Elevated Nitrate Concentrations in Franklin Surface and Groundwater: A Review

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Elevated Nitrate Concentrations in Franklin Surface and Groundwater: A Review

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Executive summary

The purpose of this report is to discuss the long standing issue of elevated nitrate concentrations in water bodies in the Franklin area and identify gaps to enable better understanding and management of this issue. We reviewed a wide range of literature and summarised long-term state of the environment (SoE) water and soil quality data and historic and current land use information for the Franklin area. The information was used to examine the links between land use and these high nitrate levels in surface and groundwater.

Long-term SoE water quality monitoring data shows elevated and increasing concentrations of nitrate in surface water and shallow groundwater in the Franklin area. Numerous households in the rural Franklin community obtain drinking water from shallow volcanic aquifers and may be susceptible to potential health effects caused by high nitrate levels. High nitrate concentrations can encourage nuisance plant and algal growth and can also affect aquatic life such as fish and invertebrates.

The Franklin area has a long history of continuous cultivation and livestock farming. Vegetable production is an integral part of the Pukekohe economy, with some of the highest production yields in the country. The frost free climate and rich volcanic soils are particularly suited to this intensive land use and Franklin's soils have been identified as some of the most productive in New Zealand.

This intensive vegetable production requires high levels of regular nitrogen fertiliser inputs. When these inputs exceed the assimilative capacity of crops the nitrate becomes susceptible to leaching through the soil profile. This leaching can be enhanced when there is a lack of carbon within a soil system. Both published literature and SoE soil quality data in the Franklin reporting area indicate that this is the case for the majority of vegetable production sites. Nitrogen can also be washed off the land via surface runoff during rainfall. This can be exacerbated by soil compaction, which has been identified as a soil quality issue for pastoral sites within the study area. Other sources of nitrate can include the mineralisation of soil organic matter, dairy farm effluent and leaking septic tank systems.

The National Policy Statement for Freshwater Management (NPSFM) has a clear objective to ensure that the quality of fresh water in Auckland is maintained or improved. The NPSFM requires certain attributes (including nitrate) to be managed within a compulsory national bottom line, which is currently not being met in Franklin. As such, best management practices that reduce the environmental footprint of intensive farming systems need to be encouraged.

A number of knowledge gaps have been identified where future research could be targeted. These include:

- nitrate transport processes between soil, groundwater and surface water;
- the spatial extent of elevated nitrate concentrations;
- nitrate source determination;
- accurate fertiliser usage;

- aquifer recharge modelling;
- groundwater residence times and chemistry.

In terms of future direction, there are increasing regional, national and global goals that aim to increase primary production through intensification without impacting on the environment. However, a conflict exists between goals to intensify and increase production and productivity, without increasing the environmental footprint of such activities. The review of literature and monitoring data included in this report demonstrates a good example of this conflict.

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1.0 Introduction

The Franklin area lies between Āwhitu Peninsula to the west and the Drury Fault to the east. Franklin is bounded by the Manukau Harbour to the north and the Waikato River to the south. The Franklin area has been subject to intensive vegetable growing and livestock farming for over a century. The frost free climate and rich volcanic soils are particularly suited to this intensive land use. These soils have been identified as some of New Zealand's most productive soils (MAF, 1975).

There is growing concern about rising nitrate concentrations in surface water and groundwater in the Franklin area, particularly the potential environmental and human health effects. The Whangamaire Stream exceeds the national bottom line for nitrate (toxicity) in the National Policy Statement for Freshwater Management (MfE, 2014). Other streams in the Franklin area that are not monitored may also be below the national bottom line. Communities will have to decide how and when the water quality in these streams will be improved (MfE, 2014).

Nitrate can originate from a number of sources. In the Franklin area, the most likely source is from fertiliser. When fertiliser inputs exceed the assimilative capacity of the crops it remains in the soil and is vulnerable to leaching. It is also possible that fertiliser is washed into the receiving environment via surface runoff during rainfall and/or irrigation events. Other sources of nitrate can include the mineralisation of organic matter, dairy farm effluent and leaking septic tank systems.

A natural abundance stable isotope study in the Franklin area by Cathcart (1996) suggested the greatest sources of nitrate were from nitrogen-based fertiliser and/or soil organic nitrogen (these two sources could not be differentiated). This made up around 75% of the nitrate in the groundwater. It was significantly greater than the human and animal waste portion, which comprised 2% (Cathcart, 1996).

Other studies in the Franklin area by Crush et al (1997) and Francis et al., (2003) have established that all rural land uses have a positive nitrogen balance, or in other words, surplus nitrogen in the system that is vulnerable to loss. There was a large range in the surplus nitrogen values. The greatest surplus occurs in winter vegetable crops, particularly potatoes, lettuces and cabbages. Winter potatoes had surplus nitrogen in the order of 429 kg N/ha. This equated to an estimated 35% of the nitrate leached below the root zone (Crush et al., 1997). Although dairy pasture had considerably less nitrogen surplus, it was still a mean value of 157 kg surplus N/ha. Francis et al. (2003) also found that there was net migration of soil-mineralised nitrogen (N) through the soil profile during the winter months when drainage (and leaching) is generally at its highest.

The objective of this report is to collate and summarise the issue of elevated nitrate concentrations in the Franklin area and to identify gaps in knowledge where future research should be targeted to manage these issues. The report also includes commentary about the future direction of some of these land use and water quality issues. We reviewed a wide range of available literature and summarised long-term water, soil and land use data for the Franklin area. This information was used to examine the links between land use and high nitrate concentrations, and the potential effects on human and ecosystem health.

2.0 Nitrogen, nitrate and the nitrogen cycle

Nitrogen (N) is an essential element for the growth of plants and animals and is the most abundant of all the fundamental macronutrients (N, C, P, O, S) (Galloway et al., 2003). Nitrogen is also a major limiting factor for growth in both natural and agricultural ecosystems (Vitousek et al., 1997). Although it is naturally abundant, it is almost entirely (>99%) in the diatomic N_2 form, which is unavailable to over 99% of living organisms (Galloway et al., 2003). Severing the triple bond and converting the non-reactive N_2 to reactive forms requires a great deal of energy. This can only be achieved by specialised N-fixing micro-organisms and during high temperature processes (Galloway et al., 2003).

New Zealand soils generally contain between 0.1 - 0.6% N in the top 15 cm. About 95% of this is in soil organic matter (decomposing plant material, humus and microbial biomass) and not immediately available for plant uptake (Haynes, 1986). Soil inorganic N accounts for less than 2% of the total soil N content and consists of ammonium (NH_4^+-N), nitrite (NO_2^--N) and nitrate (NO_3^--N). This represents a small and transient N pool that is directly available for plant uptake (Haynes, 1986). A simplified diagram of the nitrogen cycle is shown below in Figure 1.

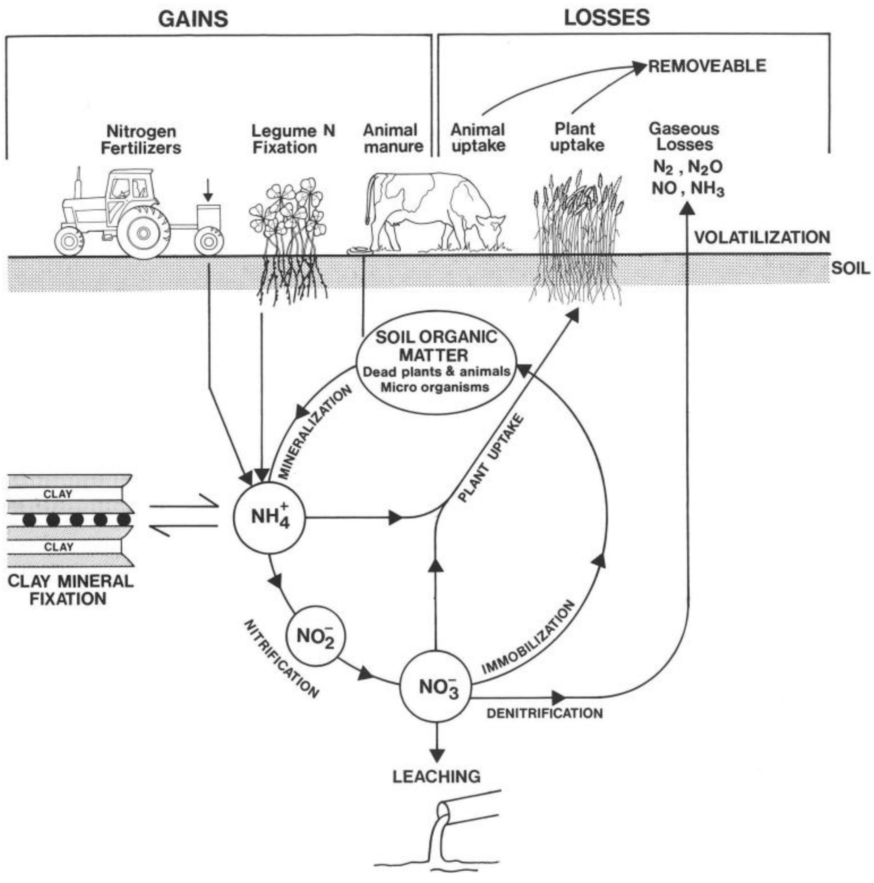


Figure 1: The soil nitrogen cycle (Di and Cameron, 2002).

2.1 Nitrogen forms and transformations

There are many forms and transformations of N that occur in the soil. These are outlined below:

- *Ammonium N*

Ammonium (NH_4^+) is an inorganic, bioavailable form of N. Ammonium is not readily leached from soil because it is electrostatically bound to negatively charged soil particles. High concentrations of ammonium in streams can indicate direct inputs of N into the system (e.g. cattle urination or defecation directly into the stream channel) or overland runoff of sediment associated N. Mineralisation of resident organic N in stream bed sediments can also introduce ammonium into the water. In the presence of nitrifying bacteria, ammonium is readily oxidised to nitrite and nitrate forms of N.

- *Ammonia N*

Ammonia (NH_3) is a gaseous form of N. The concentration of NH_3 relative to NH_4^+ is dependent on soil and water pH, with higher pH favouring the production of NH_3 as illustrated by the following equation:

$$NH_4^+ + OH^- \leftrightarrow NH_3 + H_2O$$

Ammonia produced in the top soil is readily volatilised to the atmosphere. From an agricultural perspective, NH_3 volatilisation is undesirable because it can represent a significant loss of N from the soil-plant system that could otherwise contribute to increased productivity. In water with high pH, high concentrations of NH_3 can be toxic to stream life.

- *Nitrite and nitrate N*

Nitrite (NO_2^-) and nitrate (NO_3^-) are produced via nitrification, which is the two-step biological oxidation of ammonium as described by the equations below. In the first step, ammonia oxidising bacteria (e.g. *Nitrosomas, Nitrosolobus* and *Nitrospira*) oxidise ammonium to nitrite. In the second step, nitrite is rapidly oxidised to nitrate by a group of nitrifying bacteria, *Nitrobacter.*

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ + energy$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^- + energy$$

The oxidation of nitrite to nitrate occurs very rapidly in the environment and as a result, detectable concentrations of nitrite are seldom observed. Nitrate ions are relatively stable in the environment. As a result, nitrate and nitrite are reported together, and are henceforth termed nitrate. Being negatively charged, nitrate ions are repelled by negatively charged soil particles, making them very mobile and vulnerable to leaching through the soil profile.

- *Total N*

Total N includes all forms of N present, including the organic and inorganic forms. The difference between total N and the inorganic N forms (ammonium, nitrite, and nitrate) gives the organic N (largely non-bioavailable) component.

- *Important non-nitrogen parameters*

Temperature can affect the rate at which N transformations occur, with higher temperatures generally increasing rates of reaction. Temperature can also affect in-stream biological uptake of inorganic N by macrophytes and algae. Higher temperatures generally increase reaction rates and plant growth. Nitrogen transformations can also be affected by pH. For example in streams at high pH (>8) ammonium can be transformed to ammonia; a gaseous form of N, which is toxic to stream life.

In streams, dissolved oxygen can be affected indirectly by the inorganic N concentrations. High nitrate concentrations encourage the growth of macrophytes, which, via photosynthesis, can introduce large amounts of oxygen into the water during daylight hours. However, they continue to respire at night, consuming oxygen. This can create large diurnal fluctuations in the dissolved oxygen content of streams. Also, the eventual microbial decomposition of stream algal and/or plant matter can decrease the dissolved oxygen content of the water.

2.2 Nitrogen leaching

The term 'leaching' describes the movement of N through the soil profile via drainage to below the root zone, (where it can no longer be utilised by plants), and ultimately into a groundwater system (van Kessel et al., 2009). The main form of N leached is nitrate, although small amounts of ammonium can also be leached through soil cracks or macropores. Another, less documented form of N leached is dissolved organic N (DON). Dissolved organic N has recently been recognised as a considerable contributor to the total N load leached (van Kessel et al., 2009). However, there is currently no data on DON leaching in the Franklin area so this is not discussed further in this literature review.

The extent of nitrate leached is determined by the concentration of nitrate in the soil solution and the amount of drainage that occurs through the soil over a given period of time. The amount of nitrate in the soil depends on the amount of N (if any) applied, the nitrification rate, the denitrification rate, and the rate of plant N uptake and immobilisation (Cameron et al., 2013). The characteristic of nitrate that makes it so susceptible to leaching is its negative charge, which is repelled by the bulk of negatively charged soil particles.

When large amounts of water are applied to the soil surface (e.g. heavy rainfall or irrigation), nitrate leaching may be increased due to the flow of water through macropores in the soil down to the aquifer. Conversely, when nitrate is located within soil aggregates, the drainage water may bypass it through the macropores, resulting in a slower rate of leaching, or less leaching overall.

Season and climate have a large effect on nitrate leaching with the largest losses occurring during winter when rainfall is in excess of evapotranspiration and plant uptake is low. Leaching is generally minimal in summer; however it may occur via macropore flow under heavy rainfall events. Nitrate will typically accumulate in the soil over a dry summer due to limited soil water and poor crop uptake. It can be leached over the following winter if it is not taken up by plants or immobilised beforehand. Nitrate is less prone to leaching in spring, with warmer temperatures and increasing daylight hours promoting rapid plant growth and N uptake (Cameron and Haynes, 1986). The vulnerability of land to bypass flow depends on soil structure and soil attributes that promote ponding (McLeod et al., 2005).

Nitrogen leaching vulnerability depends on the capacity of the soil to store water (a function of soil texture and depth) and the attenuation of nitrogen through denitrification (Woods et al., 2006, Lilburne et al., 2003). Irrigation and rainfall also influence nitrogen leaching (McLeod pers. comm.). Sandy soil (coarse textured) have less stored water than fine textured soils (like clay) that are poorly drained (Burk and Dalgliesh, 2008). Poorly drained soils can have higher attenuation of nitrate through denitrification (Webb et al., 2010, Stenger et al., 2008).

Nitrate leaching is also affected by the N inputs and management of the land. Nitrate leaching from undisturbed or extensively managed ecosystems is typically very low. There is generally an increase in nitrate leaching in grazed pasture systems. This is because most of the N ingested by animals (60-90%) is returned to the soil as excreta in small concentrated patches (Jarvis et al., 1995). The concentration of N in urine patches can be as high as 1000 kg N/ha (Ledgard and Menneer, 2005). Some of this urinary N will be volatilised as ammonia gas, but most will be nitrified to nitrate. This N loading rate is far in excess of what the affected pasture can utilise, therefore, the unused nitrate remains in the soil. Some of this may be denitrified or immobilised, but the majority is leached upon the onset of drainage (Selbie et al., 2015).

Timing and rate of N fertiliser and effluent applications are also important. If fertiliser and/or effluent are applied in excess of plant requirements, or are applied during periods of saturated conditions or drainage, the rates and amounts of nitrate leached increases considerably (Di, 2002, Cameron and Haynes, 1986).

Leached nitrate eventually makes its way to the groundwater. This water can remain at depth for varying lengths of time, before emerging as a spring, directly into a stream bed or lake, or into the marine environment. The proportion of leached nitrate that actually reaches surface water systems is largely unknown and depends on many factors including:

- the chemical and physical characteristics of the subsoil and aquifers
- levels of oxygenation (or lack thereof) and carbon for denitrification as well as microbial assimilation rates, and

- groundwater-surface water interaction characteristics.

2.3 Impacts of nitrogen leaching

2.3.1 Environmental health

This section focuses on a range of environmental effects as a result of nitrate enrichment in freshwater ecosystems.

2.3.1.1 Receiving environment impacts

A range of environmental effects can occur as a result of increasing nitrate concentrations in freshwater. The environmental effects include aquatic acidification; enhanced plant and algal growth, and reduced dissolved oxygen levels. This can lead to accelerated eutrophication and impacts on the growth, reproduction and survival of aquatic organisms (Camargo and Alonso, 2006).

Nutrient enrichment can affect ecosystems even at low nitrate concentrations (Glibert et al., 2005). The resulting effects of this include:

- increased nuisance algae biomass
- increased aquatic macrophyte biomass, which can impair flow, cause large fluctuations in dissolved oxygen and impact ecological health
- changes to algal and invertebrate species composition
- cyanobacteria blooms, some of which produce toxins that can kill fish, invertebrates, livestock, dogs and humans (Camargo and Alonso, 2006, Codd, 2000)
- shifts in dissolved oxygen, pH and temperature levels (Glibert et al., 2005).

2.3.1.2 Invertebrate toxicity

Nitrate can have chronic and acute impacts on aquatic invertebrates and fish. Chronic nitrate toxicity can cause behavioural and reproductive disruption, immune stress and affect physiological processes, such as gas exchange.

In comparison, acute nitrate toxicity describes a lethal nitrate concentration (Alonso, 2013). The toxicity of nitrate to both invertebrates and fish is dependent on a range of other parameters in fresh waters including hardness, pH, dissolved oxygen and water temperature (Hickey, 2013).

2.3.1.3 Multiple stressor effects

Multiple stressor effects of nutrients plus other contaminants can have a considerable effect on invertebrate health. New Zealand research found that dissolved inorganic nutrients in addition to deposited fine sediment acts in a complex and synergistic manner relative to invertebrate abundance in a streamside mesocosm experiment (a biological system which contains the physical features and organisms of an ecosystem) in an agricultural Otago catchment (Wagenhoff et al., 2011). The author states that the monitoring and management of nutrient concentrations together with inputs of fine sediment is critical for the protection of freshwater ecosystems.

2.3.1.4 Fish toxicity

While nitrate is less toxic than ammonia, nitrate is the dominant form of inorganic nitrogen in aquatic environments (Haycock et al., 1996, Camargo and Alonso, 2006). In addition, freshwater biota is more sensitive to nitrate than marine organisms, therefore the management and regulation of nitrate in freshwater ecosystems is critical for fish and invertebrate health (Camargo and Alonso, 2006).

A considerable amount of international literature exists for nitrate toxicity effects on freshwater fish species (Hickey, 2013). Chronic and acute nitrate toxicity has been studied in a range of freshwater fish, including:

- Lake trout
- Rainbow trout
- Chinook salmon
- Coho salmon
- Fathead minnows, and
- Mosquitofish.

In New Zealand, chronic toxicity has been studied for inanga (Hickey, 2013).

2.3.2 Human health

Human nitrate exposure can be derived from exogenous (external) sources or endogenously (internally) synthesised (L'hirondel, 2002). This section focuses on the potential effects of both exogenous and endogenous nitrate sources on human health.

2.3.2.1 Methaemoglobinaemia (Blue Baby Syndrome)

Methaemoglobinaemia is also known as blue baby syndrome. It is a condition that decreases the ability of blood to carry oxygen around the human body due to the oxidation of red blood cell haemoglobin to methemoglobin (Knobeloch et al., 2000).

Infants under 6 months are most susceptible to nitrate toxicity because they have not yet developed the ability to produce methemoglobin reductase, a red blood cell enzyme which converts methemoglobin back into haemoglobin (Knobeloch et al., 2000). Infants can show blueness around the mouth, hands and feet. These symptoms can be accompanied by vomiting, diarrhoea and in extreme cases seizures and death (WHO, 2014).

No cases of blue baby syndrome have been reported to the Auckland Regional Public Health Service (ARPHS) to date. This could be partly due to low incidence rates and there is typically a low rate of notification for this type of illness. It is also notoriously difficult to determine if the cause was contaminated water or food (S Baker 2015, pers. comm., 8 May).

A number of mechanisms have been described to explain the occurrence of blue baby syndrome. The cause of this illness remains uncertain. The common theory is that high nitrate drinking water in infant milk-formula is converted to nitrite by gut bacteria causing enhanced production of methaemoglobin (Knobeloch et al., 2000). However, no correlation has been found between blue baby syndrome and the consumption of exogenous nitrate (L'hirondel, 2002). This common theory is disputed by a number of authors (Avery, 1999, L'hirondel, 2002). They propose two alternative causes for the illness:

- *Infection/inflammation*

One proposed mechanism for blue baby syndrome is infective enteritis (abdominal pain, diarrhoea). This condition causes oxidation of the amino acid L-arginine in the gut. Nitric oxide (NO) is formed, and ultimately nitrate and nitrite, causing methaemoglobinaemia. This is evidence of endogenous nitrite production. It occurs irrespective of the consumption of exogenous nitrate sources from bore water or vegetables.

- *Microbial contamination*

The second mechanism for blue baby syndrome is the consumption of high nitrate bore water, in which microbial contamination is also present (L'hirondel, 2002). In this situation, nitrate is converted to nitrite within the folmula bottle by bacteria present in the bore water used to make the formula. This is avoided by: regularly testing bore water for *E. coli* and nitrate contamination; and implementing, good hygiene practices in the preparation and storage of infant formula to minimise bacterial proliferation.

2.3.2.2 Nitrate and cancer

The consumption of nitrate (in water or vegetables) together with amine-rich foods (e.g. meat, cheese) can lead to the formation of carcinogenic nitrosamines (compounds produced by reactions of nitrites with amines or amides) (NOCs) in the human body (L'hirondel, 2002). Additionally, it is thought that because the stomach is the primary recipient, that gastric cancers would result. However, while the production of NOCs does occur in the human body (or directly by inhaled tobacco smoke and consumption of cured meat products), a link between nitrate intake and gastric cancer risk is not supported by epidemiological evidence, or any cause and effect relationship (L'hirondel, 2002).

The relationship between nitrate and cancer is complex and more epidemiological research is needed. One promising finding is the link between stomach cancer and infection with the *Helicobacter pylori* bacterium (L'hirondel, 2002). Infection and inflammation of the gastric mucosa (mucus membrane layer in the stomach) stimulates the production of nitric oxide and peroxynitrite in the gut. This may be a factor in the formation of gastric cancers.

Epidemiological literature primarily focuses on the link between nitrate exposure through drinking water with various types of cancers. However, no evidence for increased risk of bladder cancer was found in a meta-analysis of international literature (Wang et al., 2012). In addition, a matched case-control study found no statistically significant relationship between pancreatic cancer cases in Taiwan from 2000-2006 (Yang et al., 2009).

