Environment Southland

State of the Environment: Groundwater Quality Technical Report

Liquid Earth
May 2010

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Executive Summary

Groundwater is an extremely valuable resource for the Southland Region. Groundwater forms an integral part of the hydrological cycle and has a significant influence on aquatic ecosystems in riverine and wetland habitats. Significant use is also made of groundwater for domestic, municipal, industrial and farm water supplies. In addition, the assimilative capacity of the regions groundwater systems plays an important role in the treatment and disposal of point and non-point source contaminant discharges.

This report provides technical background to support the Southland Region State of the Environment Report. The report reviews factors that influence groundwater quality across the Southland Region and provides an assessment of the current state and trends in groundwater quality to address the question '*Is it safe for us to drink our groundwater?*'

Analysis of available data indicates that groundwater quality in the Southland Region is influenced by a range of factors including geology, the nature and source of aquifer recharge and the overall rate of groundwater circulation within an aquifer system. In particular, the carbonate geology of Tertiary sediments in the Central Plains area exerts a significant influence on major ion chemistry in the overlying alluvial gravel aquifers. Deposition of aerosol salts in local rainfall also exerts a significant influence on groundwater chemistry which declines with distance inland from the south coast. The presence of reducing (low-oxygen) conditions also controls water chemistry in many deeper aquifers particularly with regard the presence of iron and manganese which may have a significant impact on aesthetic water quality and, in the case of manganese, exceed health standards.

The influence of human (land use) activities on groundwater quality is evident in the elevated nitrate concentrations observed across many of the more intensively farmed parts of the Southland Region. Analysis of temporal variability also shows significantly more sites exhibit statistically significant increases in major ion concentrations than show decreasing concentrations. This observation is interpreted to reflect the cumulative effect of ongoing land use intensification across much of the Southland Region which has accelerated in many areas over the last two decades.

Overall, groundwater quality is suitable for potable supply throughout a majority of Southland aquifers. The main groundwater quality issue identified by monitoring is the high incidence of microbial contamination which can result in immediate and acute impacts on human health. However, in a majority of instances, the occurrence of microbial contamination is a localised issue which can be significantly reduced by adequate wellhead protection and ensuring bores are located appropriately with respect to potential contaminant sources. Relatively simple, low-cost treatment devices are also available to ensure microbial contamination does not adversely affect potable water supplies.

Naturally elevated manganese and iron concentrations are a feature of many aquifer systems in the Southland Region, particularly those where reducing conditions are prevalent, such as the Gore Lignite Measure aquifers in Eastern Southland. Elevated concentrations of these parameters may have a significant adverse effect on aesthetic water quality and typically make the water unpalatable before concentrations (of manganese) exceed health standards.

Nitrate concentrations exceeding MAV occur in around 7 percent of bores sampled. These bores tend to occur in known nitrate 'hotspot' areas or subject to localised contamination.

1.0 Introduction

Groundwater is an extremely valuable resource for the Southland Region. Groundwater forms an integral part of the hydrological cycle and has a significant influence on aquatic ecosystems in riverine and wetland habitats. Significant use is also made of groundwater for domestic, municipal, industrial and farm water supplies. In addition, the assimilative capacity of the regions groundwater systems plays an important role in the treatment and disposal of point and non-point source contaminant discharges.

This report provides technical background to support the Southland Region State of the Environment Report, with a particular emphasis on the suitability of the groundwater quality for drinking water supply. The report reviews factors that influence groundwater quality across the Southland Region and provides an assessment of the current state and trends in groundwater quality to address the question '*Is it safe for us to drink our groundwater?*'

1.1 Regional Hydrogeology

The alluvial gravel deposits which mantle the valleys and plains of the Southland Region host an extensive groundwater resource that is widely utilised for potable (domestic, municipal, industrial and stock) water supply.

A majority of the regions aquifer systems are shallow and unconfined, receiving a significant proportion of recharge from land surface infiltration. As a consequence, groundwater quality in many of these aquifer systems can be directly influenced by contaminants introduced as a result of overlying land use.

Localised confined aquifers are present in some parts of the Southland Region where alluvial sediments are thickest. Extensive confined aquifers are also present in the Tertiary limestone and sandstone sediments which underlie the alluvial gravels, particularly in Eastern, Coastal and Central Southland. These confined aquifers are typically isolated from the land surface by intervening layers of low permeability sediments (termed *aquitards*) which reduce the potential for direct impacts on water quality from overlying land use. However, groundwater quality in confined aquifers is often influenced by natural geochemical changes that can also affect the suitability of groundwater for drinking water supply.

For the purposes of resource management the shallow unconfined aquifer systems across Southland have been subdivided into the 29 groundwater zones shown in **Figure 1.**

These groundwater zones effectively encompass separate groundwater systems and are utilised as a framework for the monitoring, investigation and management of groundwater resources in the Southland Region. These groundwater zones are in turn classified into four basic aquifer types which aggregate spatially separate aquifer systems on the basis of similarities in geology, geomorphology, groundwater/surface water interaction and observed variations in groundwater quality and levels (Environment Southland, 2002). The aquifer types defined are:

- **Riparian Aquifers**: highly permeable unconfined aquifers underlying the recent floodplains of the major river systems. Riparian aquifers exhibit a high degree of interaction with surface water which influences both the quality and quantity of the resource
- **Terrace Aquifers**: aquifer systems underlying elevated alluvial terraces along the margins of the main river valleys. These aquifer systems are recharged by rainfall and runoff from the surrounding hills and commonly have limited interaction with surface water, except where springs originate along the terrace margins
- **Lowland Aquifers:** Lowland aquifers occur extensively across the plains and downlands of the Waimea and Southland Plains. These aquifers are remnants of older, highly weathered glacial outwash gravel surfaces which are commonly dissected by numerous first and second-order streams to form a gently undulating topography
- **Fractured Rock Aquifers**: Fractured rock aquifers occur within the basement rocks of the Hokonui Hills and Catlins area where fracturing and jointing in the rock mass is sufficient to host a relatively limited groundwater resource.

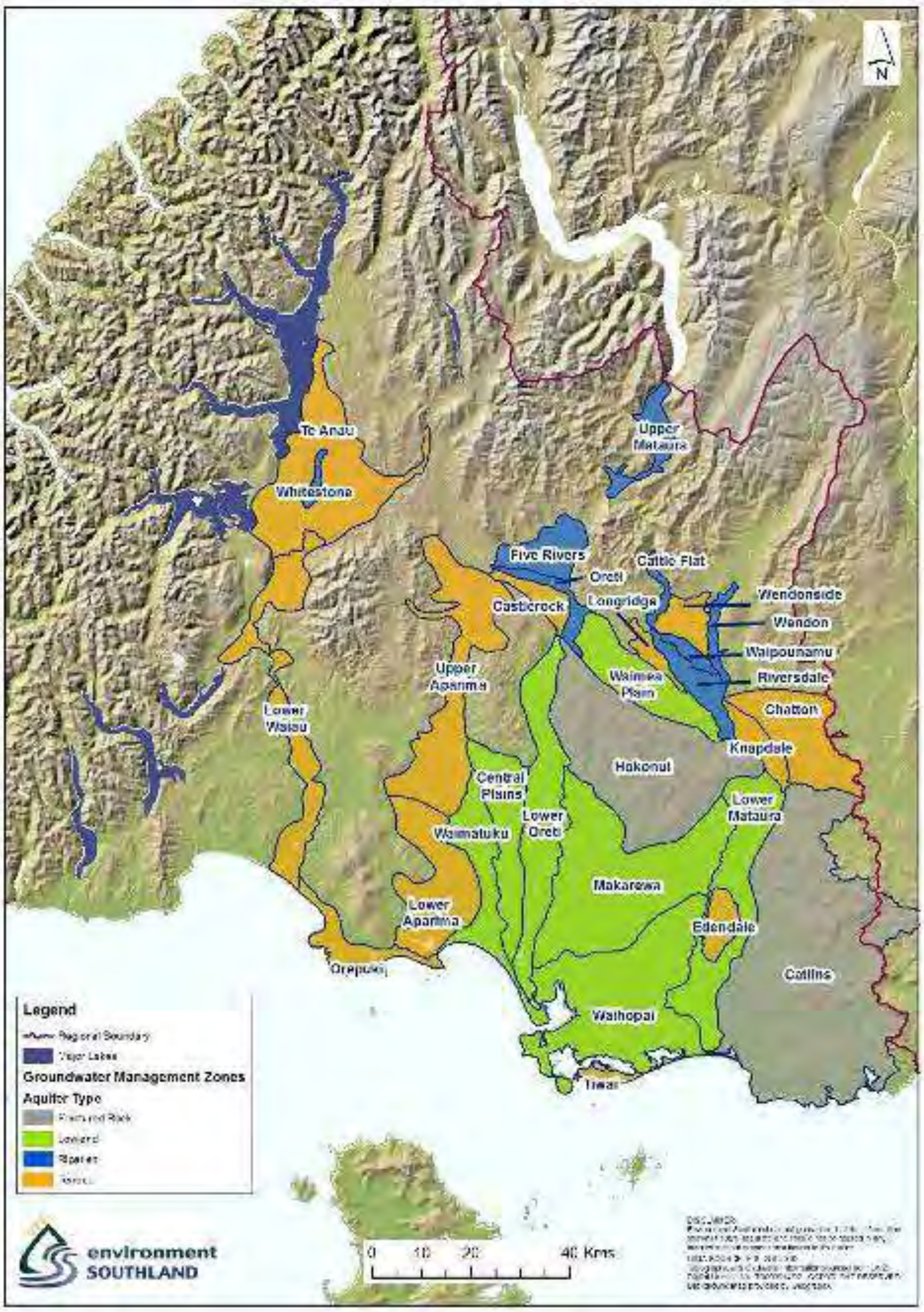


Figure 1. Groundwater management zones in the Southland Region

Due to their depth and relatively limited development, the spatial extent of confined aquifers in the Southland Region is poorly defined. **Figure 2** shows the approximate extent of confined aquifers identified in the alluvial gravel deposits as well as areas of the underlying Tertiary deposits that may host a groundwater resource of some significance.

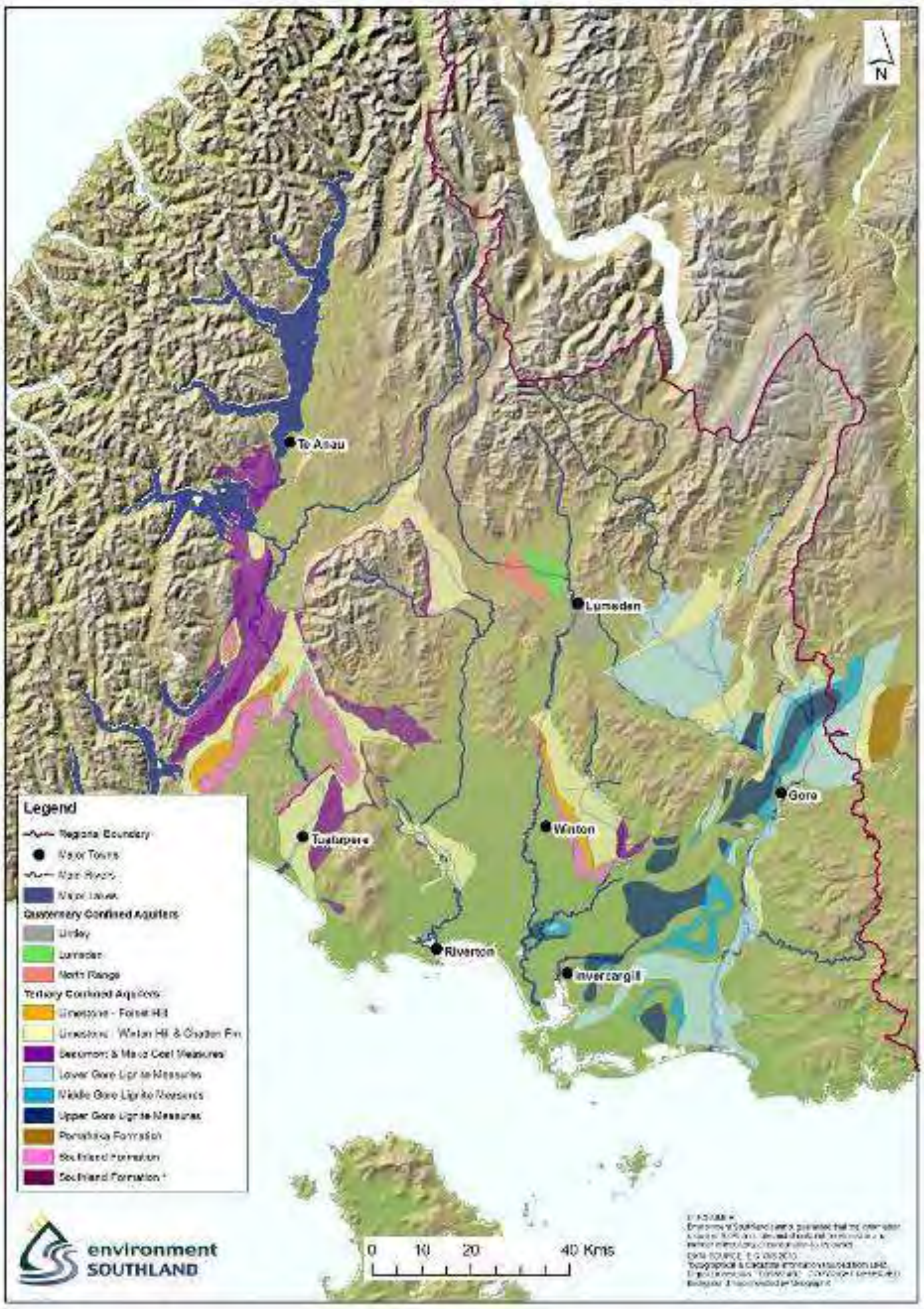


Figure 2. Approximate extent of confined aquifers in the Southland Region (modified from Lincoln Environmental and MWH, 2003)

As described in the **Section 2**, the physical characteristics of aquifer systems in the Southland Region can have a significant influence on both the quality of groundwater in its natural state and the potential for impacts resulting from human activities.

2.0 Groundwater Quality

Groundwater quality at any point within an aquifer system can be influenced by a range of factors that reflect the physical characteristics of the aquifer system itself or occur as a consequence of human activity.

Natural factors influencing groundwater quality include the nature and source of aquifer recharge, the rate and nature of groundwater flow through an aquifer system and geochemical processes resulting from the interaction between groundwater and the physical environment. Human (anthropogenic) influences on groundwater quality include the introduction of contaminants into the aquifer system as a result of land use activities or alterations in the natural flow of groundwater resulting from pumping. The following section provides a brief overview of some of the important factors influencing groundwater quality in the Southland Region.

2.1 Natural Factors Influencing Groundwater Quality

2.1.1 Aquifer recharge

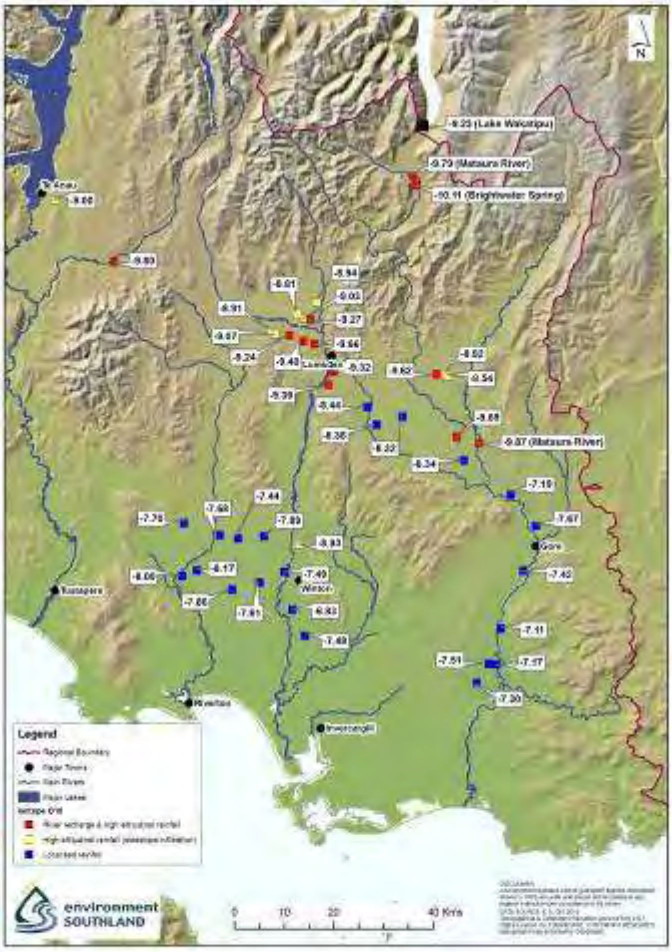
Aquifer systems in the Southland Region are typically recharged by infiltration of local rainfall, although Riparian and Terrace aquifers may also be recharged in part by flow loss from rivers and streams. While recharge from surface waters typically contains relatively low concentrations of dissolved ions, recharge via soil infiltration (i.e. land surface recharge) is often enriched with respect to parameters such as sodium, potassium, chloride and sulphate and other chemical species which accumulate during passage of water through the soil zone (Daughney, 2004). Depending on land use, recharge infiltrating through the soil zone may also contain elevated concentrations of nitrate, in contrast with the relatively low concentrations typically present in recharge from rivers and streams. As a consequence, the relative proportions of aquifer recharge derived from different recharge sources can influence groundwater quality in an aquifer system. Variations in groundwater quality reflecting the nature of aquifer recharge are evident in many aquifer systems in the Southland Region.

