Title: Groundwater in the Ruamāhanga Whaitua

Purpose: To assist the Ruamāhanga Whaitua Committee to understand the current the quality of groundwater in the whaitua

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Key points

- There have been few detectable changes in groundwater quality in the Ruamāhanga Whaitua in recent years (2005 to 2010). A reduction in nitrate, iron and manganese concentrations at a few sites represents an improvement in water quality.

- Because of their permeable nature, unconfined and semi-confined aquifers are affected by land use activities, particularly intensive land uses (urban and rural). The Ruamāhanga Whaitua supports predominantly agricultural land use and the most common effects on water quality are likely to be the presence of pathogens (monitored as the presence of *E.coli*) or elevated levels of nitrate.

- Nitrates are more likely to be elevated in unconfined aquifers. The highest nitrate concentrations are in a bore in an unconfined aquifer at Te Ore Ore and shallow unconfined aquifers around Carterton.

- Groundwater in the areas around Taratahi, Te Ore Ore, Mangatarere and Martinborough has elevated nitrate nitrogen concentrations. Elevated nitrate levels are a concern where groundwater systems discharge water to surface water.

- 40% of monitoring bores in unconfined aquifers and 16% of monitoring bores in semi-confined or confined aquifers have median nitrate concentrations above 3 mg/L.

- Concentrations of nitrate above 1.7 mg/L can be toxic to fish and invertebrates in spring-fed waters. Nitrate in groundwater that flows to surface water can contribute to enrichment-related effects such as increased algal (periphyton) growth.

- The quality of groundwater is a reflection of landuse and natural processes, such as interaction between water and rock. Confined aquifers can have naturally high levels of manganese, iron and arsenic, due to the length of time the water spends in contact with the rock. Thus, semi confined and confined aquifers typically have poorer water quality and may not meet standards and guidelines.

- Ammonia, iron and manganese concentrations above drinking water and ecosystem toxicity guidelines occur in some deep, confined aquifers of the Ruamāhanga whaitua. In general these high concentrations reflect natural processes.

- Three deep groundwater bores in the Ruamāhanga Whaitua exceed the drinking water standards for arsenic. None of these bores are used for drinking water supply.

- In the Ruamāhanga whaitua 48 bores are monitored by the Greater Wellington Regional Council (GWRC) for water quality. The quality of unconfined and semi-confined aquifers is assessed against its suitability for drinking water and aquatic ecosystem toxicity, as these aquifers can flow to surface water. The water quality in deep, confined aquifers is generally assessed only against the drinking water standards.

1. Introduction to groundwater

The purpose of this report is to provide information on the current state of groundwater quality in the Ruamāhanga Whaitua, and groundwater quality trends in recent years.

1.1 What is groundwater?

Groundwater is rainwater or river water that has travelled through the soil or river gravels to pore spaces within the underlying geology. A geological layer of sand, gravel, or fractured rock that stores water within the ground is called an aquifer. Groundwater can then flow through the aquifer where it is discharged out to sea or into fresh surface water.

The movement of surface water to groundwater is called recharge. Sources of recharge include water from rainfall, snowmelt or leakage from some lakes and rivers, and from irrigation. Groundwater can also provide recharge to rivers, streams, wetlands and springs and prevent sea water from migrating inland.

Groundwater makes up about 70 percent of the allocated fresh water resource in the Ruamāhanga Whaitua. Bores/wells pump groundwater from aquifers so water can be used for drinking, irrigation, livestock watering, industry and horticulture.

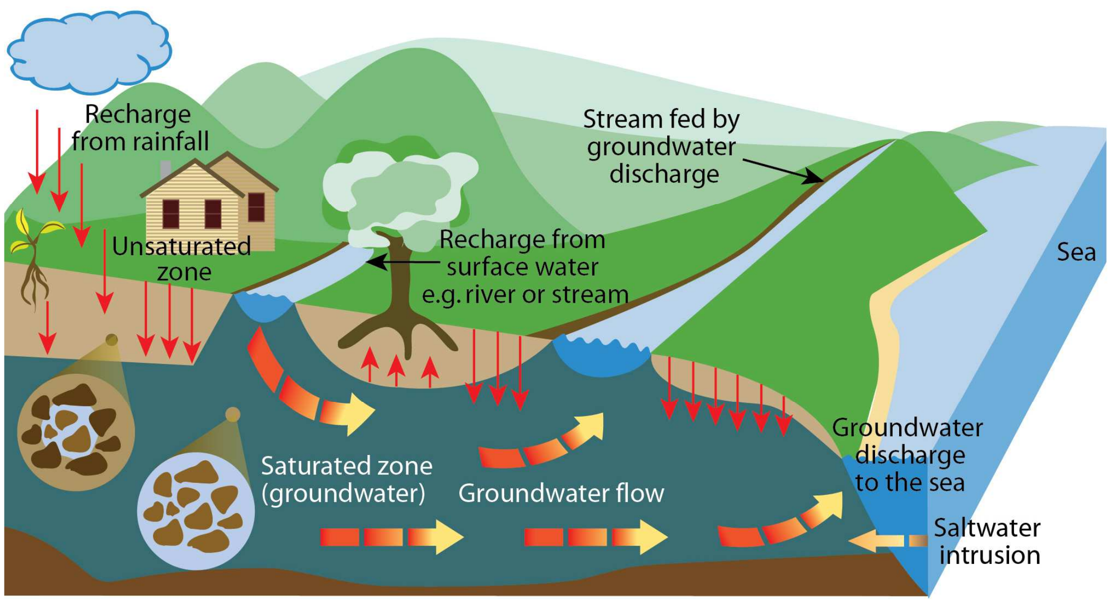

Figure 1: Illustration shows how water (from rainfall, rivers and streams) can move from the surface into the ground to form groundwater. Water can then flow from groundwater aquifers back into rivers and streams and discharge to the sea. (Source Environment Canada)

1.2 Aquifer types

Aquifers are areas of fractured rocks or porous sediments such as sand and gravel that cans store and transport groundwater. The movement of groundwater can be reduced or prevented by impermeable layers such as clay, silt or metamorphic rock, creating semi-confined and confined aquifers. There are three types of aquifer systems:

1. Unconfined aquifer: the rock and soil layer above the aquifer is permeable and allows vertical movement of water from the earth's surface to an aquifer. Often groundwater can be directly or highly connected to surface water. Groundwater level in unconfined aquifers can respond to changes in the volume of recharge (e.g. more rainfall) relatively quickly.