A cohort study of women in Iowa, USA found an increased risk of thyroid cancer with consumption of nitrate in water and food from 1986 to 2004 (Ward et al., 2010). However, the author states that due to the small number of study cases, further epidemiological research is required to provide evidence of any links between nitrate consumption and cancer risk.

2.3.2.3 Reproductive effects

A review of 12 studies which investigated the potential effects of maternal nitrate consumption on a range of adverse reproductive and developmental effects found insufficient evidence of a causal relationship (Manassaram et al., 2006). A range of outcomes have been reported in the literature. These include:

- premature birth
- spontaneous abortion
- pregnancy complications, and
- neural tube defects.

However, the existing epidemiological studies lacked individual exposure assessments. Therefore, other causative factors could not be ruled out (Manassaram et al., 2006).

3.0 The water connection

3.1 Groundwater and surface water connection

The interaction between groundwater and surface water is dynamic and varies in space and time (Guggenmos et al., 2011). It is important to understand and quantify this interaction to effectively manage these environments.

Groundwater and surface water connection is the flow of water between an unconfined aquifer and a lake, stream or the coast (Winter et al., 1998). Unconfined aquifers are also called water table or phreatic aquifers, because their upper boundary is the water table. Typically the shallowest aquifer at a given location is unconfined, meaning it does not have a confining layer between it and the surface.

This report focuses primarily on the connection between aquifers and streams as this is most relevant for the Franklin area. This connection can occur in three main ways:

Stream gains water from groundwater

Streams can gain water from an aquifer via inflow of water through the stream bed, termed a 'gaining' stream. Streams will only gain water from groundwater if the water table is higher than the surface level of the stream (Figure 2). During the dry months of summer, groundwater can supply the entire baseflow of a stream (Winter et al., 1998).

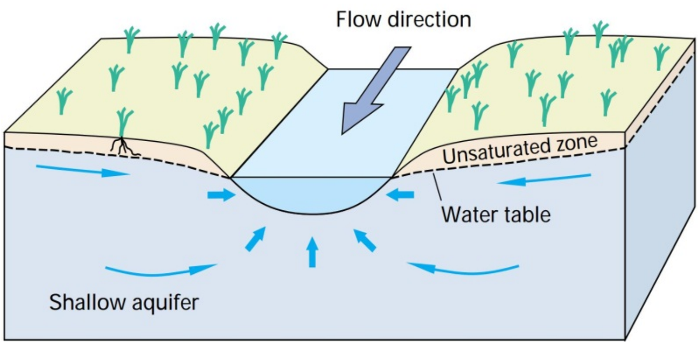


Figure 2: A stream *gaining* water from an aquifer (Winter et al., 1998)

Stream loses water to groundwater

Streams can lose water to an aquifer via outflow of water through the stream bed, termed a 'losing' stream.' Streams will only lose water to groundwater if the water table is lower than the surface level of the stream (Figure 3).

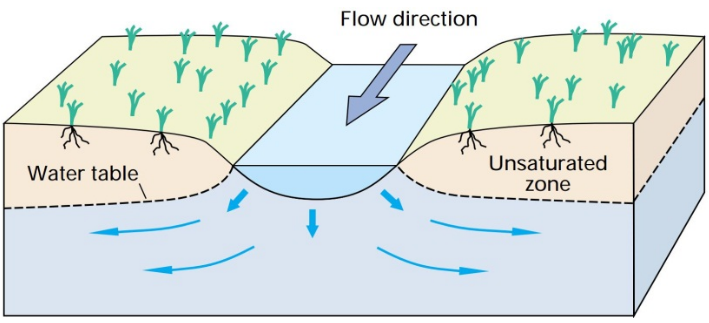


Figure 3: A stream *losing* water to an aquifer (Winter et al., 1998)

Combination

It is common for a stream to have both gaining and losing reaches along its length as a result of differences in altitude, geology and climate. Streams can also lose water to groundwater during rainfall events or flood peaks, or streams may lose water to the atmosphere as a result of plant evapotranspiration (Winter et al., 1998).

Groundwater can discharge as springs. Springs are defined as areas where groundwater naturally emerges from below the Earth's surface forming a pool or defined flow of water (Figure 4). Springs usually occur on land at the base of hills or feeding the headwaters of a stream. Springs can also occur underwater in lakes and coastal environments.

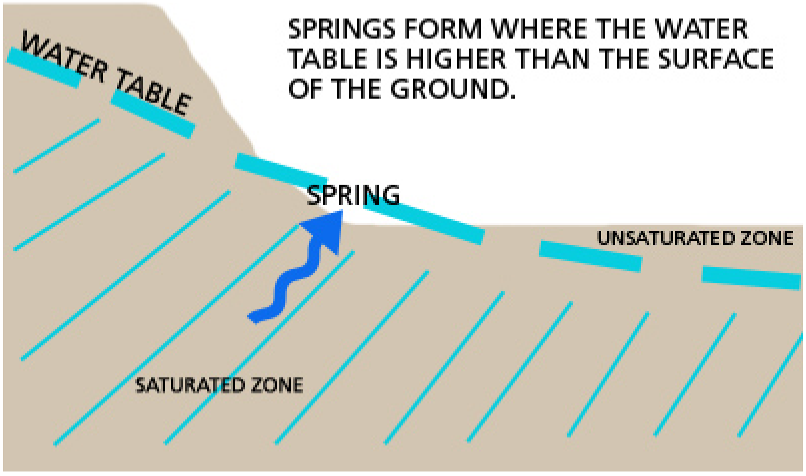


Figure 4: The cause of spring formation (www.nps.gov).

Understanding the connection between groundwater and surface water is critical to quantifying groundwater and surface water allocation limits. Knowledge of this connectivity also assists in:

- setting environmental flows in streams
- mapping the transport of contaminants, and
- understanding groundwater recharge.

3.2 Guidelines and standards for nitrate

There are a range of guidelines and standards for nitrate in groundwater, surface water and drinking water in New Zealand. The National Policy Statement for Freshwater Management (NPSFM) contains national limits for nitrate toxicity in rivers and lakes through the National Objectives Framework (MfE, 2014). This section includes information on all of the relevant nitrate guidelines and standards for New Zealand waters.

3.2.1 New Zealand Drinking Water Standards

The Drinking Water Standards for New Zealand contain standards for a wide range of water quality parameters relevant to the consumption of drinking water (MoH, 2008).

The drinking water standard for nitrate is expressed as a Maximum Acceptable Value (MAV) of 50 mg/L. This is equivalent to a MAV of approximately 11.3 mg/L for nitrate nitrogen. The 11.3 mg/L standard for nitrate nitrogen is most commonly referred to in the literature. Nitrate nitrogen is the nitrogen atom component of the nitrate molecule (NO_3^-), without the oxygen atoms.

The drinking water standard for nitrate applies to short-term exposure in drinking water. It was developed to protect bottle-fed babies against methaemoglobinaemia (MoH, 2008). As a result, the current MAV for nitrate nitrogen is likely to be unnecessarily strict for adults (Avery, 1999). The standards recommend increased monitoring and management if nitrate nitrogen reaches 5.6 mg/L; half of the current standard for nitrate nitrogen.

3.2.2 Australia and New Zealand Water Quality Guidelines

The Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines present 'trigger values' below which there is a low risk that adverse biological effects will occur (MfE, 2000). The trigger values for Nitrate + Nitrite Nitrogen are separated into values for lowland and upland steams. The value for upland streams is 0.167 mg/L while the lowland streams value is higher at 0.444 mg/L (MfE, 2000). The trigger value for upland rivers is stricter than for lowland rivers. This is to account for the generally higher land use pressure experienced in the lower reaches of rivers.

3.2.3 Nitrate Toxicity Guidelines

Freshwater nitrate toxicity guidelines have recently been published for fish and macroinvertebrates in New Zealand (Hickey, 2013). They provide 'Grading' and 'Surveillance' nitrate concentration guideline values. Toxicity values are given for acute nitrate exposure and chronic nitrate exposure across multiple levels of species protection (Table 1). Toxicity data for several New Zealand species have been incorporated into the guidelines, including inanga (*Galaxias maculatus*) and the ubiquitous mayfly (*Deleatidium sp.*).

Table 1: Nitrate toxicity guidelines for New Zealand streams (Hickey, 2013).

Guideline Type	Level of protection	System disturbance	Grading Nitrate concentration[1] (mg NO_3-N /l)	Surveillance Nitrate concentration (mg NO_3-N /l)
			Annual median	Annual 95th percentile
Chronic	99%	High conservation value	1.0	1.5
Chronic	95%	Slightly to moderately disturbed	2.4	3.5
Chronic	90%	Highly disturbed	3.8	5.6
Chronic	80%	Highly disturbed	6.9	9.8
Acute	N/A	N/A	20	30

3.2.4 New Zealand Periphyton Guidelines

The New Zealand Periphyton Guidelines were developed by the Ministry for the Environment for the protection of in-stream values from the effects of nutrient enrichment in hard-bottomed streams (Biggs, 2000). These include guidelines for the protection of a range of values, including aesthetic/recreation, trout habitat and angling and benthic biodiversity (Table 2).

The guidelines are for the indicators of algal growth: chlorophyll-*a* and Ash Free Dry Mass (AFDM). Auckland streams are predominately soft-bottomed, so these guidelines are less relevant than others described in this section.

Table 2: Periphyton cover and biomass guidelines for a range of values in hard-bottomed streams in New Zealand (Biggs, 2000).

In-stream value/variable	Diatoms/cyanobacteria	Filamentous algae
Aesthetic/recreation (1 November – 30 April)		
Maximum cover of visible stream bed	60% >0.3cm thick	30% >2cm long
Maximum AFDM (g/m^2)	N/A	35
Maximum chlorophyll-*a* (mg/m^2)	N/A	120
Benthic biodiversity		
Mean monthly chlorophyll-*a* (mg/m^2)	15	15
Maximum chlorophyll-*a* (mg/m^2)	50	50
Trout habitat and angling		
Maximum cover of whole stream bed	N/A	30% >2cm long
Maximum AFDM (g/m^2)	35	35
Maximum chlorophyll-*a* (mg/m^2)	200	120

3.2.5 National Objectives Framework

The National Policy Statement for Freshwater Management 2014 includes a National Objectives Framework (NOF). The NOF includes nitrate toxicity as an 'attribute' for protecting the value of ecosystem health in rivers (MfE, 2014). The nitrate toxicity 'states' were derived from the Hickey (2013) Nitrate Toxicity Guidelines and provide a set of 'state' bands from A to D (Table 3).

The national objective for ecosystem health in relation to nitrate is detailed below. It includes a 'National Bottom Line'. The 'National Bottom Line' is the bottom of the C and the top of the D attribute state. If a water body has an attribute state of D, it is described as over-allocated and a target state and timeframe needs to be set to improve water quality so that it does not fall into band D.

Objective A2 of the NPSFM prescribes that:

"The overall quality of fresh water with a region is maintained or improved while:

a) *protecting the significant values of outstanding freshwater bodies;*
b) *protecting the significant values of wetlands; and*
c) *improving the quality of fresh water in water bodies that have been degraded by human activities to the point of being over-allocated."*

The NPSFM also includes a range of National Bottom Lines for other river attributes, including periphyton (chlorophyll-*a*), ammonia (Appendix A), *E. coli* and dissolved oxygen (MfE, 2014).

Table 3: National Bottom Line for Nitrate (toxicity), National Policy Statement for Freshwater Management (MfE, 2014).

Value	**Ecosystem health**		
Freshwater Body Type	Rivers		
Attribute	Nitrate (Toxicity)		
Attribute Unit	mg NO_3-N/L (milligrams nitrate-nitrogen per litre)		
Attribute State	**Numeric Attribute State**		**Narrative Attribute State**
	Annual Median	Annual 95th Percentile	
A	≤1.0	≤1.5	High conservation value system. Unlikely to be effects even on sensitive species.
B	>1.0 and ≤2.4	>1.5 and ≤3.5	Some growth effect on up to 5% of species.
C	>2.4 and ≤6.9	>3.5 and ≤9.8	Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects.
National Bottom Line	6.9	9.8	
D	>6.9	>9.8	Impacts on growth of multiple species, and starts approaching acute impact level (i.e. risk of death) for sensitive species at higher concentrations (>20 mg/L).

4.0 Franklin area

4.1 Introduction

The Franklin Local Board area encompasses the area that lies between the Āwhitu Peninsula to the west, the Manukau Harbour to the north, the Drury Fault to the east, and the Waikato River to the south. However, for the purposes of this literature review the area highlighted in Figure 5 described as the '*Franklin reporting area*' will be discussed. The Franklin reporting area is 43,224 ha in size.

The topography is characterised by volcanic cones with a maximum elevation of 222 m above sea level (Pukekohe Hill), a central elevated zone (Bombay, Pukekohe and Glenbrook) and the Manukau lowlands (Viljevac et al., 2002). The land moderately slopes from the central elevated zone towards the Manukau Harbour in the north, and the Waiuku River in the west (Viljevac et al., 2002). The area south of the central elevated zone is in the Waikato region.

The climate in the Franklin area is influenced by the coastal nature of the lowlands and the rising elevation towards Pukekohe Hill. Rainfall varies slightly with an average rainfall of 1,500mm at the coastal margin rising up to 1,600mm at the top of Bombay Hill (Viljevac et al., 2002). Short duration rainfall intensities can reach 125mm per hour in a ten minute period (Coulter, 1980). The average annual sunshine hours for the area are around 2,000 hours. Temperature across the region averages 24 degree Celsius in February to 14 degree Celsius in July and August. Median annual average temperatures for Franklin range from 14 to 15 degrees Celsius (Chappell, 2012).

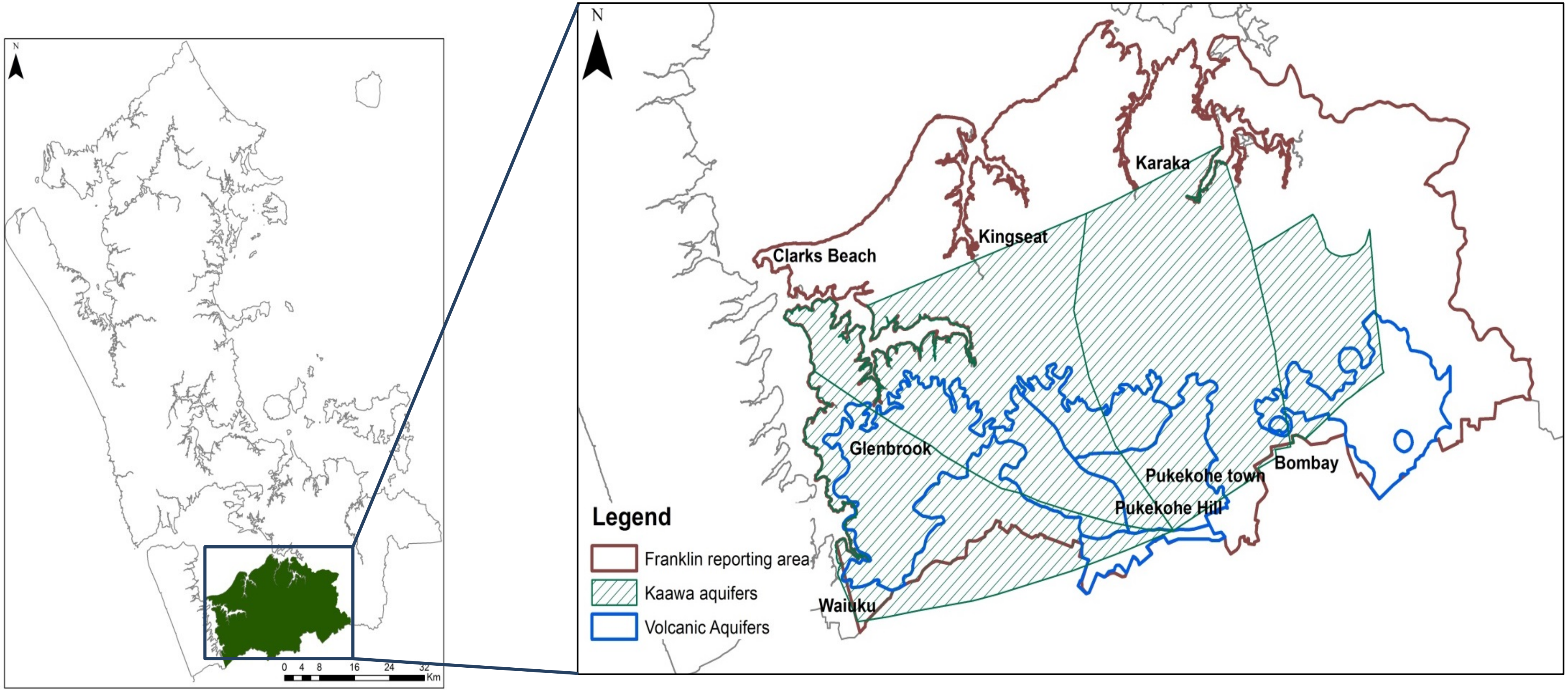


Figure 5: The Franklin reporting area is located in the south of the Auckland region and is highlighted in dark green on the left map. The right hand image illustrates the South Auckland volcanic aquifer recharge zones (overlaid in blue) and the Kaawa aquifers in grid green.

4.1.1 Franklin soils

The majority of the soils in the Franklin reporting area belong to the Granular soil order and are of volcanic origin (Figure 6) (Hewitt, 2010, Molloy, 1993). Granular soils occupy 42% of the Franklin reporting area (Orbell, 1977). They are mainly located above the volcanic aquifers (Figure 6).

There are large areas of Allophanic (32%) soils with smaller proportions of Ultic (9%), Gley (8%) and Brown (6%) soils in low-lying areas. Granular, Gley and Organic soils are found on the edges of the Kaawa aquifer. Brown and Allophanic soils are present mostly in the north of the Franklin reporting area where a large proportion of pastoral vegetative land cover is also located (Figure 10).

The Granular soils are renowned market gardening soils (e.g. Patumahoe and Pukekohe series) that have sustained intensive horticultural activity for over 100 years in some parts (Hunt, 1959, Lee and Lam, 2012, Coleman, 1967). These soils have been identified as some of New Zealand's most productive soils (MAF, 1975).

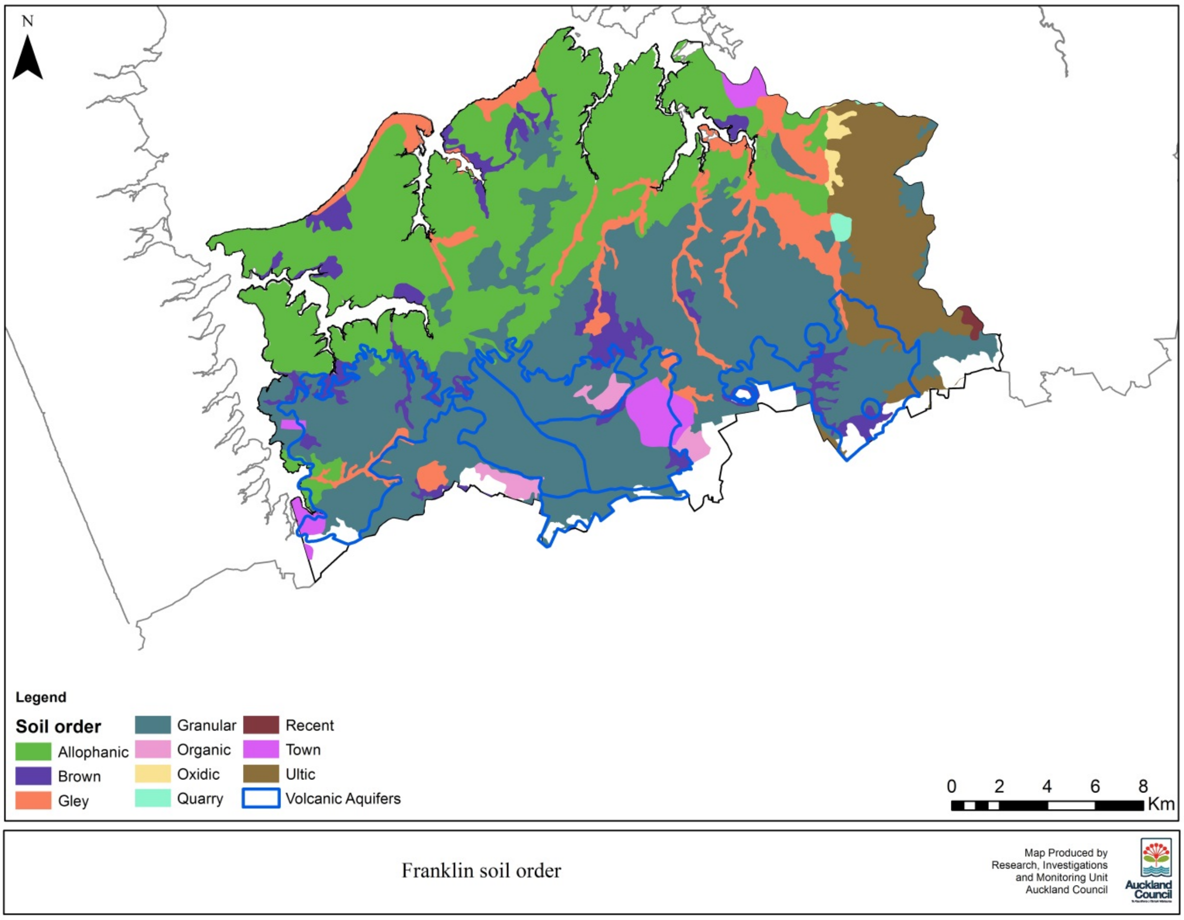


Figure 6: Map of the soil orders for the Franklin reporting area with the South Auckland volcanic aquifer recharge zones overlaid in blue.

The Granular soils are formed on a thick mantle of weathered rhyolitic airfall ash (Hamilton Ash), and over old basaltic lava flows (Franklin Basalt) (Lowe et al., 2010). Granular soils are predominantly clayey soils (Hewitt, 2010). The surface soil is sticky when wet but tends to re-aggregate into a strong granular structure after cultivation (Lowe et al., 2010). If allowed to dry, cracks develop enabling rapid drainage towards the groundwater.

Granular soils have the following properties (Hewitt, 2010):

- slow or marginally slow saturated hydraulic conductivity (water movement through soil pores) resulting in periods of perched water
- limited root depth due to penetration resistance, wetness or aluminium toxicity
- low phosphate status as phosphorus fixation may be high
- low nutrient reserves of phosphorus, potassium, and magnesium.

4.1.2 Land use capability

The majority of land in the Franklin area is considered to be elite and prime land. Using the Land Use Capability (LUC) classification system (Figure 7), elite (LUC 1) and prime (LUC classes 2 and 3) land are defined as being versatile (soils which supply the nutrients required for optimum plant growth and are good for growing food) and capable of sustaining long-term cultivation, arable cropping or pastoral systems (Lynn et al., 2009).