Land surface recharge in Southland typically occurs during the period between late autumn and early spring. Combined with relatively low rates of nutrient uptake by plants over this period, winter recharge can act to flush dissolved ions through the soil zone into underlying groundwater. This effect can be exacerbated by land management practices such as strip grazing in winter or soil cultivation in spring. These land uses may act to concentrate and/or release nutrients into infiltrating soil water resulting in seasonality in the concentrations of dissolved ions in underlying groundwater. Seasonality in the quality of groundwater recharge is most commonly observed in potassium and nitrate concentrations in shallow groundwater (Daughney, 2004), with concentrations typically peaking in mid to late spring depending on climate variability.

Box 1. Where is Southlands groundwater sourced from?

Oxygen in the atmosphere occurs in two naturally occurring isotopic forms ^{18}O and ^{16}O. The relative abundance of these two forms changes according to well documented temperature-related effects (termed *fractionation*) during evaporation and condensation (Stewart and Morgenstern, 2001). As a consequence, the ratio between ^{18}O and ^{16}O can be utilised to provide an indication of likely recharge resource for an aquifer system with recharge from lowland rainfall being enriched with respect to ^{18}O compared to that occurring in alpine precipitation (the major source of flow in the main river systems).

The figure below shows a plot of ^{18}O recorded in groundwater across the Southland Region. The data show a progressive reduction in ^{18}O values (i.e. more negative) from coastal areas across the Waimea Plain and Oreti Basin reflecting a gradual increase in elevation (reaching approximately 300 m above mean sea level at Mossburn) of local rainfall recharge. Bores located along the riparian margin of the Oreti and Mataura Rivers show more negative values, reflecting the contribution of recharge from the alpine rivers to these aquifer systems. The data confirm local rainfall as the dominant source of groundwater recharge across the Southland Region with significant recharge from the major river systems restricted to their immediate riparian margins. The data do not indicate any recharge contribution from external sources (such as discharge from Lake Wakatipu into the headwaters of the Mataura catchment).



Oxygen-18 concentrations in Southland groundwater

2.1.2 Water-Rock Interaction

Interaction with geological materials forming the host aquifer (termed *water-rock interaction*) commonly influences natural groundwater chemistry. In general, surface water and recently recharged groundwater tend to be dominated by calcium (Ca) and bicarbonate (HCO_3^-) ions due to the rapid dissolution of carbonate minerals. However, with increasing age (referred to in terms of *residence time*) groundwater commonly becomes more enriched with parameters such as sodium (Na) and chloride (Cl) as a result of the progressive dissolution of minerals from the aquifer materials. These ions have much higher solubility's so are able to accumulate to much higher concentrations over time. To describe this process geochemists commonly refer to water 'types' which classify chemistry according relative concentrations of the major ionic species present. Based on the observed relationships between dissolved ions, the natural evolution of groundwater chemistry can be analysed in terms of groundwater 'type' and inferences made with regard the nature of groundwater flow through an aquifer system.

In general, aquifer systems in the Southland Region are comprised of greywacke and quartz gravels which exert a relatively subtle effect on groundwater chemistry. Daughney (2004) identified increases in sodium (Na), chloride (Cl), bromide (Br), fluoride (F) and silica (SiO_2) in older, more evolved groundwaters in Southland.

Geology exerts the most direct influence on groundwater quality in the Southland Region in the Central Plains area west of the Oreti River and south of the Taringatura Hills. In this area dissolution of carbonate minerals derived from limestone deposits in the Kauana, Forest Hill and Isla Bank areas, results in significantly elevated hardness (further discussed in **Section 6**). Hardness is essentially a measure of the total concentration of calcium and magnesium ions in solution which, while not necessarily a health issue for potable water, may cause problems with aesthetic water quality due to the formation of an insoluble residue when used with soap, or the formation of a hard scale in pipes and hot water cylinders.

Geology also influences groundwater quality in waterbearing intervals within the extensive Tertiary lignite measure deposits present across Eastern Southland. In these aquifers the presence of organic material acts to promote development of reducing (low oxygen) geochemical conditions which causes reduction of iron pyrite in the lignite materials which in turn results in high dissolved iron concentrations in groundwater in these aquifers (further discussed in **Box 2**)

2.1.3 Biological and geochemical evolution of groundwater

In addition to changes in chemical composition resulting from the interaction of groundwater with aquifer materials, groundwater in an aquifer system may also undergo a relatively complex range of biological and chemical reactions which affect natural water quality.

Organic matter in soils is naturally degraded by soil microbes which produce high concentrations of dissolved carbon dioxide in water infiltrating through the soil zone. This process lowers the pH by increasing the carbonic acid (H_2CO_3) concentration in soil water and underlying groundwater.

Low pH is a common feature in many shallow unconfined aquifer systems recharged by rainfall infiltration in the Southland Region where pH values less than 6 are not uncommon. While the low pH of such groundwater does not, in itself, present any significant risk to drinking water the, *Drinking*

Water Standards for New Zealand 2008 specify an aesthetic guideline value of between 7.0 to 8.5 to avoid the potential for corrosion of metal pipes and fittings which may elevate concentrations of heavy metals in water used for potable supply.

The acidic nature of infiltrating groundwater initiates a range of weathering reactions with geological materials in the underlying aquifer. These reactions commonly result in bicarbonate (HCO_3^-) being the most abundant anion in shallow groundwater.

As groundwater moves through an aquifer system it may undergo many other chemical reactions which involve changes in chemical state and facilitate the gradual evolution of water quality along a particular groundwater flow path. These reactions include:

- Acid-base reactions;
- Precipitation and dissolution of minerals;
- Sorption and ion exchange;
- Oxidation-reduction reactions; and
- Biodegradation

Oxidation-reduction reactions (referred to as *redox* reactions) are an important process influencing groundwater in many aquifers in the Southland Region. These reactions essentially involve the transfer of electrons between ions in solution and are facilitated by bacteria in the aquifer system which utilise this process as an energy source (McMahon et al, 2009). Bacterially mediated redox reactions involve sequential reactions with oxygen, nitrate, manganese, iron, sulphate and finally carbon dioxide, and result in the conversion of these ions to a reduced state. The resulting reduced forms of these ions include ammonia (NH_4^+), dissolved manganese (Mn^{2+}), ferrous iron (Fe^{2+}), hydrogen sulphide (H_2S) and methane (CH_4) which may commonly affect the suitability of drinking water for potable supply due to effects on aesthetic water quality.

Due to the sequential nature of redox processes it is not uncommon to observe progressive declines in dissolved oxygen and nitrate concentrations followed by the appearance of dissolved manganese (Mn^{2+}) and ferrous iron (Fe^{2+}) along a groundwater flow path.

Box 2: Dissolved Iron in Groundwater

The effects of redox reactions in groundwater in Southland are commonly observed in deeper groundwater which may have elevated concentrations of manganese or iron. These effects are particularly pronounced in wells drawing water from confined aquifers in the Tertiary lignite measure sediments in Eastern Southland. The very high concentrations of dissolved (ferrous) iron observed in these aquifers can result in iron staining on water tanks, handbasins and toilets and even laundry, and affect the palatability of the water. If not properly managed through appropriate control measures, such elevated iron concentrations in groundwater can also result in the proliferation of iron bacteria which may cause issues associated with blockages/fouling in pumping and distribution systems.

2.1.4 Groundwater residence time

Under natural conditions groundwater moves in three dimensions through an aquifer system from areas of recharge to points of discharge. The route taken by groundwater flowing through any particular part of an aquifer system is termed the groundwater flow path and may vary in extent from tens of metres to many kilometres in the horizontal direction (following the natural piezometric gradient) and up to the total aquifer thickness in the vertical dimension. **Figure 3** shows a schematic representation of the length and travel time of various flow paths through an aquifer system.

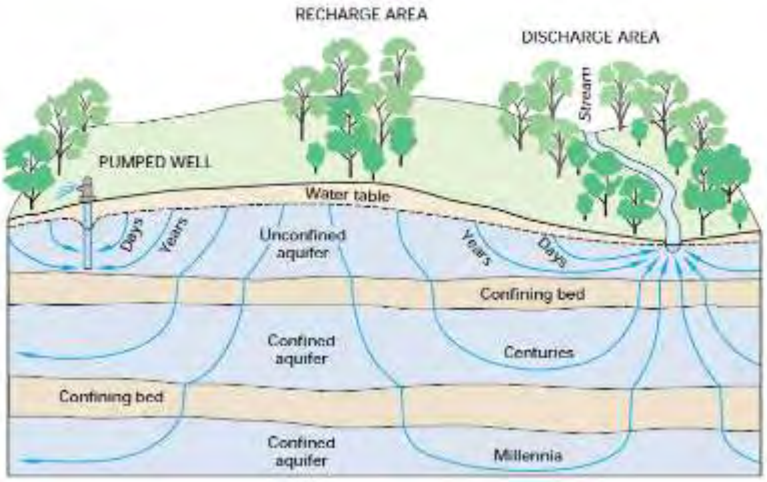


Figure 3. Schematic representation of the length of groundwater flow paths and groundwater residence time in an aquifer system (USGS, 1998)

The age (or residence time) of groundwater in an aquifer system progressively increases along a groundwater flow path from the point of recharge to the point of discharge. The increase in residence time provides greater opportunity for the water-rock and geochemical processes described in preceding sections to occur.

In many aquifer systems groundwater flow in the horizontal direction predominates over flow in the vertical direction. This means groundwater commonly flows more rapidly through the upper parts of an aquifer system with comparatively slow rates of groundwater circulation through deeper levels of the aquifer. The resulting gradation in groundwater age along deeper flow paths is often reflected in progressive changes in groundwater quality with depth. As a result, development of a conceptual level understanding of the three dimensional nature and rate of groundwater flow through an aquifer system is particularly important to developing linkages between observed changes in groundwater quality and potential causal mechanisms (such as land use activities).

The residence time of groundwater is largely determined by the rate of groundwater flow through the aquifer system. Darcy's Law, which describes the flow of water through a porous media, defines the rate of groundwater flow through an aquifer to be directly proportional to the hydraulic gradient and hydraulic conductivity of the aquifer materials:

$$V = {}^{Ki}\!/_{n}$$

Where: V = average linear groundwater velocity;

K = hydraulic conductivity; a measure of the ability of the aquifer materials to transmit water, the higher the hydraulic conductivity the easier it is for water to flow through the aquifer materials;

i = hydraulic gradient; the slope of the water table (or piezometric surface) across the aquifer system; and,

n = effective porosity; a measure of the degree of interconnectedness between individual pore spaces within the aquifer materials.

As a consequence, the physical characteristics of an aquifer system can have a significant influence on residence time of the groundwater. In aquifers (or at depths) where the rate of groundwater movement is low, there is greater time for geochemical evolution of groundwater to occur. Conversely, in groundwater systems with a high rate of groundwater flow less time is available for these natural processes to occur and, because there is a greater flux of water through the aquifer system, there is a greater potential for dilution of contaminant inputs into the aquifer system.

In the Southland Region, the physical characteristics of aquifer systems exert a significant influence on groundwater quality. In Riparian aquifers the large volumes of river recharge flowing through relatively permeable gravels means residence time is generally short and there is significant potential for contaminants to be diluted. As a consequence groundwater in these aquifers tends to contain comparatively low concentrations of dissolved ions. In contrast, Lowland aquifers typically exhibit low rates of groundwater flow allowing greater time for groundwater quality to evolve as a result of natural geochemical processes and increasing the potential for accumulation of contaminants introduced by recharge from the land surface. Groundwater quality in these aquifers (particularly at depth) typically shows some degree of geochemical evolution while at shallow depths the relatively low rate of groundwater throughflow can increase the potential for the accumulation of contaminants derived from overlying land use.

Groundwater quality in the upper levels of shallow aquifers may also be affected by climatic events such as heavy rainfall or snow. These events result in significant recharge through the soil zone which, depending on timing, can act to flush dissolved ions from the soil zone into underlying groundwater. For example, dissolved ion concentrations in a number of shallow monitoring bores on the Waimea Plain showed a significant ‘spike’ in June 2002 following rainfall of between twice to three times the monthly average over the preceding April/May period. Periods of heavy rainfall also increase the potential for localised contamination of bores and wells in situations where wellhead protection is inadequate and surface runoff can directly infiltrate into or around the well casing.

Box 3. Heenans Corner Investigation

Development of a conceptual understanding of the nature of groundwater flow through the Regions aquifer systems is important to better understand potential linkages between land use activities and the timing and magnitude of resulting effects on groundwater quality.

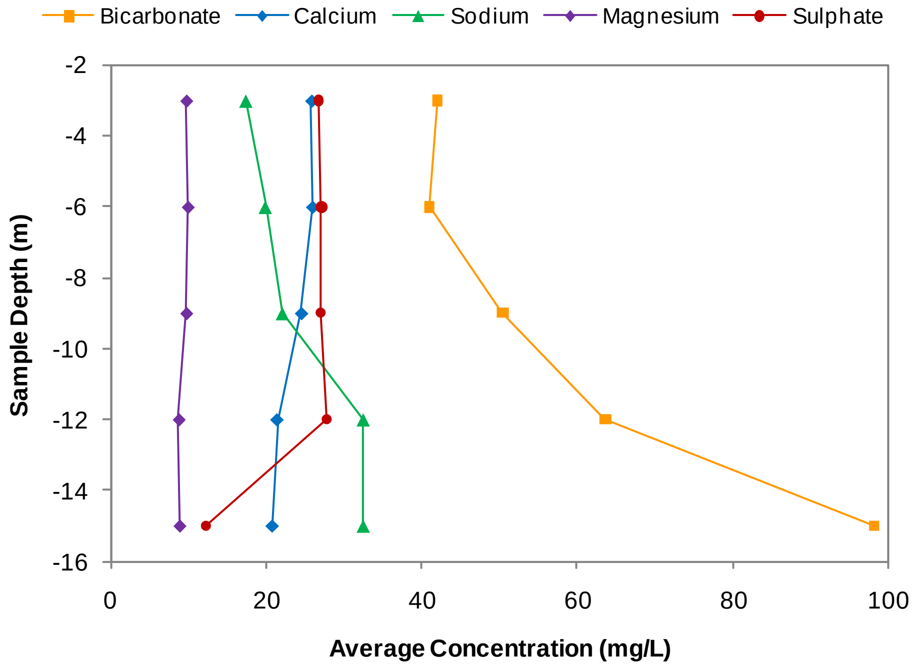
In 2005 Environment Southland installed a nested piezometer site near Heenans Corner to investigate variations in groundwater quality with depth in a Lowland aquifer setting, typical of many intensively farmed areas of the Southland Plains. The overall intention of this investigation was to collect field data and improve understanding of the relationship between changes in land use and resulting impacts on groundwater quality.

The trial site consists of five separate piezometers which are installed at 3 metre depth intervals between 3 and 15 metres below the ground surface, with the piezometers constructed in a manner which minimises the potential for vertical movement of groundwater between the respective sample intervals. Since installation, the piezometers have been sampled on a regular basis for a range of physical and chemical parameters.

Sample results indicate a general evolution of groundwater quality with depth consistent with the water-rock and geochemical processes outlined in the preceding sections of this report. For example, the plot of average major ion concentrations with depth shown below indicates a slight decrease in magnesium and calcium concentrations with depth with a corresponding increase in sodium and bicarbonate concentrations consistent with water-rock interaction processes described in **Section 2.1.2**. The concentration of sulphate decreases markedly in the lower sample interval suggesting groundwater at this depth may be relatively advanced along the redox sequence described in **Section 2.1.3**.

Overall, observed changes in major ion chemistry suggest groundwater in the upper part of the aquifer is relatively young and well mixed, with a progressive increase in groundwater age (residence time) at deeper levels. However, groundwater nitrate concentrations recorded in the upper 4 sample intervals are relatively high (11 to 12 mg/L nitrate-N) and show similar (and relatively pronounced) temporal variations consistent with rapid mixing of water through the upper part of the aquifer. Nitrate concentrations in the deepest (15 metre) sample interval, although lower than those at shallower depths, exhibit a similar pattern of temporal variation suggesting relatively rapid changes in nutrient concentrations at depth.

The reason for the apparent discrepancy in major ion chemistry and nutrient concentrations in the respective piezometers is uncertain and requires further investigation. However, results from the site do appear to confirm the conceptual model with the bulk of groundwater flow occurring through upper parts of the aquifer system with relatively slow circulation of groundwater a depth. The apparently anomalous variations in groundwater nitrate concentrations at depth emphasise the complex nature and incomplete understanding of how land use can potentially impact on groundwater quality in an underlying aquifer system.



Variations in major ion concentrations with depth at the Heenans Corner site

2.2 Anthropogenic influences on groundwater quality

Aside from variation in groundwater quality due to natural physical and geochemical processes within and between aquifer systems, groundwater can also be significantly influenced by human (anthropogenic) activities. The following section provides a brief overview of potential human influences on groundwater quality.

