An assessment of nitrate trends in groundwater across Canterbury: results from a Science Fair project

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Abstract
Nitrate-nitrogen concentration data were obtained from Canterbury Regional Council and summarised for the purpose of a Science Fair project. Nitrate-nitrogen concentrations are presented, summarised by decade, depth, and water management zone. Some of the patterns and anomalies are described, including potential sources of contamination, and the differences between zones are briefly examined.

The results confirm that, as would be expected, nitrate-nitrogen concentrations increase at shallow depth before migrating deeper into the aquifer. However, increases at depth are seen in all of the water management zones with time. The differences between the zones are marked. The influence of the Waimakariri recharge and the limitation of land use intensification within the Christchurch-West Melton zone have been successful in keeping nitrate-nitrogen concentrations low across much of the zone, though localised hotspots do occur in the south of the zone.

Within the Selwyn-Waimakariri zone concentrations are higher, with local hotspots that can be related, in some cases, to particular land use activities and/or local soil/hydrogeological conditions. Within the Ashburton zone, there have been very marked increases in nitrate-nitrogen concentrations since the 1980s. Again, in some cases, hotspots can be hypothesised to be related to particular land use activities. Overall this zone appears to have been particularly affected in terms of increased nitrate-nitrogen concentrations in groundwater.

Keywords
groundwater; nitrate; Canterbury

Introduction
Nitrogen, in the form of nitrate, nitrite, or ammonium, is a nutrient needed for plant growth. With increasing intensification of farming across Canterbury, New Zealand, there has been a consequent increase in nitrate-nitrogen concentrations in groundwater. Although nitrogen exists in the natural environment, it is also added through various forms, including manure, urea, sewage, and fertilisers. Chemical fertilisers and animal manure are commonly applied to crops to add nutrients (commonly nitrogen and phosphorus) to increase the crop output and longevity of a farming area. Grazing of livestock also contributes nitrogen through urea and manure. Any agricultural intensification, therefore, has the unwanted side-effect of nutrient leaching from the land surface. Whilst good irrigation practices can minimise nitrate leaching, it is not possible to eliminate it. For example, heavy
rain, especially when soils are close to field capacity, will generate recharge and result in nitrates leaching into groundwater.

In parts of Canterbury, nitrate-nitrogen concentrations in groundwater have shown an upward trend through recent decades, and in places have exceeded New Zealand's drinking water standard's maximum acceptable value (MAV) of 11.3 mg/L of nitrate as nitrogen equivalent (nitrate-nitrogen) (Ministry of Health, 2018). The MAV is the maximum concentration of a contaminant in drinking water that will not make consumers ill even if they drink the water all their lives (Nokes, 2008).

Dairying has been held responsible for the increase in nitrate-nitrogen concentrations that we are now seeing in groundwater and groundwater-dependent surface waters (The Economist, 2017; Hutching, 2018). Dairy intensification occurred post-1980s in Canterbury, with the ‘take off’, in terms of substantial land use change, beginning in the early 1990s (Pangborn and Woodford, 2011). However, measured nitrate-nitrogen concentrations do not necessarily fit well with these observations, and earlier land management (cropping, point source discharges from meat works, or other sources) must also have played a role in the increase observed in nitrate-nitrogen concentrations.

There are two reasons for concern about increasing nitrate-nitrogen levels in groundwater: firstly, where groundwater enters surface waters, the nitrates can contribute to eutrophication. The second reason is human health. In rural areas of Canterbury, and within Christchurch itself, groundwater is used for drinking water. High nitrate-nitrogen concentrations can lead to methemoglobinemia, where there is an excess of methemoglobin in the blood. Methenoglobin is a form of haemoglobin that is not efficient at delivering oxygen within the body; infants less than 6 months old are particularly sensitive to methemoglobinemia, resulting in ‘blue baby syndrome’. Recent work (Schullehner et al., 2018) has also suggested that even relatively low nitrate-nitrogen concentrations, of around 4 mg/L, increase the risk of colorectal cancer in humans.

A 2018 survey of 306 wells across Canterbury showed that around 28% of all samples had nitrate-nitrogen concentrations at or above half the MAV (that is, above 5.6 mg/L), whilst 48% had concentrations less than 3 mg/L (Environment Canterbury, 2019). However, the poorer quality groundwater was not evenly distributed with either location or depth. In terms of the zones, the number of wells with average nitrate-nitrogen concentrations exceeding half MAV in the Ashburton and Selwyn-Waihora zones were 77% and 44%, respectively. As expected, the higher nitrate-nitrogen concentrations were predominantly at shallower depths, though concentrations above the suggested ‘background’ value of 3 mg/L occurred at all depths.