Class 2 land occupies the greatest area (47%) in Franklin. A smaller but significant portion of land (22%) can be classified as class 3 (Figure 7). Land Use Capability classes 1, 4, 6 and 7 occupy 9%, 9%, 12% and <1%, respectively, of land in the reporting area.

The biggest uninterrupted parcel of class 1 elite land is situated to the west of Pukekohe township. This area is also the location for much of the short rotational cropping land use. This area is also above the Pukekohe volcanic aquifer recharge zone and classified as having a high leaching risk (Houlbrooke, 2008).

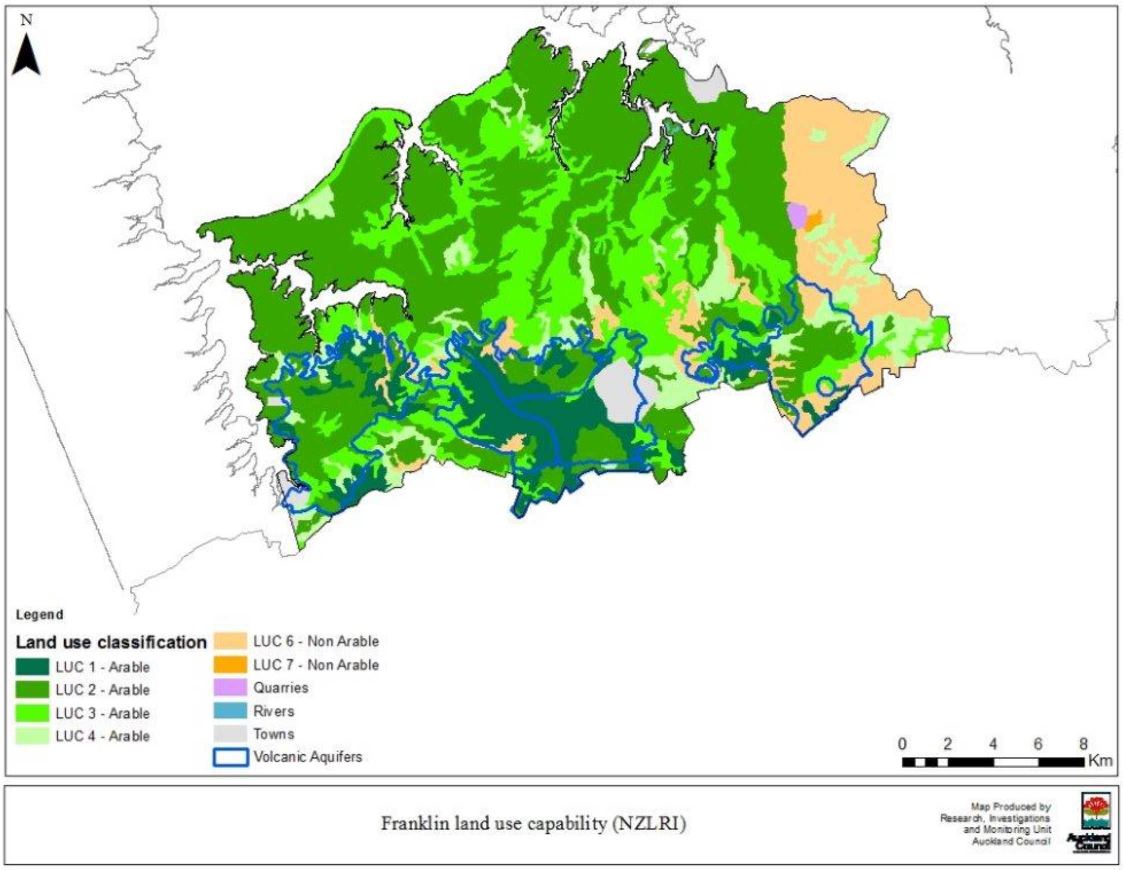


Figure 7: Distribution of land use capability (LUC) classes across the Franklin reporting area (NZLRI, 2009)

4.1.3 Soil risk categories for farm dairy effluent

The soils within the Auckland region have been classified in terms of their susceptibility to leach nitrate when dairy farm effluent (FDE) is applied (Appendix B). Houlbrooke et al. (2012) identifies three primary mechanisms for the transport of water (containing solutes and suspended solids) through soil: matrix flow, preferential flow and overland flow. Matrix flow involves the relatively uniform migration of water through and around soil aggregates and therefore provides a greater soil contact time, opportunity for nutrient attenuation and filtering of sediments and faecal micro-organisms. Soils that exhibit preferential or overland flow are capable of considerable direct loss of FDE when applied to wet soils (insufficient soil water deficit to store incoming moisture) and/or when the application rate of effluent exceeds the infiltration rate for the receiving soil. Preferential and overland flows provide little soil contact time and thus minimal opportunity for the attenuation of the applied contaminants (Houlbrooke and Monaghan, 2010).

High risk soils are those that have one or more of the following:

- preferential drainage
- coarse soil structure
- impeded drainage
- low infiltration rates

- are on land which has a slope angle of greater than 7 degrees.

Most of the Granular soils including Patumahoe and Pukekohe soil that make up the majority of the soil over the South Auckland volcanic aquifer are classified as high risk, due to subsoil preferential drainage (coarse subsoil structure) and slope (Houlbrooke et al., 2012). The New Zealand Soils Database, classifies Patumahoe and Pukekohe as being high risk on slopes greater than 7 degrees (Landcare Research, 2015).

4.1.4 Geology of Franklin

The South Auckland volcanic aquifers lie in the area surrounding and including Pukekohe Hill. The aquifers were formed by several volcanic centres that produced lava flows on the Manukau lowlands (Auckland Regional Council, 1991). The geology of the Franklin area (Figure 8) is predominately sand and volcanic basalt rock which has been previously described in detail by High (1975), Schofield (1967), Dowdle (1980) and Orbell (1977).

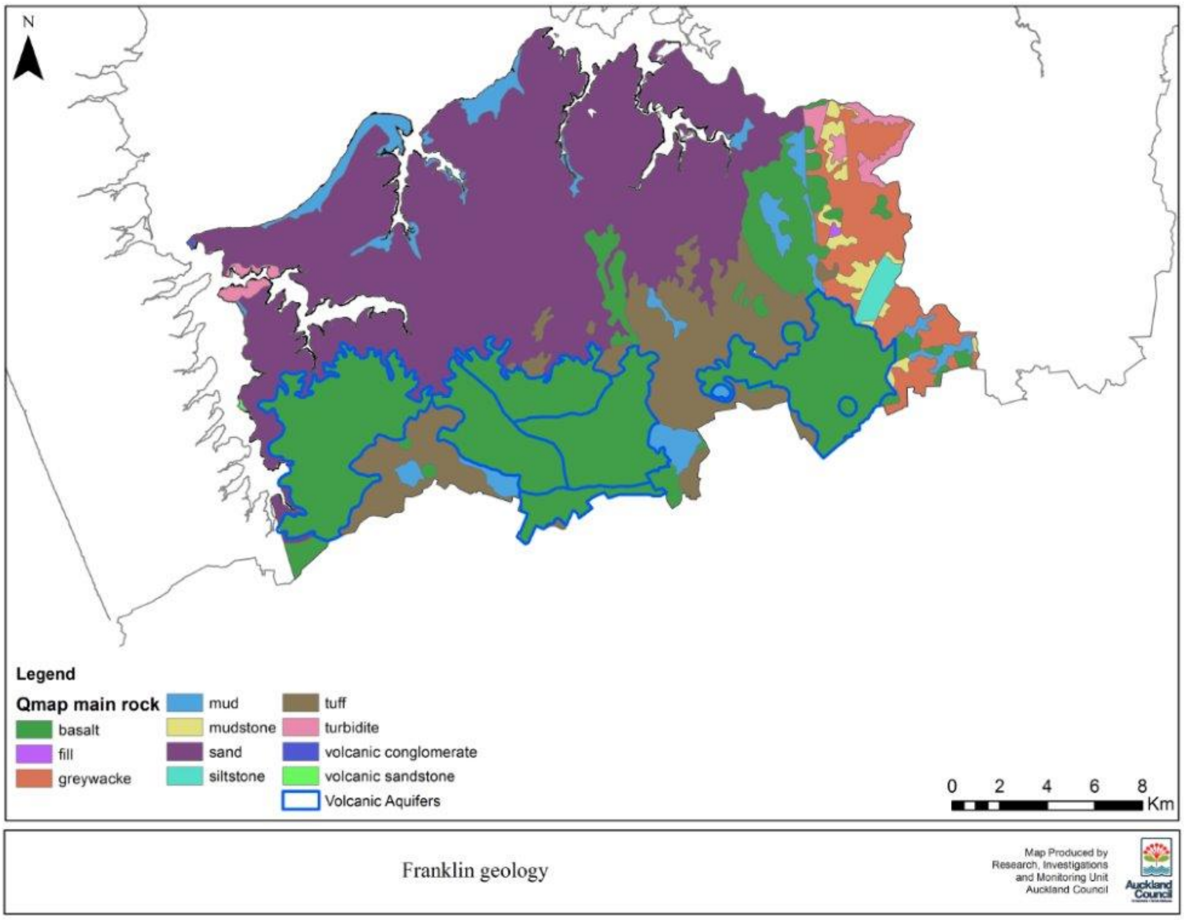


Figure 8: Geology of the Franklin reporting area (using QMAP) with the South Auckland volcanic aquifer recharge zones overlaid in blue.

Franklin aquifer types

South Auckland volcanic (basalt) aquifer

The basalt aquifers are largely shallow unconfined fractured aquifers, with some parts being semi-confined or perched. The basalt aquifers are located near the ground surface with a high water table and are relatively thin (Viljevac et al., 2002). The basalt aquifer in the Franklin area is covered by thick soil that has originated from weathering of the basalt, tuff and volcanic ash deposits (Viljevac et al., 2002). The high water holding capacity of the soil creates steady and sustainable recharge to the aquifer. It also makes it excellent for agriculture (Viljevac et al., 2002, Auckland Regional Council, 1991).

Kaawa aquifer

The Kaawa Formation in the Franklin area is a deeper confined aquifer bounded by the Waikato and Drury Fault lines. It is characterised by a porous shell bed, sand deposits and weakly cemented sandstone. In the north, towards the Manukau Harbour, the Kaawa deposits become relatively thin. The Pukekohe volcanic aquifer is the major recharge area for the Kaawa aquifer with groundwater levels in the upper volcanic aquifer influencing water levels in the Kaawa (Viljevac et al., 2002).

Waitematā Group

The Waitematā Group forms the hydrogeological base in the Franklin area due to its very low permeability. Its hydrogeological properties heavily influence groundwater flows in the Kaawa aquifer. However, it is thought that very little to no flow exchange of groundwater exists between the Kaawa aquifer and the Waitematā sediments.

Auckland Council has a record of approximately 1,200 bores in the area. For those drilled after October 1987 (when a bore permit requirement was introduced) bore records include information such as lithological logs, water level, location, drilling contractor and bore owner. However, records of bores drilled prior to 1987 are incomplete. Some records were obtained through land use survey information or resource consent processing (Viljevac et al., 2002). Other available records were obtained from drilling contractors.

4.1.5 Franklin streams

There are seven major surface water catchments that drain from Pukekohe Hill north towards the Manukau Harbour. These include the Waitangi (19.5 km^2), Mauku (38 km^2), Whangamaire (23 km^2), Whāngapōuri (51 km^2), Oira (18.5 km^2) Ngakaroa (38 km^2) and Hingaia (57 km^2) (Viljevac et al., 2002) (Figure 9). The majority of these streams gain water from the Pukekohe volcanic aquifer. Only the Hingaia and Ngakaroa streams gain water from the Bombay and Drury volcanic aquifers. A number of smaller streams flow south from Pukekohe Hill towards the Waikato River, the largest of which is the Tūtaenui Stream.

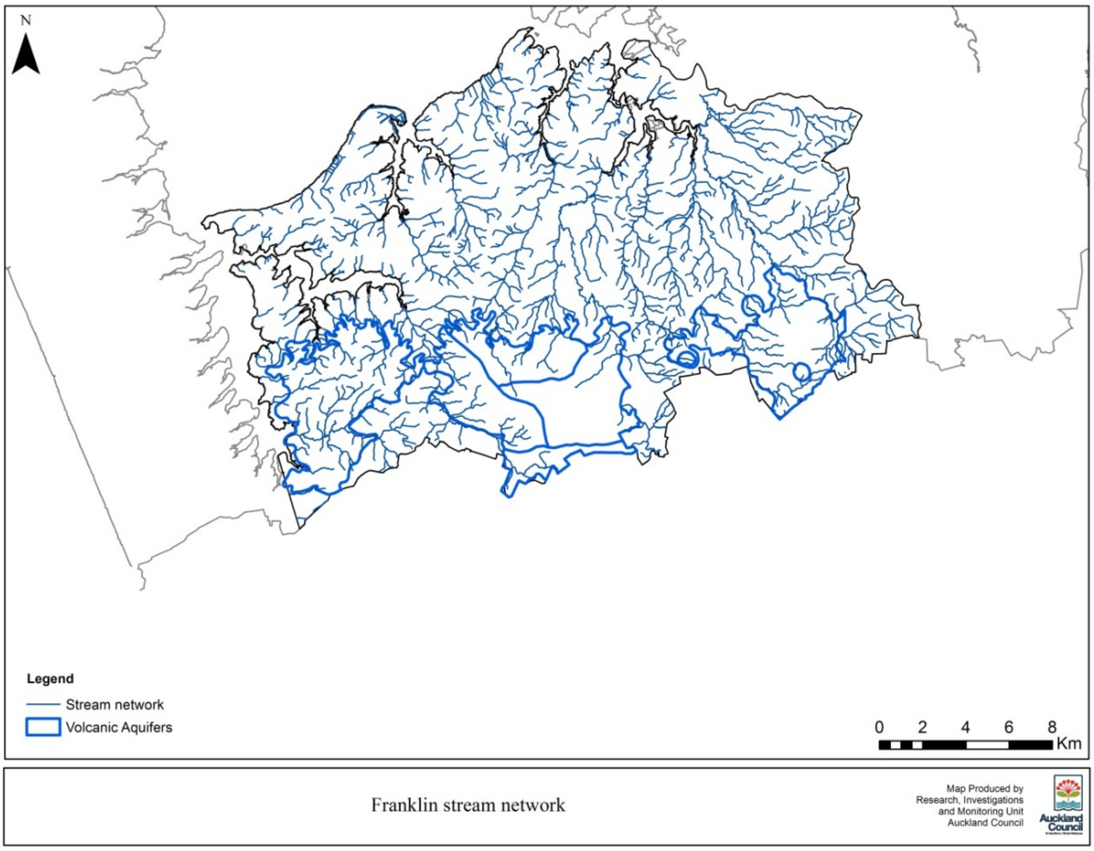


Figure 9: Streams in the Franklin reporting area with the South Auckland volcanic aquifer recharge zones overlaid in blue

4.1.6 Soil, ground and surface water interactions

The soil, groundwater and surface water systems are intricately linked and are influenced by human activities. In Franklin there is a strong interaction between rainfall events and the unconfined South Auckland volcanic aquifers. Aquifer recharge is almost exclusively by drainage of rainfall and irrigation water (Burden, 1982). This is due to the shallow nature and relatively high porosity of the Franklin soils (Auckland Regional Council, 1991). There appears to be a lag time of several months between rainfall events and increases in aquifer water levels. The volcanic aquifers are susceptible to periods of drought and are affected by high rainfall just as the soils are (Viljevac et al., 2002).

These fluctuations in aquifer levels also affect the recharge of the deeper Kaawa aquifer and the numerous ‘gaining’ streams that are fed by groundwater flowing from the Pukekohe Plateau (Auckland Regional Council, 1991, Viljevac et al., 2002). The Whāngapōuri Stream (which flows from Hickey Spring), the Whangamaire Stream (which flows out of Patumāhoe Springs) and the Mauku Stream (which has multiple sources including the Puni Springs) are all fed by aquifers recharged by drainage from the Pukekohe Hill area (Auckland Regional Council, 1991).

4.2 Franklin land use

4.2.1 Land use history

Pukekohe Hill and the wider Franklin area are renowned for vegetable production due to the volcanic soils and relatively frost free climate (Lowe et al., 2010, Basher et al., 1997). With the addition of fertiliser and lime the soils are fertile, well drained, friable and deep. This makes them particularly well-suited to intensive cultivation (Beyda, 1961).

Māori recognised the importance of the area around Pukekohe Hill for vegetable production before Europeans arrived in the area. Pukekohe Hill was cleared of native broad leaved forest between 1876 and 1900 (Lowe et al., 2010). This land remained neglected until the early 1900s when applications of superphosphate transformed the land for vegetable use (Morris, 1965).

The Franklin Times of 24 March (1937) notes that there were 900 acres (364 hectares) of potatoes and more than 200 acres (81 hectares) of onions being cultivated at the time. In the 20 years from 1943 to 1963 the number of market gardens in the Pukekohe area almost tripled from 68 to 193. The average farm size doubled from 18 acres (7.3 hectares) to 38.5 acres (15.6 hectares) (Lee and Lam, 2012) (Appendix D).

The influx of growers from the traditional salad growing areas near Auckland city resulted in the diversification of crops in the Pukekohe Hill area, yet no decline of the importance of potato and onion crops (Hunt, 1959). By 1957, there was a reported 4,000 ha under cultivation (Lee and Lam, 2012). However, from the late 1960s to the late 1970s increases in the cost of production and diminishing returns per ha caused growers to seek economies of scale and many smaller growers sold out to larger growers (Wai Shing, 1977, Wilson, 1973). For example, from 1963-1976 the area under cultivation increased from 3,600 ha to 4,300 ha while the number of growers reduced from 200 to 130 over the same time period (Wai Shing, 1977, Wilson, 1973).

In the face of increasing market pressures in the late 1990s, the vegetable industry lost further medium and small scale growers (Paterson, 2006). Prior to 1997 vegetable produce sales were auctioned at markets where buyers and sellers could directly negotiate prices that largely reflected supply and demand. The system was considered fair by most and those growers who went the extra mile to produce a quality crop were appropriately rewarded (Lee and Lam, 2012). However, the auction system collapsed in 1997 when market structures and buying and selling behaviours changed, coupled with dissatisfaction with the auction system for rapidly expanding corporate buyers. The auction system has now been replaced with direct sales to supermarkets, brokers or agents with prices generally set in advance. In New Zealand two retail organisations have a duopoly in the retail sector and control over 90% of the grocery market (Bava et al., 2009). Notwithstanding the certainty that comes with having set costs and predictable returns, assists growers in their planning, this system doesn't differentiate high-quality produce or speciality market crops and often disadvantages smaller growers (Lee and Lam, 2012). To remain competitive in the conglomerating local and global markets, many growers in the Franklin District began to expand land-holdings, form grower groups, and focus on fewer crops (Christian, 2000, McMillan, 2001).

4.2.2 Current Franklin land use

Vegetable production is still an integral part of the Pukekohe economy today. Pukekohe has some of the highest yields in the country and provides about one-third of New Zealand's fresh vegetable production (Lowe et al., 2010). The area is renowned for its potato and onion production; more of these staple crops are grown for domestic and international markets in Franklin than in any other district in New Zealand (Zealand, 2007).

With regular fertiliser inputs potato yields often exceed 50 t/ha (Lowe et al., 2010). Onion crops can yield greater than 55 t/ha and cabbages 30 t/ha with similar inputs depending on the growing season and market requirements (Lowe et al., 2010). These fertiliser inputs can total between 472 and 491 kg N/ha per crop and occur mainly at 20cm below the soil surface at planting time (Francis et al., 2003). A study by Williams et al (2000) reported rates of 400 – 500 kg N/ha applied to potatoes planted during May/June. Application rates of fertiliser vary from one crop to another but information or data on these rates is not readily available from fertiliser companies due to confidentiality and sensitivity. However, anecdotal information suggests that it is not uncommon to apply one tonne per ha of fertiliser mix to potato and onion crops that reflect the ratio 12:8:8 of N:P:K, respectively (Pukekohe Vegetable Growers Association, pers. comm.).

Data taken from the Landcover Database (LCDB Version 4) illustrates the large extent of short rotational cropping land to the southwest and west of the Pukekohe township (Figure 10). Other areas of short rotational crop land are scattered throughout Franklin with a portion in and around Bombay and Patumahoe. The total area of short rotational crop land is about 6,100 ha or 14% of the Franklin reporting area. A large proportion of this area is located directly above the South Auckland volcanic aquifer recharge areas (Figure 10)

Other rural operations such as dairy and drystock farming are also carried out in the Franklin area. Pastoral land represents the vast majority (31,273 ha or 72%) of the reporting area.

Francis et al., (2003) suggests that average dairy pastures received between 65 and 95 kg N ha^{-1} through April to October. Pasture yields are estimated to be 13.7 and 10.2 t DM/ha/year for dairy and drystock pasture, respectively (Fleming, 2008).

The Pukekohe township urban footprint represents 4% of the reporting area (1,848 ha). This is a 68% increase compared to the 1996 urban footprint. Similarly, native bush/scrub represents 4% of land in the reporting area (Figure 10).

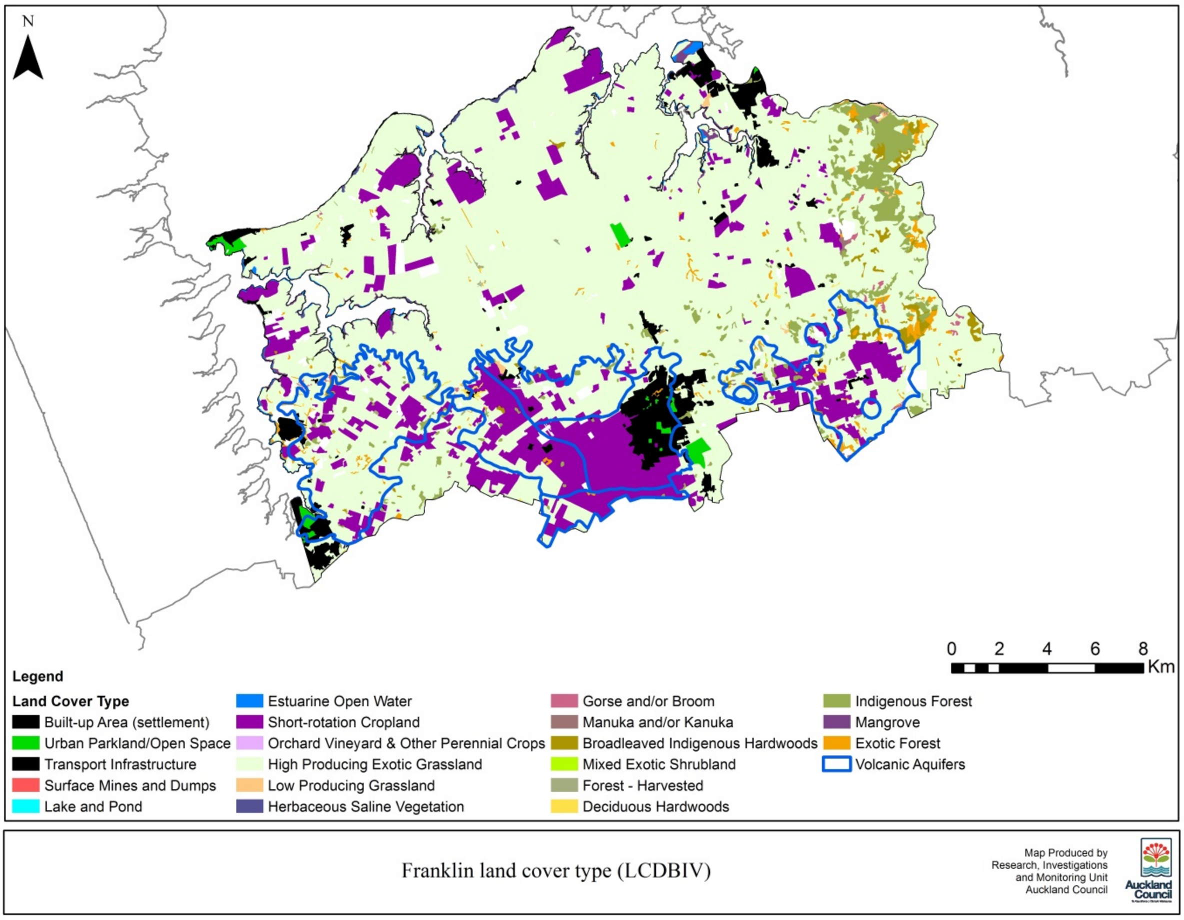


Figure 10: Map of the Franklin area land cover type, taken from Land Cover Database IV (2012) with the South Auckland volcanic aquifer recharge zones overlaid in blue.