2.2.1 Groundwater Abstraction

Under natural conditions groundwater flows through an aquifer system from the point of recharge to the discharge zone following the piezometric gradient. Localised drawdown of groundwater levels resulting from groundwater abstraction alters this natural flow pattern and, in certain hydrogeological settings, can induce the movement of water of either lesser or higher quality through the aquifer. The potential for pumping to impact on groundwater quality increases where the volume of abstraction is a significant proportion of the overall volume of water flowing through the aquifer system or where there is a marked contrast in water quality between the aquifer being pumped and other hydraulically connected (groundwater and surface water) waterbodies.

The most obvious example of groundwater quality changes induced by pumping can occur in coastal aquifers where pumping causes the inland migration of brackish or saline water (a process termed *saline intrusion*) as illustrated in **Figure 4**. Saline intrusion can result in water in bores located along the coastal margin becoming unsuitable for drinking water supply and is a significant management consideration in many coastal aquifer systems.

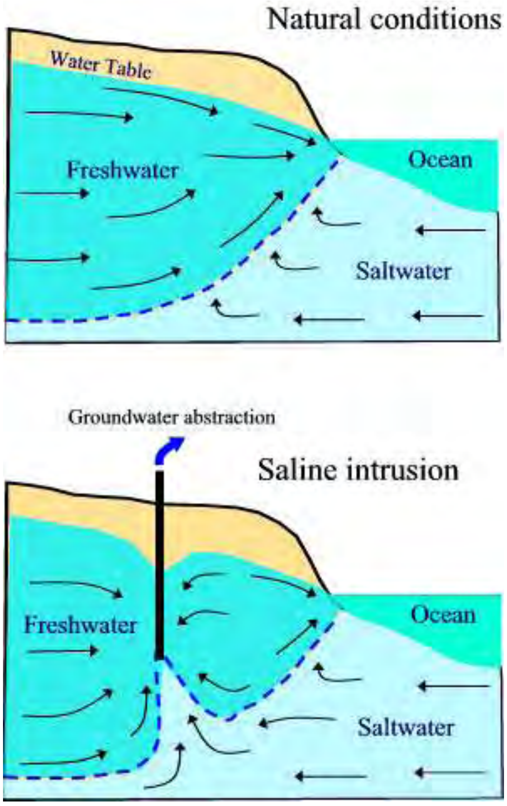


Figure 4. Schematic illustration of saline intrusion in a coastal aquifer (Environment Southland, 2002)

2.2.2 Land Use Effects

Due to infiltration from land surface being the primary source of recharge in most aquifer systems, groundwater quality may be impacted by contaminants carried by infiltrating soil water into underlying aquifers. This process has the potential to impact on the suitability of groundwater for drinking water supply and adversely affect water quality and ecology in surface waterways receiving baseflow discharge from groundwater.

Land use activities that have the potential to impact on groundwater quality are typically described as either point or non-point source discharges. The Regional Water Plan for Southland 2010 defines point source discharges as '*discharges from specific and identifiable sources (such as pipes or drains) concentrated at a given point'* whereas non-point source discharges are described as '*water contamination derived from diffuse sources where there is no single identifiable discharge point*'.

Point source discharges can include septic tanks, offal holes, silage pits, landfills, leaking effluent ponds, underground storage tanks and wastewater application systems. A number of these discharges require resource consent and all are generally controlled by way of Policies and Rules in Regional Plans and implemented by way of performance standards or consent conditions. The effects of point source discharges on groundwater quality are typically localised but may be of significant magnitude and can involve a range of potential contaminants depending on the nature of the specific discharge.

Non-point source discharges relate to the infiltration of water over a widespread area and are often associated with agricultural or horticultural land use. Contaminants applied to land, including animal wastes and fertilisers, can leach through the soil profile to groundwater. The potential magnitude of non-point source discharges can also be exacerbated by land management practices such as the timing of soil cultivation. In a primarily agricultural-based region such as Southland, the potential cumulative effects of non-point source discharges present a major challenge for the management of groundwater quality. These types of discharges are currently not subject to specific regulatory controls. However, options for management of non-point source discharges are being reviewed as part of the Discharge Plan project, particularly in sensitive environments.

3.0 Groundwater Quality Management

Environment Southland has established a framework for the management of natural resources in the Southland Region via the Regional Policy Statement (RPS). The RPS establishes high level objectives and outcomes which are implemented through detailed Policies and Rules outlined in Regional Plans covering Water, Air, Coast, Solid Waste and Effluent Application to Land.

The main Policies and Rules relating to the management of groundwater quality are outlined in the Regional Water Plan (RWP) which establishes maintenance of groundwater quality suitable for drinking as the main objective for groundwater quality management. The RWP also outlines policies to ensure that there is no net deterioration in groundwater quality as a result of point and non-point source discharges into or onto land and that groundwater quality is not adversely effected by groundwater abstraction or poorly constructed bores and wells.

3.1 Groundwater Quality Standards

The RWP specifies that the *Drinking Water Standards for New Zealand* published by the Ministry of Health are utilised as the main criteria for assessing the suitability of groundwater for drinking water supply. These standards, first published in 2000 and subsequently updated in 2005 and 2008, outline maximum acceptable values (MAV)[1] for a wide range of potential contaminants including microbial, chemical and radiological parameters. Consumption of water containing concentrations of parameters at concentrations exceeding MAV are considered to present a significant risk to human health.

The *Drinking Water Standards for New Zealand 2008* also outline aesthetic guideline values for a selected range of parameters. These values are not directly related to human health but indicate thresholds above which selected parameters have the potential to adversely affect water quality in terms of taste, odour, palatability, corrosion or other aesthetic effects.

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[1] The DWSNZ (2008) states that:

The MAV of a determinand in drinking-water represents the concentration of a determinand in the water that, on the basis of present knowledge, is not considered to cause any significant risk to the health of the consumer over their lifetime of consumption of that water.

It is noted that:

- *The MAVs set in the DWSNZ define water suitable for human consumption and hygiene. Water of higher quality may be required for special purposes (e.g. for renal dialysis, consumers who are immunocompromised, or specialist industrial and agricultural uses).*
- *For most carcenogens the MAVs in the DWSNS are the concentrations of substances in drinking-water that have been estimated to cause one additional incidence of cancer in a population of 100,000, each member of which ingests 2L per day of water containing the substance at the MAV over 70 years.*
- *For most other chemicals, MAVs have been calculated on a tolerable daily intake (TDI) approach that identifies the dose below which no evidence exists that significant adverse effects will occur.*
- *The MAVs for micro-organisms are determined differently from the chemical MAVs. Due to the limitations of existing microbial technology MAVs are not given for all micro-organisms of health significance. Instead, MAVs are defined for representative micro-organisms which indicate the potential presence of pathogenic organisms.*

Box 4. What does the Regional Water Plan for Southland 2010 say in relation to management of groundwater quality?

Objective 8 of the Regional Water Plan (RWP) for Southland 2010 establishes two primary objectives for the management of groundwater quality:

a. *To maintain groundwater quality in aquifers that already meet the Drinking Water Standards for New Zealand 2000; and,*

b. *To enhance groundwater quality in aquifers degraded by land use and discharge activities (with the exception of aquifers where ambient water quality is naturally less than the Drinking Water Standards for New Zealand 2000 to ensure general compliance with the Drinking Water Standards for New Zealand 2000 by the year 2010.*

This objective establishes suitability of groundwater for human consumption as measured against the *Drinking Water Standards for New Zealand (DWSNZ)* as the main criteria for the management of groundwater quality and seeks to enhance groundwater quality in aquifers degraded by land use and discharge activities to a drinkable standard. The objective links to Policy 25 which seeks to:

To avoid remedy or mitigate the adverse effect arising from point and non-point source discharges so there is no net deterioration in groundwater quality after reasonable mixing, unless it is consistent with the promotion of the sustainable management of natural and physical resources, as set out in Part 2 of the Resource Management Act 1991, to do so.

The Discharge Plan project, which includes a review of the current Regional Effluent Land Application Plan for Southland, may result in the incorporation of additional policies related to management of discharges which may impact on groundwater quality into the RWP.

4.0 Groundwater Use in Southland

Groundwater is extensively utilised for domestic, stock and municipal water supplies throughout the Southland Region. Groundwater is also extensively utilised for industrial and farm (particularly dairy shed) supply which also require water of potable quality.

Outside of Invercargill and Riverton (which currently source drinking water from the Oreti and Aparima Rivers respectively), virtually all other major reticulated supplies in Southland are derived from groundwater. The Ministry of Health *Drinking Water for New Zealand* database records reticulated supplies sourced from groundwater in Te Anau, Winton, Gore, Balfour-Lumsden, Mossburn, Tuatapere, Milford Sound and Otautau, servicing a total population of approximately 20,000 residents. The Long Term Council Community Plan (LTCCP) for the Southland District Council also identifies the proposed development of reticulated supplies sourced from groundwater in the Edendale-Wyndham and Riversdale areas.

Outside of areas serviced by reticulated water supplies the total number of rural properties utilising groundwater as a source of domestic and/or stock supply is unknown. Previous surveys (e.g. Hamill 1998, Belton et.al 1998) suggest over 50 percent of rural properties utilise groundwater for domestic supply with many others deriving stockwater supplies from groundwater. Assuming 50% of the rural population in areas not serviced by existing reticulated supplies derive their water supply from groundwater, the total population relying on domestic groundwater supplies in Southland is likely to be of the order of 10,000 people.

Other major uses of water in Southland which require water of potable standard include dairy shed and industrial supplies. At the current time there are approximately 670 resource consents issued by Environment Southland for dairy supplies sourced from groundwater. Groundwater of potable quality is also utilised in a number of food processing facilities in the Southland Region, the most notable of which, the Fonterra Co-operative dairy plant at Edendale utilises up to 13,000 m^3/day when at full production.

The map shown in **Figure 5** shows the location of bores recorded on the Environment Southland Wells database as being utilised for potable supply. While this information describes only a subset of existing bores and is by no means exhaustive, it does illustrate the extent to which groundwater is utilised for potable supply across virtually the entire Region.

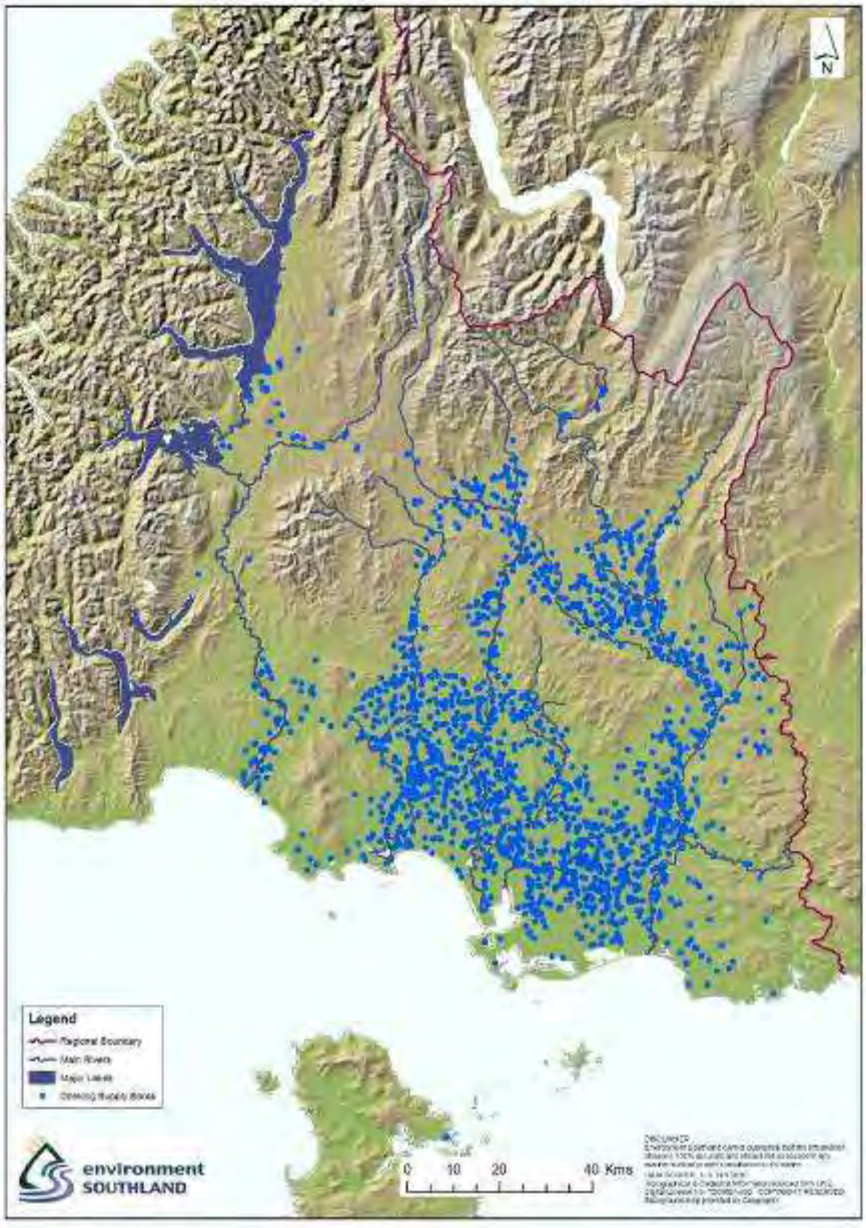

Figure 5. Map showing the distribution of bores and wells used for domestic, municipal or stock supply recorded on the Environment Southland WELLS database.

5.0 Parameters influencing the suitability of groundwater for potable supply

5.1 Micro-organisms

In contrast to other potential groundwater contaminants, micro-organisms, including bacteria, viruses and protozoa, can result in short-term, acute impacts on human and animal health by giving rise to a variety of diseases, ranging in severity from mild gastroenteritis to severe, potentially fatal illnesses.

Numerous studies have been undertaken in New Zealand and overseas (e.g. Pang 2009, Wall *et.al*. 2008, Pang *et al*. 2005) which show that due to natural processes of filtration, adsorption and die-off, groundwater contamination by micro-organisms tends to be localised near the contaminant source, except in exceptional circumstances where groundwater flow rates are particularly rapid or when viruses attach themselves to colloids. As a consequence, the majority of instances of contamination by micro-organisms are attributed to localised impacts downgradient of point source discharges (such as a septic tank or effluent disposal area) or where the wellhead is poorly constructed or maintained allowing contaminants from the land surface to enter the water supply.

Limited data is available to quantify the potential extent of waterborne illnesses resulting from contamination of drinking water supplies in the Southland Region. The Ministry of Health Public Health Surveillance Reports for 2009 records 15 notifiable disease outbreaks involving 77 individual cases in the Public Health South area, a significant number of which are described as gastroenteritis which could potentially result from consumption of contaminated drinking water (although in a majority of cases causation is difficult, if not impossible, to attribute to a specific source). However, as noted by the Ministry of Health[2] it is likely that the true incidence of waterborne illness resulting from contamination of drinking water supplies is significantly under-reported.

Although there are wide range of micro-organisms that may result in waterborne illnesses, the presence of micro-organisms in groundwater is generally measured in terms of the presence/absence of the bacteria species Escherichia coli (commonly referred to as *E. Coli*). This bacteria is commonly found in large numbers in the lower intestine of warm blooded animals which is utilised as an indicator of potential faecal contamination due to their persistence outside the body. The *Drinking Water Standards for New Zealand 2008* specify that *E.coli* should not be present in water utilised for potable supply to minimise the potential for adverse health effects.

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[2] http://www.moh.govt.nz/moh.nsf/pagesmh/5761?Open

Box 5. Microbial Contamination of Groundwater in Southland

Sampling results (further described in **Section 6.1.4**) suggest that contamination of groundwater utilised for potable supply by micro-organisms is likely to be the most widespread and significant form of groundwater contamination (in terms of acute impacts on human and stock health) occurring in the Southland Region. In a majority of instances microbial contamination of groundwater supplies is attributed to either inadequate wellhead protection or the siting of the bore or well in close proximity to a potential contaminant source. Practical steps well owners can take to minimise the potential contamination of their groundwater supply include:

- Ensuring the casing extends far enough above ground to prevent the entry of surface runoff;
- Securely sealing the top of the casing (including around pipes and cables) to prevent entry of contaminants into the bore or well;
- Enclosing the bore well within a pump shed;
- Constructing a concrete pad to seal the area around the casing;
- Ensuring the bore or well is located at least 100 metres from any potential contaminant source e.g. septic tank, effluent disposal area
- Excluding stock from the immediate vicinity of the bore or well.

Further information on ways to help minimise the potential for contamination of your water supply can be found at: http://www.es.govt.nz/environment/water/groundwater/best-practices.aspx

5.2 Nitrate

Nitrogen is a key element required to support plant growth and biological activity. Although nitrogen is a major component of the Earth's atmosphere, plant growth requires conversion of gaseous nitrogen into forms accessible to plants either by way of natural fixation (facilitated by soil bacteria) or chemical processing. Most of the nitrogen taken up by plant growth is recycled through the soil by the breakdown of organic material from plants and animals. However, a component of nitrogen is lost during these soil transformation processes either as gaseous nitrogen back to the atmosphere or through the leaching of soluble forms (nitrate and ammonia) from the soil profile. Nitrate can also be introduced into the environment by artificial fertilisers added to increase soil fertility or by discharges containing elevated nitrogen concentrations (such as wastewater discharges).

Due to its solubility, nitrate lost from the soil profile can build up in groundwater or surface water receiving environments. This can result in effects on groundwater used for drinking water supply or the aquatic ecology of surface waters due to the promotion of aquatic plant growth (a process termed *eutrophication*) and may be toxic to aquatic life in elevated concentrations.

