Chapter 16: Wairau Plain Regional Groundwater Flow

Introduction

Marlborough's groundwater resources are associated with the coastal lowland floodplains formed by sedimentary material deposited by rivers. The largest groundwater reservoirs in terms of volume and productivity underlie the Wairau Plain surrounding Blenheim.

The Wairau River has over tens of thousands of years, had sufficient energy to create the permeable gravel deposits which form high yielding natural groundwater reservoirs. In a process which is still occurring, fluvial processes sort the gravels, rounding stones or boulders and flushing out the fine sediments which clog pore spaces and slow groundwater flow.

The most permeable and highest yielding aquifers are associated with the gravels underlying the northern Wairau Plain. These gravels belong to a geological group called the Rapaura Formation. The Wairau Aquifer is a reliable source of water due to perennial recharge from the nearby Wairau River. This groundwater system known as the Wairau Aquifer is the predominant source of water for the Blenheim hinterland.

By contrast the Southern Valleys Catchments located along the southern fringe of the Wairau Plain are home to the low yielding Southern Valleys Aquifers. The Southern Valleys Aquifers are formed of lower permeability sediments and recharged by less reliable ephemeral rivers.

Located between the high yielding Wairau Aquifer and the low yielding Southern Valley Aquifers, are intermediate yielding systems beneath Woodbourne and Fairhall. The low yielding Rarangi Shallow aquifer is a special case of a sandy aquifer perched above the main aquifer near the coast.

The extent of knowledge of groundwater systems in the past was very much focused on shallow groundwater in the top 40 metres or so. The lack of deeper exploration wells carried out prior to the 1980s reflected the fact that sufficient water existed close to the surface to meet demand at that time. Severe droughts in 1998 and 2001, coupled with increasing demand for irrigation water in marginal areas, provided the impetus for deeper exploration.

The MDC were the first to drill an exploratory bore (2917) to a depth of 400 metres below the Southern Valleys to determine the existence of deep groundwater. A series of wells were drilled varying in depth from 150 to 300 metres. These exploratory wells confirmed that deeper groundwater existed and the Deep Wairau Aquifer was discovered beneath the Fairhall area in 1998.

Deeper drilling confirmed previous experience across Marlborough that the permeability of alluvial formations decreases with depth below the surface, as does aquifer or well yield. This decrease in permeability is caused by compaction of the gravel and clays due to the weight of overlying rocks, along with chemical cementing of pore spaces.

Vertical stratification

The discovery of deeper water bearing layers led to a revised conceptual understanding of regional scale groundwater flow. It is now thought that the Wairau Plain sedimentary sequence consists of three broad layers (Fig. 16.1).

The shallowest layer extends to a depth of around 20 metres below the surface and transmits the majority of subsurface Wairau Plain flow of around 7 m^3/s that originates as seepage losses from the Wairau River. The permeable nature of the gravels enables rapid flow and short groundwater residence times of five years or less, before re-emerging as freshwater springs in the mid plains area. This shallow Wairau Aquifer groundwater is chemically indistinguishable from Wairau River channel flow, and any land-use effects are either minor or diluted by the large natural flows. Flow occurs as a discrete band across a reasonably predictable depth range, which has resulted in uniform well depths across the north-western Wairau Plain.

At medium depths of around 20 to 100 metres below the surface, an estimated groundwater flow of 0.5 - 1 m^3/s occurs through the medium depth gravels inland, and subsequently within the confined aquifer near the coast. This water originates predominantly as leakage from the Wairau River channel northwest of Renwick, and arrives at the coast anywhere between

