Groundwater Report on the Balfour Groundwater Quality Study

Karen Wilson
Senior Groundwater Scientist

12 July 2010

Environment Southland is the brand name
of Southland Regional Council

Table of Contents

1. Executive Summary

The Balfour groundwater quality project was developed in response to consistently elevated (nitrate + nitrite) – nitrogen (or nitrate-N) levels in bores south-west of the Balfour township. Several of these bores contained nitrate-N concentrations, which were up to twice the maximum acceptable level in the Drinking Water Standards for New Zealand (Ministry of Health, 2008). Following preliminary work by Environment Southland into the extent, severity and cause of the contamination, a collaborative working group was established comprising of landowners, residents, the Primary Sector Water Partnership and Environment Southland. The purpose of this report is to collate, analyse and summarise available groundwater and surface water data to inform the Balfour groundwater quality study.

The geology of the Waimea Plains is made up of three terranes, which form a deep sedimentary basin that is fault controlled and has been infilled with tertiary aged marine sediments. This is overlain by a relatively thin veneer of alluvial sediments deposited during the late Quaternary period through glacial advances and retreats. Many of the gravel deposits have been reworked by major river systems resulting in a series of broad terraces flanked by recent floodplains. Geological processes, like faults and folds, have exerted a major influence over catchment hydrology and hydrogeology.

The Quaternary gravels contain an unconfined aquifer system whose characteristics are consistent with properties associated with lowland aquifers. Recharge to the aquifer is from localised rainfall, while groundwater discharge is predominately into the Waimea and Longridge Streams. The aquifer has a relatively complex groundwater flow, which generally flows in a southerly direction towards the Waimea and Longridge Streams confluence, with a bulk seepage velocity of between 175 to 480 metres per year.

Groundwater quality monitoring data shows water is characterised as being sodium-bicarbonate type waters, which is typical of groundwater with a low residence time in relatively inert aquifer media. Nitrate-N concentrations exceeded drinking water standards in 25 percent of bores sampled in the 2009 annual snapshot survey and interpolation of results from snapshot surveys between 2007 to 2008 suggest that the affected area is extending southwards (or downgradient). Trend analysis of nitrate-N data shows statistically significant increasing concentrations in three of the five monitoring bores based on a maximum of nine years of monitoring data.

Isotope and geochemistry data indicate fertiliser is the likely source of nitrate-N found in one of the monitoring bores, while the results from other sites are less clear, with some indicating wastewater could also be a major contributor.

Surface water quality results show marked increases in nitrate-N concentrations in the lower reaches of the Longridge Stream and in the Waimea Stream downstream of the Balfour township, which is consistent with groundwater discharge from the study area.

The results highlight the vulnerability of this particular hydrogeological setting to the impacts human activities can have on groundwater quality and illustrates the need for effective management of land use impacts to ensure water quality objectives are met.

2. Background

2.1 Objectives

This report is one of several being prepared to summarise available information for the Balfour groundwater quality project. The Balfour groundwater quality project was developed in response to consistently elevated nitrate-N levels in bores south-west of the Balfour township. Several of these bores contained nitrate-N concentrations, which were up to twice the maximum acceptable level in the Drinking Water Standards for New Zealand (DWSNZ) (Ministry of Health, 2008[1]). Following preliminary work by Environment Southland into the extent, severity and cause of the problem, the Primary Sector Water Partnership selected the Balfour area as one of its five national focus catchments.

Since early 2009, Environment Southland, the Primary Sector Water Partnership and landowners have been working together to try and improve understanding of the cause and impact of the elevated groundwater nitrate-N levels and to formulate a collaborative response to address the issue. Over the past 18 months, the focus has primarily been on collecting information on the groundwater resource, land use activities both past and present and to improve information dissemination among participating parties.

The primary objective of this report is to collate, analyse and summarise the hydrogeological setting and the groundwater and surface water quality information collected in the Balfour area to date. This report is intended to be a technical report on the environmental data, however, the report scope was extended to include background material on fundamental groundwater principles in order to provide context for readers unfamiliar with these concepts.

Figure 1: Photograph looking northeast over the Waimea Plains from the Glenure Hill (taken 4th December 2003)

---

[1] The Drinking Water Standards for New Zealand 2000 have been revised several times and the 2008 document represents the most recent version. In all versions the maximum acceptable value for nitrate-N has remained unchanged at 11.3 –N g/m^3

2.2 Groundwater Principles

When rain falls onto the ground, some of the water flows along the land surface to streams, lakes and other surface water bodies (termed overland flow), some evaporates and is returned back to the atmosphere, some is used by plants and some seeps into the ground. Where water seeps into the ground, some of the water will cling to particles of soil or to roots of plants to be used by plants for growth, some will be intercepted by drains and move laterally through the soil (termed interflow or bypass flow) while the rest of the water will move downwards through empty spaces or cracks until it reaches a layer of rock through which the water cannot easily move. The water then fills all the empty spaces and cracks above that layer fully saturating the material. The top of the water layer is called the water table while the water that fills the empty spaces and cracks is called groundwater[2] (USGS, 2001). These concepts are illustrated in Figure 2 and it is worth noting that at least some groundwater can be found almost everywhere.

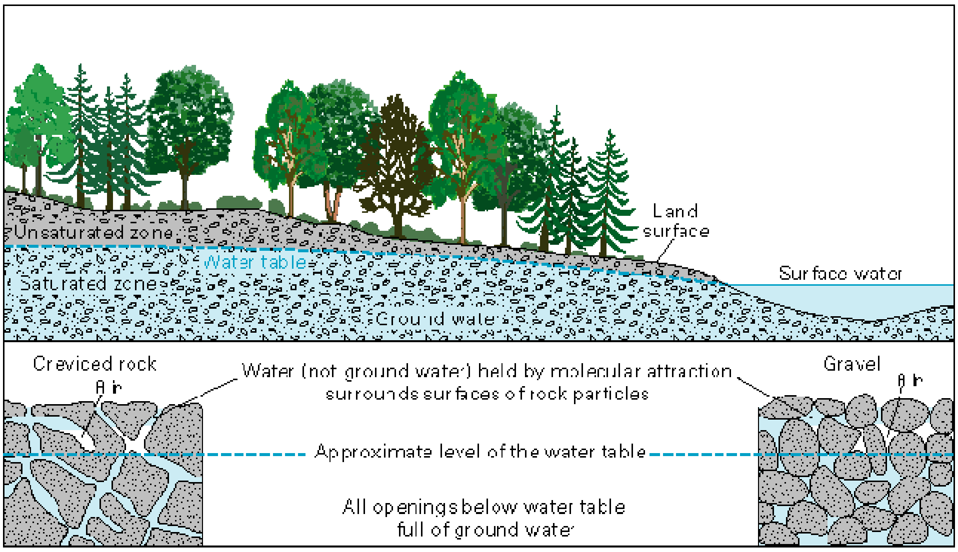

Figure 2: Schematic cross-section of an unconfined aquifer with a close-up of how water is stored between underground rock particles
[Source - USGS website[3]]

An aquifer is the name given to underground soils or rock through which groundwater can easily move in quantities sufficient to support water abstraction[4] (USGS, 2001). The amount of groundwater that can flow through the soil or rock material depends on the size and amount of pore spaces (termed porosity) and how well the pore spaces are connected (termed permeability). If a material contains pores that are not connected, water cannot move from one space to another and the materials are said to be impermeable. For example, clay may have many small pores (high porosity) but the pores are not well connected which restricts the flow of groundwater (low permeability). The same principles apply to fractured rock aquifers (e.g. limestone) where groundwater primarily moves through fractures rather than pore spaces.

Under natural conditions, the water table will vary according to a balance between recharge from rainfall (and sometimes river flow) and discharge to other water bodies including rivers, streams

---

[2] "Groundwater" is defined in the Regional Water Plan for Southland, 2010 (RWP) as subsurface water that occurs beneath the water table in soils and geological formations that are fully saturated.

[3] http://ga.water.usgs.gov/edu/earthgwaquifer.html

[4] "Aquifer" is defined in the RWP as a saturated rock or soil material capable of transmitting and yielding water in sufficient quantities for abstraction.

and lakes. The climate-driven recharge processes are highly variable while the outflow to rivers and streams are relatively constant. Consequently, the aquifer acts as a buffer where groundwater levels vary about some average condition in response to annual or longer-term climatic variations (discussed further in Section 3).

Recharge to aquifers with a shallow water table occurs over a relatively short time scale of hours to days, while the comparatively slow movement of groundwater through the aquifer system means this water is discharged over a much longer period of weeks to years. This means groundwater systems effectively function as a storage component in the hydrological system, retaining water during periods of high rainfall or river flows and releasing it back to surface water ways over subsequent months or years. The timelag between aquifer recharge and discharge varies according to proximity to recharge and discharge points, as shown in Figure 3. As an aquifer system is effectively a three dimensional flow field, proximity can refer to both vertical and lateral distance as illustrated in Figure 3. Human activities like groundwater abstraction can potentially alter the equilibrium between aquifer recharge and discharge if not appropriately managed.

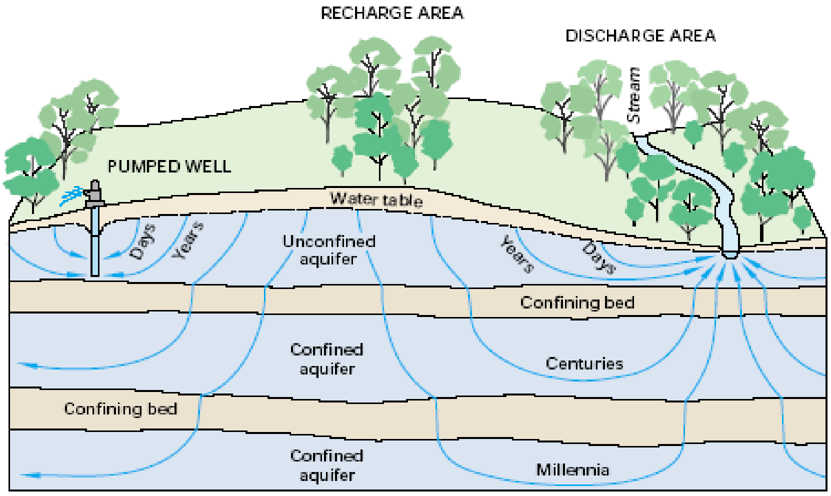

Figure 3: Schematic of groundwater flow paths which vary in length, depth and travel time from points of recharge to points of discharge in the groundwater system
[Source -Winter et al, 1998]

Groundwater and streams can interact in essentially two different ways depending on the relative hydraulic gradient. Where groundwater levels are higher than the water level in the stream, groundwater will discharge into the stream by infiltration through the stream channel. Consequently, stream flow will increase and the stream is defined as a gaining stream, while the groundwater discharge is called base flow. Conversely, when surrounding groundwater levels are lower than the stream water level, surface water will drain out of the stream into the aquifer resulting in a reduction in surface water flow and the stream is referred to as a losing stream, while the recharge to groundwater is called stream leakage. Figure 4(a) shows an example of a gaining stream while 4(b) illustrates a losing stream. The rate of stream leakage or base flow discharge is constrained by the permeability of the stream channel sediments (termed bed conductance), the relative difference in hydraulic head and the hydraulic properties of the aquifer material. Within any particular catchment, a stream may alternate between gaining and losing across its reach.

Alternatively, there may be no hydraulic connection between the aquifer and stream, in which case the stream is said to be disconnected or perched above the water table, as illustrated in

Figure 4(c). In this case, while the stream may lose water to the underlying aquifer, the rate of flow loss is not affected by changes in groundwater levels (unless the groundwater level rises to within a relatively short distance of the stream base). Characteristics of streams in the Balfour area are discussed in Section 3.6.

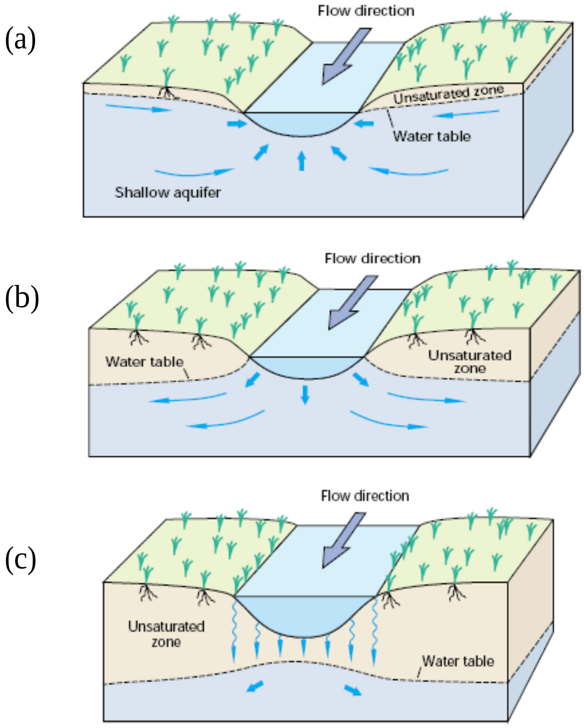

Figure 4: Schematic of groundwater – surface water interaction showing (a) a gaining stream , (b) a losing stream and (c) a disconnected or perched stream
[Source -Winter *et al*, 1998]

Groundwater quality is influenced by a number of natural factors, including recharge source, soil processes, geology, aquifer thickness and water age (referred to as residence time) and human factors like land use and abstraction. These factors can affect the suitability of groundwater for a particular use (e.g. drinking) and can result in adverse effects on aquatic ecosystems where groundwater and surface water interact.

A majority of Southland's aquifer systems are shallow and unconfined (i.e. do not have an impermeable layer at the top of the aquifer). A significant portion of recharge to these aquifers is sourced from rainfall infiltration through the land surface and as water moves down through the soil to the water table, it can contain lots of dissolved substances. Consequently, these aquifer systems can be directly influenced by contaminants introduced as a result of overlying land use. Figure 5 shows an example of how leaching under a waste disposal site has contaminated groundwater which feeds nearby supply wells and a river.

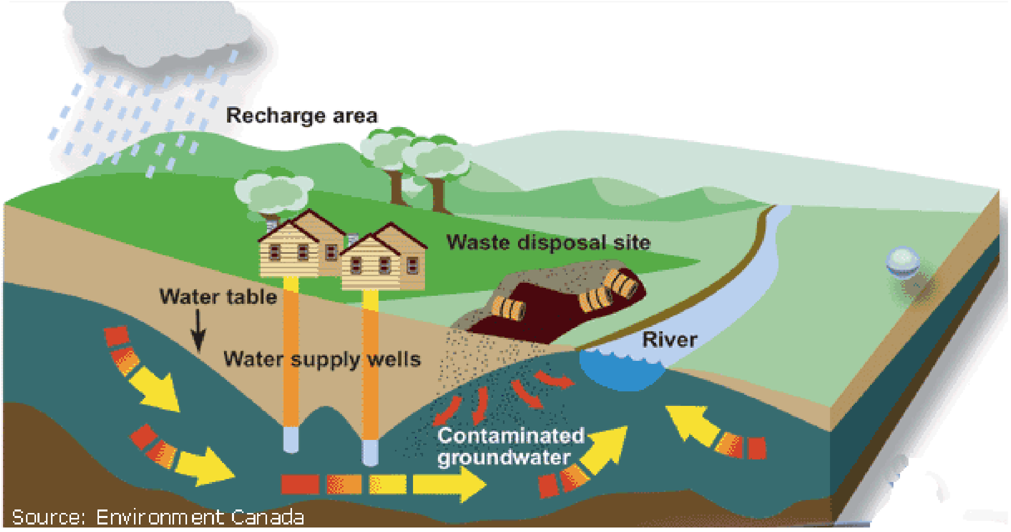

Figure 5: Schematic of groundwater contamination from a waste disposal site
[Source - USGS website[5]]

A single point (or source point) of contamination to groundwater will impact a relatively small area or volume of the aquifer, however, if there are multiple contamination points their cumulative impact could increase the concentration of a contaminant and/or impact a greater portion of the aquifer. Diffuse (or non-point source) contamination can also adversely affect groundwater quality, for example, discharges from fertilisers and waste irrigation systems which spread the contamination over a large area. Once a contaminant is within an aquifer, it may undergo chemical or biological changes depending on many factors including the geological host material, water age, aquifer depth and water fluxes. Groundwater quality results are discussed in Section 4.

---

[5] http://ga.water.usgs.gov/edu/earthgwquality.html

3. Environmental Setting

The Balfour groundwater quality study area, shown in Figure 6, is located in the Waimea Plains near the township of Balfour. The Waimea Plains are part of the middle reaches of the Mataura catchment, which is one of the 10 largest catchments in New Zealand. The Mataura River and its tributaries are recognised as one of New Zealand's top rivers for recreational fishing, particularly for brown trout, which resulted in a Water Conservation Order being introduced in 1997 to protect the outstanding biological and recreational values (Wilson, 2008).

The Waimea Plains has been used for farming for over 100 years. Between 1940 and 1980 many parts of the Mataura catchment underwent widespread willow clearing, channel straightening and artificial drainage, which significantly altered catchment hydrology (Poole, 1990). Much of this was done to improve land productivity. Over the past 30 years, land use on the Waimea Plains has generally comprised of a mix of sheep, beef and arable farming, however, more recently (in the past 10 years), increasing areas of land have been converted to dairying and dairy support, which reflects land use change occurring in other parts of Southland. In some places, this coincides with the recent development of pasture irrigation in northern Southland.

Figure 6: Map of the location of the Balfour groundwater quality study area

3.1 Geology

The southern part of the South Island is made up of at least six different ancient plates or fragments of ancient plates (known as “terranes”). The sediments of the oldest terranes (the Fiordland Terrane) were laid down over 400 million years ago on the ocean floor and these rocks can be found today in the Fiordland and Nelson areas. Most of the other terranes found in Southland collided and stuck together on the edge of Gondwana over a period of tens of millions of years and range in age from 280 to 170 million years old. About 160 million years ago, Gondwana began breaking up and at about 85 million years ago, New Zealand separated from Australia and drifted southeast leading to the formation of the Tasman Sea (Reay, 2003). As can be seen in Figure 7, the Waimea Plains are bounded by the Hokonui Hills to the south (comprised of the Murihiku Terrane), the Garvie Mountains to the north (the Caples Terrane) and are underlain by rocks of the Dun Mountain–Matai Terrane, which can be seen at the surface as erosion resistant outcrops.