4.2.2.1 Stock unit density

The Franklin area stock density map (estimated from an overlay of AgriBase and LCDB version 4) indicates the stock units per ha for a given farm parcel (Figure 11). The orange and red polygons depict farms with an intensive stocking rate (19 - 24+ SU/ha) which tend to be dairy farms.

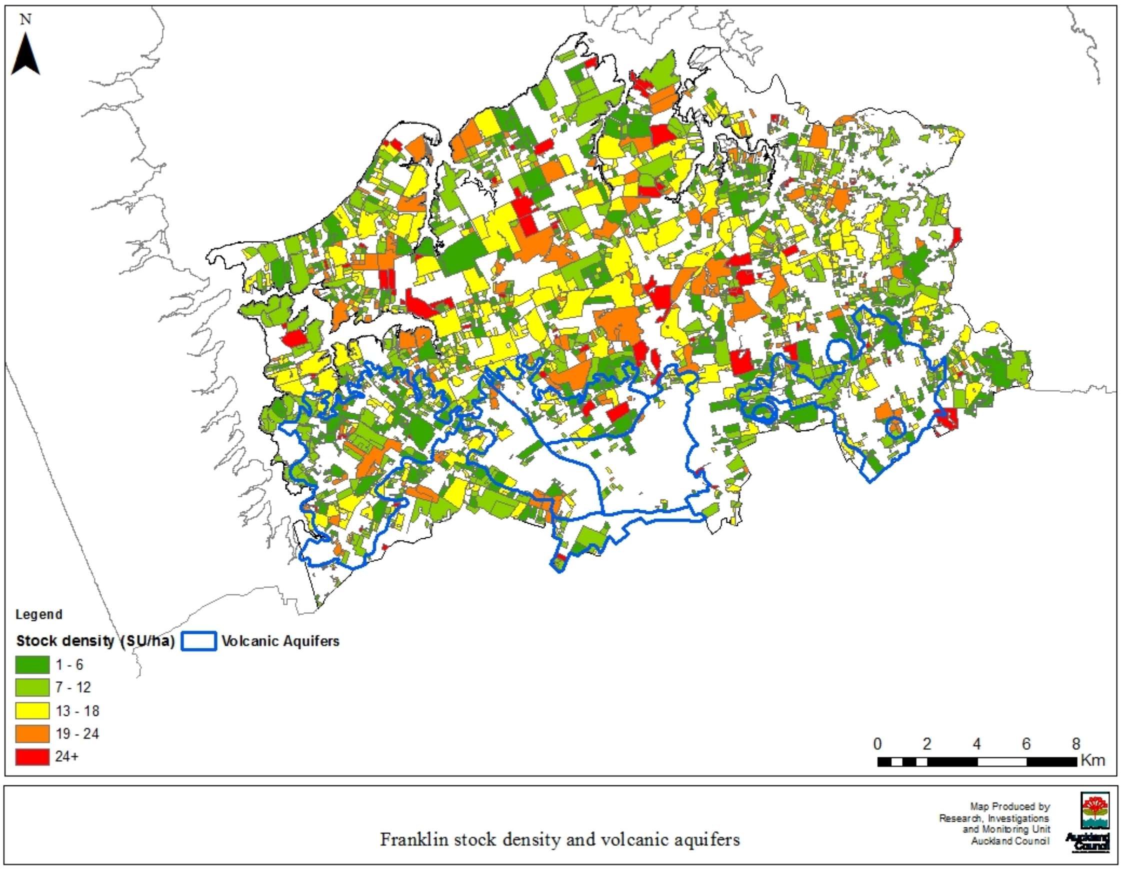


Figure 11: Map of the livestock units per hectare for the Franklin reporting area with the South Auckland volcanic aquifer recharge zones overlaid in blue.

4.2.2.2 Urban wastewater and reticulated water infrastructure

Apart from Pukekohe and Patumahoe, the rest of the South Auckland volcanic aquifer recharge area does not have any reticulated fresh water or wastewater systems. Remaining households within the recharge area have their own septic tank systems; however, the exact number is unknown. Potable water comes from either tank or bore supply.

It is not known whether on-site wastewater systems are contributing to the nitrate load in the volcanic aquifers in the Franklin area. Increased nutrient levels in surface water due to septic tank effluent from human settlement areas have been observed in other parts of New Zealand. For example Gibbs (1977) reported that the discharge of septic tank effluent from a large proportion of Taupō residents have contributed to increasing the nitrate concentration in the groundwater around the periphery of Lake Taupō.

Untreated or partially treated wastewater discharge from poorly maintained or built on-site wastewater systems contain pathogens and nutrients that can be harmful to humans and the environment (MfE, 2008). Development and intensification of rural and urban land has the potential to increase the amount of nitrate nitrogen entering the environment. It may increase by percolating into the groundwater or flowing into nearby waterways if there is no reticulated wastewater infrastructure (MfE, 2008).

5.0 State of the environment soil and water quality monitoring in Franklin area

Auckland Council operates long-term state of the environment (SoE) monitoring programmes across the region. Soil and water quality are regularly monitored in the Franklin area. The location and type of each monitoring site is illustrated in Figure 12.

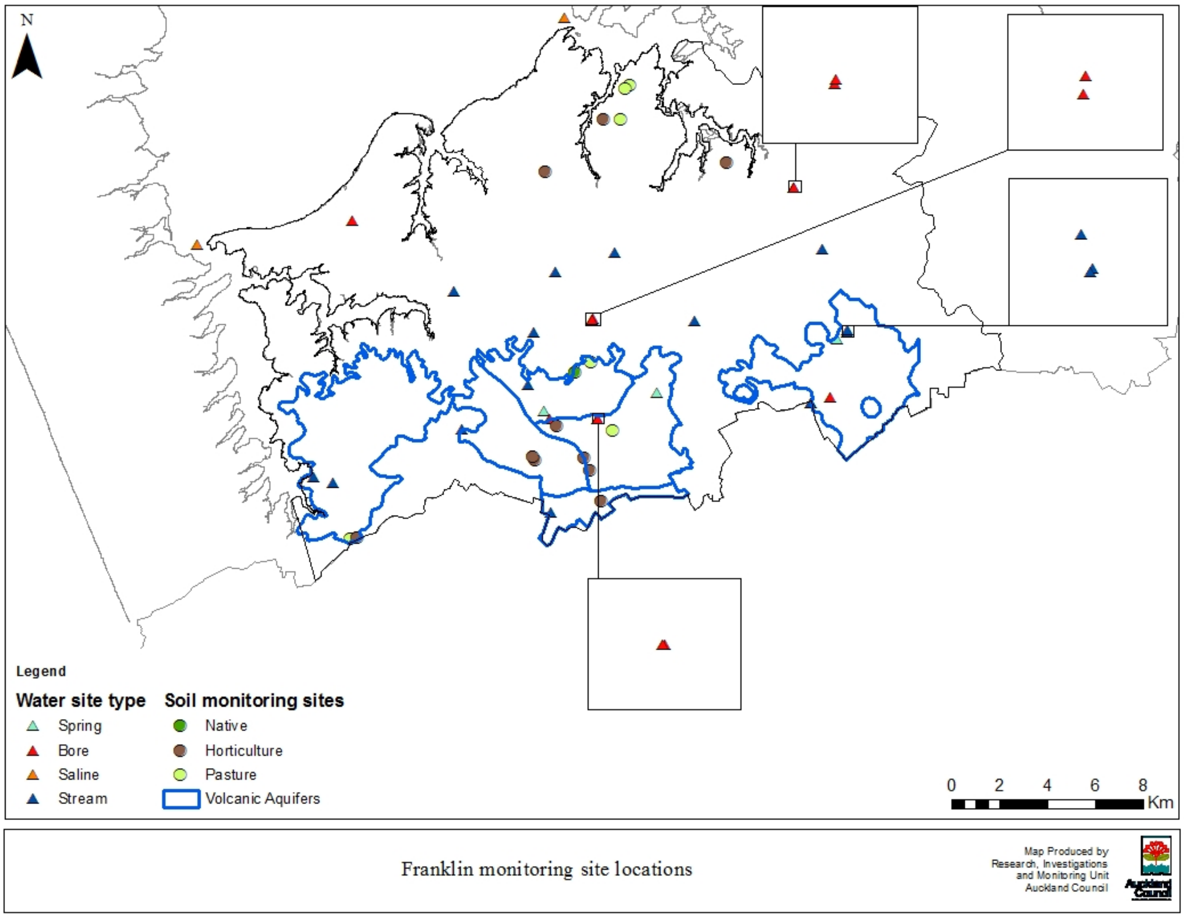


Figure 12: Auckland Council long-term state of the environment water quality and soil monitoring sites with the South Auckland volcanic aquifer recharge zones overlaid in blue.

The soil quality monitoring programme assesses a wide range of parameters and land uses across the Auckland region. There are five different land use categories (pasture, horticulture, plantation forestry, native bush and urban sites). At each location seven key soil quality indicators are measured. These include: soil pH, organic carbon (OC), total nitrogen (TN), anaerobically mineralisable nitrogen (AMN) (nitrogen mineralised under specific laboratory conditions, typically anaerobic incubation at 40ºC for 7 days), Olsen P, bulk density, and macroporosity. Seventeen of these sites are within the Franklin reporting area.

A wide range of water quality parameters are measured in river and groundwater monitoring programmes. For the purposes of this report, only the nitrogen parameters, and those that can potentially affect nitrogen cycling are presented here.

5.1 Soil quality monitoring in the Franklin area

Soil quality refers to the ability of the soil to sustain biological production, maintain environmental quality and promote both plant and animal health (Arshad and Martin, 2002, Cotching and Kidd, 2010, Schloter et al., 2003).

Soil helps regulate water, sustains plant and animal life, filters pollutants, cycle nutrients, and provides structural support. By monitoring easy to measure soil indicators, land managers can determine if particular land uses e.g. dairy farming, are sustainable and whether the soil can perform the functions necessary for its intended use (Karlen, 1997, Larson, 1991). Soil quality is affected by a combination of soil chemical and physical properties. Physical properties include soil structure, depth of soil, infiltration rates, bulk density and water holding capacity. Chemical properties include pH, soil nutrients and fertility, electrical conductance, extractable N-P-K (nitrogen-phosphorus-potassium) and organic matter.

5.1.1 Soil quality results

Seventeen sites are monitored for soil quality in the Franklin area as part of the Auckland SoE monitoring and reporting program (Figure 12).

The eight horticultural sites were last sampled in 2013 (Curran-Cournane et al., 2014a). The one native bush site was last sampled in 2012 (Curran-Cournane, 2013). Native bush sites are important to provide a baseline reference to the soil properties under a relatively unmodified land use. The eight pastoral sites were last sampled in 2009/10 (Stevenson, 2010, Fraser and Stevenson, 2011).

The results indicate Olsen P levels are exceptionally high. They exceed the recommended upper limit of 50mg/kg (Mackay et al., 2013a) by over 300mg/kg in some horticultural, or more specifically, market garden sites (Appendix C). Mean concentrations of Olsen P were also above recommended soil quality guidelines for pastoral farming sites. These results indicate that the levels of phosphorus fertiliser being applied to the soils far exceed what the plants can utilise (Figure 13).

Soil compaction in pastoral systems is a general land management issue in the wider Auckland area (Curran-Cournane et al., 2013). Macroporosity is a measure of the large air filled pore space (macropores) in the soil. It is a sensitive indicator where low macroporosity indicates issues with soil compaction. A compacted soil will be of greater risk of generating nutrient and sediment loss to the receiving environment via surface runoff (Curran Cournane et al., 2011, McDowell et al., 2003).

Trampling by heavy stock and regular heavy traffic movement on soils (especially when soils are at field capacity or saturated) is the greatest contributor to soil compaction. Macroporosity was generally within recommended soil guideline values for horticulture sites but below guideline values for pasture sites (Figure 13).

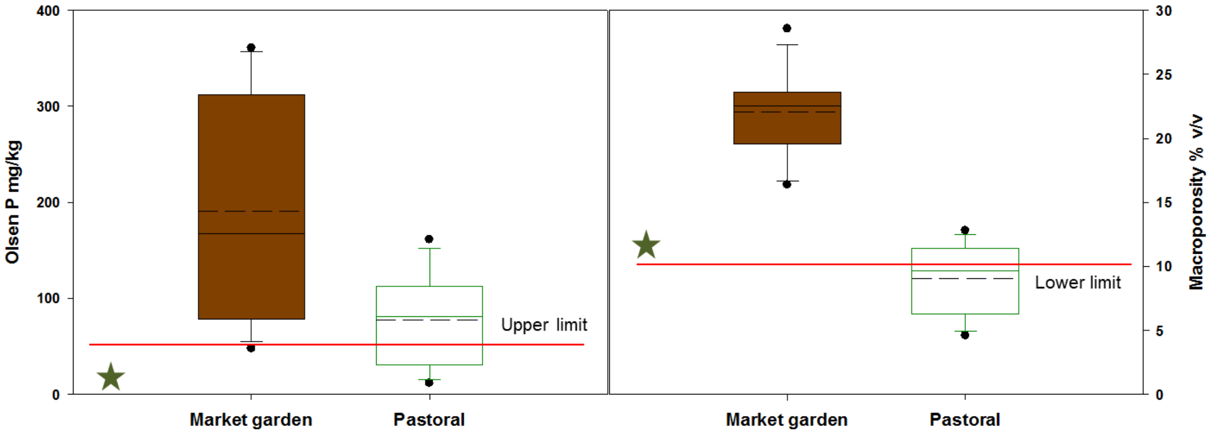


Figure 13: Mean concentrations of Olsen P (left) and macroporosity (right) for market garden and pastoral sites. The star indicates levels for the native bush site. The boxes represent the inter-quartile range (25th and 75th percentile) and the whiskers show the range of values that fall within the 10th and 90th percentile. Median and mean are shown as a straight and dashed line, respectively, in each box while the red line represents the recommended soil guideline value.

Organic carbon (OC) was within the recommended range for the Franklin pastoral sites monitored. In comparison, the OC content within horticultural sites was much lower than the recommended guidelines with the lowest recorded value of 1.8% (Appendix C). This is due to the continuous cultivation practise associated with market gardening activities (Haynes and Tregurtha, 1999).

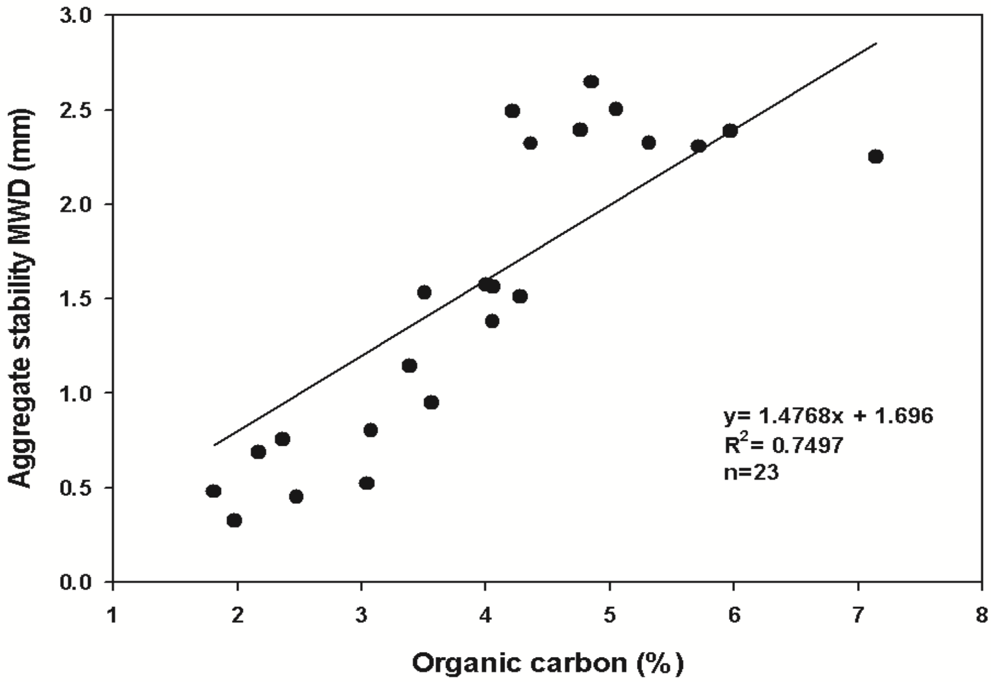


Figure 14: Relationship between organic carbon content and aggregate stability for horticultural sites across Auckland Council's soil quality monitoring network (Curran-Cournane et al., 2014a).

Low carbon content reduces the aggregate stability of the soil making it more susceptible to soil erosion (Figure 14) (Haynes and Tregurtha, 1999, Gradwell, 1971, Basher et al., 1997, Lal, 2015b). Lower aggregate stability and therefore poor soil structure has the added effect of reducing root development and plant vigour. This can significantly reduce a crop's ability to uptake nutrients. It can therefore affect crop production and also increase the likelihood of nutrients being left within the soil system where they can leach during periods of drainage (Haynes and Tregurtha, 1999).

Low levels of OC can lead to the loss of larger soil organisms such as earthworms (Stout and Dutch, 1967). It can also decrease the microbial activity which is supported by the low anaerobic mineralisable N (AMN) values (Figure 15 and Appendix C). Findings from Haynes and Tregurtha (1999) also report a decline in OC levels over time as a result of continuous cultivation. A lack of soil OC within a soil system can increase the likelihood of nutrient leaching which will be discussed in the next section.

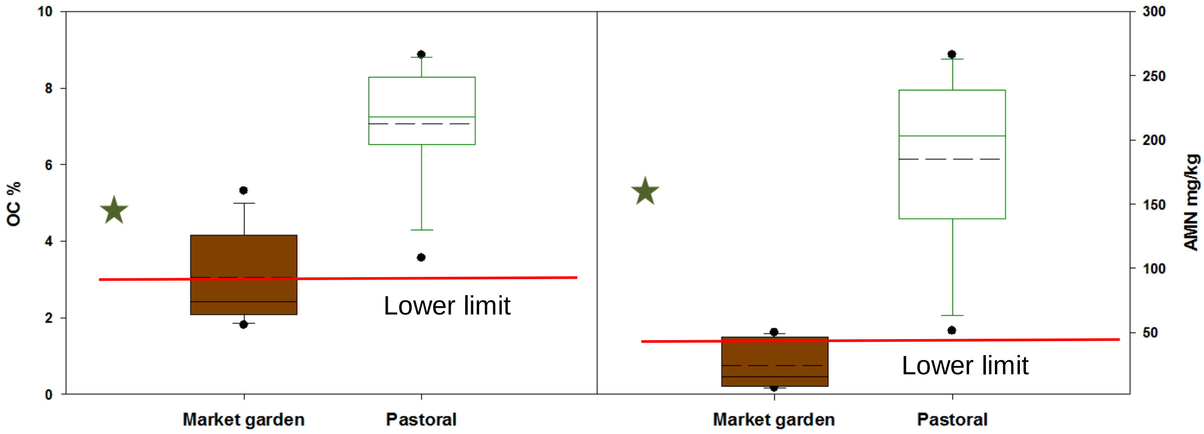


Figure 15: Mean concentrations of organic carbon and AMN for market garden and pastoral sites. The star indicates levels for the native bush site. The boxes represent the inter-quartile range (25th and 75th percentile) and the whiskers show the range of values that fall within the 10th and 90th percentile. Median and mean are shown as a straight and dashed line, respectively, in each box. Redlines indicate lower limits and concentrations of OC and AMN need to be above this line to ensure a fully functioning soil ecosystem (Curran-Cournane, 2015).

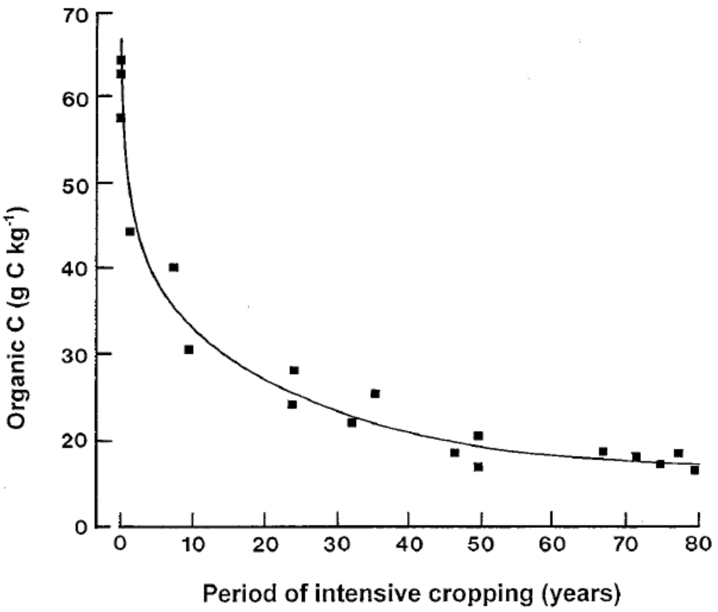


Figure 16: Effects of continuous cultivation on the soil organic carbon (OC) content of a Patumahoe clay loam in Pukekohe (Haynes and Tregurtha, 1999).

5.1.2 Impacts of land use on nitrate leaching

The high levels of nitrogen fertiliser application associated with intensive cropping is a long standing land use issue in the Franklin area and has been reported in a wide variety of reports, conference proceedings and research papers e.g. Cathcart (1996), Crush et al., (1997), Francis et al., (2003), Ledgard et al., (1997), Scoble (2000) and Williams et al., (2000). The high levels of nitrate in groundwater and streams in the reporting area can be linked to the quality of soil under this particular land use activity.