2. Semi-confined aquifer: the vertical movement of groundwater can be restricted in places within the aquifer by impermeable layers. Often semi-confined aquifers are located between confined and unconfined aquifers.

3. Confined aquifer: The vertical movement of water is restricted between two impermeable layers and there is little vertical connection between groundwater and surface water except where the aquifer may draw recharge. Often confined aquifers are located at depths ranging from 30 m to over 100 m. Groundwater in a confined aquifer can be under pressure, forming flowing artesian well (groundwater flows to the surface without a pump) and springs (puna) where a fault line disrupts the impermeable layer.

The key point is confined aquifers are underneath impermeable layers of silt or clay (aquitards) so they do not receive water and dissolved pollutants from land directly overlying them. Unconfined aquifers lack aquitards, so pollutants can leach directly into them.

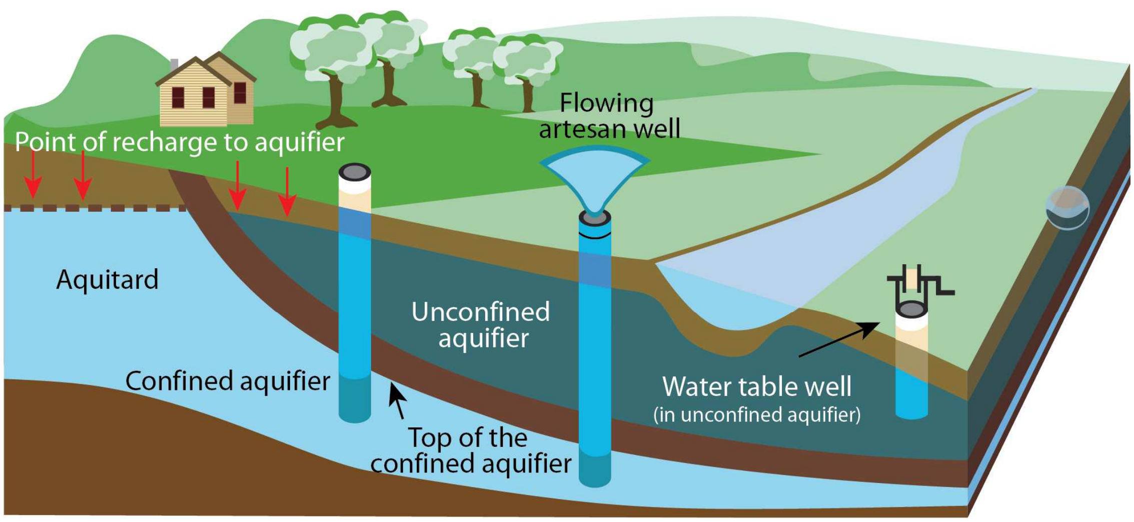

Figure 2: Illustration shows an unconfined and confined aquifer separated by an impermeable layer. ***(Source*** *Environment Canada)*

1.3 Groundwater flow and age

The origin of groundwater is complex to understand. Often the source of recharge to groundwater can be kilometres up gradient of the point of abstraction (see Figure 3). Therefore, water quality at a particular bore may not represent the land use in the immediate area.

The time taken for groundwater to migrate from the point of recharge to the point of discharge can vary depending on aquifer confinement, volume of recharge and the ability of water to move through the pore spaces of an aquifer. A confined aquifer can have water that is many years old, sometimes hundreds to thousands of years old, while the unconfined shallow aquifer above can be days, months or years old.

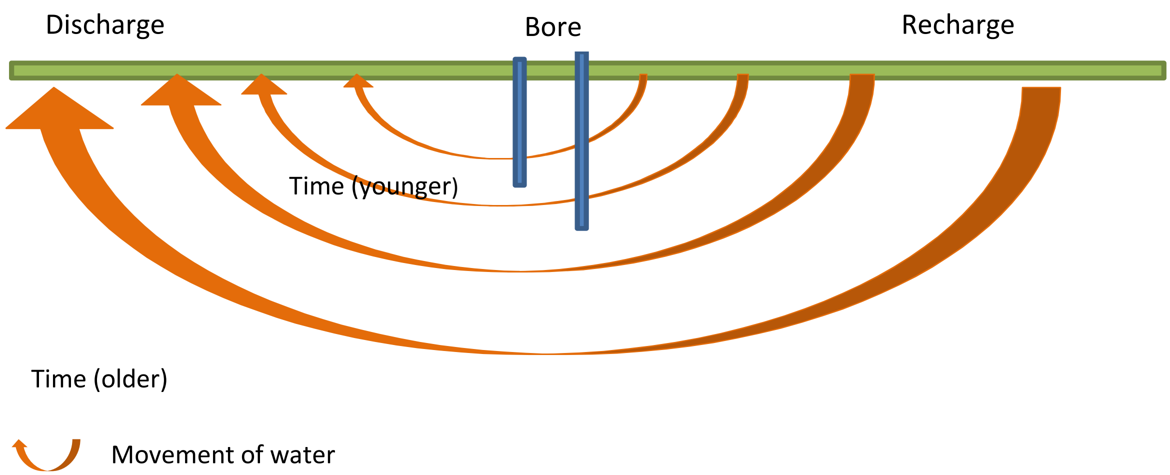

Figure 3. Illustration shows the movement of groundwater through an aquifer from the source of recharge to discharge. As groundwater moves through the aquifer both vertically and horizontally, the age of the water increases.

Understanding groundwater flow paths from recharge areas and the age of groundwater is time intensive (involving computer modelling of groundwater systems) and an expensive process.