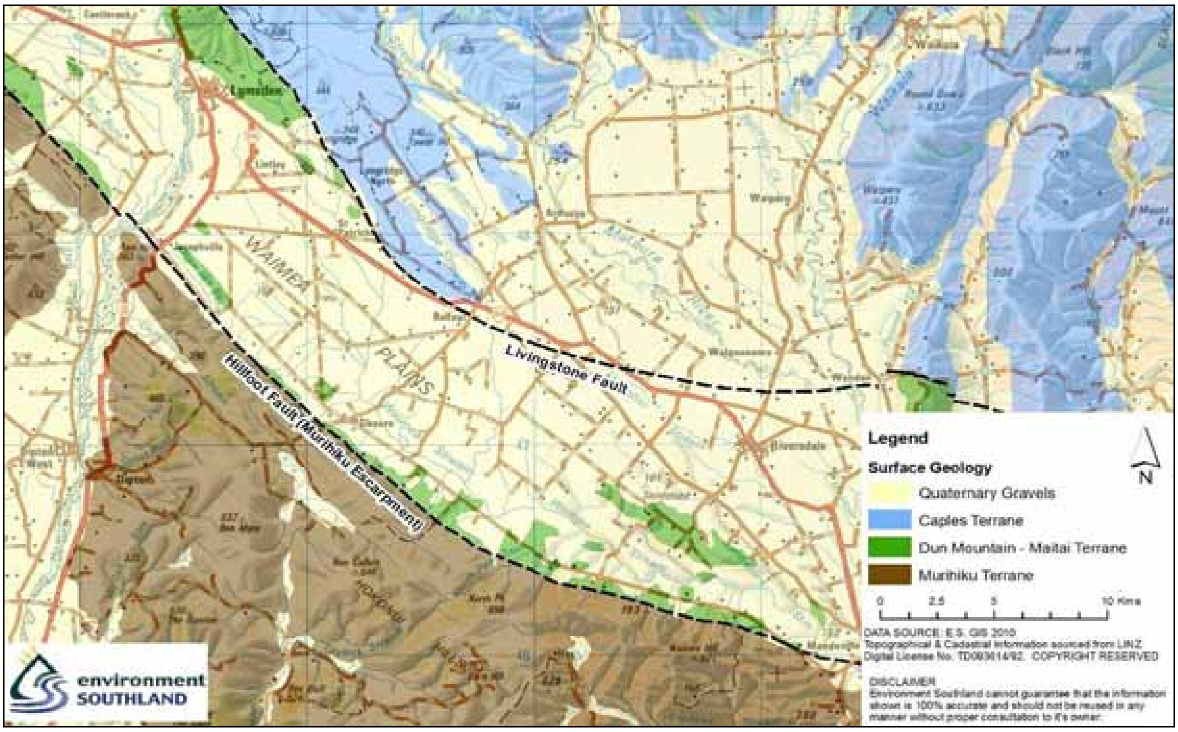

Figure 7: Map of the surface geology of the Waimea Plains using data from GNS Science [Source - Turnbull and Allibone, 2003]

The rocks of the Murihiku Terrane are mainly made of volcanic ashes laid down in the sea about 250 to 170 million years ago in a collision zone between an oceanic plate and a continent; a similar environment to that found on the South America west coast today (Reay, 2003). However, in some areas, rocks contain fossils of leaves, trees and forests (as evident at Curio Bay) suggesting that land did exist at various times. The Murihiku Terrane has a total thickness of about 10 kilometres and at about 140 million years ago during the Rangitata orogeny (or mountain building period), these rocks were folded into a U-shape (called a syncline). The resulting Southland Syncline is a distinctive and prominent feature of the Southland landscape and led to the formation of the Hokonui Hills. The northern limb of the U is nearly vertical, while the southern limb is much more gently sloping.

The narrow, discontinuous belt of rocks that make up the Dun Mountain–Matai Terrane are believed to be 280 million years old and represent a section of the top of the mantle, the overlying sea floor and up to 6 kilometres of sedimentary rocks that were thrust to the surface as a result of collision between two major plates (Reay, 2003). The rocks that make up the Caples Terrane are not well understood but appear to be mainly sands eroded from island-arc volcanoes produced in a collision-zone environment similar to that of the Murihiku Terrane.

As is shown in Figure 7, the Murihiku Terrane is separated from the Dun Mountain–Matai Terrane by the Hillfoot Fault while the Dun Mountain–Matai Terrane is separated from the Caples Terrane by the Livingston Fault. The Hillfoot Fault is steeply north–dipping and an active trace has been identified although the overlying rocks indicate only minor movement has occurred in the past approximately 20 million years (Turnbull and Allibone, 2003). The Livingstone Fault System is also steeply north-dipping and includes strike-slip movement of up to hundreds of kilometres (Turnbull and Allibone, 2003). The juxtaposition of the Dun Mountain-Matai and Caples Terranes appear to have occurred prior to about 90 million years ago and the fault is inferred to have been inactive for the past approximately 60 million years (Turnbull and Allibone, 2003).

Terranes contain the oldest rocks in an area and are sometimes referred to as “basement” rocks because they are the foundation for most subsequent geological activity. Basement rocks are overlain by Tertiary period sediments (65 to 2 million years ago), which are typically marine deposits in Southland. These in turn are overlain by Quaternary period sediments (2 million years ago to today), which are typically glacial (termed moraine) or river (termed alluvial) gravel deposits.

Following the Rangitata orogeny, there was a prolonged, quiet period (geologically speaking), during which the Rakaia and Caples Terranes were eroded resulting in the development of an extensive low relief surface (termed a peneplain) over the southern part of New Zealand. Some relatively minor geological activity (faulting) caused massive scree deposits (e.g. at Naseby) which led to topographical relief developing in a few places. By about 65 million years ago, Southland was predominately a low-lying area with large, slow meandering rivers flanked by forests that covered the area south of the Hokonui Hills (Reay, 2003).

Between 65 to 2 million years ago, low-lying land in Southland (including the Waimea Plains) were flooded, either as a result of sea level rise or from the land sinking. Some of the vegetation on the estuarine and low lying swampy land accumulated into thick layers, which were partially decomposed, buried and compressed by overlying sediments deposited as a result of a delta that was advancing across a shallow sea. This process has resulted in the extensive mudstone (marine sediment) and lignite (compressed vegetation) sequence found across much of the Southland Plains today. This sequence makes up the Eastern Southland Group sediments, which are up to 8 kilometres thick and include the Gore Lignite Measures.

The same marine transgression (i.e. marine flooding) resulted in limestone deposits found today in parts of Southland including the Balfour area. Limestone forms in shallow warm oceans and are sediments deposited by the remains of marine animals.

About 20 million years ago, the sea began to recede, and about 13 million years ago, the coastline was pretty close to the current position found today (Turnbull and Allibone, 2003). The Tertiary deposits were gently tilted and folded as a result of the Kaikoura orogeny, which began about 25 million years ago and continues today. The Southern Alps are a product of the Kaikoura orogeny.

Between 2 million years ago and 10,000 years ago the climate entered an “ice age” (i.e. the Pleistocene era), during which there were many glacial advances and retreats which ultimately sculpted the landscape we see today. A glacier is a slowly moving mass of ice that moves down a river valley under the influence of gravity. As a glacier advances, it shears out rocks from surrounding hills and mountains carrying them down the valley suspended in ice. When a glacier retreats, the suspended rocks drop out and rivers form at the face of the retreating glacier. Glaciers leave behind huge amounts of sediment, which rivers rework and transport some of the sediment downstream. There are believed to have been over 30 periods of glacial advances and retreats in Southland over the past 10,000 years where the glaciofluvial outwash gravels of the major glaciers of Fiordland and Wakatipu spread out as a great series of overlapping alluvial aprons (Reay, 2003). For the most part, the Southland lowlands remained relatively free of ice over this time, however, the lowlands were reworked by river systems depositing and eroding sediments.

Terraces build up where the supply of sediment exceeds a rivers capacity to carry it downstream so the size of the sediment found in terraces provide an indication of the size of the river which deposited the load. The present day Oreti and Mataura Rivers do not move much gravel (the sediment load is mostly silt) so it is believed the terraces found across the Southland Plains were formed as a result of river systems that where much larger than is found today. It is believed at some point in the past the ancestral-Mataura River carried much of the drainage of the present Kawarua River when the outlet of Lake Wakatipu was at Kingston. The ancestral Oreti River (sometimes called the Lumsden River) probably once joined the Mataura or Aparima Rivers to raise discharge (even above that from ice melt and climate). Today, the Mataura River flows through a 30 kilometre long gorge near Parawa, rather than flowing through an obvious gap west of Mid Dome and the Oreti River does not flow through the Mossburn gap, but flows across the Five Rivers plains then abruptly changes course near Lumsden to strike south through the Murihiku Escarpment, rather than continue down a similar grade through the Waimea Plains. It is therefore inferred that the river deflections are controlled by the north-west structural trends developed in the Rangitata orogeny and that surface water hydrology is not entirely erosion-based but also has a geological structural origin.

Rivers downcut between periods of terrace build up and as the region has undergone continual uplift during the Quaternary period, the highest terraces contain the oldest gravels while the lowest terraces and present day floodplains contain the youngest gravel material (McIntosh, 1988). The gravels in the older terraces show much greater signs of weathering, which is sometimes evident as “rotten rock” in roadside cuttings or when viewed in-situ, and can be seen where most of the spaces between the stones are filled with clay. The higher clay content in the older terraces has led to higher clay content in the soils, for example, on the Longridge terrace. In contrast, the younger gravels in the lower terraces are quite “fresh” (i.e. unweathered) and are overlain by more freely draining soils like on the Riversdale terrace. Consequently, the soils of the high terraces, which are rich in clay, retain moisture for longer and tend to “hang-on” in dry summers while soils near Riversdale give early spring growth because they warm up quickly but tend to dry out in summer, hence the need for irrigation for growing high value crops (McIntosh, 1988).

During a recent glaciation, much of the earth’s surface water was locked up as ice. This lowered river and sea levels by as much as 100 metres exposing much of the mud of river channels and the shallow submarine shelf. The mud and rock dust was dispersed by wind over large areas of Southland and Otago resulting in loess deposits which overlie the Quaternary gravel sediments. There are two main loess regions in Southland, one is in the Waimea Plains, which were formed by windblown sediments of the schists of Otago, and the other area is in central Southland, which were sourced by the rocks of the Hokonui Hills. When sediment gets blown by wind, the coarsest particles settle first and on the Waimea Plains this is evident in the Otama and Knapdale areas which have sandier deposits in the form of dunes. Further from the source, more clays accumulate as a blanket loess deposit, which resulted in the heavier (clay-rich) soils found around Waikoikoi (McIntosh, 1988). Loess deposits have been recorded up to 13 metres thick in bore logs from the Waimea Plains.

The strength of the winds can be gauged by the presence of wind polished stones (called ventifacts) in the soils. It has been concluded the winds were strong enough to strip off topsoil and given the cool climate, were probably similar to that found in the Arctic today. Pedologists (soil scientists) argue there is evidence of permafrost (or subsurface freezing) in Southland soils, but climatologists believe that the air temperature only dropped about 4ºC in the last glacial period, which is not cold enough for permafrost. One possibility is the most severe cold periods may have been short but cold enough to drop temperatures by more than 5ºC, which would have limited vegetation cover and allowed a semi-desert landscape to develop. According to this theory, the dunes and ventifacts are the relics of a desert that existed in Southland during the coldest extremes of the last glaciation (McIntosh, 1988).

In summary, the geology of the Waimea Plains is made up of three terranes, which are overlain by a deep sedimentary basin that is fault controlled and has been infilled with Tertiary aged marine sediments. This is overlain by a relatively thin veneer of alluvial sediments deposited during the late Quaternary period through glacial advances and retreats. Many of the gravel deposits have been reworked by major river systems (much larger than seen today) resulting in a series of broad terraces flanked by recent floodplains. In some areas, loess (windblown sediment) overlies the Quaternary gravel deposits. Geological processes like faults and folds have also exerted a major influence over catchment hydrology and hydrogeology.

3.2 Hydrogeology

Extensive deposits of groundwater-bearing sediments are found throughout the Southland region in a wide range of hydrogeological settings. The main aquifer forming units are the alluvial gravel deposits whose spatial extent reflects geological and geomorphologic processes, which are discussed in Section 3.1. A limited groundwater resource also occurs in the coarser-grained gravel and sand layers within the Tertiary Eastern Southland Group sediments and in areas where bedrock has sufficient jointing and fracturing within the rock mass.

For the purposes of resource management, Southland has been divided into groundwater management zones. Due to the limited information available to describe the nature and extent of various aquifer systems, especially those in the Tertiary and basement deposits, the groundwater zones are largely based on the physical characteristics of the alluvial gravel deposits and have been delineated on the basis of topographic gradient, known geology or aquifer extents, geomorphology, observed groundwater quality, groundwater level fluctuations and resource development (Hughes, 2003). The groundwater management zones have been further classified according to aquifer type on the basis of hydraulic properties and recharge/discharge characteristics. The Balfour groundwater quality study area is located in the Waimea Plains groundwater zone, which is classified as a lowland aquifer in the Regional Water Plan for Southland, 2010 (RWP).

Lowland aquifers are typically remnants of the original Quaternary gravel outwash surface, which have been locally dissected by first and second-order streams to form a gently undulating topography. The gravels are generally compromised of a relatively thin (less than 30 metres) thickness of poorly sorted, weathered gravels overlying Tertiary lignite, mudstone and limestone sediments. Due to the higher matrix clay content, lowland aquifers tend to have relatively low aquifer permeability and groundwater yields, which are typically not suited to large-scale groundwater development although localised areas of higher permeability gravels may exist.

Figures 8(a), (b) and (c) show two geological cross-sections through the study area based on information from drillers logs. Drill log data can be difficult to interpret due to variability in drilling methods and practices, as well as inconsistencies in observations and documentation between individual drillers. For this reason, the lithology has been simplified in order to show coarse changes in stratigraphy. Cross section A-A’ is oriented northwest to southeast and is roughly parallel to the groundwater flow direction (see Figure 10). The data shown in Figure 8(b) indicates a hydrogeological divide near the Waimea Stream. To the southeast of Waimea Stream, the undulating “basement” or “mudstone” rocks[6] underlie a claybound gravel layer approximately 15 metres thick. Northwest of the Waimea Stream, the “basement” rocks are located about 35 metres deep and the overlying gravels are interlaid with more clearly defined clay layers up to 10 metres thick. Cross section B-B’ is oriented northeast to southwest and Figure 8(c) shows the “basement” rocks under the Longridge terrace are much shallower than on the floodplain. Aggradation between the older gravel matrix underlying the Longridge terrace and the comparatively younger gravels of the Waimea Plains appears to extend south of Steffan Road suggesting a relatively wide, indistinct boundary between the Longridge and Waimea Plains groundwater zones.

---

[6] Observations of “basement” and “mudstone” in drill logs could refer to either the rocks of the Dun Mountain – Matai Terrane (i.e. the geological basement) or mudstone associated with the Tertiary measures of the Eastern Southland Group. Due to the uncertainties associated with drillers observations, these have been grouped together to illustrate a significant hydrogeological change.

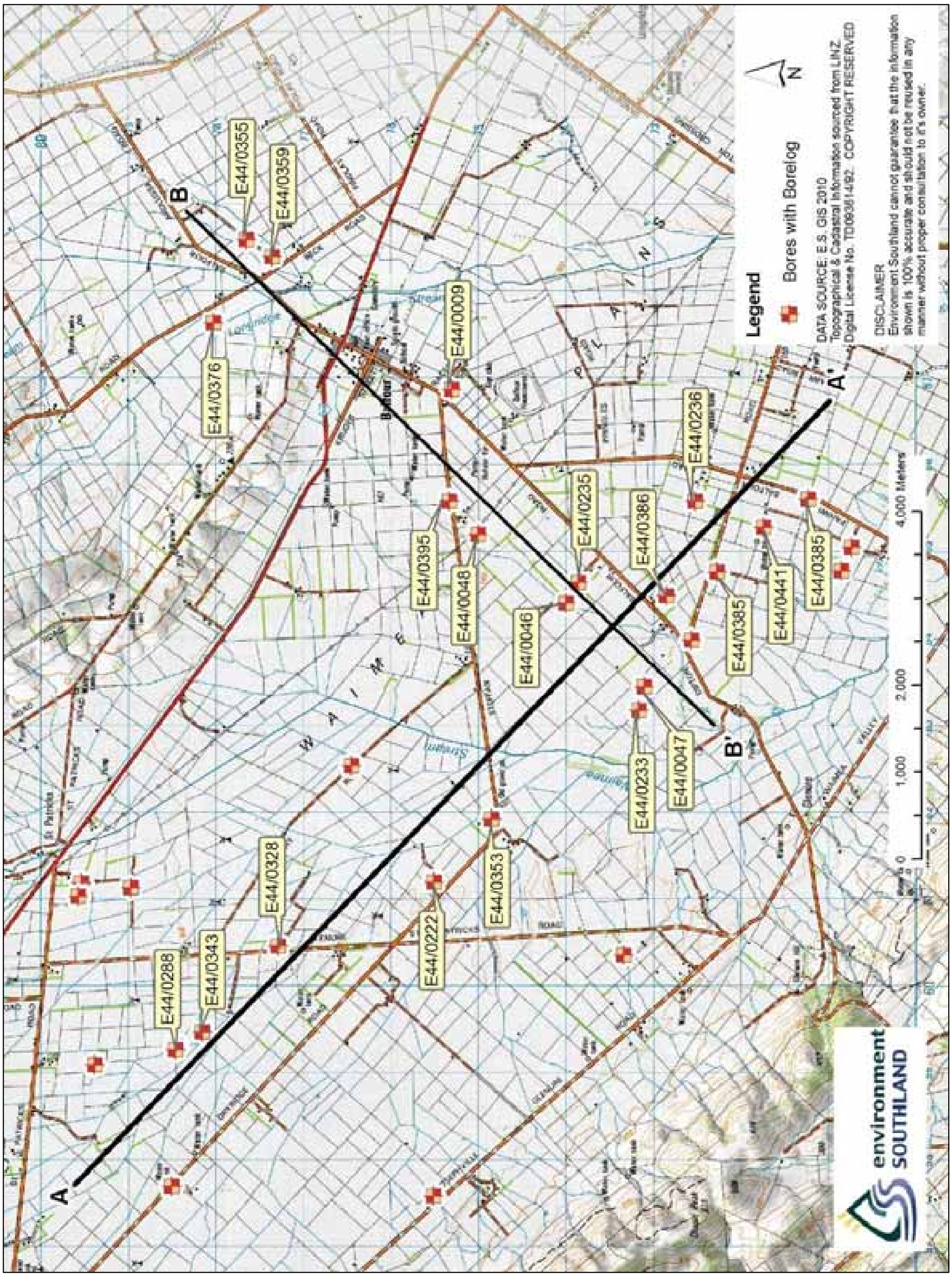

Figure 8(a): Map of the Balfour groundwater quality study area and bores used in cross-sections in Figure 8(b) and 8(c)