The current soil quality monitoring programme highlights a key issue of decreasing OC content in intensive market gardening systems, which increases the soil's vulnerability to nitrate leaching. For example, average nitrate leaching losses from dairy paddocks were about an eighth of that leached from potato paddocks in the Pukekohe area (Francis et al., 2003). Potato crops receive large amounts of N fertiliser and high N leaching losses under this crop was reported to be largely attributed to the lack of soil organic carbon in these intensive cropping systems (Crush et al., 1997).

A study by Gradwell (1971) found that a Patumahoe clay loam soil (a Granular soil) that had recently been cultivated from pasture to market gardening had an organic carbon content in excess of 5% weight. In comparison, Patumahoe clay loam soils that had been regularly cultivated and intensively cropped for vegetable production for at least a generation had an organic carbon levels of just 2%. The relationship between intensive cropping practice and the amounts of organic carbon present in the soil system in Pukekohe is outlined in Figure 16.

Table 4: Summary of the nitrogen balance data for different land uses (dairying and orcharding values are annual figures, others are for an individual crop) (Crush et al., 1997).

	No.	Mean N input	Mean N output	-- kg surplus N/ha -- Mean	Range
Dairying	5	241	84	157	142–178
Early potatoes	8	543	115	429	282–587
Main crop potatoes	8	268	176	92	29–181
Onions	14	241	123	118	17–230
Kiwifruit	4	337	171	166	124–211
Persimmons	1	116	90	26	
Winter lettuce	3	430	144	286	245–359
Summer lettuce	3	370	184	186	161–211
Squash	3	326	88	238	123–401
Summer cabbage	1	249	81	168	
Winter cabbage	1	301	59	242	
Pumpkins	1	212	92	120	

Table 5: Potential contribution of different land uses to groundwater nitrate in Pukekohe (Crush et al., 1997).

Activity	Nominal area (ha) and % of total area		Surplus N (kg/ha)	Potentially leachable N (tonnes) and% of total N	
Dairying	377	8.2	157	59	9.6
Dry stock farming	1884	40.9	30	57	9.3
Kiwifruit	133	2.8	166	22	3.5
Onions	892	19.4	118	105	17.1
Main crop potatoes	338	7.3	92	31	5.0
Early potatoes	506	11.0	429	217	35.4
Winter cabbage	94	2.0	242	20	3.2
Summer cabbage	94	2.0	168	16	2.6
Winter lettuce	35	0.7	286	10	1.6
Summer lettuce	35	0.7	186	7	1.1
Squash	105	2.2	238	25	4.0
Pumpkin	105	2.2	120	13	2.1
Sewage				30	4.9
Totals	**4598**		**612**		

Furthermore and as previously noted, Williams et al (2000) reported application rates of 400–500 kg N/ha to potato crops planted during May/June. These application rates occur at a time of year when soil temperatures and therefore plant growth and nutrient uptake are low. This can lead to large N leaching losses as high as 320 kg N/ha in a wetter than average winter (Ledgard et al., 1997).

When the N balance (inputs minus outputs) for the area of land under a variety of land uses in Pukekohe was calculated, early potatoes were reported to have the greatest risk of N leaching (217 t N/ha) followed by onions, dairying and drystock farming land uses at 105 t N/ha, 59 t N/ha and 57 t N/ha, respectively. Other land use activities such as kiwifruit, summer cabbage, winter lettuce, squash and pumpkin contributed to < 30 t N each (Crush et al., 1997), (Table 5).

Management practices that contribute to large N leaching losses include the high rates of N fertiliser application to crops; a long history with intensive cultivation which reduces the amount of organic carbon content of the soil and the ability of the soil to immobilise mineral N; and the lack of cover crop usage to retain N in the topsoil and restore the carbon content of the soil (Crush et al., 1997).

Nitrate concentrations in the volcanic aquifers of Pukekohe exceed the New Zealand drinking water standards (11.3 mg/L as N) and it has been reported that solutions to this problem requires an improved and integrated approach to soil and water management (Basher et al., 1997). The quality of surface and groundwater for the reporting area in recent years is outlined in the next section.

5.2 Groundwater monitoring in the Franklin area

Auckland Council operates a long-term groundwater quality monitoring programme, of which eight sites are currently located in the Franklin area. Geological and Nuclear Sciences (GNS) operates a national groundwater monitoring programme where four sites are located in the Franklin area. Sites within Auckland Council's groundwater quality monitoring network were selected based on the extent of groundwater use and/or intensive land use in the area.

Currently, groundwater sampling and analysis is carried out quarterly at all sites. Prior to 2012, there was a different monitoring regime, where some sites were sampled quarterly, three times per year, twice per year or annually. As a result of this previous regime, the total number of data points differs considerably between sites.

5.2.1 Franklin groundwater N concentrations

This section reports groundwater N concentrations from 1998 to 2013 at state of the environment monitoring sites (Figure 12).

Groundwater nitrate concentrations ranged from 0.0 to 36.1 mg nitrate-N/L. The greatest concentrations observed were at the Hickey Spring, Gun Club Road and Patumāhoe Spring sites. The BP Bombay, Hillview Spring and Rifle Range Road 2 sites had nitrate-N concentrations ranging between 1.0 - 27.0 mg nitrate-N/L (Figure 18a).

Some of these nitrate-N concentrations are considerably high and exceed:

- trigger values for the preservation of species in the ANZECC (Australia and New Zealand Environment and Conservation Council) water quality guidelines (4.9-12.0 mg nitrate-N/L)
- National Objectives Framework (NOF) national bottom line for nitrate toxicity (6.9 mg nitrate-N/L), and
- Ministry of Health (MoH) drinking water guidelines (11.3 mg nitrate-N/L).

Groundwater nitrite concentrations were mostly below the laboratory detection limit (<0.002 mg nitrite-N/L) and ranged from <0.002 to 0.04 mg nitrite$^-$-N/L (Figure 17b).

Groundwater ammonium concentrations ranged from 0.0 to 1.00 mg ammonium-N/L. Although there is an obvious difference in NH_4^+ concentrations between some sites (Figure 18a), all ammonium concentrations are well below the National Objectives Framework (NOF) national bottom line value (1.3 mg ammonium-N/L).

The Seagrove Road, Ostrich Farm Road 1 and 2, Fielding Road sand and volcanic, and Rifle Range Road 1 sites are all characterised by low (anoxic) dissolved oxygen conditions (median ranging from 0.07 to 0.17 mg/L) (Figure 18b). This suggests reducing conditions in these aquifers. The low nitrate concentrations at these sites (Figure 17a) could suggest that little to no mixing is occurring between these aquifers and the shallower volcanic aquifers with high nitrate concentrations.

There could be mixing between the two aquifers occurring, but a dilution effect could make this difficult to observe. Alternatively, there may be a carbon source in these aquifers, which, coupled with the anoxic conditions, would provide ideal conditions for denitrification (to nitrous oxide, N_2O or di-nitrogen gas, N_2) of nitrate that enters the aquifer.

Prior to 1977 Pukekohe Borough water was supplied from a shallow spring, Hickey Spring. The nitrate level of the spring progressively increased from 6.5 mg nitrate N/L in 1959, to 12.6 mg nitrate N/L in 1980. These figures represent an average increase of 0.28 mg nitrate N/L per year (Burden, 1982). It has subsequently increased to 20 mg nitrate N/L in 2015 (Figure 17). The spring supply has since been replaced and Pukekohe township now has a reticulated water main.

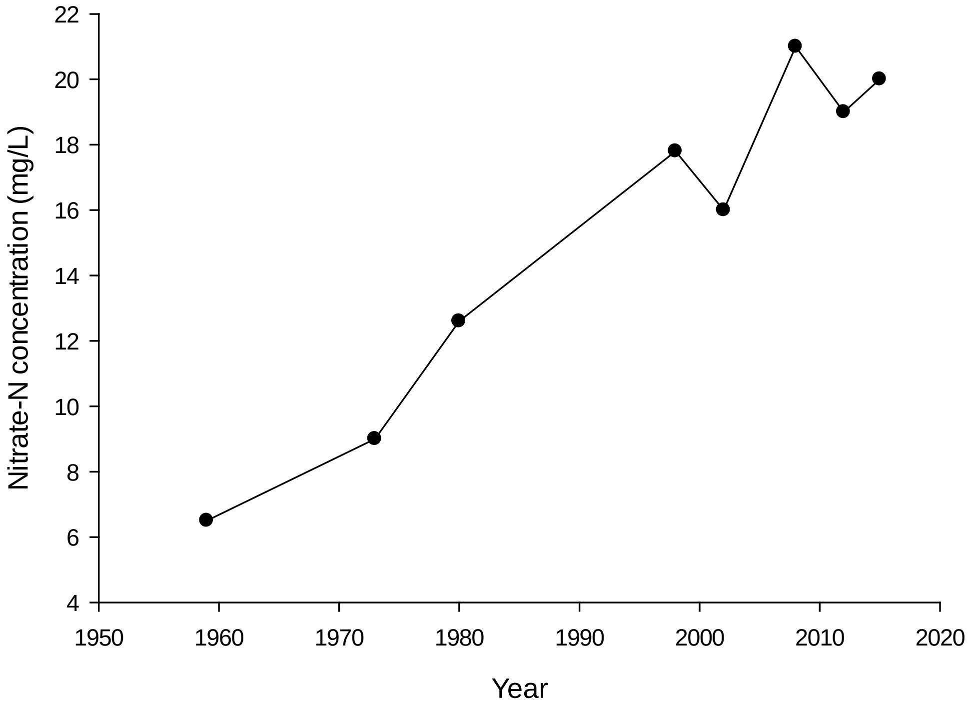
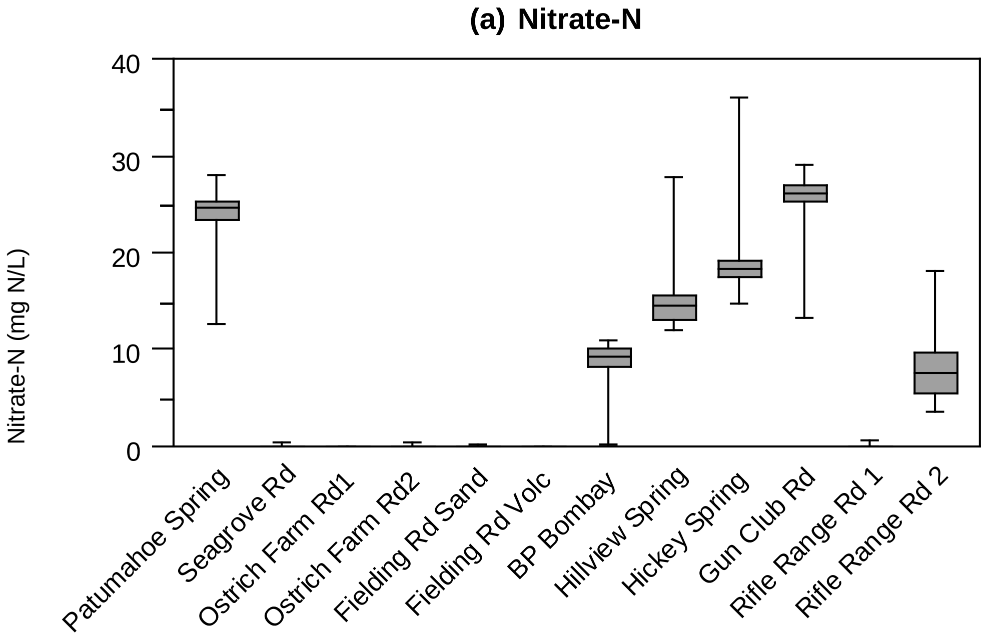


Figure 17: Nitrate-N concentrations at Hickey Spring from 1959 to 2015.



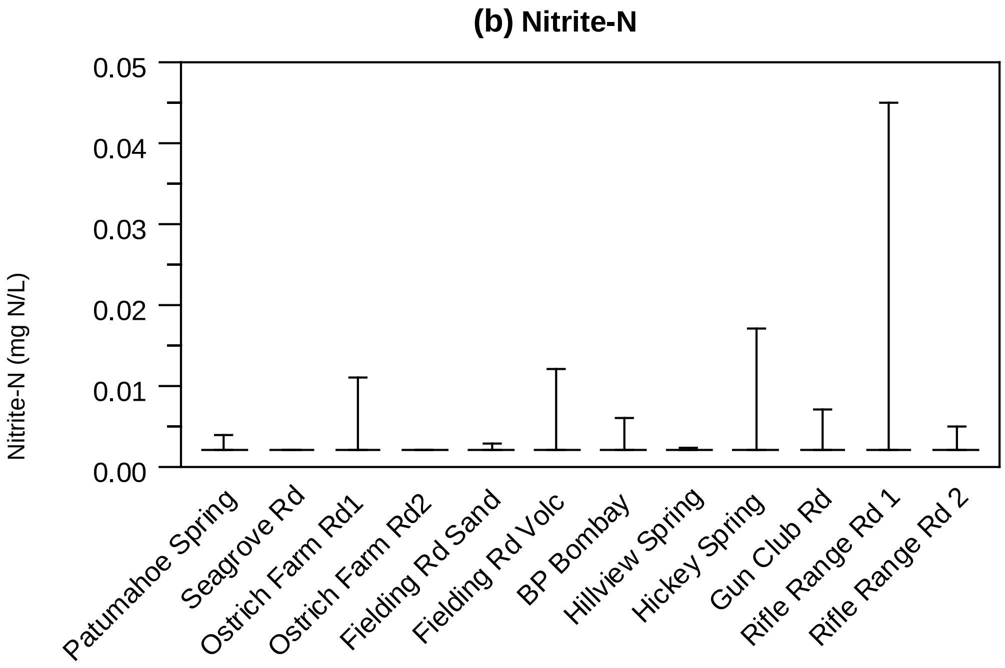


Figure 18: Box plots showing the full set of (a) nitrate-N and (b) nitrite-N at all groundwater and spring sites in the Franklin area. The boxes represent the interquartile range, the mid-line is the median, and the bars show the maximum and minimum values.

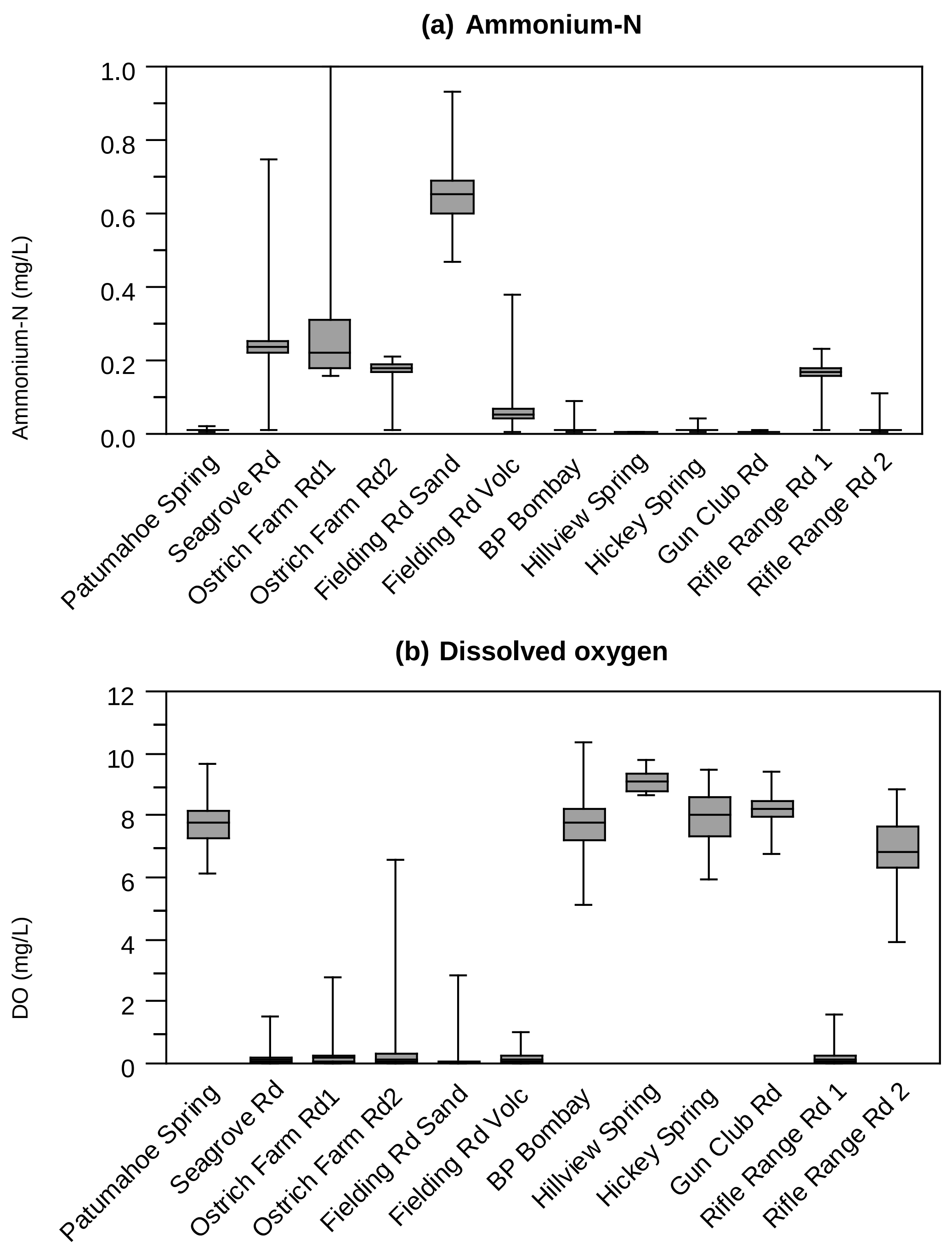


Figure 19: Box plots showing the full set of (a) ammonium-N and (b) dissolved oxygen at all groundwater and spring sites in the Franklin area. The boxes represent the interquartile range, the mid-line is the median, and the bars show the maximum and minimum values.

Table 6: Water quality statistics for ammonium, nitrate and nitrite at groundwater sites from 1998 to 2013.

Site	Count	Min	Max	Median	Mean	Standard Error
Ammonium (mg NH_4^+-N/L)						
BP Bombay	66	0.01	0.09	0.01	0.01	0.001
Fielding Rd Sand	25	0.47	0.93	0.65	0.65	0.018
Fielding Rd Volc	58	0.01	0.38	0.05	0.06	0.007
Gun Club Rd	12	0.01	0.01	0.01	0.01	0.000
Hickey Spring	34	0.01	0.04	0.01	0.01	0.002
Hillview Spring	9	0.01	0.01	0.01	0.01	0.000
Ostrich Farm Rd1	30	0.16	1.00	0.22	0.3	0.037
Ostrich Farm Rd2	62	0.01	0.21	0.18	0.17	0.004
Patumāhoe Spring	33	0.01	0.02	0.01	0.01	0.000
Rifle Range Rd 1	61	0.01	0.23	0.17	0.17	0.004
Rifle Range Rd 2	62	0	0.11	0.01	0.01	0.001
Seagrove Rd	64	0.01	0.75	0.23	0.24	0.010
Nitrate (mg NO_3^-N/L)						
BP Bombay	67	0.14	11	9.27	9.07	0.181
Fielding Rd Sand	25	0	0.25	0	0.01	0.010
Fielding Rd Volc	58	0	0.07	0.01	0.01	0.001
Gun Club Rd	12	13.3	29	26.15	24.93	1.296
Hickey Spring	138	14.8	36.1	18.4	18.57	0.191
Hillview Spring	9	12	27.8	14.6	15.54	1.607
Ostrich Farm Rd1	30	0	0.02	0	0	0.000
Ostrich Farm Rd2	62	0	0.5	0.01	0.02	0.008
Patumāhoe Spring	141	12.6	28	24.6	24.24	0.163
Rifle Range Rd 1	61	0	0.61	0	0.02	0.010
Rifle Range Rd 2	64	3.54	18	7.6	8.6	0.511
Seagrove Rd	64	0	0.39	0.01	0.02	0.006
Nitrite-N (mg NO_2^-N/L)						
BP Bombay	66	0	0.01	0	0	0.000
Fielding Rd Sand	26	0	0	0	0	0.000
Fielding Rd Volc	58	0	0.01	0	0	0.000
Gun Club Rd	12	0	0.01	0	0	0.000
Hickey Spring	74	0	0.02	0	0	0.000
Hillview Spring	9	0	0	0	0	0.000
Ostrich Farm Rd1	30	0	0.01	0	0	0.000
Ostrich Farm Rd2	23	0	0	0	0	0.000
Patumāhoe Spring	77	0	0	0	0	0.000
Rifle Range Rd 1	56	0	0.04	0	0	0.001
Rifle Range Rd 2	58	0	0.01	0	0	0.000
Seagrove Rd	22	0	0	0	0	0.000

5.2.2 Trends

Seasonally adjusted trend analyses were carried out for ammonium-N, nitrate-N and nitrite-N at all sites where data was available from 1998-2014. This analysis was done using TimeTrends Trend and Equivalence Analysis V5.0 (Jowett Consulting). Trend significance is reported at the 95% confidence level ($P < 5\%$).

There were significant declining trends in ammonium in groundwater at three sites in the Franklin area (Patumāhoe Spring, Seagrove Rd and Ostrich Farm Rd1), and one small increasing trend at one site (Ostrich Farm Rd2) (Figure 19).

There were no significant trends in nitrite concentrations (Table 7).

There were significant increasing trends in nitrate concentration at three sites (BP Bombay, Hickey Spring and Rifle Range Rd2) (Figure 20). There were also increasing trends in nitrate concentrations at other sites in the Franklin area. However, because these sites have comparatively short data sets, they were not included in this long-term trend analysis.

These increasing nitrate trends are from high 1998 baseline nitrate concentrations. These increasing nitrate trends suggest increasing inputs of nitrate to the groundwater, most likely via leaching. High concentrations of nitrate in soil to facilitate nitrate leaching likely originate from a range of inputs and land uses including nitrogenous fertiliser inputs, stock excretion, effluent discharge and background soil N.

Land management practises such as fertiliser and/or effluent application timing, stock management over winter and use of cover crops could also influence soil nitrate concentrations and therefore nitrate leaching risk.

There are no explicit environmental guideline values for nitrate in groundwater. However, the connections between groundwater and surface water in the Franklin area have implications for nitrate concentrations in surface water bodies. This is already being seen where some spring-fed rivers in the Franklin area exhibit nitrate concentrations that exceed the surface water guidelines and national bottom line values (see Section 5.3). This means mitigation and management strategies will be required to ensure these concentrations are reduced.

Table 7: Slope and significance levels of seasonally adjusted trends in ammonium-N, nitrate-N and nitrite N in groundwater at all sites.