1.4 Groundwater – surface water linkages

Mapping the degree of connectivity between groundwater and surface water can improve our understanding of contaminant flow paths between groundwater and surface water.

Groundwater has been divided into three categories of A, B and C which represent the degree of connectivity with surface water.

Groundwater in Category A is directly linked with surface water, groundwater in Category B is moderately linked and groundwater in Category C has very little connectivity to surface water. Groundwater in Categories A and B are managed under surface water allocation policy.

Fault lines and landforms can induce the flow of groundwater to surface flows. Wetlands and springs (puna) form where groundwater seeps out from fault lines, former river channels, and recent floodplains.

Shallow unconfined and semi-confined aquifers have a greater degree of connectivity with surface water systems compared to confined aquifers. Because of this connection, the volume and quality of surface water can affect the volume and water quality of groundwater. At other times the volume and quality of groundwater strongly affects the quality and amount of surface water.

- Groundwater can have high levels of nitrate and sulphate and is of concern where groundwater flows to surface water; rainfall (travelling over land), rivers, lakes and streams.

- Dilution occurs when groundwater combines with other streams, rivers or lakes and reduces the toxic levels. Groundwater is the main contributor of water to the Mangatarere River and Parkvale Stream and other lowland streams in the whaitua. Mostly, groundwater contribution is mixed with water from rainfall and nitrates from groundwater are diluted so toxic levels are not an issue. However, during low flow conditions some streams, such as the Parkvale Stream, are fed predominantly by groundwater and aquatic toxicity (due to nitrate in the groundwater) may be an issue at such times.

- Even if groundwater nitrates are sufficiently diluted in surface waters to avoid aquatic toxicity issues, groundwater nutrient inputs are likely to contribute to enrichment-related effects in streams, and have effects like an increase in periphyton.

1.5 A general summary of shallow and confined aquifers

Shallow unconfined aquifers (Category A in Figure 4)

- near earth surface
- groundwater is directly or highly connected to surface water
- recharged by river and rainfall
- oxygen rich
- nitrate-nitrogen form
- landuse practices directly influence groundwater quality
- fast moving flow
- Likely to have elevated concentrations of nitrate and sulphate, and an occasional presence of *E. coli*

Confined deep aquifers (Category C in Figure 4)

- +30m deep
- groundwater is not connected to surface water (except through puna (springs)
- recharged by rainfall, river losses, other aquifers
- oxygen poor
- ammoniacal nitrogen
- groundwater quality is influenced by recharge area- (which can be kms away)
- slow moving, contaminants in groundwater can be from past land use practices.

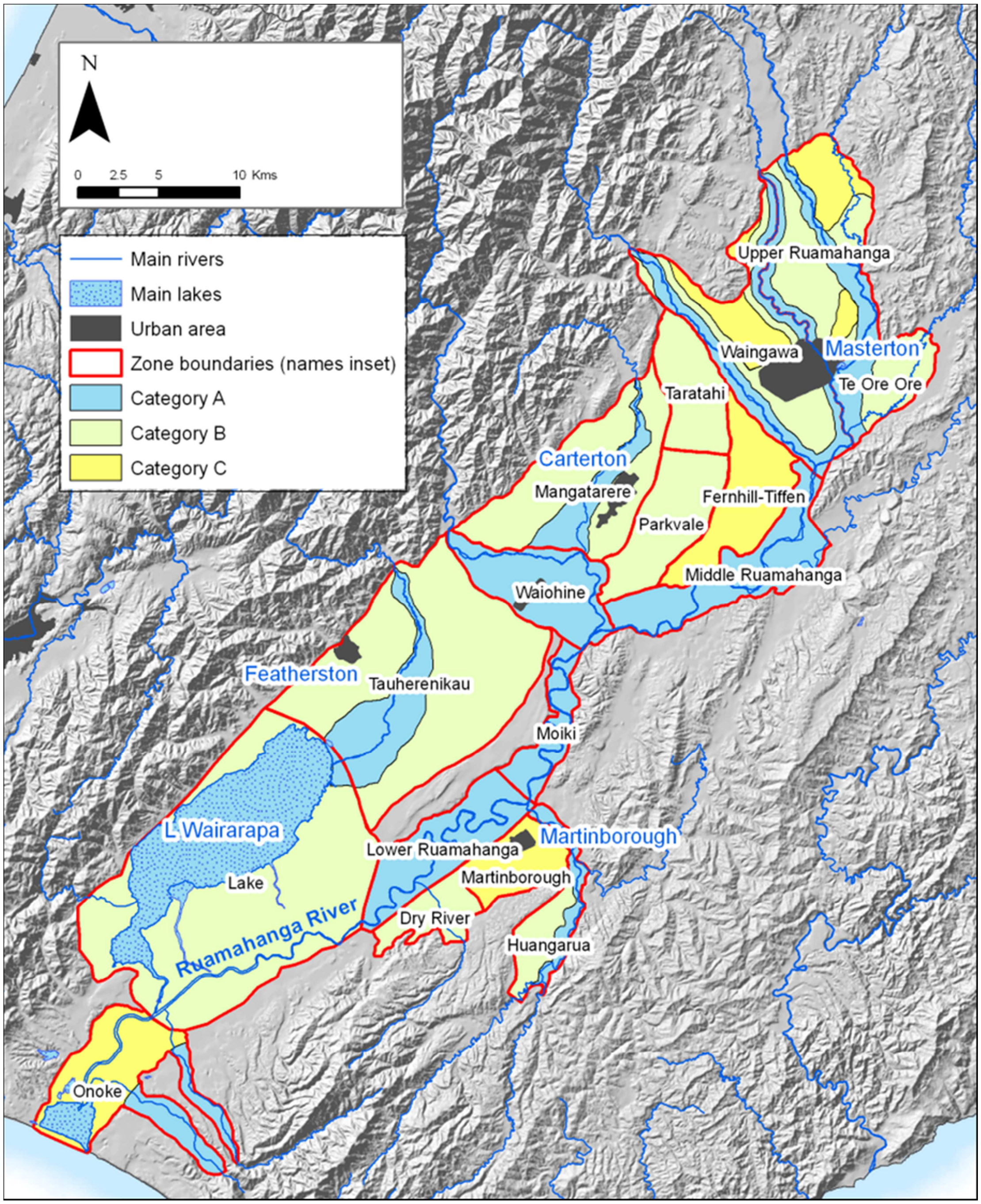

Figure 4: Groundwater zones and the degree of connection with the surface water environment