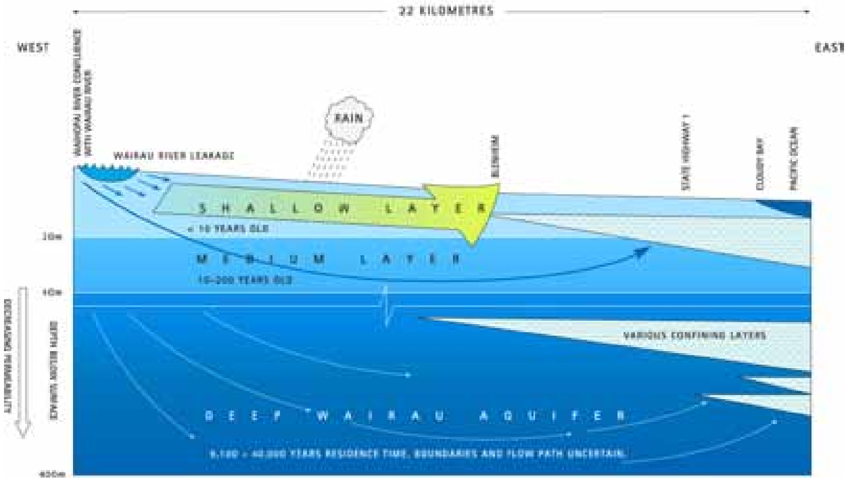


Figure 16.1: Wairau Plain stratified flow model

30 and 200 years later, depending on the route it takes (Stewart - 2008). As water leaves the river channel it flows relatively deep and as such is unaffected by rainfall recharge or landuses before it re-emerges at the surface in the Lower Wairau area as coastal springs or offshore flow. During this process it naturally evolves within the confined aquifer, and becomes chemically distinct from shallower groundwater.

The shallow and medium depth layers combine to loosely form what we currently know as the present day Wairau Aquifer. Their properties are reasonably well understood based on the information from thousands of wells drilled over the past century or more.

Underlying these layers are a series of deeper, undefined water bearing layers at depths of greater than about 150 metres that may be hydraulically linked to shallower layers. The nature of these deeper sediments or their aquifers has not yet been fully determined, as too few deep wells have been drilled into them. At a regional scale it is useful to join these sediments together into what is termed the Deep Wairau Aquifer (DWA).

There is likely to be fewer and lower yielding aquifers with increasing depth beneath the Wairau Plain. While flow rates are very low deeper in the sedimentary sequence, it is compensated for by their significant overall thickness and considerable volumes of groundwater may pass through them.

Horizontal boundaries

Groundwater flow is more rapid beneath the centre of the Wairau Plain coinciding with the greatest thickness of permeable gravels (Fig. 16.2). Conversely, groundwater velocities are lowest on the edges of the Wairau Plain at Rarangi and Riverlands, where the strata is less permeable because the gravels have experienced less reworking.

Land surface recharge derived from rainfall plays an increasingly important role with distance from the seepage zones of rivers (Stewart - 2006). This means that the proportion of Wairau River water in shallow groundwater decreases with distance from the recharge area north-west of Renwick.

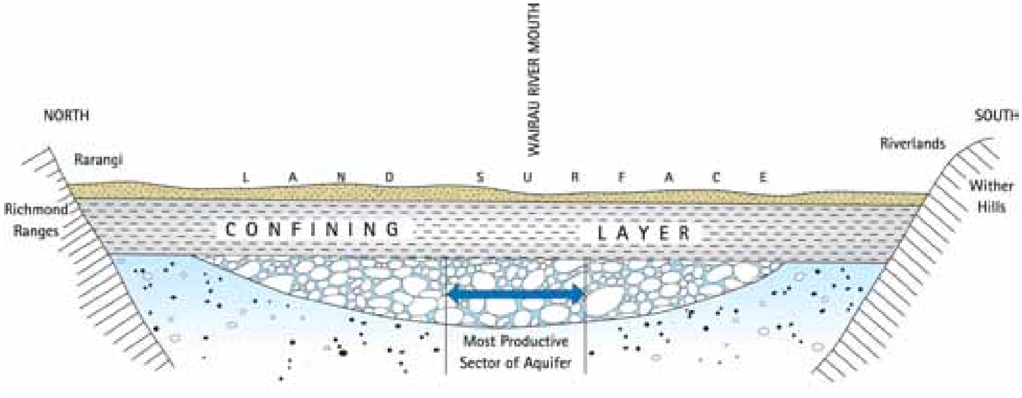


Figure 16.2: Wairau Plain sedimentary permeability

Chemical evolution cycle

Differentiating between Wairau Plain regional flow patterns or aquifers is not based on geology alone. Understanding is supported by trends in groundwater chemistry and differences in groundwater residence times.