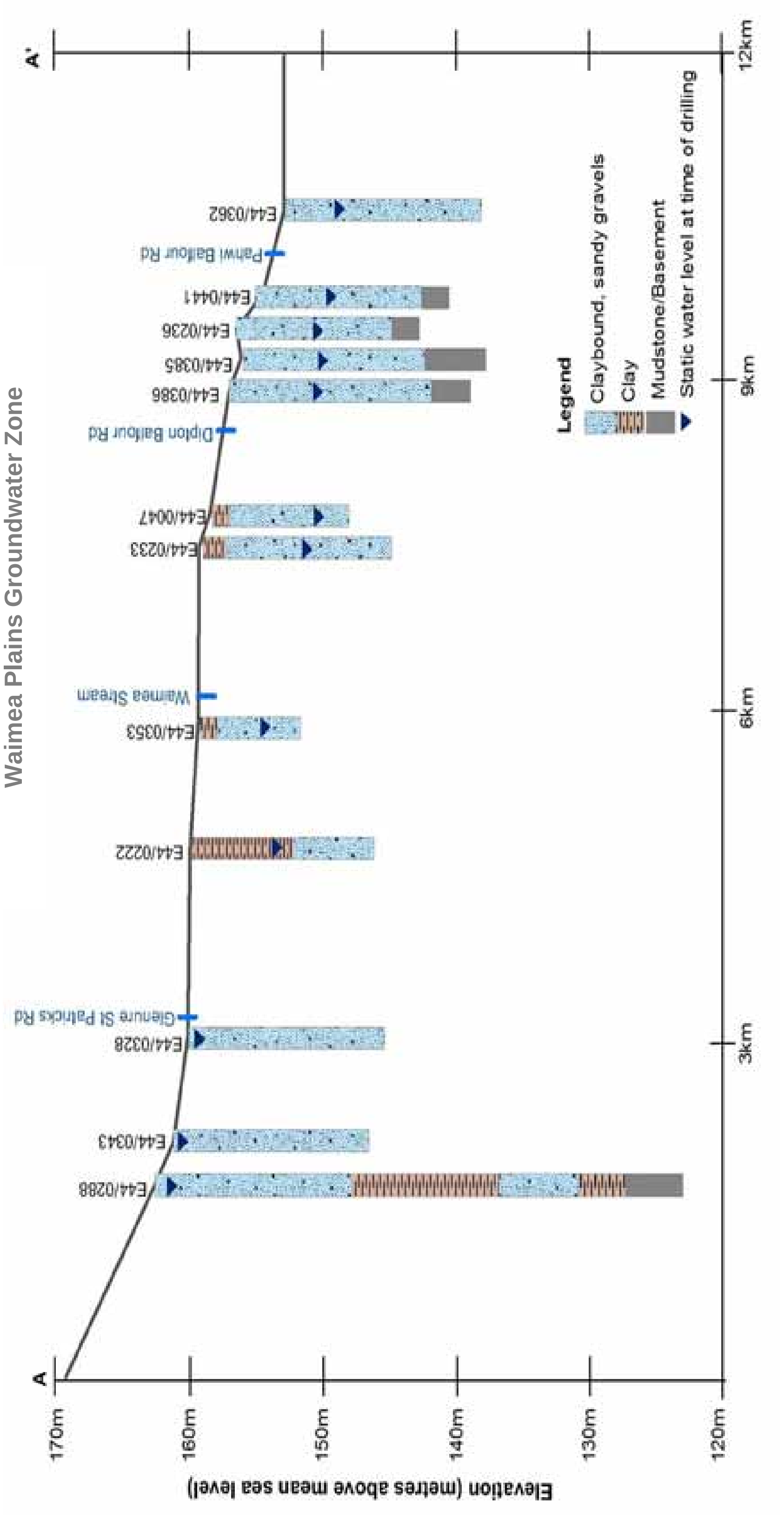

Figure 8(b): Cross-section of the lithology based on drillers log data between A-A' (position shown in Figure 8(a)) with a vertical exaggeration of 1:30

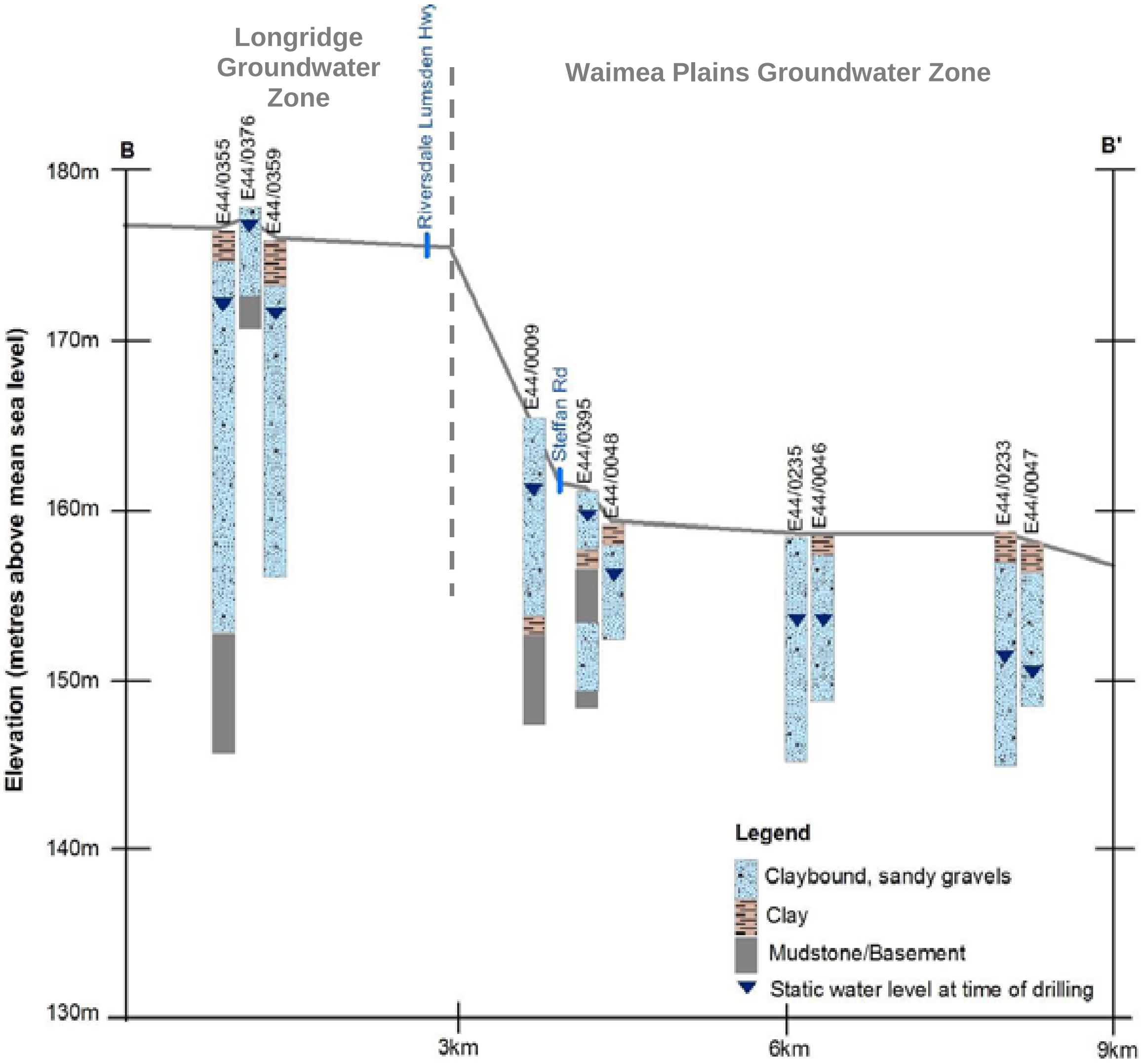

Figure 8(c): Cross-section of the lithology based on driller bore log data between B-B' (position shown in Figure 8(a)) with a vertical exaggeration of 1:30

3.3 Groundwater Hydrology

Two components of groundwater flow occur in lowland aquifers. The major component is local drainage of rainfall recharge from the higher terrace areas to the nearest stream. The second component is the deeper, sub-regional circulation of groundwater, which follows overall catchment drainage as illustrated in Figure 9. The vertical boundary between the localised and sub-regional flow components is generally indistinct.

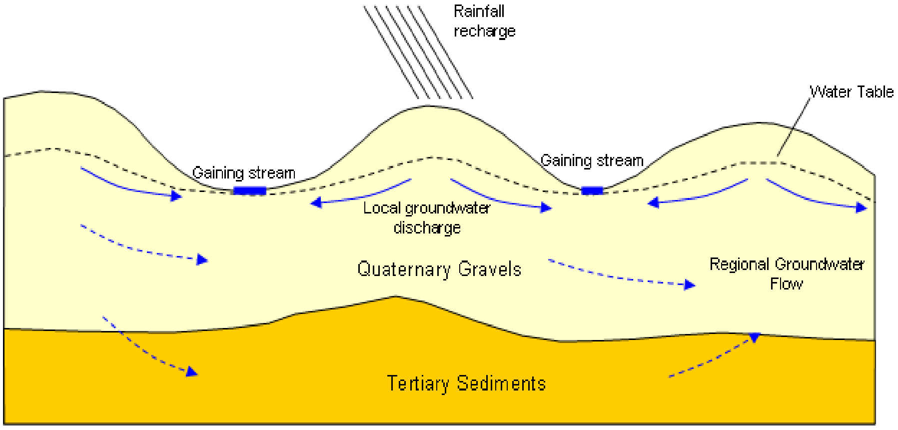

Figure 9: Schematic cross-section of the Waimea Plains groundwater zone

Environment Southland has undertaken two piezometric (or water table) surveys across the Waimea Plains. The first was completed in February 2002, as part of a regional survey of the Mandeville to Lumsden area. The results showed relatively complex groundwater flow in the Balfour area, with an overall groundwater flow in a south-easterly direction and a hydraulic gradient of approximately 0.004 (Hughes, 2008).

In September 2007, Environment Southland undertook an aquifer pump test on Pahiwi-Balfour Road. Bore E44/0351 was pumped at a constant rate of 10 litres per second for seven hours and groundwater levels were monitored manually in E44/0351 and three other monitoring bores located up to 2 kilometres away. Upon cessation of pumping, recovery was monitored for 75 minutes, or until groundwater levels were within 10 percent of the starting level. The results, summarised in Appendix 1, show drawdown curves that are more consistent with aquifer properties in a confined aquifer indicating the aquifer has a very low specific yield[7]. The Moench-Prickett (1972) solution used is a mathematical solution for confined aquifers undergoing conversion to unconfined conditions and its fit to the data may reflect the difference in aquifer properties between the much lower yielding groundwater flow in the deeper, sub-regional component of the aquifer compared with the relatively higher yielding localised flow component.

Assuming an average saturated thickness of 10 metres (estimated from bore log data), an aquifer transmissivity of 300 m^2/day, an interpolated hydraulic gradient of 0.004 and an assumed porosity of 0.25, the average bulk seepage velocity through the aquifer was calculated using Darcy's Law at 0.48 metres per day or approximately 175 metres per year (Hughes, 2008). While there is likely to be a significant difference in seepage velocity due to heterogeneity (or variability) within the alluvial gravel aquifer system, the bulk rate of groundwater flow calculated is relatively slow. This increases the vulnerability of the aquifer to cumulative land use impacts due to the low rate of dilution available, especially within the deeper, sub-regional flow component of the aquifer.

In February 2010, a finer-scale piezometric survey was undertaken in the Balfour area and the data are summarised in Figure 10. Once again, the data shows relatively complex groundwater flow which is strongly influenced by a combination of topography and geology. North of the Dipton-Balfour Road, the overall groundwater flow direction is in a south-easterly direction with

---

[7] Specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of the aquifer per unit decline of the water table. Typically, values range between 0.01 to 0.3 (Kruseman and de Ridder, 1970). The pump test data indicated a specific yield of 0.001 which is more typical of storativity for a confined aquifer.

a relatively flat interpolated hydraulic gradient of 0.002, however, there are only a few data points north of Steffan Road. South of the Dipton-Balfour Road, groundwater flow is predominately in a southerly direction towards the confluence of the Waimea and Longridge Streams. The interpolated hydraulic gradient is much steeper at 0.011. Based on these revised numbers, the bulk groundwater flow south of Dipton-Balfour Road is calculated to be 1.32 metres per day. or approximately 480 metres per year. However, interpretation of the piezometric surveying data is complicated by the drawdown effects of pumping. As can be seen in the aquifer pump test data, even relatively small pumping rates can result in measureable drawdown for extended distances due to low aquifer specific yield. Therefore, the estimates of bulk aquifer flow rate are indicative only and do not reflect what is likely to be considerable variability at any given point within the aquifer system.

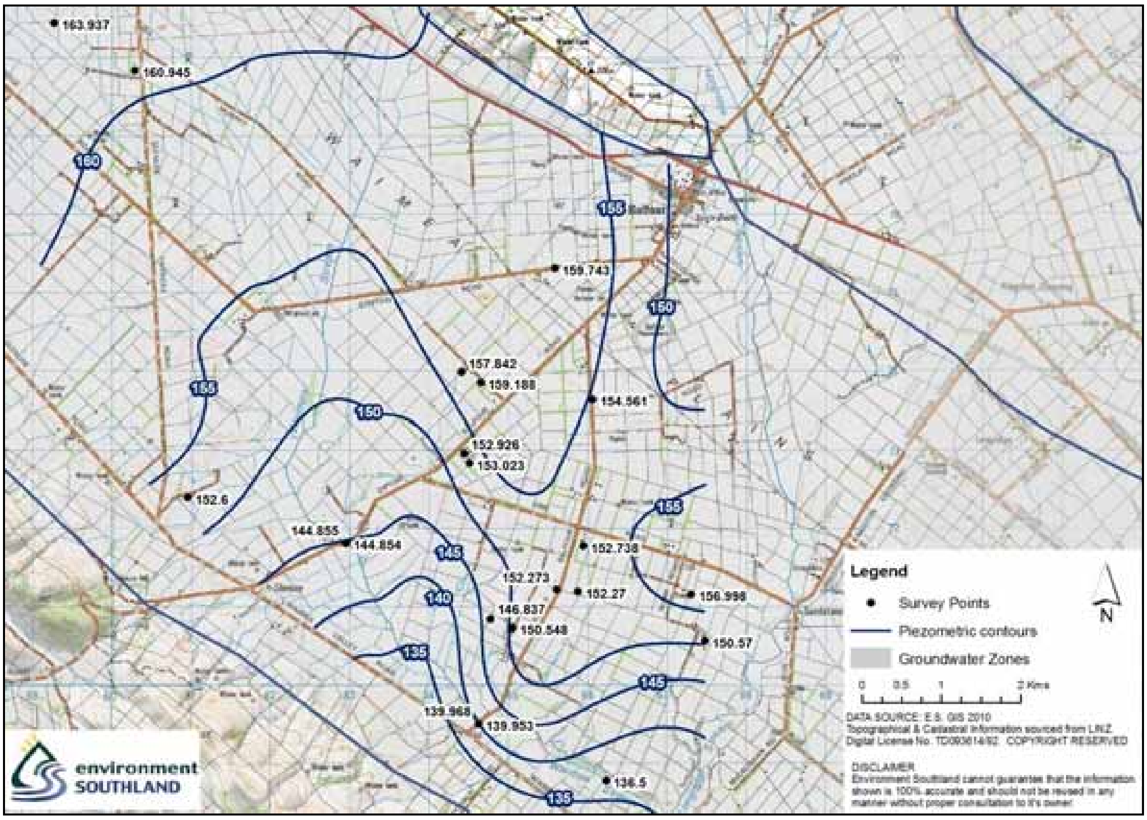

Figure 10: Map of groundwater flow on the Waimea Plains from piezometric surveying data (9-11February 2010)[8].

Overall, the hydrogeological information and piezometric surveying data show a relatively consistent pattern where the area southeast of the Dipton-Balfour Road to the confluence of the Waimea and Longridge Streams represents an aquifer discharge area. This is further reflected by the presence of springs which originate along the base of the terraces and is discussed further in Section 3.6.

---

[8] Contours made using a regularised spline interpolation method

3.4 Climate

Rainfall totals are relatively consistent across the Waimea Plains and Mid-Mataura basin, although micro-climates can form due to the influence of the Hokonui Hills on prevailing weather fronts. Table 1 shows mean (or average) annual rainfall ranges between 760 to 950 mm, with mean totals increasing towards the basin margins. The Waimea Plains generally receives less rainfall than the areas surrounding it due to the warm, dry winds of the north-westerly weather systems which frequently occur during summer. These winds increase evapotranspiration, and when prolonged or severe, may result in significant soil moisture deficits. This effect is most prevalent in the data from the Riversdale monitoring site, which generally records 5 to 10 percent less rainfall than nearby sites during the summer-autumn period. It is inferred that the difference is more pronounced during La Niña events, which tend to have a greater number of north-westerly weather fronts and coincide with drought years on the Waimea Plains. Table 1 shows mean annual rainfall totals at Riversdale are approximately 10 percent lower than other sites, which probably reflects the much shorter record length and lower summer-autumn rainfall.

Table 1: Mean annual rainfall totals for Environment Southland's monitoring sites near Balfour

Site	Record Period	Elevation (m msl*)	Mean Annual Rainfall (mm)
Balfour at Balfour Ardlussa Road	1986 - present	170	869
Lintley at Lintley District Road	1977 - present	189	955
Oreti River at Lumsden Cableway	1988 - present	208	808
Riversdale at Liverpool Street	2002 - present	128	759
Wendonside at Mahers Road	1985 – present	200	1,008

*Metres above mean sea level using Bluff 1949 datum

Figure 11 shows a plot of the mean, maximum and minimum monthly rainfall totals recorded at Environment Southland's daily rainfall reader site at Lintley. This data is consistent with other monitoring sites on the Waimea Plains and shows rainfall is distributed relatively evenly throughout the year with the driest months occurring during winter.

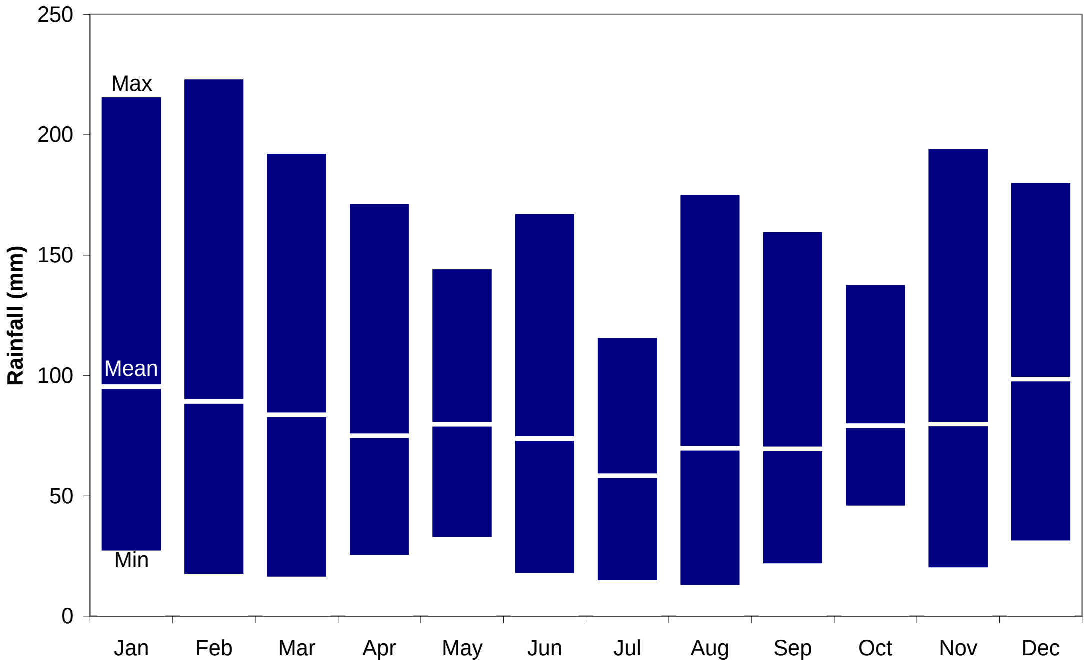

Figure 11: Graph of the monthly maximum, mean and minimum rainfall for Lintely (record period 1977-2010)

Rainfall climate patterns can also vary over time, as illustrated in Figure 12 where periods of above average rainfall are shown by a positive (or upward) slope on the graph and below average rainfall by a negative (or downward) slope on the graph. The data shows that rainfall conditions were wetter than normal from 1977 to 1998 and drier than usual from 1960 to 1976 and 1999 to 2010. The wet/dry phases in rainfall patterns generally correlate with inter-annual (e.g. the El Niño Southern Oscillation[9]) and inter-decadal (e.g. the Pacific Decadal Oscillation[10]) climate events. The apparent cyclic pattern in long-term rainfall variability has been recognised in rainfall records elsewhere in Southland (McKerchar and Henderson, 2003) and has been observed in data in other parts of the country with longer records dating back to the 1800s. Climatic variability can affect the volume of aquifer storage as discussed in Section 2.2.