Nitrate (or ammonia depending on geochemical conditions) in water utilised for potable supply has the potential to result in health effects on animals and humans. The DWSNZ 2008 specifies a MAV of

11.3 milligrams per litre for nitrate-nitrogen and 1.5 milligrams per litre for ammonia. These limits are set with particular reference to bottle-fed infants (who are susceptible to a condition known as methemoglobinemia or '*blue baby syndrome*'). For stock, nitrate concentrations of less than 400 milligrams per litre[3] are considered unlikely to adversely impact on animal health.

Groundwater nitrate levels may be elevated in areas where land use activities increase the rate of leaching losses from the soil profile or where there are large or multiple discharges of wastewater to land. With the large changes in land use that have taken place in Southland over recent years concern has increased with regard to the potential cumulative effects on groundwater quality, particularly in relation to groundwater nitrate concentrations and consequent effects on its suitability for potable supply as well as adverse effects on the quality of surface waterways which derive baseflow from groundwater.

Results of groundwater nitrate monitoring in the Southland Region are presented in **Section 6.1.5**.

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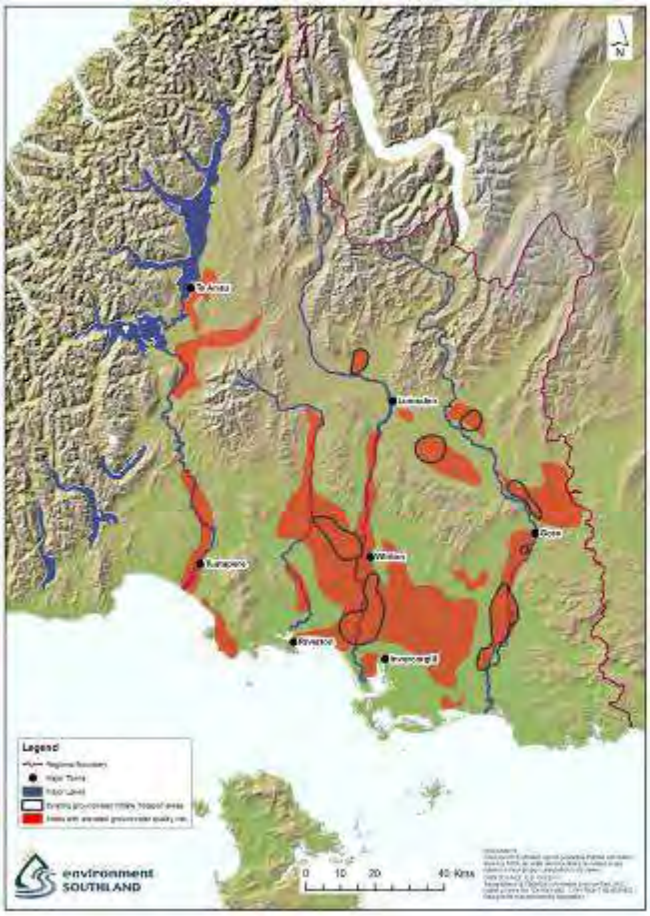
[3] *Australian and New Zealand Guidelines for fresh and marine water quality 2000.* Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand. October 2000, 3 volumes.

Box 6. Nitrate Leaching Risk

The potential for nitrate to leach from the soil into underlying groundwater is influenced by a range of factors including the intensity of land use (e.g. stocking rate per hectare, fertiliser application rates), the timing and nature of management practices adopted (e.g. soil cultivation, winter grazing) as well as and the physical properties of the soil materials (e.g. water holding capacity, drainage characteristics). In turn, the potential for nitrate concentrations to accumulate in underlying groundwater is influenced by the physical characteristics of the aquifer materials and the source of recharge.

Historical groundwater quality monitoring has identified a number of areas in the Southland Region where groundwater nitrate concentrations are elevated with respect to the drinking water standard. These areas (colloquially termed nitrate '*hotspots*') are generally restricted in spatial extent and appear to reflect the cumulative effect of current and historical land use in particular hydrogeological settings.

In 2007 Environment Southland commissioned a regional-scale assessment of the relative risk to groundwater quality associated with land disposal of farm dairy effluent (SKM 2007). Data from this initial assessment was combined with an assessment of existing groundwater quality monitoring data to derive an assessment of those areas with the greatest potential to exceed water quality standards (Liquid Earth, 2008). The resulting assessment shown below highlights those areas of Southland which are assessed as having an elevated risk of groundwater nitrate concentrations exceeding drinking water standards.



Areas of elevated groundwater nitrate risk (Liquid Earth, 2009)

5.3 Chemical Contaminants

Chemical contaminants including organic compounds such as hydrocarbons and pesticides and inorganic compounds such as metals and metalloids can affect the suitability of groundwater for drinking water supply. These compounds can be sourced from a wide variety of land use activities ranging from landfills and stormwater disposal installations through to inadvertent discharges or spills. Due to their individual physical and chemical properties, the potential mobility, persistence and toxicity of these compounds in groundwater and aquatic environments varies considerably between individual compounds.

Some chemical contaminants such as heavy metals are typically strongly bound to soil or organic matter and only become mobile in groundwater under certain conditions. In contrast, other compounds such as triazine herbicides are highly soluble and may be transported over significant distances within an aquifer system.

The risk to human health posed by these compounds ranges from short-term toxicity to long term bio-accumulative effects according to the specific chemical properties of individual compounds. The DWSNZ specify maximum acceptable values (MAV) for a wide range of chemical compounds in drinking water based on an assessed level of risk to human health resulting from either acute toxicity or lifetime exposure (equivalent to drinking the water for 75 years).

Limited information is available to characterise the occurrence of chemical contaminants in groundwater in the Southland Region. Due to the high cost of analysis, sampling for these compounds is generally restricted to compliance monitoring of specific discharges and periodic inclusion of selected parameters in the Environment Southland groundwater quality monitoring programme. In the few instances contaminants have been detected, monitoring has typically shown concentrations well below MAV and localised to a specific source.

Box 7. Pesticides in Groundwater

Trace concentrations of pesticide (herbicide) active ingredients were first detected in groundwater in the Edendale area in a national survey of pesticides in groundwater undertaken in 1994 (Close, 1996). Following results of these initial samples, Environment Southland has undertaken semi-regular analysis of pesticide concentrations in groundwater in this area.

In total, nine different herbicide active ingredients have been detected in groundwater in the Edendale groundwater zone since monitoring commenced. The compounds detected include members of the triazine and uracil chemical groups which share common characteristics including persistence and mobility in the subsurface environment which make them particularly prone to leaching. The source of the contamination is primarily attributed to horticultural operations and roadside spraying, with the widespread use of soak holes for local drainage providing a pathway for these compounds to bypass treatment in the soil zone and leach directly into groundwater.

The maximum concentrations of the individual compounds detected range from 5 to 20 percent of MAV with concentrations above detection recorded up to 6 kilometres downgradient of the potential source. Concentrations of the compounds detected show a gradual decline over time with only 4 of the 8 compounds originally detected still present in 2009. This decline in concentration is attributed to awareness of potential effects on groundwater on the part of horticultural operators and the discontinued use of products containing individual active ingredients.

Overall, as the maximum concentration of the pesticide active ingredients detected was well below the MAV, the presence of these compounds was not considered to pose any significant risk to groundwater used for potable supply. However, the ongoing detection of these compounds highlights the potential for chemical contaminants to leach from the land surface and be transported over relatively significant distances in underlying groundwater.

The limited monitoring of pesticides in groundwater undertaken across the remainder of the Southland Region has indicated some specific instances of localised groundwater contamination either due to spot spraying in the vicinity of individual wellheads or, in one case, backflow during the filling of a spray tank. Individual bore owners are therefore advised to avoid the storage and/or use of agrichemicals in the vicinity of bores and wells and to ensure suitable backflow prevention devices are installed where groundwater is used to fill spray tanks.

Box 8. Heavy Metals and Hydrocarbons

Both heavy metals and hydrocarbons pose a risk to groundwater quality when present in relatively low concentrations in water used for potable supply. The DWSNZ specify MAV for a wide range of these compounds which may be present where groundwater is contaminated by historical land use activities or where naturally occurring concentrations are elevated due to geological and geochemical conditions within an aquifer system. Many of these compounds are persistent in the environment and can accumulate to relatively high concentrations in soil.

Heavy Metals

A number of sites in Southland have been identified as potentially contaminated by heavy metals which pose a risk to human health either via direct exposure to contaminated soil or contamination of underlying groundwater. These sites include a number of historical industrial sites where material containing heavy metals was discharged to ground. In many cases the potential occurrence of these contaminants is recorded on the property title with specific investigations and remedial works undertaken to minimise risks to public health.

The most frequent occurrence of sites potentially contaminated by elevated heavy metal (and organochlorine) concentrations in Southland occurs in rural areas at historical sheep dip sites (both on-farm and communal) where a range of chemicals including arsenic, copper and zinc, lindane and dieldren were used to treat external parasites and footrot. Dipping of sheep via plunge or swim-through baths (or more latterly spray dipping) allowed excess chemicals to drain from the sheep onto the surrounding ground where concentrations of heavy metals and associated compounds could accumulate in the soil profile.

MfE (2006) estimated approximately there are approximately 50,000 historical sheep dip sites across New Zealand. While exact numbers are uncertain, given the historical extent of sheep farming in the region, it is likely a significant number are located within the Southland Region. Due to the way in which heavy metals and organochlorine compounds bind to the soil it is generally considered that historical sheep dip sites pose a limited risk to groundwater quality unless the soil is disturbed. However, property owners are advised to avoid siting bores used for potable or stock supply near the known location of sheep dips (particularly large-scale communal dips typically located near former railway sidings) or near stock yards which were in use pre-1980's.

Hydrocarbons

There have been a number of documented instances of groundwater contamination due to the presence of hydrocarbons in the Southland Region. These occurrences have typically been associated with leaks from underground storage tanks or associated pipework. Based on the investigations undertaken the overall extent of contamination appears relatively localised with little or no impact on potable water supplies. Where identified, remedial measures have also been established to remove and/or treat contaminated soil and groundwater. In recent years the oil industry has undertaken significant steps to manage the risk of hydrocarbon contamination by the upgrading of storage facilities and containment measures.

6.0 Groundwater Quality Monitoring

Environment Southland undertakes a range of groundwater quality monitoring to characterise spatial variability in groundwater quality across the Southland Region and identify trends in the condition of the resource. The current monitoring network includes the following components:

- **Baseline groundwater quality monitoring programme** - a network of approximately 45 sites distributed across the major aquifer systems which are sampled on a quarterly basis for a wide range of basic water quality determinands. This monitoring includes 7 sites sampled as part of the National Groundwater Monitoring Programme (NGMP) run by the Institute of Geological and Nuclear Sciences (GNS). In addition the baseline programme includes a relatively small number of sites (approximately 12) which are sampled on a quarterly basis for nitrate-nitrogen only.
- **Compliance monitoring** - approximately 250 sites monitored on a regular (typically annual) basis for basic water quality parameters as a condition of resource consent for land discharge of dairy effluent

- **Groundwater quality investigations monitoring programme** - monitoring for a range of purposes ranging from aquifer characterisation studies, nitrate 'hotspot' investigations to follow-up compliance monitoring

Available data from these monitoring programmes is utilised in the following section to characterise groundwater quality across the Southland Region. Data collected from the baseline, compliance and investigations monitoring programmes is used to assess spatial variations and temporal trends in groundwater nitrate and microbial quality. Analysis of other major ions is limited to data collected from the baseline groundwater quality monitoring programme due to the restricted number of parameters sampled and frequency of analysis undertaken for the compliance and investigations programmes.

Statistical analysis of water quality data presented in the following section was undertaken using a spreadsheet tool developed by Daughney (2007). Using this application site-specific calculations were made for the following parameters:

- **Median:** a measure of central tendency, calculated using log-probability regression to deal with results reported as being below an analytical detection limit, and,
- **Trend:** rate of change in each parameter, based on Sen's slope estimator for all trends that are detectable with the Mann-Kendal test at the 95% confidence interval.

The analysis of individual groundwater quality parameters is summarised in **Section 7** which provides an assessment of the suitability of the groundwater resource for potable supply, along with more general discussion of the current state and observed trends in groundwater quality across the region.

6.1 State and Trends

6.1.1 Electrical Conductivity (EC)

Electrical conductivity (EC) is a measure of the total dissolved solids (TDS) concentration in a groundwater sample, and so provides a useful indicator for general spatial and/or temporal changes in groundwater quality that may result from both natural and anthropogenic influences on groundwater quality. There are no health or ecosystem-related standards for electrical conductivity specified in DWSNZ or ANZECC. However, the DWSNZ establish a aesthetic guideline for TDS of 1000 mg/L and notes that taste may become unacceptable for potable supply at concentrations of between 600 to 1,200 mg/L[4].

Figure 6 shows a plot of the spatial distribution of median EC measured at baseline groundwater quality sites. These data show a clear spatial variation with lower EC values (typically <200 µS/cm) observed in the northern Southland with a progressive increase in EC values across the Central Plains toward the south coast where all bores typically exhibit EC values greater than 200 µS/cm. The highest values of approximately 500 µS/cm are observed in bores screened in Tertiary limestone aquifers. The spatial distribution of EC vales is interpreted to primarily reflect the influence of geology, groundwater residence time and recharge processes on groundwater quality. These factors are discussed in greater detail in the following sections.

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[4] The total dissolved solids (TDS) concentration of a water sample can be related to the electrical conductivity of a water sample. However, the exact correlation between these parameters is a function of the type and nature of dissolved ions present. However, as a general approximation, TDC concentration is typically around 0.7 times the measured EC value (in µS/cm).

Figure 6. Spatial distribution of electrical conductivity (EC) values

Figure 7 shows a plot of the calculated trend in EC values measured at the baseline groundwater quality sites. These data show 19 sites (42%) exhibit a statistically significant trend of increasing EC values while 6 (13%) exhibit a decreasing trend. No clear spatial trend is observed in the distribution of sites with either increasing or decreasing trends. The observed temporal variations in EC are interpreted to reflect localised factors relating to land use and climate in the vicinity of individual monitoring bores with the large proportion of sites with an increasing possibly reflecting the general intensification of land use across a significant proportion of the Southland Region.

Figure 7. Temporal trends in electrical conductivity (EC) values

6.1.2 Chloride (Cl) and Sodium (Na)

Chloride is a good indicator of general groundwater quality as it is a conservative ion, remaining relatively unaffected by many of the physical and geochemical processes which influence the concentration of other major ions in the soil zone and shallow groundwater. Chloride is naturally present in groundwater due to aerosol deposition in rainfall and geochemical interaction between groundwater and aquifer materials. Chloride concentrations in many forms of wastewater discharge are commonly elevated and, as a result, temporal changes in natural chloride concentrations have utility as a general indicator of the cumulative impact of land use activities on groundwater quality. The DWSNZ specify an aesthetic guideline value for chloride of 250 mg/L to avoid adverse associated with taste or corrosion in water utilised for potable supply.

Figure 8 shows the spatial distribution of median chloride concentrations. While an increase in chloride (and sodium) concentrations is commonly observed in older, more evolved groundwater, the clear gradational increase toward the coast regardless of bore depth and aquifer type indicates that aerosol deposition in rainfall is likely to be the dominant source of chloride in Southland groundwater.

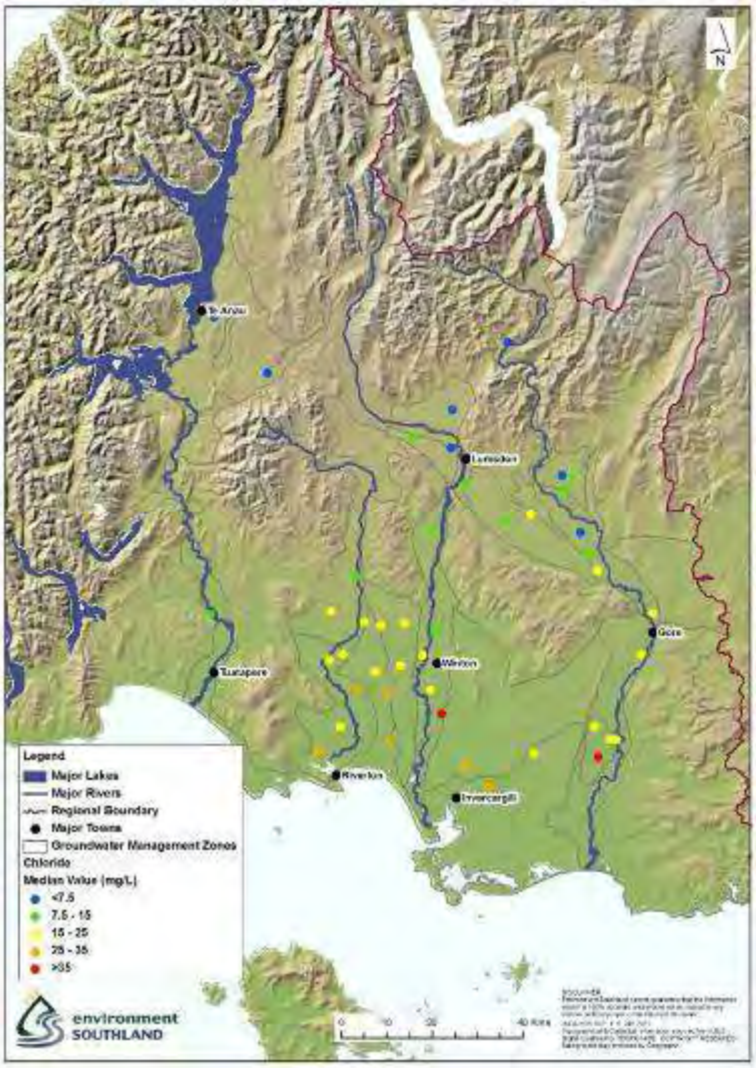

Figure 8. Spatial distribution of median chloride concentrations

Figure 9 shows a plot of the calculated trend in chloride values. This analysis shows approximately 60% of monitoring sites exhibit an increasing trend while just 4% show a decreasing trend. It is noted that the number of sites exhibiting an increasing trend for chloride is significantly higher than for any other parameter. The reason for the high number of sites exhibiting an increasing chloride trend is uncertain but may be partially related to the conservative nature of chloride compared to many other major groundwater quality parameters which are affected to a greater extent by biological, physical and chemical processes in the unsaturated zone.