Groundwater quality is not the same everywhere. The chemical attributes of a certain groundwater reflect the nature of the aquifer it has originated from. For example, older water has had the opportunity to interact chemically with the local rocks and acquire a signature reflecting that particular mineralogy.

Factors which affect groundwater chemistry include the nature of the recharge water, the residence time or degree of isolation from the atmosphere, the mineralogy of the rocks hosting the aquifer and the presence of organic matter or bacteria which drive some chemical reactions. The relative importance of each varies depending on local conditions.

The nature of shallow groundwater is virtually unchanged from its Wairau River source. Small amounts of nitrate and bacteria are added with recharge seeping down from the land surface to the water table. Medium depth groundwater has evolved chemically due to the isolating effect of the confined aquifer structure, while deep groundwater is highly mineralised as a result of advanced weathering of rocks and long residence times below ground.

Rapid changes in groundwater chemistry first occur in the soil zone. As groundwater moves deeper below the surface these processes continue, but at a far slower rate. The availability of oxygen plays a major part in driving the reactions, which determines the groundwater chemistry in the saturated zone beneath the water table.

Near the surface and in the soil zone oxygen and other gases are plentiful. Their concentrations decline with well depth and isolation from the atmosphere. Abrupt chemical changes accompany the transition of groundwater from unconfined to confined aquifer conditions near SH1 at Blenheim.

Wairau Plain groundwater begins life either as Wairau River leakage or rainfall, and drains through the soil where the first major changes in its chemical composition occur. Decaying organic matter in the soil is oxidised and releases carbon dioxide which in turn combines with groundwater to form carbonic acid (H_2CO_3). This weak acid is leached downwards to the water table where it contributes to a lowering of the pH of groundwater in the unconfined area of the Wairau Aquifer.

Soil biochemical processes are the dominant influence on the chemistry of shallow groundwaters. Groundwater underlying the north and central Wairau Plain is chemically dilute with low concentrations of dissolved minerals. This is because the groundwater is virtually unchanged from Wairau River water which provides the bulk of aquifer recharge, and has not had the opportunity to become mineralised.

As groundwater flows eastward through the Wairau Aquifer towards the coast, it's chemistry doesn't change significantly in relation to land uses because of the diluting effect of Wairau River recharge water. At this stage groundwater is also moving so quickly it has limited time to interact with any minerals in the aquifer formations. The rock types present are also composed of fairly inert silicate minerals such as quartz and feldspar.

This immature groundwater contains low levels of dissolved minerals. The major ones present are calcium, sodium, magnesium and bicarbonate. Groundwater is commonly categorised as a particular type depending on the relative mix of ions and this juvenile groundwater belongs to the Calcium-Sodium-Magnesium-Bicarbonate type.

The most plentiful aquifer forming local rock types are greywacke or argillite, which are commonly known as sandstone and mudstone. Other basement and intrusive, igneous rock types do exist, and minerals from these sources are higher in metals such as iron and magnesium. Faults are another likely source of groundwater chemistry anomalies.

Because of its unconfined structure around Renwick, the Wairau Aquifer is open to the atmosphere with abundant oxygen. When exposed to high levels of oxygen the aquifer is said to be aerobic. This means all of the reactions involving groundwater will be oxidising in nature.

