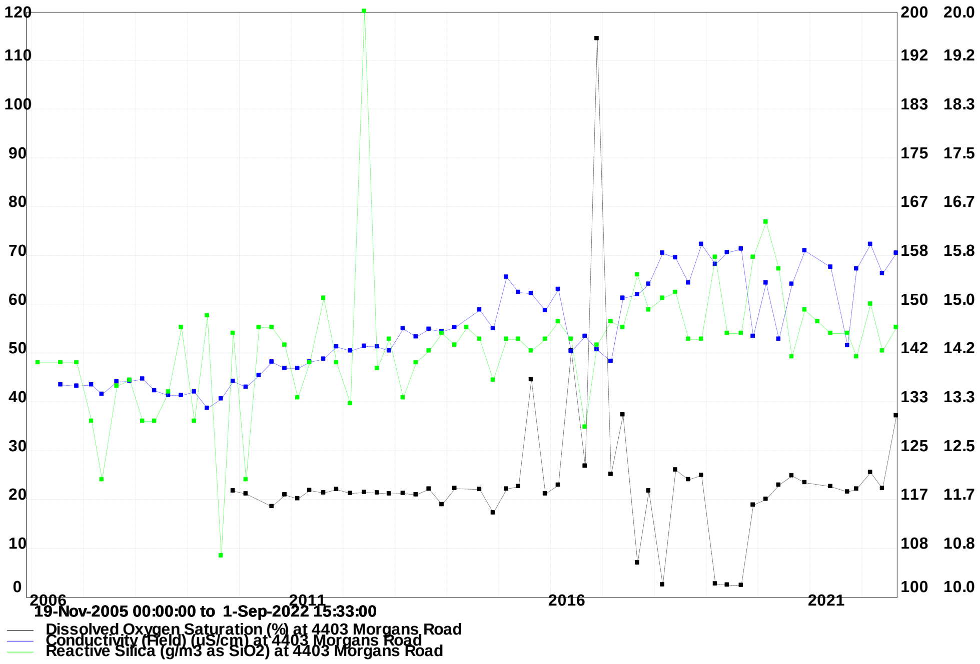



***Figure 50: Morgans Road well 4403 dissolved oxygen (black) as percent saturation versus electrical conductivity (blue) & silica (green) 2009-2022. DO as percent saturation on left hand vertical axis. Field EC on inner right hand vertical axis and silica on outer.***

## Measurement Quality

DO can only be measured in the field but results are dependent on not introducing extra oxygen through turbulence with much depending on sampling procedure. Monitoring wells Morgans Road well 4403, Lagoon Replacement well 10346 and Alabama Road well 4402 exhibit artesian pressures. The advantage of artesian pressure is it allows wells to be purged by free flowing thus reducing the possibility of oxygen being added by pumping or turbulence. Flow cells and leaking hoses can still introduce error though.

## Chloride

Chloride is relatively unreactive making it a good tracer of groundwater flow as changes in concentration are due mainly to water-rock interaction. The presence of marine sediments forming local aquifers means chloride concentrations are naturally higher than for western areas of the Wairau Aquifer.

Chloride and sodium are major constituents of seawater. MDC monitor their concentration in groundwater to improve understanding of the sensitivity of the seawater interface to groundwater abstraction and for correlating with EC values of groundwater to define potability state. To date there have been no signs of seawater intrusion based on long-term increases in chloride/sodium at MDC coastal monitoring wells.

## Regional Patterns

The regional pattern of median chloride concentration is explained by natural geochemical evolution processes and is consistent with aquifer structure (*Figure 51*).

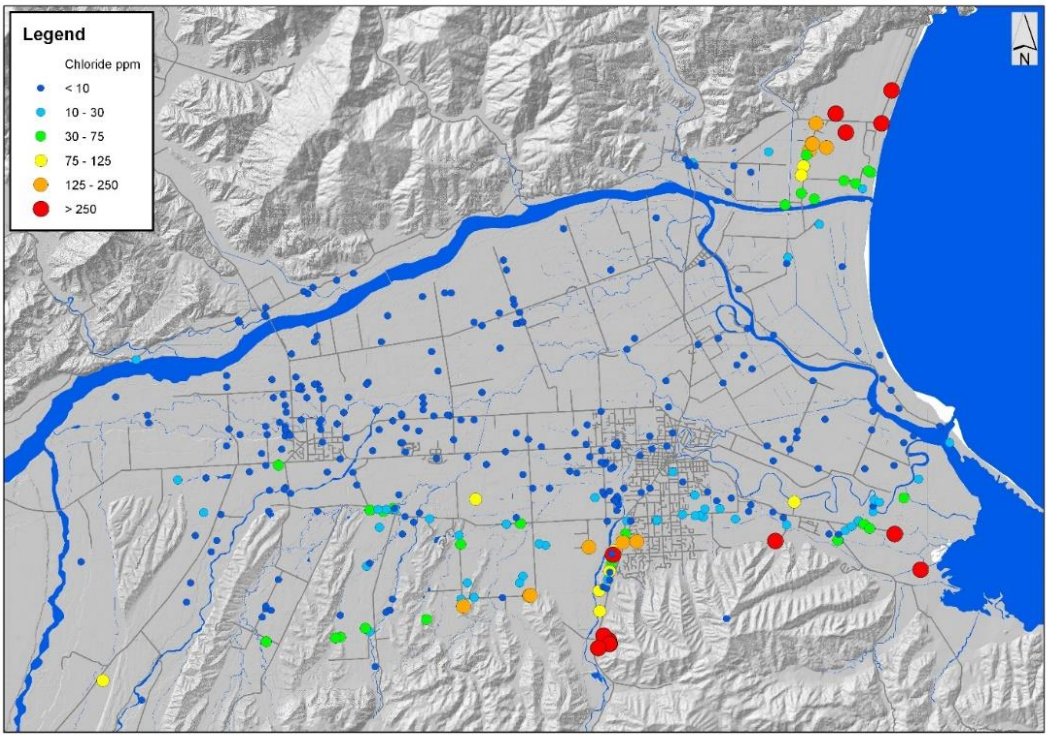



***Figure 51: Median chloride concentration (g/m3) Wairau Plain (Groundwaters of Marlborough 2011).***

## Local Values and Trends

The regional spatial pattern of chloride concentration extends to the local scale indicating a homogeneous aquifer structure (*Figure 52*). Highest chloride values occur on the edges of the aquifer and are associated with the oldest groundwater.

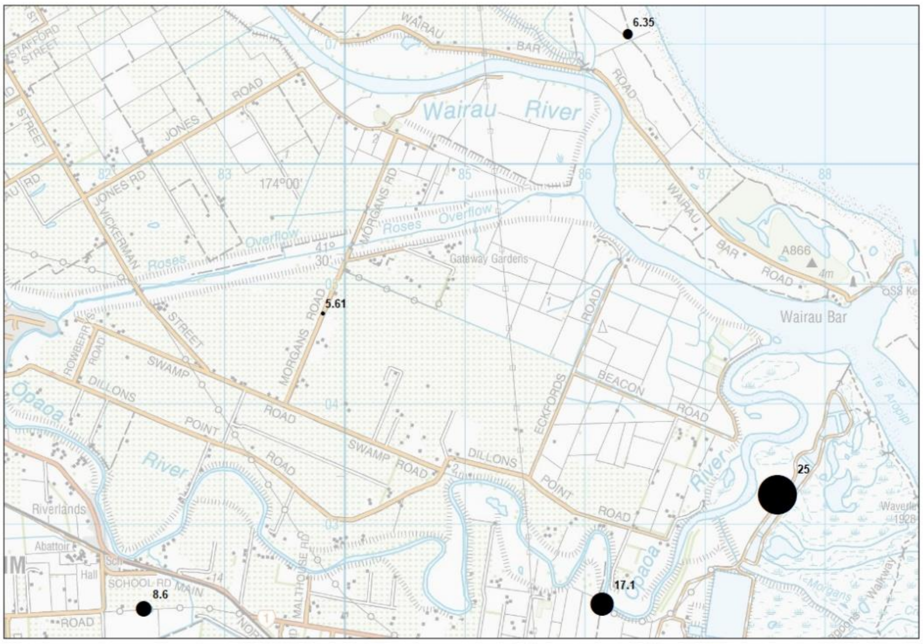



***Figure 52: Median chloride concentration (g/m3).***

The times series of chloride concentrations across the six wells mirrors that of electrical conductivity in terms of ranking (*Figure 53*). There are noticeably fewer short-term fluctuations in chloride levels at the Morgans Road 4403 and Alabama Road 4402 wells than for other sites with significant variability at Lagoon Replacement well.

There were increases in chloride concentration following the 2016 Kaikōura earthquake at Morgans Road well 4403 and Alabama Road well 4402, with values remaining elevated suggesting a permanent change in the aquifer or its structure. Concentrations are increasing at the Lagoon Replacement well 10346, but it is too early to tell if this constitutes a long-term trend or the influence of seawater. Other wells show stable levels with time (*Figure 53*).

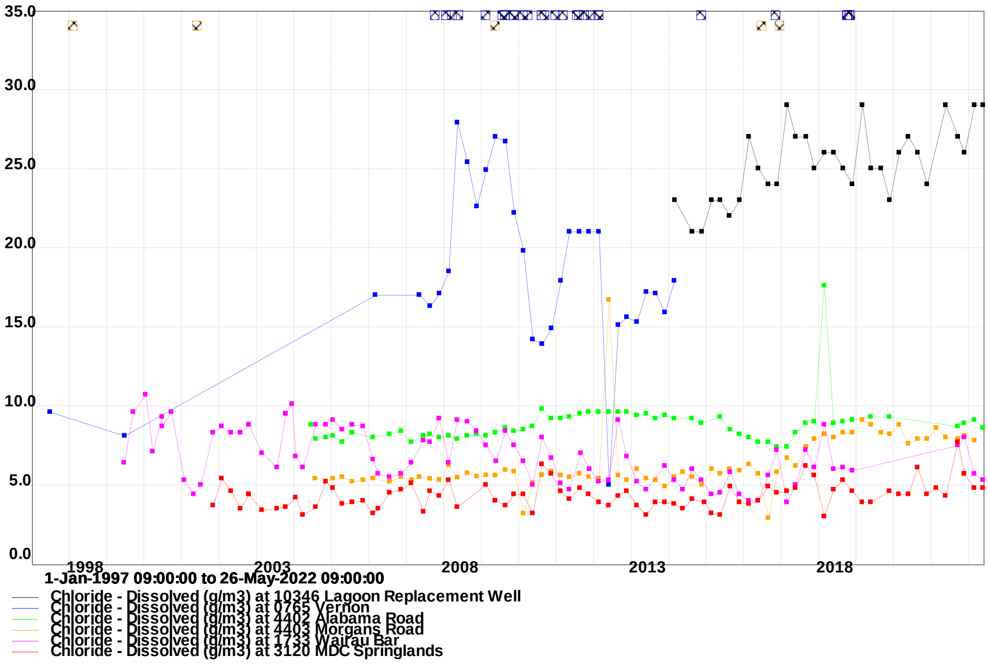



***Figure 53: Chloride concentration (g/m3) 1987-2022.***

## Causes of Variability

The highest chloride concentrations occur at the Lagoon Replacement well because of its location intercepting the most mineralised groundwater, while the seasonality presumably reflects abstraction induced shifts in chloride content.

A comparison of chloride concentration peaks show they mostly occur at the Bar well 1733 during spring or winter, and summer at the Lagoon Replacement well 10346 (*Figure 54*). Figure 54 shows the variation in groundwater elevation (grey) with chloride concentration at the Lagoon Replacement well (blue) and Bar well 1733 (blue). Lagoon Replacement well chloride concentrations have been halved for plotting purposes.

This seasonal pattern implies different mechanisms are operating beneath the centre of the Wairau Plain versus the edges at Riverlands. It supports the concept of a loading effect possibly controlling central coastal areas, and pumping effects dominating the southern and northern coastal areas at Riverlands/Rarangi.

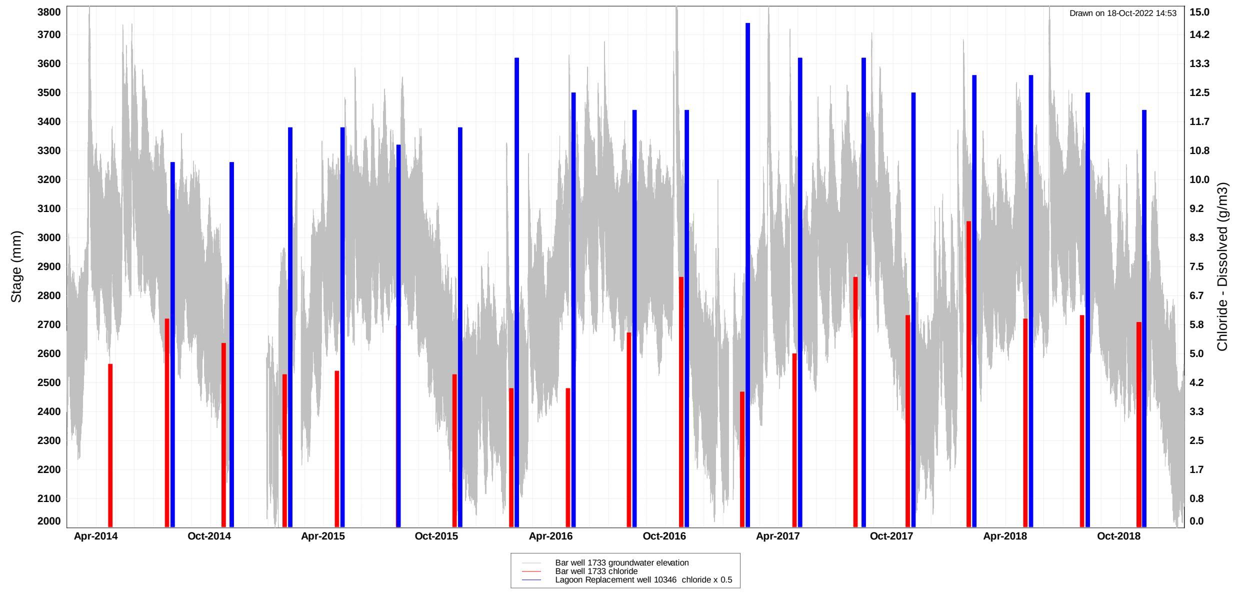



***Figure 54: Bar well chloride concentration 1733 (red) and Replacement Lagoon well chloride concentration (blue) versus Bar well 1733 groundwater elevation (grey).***

The range in chloride concentrations at the Vernon well 765 between 1987 and 2014 is very large and appears too great to be explained by natural processes alone. Interpreting the record is complicated by the gaps. A possible explanation introduced earlier was pumping from the nearby PPCS wellfield temporarily changed flow patterns by inducing groundwaters of differing chemistry towards the well.

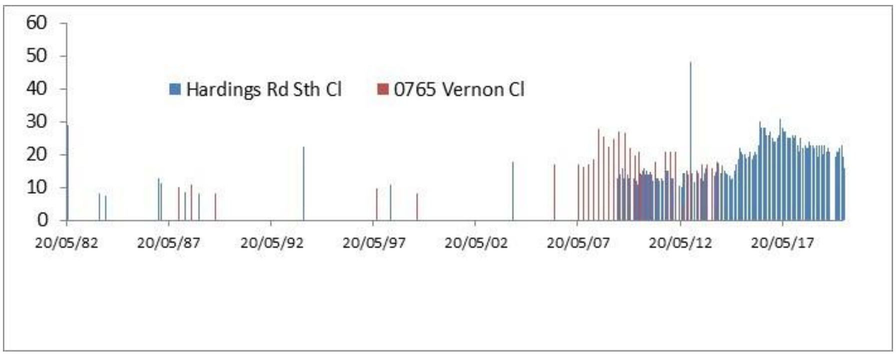



***Figure 55: Comparison of chloride (g/m3) at MDC Vernon 765 versus MDC Hardings Road south well 1147 1983-2020.***

Figure 55 shows relatively few chloride measurements exist for the early 1980's before the PPCS Freezing Works began operation to show natural state. Values appear significantly lower than today based on recent measurements at the MDC Hardings Road south well. Changes in chloride concentrations in Wairau River channel recharge water over time could not account for the increase at the Vernon well 765, and it may be related to old high salinity water in the confining sediments being released into the aquifer during earthquake shaking.

Figure 56 shows the difference in chloride concentration between the two wells forming the ex-PPCS (current MDC Cloudy Bay) Hardings Road wellfield. The north and south wells are only 200 metres apart, but a steep geochemical gradient exists which is a common characteristic of the Riverlands Aquifer. A similar gradient exists between the original Lagoon well and its replacement well 10346. Chloride levels are higher at the southern-most well in the well-field as expected being closer to the aquifer southern boundary and less transmissive gravels.

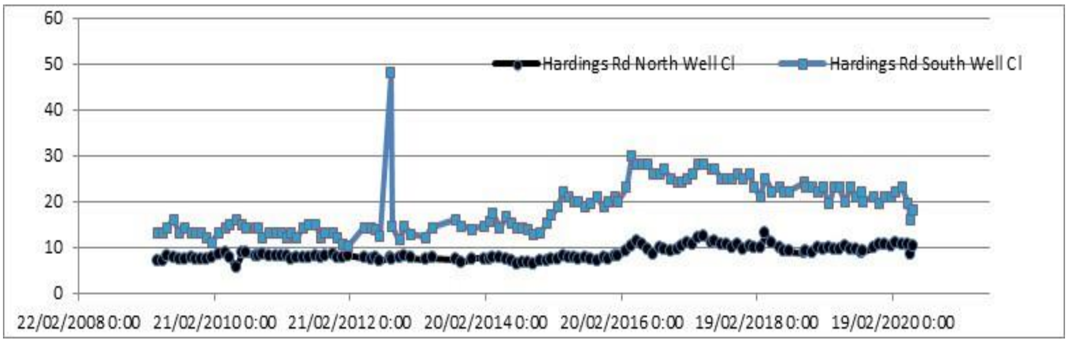



***Figure 56: Chloride concentration (g/m3) MDC Hardings Road wellfield.***

Chloride is measured seasonally at MDC sentinel wells whereas the electrical conductivity (EC) of groundwater is measured continuously by instruments at the base of coastal sentinel wells to warn of seawater intrusion. There are also manual MDC field measurements of groundwater EC taken as part of SoE surveys.

It is useful to know the chloride content of groundwater as chloride has a Guideline Value (GV) of 250 g/m$^3$ (Aesthetic Values for Drinking Water Notice 2022). An estimate of chloride content can be derived from EC based on a strong positive relationship for groundwater from the Bar well 1733 (red) and Replacement Lagoon well 10346 (blue) (*Figure 57*). Derived chloride values are well below the GV at these sites.

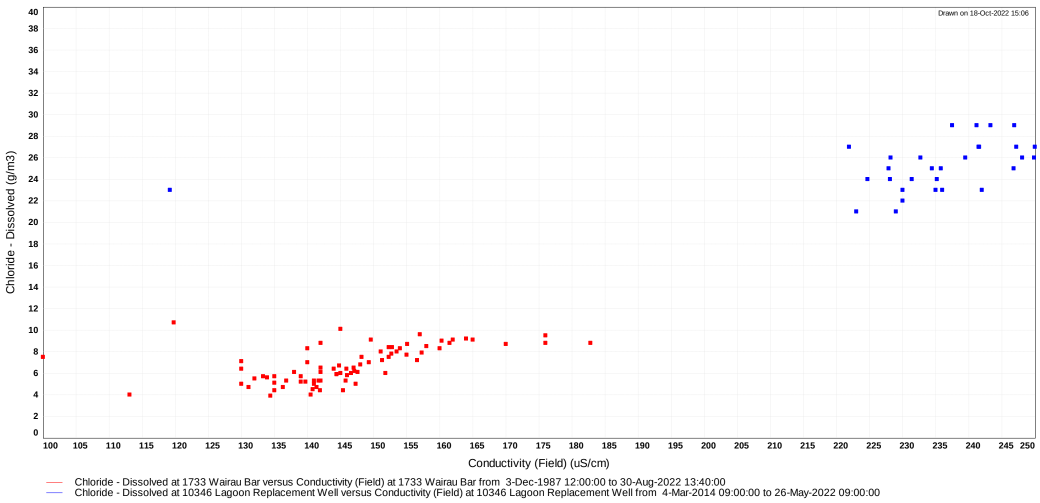



***Figure 57: Chloride concentration versus EC at Bar well 1733 and Lagoon Replacement well 10346.***

# Sodium

The main sources of sodium in Wairau Plain groundwater are likely to be from the sea and weathering of sodium rich minerals like feldspars. Fossil sodium and chloride are both likely to be present in the marine silts, sands and clays forming the confining layers of aquifers at Riverlands and in connate water trapped in the pore spaces of these geological formations. Sodium also comes from clays via reverse ion exchange processes with calcium or magnesium. Human sources of sodium include landfills and effluent disposal systems.

## Regional Patterns

At a regional scale the pattern of low sodium concentrations near the Wairau River recharge source and higher levels at the edges of the most productive aquifer areas is consistent with natural groundwater evolution processes (*Figure 58*).

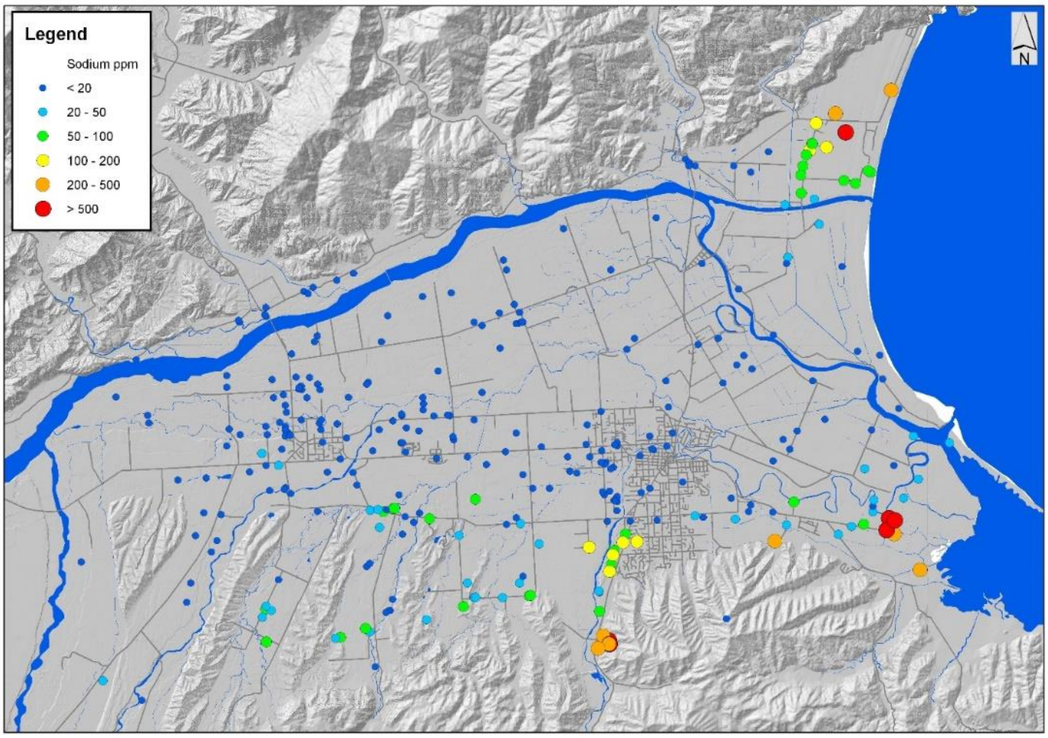



***Figure 58: Median sodium concentration (g/m3) Wairau Plain (Groundwaters of Marlborough 2011.)***

## Local Values and Trends

Median sodium concentrations are higher near the coast and Lagoon boundaries. Surprisingly, sodium values at Morgans Road well 4403 are higher than at Alabama Road well 4402 (*Figure 59*). This spatial pattern is slightly different to the distribution of median chloride concentration and electrical conductivity.