- Groundwater is in direction connection with surface water
- Some connection- groundwater and surface water
- No connection between groundwater and surface water

1.6 Uses and abstraction from groundwater

Bores and wells pump 83.9 million m^3 from the whaitua groundwater aquifers every year. It is used for drinking, irrigation, livestock watering, industry, and horticulture. Of the groundwater available for extraction, 91% is allocated to irrigation (~77 million m^3) - this is roughly equivalent to filling three Olympic size swimming pools every minute. With 65% of total groundwater (55 million m^3) allocated to dairy pasture and 26 % of total groundwater (22 million m^3) allocated to horticulture, vineyards and other irrigation.

Some of the whaitua's rural and town population rely on groundwater for drinking and stock water. Martinborough use and rely on groundwater for town water supply. Greytown and Featherston use groundwater as a supplementary supply.

Rainfall naturally replaces water pumped from aquifers (recharge). The amount of water in our aquifers will sustain our needs as long as we don't take too much. Recent years have seen large increases in the amount of surface and groundwater used in our region.

When too much groundwater is taken from aquifers:

- The level of groundwater left in aquifers lowers (lowering of the water table).
- There may not be enough water for everyone to use, resulting in competition for water.
- Less groundwater flows into streams - during extended dry periods most or all of the water present in a stream will be from groundwater.
- Land may subside.
- Salt water intrusion may occur – although this is not a problem in the Ruamāhanga whaitua as the deeper aquifers have been blocked by tectonic uplift of sediments and has created a closed system. This closed system eliminates possibilities of salt- water intrusion.

2. Influences on groundwater quality

The chemical composition of groundwater (such as pH, conductivity, turbidity, total organic carbon and major ions) can naturally occur. They are highly variable and depend on where the water comes from, the permeability of the aquifer and land cover and land uses, aquifer rock and the length of time the water is in the aquifer. Other influences are faecal bacteria and nutrients from land use practices.

2.1 Natural processes

As groundwater flows from its point of recharge to point of discharge, its chemical composition is naturally influenced by:

- Source of recharge (rainfall or river flow)
- Land cover
- Soil type and aquifer geological nature (i.e., rock type)
- How fast the water flows through the aquifer

- Confinement and depth of the aquifer system.

Levels of dissolved solids and calcium, magnesium, sodium, potassium, bicarbonate, sulphate and chloride increase the longer the aquifer matrix and groundwater are in contact. Thus slow moving aquifers are likely to have higher levels of naturally occurring ions. Groundwater in the eastern whaitua is influenced by soft marine mudstone rocks which are rich in bicarbonate. Groundwater in the western whaitua is influenced by un-weathered greywacke geology has low levels of ions.

The amount of dissolved oxygen in groundwater can influence the form of elements or chemicals that accumulate in groundwater.

- **Oxygen-rich conditions:** tend to occur in the shallow unconfined and recently recharged aquifers. Nitrogen is in the oxidised form of nitrate-nitrogen.

- **Oxygen-poor conditions:** tend to occur in semi-confined and confined aquifers or where groundwater flow is slow. Nitrogen is in the reduced form of ammoniacal nitrogen.

Manganese, iron, sulphide, methane and arsenic occur naturally and tend to accumulate in groundwater due to a long rock-water contact time and in oxygen-poor conditions. However, these variables can also be introduced to groundwater systems through human activity in the areas of recharge.

3. Land use practices influence of groundwater quality

Land use practices can directly influence groundwater quality especially in shallow and unconfined aquifers. These aquifer systems have a greater groundwater surface water connection. The recharge area influences the water quality of semi-confined and confined aquifer systems if they are in or near an area of intensive land use. In some cases contamination can be due to past land use practices. This makes it hard to gauge if current practices have improved or are causing further degradation in water quality. A study of elevated nitrate nitrogen in the Te Ore Ore aquifers suggested contamination was from fertiliser applied 20 years or more prior to the study.

Agricultural and horticultural land use can influence groundwater quality through additional inputs of nutrients and bacteria into the groundwater system. Sources include:

- effluent, fertilisers and soil cultivation leading to increases in nitrate, ammonia, sulphate, phosphorus and potassium in the groundwater system

- pesticides and herbicides

- over-application of irrigation which can cause leaching of nutrients from the soil

- abstraction of large amounts of water for irrigation – especially from confined groundwater systems can encourage recharge into the system that has a different chemical and bacteria make up and change the chemistry of the aquifer.

Other land uses that impact on groundwater quality

- on-site sewage disposal (septic tanks)

- town sewage discharge to land
- leaching from contaminated sites and landfills.

4. **Groundwater quality in the Ruamāhanga Whaitua** (based on an assessment of nine key variables)

- Median ammonia, iron and manganese concentrations exceeded drinking water or aquatic toxicity guidelines at several sites, mostly in confined aquifers in the lower Wairarapa Valley. This is a reflection of the naturally oxygen-poor conditions and the slow through-flow of water (resulting in greater rock-water interaction).
- While median nitrate concentrations are below the DWSNZ MAV of 11.3 mg/L, these concentrations are above the aquatic toxicity trigger value of 1.7 mg/L in 16 bores (Figure 1).
- Nitrates concentrations that are considered 'elevated' (>3 mg/L) or 'highly elevated' (>7 mg/L) occur in 25% of the monitoring bores. Nitrates are more likely to be elevated in unconfined aquifers as 40% of monitoring bores in unconfined aquifers and 16% of monitoring bores in semi-confined or confined aquifers have median nitrate concentrations above 3 mg/L.
- Nitrate concentrations are highest in a bore in an unconfined aquifer at Te Ore Ore (Masterton) and shallow unconfined aquifers around Mangatarere (Carterton).
- Three deep groundwater bores in the Ruamāhanga Whaitua exceed the drinking water standards for arsenic (tested on one occasion in March 2009). None of these bores are used for drinking water supply. This is a reflection of the naturally oxygen-poor conditions and the slow through-flow of water (resulting in greater rock-water interaction).
- Lead concentrations are generally low and suggests there has been no serious lead contamination of groundwater that can be attributed to human activities in the Ruamāhanga Whaitua.
- Pesticides and herbicides have not been detected in groundwater in any of the monitoring bores.