Under these conditions potential problem minerals such as manganese, iron and arsenic are in their insoluble form rather than being dissolved in groundwater, which is good news for well owners. Exceptions have been reported in places like Old Renwick Road opposite Woodbourne. At its eastern boundary the aquifer structure changes to become confined, which radically affects aquifer flow dynamics, the diffusion of atmospheric gases and as a consequence, groundwater chemistry.

The confining layer induces groundwater to the surface in low lying areas to form springs. The majority of groundwater exits the Wairau Aquifer permanently in this way with only a minor proportion entering the confined sector.

On average it takes less than five years for groundwater to leave the Wairau River, traverse the unconfined Wairau Aquifer and arrive at the springs. Dr Claude Taylor the physicist who first quantified the process in the late 1980s using environmental isotopes, described it as a shallow circulation system, with water leaving the Wairau River and returning within a short period (Taylor et al - 1992). Conversely, water entering the confined Wairau Aquifer is unlikely to rejoin the active hydrological cycle. Once within the confined Wairau Aquifer, groundwater chemistry changes markedly due to a slowing of groundwater flow rates, and a decline in dissolved oxygen levels in groundwater.

This is because isolation from the atmosphere causes a switch from oxidising to mildly reducing chemical conditions. As oxygen becomes scarcer further within the confined aquifer, reducing conditions dominate and the oxygen needed to metabolise the decay of organic matter by bacteria is scavenged from other compounds such as: nitrate, sulphate and manganese or iron/arsenic complexes.

Symptomatic of moderate reducing conditions is the presence of hydrogen sulphide gas (H_2S) in some groundwaters. More advanced reducing conditions in places like the Benmorven Aquifer are indicated by the presence of methane gas (CH_4).

Because a comparatively small volume of groundwater exists within the confined Wairau Aquifer and is moving very slowly, there is also less dilution. This means there is more opportunity for water-rock interaction, especially with the marine sediments which contain more soluble minerals. These processes lead to more mineralised groundwater, a characteristic of confined aquifer water. This is noticeable by the staining effects of well water in the lower Wairau area.

The chemistry of Deep Wairau Aquifer groundwater isn't as evolved as its long residence time and isolation from surface processes would imply. Groundwater chemistry is more variable, suggesting a series of semi-independent aquifer pockets with differing chemical conditions or inputs. The unavailability of certain minerals, or solubility constraints may be limiting the degree to which groundwater has evolved, due to the relatively inert nature of the strata within which this deep aquifer system is found.

Chemical evolution trends

The natural processes of mineralisation and oxidation have led to three distinct chemical signatures, associated with the three broad aquifer layers underlying the Wairau Plain. These processes can be analysed by plotting trends in individual dissolved minerals or chemical indices of groundwater as it travels along the flow-path.

These patterns help explain the nature of aquifer dynamics (Figures 16.3 to 16.16). The vertical lines mark the structural boundaries between unconfined and confined aquifers and the underlying Deep Wairau Aquifer.

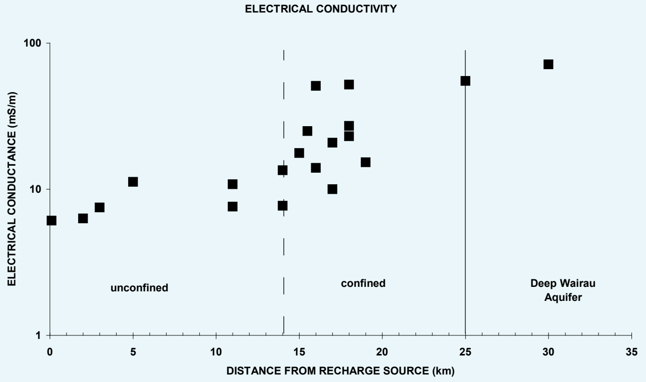


Figure 16.3: Electrical conductivity increases as groundwater becomes more mineralised. This is a function of older groundwater naturally dissolving more of the minerals in the rocks it comes into contact with. Younger groundwater starts off life as dilute rain or river water.