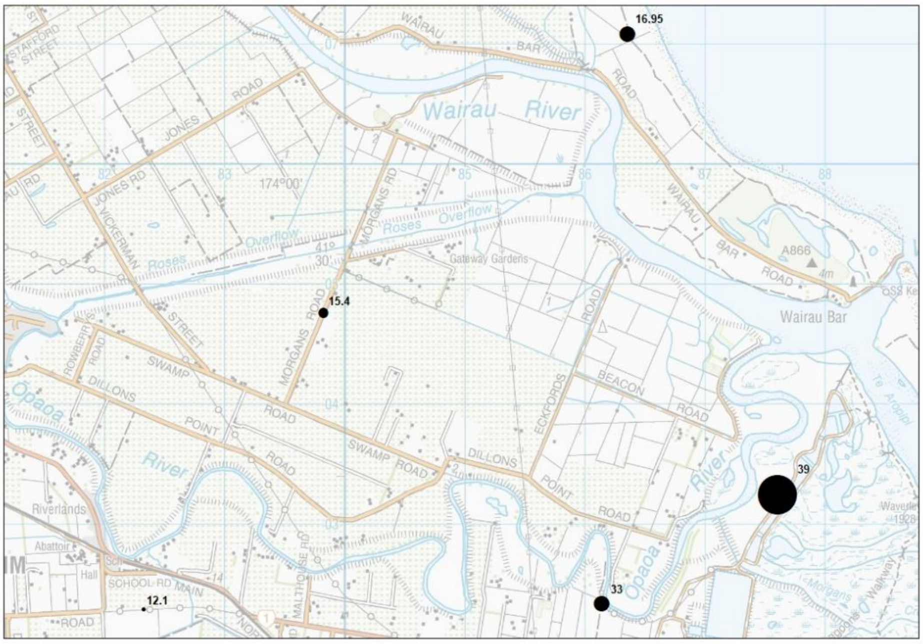



*Figure 59: Median dissolved sodium concentration (g/m3).*

There is a declining trend in sodium concentration at Bar well 1733 and an increasing trend at Lagoon Replacement well 10346 and Morgans Road well 4403 (*Figure 60*). Sodium values are relatively stable at other sites and low compared to seawater (*Figure 60*).

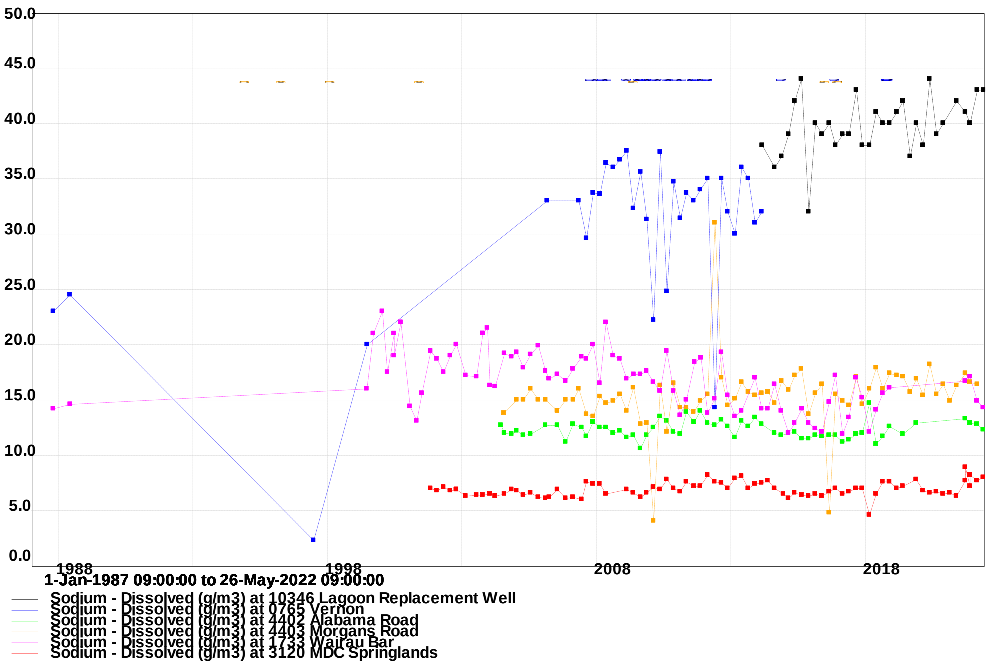



*Figure 60: Dissolved sodium concentration 1987-2020.*

## Causes of Variability

There is more variability in sodium concentrations at the Bar well 1733 and Lagoon Replacement well than other sites which is a pattern seen in other parameters suggesting less isolation from surface processes or mixing (laterally or vertically). There is not enough change in the sodium concentration of Wairau River recharge water over time to account for the increase in sodium levels at Springlands well 3120 (*Figure 61*).

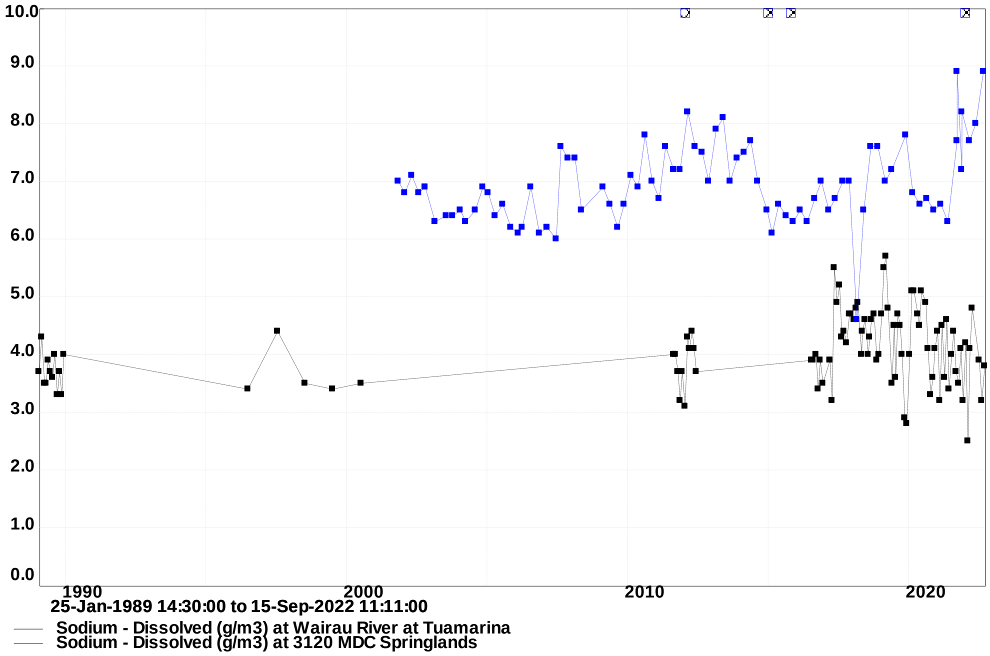



***Figure 61: Sodium concentration (g/m3) for Wairau River at State Highway 1/Tuamarina and Springlands well 3120.***

# Potassium

Human sources of potassium include artificial fertilisers and leachate from septic tanks or waste products like grape marc. Natural sources include the feldspar family of silicate minerals and their derived clays which are present in the confined aquifers of the Lower Wairau Plain.

## Regional Pattern

At a regional scale, potassium levels are low for the most productive aquifer areas underlying the northern Wairau Plain, but increase on the fringes south of Middle Renwick Road, at Riverlands and Rarangi (*Figure 62*).

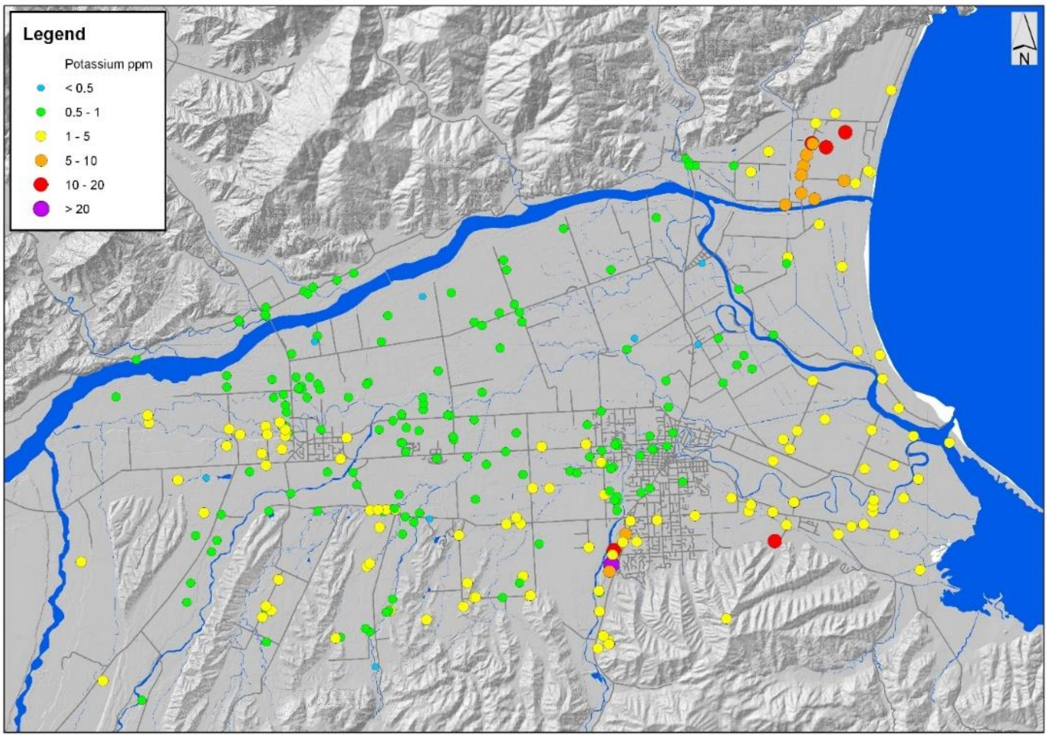



*Figure 62: Median potassium concentration (g/m3) Wairau Plain (Groundwaters of Marlborough 2011).*

## Local Values and Trends

Median potassium concentrations are low in this area at less than 5 g/m³ with all values of the same order (*Figure 63*).

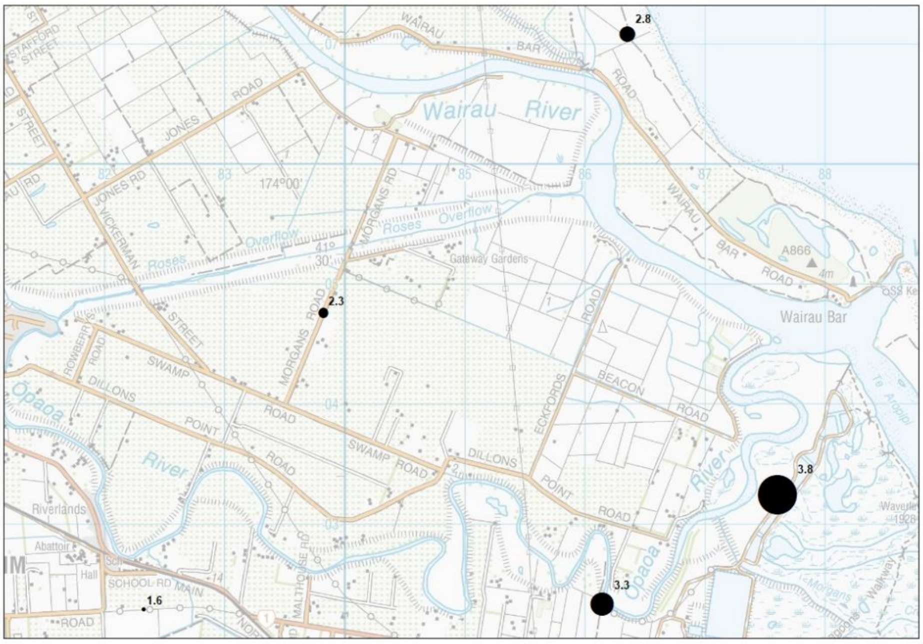



*Figure 63: Median potassium concentration (g/m3) 1987-2022.*

The hierarchy of potassium concentrations across the five sites is slightly different to the rankings for most other parameters with the lowest levels at Alabama Road well 4402 (*Figure 64*). In terms of time trends, potassium concentrations are increasing at the Lagoon Replacement well 10346 and Morgans

Road well 4403 but are reasonably stable at all other sites. Potassium levels at the upstream Springlands well 3120 representing Wairau River recharge water are low and stable (*Figure 64*).

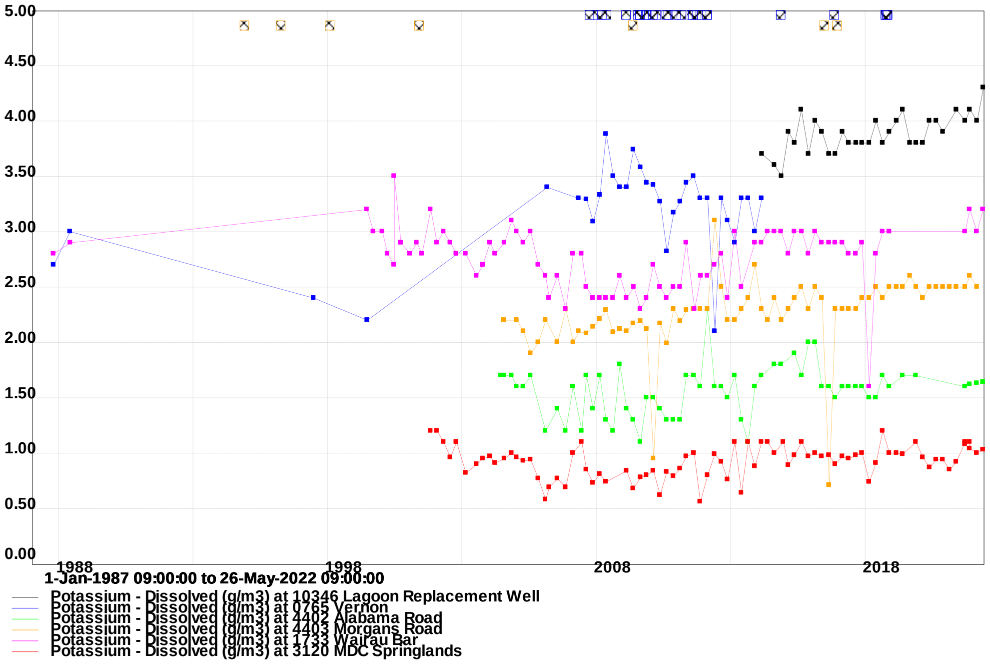



***Figure 64: Potassium concentration 1987-2022.***

## Causes of Variability

Potassium concentrations increase with the distance of groundwater travel within the confined aquifer due to water – rock interaction. A mineral source of potassium associated with the local marine geology is the likely origin.

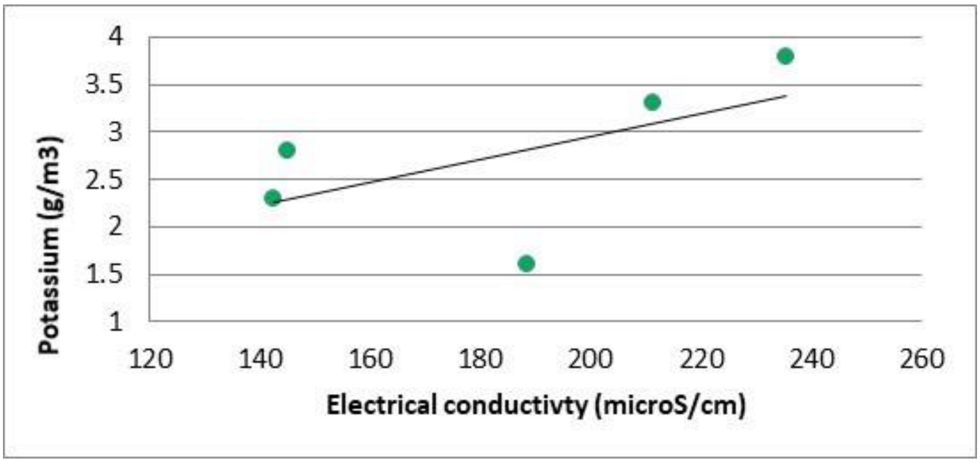



***Figure 65: Median potassium concentration versus median electrical conductivity.***

There is a strong positive correlation between potassium concentration and electrical conductivity for the four main wells in the study area (*Figure 65*). The identity of the data points can be found from *Figure 63*). This demonstrates potassium content is increasing along-with most other ionically important salts showing natural evolution of groundwater is the dominant process influencing geochemistry at Riverlands. Increasing potassium concentrations cannot be explained by changes in Wairau River potassium levels as they are stable (*Figure 66*).

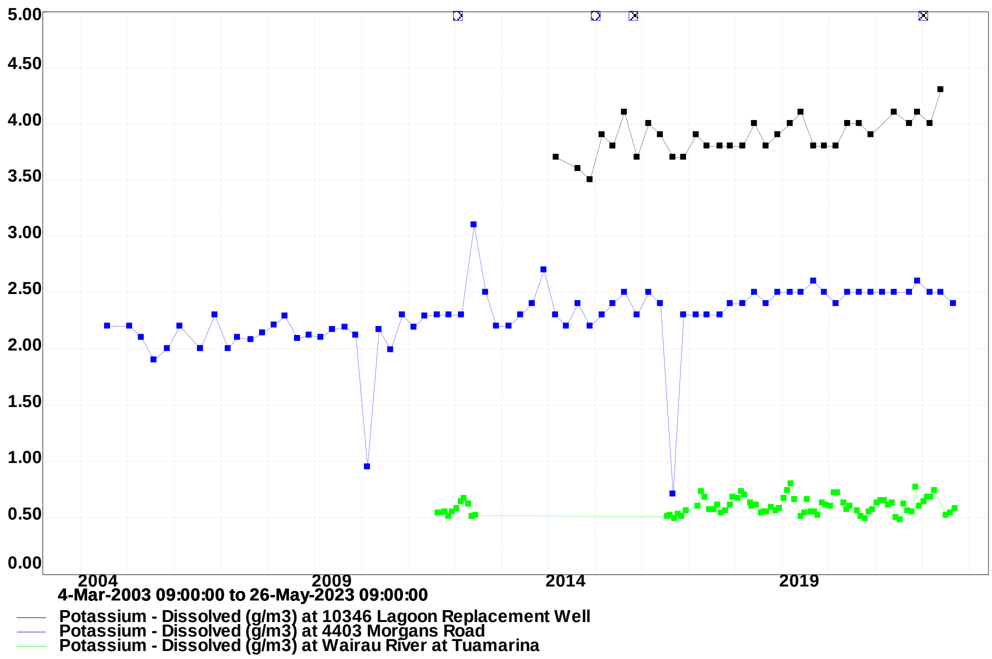



***Figure 66: Potassium concentrations of Wairau River at Tuamarina/State Highway 1 (green), Lagoon Replacement well (black) and Morgans Road well 4403 (blue) 1989-2020.***

At Bar well 1733 there is significant variability in potassium concentration with a decreasing trend through the late 1990's to about 2012, followed by an increasing trend and stable levels currently.

There was a similar pattern at Springlands well 3120 and Conders well 398 located north-west of Renwick representing Wairau River water (*Figure 67*). This suggests a regional influence.

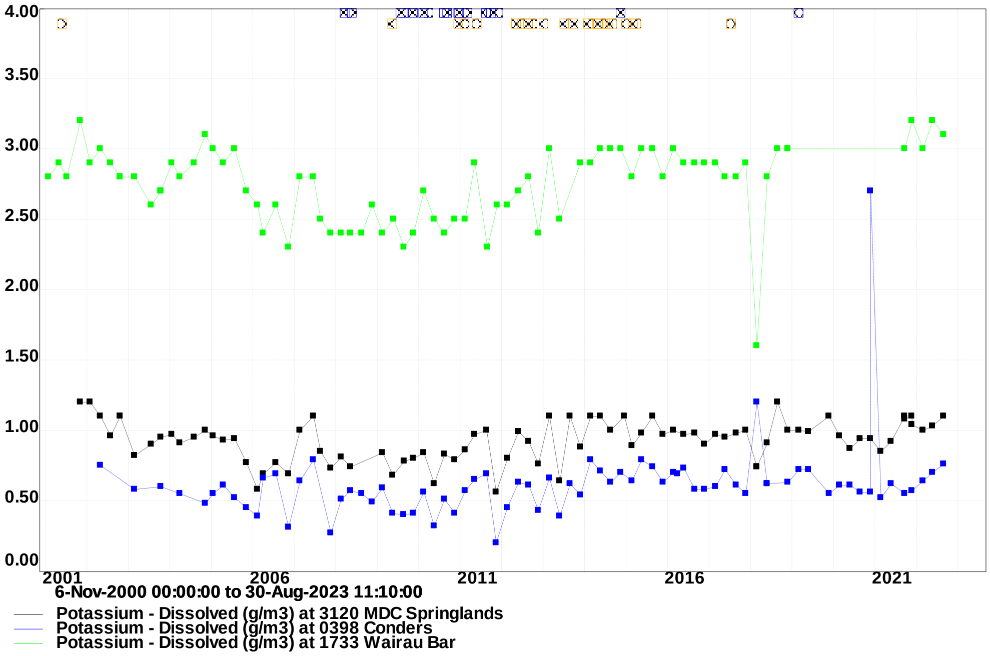



***Figure 67: Potassium concentrations at Bar well 1733 (green), Conders well 398 (blue) & Springlands well 3120 (black).***

## Calcium

Calcium can originate from artificial fertilisers and natural sources including shells/micro-fossils in the marine deposits common in this coastal area.

### Regional Pattern

The Wairau Plain pattern is slightly different to other parameters with little change in calcium concentrations from the recharge area north-west of Renwick to the coast or at Riverlands. There are higher levels in Southern Valleys groundwater at Rarangi and along the southern edge of the Wither Hills which could be a function of dilution (*Figure 68*).