---

[9] The El Niño Southern Oscillation (ENSO) is a climate pattern that occurs across the Pacific Ocean and is characterised by warming (known as *El Niño*) or cooling (known as or *La Niña*) of surface waters in the tropical eastern Pacific Ocean. When the warm oceanic phase is in effect, surface pressures in the western Pacific are high and when the cold phase is in effect surface pressures in the western Pacific are low. The clearest sign of the Southern Oscillation is the inverse relationship between surface air pressure at Darwin and Tahiti. Over periods of a month or longer, higher pressure than normal at one site is almost always concurrent with lower pressure at the other, and vice versa. The pattern reverses every few years representing a "see-saw" of a mass of air oscillating back and forth.

[10] The Pacific Decadal Oscillation (PDO) is a long-term fluctuation of the Pacific Ocean oscillating between warm and cool phases about every 20-30 years as defined by sea surface temperatures in the interior North Pacific and along the northeast Pacific coast. PDO is equally influenced by ENSO fluctuations (that have a 4-7 year cycle), changes in the atmospheric low-pressure pattern known as the Aleutian Low and changes in the Kuroshio-Oyashio current that swirls through the northern Pacific Ocean. The mechanism by which the pattern lasts has not been identified however a PDO signal has been reconstructed to 1661 through tree-ring chronologies.

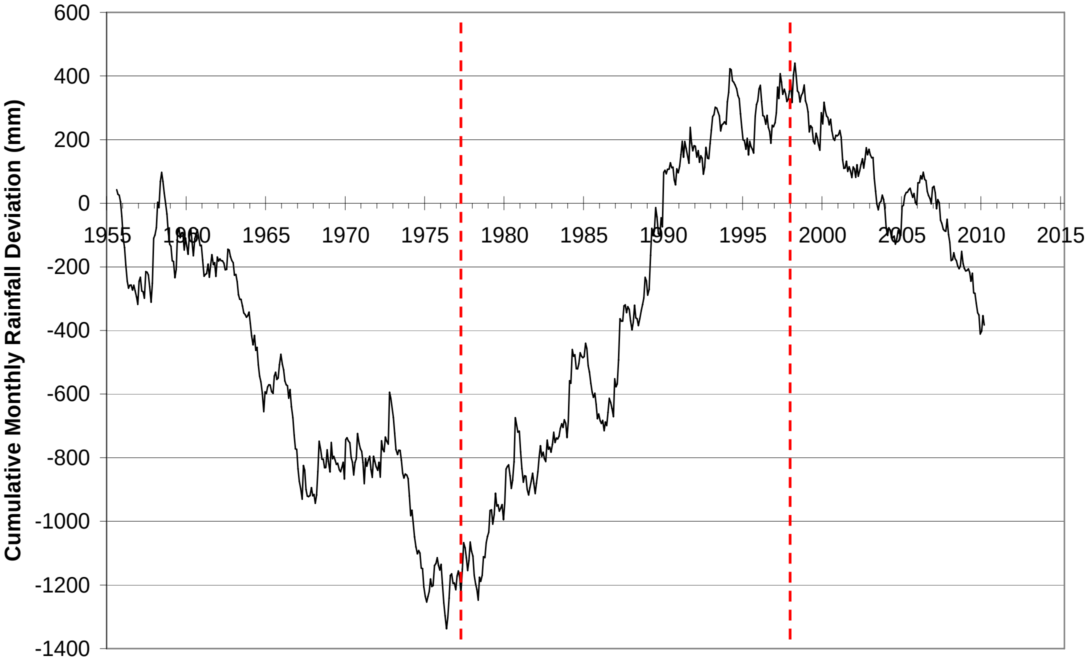

Figure 12: Graph of the cumulative monthly rainfall deviation for Lumsden with red lines showing the Interdecadal Pacific Oscillation (IPO) official phase reversals
[data and IPO dates source –NIWA]

Riddell (1984) concluded that in the Waimea catchment, evaporation accounted for slightly more than two-thirds of the mean annual rainfall between 1975 to 1983, which is considerably more than other parts of the Mataura catchment. The combination of less rainfall and greater evaporation makes the Waimea Plains much more susceptible to drought or dryness compared to the rest of the Mataura catchment.

3.5 Groundwater Levels

Environment Southland monitors nine bores in the Balfour area, two are measured quarterly as part of groundwater quality monitoring runs, five are measured monthly and two are measured continuously (readings every 30 minutes). Figure 13 shows the locations of all groundwater level monitoring sites and the frequency of monitoring. Although the groundwater level monitoring data only covers at most a 10 year period, there is sufficient data to show distinct differences between some monitoring sites. Additional information summarising groundwater level monitoring data is provided in Appendix 2.

All groundwater level monitoring sites show a consistent overall temporal pattern where groundwater levels increase during winter and spring and progressively decrease during summer and autumn. However, the amount of variability in levels and the time lag between rainfall events and aquifer recharge vary markedly across sites. Figure 14 shows that bores E44/0010, E44/0231, E44/0288 and E44/0035 all have a relatively limited seasonal variation of approximately 1.2 metres with a seasonal peak generally occurring between July and August and the seasonal minimum generally between March and April. Data from these sites suggest aquifer recharge occurs fairly rapidly once soil moisture reaches field capacity and groundwater levels decline in a relatively linear fashion as groundwater is progressively drained by the Waimea Stream and its tributaries.

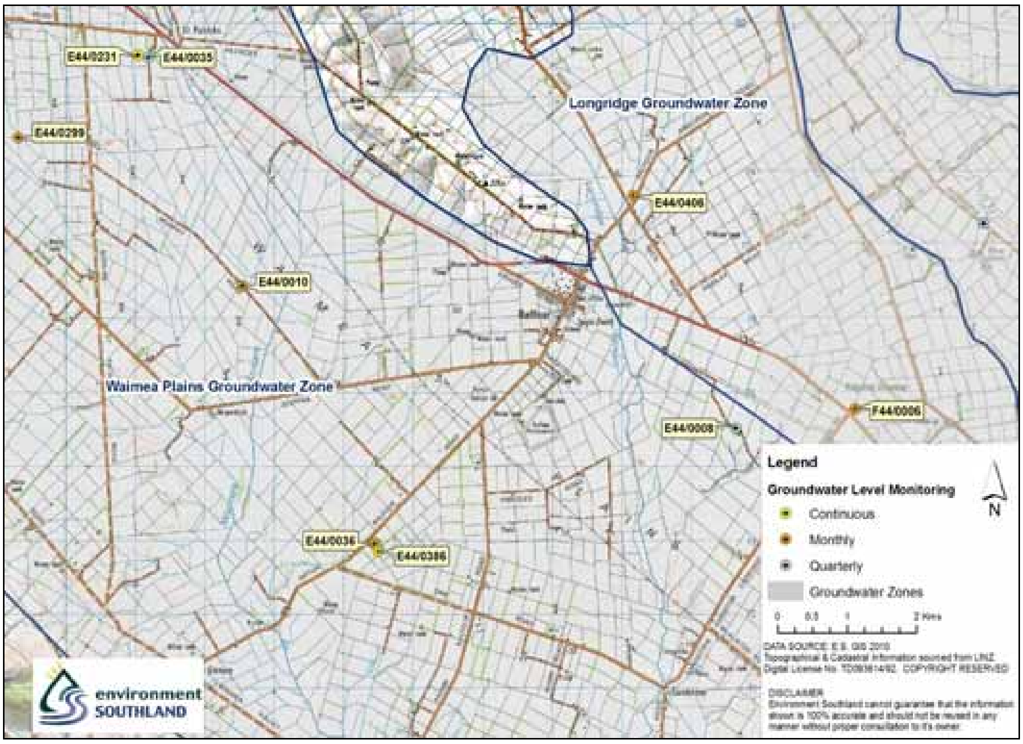

Figure 13: Map of Environment Southland's groundwater level monitoring sites in the Balfour area

Monitoring bores E44/0036 and E44/0386 show greater seasonal variability with groundwater levels fluctuating over 2 metres in any given year. Typically, groundwater levels in E44/0036 reach their seasonal minimum between April and May and their seasonal maximum between August and October indicating a longer time lag between soils reaching field capacity and aquifer recharge occurring. This could in part be due to a larger vadose (or unsaturated) zone distance between the base of the soil and water table so that rainfall recharge has to travel further, thereby taking longer to reach the aquifer. Groundwater level monitoring data also suggests significant carry-over of aquifer storage between seasons can occur as observed during winter 2002 and spring 2004 when groundwater levels increased by up to 3 metres following above average rainfall (Hughes, 2008). Increases in groundwater levels were evident for at least one to two years following the initial recharge event. E44/0036 and E44/0386 also recede in a relatively linear fashion through summer and autumn. Groundwater levels in E44/0036 typically drop about 165 mm per month in the absence of aquifer recharge, which is more rapid than E44/0010 which averages about 120 mm per month.

Groundwater level monitoring data from E44/0008 is not at a fine enough temporal scale to infer aquifer recharge or discharge characteristics, however, the data does show a fairly close linear correlation[11] to E44/0036 suggesting it is part of the same Waimea Plains aquifer system. However, given groundwater level fluctuations in both bores will reflect in part localised climate, a correlation is not conclusive evidence that both sites are within the same aquifer.

Monitoring bores F44/0006 and E44/0406 are located in the Longridge groundwater zone and exhibit distinctly different groundwater level patterns. F44/0006 fluctuates anywhere between 1 to 4 metres in any given year and typically reaches its seasonal minimum between April and

---

[11] Linear regression between E44/008 and E44/0036 has an $R^2 = 0.944$ for n=8

June and peaks between July and October. The groundwater level recession rate is approximately 250 mm per month.

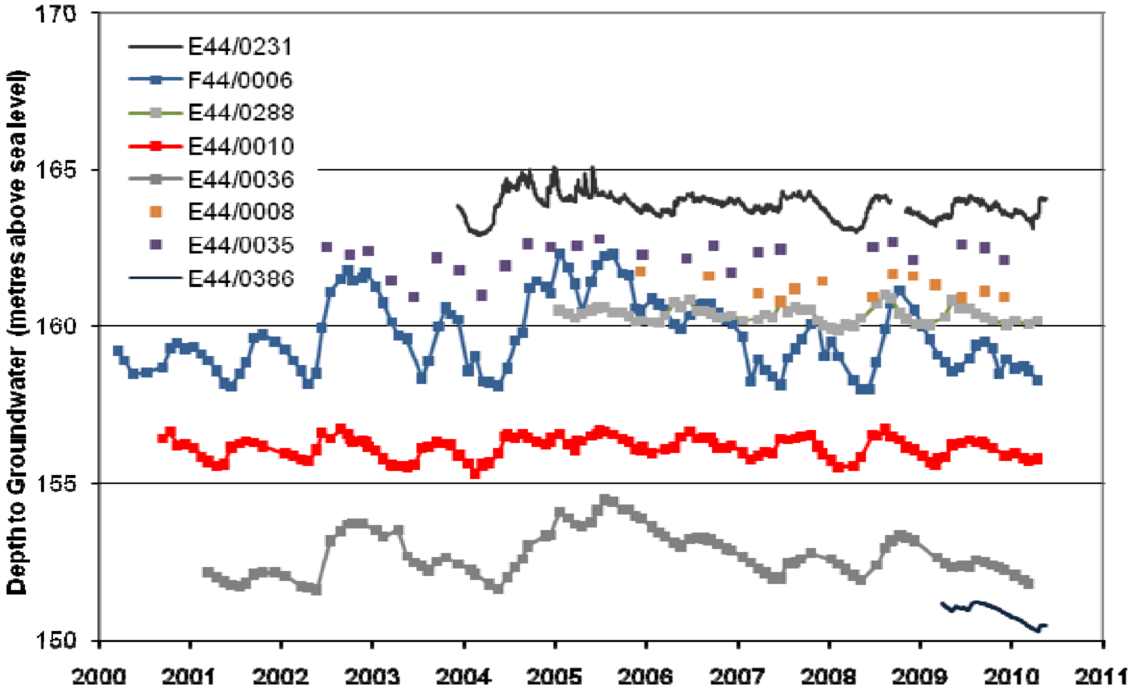

Figure 14: Graph of groundwater level monitoring data for the Balfour area

3.6 Surface Water Hydrology

The Balfour study area is located in the Waimea catchment within the mid-Mataura basin north of Gore. The Waimea catchment covers an area of approximately 400 square kilometres and is bounded by the Hokonui Hills to the south and the Lintley Ranges and Longridge terrace to the north and east respectively. The Waimea Stream is fed by a number of smaller streams, including the Sandstone, Longridge and McKellar Streams, and discharges into the Mataura River near Mandeville.

Soils over lowland aquifers are typically poorly drained due to higher clay content. This combined with the relatively low-lying topography has led to extensive development of artificial drainage (mole, tile and surface drains) resulting in significant modification of the natural hydrology of these areas. Originally, groundwater and extensive wetland areas (like the “Black Swamp”) stored and slowly released excess rainfall to surface waterways, however, with the onset of artificial drainage, water flows much more rapidly to streams, which has reduced summer stream flows. The Waimea catchment has also undergone extensive channel straightening to improve land drainage resulting in many kilometres of river length being lost. The reduced summertime flows and surrounding land use has led to the Waimea Stream having one of the poorest water quality records of monitored Southland streams and on occasion, fish kills are reported in very dry summers (Ledington, 2008).

Environment Southland, and its predecessor, the Southland Catchment Board, has been monitoring water levels in the Waimea Stream at Mandeville since 1974. The site was originally installed for flood warning purposes and in 1983, the site was shifted 200 metres upstream in order to install a slackline for improved flood gauging ability and for a more reliable rating[12] site. Due to changes at the site and changes in technology, the flow data (particularly low flow data) is only reliable from September 1983 (C Jenkins, *pers comms*). Only the reliable data has been used for the summary shown in Table 2.

Table 2: Summary statistics for spot gauging data from the Waimea Stream catchment (for sites with at least 5 gaugings)[13]

Site	Number of Gaugings	Gauging Period	Min Flow (L/s)	Median Flow (L/s)	Max Flow (L/s)
Longridge Stream					
Balfour	26	1971 - 2010	0	34	382
Orr Road	31	1976 - 2010	54	137	4,657
Sandstone - Kingston Crossing Rd	15	1978 - 1980	51	254	24,070
Sandstone Stream					
Mandeville – Kingston Crossing Rd	6	2005 - 2007	28	42	85
Waimea Stream					
St Patricks	6	1975 - 1981	0	38	147
Steffan Road	6	1977 - 2009	11	31	110
Dipton – Balfour Road	8	1977 - 2009	10	211	638
Mandeville	534	1953 - 2010	107	1,343	103,730
	(rating data)	1983 - 2010	18	1,428	244,459

In addition to the rated site at Mandeville, there have been numerous spot gaugings undertaken on streams within the Waimea catchment. Due to the increased pressure on water resources in recent years, most of the data has been collected in the past eight years. The spot gauging data has also been summarised in Table 2. The data indicate that it is not uncommon for streams to dry up in the Balfour–St Patricks area along the Riversdale Highway while fairly permanent flow has been observed south of Steffan Road. This is consistent with the groundwater hydrology data discussed in Section 3.3 and suggests streams in this area are gaining reaches draining adjacent aquifers.

In October 2009, concurrent gaugings of the Waimea and Longridge Streams and their main tributaries were undertaken in the Balfour study area. The results, illustrated in Figure 15, show both the Waimea and Longridge Streams experienced flow gains that were larger than could be accounted for by tributary inputs (which were essentially nil). This indicates that these reaches were draining groundwater and the largest increases in flow occurred in the area nearest the confluence, which is consistent with the groundwater hydrology and hydrogeological data. The hydraulic connection between the streams and surrounding aquifer means groundwater quality

---

[12] A rating is a mathematical correlation between the stage height and discharge in a stream at a given point (McKerchar and Henderson, 1987). Once a rating curve has been defined, continuous recording of stream stage height can be used to determine a continuous flow (or stream discharge) record.

[13] Many of the gaugings done in the 1970's were for floodwarning purposes so tended to be high flows. Most of the gaugings done in the past decade have been for water resource management purposes so tend to be low flows. Hence, the statistics presented in the table are only intended as indicative of the magnitude of flows experienced at the site.

will likely affect surface water quality, especially at times of base flow (generally summer and autumn) when runoff constitutes a relatively minor component of flow.

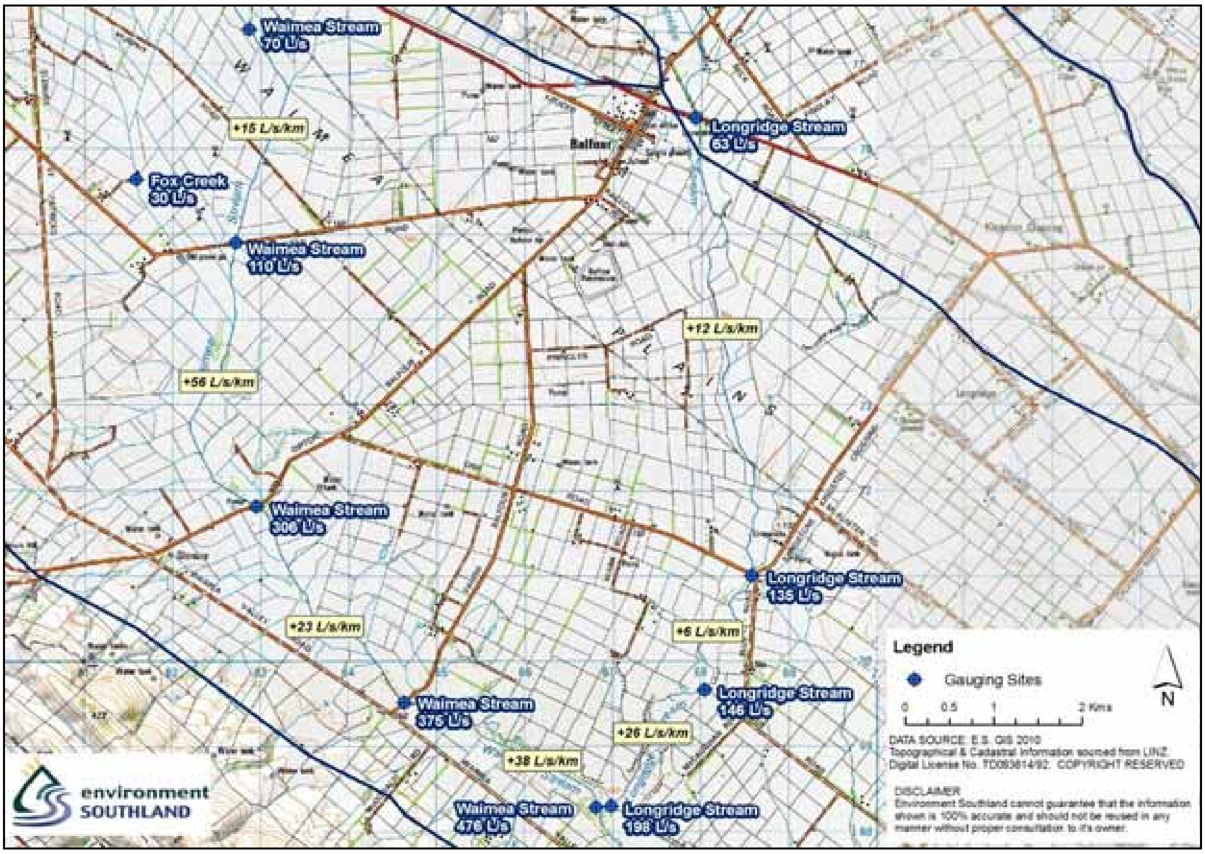

Figure 15: Map of concurrent gauging results from 19 October 2009 and calculated specific flow gains (increase in flow per unit length of stream)

4. Groundwater Quality Results

All water contains dissolved constituents and of all freshwater sources, groundwater generally contains the largest amounts of dissolved solids. This reflects the influence of both anthropogenic activities and rock-water interaction beneath the land surface. Biological and chemical processes can also significantly alter water chemistry as groundwater moves along its flow paths. The following section is intended to summarise the available groundwater quality data from the Balfour area and includes data from a range of monitoring programmes. This section will not discuss changes in land use or land management practices which can influence groundwater quality, as this is to be covered in a separate report by the Balfour Project Working Group.