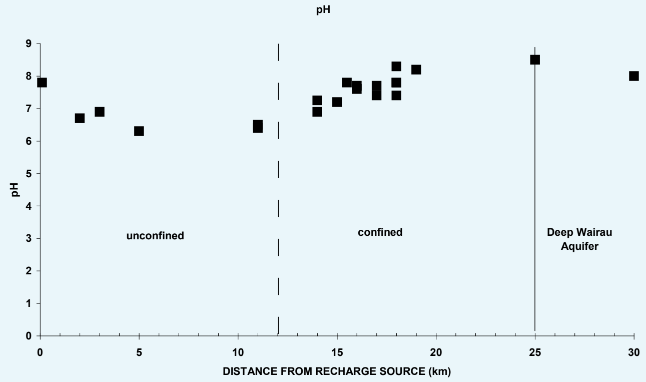


Figure 16.4: pH increases as groundwater becomes more confined. This reflects the corresponding increase in the concentration of bicarbonate in groundwater, a by-product of the reducing reactions which dominate the Wairau Plain confined aquifers. pH neutral groundwater, which constitutes the optimum type of water for public water supply, occurs naturally just inside the confined aquifer.

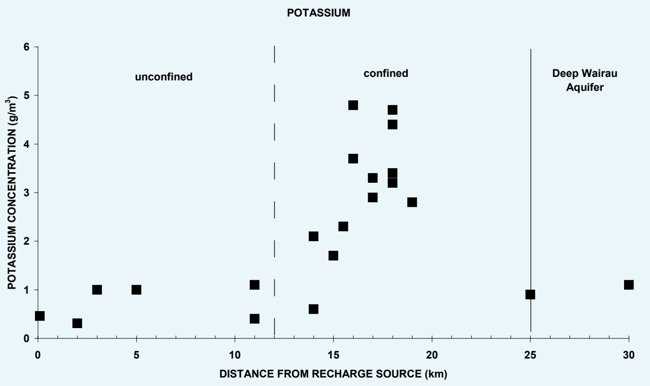


Figure 16.5: Potassium concentrations increase within the confining layer, but levels are variable in Deep Wairau Aquifer groundwaters. Increases within the confining layer, point to natural groundwater evolution, rather than land-uses or fertilisers as the likely source.

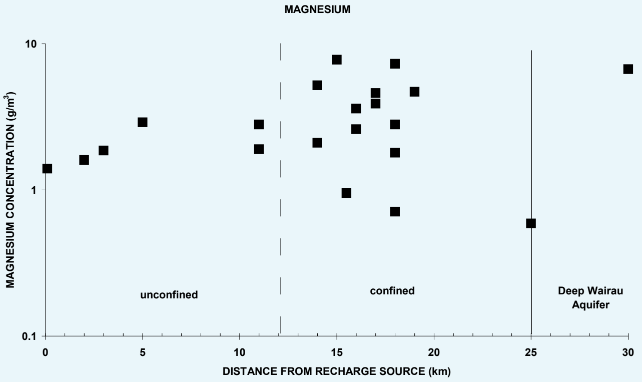


Figure 16.6: Magnesium concentrations increase within the confining layer, but levels are variable in Deep Wairau Aquifer groundwaters. Increases within the confining layer, point to natural groundwater evolution, rather than land-uses or fertilisers as the likely source.

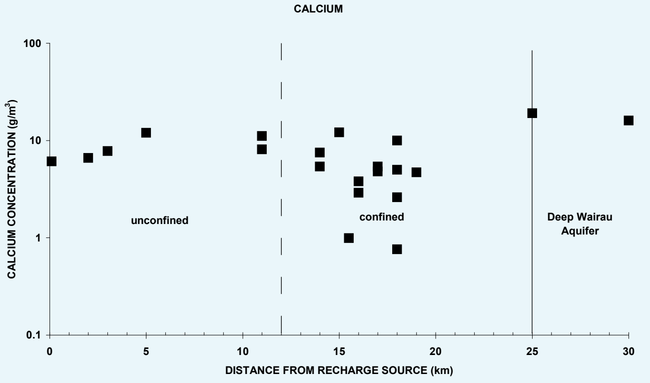


Figure 16.7: Calcium concentrations fall within the confined aquifer as expected due to cation exchange, but then increase again within the deepest aquifer layer. The increase may reflect a reversal of this process at the expense of sodium.