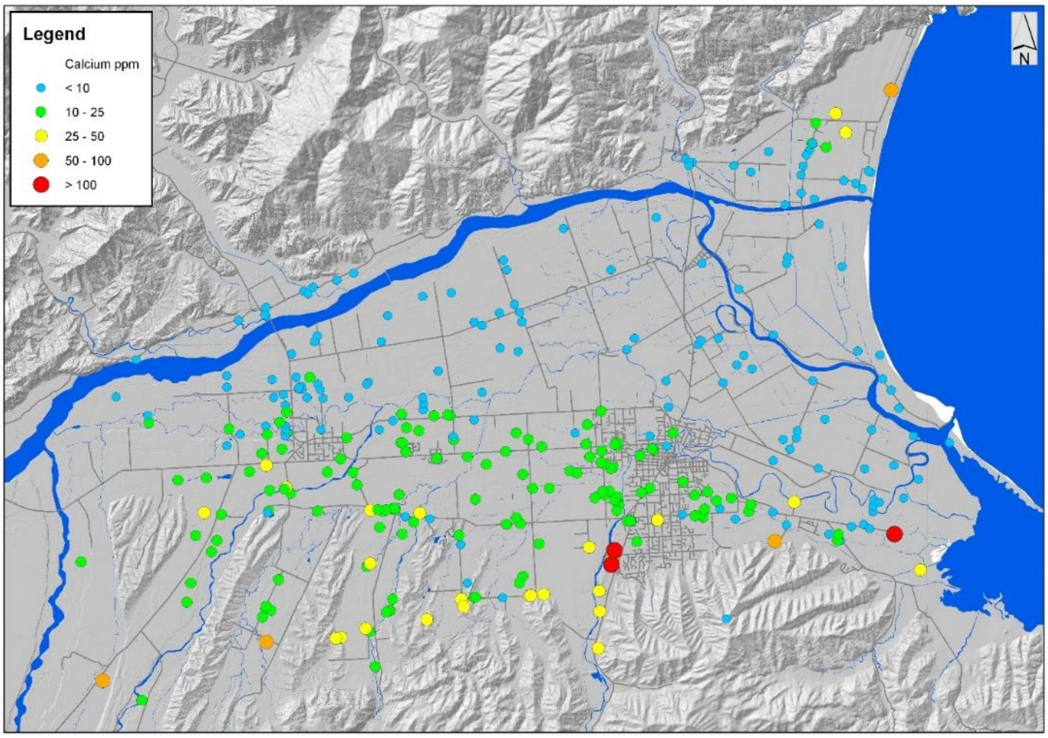



*Figure 68: Median calcium concentration (g/m3) Wairau Plain (Groundwaters of Marlborough 2011).*

## Local Values and Trends

At a local scale, median concentrations of calcium decrease with distance groundwater travels inside the confined aquifer, with lower levels at the most highly confined wells (Vernon well 765, Replacement Lagoon well 10346) (*Figure 69*). Calcium levels are relatively high at the Alabama Road well 4402 and low at the Bar well 1733.

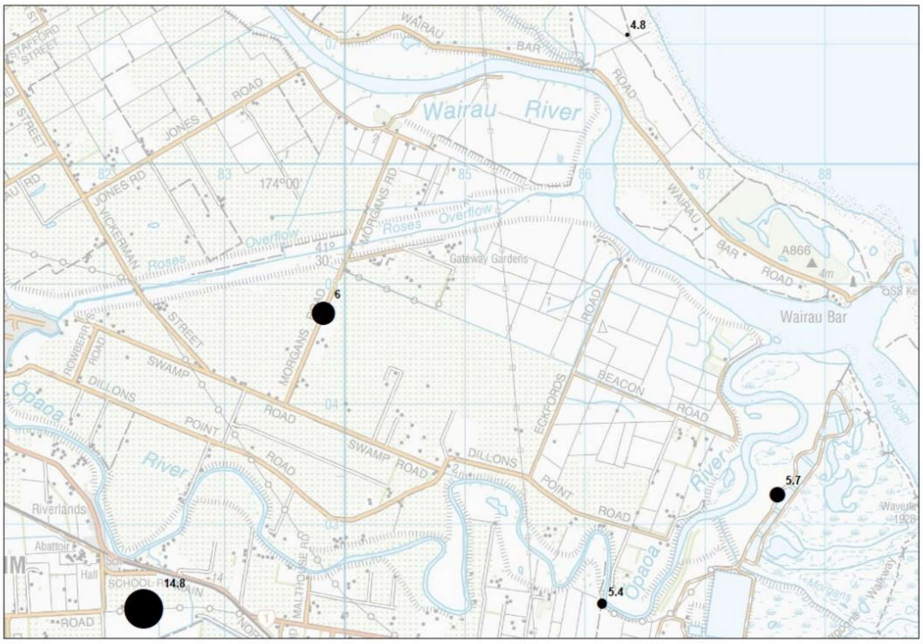



*Figure 69: Median calcium concentration (g/m3).*

The highest calcium levels occur at the Alabama Road well 4402, exceeding levels at the Springlands well 3120 representing upstream recharge (*Figure 70*). Calcium concentrations have been increasing with time at all sites since about 2000 including at Springlands well 3120.

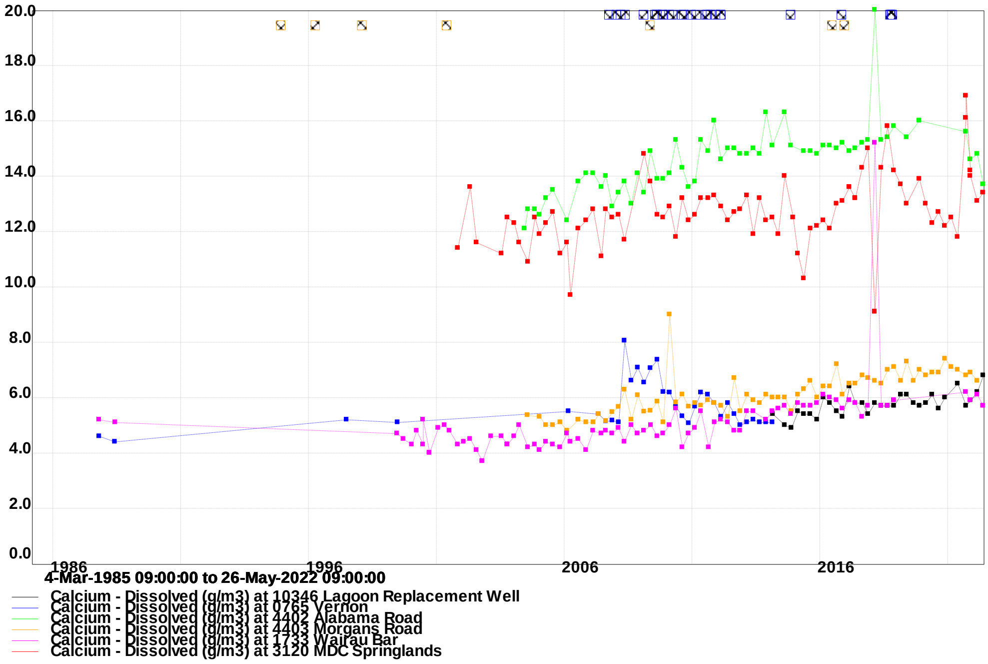



***Figure 70: Calcium concentration (g/m3) 1987-2022.***

## Causes of Variability

Declining calcium levels with increasing residence time in the confined aquifer is consistent with ion exchange between groundwater and clays forming the aquifer. The relatively high concentrations at the Alabama Road well suggest local inputs or less ion exchange (*Figure 70*).

Increasing calcium levels suggest more is available from natural or human activities, or ion exchange processes have reached a limit or are reversing. Levels of calcium in Wairau River water have not increased enough to explain the increase in calcium levels at Riverlands (*Figure 71*).

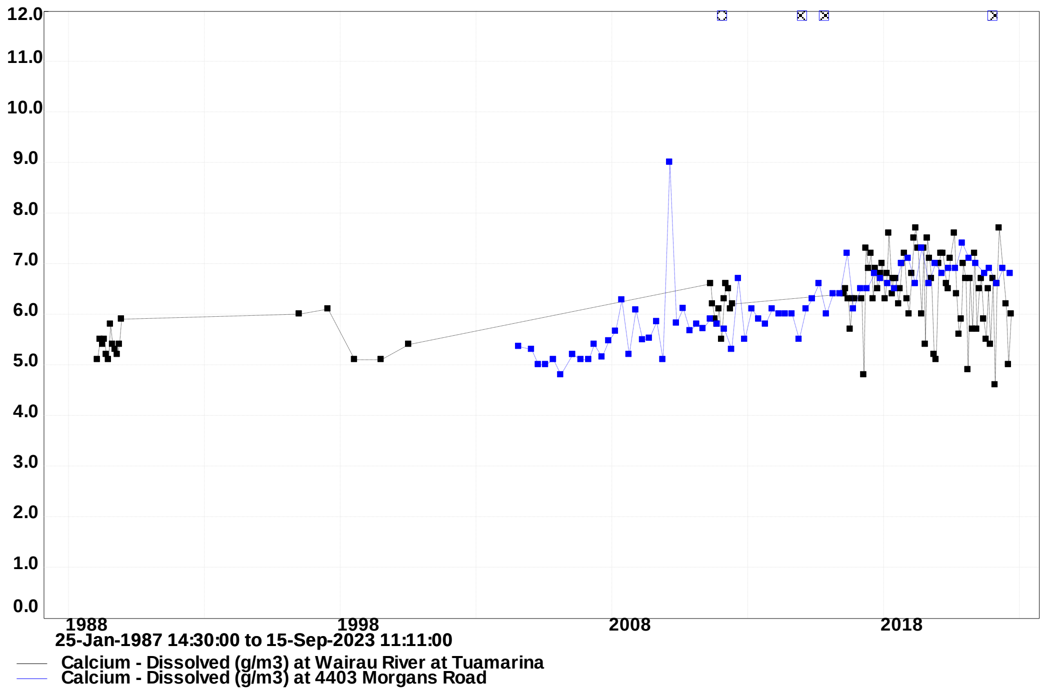



***Figure 71: Calcium concentration for Wairau River at Tuamarina/State Highway 1 (black) versus Morgans Road well 4403 (blue) 1989-2020.***

## Magnesium

Magnesium is a natural weathering product of clays forming local aquifers and an ingredient of agricultural fertilisers.

### Regional Patterns

A similar spatial pattern to calcium exists at a regional scale with little change in concentration except for higher values on the fringes of the Wairau Plain at Rarangi, Southern Valleys aquifers, Taylor River catchment and parts of the Cloudy Bay coastal area (*Figure 72*).

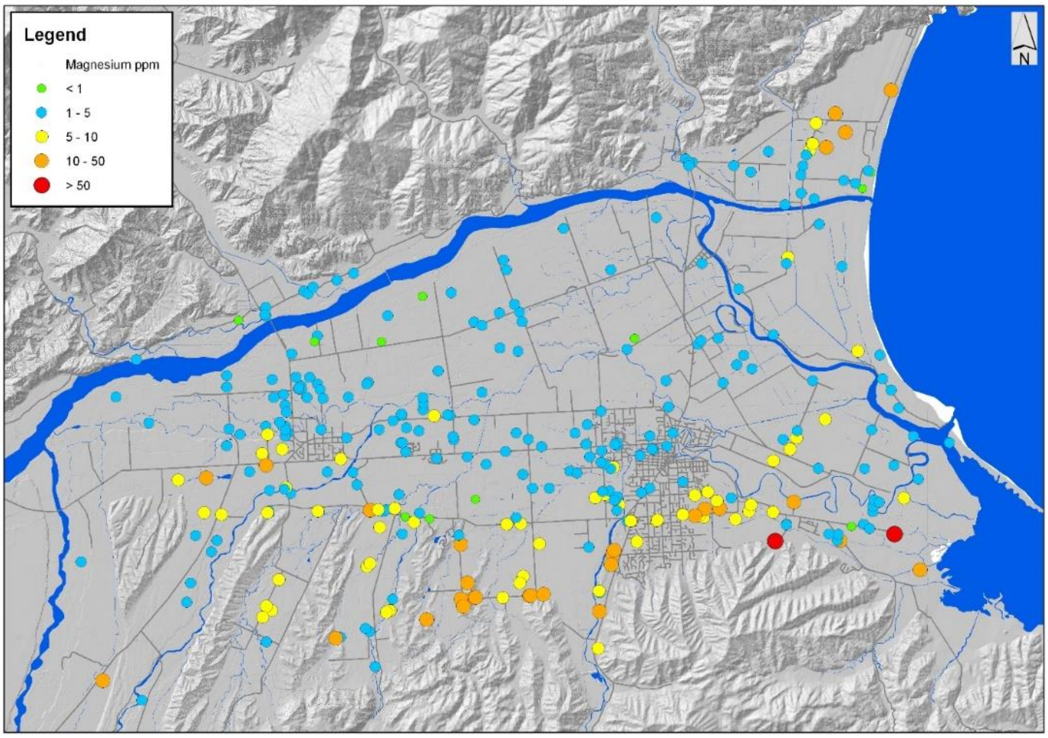



***Figure 72: Median magnesium concentration (g/m3) Wairau Plain (Groundwaters of Marlborough 2011).***

## Local Values and Trends

The local concentration pattern is more complicated than for other parameters. Magnesium concentrations are significantly higher at the Alabama Road well 4402 than all other sites including Springlands well 3120 representing upstream recharge water. Magnesium concentrations continue to increase within the confined aquifer downstream of Springlands well 3120, before declining near the coastal aquifer boundary due presumably to ion exchange processes (*Figure 73*).

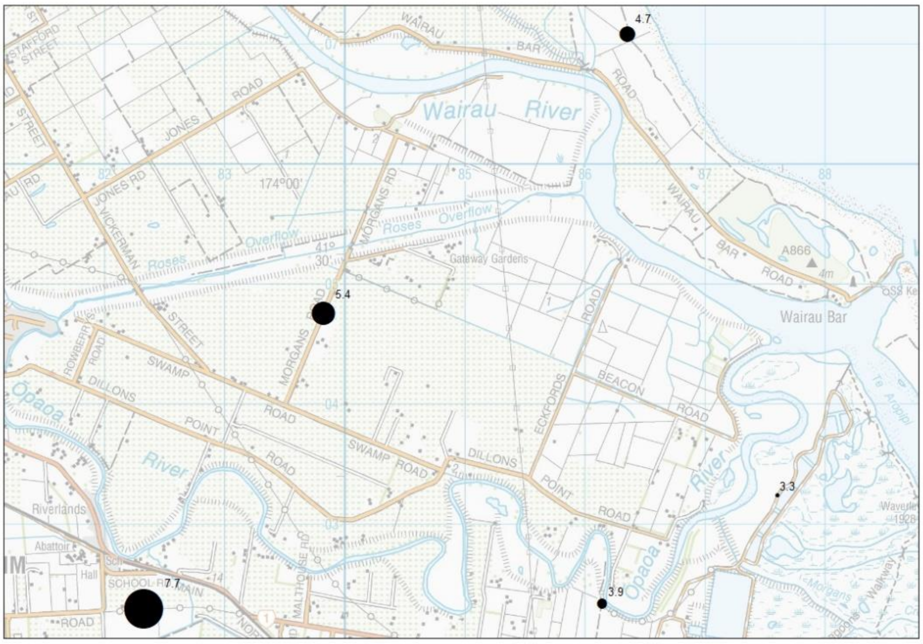



***Figure 73: Median magnesium concentration (g/m3) 1987-2020.***

Magnesium concentrations are increasing at all sites except for Alabama Road well 4402 where values have levelled out (*Figure 74*).

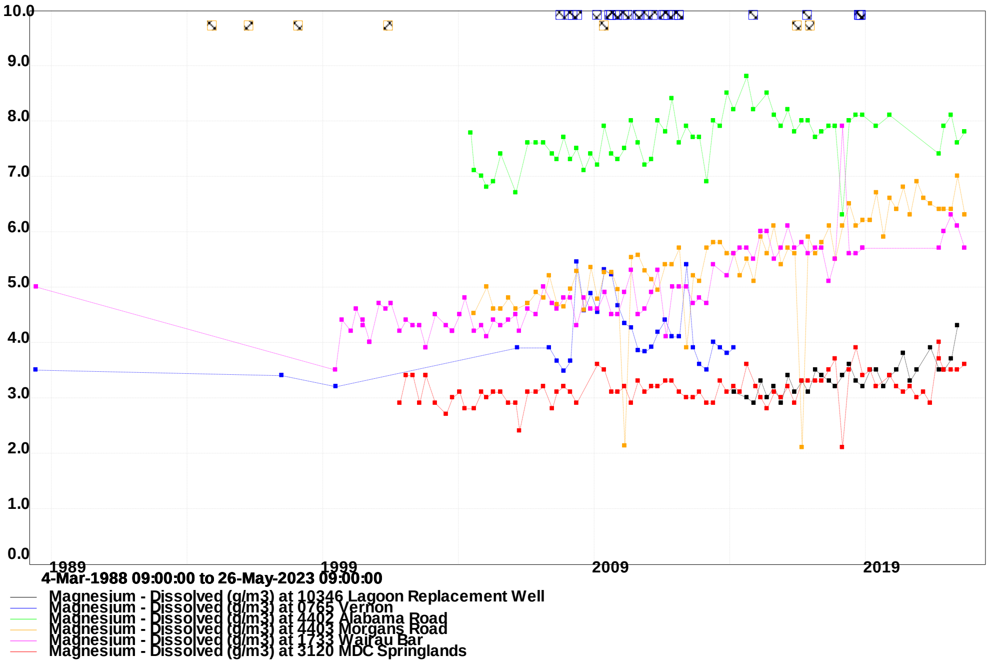



***Figure 74: Median magnesium concentration (g/m3) 1987-2022.***

## Causes of Variability

Magnesium appears to increase within the confined aquifer presumably due to natural water – rock interaction, before decreasing under advanced reducing conditions (*Figure 74*). Magnesium levels in very old groundwater from well 3278 tapping the Deep Wairau Aquifer are also low consistent with the pattern observed at Riverlands.

Magnesium concentrations at Bar well 1733 and Morgans Road well 4403 are increasing at a higher rate than changes in Wairau River concentrations can account for indicating higher localised inputs or from natural evolution processes.

Figure 75 shows concentrations of magnesium and sulphate in unconfined Wairau Aquifer groundwater at the MDC Wratts Road well 3009 follow the same seasonal pattern as nitrate-nitrogen with peaks during the wetter seasons. Significant amounts of nitrogen, magnesium and sulphate originate from land surface activities and are leached to groundwater. This is unlikely to be the case for the confined aquifers in the study area however.

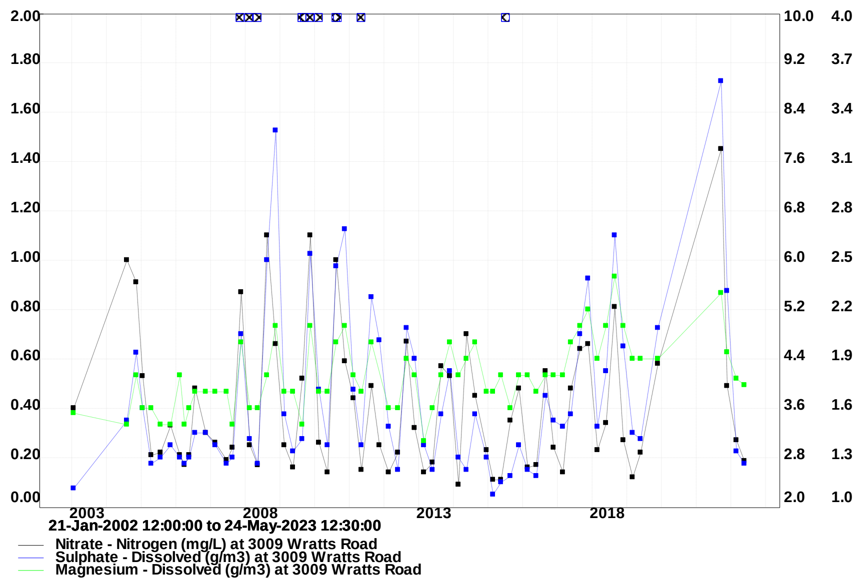



***Figure 75: nconfined Wairau Aquifer nitrate-nitrogen, sulphate & magnesium concentrations at MDC well 3009 at Wratts Road. Nitrate-nitrogen concentration on the left-hand vertical axis with sulphate and magnesium concentrations on the inner and outer left hand axis with sulphate and magnesium concentrations on the inner and outer left hand axes respectively.***

# Alkalinity

Alkalinity is a capacity measure of a groundwater to neutralise acids. Alkalinity is expressed as bicarbonate ($HCO_3$) in this MDC report. Alkalinity generally increases as groundwater becomes older and more evolved due to the by-products generated by the predominantly reduction reactions taking place in the confined Riverlands Aquifer. Alkalinity has a large influence on groundwater pH.

## Regional Patterns

At a regional scale alkalinity increases away from the Wairau River recharge source towards the Cloudy Bay coast and Southern Valleys Aquifers (*Figure 76*).

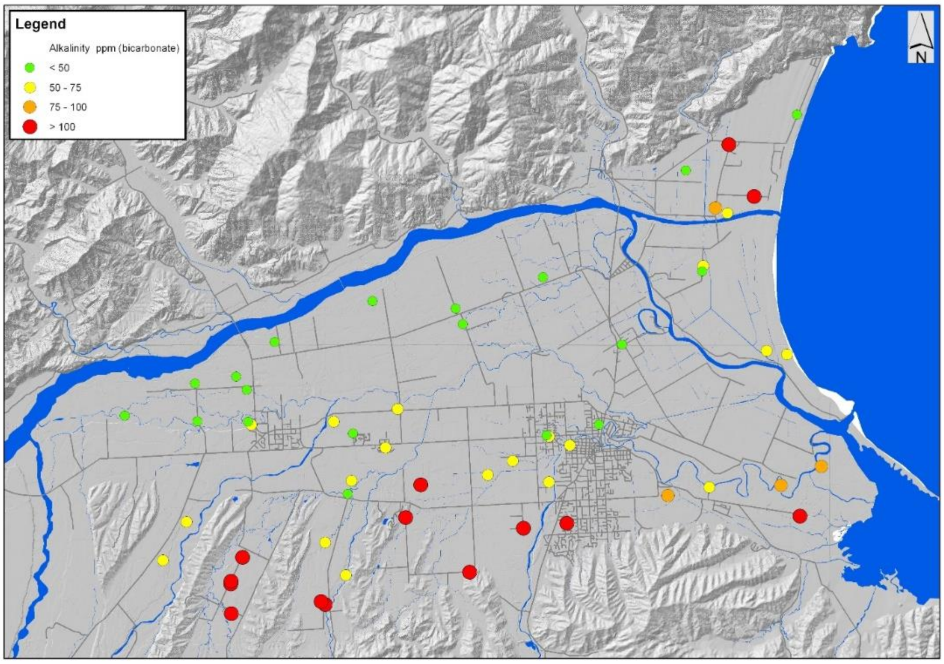


*Figure 76: Median alkalinity (g/m3) Wairau Plain excluding RSA (Groundwaters of Marlborough 2011).*

## Local Values and Trends

At a local Riverland scale alkalinity is highest on the edges of the aquifer where it is most highly confined, and lower in central areas near the Morgans Road well 4403 (*Figure 77*).