Site	Count	Data collection record	Slope (% per yr)	P value (5% sig level)
Ammonium-N				
Patumāhoe Spring	62	1998-2014	-2.59	**0.004**
Seagrove Rd	60	1998-2014	-2.18	**0.013**
Ostrich Farm Rd1	29	1998-2014	-7.95	**< 0.001**
Ostrich Farm Rd2	61	1998-2014	0.06	**0.048**
Fielding Rd Sand	25	1998-2014	-1.08	0.08
Fielding Rd Volc	58	1998-2014	-4.27	0.06
BP Bombay	60	1998-2014	-1.34	0.66
Hickey Spring	61	1998-2014	-0.35	0.79
Rifle Range Rd 1	60	1998-2014	0.39	0.49
Rifle Range Rd 2	60	1998-2014	2.79	0.36
Nitrate-N				
Patumāhoe Spring	62	1998-2014	-0.22	0.25
Seagrove Rd	60	1998-2014	-6.11	0.32
Ostrich Farm Rd1	29	1998-2014	3.41	0.37
Ostrich Farm Rd2	61	1998-2014	4.23	0.56
Fielding Rd Sand	25	1998-2014	3.67	0.81
Fielding Rd Volc	58	1998-2014	2.86	0.43
BP Bombay	60	1998-2014	1.84	**< 0.001**
Hickey Spring	61	1998-2014	0.81	**0.004**
Rifle Range Rd 1	60	1998-2014	7.16	0.51
Rifle Range Rd 2	60	1998-2014	8.84	**< 0.001**
Nitrite-N				
Patumāhoe Spring	62	1998-2014	-0.06	0.85
Seagrove Rd	60	1998-2014	No trend	No trend
Ostrich Farm Rd1	29	1998-2014	0.29	0.93
Ostrich Farm Rd2	61	1998-2014	No trend	No trend
Fielding Rd Sand	25	1998-2014	0.02	0.96
Fielding Rd Volc	58	1998-2014	2.84	0.12
BP Bombay	60	1998-2014	0.60	0.41
Hickey Spring	61	1998-2014	-1.66	0.41
Rifle Range Rd 1	60	1998-2014	-7.43	0.21
Rifle Range Rd 2	60	1998-2014	-1.31	0.07

*****bold numbers indicate statistically significant trends at the 95% confidence level.

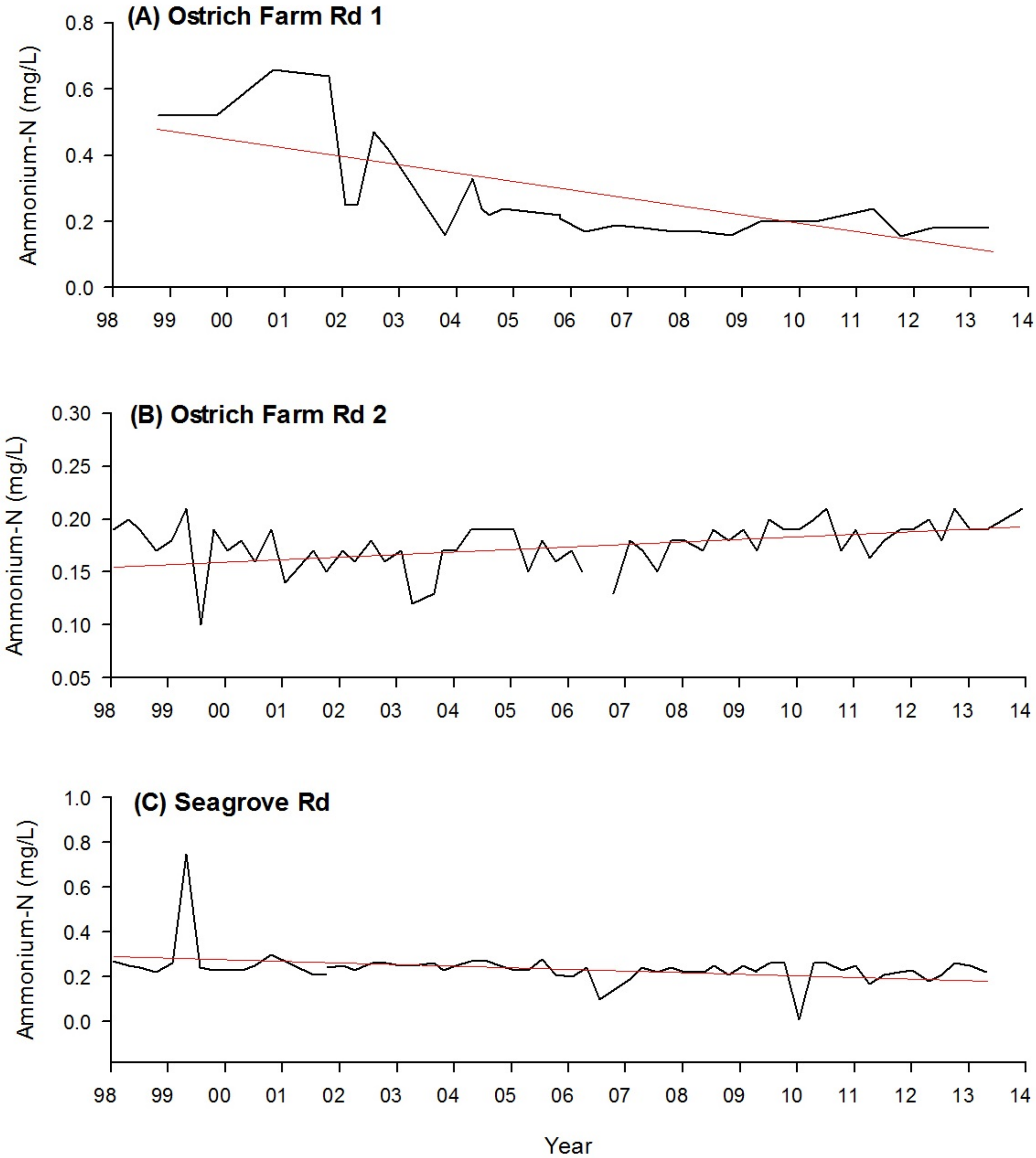


Figure 20: Significant trends in groundwater ammonium (NH_4^+-N) data at (A) Ostrich Farm Rd1, (B) Ostrich Farm Rd 2, and (C) Seagrove Rd.

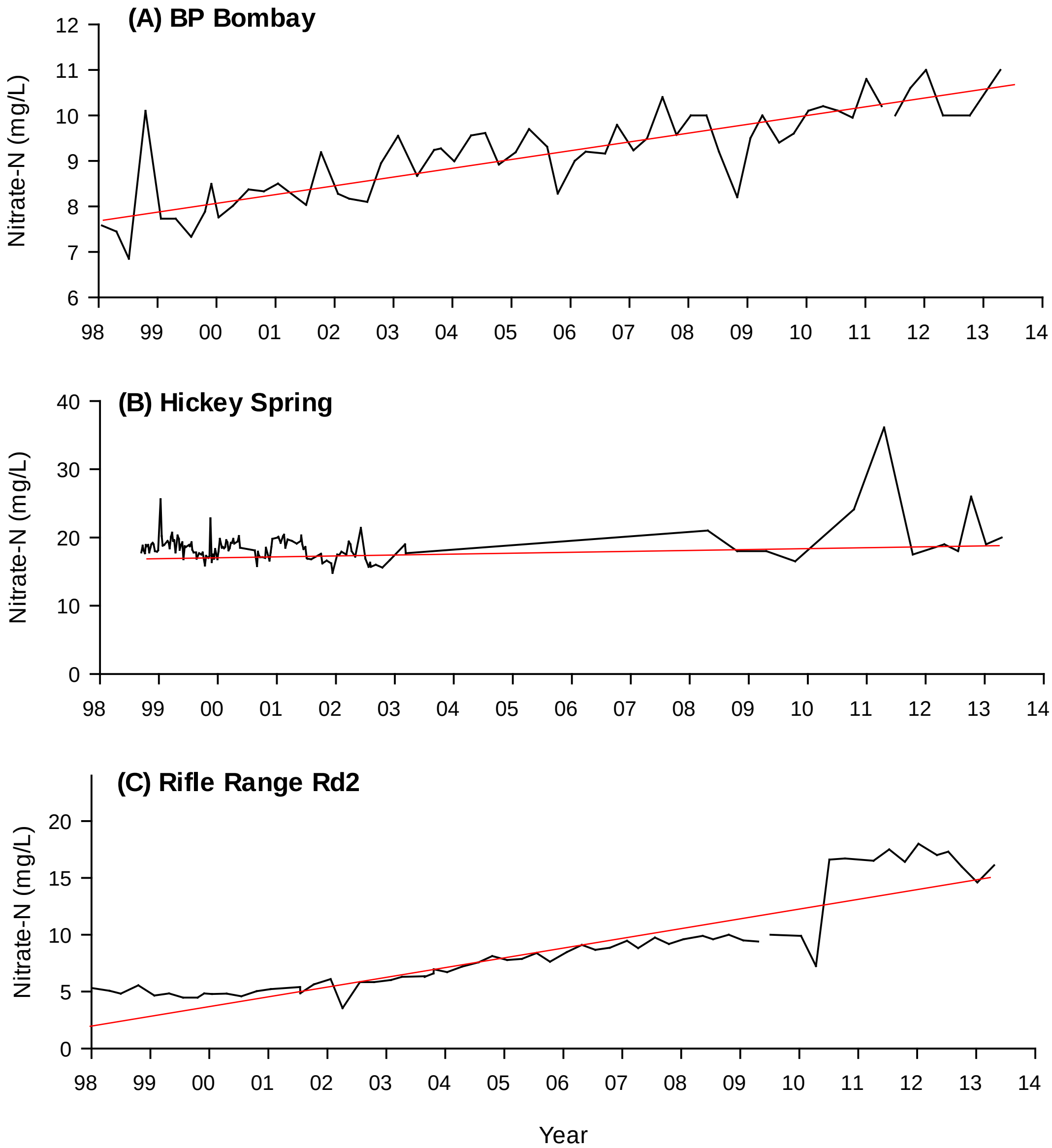


Figure 21: Significant trends in groundwater nitrate (NO_3^--N) data at (A) BP Bombay, (B) Hickey Spring and (C) Rifle Range Rd 2.

5.2.3 Groundwater age

The mean residence time (age) of groundwater in the Franklin shallow volcanic aquifers has recently been investigated by the Auckland Council Franklin Nitrate Group. Mean residence time (MRT) of shallow groundwater was determined at a total of ten bores in Pukekohe and Bombay in 2014 (van der Raaij, 2015) . A range of methods were used to predict mean residence time, including hydrochemistry, the tritium isotope and dissolved gases (CFCs and SF_6).

The MRT of groundwater from bores tested in the Bombay and Pukekohe aquifer systems ranged between 16 years and 99 years. Groundwater in Bombay aquifers showed an increase in MRT both in the direction of groundwater flow and with depth. Groundwater from Pukekohe in the upper aquifer generally had MRT younger than 50 years; and the oldest ages were seen in the lower volcanic aquifer system.

Table 8: Groundwater mean residence time (MRT). % Exponential defines the spread of the residence time distribution – a low percentage gives a narrow distribution and a high percentage a wide distribution

Well ID	Depth of sampled interval (m)	% Exponential	MRT (years)
B1	15 – 26.5	30	27 (24 – 30) [1]
B2	49.6 – 58	30	35 (33 – 39)
B3	21 – 43	30	70 (69 – 71)
B4	61.9 – 77	35	> 91
B5	? - 68	30	80 (77 – 91)
BP	65.3 – 79.4	30	63 (62 – 64)
BW	45.7 – 73	30	37 (36 – 38)
P1	24.8 – 37	70	23 (20 – 27)
P2	22 – 40.4	70	16 (14 – 19)
P3	49.7 – 72	40	99 (> 89)
P4	18.7 – 28	30	52 (47 – 56)
P5	29.2 – 42	90	38 (36 – 40)
PA	14 – 24.4	30	28 (27 – 29)
PW	46 – 78	30	89 (> 66)

1. The stated model age ranges for all wells (in brackets) result from the 95% confidence interval based on the uncertainty in tracer concentrations only and do not account for the uncertainty in ascertaining the model parameters.

Statistically significant positive relationships were found between MRT and pH, bicarbonate, dissolved reactive phosphorus, potassium, and to a lesser extent, silica. These analytes have the potential to be used as proxies for groundwater age.

Nitrate concentrations showed an inverse relationship with groundwater MRT. This is common for analytes associated with land use changes and intensification. The chemistry of younger waters reflected the impacts of recent land use, while older water retained the chemical signature of less-impacted recharge sources. However, it is difficult to use such a relationship as a groundwater age proxy as the variability in nitrate concentrations for young groundwaters is primarily a function of land use, not MRT. Although old groundwater at some wells was anoxic, there was no evidence of denitrification.

5.2.4 Groundwater and surface water connection in Franklin

There is limited information about groundwater and surface water connection in the Franklin area. Auckland Council has previously calculated baseflow ratios to predict groundwater contribution for several Franklin streams, to assist with water allocation (Wells, 2009).

Research from a recent thesis (Lironi, 2011) attempted to determine the groundwater contribution to a range of Franklin stream sites including the Hingaia, Maketū, Mauku, Ngakaroa, Oira, Puhitahi, Waitangi, Whangamaire and Whāngapōuri Streams (Table 9). A range of methods were employed to determine groundwater and surface water connection, including:

- hydrochemistry (iron, manganese, nitrite, and electrical conductivity);
- stream specific discharge (SSD), and;
- baseflow ratios.

Results of this investigation are detailed below:

Table 9: Stream sampling sites and underlying groundwater aquifer (Lironi, 2011).

Stream site	Aquifer
Waitangi DS	Glenbrook Volcanic
Whangamaire Whangamaire DS Whāngapōuri Mauku Mauku DS	Pukekohe Volcanic
Hingaia Trib Hingaia Upper Hingaia Lower Ngakaroa	Bombay Volcanic
Maketū Oira Puhitahi	Non-Volcanic aquifers (not part of the South Auckland volcanics)

Hydrochemistry

Iron (Fe), manganese (Mn) and nitrite (NO^{2-}) were unsuccessful tracers of groundwater influence at all measured stream sites. Concentrations were similar across all stream sites. Therefore, the use of these tracers may only be useful in the zone of groundwater upwelling.

The stream sites showed statistically significant differences for conductivity. Sites with higher conductivity values were found to have a greater groundwater contribution. The sites with the highest conductivity were the Hingaia tributary, Mauku, Whangamaire DS and Whāngapōuri Streams (Lironi, 2011).

Conductivity shows promise as a groundwater tracer. However, further work is needed to separate the effects of geology and catchment land use on conductivity results.

Stream specific discharge

Stream Specific Discharge (SSD) is the amount of discharge per unit of catchment area. It is calculated using Mean Annual Low Flow (MALF), and is measured in L/s/km^2. Specific discharge allows a direct comparison between sites. Streams with a high SSD generally have a high groundwater input.

Stream Specific Discharge (SSD) results for the South Auckland volcanic streams showed that the Whangamaire Stream has the greatest groundwater contribution (SSD of 22 L/s/km^2) (Table 10). The Hingaia tributary had the second highest SSD of ≈12.3 L/s/km^2, followed by the Hingaia lower, Mauku downstream and Whāngapōuri Stream sites (SSD range 4.1-7.5 L/s/km^2). The streams with the lowest groundwater contribution were the Hingaia upper, Maketū, Ngakaroa, Oira and Waitangi downstream sites (SSD range 0.8-2.6 L/s/km^2).

Table 10: Groundwater contribution measured by Stream Specific Discharge (SSD) for a number of South Auckland volcanic aquifer stream sites (Lironi, 2011). MALF is Mean Annual Low Flow. Dashed lines '-' represent data is unknown. 'DS' stands for downstream site.

Stream Site	MALF (L/s)	SSD (L/s/km^2)
Hingaia upper	80	≈2
Hingaia trib	37	≈12.3
Hingaia lower	190	<4.3
Maketū	29.3	2.4
Mauku	19.5	4.3
Mauku DS	69	4.11
Ngakaroa	12.5	2.6
Oira	4.7	0.8
Puhitahi	-	-
Waitangi DS	38	2.1
Whangamaire	82	22
Whangamaire DS	-	-
Whāngapōuri	20.8	7.5

Baseflow ratios

Baseflow ratios are calculated by comparing the 90^{th} and 50^{th} flow percentiles, and the higher this ratio the more groundwater is contributing to the stream. Baseflow ratios for the South Auckland volcanic streams showed that the Whangamaire Stream was predominately fed by groundwater (80%). The Hingaia tributary, Hingaia lower and Whāngapōuri Stream sites had significant groundwater contributions, ranging from 45-49% (Table 11).

The Maketū, Mauku, Ngakaroa and Waitangi DS stream sites showed a moderate groundwater contribution (27-35%). Baseflow ratios for the Hingaia upper and Oira Stream sites indicated that groundwater connectivity was low (13-14%). No baseflow ratios were available for the Mauku DS, Puhitahi and Whangamarie DS sites.

Table 11: Groundwater contribution (measured by baseflow ratio) to a number of South Auckland volcanics stream sites (Lironi, 2011). 'DS' stands for downstream site.

Stream Site	Baseflow Ratio[1]	AC Calculated Ratio[2]
Hingaia upper	0:14	-
Hingaia trib	0:46	-
Hingaia lower	0:45	-
Maketū	0:27	-
Mauku	0:35	-
Mauku DS	-	-
Ngakaroa	0:31	0:32
Oira	0:13	-
Puhitahi	-	-
Waitangi DS	-	0:35
Whangamaire	0:80	0:75
Whangamaire DS	-	-
Whāngapōuri	0:49	-

[1] Lironi (2011) data. [2] Wells (2009) calculated ratio.

5.3 Surface water quality monitoring in the Franklin area

The Auckland Council operates a long-term river water quality monitoring programme throughout the region. The objective of this programme is to describe and monitor the quality of the Auckland region's freshwater resources. This allows ongoing assessment and evaluation of the effects of environmental stressors and the efficacy of the council's policy initiatives and management approaches.

The programme is regionally representative. It includes a range of river sizes and substrate types. It also covers the range of different catchment land use types (urban, rural, and native and exotic forest) across the region. This allows the extrapolation of the results to infer the potential water quality of rivers that are not sampled.

Water quality is assessed monthly at 36 sites around the region. Three of these sites, the Waitangi Stream, the Whangamaire Stream and the Ngakaroa Stream are located in the Franklin area (Figure 12). The programme monitors the physical, chemical and microbiological properties of rivers (Table 12). This information is used to assess their life-supporting capacity (animals and plants) and their suitability for human use.

Table 12: Water quality parameters tested in the Franklin streams

Parameter	Units	Method
Dissolved oxygen	% sat and ppm	Field
Temperature	^{o}C	Field
Conductivity	mS/cm	Field
Salinity	Ppt	Field
pH (field)	pH units	Field and Lab
Suspended solids	Mg/L	Laboratory
Turbidity	NTU	Laboratory
Ammoniacal nitrogen	mg N/L	Laboratory
Nitrate + nitrite nitrogen	mg N/L	Laboratory
Total nitrogen	mg N/L	Laboratory
Soluble reactive phosphorus	mg P/L	Laboratory
Total phosphorus	mg P/L	Laboratory
Eschericia coli	cfu/100ml	Laboratory

5.3.1 Franklin stream N concentrations

The monthly water quality data from the river water quality programme is collated and reported annually. The results for the three streams in the Franklin region are presented in Figure 22 and Figure 23. More detail can be found in Appendix D.

Concentrations of ammonium-N are very low in all three streams, ranging from below laboratory detection levels to 0.137, 0.14 and 0.119 mg ammonium-N/L in the Waitangi, Whangamaire and Ngakaroa Streams, respectively.

Concentrations of nitrate-N were much higher, ranging from 0.02-3.39, 5.7-20 and 0.2-8.0 mg nitrate- N/L in the Waitangi, Whangamaire and Ngakaroa Streams, respectively.

Compared to other sites in the Auckland Council water quality monitoring programme, these nitrate values are elevated. In the Ngakaroa Stream nitrate concentrations exceed some of the trigger values for the preservation of species in the ANZECC (Australia and New Zealand Environment and Conservation Council) water quality guidelines (4.9-12.0 mg nitrate-N/L). In the Whangamaire Stream, nitrate concentrations considerably exceed the above-mentioned trigger values. They also exceed the National Objectives Framework (NOF) national bottom line for nitrate toxicity (6.9 mg nitrate - N/L), and Ministry of Health (MoH) drinking water guidelines (11.3 mg nitrate - N/L).

In many cases across all three streams, total N concentrations were higher than the inorganic N concentrations. This suggests there is a source of organic N in the streams. It is not known whether this is dissolved organic N or suspended sediment associated organic N in the water column.