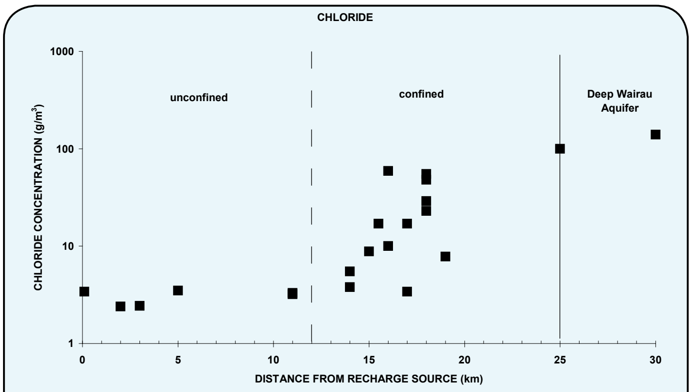
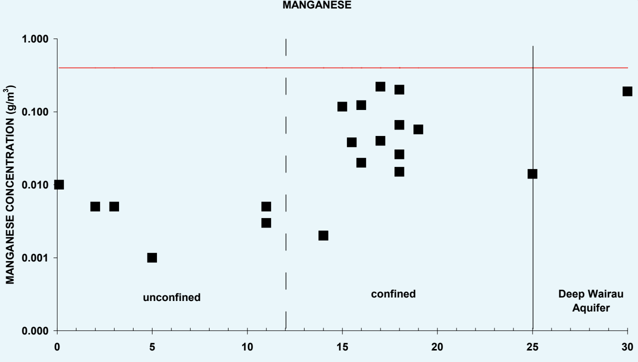
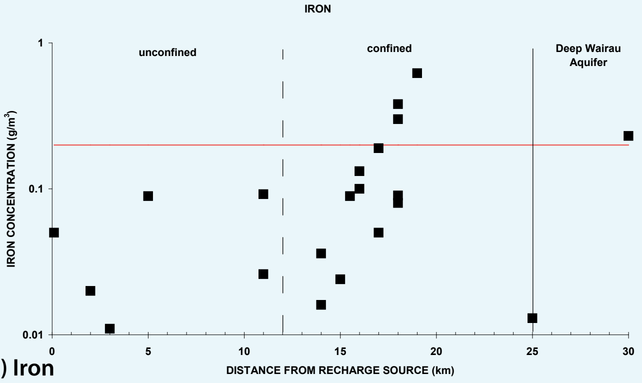


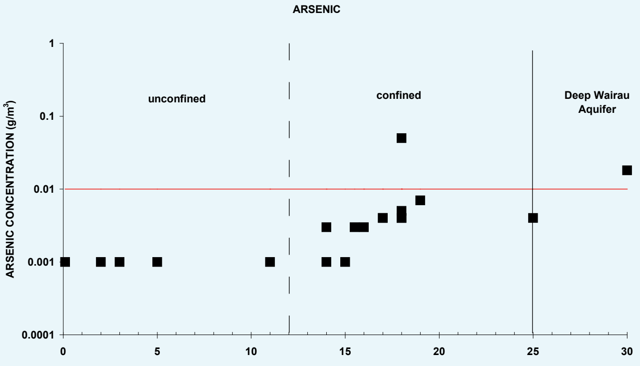
Figure 16.8: Chloride concentrations rise consistently with the degree of confinement. The steep rise in concentration as groundwater enters the confined aquifer reflects the appearance of chloride rich marine deposits in the eastern areas of the Wairau Plain, closer to the coast.