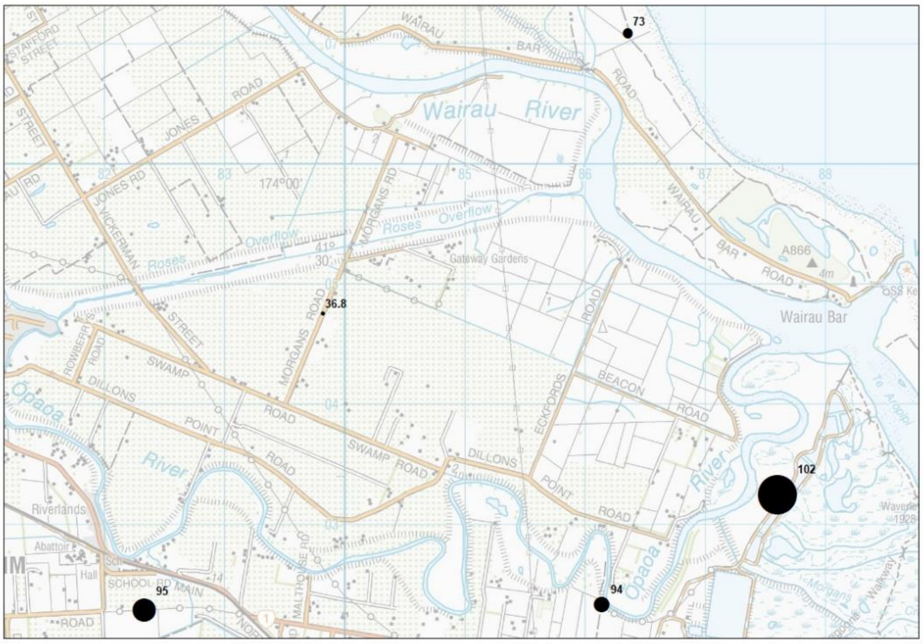



*Figure 77: Median alkalinity concentration as HCO3.*

The ranking of alkalinity by site largely matches that for electrical conductivity except for Bar well 1733 where values are relatively low for its pH (*Figure 78*). There is an increasing trend in alkalinity at all sites except for Springlands well 3120.

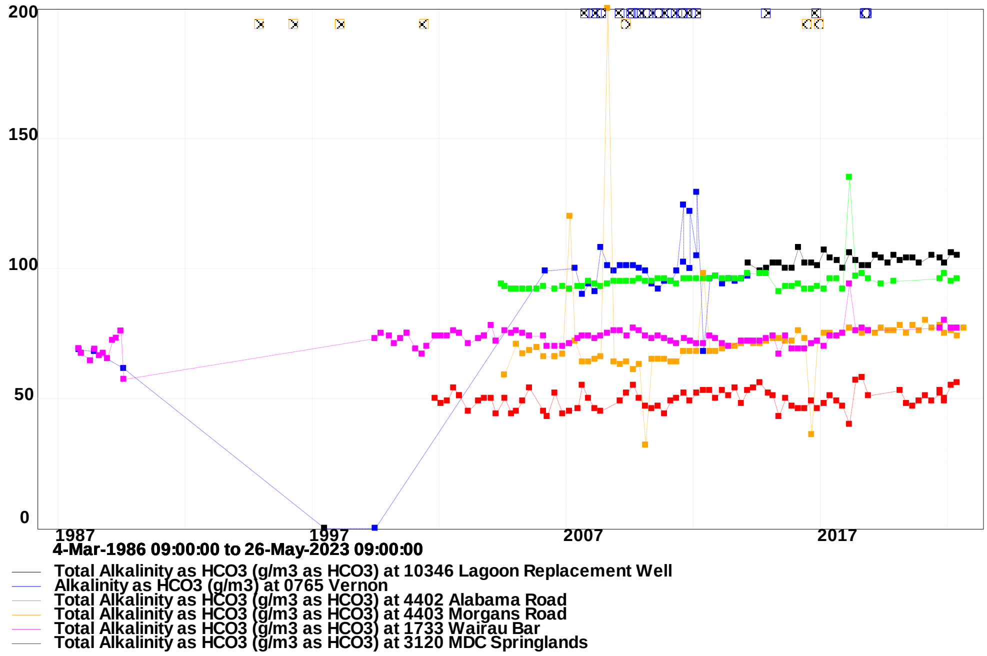


*Figure 78: Alkalinity concentration as HCO3 1987-2020.*

## Causes of Variability

The general alkalinity pattern is consistent with natural water – rock interaction being the dominant evolution process for the confined aquifers. The highest alkalinity levels correspond with the most mineralised groundwaters nearest the coast and Lagoons.

Alkalinity levels in Wairau River channel water at Tuamarina/State Highway 1 expressed as $CaCO_3$ are stable over time meaning local factors are responsible for the increasing pattern at the four wells in the study area (*Figure 79*).

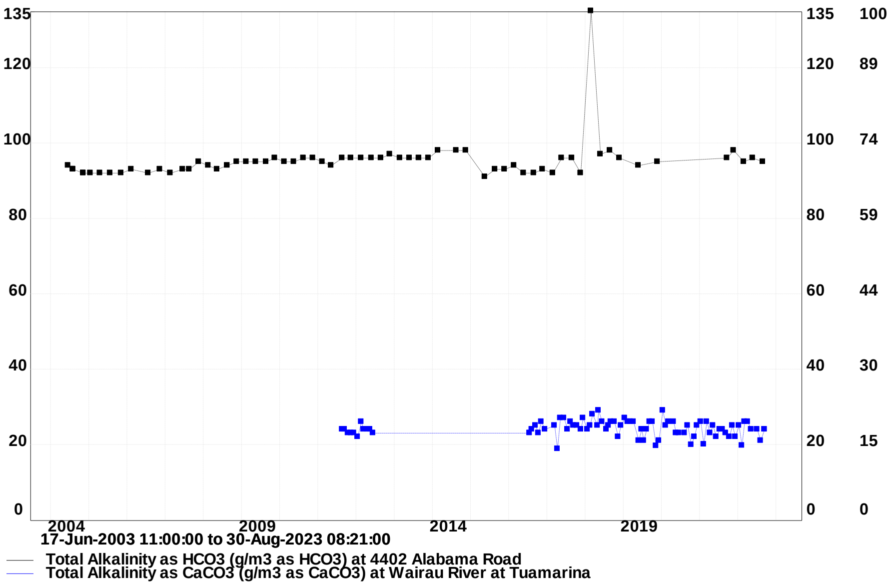



***Figure 79: Wairau River at Tuamarina alkalinity (CaCO3) (blue) versus Alabama Road well 4402 alkalinity (HCO3) (black) representing the increasing trend across all 4 sites in study area 1989-2022.***

# Iron

Iron comes from the weathering of minerals in local rocks and is widespread in some Marlborough aquifers. Iron is only soluble in groundwater under reducing aquifer conditions when oxygen levels are low and pH high. MDC field filter all groundwater samples collected as part of the SoE programme so only the dissolved iron component is measured and not iron from the well casing or adsorbed to particles. Iron does not have a Maximum Acceptable Value in the Water Services (Drinking Water Standards for New Zealand) Regulations 2022, but there is a Guidance Value (GV) of 0.32 g/m$^3$ (Taumata Arowai 2022) because of the nuisance value of oxidising iron causing staining of home white wear.

## Regional Pattern

Figure 80 shows that at a regional Wairau Plain scale there is more variability in median iron concentration than other parameters reflecting localised differences in pH and dissolved oxygen especially.

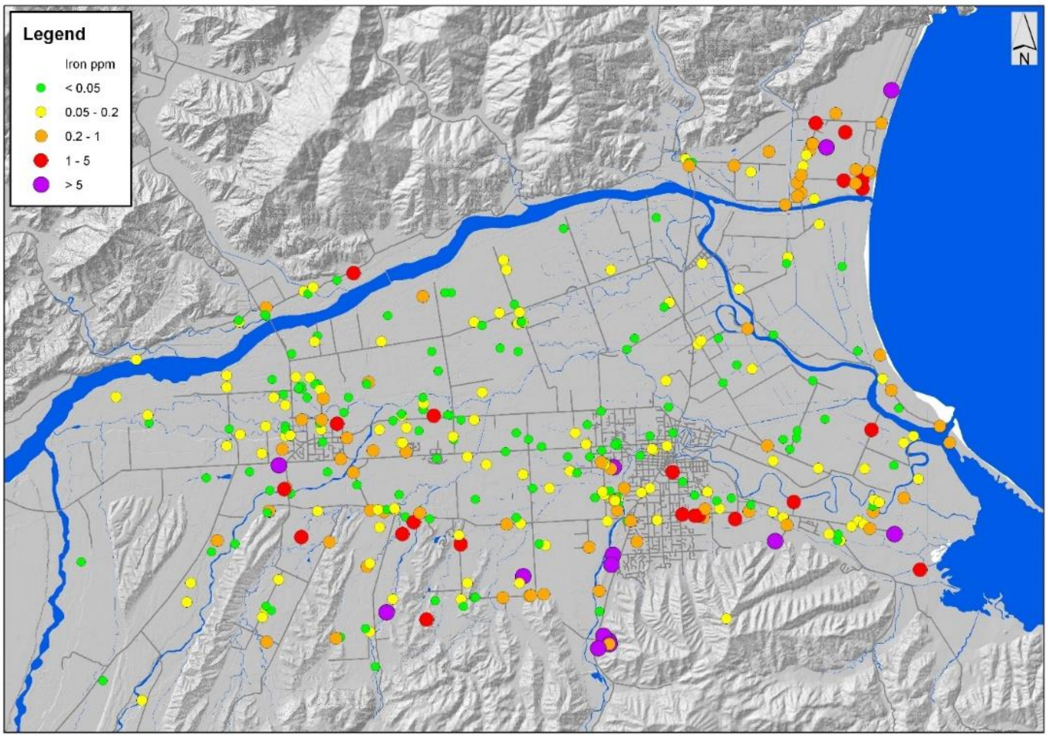



***Figure 80: Median iron concentration (g/m3) for Wairau Plain excluding RSA (Groundwaters of Marlborough 2011).***

## Local Values and Trends

The highest median iron concentration is at Bar well 1733 followed by Alabama Road well 4402 although neither of these sites exhibit the most advanced aquifer reducing conditions (*Figure 81*). Conversely Lagoon Replacement well 10346 iron concentrations are lower than expected given the evolved nature of the groundwater there. Iron levels are very low at the Morgans Road well 4403 and Springlands well 3120 (*Figure 82*).

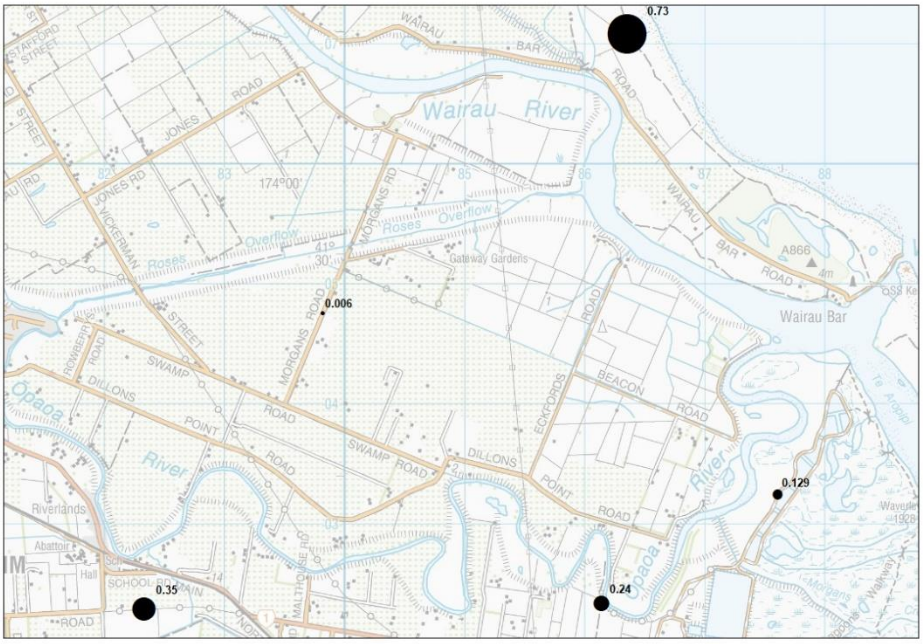



***Figure 81: Median iron concentration (g/m3).***

Iron levels are highly variable at the Bar well 1733, Vernon well 765 and Alabama Road well 4402, but there is no obvious seasonality to concentrations except for Alabama Road well 4402 (*Figure 82*).

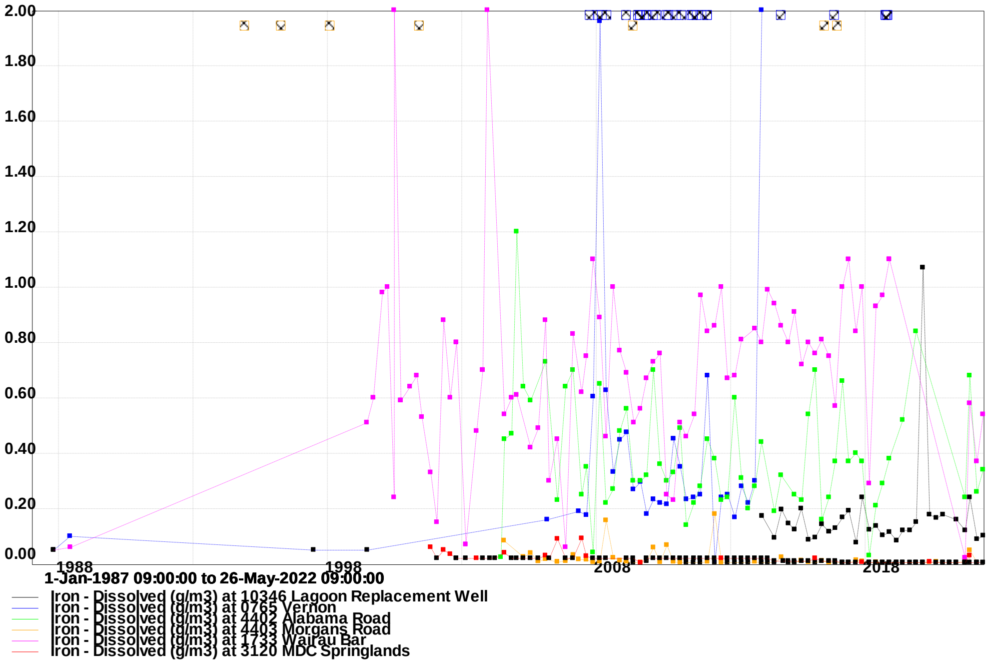



***Figure 82: Iron concentration (g/m3) 1987-2020.***

### Causes of Variability

Fluctuating iron levels at Vernon well 765 possibly reflect pumping inducing groundwaters of differing chemistry towards the well (*Figure 82*). The naturally low storativity makes natural groundwater flow patterns sensitive to abstraction.

Changes in iron content in groundwater at Bar well 1733 are more likely related to naturally induced changes in groundwater flow given the higher aquifer transmissivity beneath the central Wairau and fewer pumping influences (*Figure 82*). These potential natural influences include Wairau or Ōpaoa River floods. In both cases the arrival of groundwaters of different pH or oxygen would explain the variability in iron solubility. Its fair to say that local variations in geochemical conditions have a large influence on the variations in iron concentration.

## Manganese

Manganese comes from the natural weathering of minerals contained in local bedrock. However, it is only soluble in groundwater under the reducing conditions found in confined aquifers, which predominate at Riverlands. Manganese in drinking water at concentrations above 0.4 g/m$^3$ is harmful to human health and causes adverse aesthetic effects above 0.1 g/m$^3$ (taste threshold) and 0.04 g/m$^3$ (threshold for staining of laundry) (Taumata Arowai 2022).

### Regional Pattern

At a regional Wairau Plain scale, manganese concentrations are highest at the edges of the main aquifers or groundwater flows coinciding with the oldest, most evolved groundwater (*Figure 83*).

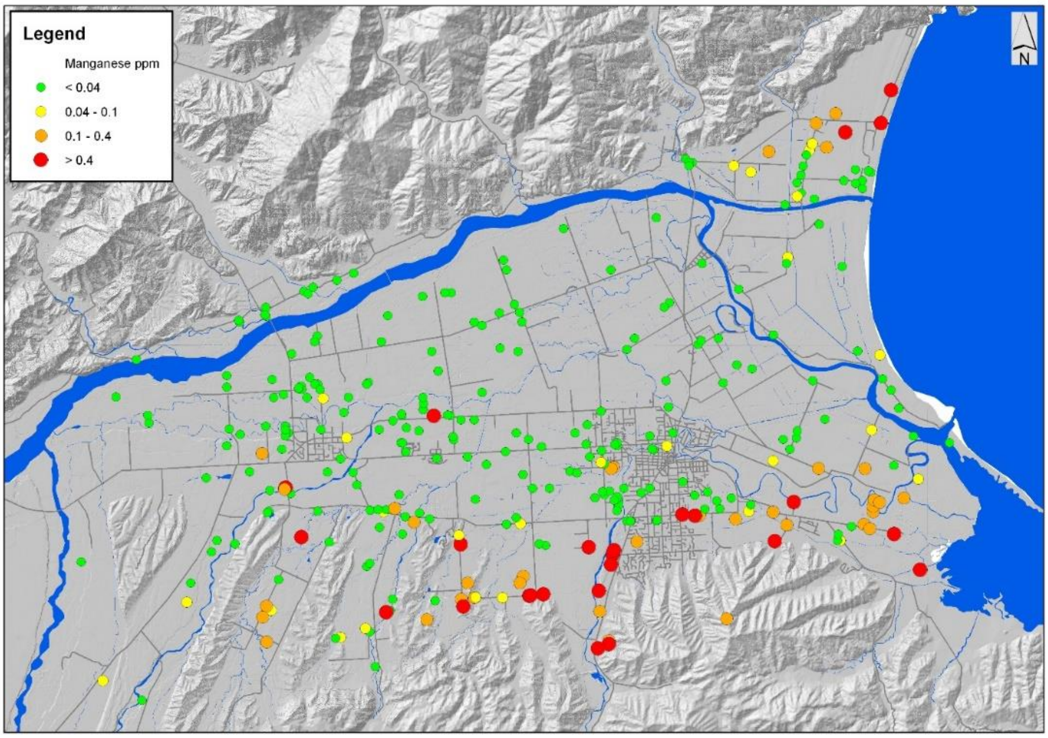



***Figure 83: Median manganese concentration (g/m3) for Wairau Plain excluding RSA (Groundwaters of Marlborough 2011).***

## Local Values and Trends

*Figure 84* shows that median manganese levels are low in groundwater at the Morgan's Road well 4403 but have increased by an order of magnitude by the time groundwater gets to the Bar well 1733, Alabama Road well 4402 and Lagoon Replacement wells through natural water-rock interaction processes. Concentrations have increased by two orders by the time groundwater arrives at the Vernon well 765.

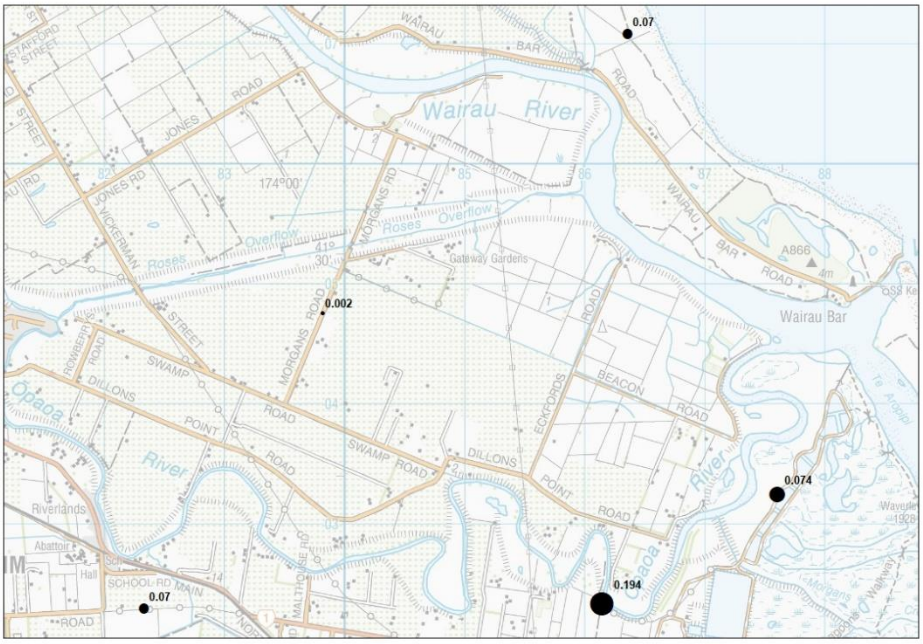


***Figure 84: Median manganese concentration (g/m3).***

Manganese levels have been increasing at the Bar well 1733 and Alabama Road well 4402 since the late 1990s and there appears to be a similar pattern developing at the Lagoon Replacement well 10346 (*Figure 85*).

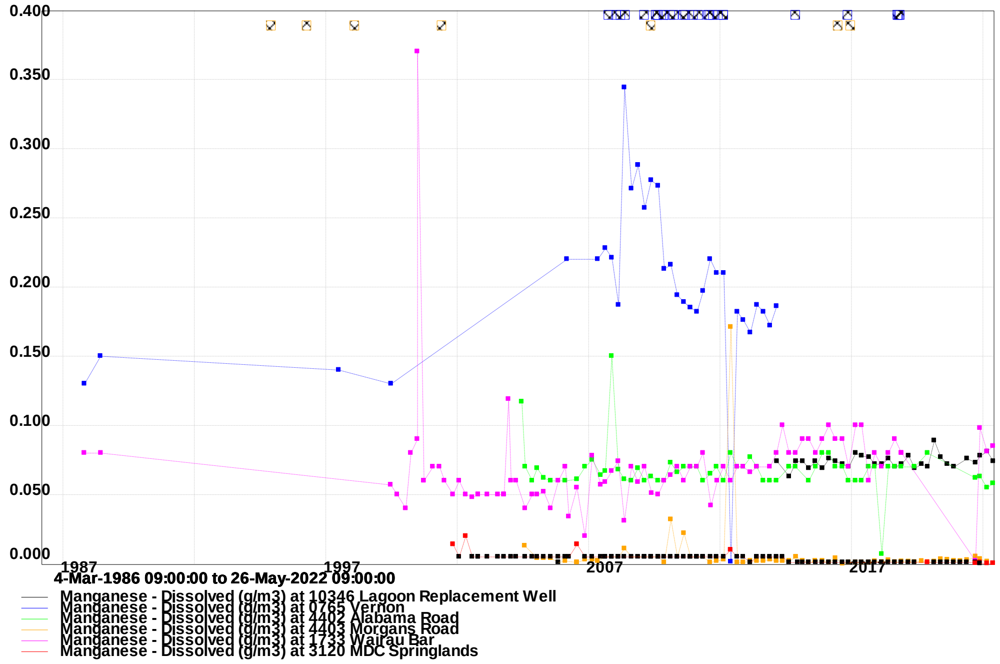



***Figure 85: Manganese concentration 1987-2020.***

## Causes of Variability

Manganese concentrations do not exceed the Maximum Acceptable Value of 0.4 parts per million in the Water Services (Drinking Water Standards for New Zealand) Regulations 2022 but were of the same order at the Vernon well 765 before MDC SoE measurements were discontinued there.

Increasing concentrations of manganese at Alabama Road well 4402, Bar well 1733 and probably Lagoon Replacement well 10346, imply aquifer conditions are becoming more reduced at these sites increasing manganese solubility.

# Arsenic

Like manganese and iron, arsenic is a naturally occurring component of groundwater originating from the weathering of minerals like arsenopyrite in local bedrock or derived alluvial sediments.  Arsenic only becomes soluble in Marlborough groundwaters under reduced aquifer conditions as for iron and manganese.