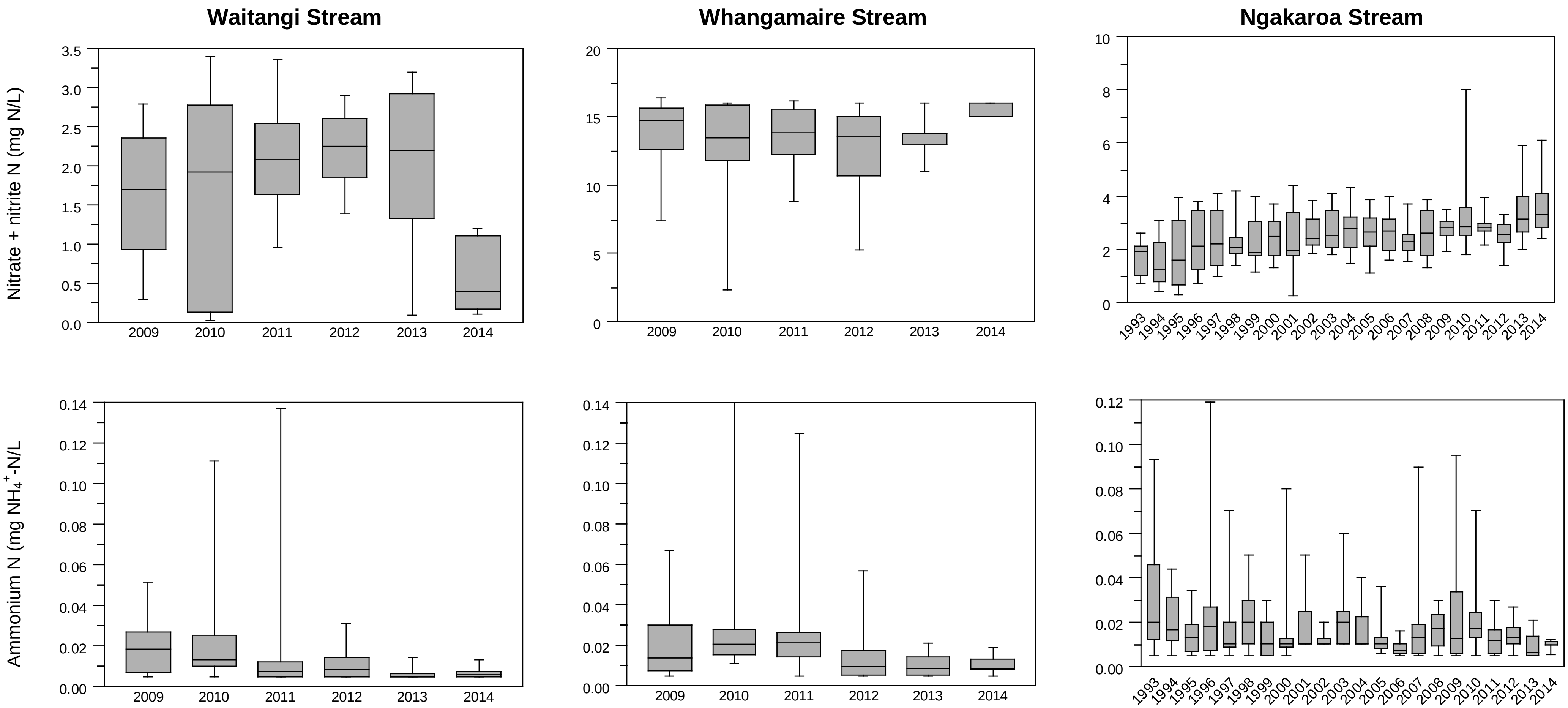


Figure 22: Full set of nitrite + nitrate-N and ammonium-N data in the Waitangi, Whangamaire and Ngakaroa Streams. The top and bottom of the boxes are the 75th and 25th percentiles, respectively; the mid-line is the median, and the bars show the maximum and minimum values

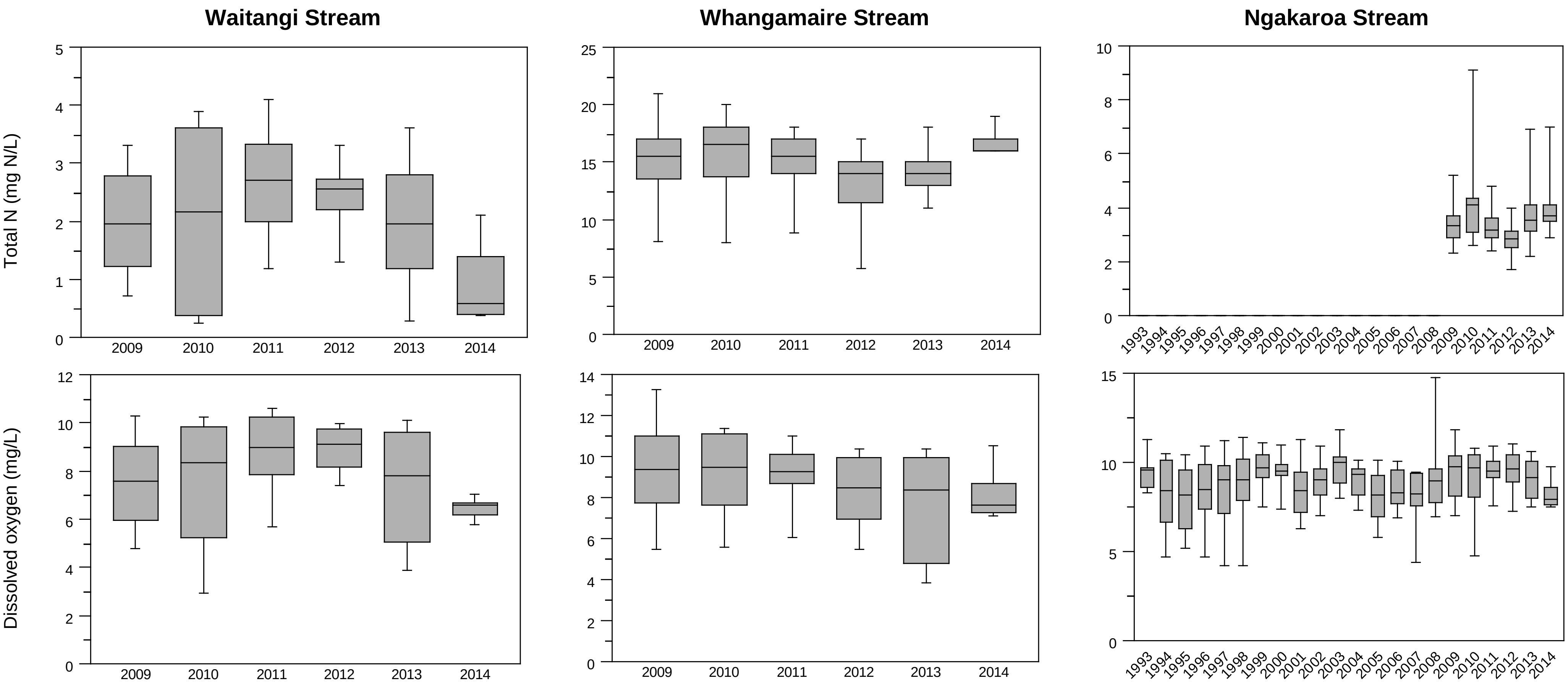


Figure 23: Full set of total N and dissolved oxygen data in the Waitangi, Whangamaire and Ngakaroa Streams. The top and bottom of the boxes are the 75th and 25th percentiles, respectively; the mid-line is the median, and the bars show the maximum and minimum values.

5.3.2 Trends

There are few statistically significant long-term trends in the Franklin streams based on the data from the Auckland Council water quality monitoring programme. Long-term trends in the Waitangi, Whangamaire and Ngakaroa Streams are shown in Figure 24, Figure 25 and Figure 26, respectively with details in Table 13.

In the Waitangi Stream, ammonium concentrations have significantly decreased since 2009 ($P < 0.05$). Nitrate concentrations are trending upwards, however this trend is not significant. Dissolved oxygen and total N concentrations have not changed.

In the Whangamaire Stream, dissolved oxygen and ammonium concentrations have significantly decreased ($P < 0.05$) since 2009. Although nitrate concentrations have not significantly changed, the fact that concentrations remain so high is a large concern. The high nitrate concentrations may also be contributing to the declining dissolved oxygen concentrations.

In the Ngakaroa Stream, dissolved oxygen and nitrate-N concentrations have significantly increased ($P < 0.001$) since 1993.

The considerable exceedance of the national bottom line for nitrate toxicity in the Whangamaire Stream and increasing concentrations in the Ngakaroa Stream show that mitigation action is required. Nitrate concentrations need to be reduced to at least the national bottom line values in the Whangamaire Stream. Further increases in nitrate concentrations need to be prevented in the Ngakaroa Stream.

All three streams are largely groundwater fed from the shallow South Auckland volcanic aquifers. Water with high concentrations of nitrate from these aquifers is supplying much of the stream base flow. The sources of the nitrate are likely to be land use related and the same as those discussed for the increasing groundwater nitrate concentrations in Section 5.2. The main transport mechanism is nitrate leaching.

Variations in physical and chemical dynamics in surface water will influence the nitrate concentrations that are introduced via the groundwater. Other inputs of water to the streams such as surface runoff after rainfall may have a dilution effect on nitrate concentrations. This will also introduce other contaminants such as fine sediment, metals, phosphorus and organically bound nitrogen to waterways.

In-stream macrophytes and plants growing on the stream edges will be able to assimilate some of the in-stream nitrate, potentially reducing its overall concentration. However, as discussed earlier in the review, photosynthesis and respiration by this plant material can cause large fluctuations in dissolved oxygen. Furthermore, overall dissolved oxygen can be ultimately reduced upon decomposition of the plant material when it dies.

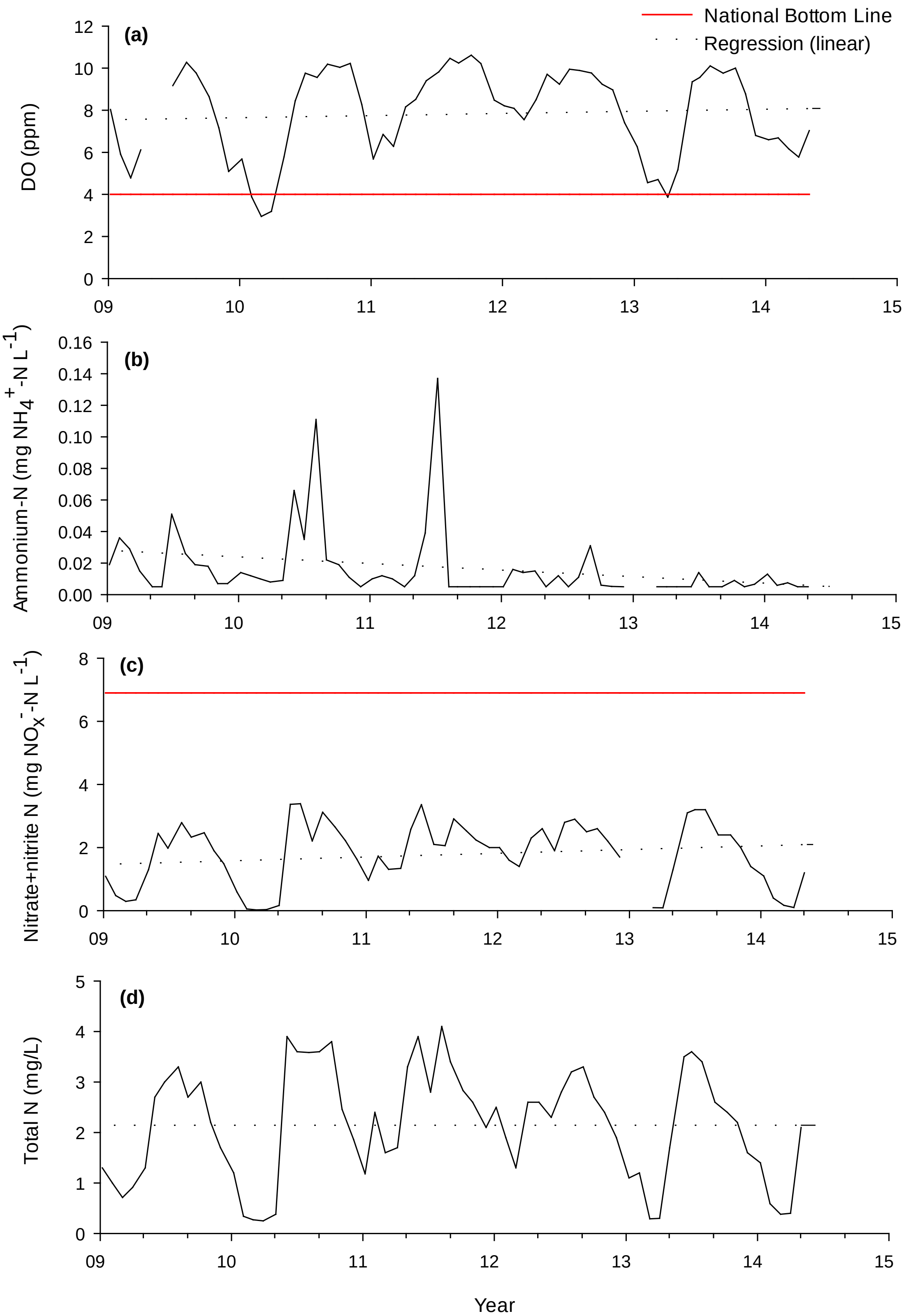


Figure 24: Trends in the Waitangi Stream for (a) dissolved oxygen, (b) ammonium-N, (c) nitrate + nitrite-N and (d) total N for the total data set (2009-2014).

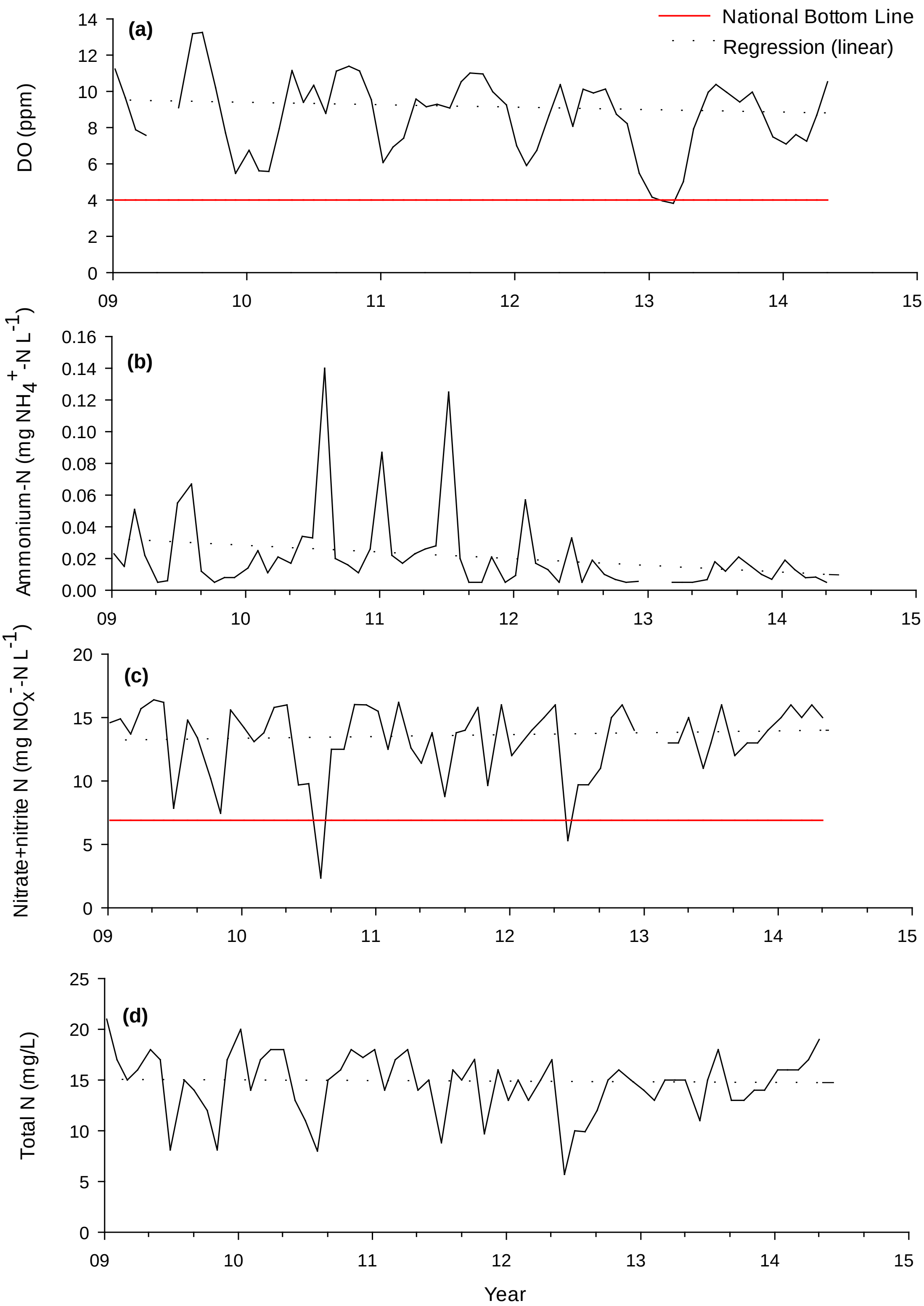


Figure 25: Trends in the Whangamaire Stream for (a) dissolved oxygen, (b) ammonium-N, (c) nitrate + nitrite-N and (d) total N for the total data set (2009-2014).

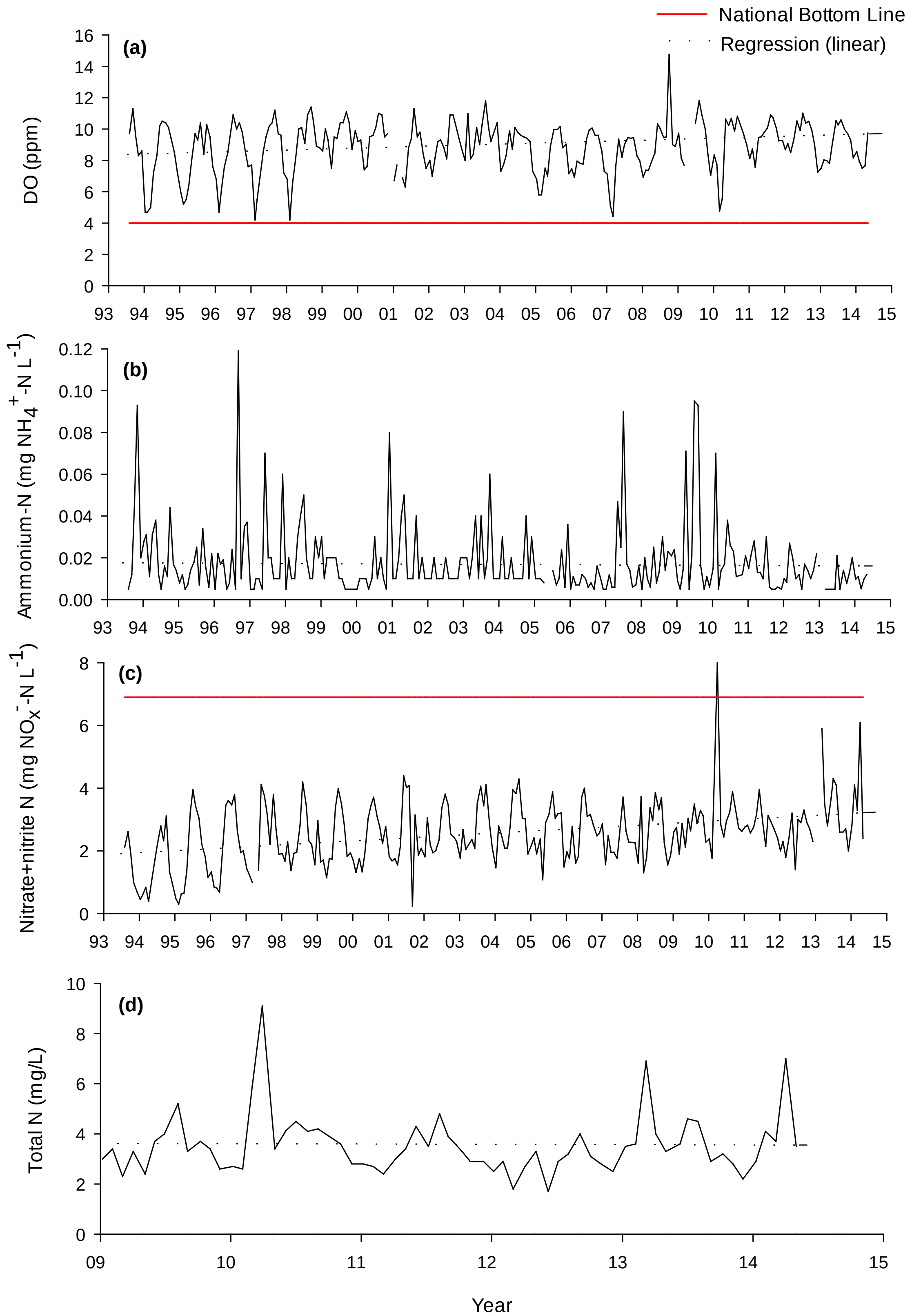


Figure 26: Trends in the Ngakaroa Stream for (a) dissolved oxygen, (b) ammonium-N, (c) nitrate + nitrite-N and (d) total N for the total data set (1993-2014).

Table 13: Slope and significance levels of seasonally adjusted trends in dissolved oxygen, ammonium-N, nitrate + nitrite-N and total N for the Waitangi, Whangamaire and Ngakaroa Streams.

Site	Count	Data collection record	Slope[a] (% per yr)	P value[b] (5% significance level)
Waitangi Stream				
Dissolved oxygen (mg/L)	63	2009-2014	1.43	> 0.05
Ammonium (mg NH_4^+-N/L)	63	2009-2014	-21.85	0.02
Nitrate + nitrate (mg NO_x^--N/L)	63	2009-2014	2.03	> 0.05
Total N (mg N/L)	65	2009-2014	-0.13	> 0.05
Whangamaire Stream				
Dissolved oxygen (mg/L)	63	2009-2014	-3.48	0.01
Ammonium (mg NH_4^+-N/L)	63	2009-2014	-16.82	0.04
Nitrate + nitrate (mg NO_x^--N/L)	63	2009-2014	0.83	> 0.05
Total N (mg N/L)	65	2009-2014	-1.35	> 0.05
Ngakaroa Stream				
Dissolved oxygen (mg/L)	244	1993-2014	0.48	< 0.001
Ammonium (mg NH_4^+-N/L)	244	1993-2014	-1.74	> 0.05
Nitrate + nitrate (mg NO_x^--N/L)	246	1993-2014	2.61	< 0.001
Total N (mg N/L)	64	2009-2014	0.18	> 0.05

[a] Positive number indicates upwards slope; negative number indicates downwards slope.

[b] P values < 0.05 = not significant; > 0.05 = significant; > 0.001 = highly significant.

5.4 Future direction

In terms of future direction, there are some bold statements and goals operating at regional, national and global levels that aim to increase primary production via intensification without impacting on the environment. For example, the Ministry for Primary Industries have national goals to double primary industry exports from 2012 levels by 2025, and in real terms this translates from $32 billion to $64 billion (MPI, 2012). ‘Our Land and Water’ National Science Challenge seeks research that enhances primary sector production and productivity without increasing the environmental footprint (MBIE, 2015). Furthermore, there are pressures to intensify agricultural and horticultural systems to ensure global food production is increased by up to 70% to provide sustenance to the forecast 9.6 billion global population by 2050 (FAO, 2010).

There is a conflict between such goals to intensify and increase production and productivity without increasing the environmental footprint associated with such activities. Therefore, the question remains whether these land use impacts on water quality in the Franklin system will realistically improve over time if the goals to increase primary production remain.

Furthermore, much of the best food producing land in the Franklin area is vulnerable to development such as the expansion of the rural urban boundary, special housing areas and rural subdivision so that there is less available land to farm on over time (Curran-Cournane et al., 2014b). This can make it difficult for farmers and growers who plan to de-intensify some of their farming practices by buying more land in order to have the option of leaving paddocks fallow with cover crops or re-sown with pasture for periods of time that allow the soil system to recover and restore in organic carbon levels.

Management options and technology are available to avoid, remedy or mitigate nitrate leaching from soil and reduce the associated impacts on the receiving environments. Some techniques for reducing nitrate leaching include:

- avoiding fertiliser application during winter
- split fertiliser application at lower rates
- direct drilling
- the use of cover crops to retain nitrogen in the topsoil and restore the carbon content of the soil
- effective stock management during winter (for example feed-pads), and low flow effluent applicators.

Not all techniques are applicable to all land use systems. Therefore, land managers must consider which methods or combination of methods will be most effective and suitable for their circumstances. For intensive cropping systems, the use of cover crops are becoming increasingly popular which can have environmental benefits such as the recovery of N in various rotations (Komatsuzaki and Wagger, 2015), as well as regulating greenhouse gas emissions via soil C sequestration (Lal, 2015a, Lal, 2015b).