a) Manganese



b) Iron



C) Arsenic

Figure 16.9: Manganese, iron and arsenic are all insoluble in oxidised groundwaters. As a result they occur in small concentrations in unconfined Wairau Aquifer groundwaters. However concentrations rise quickly once groundwater enters the confined aquifer where reducing chemical conditions dominate. Iron levels rise steeply in the confined aquifer, but are variable within the Deep Wairau Aquifer. Arsenic concentrations consistently increase through the stages of aquifer confinement.

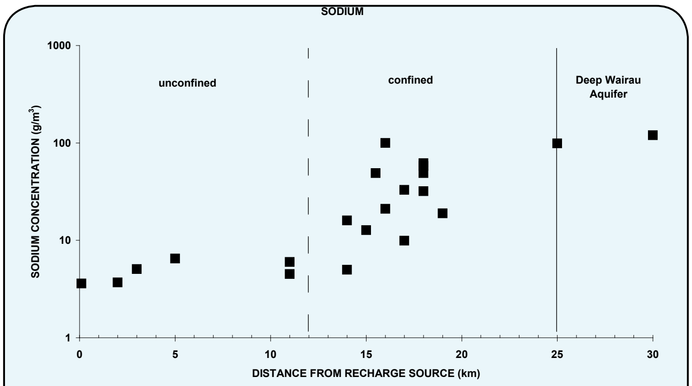


Figure 16.10: Sodium follows a similar pattern to chloride, increasing in concentration as groundwater becomes older due to the natural process of water-rock interaction. A major source of sodium is likely to be the sodium rich marine clays of the confining layer.

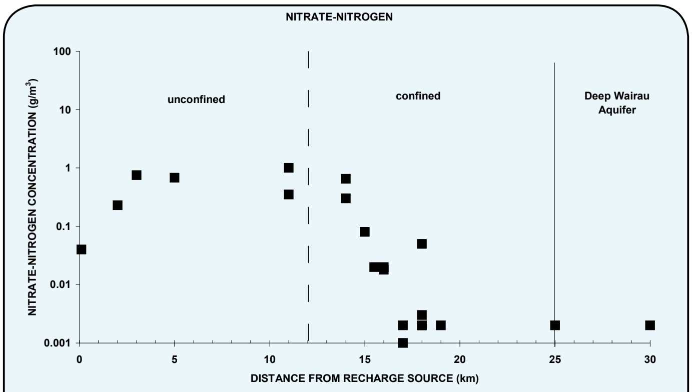


Figure 16.11: Nitrate-nitrogen levels fall dramatically once within the confined aquifer. As oxygen levels decline in the confined aquifer the nitrate-nitrogen is transformed to ammoniacal nitrogen.

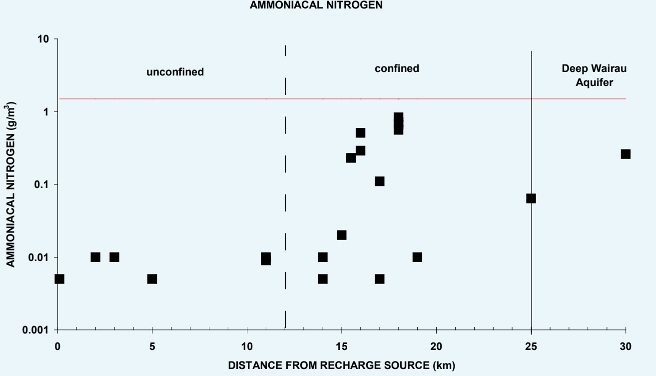


Figure 16.12: Ammoniacal nitrogen levels rise quickly in the confined aquifer. As the oxygen levels decline in the confined aquifer nitrate-nitrogen is transformed to ammoniacal nitrogen.