A general increase in nitrate-nitrogen concentrations is expected with agricultural growth. Sampling also tends to increase with agricultural growth, as concern increases about groundwater quality and because more wells are drilled and able to be sampled. Within this study, as expected, there were more samples at a shallower depth, as abstraction is usually from the shallowest aquifers first. With time, as deeper wells were drilled to access more reliable supplies and as concerns about water quality have increased, there has been an increase in sampling (both in terms of the number of sites and frequency of sampling), and also in sampling from greater depths. It can therefore be difficult to determine when upwards trends in nitrate-nitrogen concentrations at depth started to occur.

Generally, the highest nitrate-nitrogen concentrations are expected in shallower wells, and reduce with depth (Environment
Canterbury, 2019). However, sampling has shown that this is not always the case: for example, very high nitrate-nitrogen concentrations (half MAV and above) have been observed from wells screened at depths ranging between 117 and 244 metres in the Darfield area. As a science fair project, we investigated how nitrate-nitrogen concentrations varied with depth, and with time (over several decades), in different water management zones of Canterbury.

The aim of this paper is to highlight some of the observations we made when analysing the data for the science fair project. In some cases it is possible to draw some conclusions about sources and pathways, and some of the observations we found fit with previous work. This approach to investigating the data, using all available data and summarising it, rather than relying on relatively few wells with a long time series of data, enables a different view on existing data.

Method

Nitrate-nitrogen concentration data were obtained from Environment Canterbury in 2012 and updated in 2018. Some wells had numerous measurements, spanning long periods of time, whereas some wells only had one sample. By grouping the data together and assessing it spatially and temporally, we could assess whether there were any trends or patterns using all the available data, which would not be possible using fewer wells with long time series. However, this approach has the disadvantage that the results may be biased or skewed. For example, wells with single or few observations might not be representative. Also, some of the sampling might have been targeted, for example for compliance monitoring for effluent discharge, which would again skew the results.

The nitrate-nitrogen concentration data for each well was summarised (if there was more than one reading) into average nitrate-nitrogen values for each decade. Non-detects were not included in the analysis, and the data were used without any further quality checks, other than those carried out by Environment Canterbury.

We did not include any data that were available outside of the Environment Canterbury database: this was a science fair project, and the time and effort required to obtain such data was outside of the scope of the project. The fact that other data are available, for example, through research projects, reinforces the need to ensure all available data are collected and collated in one place.

Dommisse (2006) defined three separate aquifers for the Hinds area, the depths of which we used (very approximately) for this study: less than 40 m, 40–80 m, and greater than 80 m. The average nitrate-nitrogen concentration for each decade was calculated. The data were also summarised by water management zones (following those used by Environment Canterbury) with three zones being examined in detail: Christchurch-West Melton, Selwyn-Waihora, and Ashburton.

It is important to note that the depth to the water table varies across the region. Groundwater can be over 150 m deep at the top of the plains, and close to surface near the coast. Results are also complicated due to the transport pathways that occur, with groundwater upwelling, and re-emerging in lowland areas after travelling a deeper flow path. Well screen and water level depth information is not always readily available; hence, well depth was used as a proxy for sample depth. Taking all of this into account, the approach that we took is most valid when looking at relative depths of groundwater from relatively localised areas but will not be as reliable for comparison across a whole zone, from the top to bottom of the plains.

It is also important to note that the analytical techniques prior to the 1980s were less precise, especially for low concentrations
of nitrate-nitrogen, and there was less rigorous quality control in the data capture. Also, the small number of samples in the early decades means that it is possible to bias the results; for example, if a lot of the samples were from discharge monitoring, there would be a bias towards higher concentrations.

Patterns that were observed in the summarised data were explored in more detail, and this exploration forms a large part of this paper. We could not describe or investigate every pattern or anomaly but use some examples to illustrate different aspects of the data.

**Results and discussion**

**Christchurch-West Melton zone**

This zone comprises the recharge area for the confined aquifer system that supplies Christchurch with drinking water, with recharge occurring from both land surface recharge and the Waimakariri River. Recent modelling has also suggested that the Waimakariri zone to the north of the river may contribute to the aquifers under Christchurch (Etheridge and Hansen, 2019; Kreleger and Etheridge, 2019). As a result of the focus on maintaining high groundwater quality for Christchurch, intensification of farming has been limited within the zone.