## Regional Pattern

Groundwater arsenic levels are very low and in most cases at the detection limit of 0.001 g/m$^3$ for most of the central and northern Wairau Plain (*Figure 86*).  Levels are elevated at fifty percent of the maximum acceptable value (MAV) at depth in isolated parts of the Southern Valleys, Taylor River area and coastal confined aquifers due to reduced conditions.

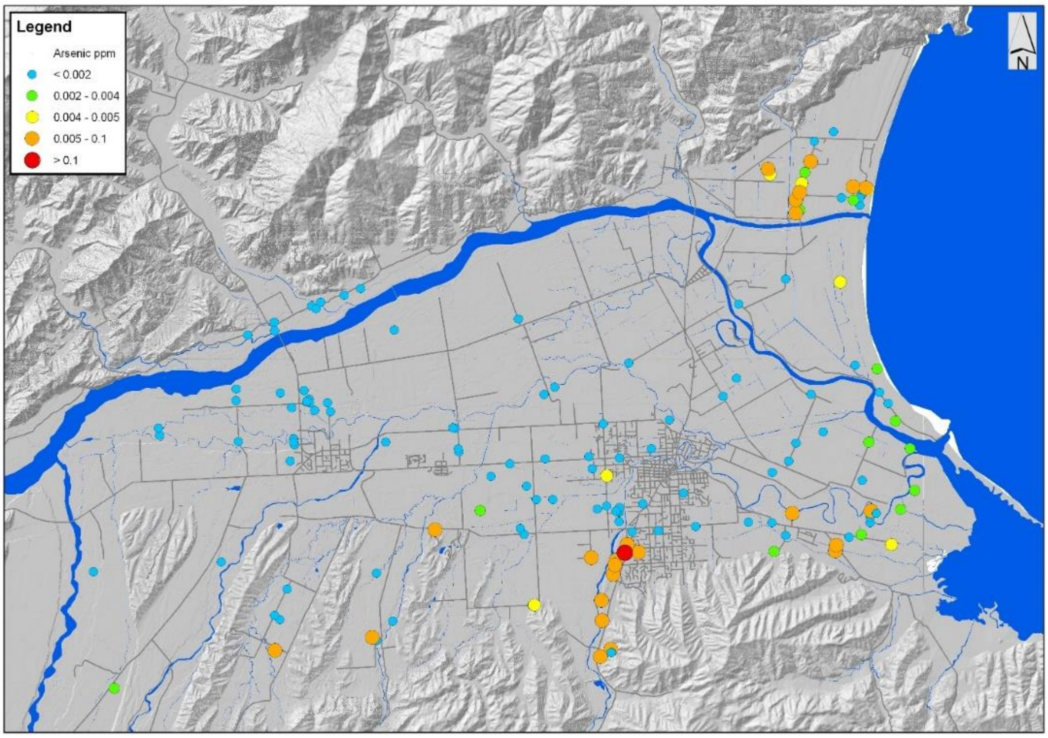



***Figure 86: Median arsenic concentration (g/m3) for Wairau Plain excluding RSA (Groundwaters of Marlborough 2011).***

## Local Values and Trends

The highest median arsenic concentration representing fifty percent of the MAV (0.01 g/m$^3$) occurs at the lagoon Replacement well 10346 located near the south-eastern edge of the Riverlands Aquifer, with very low levels at all other sites (*Figure 87*).

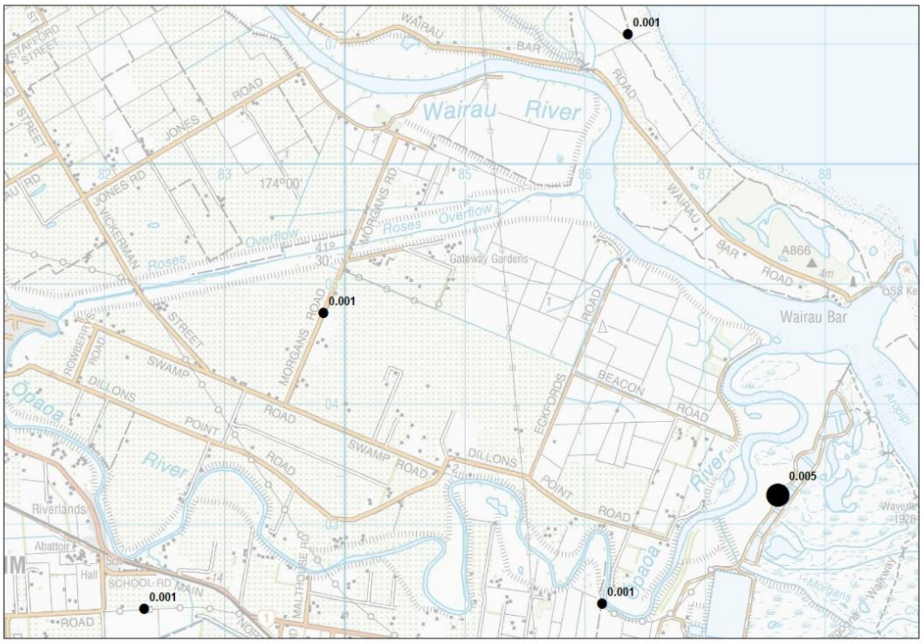



***Figure 87: Median arsenic concentration (g/m3)***

Concentrations at the Lagoon Replacement well 10346 are consistently elevated relative to the MAV (*Figure 88*). Levels at all other sites are consistently equal to the laboratory detection limit.

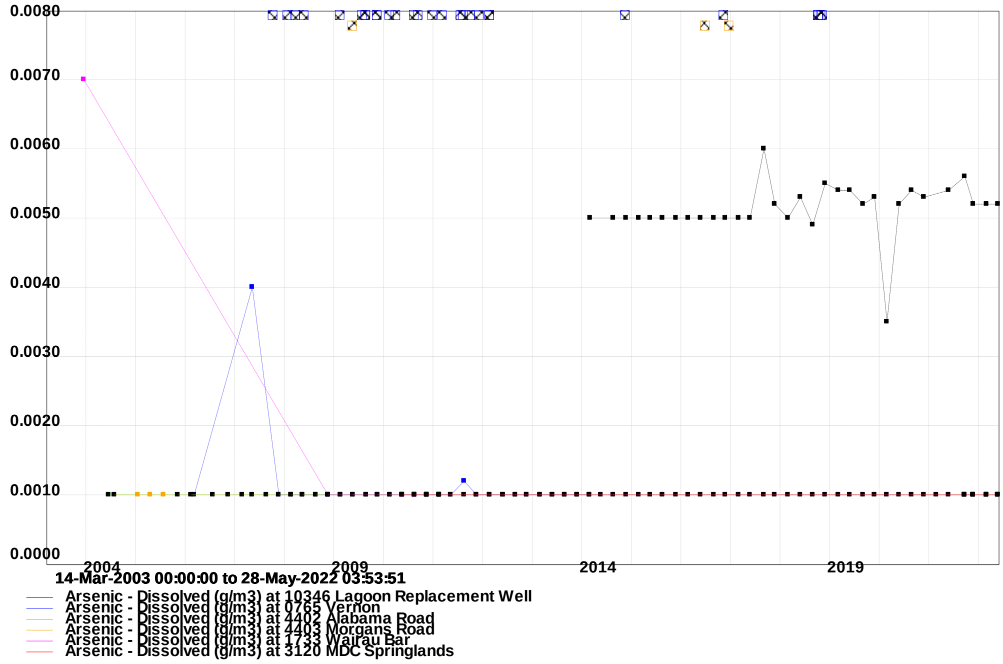



***Figure 88: Arsenic concentration 1987-2020.***

### Causes of Variability

The pattern of arsenic concentration across the study area is consistent with natural water – rock interaction processes. Groundwater evolution takes place over moderately long time periods of the order of hundreds of years based on the tritium derived residence times.

There is more of a variation from 2017 onwards which could be related to the Kaikōura earthquake (*Figure 88*). A lack of variability at most sites implies the redox potential of the groundwater in this area is relatively stable except for Lagoon Replacement well 10346.

## Silica

Silica is relatively inert making it a useful indicator of groundwater residence time. The higher the concentration of dissolved silica, generally the longer groundwater has been in contact with the aquifer forming sediments/rocks and the longer the residence time underground.

There appears to be a saturation-based limit on how much silica can be dissolved in local groundwaters as concentrations from the Deep Wairau Aquifer are not the highest in the province despite the residence times being some of the highest in New Zealand (recharged around 19,000 years before present).

### Regional Pattern

Silica concentrations are higher in groundwaters on the edges of the Wairau Plain coinciding with areas of more sluggish underground flow and longer residence time, combined with higher rates of natural mineralisation.

### Local Values and Trends

Figure 89 shows the pattern of median silica concentration with highest levels in the south-east and lowest in the north and east. Groundwaters at the Vernon and Lagoon Replacement wells have the highest silica concentrations, implying they are likely to have the longest residence times.

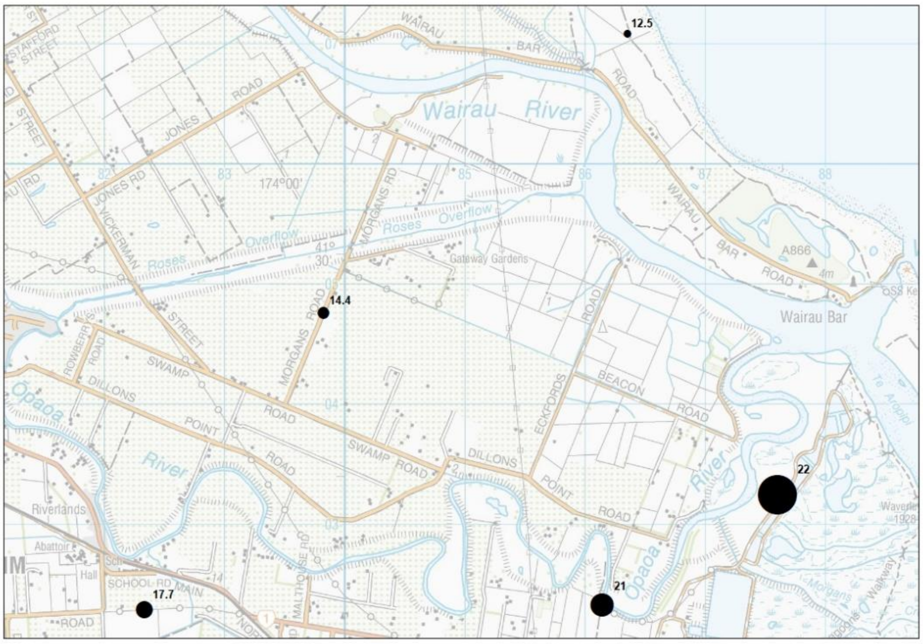



*Figure 89: Median silica concentration (g/m3).*

Morgans Road and Bar well groundwaters are likely to be the youngest, with the Alabama Road well 4402 waters having an intermediate age. This silica-based ranking is consistent with electrical conductivity but not pH, suggesting more complicated processes exist.

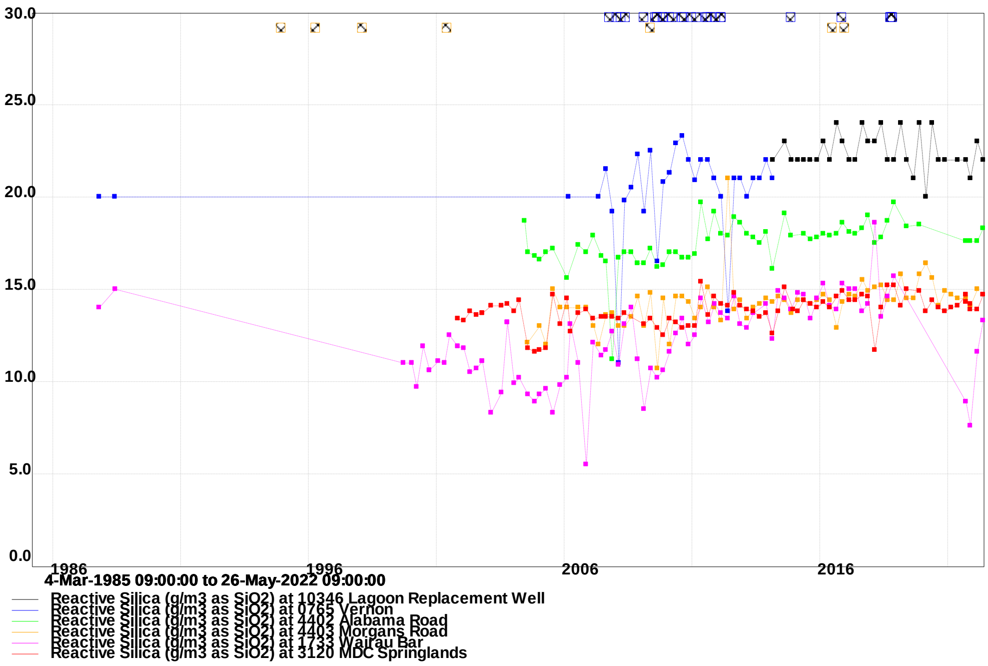



*Figure 90: Silica concentration 1987-2022.*

There is a slight increasing trend in silica at all wells in the study area except for the Lagoon Replacement well which is steady (*Figure 90*). Silica levels at the MDC Bar well 1733 declined between late 1999 and 2005 before rising, followed by low levels in late 2022 possibly related to the Wairau River floods. Silica concentrations at Bar well 1733 prior to 2011 were lower than for Springlands well 3120, reflecting either a significant variation in silica, higher groundwater throughflow or changes in local flow patterns. There is no apparent seasonality to the variations in silica except for the Lagoon Replacement well (*Figure 90*).

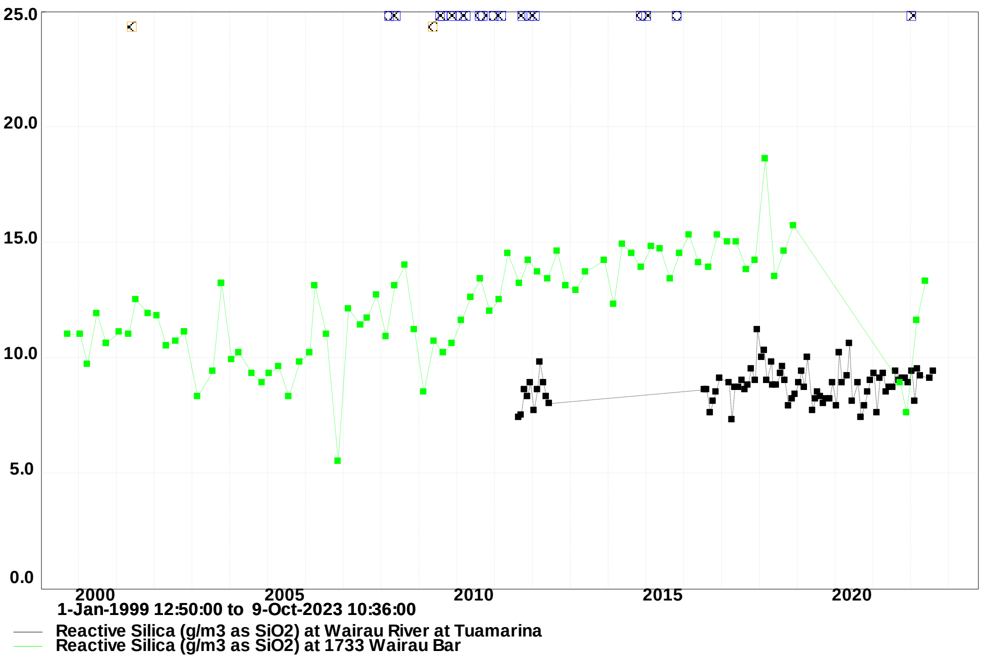



***Figure 91: Silica concentration 1999-2022 for Wairau River at Tuamarina & Bar well 1733.***

## Causes of Variability

The highest silica concentrations occur on the margins of the aquifer where groundwater flow rates are lowest and contact time with the aquifer forming rocks is greatest. The significant decrease in silica levels at Bar well 1733 in late 2021 is likely related directly or indirectly to the significant storm events in July 2021 and July/August 2022, which bought heavy rain and flooding to the Wairau. While there is also an increase in silica concentration of Wairau River water between 2011 and 2022, it may not be sufficient to explain the rate of increase of silica in groundwater within the study area (*Figure 91*).

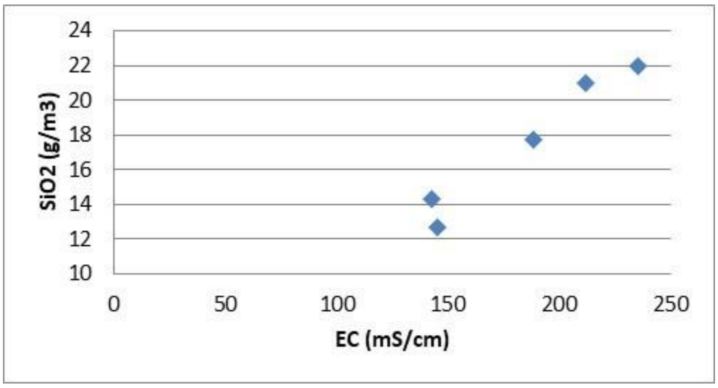



***Figure 92: Median silica concentration versus median electrical conductivity.***

There is a strong positive correlation between median silica concentration and median electrical conductivity representing all dissolved salts in local groundwaters (*Figure 92*). The well corresponding with each data point can be identified by the values in Figure 89. This relationship shows silica is a good measure of water evolution rates and residence time for the study area.

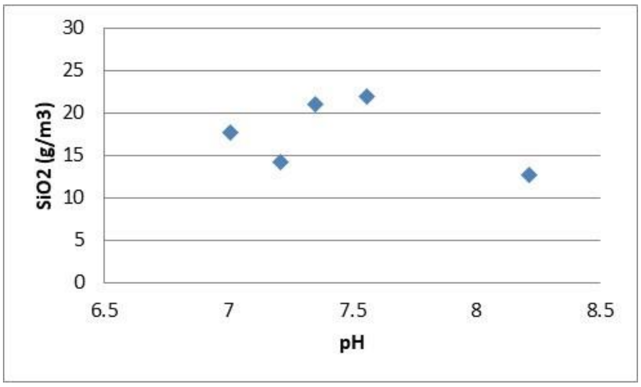



***Figure 93: Median silica concentration versus median pH.***

Median silica concentration increases with median pH, except at the Bar well 1733 (*Figure 93*). The well corresponding with each data point can be identified by the values in Figure 89. The explanation for the poor relationship might be Bar well groundwater is younger as it is moving faster through the more transmissive gravels beneath the central Cloudy Bay area.

# Boron

Boron is a minor constituent of groundwater mostly derived from natural sources like borosilicate minerals. Locally it is often associated with greywacke bedrock for some reason. Boron is an indicator of geothermal conditions and is higher in Wairau Valley groundwater due to the influence of Wairau Fault fluids.

## Regional Pattern

At a regional scale, boron concentrations are less than 0.1 g/m$^3$ across most of the Wairau Plain except in the Southern Valleys and less transmissive aquifer areas like Rarangi and Riverlands (*Figure 94*). The highest concentrations are associated with leachate from MDC landfills in the Taylor River area.

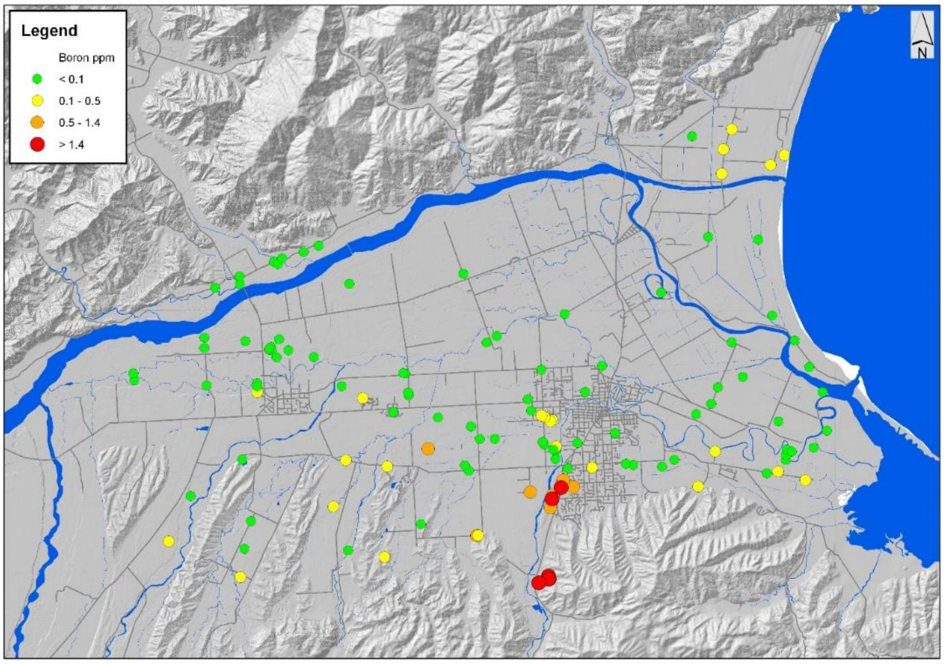



***Figure 94: Median boron concentration (g/m3) for Wairau Plain excluding RSA (Groundwaters of Marlborough 2011).***

## Local Values and Trends

Median concentrations are highest in groundwater from the Lagoon replacement well 10346 and Vernon well 765 (*Figure 95*). Boron is not regularly measured at the Bar well 1733, Springlands well 3120 or the Alabama Road well 4402 as these are NGMP (GNS Science) survey sites.

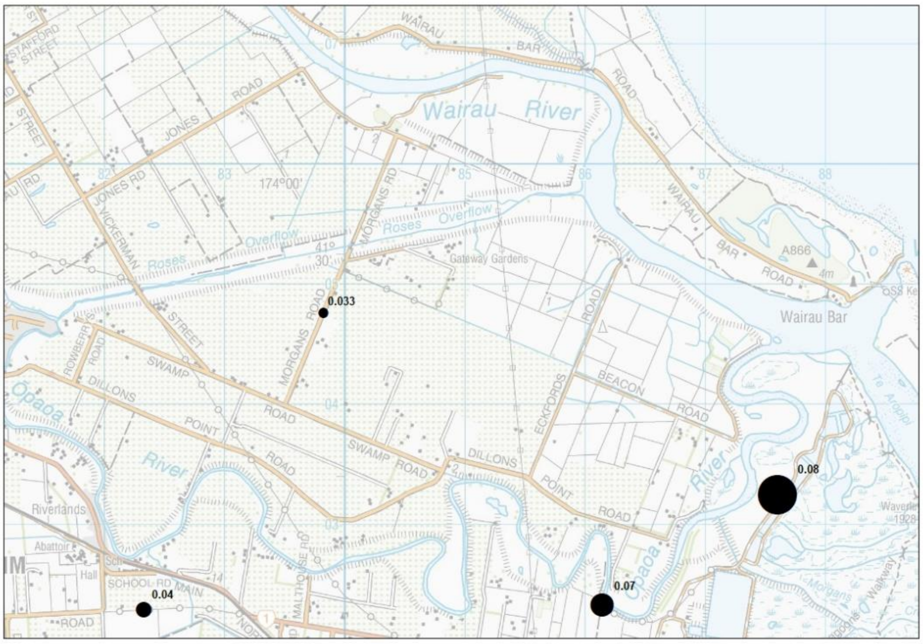



***Figure 95: Median boron concentration (g/m3).***

It is uncertain if boron concentrations are changing over time with the limited record available, but values at most sites appear stable or increasing slightly (*Figure 96*). The concentration at Vernon well 765 decreased between 1987 and the end of record in 2015. Concentrations are an order of magnitude below the MAV of 2.4 g/m³ in the Water Services (Drinking Water Standards for New Zealand) Regulations 2022. Boron is not routinely measured in Wairau River water so changes in concentration of aquifer recharge water are not known.