4.1 Background on Nitrogen in Groundwater

One of the key issues for resource management of freshwater environments in New Zealand is the management of nitrogen. Nitrogen can exist in the environment in many forms and is a key element required to support plant growth and biological activity. The atmosphere is 79 percent nitrogen gas (Canter, 1996) and when combined with hydrogen or oxygen, nitrogen-fixing bacteria in the soil convert nitrogen gas into forms available to plant life. Transformation of nitrogen compounds can occur through several mechanisms including fixation, ammonification, synthesis, nitrification and denitrification. 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 is lost back to the atmosphere as gaseous nitrogen or through leaching of soluble forms (nitrate and ammonia) from the soil. The movement and transformation of nitrogen is characterised by the nitrogen cycle as shown in Figure 16. In addition to natural sources, 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 (Hughes, 2010).

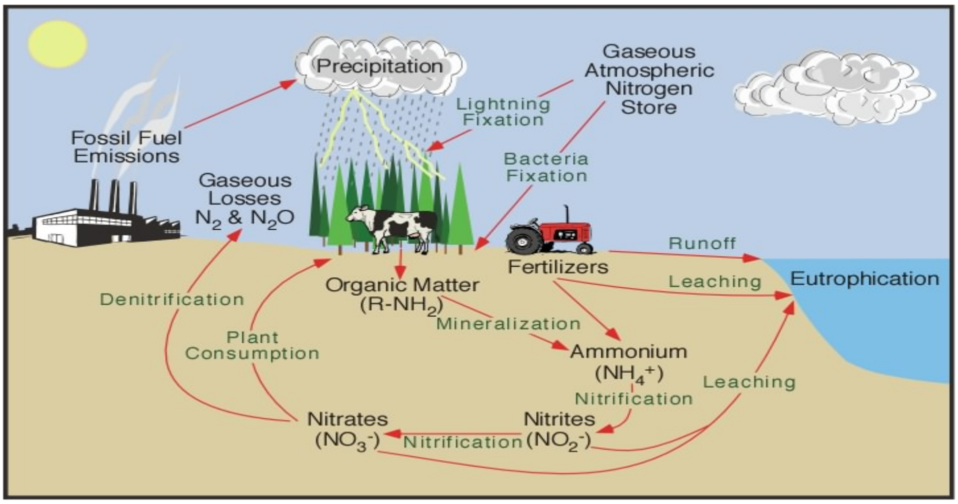

Figure 16: Schematic of the nitrogen cycle
[Source - Pidwirny, 2006]

Due to its solubility, nitrate or ammonia lost from the soil profile can build up in surface water or groundwater receiving environments. High concentrations of nitrate or ammonia in surface water can contribute to excessive growth of aquatic plant life (a process termed eutrophication), depletion of oxygen, fish kills, and general degradation of aquatic habitats. High concentrations of nitrate in groundwater is of primary concern due to the potential human health impacts from drinking water. Depending on the use of the groundwater, animals, crops or industrial processes could also be affected.

The toxicity of nitrate to humans is due to the body's reduction of nitrate to nitrite. This reaction takes place in the saliva of humans of all ages and in the gastrointestinal tract of infants during their first three months of life. Elevated levels of nitrite can lead to a condition known as methaemoglobinaemia. Methaemoglobinaemia refers to an effect in which haemoglobin is oxidised to methemoglobin and when amounts of methemoglobin in blood increases, blood oxygen levels dwindle (Canter, 1996). Infants up to three months of age are the most susceptible subpopulation with regard to nitrate. When approximately 10 percent of the total haemoglobin has been converted to methemoglobin in infants, the result is diminished oxygen transport/transfer capability in the blood, which can result in cellular anoxia and clinical cyanosis (or turns blue hence the term "blue-baby syndrome"). The effects of methemoglobinemia are rapidly reversible and there are therefore no cumulative effects. There is currently no conclusive evidence that nitrate is carcinogenic (or cancer-causing), however research is ongoing. It has been firmly established that nitrite is a precursor to carcinogenic nitrosamines and other nitrogen-nitroso compounds (Canter, 1996).

In New Zealand, the Ministry of Heath has set a maximum acceptable value (MAV) for (nitrate + nitrite) – nitrogen (henceforth called nitrate-N) of 11.3 mg/l for drinking water (2008). This is based on World Health Organisation recommendations and is for short-term exposure to protect against methaemoglobinaemia in bottle fed infants. Groundwater nitrate-N results from the study are discussed further in Sections 4.3 and 4.4.

4.2 Groundwater Isotope Studies

An isotope is an element, which has more than one form, but its form only differs with regard to the number of neutrons it has. This affects the relative atomic mass of an element and can result in different isotopes behaving slightly differently, which is what allows us to use them for a number of measurements relating to understanding past conditions[14]. Since the early 1950s, naturally occurring isotopes have been used in investigations of groundwater and surface water systems (Freeze and Cherry, 1979). Oxygen 18 (^{18}O) and deuterium (^{2}H) are mainly used as indicators of groundwater recharge source while tritium (^{3}H), carbon 14 (^{14}C), sulphur hexafluoride (SF_6) and chlorofluorocarbons (CFC) serve mainly as indicators of groundwater age. Stable (or nonradioactive) isotope ratios can also be used to help determine the source of an element as in the case of nitrogen (^{15}N:^{14}N ratio).

The various isotopic forms of water have slightly different vapour pressures and freezing points which gives rise to differences in ^{18}O and ^{2}H concentrations. When water evaporates from the ocean the water vapour is depleted in ^{18}O and ^{2}H relative to the concentrations in oceanic water. As the water vapour moves through atmospheric circulation systems, the condensation-precipitation history of the water vapour will affect the ^{18}O and ^{2}H content of precipitation at a given locality at a particular time (Freeze and Cherry, 1979). Since both

---

[14] Isotope definition sourced from www.tuition.com.hk/geography/i.htm

condensation and isotope fractionation[15] are temperature dependent, the isotope concentration can be correlated to altitude and thereby assist in identification of recharge sources. In May 2002, ^{18}O samples were taken from two bores in the Balfour area (E44/0010 and E44/0036) as part of a regional survey. The results showed consistent values of -8.44 and -8.36 respectively, which is similar to results from other shallow bores on the Waimea Plains. The ^{18}O results indicated local rainfall recharge as the dominant recharge source of groundwater (SKM, 2008).

In March 2007, a tritium (^3H) sample was taken from bore E44/0036. Tritium is a rare, but naturally occurring, hydrogen isotope. Figure 17 shows the history of tritium concentrations in rainfall and the peak in the 1960s and early 1970s is due to nuclear weapons testing. Tritium has a radioactive decay half life of 12.3 years, which can be combined with known atmospheric concentration curves to construct the mean age of water for groundwater samples less than 80 years old (GNS, 2006). The results from E44/0036 indicated a mean groundwater residence time of 3 to 7 years.

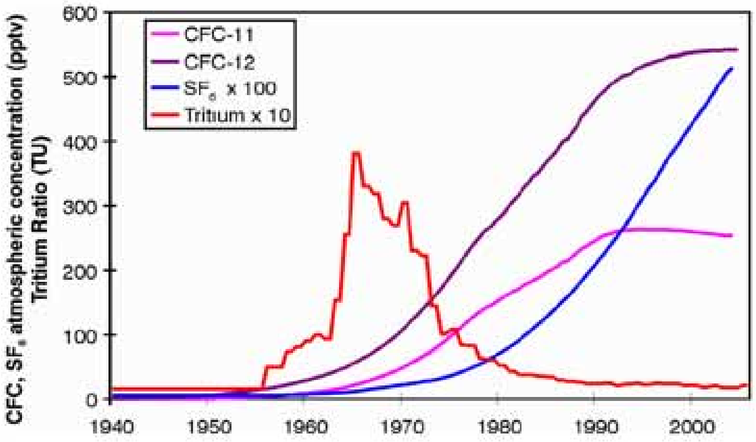

Figure 17: Plot of atmospheric CFC and SF6 levels and tritium concentrations in rainfall
[Source - GNS, 2006]

Nitrogen has two stable isotopes, 15N and 14N, and the ratio between them can be used to indicate likely sources of nitrate in a water sample. Although enriched 15N tracer studies have been commonly used in agricultural investigations for decades (Bremmer, 1965), natural abundance studies to trace natural and anthropogenic (or human) sources started with Kohl *et al* in 1971. However, it has only been in the past couple of decades that studies have taken advantage of the observation that atmospherically-derived nitrogen and fertiliser nitrogen typically have light 15N values whereas animal-derived nitrogen (such as effluents) are typically heavier in 15N (Kendall, 2004). Consequently, under favourable conditions isotope sampling can be used to indicate the dominant source of nitrate in groundwater and has been used in numerous studies (e.g. Komor and Anderson, 1993; Gellenbeck, 1994; Kreitler *et al*, 1978; Stogner, 1995). Application appears to be most successful in well-drained soils and oxygenated groundwater where nitrification is rapid and denitrification is minimal and under these conditions, 15N values are relatively conservative (Kenddall, 2004). More recently, the method has been refined to include 15N and 18O in combination to more clearly differentiate nitrate derived from atmospheric or fertiliser sources from nitrified ammonium and urea.

---

[15] Isotope fractionation refers to the process whereby the isotope content of a substance changes as a result of evaporation, condensation, freezing, melting, chemical reactions or biological processes (Freeze and Cherry, 1979).

The ratio of the common nitrogen isotope ^{14}N to its less abundant counterpart ^{15}N relative to a known standard is denoted by the symbol $d^{15}N$. Typical $d^{15}N$ ranges for fertiliser are -5 parts per million (‰) to +5 ‰ while typical waste sources have ranges greater than +10 ‰ (Kendall and McDonnell, 1998). In May 2002, Environment Southland undertook a preliminary regional study of $d^{15}N$ results where sites were selected predominately from the baseline monitoring programme where elevated nitrate-N concentrations had been measured. This survey included sampling from three bores within the Balfour study area. The results showed $d^{15}N$ concentrations that did not indicate a definitive source for the groundwater nitrate-N. Since this time, one of these bores has been sampled a further two times (E44/0036 in March 2006 and May 2010) and on each occasion, the results have become increasingly consistent with groundwater nitrate-N resulting from a fertiliser source, as shown in Figure 18. The decreasing $d^{15}N$ levels correspond with statistically significant increasing nitrate-N concentrations measured in this bore (and is discussed further in Section 4.2). In May 2010, a bore immediately upgradient, E44/0046, was also sampled for $d^{15}N$ and results determined fertiliser as being the likely nitrate-N source. The isotope monitoring results are provided in Appendix 3.

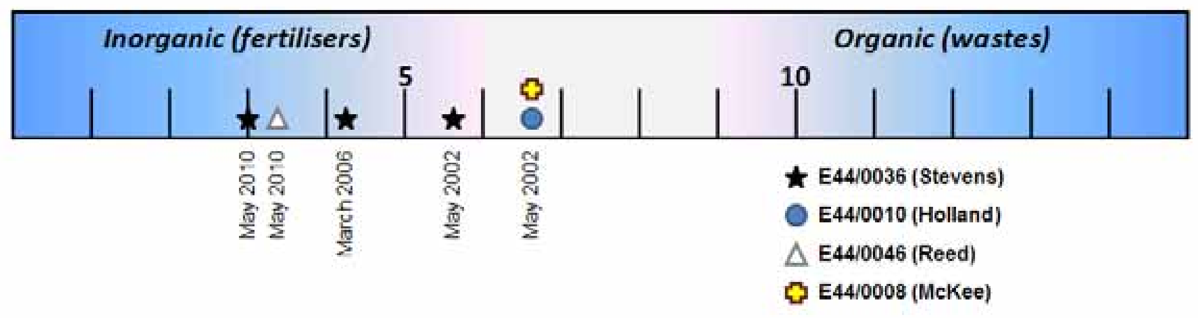

Figure 18: Plot of nitrogen isotope results (d15N in units of ‰) for samples taken in the Balfour area where inorganic nitrate sources (-5 to +5‰) are predominately fertiliser in origin and organic sources (>10‰) are from animal or human waste products
[Source - Kendall, 2004]

4.3 State of the Environment Monitoring

4.3.1 Background

Nearly all groundwater originates as either rainfall or snowmelt that infiltrates through the soil into the underlying geological materials. This water begins as being fairly diluted (i.e. contains relatively low amounts of total dissolved solids) depending on the amount of salt aerosols from the coastal environment. Reaction between rainfall, soil and geological material generally results in an increase in total dissolved solids and the dominant ions tend to shift from salt (i.e. sodium and chloride) to relative increases in calcium and bicarbonate ions as carbonate minerals dissolve rapidly relative to other minerals (Daughney and Wall, 2007). Because of groundwater's isolation from the atmosphere, it is common (but not universal) for natural microbiological and chemical processes to deplete oxygen from groundwater. In some instances, the degree of oxygen depletion can be used as a guide to the relative age of groundwater. The oxygen depletion process can also increase concentrations of elements only soluble in oxygen-reduced conditions, for example, iron, manganese, arsenic and ammonia. These chemical properties can be used to characterise groundwater quality into water "types" and inferences made with regard to the nature of groundwater flow through an aquifer system.

In general, aquifer systems within Quaternary sediments reside in greywacke and quartz gravels which exert a relatively subtle effect on groundwater chemistry (Hughes, 2010). Daughney (2004) identified increases in sodium (Na), chloride (Cl), bromide (Br), fluoride (F) and silica (SiO2) in older, more evolved groundwaters in Southland. Geology exerts a significant influence on groundwater chemistry within the extensive Tertiary measure deposits across the Southland region. For example, in the lignite measure aquifers the presence of organic materials acts to promote development of reducing (low oxygen) geochemical conditions, which causes reduction of iron pyrite that results in high dissolved iron concentrations in groundwater (Hughes, 2010).

In addition to the natural evolution of water chemistry, anthropogenic activities can increase the concentrations of certain elements found in groundwater (as discussed in Section 2.2). Examples of point source discharges include septic tanks, offal holes, silage pits, landfills, leaking effluent ponds, underground storage tanks and wastewater application systems. Many of these are controlled by way of policies and rules in regional plans and generally require a resource consent to ensure performance standards are achieved. The impacts of point source discharges on groundwater quality tend to be very localised but can be of a significant magnitude depending on the nature of the specific discharge.

Non-point source discharges relate to the infiltration of contaminants to water over a widespread area and examples include application of fertiliser and animal waste products to land. The potential magnitude of non-point source discharges can be exacerbated by land management practices such as the timing of soil cultivation (Hughes, 2010). Currently, non-point source discharges are generally not subject to specific regulatory controls and in a primary agricultural based region such as Southland, the potential cumulative effects of these discharges present a major challenge for the management of groundwater quality (Hughes, 2010).

In order to understand the condition and changes in Southland's natural and physical resources (including water quality), Environment Southland undertakes State of the Environment (SOE) monitoring. SOE monitoring is generally long-term monitoring of selected sites designed to provide a regional perspective to:

- quantify the current state of the region's natural resources;
- identify trends in the ambient condition of the region's natural resources;
- determine the cumulative effect of pressures including those from human activities;
- provide a basis for assessing environmental effects;
- identify resource management issues; and
- assist in monitoring the effectiveness of regional plans.

Environment Southland's SOE groundwater quality monitoring programme formally began in 2000. Sites were selected to provide representative samples from the region's major groundwater resources, with the main focus on monitoring shallow, unconfined aquifer systems due to their greatest resource pressure. SOE sites are sampled quarterly to enable assessment of seasonal variations and samples are analysed for all major ions, nutrients, physical parameters and microbial concentrations. Sampling is undertaken in accordance with national standards (Hughes, 2000 and Daughney *et al*, 2006) and the entire groundwater quality SOE programme underwent a review in 2004 (Daughney, 2004).

In the Balfour study area, Environment Southland has two SOE water quality monitoring bores, E44/0036 on Dipton Balfour Road and E44/0008 near the Riversdale Highway, and these sites are shown in Figure 13.

4.3.2 Groundwater quality 'types' in the Balfour area

The major groundwater ion concentrations for selected SOE sites in the Mataura catchment are shown in Figure 19 where the ion concentrations are represented as percentages of the total equivalents per litre (meq/l). Trilinear diagrams like the Piper plot are useful for visually demonstrating differences in major-ion chemistry in groundwater systems as similar aquifer types will cluster. However, because this plot represents concentrations as percentages, waters with very different total concentrations can have identical representations. Figure 20 shows the two Balfour SOE sites (i.e. E44/0036 and E44/0008) are reasonably similar in their relative ion chemistry and are similar to other lowland aquifer systems (F45/0170 and additional sites illustrated in Hughes, 2010). The riparian and terrace aquifer sites (F44/0005, E43/0028 and F45/0185) tend to plot away from the lowland aquifer sites indicating there are distinct differences in geochemistry which are likely associated with different groundwater flow characteristics.

In summary, the concentrations of the major ions of the Balfour SOE sites are relatively low and are typical of other lowland aquifer systems. The groundwater is characterised as being sodium-bicarbonate type waters, which is typical of groundwater with a low residence time in relatively inert aquifer media (Hughes, 2008).