Figure 9. Temporal trends in chloride concentrations

Figure 10 shows the distribution of median sodium concentrations. Like chloride, sodium concentrations show a gradational increase toward the south coast, again suggesting atmospheric deposition is a major source. However, the spatial distribution of sodium values is not as clear as those for chloride, possibly as a result of geochemical process within the soil zone and shallow groundwater.

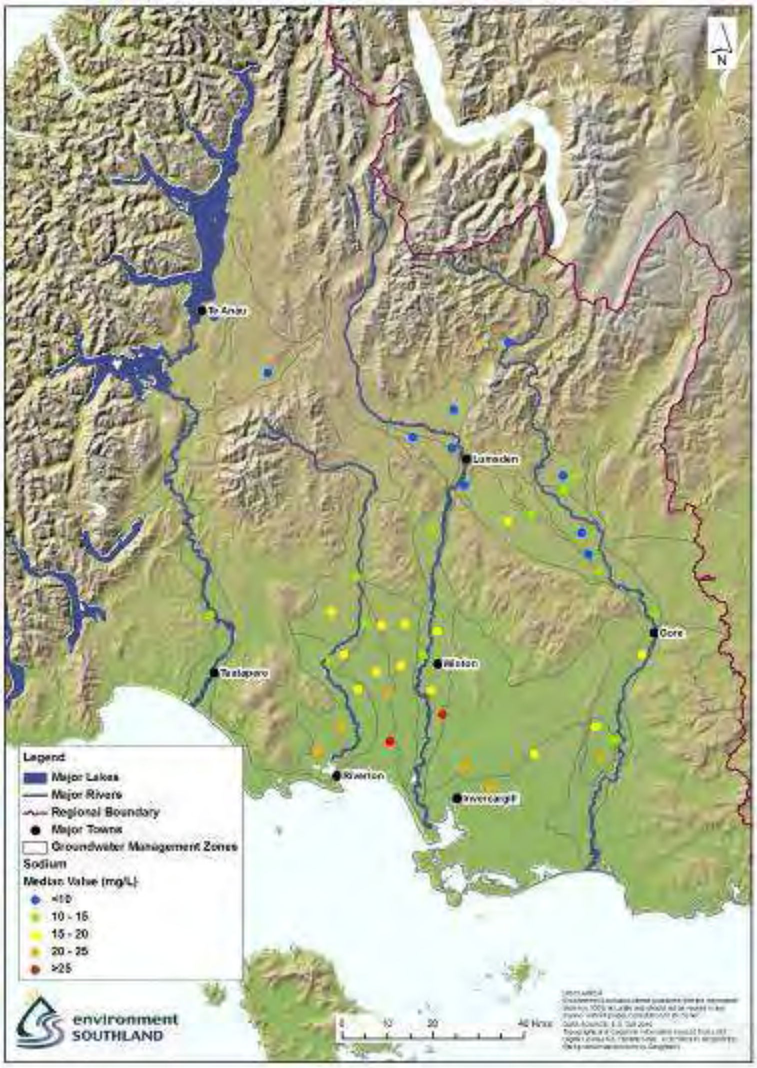

Figure 10. Spatial distribution of median sodium concentrations

Figure 11 shows the clear correlation between observed chloride and sodium concentrations at baseline groundwater quality sites reflecting the common source (aerosol deposition). With the exception of one site, all samples show a slight excess in sodium concentrations with regard to the seawater dilution line (dotted line on the graph) reflecting the enrichment of sodium due to water-rock interaction, most likely associated with cation exchange on clay minerals during soil moisture infiltration. The single baseline monitoring site (F46/0185) showing enrichment of chloride is located in the Edendale groundwater zone. Results from this site are consistent with other bores in the local area which show an obvious ‘plume’ of elevated chloride concentrations associated with the cumulative effects of historical wastewater discharge.

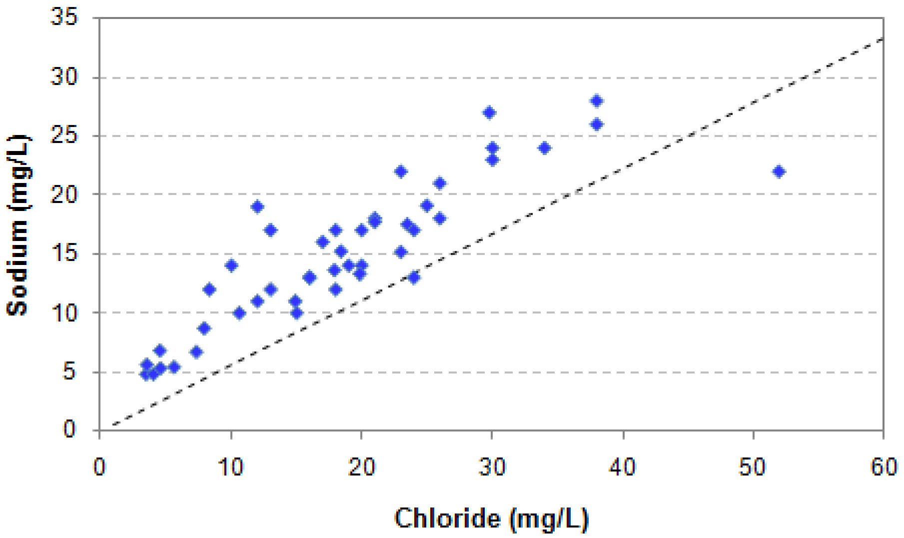

Figure 11. Observed correlation between chloride and sodium concentrations (dotted line represents the seawater dilution line)

6.1.3 Bicarbonate (HCO_3)

Bicarbonate is a major anion species present in groundwater, primarily due to the geochemical processes described in **Sections 2.1.2** and **2.1.3**. Bicarbonate has also been suggested as a potential indicator of land use intensification (Rosen, 2001), particularly related to the use of lime to maintain soil fertility.

Figure 12 shows a plot of median alkalinity[5] values measured in the baseline monitoring programme. The plot shows alkalinity values are generally low to moderate (<50 mg/L) across the northern and eastern Southland area but increase to between 50 to 100 mg/L across the Central Plains area. As expected, the highest alkalinity values (>180 mg/L as $CaCO_3$) are observed in the two bores[6] which are screened in Tertiary limestone aquifers. However, a number of other bores in this area recorded as being screened in gravel aquifers also exhibit elevated alkalinity values between 80 to 110 mg/L (as $CaCO_3$) suggesting groundwater quality in shallow groundwater in this area is influenced by carbonate minerals from the underlying Tertiary sediments.

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[5] Bicarbonate concentrations are typically measured in terms of alkalinity which is a measure of the waters ability to neutralise acids. In the Southland area alkalinity is virtually entirely due to the presence of bicarbonate ions in solution (i.e. total alkalinity is equal to bicarbonate alkalinity)

[6] D46/0003 and E46/0092

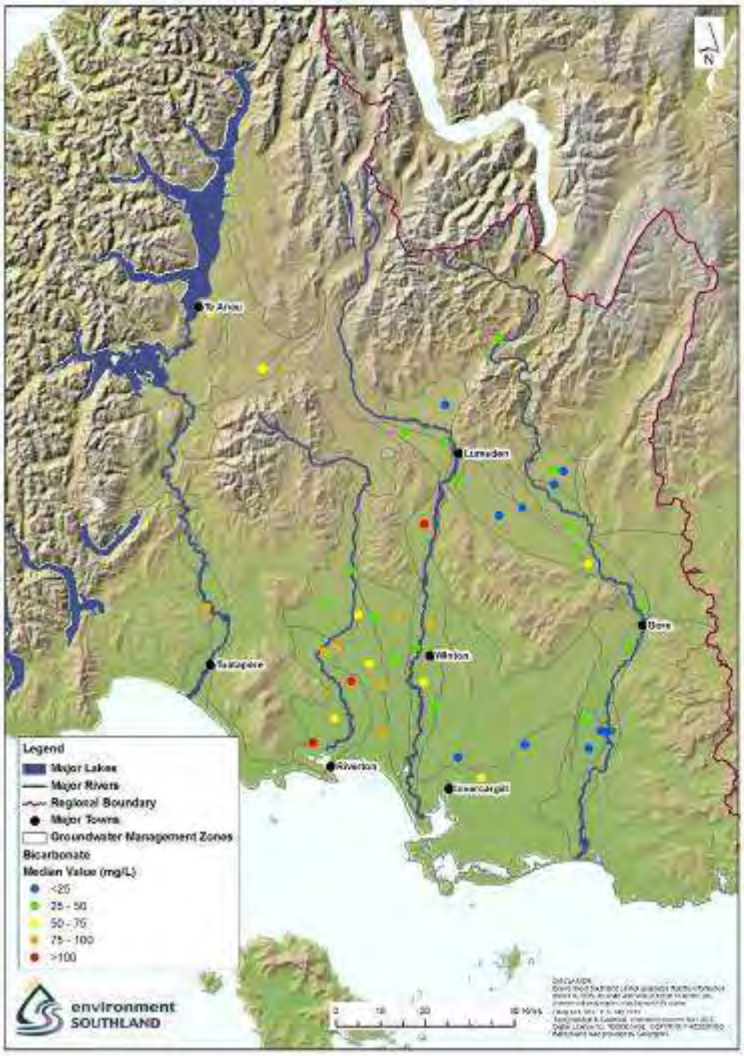

Figure 12. Spatial distribution of median bicarbonate concentrations

Figure 13 shows a plot of observed trends in groundwater alkalinity. The data show an increasing trend in 12 sites (27%) and a decreasing trend at 2 sites (4%). Sites with increasing alkalinity trends are generally located in those areas of northern and eastern Southland exhibiting lower median alkalinity concentrations.

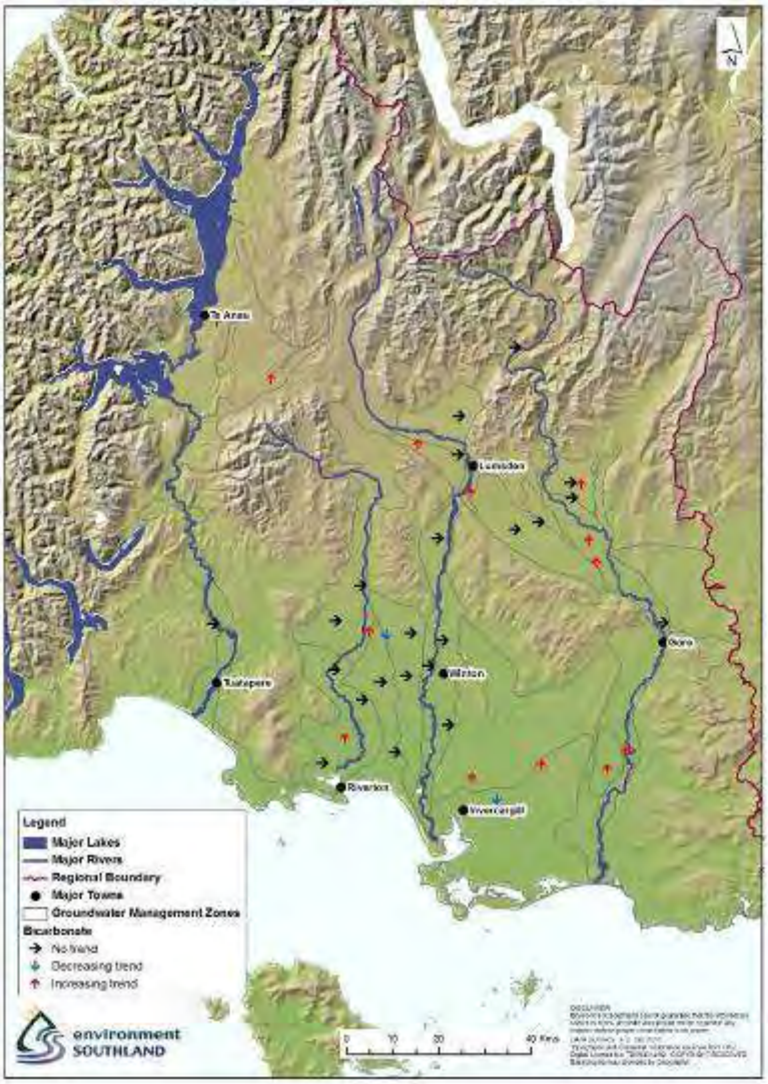

Figure 13. Temporal trends in bicarbonate concentrations

6.1.3 Calcium (Ca) and Magnesium (Mg)

Aside from sodium, calcium and magnesium are the major cation species present in Southland groundwater. The concentrations of these ions typically reflect interaction between groundwater and the host geological materials, particularly when carbonate minerals are present. Some fertilisers, primarily lime added to maintain soil pH, may also contribute to overall calcium and magnesium concentrations in underlying groundwater.

Figure 14 presents a map of median calcium concentrations. The data show calcium concentrations are typically less than 15 mg/L across northern and eastern Southland but increase significantly across the Central Plains area west of the Oreti River. This increase in calcium concentrations is interpreted to reflect the influence of Tertiary limestone deposits which underlie the alluvial graves across much of this area, outcropping at Kauana, Winton Hill and along the eastern margin of the Longwood Range. Magnesium concentrations show a similar, although less pronounced increase across the same area.

The fact that both calcium and magnesium concentrations are elevated in the Central Plains area even in bores recorded as being screened in the overlying alluvial gravels suggests that the carbonate geology of the underlying Tertiary deposits influences water quality in overlying unconfined aquifers. This may be due to incorporation of limestone within the gravel materials or as a result of circulation of groundwater through the underlying carbonate sediments.

Figure 14. Spatial distribution of median calcium concentrations

6.1.4 Total Hardness

Hardness is primarily a measure of the total amount of calcium and manganese ions dissolved in a water sample. As discussed in **Section 2.1.2**, elevated hardness does not present any health issues but may adversely impact on aesthetic water quality due to the formation of an insoluble residue when soaps and detergents are used or the deposition of hard scale in pipes and hot water cylinders. In general, water with a total hardness of less than 60 mg/L is considered '*soft*' and best suited to domestic supply while values greater than 120 mg/L are considered '*hard*' and may potentially result in aesthetic water quality issues.

As shown in **Figure 15,** reflecting the influence of the underlying carbonate geology, groundwater toward the western margin of the Central Plains area (i.e. close to and west of the Aparima River) may exhibit total hardness levels sufficiently elevated to adversely affect aesthetic water quality.

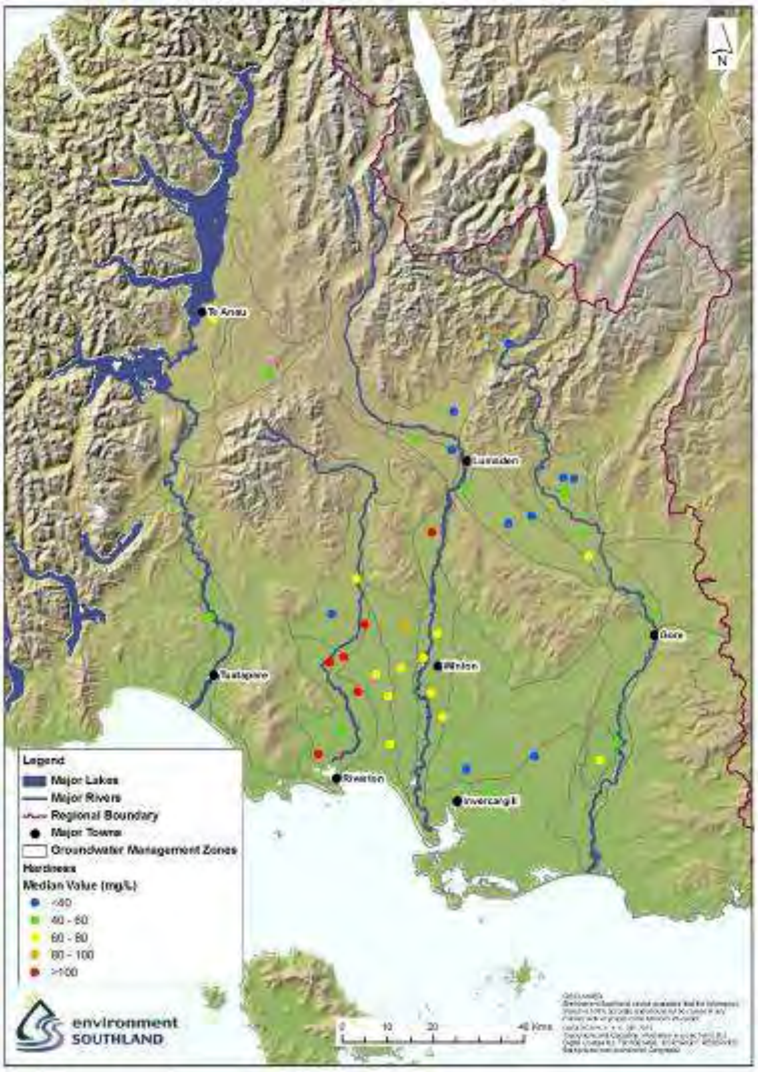

Figure 15. Spatial distribution of median Total Hardness

6.1.5 Manganese (Mn) and Iron (Fe)

The presence of elevated manganese concentrations in groundwater can result in a range of adverse effects in groundwater utilised for potable supply. The NWSNZ specifies two aesthetic guideline values for manganese; the first at 0.04 mg/L to avoid staining of laundry and the second at 0.1 mg/L which is the threshold for adverse effects on taste. The DWSNZ also specifies a MAV of 0.4 mg/L for manganese to avoid potential health effects. In regard iron the DWSNZ specifies an aesthetic guideline value of 0.2 mg/L for iron to avoid staining of laundry and sanitary ware.