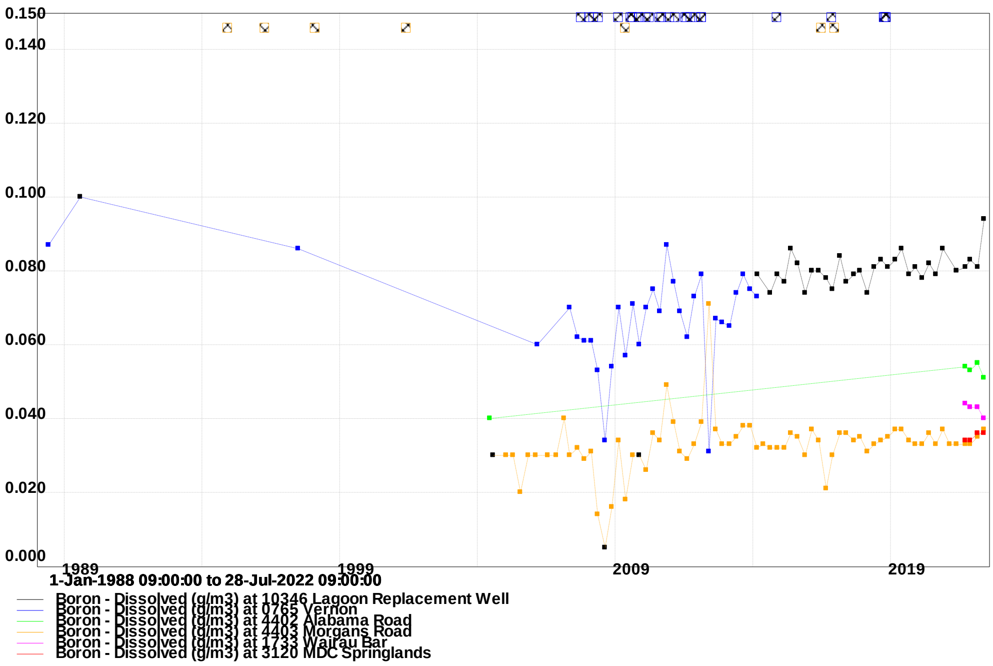


***Figure 96: Boron concentration (g/m3) 1987-2022.***

### Causes of Variability

The pattern of increasing boron concentration towards the coastal and Lagoon margins is consistent with longer water - rock interaction and natural evolution processes.

## Fluoride

Fluoride is a minor component of groundwater originating from mineral sources in rocks with a small proportion coming from seawater.

### Local Values and Trends

Fluoride concentrations are an order of magnitude higher at wells along the southern and eastern edges of the study area closest to the Lagoons compared to the Morgans Road and Bar wells (*Figure 97*).

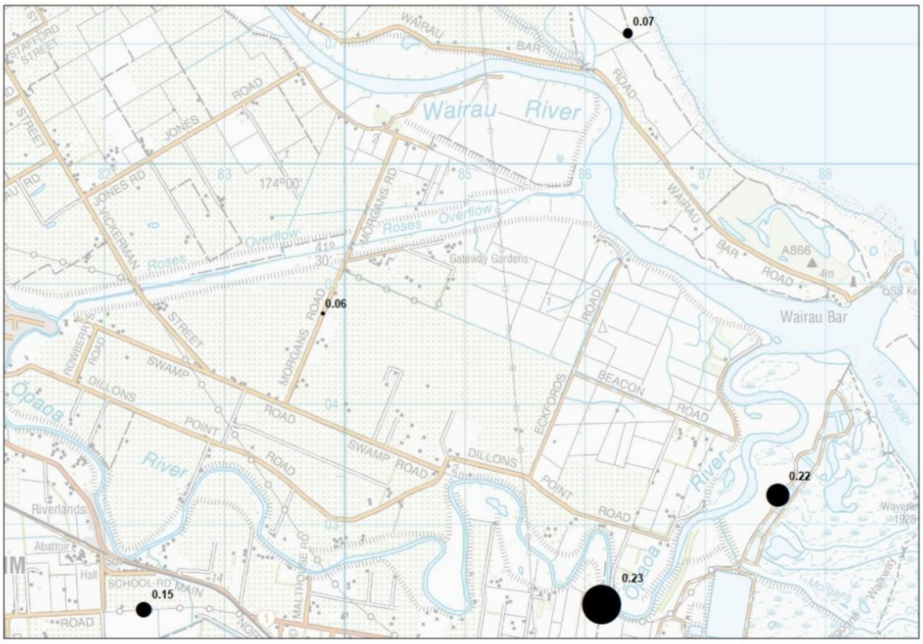



***Figure 97: Median fluoride concentration (g/m3).***

Concentrations are low compared to the MAV of 1.5 g/m$^3$ in the Water Services (Drinking Water Standards for New Zealand) Regulations 2022, and relatively stable at all sites (*Figure 98*).

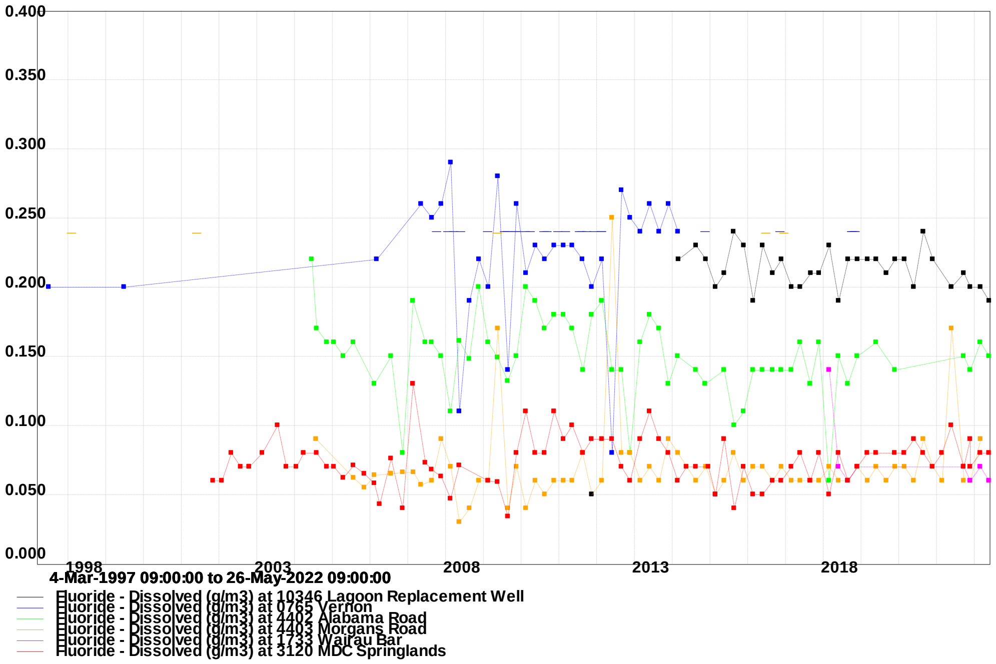



***Figure 98: Fluoride concentration (g/m3) 1998-2022.***

## Causes of Variability

The dominant process influencing fluoride levels appears to be natural groundwater evolution based on higher levels being associated with the most evolved and oldest groundwaters. Background fluoride concentrations at the upstream Springlands well 3120 representing recharge water, are similar to levels at Morgans Road well 4403 (*Figure 98*). This shows limited evolution of groundwater along the flow-path from Blenheim to Morgans Road with more rapid changes by the time water arrives at Alabama Road well 4402. MDC do not measure the concentration of fluoride in Wairau River water, so the influence of this recharge source is uncertain.

A potential sink for fluoride is ion exchange with clays forming the aquifer structure at moderate to low pH, however this process does not appear to be influencing groundwater at Riverlands as concentrations are increasing with greater residence time based on the known relationship with silica.

# Sulphate

Sulphate can originate from many sources both natural and anthropogenic. It is an ingredient in artificial fertilisers, a natural oxidation product of sulphide minerals like pyrite while elemental sulphur is widely used in Marlborough vineyards as a fungicide. Sulphate is the oxidised form of sulphur. Because it is sensitive to the pH and oxygen content of water, it changes form depending on local conditions making it a good indicator of aquifer redox state.

## Regional Pattern

Figure 99 shows sulphate levels are normally less than 5 g/m$^3$ in groundwater in the more transmissive, northern parts of the Wairau. Levels increase rapidly outside of the most transmissive northern aquifer area, with moderate to high sulphate concentrations measured in groundwaters across the Southern Valleys Catchments, with a large range of values at Rarangi.

In the more confined aquifer areas beneath Rarangi and Riverlands, sulphate concentrations decline due to natural reduction processes. Some aspects of this regional pattern are not fully understood, in particular why there is not more sulphate reduction occurring within the deeper strata of the Southern Valleys Aquifers.

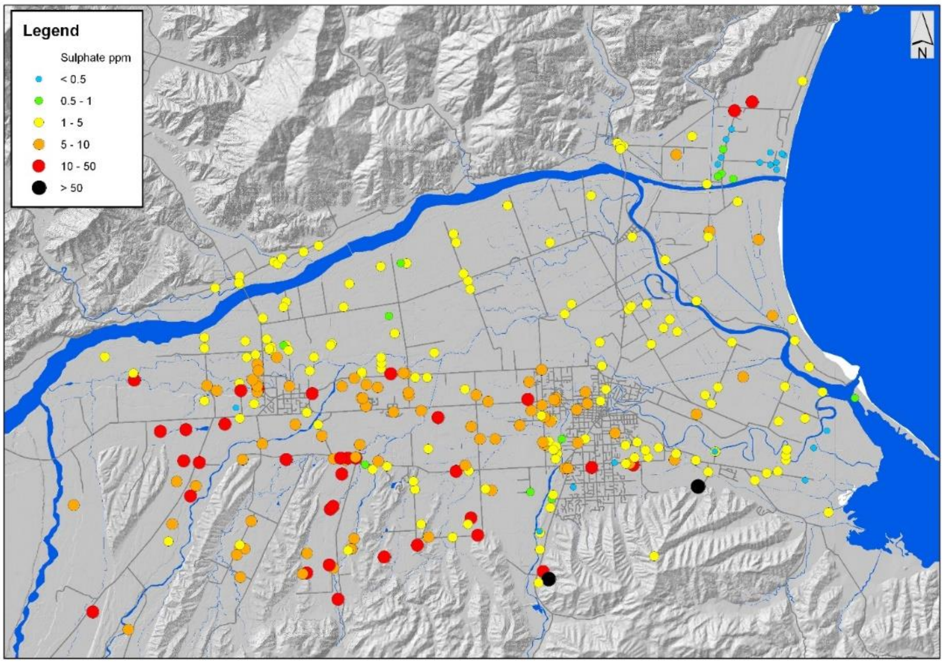



*Figure 99: Median sulphate concentration (g/m3) for Wairau Plain excluding RSA (Groundwaters of Marlborough 2011).*

## Local Values and Trends

Median sulphate concentration is highest in the north or west, and lowest near the Lagoons/Hardings Road consistent with the distribution of aquifer reducing conditions (*Figure 100*). Surprisingly, given the known confined aquifer structure at Alabama Road well 4402, sulphate levels are relatively high.

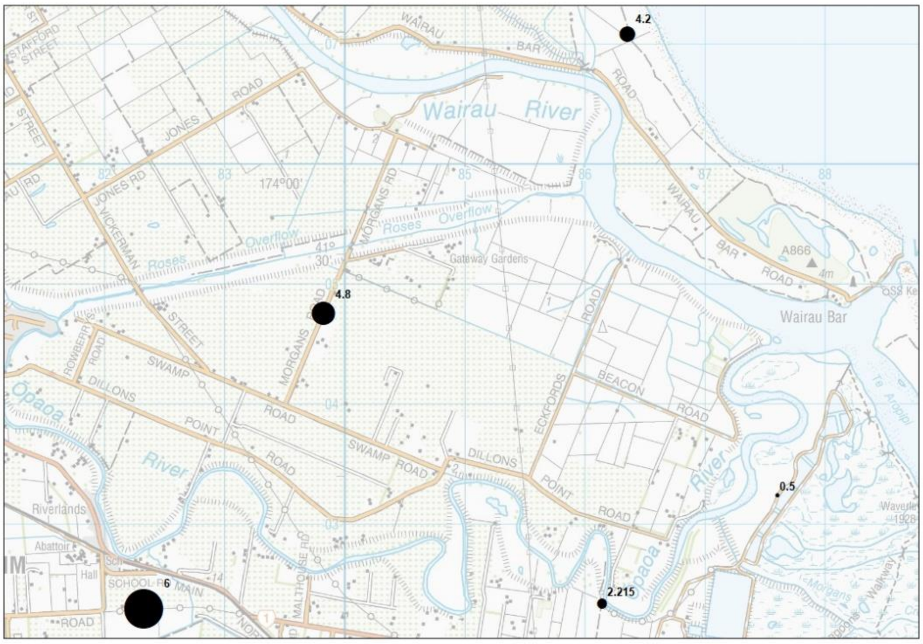



*Figure 100: Median sulphate concentration (g/m3).*

Sulphate levels are showing a slight general increase over time for Riverlands Aquifer wells except at the Riverlands Replacement well (*Figure 101*). Overall, levels are more stable than most other parameters measured. The pattern is complicated by short term cycles in the record across all sites.

There is a significant increasing trend in sulphate at the Springlands well 3120, while nitrate-nitrogen levels are declining over the same time period.

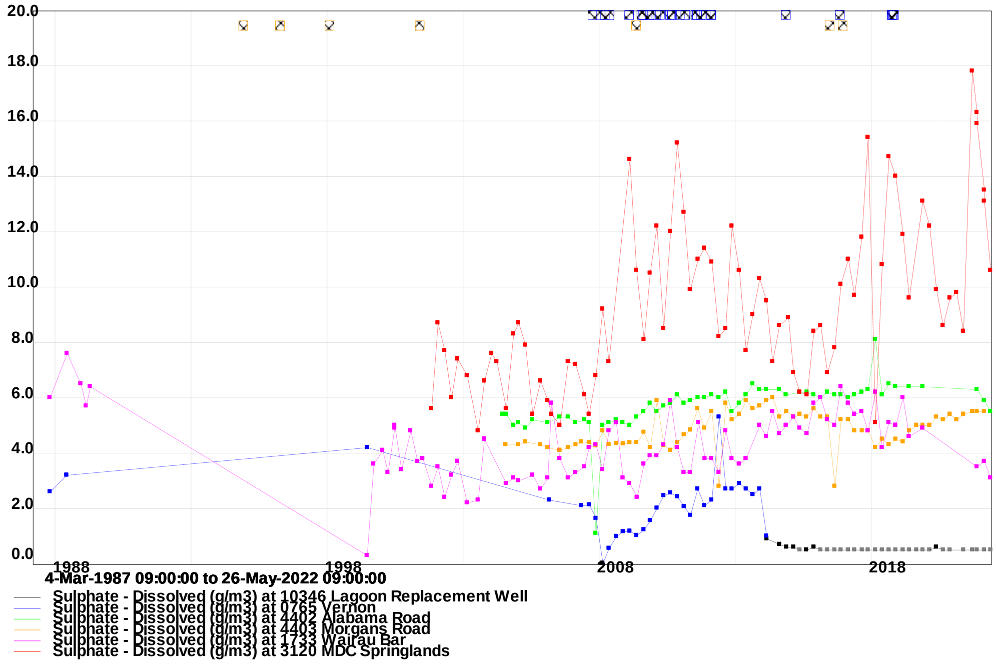



***Figure 101: Sulphate concentration (g/m3) 1987-2022.***

## Causes of Variability

Sulphate is reduced in the oxygen deficient conditions characterising highly confined aquifer areas, with very low concentrations at Lagoon Replacement well 10346 and Vernon well 765, where groundwater is oldest. Most sulphate at these two sites has been converted to sulphide gas by naturally occurring reactions within the aquifer.

Higher sulphate concentrations exist in groundwater at the Morgans Road well 4403, Alabama well 4402 and Bar well 1733, representing slightly younger groundwaters with less advanced reducing conditions. There are possibly localised inputs of sulphur to groundwater at Alabama Road.

Sulphate levels at the Morgans Road well 4403 are lower than for groundwater at Springlands well 3120 representing upstream recharge water, showing reducing conditions have converted some sulphate by the time groundwater arrives there (*Figure 101*).

Sulphate levels at well 3120 penetrating the semi-confined Wairau Aquifer have a marked seasonality caused by leaching of land surface pollutants during wetter seasons. The relative timing of when groundwater sulphate concentrations peak between unconfined and confined monitoring wells is indicative of underground travel times.

However, sulphate is not the perfect tracer because of its sensitivity to groundwater redox conditions, but the continuity of mostly Wairau River derived flow through the Wairau Aquifer makes it a useful indicator. The multi-year pattern in sulphate concentrations can be recognised in down-stream wells in its attenuated form (*Figure 101*).

Sulphate levels fluctuate significantly at Bar well 1733 which is surprising for a highly confined aquifer remote from its recharge source. A possible contributor is mixing of groundwater of different ages and compositions following different pathways underground from their recharge source, and inputs of water triggered by natural processes.

A possible trigger driving the sudden changes in groundwater chemistry are variations in aquifer loading and recharge accompanying Wairau River floods.  The added weight of flood waters may be forcing more evolved groundwater at the aquifer edges inland, while increased recharge dilutes groundwater in the coastal sector.

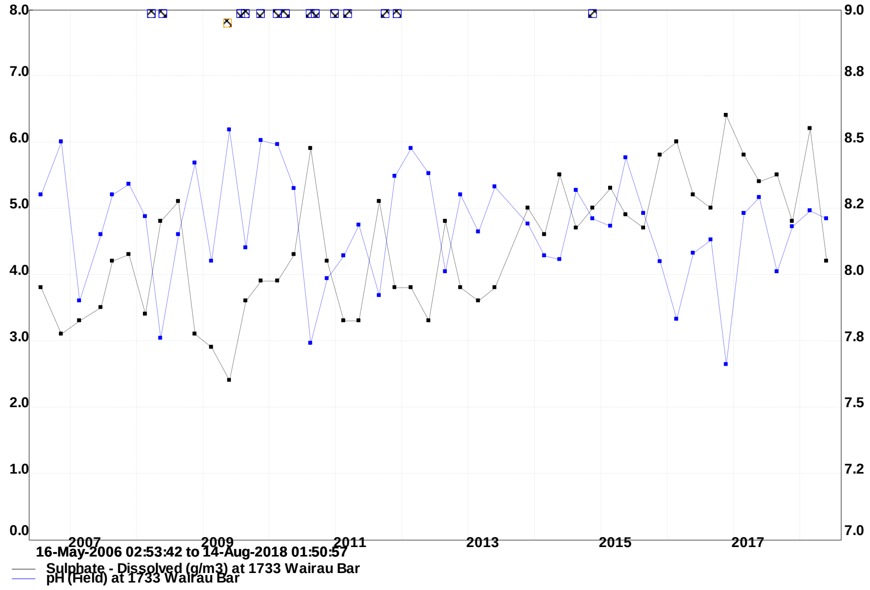



***Figure 102: Sulphate concentration versus pH for Bar well 1733.***

There is a strong negative correlation between sulphate concentration and pH consistent with the presence of reduced aquifer conditions (*Figure 102*).  The explanation for the strong positive correlation between sulphate and silica concentrations for the Bar well 1733 is uncertain (*Figure 103*).

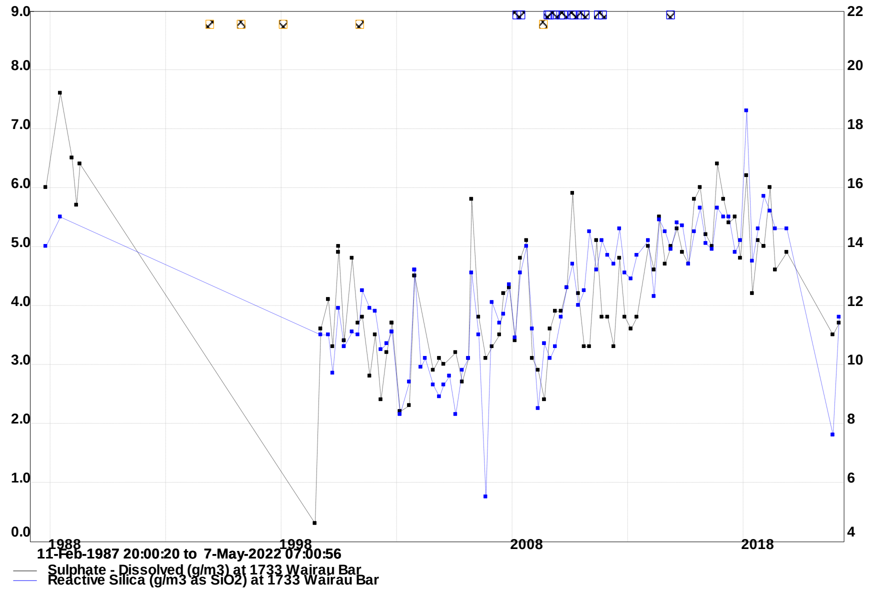



***Figure 103: Sulphate versus silica concentration for Bar well 1733.***

## Nitrate-Nitrogen

Nitrogen is the most common nutrient found in groundwater locally.  Elevated or high levels of nitrate in the environment always reflect human activities.  Nitrate is the oxidised form of nitrogen, but due to the reducing conditions present in the confined aquifers in the study area, nitrate levels are generally low and decline with distance groundwater travels along its flow path towards the Lagoons/coast.

## Land Surface Leaching Processes

While aquifers near Riverlands are fully confined and don't receive recharge locally, it is necessary to describe the pathways whereby nitrate-nitrogen enters groundwater further west. Leaching of land surface pollutants to groundwater in the unconfined aquifers upstream of Riverlands is strongly correlated with climate with higher concentrations of nitrate-nitrogen and sulphate observed during wetter months.

This is illustrated by record for MDC Wratts Road well 3009 representing unconfined Wairau Aquifer shallow groundwater 7.5 kilometres north-west of Riverlands (*Figure 104*). Elevated nitrate-nitrogen and sulphate levels in groundwater indicate agricultural inputs in this area from fertilisers, waste and possibly vineyard fungicide.