The adoption of cover crops can also provide multiple benefits for farmers including increased crop yields that are reported to continue to increase after multiple years of cover crop use (Myers and Watts, 2015). The increase in crop yields reported by Myers and Watts (2015) as a result of cover crops occurred during extreme drought events experienced in 2012 in the United States. The increase in yields was suggested to be the result of the deep rooting depth created by cover crops that provide additional root channels and help with increased rainfall infiltration as well as allowing the commodity crop roots to grow deeper. It could also have been the result of the cover crop acting as a residue blanket that reduced soil evaporation or increasing the occurrence of soil mycorrhizal fungi that can potentially increase water and nutrient uptake (Myers and Watts, 2015).

The use of cover crops can also gradually increase soil organic matter that can act as a sponge to help increase the water holding capacity of the soil. It is noteworthy that there can be occasions whereby there is a trade-off between winter cover crop production and soil water depletion in certain environments such as semiarid, drought-prone regions (Mitchell et al., 2015)

There are also a range of documents which detail good practice for nutrient management such as the *Code of Practice for Nutrient Management* for horticulture, and the *Sustainable Dairying: Water Accord* (DairyNZ, 2013) for dairy farming. However, there has not been an evaluation of the effectiveness of these documents in reducing nitrate losses, or uptake of this advice by rural landowners in the Franklin area.

Best management practices that reduce the environmental footprint of intensive farming systems need to be encouraged. It will also be required under the National Policy Statement for Freshwater which has a clear objective to ensure that the overall quality of fresh water within the region is maintained or improved. More specifically, the increasing nitrate concentrations in groundwater and surface water will need to be addressed in order to meet the compulsory nitrate (toxicity) national bottom line for ecosystem health (MfE, 2014).

6.0 Knowledge and research gaps

A number of knowledge gaps related to the issue of nitrate contamination of the South Auckland volcanic aquifers and associated surface water have been identified in this literature review and an Auckland Council Franklin Nitrate Group (FNG) workshop. The research gaps cover a range of systems, including soil, geology, surface water and groundwater.

6.1 Nitrate leaching vulnerability

An understanding of the vulnerability of Franklin soils to nitrate leaching is needed. This will help to understand and quantify the amount of nitrate that is being leached under certain land uses in Franklin. A current Council-HortNZ '*Rootzone Reality'* project will quantify nitrate leaching from three sites in the Auckland and Waikato regions. Further work may be needed to model nitrate leaching vulnerability estimates for other parts of the Franklin area.

This research could assist in the National Policy Statement for Freshwater Management (NPSFM) implementation by identifying nitrate leaching risk. It could also feed into a range of other projects including the Matrix of Good Management developed by Environment Canterbury, and a recent greenhouse nutrient solution code of practice review.

6.2 Nitrate source determination

There is a gap in our understanding of the sources of elevated nitrate in the Franklin shallow volcanic aquifers and connected streams. We suggest nitrate leaching from intensive horticultural land use is contributing to the elevated nitrate concentrations. However, there is little empirical data to substantiate this. This research gap has been identified by the Auckland Council FNG and it is currently being investigated. Research is being undertaken on the validity of the dual stable isotope abundance technique to determine the source of nitrate from a range of surface water, groundwater and soil leachate sites in Franklin.

Information from this study will add to our understanding of soil nitrogen cycling dynamics in Franklin. It may help inform the most appropriate mitigation and land use management strategies to reduce nitrate leaching. Furthermore, this work will help to inform NPSFM implementation in Franklin, where nitrate concentrations in the Whangamaire Stream, and potentially others currently not monitored, are below the national bottom line for nitrate toxicity.

6.3 Spatial extent of nitrate contamination

This review has highlighted that nitrate concentrations are elevated in some shallow volcanic aquifers in Franklin. However, we do not understand the spatial extent of this contamination within the aquifers.

A better understanding of the spatial extent of elevated nitrate concentrations in the Franklin shallow volcanic aquifers will assist in their future management. In particular the identification of groundwater protection areas to safeguard bores used for drinking water. Understanding the spatial extent of elevated nitrate will also assist in the setting of freshwater limits through the NPSFM.

6.4 Nitrate mitigation management options

Understanding land management practices that mitigate nitrate contamination is important in managing nitrate in surface water and groundwater. For example, cover crops act as a protective cover against rainfall as well as subsequent sediment and pollutant runoff when land is fallow. This will also facilitate an increase in microbiological activity and subsequently enhance the organic carbon content of the soil ecosystem which will reduce the risk of nitrate leaching (Haynes and Tregurtha, 1999).

There are a range of documents which detail good practice for nutrient management, such as the *'Nutrient Code of Practice'* for horticulture (NZFMRA, 2013) and the '*Sustainable Dairying Water Accord'* for dairy farming (Dairy NZ, 2013). However, there is a need for the evaluation of the effectiveness of these documents in reducing nitrate losses and adoption of this advice by rural landowners in the Franklin area.

6.5 Aquifer recharge

A preliminary study by the Auckland Regional Council (ARC) developed a basic recharge model for the Pukekohe volcanic aquifers (Auckland Regional Council, 1996). Further work is needed to update and improve the accuracy of the model. In particular spring flows and their relationship with groundwater levels need to be quantified. Recharge mechanisms of the Kaawa Formation also need to be understood (Auckland Regional Council, 1996).

Aquifer recharge knowledge is important in managing groundwater and surface water resource use and in determining nutrient transport. This will assist in the management of land overlying key recharge areas in Franklin. It will ensure that groundwater and surface water resource use is sustainably allocated.

6.6 Groundwater-surface water connection

This review identified a research gap in our understanding of groundwater-surface water connections in Franklin. Baseflow ratios (a method for determining groundwater-surface water connection) were reviewed for Franklin and investigated by Lironi (2011). This research identified gaps in baseflow data for the lower Whangamaire Stream.

The Franklin Nitrate Group has identified an existing Whangamaire flow site higher up in the catchment (due to be removed) that could be relocated further downstream to better capture baseflow data. This information would provide a better understanding of groundwater-surface water connection particularly in the Whangamaire Stream. It could also be applied to other streams in the Franklin area. It would assist in the management of nitrate through the NPSFM as the Whangamaire Stream is currently below the national bottom line for nitrate (toxicity).

6.7 Fertiliser use

While estimates of fertiliser use can be found in the literature, actual fertiliser use data from horticultural and agricultural properties is needed in order to estimate nitrate leaching risks. The FNG is currently discussing this with the Pukekohe Vegetable Growers Association (PVGA), individual growers and fertiliser companies. The more that fertiliser data is shared, the more accurate model outputs (e.g. from OVERSEER®) will be. Fertiliser use information will also assist in setting and allocating freshwater limits through the NPSFM.

6.8 Urban nitrate contributions

There is little understanding of the potential nitrate contributions from urban land use activities on stream and groundwater quality in the Franklin area. This could include nitrate from sources such as urban stormwater, fertilised residential lawns or sports parks, industrial activities or discharges and golf courses. While the total nitrogen load from these activities to the shallow volcanic aquifers is likely to be relatively low compared with rural land uses, it would be useful to determine the relative nitrate contribution from urban sources.

6.9 Digital soil maps

Current soil maps for the Auckland region are low resolution (1:50,000). There is a need for higher resolution (farm scale) soil maps to better characterise soil types. This information could be used to more accurately estimate nitrate leaching risk. This in turn will assist in meeting freshwater limits set through the NPSFM.

Detailed farm-scale soil maps are also important for helping land managers make operational and environmental decisions. This gap is currently part of an Auckland Council Digital Soil Map (DSM) research project which will provide high resolution farm-scale soil maps (including Land Use Capability) for the Franklin area. This information will be used to update S-map, providing better information for OVERSEER®. Aeromagnetic surveys will also provide high resolution radiometric data, improving the current Q-map geology information for Franklin.

6.10 Sub-surface drainage

Sub-surface drainage appears to be common underneath vegetable crops. Particularly in areas of Franklin with semi permeable or impermeable soil layers, such as Patumāhoe clay loams. Sub-surface drainage can also be found on dairy farms. It will be important to understand the depth, density and spatial extent of sub-surface drainage networks in Franklin in order to determine how this affects water transport processes such as groundwater recharge, nitrate leaching and surface or sub-surface runoff. This information will also be useful to understand how water can be best managed on horticultural land to minimise nutrient and sediment loss.

6.11 Sediment ponds

Sediment ponds are recommended as good management practice on horticultural land and there are existing *'Erosion and Sediment Control Guidelines for Vegetable Production'* in Franklin (Barber, 2012). Sediment management is beyond the scope of this literature review. However, there is a gap in our understanding of typical concentrations of nitrogen contained within sediment retention ponds. Furthermore, we also need to understand the role that sediment ponds have in transporting nitrate, particularly to shallow unconfined aquifers.

7.0 Conclusions

Nitrogen

- There is increasing concern about nitrate concentrations in surface water and groundwater in the Franklin area.

- High nitrate concentrations can be toxic to aquatic life such as fish and invertebrates and impact algal biomass, species composition, pH and dissolved oxygen levels.

- Consumption of drinking water with high nitrate concentrations can potentially cause blue baby syndrome, reducing the ability of the blood to transport oxygen in infants.

- There are a range of existing guidelines and standards for nitrate nitrogen in freshwater bodies. In particular, a national bottom line for nitrate toxicity has recently been developed for protecting ecosystem health values in rivers (MfE, 2014).

- Groundwater and surface water are connected in some parts of the Franklin area, demonstrating a linkage between elevated nitrate concentrations in groundwater and streams.

- While not a focus of this report, there are a range of land use management practices and mitigation options could be implemented to reduce nitrate loss in the Franklin area.

Franklin land use and water quality

- The Franklin area has been subject to intensive vegetable growing and livestock farming for over a century. The frost free climate and volcanically derived soils are particularly suited to this intensive land use. These soils have been identified as some of New Zealand’s most productive soils (MAF, 1975).

- The soils in the Franklin area are considered highly vulnerable to nitrate leaching (Houlbrooke et al., 2012) due to their susceptibility to preferential drainage. Irrigation and rainfall can increase this risk.

- Vegetable production is an integral part of the Pukekohe economy today producing some of the highest yields in the county. However, fertiliser inputs associated with vegetable growing are high and can total between 472 and 491 kg N/ha per crop (Francis et al., 2003).

- The high levels of nitrate associated with intensive cropping have been a long standing land use issue in the Franklin area which has been reported in a wide variety of reports, conference proceedings and research papers e.g. Cathcart (1996), Crush et al., (1997), Francis et al., (2003), Ledgard et al., (1997), Scoble (2000) and Williams et al., (2000). The high levels of nitrate in the reporting area can be linked to high usage of nitrogen fertilisers and the lack of organic carbon in the soil system under this particular land use activity. This has been observed from data collected as part of the state of the environment (SoE) soil quality monitoring programme.

- A lack of carbon in the soil system renders a soil more vulnerable to nitrogen leaching when large amounts of fertiliser are applied. This can have an accumulative detrimental effect on water quality in the receiving environment.

- The long-term SoE water quality monitoring shows high and increasing concentrations of nitrate in both surface water and shallow groundwater. River water quality and groundwater quality monitoring indicates that levels of nitrate exceed recommended health and environmental guidelines in some streams and aquifers in the Franklin area and the NPSFM national bottom line for nitrate (toxicity).

- Dairy and drystock farming are also common in the Franklin area. Average dairy pastures can receive nitrogen inputs of between 65 and 95 kg N ha^{-1} through April to October, from nitrogen-based fertilisers and the application of dairy effluent to land. While levels of soil organic carbon are within recommended guideline ranges for pastoral farmland in the Franklin reporting area issues with soil compaction have been observed for pastoral soil sites. A compacted soil will be at greater risk of generating nutrient and sediment loss to the receiving environment via surface runoff (Curran Cournane et al., 2011).

Knowledge and research gaps

- This review identified a number of knowledge gaps regarding land use management and soil. More information is needed around nitrate mitigation management options, fertiliser use, urban nitrate contributions, farm-scale soil mapping, sub-surface drainage on horticultural and agricultural land and nitrate leaching risk of horticultural sediment ponds.

- This review also identified knowledge gaps regarding groundwater and surface water. These included a need for further research in the Franklin area to better characterise the nitrogen cycling dynamics and leaching risks associated with horticultural land use, the spatial extent and source of elevated nitrate concentrations and aquifer recharge, surface water groundwater connection and groundwater age.

Future direction

- There are increasing regional, national and global goals that aim to increase primary production through intensification without impacting on the environment. However, there is a level of paradox existing between goals to intensify and increase production and productivity without increasing the environmental footprint of such activities. The review of literature and monitoring data included in this report demonstrates a good example of this.

- Much of the best farmland in the Franklin area is vulnerable to development such as the expansion of the rural urban boundary, special housing areas and rural subdivision so that there will be less available land to farm on over time. This can make it difficult for farmers and growers who want to de-intensify some of their farming practices by buying more land in order to have the option of leaving paddocks fallow with cover crops or re-sown with pasture for periods of time that allow the soil system to recover and restore in organic carbon levels.

- Best management practices that reduce the environmental footprint of intensive farming systems need to be encouraged and landowner uptake rates measured. Adoption of best management practices will also be required under the National Policy Statement for Freshwater, along with setting freshwater limits.

- The NPSFM has an objective to ensure that the overall quality of fresh water within the region is maintained or improved. More specifically, increasing nitrate concentrations in groundwater and surface water in Franklin will need to be addressed in order to meet the compulsory nitrate (toxicity) national bottom line for ecosystem health (MfE, 2014).

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Appendix A Ammonium toxicity attribute states

Ammonium toxicity attribute states, National Policy Statement for Freshwater Management (MfE, 2014)

Value	Ecosystem health		
Freshwater Body Type	Lakes and rivers		
Attribute	Ammonia (Toxicity)		
Attribute Unit	mg NH_4-N/L (milligrams ammoniacal nitrogen per litre)		
Attribute State	**Numeric Attribute State**		**Narrative Attribute State**
	Annual Median*	Annual Maximum*	
A	≤0.03	≤0.05	99% species protection level: No observed effect on any species tested
B	>0.03 and ≤0.24	>0.05 and ≤0.40	95% species protection level: Starts impacting occasionally on the 5% most sensitive species
C	>0.24 and ≤1.30	>0.40 and ≤2.20	80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)
National Bottom Line	1.30	2.20	
D	>1.30	>2.20	Starts approaching acute impact level (ie risk of death) for sensitive species

* Based on pH 8 and temperature of 20̊C.

Compliance with the numeric attribute states should be undertaken after pH adjustment

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Appendix B Soil risk categories for dairy effluent discharge in Auckland

Soil risk categories for dairy effluent discharge in Auckland (Houlbrooke et al., 2012).

Category	A	B	C	D	E
Soil and landscape feature	Artificial drainage or coarse soil structure	Impeded drainage or low infiltration rate	Sloping land (>7°) or land with hump & hollow drainage	Well drained flat land (<7°)	Other well drained but very light[x] flat land (<7°)
Risk	High	High	High	Low	Low
Application depth (mm)	< SWD*	< SWD	< SWD	< 50% of PAW#	≤ 10 mm & < 50% of PAW#
Instantaneous application rate (mm/hr)	N/A**	N/A**	< soil infiltration rate	N/A	N/A
Average application rate (mm/hr)	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate
Storage requirement	Apply only when SWD exists	Apply only when SWD exists	Apply only when SWD exists	24 hours drainage post saturation	24 hours drainage post saturation
Maximum N load	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr
Max depth: High rate tool	10 mm	10 mm	10 mm***	25 mm## (10 mm at field capacity)	10 mm
Max depth: Low rate tool	25 mm	25 mm	10 mm	25 mm	10 mm

* SWD = soil water deficit, within 300 mm depth. # PAW = Plant available water in the top 300 mm of soil, x Very stony sandy layer ** N/A = Not an essential criteria, however level of risk and management is lowered if using low application rates. *** This method only applicable where instantaneous application rate < infiltration rate. ## 25 mm is the suggested maximum application depth when a suitable SWD exists (≥ 15 mm). Field capacity should not be exceeded by more than 10 mm using a high rate irrigator.

Appendix C Soil quality data

Table 1: Soil quality results for soil sampling sites in the Franklin reporting area

Soil parameter	Horticulture (n=8)	Pasture (n=8)	Native bush (n=1)
pH	6.6 (6.0-7.2)	6.2 (5.9-6.5)	6.0
OC (%)	3.1 (1.8-5.3)	7.1 (3.6-8.9)	7.0
TN (%)	0.28 (0.16-0.43)	0.64 (0.30-0.82)	0.50
Olsen P[1]	191 (48-361)	78 (12-161)	4
Anaerobic mineralisable N[1]	25 (7-50)	185 (51-266)	169
Bulk density (g/cm3)	1.03 (0.97-1.16)	1.00 (0.81-1.10)	0.87
Macroporosity (-10kPa % v/v)	22 (16-29)	9 (5-13)	11

Horticulture: Market gardens (n=7) and an orchard

Pasture: Dairy (n=2) and lifestyle blocks (n=6)

[1] Units: mg/kg

Table 2: Provisional target ranges for soil quality under horticultural land cover **(Curran-Cournane et al 2014).**

Soil order	pH[1]	OC[1] mg/kg	TN[1] mg/kg	Olsen P[2] mg/kg	AMN[2] mg/kg	Bulk[1] density g/cm[3]	Macro[3] -10kPa	Agg stab (MWD) mm[1]	C/N[4]
Allophanic	5.5-7.2	4+	n/a	20-50	40+	>0.6-1.2	10-30	>1.5	7-30
Brown	5.5-7.2	3.5+	n/a	20-40	40+	>0.6-1.3	10-30	>1.5	7-30
Gley	5.5-7.2	3.5+	n/a	20-40	40+	>0.6-1.3	10-30	>1.5	7-30
Granular	5.5-7.2	3.5+	n/a	20-50	40+	>0.6-1.3	10-30	>1.5	7-30
Organic	5.0-7.0	n/a	n/a	20-40	40+	0.3-0.7	10-30	>1.5	7-30
Recent	5.5-7.2	3+	n/a	20-40	40+	>0.75-1.3	10-30	>1.5	7-30
Ultic	5.5-7.2	3.5+	n/a	20-40	40+	>0.6-1.3	10-30	>1.5	7-30

[1] Adapted from Sparling *et al.* 2003, [2] Mackay *et al.* (2013b), [3] Mackay *et al.* (2006).

[4] C/N ratio is not considered a key soil quality indicator but a guideline range for soil orders is provided.

Appendix D Auckland Council stream monitoring data, 2009-2013

Water quality statistics for ammonium, nitrate and total N in the Waitangi, Whangamaire and Ngakaroa Streams from 2009-2013.

Site	Count	Min	Max	Median	Mean	Standard Error
Waitangi Stream						
Ammonium (mg NH_4^+-N/L)						
2009	12	0.003	0.051	0.019	0.020	0.004
2010	12	0.003	0.111	0.013	0.027	0.0091
2011	12	0.003	0.137	0.008	0.020	0.0111
2012	12	0.003	0.031	0.009	0.010	0.0024
2013	12	0.003	0.014	0.005	0.006	0.0009
Nitrate + nitrate (mg NOx¯N/L)						
2009	12	0.295	2.790	1.695	1.576	0.255
2010	12	0.024	3.390	1.920	1.621	0.3983
2011	12	0.957	3.360	2.080	2.093	0.2010
2012	12	1.400	2.900	2.250	2.208	0.1417
2013	12	0.090	3.200	2.200	1.937	0.3397
Total N (mg N/L)						
2009	12	0.71	3.30	1.95	1.99	0.27
2010	12	0.25	3.90	2.16	2.10	0.449
2011	12	1.18	4.10	2.70	2.66	0.265
2012	12	1.30	3.30	2.55	2.46	0.162
2013	12	0.290	3.600	1.950	1.991	0.3353
Whangamaire Stream						
Ammonium (mg NH_4^+-N/L)						
2009	12	0.003	0.067	0.014	0.023	0.006
2010	12	0.011	0.140	0.021	0.031	0.0102
2011	12	0.003	0.125	0.022	0.031	0.0107
2012	12	0.003	0.057	0.010	0.015	0.0046
2013	12	0.003	0.021	0.008	0.009	0.0019
Nitrate + nitrate (mg NOx¯N/L)						
2009	12	7.450	16.400	14.700	13.399	0.910
2010	12	2.350	16.020	13.450	12.644	1.1377
2011	12	8.770	16.200	13.800	13.334	0.7094
2012	12	5.300	16.000	13.500	12.558	0.9200
2013	12	11.000	16.000	13.000	13.167	0.3860
Total N (mg N/L)						
2009	12	8.10	21.00	15.50	14.85	1.11
2010	12	8.00	20.00	16.50	15.43	0.991
2011	12	8.80	18.00	15.50	14.88	0.855
2012	12	5.70	17.00	14.00	13.05	0.929
2013	12	11.00	18.00	14.00	14.17	0.499

Site	Count	Min	Max	Median	Mean	Standard Error
Ngakaroa Stream						
Ammonium (mg NH_4^+-N/L)						
2009	12	0.003	0.095	0.013	0.029	0.010
2010	12	0.003	0.070	0.016	0.022	0.0051
2011	12	0.003	0.030	0.012	0.013	0.0028
2012	12	0.003	0.027	0.013	0.014	0.0019
2013	12	0.003	0.021	0.007	0.010	0.0022
Nitrate + nitrate (mg NOx^-N/L)						
2009	12	1.900	3.490	2.810	2.747	0.137
2010	12	1.770	8.010	2.890	3.402	0.4741
2011	12	2.150	3.950	2.790	2.853	0.1293
2012	12	1.400	3.300	2.550	2.517	0.1691
2013	12	2.000	5.900	3.250	3.392	0.2989
Total N (mg N/L)						
2009	12	2.30	5.20	3.35	3.36	0.23
2010	12	2.60	9.10	4.11	4.32	0.515
2011	12	2.40	4.80	3.18	3.33	0.204
2012	12	1.70	4.00	2.85	2.78	0.182
2013	12	2.200	6.900	3.550	3.758	0.3472

Appendix E Auckland Council groundwater monitoring site location

Auckland Council groundwater monitoring site details for the Franklin area.

Site name	Site type	Monitored by	Dominant land use	Easting	Northing	Monitoring began
BP Bombay	Bore	AC	Rural	1775891	5881877	1998
Fielding Rd Sand	Bore	AC	Rural	1774435	5890642	1998
Fielding Rd Volc	Bore	AC	Rural	1774435	5890642	1998
Gun Club Rd	Bore	AC	Rural	1764229	5880963	2006
Hickey Spring	Spring	AC	Urban	1768720	5882057	1998
Hillview Spring	Spring	AC	Rural	1776245	5884311	2010
Ostrich Farm Rd1	Bore	GNS	Rural	1766043	5885072	1998
Ostrich Farm Rd2	Bore	AC	Rural	1766052	5885143	1996
Patumāhoe Spring	Spring	AC	Rural	1763970	5881269	1998
Rifle Range Rd 1	Bore	GNS	Rural	1766295	5880987	1998
Rifle Range Rd 2	Bore	GNS	Rural	1766295	5880987	1997
Seagrove Rd	Bore	GNS	Rural	1755957	5889239	1997

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