Figure 16 shows the spatial distribution of manganese concentrations. The data show the presence of manganese concentrations in excess of MAV in two bores[7], both of which are screened in alluvial gravel aquifers which exhibit reducing conditions possibly due to a combination of extended residence time and the local presence of organic sediments within the aquifer materials. It is noted that neither of these bores is used for potable supply due to the general unpalatability of the water. Manganese concentrations above the aesthetic guideline values are also observed in two bores near Invercargill screened in lignite measure aquifers and in Dipton and Mandeville areas[8].

Overall, the presence of manganese concentrations above DWSNZ aesthetic guideline value is relatively common (occurring in 13% of baseline sites) across Southland and is typically associated with reducing (low-oxygen) conditions in both alluvial gravel and Tertiary aquifers. Although manganese concentrations above the MAV are observed, bores containing elevated concentrations are typically not used for potable supply due to adverse effects on aesthetic water quality.

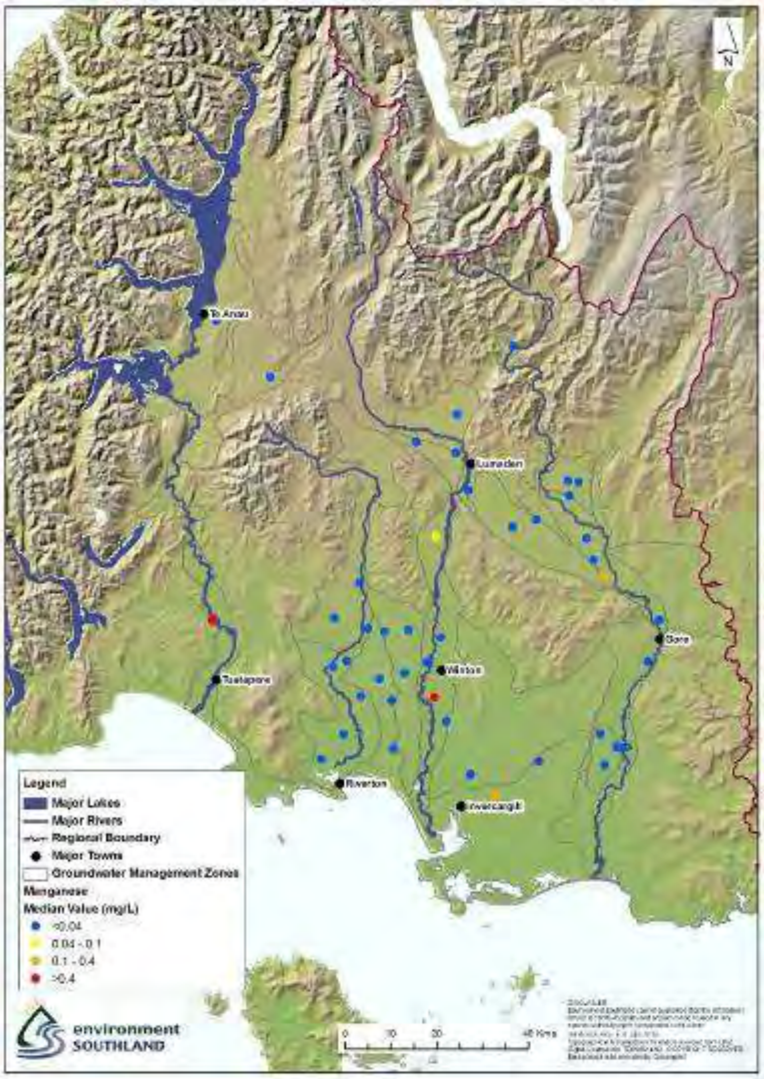

Figure 16. Median manganese concentrations

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[7] D45/0036 and E46/0104

[8] E46/0098, E46/0096, F45/0350 and E44/0044

The spatial distribution of iron concentrations exceeding the DWSNZ aesthetic guideline value show a similar pattern to manganese concentrations, occurring in Tertiary lignite measure aquifers and in areas where alluvial gravel aquifers exhibit reducing (low-oxygen) conditions. The two baseline monitoring sites[9] screened in lignite measure aquifers exhibit significantly elevated median iron concentrations of 7.1 and 6.8 mg/L respectively. Iron concentrations of this order (or higher) are commonly observed in lignite measure aquifers in eastern Southland due to the strongly reducing conditions promoted by the presence of significant quantities or organic material in carbonaceous sediments of the Eastern Southland Group and the presence of iron pyrite in the lignite deposits which releases ferrous (Fe^{2+}) ions into solution when subject to reducing conditions.

Overall, iron and manganese concentrations in groundwater affect a significant number of bores and wells across the Southland Region where reducing conditions are present. However, groundwater from aquifers containing manganese concentrations in excess of MAV are not frequently utilised for potable supply due to aesthetic water quality effects (both due to manganese and coincident elevated iron concentrations) which commonly make the water unsuitable for potable use before concentrations exceed this threshold. Where water is used for potable supply (in the absence of an alternative source) the water is typically treated (typically by aeration) prior to use.

6.1.6 Microbial Quality

At the current time approximately 200 individual bores are sampled for indicator bacteria (*E.coli*) on a regular basis as part of the Environment Southland regional baseline and compliance monitoring programmes.

Figure 17 shows a plot of the number of sites at which indicator bacteria have been detected (i.e. sites exceeding the DWSNZ MAV of <1cfu/100 mL) in one or more samples as a function of the total number of sites sampled per year since 2001. These data indicate a gradual reduction in the overall percentage of sites where indicator bacteria were detected from a peak of 53% of sites sampled in 2003 to 22% of sites sampled in 2009. The ongoing reduction in the rate of detection in indicator bacteria in the bores sampled is largely attributed to an increasing number of newly constructed bores which have a better standard of wellhead protection and ongoing efforts by Environment Southland to increase awareness among groundwater users of the need to ensure wellhead protection and undertake bore maintenance to ensure groundwater quality.

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[9] E46/0096 and E46/0098

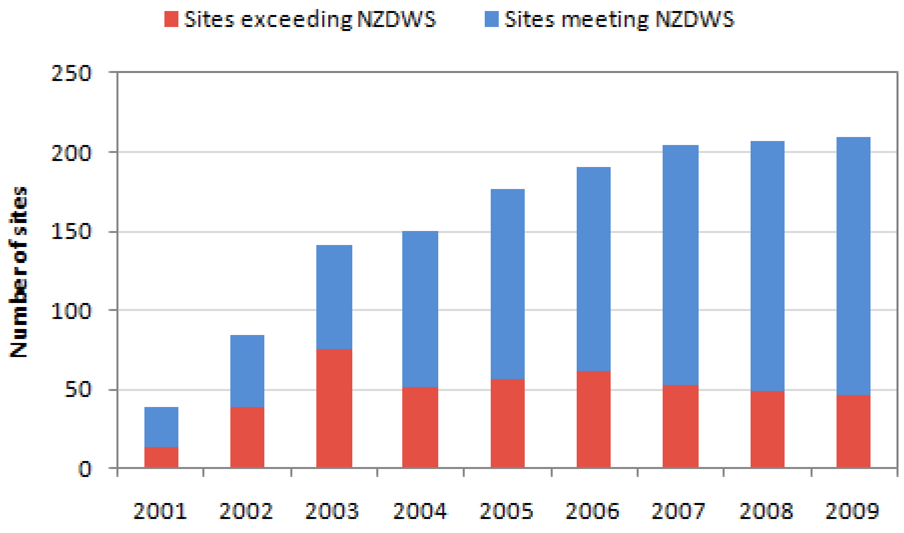

Figure 17. Number of monitoring bores showing the presence of indicator bacteria (*E.coli*)

The incidence of microbial contamination in bores monitored in the Southland Region is consistent with groundwater monitoring results for the whole of New Zealand reported by GNS (2009). This assessment analysed the results from 701 groundwater monitoring sites sampled across New Zealand over the period 1995-2008 of which 23 percent had median *E.coli* concentrations above the MAV for human consumption (<1 cfu/100 mL).

Although 20 percent of sampling sites affected by microbial contamination is relatively high, the actual number of bores and wells utilised for potable supply which are at risk of contamination by micro-organisms in the Southland Region is likely to be higher than this figure. Sites sampled on a regular basis by the Environment Southland are typically selected based on criteria to limit the potential for localised contamination. As an example, results of a groundwater quality survey of 350 bores and wells across the Southland Region in 1998 showed the presence of indicator bacteria in approximately 40 percent of sites sampled (Hamill, 1998). Results of this study showed contamination was more common in large diameter wells, at sites with poor wellhead protection or where the bore or well was located within 50 metres of a septic tank.

Overall, given the potential for acute effects on human health, microbial contamination of groundwater supplies is currently the most significant issue affecting its suitability for potable supply across the Southland Region. As outlined in **Box 5**, in virtually all instances, the potential for microbial contamination of individual bores and wells can be significantly reduced by ensuring wellhead protection is of an adequate standard and bores and wells are located away from immediate sources of contamination.

6.1.7 Nitrate

As a consequence of the significant changes in land use which have occurred since the mid-1990's, spatial and temporal changes in groundwater nitrate concentrations have become a major focus for management of groundwater quality in the Southland Region. Groundwater containing elevated nitrate concentrations can affect the water quality and ecology in streams with a significant component of baseflow derived from groundwater and present a health risk at concentrations greater than 11.3 mg/L (as N) when utilised for potable supply.

A significant amount of monitoring data is available to assist characterisation of groundwater nitrate concentrations in the Southland Region. This information falls into four categories:

1. Results from the Environment Southland baseline groundwater monitoring programme. This data is collected on a quarterly basis from a selected number of monitoring sites and is suitable for assessment of state and trends in groundwater nitrate concentrations;
2. Results of compliance monitoring undertaken by Environment Southland primarily for farm dairy effluent discharge consents. This data is useful for establishing the spatial (and depth) distribution of groundwater nitrate concentration but generally has an insufficient period of record and/or sampling frequency to allow assessment of temporal trends;
3. Data collected for the Environment Southland groundwater quality investigations monitoring programme. This data includes samples collected from aquifer characterisation studies as well as localised investigations into groundwater nitrate ‘hotspot’ areas.
4. Miscellaneous sample results from one-off or localised sampling surveys including samples collected by drillers immediately following bore installation. In many cases this information is of uncertain provenance so has to be considered in the overall context of data derived from baseline and compliance monitoring.

Overall, the existing groundwater nitrate data set held by Environment Southland includes samples from approximately 950 individual bores collected since 1998. This data set is used in the following section to characterise spatial and depth variation in observed groundwater nitrate concentrations. Of this sample population, only relatively small sub-set (58 sites) currently have sufficient data to enable statistical analysis of temporal trends in groundwater nitrate concentrations.

In order to illustrate the spatial distribution of groundwater nitrate concentrations **Figure 18** shows a plot of median concentrations from all sites for which groundwater nitrate data is available compared to the DWSNZ MAV of 11.3 mg/L nitrate-N. The data show a pattern of elevated nitrate concentrations (>50% of MAV) across the Waimea Plain from Balfour to Knapdale and around an axis extending across Eastern and Central Southland from Edendale to Otautau. Groundwater nitrate concentrations around the periphery of these areas tend to be less than 50% of MAV.

Overall, allowing for localised influences at individual sample sites, areas showing elevated nitrate concentrations tend to correspond with those areas of highest groundwater nitrate risk identified in **Box 6**. The figure also highlights nitrate ‘hotspot’ areas where elevated nitrate concentrations are spatially aggregated including Balfour, Wendonside, Knapdale, Edendale and areas of the Oreti Plains. In order to better define the magnitude and extent of groundwater nitrate concentrations Environment Southland has undertaken detailed sampling in a majority of these areas as part of its groundwater quality investigations monitoring programme. Results of these investigations (e.g. SKM, 2008) typically show that groundwater nitrate concentrations exhibit relatively complex spatial and temporal variability inferred to reflect the cumulative effects of historical and current land use which are seldom attributable to a single source or land use activity.

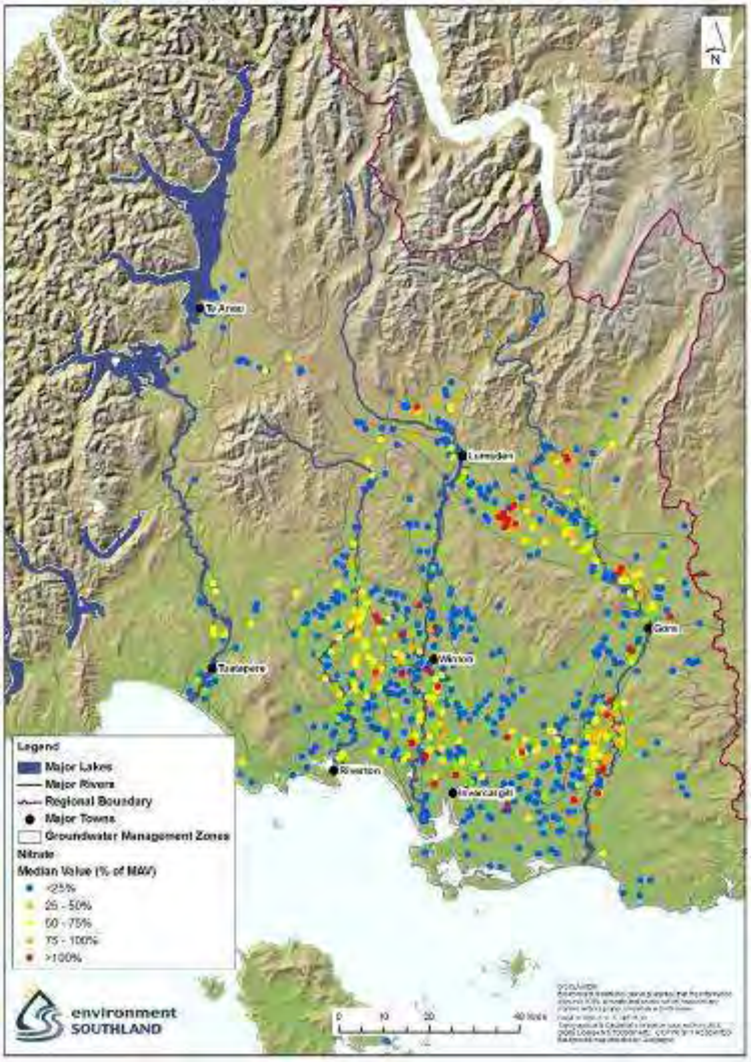

Figure 18. Spatial distribution of groundwater nitrate concentrations

Table 1 lists the median nitrate concentrations for individual groundwater zones and confined aquifers using aquifer type and geology data recorded on the Environment Southland WELLS database, and calculates a weighted average nitrate concentration for each aquifer type classification[10]. The table also notes the number of sites exceeding MAV in each groundwater zone/confined aquifer. Calculated upper and lower quartile nitrate concentrations[11] are provided as an indication of the spread of nitrate concentrations observed within an individual groundwater zone or confined aquifer as a number of sites exhibit concentrations which appear anomalously high, possibly due to localised factors (such as wellhead protection) influencing groundwater quality individual sampling sites, particularly in the miscellaneous and compliance data sets.

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[10] Based on the number of sampling sites and calculated median nitrate concentration for each individual groundwater zone/ confined aquifer.