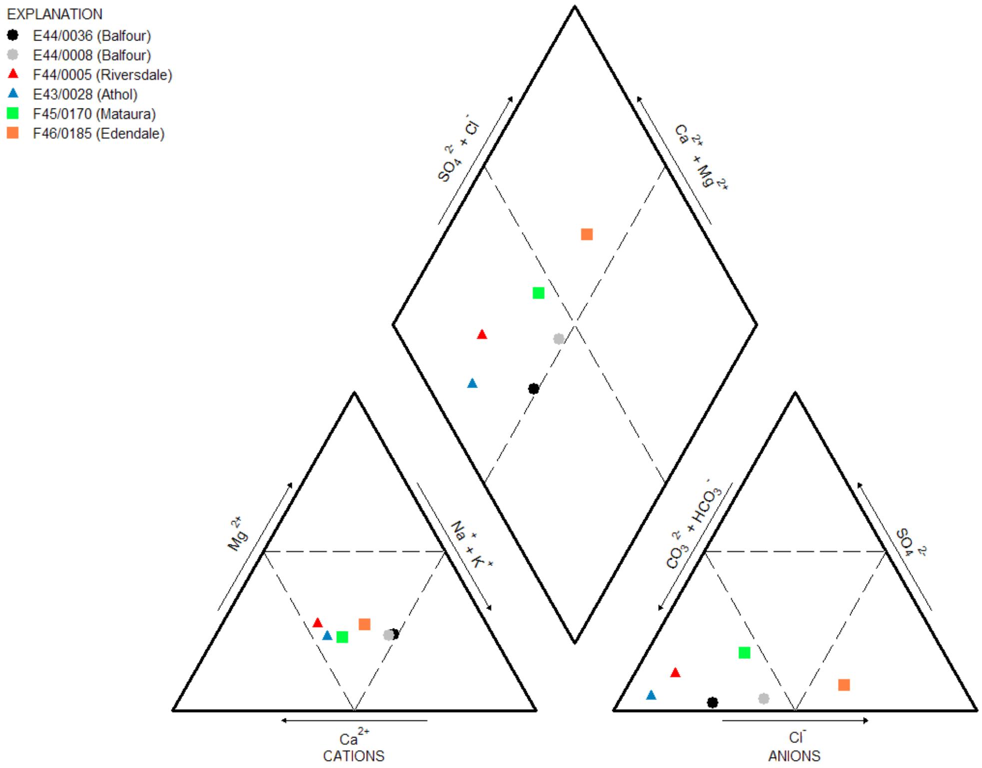

Figure 19: Piper-plot of the median value of the major ion chemistry from selected SOE monitoring sites in the Mataura catchment

4.3.3 Groundwater quality trends in the Balfour area

Trend analysis is used to quantify changes in water chemistry over time and is particularly useful for monitoring the effect of changes in resource pressure. Environment Southland has recently completed a review of all groundwater quality monitoring data including trend analysis (using Daughney, 2007 trend analysis software). The results of this work are reported in Hughes (2010) and the data and analysis from this report have been used in the following section.

Trend analysis on nine years of data from E44/0036 showed statistically significant increasing trends in calcium, magnesium, chloride and nitrate-N and Figure 20 shows that nitrate-N concentrations are increasing at the greatest rate of 0.3 mg/l per year. Analysis of 10 years of data from E44/0008 shows statistically significant increasing trends in chloride, magnesium, calcium, nitrate-N, sulphate and sodium with chloride concentrations increasing at the greatest rate of 0.5 mg/l per year. For both sites, the ions that are showing temporal changes are consistent with indicators of impacts of land use activities, however, the different range of ions displaying trends could indicate different causes.

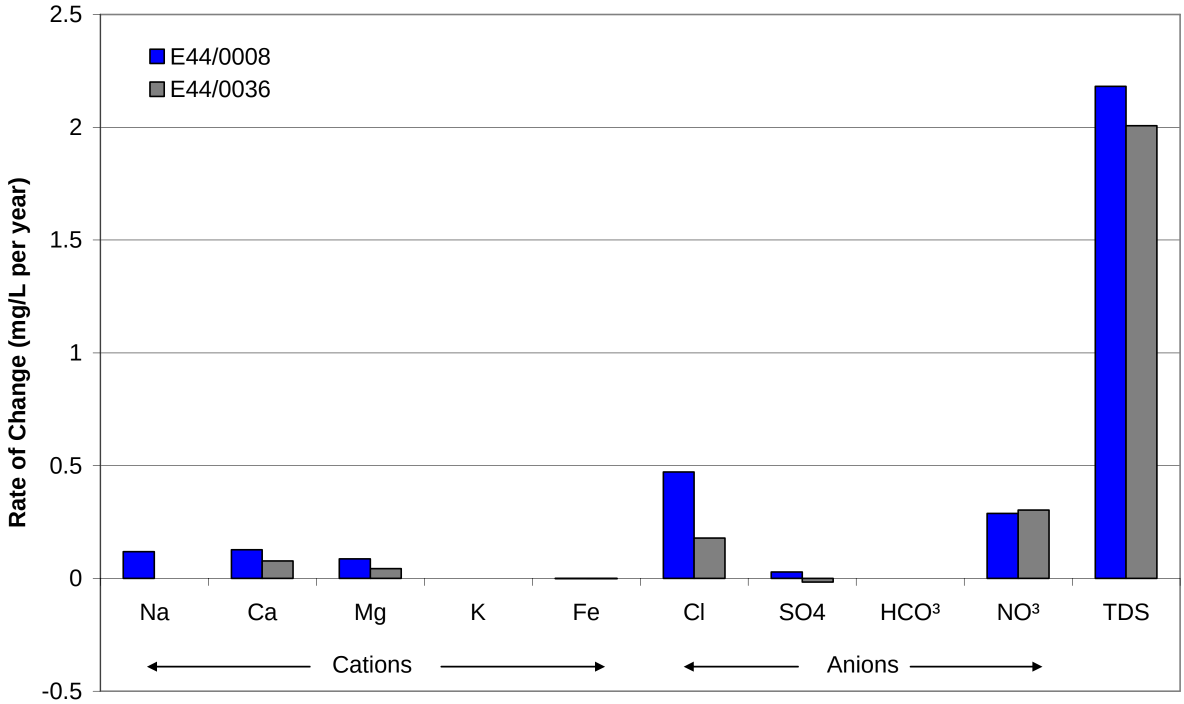

Figure 20: Graph of trends in water chemistry for bores E44/0036 and E44/0008[16]

In addition to SOE monitoring, Environment Southland has been monitoring nitrate-N concentrations in E44/0010 since early 2002, as part of a supplementary groundwater quality monitoring programme, and has undertaken semi-regular dairy compliance monitoring in E44/0046 and E44/0047 since 2003. Fortuitously, the landowner was able to provide additional groundwater quality data pre-dating Environment Southland's monitoring for bore E44/0046. The data from these monitoring sites are shown in Figure 21 and shows groundwater nitrate-N

---

[16] Na = sodium, Ca = calcium, Mg = magnesium, K = potassium, Fe = iron, Cl = chloride, SO_4 = sulphate, HCO_3 = bicarbonate, NO_3 = nitrate and TDS = total dissolved solids

concentrations are significantly elevated above the MAV of 11.3 mg/l in DWSNZ (Ministry of Health, 2008) in three of the five monitoring bores.

Statistical analysis shows E44/0036, E44/0008 and E44/0047 all have increasing nitrate-N concentrations. All three of the bores were below the NZDWS in 2005, however, since then, E44/0036 and E44/0047 have been measuring nitrate-N concentrations between 9.6 and 14.5 mg/l and are regularly above the MAV of 11.3 mg/l. Prior to 2005, these bores had relatively stable nitrate-N concentrations ranging between 8.7 to 11.0 mg/l. Although nitrate-N concentrations in E44/0008 are currently below the MAV, based on the current trajectory this bore will reach the MAV in about 5 to 10 years. Nitrate-N concentrations in E44/0046 have ranged between 17 to 21.4 mg/l over a nine year period and this site did not show any statistical significant temporal trends. No sites (with the possible exception of E44/0010) show any apparent or statistically significant seasonal variation.

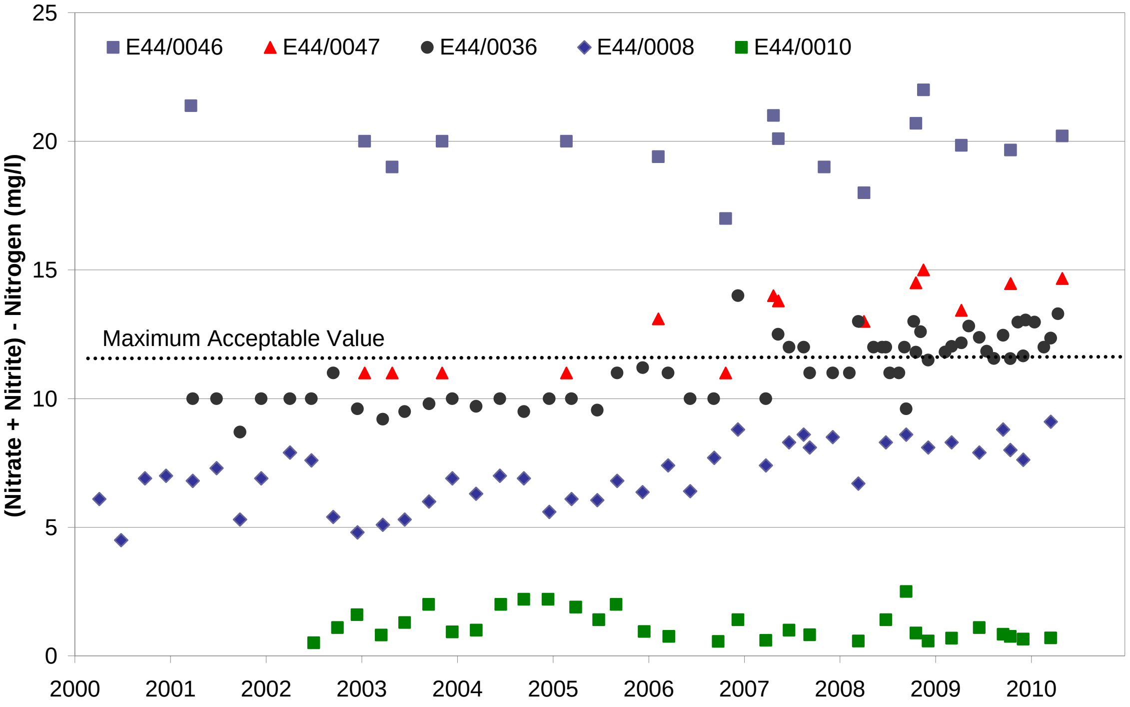

Figure 21: Graph of nitrate-N trends in ES monitoring bores in the Balfour area

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 groundwater (Hughes, 2010). Naturally occurring chloride in groundwater is derived from aerosol deposition in rainfall and rock-water interaction while anthropogenic sources are generally derived from wastewater discharge and to a lesser extent, some fertilisers. Regionally, it was found 60 percent of SOE sites had increasing chloride trends and the number of sites exhibiting an increasing trend for chloride was significantly higher than for any other parameter (Hughes, 2010).

Chloride (and sodium) are also useful to help indicate the source of nitrate contamination because the presence of elevated concentrations and a positive relationship between these determinants is a good indication of sewage contamination due to the high levels of salts in human and animal effluent (Rosen, 2001 and Baker, 2004). The trend analysis and a comparison of the ratio between chloride and nitrate-N for E44/0008 (shown in Figures 20 and 22) suggests that at least some of the likely nitrate source is from animal or human waste. However, the same analysis for E44/0036 does not show the same positive relationship suggesting fertiliser and/or soil mineralisation are the likely sources of nitrate-N, which is consistent with the isotope results (Section 4.2). Interestingly, although there are only a few sample points, bores E44/0046 and E44/0047 plot on the same linear regression as E44/0008, as shown in Figure 22. This would suggest some of the nitrate-N observed in these bores is also sourced from animal or human waste, which is not consistent with the single d^{15}N sample taken in E44/0046 that suggested fertiliser was the likely source. Figure 23 also shows that E44/0010, which has low levels of nitrate-N, has relatively high levels of chloride, which is unusual for a lowland aquifer.

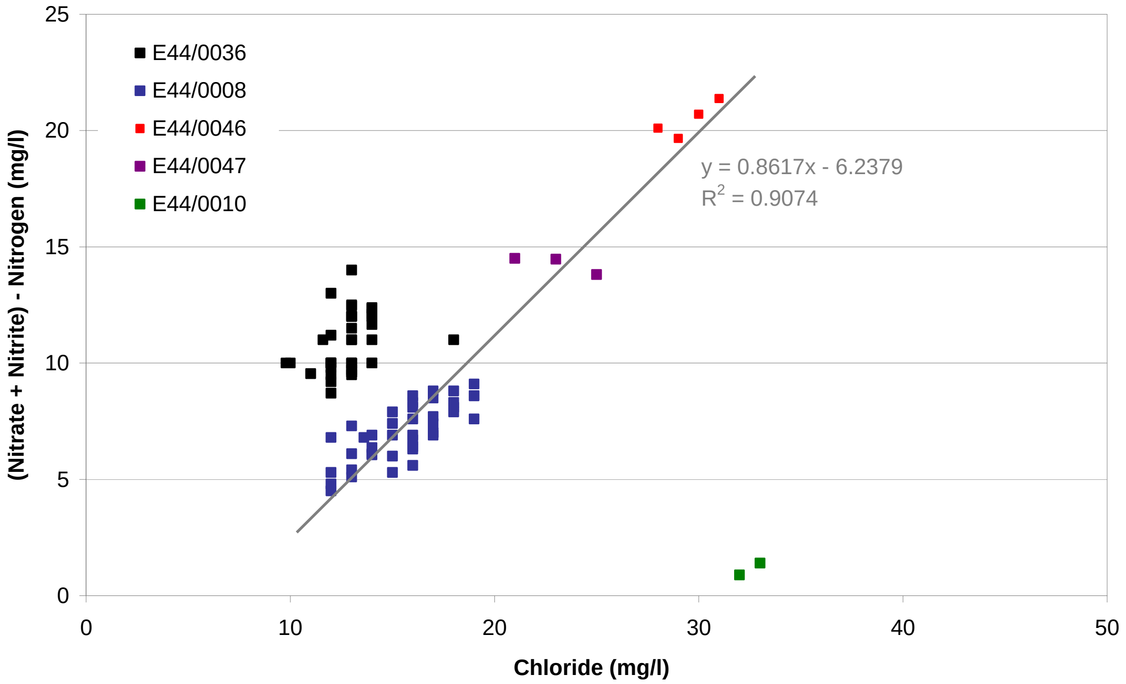

Figure 22: Graph of nitrate-N and chloride levels (each point is a separate sample and the linear regression excludes E44/0036 and E44/0010)

Appendix 4 summarises the major natural and anthropogenic activities, which can result in changes in groundwater chemistry. Based on this, and the data presented so far, it can be concluded that nitrate-N concentrations in E44/0036 exceed the DWSNZ and are increasing. Isotope and geochemistry sampling from this bore indicate fertiliser is the likely nitrate-N source. Monitoring data from E44/0008 show nitrate-N concentrations are currently below the DWSNZ but are increasing and are relatively close to the MAV. Nitrate-N in this bore is likely to come from a range of sources with the chloride–nitrate-N relationship suggesting wastewater is a major contributor. Monitoring data from E44/0046 show nitrate-N has been well above the MAV for the past nine years and concentrations have been reasonably consistent at about 20 mg/l. Nitrate-N concentrations in E44/0047 also exceed the DWSNZ and are increasing. The likely source of nitrate-N for these two bores is unclear with a d^{15}N sample from E44/0046 indicating the major nitrate-N source is fertiliser while the nitrate-N relationship with chloride suggests wastewater is a contributor.

4.4 Snapshot Surveys

In order to improve definition of the extent and magnitude of elevated groundwater nitrate-N levels, Environment Southland undertook a snapshot survey in May 2007. This survey involved collection of samples from eight bores in the local area along with samples from two sites in the Waimea Stream. The results showed an estimated affected area of approximately 1,640 hectares where groundwater nitrate-N levels exceeded MAV.

In October 2008, these bores were re-sampled and following increased concentrations of nitrate-N levels in some of the bores, additional bores were sampled in November 2008 extending the survey area down-gradient and eastwards. In order to quantify the temporal effect between the two 2008 sampling runs, two bores were sampled in both runs (E44/0036 and E44/0377). Nitrate-N levels in E44/0036 increased from 11.8 to 12.6 mg/l while concentrations in E44/0377 increased from 18.8 to 19.3 mg/L. These results show an increase in nitrate-N concentration between sampling runs, however, the variation is within 7 percent. In total, 10 bores were sampled along with three sites in the Waimea Stream.

In 2009, the snapshot survey was significantly expanded both in terms of spatial extent and sampling parameters. A total of 32 bores and 16 surface water sites were sampled and flow gaugings were undertaken at 10 sites over a two day period in October 2009. The nitrate-N results for all bores sampled in the three snapshot surveys are shown in Figure 23 and all results, including some additional ad-hoc sampling, are tabled in Appendix 5 and 6.

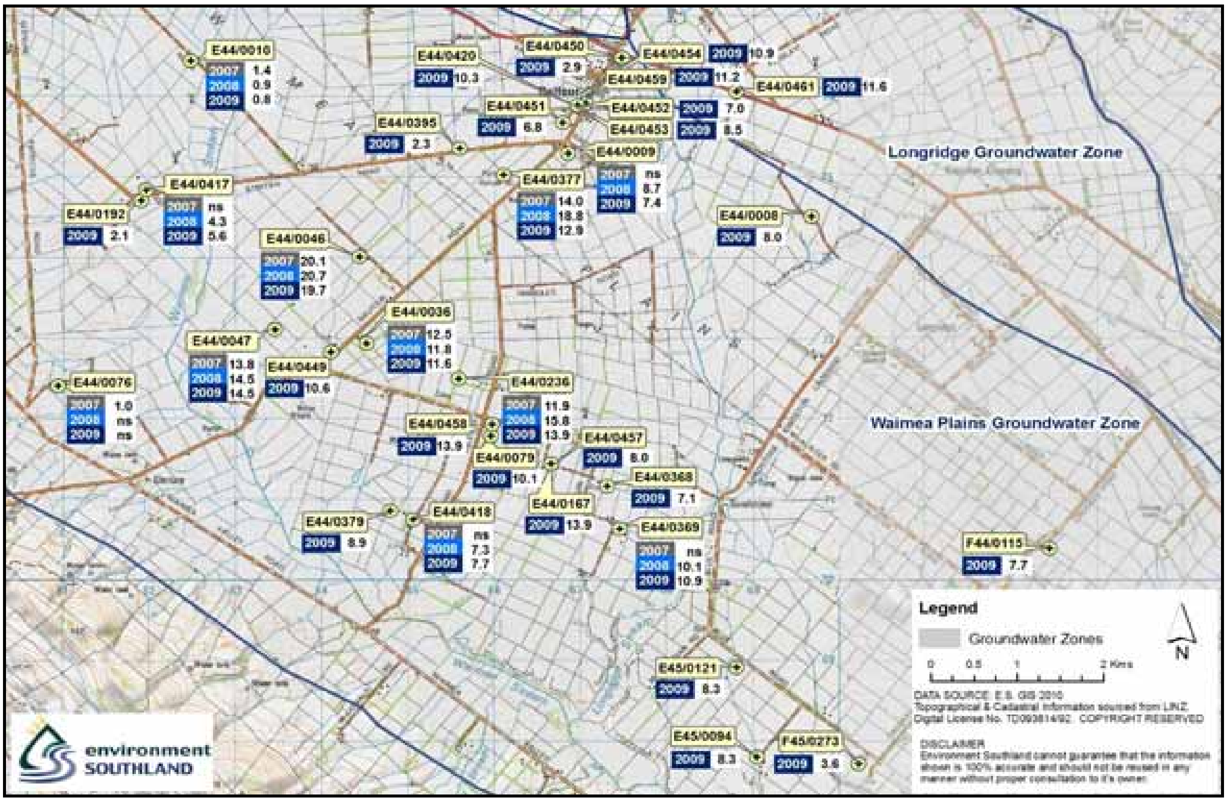

Figure 23: Map of the annual snapshot survey nitrate-N results in mg/l (note "ns" means no sample taken)

The groundwater snapshot survey data was analysed using spatial analysis tools in order to interpolate nitrate-N concentrations between bores. The analysis assumes the aquifer is isotropic (or uniform in all directions) and homogeneous (or of uniform composition throughout), which is clearly not realistic, however, it provides a useful visual estimation of the variation in nitrate-N concentrations across the survey area and between snapshot surveys. The results, shown in Figure 24, show the interpolated[17] affected area where groundwater nitrate-N concentrations exceeding MAV have increased from approximately 1,640 hectares in 2007 to 1,990 hectares in 2008 to 2,630 hectares in 2009. The progressive increase in the affected area is generally towards the south, which is consistent with the groundwater flow direction shown in Figure 10.