Assessing the summarised data by decade, the zone can be seen to have relatively low nitrate-nitrogen concentrations (Fig. 1).

There is a very clear depth limit within which higher nitrate-nitrogen concentrations are observed (Fig. 2), with bores deeper than 80 m showing concentrations predominantly below 0.5 mg/L. Over the whole zone, shallow and intermediate wells showed higher concentrations in the 1970s, with average concentrations in the shallow wells of around 3.5 mg/L which have since decreased. Nitrate-nitrogen concentrations in deeper wells have only increased recently, and remain less than 1 mg/L. The apparent increase in concentrations in the 1970s and 1980s may be a reflection of sampling bias. As discussed later, the increase in the 1970s may also be a consequence of high recharge in the late 1970s causing higher leaching than usual. The decline in concentrations

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**Figure 1** – Average nitrate-nitrogen concentrations per decade in the Christchurch-West Melton zone divided into well depth categories

**Figure 2** – Distribution of nitrate-nitrogen concentrations vs depth by decade in the Christchurch/West Melton zone
since the 1970s and 1980s, and the very high concentrations in some parts of the area, may also reflect specific discharges to land, for example from Islington Meat Works.

Daughney and Reeves (2005) and Morgenstern and Daughney (2012) suggested that groundwater with median nitrate-nitrogen concentrations between around 2.5 and 3.5 mg/L are indicative of human impact. A guideline value of 3 mg/L was therefore adopted by Environment Canterbury to identify median nitrate-nitrogen concentrations above what would be expected in natural conditions. This does not actually represent the 'natural' background, which, based on the observations from this zone, may be closer to 0.5 mg/L nitrate-nitrogen.

Spatially, there is a distinct pattern, and the zone can effectively be divided into two areas. The northern and eastern part of the city is dominated by groundwater with nitrate-nitrogen concentrations of less than 2 mg/L, concentrations which have not changed across the six decades assessed (Figs. 3 and 4). South of approximately the Hagley Park area and west of the Yaldhurst Road, nitrate-nitrogen concentrations in

**Figure 3** – Spatial distribution of nitrate-nitrogen concentrations in the Christchurch-West Melton zone (1960s)

**Figure 4** – Spatial distribution of nitrate-nitrogen concentrations in the Christchurch-West Melton zone (1990s–2010s)
groundwater can be much higher, some exceeding the MAV of 11.3 mg/L nitrate-nitrogen.

As is typical with analysis of data over a long time period, there are very few wells that have sufficient data to draw conclusions to support this apparent rise in nitrate-nitrogen concentrations in groundwater in the 1970s. Four wells in the area (M36/1225, M36/1057, M36/0974 and M36/1059), have data spanning the seven decades (1950s to 2010s), and have relatively high nitrate-nitrogen concentrations (Fig. 5); these are all between 32 and 41 m deep, and all located in the south side of Christchurch. Both M36/1225 and M36/1059 show a peak around 1982; the other two show maximum values around 1990/91. M36/1059 shows a gradual decline in the following decades. The only deeper well with sufficient data (M35/1864, 73 m deep) peaked at 1 mg/L in 1975 then decreased, and only in 2012 exceeded 1 mg/L again. Based on the available information, it is therefore difficult to determine whether there was a real peak in the 1970s or if the apparent peak was due to sampling focus. However, work by Close et al. (1995) showed that nitrate-nitrogen concentrations were elevated in the late 1970s in mid-Canterbury, due to a sequence of wetter, higher recharge years, and it is possible that the elevated concentrations observed here reflect this.

The low nitrate-nitrogen concentrations may be due to several reasons:
• land use controls enforced to protect groundwater supply;
• recharge from Waimakariri River, particularly in the northern and eastern area;
• the effects of land use intensification have not yet become apparent due to long travel times;
• some denitrification may have occurred, particularly in the deeper, confined aquifers.

Selwyn-Waihora zone
The Selwyn-Waihora zone extends from the foothills in the west through to Lake Ellesmere/Te Waihora in the east. Nitrate-nitrogen concentrations at all sampling locations had decadal averages of less than 2 mg/L in the 1950s–1960s (Fig. 6). In the shallow wells, average nitrate-nitrogen concentrations were high, at around 5 mg/L, in the 1970s and are only slightly below that now. Those at 40–80 m depth declined in the 1990s from a high in the 1980s, but have increased again in the decades since. Concentrations in the deeper wells have generally shown a steady increase since the 1960s.