[11] Figures for upper and lower quartile nitrate concentrations are provided where the number of samples exceeds 5

Table 1. Median groundwater nitrate concentrations per groundwater zone and confined aquifer

Groundwater Zone / Aquifer Name	Aquifer Type	No of sites	No of sites exceeding MAV	Nitrate-N (mg/L)		
				Median	Lower Quartile	Upper Quartile
Castlerock	Terrace	10	0	3.2	2.5	4.6
Chatton	Terrace	10	1	0.2	0.09	3.8
Edendale	Terrace	49	0	4.9	1.8	7.3
Longridge	Terrace	4	0	2.4		
Lower Aparima	Terrace	41	0	1.4	0.2	3.4
Lower Waiau	Terrace	25	0	2.2	0.9	4.8
Orepuki	Terrace	5	0	0.5		
Te Anau	Terrace	17	0	1.5	0.3	2.0
Tiwai	Terrace	1	0	0.3		
Upper Aparima	Terrace	57	0	3.2	1.0	5.7
Wendonside	Terrace	19	2	3.4	1.9	9.3
Number of Sites		**238**	**3**			
Weighted Average				**2.8**		
Central Plains	Lowland	62	4	1.1	0.03	4.4
Knapdale	Lowland	34	2	6.2	3.6	8.0
Lower Mataura	Lowland	79	7	4.1	0.6	8.7
Lower Oreti	Lowland	69	1	1.2	0.08	4.3
Waihopai	Lowland	78	2	0.25	0.01	2.5
Waimatuku	Lowland	29	1	5.7	2.2	7.6
Makarewa	Lowland	81	1	0.5	0.06	4.8
Waimea Plain	Lowland	41	8	6.1	2.3	10
Number of Sites		**473**	**26**			
Weighted Average				**2.5**		
Cattle Flat	Riparian	2	0	0.8		
Five Rivers	Riparian	19	1	4.6	1.4	6.8
Oreti	Riparian	6	0	3.0	2.5	4.8
Riversdale	Riparian	50	0	3.0	1.8	5.1
Upper Mataura	Riparian	9	0	1.3	0.9	4.6
Waipounamu	Riparian	6	0	3.1	2.7	6.9
Wendon	Riparian	9	0	4.0	3.6	4.9
Whitestone	Riparian	1	0	0.3		
Number of Sites		**102**	**1**			
Weighted Average				**3.2**		
Lumsden Aquifer	Confined	13	0	1.1	0.9	1.5
North Range Aquifer	Confined	1	0	2.9		
Lintley Aquifer	Semi-Confined	3	0	3.7		
Garvie Aquifer	Confined	4	0	2.9		
Number of Sites		**21**	**0**			
Weighted Average				**1.9**		
Gore Lignite Measures	Confined	51	0	0.1	0.01	0.6
Miscellaneous Tertiary	Semi-confined	18	0	1.6	0.2	5.7
Number of Sites		**69**	**0**			
Weighted Average				**0.5**		
Catlins	Fractured Rock	12	0	0.1	0.03	0.7
Hokonui	Fractured Rock	4	0			
Murihiku	Fractured Rock	25	0	0.3	0.02	1.9
Number of Sites		**37**	**0**			
Weighted Average				**0.2**		

Based on the assessment outlined in **Table 1** the highest median groundwater nitrate concentrations are recorded in the Knapdale (6.2 mg/L), Waimea Plain (6.1 mg/L) and Waimatuku (5.7 mg/L) groundwater zones which are classified as Lowland aquifers. However, when averaged across all groundwater zones, Lowland aquifers have a lower average nitrate concentration (2.8 mg/L) than that calculated for Riparian aquifers (3.2 mg/L).

The apparent discrepancy between highest median nitrate concentrations being observed in individual Lowland aquifers and the relatively low average nitrate concentration for this aquifer type is interpreted to reflect the range of geochemical conditions present in these aquifers with increasing depth. For example, **Figure 19** shows a plot of bore depth against median nitrate concentration in the Knapdale, Waimatuku, Waihopai and Central Plains groundwater zones. These data clearly show that nitrate concentrations in excess of 1 mg/L are rarely observed in bores deeper than 20 metres, while concentrations above this depth may be significantly elevated. This suggests that nitrate concentrations may be elevated in the upper levels of these aquifers due to the prevalence of oxygen-rich groundwater derived from land surface recharge. However, where groundwater residence time increases and reducing (low oxygen) conditions prevail at depth, nitrate concentrations are significantly lower, possibly reflecting either recharge of groundwater prior to significant land use intensification or conversion of nitrate to other forms of nitrogen (e.g. NH_4, N_2 or N_2O) due to the redox processes outlined in **Section 2.1.3**. The depth of the transition from oxidised to reduced conditions is termed the *redoxcline* and appears to occur approximately 20 metres below the land surface in the groundwater zones illustrated.

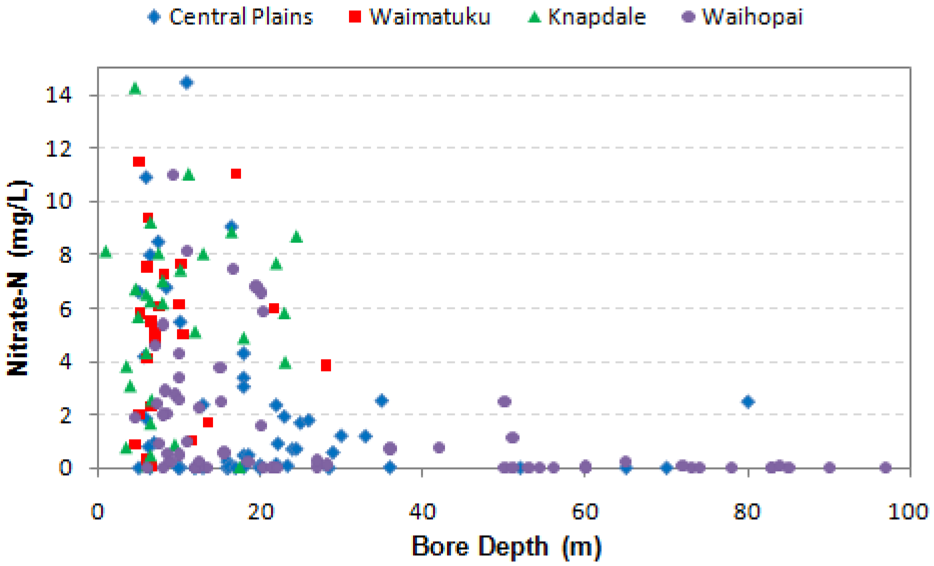

Figure 19. Variation of groundwater nitrate concentration with depth in four Lowland aquifers

The presence of low nitrate groundwater at depth in Lowland aquifers helps explain the overall contrast in groundwater median groundwater nitrate concentrations in Lowland aquifers listed in **Table 1**. Where these aquifer have a limited saturated thickness or a majority of bores are shallow (<20 metres) such as in the Knapdale, Waimea Plains and Waimatuku groundwater zones, bores draw shallow, oxidised groundwater that may be impacted by localised land use. However, in those Lowland aquifers where a greater number of bores are screened at depth, average nitrate concentrations are lower reflecting the older and/or more reduced nature of groundwater at depth. The occurrence of localised impacts of land use impacting on shallow groundwater may also help explain the significantly higher number of sites exceeding MAV in Lowland aquifers than any other aquifer type.

Highest average nitrate concentrations are observed in Riparian aquifers. Despite the contribution of low nitrate surface water recharge to the overall water budget in this aquifer type, the higher nitrate concentrations in these areas may reflect a combination of the thin, highly permeable nature of alluvial soils which enable relatively rapid leaching of nutrients from the land surface combined with the generally higher intensity of land use (including the use of well-drained soils for over-wintering of stock) in these areas.

Lowest nitrate concentrations are observed in confined and fractured rock aquifers. This is inferred to reflect the residence time of water within these relatively deep aquifers combined with the prevalence of reducing conditions. These effects are particularly pronounced in aquifers in the Gore Lignite Measures in Eastern Southland which, as previously described, commonly exhibit highly reducing conditions.

Figure 20 shows a plot of measured nitrate concentrations (in terms of median concentrations where more than one sample recorded per site per year) as a percentage of MAV for data recorded over the period 1997 to 2009. The data show that between 60 to 80 percent of sites sampled have nitrate concentrations less than 50% of MAV with nitrate concentrations exceeding MAV at between 3 to 7 percent of sites. In themselves, these figures may over-estimate the actual extent of bores affected by nitrate concentrations due to bias introduced as a result of investigations initiated to improve definition of the extent and magnitude of nitrate ‘hotspot’ areas and compliance monitoring at sites with an elevated potential to be impacted by localised contaminant sources. However, the data do indicate that a relatively low percentage of bores (~15%) are affected by groundwater nitrate concentrations in excess of 75% of MAV.

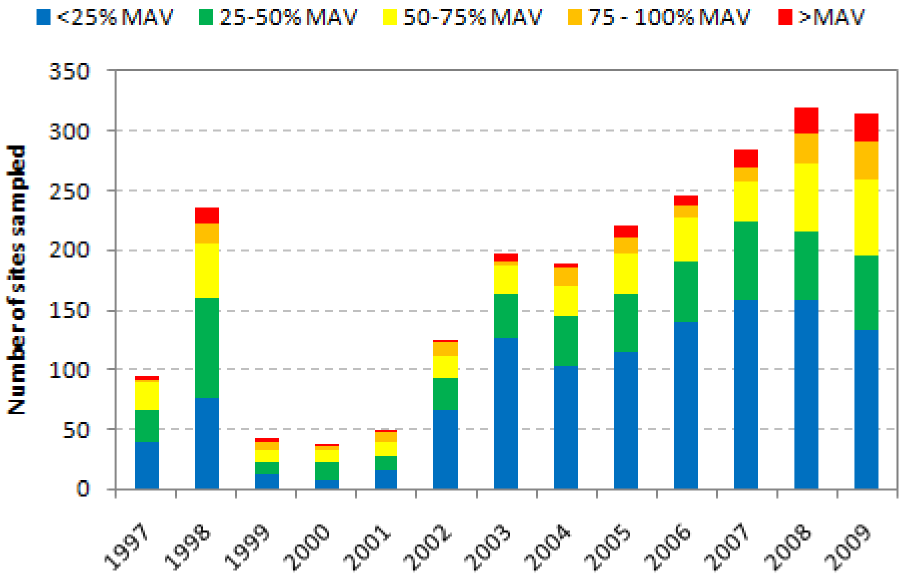

Figure 20. Median nitrate concentrations recorded between 1997 to 2009 as a percentage of MAV.

Figure 21 shows the spatial distribution of calculated trends in groundwater nitrate concentrations at Environment Southland baseline monitoring sites. The data show that of the 58 sites with sufficient data to enable assessment of temporal trends, 29 (50%) showed no statistically significant temporal trends while 21 (36%) exhibited an increasing trend and 8 (14%) a declining trend. No clearly identifiable spatial distribution is observed in the calculated nitrate trends although, as outlined in **Table 2,** Terrace aquifers exhibited a lower percentage of sites with increasing nitrate trends compared to Lowland and Riparian aquifers. While this observation may be an artefact of the relatively small sample size, it is noted that Terrace aquifers also exhibit lower median nitrate concentrations compared to Lowland and Riparian aquifers, possibly reflecting their location around the margins of the Southland Plains and inland valleys where land use intensity has historically been lower.

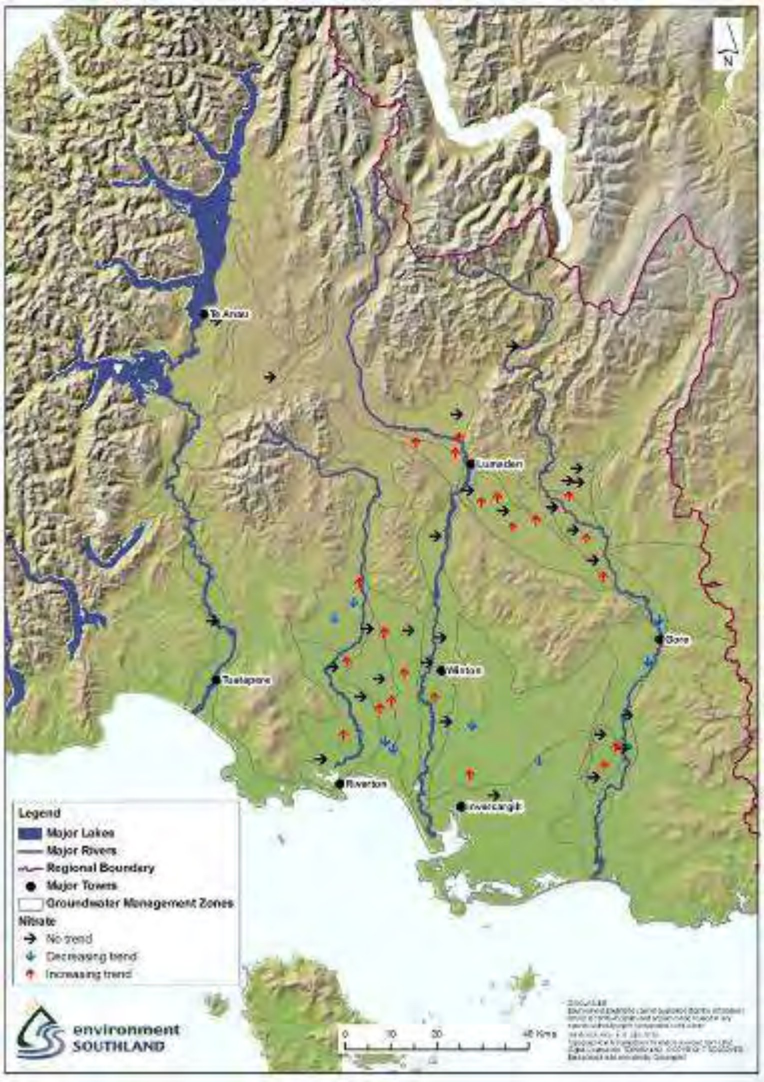

Figure 21. Temporal trends in groundwater nitrate concentrations

Table 2. Temporal trends in groundwater nitrate concentrations by aquifer type

Aquifer Type	No. of sites	No trend	Increasing trend	Decreasing trend
Lowland	27	41%	37%	22%
Terrace	18	61%	28%	11%
Riparian	10	60%	40%	-
Confined	3	33%	66%*	-
	58	**50%**	**36%**	**14%**

* Due to the small sample size, overall trend for confined aquifers should be interpreted with some caution

In terms of observed temporal trends in groundwater nitrate concentrations at individual groundwater monitoring sites, **Figure 22** shows a time-series plot of nitrate concentrations in selected bores. These data illustrate the general range of temporal trends observed across the monitoring network including:

- A relatively stable increasing trend with some seasonal variation (E44/0008)
- An increasing trend punctuated by a large unexplained 'spike' (E45/0011)
- A virtually linear increasing trend (E44/0035)
- A gradual decline followed by stabilisation of nitrate concentrations (E45/0156)
- Seasonally variable concentrations which show no obvious long-term trend (F44/0039)

As illustrated, nitrate concentrations show a wide range of temporal trends and it is often difficult to attribute observed variations to any observed changes in the surrounding environment, particularly in terms of short-term variations such as those illustrated at E45/0011.

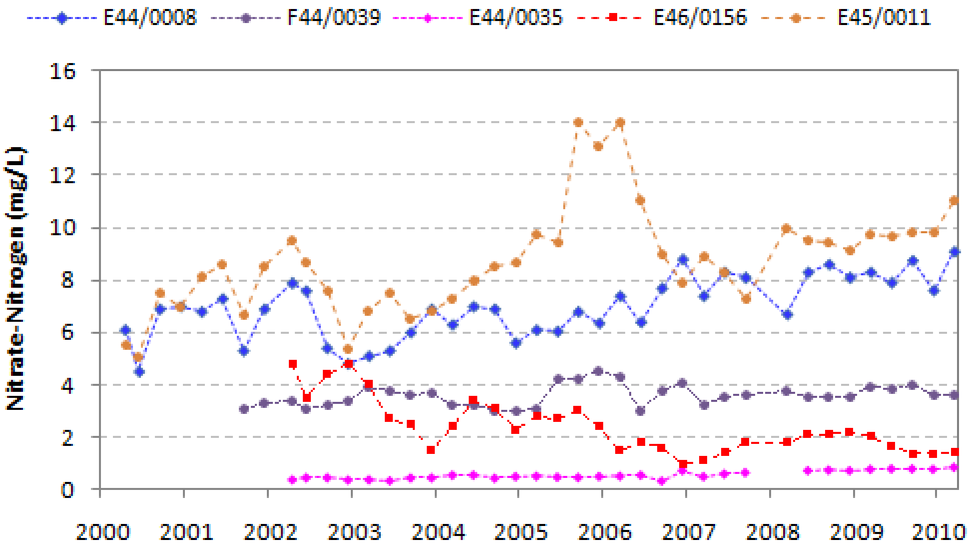

Figure 22. Observed temporal trends in groundwater nitrate concentrations at selected monitoring sites

GNS (2009) analysed groundwater quality data from approximately 970 state of the environment (SOE) groundwater quality monitoring sites sampled by Regional Councils across New Zealand on a regular basis over the period 1995-2008[12]. Results of this assessment, listed in **Table 3** below, indicate a national median groundwater nitrate concentration from all sites of 1.7 mg/L nitrate-N. The corresponding figure from the Southland Region was 3.4 mg/L nitrate-N, which was the second equal highest regional concentration (after Waikato 4.2 mg/L and Canterbury 3.4 mg/L). Analysis in the preceding section using a wider data set from Southland estimated the regional median concentration to be 2.4 mg/L. Using either figure Southland groundwater nitrate concentrations are higher than all other regions except Waikato and Canterbury.

The GNS (2009) report also calculated that 20% of groundwater monitoring sites included in Regional Council State of the Environment (SOE) monitoring programmes across New Zealand showed an increasing trend for nitrate with 12% showing a decreasing trend. Comparison with figures in **Table 2** above indicates that the overall number of groundwater monitoring sites in Southland showing an increasing nitrate trend (36%) is almost twice the national average. Possible reasons for the significantly higher frequency on increasing nitrate trends in the Southland Region may include:

- The scale and extent of land use intensification occurring in the Southland Region since the mid-1990's compared to that occurring in other regions; and,
- As observed in the GNS (2009) report, the prevalence of oxygen rich conditions which favour the persistence of nitrate in shallow groundwater across the Southland Region compared to other regions which have a higher prevalence of reducing geochemical conditions.