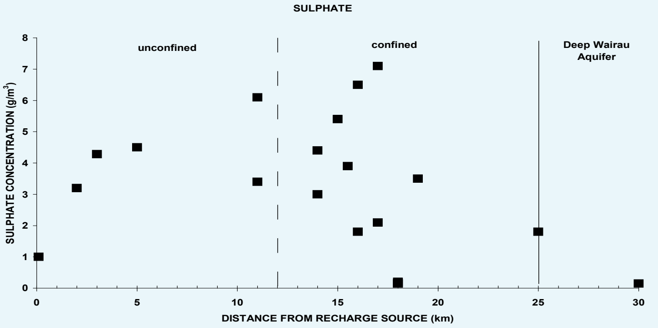


Figure 16.13: Sulphate levels decline in the low oxygen reducing conditions of the confined aquifers where it is transformed into hydrogen sulphide gas.

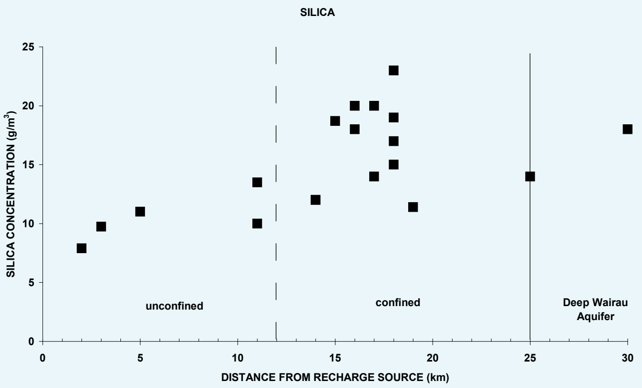


Figure 16.14: Silica levels increase under confined conditions and correlate well with groundwater residence time. Concentrations appear to reach saturation in Deep Wairau Aquifer groundwater.

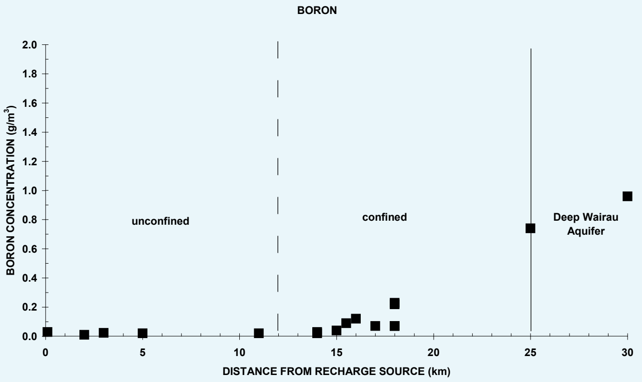


Figure 16.15: Boron levels rise soon after groundwater enters the confined aquifer, and consistently increase in concentration in the isolated conditions of the Deep Wairau Aquifer.

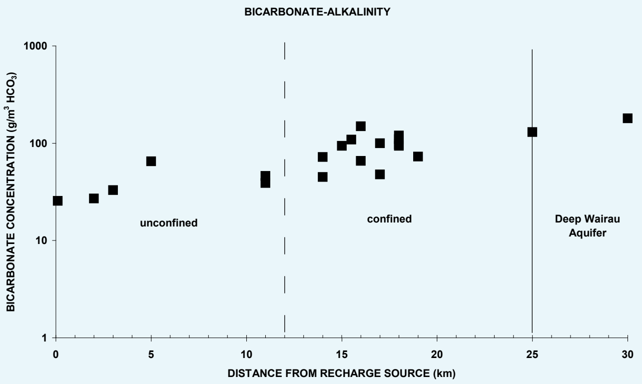


Figure 16.16: Alkalinity is dominated by bicarbonate (HCO_3) in Marlborough groundwaters due to the local pH range. Bicarbonate increases with the degree of aquifer confinement. The major sources of bicarbonate in confined aquifers are generally the by-products of reduction reactions.

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