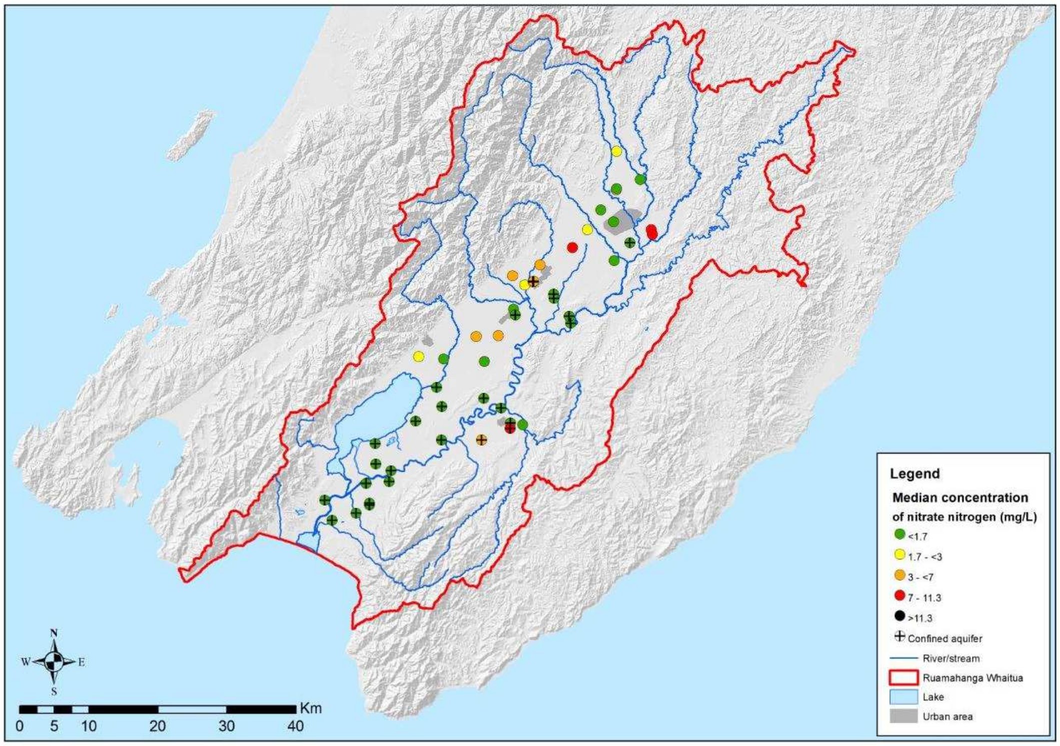

Figure 5: Median nitrate nitrogen concentrations for monitoring bores in the Ruamāhanga Whaitua sampled quarterly over August 2005 to July 2010.

- nitrate is below the trigger value for aquatic toxicity[1] (1.7 mg/L).
- elevated nitrate
- highly elevated nitrate

4.1 Groundwater drinking water quality index

Unconfined or semi-confined aquifers generally have the best water quality. Despite human influence, their high recharge volumes are able to prevent contaminant accumulation in the aquifers. The Drinking WQI classified:

- 42% (20) of the 48 monitoring bores as being 'excellent' for drinking
- 25 % (12) of the bores as 'good' for drinking
- 33% (16) bores as 'fair' or 'poor' for drinking. These are mostly located in confined aquifers around the lower Wairarapa valley where natural processes tend to make the groundwater unsuitable for drinking.

[1] Note that since the Tidswell et al. (2012) report, the nitrate toxicity guidelines have been updated (see Hickey 2013).

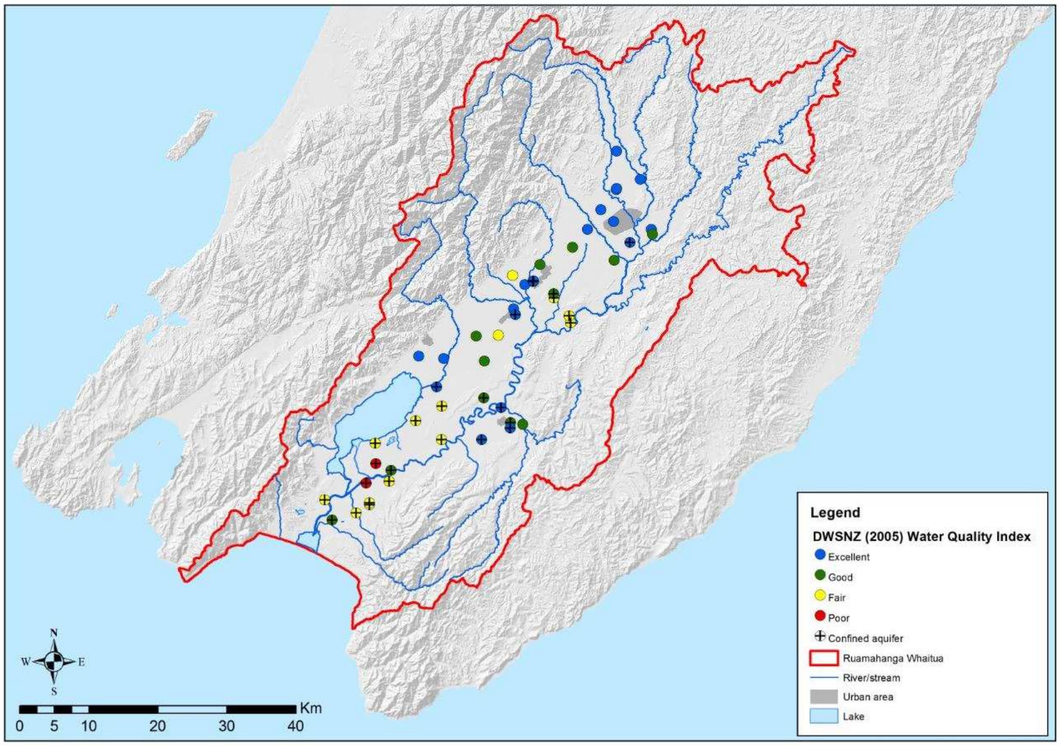

Figure 6: Drinking WQI classifications for 48 monitoring bores in the Ruamāhanga whaitua. A black cross indicates where a bore is in a confined aquifer.