Table 3. Summary of median concentrations and temporal trends in groundwater nitrate across New Zealand (figures for the Southland Region from this report, all other data derived from GNS (2009))

Region	No. of sites	Median NO_3-N (mg/L)	Temporal Trends		
			% Increasing	% Decreasing	% No Trend
Northland	37	0.6	8.1	8.1	83.8
Auckland	21	0.1	14.3	28.6	57.1
Waikato	110	4.2	32.7	20.0	47.3
Bay of Plenty	53	0.1	5.7	7.5	86.8
Hawke's Bay	45	0.1	17.8	8.9	73.3
Manawatu-Wanganui	21	0.8	9.5	19.0	71.4
Taranaki	70	2.0	7.1	12.9	80.0
Wellington	71	0.6	5.6	19.7	74.6
Tasman	16	1.5	25.0	18.8	56.3
Marlborough	23	0.5	21.7	8.7	69.6
West Coast	8	1.1	50.0	0.0	50.0
Canterbury	272	3.4	29.8	5.9	64.3
Otago	98	0.8	12.2	11.2	76.5
Southland	**58**	**2.4**	**36.2**	**13.8**	**50.0**

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[12] This assessment used only data derived from the Environment Southland baseline monitoring programme

7.0 Discussion

7.1 General Groundwater Quality

Based on an analysis of results from the baseline monitoring programme, **Table 4** outlines median concentrations of major ions, both for the Southland Region as a whole and separated by aquifer type. In terms of median concentrations the data show a progression in major ion concentrations between aquifer types reflecting the influence of recharge source (soil moisture infiltration vs river recharge) and residence time (water-rock interaction and redox processes) within the various aquifer types[13]. In general, Riparian aquifers show lowest overall dissolved ion concentrations reflecting the contribution of river recharge (containing low dissolved ion concentrations) and shorter residence time due to relatively rapid groundwater flow through permeable gravel deposits. Dissolved ion concentrations are generally highest in Lowland aquifers reflecting recharge almost exclusively from local rainfall infiltration and the relatively slow circulation of water, particularly at depth, which provides sufficient time for water quality changes to result from water-rock interaction and redox processes. As described in **Section 6.5**, the change to more reducing conditions at depth in Lowland aquifers may in part explain the lower median sulphate concentrations in Lowland aquifers compared to other aquifer types.

Table 4. Median groundwater quality from Environment Southland baseline water quality monitoring sites

Parameter	Units	Median	Median by Aquifer Type			
			Lowland	Terrace	Riparian	Confined
Number of Sites		45	19	15	7	4
Electrical Conductivity	µS/cm	208	230	194	160	186
pH		6.5	6.5	6.6	6.5	6.8
Total Hardness	mg/L as $CaCO_3$	60	63	64	45	47
Total Alkalinity	mg/L as $CaCO_3$	41	43	54	28	50
Chloride	mg/L	18.0	22.0	17.0	10.6	21.0
Sulphate	mg/L	5.6	3.9	6.6	8.6	2.7
Calcium	mg/L	14.0	15.0	14.0	12.1	8.9
Magnesium	mg/L	6.2	6.5	6.1	4.5	5.8
Sodium	mg/L	14.0	17.3	13.3	10.0	16.4
Potassium	mg/L	0.9	0.9	0.8	1.1	0.9
Iron	mg/L	0.006	0.11	0.004	0.004	3.1
Manganese	mg/L	0.001	0.001	0.003	0.001	0.10
Nitrate-Nitrogen	mg/L	3.5	4.8	2.8	4.5	0.6
Dissolved Reactive Phosphorus	mg/L	0.016	0.016	0.019	0.11	0.027

However, as shown on **Figure 23**, when plotted on a piper diagram median groundwater quality results from individual monitoring sites show significant scatter, with no clear differentiation between the various aquifer types. In fact, when average concentrations for each aquifer type are plotted,

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[13] The number of confined aquifer samples is considered insufficient to provide a realistic approximation of water quality in this aquifer type.

there is little obvious differentiation in regard to average ‘water type’ although relative concentrations increase as previously described.

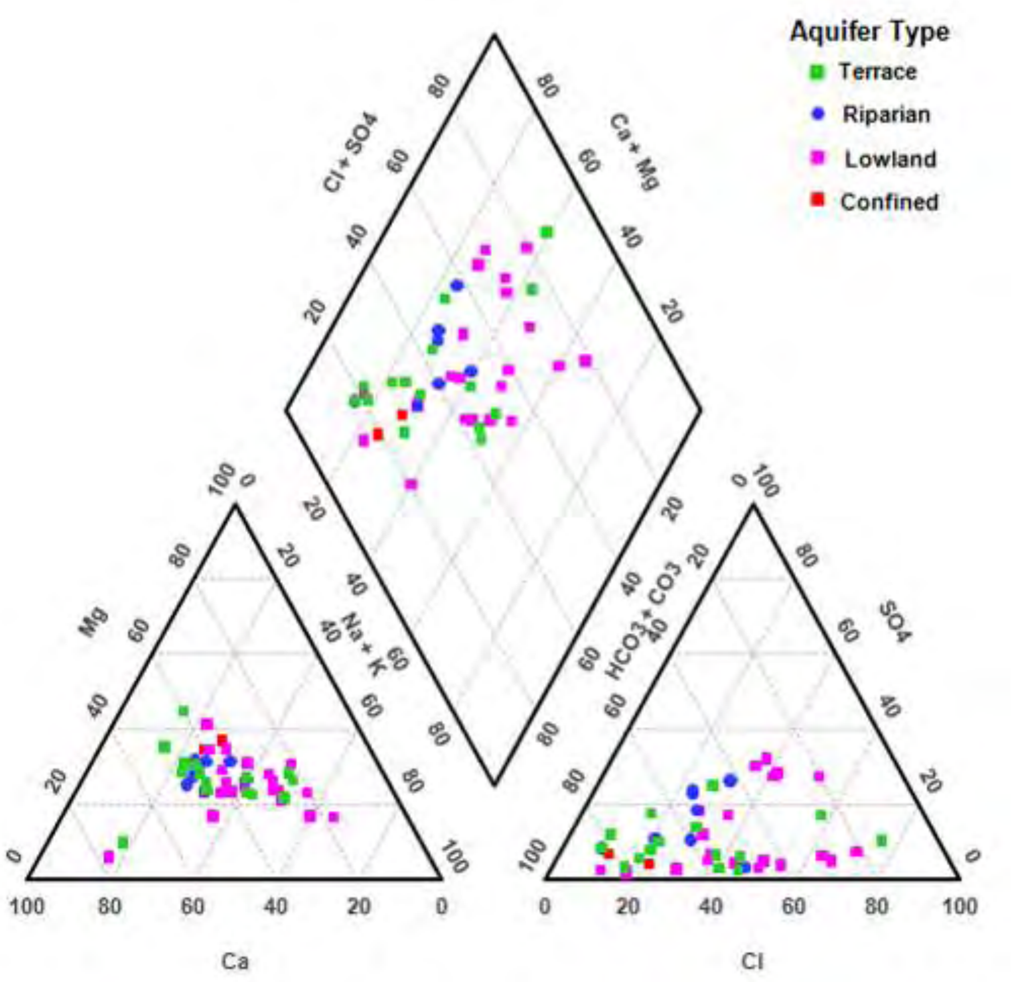

Figure 23. Piper plot of major ion chemistry from baseline monitoring sites

Examination of the spatial distribution of individual parameters concentrations indicate two processes may significantly influence the amount of scatter observed in the groundwater quality data and act to mask the more subtle influences associated with differences in aquifer type. The first is the obvious carbonate influence on groundwater in the Central Plains area (e.g. west of the Oreti River and South of the Taringatura Hills). Although only two bores included in the baseline monitoring programme in this area are known to be screened in Tertiary limestone (Winton Hill Formation) aquifers, the influence of the carbonate geology is observed in terms of alkalinity, calcium and to a lesser degree magnesium concentrations[14] in shallow unconfined terrace and lowland aquifers in this area.

The second process which appears to exert a significant geographical influence of groundwater quality is the aerosol deposition of salts (particularly sodium and chloride) in rainfall along the south coast. This effect is clearly evident in the plots of the spatial distribution of sodium and chloride concentrations shown in **Section 6.1.2** which show a relatively consistent decrease in concentration inland from the coast.

These processes help explain some of the scatter evident in terms of 'water type', particularly in areas south of the Taringatura/Hokonui Hills. For example, in the west of this area water types are dominated by the presence of elevated calcium and bicarbonate concentrations, while to the east of the Oreti River the carbonate influence declines significantly and major ion chemistry tends to be dominated by chloride and bicarbonate.

The overall influence of both carbonate geology and coastal deposition of aerosol salts on water chemistry is illustrated in **Figure 24** below which shows the median milliequivalent concentrations of major ions across three nominal geographic zones. The northern zone includes all sites north of the Hokonui/Taringatura Hills while the Central and Eastern zones represent sites located south of these hills, and to the west and east of the Oreti River respectively. The figure clearly shows the dominating influence of bicarbonate, calcium and magnesium in the central zone reflecting the local carbonate geology, while a clear gradient is evident in relative chloride and sodium concentrations between the more coastal location of monitoring sites in the eastern zone and those in the northern zone further inland.

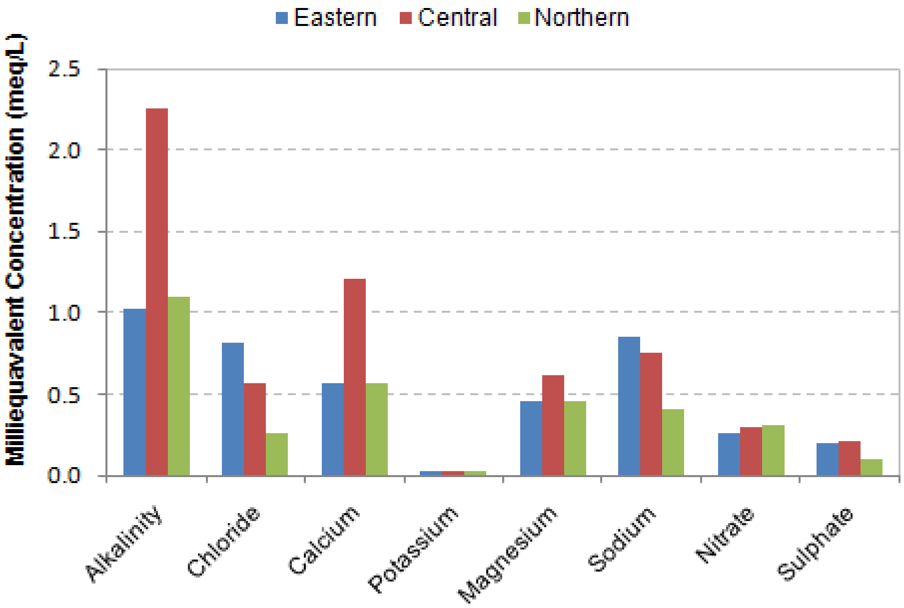

Figure 24. Median milliequivalent concentrations of major ions in the eastern, central and northern geographic areas.

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[14] This obviously also influences total hardness which is a product of total calcium and magnesium concentration.

Table 5 summarises the calculated temporal trends for major ions observed in the Environment Southland baseline groundwater quality sites. The data show that, with the exception of potassium and DRP, the percentage of sites showing increasing trends is significantly in excess of sites showing decreasing trends. This suggests a net decline in groundwater quality across a significant portion of the Southland Region which is consistent with ongoing intensification of land use. However, with the exception of nitrate, the rate of change in major ion concentrations is unlikely to result in any significant issues in terms of suitability of the water for potable supply over the medium to long-term.

It is interesting to note that although sodium, calcium and sulphate showed increasing and decreasing trends at an identical proportion of sites, a common trend in all three parameters was only observed in 3 individual monitoring bores. This suggests the observed temporal trends reflect localised characteristics of water quality within the recharge area associated with each monitoring site rather than a consistent regional influence.

Table 5. Percentage of baseline sites exhibiting temporal trends in major ion and nutrient concentrations

Trend	Alkalinity	Cl	SO_4	Ca	Mg	K	Na	NO_3-N	DRP
% Increasing	34	62	31	31	24	4	31	40	7
% Decreasing	8	4	13	13	7	11	13	11	16
% No Trend	58	34	56	56	69	84	56	49	33

7.2 Suitability of Groundwater for Potable Water Supply

Given the widespread use of groundwater for municipal and domestic water supplies, ensuring water quality is suitable for potable supply is an important resource management issue for the Southland Region. **Table 6** shows the rate of exceedence of the DWSNZ (2008) MAV and aesthetic water quality guidelines for Environment Southland baseline and compliance water quality sites sampled during 2010. The most notable feature of these data is the high rate of exceedence for indicator bacteria (*E.coli*) which were detected above the MAV in one or more samples from approximately 20% of the total number of sampling sites. These results indicate that microbial contamination is the most widespread and significant issue affecting the suitability of groundwater for potable supply in the Southland Region. As discussed in **Section 5.1**, the presence of indicator bacteria typically reflects contamination of a bore or well from local sources.

Available groundwater quality data indicate that approximately 7% of bores sampled exceed the DWSNZ MAV for nitrate, with 15% of sites exhibiting concentrations greater than 75% of MAV. Sites showing elevated nitrate concentrations (>75% MAV) tend to be clustered around known nitrate ‘hotspot’ areas. Elsewhere, isolated nitrate concentrations exceeding MAV are commonly associated with contamination resulting from localised factors (such as wellhead protection or the proximity of the bore to a specific contaminant source).

The data also indicate that naturally occurring manganese concentrations exceed the MAV for a relatively small number of sites sampled (4%). These sites are typically located in aquifer systems containing reduced groundwater. In many cases bores exceeding the MAV for manganese are also affected by elevated iron concentrations, the combination of which significantly reduce aesthetic water quality to the point where bores containing manganese above MAV are seldom used for potable supply.

The limited data available tend to suggest that other groundwater quality parameters which can affect the suitability of groundwater for potable supply such as pesticides, heavy metals and hydrocarbons only occur in localised areas around specific contaminant sources and, in the case of pesticides, occur at concentrations well below levels of health concern.

Table 6. Exceedence of DWSNZ Maximum Acceptable Values (MAV) and aesthetic guidelines for Environment Southland baseline water quality sites sampled in 2009.

Parameter	No sites sampled	Water Quality Standards		Aesthetic Water Quality	
		MAV	% sites exceeding	Guideline Value	% sites exceeding
E.coli	209	<1	21%		
Manganese	45	0.4	4%	0.04	20%
Nitrate-Nitrogen	314	11.3	7%		
Fluoride	7	1.5	0%		
pH	45			7.0 - 8.5	84%
Chloride	45			250	0%
Total Hardness	38			200	2%
Sulphate	45			250	0%
Sodium	45			200	0%
Iron	45			0.2	11%

In terms of aesthetic water quality, the main parameters exceeding guideline values are pH, total hardness, iron and manganese. Due to the processes occurring during land surface recharge described in **Section 2.1.3**, shallow groundwater throughout Southland commonly exhibits pH values which are outside the range recommended by the DWSNZ guideline (7.0 to 8.5). Low pH water can affect aesthetic water quality due to its acidic character which can result in corrosion particularly when sitting for any period in galvanised or metal piping. This can result in small amounts of the metal being dissolved in the water (a process termed *plumbosolvency*) which can then be delivered through the reticulation system.

Iron and manganese concentrations in excess of aesthetic guidelines are commonly observed in many aquifer systems where groundwater is reduced (oxygen-poor) as a result of geological conditions and/or the rate of groundwater throughflow. Elevated concentrations of these ions can result in problems with aesthetic water quality issues such as staining of laundry and sanitary ware and in some cases the growth of iron bacteria within reticulation systems.

Total hardness may exceed guideline values in the Southland Region in bores drawing from Tertiary limestone aquifers, particularly in the Central Plains area to the west of the Aparima River.

Overall, groundwater quality is suitable for potable supply throughout a majority of Southland aquifers. The main groundwater quality issue identified by monitoring is the high incidence of microbial contamination which can result in immediate and acute impacts on human health. However, in a majority of instances, the occurrence of microbial contamination is a localised issue which can be significantly reduced by adequate wellhead protection and ensuring bores are located appropriately with respect to potential contaminant sources. Relatively simple, low-cost treatment devices are also available to ensure microbial contamination does not adversely affect potable water supplies.

Naturally elevated manganese and iron concentrations are a feature of many aquifer systems in the Southland Region and adversely affect aesthetic water quality. Due to the combined effects of these parameters on aesthetic water quality, bores containing manganese concentrations in excess of MAV are seldom used for potable water supply. However, where no alternative water source exists concentrations of these parameters can be reduced to acceptable levels by relatively simple treatment options typically involving aeration and/or ion exchange methods.

Analysis of temporal trends in groundwater nitrate concentrations indicate nitrate concentrations are increasing across many parts of the Southland Region although nitrate concentrations in excess of DWSNZ MAV tend to occur in localised ‘hotspot’ areas where concentrations are elevated as a result of the cumulative effects of historical and/or current land use. However, elevated nitrate concentrations in individual bores and wells may also be measured in bores affected by localised contamination.

8.0 References

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