The summarised data in Figure 6 suggest nitrate-nitrogen concentrations were again relatively high in the 1970s followed by
somewhat lower concentrations through the following decades, though with a gradual increasing trend since the 1990s. When assessing the data in more detail, it is difficult to be clear about the trend in nitrate-nitrogen concentrations, as few bores have sampling records spanning the entire period analysed, and many bores were only sampled once in the late 1970s. As discussed earlier, work by Close et al. (1995) indicated that variable recharge was more significant than increasing levels of land use intensification when comparing two particular time periods. Groundwater levels were observed to be high in the late 1970s due to a sequence of wetter, higher recharge years (Burden, 1982; Close et al., 1995), and this is likely to have had an impact on the results shown here. Sampling in this period – from about 1977 onwards – may also have been biased by an increase in site-specific investigations by the North Canterbury Catchment Board into a number of point sources of contamination.

When the 1970s and 1980s are examined in further detail, there are records that show a significant drop in nitrate-nitrogen concentrations between the 1970s and 1980s, most being in the lower/mid Plains (Fig. 7). For example, an area to the south east of Prebbleton was investigated further (Fig. 8). Although this is only a period of a few years, there does appear to be a consistent decline over this period suggesting that, rather than a localised contamination issue, this might reflect the higher recharge in the late 1970s causing elevated nitrate-nitrogen concentrations.

In the early three decades, elevated nitrate-nitrogen concentrations (up to 10 mg/L) are predominantly limited to less than 50 m depth (Fig. 9). In the latter three decades, there is a clear increase in concentrations at depths up to 100 m and greater. This increase at depth is important to note: high nitrate-nitrogen concentrations are not limited to the water table aquifer, but increase at all depths with time.

Figure 6 – Average nitrate-nitrogen concentrations in the Selwyn/Te Waihora Zone by decade, divided into well depth categories

Figure 7 – Comparison of average nitrate-nitrogen concentrations between the 1970s and 1980s in the Selwyn-Waihora zone
Groundwater from the zone drains into Te Waihora, one of the most polluted lakes in New Zealand (Mitchell, 2016); investigations into its water quality and mitigation approaches have been ongoing for many years. Nitrate-nitrogen inputs into the lake are 98% from surface water tributaries (Hayward, 2010) with estimated groundwater inputs into the lake being around 0.44 m$^3$/s (Ettema and Moore, 1995). From the data for this project, the higher nitrate-nitrogen concentrations, in general, occur in groundwater further up the plains. It is possible that these then affect nitrate-nitrogen concentrations in the spring-fed streams, which then feed into Te Waihora.

There appears to be an area around the margins of the lake, represented by a number of wells (predominantly shallow, but with depths up to 120 m), which has had average nitrate-nitrogen concentrations below 2 mg/L throughout the period investigated (Fig. 10). Based on the 1990s data, the highest average nitrate-nitrogen concentration recorded within 10 km of Te Waihora was 8.9 mg/L, but the overall average from bores within 10 km of the lake was 1.9 mg/L. This suggests that, while there are some ‘hotspots’, the overall groundwater quality (in terms of nitrate-nitrogen concentrations) within this area is good. In contrast, for the remainder of the zone (excluding this buffer), the maximum is 15 mg/L and the average is 4.1 mg/L.

What is quite marked is a region with higher nitrate-nitrogen concentrations to the west of this low nitrate zone, extending through the Southbridge area (see Fig. 13),
and bounded on both sides by lower nitrate-nitrogen concentrations. This spatial pattern is maintained throughout the period of study. Ford et al. (2017) suggested that the upwelling of deep groundwater, plus denitrification in the sediments around the lake, help to maintain the low concentrations close to the lake, but they do not mention the anomalously high nitrate-nitrogen concentrations through the Southbridge area. There is a meat processing factory up-hydraulic gradient from this region (see Fig.11), and it is possible that discharge of effluent from this caused elevated nitrate-nitrogen concentrations through the Southbridge area. However, the elevated nitrate-nitrogen concentrations may also be a reflection of soils in the area. The area with the higher nitrate-nitrogen concentrations is on more freely draining soils. More freely draining soils provide more opportunity for nitrate leaching and might result in higher concentrations in groundwater. The influence of the Rakaia River to the south might also be to dilute nitrate-nitrogen concentrations in groundwater with low-concentration alpine river water.