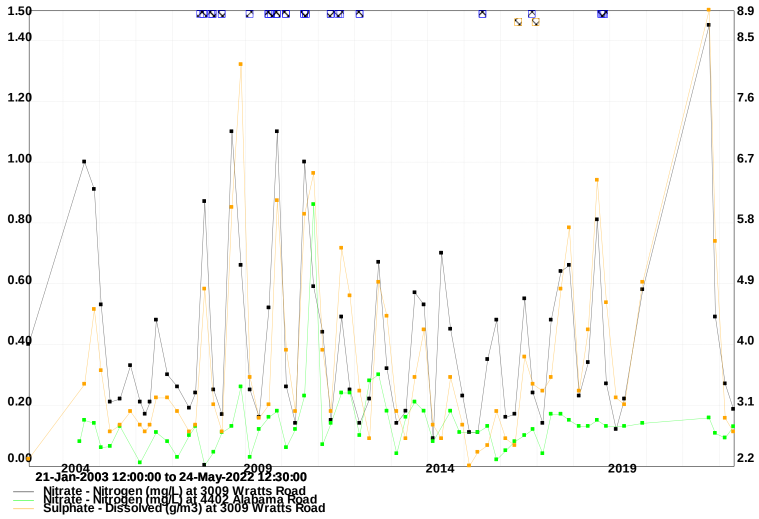



***Figure 104: Groundwater nitrate-nitrogen and sulphate concentration peaks in shallow Wairau Aquifer groundwater at Wratts Road well 3009 versus nitrate-nitrogen at Riverlands Aquifer well 4402. Nitrate-nitrogen concentration is shown on the left-hand vertical axis with sulphate concentration on the right-hand vertical axis.***

Groundwater nitrate-nitrogen and sulphate levels peak in Spring coinciding with the highest rainfall and leaching of land surface contaminants to the water table (*Figure 104*). The July 2021 storm generated the highest levels of nitrate-nitrogen and sulphate measured to date in groundwater at well 3009 based on 26 years of record.

While direct, local leaching should not affect the Riverlands Aquifer because its confined structure, there appears to be some seasonal variation in nitrate-nitrogen and sulphate levels at well 4402, maybe because this well is closer to the leading (western) edge of the aquifer than other monitoring wells.

## Regional Pattern

Figure 105 shows that at a regional scale nitrate-nitrogen levels are low at Riverlands relative to the rest of the Wairau Plain south of New Renwick Road. There are variable levels in Southern Valleys groundwater with low concentrations reflecting denitrification processes associated with deep aquifer layers and higher values linked with human waste or fertilisers, predominantly in shallower layers.

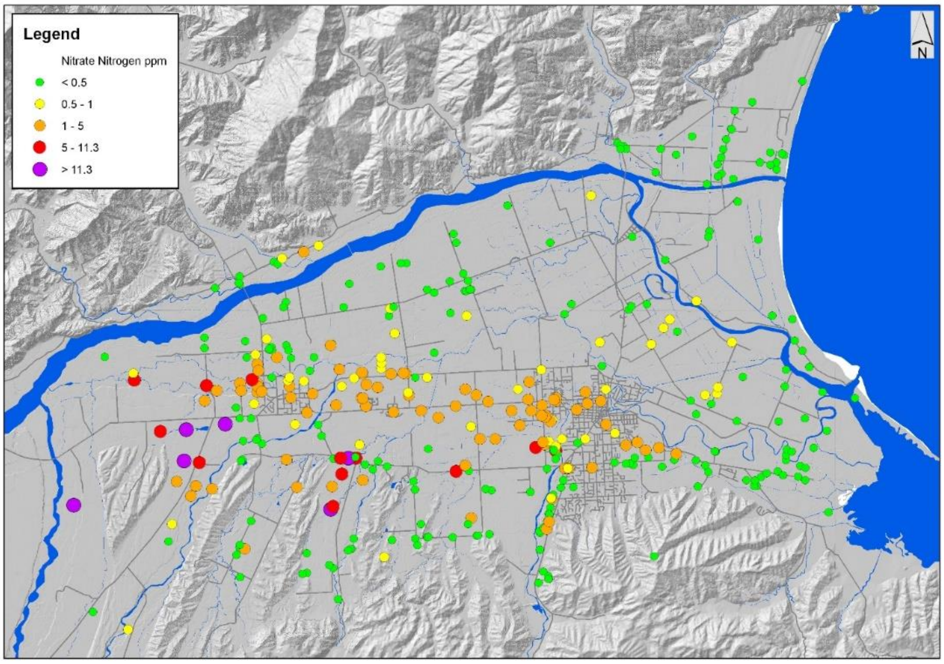



***Figure 105: Nitrate-Nitrogen median concentration (g/m3) excluding Rarangi Shallow Aquifer (Groundwaters of Marlborough 2011).***

## Local Values and Trends

The local distribution of median nitrate-nitrogen concentrations is shown in Figure 106. The lowest concentrations are in the south-east with virtually no nitrate in groundwater at either the Vernon well 765 or Lagoon Replacement well 10346.

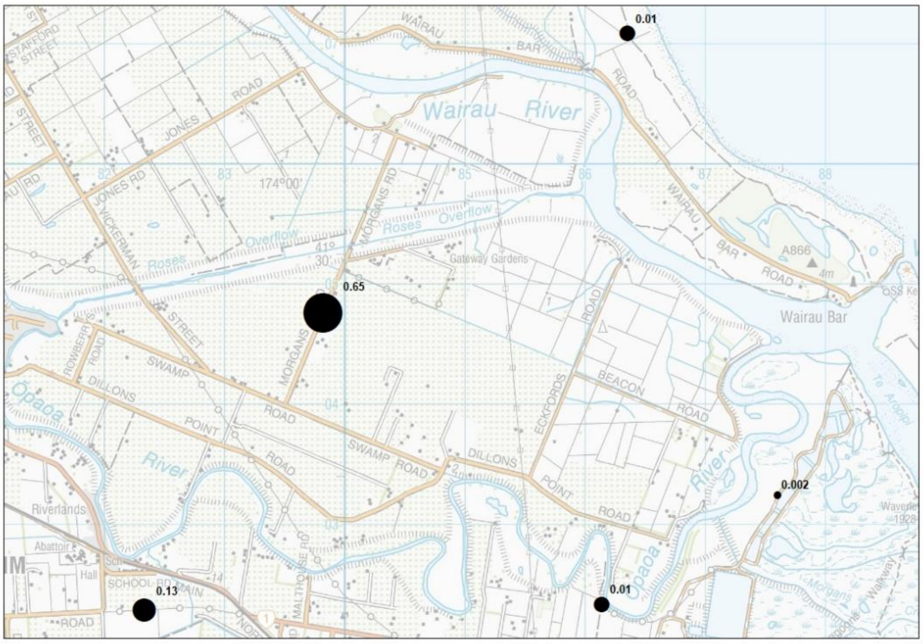



***Figure 106: Median nitrate-nitrogen concentration (g/m3).***

Median nitrate-nitrogen concentrations at the Morgans Road well 4403 and Alabama Road well 4402 are low by unconfined aquifer standards but indicate aquifer conditions there are still relatively oxygenated compared to the other three sites in the study area (*Figure 106*). Except for the

Springlands well 3120, only Alabama Road well 4402 showed a marked seasonal variation in nitrate-nitrogen concentrations with peaks in Spring or Winter (*Figure 107*).

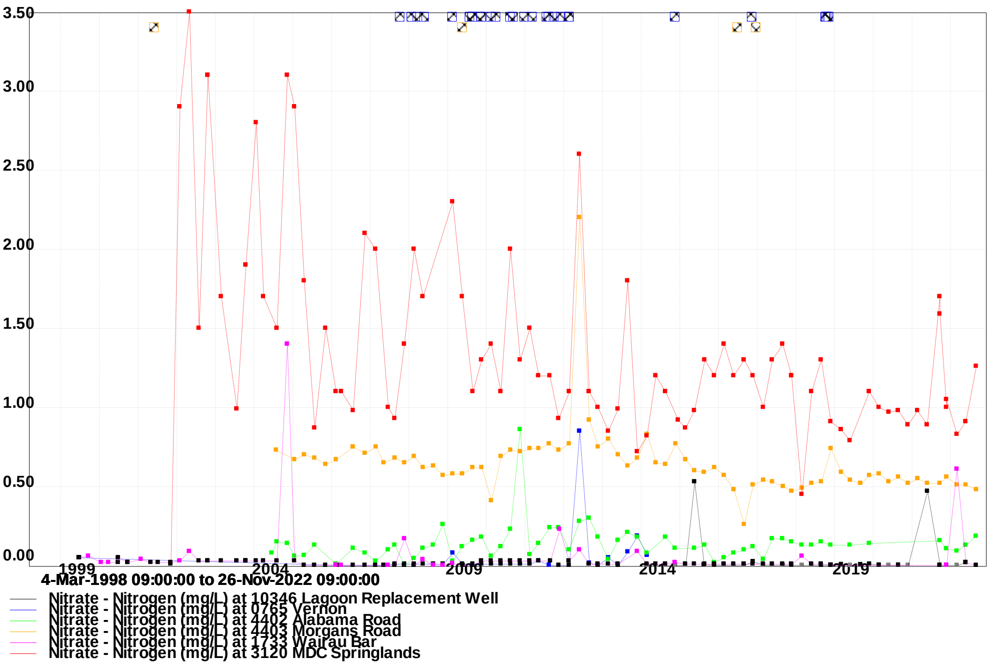



***Figure 107: Nitrate-Nitrogen concentration (g/m3) 1987-2022.***

In terms of time trends, there is a distinct high at the Morgan's Road well 4403 in 2012 which is likely to reflect cumulative leaching associated with higher rainfall in 2008 and 2010 (*Figure 107*). Nitrate-nitrogen levels spiked at Springlands well 3120 in late 2021 and again in mid-2022 in response to the July 2021 and July/August 2022 storms. There was a spike in nitrate-nitrogen levels at the Bar well 1733 in early 2022 probably related to the July 2021 storm. At all other sites nitrate-nitrogen concentrations are stable or declining with time, particularly at Springlands well 3120 (*Figure 107*). This pattern is consistent with the conversion of the Wairau Plain to vineyard with lower nutrient inputs.

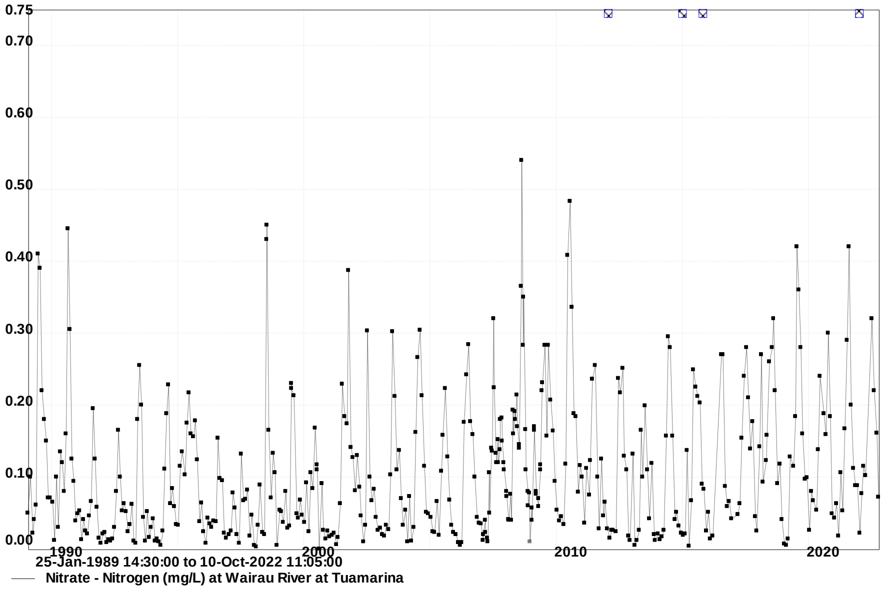



***Figure 108: Wairau River at Tuamarina nitrate-nitrogen concentration 1989-2022.***

The nitrate-nitrogen concentration of Wairau River water at Tuamarina is increasing slightly over time due presumably to greater inputs from human activities and slightly lower channel flows (*Figure 108*).

## Causes of Variability

Given wells in the study area are located at the end of a long groundwater flow path, nitrate-nitrogen concentrations reflect the net effect of inputs and attenuation processes along the way. For wells tapping the most highly confined aquifers (Lagoon Replacement well 10346), the dominance of denitrification processes means most of the nitrate-nitrogen has been consumed. However, low levels currently don't necessarily mean higher levels didn't previously exist.

The higher nitrate-nitrogen concentration in groundwater at the Morgan's Road well 4403 and to a lesser extent Alabama Road well 4402, reflect upstream land use inputs that have not been exposed to reducing conditions to the same extent as older groundwater further within the confined aquifer (*Figure 107*).

The seasonal variability despite the high degree of aquifer confinement shows either there are surface inputs of nitrate-nitrogen near the south-western edge of the confining layer, or seasonal sinks consuming nitrate. Either way the aquifer is not a closed system.

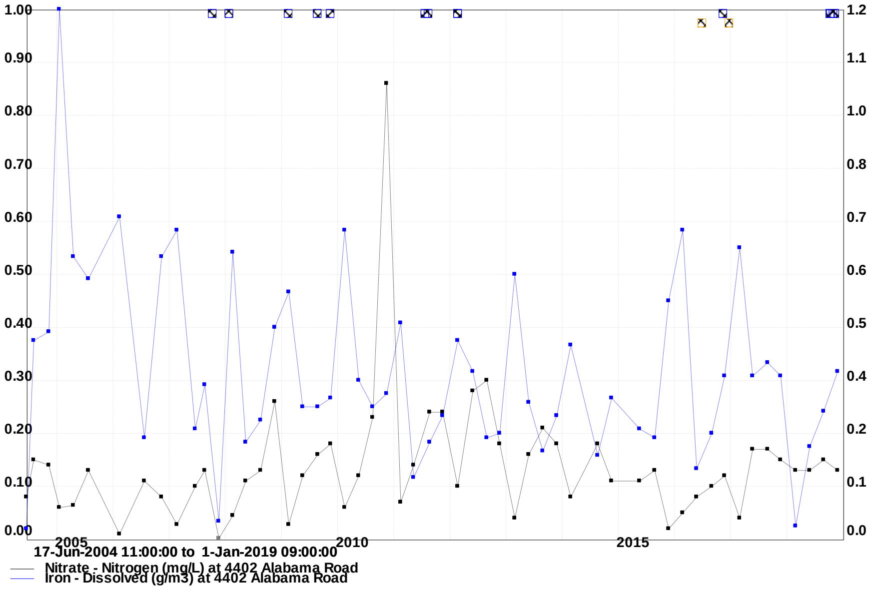



***Figure 109: Iron and nitrate-nitrogen concentrations at Alabama Road well 4402 where nitrate-nitrogen concentration is black and iron concentration is blue. Nitrate-nitrogen concentration on left hand vertical axis.***

A comparison of the seasonality of nitrate-nitrogen and iron concentrations for Alabama Road well 4402 shows that when one peaks the other is generally at a minimum as would be expected hydrochemically (*Figure 109*). Conversely for groundwater at the bar well 1733, higher iron concentrations correspond with higher pH (*Figure 110*).

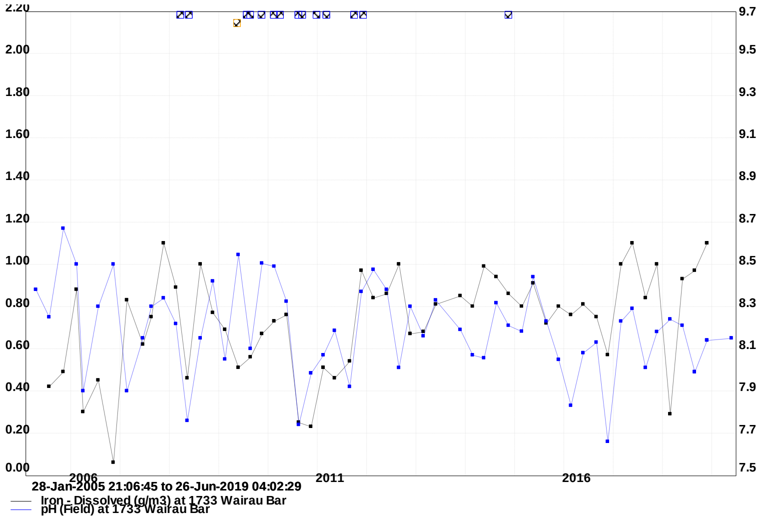



***Figure 110: Iron concentration versus pH at Bar well 1733 where iron concentration is black, and pH is blue. Iron concentration on the left-hand vertical axis.***

## Ammoniacal-Nitrogen

Ammoniacal nitrogen is the reduced form of nitrogen and the most common form found in confined aquifers in Marlborough, including those beneath the south-eastern Wairau Plain where limited oxygen and high pH means reducing chemical conditions dominate. Ammoniacal nitrogen levels above 0.1 g/m$^3$ generally indicate advanced reducing conditions in an aquifer and several wells intercepting the most highly confined part of the Riverlands Aquifer have values of this order (*Figure 111*).

### Regional Pattern

From a regional perspective there is a clear pattern of higher ammoniacal nitrogen concentrations on the boundaries of the main aquifers where groundwater flow is low and stagnant (*Figure 111*). High ammoniacal nitrogen concentrations of greater than 1.5 g/m$^3$ are known to occur at Riverlands and Blenheim landfills in the Taylor River area (*Figure 111*).

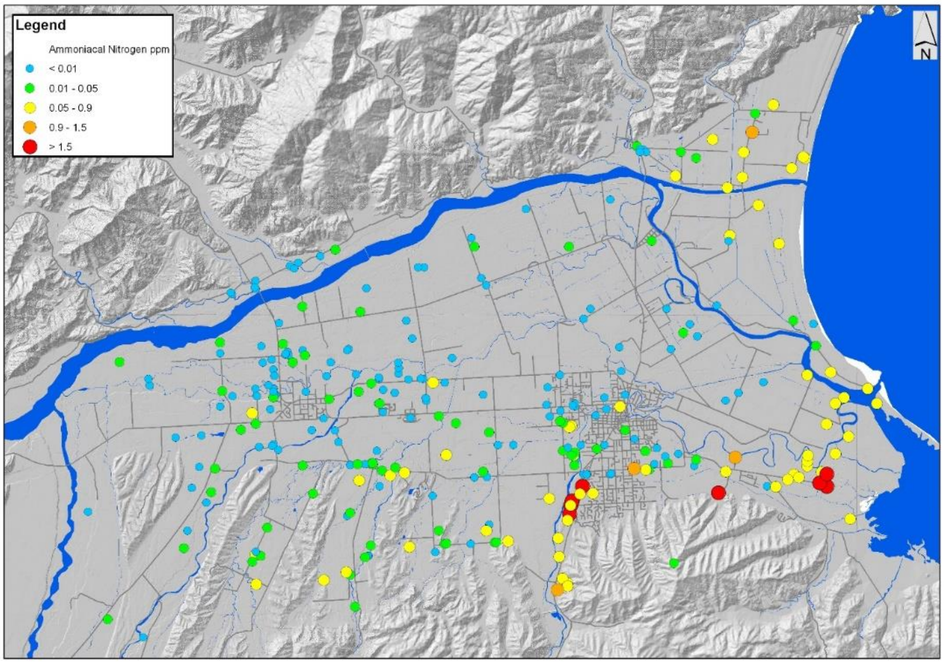


***Figure 111: Ammoniacal-Nitrogen median concentration (g/m3) excluding Rarangi Shallow Aquifer (Groundwaters of Marlborough 2011).***

## Local Values and Trends

There are low levels of ammoniacal nitrogen in groundwater at the MDC SoE monitoring wells, except for the Lagoon Replacement well and Vernon well 765 (*Figure 112*). Median concentrations at the Lagoon Replacement well 10346 and Vernon well 765 are 0.68 and 0.38 g/m$^3$ respectively indicating advanced reducing conditions (*Figure 112*). This implies the oldest and most evolved groundwater occurs in the vicinity of these wells, although other indicators of a high mineralising environment like pH aren't exceptionally high.

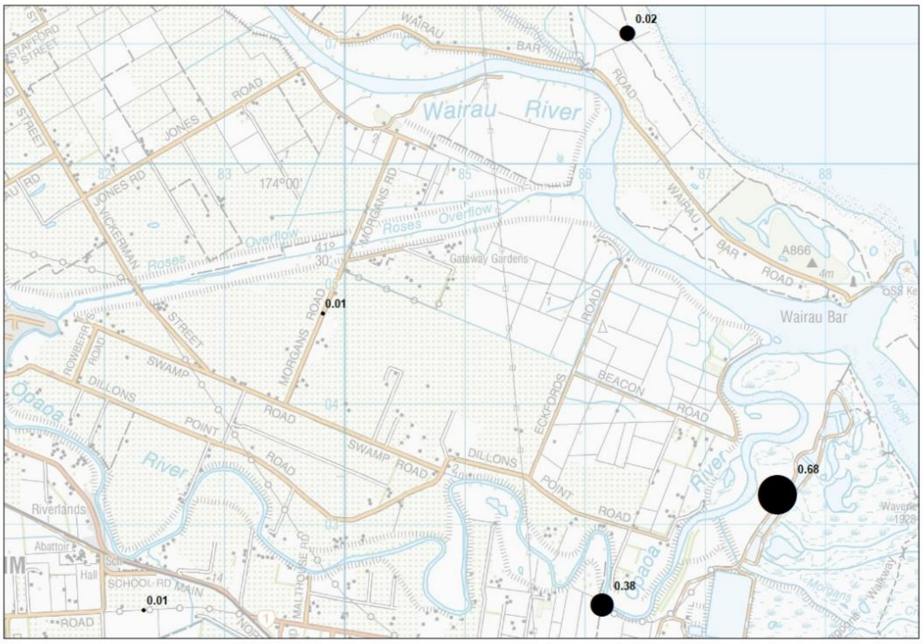



***Figure 112: Median ammoniacal nitrogen concentration (g/m3).***

There are indications of a slight increase over time in ammoniacal nitrogen levels at Bar well 1733 and Lagoon Replacement well 10346, although the record at this last site remains short (*Figure 113*).

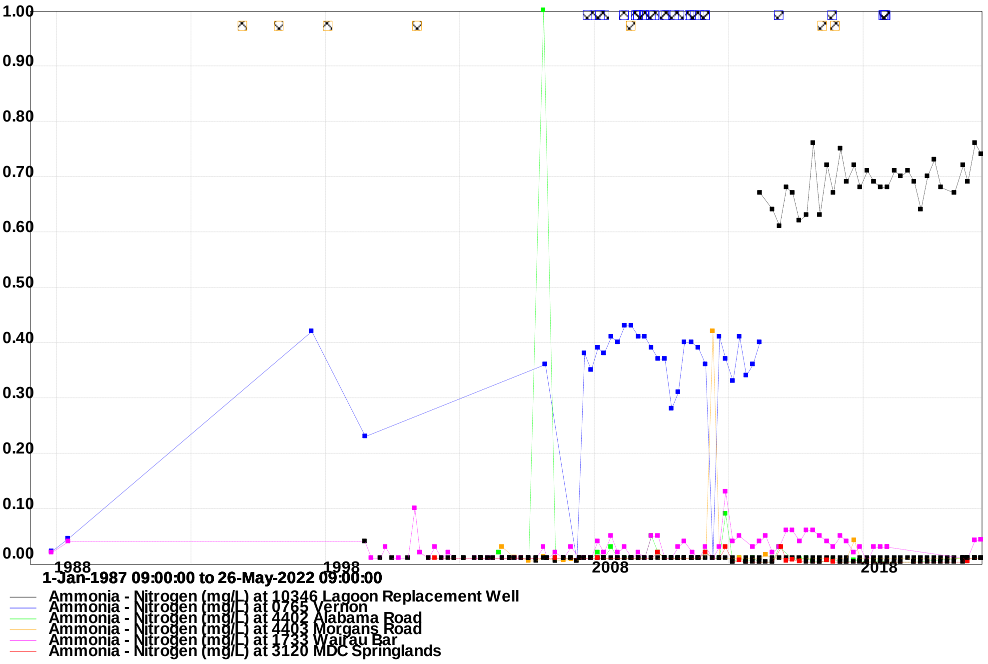



***Figure 113: Ammoniacal nitrogen concentration 1987-2020.***

### Causes of Variability

Ammoniacal nitrogen concentrations in Wairau River channel water at Tuamarina have declined between 1989 and 2016 so the cause of any increase in the Riverlands area cannot be attributed to the nature of the distant recharge water. Ammoniacal-nitrogen levels weren't strongly correlated with either pH or dissolved oxygen at any of the wells in the study area.