4.2 Aquatic ecosystems water quality index

The guideline values used in the Aquatic Ecosystem WQI are lower (i.e. more stringent) than values used in the Drinking WQI. As a result, 50% (24) of the 48 monitoring bores are considered 'fair' or 'poor' from an aquatic ecosystem perspective. The poor water quality rating generally reflects the more stringent aquatic toxicity guidelines for nitrate and zinc.

- Half of the 24 bores considered 'fair' or 'poor' are located in confined aquifers (mainly in the lower Wairarapa Valley) where discharge to surface water is minimal. Many of these bores fail to meet acceptable levels of ammoniacal nitrogen – a reflection of the naturally oxygen-poor aquifers in which they are located.

- The remaining 12 located in the semi confined or unconfined aquifers fail to meet aquatic toxicity trigger value for nitrate. Poor water quality is of more concern because these aquifers are more likely to discharge water as springs or contribute flow to rivers and streams (groundwater and surface water well connected)

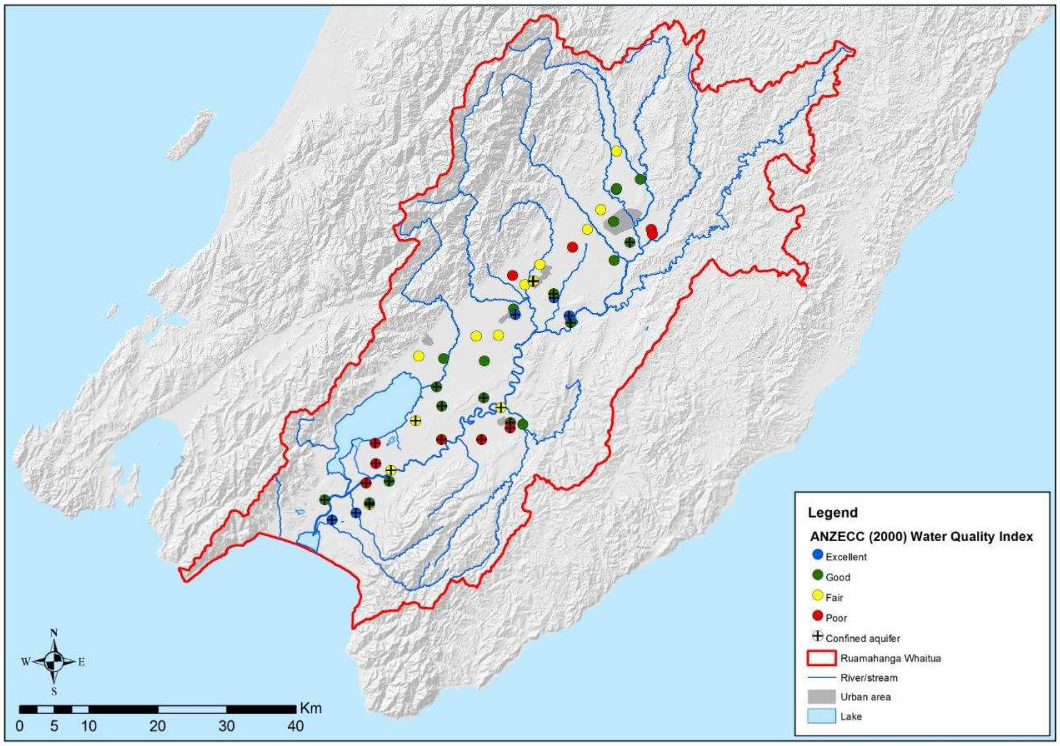

Figure 7: Aquatic Ecosystem WQI classifications for 48 monitoring bores in the Ruamāhanga whaitua. A black cross indicates where a bore is in a confined aquifer.

Analysis of monitoring data from 2005 to 2010 indicates that:

- Groundwater quality for drinking water is generally relatively good
- Ammonia, iron and manganese exceed DWSNZ (2005) MAVs in a number of bores in the Whaitua. These bores are generally located in semi-confined to confined oxygen-poor aquifers that naturally exhibit elevated concentrations of these elements (as a result of longer residence time within the aquifer and greater rock-water interaction).

From an aquatic ecosystem toxicity perspective, groundwater quality is not so good. The thresholds for aquatic toxicity are considerably lower than those for potable water supply. Nitrate concentrations are elevated or highly elevated in about a quarter of the monitoring bores, mostly located in unconfined or semi-confined aquifers. Along with nitrate, elevated sulphates and occasional detection of E. coli in shallow, unconfined aquifers of the Ruamāhanga Whaitua indicate the impact of intensive land use on groundwater quality in these aquifers.

5. Is groundwater quality getting better or worse?

There was little change in groundwater quality during the period 2005 to 2010.

- Seven bores show an increase or decrease in iron and manganese. The reason(s) for these changes are unclear but could be due to changing groundwater flow patterns (due to a climate cycle or a change in water abstraction), or changes in concentration in the recharge water These bores are located in confined aquifers of the mid to lower Ruamāhanga valley. Iron and manganese frequently co-occur in groundwater naturally under oxygen poor conditions in confined aquifer.