**Figure 11** – Spatial distribution of nitrate-nitrogen concentrations in the Southbridge area (1990s–2010s), focussing on the south western area, and highlighting the area with elevated nitrate-nitrogen concentration. The blue star represents the location of a meat processing factory, and the arrow illustrates the general hydraulic gradient.
Nitrate-nitrogen concentrations for several wells in the Te Waihora area are plotted in Figure 12, with locations shown in Figure 13. M36/5128 and M36/0712 show the very low nitrate-nitrogen concentrations that are ‘typical’ within the area bounding the lake. L36/0200 and L36/0682 have shown elevated nitrate-nitrogen concentrations since sampling began in the 1980s and a clear upward trend since. These are higher in the catchment than the other wells. M36/0698 and L36/0871 are both in the Southbridge area, and show concentrations that were slightly elevated up to around 2000 and have increased since, with L36/0871 peaking at over 10 mg/L in recent years. M36/3683 is slightly anomalous; it is within the 10 km buffer of the lake, where groundwater nitrate-nitrogen concentrations are generally very low, but has shown an increasing trend since the late 1990s.

The Darfield area, the original focus of this project, also shows rather mixed results. Figure 14 shows average nitrate-nitrogen concentrations for 2000–2009 as an example. All bores are between 100 m and 250 m depth, and there is no shallow water table in the area. There is an area to the east of Darfield with nitrate-nitrogen concentrations that have exceeded the 11.3 mg/L MAV. Even

Figure 12 – Nitrate-nitrogen concentrations in Selwyn-Waihora bores

Figure 13 – Location of selected Selwyn-Te Waihora bores
at 223 m depth, an elevated nitrate-nitrogen concentration of 7.9 mg/L has been recorded, though there appears to be no evidence of an increasing trend at this depth. At depths closer to 100 m, there is some evidence that nitrate-nitrogen concentrations have increased, as shown in L35/0190 (120 m deep) (Fig. 15). It is not possible to trace when or how the upward trend in nitrate-nitrogen concentrations started due to lack of data, although the cause has previously been attributed to a history of cropping in the upper plains (M. Hanson, pers. comm.). The fact that nitrates can be transported through the vadose zone to significant depth is important to note.

**Ashburton zone**

There are very few samples in the Ashburton zone before the 1980s, other than a few samples taken from bores less than 40 m deep in the 1970s. There were no samples from deep wells until the 1990s. The lack of samples suggests that groundwater abstraction was predominantly from the shallower aquifers. When looking at the summarised data, there was a significant increase in nitrate-nitrogen concentrations between the 1980s and 1990s which has continued to present day (Fig. 16). However, there were only nine sampled bores for the 1980s, 103 for the 1990s, and 517 for the 2000s, so the apparent increase could be partly attributed to this increase in samples.

**Figure 14** – Average nitrate-nitrogen concentrations for the Darfield area for the 2000–2010 decade.

**Figure 15** – Nitrate-nitrogen concentrations in L35/0190 from 1980 to 2015

**Figure 16** – Average nitrate-nitrogen concentrations in the Ashburton zone by decade
The distribution of nitrate-nitrogen concentrations with depth (Fig. 17) shows much higher concentrations at all depths relative to the other zones. The nitrate-nitrogen concentrations at depths to 50 m have been up to 25 mg/L, and are, occasionally, much higher than this. There are a very large numbers of bores with concentrations that exceed the 11.3 mg/L MAV throughout the decades, and there are also substantially deeper bores with elevated concentrations. One of the marked differences between Ashburton and the other zones is that in groundwater deeper than 50 m the nitrate-nitrogen concentrations are predominantly elevated.

Some areas in the Ashburton zone have exceptionally high nitrate-nitrogen concentrations in groundwater. We carried out further assessment of one of these areas. In the Netherby area, on the eastern side of the Ashburton township, there is an area with nitrate-nitrogen concentrations that have exceeded 30 mg/L in the past. These are likely to be associated with Ashburton Meat Works (Hayward & Hanson, 2004). It is notable that L37/0915 (9.3 m deep) and L37/0918 (14.2 m deep) have similarly high nitrate-nitrogen concentrations: they were highest in 1990s and have been reducing since though are predominantly still above the MAV of 11.3 mg/L. L37/0915 is located at the site where the meat works dispose of their waste to land and L37/0918 is less than 500 m down-hydraulic gradient from the meat works (see Fig. 18). In contrast, L37/0914 (20 m deep and up-gradient) and L37/0439 (9.1 m deep and cross-gradient) generally had much lower in concentrations in the 1990s, but appear to have a slight rising trend since.