## Phosphorus

Phosphorus can originate from human activities or natural processes. Phosphorus is found in fertilisers and domestic waste or human sewage. In terms of natural sources, phosphorus is weathered from the mineral apatite which is uncommon in local Marlborough rocks or derived sediments. MDC measure the dissolved reactive form of phosphorus (DRP) because it is most relevant for understanding levels in groundwater and the impacts on surface water quality processes.

DRP levels are generally low in New Zealand groundwaters according to LAWA (Land and Water Aoteroa) with concentrations mostly less than 0.1 g/m$^3$. Phosphorus is very reactive and adsorbs onto soil particles particularly iron oxides or is taken up by plants rather than becoming dissolved in groundwater. Phosphorous is more likely to become adsorbed if groundwater pH is low and dissolved oxygen content high.

This immobility in the natural environment means phosphorus doesn't reach the water table in large quantities. MDC continue to monitor DRP in groundwater because of the exchange with surface water and its potential to leach to groundwater at some stage in the future.

### Local Values and Trends

Concentrations vary by three orders of magnitude across the study area with the highest values at Lagoon Replacement well 10346 followed closely by the Vernon well 765. There are intermediate values at the Morgans Road and Bar wells, with lower values at the Alabama Road well 4402. (*Figure 114*).

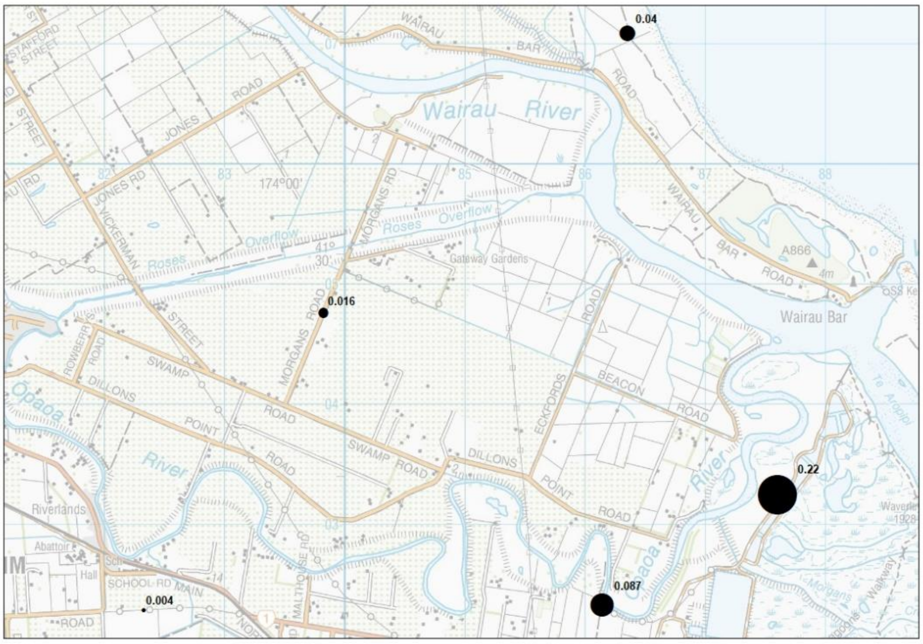



*Figure 114: Median dissolved reactive phosphorus concentration (g/m3).*

The large variation in ammoniacal-nitrogen concentration across the study area indicates the presence of steep chemical gradients but over relatively long time periods as groundwater is moving slowly.

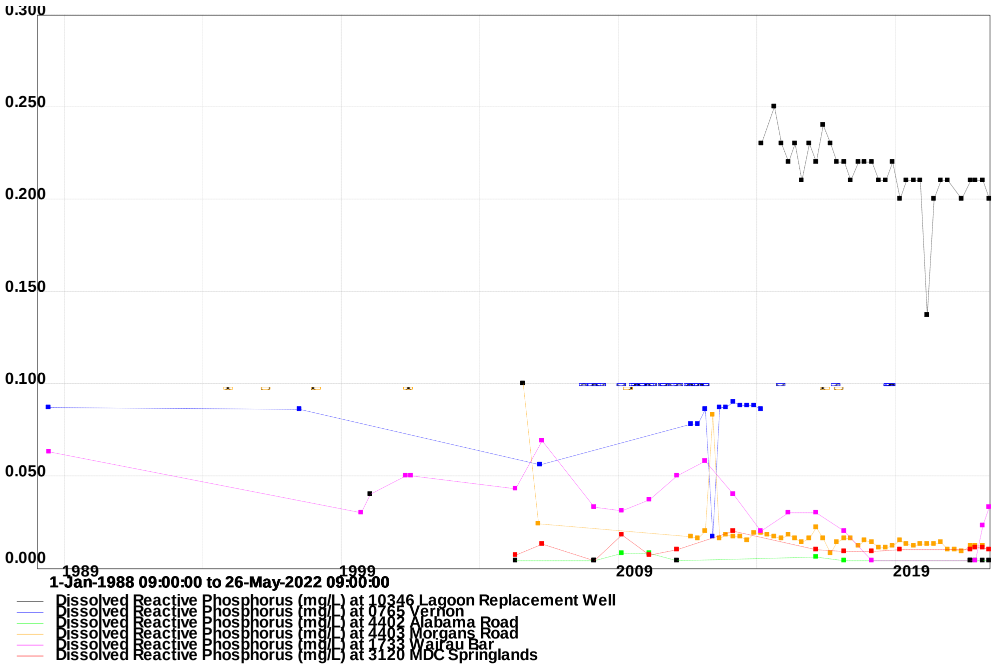



*Figure 115: Dissolved reactive phosphorus concentration (g/m3) 1987-2022.*

## Causes of Variability

The isolation of wells with high phosphorus values from land surface sources and the presence of advanced reducing conditions locally point to natural processes being responsible for the phosphorus (*Figure 115*).

# Bromide

Bromide like chloride is a conservative constituent of groundwater meaning it is largely unaffected by chemical reactions, is not easily adsorbed and occurs in low concentrations in most rock forming minerals. These properties make it an excellent tracer of groundwater flow and for identifying the origin or evolution of groundwater.

Bromide occurs in higher concentrations in seawater than freshwater making it a key indicator of the influence of seawater on groundwater and connate water from marine formations found beneath the south-eastern Wairau. MDC measure the concentrations of sodium, chloride, bromide seasonally and the electrical conductivity of coastal groundwaters continuously.

Bromide enters groundwater from human activities as well as from natural sources. It used to be an indicator of road runoff when historically bromine was an additive in petrol and until recently was used in solvents and pesticides like trichloroethylene and methyl bromide.

## Local Values and Trends

The distribution of median bromide concentration shows values increase with distance inside the confining aquifer and reach their maximum at the probable aquifer boundary near the Lagoons where groundwater flow becomes extremely sluggish (*Figure 116*).

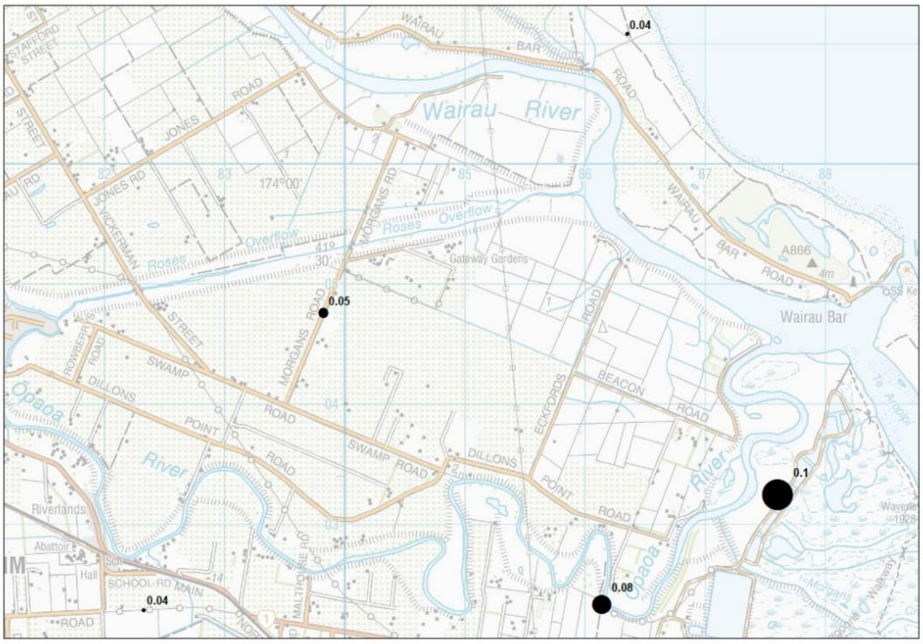



***Figure 116: Median bromide concentration (g/m3) for MDC State of the Environment surveys.***

Concentrations appear to be rising slightly at the Lagoon Replacement well 10346, but stationary or declining at other sites. A longer record is needed to confirm the existence of any time trends (*Figure 117*).

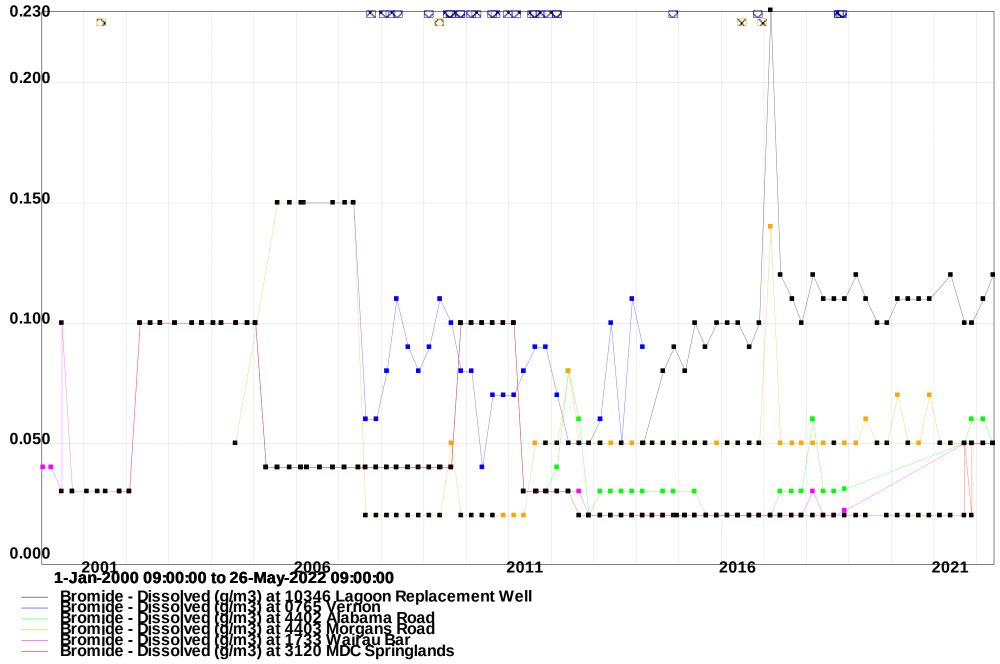



***Figure 117: Bromide concentration at MDC monitoring wells.***

## Chemical indicators of seawater intrusion

The MDC district plan (proposed Marlborough Environment Plan) policies aim to maintain aquifer levels above a minimum threshold to provide sufficient pressure within the confined Riverlands and Wairau Aquifers to prevent seawater intrusion. Proof of the onset of seawater intrusion is a sustained increase in the electrical conductivity of groundwater in response to abstraction.

Rises in groundwater electrical conductivity can also be caused by natural processes like leaching of accumulated sea spray, or salts related to human activities (septic tanks/soakage fields) at the surface. This mechnism only affects shallow groundwater systems and not the confined aquifers beneath the south-east Wairau Plain. Typically, leaching peaks in spring or autumn coinciding with the first rains after summer and is unrelated to consented abstraction.

The proximity of the seawater interface to freshwater wells can also be determined using the ratios of particular elements or compounds present in local coastal groundwater. Bicarbonate and calcium are major components of freshwater, but minor constituents of seawater. Conversely chloride dominates the composition of seawater while magnesium is a major component.

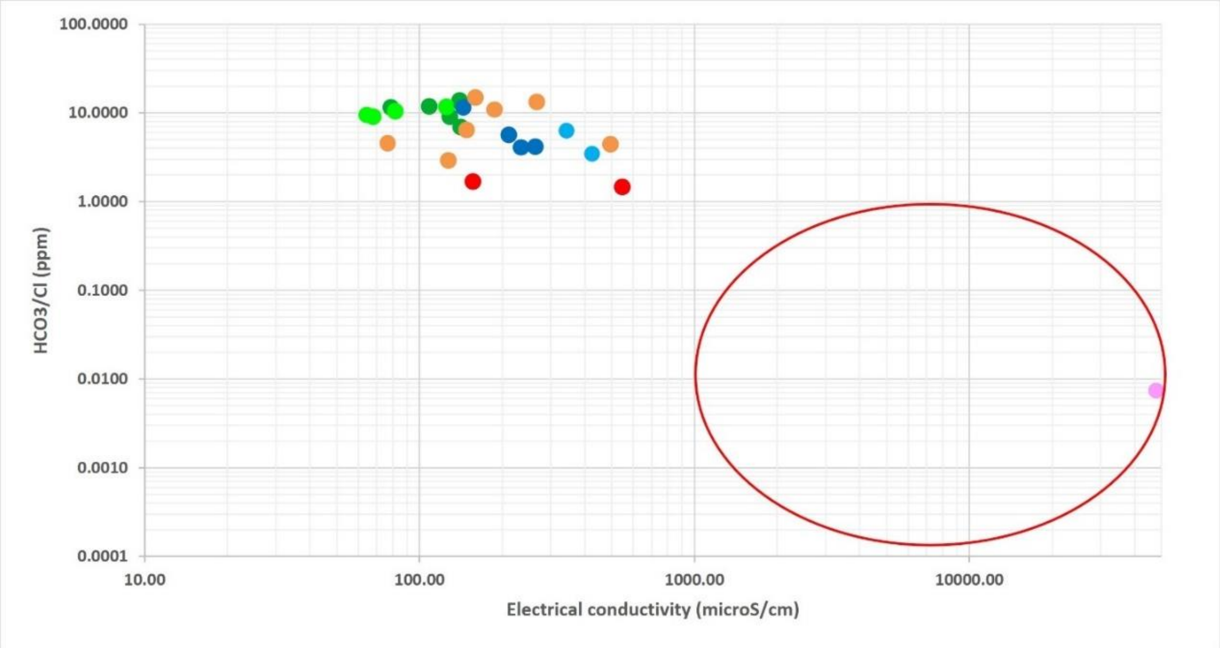



***Figure 118: Groundwater HCO3/CL ratio versus electrical conductivity.***

Ratios of the concentrations of calcium to magnesium and bicarbonate to chloride are normally greater than one for freshwater and lower than one for seawater. Several of these ratios for Wairau groundwaters including those at Riverlands will be examined to see if there are any signs of seawater intrusion occurring.

Figure 118 shows the ratio of median bicarbonate to median chloride versus electrical conductivity (EC) for a spectrum of Wairau Plain groundwaters. The colours denote different groundwater types with seawater marked pink. The green points represent dilute groundwaters associated with rivers or recently recharged groundwater in the Renwick area, orange represents more evolved groundwater in the Southern Valleys or elsewhere, while red are older mineralised groundwaters. Blue are coastal groundwaters with the lighter shade being from shallow wells and the darker shaded points from deeper wells, including those from Riverlands.

The red ellipse denotes the area of the graph where the combination of high EC and a low $HCO_3$/Cl ratio is likely to represent the influence of seawater on groundwater (*Figure 118*). There are currently no indications of seawater intrusion affecting wells despite some deeper coastal groundwaters approaching the $HCO_3$/Cl ratio threshold of one, as EC remains low. Interestingly the shallow coastal groundwaters have some of the highest EC, but the $HCO_3$/Cl ratio shows no chemical trace of saltwater.

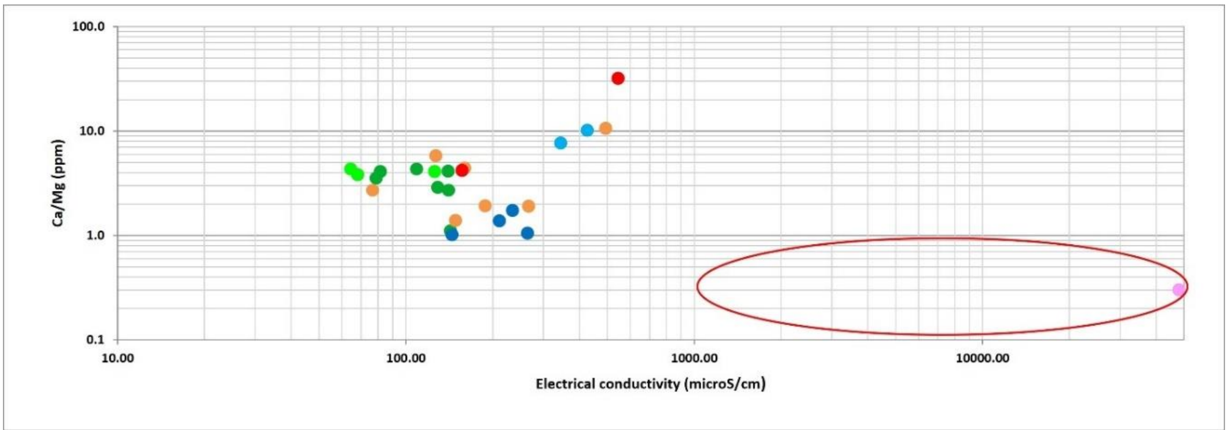


***Figure 119: Groundwater Ca/Mg ratio versus electrical conductivity.***

Figure 119 shows the ratio of calcium to magnesium versus the electrical conductivity of groundwaters for the same series of sites as Figure 118. While some sites equal the calcium to magnesium threshold of one, the low EC values mean the water is still dilute and not affected by saltwater.

The ratio of chloride to bromide is especially useful for detecting the presence of seawater intrusion for the reasons discussed. The molar mass ratio is plotted this time against chloride concentration (*Figure 120*). While the concentrations may change along the aquifer flow path, the ratio won't unless new water is added with a different Cl/Br ratio.

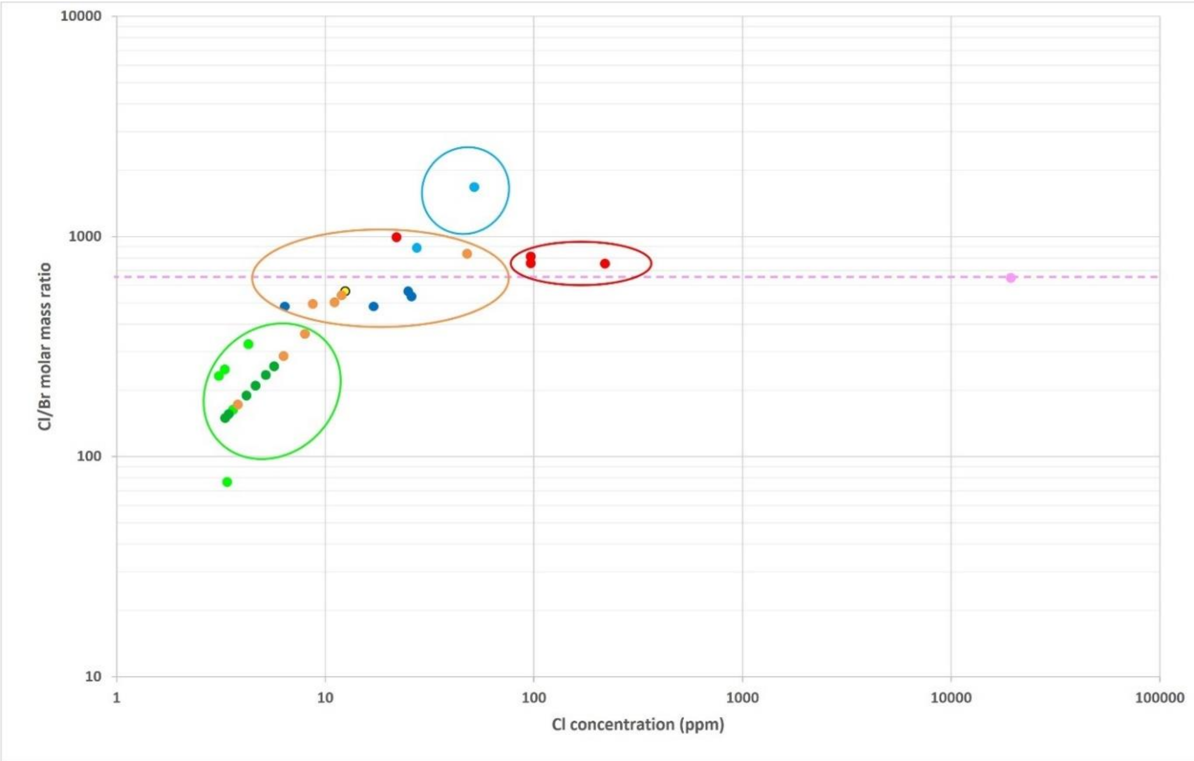



***Figure 120: Groundwater Cl/Br ratio versus Cl concentration.***

The dashed pink horizontal line in Figure 120 indicates the seawater ratio and the pink dot is the actual signature. While groundwaters plot near the Cl/Br ratio, chloride levels remain low. The cluster of groundwaters enclosed by the green ellipse are dilute and related to Wairau River type water marked by the lower green point sitting outside the circle (*Figure 120*).

The central group of points enclosed by the orange ellipse straddle the seawater line and include coastal Wairau Plain groundwaters, but none match the seawater ratio exactly or contain sufficiently high chloride. The most coastal MDC monitoring well representing the Riverlands Aquifer (Lagoon Replacement well 10346) marked dark blue and plots just below the seawater line.

The light blue coloured point sitting above the seawater line with a Cl/Br ratio of 1674 and enclosed in the light blue circle represents shallow coastal groundwater possibly affected by wastewater from nearby rural residential properties. The three groundwaters enclosed in the red ellipse are old evolved groundwaters or contaminated groundwater from near the MDC Blue gums landfill to illustrate the influence of waste or high chloride on the Cl/Br ratio (*Figure 120*).

# 10. References

*Aesthetic Values for Drinking Water Notice 2022*: Taumata Arowai

*Groundwaters of Marlborough*: Marlborough District Council - 2011

*Riverlands Aquifer Resource Review*: Scott Wilson, Water Matters Ltd - 2008

*Riverlands Groundwater Model and Aquifer Sustainability Assessment*: Scott Wilson, Water Matters - 2010

*Water Science (Drinking Water Standards for New Zealand) Regulations 2022*: Taumata Arowai