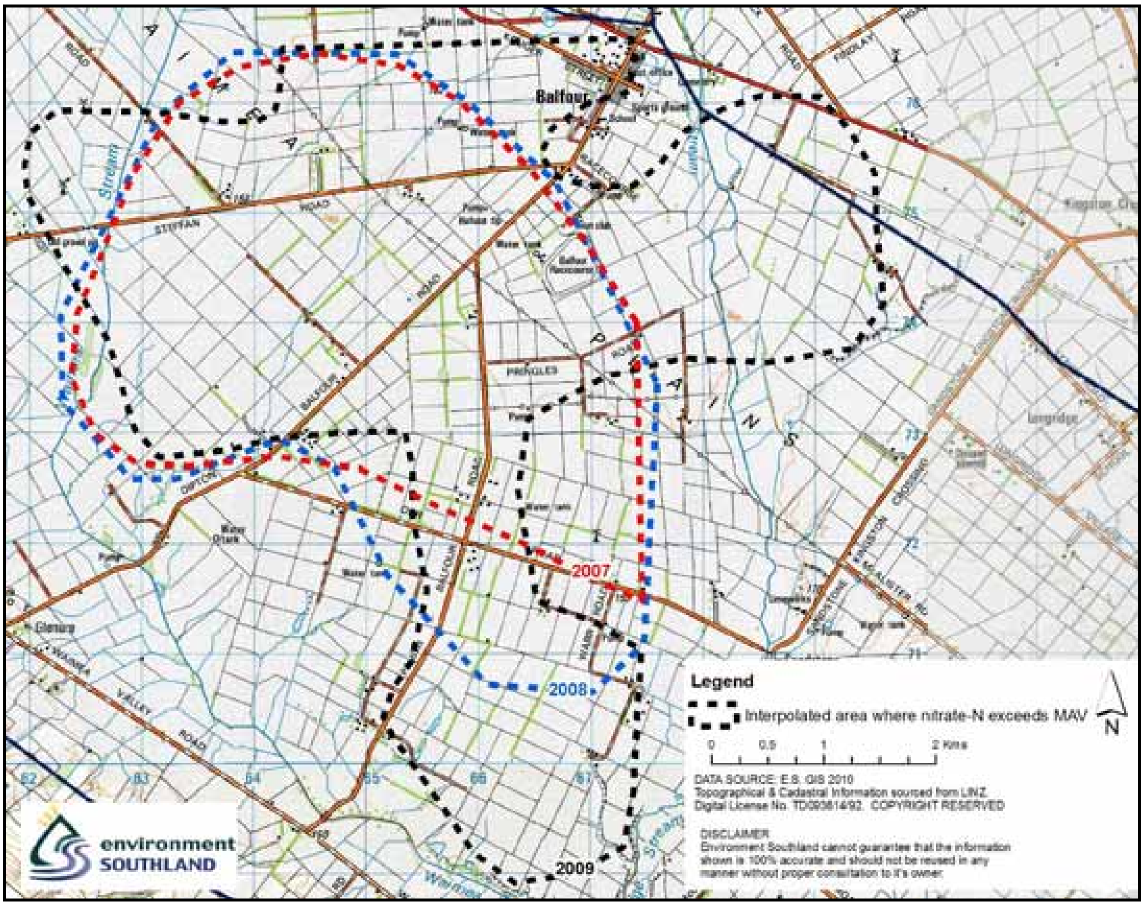

Figure 24: Map of interpolated areas where groundwater nitrate-N values exceed the DWSNZ based on data collected in the 2007, 2008 and 2009 snapshot surveys

---

[17] Monitoring data was interpolated using a regularised spline method with a 0.1 weight and 8 points.

5. Surface Water Quality Results

Elevated nutrient levels in surface water (generally in the various forms of nitrogen and phosphorous) can promote the growth of nuisance aquatic plants, which can in turn reduce water clarity, increase oxygen reduction, and, in extreme cases, can lead to the death of aquatic organisms. In order to establish safe thresholds for surface water quality, Australia and New Zealand jointly produced guidelines, which set limits on pollutant concentrations for surface water and marine environments. This standard is currently under review, however, until the review is complete, the existing guidelines (ANZECC, 2000) are still effective.

Even as far back as 1984, the Waimea Stream had been identified as having the highest nitrate-N and ammonia-N concentrations within the Mataura catchment and was believed to be having a significant effect on water quality in the Mataura River (Riddell, 1984). More recently, data analysis completed in 2010 shows nitrate-N concentrations in the Waimea Stream at the Mandeville SOE monitoring site exhibits a statistically significant increasing trend (K Meijer, *pers comms*). It is not the intention of this report to provide a comprehensive review of surface water quality in the Waimea catchment. Rather, the objective of this section is to present the available surface water quality data from the Balfour study area and to consider the potential impacts groundwater quality might be having on nitrate-N levels in surface water quality.

5.1 Surface Water Nitrate Results

As part of its surface water quality monitoring programme, Environment Southland has been sampling the Waimea Stream at Murphy Road and Pahiwi–Balfour Road monthly since 2005. While a range of parameters are sampled, this report is only concerned with nitrate-N results as an indicator of the influence of groundwater discharge on surface water quality. The Murphy Road site is immediately upgradient of the inferred Balfour groundwater quality problem area, while the Pahiwi–Balfour Road site is situated in the groundwater discharge area near the confluence of the Waimea and Longridge Streams.

As can be seen in Figure 25, both sites appear to display seasonal fluctuations where nitrate-N concentrations peak during winter and spring and are lowest during summer and early autumn, however, there is insufficient data to assess trends in a statistically meaningful way. This apparent pattern is typical of many lowland streams which are surrounded by intensive land use where runoff over the land surface and discharge from mole and tile drains increase nutrient concentrations during wetter periods.

It is evident in Figure 25 that nitrate-N concentrations in the downstream Pahiwi–Balfour site are greater than that measured at Murphy Road. The difference ranges between 0.4 to 3.6 mg/l and is generally highest during drier times of the year (i.e. during summer and autumn). This is interpreted to reflect the influence of base flow discharge on surface water quality and specifically, the greater amount of groundwater discharged into the downstream site which appears to keep nitrate-N levels elevated above the ANZECC (2000) guideline value all year round.

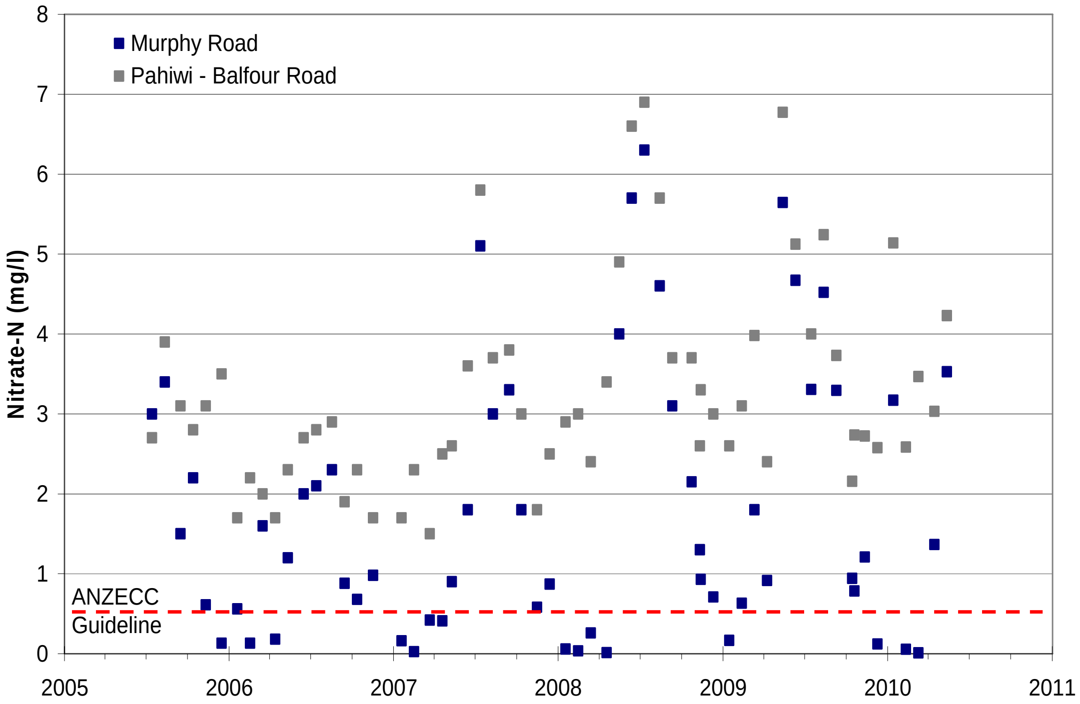

Figure 25: **Graph of nitrate-N surface water quality results for the Waimea Stream at Murphy Road and Pahiwi-Balfour Road**

The influence of groundwater discharge on surface water nitrate-N concentrations is also apparent in the snapshot survey results shown in Figure 26. Concentrations show a marked increase in the Waimea Stream downstream of Steffan Road and in the Longridge Stream downstream of Orr Road, which is consistent with the groundwater discharge zone identified in Section 3 of this report.

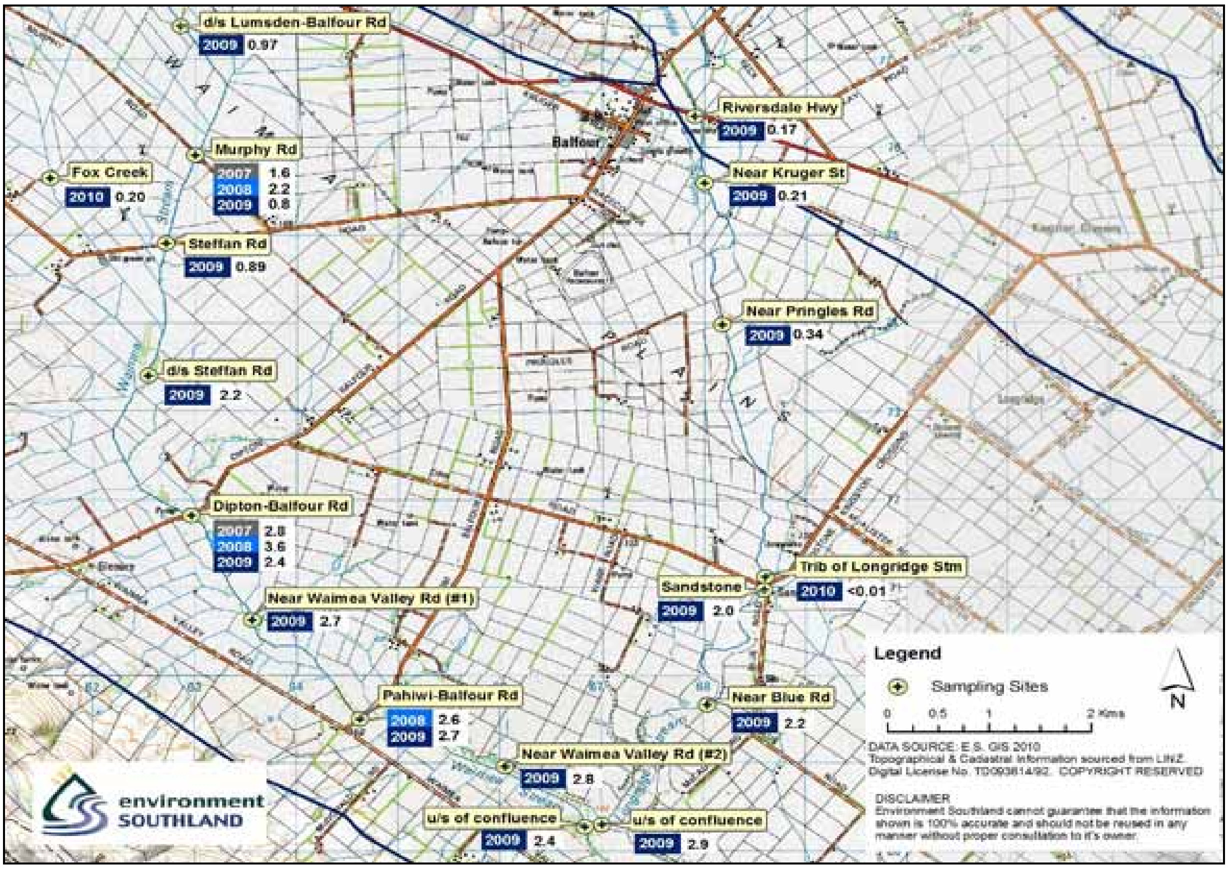

Figure 26: Map of the annual snapshot survey surface water quality nitrate-N results in mg/l (note the ANZECC, 2000 guideline value is 0.44 mg/l for lowland streams)

In summary, the surface water quality results support findings of other data presented in this report where groundwater from the study area is discharging into the lower reaches of the Longridge Stream and the Waimea Stream downstream of the Balfour township. The elevated nitrate-N concentrations present in groundwater appears to be contributing to the high levels of nitrate-N observed in the Waimea Stream, and potentially even influencing water quality in the Mataura River.

6. Summary

The Balfour groundwater quality study area is located in the Waimea catchment which appears to be an area of relatively high geological complexity. The geology of Waimea Plains is made up of three terranes, which form a deep sedimentary basin that is fault controlled and has been infilled with marine, glaciofluvial and alluvial sediments. The contact between the basement geology and overlying sediments appears to exert significant influence over existing surface water hydrology and hydrogeology, as catchment drainage does not always follow surface topography. The complexities of the area unfortunately add to the uncertainties in interpreting data, however, the following conclusions can be made based on data present in this report:

- the Quaternary gravels in the Balfour area contain an unconfined aquifer system whose characteristics are consistent with properties associated with lowland aquifers. Gravel thickness appears to increase north of Steffan Road from approximately 20 metres near Orr Road to 40 metres north of Murphy Road. In addition, silty clay layers up to 11 metres thick have only been recorded in bore logs north of Steffan Road which suggests changes in hydrogeology across Steffan Road, possibly reflecting different aquifers which may have limited hydraulic connection;

- piezometric surveying data indicates a relatively complex groundwater flow pattern, which is strongly influenced by a combination of topography and geology. South of Steffan Road, the data indicates the gradient steepens to 0.011 and predominately flows in a southerly direction towards the confluence of the Waimea and Longridge Streams. The shape of the contours around the streams also suggests the Waimea and Longridge Streams are gaining in flow due to drainage from groundwater in their middle and lower reaches respectively;

- pump test and other data suggest there are two components to groundwater flow, a relatively shallow circulation comprised of local drainage of rainfall recharge from surrounding terraces to the nearest stream and a deeper, slower, sub-regional circulation of groundwater, which follows overall catchment drainage. The bulk groundwater flow rate is estimated to be somewhere between 175 to 480 metres per year, however, there is likely to be considerable variability at any given point within the aquifer due to heterogeneity;

- groundwater level and isotope monitoring data show aquifer recharge is predominately from localised rainfall leaching through the land surface while piezometric and hydrological data indicate groundwater discharge is predominately into the Waimea and Longridge Streams south of the Riversdale Highway;

- in general, the major ion concentrations in groundwater are relatively low and can be characterised as being sodium-bicarbonate type waters, which are typical of groundwater flow with a low residence time in relatively inert aquifer media. Isotope samples indicate groundwater in the study area has a mean residence time of 3 to 7 years;

- Nitrate-N concentrations show a statistically significant increase in three of five monitoring bores that have sufficient data for analysis. Of the 32 bores sampled in the 2009 snapshot survey, eight (or 25 percent) contained nitrate-N concentrations which exceeded drinking water standards. Nearly half of the bores sampled had nitrate-N concentrations, which were greater than 75 percent of the MAV. While the annual snapshot surveys only offer a reflection of groundwater quality for a particular point in time, the spot measurements combined with the trend data indicate the affected area is extending towards the south, which is consistent with the groundwater flow direction;

- isotope and geochemical data indicate fertiliser is the likely source for nitrate-N found in monitoring bore E44/0036, however, the nitrate-N source for other monitoring sites is less clear, as the chloride–nitrate-N relationship suggests human or animal wastewater could also be a major contributor;

- Nitrate-N concentrations in samples taken from the Longridge and Waimea Stream within the study area indicate the elevated groundwater nitrate-N concentrations are probably contributing to the high levels observed in these streams, which exceed surface water quality standards for aquatic health.

In conclusion, the findings in this report highlight the vulnerability of this particular hydrogeological setting to land use impacts on groundwater quality. The combination of low aquifer permeability, aquifer recharge from local rainfall infiltration and relatively slow rates of groundwater circulation increases the potential for nitrate-N to accumulate within the aquifer. As most of the nitrate-N found in groundwater is introduced as a result of human activities, effective management of land use impacts is required to ensure water quality objectives are met in the Balfour area and in other areas like it.

7. References

Baker, T., 2004. Groundwater Quality and Farm Nitrogen Management on the West Coast, South Island, New Zealand. Thesis for a MSc (hons) for Victoria University of Wellington.

Canter, L, W., 1996. Nitrates in Groundwater. CRC Press, Inc, United States of America. ISBN 0-87371-569-1. 260p.

Craw. D., and Norris, R. J., (chapter 2 authors). 2003. The Natural History of Southern New Zealand. University of Otago Press. ISBN 877133 515. pp17-35.

Daughney, C. J., 2004. Review of the Environment Southland Baseline Groundwater Quality Monitoring Programme. GNS Science client report 2004/68 prepared for Environment Southland, May 2004. 75p.

Daughney, C. J., Jones, A., Baker. T., Hanson. C., Davidson, P., Zemansky, G., Reeves, R., and Thompson, M., 2006. A National Protocol for State of the Environment Groundwater Sampling in New Zealand. Published by the Ministry for the Environment, November 2006, Greater Wellington publication number GW/EMI-T-06/249, GNS Science Miscellaneous Series 5. ISBN 0-478-30112-X. 52p.

Daughney, C. J., 2007. Spreadsheet for automatic processing of water quality data: 2007 update. GNS Science report 2007/17.

Daughney, C. J. and Wall, M., 2007. State and Trends of Groundwater Quality in New Zealand (1995-2006). GNS Science Consultancy report 2007/23 prepared for the Ministry for the Environment, February 2007. 66p.

Environment Southland, 2010. Regional Water Plan for Southland, 2010. Environment Southland publication No 2010-03, March 2010. ISBN 0-909043-40-X.