It is interesting to observe the changing nitrate-nitrogen concentrations with depth. Two deeper bores (L37/1438, 30 m deep and L37/1453, 36 m deep) are located at the same position as two of the above bores (L37/0914 and L37/0439). The deeper bores, overall, show very similar nitrate-nitrogen concentrations to the shallower ones (Fig. 19), suggesting again that nitrate-nitrogen is able to leach to depth relatively rapidly. The deeper data appear smoother, without the variability shown by the shallower data, which may reflect dispersion and mixing as the nitrate-nitrogen moves down through the aquifer system. The deeper wells also do not show the decline in nitrate-nitrogen concentrations in 2015/16 that can be seen in the shallower wells. This decline is hypothesised to be a result of the low winter recharge, with L37/0439 (9.1 m deep)
showing a marked rise towards the end of the record, in response to recharge.

The rapidity with which nitrate-nitrogen concentrations increased in response to recharge, particularly at depth, could suggest that transport through the upper layers is very rapid.

**Differences between zones**

The marked differences between nitrate-nitrogen concentrations in the zones are illustrated in Figure 20 showing nitrate-nitrogen concentrations for the 2000s. As previously discussed, the low nitrate-nitrogen concentrations in the Christchurch-West Melton zone, particularly at greater depths, are likely to be a consequence of limiting agricultural intensification within the zone, and the contribution of the Waimakariri River to recharge. The considerably higher concentrations at all depths in the Ashburton zone may be a reflection of greater nutrient losses from land use practices, as well as higher leakage between layers, relative to the other zones. There is also not likely to be the same upward hydraulic gradient and upwelling of deep groundwater in the lower Ashburton plains, as there is in the Christchurch coastal area, due to the lack of confining layers. The reasons for the differences between the Ashburton Zone and other zones are worth further investigation, as they may help to inform our understanding of land use impacts and nutrient transport processes, and how these impact on nitrate-nitrogen in groundwater.

**Summary**

This study identified various spatial and temporal patterns in nitrate-nitrogen concentration across three areas of Canterbury. Land use affects the amount of nitrate-nitrogen that is generated, and hence available to leach to groundwater. Dairy farming has expanded rapidly in Canterbury since the early 1990s (Pangborn and Woodford, 2011), but was preceded by other farming and land use, which may also have had an impact on nitrate-nitrogen concentrations in groundwater. Nitrate-nitrogen concentrations in groundwater were already high in the 1970s and 1980s in the Selwyn-Te Waihora and Christchurch-West...
Melton zones, which could reflect drivers other than dairy farming, for example, cropping and/or discharges. However, changing nitrate-nitrogen concentrations in groundwater may not simply be related to land use. Close et al. (1995) studied nitrate-nitrogen concentrations in a set of wells in the mid-Canterbury area during 1978/79 and 1990/91. One factor identified in their paper was the importance of variable recharge on observed groundwater quality. They found that variable recharge was more significant than increasing levels of land use intensification when comparing these two particular time periods. Hayward & Hanson (2004) also observed the influence of high recharge on nitrate-nitrogen concentrations in the Ashburton area. Over several decades, the influence of high or low recharge years would not be significant, and land use change is likely to be more important over such long time periods. However, it is possible that the high recharge years in the late 1970s were enough to have an influence on nitrate-nitrogen concentrations, possibly due to a lack of sampling in the early 1970s, and an undue influence from sampling in the late 1970s.

The data show that there were more samples at a shallower depth, as expected, as abstraction is usually from the shallowest aquifers first. With time, as deeper holes are drilled to access more reliable supplies, and as concerns about water quality have increased, there has been an increase in sampling (both in terms of the number of sites and frequency of sampling).