- Groundwater quality has improved with decreasing trends of nitrate at five bores (three upper Ruamāhanga Valley and two in the middle Ruamāhanga Valley). In one case, nitrate concentrations have been decreasing since 1998 in a bore in an unconfined aquifer on Norfolk Road near Masterton.

6. Knowledge gaps

- The recharge area and age of groundwater is largely unknown for many monitoring bores in the Wairarapa. Water can enter a recharge area aquifer meters or kilometres upgradient of where it is drawn out or sampled for water quality. Mapping groundwater flow paths to the bore is difficult and costly. Limited understanding of contaminant flow paths to aquifer systems limits the capacity to manage activities which can degrade water quality. GWRC is currently undertaking work to understand the source, flow path and migration time of water to groundwater bores in the monitoring network.

- Fault structures prevent interaction between confined aquifer and the sea in the lower Wairarapa Valley. However, the effects on sea level change on the tidal zone around Lake Wairarapa and the shallow aquifers are unknown.

- We know where the areas of surface and groundwater interaction are. We do not know the proportion of flow that groundwater contributes to surface water. This would be useful in areas where groundwater nitrate concentrations are highly elevated.

- There is a growing awareness for the need to protect groundwater ecosystems in their own right. Groundwater ecosystems include organisms such as stygofauna and bacteria that live within the pore spaces of the aquifer. Not much is known about stygofauna and groundwater bacteria, however, it is thought they play a vital role in cleansing groundwater and maintaining aquifer productivity.

Figure 8: The Stygofauna species, Cruregen fontanus belongs to the isopod family (same group as pill bugs and slaters). It can grow to 20mm long and endemic to New Zealand. This specie of Stygofauna can be found in the Ruamahanga whaitua. *(Souce N. Boustead, NIWA)*

For more information

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Appendix 1: Technical notes about groundwater

While median nitrate concentrations are below the DWSNZ (2005) MAV of 11.3 mg/L at all sampling sites in the whaitua, concentrations are above the aquatic toxicity trigger value of 1.7 mg/L in 16 bores (Figure 1). Further, nitrate concentrations are considered 'elevated' (>3 mg/L) or 'highly elevated' (>7 mg/L) in 25% of the monitoring bores. Nitrates are more likely to be elevated in unconfined aquifers: 40% of monitoring bores in unconfined aquifers and 16% of monitoring bores in semi-confined or confined aquifers have median nitrate concentrations above 3 mg/L. Nitrate concentrations are highest in a bore in an unconfined aquifer at Te Ore Ore (near Masterton); and shallow unconfined

Appendix 2. Groundwater monitoring

How does GWRC monitor groundwater quality?

GWRC has monitored groundwater quality in the Wairarapa since 1997.

Since 2003 monitoring has occurred four times a year at 48 bores. Groundwater is tested for 31 different variables, including the nine key indicators described in Table 1: pH, conductivity, turbidity, faecal indicator bacteria, total organic carbon, dissolved nutrients and major ions. The monitoring bores represent the range of aquifer conditions (confined, semi-confined and unconfined) and spatial coverage of aquifers within the geologically complex whaitua.

Groundwater quality: how it is assessed

Table 1 is a summary of the current state of groundwater quality across the whaitua is assessed from August 2005 to 31 July 2010, as reported by Tidswell et al. (2012). Some of the nine key variables selected are considered indicators of human impact, human and ecological health risk, or natural groundwater chemistry.

Table 1: Key indicators used to understand the quality of groundwater in the Ruamāhanga Whaitua.

(Source: After Daughney & Randall 2009)

Variable	Explanation for inclusion as a key variable
Total dissolved solids (TDS)	TDS can provide a useful indicator for spatial and/or temporal changes in abstraction, salt water intrusion, recharge mechanism, etc. Although there are no recognised health or ecosystem risks associated with elevated TDS concentrations in drinking water, the DWSNZ (2005) includes an aesthetic GV of 1,000 mg/L (taste threshold) and ANZECC (2000) contain a stockwater threshold of 2,000–2,500 mg/L (the point at which productivity of stock drinking the water may decline).
Nitrite nitrogen (Nitrite)	Consumption of groundwater with excessive nitrite concentrations can adversely affect human and stock health. DWSNZ (2005) and ANZECC (2000) specify a MAV of 0.06 mg/L and a stockwater TV of 30 mg/L.
Nitrate nitrogen (Nitrate)	Nitrate is routinely monitored for health and environmental reasons. Consumption of groundwater with excessive concentrations of nitrate can adversely affect human (and stock) health, and elevated concentrations of nitrate in groundwater can contribute to eutrophication of surface waters. The DWSNZ (2005) specify a MAV of 11.3 mg/L for nitrate. For assessing aquatic toxicity a threshold of 1.7 mg/L (Hickey & Martin 2009) is used in this report.
Ammoniacal nitrogen (Ammonia)	In the absence of nitrate in the groundwater chemical profile, ammonia can show whether land use is having an impact on groundwater quality, or if the natural conditions in the aquifer makes detection of land use impacts difficult. The DWSNZ (2005) specifies a GV of 1.5 mg/L and ANZECC (2000) specifies a lowland river TV of 0.021 mg/L. ANZECC (2000) also specifies thresholds for aquatic toxicity; although these TVs vary with pH, for simplicity of reporting, the default toxicity TV (95% species protection level and applicable at pH 8.0) of 0.9 mg/L has been used here.
Iron (Fe)	There are no recognised health or ecosystem risks associated with groundwater enriched with dissolved iron but elevated concentrations in groundwater may indicate the possible occurrence of arsenic, which is not routinely monitored in groundwater in the Wellington region. Iron is only soluble under oxygen-poor conditions, so complements the interpretation of ammonia and nitrate concentrations in groundwater. The DWSNZ (2000) lists an aesthetic GV for iron of 0.2 mg/L (taste threshold).
Manganese (Mn)	Due to risks to human health and freshwater ecosystems, the DWSNZ (2005) specifies a MAV of 0.4 mg/L and the ANZECC (2000) guidelines include an aquatic toxicity TV (95% species protection level) of 1.9 mg/L. The DWSNZ (2005) also includes an aesthetic GV of 0.04 mg/L (taste threshold and prevention of staining of laundry and whiteware). Like iron, manganese is only soluble in oxygen-poor groundwater and so can aid the understanding of measured concentrations of nitrate.
Fluoride	Consumption of groundwater with excessive concentrations of fluoride can adversely affect human and stock health. The DWSNZ (2005) and ANZECC (2000) specify a MAV of 1.5 mg/L and a stockwater TV of 2 mg/L for fluoride, respectively.
Lead	Consumption of groundwater with excessive concentrations of lead can adversely affect human and aquatic ecosystem health. The DWSNZ (2005) and ANZECC (2000) specify a MAV of 0.1 mg/L and an aquatic toxicity TV (95% species protection level) of 0.0034 mg/L for lead, respectively.
Escherichia coli (*E. coli*)	*E. coli* is a species of bacteria that indicates the presence of faecal matter in groundwater. The DWSNZ (2005) and ANZECC (2000) specify a MAV of <1 cfu/100mL and a stockwater TV (median) of 100 cfu/100mL for *E. coli* respectively.