Freeze, R. A., and Cherry, J. A., 1979. Groundwater. Prentice Hall, Inc, United States of the America. ISBN 0-13-365312-9. 524p.

Gellenbeck, K. J., 1994. Isotopic compositions and sources of nitrate in groundwater from western Salt River Valley, Arizona. U. S. Geological Survey Water Resources Investigations Report 94-4063. 53p.

GNS Science, 2006. Water age dating for testing groundwater security. Published by GNS Science, May 2006. 7p.

Hughes, B. N., 2000. Groundwater Sampling Guide. Environment Southland unpublished document.

Hughes, B. N., 2003. Proposed Framework for Groundwater Allocation in the Southland Region. Environment Southland unpublished report. 60p.

Hughes, B. N., 2008. Balfour Nitrate Hotspot. Prepared by Sinclair Knight Merz for Environment Southland, June 2008. 23p.

Hughes, B. N., 2010. Environment Southland State of the Environment: Groundwater Quality Technical Report. Prepared by Liquid Earth Limited for Environment Southland, May 2010. 58p.

Kendall, C. A., and McDonnell, J. J., 1998. Isotope tracers in catchment hydrology. Elsvier, Amsterdam.

Kendall, C., and Doctor, D.H., 2004, Stable isotope applications in hydrologic studies, *in* Drever, J.I., ed., Surface and ground water, weathering, and soils: Treatise on Geochemistry, v. 5

Komor, S. C., and Anderson H. W., Jr., 1993. Nitrogen isotopes as indicators of nitrate sources in Minnesota sand-plain aquifers. *Ground Water* 31(2): 260-270.

Kreitler, C. W., Ragone, S., E., and Katz, B. V. E., 1978. Nitrogen-isotope ratios of groundwater nitrate, Long island, New York. *Ground Water* 10: 404-409.

Kruseman, G. P., and de Ridder, N. A., 1970. Analysis and Evaluation of Pumping Test Data (2nd Edition). International Institute for Land Reclamation and Improvement, The Netherlands. ISBN 90 70754 207. 287p.

Ledington, S. A., 2008. Surface Water Resource Zone Information Sheets. Published by Environment Southland. 17p.

McIntosh, P. D., 1988. The Evolution of the Waimea Plains. The Southland Times newspaper “Signpost” article dated Wednesday, 9th March 1988.

McKerchar, A I., and Henderson, R D., 1987. Drawing and checking Stage/Discharge Rating Curves. Publication No 11 of the Hydrology Centre, Christchurch. ISSN 0112-1197. 29p.

McKerchar, A I., and Henderson, R D., 2003. Shifts in flood and low-flow regimes due to interdecadal climate variations. *Hydrological Sciences Journal* 48(4): 634-654.

Ministry of Health, 2008. The New Zealand Drinking Water Standards. Published by the Ministry of Health. 171p.

Moench, A. F., and Prickett, T. A., 1972. Radial flow in an infinite aquifer undergoing conversion from artesian to water-table conditions. *Water Resources Research* 8(2): 494-499.

Morgan, M., and Evans, C., 2003. Southland Water Resources Study – Stages 1 to 3. Report number 4597/1 prepared by Lincoln Environmental and MWH for Venture Southland, September 2003. SFF funding. 118p.

Pidwirny, M., 2006. “The Nitrogen Cycle”. Fundamentals of Physical Geography, 2nd Edition. July, 2010. http://www.physicalgeography.net/fundamentals/9s.html

Poole, M., 1990. While Water Flows – A History of the Southland Catchment Board. Published by the Southland Regional Council. 124p.

Reay, T., (chapter 1 author). 2003. The Natural History of Southern New Zealand. University of Otago Press. ISBN 877133 515. pp1-17.

Riddell, D. C., 1984. Surface Water Hydrology of the Mataura River Catchment. Published by the Southland Catchment Board and Regional Water Board, December 1984. 124p.

Rosen, M. R., 2001. Hydrochemistry of New Zealand's Aquifers. In *Groundwaters of New Zealand* (Eds Rosen, M.R. and White, P. A.), New Zealand Hydrological Society. Caxton Press, Christchurch.

Rosen, M. R., Cameron, S., and Reeves, R. R., 2001. Determination of non-point source chemical groundwater quality indicators for New Zealand aquifers. GNS Science Report 2001/05 prepared for the Ministry for the Environment, January 2001.

Stogner, R. W., Sr., 1995. Variability of nitrate concentrations in the shallow ground water in a selected area of the San Luis Valley, South-Central Colorado. U. S. Geological Survey Fact Sheet 004-97. 4p.

Turnbull, A. M., and Allibone, A. H. (compliers) 2003. Geology of the Murihiku Area. Institute of Geological and Nuclear Sciences 1:250 000 geological map 20. ISBN 0-478-09800-6. 1 sheet and 74p.

USGS, 2001. What is Ground Water? U.S. Geological Survey Circular 93-643. 2p.

Wilson, K. L., 2008. Surface Water and Groundwater Relationships in the Mataura Catchment above Gore. Environment Southland Publication number 2008-003, February 2008. 62p.

Winter, T. C., Harvey, J. W., Franke, O. L., and Alley, W. M., 1998. Ground Water and Surface Water; A Single Resource. U.S. Geological Survey Circular 1139. 79p.

8. Appendices

Appendix 1: Pump Test Results

Analysis of aquifer pump test on date using Aqtesolv software. E44/0351 is the pumped bore and E44/0079 is a monitoring bore located 700 metres to the north. No drawdown was detected in the other monitoring bores.

Method	Transmissivity (m^2/day)	Comment
Theis (drawdown)	540	Poor fit on recovery data using E44/0351
Theis (recovery)	1,740	Poor fit on drawdown data using E44/0351
Cooper – Jacob	350 – 1,190	Range between early time and late time data (E44/0351)
Cooper – Jacob	480	S=0.0002132 using E44/0079
Moench-Prickett	**352**	**Best fit using data from both E44/0351 and E44/0079**

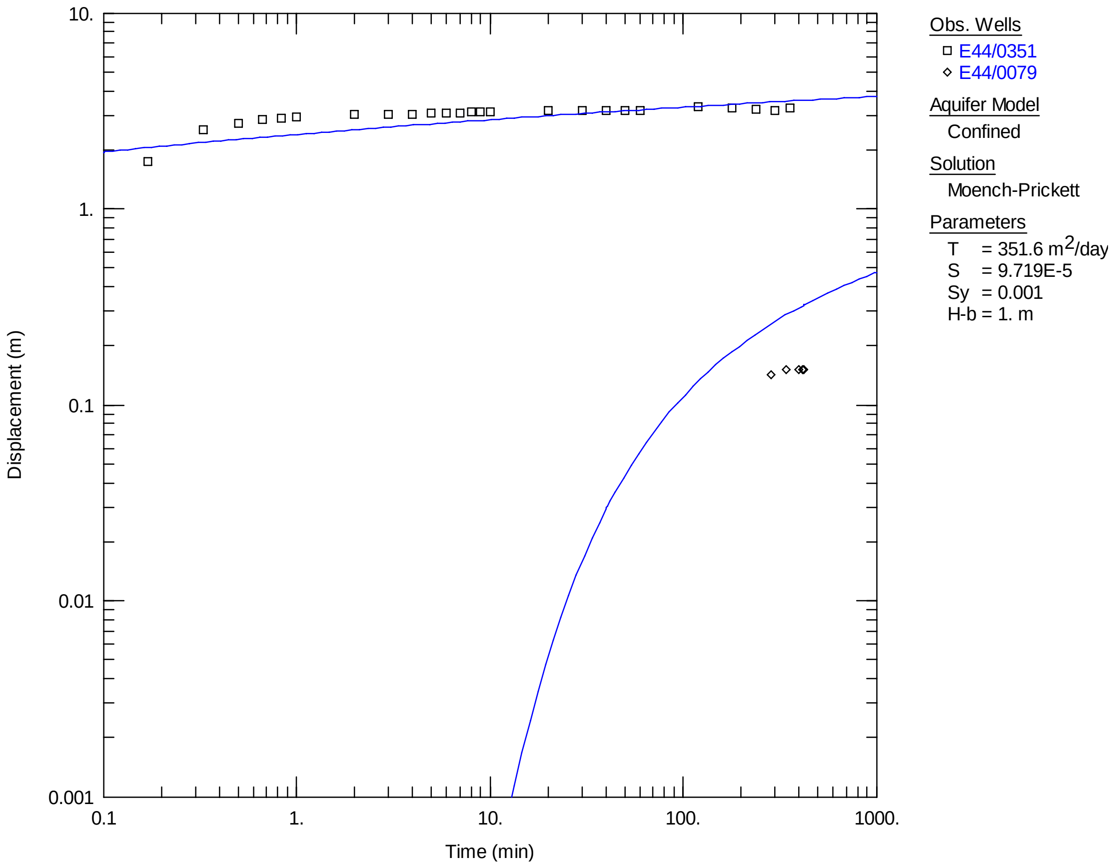

Figure of the time – drawdown data and solution curve sourced from Aqtesolv.

Appendix 2: Groundwater Level Statistics

Groundwater level statistics for Environment Southland's monitoring sites near Balfour (in metres below ground).

Site	Record Start	Elevation (m msl*)	Min Reading	Max Reading	Median Level	Range (m)
Waimea Plains Groundwater Zone						
E44/0231	Dec 03	166	-3.07 (Mar 04)	-0.92 (Jun 05)	-2.10	2.15
E44/0035	Jul 02	165	-4.05 (Jun 03)	-2.19 (Jun 05)	-2.63	1.86
E44/0288	Jan-05	162	-2.10 (Feb 08)	-0.97 (Aug 08)	-1.65	1.13
E44/0010	Sep-00	159	-3.66 (Feb 04)	-2.26 (Oct 05)	-2.82	1.40
E44/0036	Mar-01	157	-5.37 (May 02)	-2.52 (Jul 05)	-4.41	2.85
E44/0386	Apr-09	156	-6.39 (Apr 10)	-5.47 (Aug 09)	-5.71	0.92
E44/0008	Dec-05	165	-4.20 (Jun 07)	-3.22 (Dec 05)	-3.80	0.98
Longridge Groundwater Zone						
E44/0406	Jul-08	177	-2.43 (Mar 10)	-1.03 (Aug 08)	-1.80	1.40
F44/0006	Mar-00	165	-6.99 (May 08)	-2.67 (Jan 05)	-5.46	4.32

*Metres above mean sea level using Bluff 1949 datum (source: Digital Elevation Model)

Appendix 3: Groundwater Isotope Results

All sampling was undertaken by Environment Southland staff in accordance with national sampling protocols. Isotope results were obtained by the National Isotope Centre, GNS Science and nitrate-N results by an ISO accredited laboratory.

Site	Date	d15N (‰)	NO_3 (-N mg/l)	d18O (‰)
E44/0008	May 2002	6.7	6.6	
E44/0010	May 2002	6.7	1.6	-8.44
E44/0036	May 2002	5.7	10.0	-8.36
	March 2006	4.04		
	May 2010	3.0	12	
E44/0046	May 2010	3.5	21	

Appendix 4: Groundwater Indicators

Summary of main chemical indicators used in groundwater quality (summarised from Rosen *et al*, 2001).

Chemical (Symbol)	Natural reasons for change	Anthropogenic reasons for change
Nitrate (NO_3-N)	Seasonal variations from recharge input	Fertilisers, animal or human waste
Chloride (Cl)	Seasonal variations from recharge input	Fertilisers, animal or human waste; chloride ratios can be used to help distinguish between anthropogenic sources
Sodium (Na)	Seasonal variations from recharge input	Fertilisers, animal or human waste
Bicarbonate (HCO_3)	Weathering of calcite and feldspars	Dairy shed runoff, addition of lime fertilsers
Calcium (Ca)	Weathering of rocks and soils, climate change	Fertilisers (lime)
Sulphate (SO_4)	Weathering of pyrite	Fertilisers
Potassium (K)	Weathering of rocks and soils, climate change	Fertilisers, animal or human waste
Iron (Fe)	Oxygen-reduction conditions	Industry, mining

Appendix 5: Snapshot Survey Groundwater Quality Results from 2007 to 2009

Site	Easting	Northing	Date	Water Temp (ºC)	Field EC (uS/cm)	NO_3-N (mg/l)	Chloride (mg/l)	Lab EC (uS/cm)	E-coli (MPN)	Dissolved Na (mg/L)
E44/0008	2169642	5474516	20/10/09	9.8		8.0				
E44/0009	2166872	5475301	23/10/08	12.0	193	8.7	19	188	<1	<0.010
			17/12/09			7.4				
E44/0010	2162544	5476445	15/05/07	10.4	288	1.4	33		<1	
			23/10/08	10.0	290	0.89	32	290	<1	<0.010
			20/10/09	9.9		0.76				
E44/0036	2164438	5472955	15/05/07	11.5	192	12.5	13		<1	18
			23/10/08	11.2	190	11.8	13	186	<1	<0.010
			20/10/09	11.6	192	11.6				
E44/0046	2164412	5473991	15/05/07	10.4	296	20.1	28		<1	22
			23/10/08	11.6	312	20.7	30	301	<1	<0.010
			20/10/09	10.5	310	19.7	29	284	<1	1.2
E44/0047	2163447	5473097	15/05/07	10.9	214	13.8	25		1	18
			23/10/08	11.5	227	14.5	21	221	<1	<0.010
			20/10/09	10.5	234	14.5	23	214	<1	0.82
E44/0076	2160958	5472402	15/05/07	10.9	186	1.0	13		84	
E44/0079	2165945	5471787	20/10/09	10.7	175	10.1				
E44/0167	2166591	5471425	20/10/09	10.6	225	13.9				
E44/0192	2161900	5474700	20/10/09	11.8		2.1				
E44/0236	2165584	5472521	15/05/07	10.5	189	11.9	14		10	
			23/10/08	10.6	221	15.8	15	213	<1	<0.010
			20/10/09	10.5		13.9				
E44/0368	2167305	5471164	20/10/09	12.1	182	7.1				
E44/0369	2167464	5470641	10/12/07			10.0				
			23/10/08	11.2	218	10.1	26	216	<1	<0.010
			20/10/09	12.6	235	10.9				
E44/0377	2166106	5475047	10/12/07			14	25		<1	
			23/10/08	9.2	248	18.8	22	242	<1	<0.010
			10/11/08			19				
			17/12/09			12.9	16	173		0.76
E44/0379	2164781	5470849	20/10/09	11.3		8.9				
E44/0395	2165583	5475326	20/10/09	9.7	152	2.3	13	139		2.4
			17/12/09			2.5				
E44/0417	2161926	5474845	23/10/08	10.0	152	4.3	9.6	149	1	<0.010
			20/10/09	11.2		5.6				
E44/0418	2165046	5470751	23/10/08	10.2	151	7.3	13	144	<1	<0.010
			20/10/09	9.8		7.7	15	163		1.9
E44/0420	2166932	5475854	20/10/09	9.5	262	10.3	27	248		2.0
E44/0449	2164120	5472872	20/10/09	11.2	190	10.6				
E44/0450	2167503	5476514	20/10/09	9.7		2.9	16	196		2.2
E44/0451	2166788	5475672	20/10/09	10.1	144	6.8				
E44/0452	2167011	5475870	20/10/09	11.5	215	7.0				

Site	Easting	Northing	Date	Water Temp (°C)	Field EC (uS/cm)	NO_3-N (mg/l)	Chloride (mg/l)	Lab EC (uS/cm)	E-coli (MPN)	Dissolved Na (mg/L)
E44/0453	2167022	5475888	20/10/09	12.2	208	8.5				
E44/0454	2167045	5475915	20/10/09	13.1	205	10.9	13	172		2.0
E44/0457	2166617	5471475	20/10/09	13.1	225	8.0				
E44/0458	2165953	5471903	20/10/09	9.6	183	13.9				
E44/0459	2167045	5475933	20/10/09	11.6	242	11.2				
E44/0461	2168755	5476102	20/10/09	9.6		11.6				
E45/0094	2169050	5467852	20/10/09	8.8		8.3				
E45/0121	2168780	5468925	20/10/09	11.5	186	8.3	20	180		6.0
F44/0115	2172413	5470376	29/10/09	10.7	190	7.7				
F45/0273	2169642	5474516	20/10/09	10.0		3.6				

Appendix 6: Snapshot Survey Surface Water Quality Results from 2007 to 2009

Site	**Easting**	**Northing**	**Date**	**Q (l/s)**	**NO_3-N (mg/l)**	**Nitrite (mg/l)**	**NH_4-N (mg/L)**	**Total N (mg/l)**	**TKN (mg/l)**	**Cl (mg/l)**	**EC (uS/cm)**	**Total P (mg/l)**	**E-coli (MPN)**
Waimea Stream													
d/s Balfour-Lumsden Rd	2162872	5477402	19/10/09	70	0.97	0.0048	<0.010	1.3	0.34	7.1	120	0.016	359
Murphy Road	2163010	5475905	15/05/07		1.6					12	148		68
			23/10/08		2.2		<0.010			13	168		128
			19/10/09		0.79	0.0081							
Steffan Road	2162722	5474901	19/10/09	110	0.89	0.0062	0.012	1.4	0.47	10	147	0.026	74
Btwn Steffan & Dipton-Balfour Rd	2162549	5473422	19/10/09		2.2	0.0099							
Dipton-Balfour Rd	2162955	5471820	15/05/07		2.8					26	189		280
			23/10/08		3.6		0.013			17	212		83
			19/10/09	306	2.4	0.011	0.015	3.1	0.74	14	191	0.028	1010
Pahiwi-Balfour Rd	2164631	5469518	10/11/08		2.6								109
			19/10/09	375	2.7	0.013	0.013	3.3	0.52	15	190	0.022	228
Near Waimea Valley Rd (#1)	2166050	5468973	19/10/09		2.7	0.016							
Near Waimea Valley Rd (#2)	2163547	5470633	19/10/09		2.8	0.011							
u/s Longridge Stm Confluence	2166812	5468291	19/10/09	476	2.4	0.016	0.011	3	0.53	14	183	0.03	121
Longridge Stream													
Balfour-Riversdale Rd	2167940	5476364	19/10/09	63	0.17	0.012	0.028	1	0.83	11	190	0.056	231
Near Kruger St	2168019	5475594	19/10/09		0.21	0.014							
Near Pringles Rd	2168177	5474000	19/10/09		0.34	0.015							
Sandstone (near Orr Rd)	2168574	5471013	19/10/09	135	2.0	0.014	0.025	2.7	0.71	14	173	0.066	465
Near Blue Rd	2168042	5469670	19/10/09	146	2.2	0.018	0.02	3	0.76	14	178	0.062	428
u/s Waimea Stm confluence	2166983	5468305	19/10/09	198	2.9	0.022	0.015	3.5	0.68	15	182	0.056	183
Other Streams													
Tributary of the Longridge Stream	2168611	5471097	24/02/10		0.001		0.35	0.48	0.47	22			
Fox Ck 400m u/s Waimea confl	2161591	5475643	24/02/10	30	0.201								

Site	Easting	Northing	Date	Q (l/s)	NO_3-N (mg/l)	Nitrite (mg/l)	NH_4-N (mg/L)	Total N (mg/l)	TKN (mg/l)	Cl (mg/l)	EC (uS/cm)	Total P (mg/l)	E-coli (MPN)
Spring (E45/0524)	2166392	5468848	20/10/09		8.4						175		