The original aim of the project was to investigate areas where nitrate-nitrogen concentrations had significantly increased at depth, and whether the rise was gradual or sudden. The main problem in drawing conclusions on these issues is the lack of data; both the Darfield and Ashburton areas have little data before the 1990s available on the Environment Canterbury database, and when sampling started the nitrate-nitrogen concentrations were already relatively high. The lack of samples in the early decades means there isn’t a history of the increase in nitrate-nitrogen concentrations in many areas. The absence of samples may reflect the lack of concern and/or awareness about groundwater quality (particularly deep groundwater) in the early decades, or it could be due to the fact that there were few bores drilled for groundwater abstraction.

The rapid increase in nitrate-nitrogen concentrations to the very high levels now seen in Ashburton, and the elevated concentrations at depth, is concerning and suggests rapid movement from surface to depth. The co-located wells at different depths in the Ashburton area show similar nitrate-nitrogen concentrations, but rather less temporal variability in the deeper wells, and may indicate dispersion and mixing as the nitrate-nitrogen moves down through the aquifer system. The high concentrations in deep wells in the Darfield area have been detected since sampling began and suggest that nitrate can be transported relatively quickly through a thick vadose zone.

Land use restrictions and/or river dilution has kept nitrate-nitrogen concentrations low in the Christchurch-West Melton zone. However, the zone is divided into a northern part, with very low nitrate-nitrogen concentrations, and a southern component, which shows the impacts of agriculture and discharges to land, in terms of elevated nitrate-nitrogen concentrations.

The Selwyn-Waihora zone shows quite mixed results in terms of the pattern of nitrate-nitrogen concentrations, both spatially and temporally. High nitrate-nitrogen concentrations were observed in the 1970s, the cause of which is unknown, but could be related to the timing of sampling and excessive nitrate leaching in the late 1970s when recharge was high. The area around Te Waihora generally shows very low
nitrate-nitrogen concentrations, which has been suggested to be caused by upward flow from deeper layers and/or denitrification in the organic-rich, heavy soils around the lake. However, a region of higher nitrate-nitrogen concentrations occurs towards the southern end of the lake, which is possibly a result of effluent discharge and other land uses up-gradient, combined with a hydrogeological setting that is more susceptible to nitrate accumulation.

The Ashburton area, overall, shows the most impacted groundwater, with nitrate-nitrogen concentrations being elevated at all depths. Some of the areas affected could be impacted by disposal of meat works effluent, but this does not explain the high concentrations across the whole zone, which is likely to be a result of historical and ongoing land use.

The distribution of nitrate-nitrogen concentrations with depth within each zone is quite different. In the Christchurch-West Melton zone, elevated nitrate-nitrogen concentrations are mainly limited to wells that are less than 50 m deep. Moving southwards, nitrate-nitrogen concentrations increase both in magnitude, and with depth, in the Selwyn-Waihora and Ashburton zones.

**Conclusions**

The main conclusion from this study is that nitrate-nitrogen concentrations in groundwater across Canterbury are highly variable, both spatially and temporally. Whilst the Christchurch-West Melton zone has, on the whole, relatively low nitrate-nitrogen concentrations in groundwater, the Ashburton area has a much greater nutrient contamination issue. Concentrations are also highly variable across relatively small areas, possibly reflecting factors such as local contamination sources and soil conditions.

Temporally, there is evidence of groundwater being impacted, in terms of elevated nitrate-nitrogen concentrations, before dairy farming expansion occurred in Canterbury. The influence of low and high recharge periods is also evident, with high recharge in the late 1970s possibly causing high observed nitrate-nitrogen concentrations in groundwater.

Nitrate concentrations generally decrease with depth, but in places, increasing concentrations in deep wells have been detected. There is some evidence of ‘damping’ of the signature with increasing depth, with less temporal variability in nitrate-nitrogen concentrations in some deeper wells compared with shallower wells.

This study has highlighted the high degree of variability, both temporally and spatially, in terms of nitrate-nitrogen concentrations in groundwater. It has shown differences between the different zones investigated, between the depths investigated, and has also highlighted the overall changes in nitrate-nitrogen concentrations over several decades. Using all available data, whilst having drawbacks (such as whether samples are representative), does allow a view of the patterns in nitrate-nitrogen concentrations that is not possible with a few long time series datasets.

**Acknowledgements**

The project started as a Science Fair project. It was highly popular with the judges, but missed out on a prize, the reason being that there was no actual experiment, but instead simply an analysis of data. The purpose of science fairs is that they are an opportunity for students to apply scientific methods to conduct independent research. Whilst the lack of a prize could be construed as a failed project, the interest from the judges, and ability to communicate the science clearly to them, could instead be interpreted as a being a success.
References