The median results for the 5-year period are generally compared to:

- Drinking Water Standards New Zealand (DWSNZ) (2005) 'maximum acceptable values' (MAV) for drinking water (potable supply).

- ANZECC (2000) 'trigger values' for aquatic ecosystem toxicity and/or stockwater. However, aquatic ecosystem toxicity is most relevant in places where groundwater interacts with surface water ecosystems – in springfed streams or wetlands, or where waterways receive significant flow from groundwater.

In addition to the nine key variables, the Drinking Water Quality Index (WQI) and Aquatic Ecosystem WQI are used to 'rank' water quality across monitoring sites[2].

- WQI – summarises overall groundwater quality for potable use

- Aquatic Ecosystem WQI – summarises the potential for toxicity-related impacts of groundwater discharge to aquatic ecosystems.

Appendix 3. Water Quality Index

The Canadian WQI, on which the indices in this section have been based, is based on three elements:

- *Scope*: the number of variables that do not meet the assigned compliance thresholds (known as the *objectives*) on at least one sampling occasion.

- *Frequency*: the frequency with which individual sample results fail to meet the assigned compliance thresholds.

- *Magnitude*: the amount by which individual sample results fail to meet the assigned compliance thresholds.

The three elements are combined to produce a single WQI value between 0 and 100 where the higher the value, the better the water quality (see Tidswell et al. (2012) for calculation details). Once the WQI value has been determined, water quality is ranked by assigning it to one of the four categories outlined in Table 2. CCME (2001) note that the assignment of WQI values to these categories is somewhat subjective; the categories presented in Table 2 have been drawn from Auckland Regional Council (ARC 2010) who also evaluated groundwater quality for potable use and aquatic ecosystem purposes (but using a different suite of variables).

Table 2: Class thresholds in the two water quality indices used to assess the suitability of groundwater for potable drinking water and aquatic ecosystems purposes

(Source ARC 2010)

Class	Drinking WQI	Aquatic ecosystems WQI
Excellent	**>90**	**>90**
Good	**70–90**	**75–90**
Fair	**50–70**	**60–75**
Poor	**<50**	**<60**

[2] The indices have only been used once by GWRC to communicate overall water quality in terms of suitability for drinking and aquatic ecosystems.

Thirteen water quality variables were selected for inclusion in the Drinking WQI (Table 3). Most of these variables align with those used by ARC (2010), with the compliance thresholds drawn from the DWSNZ (2005); these include seven variables which have maximum acceptable values (MAV) for inorganic determinands of health significance, and six variables which have guideline values (GV) for aesthetic determinands. For ease of calculation, all variables were given equal weighting in the WQI; in practice, variables that exceed an MAV should probably carry a higher weighting to reflect their greater importance from a human health perspective.

The aquatic ecosystems WQI is based on key nutrients and trace elements that have at times been present at elevated concentrations in some GQSoE samples (Table 3). The compliance thresholds have largely been taken from the ANZECC (2000) freshwater toxicity trigger values (95% species protection level). Dissolved reactive phosphorus (DRP), although not a toxicant, was initially included in the WQI since it is a key soluble nutrient that has the potential to contribute to nuisance plant growth in surface water ecosystems. However, the only available ANZECC (2000) trigger value (0.010 mg/L for lowland streams) was considered overly conservative and would have severely biased WQI calculations (almost all of the 71 bores recorded a DRP concentration above 0.010 mg/L on one or more sampling occasions over the reporting period).

Table 3: Groundwater variables and guideline thresholds used in the Drinking WQI and the Aquatic Ecosystems WQI

Variable	Drinking WQI[1] DWSNZ (2005) (mg/L)	Aquatic Ecosystems WQI ANZECC (2000) toxicity TV (mg/L)
Dissolved boron	**<1.4**	
Fluoride	**<1.5**	
Dissolved lead	**<0.01**	**0.0034**
Dissolved manganese	**<0.4**	**1.94**
Nitrate nitrogen	**<11.3**	**1.7**
Nitrite nitrogen	**<0.06**	
E. coli	**<1**	
Chloride	**<250**	
Total hardness	**<200**	
Dissolved iron	**<0.2**	
pH (Lab)	**7.0–8.5**	
Dissolved sodium	**<200**	
Sulphate	**<250**	
Total dissolved solids	**<1,000**	
Dissolved zinc	**<1.5**	**0.008**
Ammoniacal nitrogen	**<1.5**	**0.9**

[1] DWZNZ (2005) MAVs denoted by grey shading, GVs are un-shaded.

Note that:

- The Drinking WQI is being applied to natural groundwater – poor quality water in some bores could be brought up to potable supply standards through appropriate treatment;
- For simplicity, the thresholds for the Aquatic Ecosystems WQI have been set on the assumption that groundwater makes up the entire surface water flow – as noted in Section 4.2.1(b), in reality, there will be some dilution of groundwater by surface water.